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Enjoy & Master Advanced Biology

Topical Questions and Examinations: Form Six Topics

Ngaiza Series of Advanced Biology

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Every effort has been made to ensure the accuracy of the content in this book. The publisher welcomes corrections and suggestions for future editions.

TABLE OF CONTENTS

PREFACE

This book was written because you deserve better.

Advanced Level Biology rewards understanding, yet many students reach Form Six having survived Form Five on memory alone, able to name parts they cannot explain and to recite processes they cannot reason through. Biology feels familiar, because we all breathe, eat, fall ill, and watch things grow, so it is easy to believe you understand it when you have only memorised it. Students memorise what happens, sit examinations that ask how and why, and leave believing Biology is a list of facts to be recalled under pressure. That is not Biology. That is memorisation dressed as understanding.

Biology is the study of life in action: how water climbs to the top of a tall tree, how the heart drives blood to every organ, how a single fertilised cell grows into a whole creature, how characteristics pass from parents to their children, and how living things share and shape the world around them. It is the science in which you are the subject, with your own heart, your own genes, your own place in the living world. It is powerful, deeply personal, and far more logical than its reputation suggests. But mastering it under examination conditions takes more than a textbook to read. It takes practice: attempting real questions, building real answers, and learning, answer by answer, how to turn what you know into marks. That is what this book sets out to give you.

Why a book of questions and answers?

You do not learn to swim by reading about water, and you do not learn Biology by reading model answers. You learn it by attempting a question, getting it wrong, finding out exactly why, and trying again. This book is built entirely around that truth. Every concept in the Form Six syllabus is turned into questions you must answer yourself, each followed by a full model answer that shows not only the correct biology but the exact, connected English that earns NECTA marks. Used honestly, with the answer covered until you have written your own, it trains the two things the examination really tests: understanding the mechanism, and explaining it clearly.

How this book is organised

The book covers the whole Form Six course in seven chapters: Transportation in Plants, Transportation in Animals, Growth and Development, Reproduction, Genetics, Evolution, and Ecology.

The first part, Topical Questions and Answers, takes each chapter in turn. Every question is followed at once by its model answer, so you can attempt it and then check yourself immediately. Within each chapter the questions rise through three tiers.

BINDER questions anchor the core mechanism. Even here they ask you to explain how and why, never merely to state what. If you can answer these, you own the concept.

REAL questions carry the biology into real Tanzanian life, into health, farming, and the environment, where the subject actually lives.

HOT questions push you to examination standard and beyond, drawing several topics together and demanding genuine reasoning rather than recall.

The second part, the Examinations, brings together complete papers modelled on the NECTA format. Each paper is followed by full worked solutions, so that every question in this book, from the first to the last, has a complete, well-reasoned answer you can learn from, but only after you have attempted it with the book closed.

Before the questions begin, a short Student Survival Guide shows you how to study Biology, how to use this book, and how to beat the two traps, false confidence and weak scientific English, that quietly cost good students their marks. Read it first. It is the shortest and most important part of the book.

The team behind this book

Enjoy and Master Advanced Biology is the work of the Ngaiza Education Hub, built by a team of experienced biology educators who share one conviction: that Tanzanian students deserve world-class materials written for their context, their syllabus, and their aspirations.

Writers: Mr. Lameck Msangi, Mr. Godson Stephen, and Mr. Peter Marco.

Editors: Dr. Protase Reuben and Dr. Pius Magoyo.

Designer: Mr. Frank Mwita.

I am grateful to every member of this team for their dedication, their expertise, and their refusal to settle for "good enough." I thank too the students whose hard questions and honest struggles shaped every answer in this book. They reminded us, again and again, that a question a student cannot learn from has failed, no matter how correct its biology may be.

To every Form Six student opening this book for the first time: Biology is not as hard as its reputation, and it is not as easy as it first feels. It is as logical as any living thing is built to be, and as satisfying as a puzzle that finally clicks. Give it your honest effort, with the answer covered and your pen moving, and this book will give you its honest best in return.

Ngaiza, Lusima
Series Creator and Director

This book is dedicated to every Tanzanian student who was told that Biology is just memorisation. It is not, and this book will prove it to you.

STUDENT SURVIVAL GUIDE

How to turn what you know into marks.

Why Biology Feels Easy, Then Betrays You

By Form Six you carry a year of Advanced Biology and a lifetime of living it. You know that blood moves, that plants drink, that children resemble their parents, that living things share a habitat. The topics ahead feel like home, and that comfort is exactly what makes Biology the most dangerous subject on your timetable.

The first trap is false confidence. Because the material feels familiar, it feels mastered, and that easy feeling fools strong students every year. The examination does not ask what happens; it asks how and why. You know blood carries oxygen, but explain how it loads oxygen in the lungs and releases it in a working muscle, and the easy feeling vanishes. The distance between knowing *what* and explaining *how* is where most marks are won or lost.

The second trap is the language barrier. Even when you understand the mechanism, you still have to put it on paper in clear, connected English, one cause leading into the next, in the order the examiner rewards. Scientific English is not built like everyday Swahili, and almost nobody is taught to cross that gap. So a student who truly understands natural selection can lose half the marks because the sentences arrive broken, out of order, or missing the words that carry the logic.

On the answer sheet the two traps look identical. Both produce a weak, disjointed answer that bleeds marks, yet their cures are opposite. One student must understand the biology more deeply; the other understands it well and only needs to learn how to say it. This book is built to fix both at once, because every model answer shows you the mechanism and the exact English that earns the marks.

One example makes the difference clear.

The same question, answered by two students.

The question. Explain why a red blood cell bursts when it is placed in distilled water.

The confident answer that fails. Water enters the cell until it bursts. *(It is true, yet it names no cause and earns almost nothing.)*

The answer that scores. The cytoplasm of the red cell has a lower, more negative water potential than the distilled water around it. Water therefore moves into the cell by osmosis, across the partially permeable cell surface membrane and down the water potential gradient. Because an animal cell has no cell wall to resist the inflow, the cell swells until the membrane bursts, in what is called haemolysis.

Both students *knew* the answer; only the second one explained it, and only the second one scores. That gap, repeated across a three-hour paper, separates a pass from a distinction. This guide, and every answer that follows it, exists to put you on the right side of it: from knowing to understanding.

How to Use This Book

This is not a book to read. It is a book to work. A model answer you have only read feels learned and is forgotten by morning; a model answer you have struggled toward, and then compared against your own, is learned for good. Work every question in four steps.

1. **Cover the model answer.** Read the question, then answer it in full on paper, in proper sentences, before you look at anything.
2. **Uncover and compare.** Read the model answer twice, once for the biology and once for the English. Did you get the mechanism? Did you connect it the way the model does?
3. **Mark yourself honestly.** Award yourself a point only where your answer truly made the same point. A near miss is a miss.
4. **Fix one thing, then move on.** Correct your single biggest error in your own words, and carry that lesson into the next question.

Climb the ladder, and do not skip the bottom rung. The questions rise through three tiers. BINDER builds the core mechanism, REAL applies it to real Tanzanian situations in health, farming and the environment, and HOT pushes into higher-order reasoning across topics. A student who jumps to HOT before owning BINDER is trying to enter a house through the top window. Work each chapter in order.

Treat the examination papers as real examinations. The papers at the end of this book are not extra questions. Sit each one in a quiet room, against the clock, with the book closed, then mark it against the solutions. That is the closest rehearsal for the real day you can get.

How to Write Biology for Marks

Marks in Biology are not awarded for knowing. They are awarded for showing that you know, in writing, in the right order. Two habits carry most of those marks.

Lead with the point, then explain it. State the thing the question asks for first, in a few words, then give the reasoning behind it. The examiner is trained to find the point, tick it, and read on for the explanation that earns the rest. Bury the point at the end of a long sentence and you force a tired examiner to hunt for it, and a point that cannot be found cannot be marked.

Join your ideas with the words that carry cause and effect. A NECTA answer is a chain in which one event causes the next. The words that build that chain are *because, so, as a result, which in turn, consequently*, and *whereby*. Use them on purpose. They are the whole difference between a list of true statements and an explanation.

One example shows both habits at work.

The same biology, written two ways.

The question. Explain how a population of insects becomes resistant to an insecticide.

The common answer that fails (low marks). The insects got used to the insecticide, so over time their bodies adapted to survive it. *(This is the usual mistake: it imagines the insects changed because they needed to.)*

The same biology as a chain (full marks). Within the population there is variation, and a few insects already carry an allele for resistance. When the insecticide is sprayed it kills the susceptible insects, whereas the resistant ones survive. Because these survivors breed and pass the resistance allele to their offspring, the proportion of resistant insects rises with each generation, and so the whole population becomes resistant.

Notice that the second answer adds no new facts. It only connects the ones already there, in the right order. That connecting is the skill this whole book is teaching you, answer after answer.

How to Draw Biology for Marks

Diagrams carry marks that most students give away. A drawing is not decoration; it is an answer made of lines, and it is marked as strictly as a sentence.

Get the proportions right before anything else. A nucleus that fills half the cell, or one heart chamber drawn larger than the rest, loses marks before a single label is read. Look first, then draw what is actually there.

Use single, clean lines. One firm line, not a furry sketch built from many short strokes. Keep a sharp pencil, and use a ruler wherever the structure is straight.

Rule your label lines, and never let them cross. Each label line is straight, drawn with a ruler, and touches the exact structure it names. Crossing or wandering label lines confuse the examiner and cost marks.

Label only the parts that carry marks. Do not decorate the drawing with every detail you know. Label the structures the question is about, using the correct biological term, and underline any scientific name, since underlining is the handwritten form of italics. Underline the two parts of the name separately, the genus and the species each on its own, for example Zea mays.

Show the scale or magnification when one is given. If a question provides a measurement or magnification, show it, and for cells and organelles add a labelled scale bar. A few diagrams return again and again in NECTA at this level, among them the transverse section of a dicot stem, the internal structure of the heart, a stage of meiosis and the DNA molecule. Practise each until you can draw it cleanly from memory in two minutes.

How to Fail Productively

You will get questions wrong. Every strong student does. What decides your grade is the five minutes after you get one wrong.

The unproductive response is to erase your attempt, read the model answer, nod, and move on. Your page looks complete and your memory has learned nothing, because you only watched someone else answer.

The productive response is to stop, and not erase. Set your answer beside the model and find the exact point where they part. Then name the cause: was it the biology, because you did not understand the mechanism; the English, because you understood it but could not connect it; or the question, because you answered what you expected instead of what was asked? Fix that one thing, cover the model again, and rewrite the answer from the start.

Those three causes need three different cures, and naming yours is half the cure. A wrong answer you have diagnosed is worth more than a right answer you copied.

How to Revise on Your Own

Most revision feels productive and is not. Be honest about which kind you are doing. Re-reading model answers, highlighting them, and copying them out neatly all feel like work, but your eyes move while your memory rests. A beautiful notebook is not understanding. These methods are.

Sit the examination papers under the clock. The papers at the back of this book are your single best revision tool. Do one in a quiet room, timed, with the book closed, then mark it against the solutions. Nothing else rehearses the real pressure.

Explain a mechanism out loud, as if to someone who knows nothing. Where you stumble is precisely what you have not understood yet. The silence is the lesson.

Teach a friend, and let them ask why. The moment you cannot answer their question is your revision target for the evening.

Redo the questions you got wrong, not the ones you got right. Return after a week to the answers you missed and do them again from a blank page.

Revise your weakest topic first, not your favourite. The topic you enjoy is the one you already know; the topic you avoid is the one the paper will ask.

How to Face NECTA

The examination does not test how clever you are. It tests whether you can show what you know, clearly, under pressure, in a fixed time. That is a skill, and skills can be practised.

Read every question twice before you write. Most lost marks come from answering the question you expected instead of the one on the paper. The second reading catches the word the first reading missed.

Obey the command word. Each command word asks for a particular kind of answer, and giving the wrong kind loses marks even when your biology is correct.

Command word	What it asks for
State, Name, List	Give the fact or item only, briefly, with no explanation.
Define, What is meant by	Give the exact, formal meaning of the term.
Outline	Give the main points or steps only, without the detail.
Describe	Give an orderly account of what is seen or what happens, step by step, with no reasons.
Explain	Give the reason why. Every explain answer needs a because.
Account for	Explain why an observation or result happens the way it does.
Suggest	Apply what you know to an unfamiliar case; a sensible, reasoned answer is rewarded even where more than one is possible.
Compare	Give similarities and differences together, point against point.
Distinguish, Differentiate	Give the differences directly, side by side, not two separate descriptions.
Discuss	Weigh more than one side: reasons for and against, advantages and disadvantages.
With the aid of a labelled diagram	A diagram is compulsory and carries marks; an answer without one is capped.
Calculate	Work out the number, showing each step and its unit, as in water potential and the Hardy-Weinberg equation.

Show your reasoning, not just the conclusion. A bare conclusion scores little; the marks live in the steps between the question and the answer. Write the chain.

In data questions, read the axes, quote the figures, then explain. First state what the graph or table shows, using actual values with their units, then explain why it happens. Describing and explaining are two separate sets of marks.

Check that a calculated answer is sensible. An allele frequency must lie between 0 and 1, and a cell's water potential is normally negative or zero. An answer outside the expected range is a signal to recheck, and saying so earns credit for biological awareness.

Watch the clock, and leave nothing blank. Marks are easiest to win at the start of an answer and hardest at the end, so a question half answered is worth more than a question never reached. Spend your time by the marks, not by your interest.

The night before, do not cram. Your brain files what you have learned while you sleep. A calm student who rests well outperforms a tired one who revised until midnight. Rest is part of the preparation.

You now carry what the strongest students bring into the hall and most never receive: a way to use this book that turns reading into practice, the language to write biology that scores, the technique to draw it for full marks, an honest method of revision, and a clear plan for the examination itself. Turn the page, cover the first model answer, and begin. The biology is waiting, and it is better than its reputation.

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PART ONE
TOPICAL QUESTIONS AND ANSWERS

Chapter 1

TRANSPORTATION IN PLANTS

BINDER QUESTIONS

Work through each question in order: attempt it on paper, then check the model answer beneath. Every answer leads with the mark-bearing point in bold, and a False Confidence Alert names the mistake that most often costs marks on that question.

Question 1

A maize plant in a shamba is many thousands of cells thick and grows taller than the farmer, yet every one of its cells needs water, mineral salts and food. Explain why such a plant cannot depend on diffusion alone to supply its cells.

Model Answer

Diffusion alone cannot supply a large plant because it is effective only over very short distances, so the plant must have a transport system. Diffusion moves substances quickly only across a gap as small as a single cell. In a maize plant the journey from the roots in the soil to the leaves at the top is measured in metres, and a molecule would take far too long to diffuse over such a distance to keep the cells alive. **Because the body is also many cells thick, the cells deep inside are cut off from direct contact with the soil and the air.** For these reasons the plant needs a dedicated transport system to carry water and mineral salts up from the roots and to carry manufactured food from the leaves to every other part.

> **False Confidence Alert**
> Most students answer that the plant simply uses diffusion and osmosis, and stop there. That loses the marks: the point is that diffusion acts only over very short distances, so a tall, many-celled plant must have a transport system.

Question 2

The vascular system of a flowering plant is built from two transporting tissues. Name the two tissues and explain how the work of transport is divided between them.

Model Answer

The vascular system is the transport network of the plant, and its work is shared between two tissues, *the xylem* and *the phloem*.

The xylem carries water and dissolved mineral salts in one direction only, upward from the roots to the stem and leaves; it forms a continuous system of tubes reaching from the root right up into the leaf. **The phloem carries manufactured food, mainly sugar, away from the leaves to wherever it is used or stored,** and it can move this food in both directions, upward and downward. In this way the upward water stream and the two-way food stream are kept in separate tissues, each suited to its own task.

> **False Confidence Alert**
> The commonest mistake is to swap the tissues, saying the phloem carries water and the xylem carries food. The marks are for the correct pairing, so a reversed answer scores nothing.

Question 3

A student asks why a plant needs two different conducting tissues instead of one single all-purpose pipe. Give a reasoned answer.

Model Answer

Two tissues are needed because the plant has two different loads to move in two different directions, and each tissue is built for its own load.

Water and mineral salts must travel upward only, from the soil to the leaves, and the xylem is built for this: its cells are dead, empty and strengthened with lignin, forming hollow tubes that offer little resistance to a one-way stream of water. **Manufactured food must travel from the leaves to many destinations, both upward and downward, and the phloem is built for this:** its sieve tubes are living and are kept working by companion cells, so they can load and unload sugar and move it either way. A single pipe could not be both a dead hollow tube and a living, controlled one, so the work is split between two tissues.

> **False Confidence Alert**
> Many students answer only that one tissue carries water and the other food, and stop. The question asks why two are needed, so the marks come from linking each load and its direction to the matching structure.

Question 4

Xylem runs as an unbroken system of tubes from the root, up the stem and into every leaf. State the two functions this tissue performs, and explain how its continuous, lignified form suits each of them.

Model Answer

Xylem has two functions: it conducts water and dissolved mineral salts, and it gives the plant mechanical support. Each function is matched by a feature of its form.

The continuous column suits conduction: the cells are dead and joined end to end into unbroken tubes running from root to leaf, so water drawn out at the top is replaced from below without a break. **The lignified wall suits support:** the walls are thickened and stiffened with lignin, so the tubes resist the inward pull of the water under tension and also hold the stem upright.

> **False Confidence Alert**
> Most students give only the conducting role and forget that xylem also supports the plant. That loses half the marks, because the same lignified walls that carry the water also hold the stem up.

Question 5

Xylem is not a single kind of cell. Name the four kinds of cell that build it and give the job of each.

Model Answer

Xylem is a compound tissue built from four kinds of cell, two that conduct and two with other roles:

1) **Vessel elements:** wide, dead, hollow cells joined end to end through perforation plates to form the main water-conducting tubes.
2) **Tracheids:** narrower dead cells with tapering, imperforate ends, through whose pits water passes; they conduct water and add support.
3) **Xylem fibres:** long, narrow, thick-walled dead cells that give the tissue extra mechanical strength.
4) **Xylem parenchyma:** the only living cells, which store food such as starch and move water sideways over short distances.

> **False Confidence Alert**
> Many name only the vessels and tracheids and leave out the fibres and the parenchyma, or wrongly call the parenchyma dead. The marks are for all four cell types, and the parenchyma must be named as the living, food-storing cell.

Question 6

Three features of the xylem wall are the lignified thickening, the pits and the perforation plates. Explain how each one fits the work the xylem does.

Model Answer

Each wall feature is matched to a task the xylem must perform:

1) **Lignified thickening:** the lignin stiffens the wall so the tube does not collapse under the tension of the rising water, and it supports the plant.
2) **Pits:** these thin gaps, where there is no lignin, let water pass sideways from one element to the next and out to neighbouring cells.
3) **Perforation plates:** the open end walls between vessel elements join them into a continuous pipe, so water flows straight up with little resistance.

> **False Confidence Alert**
> A common mistake is to swap the pits and the perforation plates, saying that water rises up the plant through the pits. Pits let water cross sideways between cells, whereas the perforation plates are the open end walls that join vessels into a vertical pipe.

Question 7

The two conducting cells of the xylem are easy to tell apart once they are drawn. Draw a large, clearly labelled diagram of xylem tissue showing a vessel element and a tracheid, with the perforation plate, the pits and the primary and secondary cell walls labelled, then state which feature lets the vessel carry water more freely than the tracheid.

Model Answer

The labelled structure of xylem is shown below.

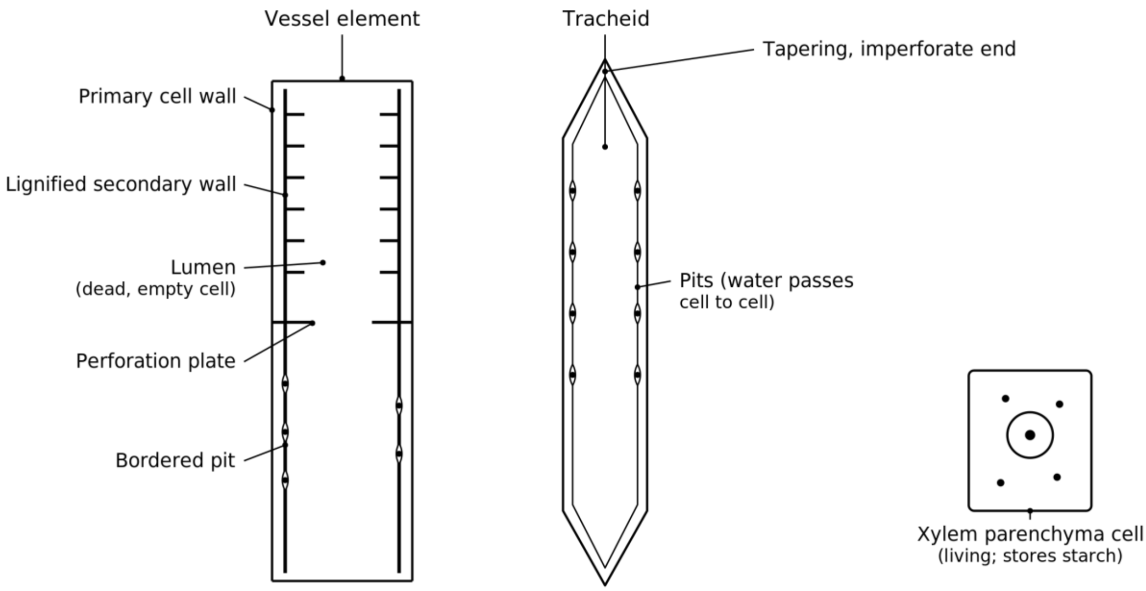


Figure 1.2: *The structure of xylem - a vessel element, a tracheid and a xylem parenchyma cell.*

The perforation plates are the feature that lets the vessel carry water more freely: they join the vessel elements end to end into an open, continuous pipe, whereas the tracheid has no perforations and water must pass more slowly through its pits.

> **False Confidence Alert**
> The commonest error is to draw the vessel with closed end walls and no perforation plate, so it looks just like a tracheid. Draw the vessel as a wide, open-ended tube and the tracheid as narrow with tapering, imperforate ends, because that contrast is what earns the marks.

Question 8

Both tracheids and vessel elements carry water, yet a vessel carries it more freely. Compare the two cells and explain why the vessel is the better conductor.

Model Answer

A vessel conducts water more freely than a tracheid because its end walls are perforated, while those of a tracheid are not. Vessel elements are wide and joined end to end through open perforation plates into continuous tubes, so water flows straight up with little resistance. A tracheid is narrower and its end walls are tapering and imperforate, so water must pass from one tracheid to the next through the side pits, which slows it. Both cells are dead and lignified at maturity, but the open vessel offers the easier path.

> **False Confidence Alert**
> Students often write that tracheids also have perforation plates, which removes the very difference being tested. Only vessels have perforated end walls; a tracheid is imperforate, so water must cross through its pits.

Question 9

A student claims that water travels up the xylem and not the phloem. Describe the evidence from simple experiments that supports this claim, and say what each experiment shows.

Model Answer

Several simple experiments show that it is the xylem, not the phloem, that carries water:

1) **The dye test:** a leafy shoot stood in red eosin takes up the dye, and when the stem is later cut across only the xylem is stained, showing water moved there.
2) **Ringing the bark:** removing the outer bark with its phloem does not stop water reaching the leaves, but cutting into the xylem makes the leaves wilt, showing the water path is the xylem.
3) **The poison test:** a metabolic poison such as cyanide does not stop the flow, showing that transport through the dead xylem is passive and not driven by living cells.
4) **Blocking the tubes:** when the lumen of the vessels and tracheids is blocked with fat, water uptake stops and the plant wilts, confirming the xylem is the route.

> **False Confidence Alert**
> Many students describe each experiment but never say what it proves, and the mark is for the conclusion. End each piece of evidence by stating plainly that it shows water travels in the xylem.

Question 10

The xylem is the tissue responsible for transporting water and dissolved mineral salts through a plant. Explain how the xylem is adapted to carry water and dissolved mineral salts efficiently from the roots to the leaves.

Model Answer

The xylem is well adapted to raise water in several ways:

1) **Continuous tubes:** vessel elements join end to end through perforation plates, giving an unbroken column from root to leaf.
2) **Narrow lumen:** the fine bore helps water rise by capillarity and keeps the water column from breaking.
3) **Dead, empty cells:** with no cytoplasm or cross walls in the way, the tubes offer little resistance to the flow.
4) **Lignified walls:** the stiff walls stop the tubes collapsing under tension and hold the plant up.
5) **Pits in the side walls:** these let water move sideways between elements and out to the surrounding living cells.

False Confidence Alert
A bare list of features with no link to function scores poorly, and borrowing the phloem's living, energy-using features loses marks outright. Tie each feature to how it helps water rise, and remember the xylem is dead and works without energy.

Question 11

Phloem is the living tissue that carries the food a plant makes. Name the four kinds of cell that build it and give the job of each.

Model Answer

Phloem is a living tissue built from four kinds of cell:

1) **Sieve tube members:** living but enucleate cells joined end to end through sieve plates to form the tubes that carry the food.
2) **Companion cells:** small cells packed with cytoplasm, a nucleus and many mitochondria, which keep the sieve tube members alive and load sugar into them.
3) **Phloem parenchyma:** living cells that store food and help move materials sideways over short distances.
4) **Phloem fibres:** dead, thick-walled cells that give the tissue mechanical strength.

False Confidence Alert
Many students call the phloem dead like the xylem, or leave out the companion cells. The phloem is living, and all four cell types carry marks, the companion cells most of all.

Question 12

Describe how a sieve tube member is built, and explain how its structure suits the rapid movement of food.

Model Answer

A sieve tube member is a living tube with very little inside it and open sieve plates at its ends, and both features speed the flow of food. At maturity it loses its nucleus and most of its organelles, leaving a clear lumen through which the phloem sap meets little resistance. Its end walls become sieve plates whose pores, widened from plasmodesmata, open one cell into the next, so the sap streams straight from member to member. A thin layer of cytoplasm lines the cellulose wall, and the cell is kept alive and working by its companion cell.

False Confidence Alert
A common mistake is to say the sieve tube member keeps its nucleus, or that it is dead like a xylem vessel. It is living but loses its nucleus and most organelles at maturity, and it is joined by open sieve plates, not by perforation plates.

Question 13

Flowering plants and the cone-bearing plants conduct food in slightly different cells. Distinguish a sieve tube member from a sieve cell.

Model Answer

The two differ in their pores, their helper cells and their efficiency:

1) **Pores:** a sieve tube member, found in flowering plants, has true sieve plates with large pores on its end walls, whereas a sieve cell, found in conifers, has only narrow sieve areas on its side walls.
2) **Helper cell:** each sieve tube member is served by a companion cell, whereas a sieve cell is served instead by an albuminous cell.
3) **Efficiency:** the sieve tube member is wider, more advanced and conducts food faster, whereas the sieve cell is narrower, more primitive and conducts more slowly.

False Confidence Alert
Students often treat sieve cells and sieve tube members as the same thing. The mark is for the contrast: sieve plates and companion cells in flowering plants against sieve areas and albuminous cells in conifers.

Question 14

A sieve tube member has no nucleus, yet it stays alive and keeps moving food. Explain how the companion cell makes this possible.

Model Answer

The companion cell is the life-support of the sieve tube member: it keeps the enucleate tube alive and powers the loading of sugar. It has a nucleus that controls both its own activities and those of the sieve tube member, which has lost its own. It is packed with mitochondria that release the ATP needed to load sugar into the sieve tube by active transport. The two cells are joined by many plasmodesmata, so materials and signals pass freely between them.

False Confidence Alert
The usual error is to say that the companion cell carries the food itself. It does not conduct the sap; it keeps the sieve tube member alive and supplies the ATP that loads sugar into it.

Question 15

The sieve tube member cannot keep itself alive, so a companion cell works closely beside it. Draw a large, clearly labelled diagram of a sieve tube member and its companion cell, with the sieve plate, the companion cell nucleus, the mitochondria and the plasmodesmata labelled, then state what the companion cell does for the sieve tube member.

Model Answer

The labelled sieve tube member and companion cell are shown below.

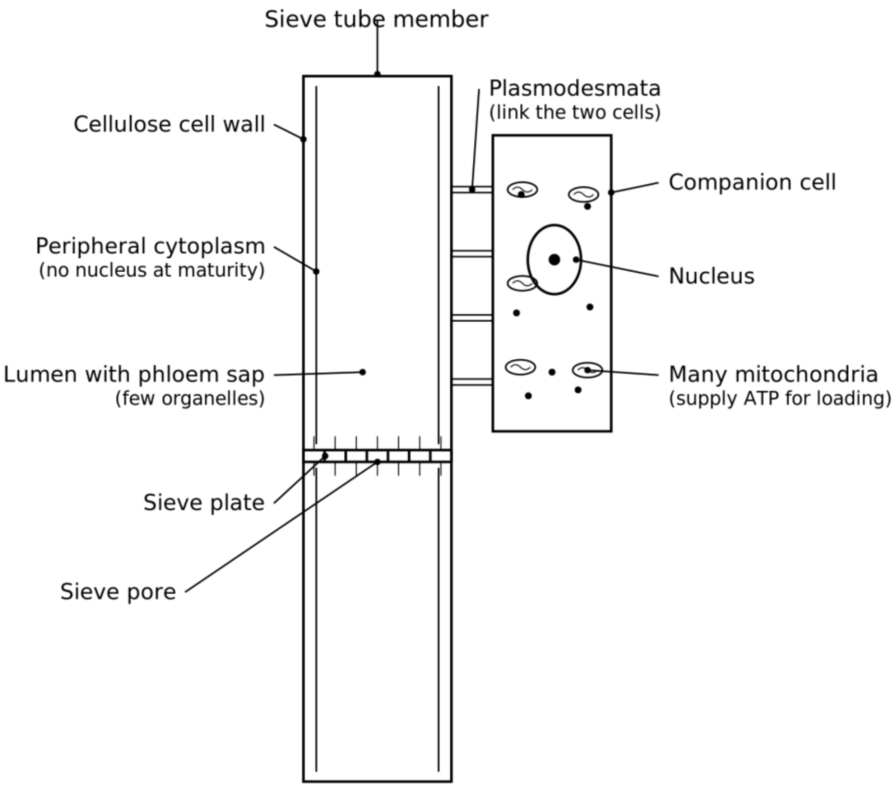


Figure 1.3: *A sieve tube member and its companion cell.*

The companion cell keeps the sieve tube member alive and loads sugar into it: its many mitochondria supply the ATP for loading, and materials pass between the two cells through the plasmodesmata.

> **False Confidence Alert**
> The commonest error is to draw a nucleus inside the sieve tube member, which has none at maturity. Show the nucleus only in the companion cell, and include the sieve plate with its pores and the plasmodesmata joining the two cells, because those carry the marks.

Question 16

The movement of food through a plant has been investigated using a number of experiments. Describe the evidence from experiments that shows the phloem carries the food made in the leaves, and say what each piece of evidence shows.

Model Answer

Several experiments show that organic food travels in the phloem:

1) **The aphid stylet:** when a feeding aphid is anaesthetised and cut from its mouthpart, sugary sap flows out of the stylet left in the phloem, showing the phloem is full of food under pressure.
2) **Ringing the bark:** removing a ring of bark with its phloem makes sugar pile up just above the ring, showing food moves down through the phloem.
3) **The radioactive tracer:** when a leaf is given carbon dioxide made with radioactive carbon-14, the label later appears in the phloem, showing the food made in the leaf is carried there.
4) **Day against night:** the sugar in the phloem is higher by day, when photosynthesis is making food, than at night, showing the phloem carries the products of photosynthesis.

> **False Confidence Alert**
> Many students describe each experiment but never state what it proves, and the mark is for the conclusion. End each piece of evidence by saying plainly that it shows food travels in the phloem.

Question 17

The phloem forms part of the plant's transport system and is responsible for the movement of organic nutrients. Explain how the phloem is adapted to carry food from the leaves to the rest of the plant.

Model Answer

The phloem is well adapted to translocate food in several ways:

1) **Continuous sieve tubes:** the sieve tube members join end to end into long tubes through which the sap can flow.
2) **Open sieve plates:** their pores open one member into the next, giving the sap a path of low resistance.
3) **Little cell content:** the loss of the nucleus and most organelles clears the lumen for easy flow.
4) **Companion cells:** their mitochondria supply the ATP that loads sugar into the tubes and keeps them working.
5) **Plasmodesmata:** these link companion cell to sieve tube so that sugar can be loaded and unloaded.

> **False Confidence Alert**
> A frequent mistake is to give the xylem's features, such as lignin and dead empty cells, for the phloem. The phloem is living and uses energy, so tie each feature to the loading and the flow of food.

Question 18

A stem cut across shows at once whether it came from a monocot or a dicot. Draw the arrangement of the vascular tissue seen in a transverse section of a young dicotyledonous stem, labelling the xylem, cambium and phloem in one bundle. Then state how the arrangement differs in a monocotyledonous stem.

Model Answer

In a dicot stem the vascular bundles are set in a ring, each with phloem to the outside, xylem to the inside and cambium between, as shown in the following figure.

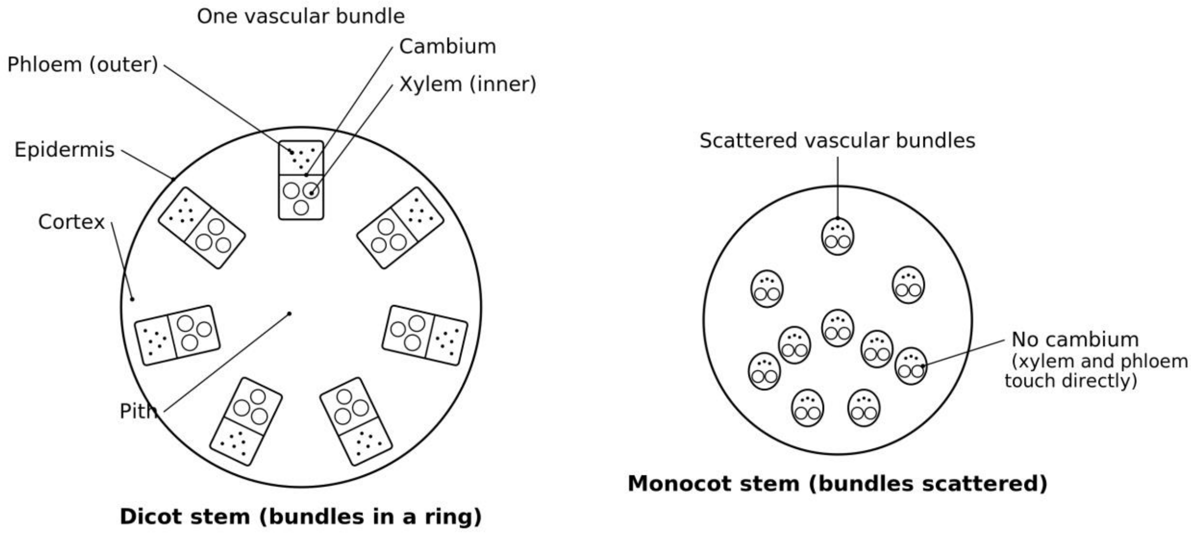


Figure 1.4: *Vascular bundles in a dicot stem (set in a ring) and in a monocot stem (scattered).*

How the monocot differs: in a monocot stem the bundles are scattered throughout the ground tissue instead of forming a ring, and they have no cambium, so a monocot stem cannot grow in thickness as a dicot stem can.

False Confidence Alert
The commonest error is to scatter the bundles in the dicot, or to leave out the cambium between the xylem and phloem. Draw them in a neat ring with phloem outside, xylem inside and cambium between, because that arrangement is what earns the mark.

Question 19

Plants rely on both passive and active mechanisms to move substances into and out of their cells. What is meant by passive transport and by active transport? Give the key idea of each, with a plant example.

Model Answer

Passive transport is the movement of substances down their concentration gradient, without the cell spending any energy. For example, oxygen and carbon dioxide diffuse freely across a plant cell membrane from where they are more concentrated to where they are less.

Active transport is the movement of substances against their concentration gradient, which the cell pays for with energy from ATP. For example, a root cell takes up nitrate ions from dilute soil into its more concentrated cytoplasm by active transport.

False Confidence Alert
Many students think that all uptake into a cell must be active, or that osmosis costs energy. Only movement against the gradient is active; movement down a gradient, osmosis included, is passive and free.

Question 20

A root cell can take up a mineral ion even when the soil around it is more dilute than the cell. Explain why this movement needs both energy and a carrier protein.

Model Answer

The movement needs energy because the ion is being moved against its concentration gradient, which cannot happen on its own. Diffusion moves substances only down a gradient; to drive the ion the other way, from the dilute soil into the more concentrated cell, the cell must do work. The work is done by a carrier protein in the membrane, a pump, which binds the ion and changes shape to carry it across. That change of shape is driven by energy released from ATP, which the cell makes in respiration.

> **False Confidence Alert**
> A common mistake is to say the ion simply diffuses into the cell. It cannot, because it is moving against its gradient, which is the very reason a carrier protein and energy from ATP are needed.

Question 21

Although both passive and active transport move substances across cell membranes, they operate in fundamentally different ways. Set out the main differences between passive and active transport, explaining why each difference holds.

Model Answer

Passive and active transport differ in several linked ways:

1) **Energy:** passive transport uses none, whereas active transport spends ATP, because only active transport does work against the gradient.
2) **Gradient:** passive transport runs down the concentration gradient, whereas active transport runs against it.
3) **Equilibrium:** passive transport slows and stops once the two sides are equal, whereas active transport can hold a difference in place by pumping continuously.
4) **Proteins:** passive transport may use a channel protein or none, whereas active transport needs a carrier protein working as a pump.

> **False Confidence Alert**
> Students often list the differences but cannot say why each holds, and the marks are for the reason. Tie every contrast back to the one root difference, that only active transport does work against the gradient.

Question 22

Many of the vital functions of a plant depend on the movement of water between cells and tissues. What is meant by osmosis, and explain why it is so important in the life of a plant.

Model Answer

Osmosis is the movement of water molecules across a partially permeable membrane, from a region of higher water potential to a region of lower water potential.

It is important to the plant in several ways:

1) **Turgor:** water drawn in by osmosis presses the cytoplasm against the cell wall, and this turgor holds up the leaves and the soft, young stems.
2) **Opening the stomata:** when the guard cells take in water by osmosis they swell and the pore opens, letting in carbon dioxide for photosynthesis.
3) **Cell-to-cell movement:** water passes from cell to cell across the root and through the plant by osmosis, following the water potential gradient.

> **False Confidence Alert**
> The usual error is to define osmosis as water moving from a high to a low concentration, leaving out the membrane and water potential. Name the partially permeable membrane and say water moves from high to low water potential, or the definition loses marks.

Question 23

Plant cells respond differently when placed in solutions of different concentrations because water moves across their partially permeable membranes. Describe and explain what happens to a plant cell when it is placed in (a) a dilute solution or pure water, and (b) a concentrated solution.

Model Answer

In a dilute solution the cell takes in water and becomes turgid. The cell sap has a lower water potential than the dilute solution outside, so water enters by osmosis; the cell swells until the wall pushes back, and the firm, swollen cell is said to be turgid.

In a concentrated solution the cell loses water and may become plasmolysed. Now the solution outside has the lower water potential, so water leaves the cell by osmosis; the cell first becomes flaccid, and if much water is lost the cytoplasm shrinks away from the wall, a state called plasmolysis.

False Confidence Alert
Many students write that a plant cell bursts in pure water, as an animal cell would. The strong cellulose wall prevents bursting; the cell only becomes turgid, and in a concentrated solution it is flaccid or plasmolysed, not burst.

Question 24

Osmosis can be demonstrated using a simple model in which two solutions are separated by a partially permeable membrane. Draw a labelled diagram to model osmosis across a partially permeable membrane. Show clearly the difference between the two solutions and the direction in which water moves.

Model Answer

The osmosis model is shown below.

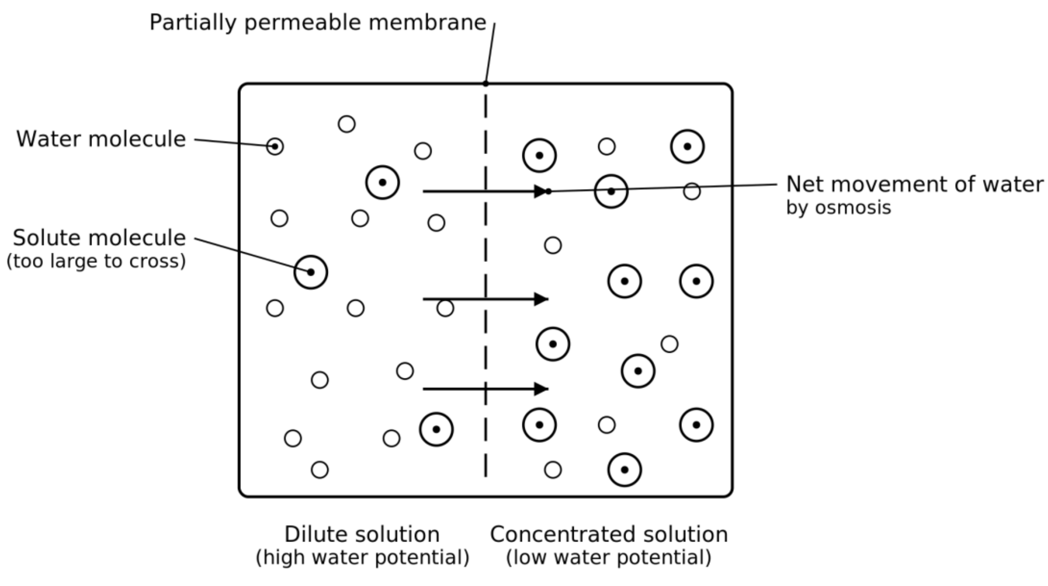


Figure 1.5: *A model of osmosis across a partially permeable membrane.*

False Confidence Alert
The commonest error is to draw arrows for the solute crossing the membrane, or to point the water the wrong way. Show only water crossing, from the dilute side to the concentrated side, with the solute molecules too large to pass.

Question 25

Substances can cross cell membranes by different forms of diffusion. Distinguish simple diffusion from facilitated diffusion, and explain the part played by membrane proteins.

Model Answer

Both simple and facilitated diffusion move substances down a concentration gradient without using energy; they differ in whether a protein is needed to cross the membrane. In simple diffusion, small or lipid-soluble molecules such as oxygen and carbon dioxide pass straight through the membrane. In facilitated diffusion, ions and larger water-soluble molecules cannot cross the lipid layer on their own, so they pass through transport proteins: channel proteins form pores that let particular ions through, while carrier proteins bind the molecule and change shape to ferry it across. Even so, both move only down the gradient.

> **False Confidence Alert**
> Students often say that facilitated diffusion uses energy because it uses a protein. It does not; it is still passive and runs down the gradient, the protein only giving a route across the lipid layer.

Question 26

The rate at which substances enter or leave plant cells by diffusion depends on several factors. State and explain the factors that affect the rate at which a substance diffuses across a plant cell membrane.

Model Answer

Three main factors set the rate of diffusion:

1) **The concentration gradient:** the steeper the difference between the two sides, the faster the net diffusion.
2) **The surface area:** the larger the area of membrane available, the more molecules cross in a given time, which is why absorbing surfaces are often folded.
3) **The distance:** the thinner the membrane or the shorter the path, the faster the diffusion, so exchange surfaces are usually very thin.

> **False Confidence Alert**
>
> A bare list of factors with no direction of effect scores little, and adding energy as a factor is wrong for diffusion. Say which way each factor changes the rate, and remember that diffusion is passive.

Question 27

Osmosis is sometimes called a special kind of diffusion. Explain how osmosis is like ordinary diffusion and how it differs.

Model Answer

Osmosis is like diffusion in that both are passive and move particles down a gradient, from high to low concentration, using no energy. It differs in three ways:

1) **What moves:** osmosis moves only water, not the dissolved solutes.
2) **The membrane:** osmosis needs a partially permeable membrane between the two solutions.
3) **The gradient:** the gradient that matters is the water potential gradient, so water moves from the more dilute solution to the more concentrated one.

> **False Confidence Alert**
>
> The usual mistake is to say that osmosis carries the dissolved solutes along with the water. Osmosis moves water only, across a partially permeable membrane, down the water potential gradient.

Question 28

Most water and mineral salts are taken in at the root hair zone. State the functions of the root, then explain how a root hair is adapted for absorption.

Model Answer

The root has three functions: it anchors the plant in the soil, it absorbs water and mineral salts, and in some plants it stores food. The root hair, an outgrowth of an epidermal cell, is well adapted for the absorbing role:

1) **Many and long:** each root hair is a long, thin extension of an epidermal cell, and there are very many of them, giving a large surface area for absorption.
2) **Thin wall, no cuticle:** the wall is thin and has no cuticle, so water passes in freely.
3) **Close to the soil water:** the sticky wall grips the soil particles and the film of water around them, keeping the hair in contact with its supply.

False Confidence Alert
Many students give only absorption and forget that the root also anchors the plant and may store food. All three functions can earn marks, and the root hair must be described as having no cuticle, not a thick covering.

Question 29

The root hair is shaped above all for taking in water. Draw a large, labelled diagram of a root hair cell as it absorbs water from the soil, including the cell wall, the cell surface membrane, the cytoplasm, the nucleus and the large vacuole, then state the feature that gives the cell its large surface area.

Model Answer

The labelled root hair cell is shown below.

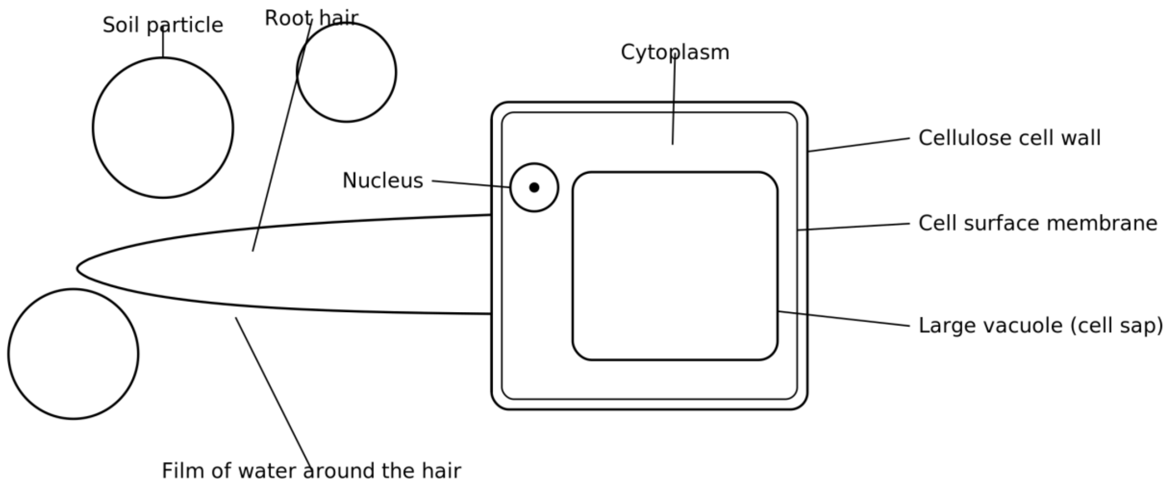


Figure 1.6: *A root hair cell absorbing water from the soil.*

The long, narrow shape of the root hair is the feature that gives the cell its large surface area, over which it absorbs water and dissolved mineral salts from the film of water around the soil particles.

False Confidence Alert
The commonest error is to draw the root hair short and stubby, or to give it a cuticle. Draw it as a long, thin extension with a thin wall and no cuticle, because that large, bare surface is the whole point of the cell.

Question 30

Across the root, water travels from the root hairs to the xylem by three pathways. Name them and explain how water moves in each.

Model Answer

Water crosses the root by three pathways:

1) **The apoplast pathway:** water moves through the cell walls and the spaces between cells, without entering any cytoplasm.
2) **The symplast pathway:** water moves through the cytoplasm of the cells, passing from one cell to the next through the plasmodesmata.
3) **The vacuolar pathway:** water moves from vacuole to vacuole, crossing the cell membranes and tonoplasts by osmosis.

False Confidence Alert
Students often confuse the apoplast and the symplast. The apoplast is the route through the cell walls, whereas the symplast is the route through the living cytoplasm and the plasmodesmata.

Question 31

The three pathways across the root do not all carry the same amount of water. Explain why the apoplast carries the most and the vacuolar pathway the least.

Model Answer

The apoplast carries the most water because it offers the least resistance, while the vacuolar carries the least because it offers the most. In the apoplast, water soaks through the open network of cellulose walls and spaces without crossing a single membrane, so it flows freely and in large amounts. In the vacuolar pathway, water must cross the cell membrane and the tonoplast at every cell by osmosis, and these membranes resist the flow, so little water takes this route. The symplast lies between the two in the amount it carries.

False Confidence Alert
A common mistake is to say the three pathways carry equal amounts of water. They do not, because the vacuolar route must cross membranes that resist the flow, while the apoplast crosses none and so carries the most.

Question 32

Water crossing the root can take three routes, but only one of them is stopped at the endodermis. Draw a diagram of a section across the root to show the apoplast, symplast and vacuolar pathways, and mark where the Casparian strip acts.

Model Answer

The three pathways across the root are shown below.

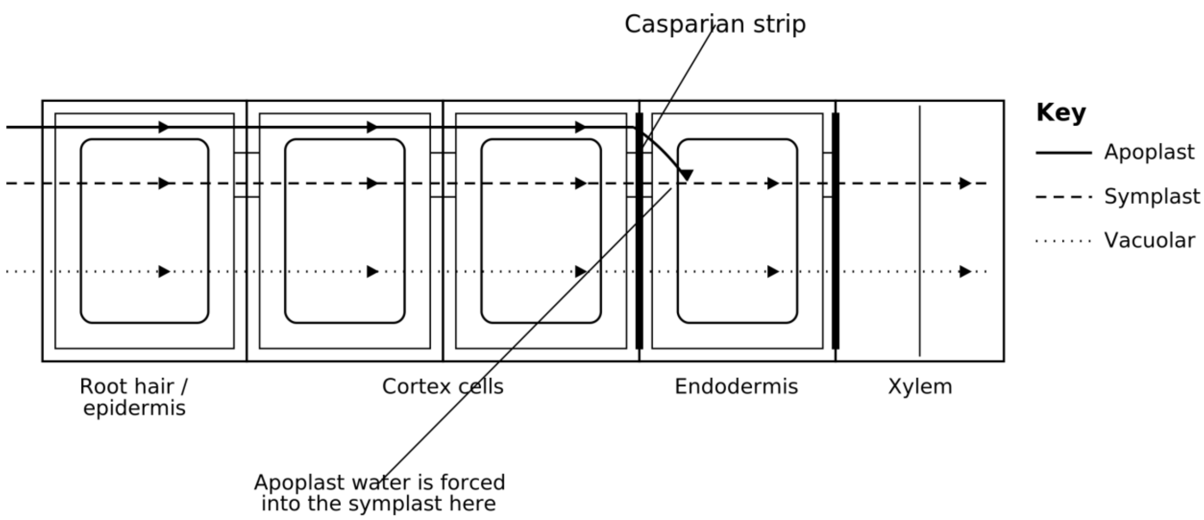


Figure 1.7: *The apoplast, symplast and vacuolar pathways across the root.*

The Casparian strip stops the water travelling in the apoplast at the endodermis, forcing it into the symplast so that the cell membrane can choose which salts pass on to the xylem.

False Confidence Alert
The commonest error is to leave out the Casparian strip, or to let the apoplast run straight through the endodermis. Show the strip on the endodermis and the apoplast water turning into the symplast there, because that diversion is the mark.

Question 33

At the endodermis the plant takes control of exactly what is allowed into its xylem. Explain what the Casparian strip is and the part it plays in the movement of water and salts into the xylem.

Model Answer

The Casparian strip is a waterproof band of suberin in the walls of the endodermal cells, and it forces water out of the apoplast and into the living cytoplasm. Because suberin will not let water through, water travelling in the apoplast cannot cross the endodermis through the walls; it is made to enter the cytoplasm, joining the symplast pathway. This gives the plant control over what reaches the xylem, because the cell membrane can select which salts pass; the salts are then actively pumped into the xylem, which lowers its water potential and draws water in after them.

False Confidence Alert
Many students place the Casparian strip in the cortex, or say it stops water altogether. It lies in the endodermis, and it does not stop water but diverts it from the apoplast into the cytoplasm, giving the cell control over what reaches the xylem.

Question 34

Water rises from the roots to the top of a tall tree against gravity. Outline the forces that bring about this ascent of sap.

Model Answer

Several forces act together to raise the water, the ascent of sap:

1) **Transpiration pull:** water evaporating from the leaves pulls the whole water column up behind it, and this is the main force.
2) **Cohesion and adhesion:** water molecules cling to one another and to the xylem walls, holding the column unbroken so the pull is passed all the way down.
3) **Root pressure:** osmotic uptake of water at the root pushes the column a little way up the stem from below.
4) **Capillarity:** the very narrow xylem tubes draw water up a short way by capillary action.

False Confidence Alert
A frequent mistake is to name only one force, usually root pressure, as raising the sap. The main force is transpiration pull; root pressure and capillarity only help, and the marks are for the set of forces and their relative parts.

Question 35

A rope can be pulled from above only while it stays in one piece, and the same is true of a column of water. Using the cohesion-tension theory, explain how a continuous column of water is pulled up the xylem, and why the column must not break.

Model Answer

The cohesion-tension theory explains the ascent of sap as a pull from the top acting on an unbroken column of water that is held together by cohesion. As water evaporates from the leaves during transpiration, it lowers the water potential there and sets up a tension, a pull, at the top of the xylem. Because water molecules are cohesive and cling to one another, this pull is passed down the whole column, drawing water up from the roots. The column must stay unbroken: if an air bubble breaks it, the cohesion is lost and that vessel can no longer lift water.

False Confidence Alert
Students often write that water is pushed up from the roots. In the cohesion-tension theory the water is pulled from the top, and the pull works only because cohesion holds the column unbroken.

Question 36

On a still night, drops of water gather at the edges of some leaves. Explain what root pressure is, give one piece of evidence for it, and state why it cannot be the main force raising water in a tall tree.

Model Answer

Root pressure is a push from below, set up when salts are actively pumped into the xylem of the root, lowering its water potential so that water follows by osmosis and is forced up the stem. The evidence for it is guttation: at night, when transpiration is low, drops of water are pushed out at the leaf margins through hydathodes by root pressure. However, root pressure is weak and can lift water only a short way, so it cannot raise water to the top of a tall tree; the main force there is transpiration pull.

False Confidence Alert
The usual mistake is to call root pressure the main force lifting water up a tall tree. It is weak and reaches only a short way, and it is shown by guttation at night, whereas the main force is transpiration pull.

Question 37

The tallest trees lift water higher than any village pump could manage. Explain why transpiration pull alone is able to raise water to the very top of a tall tree.

Model Answer

Transpiration pull can raise water to the top of the tallest tree because the constant evaporation at the leaves keeps up a steady tension on an unbroken, cohesive column of water. So long as the sun drives evaporation from the leaves, water keeps leaving the top of the xylem, and the cohesive column is drawn up behind it without a break. Because the pull comes from the top and is passed down the whole column, it does not weaken with height, so it works whatever the height of the tree. Root pressure and capillarity only assist it.

False Confidence Alert
Students sometimes think a taller tree needs ever more root pressure to push the water higher. It does not, because transpiration pull comes from the top and is passed down an unbroken column, so it works to any height.

Question 38

A sugar molecule and a potassium ion both cross the cell membrane, but they do not obey quite the same rule. Explain why an uncharged solute moves on its concentration gradient alone, while a charged ion moves on an electrochemical gradient.

Model Answer

An uncharged solute, such as a sugar, moves only on its concentration gradient because it carries no electric charge. Having no charge, it is not pushed or pulled by the electrical state of the membrane, so the one thing that drives it is the difference in its concentration between the two sides, and it moves from where it is more concentrated to where it is less.

A charged ion, such as potassium, moves on an electrochemical gradient because it feels both its concentration difference and the electrical charge across the membrane. The membrane normally carries a charge, and this electrical force adds to or opposes the concentration force, so the ion answers to the two together; that combined gradient is what we call electrochemical.

False Confidence Alert
Many students treat an ion just like a sugar, as though only its concentration mattered. An ion also feels the charge across the membrane, so its movement is set by the electrochemical gradient, not by the concentration gradient alone.

Question 39

The membrane lets some ions through pores that can open and shut. Explain how an ion channel works, and why such channels are described as selective.

Model Answer

An ion channel is a protein with a water-filled pore through which ions cross the membrane, and it is often gated, opening or closing in answer to a signal. When the gate opens, ions pass through the pore down their gradient; when it shuts, they cannot pass. The gate may open to a change in voltage or to a particular molecule binding to it, so the cell decides when ions move.

A channel is selective because its pore is built to fit only ions of a certain size and charge. Each kind of channel admits its own ion and turns the others away, which lets the cell control exactly which ions enter or leave.

False Confidence Alert
A common error is to say the channel pumps the ions across. A channel only opens a passive route, so the ions move down their own gradient through it and no energy is used.

Question 40

Some substances are too large or too particular to slip through a channel, so a carrier protein ferries them instead. Explain how a carrier protein moves a solute across the membrane, and how it differs from a channel.

Model Answer

A carrier protein moves a solute by binding it on one side of the membrane and then changing shape to release it on the other side. The solute fits a particular site on the carrier; the carrier flexes, taking the solute through, then returns to its first shape to pick up another. This binding and flexing works much like an enzyme handling its substrate.

A carrier differs from a channel in being slower but able to handle a wider range of solutes, and in being able to work either passively or actively. A channel is an open pore that lets ions rush through down their gradient, whereas a carrier handles one solute at a time and, when it uses energy, can even move a solute against its gradient.

False Confidence Alert
Students often say a carrier protein always uses energy. It does not, for carrier transport is passive when it runs down the gradient, as facilitated diffusion, and active only when it pumps a solute against the gradient.

Question 41

The sodium-potassium pump is the best known of the membrane pumps, and it never stops working in a living cell. Draw a large, labelled diagram of the sodium-potassium pump in the cell membrane, then state how it uses ATP to move the two kinds of ion.

Model Answer

The labelled sodium-potassium pump is shown below.

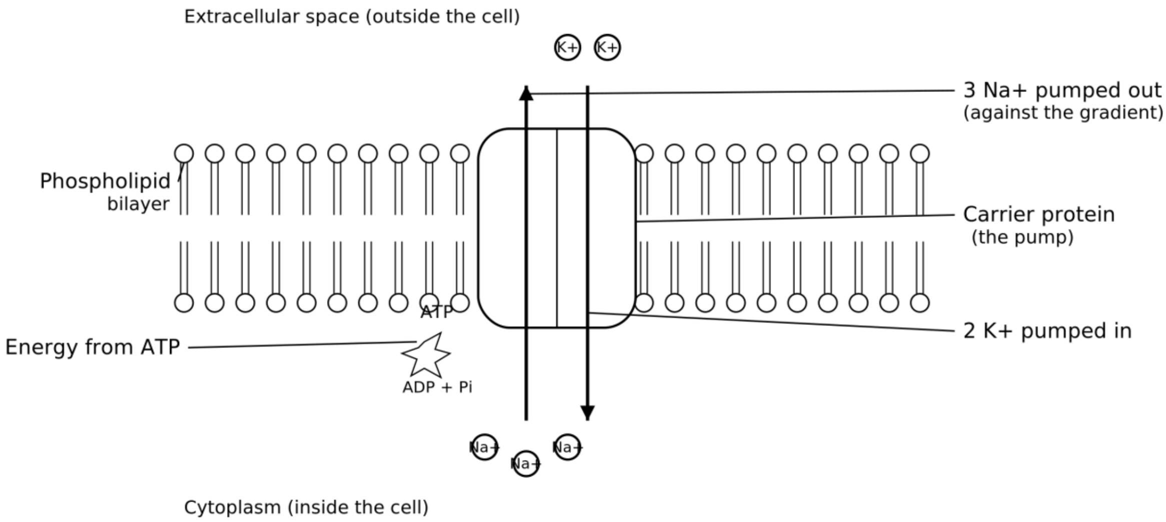


Figure 1.8: *The sodium-potassium pump in the cell membrane.*

The pump uses the energy from ATP to drive the ions against their gradients: as one molecule of ATP is split into ADP and phosphate, the carrier protein changes shape and forces three sodium ions out of the cell and two potassium ions in.

False Confidence Alert
The commonest error is to draw the ions moving down their gradients, as if no energy were needed. Show three sodium ions driven out and two potassium ions in, against their gradients, powered by the splitting of ATP.

Question 42

Not every pump leaves the membrane in the same electrical state once it has worked. Distinguish an electroneutral pump from an electrogenic pump, giving an example of each.

Model Answer

The two kinds of pump differ in whether they change the net charge across the membrane:

1) **Electroneutral pump:** it moves an equal amount of charge in each direction, so the membrane is left with no net change of charge; the H+/K+-ATPase, which pumps one H+ out for each K+ taken in, is an example.

2) **Electrogenic pump:** it moves unequal amounts of charge, so it leaves a net charge across the membrane; the Na+/K+-ATPase, pumping three Na+ out for every two K+ in, is an example, as is the H+-ATPase.

False Confidence Alert
Students often confuse the two pumps. The mark is in the net charge: an electroneutral pump leaves none, as the H+/K+-ATPase does, while an electrogenic pump leaves a net charge, as the Na+/K+-ATPase does.

Question 43

Most of the water a plant takes up never stays in it, but escapes into the air. Explain what transpiration is and the routes by which a plant loses its water vapour.

Model Answer

Transpiration is the loss of water vapour from a plant, chiefly by evaporation from the leaves into the drier air outside. It leaves the plant by three routes:

1) **Through the stomata:** about nine-tenths of the water lost passes out as vapour through the open stomatal pores.
2) **Through the cuticle:** a small amount, about one-tenth, evaporates straight through the waxy cuticle of the leaf.
3) **Through the lenticels:** a tiny amount escapes through the lenticels, the small openings in the bark of stems.

False Confidence Alert
A common mistake is to call any loss of water transpiration, including the liquid drops of guttation. Transpiration is the loss of water as vapour, and by far the greatest part of it goes through the stomata.

Question 44

When the guard cells fill with water the pore between them opens, even though both cells swell. Explain how the change in turgor of the guard cells opens and closes the stoma.

Model Answer

The stoma opens because the two guard cells become turgid and bow apart, and it closes when they lose water and slacken together. When water enters the guard cells by osmosis they swell; but because the inner wall, next to the pore, is thicker and less stretchy than the thin outer wall, the outer wall lengthens more and the cell curves into a kidney shape. The two cells therefore bow away from each other and the pore between them opens. When the guard cells lose water and become flaccid they straighten, come together, and the pore closes.

False Confidence Alert
The usual error is to forget the unequal walls and argue that swelling should close the pore. It is the thin outer wall stretching more than the thick inner wall that curves each guard cell, so the cells bow apart and the pore opens.

Question 45

Scientists have explained the opening of stomata in two different ways, and the later explanation is now preferred. Compare the starch-sugar hypothesis with the potassium-ion hypothesis, and say why the potassium-ion hypothesis is favoured.

Model Answer

The starch-sugar hypothesis says the guard cells open the pore by turning starch into sugar, while the potassium-ion hypothesis says they do it by pumping in potassium ions. In the first, sugar made in daylight lowers the water potential of the guard cells, so water enters them by osmosis; in the second, potassium ions, together with chloride ions, are actively pumped into the guard cells in the light, and this lowers the water potential so that water enters.

The potassium-ion hypothesis is favoured because it fits the evidence that the older one cannot. Experiments show that stomata can open even when there is far too little sugar to draw in the water, and that potassium builds up in the guard cells as they open; the slow change of starch to sugar is also too sluggish to move water as fast as the stomata are seen to respond.

False Confidence Alert
Students sometimes give the starch-sugar hypothesis as the accepted explanation. It has been set aside because the sugar made is too little and too slow, while the potassium-ion hypothesis, backed by the measured build-up of potassium, is the one now favoured.

Question 46

A stoma looks quite different when it is open and when it is shut. Draw labelled diagrams of a pair of guard cells with the stoma open and with it closed, and mark the thickened inner wall that makes the opening possible.

Model Answer

The open and the closed stoma are shown below.

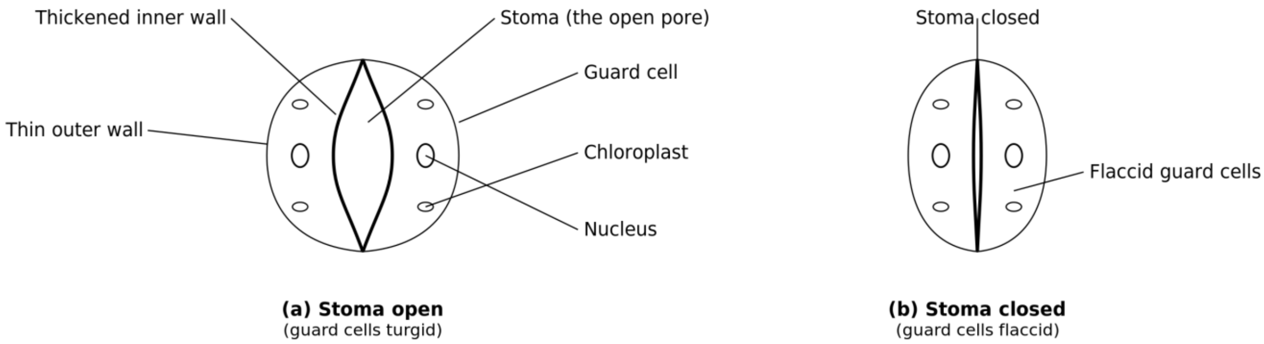


Figure 1.9: *A pair of guard cells with the stoma (a) open and (b) closed.*

The thickened inner wall is the key to the opening: because it is far less stretchy than the thin outer wall, the turgid guard cell curves away from the pore, so the open stoma shows the cells bowed apart while the closed stoma shows them straight and together.

False Confidence Alert
The commonest error is to draw the guard-cell walls the same thickness all round. Show the inner wall, next to the pore, clearly thicker than the outer wall, because that difference is what makes the cells bow apart when they swell.

Question 47

The rate at which a plant transpires rises and falls with the weather, and depends, too, on the plant itself. Set out the external and the internal factors that affect the rate of transpiration, saying how each one changes it.

Model Answer

The factors are of two kinds, those in the surroundings and those in the plant. The external factors are:

1) **Humidity:** the drier the air, the steeper the water potential gradient out of the leaf, so the faster the transpiration.
2) **Wind:** moving air sweeps away the moist layer at the leaf surface, keeping the gradient steep and speeding transpiration.
3) **Temperature:** warmth gives the water molecules more energy and lowers the humidity of the air, so transpiration rises.
4) **Light:** light opens the stomata, so transpiration is faster in bright light and slower in the dark.
5) **Soil water:** when the soil is dry the plant has little water to spare, so transpiration falls.

The internal factors are:

1) **Leaf surface area:** the larger the leaf area, the more surface there is from which to lose water, so the faster the transpiration.
2) **Thickness of cuticle:** a thicker waxy cuticle cuts down the water lost through the leaf surface.

3) **Number and position of stomata:** the more stomata there are, and the more exposed they are, the faster the loss of water.

False Confidence Alert
A bare list that does not say which way each factor pushes the rate scores little, and mixing the plant's own features with the weather loses the structure. Keep the external and internal factors apart, and say for each whether it speeds transpiration or slows it.

Question 48

On a cool, still morning some plants carry drops of water at their leaf edges, and this is not the same as the vapour they breathe out by day. Distinguish guttation from transpiration.

Model Answer

Guttation and transpiration both lose water from the plant, but they differ in several ways:

1) **Form of the water:** guttation loses liquid water in drops, whereas transpiration loses water as vapour.
2) **Route:** guttation passes through special pores called hydathodes at the leaf margin, whereas transpiration goes mainly through the stomata.
3) **Driving force:** guttation is pushed out from below by root pressure, whereas transpiration is drawn out by evaporation, the transpiration pull.
4) **Time of day:** guttation happens at night and early morning when transpiration is low, whereas transpiration is fastest by day.
5) **What the water carries:** the drops of guttation contain dissolved salts, whereas the vapour of transpiration is pure water.

False Confidence Alert
Students often mistake the dew on a leaf for guttation. Dew is water from the air condensing on the cool leaf, whereas guttation is the plant's own water pushed out through the hydathodes by root pressure.

Question 49

The food a plant makes in its leaves must reach roots, fruits and buds that cannot feed themselves. Explain what is meant by translocation, using the terms source and sink, and explain why it can run in either direction, unlike the flow in the xylem.

Model Answer

Translocation is the carrying of manufactured food, mainly sugar, through the phloem from where it is made or stored to where it is used or stored. The place that supplies the food, such as a photosynthesising leaf, is called the source, and the place that receives it, such as a growing root or fruit, is called the sink.

Translocation can run in either direction because a part of the plant may be a source at one time and a sink at another. In the wet season a storage root gives up its food and acts as a source, sending sugar up to the new shoots, while in the growing season it receives food and acts as a sink. The xylem, by contrast, carries water in one direction only, always upward from the roots.

False Confidence Alert
Many students say the phloem always carries food downwards from the leaves. It carries food towards any sink, upward or downward, because a store can be a source in one season and a sink in another.

Question 50

Although a plant makes glucose in its leaves, it is mostly sucrose that travels in the phloem. Explain why sucrose, rather than glucose, is the sugar the plant moves about.

Model Answer

Sucrose is chosen for transport because it is freely soluble, so it is easily carried in the sap, yet chemically rather inactive, so it is not used up on the way. Being a disaccharide, sucrose dissolves readily and moves easily in the watery phloem sap; but unlike glucose it does not readily enter the cell's reactions, so it reaches the sink unchanged. On arrival it is broken down to glucose and fructose, ready to be used or stored.

> **False Confidence Alert**
> A common mistake is to say the plant transports glucose. It is sucrose that moves, because it is soluble yet unreactive, and it is only changed back to glucose once it reaches the sink.

Question 51

From the green cells where it is made, a sugar molecule must find its way to a root far below. Describe the path that manufactured food follows from the leaf to a sink.

Model Answer

The food made in the leaf passes from the photosynthesising cells into the phloem, travels along the sieve tubes, and is unloaded at the sink. Sugar made in the mesophyll cells is first loaded into the companion cells and then into the sieve tube members, the conducting cells of the phloem. It then moves along the continuous sieve tubes, through their sieve plates, towards the sink; at the sink, such as a root or a fruit, the sugar is unloaded from the sieve tubes for use or storage.

> **False Confidence Alert**
> Students sometimes route the food through the xylem. The manufactured food travels in the phloem, along the sieve tubes, from the leaf source to the sink.

Question 52

Several features of the phloem make it well suited to carrying large amounts of food over long distances. Set out the main features of translocation in the phloem.

Model Answer

The phloem shows several features that fit it for translocation:

1) **Large amounts are carried:** the quantity of food the plant uses and stores shows that the phloem moves a great deal of material.
2) **The flow is rapid:** food moves through the sieve tubes far faster than it could travel by diffusion alone.
3) **The distance is long:** in a tall tree the food travels many metres from the leaves down to the roots.
4) **Only the young phloem conducts:** the newly formed phloem, the metaphloem, does the carrying, while the older phloem is crushed and stops conducting.

> **False Confidence Alert**
> A common error is to say that all the phloem conducts food. Only the young, living phloem, the metaphloem, carries food; the older phloem is crushed as the stem grows and no longer conducts.

Question 53

The most widely accepted explanation of how food moves in the phloem was put forward by Münch in 1930. Explain how the mass-flow hypothesis accounts for the movement of food from source to sink.

Model Answer

The mass-flow hypothesis explains translocation as a bulk flow of sap driven by a difference in pressure between the source and the sink. At the source, sugar is actively loaded into the sieve tubes, which lowers their water potential, so water enters from the nearby xylem by osmosis and raises the pressure there. At the sink, sugar is removed from the sieve tubes, so water leaves them and the pressure falls. Because the source is at high pressure and the sink at low pressure, the sugary sap flows in mass from source to sink down the pressure gradient.

False Confidence Alert
Students often say the sugar simply diffuses along the phloem. In the mass-flow hypothesis the whole sap is pushed bodily from source to sink by a pressure difference, set up by the loading of sugar and the entry of water by osmosis.

Question 54

Münch built a working model of two joined osmometers to show how a difference in pressure can drive a flow. Draw a labelled diagram of Münch's mass-flow model, and state what each of the two containers represents in the plant.

Model Answer

Münch's mass-flow model is shown below.

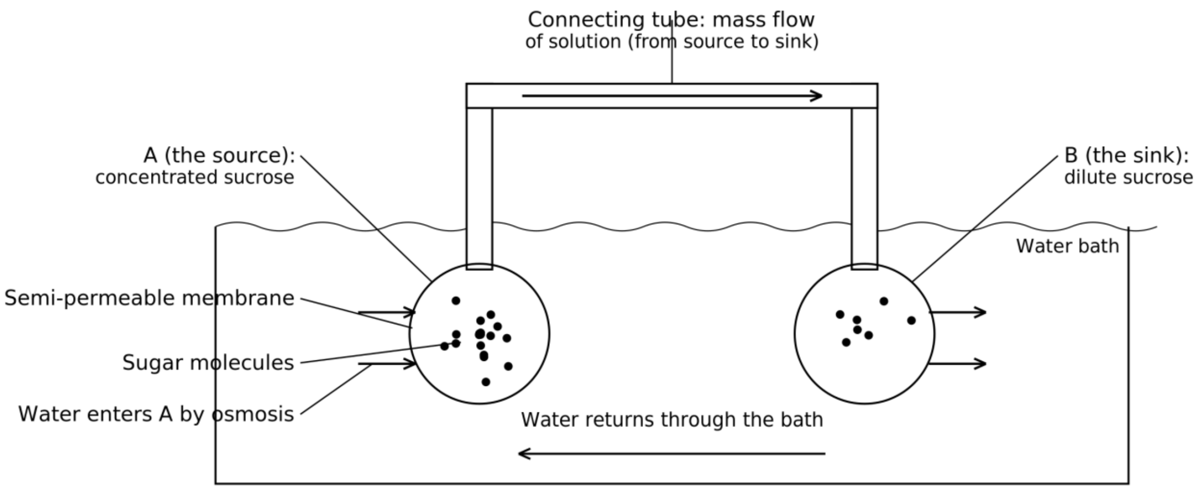


Figure 1.10: *Münch's mass-flow model of translocation.*

Container A, holding the concentrated sucrose, represents the source such as a leaf, and container B, holding the dilute sucrose, represents the sink such as a root: water entering A raises its pressure, so the solution flows through the tube to B, just as sap flows from source to sink in the plant.

False Confidence Alert
The commonest error is to show the solution flowing from the dilute side to the concentrated side. Show the mass flow going from the concentrated source (A) to the dilute sink (B), and include the semi-permeable membranes through which water enters.

Question 55

The mass flow keeps going only because sugar is put into the phloem at one end and taken out at the other. Explain the loading of sucrose at the source and its unloading at the sink, and why these steps need energy.

Model Answer

At the source, sucrose is actively loaded into the sieve tubes, and this needs energy because the sugar is moved against its concentration gradient. The companion cells use ATP to pump sucrose from the leaf cells into the sieve tubes, building a high concentration there; this draws in water by osmosis and creates the pressure that drives the flow.

At the sink, sucrose is unloaded from the sieve tubes into the receiving cells, again against its gradient and so again needing energy. Removing the sugar lowers its concentration in the sieve tubes at the sink, water leaves, and the pressure there falls, which keeps the sap flowing towards the sink.

False Confidence Alert
A common mistake is to treat the loading and unloading of sugar as passive. Both are usually active, using ATP to move sucrose against its gradient, which is why phloem that has been poisoned stops translocating.

Question 56

Several observations support the idea that food moves through the phloem by mass flow. Give the evidence for the mass-flow hypothesis, and say what each observation shows.

Model Answer

Several observations support the mass-flow hypothesis:

1) **The aphid stylet:** when a feeding aphid is cut from its mouthpart, sap keeps flowing from the stylet for a long time, showing the phloem sap is under pressure as the hypothesis requires.
2) **The high pH of the sap:** the phloem sap has a higher pH than expected, because hydrogen ions are actively pumped out during the loading of sugar.
3) **The speed of movement:** food moves through the phloem far faster than diffusion could carry it, which fits a bulk flow driven by pressure.
4) **The match of rate to pressure:** the measured rate of transport agrees with the pressure differences measured between the sources and the sinks.

False Confidence Alert
Many students give the observations but never say what they prove, and the mark is for the link. End each piece of evidence by stating that it supports the movement of food by mass flow under pressure.

Question 57

Water and food both travel through a plant, but in different tissues and by different means. Distinguish translocation in the phloem from the ascent of sap in the xylem.

Model Answer

The two transport streams differ in several ways:

1) **Tissue:** translocation takes place in the phloem, whereas the ascent of sap takes place in the xylem.
2) **Material carried:** the phloem carries manufactured food, mainly sugar, whereas the xylem carries water and dissolved mineral salts.
3) **Direction:** translocation can go either upward or downward, whereas the ascent of sap goes upward only.
4) **Driving force:** translocation is driven by a pressure difference set up by active loading, whereas the ascent of sap is drawn up by the transpiration pull.
5) **Living or dead cells:** the phloem sieve tubes are living, whereas the xylem vessels are dead at maturity.

False Confidence Alert
Students often muddle the two streams. Keep them apart: food in the living phloem moving either way by a pressure difference, against water and salts in the dead xylem moving up only by the transpiration pull.

REAL QUESTIONS

These questions test whether you can take the biology of transport and use it in real, Tanzanian situations: the farm, the orchard, the garden and the kitchen. A few present a confident but mistaken claim for you to put right. As before, each answer leads with the mark-bearing point in bold, and a False Confidence Alert names the mistake that most often costs marks.

Question 58

A young bean plant must carry water up from its roots while, at the same time, sending the food its leaves make down to those same roots. Explain how the plant carries out these two opposite journeys at once.

Model Answer

The plant carries out the two journeys in two separate tissues that lie side by side in its vascular bundles, the xylem and the phloem. The xylem carries water and mineral salts in one direction only, upward from the roots to the leaves, pulled up by the transpiration stream. The phloem carries the food made in the leaves the other way, down to the roots and to wherever else it is needed, driven by the pressure of translocation. Because the upward water and the downward food travel in different tissues, the two streams pass each other without interfering.

> **False Confidence Alert**
> Students sometimes picture a single set of tubes carrying both water and food in opposite directions at once. The two journeys are kept in separate tissues, water up the xylem and food through the phloem, so they never clash.

Question 59

In some orchards a complete ring of bark is cut from right around the trunk of a fruit tree, and in time the tree dies. The bark that is removed takes the phloem with it. Explain why this kills the tree.

Model Answer

Removing the ring of bark cuts through the phloem all the way round, so manufactured food can no longer be carried down from the leaves to the roots. The leaves above the ring still make sugar and still receive water through the xylem, which lies deeper and is not removed, so the top of the tree lives on for a time. But the roots below the ring are now cut off from their food supply; with no sugar reaching them they cannot respire, grow or take in water, so they die, and the whole tree follows.

> **False Confidence Alert**
> Many students say ringing kills the tree by cutting off its water. It does not touch the xylem, which lies deeper, so it is the roots starving of food, not a lack of water, that kills the tree.

Question 60

A student stands the cut stem of a balsam plant in red dye for an hour, then cuts the stem across to look at the inside. Explain what the student will see, and what it shows about the path of water.

Model Answer

The student will see that only the xylem is stained red, which shows that water travels up the plant through the xylem. As the plant draws water up the cut stem, the red dye is carried along with it; because the dye goes only where the water goes, it stains the xylem and not the other tissues. When the stem is cut across, the ring of red marks the position of the xylem, proving that it is the xylem, and not the phloem, that carries water up the plant.

> **False Confidence Alert**
> A common mistake is to expect the whole stem to turn red. Only the xylem stains, because only the xylem carries the water that brings the dye, and showing this is the very point of the experiment.

Question 61

A banana plant grows very fast, stands several metres tall and bears broad leaves that lose water quickly. Explain how its xylem and phloem are suited to supporting such rapid growth.

Model Answer

The xylem and phloem suit the banana's fast growth by carrying water and food quickly and in large amounts, keeping pace with the plant. The wide, hollow xylem vessels carry a large, swift stream of water up to the broad leaves, replacing the great amount they lose and supplying the water for photosynthesis. The phloem carries the plentiful sugar the leaves make to the fast-growing stem, the developing fruit and the underground sucker, so that every growing part is fed. A plant growing this fast could not supply its distant parts without such ready transport.

False Confidence Alert
Students often think only of the water stream when a plant grows fast. The xylem supplies the thirsty leaves with water, but it is the phloem that carries the sugar to the rapidly growing stem and fruit.

Question 62

A cut flower left out of water soon wilts, but it revives when its stem is put in water, and it revives best if the stem is cut again under the water. Explain these observations.

Model Answer

The flower wilts because, cut off from water, it keeps losing water by transpiration until its cells lose their turgor, and it revives when stood in water because the xylem draws the water up again and the cells become turgid once more. A turgid cell is firm and holds the petals and stem up, so as water returns the flower stiffens and stands.

Cutting the stem again under water helps because it removes the air that has been drawn into the xylem. When a stem is cut in the open air, air is sucked into the open vessels and breaks the columns of water, so water can no longer rise; cutting under water lets water, not air, enter the vessels, so the unbroken columns can carry water up to the flower.

False Confidence Alert
Students often miss why the second cut must be made under water. A cut made in air lets air into the xylem and breaks the water columns, so the stem is re-cut under water to keep the columns whole.

Question 63

Kipanga says, with great confidence: '*The phloem is dead and hollow just like the xylem, and it is the xylem that carries the sugary food down from the leaves to the roots.*' Identify the mistakes in his statement and explain what is correct.

Model Answer

Kipanga is wrong on both counts: the phloem is living, not dead, and it is the phloem, not the xylem, that carries the food. The phloem is built of living cells, the sieve tube members kept working by their companion cells; it is only the xylem that is dead and hollow. And it is the phloem that carries the sugary food from the leaves to the roots and other parts, by translocation. The xylem carries water and mineral salts, and only upward, so it cannot be the tissue taking food down to the roots.

False Confidence Alert
Students often correct the second claim but let the first one stand, agreeing that the phloem is dead like the xylem. Put both right: the phloem is living, and it is the phloem, not the xylem, that carries the food.

Question 64

When the bark of some trees is wounded, a sweet, sticky sap oozes out and attracts ants and other insects. Explain which transport tissue this sweet sap comes from, and why it is sweet.

Model Answer

The sweet sap comes from the phloem, because the phloem is the tissue that carries the plant's dissolved sugar. The phloem sieve tubes are full of sugary sap under pressure, translocated from the leaves; when the bark is wounded these sieve tubes are cut and the sap leaks out. It is sweet because its main solute is sucrose, the sugar the leaves make and the plant moves to its sinks. The watery sap of the xylem, by contrast, carries only water and mineral salts and is not sweet.

False Confidence Alert
Students sometimes guess that the sap is xylem sap. The xylem carries only water and mineral salts, whereas the sweet, sugary sap that draws the insects is phloem sap, full of translocated sucrose.

Question 65

Vegetables in a garden often droop in the heat of the midday sun but stand up again in the cool of the evening. Explain these changes in terms of the water in the plant and the state of its cells.

Model Answer

The plant droops at midday because it is losing water by transpiration faster than its roots can take it up, so its cells lose water and become flaccid. As a cell loses water its vacuole shrinks and the cytoplasm no longer presses out against the wall; the cell loses its turgor, and without the firmness of turgid cells the soft stems and leaves can no longer hold themselves up, so the plant droops.

By evening the plant stands up again because, as transpiration slows in the cool, the roots catch up and water returns to the cells by osmosis. The returning water refills the vacuoles and restores the turgor pressure against the walls, so the cells become firm once more and the stems and leaves are held up again.

False Confidence Alert
Students sometimes think a plant drooping at midday is dying or that the soil has run dry. It is only a temporary loss of turgor, because water is leaving faster than it is taken up; once transpiration slows, water returns by osmosis and the plant recovers.

Question 66

Along the coast, fish are preserved by packing them in plenty of salt, and at home fruit is preserved by boiling it in a thick sugar syrup. Explain how the salt and the sugar keep the food from going bad.

Model Answer

The salt and the sugar preserve the food by drawing water out of any spoilage microbes by osmosis, so that the microbes cannot live and multiply. The strong salt or sugar solution around the food has a much lower water potential than the inside of a bacterium or mould; water therefore leaves the microbe by osmosis across its membrane, and the microbe is dehydrated and either dies or cannot grow. With the decay organisms unable to act, the food does not rot, and the loss of water also makes the food itself a poorer home for decay.

False Confidence Alert
A common mistake is to say the salt or sugar simply poisons the microbes. It works by osmosis, drawing water out of the microbes into the strong solution, so that they are dehydrated and cannot grow.

Question 67

A maize plant can go on absorbing nitrate ions from the soil even when there is already more nitrate inside its root cells than in the soil water around them. Explain how the root is able to do this.

Model Answer

The root takes in the nitrate by active transport, which can move an ion against its concentration gradient by using energy. Because there is already more nitrate inside the cell than outside, the ion cannot enter by diffusion, which moves substances only from a high to a low concentration. Instead, carrier proteins in the membrane of the root hair cell bind the nitrate and pump it inward, against the gradient. The energy for this pumping comes from ATP made by the cell in respiration, which is why a waterlogged, airless root soon stops taking up mineral salts.

> **False Confidence Alert**
> Students often say the nitrate simply diffuses into the root. It cannot, because it is moving from a lower to a higher concentration, and that needs active transport, a carrier protein and energy from respiration.

Question 68

Kipanga announces, with great confidence: *'Osmosis is just the diffusion of any dissolved substance through a membrane, and active transport, like everything else, simply moves things from where they are crowded to where they are not.'* Point out what is wrong in his statement and give the correct account.

Model Answer

Kipanga is wrong that osmosis is the diffusion of any dissolved substance: osmosis is the movement of water alone, across a partially permeable membrane, from a higher to a lower water potential. It is the water that moves, not the dissolved solutes, and it must cross a partially permeable membrane; the ordinary diffusion of a dissolved substance is a different process.

He is also wrong that active transport moves things from crowded to less crowded: active transport moves substances against their concentration gradient, from where they are less concentrated to where they are more. That is exactly what makes it active, because moving substances the other way, up the gradient, needs energy from ATP, whereas only passive processes such as diffusion run from high to low concentration.

> **False Confidence Alert**
> Students often catch the osmosis error but let the second claim pass, agreeing that transport runs from crowded to less crowded. Correct both: osmosis moves only water across a partially permeable membrane, and active transport moves solutes against the gradient, using energy.

Question 69

A seedling lifted carelessly from a nursery bed and replanted often wilts for several days, even when it is watered. Knowing what the root hairs are and the work they do, explain why this happens.

Model Answer

The seedling wilts because lifting it tears off the delicate root hairs, and without them the root can no longer take up enough water to replace what the leaves lose. The root hairs are fine outgrowths of the epidermal cells that give the root its huge surface for absorbing water and mineral salts; they are very delicate and are stripped off when a plant is pulled from the soil. With its root hairs gone, the seedling absorbs little water while its leaves go on transpiring, so it wilts. It recovers only after some days, once the root has grown new root hairs and absorption is restored.

> **False Confidence Alert**
> Students often blame the wilting on dry soil or too little watering. The real cause is the loss of the torn root hairs, so the root cannot absorb fast enough until new root hairs grow.

Question 70

Follow a single drop of water as it travels from the surface of a root hair across the cortex to the xylem. Describe the apoplast and the symplast pathways it may take.

Model Answer

Most of the water crosses the cortex by the apoplast pathway, soaking through the cell walls and the spaces between the cells without entering any cytoplasm. From the root hair it passes through the continuous network of wet cellulose walls, moving freely and in large amounts until it reaches the endodermis.

Some of the water crosses by the symplast pathway, passing through the cytoplasm of the cortex cells and moving from one cell to the next through the plasmodesmata. At the endodermis the waterproof Casparian strip blocks the apoplast, so all the water is forced into the symplast to cross the living endodermal cells before it can reach the xylem.

False Confidence Alert
Students often swap the two routes or forget the endodermis. The apoplast goes through the cell walls and the symplast through the cytoplasm, and at the endodermis the Casparian strip forces all the water into the symplast.

Question 71

A tall Eucalyptus by a Tanzanian roadside may stand more than fifty metres high, yet it lifts water from its roots to the topmost leaves without any pump. Explain how the water is raised so high.

Model Answer

The water is raised mainly by the transpiration pull, a suction set up at the top of the tree as water evaporates from the leaves. As water leaves the leaves by transpiration it lowers their water potential and puts the water in the xylem under tension. Because water molecules are cohesive and cling to one another, this pull is passed down the unbroken columns of water in the xylem, drawing water all the way up from the roots. The pull comes from the top, so it does not weaken with height and can raise water even to the crown of so tall a tree; root pressure and capillarity only help.

False Confidence Alert
Students often say root pressure pushes the water to the top. Root pressure is far too weak for a tall tree; the water is pulled up from above by the transpiration pull acting on a cohesive, unbroken column.

Question 72

Early one morning Mr. Mchunguzi notices tiny drops of water sitting along the very edges of the leaves of the grass and the young maize, and by mid-morning they are gone. Explain how these drops form and why they disappear later.

Model Answer

The drops form by guttation, the pushing out of liquid water through special pores at the leaf margins called hydathodes. At night the air is cool and damp and transpiration almost stops, but the roots go on actively taking up salts, and the water that follows them by osmosis builds up a root pressure; this pressure forces water up and out through the hydathodes as drops.

The drops disappear by mid-morning because, as the sun rises and the air warms and dries, transpiration begins again. Once the leaves are losing water as vapour the root pressure no longer forces water out, and the drops already formed simply evaporate into the air.

False Confidence Alert
Students often call these drops dew. Dew is water from the air condensing on a cool surface, whereas these drops are the plant's own water pushed out through the hydathodes by root pressure.

Question 73

A farmer is puzzled that his bean plants wilt in the heat of the afternoon, even though he watered them well in the morning and the soil is still moist. Explain why the plants wilt in spite of the wet soil.

Model Answer

The plants wilt because in the afternoon heat they lose water by transpiration faster than the roots can take it up, even from moist soil. The strong midday sun and the dry air make the leaves transpire very fast; although the soil holds plenty of water, the roots and xylem can move it up only at a limited rate, which falls behind the rate of loss, so the cells lose water and turgor and the plant droops. As the afternoon cools and transpiration slows, uptake catches up and the plants recover, so the wilting is temporary and not a sign of dry soil.

> **False Confidence Alert**
> The farmer's mistake is to think wilting must mean dry soil. Here the soil is moist; the plant wilts only because midday transpiration outruns uptake, and it recovers by itself as the day cools.

Question 74

Plants of dry places, such as the sisal of the drylands and the spiny cactus, are built to lose very little water. Explain how the features of such plants cut down their transpiration.

Model Answer

Plants of dry places have several features that cut down the water lost by transpiration:

1) **Reduced leaf surface:** leaves reduced to spines, as in the cactus, or made narrow and tough, give only a small surface from which water can evaporate.
2) **A thick waxy cuticle:** a heavy cuticle over the leaf and stem greatly reduces the water lost straight through the surface.
3) **Few, sunken stomata:** fewer stomata, often sunk in pits, reduce and shelter the openings through which most water is lost.
4) **Water storage:** fleshy tissues, as in the sisal leaf and the cactus stem, store water to carry the plant through the dry spells.

> **False Confidence Alert**
> Students sometimes say such plants do not transpire at all. They still transpire, but their reduced surface, thick cuticle and few sunken stomata cut the loss down to a minimum.

Question 75

A leafy green vegetable that has flopped over in the sun stands firm again within a few hours of being watered. Explain how the return of water makes a plant that has no wood in it stand up straight.

Model Answer

A soft, non-woody plant is held up by the turgor of its cells, so when watering restores that turgor the plant becomes firm and stands again. As water is taken up and enters the cells by osmosis it fills their vacuoles and presses the cytoplasm out against the cell walls; this turgor pressure makes each cell firm and stiff. Packed tightly together, the many turgid cells give the soft stem and leaves enough rigidity to hold themselves upright. While the plant was short of water its cells were flaccid and could not do this, so it flopped over.

> **False Confidence Alert**
> Students forget that a plant without wood depends on turgor for its support. It is the water-filled, turgid cells pressing on their walls that hold a soft plant up, so losing that water lets it flop.

Question 76

A farmer scatters a potassium fertiliser on the soil around his maize, and within a few days the potassium can be found in the topmost leaves. Explain how the potassium gets from the soil up into the highest leaves.

Model Answer

The potassium first enters the root by active transport, because it has to be taken up against its concentration gradient. The root hair cells use energy from respiration to pump the potassium ions in from the dilute soil water, where they are less concentrated than inside the cell.

Once inside the root, the potassium is carried up to the leaves dissolved in the water of the transpiration stream. It passes into the xylem and is swept upward with the water that is pulled up by transpiration, reaching even the topmost leaves where it is used; in this way the upward water current also delivers the plant's mineral salts.

False Confidence Alert
Students sometimes send the mineral salts up the phloem, or imagine they rise on their own. Mineral salts are taken up actively at the root and then carried up in the xylem, dissolved in the transpiration stream.

Question 77

A careful gardener transplants seedlings late in the evening, shades them for a few days, waters them well, and may even pinch off some of the leaves. Explain how each of these practices helps the seedling to survive.

Model Answer

Each practice helps by cutting the seedling's loss of water while its damaged roots recover:

Transplanting in the evening: the cool, still, damp evening air keeps transpiration low through the night, giving the roots time to settle before the next hot day.

Shading the seedling: shade keeps it cooler and out of the direct sun, so its stomata lose less water by transpiration.

Watering it well: plenty of water in the soil lets the recovering roots take up what they can to replace the losses.

Removing some leaves: fewer leaves mean a smaller surface for transpiration, so the seedling loses less water than its weakened roots can replace.

False Confidence Alert
Students often explain these steps as feeding or strengthening the plant. Each one works by reducing the loss of water by transpiration while the torn roots, short of root hairs, recover their power to absorb.

Question 78

Washing dries fastest, and crops wilt soonest, on a day that is hot, dry and windy. Explain why these three conditions together make a plant lose water so quickly.

Model Answer

Each of the three conditions speeds the loss of water vapour, and together they make transpiration fastest:

Heat: warmth gives the water molecules more energy to evaporate, and it lowers the humidity of the air, so water leaves the leaf faster.

Dry air: the drier the air, the steeper the difference in water potential between the moist leaf and the air outside, so water diffuses out more quickly.

Wind: moving air sweeps away the moist layer that gathers at the leaf surface, keeping the gradient steep and the loss rapid.

False Confidence Alert
Students often credit the heat alone. Dry air steepens the water potential gradient and wind sweeps away the moist layer at the leaf surface, so all three together drive the fastest loss.

Question 79

Kipanga claims: '*Plants open their stomata at night so that they can breathe in the cool air, and water reaches the top of even the tallest tree because root pressure pushes it all the way up.*' Identify the mistakes in his claim and give the correct account.

Model Answer

Kipanga is wrong that stomata open at night for breathing: in most plants the stomata close at night and open by day. The stomata open in the light because that is when the plant needs to take in carbon dioxide for photosynthesis; at night, with no photosynthesis, they close, which also saves water. Plants do exchange gases at night, but by slow diffusion through the leaf, not by opening the stomata.

He is also wrong that root pressure pushes water to the top of the tallest tree: root pressure is weak and reaches only a little way up the stem. The water is drawn up mainly by the transpiration pull from the leaves, acting on a cohesive, unbroken column of water in the xylem, while root pressure and capillarity give only minor help.

False Confidence Alert
Students often spot the night-stomata error but let the root-pressure claim stand, correcting only one of the two. Put both right: stomata open by day to take in carbon dioxide, and the main lifting force is the transpiration pull, not root pressure.

Question 80

A cassava plant stores in its swollen roots the food that its leaves make, and it is these food stores that the farmer harvests and eats. Explain why the transport of food through the phloem matters so much to a crop plant like cassava.

Model Answer

Carrying food through the phloem matters to the plant in several ways, and to the farmer most of all:

1) **Feeding the non-green parts:** the roots, growing buds and developing tubers cannot make their own food, so they depend on the sugar brought to them through the phloem in order to respire and grow.
2) **Building up stores:** the phloem carries the surplus sugar from the leaves to storage organs such as the cassava root, where it is laid down as starch for later use.
3) **Filling the harvest:** the size and the food value of what the farmer harvests, whether cassava roots, maize grain or banana fruit, depend on how much food the phloem delivers to those sinks.

False Confidence Alert
Students sometimes imagine the cassava root makes the starch it stores. The root makes no food of its own; the sugar is made in the leaves and carried to the root through the phloem, where it is then stored as starch.

Question 81

Without a steady stream of water rising through its xylem, a maize crop would soon fail. Explain why the transport of water up to the leaves is so important to the plant.

Model Answer

Water carried up through the xylem is vital to the plant for several reasons:

1) **Photosynthesis:** water is a raw material for making sugar in the leaves, so without it the plant cannot make food.
2) **Support:** water keeps the cells turgid, and this turgor holds up the soft stems and leaves; short of water the plant wilts.

3) **Carrying minerals:** the rising water carries the dissolved mineral salts with it, delivering them from the soil up to the leaves and other parts.
4) **Cooling:** the water that evaporates from the leaves in transpiration cools them, protecting them from overheating in the strong sun.

> **False Confidence Alert**
> Students often give only photosynthesis as the use of water. The rising water also keeps the plant turgid and upright, carries its mineral salts and cools the leaves, and each of these can earn marks.

Question 82

When a complete ring of bark is cut from a branch, the bark just above the ring swells, and any fruit on that branch grows larger than usual, while the part below the ring is starved. Explain why the sugar gathers above the ring.

Model Answer

The sugar gathers above the ring because removing the bark removes the phloem, and the food moving down from the leaves can travel no further than the cut. The leaves above the ring go on making sugar and loading it into the phloem, which would normally carry it downward past that point; with the phloem cut, the sugar can no longer cross the ring, so it builds up in the bark just above it. There the bark swells and the fruit, well supplied with sugar, grows large, while the roots and other parts below the ring, cut off from the food, are starved. This is also why ringing is taken as evidence that the phloem carries food, and carries it downward.

> **False Confidence Alert**
> Students sometimes say the swelling above the ring is a build-up of water. It is a build-up of sugar, because the ring cuts the phloem so the food coming down from the leaves can go no further.

Question 83

A mango or a flame tree may drop its leaves in the dry season and then burst into new leaf again before the rains. Explain how the direction of food movement in the phloem changes between these times, using the ideas of source and sink.

Model Answer

While the tree is in full leaf, the leaves are the source and food moves from them down to the roots and trunk, which act as sinks and store it. The leaves make sugar, load it into the phloem, and it is translocated to the storage tissues of the trunk and roots, where it is laid down for later use.

When the leafless tree bursts into new leaf, the flow reverses: the store becomes the source and the growing buds become the sinks. With no leaves yet to make food, the tree draws on the sugar stored in its trunk and roots; this stored food is now loaded into the phloem and carried upward to the opening buds and new shoots, so the tissue that was a sink now acts as a source. This shows how translocation can run either way as the source and the sink change.

> **False Confidence Alert**
> Students often think the phloem always carries food in one fixed direction. Its direction depends on where the source and the sink lie, so the very same store can send food up in one season and receive it down in another.

Question 84

Kipanga insists: *'The phloem carries food in one direction only, downward from the leaves to the roots, and it does so simply by diffusion, like any dissolved substance spreading out.'* Point out the mistakes in his statement and give the correct account.

Model Answer

Kipanga is wrong that the phloem carries food only downward: it carries food in either direction, from any source to any sink. Food does go down to the roots from the leaves, but it also goes up to growing buds, flowers and fruits, and a store can send food upward when it becomes a source; the direction is set by where the sources and the sinks are, not fixed downward.

He is also wrong that translocation is simple diffusion: it is a bulk flow of sap driven by a difference in pressure, and it uses energy. Sugar is actively loaded into the phloem at the source, water follows by osmosis and builds up a pressure, and the whole sap is then pushed in mass to the sink, far faster than diffusion could move it.

> **False Confidence Alert**
> Students often correct the one-way claim but accept that translocation is mere diffusion. Both are wrong: the phloem carries food either way, from source to sink, and it does so by a pressure-driven mass flow that uses energy.

HOT QUESTIONS

These questions go beyond single facts. They ask you to put ideas together, to weigh evidence and reach a judgement, and to reason your way through unfamiliar cases. As before, each answer leads with the mark-bearing point in bold, and a False Confidence Alert names the mistake that most often costs marks.

Question 85

Imagine a plant in which both conducting tissues suddenly stopped working at the same moment. Predict what would become of the plant, reasoning from the job that each tissue does.

Model Answer

If the xylem stopped, the plant would quickly wilt and dry out, because no water or mineral salts could reach the leaves. The leaves would go on losing water by transpiration with nothing to replace it, so the cells would lose their turgor and the plant would droop; starved of water and minerals, photosynthesis would also halt, and the plant would die of drought even in moist soil.

If the phloem stopped, the leaves might last a while, but the rest of the plant would starve, because no food could be carried to it. The roots, buds and fruits, which cannot make their own food, would receive no sugar; unable to respire or grow, the roots would die, and with the roots gone the whole plant would follow. The plant cannot live without both streams, the one bringing water up and the one taking food out.

> **False Confidence Alert**
> Students often describe only the wilting from xylem failure and forget the starvation from phloem failure. A full answer reasons from both tissues: no water up the xylem dries the plant out, and no food through the phloem starves its non-green parts.

Question 86

The xylem owes its success as a water-carrier to several features: its dead, empty cells, its narrow lignified tubes and its perforation plates. Weigh these features and judge which one contributes most to its efficiency.

Model Answer

All three features matter, but the dead, empty cells joined into open tubes contribute most, because without them the other features would have nothing to act upon. The death of the cells, with the loss of their contents and cross walls, leaves a clear, continuous channel that offers almost no resistance to flow, and this is the very thing that lets water move at all. The perforation plates extend this openness by joining vessel elements into long pipes, and the lignified walls keep those pipes from collapsing under the tension of the rising water, so both of these serve the open channel rather than replace it. The narrow bore aids capillarity and the lignin gives support, but it is the empty, continuous lumen that actually carries the water, so it weighs heaviest.

> **False Confidence Alert**
> Students often just list the features without weighing them, which a judging question will not reward. You must compare the features and commit to one, giving the reason it outweighs the others.

Question 87

Kipanga argues that *a sieve tube member could manage perfectly well on its own*, while **Kipute** argues that *it would die without its companion cell.* Judge whose view is correct, and justify your decision.

Model Answer

Kipute is correct: a sieve tube member could not function for long without its companion cell. At maturity the sieve tube member loses its nucleus and most of its organelles, so it can no longer make proteins or release enough energy to keep itself alive and to load sugar. The companion cell keeps its own nucleus and is packed with mitochondria, and through the plasmodesmata it controls the sieve tube member and supplies the ATP for loading. Cut off from its companion cell, the sieve tube member would soon fail, so Kipanga is wrong.

> **False Confidence Alert**
> Students sometimes side with the first speaker, because the sieve tube is the cell that visibly carries the food. The marks are for seeing that the enucleate sieve tube depends on its companion cell, and for justifying that verdict, not merely asserting it.

Question 88

A student examines an unfamiliar plant tissue and finds it made of living, elongated cells joined end to end by perforated cross-walls, with no lignin thickening. Decide whether this tissue is more like xylem or like phloem, and give your reasons.

Model Answer

The tissue is more like phloem than xylem, because it is living and unlignified and its perforated cross-walls resemble sieve plates. Xylem, the water-carrier, is built of dead cells with thick lignified walls, so a living, unlignified tissue cannot be xylem. Phloem, the food-carrier, is built of living cells, the sieve tube members, joined end to end by perforated sieve plates and lacking lignin, which is exactly what is described. The living nature, the absence of lignin and the perforated cross-walls together point firmly to phloem.

> **False Confidence Alert**
> Students often seize on the perforated cross-walls and call the tissue xylem, because vessels have perforation plates too. The deciding clues here are that the cells are living and unlignified, which rules out the dead, lignified xylem and points to phloem.

Question 89

For water to travel all the way from the soil into the xylem at the centre of the root, the water potential must change in a definite way along that route. State how the water potential must change from the soil to the xylem, and explain why such a gradient, rather than any pumping of the water itself, is enough to draw the water steadily inward.

Model Answer

The water potential must fall steadily, becoming more and more negative, from the soil through the root hair, the cortex and the endodermis to the xylem. The soil water has the highest (least negative) water potential and the xylem sap the lowest (most negative), so every cell along the route has a slightly lower water potential than the one just outside it.

Because water always moves by osmosis from a higher to a lower water potential, this downhill gradient draws water inward at every step without the plant having to pump the water itself. The gradient is kept up at the inner end, as transpiration steadily removes water from the xylem and as salts are loaded into it to hold its water potential low, so the water goes on flowing inward passively, down a slope it is never pushed up.

> **False Confidence Alert**
> Students often say that water is pumped into the root, but the water itself moves passively down the water potential gradient. What the plant spends energy on is loading salts to keep that gradient steep, not on moving the water.

Question 90

On a cool, still, humid night transpiration almost stops, yet a well-watered plant goes on absorbing mineral salts and may even force water up its stem as root pressure. Explain how the plant can still take up water and salts when the transpiration pull has all but disappeared, and say what this reveals about the part active transport plays in uptake.

Model Answer

Even with the transpiration pull gone, the root cells go on actively pumping mineral salts from the soil into the root and on into the xylem, using energy (ATP) from respiration. Because this loading is active, it does not depend on any pull from the leaves and can carry on through the night.

As the salts build up in the xylem, they lower its water potential, so water follows them inward by osmosis and is pushed up the stem as root pressure. This reveals that the uptake of salts is at bottom an active process driven by respiration, and that it can in turn drive the uptake of water even when the passive transpiration pull is absent.

> **False Confidence Alert**
> Students often treat all uptake as one passive process tied to transpiration, and so cannot explain how it carries on at night. The key is that salts are actively pumped using respiratory energy, and the water then follows them osmotically as root pressure.

Question 91

Kipanga insists that *osmosis must use up the cell's energy, since taking in water is surely a form of uptake;* **Kipute** replies that *osmosis needs no energy from the cell at all.* Judge whose view is correct, and justify your decision.

Model Answer

Kipute is correct: osmosis needs no energy from the cell, because it is simply the diffusion of water down a water potential gradient. The water molecules move of their own accord from a region of higher water potential to one of lower, driven by their own random motion and by the difference in potential, not by any ATP the cell spends. The cell spends energy only when it moves a substance against its gradient, as in the active pumping of salts, and the water that then follows by osmosis still moves passively. Kipanga has confused taking water in with spending energy to do so, and is therefore wrong.

> **False Confidence Alert**
> Students sometimes assume that anything entering the cell must cost it energy, and so side with the wrong speaker. Only movement against a gradient needs ATP; osmosis runs downhill on the water potential gradient and is free to the cell.

Question 92

Transpiration has often been called a necessary evil. Drawing on both the harm it does to the plant and the benefits it brings, evaluate this description and reach a judgement on whether it is a fair one.

Model Answer

The description is fair, because transpiration is both a serious cost to the plant and an unavoidable benefit it cannot do without. On the harmful side, it drains the plant of enormous quantities of water, and on a hot, dry, windy day this loss can outrun uptake, wilt the leaves and, if it continues, kill the plant; the plant is also forced to spend resources on adaptations to curb it.

On the necessary side, transpiration is the price the plant pays for keeping its stomata open to take in the carbon dioxide it needs for photosynthesis, and it brings real gains of its own. The stream of escaping water creates the transpiration pull that draws water and dissolved mineral salts up to the leaves, and the evaporation cools the leaf in strong sun. Weighing the two, the costs are real but the benefits, together with the fact that the water loss is the inevitable companion of gas exchange, make transpiration genuinely necessary, so the phrase is fair.

False Confidence Alert
Students often list only the harm and dismiss transpiration as pure waste, which cannot reach a balanced judgement. The marks come from weighing both sides, showing that the water loss is the unavoidable price of open stomata and that it usefully pulls water and salts upward.

Question 93

Suppose a mutant plant grew an endodermis whose cells lacked the Casparian strip. Predict how this would affect the movement of water and mineral salts into the xylem, and explain the reasoning behind your prediction.

Model Answer

The plant would lose its control over what enters the xylem, and its root pressure would fail, because the Casparian strip is the waterproof band that normally forces water and salts to pass through the living cells of the endodermis. Normally the strip blocks the apoplast (the cell-wall route), so water and dissolved salts must cross a cell membrane before reaching the xylem, and at that membrane the plant can select which minerals to admit and can stop them leaking back out. Without the strip, water and salts would slip straight through the cell walls into the xylem unchecked, the plant could no longer choose what it takes up, and it could not hold a high salt concentration in the xylem; since root pressure depends on that built-up concentration lowering the xylem water potential, root pressure would be lost.

False Confidence Alert
Students often forget what the Casparian strip actually does and so cannot say what its loss would cost. State plainly that it blocks the apoplast route to force water through the cell membranes, so without it the plant loses both its checkpoint on minerals and its root pressure.

Question 94

On a single bright, breezy afternoon the rate at which a leaf transpires is set both by the conditions around it and by the structure of the leaf itself. Explain how these outside conditions and the leaf's own features act together to fix the rate of transpiration at that moment.

Model Answer

The outside conditions decide how strongly the air pulls water out of the leaf at that moment. Bright light opens the stomata wider, high temperature gives the water molecules more energy to evaporate, low humidity steepens the gradient between the moist leaf and the drier air, and the breeze sweeps away the water vapour as fast as it escapes; together they raise the evaporative demand on the leaf.

The leaf's own structure decides how much of that demand the plant actually allows to be met. The number and spread of its stomata, the area of its surface, the thickness of its waxy cuticle and whether the stomata are open or closed all set the size of the doorway through which water may leave. The true rate is therefore the two working together: the air may pull hard, but a leaf with few stomata and a thick cuticle still loses little, while a thin-cuticled leaf with many open stomata loses much, so neither the conditions nor the structure can be judged alone.

> **False Confidence Alert**
> Students often answer with the external conditions only (heat, wind, low humidity) and forget the leaf's own structure. A full answer shows the two acting together: the conditions set the demand for water, while the leaf's stomata and cuticle set how much it actually lets go.

Question 95

Kipanga explains the opening of stomata by the old starch-sugar hypothesis, while Kipute explains it by the uptake of potassium ions. Judge which account better explains how a stoma opens in the light, and justify your choice.

Model Answer

Kipute's potassium-ion account is the better explanation of how a stoma opens in the light. On this view the guard cells actively take in potassium ions in the light, using energy from ATP; the ions lower the water potential of the guard cells, so water enters them by osmosis, they swell and become turgid, and their unevenly thickened walls make them bow apart so the pore opens. The older starch-sugar hypothesis, which supposed that starch in the guard cells turns into sugar to raise their solute content, is now thought too slow to account for the speed with which stomata are seen to open, so it is no longer accepted as the main explanation. Kipute's account therefore fits the evidence better, and Kipanga's is the outdated one.

> **False Confidence Alert**
> Students often back the starch-sugar hypothesis because it sounds simpler, without noting that it is too slow to explain the rapid opening that is actually observed. The marks go to choosing the potassium-ion account and explaining how the active uptake of ions lowers the guard cells' water potential.

Question 96

Trace the complete journey of a single water molecule from the soil water surrounding a root to the moment it escapes into the atmosphere, naming in order the cells and tissues it passes and the forces that move it.

Model Answer

The journey begins when the molecule is absorbed from the soil into a root hair cell by osmosis, the soil water having a higher water potential than the sap of the root hair. From there it crosses the cortex from cell to cell by the apoplast, symplast and vacuolar pathways until it reaches the endodermis, where the waterproof Casparian strip forces it to pass through the cell membrane, the symplast route, before it enters the xylem at the centre of the root.

Once in the xylem the molecule is carried upward in a continuous, cohesive column, pushed a little from below by root pressure but drawn mainly from above by the transpiration pull. The water molecules hold together by cohesion and cling to the vessel walls by adhesion, so the whole thread is pulled up unbroken. Reaching a leaf, the molecule leaves the xylem and enters a mesophyll cell, evaporates from the wet cell wall into the air spaces of the leaf, and finally diffuses out through an open stoma into the atmosphere as water vapour.

> **False Confidence Alert**
> Students often leap straight from soil to leaf and leave the forces out. Name each force in its place: osmosis into the root hair, the transpiration pull lifting the cohesive column, and evaporation followed by diffusion out through the stomata.

Question 97

Two forces are said to raise water up a plant: root pressure pushing from below and the transpiration pull drawing from above. Weigh the two against each other and judge which is the more important in the ascent of sap, especially in a tall tree.

Model Answer

The transpiration pull is by far the more important force in the ascent of sap, above all in a tall tree. Root pressure is weak: it works only from below, shows itself mainly at night when transpiration is low, is missing altogether in many plants, and can push water up by no more than a few metres, so it could never lift water to the crown of a tall tree. The transpiration pull, by contrast, arises from evaporation at the leaves and tugs on the whole cohesive water column from the top, so it can act over the full height of even the tallest tree and operates strongly whenever the plant is transpiring. Weighing the two, root pressure plays at most a small, supporting part, such as in guttation or in refilling broken columns, while the transpiration pull is the main engine of the ascent of sap.

False Confidence Alert
Students often treat the two forces as equal partners and award them the same weight. The marks are for judging the transpiration pull the major force, since root pressure is weak and cannot raise water to the top of a tall tree.

Question 98

The mass-flow hypothesis is the most widely accepted explanation of translocation, yet it is not free of difficulties. Evaluate the hypothesis, weighing the evidence that supports it against the objections raised against it, and judge how well it accounts for the movement of food in the phloem.

Model Answer

The hypothesis explains the bulk movement of food as a flow driven by a pressure difference between source and sink, and several lines of evidence support it. It proposes that sugar loaded into the sieve tubes at the source lowers their water potential, so water enters from the xylem by osmosis and raises the pressure there, while at the sink the sugar is removed, water leaves and the pressure falls, so the sap is pushed from the high-pressure source to the low-pressure sink. Aphid-stylet studies show that phloem sap is indeed under pressure and flows faster nearer the source, and ringing experiments show sugar piling up above the ring, both pointing to a pressure-driven flow from source to sink.

Against this, there are real objections, so the hypothesis cannot be accepted as a complete account. It is a purely physical, passive model, yet translocation stops when the sieve tubes are killed or starved of oxygen, which a passive pressure-flow should not require; different solutes are seen to move in different directions or at different speeds in the same tissue, which one simple bulk flow cannot easily explain; and the sieve plates seem to stand in the way of such a flow. Weighing the two, the hypothesis accounts well for the bulk transport of sugar down a pressure gradient and is backed by the pressure and ringing evidence, but it cannot by itself explain the need for living, respiring cells; it is therefore the best general explanation we have, though an incomplete one.

False Confidence Alert
Students often present the mass-flow hypothesis as if it were proved beyond doubt and offer only the supporting evidence. A judging answer must also raise the objections, above all its dependence on living cells, before reaching a balanced verdict.

Question 99

Münch modelled translocation with two osmometers, one holding a strong sugar solution and one a weak solution, joined by a tube and standing in water. Use this model to explain how a pressure difference can drive sap from a source to a sink in a real plant, and point out the one important feature of the living plant that the model leaves out.

Model Answer

In the model, the osmometer of strong sugar solution behaves like the source and the weak one like the sink, and the pressure difference between them drives the flow along the tube. The strong solution draws in water osmotically from the surrounding water, so its pressure rises and it pushes solution along the connecting tube to the weak osmometer, where the lower pressure lets water pass out again. In the plant this matches the loading of sugar into the sieve tubes at the source, where water then follows from the xylem and the pressure rises, and the unloading of sugar at the sink, where water leaves and the pressure falls, so the sap is driven from source to sink down the pressure gradient.

What the model leaves out is the living, energy-spending cell. In the apparatus the concentration difference simply runs down as the solutions equalise, and the flow then stops; in the living plant the difference is held up because sugar is actively loaded at the source and actively unloaded at the sink, using energy from respiring cells. The model is purely physical and has no living cells, so it cannot show this active maintenance of the gradient that keeps real translocation going.

> **False Confidence Alert**
> Students often describe Münch's apparatus but stop before saying what it fails to capture. The mark you must secure is that the model's gradient runs down and stops, whereas the living plant keeps it up by actively loading and unloading sugar.

Question 100

Kipanga argues that*, since the xylem carries water perfectly well through dead cells, the phloem could equally carry food through dead cells;* **Kipute** argues that *the phloem must be built of living cells.* Judge whose view is correct, and justify your decision.

Model Answer

Kipute is correct: the phloem must be built of living cells, because its kind of transport is quite different from that of the xylem. Water rises in the xylem by a passive physical pull, the transpiration pull, which needs no help from the cells, so dead, empty tubes serve it perfectly. Translocation, by contrast, depends on sugar being actively loaded into the sieve tubes at the source and unloaded at the sink, and this active work needs energy from respiration, which only living cells, the companion cells working through the living sieve tube members, can supply. This is why phloem transport stops when the tissue is killed or deprived of oxygen, while xylem flow does not, so Kipanga's analogy breaks down and is wrong.

> **False Confidence Alert**
> Students often accept the xylem-phloem analogy and conclude that dead cells would do for both. The marks are for seeing that phloem transport is active and needs the energy of living cells, unlike the passive pull that drives the dead xylem.

Chapter 2

TRANSPORTATION IN ANIMALS

BINDER QUESTIONS

Work through each question in order: attempt your own answer first, then check it against the model answer and against the False Confidence Alert that follows, which warns of the mistake that most often costs marks.

Question 1

A single-celled *Amoeba* living in a pond takes in all the oxygen and food it needs straight through its surface, but a goat feeding on the bank beside that pond could never survive in the same way. Explain why a large, active animal cannot rely on diffusion alone to supply its cells, and why this shortfall forces it to run a dedicated transport system.

Model Answer

Diffusion is rapid only across very short distances. As an animal grows larger, its volume rises far faster than its surface area, so its surface-area-to-volume ratio falls and the body surface becomes far too small to serve all the cells inside it. The innermost cells also lie deep within the body, many centimetres from that surface, and diffusion over such a distance is hopelessly slow. A goat is warm-blooded and active as well, so its cells consume oxygen and release carbon dioxide and wastes quickly, and diffusion simply cannot move materials in and out fast enough to keep pace with this demand.

A large, active animal therefore needs a mass-transport system. This is a circulating fluid, the blood, driven by a pump through a network of vessels, which carries oxygen and digested food to every cell and removes carbon dioxide and other wastes, while also spreading hormones and heat. By bringing the supply close to each cell and keeping it moving, the system shortens the final diffusion distance at the tissues and overcomes the limits that the animal's size and activity would otherwise impose.

> **False Confidence Alert**
> Students often answer only that the animal is too big and stop there. The mark is for the reason size matters, that the surface-area-to-volume ratio falls and the diffusion distance to the inner cells grows too great for diffusion to supply them quickly enough.

Question 2

Whenever the transport system of a mammal is drawn, the same three working parts appear again and again. Describe these three components of the vertebrate circulatory system and state clearly the job that each one carries out in moving materials around the body.

Model Answer

1) **The blood:** the fluid connective tissue in which the materials are carried, with oxygen, digested food, carbon dioxide, wastes, hormones and heat either dissolved in its plasma or held within its cells.
2) **The blood vessels:** the network of tubes, namely the arteries, the veins and the capillaries, that holds the blood and directs it to and from every organ along defined routes.
3) **The heart:** the muscular pump that contracts rhythmically to push the blood through the vessels and keep it flowing steadily in one direction.

Each part depends on the others, and it is this division of labour, a fluid to carry, vessels to direct and a pump to drive, that lets materials reach cells lying far from any exchange surface.

> **False Confidence Alert**
> Students often name the three parts but forget to give the work each does, and so lose half the marks. Each component scores only when it is tied to its job, the blood that carries, the vessels that contain and direct, and the heart that drives the flow.

Question 3

A bicycle pump, a length of hosepipe and a bucket of water are each useless on their own for carrying water to a distant garden, yet together they manage the task. Using this idea, explain why the heart, the blood vessels and the blood can move materials only when all three act together, and state what would fail if any one of them were absent.

Model Answer

The three parts succeed only in combination, because each supplies what the others lack. The blood can carry dissolved materials but cannot move itself; the vessels can hold the blood and aim it at the organs but cannot push it; and the heart can build up pressure but has nothing to deliver without a fluid to drive, and nowhere to send it without tubes to carry it through. Working together, the heart raises the pressure, the vessels confine and direct that pressurised blood, and the blood ferries its load to and from the cells.

Remove any single part and transport collapses. Without the blood there is no medium to carry oxygen, food or wastes at all; without the vessels the blood cannot be held under pressure or guided to particular organs, so it cannot be circulated; and without the heart the blood has no driving force and simply stands still, leaving the cells dependent once more on slow diffusion. The system is therefore only as useful as its three parts working as one.

> **False Confidence Alert**
> Students often treat the heart on its own as the transport system and write only about its pumping. The marks require showing that the pump is powerless without a fluid to drive and without vessels to confine and direct that flow.

Question 4

Before the blood is taken apart and studied piece by piece, it helps to meet it through the three broad jobs it does for the whole body. Outline these three roles of blood, transport, protection and regulation, giving one clear example of each so that the difference between them is obvious.

Model Answer

1) **Transport:** it carries materials from one part of the body to another, for example oxygen from the lungs to a working muscle, digested food from the gut, carbon dioxide and urea to the organs that remove them, and hormones from the glands to their target organs.
2) **Protection:** it defends the body against disease and against its own loss, for example the white cells that engulf invading bacteria and the platelets and fibrin that clot a cut and seal the wound.
3) **Regulation:** it keeps the internal conditions of the body steady, for example spreading heat from the core to hold a constant body temperature, and buffering hydrogen ions to keep the blood pH within its narrow range of about 7.35 to 7.45.

> **False Confidence Alert**
> Students often blur protection and regulation and offer an example that fits the wrong role. Protection is defence against invaders and against blood loss, while regulation is the steadying of conditions such as temperature, pH and water, and the example given must match the role named.

Question 5

A sample of fresh blood left to stand, or spun gently in a tube, settles into a pale straw-coloured upper layer and a dark red lower layer. Explain what each layer is, and then say why three measured properties of blood, its split of roughly 55 percent upper layer to 45 percent lower layer, its pH of about 7.35 to 7.45, and its thickness of about four and a half to five and a half times that of water, each suit the work the blood must do.

Model Answer

The two layers are the parts of blood, separated by their density. The pale upper layer is the plasma, the watery fluid that makes up about 55 percent of the blood and carries the dissolved materials. The dark red lower layer is the packed cells, about 45 percent of the blood and mostly red blood cells, which sink because they are denser than the plasma. Together the two show that blood is a fluid tissue, a fluid (plasma) in which living cells are suspended.

Each measured property fits the blood to its task. The roughly 55 to 45 balance gives enough fluid to keep the cells flowing freely and to hold the dissolved load, while still packing in enough red cells to carry plenty of oxygen. The pH of about 7.35 to 7.45, slightly alkaline, is the narrow band within which the blood's enzymes and its haemoglobin work properly, so the blood is buffered to hold it steady. The viscosity of about four and a half to five and a half times that of water makes the blood thick enough to move as a steady stream under pressure, yet not so thick that the heart cannot push it through the narrow vessels.

False Confidence Alert
Students often quote the percentages and the pH as bare figures and stop, which earns nothing on its own. Each value scores only when it is tied to a consequence, the balance of fluid to cells, the narrow range the enzymes and haemoglobin tolerate, or the load the heart is able to pump.

Question 6

Every cell in a large mammal, from a brain cell to a toe muscle, depends on a delivery and collection service it never sees. Describe how the blood carries out its transport role, naming the main materials it moves and stating, for each one, where the blood picks it up and where it delivers it.

Model Answer

1) **Respiratory gases:** oxygen is picked up at the lungs and delivered to all the respiring cells, while carbon dioxide is picked up at those cells and delivered to the lungs to be breathed out.
2) **Digested food:** glucose, amino acids and other products are picked up at the gut wall and the liver and delivered to the cells that use or store them.
3) **Nitrogenous wastes:** urea is picked up where it is made in the liver and delivered to the kidneys, which remove it from the body.
4) **Hormones:** these are picked up from the endocrine glands that make them and delivered to the particular target organs they control.
5) **Heat:** warmth is picked up from busy organs such as the liver and the muscles and spread to cooler parts and to the skin.

False Confidence Alert
Students often answer only that the blood carries oxygen and stop there. Full marks need the range of cargoes and, for each, both the place it is picked up and the place it is delivered, because transport is defined by the journey from one part of the body to another.

Question 7

Besides ferrying materials about, the blood does two further jobs that keep the body safe and steady. Explain how the blood protects the body and how it regulates the body's internal conditions, giving an example of each so that the two roles are not confused.

Model Answer

1) **Protection:** the blood defends the body against disease and against the loss of blood itself, for example through the white cells that engulf or make antibodies against invading microbes, and through the platelets and fibrin that clot a wound and seal it.
2) **Regulation:** the blood keeps the internal conditions steady, for example by carrying heat from the core to the skin to hold a constant body temperature, and by buffering hydrogen ions to keep the pH close to 7.4, as well as balancing water and salts.

False Confidence Alert
Students often give a clotting or white-cell example when asked about regulation, or a temperature example when asked about protection. Protection is defence against invaders and against bleeding, while regulation is the steadying of conditions such as temperature, pH and water, and each example must match the role it is given for.

Question 8

The blood's most urgent cargo is oxygen, yet oxygen dissolves only very slightly in watery plasma. Explain how the blood overcomes the poor solubility of oxygen so as to carry it from the lungs to the tissues, and how the same arrangement lets the oxygen be released exactly where it is needed.

Model Answer

Oxygen is carried bound to haemoglobin inside the red blood cells, not dissolved in the plasma. In the lungs, where oxygen is plentiful, each haemoglobin molecule binds oxygen to form oxyhaemoglobin. Because every red cell is packed with haemoglobin, this loads far more oxygen into the blood than the plasma could ever dissolve on its own.

At the tissues the binding reverses. Where the cells are respiring, oxygen is scarce, so the oxyhaemoglobin gives up its oxygen, which then diffuses out to the cells. The joining of oxygen to haemoglobin is therefore reversible, holding firm where oxygen is plentiful in the lungs and letting go where oxygen is scarce in the tissues, so that haemoglobin collects oxygen in one place and releases it in another.

False Confidence Alert
Students often write that oxygen is carried dissolved in the plasma. Only a very small amount travels that way, and the marks are for oxygen carried bound to haemoglobin as oxyhaemoglobin inside the red cells.

Question 9

Carbon dioxide leaving the respiring cells must be carried back to the lungs, and the blood manages this in three different ways at the same time. Describe the three ways in which the blood transports carbon dioxide from the tissues to the lungs, and then explain why the chloride shift is needed while the largest of the three is carried out.

Model Answer

1) **As hydrogencarbonate ions, the largest share:** inside the red cell the carbon dioxide joins water, under the enzyme carbonic anhydrase, to form carbonic acid, which at once splits into hydrogen ions and hydrogencarbonate ions; the hydrogencarbonate ions then pass out into the plasma.
2) **As carbaminohaemoglobin:** some of the carbon dioxide binds directly to the haemoglobin protein in the red cells.
3) **Dissolved in the plasma:** a small amount is simply carried dissolved as carbon dioxide in the watery plasma.

The chloride shift keeps the first and largest route working. As the negatively charged hydrogencarbonate ions move out of the red cell into the plasma, they would leave the cell with too much positive charge inside. To balance this, negatively charged chloride ions move from the plasma into the red cell. This inward movement of chloride, the chloride shift, keeps the red cell electrically balanced so that carbon dioxide can keep being converted to hydrogencarbonate and carried away.

False Confidence Alert
Students often name only the hydrogencarbonate route and leave out the chloride shift altogether. The mark for the shift is for the inward movement of chloride ions that balances the charge left behind when the hydrogencarbonate ions move out of the red cell.

Question 10

The exchange of the two respiratory gases at a respiring tissue can be drawn as a single connected scheme. Draw a labelled diagram to show how oxygen and carbon dioxide are exchanged between a respiring body cell and a red blood cell, and then state in one sentence what the chloride shift achieves on your diagram.

Model Answer

The labelled diagram is shown in Figure 2.1 below. It shows the body cell using oxygen and releasing carbon dioxide, and the red blood cell taking up that carbon dioxide and releasing oxygen, with the reactions that convert the carbon dioxide laid out inside the red cell.

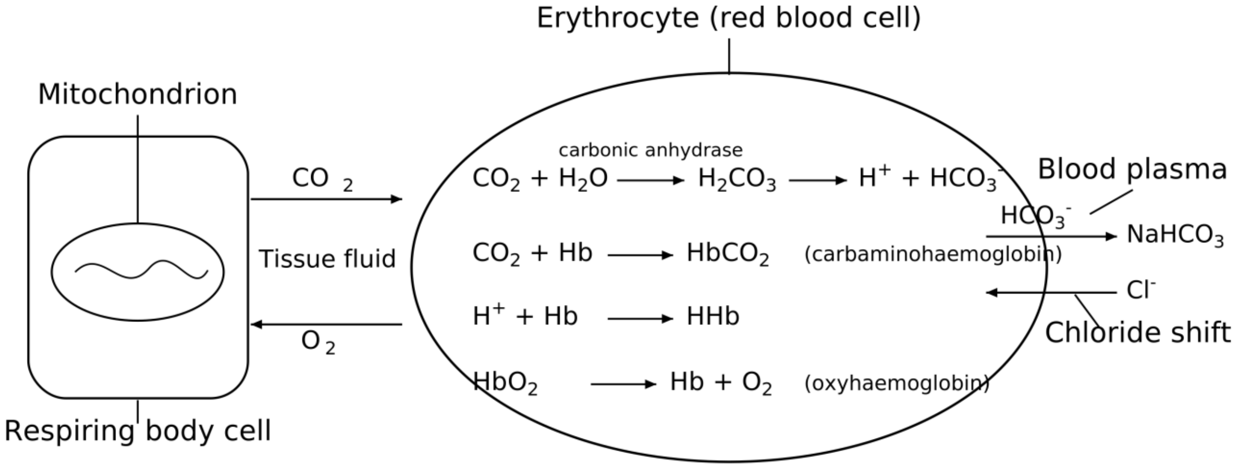


Figure 2.1: *The transport of oxygen and carbon dioxide in the blood at a respiring tissue.*

What the chloride shift achieves: on the diagram it is the inward movement of chloride ions that balances the charge left behind as hydrogencarbonate ions move out of the red cell into the plasma, so that carbon dioxide can keep being carried away as hydrogencarbonate.

> **False Confidence Alert**
> Students often draw the oxygen and carbon dioxide arrows pointing the same way. At a respiring tissue the arrows must oppose each other, with oxygen passing from the red cell to the body cell and carbon dioxide passing from the body cell to the red cell.

Question 11

The many parts of blood are easiest to hold in the mind as a branching scheme that splits the whole into its two halves and then into their contents. Draw such a scheme for the composition of blood, dividing whole blood into its two main parts and naming what each part contains, and then state which of the two parts carries the dissolved materials.

Model Answer

The labelled scheme is shown in Figure 2.2. It divides whole blood into the plasma and the formed elements. The plasma holds water together with its dissolved proteins (the albumins, globulins and fibrinogens), nutrients, amino acids, nitrogenous wastes, gases and electrolytes; the formed elements are the erythrocytes, the leukocytes (the granulocytes and the agranulocytes) and the platelets.

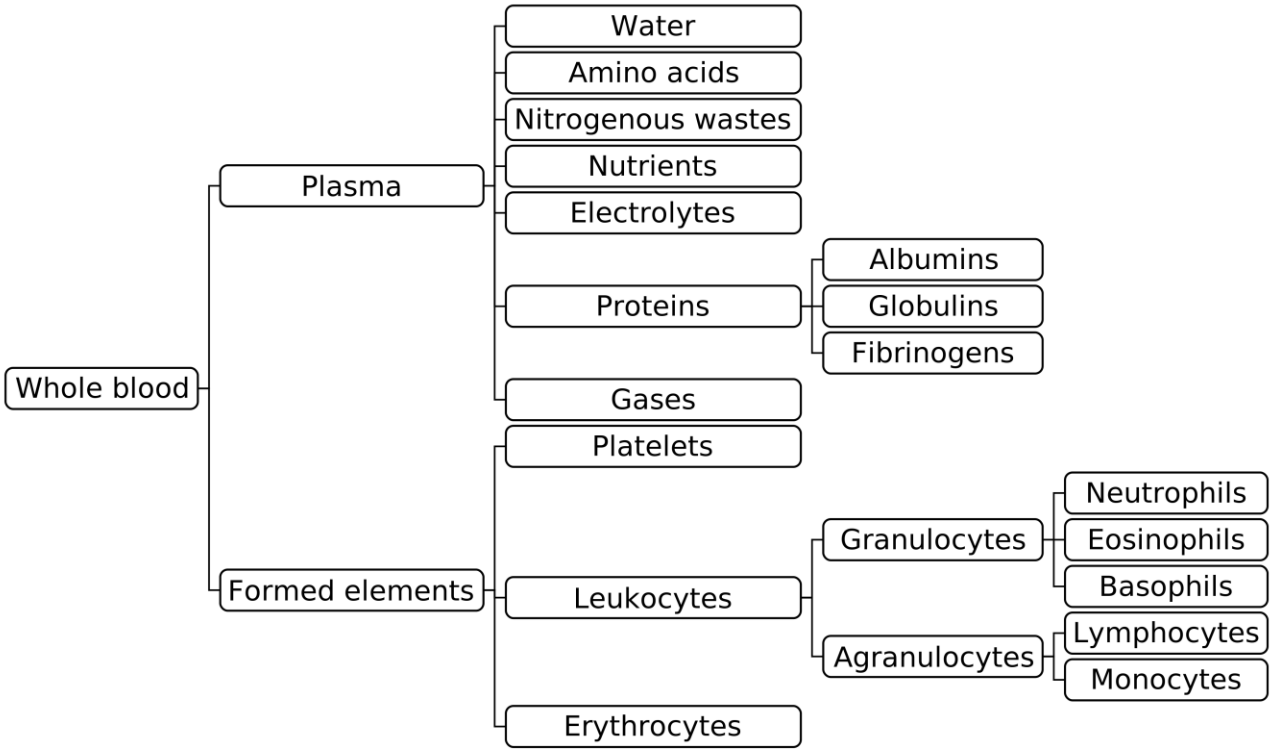


Figure 2.2: *The composition of blood, divided into plasma and the formed elements.*

Which part carries the dissolved materials: the plasma. The dissolved substances are all carried in the watery plasma, while the formed elements are the cells and cell fragments suspended in that plasma.

False Confidence Alert
Students often list the cells and the dissolved substances together as though they sat in the same place. The dissolved materials are carried in the plasma, while the formed elements are the cells and fragments suspended in it, and the scheme must keep the two apart.

Question 12

When the cells are spun out of a blood sample, a pale straw-coloured fluid is left behind, and most of it is simply water. Explain what blood plasma is and why it is about nine-tenths water, showing how that high water content lets the plasma do its job.

Model Answer

Plasma is the pale yellow liquid part of blood, a little over half its volume, in which the cells are suspended and the dissolved materials are carried. The cells float in it, and everything the blood transports in solution, from glucose to hormones, is dissolved in it. About nine-tenths of the plasma is water, and the remaining tenth is the dissolved load of proteins, nutrients, gases, salts, wastes and hormones.

The plasma is mostly water because water is the medium that dissolves and carries nearly everything the blood moves. As a liquid solvent, water lets glucose, salts, wastes, hormones and gases dissolve and travel freely, and it stays fluid enough to flow through the narrowest vessels while carrying the cells along with it. Water also takes in and spreads heat readily, which is what lets the blood share warmth around the body in its regulating role.

False Confidence Alert
Students often describe plasma as just water and forget the load it carries. Plasma is about nine-tenths water, but it is the dissolved tenth, the proteins, foods, salts, wastes and gases, that makes the water useful as a transport medium.

Question 13

Of everything dissolved in the plasma, the proteins are the most plentiful, and they fall into three kinds with different jobs. Name the three groups of plasma proteins and explain the role that each one plays for the body.

Model Answer

1) **Albumins:** the smallest and most plentiful of the three; they draw water back into the blood by osmosis, and so help to keep the right amount of fluid in the vessels, and they also carry some substances about in the plasma.
2) **Globulins:** these include the antibodies that defend the body against disease, and others that transport materials such as lipids and cholesterol around the body.
3) **Fibrinogens:** these are the clotting proteins; when a vessel is injured they are converted into fibrin, the threads that form the mesh of a clot and seal the wound.

> **False Confidence Alert**
> Students often remember fibrinogen for clotting but swap the roles of albumins and globulins. Albumins mainly hold water in the blood by osmosis and carry substances, while globulins include the antibodies of defence, and matching the wrong role to the wrong protein loses the mark.

Question 14

Besides its proteins, the plasma carries a constantly changing load of smaller substances, each picked up at one organ and set down at another. Describe the other materials, apart from the proteins, that are dissolved in the plasma, and for each one say where it is picked up and where it is going.

Model Answer

1) **Nutrients:** glucose, fatty acids, glycerol and vitamins are picked up at the gut wall and the liver and carried to the cells that use or store them.
2) **Amino acids:** absorbed from digested food and released as body proteins are broken down, they are carried to the cells that build new proteins.
3) **Nitrogenous wastes:** urea, uric acid and creatinine are picked up from the liver and tissues where they form and carried to the kidneys to be removed.
4) **Respiratory gases:** a small amount of oxygen and carbon dioxide travels dissolved in the plasma (most is carried by the red cells), passing between the lungs and the respiring tissues.
5) **Electrolytes:** mineral ions such as sodium, potassium, calcium, chloride and hydrogencarbonate are absorbed from food and adjusted by the kidneys, and they keep the salt balance, the pH and the osmotic pull of the blood steady.

> **False Confidence Alert**
> Students often lump all the plasma solutes together as food. The plasma also carries nitrogenous wastes bound for the kidneys, gases passing between the lungs and the tissues, and electrolytes that balance the blood, and each deserves its own job and journey.

Question 15

A red blood cell does essentially one job, the carrying of oxygen, and almost everything about its shape and contents is bent to that end. Explain how the red blood cell is adapted to carry oxygen, taking its biconcave shape, its lack of a nucleus and mitochondria, and its filling of haemoglobin, and showing how each feature helps the job.

Model Answer

1) **Biconcave disc shape:** it gives the cell a large surface area for its volume, so that oxygen and carbon dioxide can diffuse in and out quickly, and the thin centre keeps no part of the interior far from the surface.

2) **No nucleus:** the space a nucleus would take up is instead filled with haemoglobin, so the cell carries more oxygen, and losing the nucleus also helps give the cell its flattened biconcave shape.
3) **No mitochondria:** the mature cell respires without oxygen and so does not use up any of the oxygen it is carrying, leaving all of it to be delivered to the tissues.
4) **Packed with haemoglobin:** about a third of the cell is haemoglobin, the red pigment that actually binds the oxygen, so each cell carries a large load.
5) **Small and flexible:** the cell is tiny and bends easily, so it can pass in single file through the narrowest capillaries and bring oxygen close to every body cell.

False Confidence Alert
Students often write only that the red cell contains haemoglobin and stop. Full marks need several adaptations each tied to the job, the biconcave shape for surface area, the loss of the nucleus to make room for haemoglobin, and the lack of mitochondria so the cell does not use the oxygen it carries.

Question 16

Having thrown out its nucleus and mitochondria while it was being made, a mature red blood cell pays a price for being such an efficient oxygen carrier. Explain why such a cell can neither divide to make new cells nor repair itself when damaged, and say what this means for how the body keeps up its supply.

Model Answer

A red blood cell can neither divide nor repair itself because it has lost its nucleus. The nucleus holds the genetic material (DNA) that directs cell division by mitosis and that orders the making of the new proteins needed to mend damage; with no nucleus the cell can do neither. Having also lost its mitochondria, it cannot raise much energy for such work in any case.

This means the body must keep replacing its red cells from elsewhere. Because worn or damaged red cells cannot mend or multiply themselves, they are removed and fresh ones are made in the red bone marrow, so that the total number, and with it the oxygen-carrying power of the blood, is held steady.

False Confidence Alert
Students often say the red cell cannot divide simply because it is small or specialised. The exact reason is the loss of the nucleus, which carries the DNA needed both for mitosis and for making the proteins of repair.

Question 17

The shape of the red blood cell is best understood by drawing it both from above and in section. Draw the red blood cell as seen from the surface and in section through its centre, label the drawing, and then explain what the biconcave shape does for the cell.

Model Answer

The labelled drawing is shown in Figure 2.3. Seen from above the cell is a rounded disc with a paler, thinner centre; in section it is a biconcave lens, thick at the rim and thin in the middle, bounded by the cell surface membrane and filled with haemoglobin, with no nucleus.

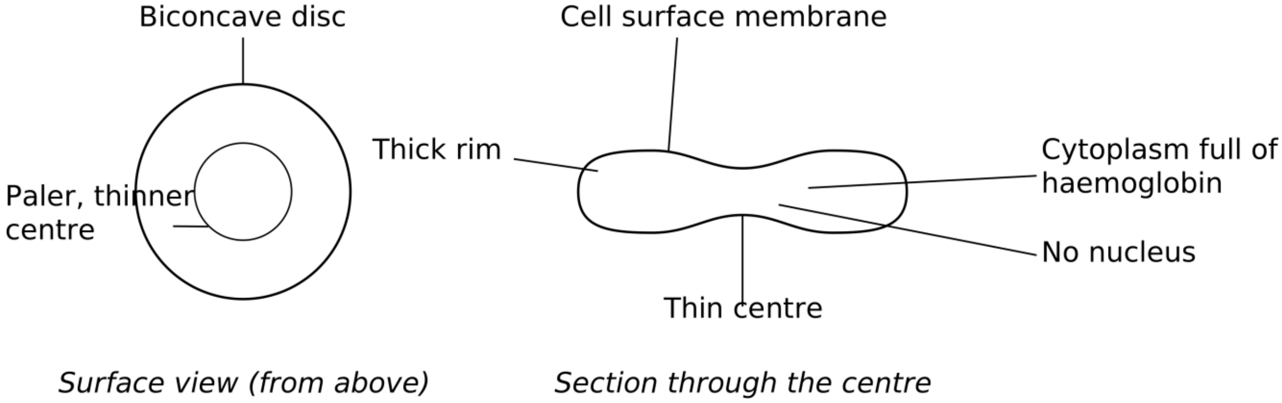


Figure 2.3: *The red blood cell in surface view and in section through the centre.*

What the biconcave shape does: it gives the cell a large surface area for its volume, which lets oxygen and carbon dioxide diffuse in and out rapidly, and the thin centre keeps the inside of the cell close to the surface, so no haemoglobin lies far from where the gases cross.

False Confidence Alert
Students often draw only the round surface view and leave out the section, losing the marks for the biconcave shape. Both views are needed, and the section must show the cell thick at the rim and thin at the centre.

Question 18

The white blood cells are far fewer than the red, but they are the body's defence force, and they fall into two families. Describe how the white blood cells are divided into granulocytes and agranulocytes, naming the cells in each family and giving the defensive job of each.

Model Answer

The white cells are grouped by whether their cytoplasm holds visible grains. The granulocytes have grainy cytoplasm; the agranulocytes do not.

1) **Neutrophils (a granulocyte):** the most numerous white cells; they engulf and destroy bacteria by phagocytosis.
2) **Eosinophils (a granulocyte):** they attack larger parasites such as worms and help to damp down allergic reactions.
3) **Basophils (a granulocyte):** they release histamine, which widens vessels during inflammation, and heparin, which prevents the blood from clotting.
4) **Lymphocytes (an agranulocyte):** they drive the immune response, making antibodies against invaders and holding the memory of past infections.
5) **Monocytes (an agranulocyte):** the largest white cells; they become macrophages that engulf microbes and clear away dead cells and debris.

False Confidence Alert
Students often name the white cells but forget what each one does, or muddle the two families. The granulocytes are the neutrophils, eosinophils and basophils, the agranulocytes are the lymphocytes and monocytes, and each must be given its own defensive role.

Question 19

Unlike the red cells, which throw away their nucleus and organelles, the white cells keep theirs throughout life. Explain why the white blood cells keep their nuclei and organelles when the red cells lose theirs, relating the difference to the very different jobs the two kinds of cell do.

Model Answer

The white cells keep their nuclei and organelles because their work demands them. A white cell must make proteins such as enzymes and antibodies, move about, engulf microbes, and, for some kinds, divide and multiply rapidly when an infection strikes; all of this needs the nucleus, with its DNA, to direct the making of proteins and the dividing of the cell, and needs mitochondria and other organelles to supply the energy and do the work.

The red cell, by contrast, has only to carry oxygen. It does this better by losing those very parts, which makes room for more haemoglobin and gives it the biconcave shape, even though the loss leaves it unable to divide or repair. The difference in what the two cells contain therefore follows directly from the difference in what they have to do.

> **False Confidence Alert**
> Students often state that white cells keep their nuclei without saying why. The reason is functional: white cells must make proteins like antibodies, move, engulf and divide, all of which need the nucleus and organelles, whereas the red cell gives them up to carry more haemoglobin.

Question 20

The smallest of the formed elements are not whole cells at all but fragments, and their work is to stop bleeding. Explain what platelets are, and describe the several ways in which they help to stop the loss of blood when a vessel is injured.

Model Answer

Platelets are tiny fragments of cytoplasm pinched off from large cells in the bone marrow; they have no nucleus and are not whole cells. When a vessel is injured they help to stop bleeding in several ways.

1) **They cause vascular spasm:** they release chemicals that make the broken vessel narrow, cutting down the flow of blood through it.
2) **They form a platelet plug:** they stick to the damaged wall and to one another, piling up into a plug that temporarily seals the gap.
3) **They release clotting factors:** they set free substances that trigger the chain of reactions which forms the fibrin clot.

> **False Confidence Alert**
> Students often call platelets cells and credit them only with clotting. Platelets are fragments of cytoplasm with no nucleus, and besides triggering the fibrin clot they also make the vessel narrow and build the first platelet plug.

Question 21

Because a red blood cell cannot mend itself and lasts only a few months, the body runs a constant cycle of making and destroying these cells. State where the red blood cells are made and where the worn-out ones are destroyed, give roughly how long a red cell lasts, and explain why this constant renewal is necessary.

Model Answer

Red blood cells are made in the red bone marrow, and the worn-out ones are broken down mainly in the spleen, with the liver also taking part; a red cell lasts about 120 days. New cells are produced as fast as old ones are removed.

This constant renewal is necessary because a red cell cannot repair itself, having no nucleus. As it ages its membrane grows fragile and it can no longer carry oxygen well, so the body removes these old cells and replaces them with fresh ones from the marrow, keeping the number of red cells, and so the oxygen-carrying power of the blood, steady.

> **False Confidence Alert**
> Students often say red cells are made in the bone and destroyed in the blood. They are made in the red bone marrow and destroyed mainly in the spleen after about 120 days, and the renewal is needed because the cell cannot repair its own ageing membrane.

Question 22

Set side by side, the three formed elements differ in almost every way except that they all travel in the plasma. Compare the red blood cells, the white blood cells and the platelets in their structure, their numbers, their lifespan and their function, and then explain why only the white cells are counted as true cells.

Model Answer

1) **Red blood cells:** biconcave discs with no nucleus, packed with haemoglobin; the most numerous by far; they last about 120 days; they carry oxygen and some carbon dioxide.
2) **White blood cells:** larger cells that keep their nucleus and organelles; far fewer, less than one in a hundred blood cells; some last only days, others for years; they defend the body against disease.
3) **Platelets:** tiny fragments of cytoplasm with no nucleus; fewer than the red cells but more than the white; they last about a week; they start the clotting of blood.

Why only the white cells are true cells: only they keep a nucleus and a full set of organelles, so only they are complete cells; the red cells have lost their nucleus and the platelets are merely fragments of cytoplasm, so neither counts as a true cell.

False Confidence Alert
Students often call all three simply blood cells. Only the white cells are true cells, because the red cells have lost their nucleus and the platelets are only fragments of cytoplasm, not whole cells.

Question 23

When a blood vessel is cut, the body can afford neither to lose blood freely nor to let clots form where they are not wanted. Explain what is meant by haemostasis and why its three stages, vascular spasm, the platelet plug and coagulation, follow one another in that order to stop bleeding without clotting the whole circulation.

Model Answer

Haemostasis is the body's response to a damaged blood vessel, the stopping of bleeding by sealing the injury with a clot. It is carried out in three ordered stages: first the vessel narrows in vascular spasm, then the platelets build a temporary plug, and finally a tough fibrin clot sets to seal the break.

The stages follow in that order because each acts faster than the next and buys it time, while keeping the clotting local. The spasm acts within moments to cut down the flow; the platelet plug forms within seconds to seal the gap loosely; and the slower coagulation then lays down a firm fibrin clot that holds until the vessel heals. Because each step is triggered only at the injured part, the blood elsewhere stays fluid and the whole circulation is never clotted.

False Confidence Alert
Students often list the three stages in the wrong order, or give them without saying why the order matters. The sequence is vascular spasm, then platelet plug, then coagulation, each faster step buying time for the slower, firmer one that follows.

Question 24

The very first response to a cut vessel happens within moments and needs no clot at all. Explain how vascular spasm works as the first stage of haemostasis, what sets it off, and why this immediate narrowing of the vessel matters.

Model Answer

Vascular spasm is the sudden narrowing, or constriction, of the broken blood vessel. The smooth muscle in the wall of the vessel contracts, squeezing the vessel narrower so that much less blood can flow through the damaged stretch.

It is set off by chemicals released from the injured lining and from the platelets, and by reflexes from pain receptors in the vessel wall. By cutting down the flow at once, and lasting some twenty to thirty minutes, the spasm limits the loss of blood and gives the slower platelet plug and fibrin clot the time they need to form.

False Confidence Alert
Students often think that clotting is the first thing to happen at a wound. The first response is vascular spasm, the immediate narrowing of the vessel, which cuts the blood flow long before the slower fibrin clot can form.

Question 25

Where the lining of a vessel is torn, the platelets that normally drift past untouched are suddenly made to stop and stick. Explain how a platelet plug forms at an injury, and how the body keeps that plug from spreading to the undamaged parts of the vessel.

Model Answer

A platelet plug forms when platelets stick to the damaged wall and to one another. Where the lining is torn, the collagen fibres beneath it are exposed; the platelets cling to this collagen, change shape and grow sticky, so that more and more platelets pile onto them until a plug builds up and temporarily seals the gap.

The body keeps the plug local by means of the healthy lining around the wound. The undamaged lining releases nitric oxide and prostacyclin, which stop platelets sticking to it, so the plug forms only over the injured patch and does not spread along the vessel.

False Confidence Alert
Students often describe the platelet plug but forget what holds it in place. The healthy vessel lining releases nitric oxide and prostacyclin that prevent platelets sticking to it, so the plug builds up only at the injured part.

Question 26

The final and firmest seal is the blood clot itself, built in a short chain of three reactions. Describe the three steps by which a blood clot forms, from the first signal of damage to the appearance of fibrin.

Model Answer

1) **A prothrombin activator is formed:** the damage to the vessel sets off a series of chemical reactions in the blood that produce a substance called prothrombin activator.
2) **Prothrombin is changed into thrombin:** the prothrombin activator converts the plasma protein prothrombin into the enzyme thrombin.
3) **Fibrinogen is changed into fibrin:** the thrombin then acts on the soluble plasma protein fibrinogen and converts it into insoluble threads of fibrin.

False Confidence Alert
Students often jump straight from prothrombin to fibrin and leave thrombin out. The order is: the damage forms prothrombin activator, which changes prothrombin into thrombin, and the thrombin then changes fibrinogen into fibrin.

Question 27

The whole clotting chain exists to make one substance, fibrin, and the nature of fibrin is exactly suited to sealing a wound. Explain why fibrin, rather than the fibrinogen it is made from, is able to seal a damaged vessel, relating its properties to the job it does.

Model Answer

Fibrin can seal a wound because it is insoluble and fibrous, whereas the fibrinogen it comes from is soluble and stays dissolved in the plasma. As thrombin converts fibrinogen into fibrin, the fibrin leaves solution as fine, needle-like threads. These threads weave across the break in the vessel to form a mesh, and the mesh traps the passing blood cells and sets into a firm clot that plugs the gap until the wall is repaired. Fibrinogen, being soluble, could never do this; it must first be turned into the insoluble fibrin.

False Confidence Alert
Students often say that fibrinogen seals the wound. It is fibrin, the insoluble fibrous form, that makes the sealing mesh; the fibrinogen stays dissolved in the plasma until thrombin converts it into fibrin.

Question 28

A finished clot is not made of any one thing but of platelets, fibrin threads and trapped blood cells working together. Explain how these three act together to build and seal a clot at an injured vessel.

Model Answer

The three work in turn to turn a loose plug into a firm seal. First the platelets gather at the wound and form a soft temporary plug, and they release the factors that start the clotting chain. The thrombin produced then lays down fibrin, whose threads form a mesh across the break. As the blood flows by, red and white cells are caught in this mesh, and together with the platelets they are bound into a solid clot that blocks the gap. The clot holds firm until the vessel heals, after which it is broken down and removed.

False Confidence Alert
Students often treat the clot as fibrin alone, or as platelets alone. A clot is built from all three together: the platelet plug that forms first, the fibrin mesh that thrombin lays down, and the blood cells trapped within that mesh.

Question 29

Tucked between the two lungs and beating without rest from before birth until death, the heart is commonly called the body's most important organ. Explain where the heart lies and why it is regarded as the most vital organ, relating its position and its ceaseless work to the job it does.

Model Answer

The heart is a muscular organ lying in the chest between the two lungs, just behind the breastbone, with its pointed apex resting above the diaphragm. It is the central pump of the circulatory system, beating about seventy-two times a minute to drive blood through the vessels to every part of the body.

It is regarded as the most vital organ because every other organ depends on the blood it pumps. The blood it drives carries oxygen and nutrients to all the cells and carries their wastes away, so if the heart stops even for a short time the whole body is starved of oxygen at once, which is why a fault in the heart has such drastic consequences.

False Confidence Alert
One easy slip is to call the heart vital merely because it pumps blood. The sharper point is that no other organ can take over its work even briefly, so within minutes of its stopping every other organ, the brain included, begins to die.

Question 30

Press a finger to a baby's pulse and then to a grandparent's, and the baby's races far ahead. Explain why the heart rate is faster in young children than in adults, reasoning from their body size and their rate of metabolism.

Model Answer

A child's heart beats faster because a small body loses heat quickly and so must burn fuel fast. A young child has a large surface area compared with its volume, so it loses heat rapidly from that surface and must keep up a high metabolic rate to stay warm. A high metabolic rate means the cells use oxygen and nutrients quickly, and the rapid growth of childhood burns fuel quickly too, so the heart must beat faster to deliver blood at the rate the body demands. As the body grows larger and its surface-area-to-volume ratio falls, the metabolic rate eases and the resting heart rate slows towards the adult value.

False Confidence Alert
Watch out: many answers credit a child's fast heart simply to being more active. The deeper reason is the high surface-area-to-volume ratio of a small body, which loses heat quickly and so forces a faster metabolism that the heart must keep supplied.

Question 31

The heart does not beat bare against the chest but inside a tough, fluid-filled bag. Describe the pericardium, and explain how its make-up lets the heart beat freely without being damaged.

Model Answer

The pericardium is the double-walled, tough sac that surrounds the heart and holds it within a fluid-filled space called the pericardial cavity. It has two layers: the inner (visceral) layer that covers the surface of the heart itself, and the outer (parietal) layer that forms the surrounding sac.

Its make-up lets the heart beat freely because of the serous fluid it produces between the two layers. This fluid lubricates the surfaces so that they slide over each other without rubbing, which prevents friction between the beating heart and the organs around it; at the same time the tough sac holds the heart firmly in position and leaves it a hollow space in which to expand as it fills.

> **False Confidence Alert**
> Beware of writing only that the pericardium protects the heart. Its real value is the film of serous fluid between its two layers, which lets the surfaces slide so that the constantly beating heart is never worn down by friction.

Question 32

The wall of the heart, like the wall of a building, is built up in layers, each with its own part to play. Name the three layers of the heart wall and give the job that each one does.

Model Answer

1) **Epicardium:** the thin outer layer, a serous membrane that lubricates and protects the outside of the heart.
2) **Myocardium:** the thick middle layer of cardiac muscle, which contracts to do the actual pumping of the blood.
3) **Endocardium:** the thin, smooth inner lining that covers the inside of the chambers and the valves, giving the blood a smooth surface to flow over.

> **False Confidence Alert**
> Many candidates lose the mark by naming the layers without tying the myocardium to the pumping. The point worth holding onto is that the whole force of the heartbeat comes from this single muscular layer, which is why its thickness, and nothing else, sets how hard a chamber can pump.

Question 33

Not all parts of the muscular wall are built to the same thickness, and the differences are no accident. Explain why the myocardium is the thickest of the three layers, and why the muscle of the left ventricle is thicker than that of the right.

Model Answer

The myocardium is the thickest layer because it is the one that contracts to pump the blood. The force that drives blood out of the heart comes from this muscle, so the pumping chambers need a great deal of it, whereas the epicardium and endocardium only cover surfaces and can stay thin.

The left ventricle has thicker muscle than the right because it must pump blood much further and against far greater resistance. The left ventricle drives oxygenated blood all the way round the body through the systemic circulation, which needs a high pressure, while the right ventricle pumps blood only the short distance to the nearby lungs at a much lower pressure; more muscle gives the greater force the left side needs.

> **False Confidence Alert**
> It is tempting to answer that the left ventricle is thicker because it holds more blood. In fact the two ventricles pump almost the same volume; the extra muscle gives pressure, not capacity, because the left must drive blood through the whole body while the right reaches only the lungs.

Question 34

The heart is not one pump but four linked chambers, and they are not all built alike. Explain how the four chambers differ from one another, relating the wall of each kind to the work it has to do.

Model Answer

1) **The two atria:** the upper, thin-walled receiving chambers; they collect blood returning along the veins and need only push it a short way down into the ventricles, so their walls are thin.
2) **The two ventricles:** the lower, thick-walled pumping chambers; they force blood out into the arteries and around the body, so their walls are muscular and thick, the left ventricle being the thickest of all.

False Confidence Alert
Weaker answers treat all four chambers as the same kind of pump. The insight is that the atria are little more than collecting chambers that top up the ventricles, so the real pumping out of the heart is done by the ventricles alone.

Question 35

A labelled section of the heart shows at a glance how its chambers, valves and great vessels are arranged. Draw a labelled longitudinal section of the heart, showing its four chambers, its valves and the great vessels, and mark which side carries oxygenated blood.

Model Answer

The labelled section is shown in Figure 2.4 below. The right side of the heart (drawn on the left of the diagram) receives deoxygenated blood from the venae cavae into the right atrium and pumps it through the right ventricle towards the lungs; the left side receives oxygenated blood from the pulmonary veins into the left atrium and pumps it through the left ventricle out to the body.

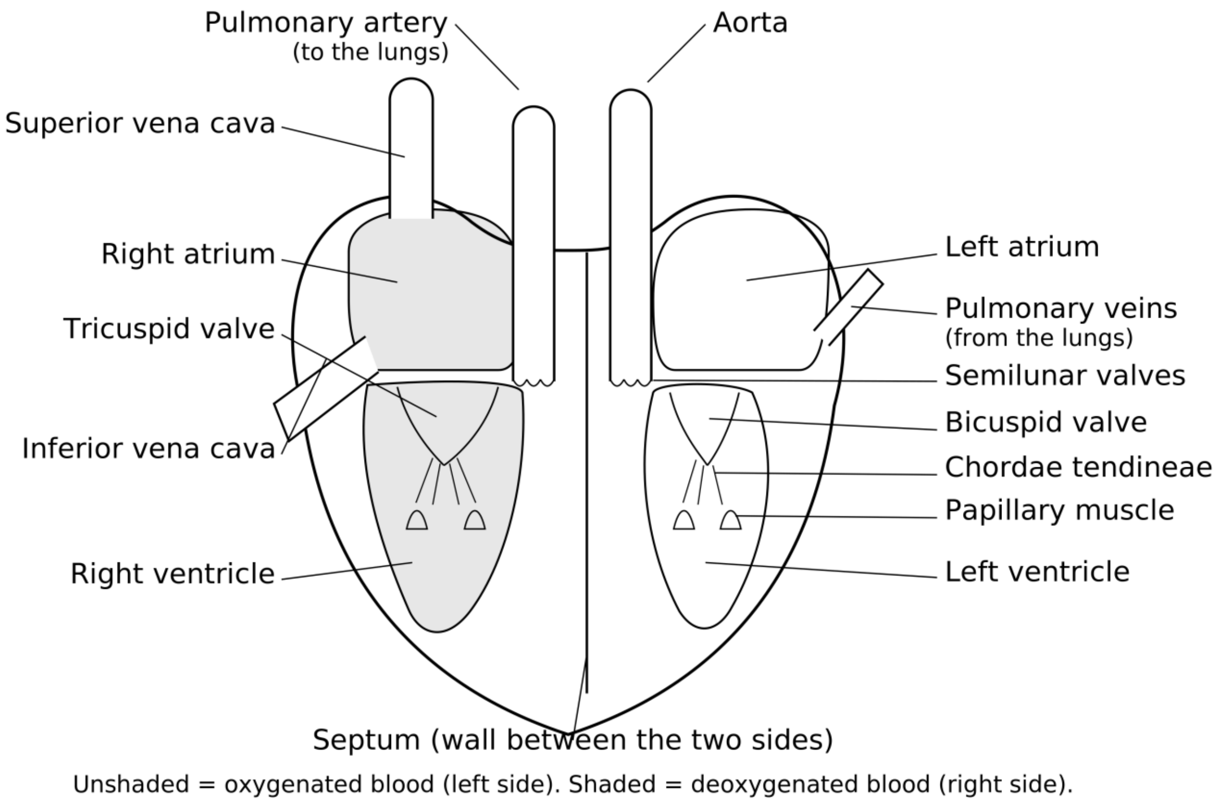


Figure 2.4: *A longitudinal section of the heart, showing the chambers, valves and great vessels.*

Which side carries oxygenated blood: the left side of the heart carries oxygenated blood and the right side carries deoxygenated blood, and the septum between them keeps the two from mixing.

False Confidence Alert
A favourite mistake is to draw the heart's right side on the right of the page. The section is drawn as though facing the body, so the right atrium and right ventricle sit on the viewer's left, which is also the side from which the pulmonary artery, not the aorta, leaves.

Question 36

Blood must move through the heart in one direction only, and four valves see to it that none of it slips backwards. Explain how the atrioventricular valves and the semilunar valves together keep the blood flowing one way through the heart, naming each valve and where it lies.

Model Answer

1) **The atrioventricular valves:** the tricuspid valve (between the right atrium and right ventricle) and the bicuspid valve (between the left atrium and left ventricle); they open to let blood pass down from the atria into the ventricles, then close as the ventricles contract so that no blood can flow back up into the atria.

2) **The semilunar valves:** the pulmonary valve (at the base of the pulmonary artery) and the aortic valve (at the base of the aorta); they open to let blood leave the ventricles for the arteries, then close as the ventricles relax so that no blood can fall back into the ventricles.

Working together, by opening only in the forward direction and snapping shut against any backward push, the four valves make the blood travel one way through the heart.

False Confidence Alert
It is tempting to picture the valves actively pushing the blood along. In truth they are passive flaps, moved only by the pressure of the blood itself, opening one way and slamming shut the instant the pressure tries to reverse.

Question 37

When the ventricles contract with great force, the atrioventricular valves are in danger of being blown back up into the atria, and a set of fine tendons holds them in check. Explain how the chordae tendineae stop these valves from turning inside-out when the ventricles contract, and say what is meant by regurgitation.

Model Answer

The chordae tendineae are strong, thread-like tendons that join the free edges of the tricuspid and bicuspid valve cusps to the papillary muscles on the ventricle walls. When a ventricle contracts, the high pressure of the blood pushes up against the closed valve; the chordae tendineae, pulled taut by the papillary muscles, act like the guy-ropes of a parachute and hold the cusps in place, so the valve cannot be forced backwards (everted) into the atrium.

Regurgitation means the backward flow of blood. Here it would be the leaking of blood from the ventricle back into the atrium when a valve fails to hold; by keeping the valve firmly shut against the pressure, the chordae tendineae prevent it.

False Confidence Alert
A common slip is to say the chordae tendineae open and close the valve. They do neither; they merely anchor the cusps so that the force of ventricular contraction cannot turn them inside-out, much as a taut string keeps a kite from flipping over.

Question 38

Follow a single portion of blood returning tired and oxygen-poor from the body, and you can trace its whole journey through the heart. Trace the path of blood through the heart from the venae cavae to the aorta, naming in order every chamber and valve it passes, and noting where it becomes oxygenated.

Model Answer

1) **The venae cavae** (superior and inferior) bring deoxygenated blood from the body into the right atrium.
2) **Through the tricuspid valve,** the blood passes from the right atrium into the right ventricle.
3) **Through the pulmonary valve,** the right ventricle pumps the blood into the pulmonary artery, which carries it to the lungs; there it loses carbon dioxide and gains oxygen.
4) **Along the pulmonary veins,** the now-oxygenated blood returns from the lungs into the left atrium.
5) **Through the bicuspid valve,** the blood passes from the left atrium into the left ventricle.
6) **Through the aortic valve,** the left ventricle pumps the blood into the aorta, which carries it out to the whole body.

False Confidence Alert
Weaker answers let the blood cross straight from the right side to the left inside the heart. The two sides never connect, so the blood is obliged to leave for the lungs and return before it can reach the left side at all.

Question 39

Press an ear to a friend's chest and the heartbeat comes as two sounds, written down as a 'lub' and a 'dup'. Explain what causes these two heart sounds, relating each one to the closing of a particular set of valves.

Model Answer

The 'lub': the first and longer sound, made by the closing of the atrioventricular valves (the tricuspid and the bicuspid) as the ventricles begin to contract.

The 'dup': the second, shorter and sharper sound, made by the closing of the semilunar valves (the pulmonary and the aortic) as the ventricles relax at the end of their contraction.

In both cases the sound is the valves snapping shut, not the heart muscle or the blood itself.

False Confidence Alert
It is easy to assume the heartbeat sounds are the muscle contracting. They are in fact the valves snapping shut, which is exactly why a faulty valve alters the sound of the heart long before the muscle itself is affected.

Question 40

A doctor listening to a heart is really listening to its valves, so any sound out of the ordinary points straight to them. Explain why a heart sound other than the normal 'lub-dup' usually signals a valve fault, and what such an added sound, a murmur, tells the doctor.

Model Answer

A murmur signals a valve fault because the normal sounds are made by the valves closing cleanly, so any extra noise is the sound of blood passing awkwardly through a valve that is not working. A valve that does not close fully lets blood leak backwards through it, and a valve that does not open fully forces the blood to squeeze through a narrowed gap; either way the disturbed flow makes a murmur. The doctor can often tell which valve is at fault, and whether it is leaking or narrowed, from exactly when in the lub-dup cycle the murmur is heard.

False Confidence Alert
Do not mistake the murmur for the disease itself. It is only the sound of blood leaking through, or being forced past, a faulty valve, a sign that points to the valve rather than being the fault that lies within it.

Question 41

How hard the heart is working can be caught in a single figure: the volume of blood it pumps out each minute. Explain what is meant by cardiac output and how it is worked out from the stroke volume and the heart rate, and say what it tells us about the heart.

Model Answer

Cardiac output is the volume of blood pumped out by a ventricle in one minute, usually measured in litres per minute. It is found by multiplying the stroke volume, the volume pumped out at each beat (in millilitres), by the heart rate, the number of beats in a minute: cardiac output = stroke volume × heart rate.

It tells us whether the heart is meeting the body's demand for oxygen and nutrients. For a resting adult of about 70 kg, a stroke volume near 70 mL and a heart rate near 70 beats per minute give a cardiac output of about 5 litres per minute, and this figure rises during exercise, when the body's demand is greater.

> **False Confidence Alert**
> Watch out: a fast heart rate on its own does not mean a large cardiac output. Output is the heart rate multiplied by the stroke volume, so a quick but poorly-filling heart can pump less than a slow but strongly-filling one.

Question 42

Because the three quantities are tied together by one simple equation, knowing any two of them gives the third. A person's heart beats 75 times a minute and pumps 70 mL of blood at each beat; work out the cardiac output, and then explain how you would find the stroke volume if instead you knew the cardiac output and the heart rate.

Model Answer

Cardiac output = stroke volume × heart rate = 70 mL × 75 per minute = 5250 mL per minute, which is 5.25 litres per minute.

If the cardiac output and the heart rate were known instead, the stroke volume would be found by rearranging the same equation: stroke volume = cardiac output ÷ heart rate. For example, 5250 mL per minute ÷ 75 beats per minute gives a stroke volume of 70 mL per beat.

> **False Confidence Alert**
> One easy mistake is to leave the working in mixed units. Keep the stroke volume in millilitres and the heart rate per minute, multiply to get millilitres per minute, and only then convert to litres per minute, the units in which cardiac output is normally given.

Question 43

The heart's chambers, valves and major blood vessels form one integrated system. The overall function of the heart can therefore be understood as one connected picture. Draw together how the chambers, the valves and the two types of blood vessel enable the heart to pump oxygenated and deoxygenated blood around the body without the two ever mixing.

Model Answer

The heart works as a double pump whose two sides never mix their blood. The right side (the right atrium and right ventricle) receives deoxygenated blood from the body along the venae cavae and pumps it through the pulmonary artery to the lungs; the left side (the left atrium and left ventricle) receives oxygenated blood from the lungs along the pulmonary veins and pumps it through the aorta to the body. The valves keep the blood moving one way through each side, the veins always bring blood towards the heart while the arteries carry it away, and the septum between the two sides keeps the oxygenated and deoxygenated streams completely apart, so the two never meet.

> **False Confidence Alert**
> A favourite error is to call the blood in the pulmonary artery 'arterial', and so oxygenated. A vessel is named an artery for carrying blood away from the heart, not for the blood it holds, which is why the pulmonary artery in fact carries deoxygenated blood.

Question 44

One heartbeat is not a single squeeze but a fixed sequence of fillings and contractions that repeats about seventy times a minute. Explain what is meant by the cardiac cycle, and why its events are grouped into phases of diastole (relaxation) and systole (contraction).

Model Answer

The cardiac cycle is the full sequence of events in one heartbeat, from the start of one filling to the start of the next, repeated with every beat. Its events fall into two kinds. Diastole is when a chamber relaxes and fills with blood; systole is when a chamber contracts and drives blood out. Because the atria and the ventricles take their turns, we speak of atrial diastole and atrial systole, then ventricular diastole and ventricular systole, and it is this orderly alternation of filling and emptying that keeps the blood moving forward.

> **False Confidence Alert**
> A common error is to imagine the whole heart contracting in one go. In truth the atria and the ventricles contract at separate moments, and it is exactly this staggering, atria first and ventricles just after, that lets the atria fill the ventricles before the ventricles pump them empty.

Question 45

In each heartbeat the two atria pass through a relaxed, filling phase, called atrial diastole, and then a contracting phase, called atrial systole. Describe what happens during atrial diastole and during atrial systole, saying in each what the atria are doing and which valves are open.

Model Answer

Atrial diastole: the atria are relaxed and fill with blood returning along the veins, the venae cavae into the right atrium and the pulmonary veins into the left. The atrioventricular valves are open, so this blood also runs straight on into the relaxing ventricles below, while the semilunar valves stay shut.

Atrial systole: the two atria contract together and squeeze the last of their blood down through the still-open atrioventricular valves into the ventricles, topping them up. The semilunar valves remain shut, so no blood yet leaves for the arteries.

> **False Confidence Alert**
> Beware of thinking the atria do most of the pumping. The ventricles are already about three-quarters full by the time the atria contract, so atrial systole only tops them up, which is exactly why the atria need so little muscle.

Question 46

During a heartbeat the atria first relax and fill (atrial diastole) and then contract (atrial systole). Draw simple diagrams to show the heart in each of these two phases, marking the state of the atria, the direction of blood flow and which valves are open; then state what keeps blood from leaving for the arteries during these phases.

Model Answer

The diagrams are shown in Figure 2.5. In atrial diastole the relaxed atria fill from the veins, and blood passes on through the open atrioventricular valves into the ventricles; in atrial systole the atria contract and drive the last of the blood through those same valves into the ventricles.

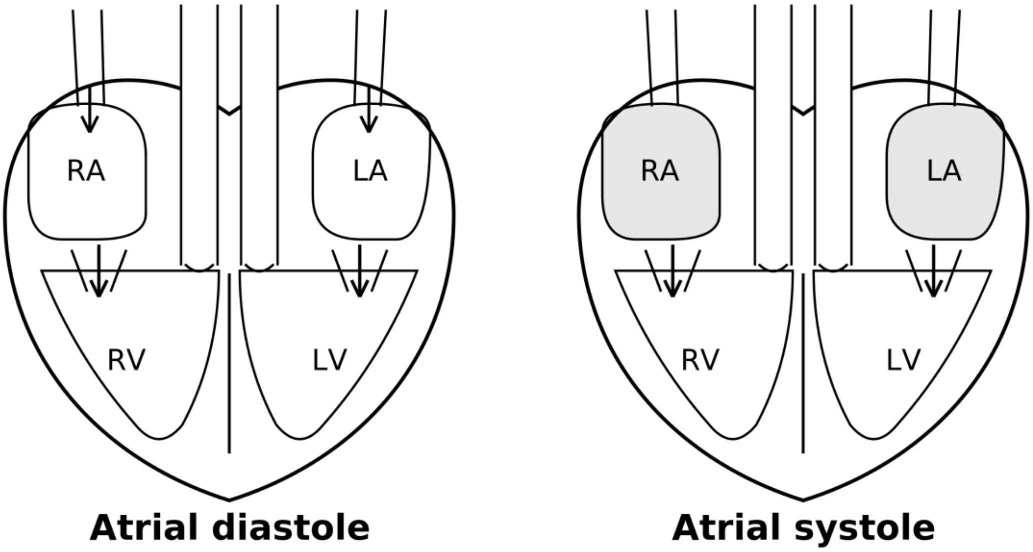


Figure 2.5: *The heart in atrial diastole (left) and atrial systole (right).*

What keeps blood from leaving for the arteries: the semilunar valves stay shut all through both phases, so no blood can leave the ventricles for the pulmonary artery or the aorta until the ventricles themselves contract.

> **False Confidence Alert**
> Do not draw the semilunar valves open in these two phases. The arteries are sealed off throughout atrial filling and contraction, with only the atrioventricular valves open, a point examiners use to test whether you really follow the order of the cycle.

Question 47

Within each heartbeat the ventricles pass through a filling phase, called ventricular diastole, and a contracting phase, called ventricular systole. Describe what happens during ventricular diastole and during ventricular systole, saying which valves open and close in each, and link the closing of the valves to the two heart sounds.

Model Answer

Ventricular diastole: the ventricles relax and fill. The atrioventricular valves are open, so blood flows in from the atria, while the semilunar valves are shut; the snapping shut of those semilunar valves at the start of this relaxation makes the second heart sound, the 'dup'.

Ventricular systole: the ventricles contract powerfully. The atrioventricular valves close, making the first heart sound, the 'lub', so blood cannot return to the atria, and the rising pressure forces the semilunar valves open so blood is driven into the pulmonary artery and the aorta.

> **False Confidence Alert**
> Many candidates muddle which sound comes when. The 'lub' marks the start of ventricular systole, as the atrioventricular valves shut, and the 'dup' marks its end, as the semilunar valves shut, so the two sounds bracket the ventricles' squeeze.

Question 48

During a heartbeat the ventricles first relax and fill (ventricular diastole) and then contract powerfully (ventricular systole). Draw simple diagrams to show the heart in each of these two phases, marking the state of the ventricles, the blood flow and the valves; then explain why the atrioventricular and the semilunar valves are never open at the same moment.

Model Answer

The diagrams are shown in Figure 2.6 below. In ventricular diastole the relaxed ventricles fill through the open atrioventricular valves while the semilunar valves stay shut; in ventricular systole the ventricles contract, the atrioventricular valves close and the semilunar valves open, so blood is driven into the arteries.

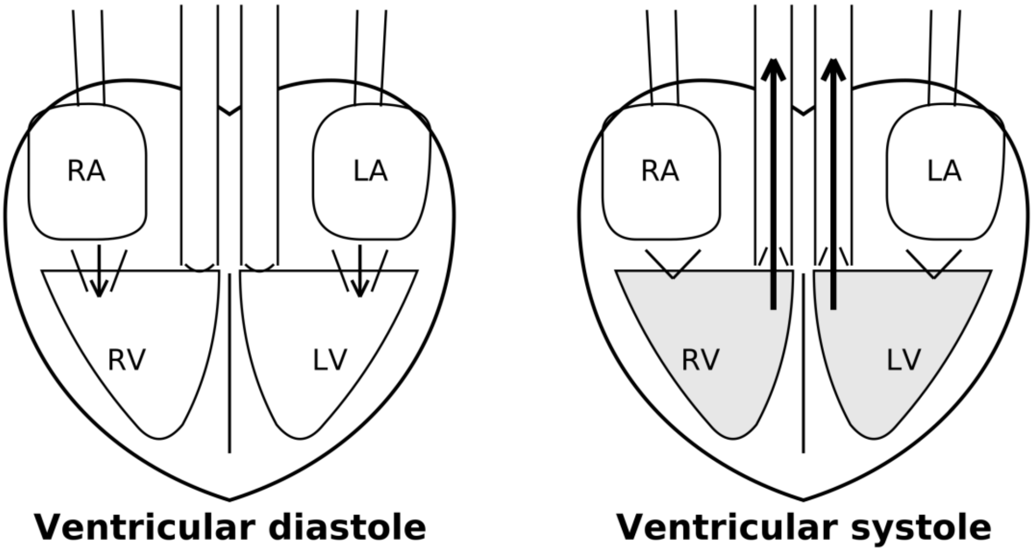


Figure 2.6: *The heart in ventricular diastole (left) and ventricular systole (right).*

Why the two sets of valves are never open together: a ventricle is either filling or emptying, never both at once. While blood is entering from the atrium the atrioventricular valve is open and the semilunar valve shut; while blood is leaving for the artery the semilunar valve is open and the atrioventricular valve shut. This one-at-a-time arrangement is what keeps the blood moving forward and never back.

> **False Confidence Alert**
> A frequent slip is to show both sets of valves open in the same diagram. A ventricle cannot fill and empty at the same instant, so an open atrioventricular valve always goes with a shut semilunar valve, and the other way round.

Question 49

The heartbeat is not triggered by the brain but by the heart's own electrical wiring, a set of specialised tissues that fire and pass the signal on in a fixed order. Describe the heart's conducting system, naming the sinoatrial node and the atrioventricular node, and explain how the wave of excitation passes through it to make the chambers contract in the right order.

Model Answer

The conducting system is the heart's own built-in electrical wiring, which sets and spreads each heartbeat. The sinoatrial (SA) node, a patch of specialised tissue in the wall of the right atrium, is the pacemaker: it sends out a wave of excitation at a regular rate, fixing the heart rate without any signal from the brain.

From the SA node the wave spreads in a set order. It passes across both atria and makes them contract, then reaches the atrioventricular (AV) node, which lies between the atria and the ventricles. The AV node holds the signal back for a moment, so the atria can finish emptying into the ventricles, and then passes it down through the walls of the ventricles, making them contract from the apex, the lower tip of the heart, upwards. This order, atria first and ventricles just after, ensures the ventricles are full before they pump.

> **False Confidence Alert**
> A frequent misunderstanding is that a nerve from the brain fires each heartbeat. The heart sets its own beat at the SA node, and the nerves that reach it only quicken or slow that beat; they never start it.

Question 50

Cardiac muscle is found nowhere else in the body, and under the microscope it looks unlike the muscle of the limbs. Describe the structure of cardiac muscle, taking its fibres, its striations, its nuclei, its mitochondria and the intercalated discs between its cells.

Model Answer

Branching fibres: the muscle is made of fibres that branch and join one another into a connected network, rather than lying as separate parallel fibres.

Cross-striations: the fibres show light and dark bands, because their actin and myosin filaments are lined up in register, as in skeletal muscle.

One or two central nuclei: each cell has only one or two nuclei, lying in the middle of the fibre rather than at its edge.

Many mitochondria: the cells are packed with large mitochondria, far more than skeletal muscle has.

Intercalated discs: where two cells meet end to end there is a dark, stepped junction called an intercalated disc, which joins the cells firmly and lets excitation pass quickly from one to the next.

False Confidence Alert
Beware of describing cardiac muscle as merely skeletal muscle under a new name. The branching network and the intercalated discs are unique to it, and they are precisely what let the whole sheet of muscle contract as one.

Question 51

Cardiac muscle is best understood by drawing a small piece of the tissue and labelling its distinctive parts. Draw a labelled diagram of cardiac muscle, showing its branching fibres, its cross-striations, its central nuclei and the intercalated discs, then state what the intercalated discs do for the working of the heart.

Model Answer

The labelled diagram is shown in Figure 2.7 below. It shows the muscle fibres branching and joining into a network, the cross-striations along each fibre, a central nucleus in each cell, and the stepped intercalated discs where the cells meet end to end.

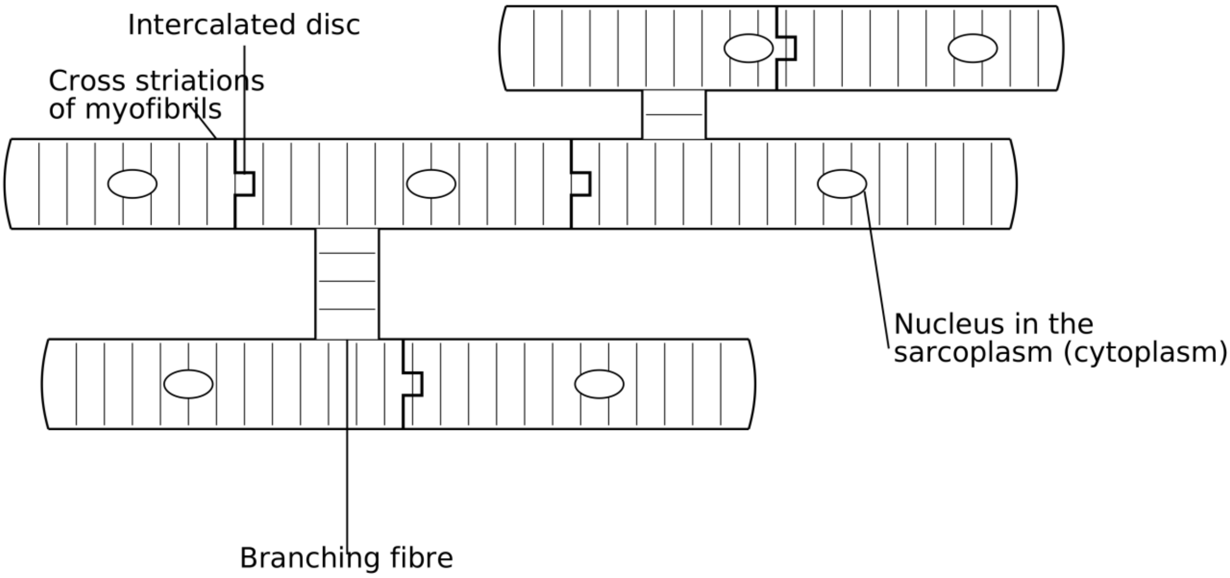


Figure 2.7: *The structure of cardiac muscle.*

What the intercalated discs do: they join the muscle cells firmly end to end and let the wave of excitation pass swiftly from one cell to the next, so that the whole mass of muscle contracts together as a single unit.

False Confidence Alert
Avoid drawing cardiac muscle as straight, separate fibres like a bundle of threads. Its defining feature is that the fibres branch and connect, and a drawing that misses this misses the very thing that lets the heart beat as one.

Question 52

A heart taken out of the body and kept in a warm, balanced salt solution will go on beating for a time, all by itself. Explain what is meant by saying that cardiac muscle is myogenic, and how its structure lets the whole heart contract as one without any nerve telling it to.

Model Answer

To say cardiac muscle is myogenic means that it generates its own beat from within the muscle itself, rather than waiting for an impulse from a nerve. The rhythm is set by the pacemaker, the SA node, and the muscle goes on contracting rhythmically of its own accord; this property, also called autorhythmicity, is why a heart can keep beating even when cut off from the nervous system.

Its structure lets the whole heart act as one because the fibres branch and join into a network, linked by the intercalated discs. The excitation that begins at the pacemaker spreads through these junctions from cell to cell, so quickly and so completely that all the muscle of a chamber contracts almost together, squeezing out the blood as a single coordinated unit.

> **False Confidence Alert**
> A tempting answer is that myogenic simply means made of muscle. It actually means the beat originates in the muscle itself, the real contrast being with the neurogenic hearts of some animals, whose beat must be started by a nerve.

Question 53

The heart must beat without rest for a whole lifetime, and the muscle that does this work is built for the task in several ways. Explain how cardiac muscle is adapted for pumping without rest, taking its strength, its energy supply, its blood supply and its tireless, coordinated contraction.

Model Answer

1) **Strong, striated fibres:** the fibres are tough and rich in actin and myosin, so they contract forcefully enough to drive blood around the whole body, beat after beat.
2) **Many mitochondria:** the cells are packed with mitochondria that supply, by aerobic respiration, the large and steady amount of energy the ceaseless work demands.
3) **A rich blood supply:** the muscle has its own coronary blood vessels bringing a constant flow of oxygen and glucose and carrying wastes away, so it never runs short of fuel, and it can even use lactic acid as a fuel.
4) **A branching network with intercalated discs:** the connected fibres let the excitation spread from cell to cell, so the muscle contracts as one coordinated unit and gives an effective squeeze.
5) **Its own myogenic rhythm:** the muscle sets and keeps its own steady beat, so it neither tires nor depends on the brain to keep it going.

> **False Confidence Alert**
> Many candidates list having many mitochondria without saying why it matters. The point is that the heart respires aerobically almost all the time and cannot run up an oxygen debt, so any failure of its oxygen supply stops it quickly, unlike a leg muscle that can work briefly without oxygen.

Question 54

Animals move their transport fluid around the body by one of two basic plans, the open and the closed circulatory system. Explain how an open circulatory system works and how a closed circulatory system works, naming a group of animals that uses each, and state the key difference between the two.

Model Answer

Open system: the heart pumps the transport fluid, called haemolymph, through short vessels into the large open spaces of the body cavity, the haemocoel, where it bathes the organs directly before draining slowly back to the heart through openings called ostia. The fluid is under low pressure and moves slowly. It is found in arthropods, such as insects and crustaceans, and in most molluscs.

Closed system: the heart pumps blood that is kept inside a continuous network of vessels, passing from arteries into fine capillaries that reach the tissues and returning through veins, so the blood never leaves the vessels. It is under higher pressure and moves quickly. It is found in annelids, such as the earthworm, and in all vertebrates.

Key difference: in an open system the fluid leaves the vessels to bathe the tissues directly, while in a closed system the blood stays within the vessels all the way round.

False Confidence Alert
It is tempting to picture an open system as having no heart and no vessels at all. In truth it has both a heart and short arteries; what makes it open is only that the fluid is then released into the body cavity rather than being kept inside capillaries the whole way.

Question 55

In an open circulatory system the transport fluid leaves the vessels to bathe the organs directly, whereas in a closed system it stays inside the vessels throughout. Draw simple, labelled diagrams to contrast the open and the closed plans, showing in each the heart, the vessels and the path taken by the fluid; then name the one structure, present in the closed plan but absent from the open plan, that your diagrams make clearest.

Model Answer

The two plans are contrasted in Figure 2.8 below. In the open plan the heart drives haemolymph out of a short aorta into the haemocoel, where it bathes the organs and then seeps back through the ostia; in the closed plan the blood is driven through arteries, capillaries and veins and is never let out into the body cavity.

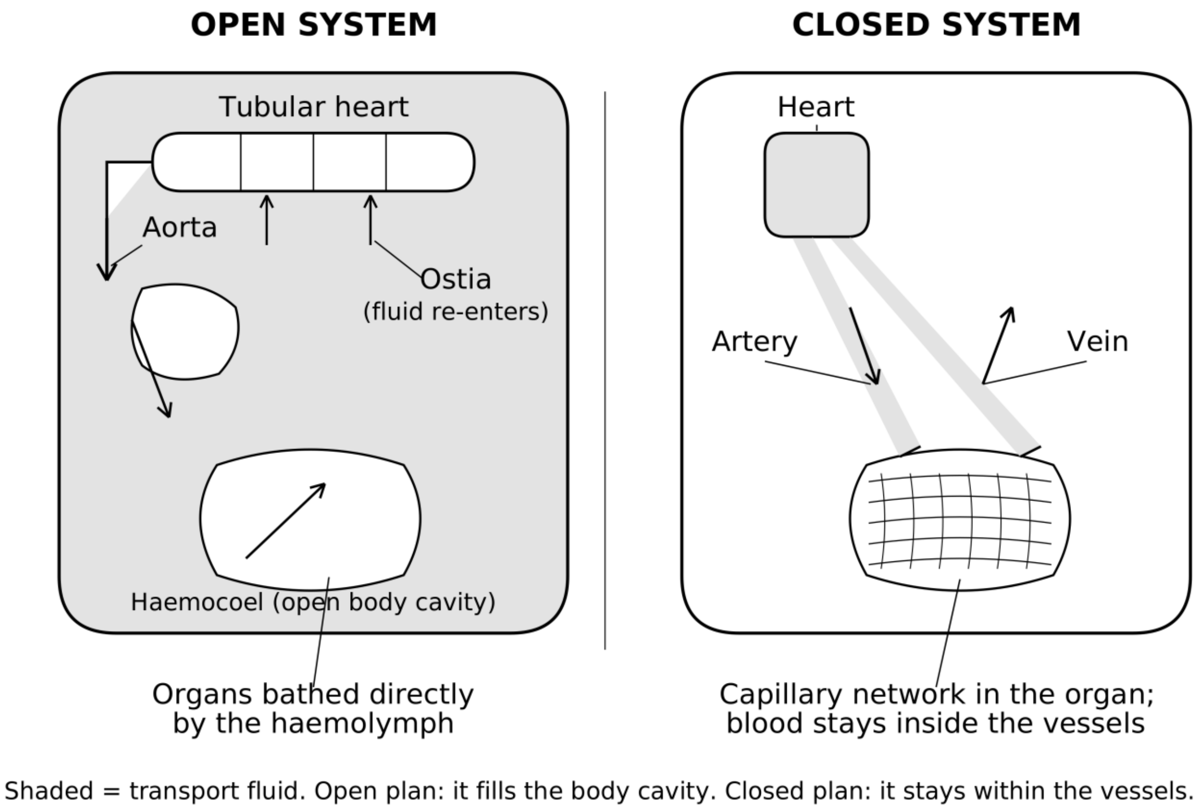


Figure 2.8: *Open (left) and closed (right) circulatory plans.*

The structure present in the closed plan but absent from the open plan: a network of capillaries. In the closed system the blood reaches the tissues through fine capillaries and returns in veins; the open system has no capillaries, the haemolymph simply spilling into the haemocoel.

False Confidence Alert
Do not be drawn into sketching capillaries on the open side of your diagram. The open plan has none: the haemolymph is simply tipped into the body cavity and seeps back, which is exactly why it cannot be aimed at one hard-working organ the way blood in a closed capillary bed can.

Question 56

The open and the closed circulatory plans can be set side by side on several features. Compare an open circulatory system with a closed one point by point, considering whether the fluid is held in vessels, the pressure reached, the speed of flow and the control over where the fluid is sent, and relate each difference to the kind of life the animal can lead.

Model Answer

1) **Confinement of the fluid:** in an open system the fluid leaves the vessels to fill the body cavity, whereas in a closed system the blood is kept within the vessels.
2) **Pressure:** an open system works at low pressure, a closed system at high pressure.
3) **Speed of flow:** the fluid moves slowly in an open system but rapidly in a closed one.
4) **Control of distribution:** an open system cannot direct its fluid to a chosen organ, while a closed system can raise or lower the flow to particular organs by widening or narrowing its vessels.

Relating this to the animal: because a closed system delivers oxygen and food quickly, at high pressure and to the exact place needed, it can support a large and active animal; the slow, low-pressure open system suits only smaller or less active animals.

False Confidence Alert
Beware of writing that an open system is simply a worse version of a closed one. For a small insect a low-pressure open system is quite enough, because the insect supplies its tissues with oxygen through air tubes, so its haemolymph is freed from the work of carrying oxygen at all.

Question 57

In a fish the blood follows a single circuit. Explain how single circulation works in a fish, tracing the blood from the heart through the gills to the body and back to the heart, and explain why the blood pressure falls once the blood has passed through the gills.

Model Answer

How single circulation works: the fish heart has just one atrium and one ventricle and holds only deoxygenated blood. The ventricle pumps this blood along the ventral aorta to the gills, where it is oxygenated; from the gills the oxygenated blood is carried in the dorsal aorta to the rest of the body, where it gives up its oxygen to the tissues; the blood, now deoxygenated, then returns through the veins to the heart. Because the blood passes through the heart only once in each complete circuit, the plan is called single circulation.

Why the pressure falls at the gills: at the gills the blood is forced through a vast bed of very narrow capillaries that offer great resistance. Much of the pressure given by the heart is used up in squeezing through these gill capillaries, so the blood leaves the gills at low pressure and travels on to the body slowly. This slow delivery of oxygen is what limits how active a fish can be.

False Confidence Alert
Many candidates lose the mark by saying the fish heart pumps oxygenated blood. The single heart of a fish holds only deoxygenated blood, because the blood is oxygenated at the gills after it leaves the heart, not before it enters.

Question 58

A fish moves its blood around a single circuit: from the heart to the gills, on to the body, and back to the heart. Draw a simple, labelled diagram of the single-circulation plan of a fish, showing the heart, the gills and the body and the direction of flow, and marking clearly the point at which the blood becomes oxygenated; then state the disadvantage this single circuit places on the fish.

Model Answer

The single-circulation plan is shown in Figure 2.9. The blood becomes oxygenated as it passes through the gills, the point marked on the figure; before the gills, in the heart and the ventral aorta, the blood is deoxygenated.

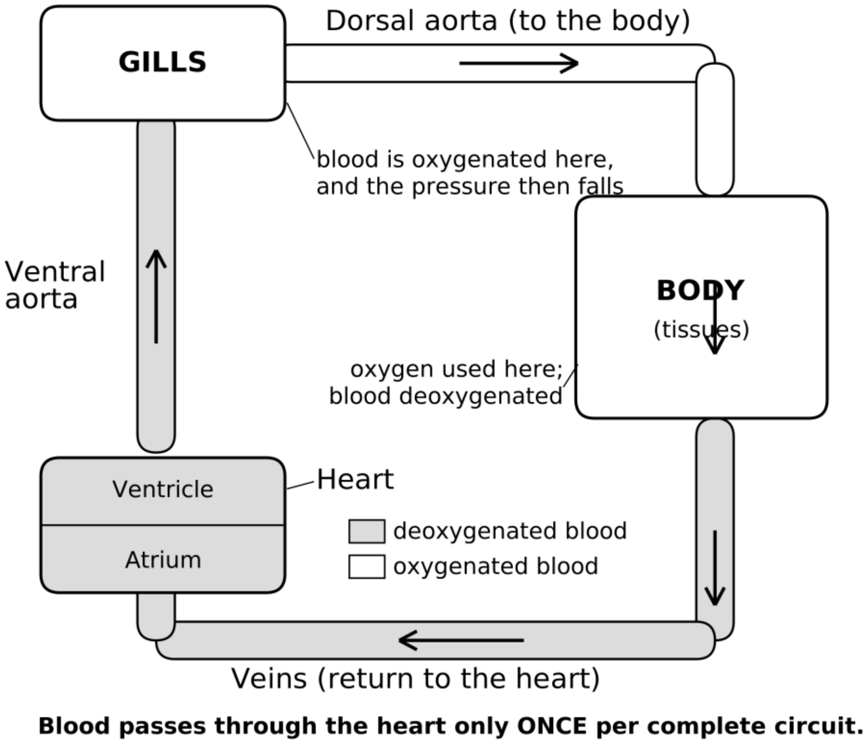


Figure 2.9: *Single circulation in a fish; blood passes through the heart once per circuit.*

The disadvantage of the single circuit: because the blood must pass through the narrow gill capillaries on its way to the body, it loses most of its pressure at the gills and so flows on to the tissues slowly. Oxygen and food are therefore delivered slowly, which limits the level of activity the fish can sustain.

False Confidence Alert
Watch out: the disadvantage of single circulation is not that the fish has too few blood vessels. It is the single drop in pressure, lost as the blood is squeezed through the narrow gill capillaries, that leaves too little force to drive the blood quickly on to the body.

Question 59

In a mammal the blood follows a double circuit, passing through the heart twice in each complete journey round the body. Explain how double circulation works, naming the two circuits and the side of the heart that drives each, and explain why the fully divided heart is able to keep oxygenated and deoxygenated blood apart.

Model Answer

How double circulation works: the blood passes through the heart twice in one complete circuit. The right side of the heart drives the pulmonary circuit: it pumps deoxygenated blood to the lungs, where the blood is oxygenated, and the blood then returns to the left side of the heart. The left side drives the systemic circuit: it pumps the oxygenated blood out to the whole body, where the oxygen is given up, and the deoxygenated blood returns to the right side. The blood is therefore pumped once to the lungs and once to the body, crossing the heart twice.

Why the divided heart keeps the two streams apart: the heart is divided down the middle by a complete wall, the septum, so that the right side, which carries deoxygenated blood, never mixes with the left side, which carries oxygenated blood. Keeping the streams separate means the blood sent to the body is fully oxygenated and can be driven at high pressure, and it is this that allows a mammal to be large and very active.

False Confidence Alert
It is easy to assume that passing through the heart twice means two separate heartbeats. In fact both sides of the heart contract together in one beat; the twice refers to the blood crossing the heart at two points in its journey, once on the way to the lungs and once on the way to the body.

Question 60

A mammal pumps its blood around two linked circuits through a four-chambered heart. Draw a simple, labelled diagram of the double-circulation plan, showing the heart, the lungs and the body, labelling the pulmonary and the systemic circuits and the main vessels, and marking where the blood is oxygenated and where it is deoxygenated; then state the advantage that the double circuit gives a mammal over a fish.

Model Answer

The double-circulation plan is shown in Figure 2.10 below. The pulmonary circuit carries deoxygenated blood from the right side of the heart to the lungs and brings oxygenated blood back to the left side; the systemic circuit carries oxygenated blood from the left side to the body and brings deoxygenated blood back to the right side.

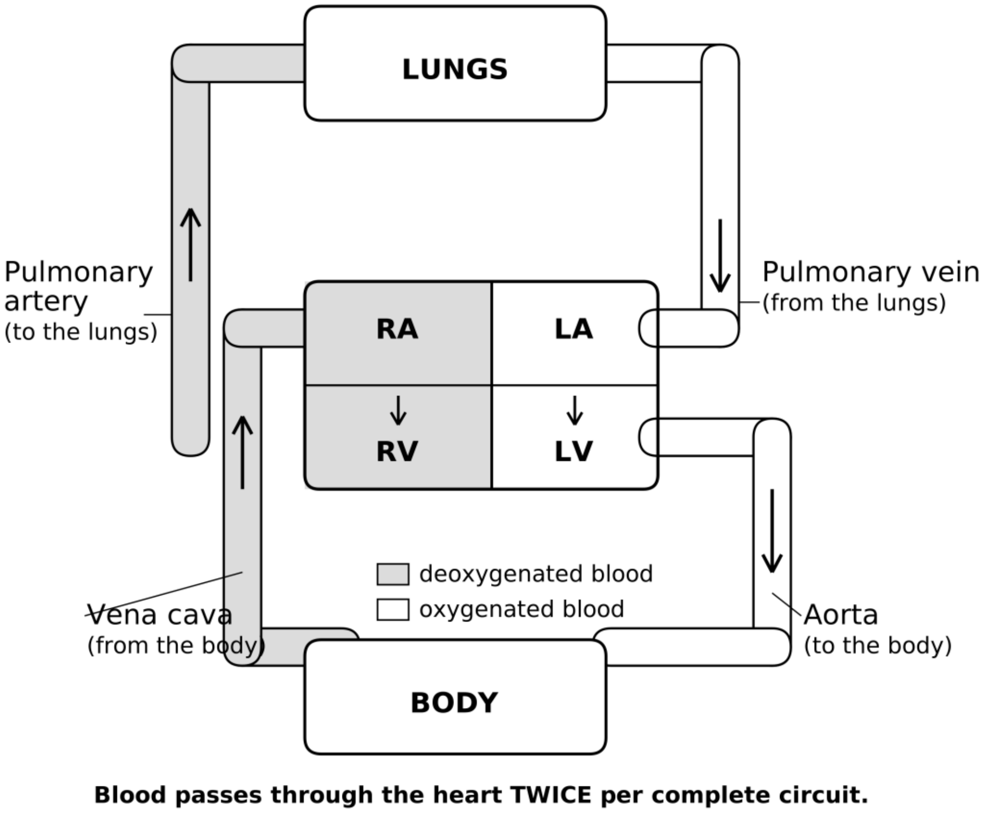


Figure 2.10: *Double circulation in a mammal; blood crosses the heart twice per circuit.*

The advantage over a fish: in the mammal the blood is returned to the heart after the lungs and given a second, powerful push before it travels to the body, so it moves round at high pressure and delivers oxygen quickly. A fish, with a single circuit, loses its pressure at the gills and supplies the body slowly; the double circuit therefore lets a mammal sustain a much higher level of activity.

False Confidence Alert
A frequent error is to draw a single loop running heart to lungs to body and back. The whole point of the double plan is that the blood returns to the heart after the lungs, so the diagram must show two loops meeting at the heart, not one continuous ring.

Question 61

The mammalian circulation is made up of three named circuits: the pulmonary, the systemic and the coronary. Name and follow each of these three circuits in turn, stating where it begins and ends and what each one supplies.

Model Answer

Pulmonary circuit: it runs from the right ventricle, along the pulmonary artery to the lungs, and back by the pulmonary veins to the left atrium. It carries deoxygenated blood to the lungs to be oxygenated and returns oxygenated blood to the heart.

Systemic circuit: it runs from the left ventricle, along the aorta to all the organs and tissues of the body, and back by the venae cavae to the right atrium. It supplies the whole body with oxygenated blood and returns the deoxygenated blood to the heart.

Coronary circuit: it runs from the aorta, along the coronary arteries into the wall of the heart itself, and back by the coronary veins to the right atrium. It supplies the heart muscle with its own oxygen and food.

False Confidence Alert
One easy mistake is to forget that the heart needs a blood supply of its own. Although the chambers are full of blood, that blood rushes straight through and cannot feed the thick muscle of the wall, which is why the coronary circuit exists and why a blocked coronary artery is so dangerous.

Question 62

Before birth a baby cannot breathe air or take food through its gut, yet its cells still need oxygen and nourishment. Explain why the circulation of a foetus differs from that of an adult, and state how the foetus obtains its oxygen and food.

Model Answer

Why it differs: the foetal circulation differs because the lungs and the gut, and largely the liver, are not yet working. The lungs are collapsed and filled with fluid, so they cannot take in oxygen, and no food is eaten through the gut. The circulation is therefore arranged to send most of the blood past these resting organs rather than through them.

How the foetus is supplied: the foetus obtains its oxygen and food from the mother across the placenta. There the blood of the mother and the blood of the foetus flow very close together without mixing, so that oxygen, glucose and other nutrients diffuse from the mother to the foetus, while carbon dioxide and wastes diffuse the other way. The placenta thus does the work of the lungs and the gut until birth.

False Confidence Alert
It is tempting to say the foetus breathes through the placenta. No breathing happens at all before birth; oxygen merely diffuses from the mother to the foetus down a gradient, which is why the unborn baby depends completely on the mother continuing to breathe for it.

Question 63

The foetus is joined to the placenta by the umbilical cord, which contains the umbilical vein and the umbilical arteries. Trace the blood passing between the foetus and the placenta, naming what the umbilical vein carries and what the umbilical arteries carry, and explain why these names seem to be the opposite of the usual rule.

Model Answer

1) **Umbilical vein:** carries oxygenated blood, rich in oxygen and food, from the placenta to the foetus.
2) **Umbilical arteries:** carry deoxygenated blood, loaded with carbon dioxide and wastes, from the foetus back to the placenta.

Why the names seem reversed: at first this seems to break the rule that arteries carry oxygenated blood and veins carry deoxygenated blood. But that oxygen rule is only a general one; the true rule is that an artery carries blood away from the heart and a vein carries it towards the heart. The umbilical arteries carry blood away from the foetal heart to the placenta, and the umbilical vein carries it back towards the heart, so the names are correct by the proper rule even though the oxygen they carry is reversed.

False Confidence Alert
A common slip is to assume the umbilical vein must carry deoxygenated blood simply because veins usually do. Whether a vessel is an artery or a vein depends on the direction of flow relative to the heart, not on the oxygen it carries, and the umbilical vessels are the classic exception that proves the point.

Question 64

In the foetus, blood travels between the placenta and the body and is steered past the lungs and the liver, which are not yet working. Draw a simple, labelled diagram of the foetal circulation, showing the placenta, the umbilical vessels, the liver, the heart and the lungs, and marking the three shunts (the ductus venosus, the foramen ovale and the ductus arteriosus); then state, in one sentence, what all three shunts have in common.

Model Answer

The foetal circulation is shown in Figure 2.11 below. Oxygenated blood travels from the placenta along the umbilical vein; most of it is led past the liver by the ductus venosus into the inferior vena cava and on to the right atrium. From there much of it passes through the foramen ovale into the left atrium, and so to the left ventricle and the aorta for the body. Blood that does enter the right ventricle and the pulmonary trunk is led across by the ductus arteriosus into the aorta, again missing the lungs, while deoxygenated blood returns to the placenta along the umbilical arteries.

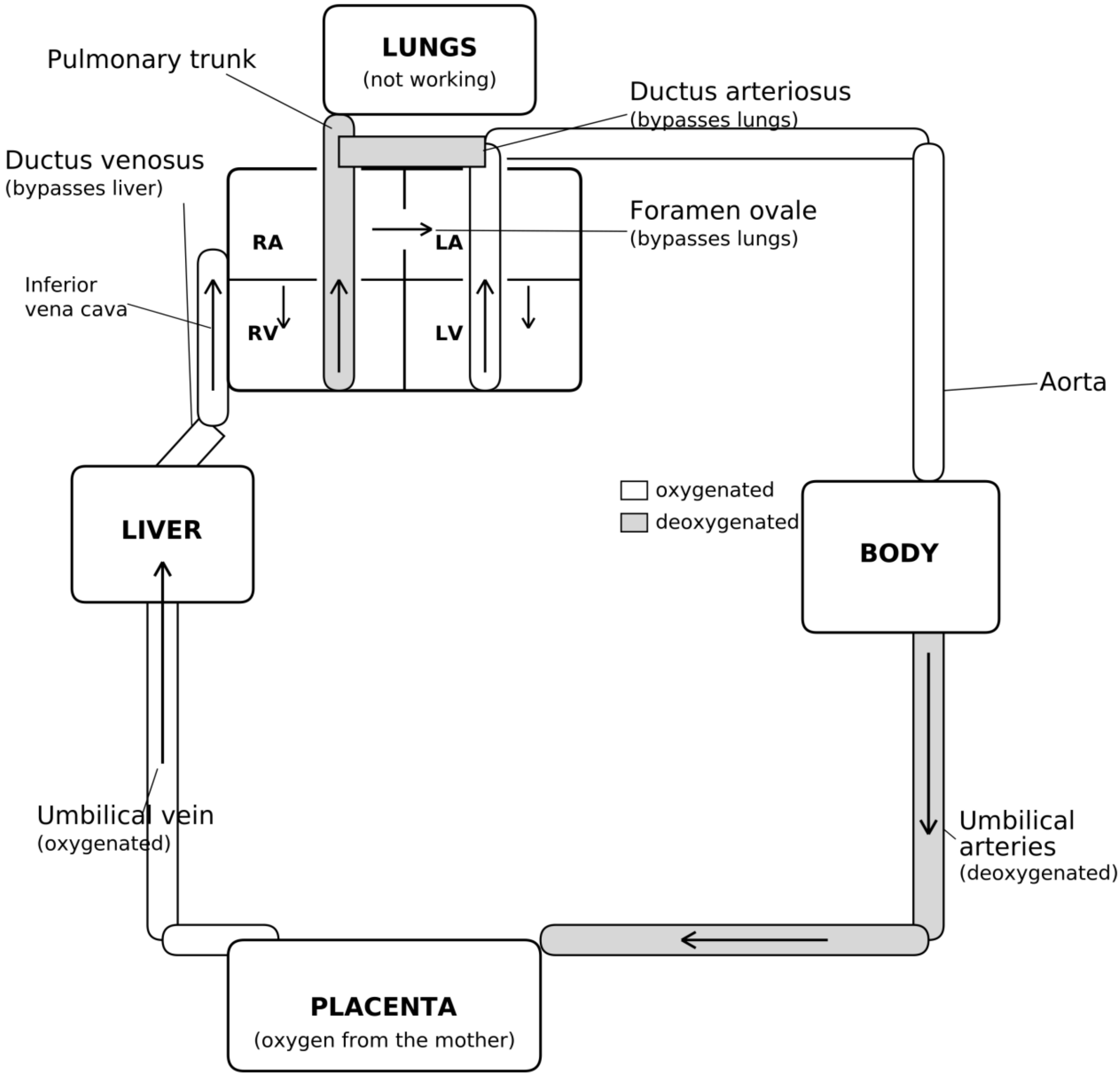


Figure 2.11: *Foetal circulation, with the three shunts that bypass the resting lungs and liver.*

What the three shunts have in common: each one diverts blood past an organ that is not yet working, the ductus venosus past the liver and the foramen ovale and the ductus arteriosus past the lungs.

False Confidence Alert
Beware of drawing the blood flowing through the lungs as it would in an adult. In the foetus the collapsed lungs offer high resistance, so the diagram must show most of the blood taking the short cuts around them; leaving out the shunts is the commonest way to lose marks here.

Question 65

The foetal circulation contains three shunts: the ductus venosus, the foramen ovale and the ductus arteriosus. State what each of these three shunts does, making clear which organ each one allows the blood to bypass.

Model Answer

Ductus venosus: a short vessel that lets most of the oxygenated blood from the umbilical vein bypass the liver by joining straight into the inferior vena cava.

Foramen ovale: an opening in the wall between the right and left atria that lets blood pass directly from the right atrium to the left atrium, bypassing the lungs.

Ductus arteriosus: a short vessel joining the pulmonary trunk to the aorta, so that blood pumped towards the lungs is led across into the aorta, again bypassing the lungs.

False Confidence Alert
Many candidates muddle the two arterial shunts. The foramen ovale is a hole between the two atria, whereas the ductus arteriosus is a vessel between the two great arteries; both skip the lungs, but at different points in the heart's plumbing.

Question 66

In the foetus, the shunts send most of the blood past the lungs and the liver. Explain why bypassing these two organs is the sensible arrangement before birth, and what would be wasted if the blood did not bypass them.

Model Answer

Why bypassing is sensible: it is sensible because, before birth, these organs are not yet doing their usual work. The lungs are collapsed and filled with fluid, so they cannot add oxygen to the blood; the placenta already supplies the oxygen. The liver, too, is largely inactive before birth, because the mother handles the foetus's processing, so the rich blood from the placenta is better sent straight on to the body than held up in the liver.

What would be wasted otherwise: if the blood did not bypass them, much energy would be wasted pushing the whole flow through the high resistance of the collapsed lungs for no gain in oxygen, and the limited oxygen would be held up in organs that cannot use it. By shunting the blood past both, the foetus delivers its precious oxygen quickly to the organs that need it most, such as the brain and the heart.

False Confidence Alert
It is easy to think the bypassed organs receive no blood at all. They still get a small supply to keep their own tissues alive and growing; the shunts divert only the bulk of the flow, so the lungs and liver are nourished without being forced to do work they cannot yet perform.

Question 67

The red cells of a foetus contain a special kind of haemoglobin, called foetal haemoglobin, which differs from the adult kind. Explain why foetal haemoglobin has a higher affinity for oxygen than adult haemoglobin, and how this higher affinity helps the foetus to obtain oxygen from its mother.

Model Answer

Higher affinity: foetal haemoglobin has a higher affinity for oxygen, which means it binds oxygen more strongly and becomes fully loaded even where the oxygen level is fairly low. Adult haemoglobin, by contrast, holds oxygen a little less tightly.

How this helps the foetus: at the placenta the mother's blood and the foetal blood flow very close together, and oxygen has to pass from the mother to the foetus. Because foetal haemoglobin pulls oxygen more strongly than the mother's haemoglobin holds it, oxygen leaves the mother's red cells and is taken up by the foetal red cells, even though the oxygen level in the placenta is not high. Without this stronger pull the foetus could not take enough oxygen from the mother's already partly unloaded blood.

False Confidence Alert
Weaker answers assume the foetus simply receives oxygen-rich blood from the mother directly. The two bloods never mix; oxygen only diffuses across the placenta, and it does so because foetal haemoglobin out-competes the mother's for it, an advantage that is lost after birth when adult haemoglobin takes over.

Question 68

At the moment of birth a baby must suddenly switch from being supplied by the placenta to using its own lungs. Describe the main changes that take place in the circulation at birth, and explain why each of the three shunts must now close.

Model Answer

The changes at birth: the baby takes its first breaths and the lungs inflate with air for the first time. This opens up the blood vessels of the lungs and sharply lowers the resistance to flow through them, so blood now passes freely to the lungs to be oxygenated. At the same time the placenta is cut off when the cord is tied, and the pressures on the two sides of the heart change. As a result the three foetal shunts close.

1) **The foramen ovale closes** because blood now returns from the working lungs into the left atrium, raising its pressure above that of the right atrium; this presses a flap over the opening and seals it, so blood no longer skips the lungs.
2) **The ductus arteriosus closes** because the lungs are now working and must receive blood; as it constricts, blood from the pulmonary trunk is sent into the lungs instead of being led across to the aorta.
3) **The ductus venosus closes** because, with the placenta gone, no blood arrives along the umbilical vein, so the bypass is no longer needed and the liver receives its full supply.

False Confidence Alert
Watch out: it is the lungs starting to work, not the birth itself, that triggers these changes. The first breaths drop the resistance in the lungs and reverse the pressures across the heart, and it is this reversal of pressure that snaps the foramen ovale shut.

Question 69

Soon after a baby is born, the umbilical cord is tied and then cut. Explain how the tying of the umbilical cord helps to bring about the changes in the newborn's circulation.

Model Answer

Tying the cord cuts the baby off from the placenta. While the placenta was attached it removed carbon dioxide and supplied oxygen; once it is shut off, carbon dioxide begins to build up in the baby's blood. This rising carbon dioxide stimulates the breathing centre in the brain and drives the baby to take its first breaths, inflating the lungs. Removing the placenta also takes away the large, low-resistance placental circuit, which raises the pressure on the systemic and left side of the heart; together with the inflating lungs, these pressure changes help to close the foramen ovale and the other shunts. So tying the cord both triggers breathing and helps shut the foetal shunts.

False Confidence Alert
Do not assume the baby breathes first and the cord is then cut as a quite separate event. The two are linked: removing the placenta lets carbon dioxide rise in the blood, and it is partly this that drives the very first breath, so the cord and the lungs work together to start the newborn's own circulation.

Question 70

The circulation of a foetus and that of a newborn or adult differ in several clear ways. Compare foetal circulation with adult circulation point by point, considering the umbilical vessels, the three shunts, the working of the lungs, the haemoglobin, and the source of oxygen.

Model Answer

1) **Umbilical vessels:** present in the foetus, where the umbilical vein and arteries link it to the placenta; absent in the adult.
2) **The three shunts:** the ductus venosus, foramen ovale and ductus arteriosus are open in the foetus to bypass the liver and lungs, but closed in the adult.
3) **The lungs:** not working in the foetus and largely bypassed; fully working in the adult.
4) **The haemoglobin:** the foetus has foetal haemoglobin of higher oxygen affinity, while the adult has adult haemoglobin of lower affinity.
5) **The source of oxygen:** the foetus obtains oxygen from the mother across the placenta, while the adult obtains it from its own lungs.

The thread behind them all: every one of these differences follows from a single fact, that before birth the foetus cannot use its own lungs and gut and so depends on the placenta; its circulation is simply arranged to make the most of that supply.

False Confidence Alert
The differences are easy to list, but examiners look for the reason behind them. The single thread is the placenta: the umbilical vessels, the shunts and the special haemoglobin all exist only because the foetus depends on its mother for oxygen, which is why they all close or disappear once the lungs take over.

REAL QUESTIONS

The REAL questions take the ideas built up in the BINDER tier and put them to work on the kind of situations and reasoning the examiner sets: real bodies, real disorders and real comparisons. The biology is the same, but now you must apply it. As before, attempt each question fully before reading its model answer and the False Confidence Alert.

Question 71

Animals differ enormously in size and in how active they are, and this decides how much they depend on a transport system. Taking a large, active mammal and a tiny, flat, slow-moving flatworm as your two examples, explain why one cannot survive on diffusion alone while the other can, relating your answer to each animal's size and level of activity.

Model Answer

The flatworm: it is tiny and very thin, so every one of its cells lies close to the body surface and the distance any substance must diffuse is short. It is also slow and sluggish, with a low demand for oxygen and food. Simple diffusion across its body surface therefore delivers enough oxygen and removes enough waste, and the animal needs no transport system at all.

The large active mammal: it is bulky, so most of its cells lie deep inside, far from the lungs and the gut, and diffusion across such distances would be far too slow to keep them supplied. Being highly active, its cells also demand oxygen and food quickly and produce waste fast. It therefore needs a transport system, blood driven by a heart through vessels, to carry materials rapidly to and from every cell. In short, the greater an animal's size and activity, the greater its need for a transport system.

False Confidence Alert
Weaker answers say a large animal needs a transport system simply because it is big. The real reason is that as an animal grows, its volume, the number of cells needing supply, rises faster than its surface area, where exchange happens, so diffusion alone can no longer keep pace.

Question 72

A person is found to have a far lower level of haemoglobin in their blood than normal, a condition called anaemia. Explain how this affects the transport of oxygen in the body, and how it would make the person feel, and why.

Model Answer

Effect on oxygen transport: haemoglobin is the molecule inside the red cells that binds and carries oxygen. With much less haemoglobin, the blood can carry far less oxygen even if the heart and lungs are working normally, so the tissues receive less oxygen than they need.

How the person feels, and why: the person feels tired, weak and easily breathless, especially on exertion, because their muscles and organs cannot get enough oxygen to release energy by aerobic respiration. They often look pale and may have a fast heartbeat, as the heart pumps faster to make up for the reduced oxygen-carrying power of the blood.

False Confidence Alert
A common slip is to think anaemia means the person has too little blood. The volume of blood can be perfectly normal; what is short is the haemoglobin inside the red cells, so the blood is there but its power to carry oxygen is reduced.

Question 73

A patient with liver damage makes too little plasma protein. Explain why this single shortage leads to three separate problems: tissue swelling, poor blood clotting and weakened defence against infection.

Model Answer

Tissue swelling: the plasma proteins, chiefly the albumins, give blood the osmotic pull that draws tissue fluid back into the capillaries. With too few of them, fluid is left behind in the tissues and they swell.

Poor clotting: the clotting protein fibrinogen is made in the liver, so when the liver fails there is too little fibrinogen, the blood cannot form its fibrin mesh properly, and it clots slowly.

Weakened defence: some of the globulins act as antibodies; with fewer plasma proteins the body has fewer antibodies and so fights infection less well.

False Confidence Alert
It is tempting to treat all plasma proteins as one substance. They do quite different jobs, so a single shortage shows up in three separate ways at once, which is exactly why low plasma protein is such a revealing sign of liver trouble.

Question 74

As blood travels round the body, its composition keeps changing depending on the organ it has just passed. Describe how the blood changes as it passes through the lungs, the small intestine, the kidneys and an actively respiring muscle.

Model Answer

At the lungs: the blood loses carbon dioxide and gains oxygen, so it leaves more oxygenated.

At the small intestine: the blood absorbs digested food such as glucose and amino acids, so it leaves rich in nutrients.

At the kidneys: the blood loses urea and excess water and salts, so it leaves cleaner, with less nitrogenous waste.

At an active muscle: the blood gives up oxygen and glucose and takes on carbon dioxide and other wastes, so it leaves more deoxygenated and waste-laden.

False Confidence Alert
A frequent error is to picture blood as the same everywhere in the body. Its make-up depends on the organ it has just left, which is why a sample taken from a vein leaving the gut is quite different from one leaving a working muscle.

Question 75

Blood is classified as a type of connective tissue, even though it is a flowing liquid rather than a solid. Explain, from what blood is actually made of, why it is grouped with the connective tissues.

Model Answer

A connective tissue is built of cells scattered through a non-living background material called a matrix. Blood fits this exactly: it has cells, the red cells, white cells and platelets, suspended in a fluid matrix, the plasma. Like other connective tissues it arises from the same kind of embryonic tissue, and it serves to link the parts of the body together, here by carrying materials between them. Its one unusual feature is that its matrix is a liquid rather than something solid or jelly-like, so it is called a fluid connective tissue.

> **False Confidence Alert**
> It is easy to assume a tissue must be firm or solid. What makes a tissue connective is cells held within a matrix, not how stiff that matrix is, so a liquid such as blood qualifies just as bone and cartilage do.

Question 76

A person who moves to live at high altitude, or who trains hard as an athlete, gradually comes to have more red blood cells in their blood than before. Explain why this happens and how it helps them.

Model Answer

Why more red cells are made: at high altitude the air is thinner and holds less oxygen, so the blood leaving the lungs carries less oxygen than usual; in hard training the muscles repeatedly demand more oxygen than the blood can easily supply. In both cases the tissues sense a shortage of oxygen, and the kidneys respond by releasing a hormone that stimulates the red bone marrow to make more red cells.

How it helps: with more red cells the blood holds more haemoglobin and can therefore carry more oxygen with each circuit, helping the person cope with the thin mountain air or the heavy oxygen demand of exercise.

> **False Confidence Alert**
> Watch out: the extra red cells do not appear at once. It takes the marrow days or weeks to build up their numbers, which is why climbers and athletes must arrive early to acclimatise before they feel the benefit.

Question 77

In a revision group a student named Kipanga argues: *'Red blood cells do the vital job of carrying oxygen, so they must be packed with mitochondria and must keep a nucleus to control all that important work.'* Identify what is wrong with Kipanga's claim, and explain the correct biology.

Model Answer

Kipanga is mistaken. A mature mammalian red blood cell has no nucleus and no mitochondria. Far from being a weakness, this is exactly how the cell is adapted to its job. Losing the nucleus and the other organelles leaves more room inside the cell for haemoglobin, so it can carry more oxygen, and it lets the cell take up its thin biconcave shape for a large surface area. Because it has no mitochondria, the red cell does not burn up in its own respiration any of the oxygen it is carrying, so all of that oxygen is delivered to the tissues. The red cell is therefore specialised by what it gives up, not by what it packs in.

> **False Confidence Alert**
> A favourite wrong answer is that an important cell must be a complex, fully equipped one. The red cell shows the opposite: it is specialised by sacrificing its nucleus and mitochondria, precisely so that it can do its single job of carrying oxygen better.

Question 78

Blood clotting works as a cascade of clotting factors that ends by turning fibrinogen into a fibrin mesh. Explain why a person who has haemophilia (a lack of one of the clotting factors) or who is short of vitamin K bleeds badly even from a small wound.

Model Answer

Clotting is a chain reaction. In the cascade each clotting factor activates the next, the sequence ending when fibrinogen is turned into a mesh of fibrin that traps blood cells and seals the wound. If even one factor is missing, as in haemophilia, the chain is broken at that step and the cascade cannot reach the fibrin stage, so a firm clot never forms and the bleeding goes on. Vitamin K is needed by the liver to manufacture several of these factors, including prothrombin; without it, too few factors are made and the cascade again fails. In both cases a platelet plug may still form, but without the reinforcing fibrin mesh it is too weak to hold, so even a small wound bleeds for a long time.

> **False Confidence Alert**
> It is tempting to think that one missing factor would only slow clotting a little. Because the factors act in a chain where each one switches on the next, the loss of a single factor halts the whole sequence beyond it, which is why haemophilia is so dangerous.

Question 79

Kipanga tells his revision group: *'A blood clot is just a clump of platelets, so a platelet plug and a blood clot are really the same thing.'* Identify the two mistakes in Kipanga's statement and give the correct biology.

Model Answer

Kipanga is wrong on two counts.

1) **A clot is not platelets alone:** a true blood clot is a mesh of fibrin threads in which platelets, red cells and white cells are all trapped. It is the fibrin, not the platelets, that gives the clot its strength.
2) **The plug and the clot are not the same:** the platelet plug is the quick, temporary first seal, made of platelets sticking together at the wound; the blood clot is the firmer, later structure formed when a fibrin mesh reinforces that plug. The plug comes first and is weak; the clot follows and is strong.

> **False Confidence Alert**
> A common slip is to use the words plug and clot as if they meant one thing. They are two stages: the platelet plug is the emergency patch, the fibrin clot is the permanent repair, and an answer that blurs them loses the marks for sequence.

Question 80

Trace the journey of a single red blood cell that sets out from the right coronary artery and travels all the way round the circulation until it returns to its starting point, naming in order each heart valve it passes through.

Model Answer

The journey: from the right coronary artery the red cell flows into the capillaries of the heart muscle, gives up its oxygen there, and is collected by the coronary veins, which empty into the right atrium. From the right atrium it passes through the tricuspid (right atrioventricular) valve into the right ventricle, then through the pulmonary semilunar valve into the pulmonary artery, which carries it to the lungs to be oxygenated. It returns by the pulmonary vein to the left atrium, passes through the bicuspid (left atrioventricular) valve into the left ventricle, and is driven through the aortic semilunar valve into the aorta. Because the coronary arteries branch from the very start of the aorta, the red cell can now re-enter the right coronary artery where it began.

The valves crossed, in order: tricuspid valve, pulmonary semilunar valve, bicuspid valve, aortic semilunar valve.

> **False Confidence Alert**
> Many candidates forget that the heart feeds itself first. The coronary arteries branch from the very start of the aorta, so the freshest, most oxygen-rich blood is sent to the heart muscle before anywhere else, which is why a blocked coronary artery is so quickly dangerous.

Question 81

At a check-up a doctor hears a heart murmur and finds that the patient's bicuspid valve does not close properly and leaks. Explain why a leaking bicuspid valve makes the heart pump less efficiently.

Model Answer

The bicuspid valve sits between the left atrium and the left ventricle and should shut tightly when the ventricle contracts, so that all the blood is forced forward into the aorta. If it leaks, then each time the left ventricle contracts some blood is pushed backwards into the left atrium instead of forward into the aorta. Less blood is therefore delivered to the body with each beat, so the heart must beat harder and faster to supply the same amount, and it tires more easily; the backward rush of blood is the swishing sound heard as the murmur. Over time this extra work can enlarge and weaken the heart.

False Confidence Alert
It is easy to think a leaky valve merely makes a noise. The murmur is only the sign; the real fault is that blood travels backwards, so the heart wastes effort re-pumping the same blood and delivers less to the body with every stroke.

Question 82

A blood-pressure reading is written as two numbers, for example 120 over 80. Explain what the higher (systolic) and the lower (diastolic) numbers each represent, and why the systolic is always the larger of the two.

Model Answer

What the numbers mean: the two figures give the pressure of the blood in the main arteries at two moments of the heartbeat. The higher number, the systolic pressure, is the pressure when the ventricles contract and drive blood into the arteries; it is the peak pressure. The lower number, the diastolic pressure, is the pressure that remains while the ventricles relax and refill between beats; it is the lowest the arterial pressure falls to.

Why systolic is larger: the systolic is always the greater because it is measured at the very moment the heart is actively pushing blood out, whereas the diastolic is measured when the heart is resting and only the recoil of the stretched artery walls keeps the blood under pressure.

False Confidence Alert
Watch out: the lower number is not zero. Even while the heart relaxes, the elastic artery walls recoil and keep the blood under pressure, which is why blood keeps flowing smoothly between beats instead of stopping and starting.

Question 83

A trained athlete may have a resting heart rate of only about 50 beats per minute, well below the average of about 70, and yet still supply the body with enough blood at rest. Explain how this is possible, using the idea of stroke volume.

Model Answer

Cardiac output, the volume of blood pumped each minute, is the stroke volume (the blood pumped per beat) multiplied by the heart rate. Training strengthens and enlarges the heart muscle, so the athlete's heart pumps a larger volume with every beat, that is, it has a bigger stroke volume. Because each beat now does more work, fewer beats are needed to pump the same total each minute, so the heart can beat more slowly at rest and still meet the body's needs. A large stroke volume at 50 beats a minute can give the same cardiac output as a smaller stroke volume at 70. The slow resting rate is therefore a sign of an efficient, well-trained heart.

False Confidence Alert
A favourite mistake is to read a slow heart rate as a weak heart. In a trained athlete the truth is the opposite: the heart is so strong that each beat pumps more, so it needs fewer beats, and the low resting rate is a mark of fitness, not of weakness.

Question 84

Kipanga claims: *'The left side of the heart carries deoxygenated blood, and it is the atria that pump the blood out to the whole body.'* Identify the two errors in Kipanga's claim and state the correct biology.

Model Answer

Kipanga makes two errors.

1) **The left side does not carry deoxygenated blood:** the left side of the heart receives oxygenated blood from the lungs along the pulmonary veins and pumps it to the body. It is the right side that carries deoxygenated blood, receiving it from the body and sending it on to the lungs.
2) **The atria do not pump blood to the body:** the atria are thin-walled chambers that merely receive blood and pass it down into the ventricles. It is the ventricles, above all the thick-walled left ventricle, that pump blood out, the left ventricle to the whole body and the right ventricle to the lungs.

False Confidence Alert
A common error is to muddle which side and which chambers do the heavy work. Hold on to the rule: right side carries deoxygenated blood to the lungs, left side carries oxygenated blood to the body, and it is always the ventricles, never the atria, that drive blood out of the heart.

Question 85

Within a single heartbeat, describe what is happening to the flow of blood through the heart during atrial systole and during ventricular diastole, saying for each which chambers are active, which way the blood moves, and which valves are open.

Model Answer

1) **Atrial systole:** the two atria contract while the ventricles stay relaxed. This squeezes the blood in the atria downwards through the open atrioventricular valves (tricuspid and bicuspid) into the ventricles, topping them up. The semilunar valves remain shut, so no blood yet leaves for the arteries.
2) **Ventricular diastole:** the ventricles are relaxed and filling. Blood runs into them from the atria through the same open atrioventricular valves, while the semilunar valves stay shut so the ventricles fill without losing any blood to the arteries.

How the two relate: these two phases coincide. Atrial systole takes place during ventricular diastole, so the contraction of the atria is simply the final top-up of the ventricles as they fill.

False Confidence Alert
It is easy to treat atrial systole and ventricular diastole as two separate, unrelated events. In fact they happen together: the atria contract precisely while the ventricles are relaxed and filling, so atrial systole is just the last push of ventricular filling.

Question 86

The sinoatrial node sets the rhythm of the heartbeat. Explain what would happen to the heartbeat if the sinoatrial node were damaged, and what an artificial pacemaker does to put this right.

Model Answer

If the sinoatrial node is damaged: the sinoatrial node is the heart's own natural pacemaker, firing regular electrical impulses that spread through the muscle and set the rate and rhythm of the beat. If it is damaged it can no longer set a steady rhythm, so the heartbeat becomes slow, irregular or poorly coordinated, and the heart pumps blood less effectively.

What an artificial pacemaker does: an artificial pacemaker is a small electronic device fitted to take over the node's job. It sends out its own regular electrical impulses to the heart muscle, restoring a steady, properly timed beat.

False Confidence Alert
A common slip is to think the heart would stop altogether if the sinoatrial node failed. Other parts of the conducting system can take over and fire on their own, but only slowly and unreliably, which is why a pacemaker is needed to restore a proper rhythm rather than to start the heart from nothing.

Question 87

A muscle in the leg tires and aches after hard exercise, yet the heart muscle beats every minute of a person's life without ever tiring. Explain, from the structure of cardiac muscle and its blood supply, why the heart does not fatigue.

Model Answer

1) **It rests between beats:** each contraction is followed by a relaxation of similar length, so the heart muscle actually spends about half of its time resting, which a hard-worked leg muscle does not.
2) **It has a rich oxygen supply:** the coronary arteries keep the heart muscle well supplied with oxygen and glucose, and the muscle is packed with mitochondria, so it respires aerobically all the time and never builds up the lactic acid that makes other muscles ache.
3) **It is myogenic and joined into one unit:** the muscle sets its own steady rhythm, and its fibres are linked by intercalated discs so they contract together as a coordinated whole, spreading the work evenly.

> **False Confidence Alert**
> Do not be misled into thinking the heart never rests because it never stops. It rests in short bursts between every single beat, and its constant aerobic supply means it never falls into the oxygen debt that tires a sprinting leg.

Question 88

Kipanga insists: *'The heartbeat is started by a nerve coming from the brain, and all four chambers contract at the same instant to push the blood out.'* Identify the two errors in Kipanga's claim and give the correct biology.

Model Answer

Kipanga makes two errors.

1) **The beat is not started by the brain:** the heart is myogenic, which means the beat begins within the heart muscle itself, at the sinoatrial node, not from a nerve. Nerves from the brain can speed the beat up or slow it down, but they do not start it, which is why a heart can keep beating even when removed from the body.
2) **The four chambers do not contract at once:** the atria contract first, pushing blood into the ventricles; then, a moment later, the ventricles contract to drive blood out. This ordered delay is essential, for if all four contracted together the ventricles would have no chance to fill.

> **False Confidence Alert**
> A favourite wrong answer is that the brain drives each beat and the whole heart squeezes at once. The opposite is true: the beat arises inside the heart, and the atria and ventricles must contract in turn, or the pump could never fill before it emptied.

Question 89

Compare how an open circulatory system in an insect and a closed circulatory system in a mammal shape the delivery of oxygen, the use of energy, and the level of activity each animal can reach.

Model Answer

Oxygen delivery: in the insect the slow, low-pressure haemolymph does not carry oxygen to the tissues at all; oxygen is delivered separately and directly by air tubes called tracheae. In the mammal the fast, high-pressure blood carries oxygen on haemoglobin straight to every tissue through capillaries.

Use of energy: the insect's open system is cheap to run, needing only a simple tube heart working at low pressure. The mammal's closed system is costly, needing a powerful four-chambered heart to keep the blood at high pressure.

Level of activity: because the mammal delivers oxygen and food quickly and where they are needed, it can sustain a high, continuous level of activity; the insect's slower supply helps limit it to a smaller size and to shorter bursts of effort.

False Confidence Alert
Watch out: do not say the insect's open system delivers oxygen poorly. Its blood does not carry oxygen at all, because the tracheae do that job directly, which is the very reason an insect can manage with such a simple, low-pressure circulation.

Question 90

A fish has a single circulation while a mammal has a double circulation. Explain why the single circulation of a fish limits how active it can be, compared with the double circulation of a mammal.

Model Answer

In the fish (single circulation): the blood is pumped once by the heart to the gills, where it is oxygenated, and from the gills it must travel straight on to the rest of the body before returning to the heart. As it squeezes through the narrow gill capillaries it loses most of its pressure, so it flows on to the body slowly; oxygen and food are therefore delivered slowly.

In the mammal (double circulation): the blood returns to the heart after the lungs and is given a second, powerful push before being sent to the body, so it reaches the tissues quickly and at high pressure. Because the mammal supplies its tissues so much faster, it can keep up a high level of activity and a warm body, whereas the fish, with its slow supply, is held to a lower level of activity.

False Confidence Alert
A common error is to think the fish's heart is simply too weak. The limit lies in the design, not the strength: in a single circuit all the blood loses its pressure at the gills before it reaches the body, the very problem the double circuit cures by re-pressurising the blood after the lungs.

Question 91

As blood travels round the body it flows at very different speeds in different vessels. State in which type of vessel the blood flows fastest and in which it flows slowest, and explain the reason for each.

Model Answer

Fastest, in the aorta and large arteries: here the blood has just been driven out by the powerful ventricle at high pressure, and it passes through a vessel of relatively small total cross-section, so it moves quickly.

Slowest, in the capillaries: although each capillary is tiny, there are so many millions of them that their combined cross-sectional area is enormous, so the same volume of blood spreads out and slows right down. This slow flow is useful, as it gives time for the exchange of materials between the blood and the tissues.

False Confidence Alert
Many candidates expect the narrow capillaries to speed the blood up, like a thumb pressed on a hose. The opposite happens, because the blood enters not one capillary but millions at once, and their huge combined cross-section slows the flow, which is exactly what exchange needs.

Question 92

Kipanga claims: *'Insects have no heart at all, and in any case every animal has a double circulation just like ours.'* Identify the two errors in Kipanga's claim and state the correct biology.

Model Answer

Kipanga is wrong on both points.

1) **Insects do have a heart:** an insect has a simple tube-shaped heart along its back that pumps haemolymph out into the body cavity. The heart is simple and the system is open, but it is wrong to say there is no heart.

2) **Not every animal has a double circulation:** the double circulation is found in mammals and birds, and is the plan in our own bodies, but a fish has a single circulation, and many invertebrates such as insects have an open system that is neither single nor double in the vertebrate sense. The double circuit is one design among several, not a universal rule.

False Confidence Alert
Beware of assuming that other animals are built just like us. Circulation comes in several designs, open and closed, single and double, each suited to the animal's size and way of life, so our double circulation is one solution and not the only one.

Question 93

The circulation of a foetus in a placental mammal differs in several important ways from that of an adult. Set out eight points of difference between foetal and adult circulation.

Model Answer

1) **Umbilical vein:** present in the foetus, carrying oxygenated blood from the placenta; absent in the adult.
2) **Umbilical arteries:** present in the foetus, carrying deoxygenated blood to the placenta; absent in the adult.
3) **Ductus venosus:** open in the foetus, letting blood bypass the liver; closed in the adult.
4) **Foramen ovale:** open in the foetus, letting blood pass from the right atrium to the left and so bypass the lungs; closed in the adult.
5) **Ductus arteriosus:** open in the foetus, carrying blood from the pulmonary artery to the aorta and so bypassing the lungs; closed in the adult.
6) **The lungs:** not working and largely bypassed in the foetus; fully working in the adult.
7) **Haemoglobin:** foetal haemoglobin, of higher oxygen affinity, in the foetus; adult haemoglobin, of lower affinity, in the adult.
8) **Source of oxygen:** the placenta, from the mother, in the foetus; the animal's own lungs in the adult.

Question 94

In some babies the foramen ovale fails to close after birth, leaving a hole in the heart between the two atria. Explain why such a child may become breathless and look blue, especially when active.

Model Answer

After birth the foramen ovale should close so that the two sides of the heart are kept fully separate, the right side handling deoxygenated blood and the left side oxygenated blood. If the hole stays open, blood can pass through it between the atria, so oxygenated and deoxygenated blood mix. Some deoxygenated blood is then pumped out to the body without first going to the lungs, so the blood reaching the tissues carries less oxygen than it should. The child therefore tires and becomes breathless easily, as the body struggles to make up the shortage, and the skin and lips may look blue, a sign called cyanosis, because of the poorly oxygenated blood, especially during activity when the demand for oxygen is high.

False Confidence Alert
A common slip is to think a hole between the atria lets blood leak out of the heart. The blood stays inside the heart; the trouble is that it crosses from one side to the other, mixing oxygenated and deoxygenated blood so that less oxygen reaches the body.

Question 95

A foetal mammal, a deep-diving seal and a person living high in the mountains all face the challenge of obtaining enough oxygen in difficult conditions. Describe how each is adapted to obtain or hold on to oxygen, drawing in particular on the idea of haemoglobin with a high affinity for oxygen.

Model Answer

The foetus: it has foetal haemoglobin, which has a higher affinity for oxygen than the mother's adult haemoglobin. This lets the foetus draw oxygen from the mother's blood across the placenta, even though the oxygen level there is fairly low.

The diving seal: it carries large stores of haemoglobin in its blood and myoglobin, an oxygen-storing pigment of even higher affinity, in its muscles, so it can load up with oxygen before a dive and release it slowly to the tissues while underwater, where no fresh air is available.

The mountain dweller: living where the air is thin and poor in oxygen, the person makes extra red cells, so the blood carries more haemoglobin and can capture and carry more of the scarce oxygen with each circuit.

False Confidence Alert
Watch out: a high affinity for oxygen is only an advantage where oxygen must be captured from a poor supply. The same tight grip that helps the foetus and the diver take oxygen up would be a drawback in an ordinary active tissue, which needs haemoglobin that also gives its oxygen up easily.

Question 96

Kipanga argues: *'The foetus breathes with its own lungs inside the womb, and the umbilical vein carries deoxygenated blood away from the foetus.'* Identify the two errors in Kipanga's claim and give the correct biology.

Model Answer

Kipanga makes two errors.

1) **The foetus does not breathe with its lungs:** before birth the lungs are collapsed, filled with fluid and not working. The foetus gets its oxygen from the mother across the placenta by diffusion, not by breathing air, which is exactly why the lungs are largely bypassed in the foetus.
2) **The umbilical vein does not carry deoxygenated blood away:** the umbilical vein carries oxygenated blood from the placenta to the foetus. It is the umbilical arteries that carry deoxygenated blood away from the foetus to the placenta.

False Confidence Alert
A favourite wrong answer reverses the umbilical vessels. Settle it by the rule of direction: the vein brings the fresh, oxygenated blood in from the placenta, while the arteries carry the used, deoxygenated blood out to it.

HOT QUESTIONS

The HOT questions are the highest tier. They do not ask for more facts than you already have; they ask you to put facts together, to weigh and judge, and to reason about new or unfamiliar situations. Take your time, think before you write, and set out your reasoning step by step. Attempt each question fully before reading its model answer and the False Confidence Alert.

Question 97

A transport system has three working parts: the blood that carries materials, the vessels that form the network, and the heart that drives the flow. Predict and explain what would happen to a large, active animal if each of these three parts failed in turn.

Model Answer

If the blood failed (for example, if it could no longer carry oxygen): the vessels and heart might still work, but with nothing to carry oxygen, food and wastes, the cells would quickly be starved of oxygen and poisoned by their own wastes. Transport would cease even though the pipes and the pump were intact.

If the vessels failed (for example, if they burst or became blocked): the blood would leak away or be unable to reach the tissues, so even healthy blood and a strong heart could not deliver materials to the cells beyond the break or the blockage.

If the heart failed (if it stopped pumping): the blood would stop moving, so although the blood and vessels were sound, nothing would drive the materials around the body and the cells would again be cut off.

The lesson: in every case the whole system fails, because the three parts depend upon one another, a fluid to carry, a network to carry it through, and a pump to drive it. Remove any one and transport stops, which is why a large, active animal cannot survive the loss of a single part.

> **False Confidence Alert**
> It is tempting to rank one part as the most important. In truth none can do its work without the other two, so a transport system is only as good as its weakest part, never just its strongest.

Question 98

The red blood cell has several features that suit it to carrying oxygen: it is packed with haemoglobin, it has lost its nucleus, it has a biconcave shape, and it is small and flexible. Weighing these features against one another, evaluate which single one contributes most to its oxygen-carrying efficiency, and justify your choice.

Model Answer

All four features help, but they are not equal in importance. The biconcave shape gives a large surface area for fast gas exchange and lets the cell bend through narrow capillaries; the small size keeps every part of the cell close to its surface; the loss of the nucleus frees space and allows the thin shape. Yet each of these only serves one central feature, the haemoglobin. It is the haemoglobin that actually binds and carries the oxygen; without it, a biconcave, flexible, nucleus-free cell would carry almost none. The other features are best understood as adaptations that increase how much haemoglobin the cell can hold and how quickly that haemoglobin can be loaded and unloaded. The haemoglobin therefore contributes most, because it is the feature that does the carrying, while the rest exist to serve it.

> **False Confidence Alert**
> A common slip is to choose the biconcave shape because it is the most striking adaptation. The shape only speeds the loading of haemoglobin; it is the haemoglobin itself that holds the oxygen, so the shape works in service of the haemoglobin, not the other way round.

Question 99

Suppose the liver suddenly almost stops making plasma proteins. Predict the effects on the osmotic balance of the blood, on defence against infection and on clotting, and then judge which of these poses the most immediate threat to survival, giving your reasons.

Model Answer

The effects: with few plasma proteins the blood loses much of its osmotic pull, so tissue fluid is no longer drawn back into the capillaries and the tissues swell badly; with fewer globulins there are fewer antibodies, so defence against infection weakens; and with little fibrinogen the blood clots poorly, so wounds bleed for a long time.

The judgement: although all three are dangerous, the poor clotting and the loss of osmotic balance threaten life soonest. A serious bleed that will not clot can be fatal within minutes or hours, and severe swelling, especially fluid gathering in the lungs, can quickly block proper gas exchange. Weakened immunity is also dangerous, but it usually acts more slowly, over days, as infections take hold. The most immediate threats are therefore the bleeding and the fluid shift, with infection a slower, though still serious, danger.

> **False Confidence Alert**
> Watch out: do not treat the three effects as equally urgent. The body can manage for a time with weakened defences, but uncontrolled bleeding or fluid flooding the lungs can kill within hours, so judging the threat means weighing how fast each acts, not only how serious it is.

Question 100

When carbon dioxide from respiring tissues enters a red blood cell, it is turned into hydrogencarbonate ions, which then move out of the cell into the plasma. Reason why a movement of chloride ions into the red cell, the chloride shift, must accompany this, and explain what would happen without it.

Model Answer

Inside the red cell, carbon dioxide combines with water to form carbonic acid, which splits into hydrogen ions and hydrogencarbonate ions. The hydrogencarbonate ions, being negatively charged, diffuse out of the cell into the plasma down their concentration gradient. If only these negative ions left, the inside of the cell would grow more and more positively charged, and that build-up of positive charge would soon pull the hydrogencarbonate ions back and stop them leaving. To prevent this, chloride ions, which are also negative, move into the cell from the plasma as the hydrogencarbonate ions move out. This inward chloride shift balances the charge and keeps the cell electrically neutral, so hydrogencarbonate can keep leaving and the blood can keep loading carbon dioxide. Without the chloride shift, the charge imbalance would soon halt the export of hydrogencarbonate, and the blood could not carry carbon dioxide efficiently.

False Confidence Alert
A favourite wrong answer is that the chloride shift carries the carbon dioxide. It does not; the chloride merely replaces the negative charge lost as hydrogencarbonate leaves, and it is this balancing of charge, not any carrying of gas, that allows carbon dioxide transport to continue.

Question 101

Two students argue about the red blood cell. Kipanga says: *'A mature red cell has no nucleus and no mitochondria, so it is not really a living cell at all, just a bag of haemoglobin.*' Kipute says: *'It is still a living cell, because it is part of a living body and does an important job.'* Judge which student is closer to the truth, and explain the biology that settles the matter.

Model Answer

Kipute is closer to the truth, though neither is wholly right. A mature mammalian red cell is certainly unusual: having lost its nucleus and mitochondria, it cannot make new proteins, cannot divide and cannot repair itself, and it must respire anaerobically; in these ways it is less fully alive than a typical cell. But it is not a mere dead bag of haemoglobin. It has a living cell-surface membrane that controls what passes in and out, it carries out chemical reactions such as the carbonic-anhydrase reaction of the chloride shift, it uses energy to hold its shape and to pump ions, and it stays alive for about 120 days before being broken down. It is therefore best described as a living cell that is highly specialised by the loss of certain structures, not as a non-living object. Kipanga is right that it is stripped down, but wrong to conclude it is not alive; here the test of life is the cell's active, energy-using membrane and chemistry, not whether it still keeps a nucleus.

False Confidence Alert
It is easy to judge life only by the checklist of organelles. A cell can lose its nucleus and mitochondria and still be alive, because what marks it as living is its active membrane and its ongoing chemistry, not whether it keeps every structure that a typical cell has.

Question 102

Haemostasis stops bleeding in three stages: vascular spasm, the platelet plug, and the coagulation cascade that builds a fibrin clot. Predict how haemostasis would be affected, first if the lining of a blood vessel were damaged or diseased, and then if the platelet count were very low, explaining your reasoning in each case.

Model Answer

If the vessel lining is damaged or diseased: a healthy lining is smooth and releases substances that stop platelets sticking, so it normally keeps clotting switched off inside an intact vessel. If the lining is damaged or diseased, platelets may stick and clump even where there is no wound, so a platelet plug and then a clot can form inside an unbroken vessel, a dangerous thrombosis. The spasm and the cascade still work, but they may now be triggered in the wrong place; at a true wound, of course, this same exposure of the damaged lining is the normal signal that starts clotting.

If the platelet count is very low: the vascular spasm, which is mainly the contraction of the vessel muscle, can still take place, but the platelet plug cannot form properly because there are too few platelets to clump together. Because platelets also release factors that help drive the coagulation cascade, the cascade itself is weakened too. The second stage therefore largely fails and the third is impaired, so even small wounds bleed for a long time.

False Confidence Alert
It is tempting to think a smooth vessel lining has nothing to do with clotting. In fact the healthy lining actively prevents clots; clotting is switched on when that lining is broken or diseased, which is why damage in the wrong place can cause a thrombosis inside an intact vessel.

Question 103

Two students discuss clotting. Kipanga says: *'Clotting is a runaway positive-feedback process, because each step makes the next happen faster, so once it starts it only speeds up.'* Kipute says: *'If that were true, the whole body would set solid after a single cut, so clotting cannot be positive feedback at all.'* Judge how far each is right, and explain why the control of clotting matters.

Model Answer

Each student holds part of the truth. Kipanga is right that the cascade does behave like positive feedback: once thrombin is formed it activates more of the factors that make still more thrombin, so the clot builds quickly at the wound. This rapid amplification is exactly what is needed to seal a wound fast. But Kipute is right that it cannot be allowed to run away, for if it did, a single cut would clot the whole circulation.

The resolution: clotting is a positive-feedback process that is tightly controlled and kept local. The healthy lining beyond the wound releases substances that stop platelets sticking; natural anticoagulants in the plasma destroy any clotting factors that drift away from the wound; and so the clot is confined to the damaged spot. Its control matters because uncontrolled clotting would block vessels and kill, as in a thrombosis or an embolism, while too little clotting would let a person bleed to death; survival depends on holding the balance between the two.

False Confidence Alert
A common error is to treat positive feedback as always meaning out of control. Clotting shows that a positive-feedback process can be both fast and safe, provided it is switched off at the edges and prevented from spreading beyond where it is needed.

Question 104

The left ventricle is the strongest, most muscular chamber of the heart. Three features are offered to explain this: its thick muscular wall, the high pressure it must generate, and the long distance over which it must drive blood. Evaluate which of these best accounts for the left ventricle being the strongest chamber, and justify your choice.

Model Answer

These three are not on the same footing. The thick muscular wall is not really the reason the left ventricle is strong; it is the strength itself, the visible result. The true cause lies in what the chamber must do: the left ventricle drives blood out through the aorta to the whole body, a vast network of vessels that resists the flow, so it must generate a high pressure to push blood all that way and back. The long distance and the wide systemic network are why such a high pressure is needed, and the high pressure is why the wall must be so thick. The feature that best accounts for the left ventricle being the strongest chamber is therefore the high pressure it must generate to supply the whole body; the thick wall is simply the heart's response to that demand. This is confirmed by the right ventricle, which pumps the same volume but only to the nearby lungs at low pressure, and so has a much thinner wall.

False Confidence Alert
A common slip is to say the left ventricle is strong because it has a thick wall. That reverses cause and effect: the wall is thick because the chamber must generate a high pressure to reach the whole body, not the other way round.

Question 105

Predict how the heart's output would be affected, first if the chordae tendineae of an atrioventricular valve were torn, and then if a semilunar valve became stiff and could not open fully, explaining your reasoning in each case.

Model Answer

If the chordae tendineae are torn: the chordae tendineae are the cords that anchor the atrioventricular valve cusps and stop them turning inside-out when the ventricle contracts. If they tear, the valve is blown back into the atrium under the high pressure of ventricular systole, so blood leaks backwards into the atrium instead of being driven forward into the artery. Less blood leaves with each beat, so the heart's output falls and the heart must work harder to make up the loss.

If a semilunar valve becomes stiff: the semilunar valve guards the exit from the ventricle into the artery. If it cannot open fully, the narrowed opening resists the outflow, so the ventricle must build a much higher pressure to force the same blood through, and even then less blood may leave with each beat. The heart's output falls, and the ventricle is strained by the extra work.

False Confidence Alert
Watch out: a faulty valve lowers output whether it leaks or sticks. A leaking valve lets blood pass backwards, while a stiff valve blocks it going forwards, but in both cases less blood reaches the body with each beat.

Question 106

Two students argue about the heart's valves. Kipanga says: *'The valves are not essential; the heart is such a powerful pump that even without them it could still force blood round the body.'* Kipute says: *'Without valves the heart could not pump effectively at all, because the blood would simply slosh back and forth.'* Judge which position is closer to the truth, reasoning from pressure and the direction of flow.

Model Answer

Kipute is much closer to the truth. A pump can only move a fluid forward if it can stop that fluid from flowing back, and the valves are what turn the heart's squeezing into a one-way flow. When a ventricle contracts it raises the pressure inside, but pressure pushes blood in every direction at once. Without the atrioventricular valve, much of the blood would be driven backwards into the atrium; without the semilunar valve, blood already pushed into the artery would fall back into the ventricle as it relaxed. The heart would then merely slosh the same blood to and fro, doing work but moving little of it onward, so the body would not be supplied. Kipanga is right that the heart is a strong pump, but strength alone cannot give direction; it is the valves, by closing at the right moments, that turn the heart's pressure changes into a steady forward circulation. The heart could not work as a circulatory pump without them.

False Confidence Alert
Many candidates assume that raw pumping power can drive blood round without valves. Pressure pushes blood both ways at once, so without valves to shut the back door the heart would move blood to and fro but not onward, which is why valves, and not muscle alone, make circulation possible.

Question 107

Cardiac muscle differs from the skeletal muscle of the limbs in several ways: it is myogenic, its fibres branch and join through intercalated discs, it is richly supplied with mitochondria and blood, and it cannot be held in a continuous contraction (it cannot be tetanised). Analyse how these features work together to let the heart pump continuously and rhythmically for a lifetime.

Model Answer

Each feature plays its part, and together they make lifelong rhythmic pumping possible. Being myogenic, the muscle generates its own regular impulse at the sinoatrial node, so the heart sets its own steady beat without waiting for signals from the brain. Because the fibres branch and are joined by intercalated discs, which contain gap junctions, the impulse spreads at once from cell to cell and the whole muscle contracts together as one coordinated unit, giving a single firm squeeze rather than a ragged one. The rich supply of mitochondria, fed by the constant flow through the coronary arteries, lets the muscle respire aerobically all the time, so it never runs short of energy nor builds up the lactic acid that tires other muscles. And because cardiac muscle cannot be tetanised, every contraction must be followed by a relaxation, so the heart is forced to rest and refill between beats and can never lock up in a fatiguing, continuous contraction. A self-starting, coordinated, tireless muscle that is compelled to rest between beats is exactly what is needed to pump on, rhythmically, for a lifetime.

False Confidence Alert
It is tempting to credit a single feature, such as the good blood supply, for the heart's endurance. No one feature would be enough alone: a tireless muscle that could be tetanised would still seize up, and a self-starting one without coordination would only twitch, so it is the combination that makes lifelong pumping possible.

Question 108

Predict how damage to part of the heart's muscle, for example after its own blood supply is cut off in a heart attack, would affect the efficiency of the heart and the circulation of blood through the body.

Model Answer

If part of the heart muscle is damaged it can no longer contract properly. The heart's squeeze becomes weaker and less coordinated, so it pumps out less blood with each beat and its output falls; the dead patch of wall may even bulge instead of contracting, wasting some of the effort of the healthy muscle. With a lower output the body's tissues receive less oxygen and food, so the person tires quickly, becomes breathless and may feel faint. If the damage reaches the conducting system, the rhythm itself may turn irregular, making the pumping less effective still. Blood may also back up behind the weakened side, raising the pressure in the veins and causing fluid to gather in the lungs or the limbs. In severe cases the heart can no longer supply enough blood to meet the body's needs at all, which is heart failure.

False Confidence Alert
Watch out: damaged heart muscle does not grow back like a healing cut on the skin. Cardiac muscle cannot divide to replace itself, so the dead area is replaced by non-contracting scar tissue, which is why the loss of pumping power after a heart attack is usually permanent.

Question 109

Two students argue. Kipanga says: *'A heart cannot beat once it is removed from the body, because it is the brain that drives every heartbeat through nerves.'* Kipute says: *'A heart taken out of the body and supplied with warm, oxygenated fluid can keep beating on its own for a while.'* Judge which student is right, reasoning from what actually makes the heart beat.

Model Answer

Kipute is right. The heart is myogenic, which means each beat begins within the heart muscle itself, at the sinoatrial node, and not from any nerve coming from the brain. The brain, through its nerves, can only speed the beat up or slow it down to match the body's needs; it does not start each beat. This is why a heart removed from the body will go on beating by itself for a time, as long as it is kept warm and supplied with oxygen and nutrients, the very fact that makes heart transplants possible. Kipanga has confused two different things: the brain adjusts the rate of the beat, but the heart sets the beat. The heartbeat is the heart's own, and it does not cease simply because the heart has left the body.

False Confidence Alert
Do not assume that anything the brain influences must also be started by the brain. The brain only adjusts the heart rate; the beat itself arises in the heart, which is exactly why an isolated heart, or a transplanted one whose nerves have been cut, still beats.

Question 110

Open and closed circulatory systems each have their advantages and their drawbacks. Evaluate the strengths and weaknesses of the two designs, and judge the kind of animal and way of life that each one suits best.

Model Answer

The closed system: it is fast, works at high pressure, and lets blood be steered to particular organs, so it delivers oxygen and food quickly and precisely; its drawbacks are that it needs a powerful heart and is costly in energy to run.

The open system: it is slow and low-pressure and cannot direct its fluid to one organ, so its delivery is sluggish; but it is simple, cheap to run, and needs only a small tube heart.

The judgement: the closed system suits large, active animals such as mammals and birds, whose busy tissues demand a fast, controlled supply; the open system suits small, less active animals such as insects and many molluscs, whose lower demands a slow supply can still meet, especially in insects, where the tracheae deliver oxygen directly and so free the blood from carrying it. Neither design is simply better; each is the better fit for the size and the way of life of the animal that has it.

False Confidence Alert
A common slip is to call the closed system superior in every way. It is superior only where its speed and control are worth their high cost; for a small, sluggish insect the cheap, simple open system is the more sensible design.

Question 111

In a mammal the heart keeps the pulmonary circuit, to the lungs, and the systemic circuit, to the body, completely separate. Predict what would happen to the supply of oxygen to the body, and to the animal's way of life, if the two circuits were allowed to mix, as they would if there were a large hole in the septum.

Model Answer

If the two circuits mixed, oxygenated blood returning from the lungs would blend with deoxygenated blood returning from the body, so the blood pumped out to the tissues would be only partly oxygenated. The body would then receive less oxygen with every beat. To make up the shortage the heart would have to pump faster and harder, and the animal would tire easily and could not sustain hard activity. The mixing also wastes effort, since some already-oxygenated blood would be sent back to the lungs and some deoxygenated blood out to the body. The high, even pressure of a fully separated double circulation would be lost. An animal whose circulation mixed in this way could not keep up the fast metabolism and the warm, active life that mammals lead; it would be held to a lower, more sluggish level of activity.

False Confidence Alert
Weaker answers assume a little mixing would hardly matter. Even a modest leak lowers the oxygen in every beat sent to the body, and because a mammal's whole warm-blooded, active life depends on a rich oxygen supply, the effect on what the animal can do is far greater than the size of the hole suggests.

Question 112

Two students judge the fish. **Kipanga** says: *'Single circulation is less evolved than double circulation, because it is simpler and delivers blood less well, so the fish is a more primitive, lower animal.'* **Kipute** says: *'Single circulation is not worse, only different; it suits the fish perfectly well.'* Judge how far each is right, reasoning about what evolution actually means.

Model Answer

Kipute holds the sounder view, though the matter needs care. It is true, as Kipanga says, that single circulation delivers blood at lower pressure and more slowly than double circulation, and that the double system supports a higher level of activity. But the idea of being less evolved is misleading. Evolution does not climb a ladder from lower to higher; it shapes each animal to fit its own way of life. The fish's single circulation suits a cool-bodied animal that lives in water, whose oxygen demands are lower and whose weight is supported by the water around it, and it has served fish well for hundreds of millions of years. Double circulation is not better in some absolute sense, but a different solution that fits the high, warm metabolism of mammals and birds. So Kipanga is right about the difference in performance but wrong to call the fish primitive or lower, while Kipute is right that the single circuit is not worse, only fitted to a different life.

False Confidence Alert
A common error is to rank living things as higher and lower, with ourselves at the top. Evolution fits each species to its own conditions rather than improving towards us, so a fish is not a failed mammal but a thoroughly successful fish.

Question 113

After birth the three foetal shunts, the ductus venosus, the foramen ovale and the ductus arteriosus, normally close. Predict the impact on a newborn baby if these shunts failed to close, and evaluate which failure would be the most serious.

Model Answer

1) **If the ductus venosus stayed open:** some blood from the gut would keep bypassing the liver, so the liver would not fully take over its work of processing absorbed food and removing toxins. This is the least immediately dangerous of the three.
2) **If the foramen ovale stayed open:** blood could pass and mix between the two atria, so the oxygenated blood reaching the body would be delivered less efficiently; this is usually the milder of the two heart defects, though the baby may tire or grow breathless when very active.
3) **If the ductus arteriosus stayed open:** blood would still be shunted between the pulmonary artery and the aorta, upsetting the balance between the two circuits, overloading the lungs or the heart and leaving the body short of oxygen.

Which is most serious: the failures that involve the heart and lungs matter more than the open ductus venosus, because they upset the oxygen supply and strain the heart. The most serious is usually a large open ductus arteriosus, which can flood the lungs and overload the heart and lead to heart failure if it is not corrected; an open foramen ovale is generally the milder of the two and may cause few problems. The open ductus venosus matters least, because the liver, though bypassed, is not vital to survival in the way that the oxygen supply is.

False Confidence Alert
It is tempting to treat all three failures as equally serious. They are not: a shunt that lowers the oxygen reaching the body or strains the heart threatens life far sooner than one that merely allows the liver to be bypassed.

Question 114

In the foetus, oxygenated and deoxygenated blood are allowed to mix to some extent, yet the same mixing would endanger an adult. Reason why the foetus can tolerate this mixing while the adult cannot.

Model Answer

The foetus can tolerate mixing because its whole situation differs from the adult's. First, the foetus does not depend on its own lungs for oxygen; it draws oxygen from the mother across the placenta, helped by foetal haemoglobin, which has a high affinity for oxygen and so loads even from a modest supply.

Second, the foetus is not very active, is kept warm inside the mother, and has a low oxygen demand, so it can manage on partly mixed, less-than-fully-oxygenated blood. Third, it grows slowly and does not need the high, sustained oxygen delivery that an active, warm-blooded adult requires.

The adult, by contrast, is highly active, holds a warm body and has a high, constant oxygen demand that can only be met by fully oxygenated blood delivered at high pressure. Mixing would lower the oxygen in every beat and leave the adult unable to meet that demand. So the very mixing that is harmless in the sheltered, low-demand life of the foetus would be dangerous in the active, high-demand life of the adult.

False Confidence Alert
Watch out: do not say the foetus tolerates mixing because its blood is somehow special. The deeper reason is its way of life, low activity, warmth from the mother, oxygen from the placenta and high-affinity haemoglobin together mean it simply does not need the fully separated, high-oxygen supply that an active adult must have.

Question 115

Two students argue about naming. **Kipanga** says: *'The umbilical artery carries deoxygenated blood, so it should really be called a vein; calling it an artery is just wrong.'* **Kipute** says: *'It is correctly called an artery, even though it carries deoxygenated blood.'* Judge who is right, and explain the rule that decides what counts as an artery and what counts as a vein.

Model Answer

Kipute is right. The names artery and vein are not decided by whether the blood is oxygenated or deoxygenated; they are decided by the direction of flow relative to the heart. An artery carries blood away from the heart, while a vein carries blood towards the heart. The umbilical arteries carry blood away from the foetus's heart, out to the placenta, so they are correctly called arteries, even though that blood happens to be deoxygenated. The same point is shown by the pulmonary artery, which carries deoxygenated blood away from the heart to the lungs and is still an artery, and by the pulmonary vein, which carries oxygenated blood back to the heart and is still a vein. Kipanga has mistaken a common pattern, that most arteries happen to carry oxygenated blood, for the actual rule. So the umbilical artery is rightly named, by the rule of direction, not by the oxygen it carries.

False Confidence Alert
A favourite wrong answer is to define an artery as a vessel that carries oxygenated blood. That is only usually true; the real rule is the direction of flow away from the heart, and the umbilical and pulmonary vessels are the clearest reminders that the oxygen content does not decide the name.

Chapter 3

GROWTH AND DEVELOPMENT

BINDER QUESTIONS

Work through each question in order: attempt your own answer first, then check it against the model answer and against the False Confidence Alert that follows, which warns of the mistake that most often costs marks.

Question 1

Every cell in your body arose when an earlier cell grew and then split into two. This orderly round of growth and division is called the cell cycle. Explain what the cell cycle is, name the phases a cell passes through, and explain why a cell spends most of its life in interphase rather than in division.

Model Answer

The cell cycle is the orderly sequence of events by which a cell grows and then divides into two daughter cells. It runs first through a long preparatory period called interphase, which is made up of three phases, the first growth phase (G_1), the synthesis phase (S) and the second growth phase (G_2); this is followed by the mitotic phase, in which the nucleus divides by mitosis and the cytoplasm divides by cytokinesis. The two new cells may then begin the cycle again.

A cell spends most of its life in interphase because that is when all the work of preparation is done. During interphase the cell grows to full size, carries out its normal metabolic duties, makes new organelles and, above all, copies its entire set of DNA so that each daughter can receive a complete copy. Division itself is brief by comparison, and the cell cannot divide safely until this long preparation is finished, so interphase fills about ninety per cent of the cycle.

False Confidence Alert
Students often call interphase the 'resting phase' and treat it as a gap when nothing happens. Interphase is in fact the busiest part of the cycle, the time when the cell grows and copies its DNA, and the mark is lost if it is described as a period of rest.

Question 2

Draw a simple labelled diagram of the cell cycle. On your diagram, name each phase and state briefly what the cell does or prepares in each.

Model Answer

The cell cycle is shown in Figure 3.1. The cycle turns in one direction, through the three phases of interphase and then the short mitotic phase, before the daughter cells start again. What the cell does in each phase is as follows:

G_1 (first growth phase): the cell grows and carries out its normal activities and metabolism.

S (synthesis phase): the DNA is replicated, so each chromosome becomes two identical sister chromatids.

G_2 (second growth phase): the cell grows a little more and makes the proteins and the energy it will need to divide.

M phase (mitosis and cytokinesis): the nucleus divides by mitosis and then the cytoplasm divides by cytokinesis, giving two identical cells.

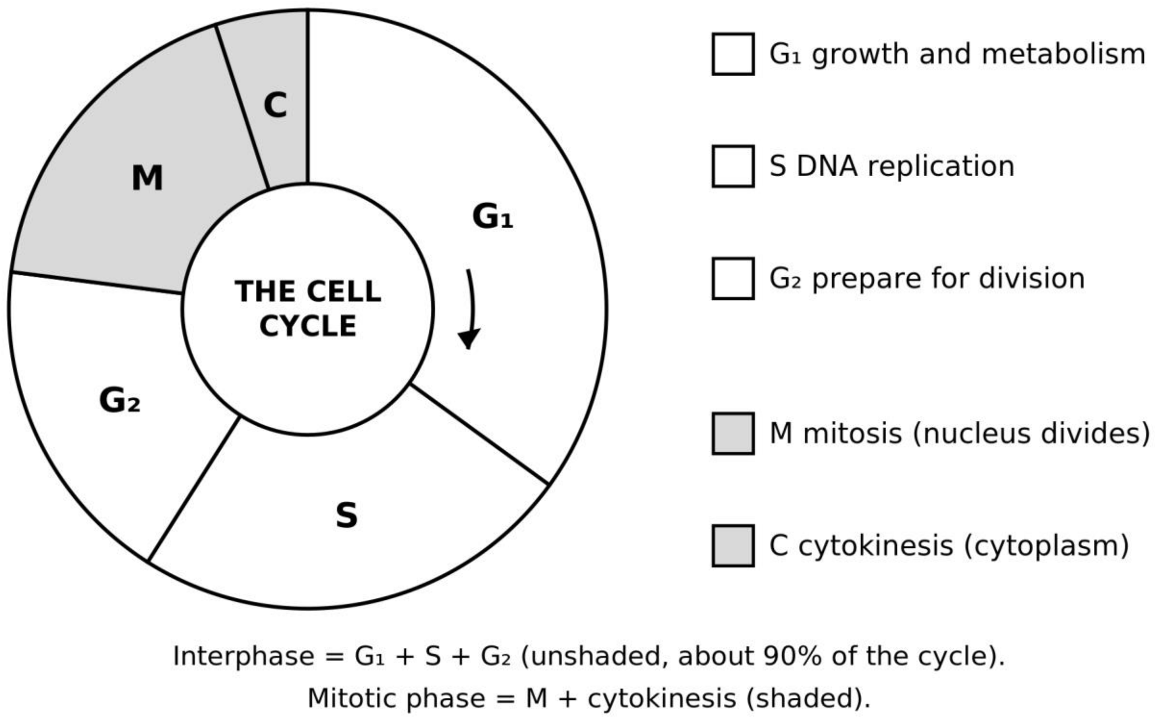


Figure 3.1: *The cell cycle, showing interphase (G_1, S and G_2) and the mitotic phase.*

False Confidence Alert
A common error is to draw the mitotic phase as half the wheel. Mitosis and cytokinesis together take up only a small slice of the cycle, while interphase fills most of it, and a diagram that reverses these proportions misreads the biology.

Question 3

Interphase is far from a period of rest. Describe what happens in each of its three sub-phases, G_1, S and G_2, and explain why the cell must copy its DNA before it begins to divide.

Model Answer

G_1, the first growth phase: the cell grows to its full size, makes new organelles such as mitochondria and ribosomes, and carries out its ordinary work.

S, the synthesis phase: the cell replicates its DNA, so that every chromosome is copied into two identical sister chromatids joined at a centromere.

G_2, the second growth phase: the cell grows a little further and stores the energy and the proteins, including those that will build the spindle, ready for division.

The DNA must be copied before division so that each daughter cell receives a full set. If the cell divided without first doubling its DNA, each daughter would inherit only half of the genetic instructions and could not work. Copying the DNA first, and then passing one copy to each side, is what keeps the two new cells complete and identical.

False Confidence Alert
Students sometimes place DNA replication inside mitosis. The DNA is copied earlier, during the S phase of interphase; by the time mitosis begins each chromosome already consists of two chromatids, and mitosis only separates them.

Question 4

Mitosis is a continuous process, but for study it is divided into four stages. Describe what happens to the chromosomes in prophase, metaphase, anaphase and telophase, and explain why the stages must follow in that order.

Model Answer

Prophase: the chromosomes condense and become short and thick, each now visible as two sister chromatids joined at a centromere; the spindle begins to form and the nuclear membrane and nucleolus break down.

Metaphase: the chromosomes line up along the equator of the spindle, each held by its centromere to spindle fibres running from both poles.

Anaphase: the centromeres split and the spindle fibres pull the sister chromatids apart, drawing one chromatid of each pair to each pole, so that both poles receive an identical set.

Telophase: the chromatids reach the poles and uncoil into chromatin, a new nuclear membrane and nucleolus form around each group to give two daughter nuclei, and the spindle then disappears.

The order cannot be changed because each stage prepares for the next. The chromosomes must be condensed and attached to the spindle before they can be lined up, they must be lined up at the equator before they can be separated evenly, and they can only be wrapped in new nuclei once they have reached the poles. Any other order would share the chromosomes unequally.

False Confidence Alert
A frequent slip is to say the chromosomes are pulled apart at metaphase. At metaphase they are only lined up at the equator; the actual separation of the chromatids happens at anaphase, when the centromeres split.

Question 5

Draw the four stages of mitosis as they appear in an animal cell. Label the chromosomes, the spindle fibres and the equator, and show how the chromosomes change position from one stage to the next.

Model Answer

The four stages are shown in Figure 3.2. Read from left to right, the figure shows the chromosomes condensing in prophase, lining up on the equator in metaphase, being pulled apart to the poles in anaphase, and finally being enclosed in two new nuclei in telophase.

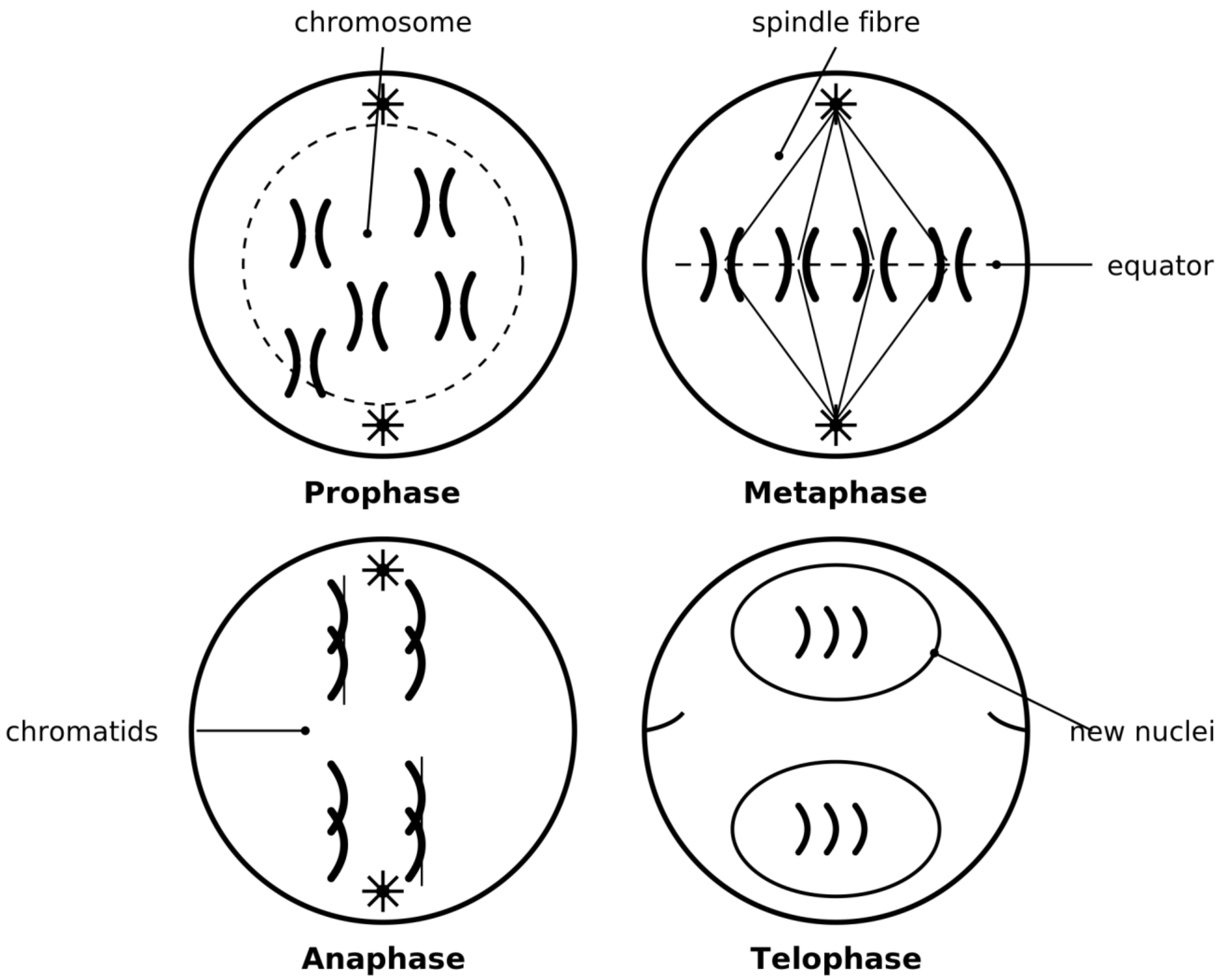


Figure 3.2: *The four stages of mitosis in an animal cell.*

False Confidence Alert
Students often forget to show the spindle at all, or draw the chromosomes the same in every stage. The marks come from showing the change: paired chromatids on the equator in metaphase, then single chromatids travelling to opposite poles in anaphase.

Question 6

After mitosis, the two daughter cells are exact genetic copies of the parent cell and of each other. Explain why mitosis produces daughter nuclei that are genetically identical to the parent nucleus.

Model Answer

Mitosis produces identical nuclei because the DNA is first copied exactly and then shared out equally. Before mitosis, in the S phase, every chromosome is replicated into two identical sister chromatids that carry exactly the same genes. During mitosis these chromatids are separated so that one of each pair passes to each pole. Each daughter nucleus therefore receives one complete copy of every chromosome, with the same number and the same genes as the parent, so the two cells are genetically identical.

False Confidence Alert
It is not enough to say the cell 'just copies itself'. The marks are for the mechanism: the exact copying of each chromosome in the S phase, followed by the equal separation of the identical chromatids during mitosis.

Question 7

A human body cell has 46 chromosomes, and so does every new cell it makes by mitosis. Explain how the copying of DNA in the S phase allows mitosis to keep the chromosome number constant from one cell generation to the next.

Model Answer

The chromosome number stays constant because the cell first doubles its chromosomes and then halves the doubled amount. In the S phase each of the 46 chromosomes is copied into two identical chromatids, so for a time the cell holds a double quantity of DNA. In mitosis the sister chromatids are separated, one to each daughter, so each new cell ends up with 46 single chromosomes, exactly what the parent had. This copy-first, separate-later sequence is what lets growth add cell after cell without ever changing the chromosome number.

> **False Confidence Alert**
> Students sometimes think mitosis adds chromosomes because the DNA doubles. The doubling is only temporary; the separation at anaphase restores the original number, so the daughter cells carry the same count as the parent, not double.

Question 8

Once the nucleus has divided, the cytoplasm itself must be split in two, a step called cytokinesis. Explain how cytokinesis differs between an animal cell and a plant cell, and why the plant cell wall is the reason for the difference.

Model Answer

In an animal cell the cell is pinched in two from the outside, while in a plant cell a new wall is built across the middle from the inside. The two processes reach the same end, two separate cells, by opposite means:

Animal cell: a ring of protein just beneath the cell surface membrane tightens like a drawstring, pulling the membrane inward to form a cleavage furrow that deepens until the cell is pinched into two.

Plant cell: a row of vesicles gathers along the middle and fuses to form a cell plate, which grows outward and develops into a new cell wall that separates the two daughter cells.

The difference exists because of the rigid plant cell wall. A plant cell is enclosed by a stiff wall that cannot be squeezed inward, so it must instead lay down a new partition from the centre outward. An animal cell has only a flexible membrane, so it can simply be pinched in two.

> **False Confidence Alert**
> Students often write that both cells 'pinch in two'. Only the animal cell forms a cleavage furrow; the walled plant cell cannot be pinched and instead builds a cell plate outward into a new wall.

Question 9

Draw and label diagrams to contrast cytokinesis in an animal cell and in a plant cell, clearly showing the cleavage furrow in one and the cell plate in the other.

Model Answer

The two kinds of cytokinesis are contrasted in Figure 3.3. In the animal cell the surface membrane is drawn inward as a cleavage furrow until the cell is pinched apart, while in the plant cell a cell plate forms across the middle and grows out to become a new cell wall.

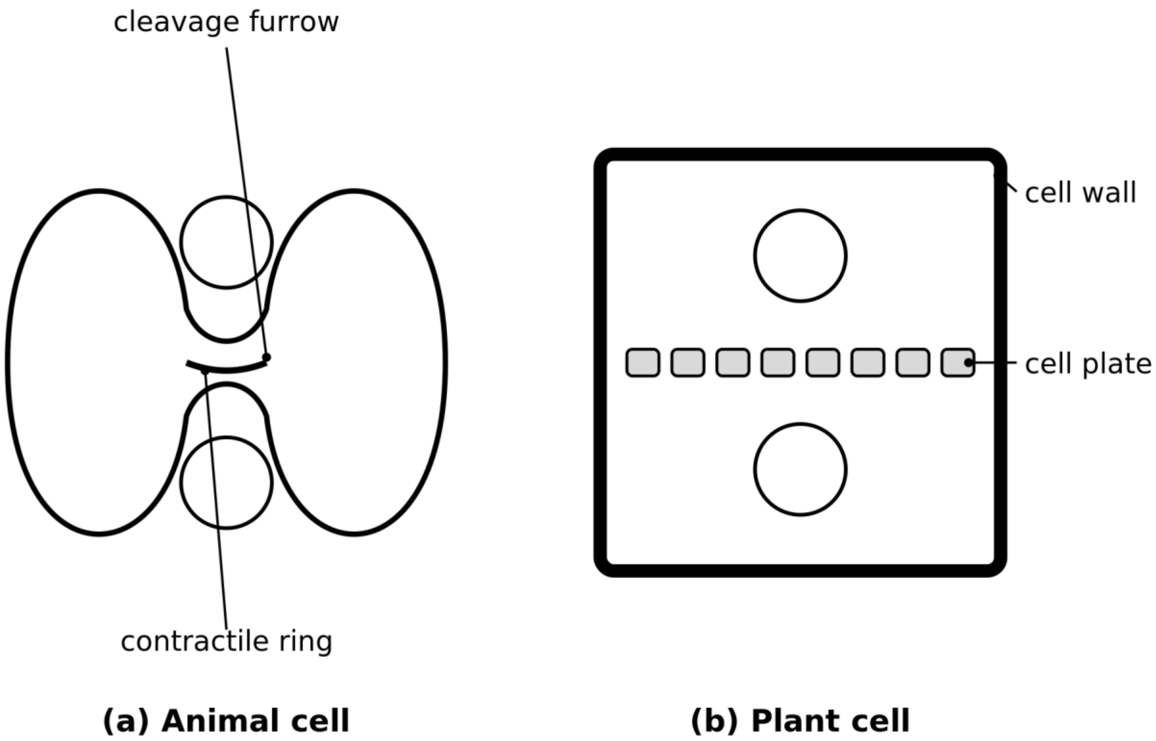


Figure 3.3: *Cytokinesis in (a) an animal cell, by a cleavage furrow, and (b) a plant cell, by a cell plate.*

False Confidence Alert
A common error is to draw a cell plate inside the animal cell, or a furrow on the plant cell. Match each to its cell: the furrow belongs to the wall-less animal cell, the cell plate to the walled plant cell.

Question 10

Mitosis does not take place everywhere in a plant or an animal, but only in particular places. State where mitosis occurs in plants and in animals, and explain why active division is confined to these regions.

Model Answer

In plants: mitosis is confined to the meristems, the dividing tissues at the tips of the roots and shoots, in the lateral cambium between the xylem and phloem, and at the nodes of some stems, which is why a plant grows in length and in girth only from these growing points.

In animals: mitosis occurs in the body, or somatic, cells; it is very active in the growing embryo, continues after birth to add and replace cells, slows or stops in many mature organs such as the brain and kidneys, but stays rapid where cells are constantly lost, such as the skin and the lining of the gut.

Division is confined to these regions because that is where new cells are needed. Concentrating growth and replacement in particular tissues lets the organism build and repair itself in an orderly way, while organs that have reached their working size stop dividing so that they do not grow out of proportion.

False Confidence Alert
Students sometimes say mitosis happens 'all over' the plant. In plants division is restricted to the meristems; the rest of the plant body is made of mature cells that have stopped dividing.

Question 11

Mitosis matters to living things for several reasons beyond simply making cells. Outline the significance of mitosis to living organisms, giving a clear example of each role.

Model Answer

1) **Genetic stability:** it produces daughter cells genetically identical to the parent, so the characteristics of the organism are preserved exactly from one cell to the next.
2) **Growth:** it increases the number of cells, allowing a single fertilised egg to build up into a whole multicellular body.
3) **Healing and replacement:** it replaces cells that are worn out or damaged, for example closing a wound or renewing the lining of the gut.
4) **Regeneration:** it allows the regrowth of a lost part, as when a lizard regrows its tail.
5) **Asexual reproduction:** in many single-celled organisms it is the means of reproduction, one cell dividing into two new individuals.
6) **Medical value:** understanding mitosis helps in treating diseases such as cancer, which is uncontrolled mitosis, and underlies the growing of cells in tissue culture.

False Confidence Alert
Students often give only 'growth' and stop. The question asks for the range of roles, genetic stability, growth, repair, regeneration and asexual reproduction, and each needs its own example to earn full marks.

Question 12

When you cut your finger the wound soon closes, and a lizard that loses its tail can grow a new one. Explain how mitosis makes both the healing of a wound and the regeneration of a lost part possible.

Model Answer

Both depend on mitosis making new, identical cells to replace those that are missing. When the skin is cut, the cells around the wound divide repeatedly by mitosis, and because each division yields cells genetically identical to the originals, the new tissue is the same as the tissue it replaces, so the gap is filled and sealed. In the same way, when a lizard loses its tail, the cells at the stump divide by mitosis to build new tissue of the same kind, and the tail grows back. Because mitosis copies the genetic instructions exactly, the repaired or regrown part matches the original instead of being something different.

False Confidence Alert
It is not enough to say the body 'makes new cells'. The marks are for linking healing and regeneration to mitosis in particular, and to the fact that mitosis makes identical cells, so the new tissue matches the old.

Question 13

Growth and repair use mitosis, while the making of gametes uses a different division called meiosis. Explain the key difference between the two in terms of chromosome number, and explain why growth must use mitosis and not meiosis.

Model Answer

The key difference is that mitosis keeps the chromosome number the same, while meiosis halves it. Mitosis produces two daughter cells, each with the full chromosome number and identical to the parent; meiosis produces cells with half the number, which go on to become the gametes.

Growth must use mitosis because the new body cells need the full set of chromosomes. If growth used meiosis, every new cell would have only half the chromosomes and could not work properly, and the body would lose half of its genetic information at each division. By keeping the number constant, mitosis lets the body add identical, fully equipped cells, while meiosis is kept for forming gametes, where halving is necessary so that the full number is restored at fertilisation. Meiosis itself is studied fully in the next chapter, on reproduction.

False Confidence Alert
Students sometimes muddle the two and say mitosis halves the chromosome number. It is meiosis that halves it; mitosis keeps it constant, which is exactly why growth and repair rely on mitosis.

Question 14

When the size, mass or number of cells of a growing organism is plotted against time, the points trace out a curve with a characteristic shape. Name this curve, describe its shape, and explain what each part of it tells us about the rate of growth.

Model Answer

The curve is S-shaped, and is called the sigmoid growth curve, shown in Figure 3.4. It is read in three parts, each standing for a different rate of growth:

1) **A slow start**: at first growth is slow, because the organism, or the population of cells, is still small and few cells are yet dividing.
2) **A rapid, almost exponential middle**: growth then speeds up sharply as many cells divide together, and this gives the steep part of the curve.
3) **A levelling-off**: growth finally slows and the curve flattens, as the organism nears its full size or its food, space or other resources begin to run short.

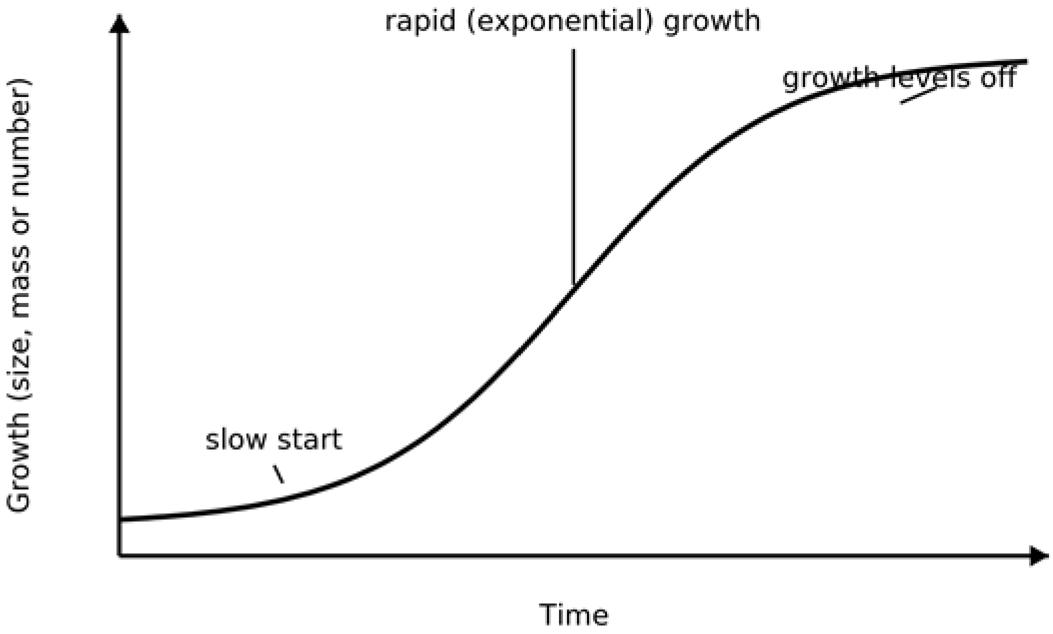


Figure 3.4: *The sigmoid (S-shaped) growth curve.*

False Confidence Alert
Students often write only that the organism gets bigger with time, and draw a straight rising line. The growth curve is not a straight line but an S shape, and the marks are for the three parts: the slow start, the rapid middle and the levelling-off.

Question 15

In some animals, such as fish, a young individual and a full-grown adult have almost exactly the same body shape. Explain what is meant by isometric growth, and why this pattern suits an animal such as a fish.

Model Answer

Isometric growth is growth in which all parts of the body grow at the same rate, so the proportions, and therefore the overall shape, stay the same as the organism gets larger. A young fish and an older fish differ in size but look alike, because every part, the head, the trunk and the fins, has enlarged by the same factor.

This pattern suits a fish because its shape already fits its life from the very start. A streamlined body lets even a young fish swim and feed efficiently in water, so there is no advantage in changing its proportions as it grows; keeping the same shape keeps it well adapted at every size.

> **False Confidence Alert**
> Students sometimes say isometric growth means the animal grows evenly, without saying what stays the same. The mark is for the idea that all parts grow at the same rate, so the body proportions and the shape are unchanged while only the size increases.

Question 16

Isometric growth is shown most simply by drawing the same kind of animal at two ages. Draw simple diagrams to show isometric growth in a fish, and use them to make clear what stays the same and what changes as the animal grows.

Model Answer

Isometric growth in a fish is shown in Figure 3.5 below. The young fish and the older fish have exactly the same shape; only the overall size has increased, because every part of the body has grown by the same factor. The proportions, such as the size of the head compared with the body, are identical in both.

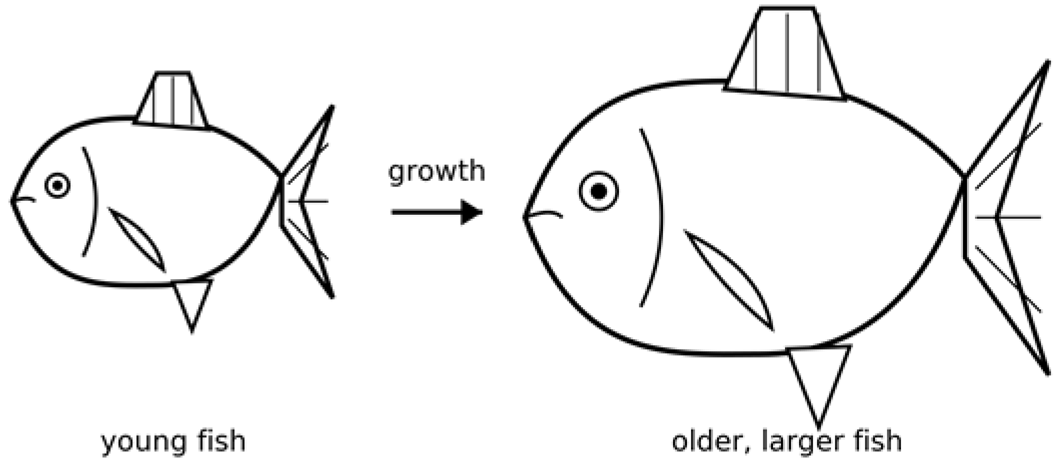


Figure 3.5: *Isometric growth in a fish: the body shape is unchanged as the size increases.*

> **False Confidence Alert**
> A common mistake is to draw the older fish with a bigger head or longer fins in proportion. In isometric growth the proportions must be identical in both drawings; only the overall size differs.

Question 17

A newborn baby has a head that is very large compared with its body, while an adult's head is a much smaller fraction of the whole. Explain what is meant by allometric growth, and why it causes the proportions of the body to change with age.

Model Answer

Allometric growth is growth in which different parts of the body grow at different rates, so the proportions of the body change as the organism develops. Because one part enlarges faster than another, the shape of the body does not stay the same. The head, which grows early and fast, makes up a large share of a small baby, but as the trunk and limbs grow faster later on, the head comes to be a smaller fraction of the adult.

The proportions change because each organ grows on its own timetable, matched to when the body needs it. The brain grows early, because the young child needs it at once; the reproductive organs grow late, near puberty, when they are first needed; and so the balance between the parts shifts steadily with age.

False Confidence Alert
Students often confuse allometric growth with isometric growth. In allometric growth the parts grow at different rates so the proportions change; it is isometric growth that keeps the proportions the same.

Question 18

Allometric growth shows up most clearly when the growth of several organs is plotted together. Draw a single set of axes showing how the brain, the thymus gland and the reproductive organs grow at different rates from birth to adulthood, and use the curves to explain what allometric growth means.

Model Answer

The allometric growth of these organs is shown in Figure 3.6 below. Each organ follows a curve of a different shape: the brain grows quickly and reaches its final size early; the thymus grows fast in childhood and then shrinks again; the reproductive organs stay small until late and then grow rapidly near puberty; and the body as a whole follows a gentle S-shaped curve. Because the curves differ, the parts grow at different rates, and this is exactly what allometric growth means.

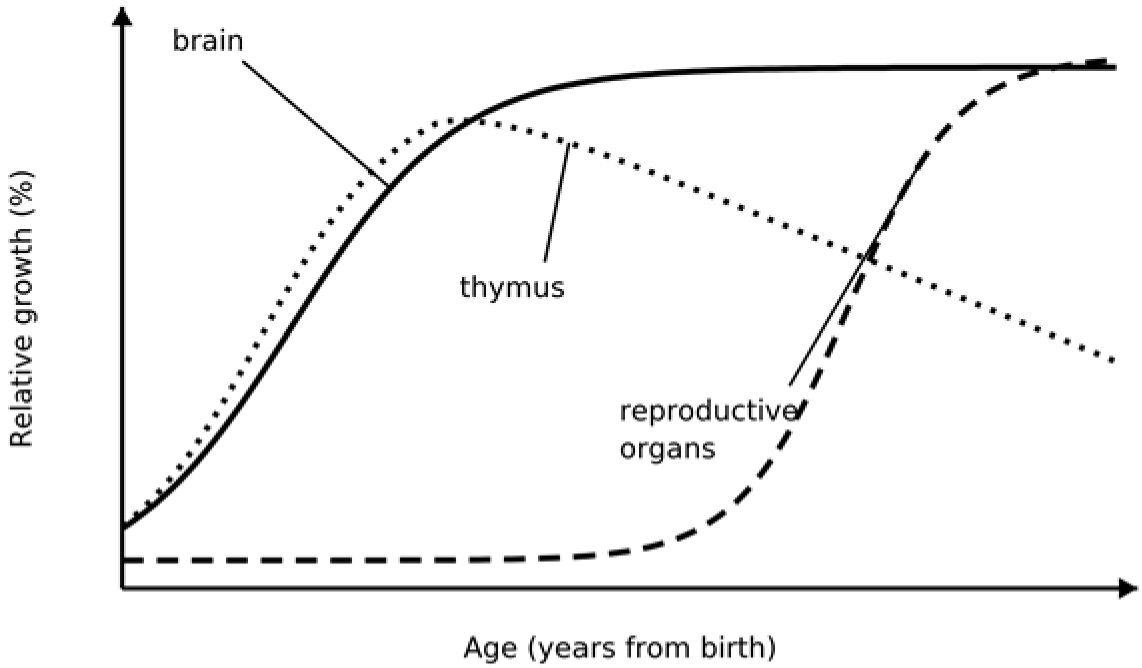


Figure 3.6: *Allometric growth: the brain, thymus and reproductive organs grow at different rates.*

False Confidence Alert
Students often draw all the organs following one and the same curve. The whole point of the figure is that each organ has a different curve, the brain early, the reproductive organs late and the thymus rising then falling, which is why the body's proportions change with age.

Question 19

Humans, insects and birds all stop growing once they reach maturity, unlike a tree, which keeps growing throughout its life. Explain what is meant by limited (determinate) growth, and what happens to such an organism after growth has stopped.

Model Answer

Limited, or determinate, growth is growth that stops once the organism reaches a definite adult size at maturity. Humans, insects and birds grow to a more or less fixed size and then grow no more, however long they go on living; the final size is much the same for all healthy members of the species.

After growth has stopped, the organism is maintained, then ages and dies. Once the adult size is reached the body is repaired and maintained rather than enlarged; in time it undergoes senescence, its functions decline, and eventually it dies.

> **False Confidence Alert**
> Students sometimes think limited growth means the organism stops growing only because it runs out of food. It is not about food: in determinate growth the organism is programmed to stop at a set adult size at maturity, even when food is plentiful.

Question 20

When the dry mass of an annual plant such as a bean is measured from germination to death, the curve first dips, then rises steeply, and finally falls. Account for the early fall, the steep rise and the final fall in dry mass.

Model Answer

The dry mass of an annual plant follows the curve shown in Figure 3.7, which has three parts. Each part reflects the balance between the food the plant makes and the food it uses up:

1) **The early fall**: just after germination the seedling has no leaves yet, so it cannot make food; it respires the food stored in its cotyledons or endosperm, and using up this store lowers the dry mass.
2) **The steep rise**: once the first leaves open and begin to photosynthesise, the plant makes far more food than it uses, so dry mass climbs rapidly as new tissue is built.
3) **The final fall**: when the mature plant has flowered and set seed it begins to die back, and the loss of leaves and seeds, with continued respiration, now outweighs the food made, so dry mass falls at senescence.

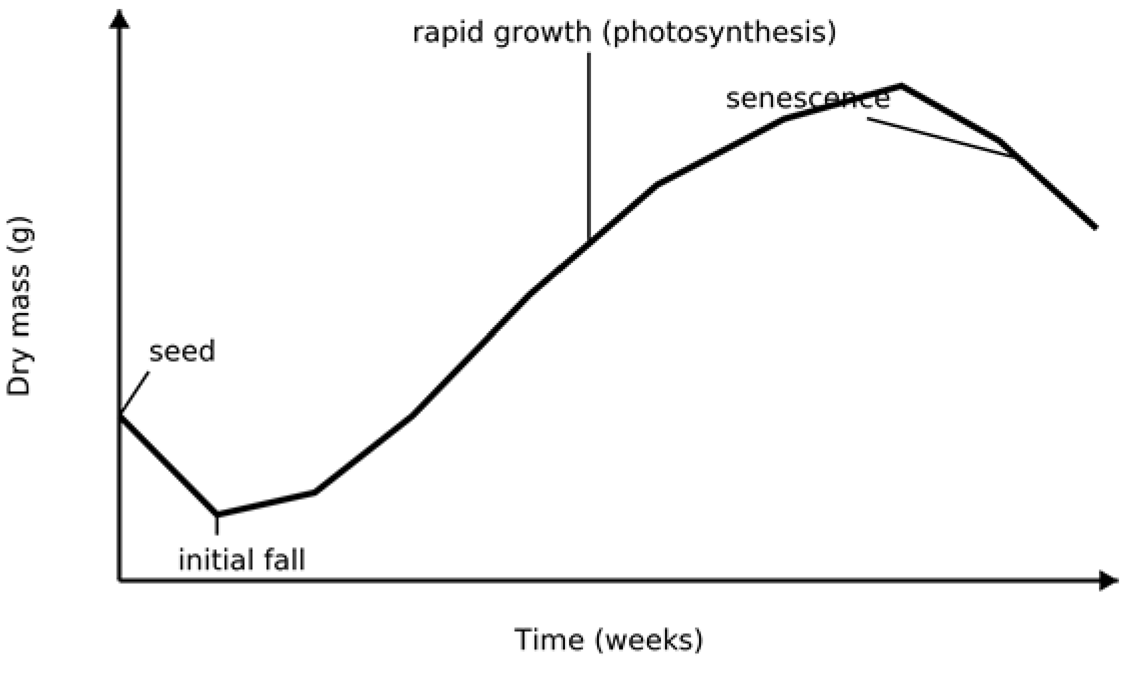


Figure 3.7: *The growth curve of an annual plant (dry mass against time).*

> **False Confidence Alert**
> Students often forget the early dip and start the curve rising from zero. The dry mass falls at first because the seed is respiring its stored food before any leaves can photosynthesise; only after the leaves open does the mass begin to rise.

Question 21

A plant gains in dry mass at some times of its life and loses it at others. Using the ideas of anabolism and catabolism, explain why a plant gains dry mass during its main growth phase but loses it during senescence.

Model Answer

A plant gains dry mass only when anabolism is greater than catabolism. Anabolism is the building up of complex substances, such as making sugars, starch, proteins and new tissue, while catabolism is the breaking down of substances, such as respiring sugars to release energy. The dry mass rises or falls according to which of these is winning.

During the main growth phase, anabolism outpaces catabolism, so mass is gained. The photosynthesising leaves build food and new tissue faster than respiration breaks food down, so there is a net gain in dry mass.

During senescence, catabolism outpaces anabolism, so mass is lost. Little new material is now made, while respiration and the breakdown and loss of tissues go on, so the balance tips the other way and the dry mass falls.

> **False Confidence Alert**
> Students often treat growth as only building up, and forget that breaking down is going on at the same time. Dry mass rises only while anabolism (building up) is faster than catabolism (breaking down); when the balance reverses, mass is lost.

Question 22

The growth of a human from birth to old age does not happen at a steady rate. Describe the four main phases of the human growth curve, and explain what drives the rapid growth of the adolescent phase.

Model Answer

1) **Infancy**: growth is very rapid, the newborn growing quickly through its first few years.
2) **The juvenile stage**: growth slows to a steady, gentle rate through childhood.
3) **Adolescence**: growth speeds up again into a rapid growth spurt, as the body reaches sexual maturity.
4) **Adulthood**: growth slows and then stops at the final adult size, with senescence following in old age.

The adolescent growth spurt is driven by hormones. It is brought about by an increased output of growth hormone and thyroid hormones, together with the sex hormones that bring sexual maturity, and these act together to speed up the growth of the bones, the muscles and the organs.

> **False Confidence Alert**
> Students often describe human growth as steady from birth to adulthood. It is not: growth is rapid in infancy, slow in the juvenile stage, rapid again at the adolescent spurt, and then stops in adulthood, and the marks are for recognising these separate phases.

Question 23

The changing pace of human growth shows up at once when growth is plotted against age. Draw the human growth curve from birth to old age, mark the four phases of growth on it, and show clearly where the adolescent growth spurt occurs.

Model Answer

The human growth curve is shown in Figure 3.8. It rises steeply during infancy, more gently through the juvenile stage, steeply again at the adolescent growth spurt, and then flattens in adulthood before a slight fall in old age. The four phases are marked along the curve.

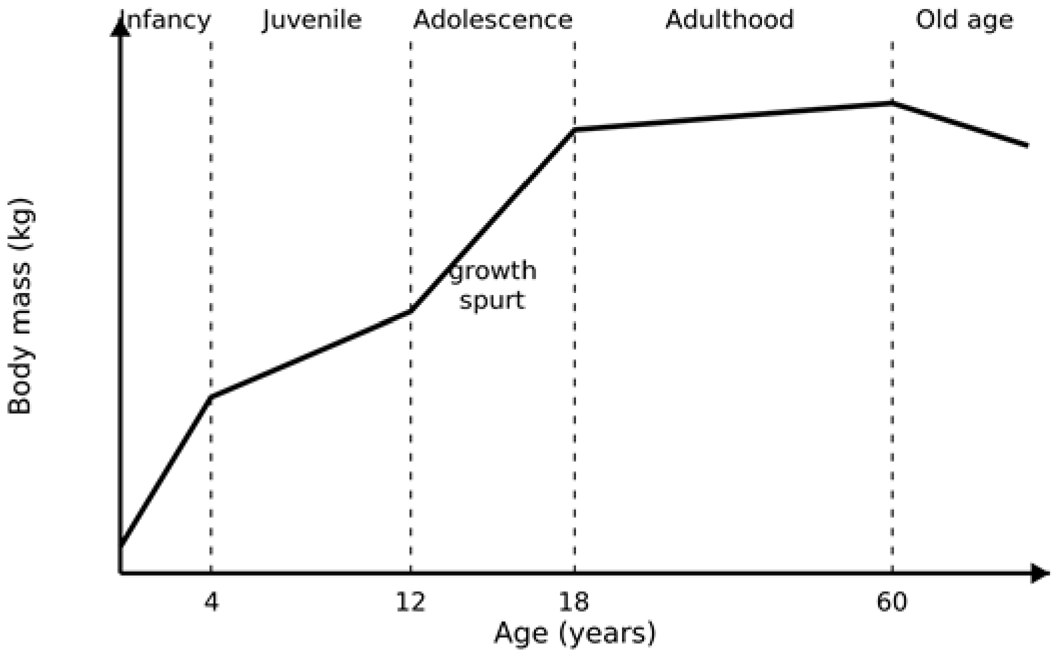


Figure 3.8: *The human growth curve, with its four phases.*

False Confidence Alert
A common error is to draw a single smooth curve with no change of slope. The human curve must show the change of pace, above all the steep adolescent spurt sitting between the gentle juvenile stage and the flat adult plateau.

Question 24

An insect such as a cockroach does not grow smoothly but in a series of sudden steps. Explain why arthropods grow in steps, and why each step depends on moulting.

Model Answer

Arthropods grow in steps because the body is enclosed in a hard, inelastic exoskeleton that cannot stretch. As the animal grows, the rigid cuticle cannot expand, so an increase in size is impossible until the old exoskeleton has been shed.

Each step in size therefore depends on moulting (ecdysis). The animal sheds its old exoskeleton, and while the new one beneath is still soft it quickly takes in air or water and swells to a larger size; the new cuticle then hardens and growth stops again until the next moult. The result is the step-like, discontinuous curve shown in Figure 3.9, in which the flat parts are the instars, the stages between moults when length does not change, and each sudden rise marks a moult.

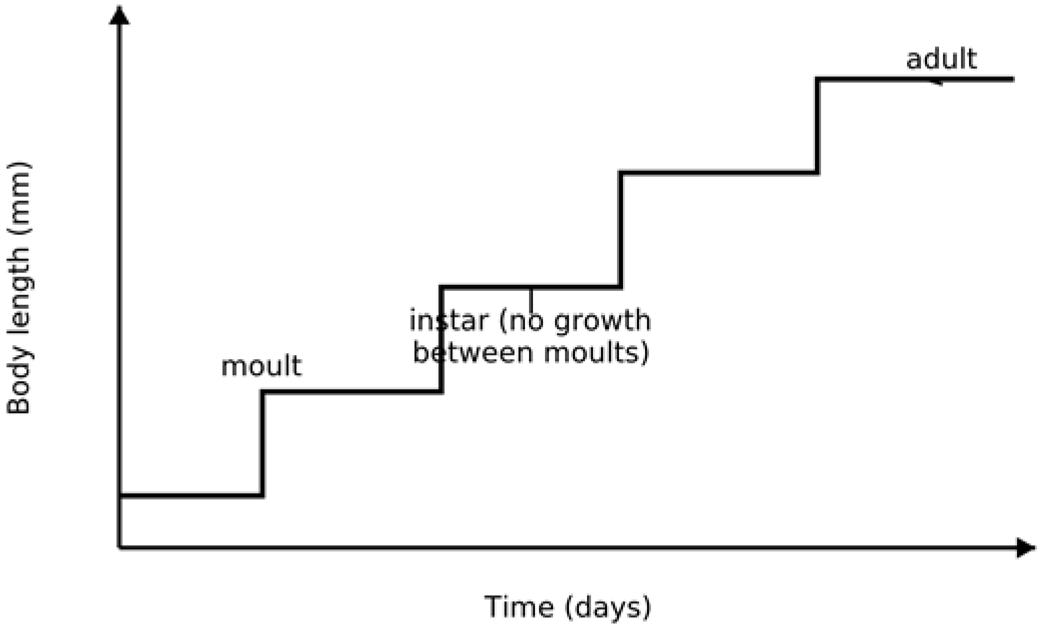


Figure 3.9: *Discontinuous (step) growth in an arthropod.*

False Confidence Alert
Students often say the arthropod grows steadily and just sheds its skin now and then. The growth itself is discontinuous: the animal can only enlarge in the short time just after a moult, while the new exoskeleton is still soft, which is why the curve rises in steps.

Question 25

Moulting in an insect is controlled by two hormones working together. Name these two hormones and the glands that make them, and explain how the balance between them decides whether a moult produces another larva or the adult.

Model Answer

Ecdysone, the moulting hormone: it is produced by the prothoracic gland, and it triggers each moult, the shedding of the old exoskeleton.

Juvenile hormone (neotenin): it is produced by the corpus allatum, and its level decides what kind of body the moult will produce.

The balance between the two hormones decides the outcome of each moult. When ecdysone triggers a moult while juvenile hormone is still at a high level, the result is another larval stage; when the juvenile hormone level is low, the moult produces a pupa; and when juvenile hormone is absent, the final moult produces the adult (the imago). In short, ecdysone decides when to moult, while juvenile hormone decides what to become.

False Confidence Alert
Students often name only one hormone, or swap their jobs. Ecdysone (from the prothoracic gland) triggers the moult, while juvenile hormone (from the corpus allatum) decides whether the moult gives another larva or the adult; both must appear in the answer.

Question 26

Unlike a human, a tree or a fish keeps on growing for as long as it lives. Explain what is meant by indeterminate growth, and why the growth curve of such an organism is drawn as a series of sigmoid curves.

Model Answer

Indeterminate, or unlimited, growth is growth that continues throughout life and does not stop at a fixed adult size. Perennial plants such as woody trees, and animals such as most fish, molluscs and reptiles, keep growing even after they are mature, so they have no single final size.

The curve is drawn as a series of sigmoid curves because the growth comes in yearly bursts that follow the seasons. In the wet, favourable season the organism grows fast, giving the steep part of a sigmoid; in the dry, unfavourable season growth slows almost to a stop, giving a flat part. Each year therefore adds one more sigmoid step, and the steps stacked together, with an average line drawn through them, show the size rising again and again without ever levelling off for good, as in Figure 3.10.

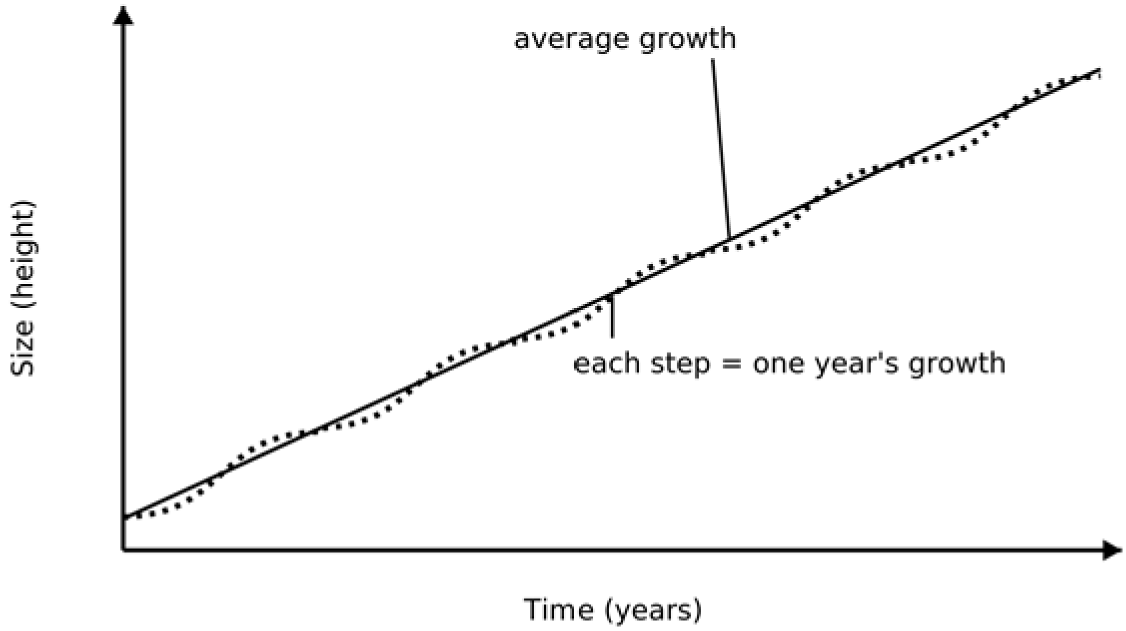


Figure 3.10: *Indeterminate growth: a series of sigmoid curves in a perennial plant.*

False Confidence Alert
Students sometimes think indeterminate growth means a steady, constant rate of growth. It does not: growth is unlimited over the lifetime but still comes in seasonal bursts, fast in the wet season and slow in the dry, which is why the curve is a series of sigmoids and not a straight line.

Question 27

A plant does not grow all over its body the way an animal does, but only in a few special regions of dividing cells. Explain what a meristem is, then name the three kinds of meristem in a flowering plant, saying where each one lies and the growth it brings about.

Model Answer

A meristem is a region of unspecialised cells that keep the power to divide by mitosis throughout the life of the plant. Growth is confined to these regions, while the rest of the plant body is made of mature cells that have stopped dividing. There are three kinds:

1) **Apical meristems**: found at the tips of the roots and the shoots, they bring about growth in length, that is, primary growth.
2) **Lateral meristems**: found as cylinders along the sides of the stem and root (the cambium), they bring about growth in thickness, or girth, that is, secondary growth.
3) **Intercalary meristems**: found at the nodes, especially in grasses, they lengthen the stem between the nodes and help repair a damaged leaf.

False Confidence Alert
Students often say a plant grows from every part, as an animal does. Growth is confined to the meristems, and the rest of the plant is mature tissue that no longer divides, which is why a plant lengthens only at its tips and thickens only at its cambium.

Question 28

The three kinds of meristem each sit in a particular place, and a single labelled plant shows at a glance where each one works. Draw a labelled diagram of a young plant to show the positions of the apical, the lateral and the intercalary meristems.

Model Answer

The positions of the three meristems are shown in Figure 3.11 below. The apical meristems sit at the very tip of the shoot and of the root, where they lengthen the plant; the lateral meristem runs as a cylinder down the inside of the stem and root, where it thickens them; and the intercalary meristems lie at the nodes.

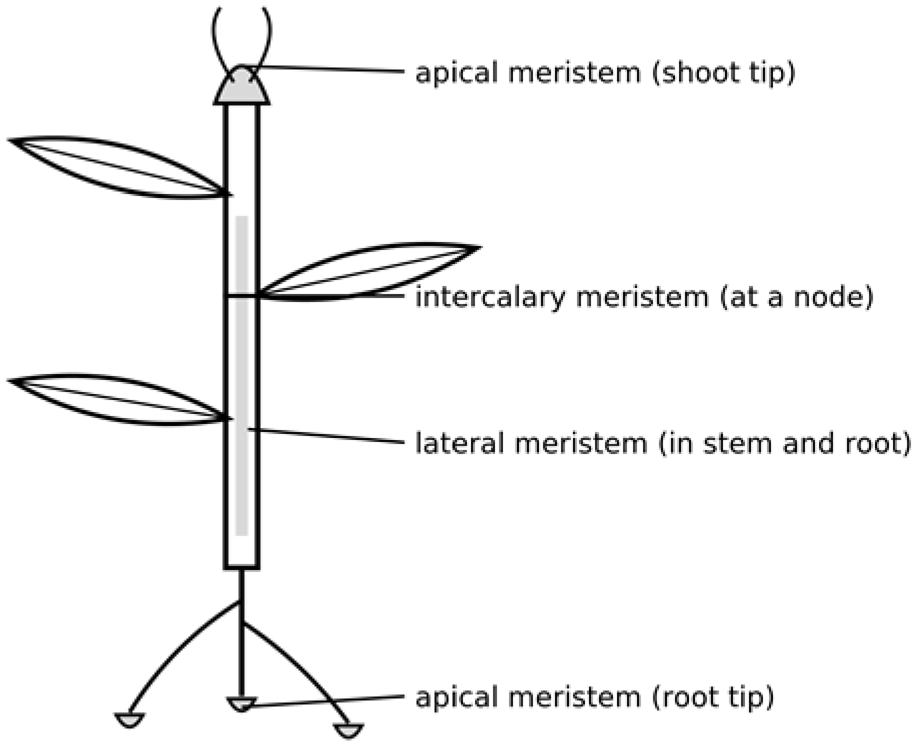


Figure 3.11: *The positions of the apical, lateral and intercalary meristems in a plant.*

False Confidence Alert
A common mistake is to draw the lateral meristem only at the tip, or to place the intercalary meristem at the shoot apex. Keep each to its own place: apical at the tips, lateral along the sides, and intercalary at the nodes.

Question 29

Under the microscope a cell from a meristem looks very different from a mature cell, and every difference fits it for constant division. Describe the features of a meristematic cell, and explain how each one suits it to rapid cell division.

Model Answer

1) **Thin cellulose walls**: they let the cell divide and grow quickly, and let materials pass in and out easily.
2) **Dense cytoplasm**: it is packed with the organelles and the materials needed to build two new cells.

3) **A large nucleus**: it controls the frequent divisions and holds the DNA that must be copied before each one.
4) **Small or no vacuoles**: the cell is not yet filled by a large sap vacuole, so there is room for division.
5) **Many ribosomes and mitochondria**: they supply the proteins and the energy that rapid division demands.

> **False Confidence Alert**
> Students often describe a meristematic cell as simply a small cell. The marks come from tying each feature to division: thin walls and dense cytoplasm for fast building, a large nucleus to control it, small vacuoles to leave room, and many mitochondria for energy.

Question 30

Behind the tip of a growing root the cells pass through three regions, one after another, as the root lengthens. Describe the three zones of primary growth in a root, and state what happens to the cells in each.

Model Answer

1) **The zone of cell division**: just behind the root cap, the meristematic cells divide rapidly by mitosis to make new cells.
2) **The zone of elongation**: a little further back, the new cells take in water and stretch lengthways, and it is this stretching that pushes the root tip forward through the soil.
3) **The zone of differentiation (maturation)**: further back still, the elongated cells specialise into the mature tissues, such as the xylem, the phloem and the root hairs.

> **False Confidence Alert**
> Students sometimes think the dividing cells themselves push the root through the soil. It is not the division but the elongation, in the zone just behind the dividing zone, that lengthens the root; division only supplies the new cells.

Question 31

New cells are made by division, yet it is not division that makes a root or a shoot longer. Explain why the taking in of water and the swelling of a large vacuole, rather than cell division, is responsible for most of the increase in length.

Model Answer

Most of the increase in length comes from cell vacuolation, not from cell division. In the zone of elongation, each young cell takes in water by osmosis, and the water gathers in small vacuoles that join into one large central vacuole. As this vacuole fills, it presses outward and the cell stretches, mainly lengthways, so the cell becomes far longer than before.

Division on its own would only add more small cells without lengthening the organ. Cell division simply raises the number of cells; it is the swelling of each new cell by its vacuole that adds real length, which is why a root or shoot grows longest in the zone of elongation and not in the zone of division.

> **False Confidence Alert**
> Students often credit all growth in length to mitosis. Mitosis only makes the cells; the actual lengthening is done by vacuolation, as each cell takes in water and its enlarging vacuole stretches it lengthways.

Question 32

At the growing tip the apical meristem is already sorted into three layers, and each layer goes on to build a different part of the plant body. Name the three primary meristems, and state the mature tissue that each one forms.

Model Answer

1) **The protoderm**: the outer layer, which forms the epidermis that covers and protects the plant.

2) **The ground meristem**: the middle layer, which forms the ground tissues, such as the cortex and the packing parenchyma.
3) **The procambium**: the inner core, which forms the vascular tissues, the xylem and the phloem, with the vascular cambium between them.

False Confidence Alert
Students often confuse the primary meristems with the tissues they form. The protoderm is not itself the epidermis but the layer that makes it; in the same way the ground meristem makes the ground tissue and the procambium makes the vascular tissue.

Question 33

At the very tip of a shoot the apical meristem is already sorted into the layers that will build the stem, and a labelled section shows this at a glance. Draw a labelled diagram of a longitudinal section through a shoot apex, showing the apical meristem, a leaf primordium and the three primary meristems.

Model Answer

The shoot apex is shown in Figure 3.12 below. The apical meristem sits as a dome at the very tip; small leaf primordia bulge from its sides; and just behind the dome lie the three primary meristems, the protoderm on the outside, the ground meristem in the middle and the procambium in the core.

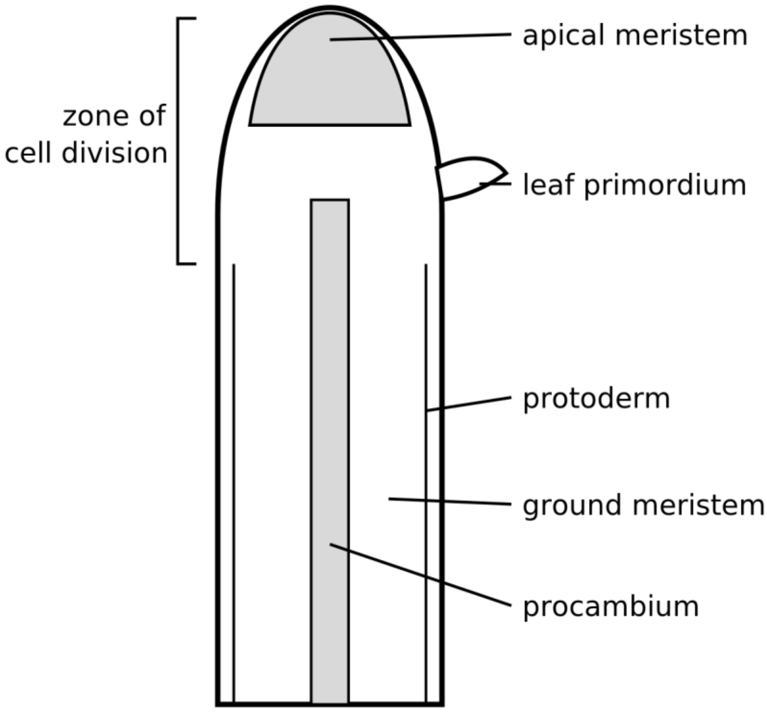


Figure 3.12: *A longitudinal section through a shoot apex.*

False Confidence Alert
A common mistake is to label the three primary meristems as the tissues they form. The protoderm, ground meristem and procambium are still dividing layers; the epidermis, ground tissue and vascular tissue are only what they later become.

Question 34

If you stain the very tip of an onion root and look along it under the microscope, the cells fall into clear regions one behind another. Starting from the tip, describe the regions of the root apex and what each one does.

Model Answer

1) **The root cap**: a thimble of cells covering the tip, which protects the delicate meristem as the root is pushed through the soil and helps the root sense gravity.
2) **The quiescent zone**: a small group of slowly dividing cells just behind the cap, which acts as a reserve and an organising centre for the meristem.
3) **The zone of cell division**: the meristem just behind the cap, where cells divide rapidly by mitosis to make new cells.
4) **The zone of cell elongation**: where the new cells take in water and stretch lengthways, and it is this stretching that drives the tip forward.
5) **The zone of cell differentiation**: where the elongated cells specialise into the mature tissues and the root hairs appear.

False Confidence Alert
Students often leave out the root cap and the quiescent zone. The cap protects the tip, and the quiescent zone is a slowly dividing reserve; both belong in the answer, ahead of the zones of division, elongation and differentiation.

Question 35

A single labelled diagram of a root tip shows the protective cap, the dividing region and the zones behind it all at once. Draw a labelled longitudinal section of a root apex, showing the root cap, the quiescent zone and the zones of cell division, elongation and differentiation.

Model Answer

The root apex is shown in Figure 3.13 below. The root cap covers the tip; the quiescent zone lies just within it; and behind these come the zone of cell division, then the zone of elongation, then the zone of differentiation, where the root hairs appear.

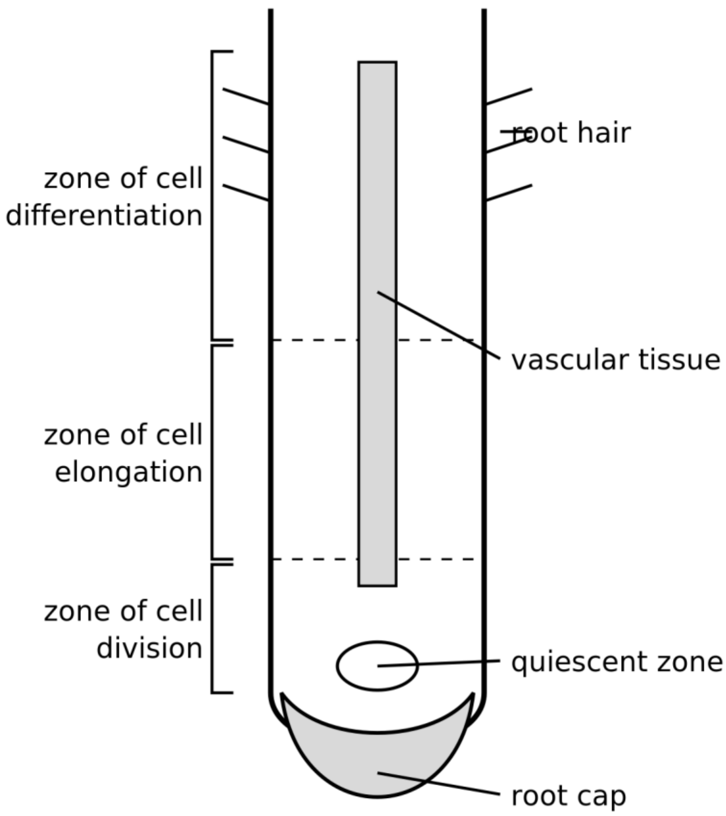


Figure 3.13: *A longitudinal section through a root apex.*

False Confidence Alert
A frequent error is to draw the root hairs at the very tip. Root hairs form well back, in the zone of differentiation; the tip itself carries the cap and the dividing cells, which have no hairs.

Question 36

Growth in length is the work of the apical meristems, but a tree also grows in thickness, and that is the work of two more meristems. Name the two lateral meristems, and state where each one lies and the part it plays in secondary growth.

Model Answer

1) **The vascular cambium**: a ring of dividing cells lying between the xylem and the phloem, which makes the secondary xylem and secondary phloem that thicken the stem and root.
2) **The cork cambium**: a ring lying nearer the outside, which makes the cork (periderm) that replaces the epidermis and protects the widening stem.

Because they lack these lateral meristems, most monocotyledons and herbaceous plants show little or no secondary growth. Plants such as maize and the grasses have no vascular cambium, so they add almost no girth and never become woody.

False Confidence Alert
Students often think every plant thickens with age. Only plants with lateral meristems do; most monocotyledons, such as maize and the grasses, lack a vascular cambium and so add almost no girth.

Question 37

The vascular cambium is not made of one kind of cell but of two, and they build the wood in two different directions. Distinguish the fusiform initials from the ray initials, and state what each one produces.

Model Answer

The fusiform initials: long, tapering cells that divide to form the axial system, the vessels, tracheids and fibres of the xylem and the sieve tubes of the phloem, which run up and down the stem. Whereas:

The ray initials: short, roughly box-shaped cells that divide to form the medullary rays, the bands of parenchyma that run sideways across the wood, carrying materials radially and storing food.

False Confidence Alert
Students often treat the cambium as a single kind of cell. It has two: the fusiform initials build the up-and-down (axial) tissues, while the ray initials build the side-to-side (radial) rays.

Question 38

Once a young stem has stopped lengthening, the vascular cambium takes over and the stem begins to thicken year by year. Explain how the vascular cambium brings about secondary growth in a woody stem, and why the wood it makes gives the stem its strength.

Model Answer

The vascular cambium thickens the stem by dividing to add new vascular tissue on both of its faces. As its cells divide, they cut off secondary xylem towards the inside and secondary phloem towards the outside, so the core of xylem grows steadily wider while a thinner layer of phloem is added outside it, and the older primary phloem is crushed and pushed outward.

The wood gives strength because the secondary xylem is heavily lignified. The walls of the secondary xylem are thickened with lignin, a hard and rigid material, so the great bulk of wood laid down over the years builds a strong trunk able to hold up a tall tree.

False Confidence Alert
Students often say the cambium makes xylem and phloem on the same side. It does not: it lays secondary xylem to the inside and secondary phloem to the outside, which is why a trunk is mostly wood (xylem) with only a thin layer of phloem beneath the bark.

Question 39

As a stem widens, its thin outer skin is stretched and torn, and yet the tree is not left exposed. Explain how the cork cambium protects the thickening stem, and what the bark of a tree actually is.

Model Answer

As the stem widens, the cork cambium forms a new protective layer to replace the torn epidermis. The original epidermis cannot keep pace and splits as the stem thickens, so a cork cambium arises beneath it and divides to make cork cells; these become waterproof with a fatty material and die, forming a tough outer skin called the periderm.

The bark is all of the tissue lying outside the vascular cambium. It is made up of the cork (periderm) together with the crushed secondary phloem, and it waterproofs the trunk, guards it against physical damage and helps keep out pests and disease.

False Confidence Alert
Students often call only the rough outer layer the bark. The bark is everything outside the vascular cambium, the cork together with the phloem, and not just a single dead crust.

Question 40

A transverse section of a woody stem shows the rings of tissue that secondary growth has laid down over the years. Draw and label a transverse section of a woody dicotyledonous stem, showing the pith, the primary and secondary xylem, the vascular cambium, the secondary and primary phloem and the bark.

Model Answer

A transverse section of the woody stem is shown in Figure 3.14 below. From the centre outward lie the pith, the primary xylem, then the wide band of secondary xylem (the wood), the vascular cambium, the secondary phloem, the primary phloem and the periderm or bark; the medullary rays run radially across the wood.

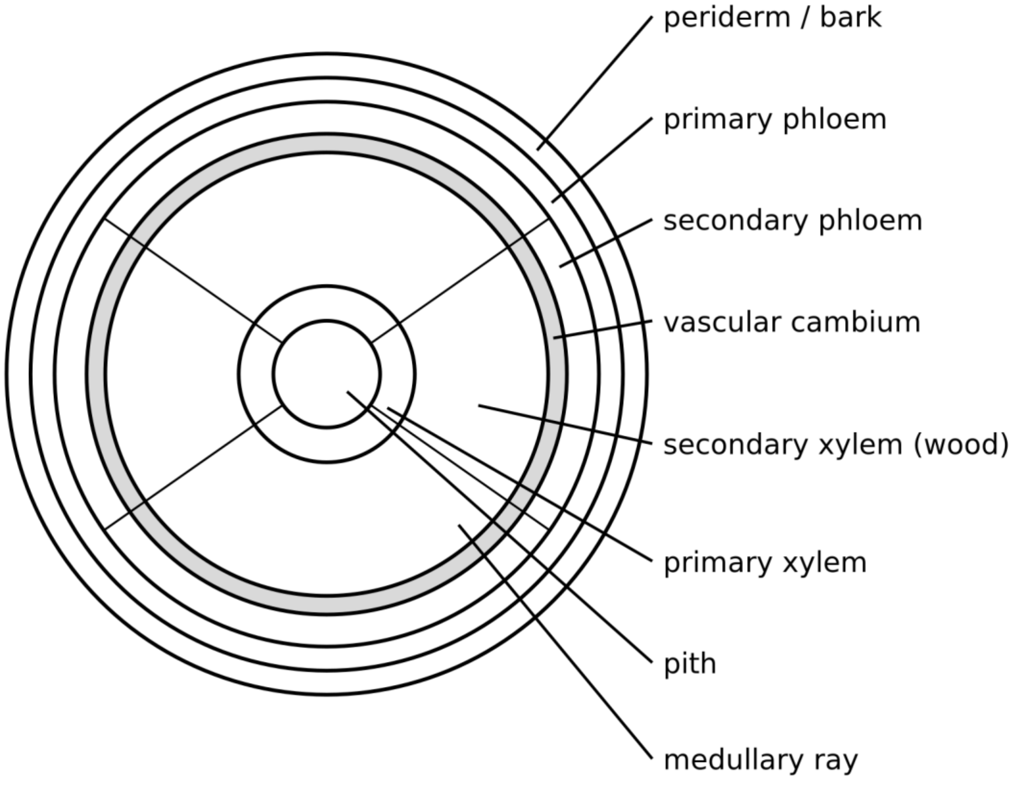


Figure 3.14: *A transverse section of a woody dicotyledonous stem after secondary growth.*

False Confidence Alert
A common error is to draw the phloem inside the xylem. From the centre outward the order is xylem, then cambium, then phloem, then bark; the cambium always sits between the xylem it makes inside and the phloem it makes outside.

Question 41

Secondary growth is not confined to the stem, for a woody root thickens in much the same way. Explain how secondary growth in a root resembles that in the stem, and the one extra change the root must make.

Model Answer

Secondary growth in the root works just as in the stem, through the same two cambia. A vascular cambium forms between the xylem and the phloem and lays down secondary xylem inward and secondary phloem outward to thicken the root, while a cork cambium produces a protective periderm.

The one extra change is that the root must shed and replace its outer layers. As the root thickens, its epidermis and cortex are split and lost, and the cork cambium, which arises in the pericycle, provides the new protective covering in their place.

False Confidence Alert
Students often think only stems show secondary growth. Woody roots thicken too, by the same vascular and cork cambia; the difference is that the root sheds its epidermis and cortex as it widens.

Question 42

A transverse section of a thickened root shows the same rings as the stem, but arranged a little differently. Draw and label a transverse section of a root that has undergone secondary growth, showing the xylem at the centre, the vascular cambium, the phloem, the pericycle and the outer layers.

Model Answer

A transverse section of the root is shown in Figure 3.15 below. The primary xylem lies at the centre; around it come the secondary xylem, the vascular cambium and the secondary phloem; and outside these lie the pericycle, the endodermis, the cortex and the epidermis.

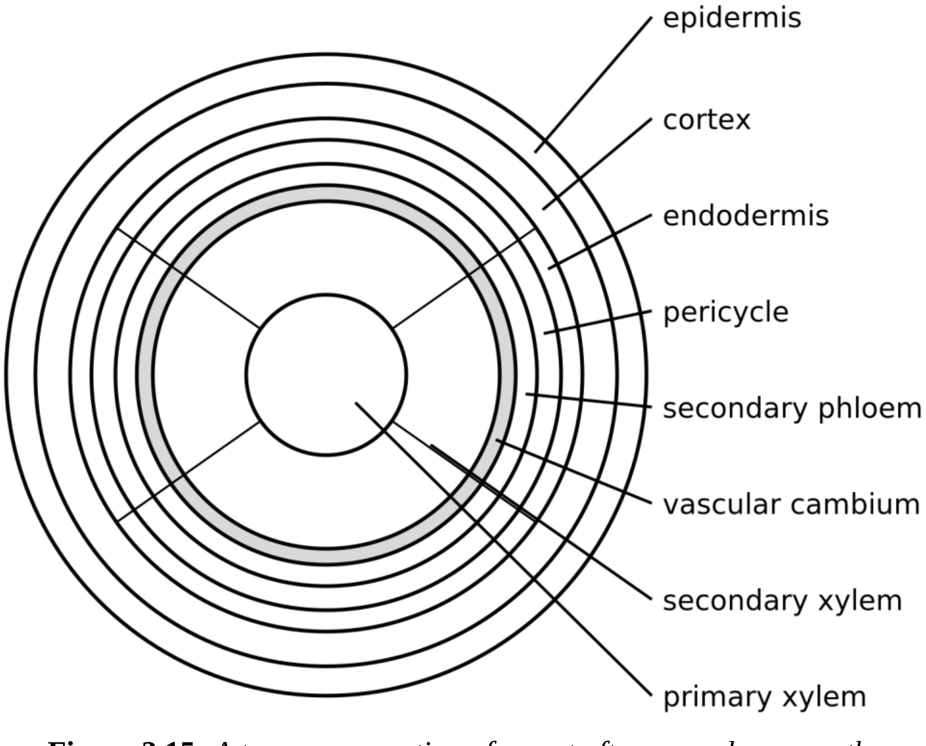


Figure 3.15: *A transverse section of a root after secondary growth.*

False Confidence Alert
Students often forget the pericycle and endodermis when drawing a root section. These lie just outside the vascular tissue, and they are where the cork cambium and the lateral roots arise, so they earn marks.

Question 43

A young plant often grows tall and spindly with few side branches, yet pinching out its tip soon makes it grow bushy. Explain where lateral branches come from, and how apical dominance controls them.

Model Answer

Lateral branches grow out from axillary buds, which sit in the angle between a leaf and the stem. Each axillary bud is a small, dormant shoot that is able to grow into a side branch.

Apical dominance holds these buds in check by means of a hormone from the shoot tip. The apical meristem at the tip makes auxin, which passes down the stem and suppresses the axillary buds below, so the plant grows mainly upward; when the tip is removed, as in pinching out or pruning, the auxin supply is cut and the freed buds grow out, making the plant bushy.

False Confidence Alert
Students often say the side buds are simply asleep. They are actively held back by auxin from the growing tip; remove the tip and they grow, which is exactly why pruning encourages bushy growth.

Question 44

Side branches on a shoot begin at the surface, but the side roots of a plant push out from deep inside the parent root. Explain where lateral roots arise, and why this deep, endogenous origin matters.

Model Answer

Lateral roots arise deep inside the parent root, from a layer called the pericycle. The pericycle lies just within the endodermis, next to the vascular tissue; cells there begin to divide and push a new root outward through the cortex and the epidermis, and because they start from within, this is called an endogenous origin.

This deep origin matters because it joins the new root firmly to the water-carrying tissue of the parent. The lateral root forms right beside the central vascular cylinder, so its xylem and phloem link directly with those of the main root, giving an unbroken pathway for water and food; a root that merely grew from the surface would lack this secure connection. Lateral shoots, by contrast, arise at the surface from axillary buds, an exogenous origin.

False Confidence Alert
Students often assume side roots branch from the surface as side shoots do. Lateral roots are endogenous, arising deep in the pericycle and bursting out through the cortex, while lateral shoots are exogenous, arising at the surface from axillary buds.

Question 45

A dry bean seed kept in a paper bag on a shelf stays unchanged for months, yet the same seed planted in warm, moist soil quickly sprouts. State the conditions a seed needs in order to germinate, and explain why each one is necessary.

Model Answer

1) **Water**: it is taken up by the dry seed, swelling it and splitting the testa, and it activates the enzymes that break down and mobilise the stored food.
2) **A suitable (optimum) temperature**: warmth is needed for those enzymes to work; when it is too cold they act too slowly, and when it is too hot they are destroyed.
3) **Oxygen**: it is needed for the aerobic respiration that releases the energy to drive the growth of the embryo.

These are the external conditions; a seed will still fail to germinate, however, unless its own internal state allows it, that is, unless the seed is mature, alive and not dormant.

> **False Confidence Alert**
> Students often list sunlight among the needs of a germinating seed. Most seeds do not need light to germinate, and many germinate underground in the dark; the true needs are water, a suitable temperature and oxygen.

Question 46

A freshly harvested groundnut seed may refuse to grow even when it is given water, warmth and air, the very things that should make it sprout. Explain what is meant by seed dormancy, and why a dormant seed is not the same as a dead one.

Model Answer

Seed dormancy is a resting state in which a living, mature seed fails to germinate even when the outside conditions are favourable. The seed is held back not by any lack of water, warmth or oxygen, but by some block within itself, so that it waits instead of growing.

A dormant seed is not dead, only inactive. It is still alive, with a living embryo and its food stores intact, and it can germinate later once the block is removed; a dead seed, by contrast, can never germinate, however good the conditions.

> **False Confidence Alert**
> Students often treat a seed that will not germinate as a dead seed. A dormant seed is very much alive; it is only resting, held back by an internal block, and it will grow once that block is lifted.

Question 47

Dormancy may be built into a seed from the very start, or it may come over a seed only later. Distinguish between primary and secondary seed dormancy, and give the cause of each.

Model Answer

Primary (innate) dormancy: it is present in the seed from the moment it is shed from the parent plant, built in by the seed itself, for example by a hard coat or a growth inhibitor. Whereas:

Secondary (induced) dormancy: it develops in a seed that was at first able to germinate but is forced into rest by an unfavourable condition met after it is shed, such as a spell of unsuitable temperature or a shortage of oxygen.

> **False Confidence Alert**
> Students often think all dormancy is built into the seed from the start. Only primary dormancy is; secondary dormancy is imposed later, by harsh conditions, on a seed that could once have germinated.

Question 48

A seed may be born dormant for more than one reason, and a farmer who understands these can treat the seed accordingly. Describe the main causes of primary dormancy in seeds.

Model Answer

1) **An immature embryo**: in some seeds the embryo is not yet fully formed when the seed is shed, and it must finish its development before it can grow.
2) **A hard or impermeable testa**: a tough seed coat may shut out the water and oxygen the embryo needs, or be too hard for the embryo to break through.
3) **Growth inhibitors**: chemicals within the seed, such as abscisic acid, hold the embryo in check, and they must be removed or broken down before germination can begin.

False Confidence Alert
Students often give only the hard seed coat as the cause of dormancy. A hard testa is one cause, but an immature embryo and chemical inhibitors such as abscisic acid matter just as much, and a full answer names them too.

Question 49

The seeds of some plants will not germinate straight after harvest, but the very same seeds sprout readily a few months later, with no treatment at all. Explain what after-ripening is, and why such seeds need a period of dry storage before they will grow.

Model Answer

After-ripening is a period of dry storage during which slow internal changes prepare a seed to germinate. Throughout this time the seed is alive but resting, and chemical changes go on within it, such as the breakdown of growth inhibitors and the final maturing of the embryo.

Such seeds need the delay because they are simply not ready to germinate when first shed. If they could sprout at once, they might come up in the wrong season; the after-ripening period holds them back until the changes are complete and a more suitable time has come.

False Confidence Alert
Students sometimes think after-ripening means the seed is rotting or spoiling in store. It is the opposite: the seed is quietly completing its preparation for growth, and only after this is it able to germinate.

Question 50

A seed that lands in ground which is too hot, too dry or short of air may shut down and refuse to grow even after conditions improve. Explain how secondary dormancy comes about, and why it can be useful to the seed.

Model Answer

Secondary dormancy is brought on when a seed that could have germinated meets unfavourable conditions after it is shed. A spell of unsuitable temperature, a shortage of oxygen or water, or deep shade can force the seed into a deeper rest, so that it no longer germinates even when good conditions return.

It is useful because it stops the seed from sprouting at a hopeless moment. By shutting down when conditions first turn bad, the seed avoids germinating into a season that would kill the seedling, and it waits instead for a clearer sign that the time is right.

False Confidence Alert
Students often confuse secondary dormancy with merely failing to germinate for lack of water. In secondary dormancy the seed actively enters a resting state because of the harsh conditions, and it stays dormant even after those conditions are relieved.

Question 51

A seed with a hard, waterproof coat will not germinate until that coat is breached, and nature and the farmer each have their ways of doing it. Describe how scarification breaks the dormancy of a hard-coated seed, and the ways it can be brought about.

Model Answer

Scarification is the weakening or breaking of a hard seed coat so that water and oxygen can reach the embryo. It can be brought about in several ways:

1) **Mechanical scarification**: the coat is scratched, filed, chipped or rubbed against a rough surface, such as sandpaper, to wear it thin.

2) **Chemical scarification**: the seed is dipped briefly in a strong acid, such as concentrated sulphuric acid, which eats away part of the hard coat.
3) **Natural (biological) scarification**: the seed passes through the gut of an animal that has eaten the fruit, and the digestive juices soften the coat before the seed is dropped in the dung.

> **False Confidence Alert**
> Students often think scarification means damaging the embryo. It is only the hard coat that is weakened; the living embryo inside must be left unharmed, which is why the acid treatment is kept brief.

Question 52

Not every dormant seed has a hard coat; some are held back by their chemistry or by the season, and these are broken in other ways. Describe how stratification, light and gibberellins can each break seed dormancy.

Model Answer

Stratification: a moist seed is given a spell of cold (cold stratification), which mimics the passing of winter, or in some plants a spell of heat from a bush fire, which cracks or softens the hard seed coat so that water and oxygen can enter; each treatment signals that the right season has come.

Light: some seeds germinate only after they have received light, which tells them they lie at or near the soil surface, where a seedling can quickly reach the air.

Gibberellins: these plant hormones, applied to the seed or formed within it, break dormancy directly by switching on the enzymes that mobilise the food and start growth, and they can stand in for the cold or the light a seed would otherwise need.

> **False Confidence Alert**
> Students often assume that cold always preserves dormancy and warmth always breaks it. For many seeds it is the other way round: a period of moist cold is exactly what breaks the dormancy, because it mimics the passing of winter.

Question 53

Dormancy might seem a nuisance, holding back the very seed a farmer wants to sprout, yet in the wild it is a great advantage to the plant. Outline the importance of seed dormancy to a plant, and note the disadvantage it can bring.

Model Answer

1) **Survival of the unfavourable season**: the seed waits out a drought or a cold spell as a dormant seed, and germinates only when conditions are safe.
2) **Timing of germination**: dormancy synchronises sprouting with the start of the rains or the growing season, when the seedling has its best chance.
3) **Spreading of germination**: because seeds break dormancy at different times, a whole batch does not come up at once, so a single bad spell cannot destroy them all.
4) **Aid to dispersal**: a dormant, hard-coated seed can survive a long journey by wind, water or animal gut, germinating only where it finally settles.

The one real disadvantage is to the farmer: dormancy makes a sown crop come up unevenly and late, so seeds are often treated to break their dormancy before planting.

> **False Confidence Alert**
> Students often see dormancy only as a problem because it delays germination. To the wild plant it is a survival device, timing germination to the right season and spreading the risk; it is a nuisance mainly to the farmer who wants a prompt, even crop.

Question 54

Two bags of maize may look identical, yet seed from one sprouts well while seed from the other hardly grows at all. Explain what is meant by seed viability, and state the factors that determine whether a seed is still viable.

Model Answer

Seed viability is the ability of a seed to germinate and grow into a seedling when it is given the right conditions. A viable seed is alive and able to grow; a non-viable seed cannot grow, however good the conditions. Whether a seed stays viable depends on:

1) **Maturity of the embryo**: only a fully formed, healthy embryo is able to germinate.
2) **Active enzymes and food store**: the seed must still hold its food reserves and the living enzymes needed to use them.
3) **Freedom from disease and damage**: a seed attacked by mould or insects, or bruised by rough handling, loses its viability.
4) **Age and storage**: viability falls as a seed ages, and the faster if it is stored damp, warm or otherwise badly.

False Confidence Alert
Students often assume that any whole, healthy-looking seed will grow. Viability is about whether the seed is still alive within; an old or badly stored seed may look perfect yet have lost its living embryo and so fail to germinate.

Question 55

Rather than wait weeks to see whether stored seed will grow, a seed merchant can test its viability in a single afternoon with a simple stain. Explain how the tetrazolium test shows whether a seed is viable.

Model Answer

The tetrazolium test stains the living tissue of a seed red, so that a viable seed can be told at a glance. The seed is cut open and soaked in a colourless tetrazolium solution; the living cells of the embryo, which are respiring, carry active enzymes that change the colourless chemical into a red dye.

A red embryo means the seed is alive, while a colourless one means it is dead. Where the embryo tissue turns red, its cells are respiring and the seed is viable; where it stays colourless, the cells are not respiring and the seed is non-viable. The depth and the pattern of the red also show how strong the seed is.

False Confidence Alert
Students sometimes think the seed germinates during the tetrazolium test. It does not; the test does not grow the seed at all, but simply reveals, by the red stain of respiring tissue, whether the embryo is still alive.

Question 56

We speak loosely of a balloon growing as it is blown up, but a biologist means something more exact when an animal grows. Explain what is meant by growth in an animal, and why a true increase in size is not the same as merely swelling with water or a heavy meal.

Model Answer

Growth in an animal is a permanent, irreversible increase in its size, dry mass and complexity, brought about by the making of new living material. It is achieved by forming new cells and new protoplasm, and not by any passing change in bulk.

A true increase in size is therefore not the same as a swelling. A balloon blown with air, or a body bloated with water or a large meal, is bigger only for the moment and shrinks again; real growth adds permanent living material, and measured as a rise in dry mass it does not reverse when the water or food has gone.

False Confidence Alert
Students often define growth simply as getting bigger. A short-lived swelling with water or food makes a body bigger yet is not growth; growth is the permanent increase in living material, best measured as a rise in dry mass.

Question 57

Every animal, however large, began life as a single cell no bigger than a full stop. Explain how an animal begins its growth from that single cell, and why its earliest growth is almost entirely a matter of cell division.

Model Answer

An animal begins as a single fertilised egg, the zygote, which grows by dividing again and again through mitosis. The zygote divides into two cells, then four, then many, each a faithful copy of the first, and this growing ball of cells becomes the embryo.

The earliest growth is almost all cell division because the first need is simply for more cells. Before the body can take shape it must build up a large enough number of cells to work with; only once these are made do they begin to enlarge and to specialise, so the very start of growth is dominated by mitosis.

False Confidence Alert
Students sometimes picture the embryo as growing mainly by its cells getting bigger. At the start it is the number of cells that rises, by repeated mitosis; the enlargement and specialising of those cells come afterwards.

Question 58

A human being passes through a fixed series of stages between fertilisation and the full-grown adult. Describe the stages of growth and development of a mammal, from the fertilised egg to the adult.

Model Answer

1) **The zygote**: the fertilised egg, which divides by mitosis into a ball of cells as it travels to the womb.
2) **The embryo**: the ball of cells implants in the wall of the uterus, and its cells begin to differentiate into the first tissues and organs.
3) **The foetus**: once the main organs are formed and recognisable, the young mammal is called a foetus, and it grows and matures through the gestation period, nourished through the placenta.
4) **Birth**: at the end of gestation the young is born, able to live outside the mother.
5) **Growth to the adult**: after birth the young grows steadily, under the control of hormones such as growth hormone, until it reaches the adult size.

False Confidence Alert
Students often jump straight from fertilised egg to baby. The marks are for the ordered stages, the zygote, the embryo, the foetus, birth, and then growth to the adult, each named in its turn.

Question 59

A newborn goat is a small version of its parents, but a newly hatched housefly is a maggot that looks nothing like the adult. Explain why mammals are born resembling the adult while many other animals hatch as immature forms, and name the two patterns of development this shows.

Model Answer

The difference lies in how fully the young has developed before it is born or hatched. A mammal develops slowly inside the mother, nourished through the placenta, so that it is already a small adult shape at birth; an animal whose egg holds only a limited food store hatches early, as an immature form that must feed and develop further on its own.

Direct development: the young is born or hatched as a miniature of the adult and simply grows larger, as in mammals and birds.

Indirect development: the young hatches as a larva quite unlike the adult, and must change form (metamorphose) before it becomes an adult, as in many insects and amphibians.

> **False Confidence Alert**
> Students often assume every young animal looks like a small adult. Only animals with direct development do; in indirect development the young hatches as a larva, such as a maggot or a tadpole, that looks nothing like the adult until it metamorphoses.

Question 60

If growth were only a matter of making more cells, an animal would end up as a shapeless heap of identical cells. Explain why differentiation is an essential part of growth and development, and what it adds to the mere increase in cell number.

Model Answer

Differentiation is the process by which unspecialised cells become different from one another and take on particular jobs. As the embryo grows, its cells do not all stay alike; some become nerve cells, some muscle, some blood, each one shaped and equipped for its task.

It is essential because growth is the building of a working body, not just a larger mass of cells. Cell division alone would give only a bigger ball of identical cells; it is differentiation that turns those cells into the many tissues and organs, so that the animal takes on a form that can function. Growth and differentiation together, an increase in number and size plus specialisation, make development.

> **False Confidence Alert**
> Students often treat growth as only an increase in cell number and size. Without differentiation the new cells would all be alike and useless; it is the specialising of cells into tissues and organs that turns growth into a working, developed body.

Question 61

A caterpillar and the butterfly it becomes look so unlike each other that one would never guess they are the same animal. Explain what is meant by metamorphosis, and name the main groups of animals that undergo it.

Model Answer

Metamorphosis is the abrupt change in body form and way of life that some animals undergo as they develop from the young into the adult. The young hatches in one form and is then remodelled, often completely, into an adult that may look and live quite differently.

It is shown by several groups of animals. Chief among them are the insects, such as the housefly, the butterfly and the cockroach, and the amphibians, such as the frog and the toad; it occurs also in crustaceans, such as crabs, and in some fish.

By changing form in this way, the young and the adult can live in different places and feed on different foods, so that they do not compete with one another.

> **False Confidence Alert**
>
> Students often think metamorphosis means simply growing bigger. It is far more than growth: it is a change of body form and function, so that the adult is built differently from the young and often leads a different life.

Question 62

Metamorphosis does not happen by chance; it is switched on and steered by conditions both inside and around the animal. Describe the factors that control metamorphosis, and the special part that thyroxine plays in the amphibians.

Model Answer

1) **Hormones**: chemical messengers within the body switch metamorphosis on and steer its stages; in insects these are the moulting hormone and the juvenile hormone, and in amphibians it is thyroxine.
2) **Temperature**: warmth speeds metamorphosis up and cold slows it down, so a tadpole changes faster in warm water than in cold.
3) **Nutrients**: a good food supply is needed to fuel the rebuilding of the body, and a starved larva or tadpole develops slowly or not at all.

In the amphibians, thyroxine is the master signal for metamorphosis. This hormone, made by the thyroid gland and needing iodine in order to be made, triggers the changes that turn a tadpole into a frog; without enough iodine, and so without thyroxine, the tadpole cannot complete its metamorphosis.

False Confidence Alert
Students often name only temperature. Hormones are the true controllers, switching metamorphosis on and steering it; in amphibians it is thyroxine, which needs iodine, that drives the change, while temperature and food affect only its speed.

Question 63

Whether an insect's moult produces another larva or finally the adult is decided by a balance of two hormones. Name these two hormones and the glands that make them, and explain how the balance between them controls metamorphosis.

Model Answer

1) **Ecdysone, the moulting hormone**: it is made by the prothoracic gland and triggers each moult, under the control of the brain's neurosecretory cells.
2) **Juvenile hormone (neotenin)**: it is made by the corpus allatum, and its level decides what form the moult produces.

The balance between the two decides the outcome of each moult. While the juvenile hormone is high, a moult gives another larva; as its level falls, a moult gives a pupa; and when the juvenile hormone is absent, the final moult gives the adult. So ecdysone says when to moult, and juvenile hormone says what to become.

False Confidence Alert
Students often name only one hormone, or confuse their jobs. Ecdysone, from the prothoracic gland, triggers the moult; juvenile hormone, from the corpus allatum, decides whether the moult yields another larva, a pupa or the adult.

Question 64

In a housefly or a butterfly the young is a crawling, feeding stage utterly unlike the flying adult, with a resting stage in between. Describe the four stages of complete metamorphosis, and explain why it is an advantage that the larva and the adult are so different.

Model Answer

1) **Egg**: laid by the adult, it hatches into the larva.
2) **Larva**: a worm-like feeding stage, such as the maggot or caterpillar, that eats greedily and grows, moulting as it goes.
3) **Pupa**: a resting, non-feeding stage in which the larval body is broken down and rebuilt into the adult.
4) **Adult (imago)**: the mature, often winged stage that reproduces and lays the next eggs.

Their difference is an advantage because the larva and the adult do not compete with each other. The two stages live in different places and eat different foods, the caterpillar on leaves and the butterfly on nectar, so the young take no food from the adults; the larva can specialise in feeding and growth, while the adult specialises in dispersal and reproduction.

False Confidence Alert
Students often leave out the pupa, or call it a dead stage. The pupa is very much alive; although it does not feed or move, it is where the larval body is rebuilt into the adult, and complete metamorphosis cannot occur without it.

Question 65

The four stages of complete metamorphosis are seen clearly in the life cycle of the common housefly. Draw a labelled diagram of the life cycle of a housefly.

Model Answer

The life cycle of the housefly is shown in Figure 3.16 below. The adult lays eggs, which hatch into larvae (maggots); each larva feeds and grows, then becomes a resting pupa; and from the pupa emerges the adult fly, which lays the next eggs and so begins the cycle again.

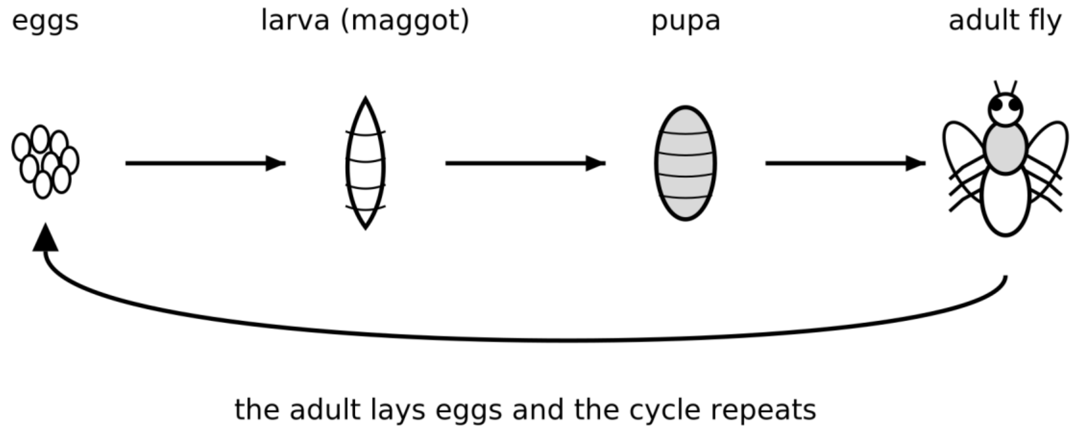


Figure 3.16: *The life cycle of a housefly, an example of complete metamorphosis.*

False Confidence Alert
A common mistake is to draw the stages as a straight line that simply stops at the adult. Show it as a cycle: the adult lays eggs, and the four stages follow one another round again.

Question 66

A young cockroach is, in effect, a small wingless copy of its parents, and it grows up without any resting stage. Describe the stages of incomplete metamorphosis, and explain what is meant by an instar and by the imago.

Model Answer

1) **Egg**: the eggs hatch directly into nymphs.
2) **Nymph**: a young stage that already looks much like the adult but is smaller and wingless; it feeds and grows, moulting several times.
3) **Adult**: the mature, winged stage that reproduces.

An instar is the stage between two moults, and the imago is the final adult. Because the nymph's cuticle cannot stretch, it must moult in order to grow; each form between one moult and the next is an instar, and the nymph passes through several instars, becoming larger and more adult-like each time, until the last moult produces the fully formed adult, the imago.

False Confidence Alert
Students often expect a pupa in every insect life cycle. Incomplete metamorphosis has no pupa: the nymph changes gradually into the adult through a series of moults, with no resting stage between.

Question 67

Incomplete metamorphosis is shown well by the cockroach, whose young is simply a wingless version of the adult. Draw a labelled diagram of the life cycle of a cockroach.

Model Answer

The life cycle of the cockroach is shown in Figure 3.17 below. The adult lays its eggs in a case; these hatch into nymphs that resemble the adult but are smaller and wingless; and the nymph moults through several instars, growing wings and maturing, until it becomes the adult, which lays the next eggs.

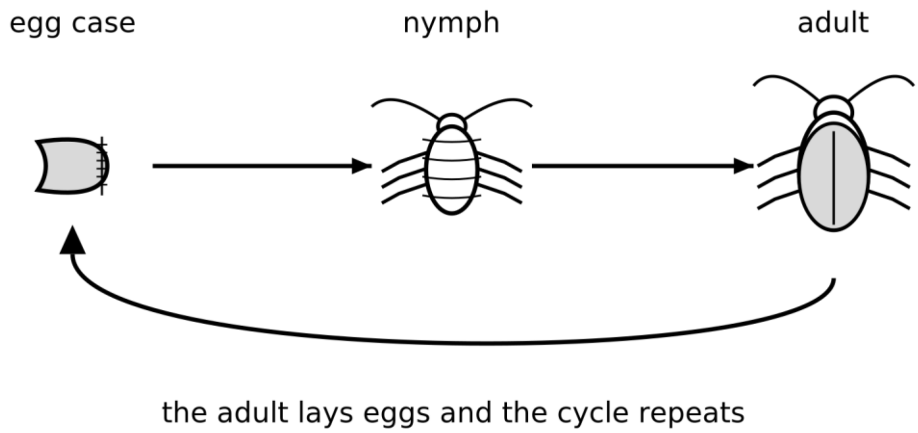


Figure 3.17: *The life cycle of a cockroach, an example of incomplete metamorphosis*.

False Confidence Alert
A common error is to draw the nymph looking nothing like the adult, as a larva would. In incomplete metamorphosis the nymph already resembles the adult; it is only smaller and lacks fully formed wings.

Question 68

Both the housefly and the cockroach are insects that undergo metamorphosis, yet their life cycles differ in important ways. Compare complete and incomplete metamorphosis, point by point.

Model Answer

1) **Number of stages**: complete metamorphosis has four stages (egg, larva, pupa, adult), while incomplete metamorphosis has three (egg, nymph, adult).
2) **The resting (pupal) stage**: complete metamorphosis has a pupa, in which the body is rebuilt, while incomplete metamorphosis has no pupa.
3) **The young**: in complete metamorphosis the young is a larva quite unlike the adult, while in incomplete metamorphosis the nymph already resembles the adult.
4) **How the change happens**: in complete metamorphosis the change to the adult is abrupt, taking place in the pupa, while in incomplete metamorphosis it is gradual, over several moults.

False Confidence Alert
Students often say the only difference is the number of stages. The deeper difference is the pupa and what it means: a larva unlike the adult, rebuilt abruptly in a pupa (complete), against a nymph like the adult that changes gradually with no pupa (incomplete).

Question 69

A tadpole is a gilled, tailed, water-living animal, yet it becomes a lung-breathing, four-legged frog able to live on land. Describe the changes that take place as a tadpole metamorphoses into an adult frog.

Model Answer

It undergoes the following changes:

1) **Limbs grow**: the legless tadpole grows first its hind legs and then its front legs.
2) **Breathing changes**: the gills used for breathing in water are lost and are replaced by lungs for breathing air on land.
3) **The tail is absorbed**: the swimming tail is gradually reabsorbed into the body until it disappears.
4) **The diet changes**: the plant-eating tadpole, which scrapes algae, becomes a flesh-eating frog that catches insects, and its mouth and gut change to suit.

These changes are driven by the hormone thyroxine. Thyroxine from the thyroid gland, which needs iodine to be made, switches on the whole transformation, so that the water-living tadpole is rebuilt into a frog that can live on land.

False Confidence Alert
Students often think the tadpole's tail simply drops off. It is not shed but reabsorbed, its materials taken back into the body and used as the young frog grows.

Question 70

The change from a water-living tadpole to a land-living frog is one of the clearest examples of metamorphosis there is. Draw a labelled diagram of the life cycle of a frog.

Model Answer

The life cycle of the frog is shown in Figure 3.18 below. The adult lays its eggs (spawn) in water; these hatch into tadpoles, which breathe with gills and swim with a tail; the tadpole then grows legs and develops lungs; and at last the tail is absorbed and the young frog leaves the water as an adult, which returns to lay the next spawn.

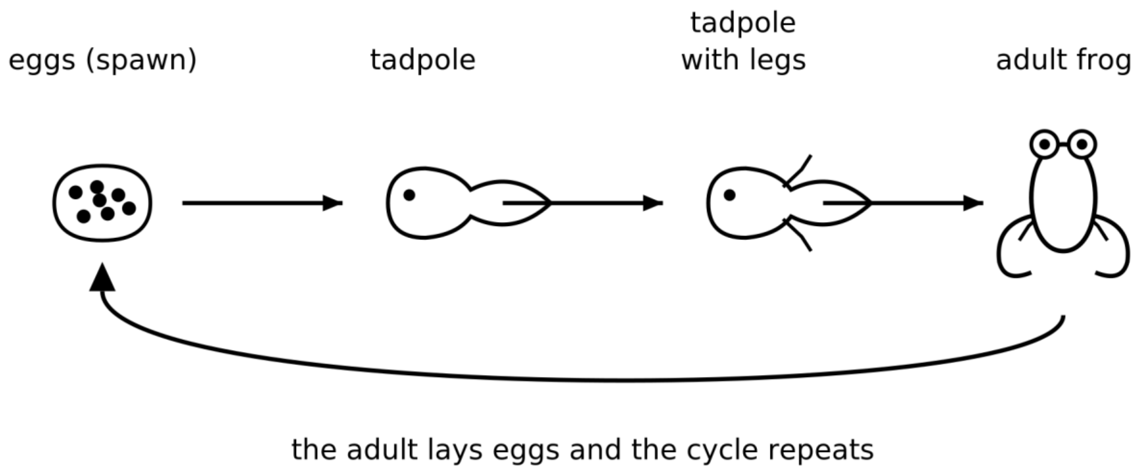


Figure 3.18: *The life cycle of a frog.*

False Confidence Alert
A common mistake is to draw the frog laying its eggs on land like a bird. The frog lays its eggs in water, where the tadpoles hatch and live until they have changed enough to come ashore.

REAL QUESTIONS

These questions test whether you can take the biology of growth and development and use it in real, Tanzanian situations: the clinic, the farm and the field. Attempt each answer yourself first, then check it against the model answer and the False Confidence Alert that follows, which names the mistake that most often costs marks.

Question 71

When a spinal nerve is torn in a road accident, the nerve cells that are lost are never replaced; and a red blood cell that is destroyed cannot divide to replace itself. Explain why cells that have lost the power to divide cannot be replaced when they are damaged.

Model Answer

A damaged cell can be replaced only by the mitosis of another living cell, and a cell that has permanently left the cell cycle can no longer divide. Mature nerve cells and mature red blood cells have stopped dividing for good: the neurone is locked out of the cell cycle for life, and the red cell has even lost its nucleus, so it has no DNA to copy and no chromosomes to separate. Since such a cell cannot carry out mitosis, it cannot make a replacement for itself; any new red cells must instead be formed by the dividing stem cells of the bone marrow.

> **False Confidence Alert**
> Students often say a damaged nerve or red cell simply repairs itself by dividing. A fully mature nerve or red cell has left the cell cycle, and the red cell has no nucleus at all, so it cannot divide; any replacement must come from unspecialised stem cells.

Question 72

In a stained squash of an onion root tip, a student finds that most of the cells show no visible chromosomes, while only a few show the chromosomes condensed and arranged for division. Interpret this observation, and say what it tells us about the cell cycle.

Model Answer

Most of the cells show no visible chromosomes because they are in interphase, which is by far the longest stage of the cell cycle. During interphase the chromosomes are spread out as fine chromatin and cannot be seen as separate bodies, whereas the few cells showing distinct, condensed chromosomes are the ones actually in mitosis. Because the squash fixes every cell at one instant, the number caught in each stage reflects how long that stage lasts; the fact that interphase cells form the great majority therefore shows that the cell spends most of its cycle in interphase and only a short time in division.

> **False Confidence Alert**
> Students often read most cells not dividing as meaning the root tip is resting or inactive. The opposite is true: interphase is the busy stage of growth and DNA copying, and its cells fill the field simply because it is the longest part of the cycle.

Question 73

Colchicine, a drug obtained from a plant, prevents the spindle fibres from forming in a dividing cell. Explain why a cell treated with such a drug becomes stuck at metaphase and cannot complete mitosis.

Model Answer

The cell halts at metaphase because the separation of the sister chromatids depends entirely on the spindle, which the drug has prevented from forming. By metaphase the doubled chromosomes have already lined up on the equator, but the movement that drags the sister chromatids to opposite poles at anaphase is produced by the shortening spindle fibres attached to their centromeres. With no spindle to attach to and to pull them, the chromatids cannot be drawn apart, so the cell cannot enter anaphase and is held at metaphase, unable to finish dividing.

False Confidence Alert
Students sometimes think a spindle poison stops the chromosomes being copied. The DNA was already copied in interphase; the spindle only separates those copies at anaphase, so blocking it freezes the cell at metaphase with its chromatids unable to part.

Question 74

A cancer patient on radiotherapy or chemotherapy often develops anaemia, a lowered resistance to infection, a sore damaged gut and loss of hair. Explain why these fast-dividing tissues are the first to be harmed by the treatment.

Model Answer

These tissues are harmed first because the treatment strikes cells that are actively dividing, and they are the tissues whose cells divide most often. Radiation and anti-cancer drugs act by damaging DNA or blocking mitosis, so a cell is most vulnerable while it is copying its DNA and dividing. The bone marrow that makes blood cells, the lining of the gut and the hair follicles all renew themselves constantly by rapid mitosis, so a large share of their cells are dividing at any moment. The treatment is aimed at the fast-dividing cancer cells, but these normal tissues are caught for the very same reason, and so anaemia, infection, gut damage and hair loss follow.

False Confidence Alert
Students often assume the drugs attack only cancer cells. They attack cells that are dividing; cancer cells divide fastest, but the bone marrow, gut lining and hair follicles divide rapidly too, and are damaged for exactly the same reason.

Question 75

Kipanga writes: *'In mitosis the chromosome number is halved, so each daughter cell receives half the chromosomes of the parent; and the chromosomes are copied during prophase, just before they line up.'* Point out the mistakes in his statement and give the correct account.

Model Answer

Kipanga is wrong that mitosis halves the chromosome number: mitosis keeps the number unchanged, so each daughter cell has exactly the same number of chromosomes as the parent. It is meiosis, not mitosis, that halves the chromosome number; mitosis is the division that produces two genetically identical cells for growth and repair, each carrying the full parental set.

He is also wrong that the chromosomes are copied during prophase: they are copied earlier, during the interphase that comes before mitosis. The DNA is replicated in the S phase of interphase, so that by the time prophase begins each chromosome already consists of two identical sister chromatids; prophase merely condenses these already-doubled chromosomes, it does not copy them.

False Confidence Alert
Students often confuse mitosis with meiosis and place the DNA copying inside mitosis. Mitosis keeps the chromosome number constant while meiosis halves it, and the copying happens in interphase, in the S phase, not in prophase.

Question 76

In a young child the thymus gland in the chest is large and grows quickly, yet in an adult it has shrunk to a small remnant. Using the idea of allometric (differential) growth, explain why the thymus grows fast in childhood and then shrinks, even while the body as a whole is still growing.

Model Answer

Different organs follow their own growth timetables rather than the growth curve of the body as a whole, and the thymus is timed to grow early because that is when its work is most needed. The thymus builds up the body's defences by developing the lymphocytes of the immune system, work that matters most in the early years while immunity is still being established; so it grows rapidly in childhood and reaches its largest size around puberty. Once the immune system is largely set up the need for it falls, and the gland slowly shrinks even though the rest of the body is still enlarging. This unequal growth of the different parts is what is meant by allometric, or differential, growth.

False Confidence Alert
Students often assume every organ keeps growing for as long as the body does. Organs grow at their own rates and times: the thymus reaches its peak in childhood and then regresses, because its task of building immunity is an early one.

Question 77

A stand of maize in a field, like a human being, does not grow at a steady rate but follows an S-shaped (sigmoid) growth curve. Explain the shape of this curve, and state what finally sets the size the crop reaches.

Model Answer

The S-shaped curve has three phases: a slow start, a rapid middle and a leveling-off at the end. At first growth is slow while the young plants are putting out roots and their first few leaves; then, with a large leaf area now trapping light, growth becomes rapid and the curve rises steeply; finally the curve flattens as the crop matures and growth slows almost to a stop. The size finally reached is set partly by the inherited make-up of the variety and partly by the supply of resources, water, mineral salts, light and space, which limit how large the crop can grow.

False Confidence Alert
Students often think a crop grows fastest at the very beginning. Growth is slowest at the start, while the seedlings are establishing themselves; it is fastest in the middle phase, once a full leaf area is intercepting the light.

Question 78

A researcher harvests maize plants at intervals, dries them and plots their dry mass against time to give a field growth curve. Explain how the curve is read to say when the crop is gaining dry mass fastest, and why dry mass is used rather than fresh mass.

Model Answer

The crop is gaining dry mass fastest where the curve is steepest, that is, where its gradient is greatest. The slope of the curve measures the rate of growth, so the place where the line rises most steeply marks the time when the crop is adding material most quickly; this occurs in the middle part of the S-curve, when the canopy is fully out and trapping the most light.

Dry mass is used rather than fresh mass because fresh mass changes with the water in the plant, which rises and falls with watering and the time of day, whereas dry mass measures the real material the plant has built and so gives a true measure of growth.

False Confidence Alert
Students often read the highest point of the curve as the time of fastest growth. The highest point is where growth has almost stopped; the fastest growth is where the curve is steepest, not where it is highest.

Question 79

Around the teenage years a boy or girl suddenly grows taller very quickly in what is called the adolescent growth spurt. Explain how this spurt is related to the timing of puberty, and name the hormones that bring it about.

Model Answer

The growth spurt comes with puberty because puberty switches on a surge of growth-promoting hormones, and it ends when the sex hormones later close the growing regions of the bones. As puberty begins, the growth hormone from the pituitary acts together with the sex hormones, testosterone in boys and oestrogen in girls, to drive a rapid increase in height and muscle; this is why the spurt and puberty arrive together. The sex hormones, mainly oestrogen, later cause the growth plates at the ends of the long bones to fuse, and once they have fused height growth stops, so the adult height is fixed.

> **False Confidence Alert**
> Students often name only growth hormone. The adolescent spurt is driven by growth hormone together with the sex hormones, testosterone and oestrogen, and it is the sex hormones, chiefly oestrogen, that later fuse the bone growth plates and bring the increase in height to an end.

Question 80

Kipanga insists: *'All the parts of the body grow at the same rate, and growth simply means a rise in mass, so anything that gains mass is growing.'* Point out the mistakes in his statement and give the correct account.

Model Answer

Kipanga is wrong that all parts grow at the same rate: different parts grow at different rates and at different times, which is called allometric or differential growth. This is why the proportions of the body change as it develops; in a baby the head is very large for the body, while later the limbs grow faster and catch up, and an organ such as the thymus may even shrink while the rest is still growing.

He is also wrong that any gain in mass is growth: true growth is a permanent increase in size and dry mass, brought about by cell division, enlargement and differentiation. A simple rise in fresh mass can mislead, because a body may gain mass for a time by taking in water or food without truly growing, and a germinating seed actually loses dry mass while it is plainly growing; this is why growth is measured by dry mass.

> **False Confidence Alert**
> Students often treat any increase in mass as growth and assume the body grows evenly. Fresh mass can rise merely from water uptake; true growth is a permanent gain in dry mass through cell division and enlargement, and because the parts grow at different rates the body's proportions change as it develops.

Question 81

A boy hammers a nail into the trunk of a young mango tree at the height of his shoulder. Years later, when the tree is much taller, he finds the nail still at the same height above the ground. Explain this observation.

Model Answer

The nail stays at the same height because a plant grows in length only at the tips of its shoots and roots, not all along the trunk. Growth in length, or primary growth, is the work of the apical meristems at the very tips; once a length of trunk has been laid down below the growing tip, its cells no longer elongate, so that part of the trunk simply stays where it is. The tree therefore adds new height only at the top, while the point where the nail sits does not move upward; year by year the trunk merely grows thicker around the nail, and may in time grow over it.

> **False Confidence Alert**
> Students often imagine the whole trunk stretches as the tree grows, carrying the nail up with it. Only the tips grow in length; the older trunk below does not elongate, so a mark made on it stays at the same height for the life of the tree.

Question 82

A forestry officer notices that a sunflower shoots up and flowers within a single season, while a young pine planted beside it grows more slowly but its trunk thickens year after year into wood. Explain the difference in their growth patterns, and why the pine thickens while the sunflower does not.

Model Answer

The sunflower is a soft annual that grows mainly in length and finishes in one season, whereas the pine is a woody perennial that adds new wood and thickens year after year. The sunflower depends almost entirely on primary growth from its apical meristems, so it grows tall quickly, stays soft and herbaceous, and flowers and dies within the year.

The pine, by contrast, has an active lateral meristem, the vascular cambium, which lays down a fresh layer of secondary xylem, that is wood, each year; this is secondary growth, and it is what makes the trunk thicken and turn woody. The sunflower has only limited secondary growth, and so it never builds a thick woody trunk.

False Confidence Alert
Students often think the pine thickens simply because it lives longer. The real reason is its vascular cambium: this lateral meristem makes new wood each year, giving secondary growth, while the soft annual sunflower has very little and so stays slender.

Question 83

A gardener who wants a hedge to grow thick and bushy is told to keep cutting off the growing tips of the shoots. Explain why removing the tip of a shoot makes the plant grow bushy, using the idea of apical dominance.

Model Answer

Cutting off the tip makes the plant bushy because it removes the apical bud, and with it the apical dominance that was holding back the side buds. The apical bud at the tip of a shoot makes the hormone auxin, which passes down the shoot and suppresses the growth of the lateral buds below it, so that the shoot grows mainly upward; this suppression is what is meant by apical dominance. When the gardener cuts the tip off, the source of auxin is removed, the lateral buds are freed from suppression, and they grow out into many side shoots, so the hedge becomes thick and bushy.

False Confidence Alert
Students sometimes think cutting the tip simply makes the plant grow faster. It does not add growth; it removes the apical bud and its auxin, releasing the side buds that were held back, and it is their growth that makes the plant bushy.

Question 84

When a tree is felled, the cut end of the trunk shows a pattern of rings, and a forester can read from them both the age of the tree and which years were good or bad. Explain how the annual rings are formed, and how they reveal this information.

Model Answer

Each ring is one year's growth of secondary xylem laid down by the vascular cambium, so counting the rings gives the tree's age and the width of each ring shows how good that year was. In the wet, favourable part of the year the cambium makes wide, large-celled wood, and in the drier part it makes narrow, small-celled wood, and the two together make up one ring for that year; the number of rings is therefore the number of years the tree has grown. A wide ring marks a good year, with plenty of water and rapid growth, whereas a narrow ring marks a poor or dry year in which the tree grew little.

False Confidence Alert
Students often think each ring is one layer of bark. The rings are rings of wood, that is secondary xylem, added by the cambium, one for each year; it is their number that gives the age and their width that tells the good years from the bad.

Question 85

A plant grows both taller and thicker, but these two kinds of growth are the work of two different meristems. Distinguish the role of the apical meristem in primary growth from that of the lateral meristem in secondary growth.

Model Answer

The apical meristem, found at the tips of the shoots and roots, carries out primary growth, which is growth in length. It divides to make the shoot taller and the roots longer and to form the primary tissues, and it is present in every plant.

The lateral meristem, a cylinder of cambium running down the stem and root, carries out secondary growth, which is growth in girth. Its vascular cambium lays down secondary xylem and secondary phloem, so that the stem and root thicken into wood, and it is active chiefly in woody plants such as trees and shrubs.

False Confidence Alert
Students often muddle the two and say the apical meristem thickens the stem. The apical meristem at the tips makes the plant longer (primary growth), while the lateral cambium along the sides makes it thicker (secondary growth).

Question 86

Kipanga claims: *'A tree grows taller from its base, pushing the top higher each year; and every plant, given time, will thicken into wood by secondary growth.'* Point out the mistakes in his statement and give the correct account.

Model Answer

Kipanga is wrong that a tree grows taller from its base: a tree grows taller only at its tips, where the apical meristems are. The trunk below the growing tip does not elongate once it has formed, which is why a nail driven into a trunk stays at the same height; new height is added at the top, not pushed up from below.

He is also wrong that every plant thickens into wood: secondary growth occurs mainly in woody plants such as the pine and other trees and shrubs, not in all plants. Monocots such as maize, grasses and the palm, and most soft herbs, have little or no secondary growth from a cambium, and so they never form a thick woody trunk however long they live.

False Confidence Alert
Students often picture a tree rising from its base like a wall being built higher, and assume every plant turns woody in time. Height is added only at the tips, and secondary thickening is the work of the cambium, found mainly in woody plants, not in monocots or soft herbs.

Question 87

A farmer stores his maize grain in a sack, and when he plants some of it a year later he finds that far fewer seeds come up than when the grain was fresh. Explain, in terms of seed viability, why the stored maize germinates so poorly after a year.

Model Answer

The stored maize germinates poorly because seeds gradually lose their viability, that is, their power to germinate, as they grow older. A seed is alive, and like any living thing it slowly uses up the food reserve stored in it while its delicate cell contents and enzymes break down over time; the longer it is kept, the more of its embryos die, so its viability falls. After a year in the sack many of the maize embryos are no longer alive, and only the few that remain viable can still germinate, which is why so few seedlings come up. This is why farmers prefer to plant fresh seed, or to keep it cool and dry to slow the loss of viability.

False Confidence Alert
Students often think a seed lasts for ever and will grow whenever it is finally planted. A seed is alive and loses its viability with age, so old stored seed germinates poorly; the longer it is kept, the fewer of its embryos remain alive.

Question 88

Acacia and many other hard-coated seeds of the bush germinate far better after a bush fire has passed over them, or after they have passed through the gut of a grazing cow. Explain why these seeds germinate better after such treatment.

Model Answer

These seeds have a hard, water-tight coat that holds them dormant, and a bush fire breaks that coat by heat. The heat of the fire cracks and softens the tough seed coat; once the coat is broken, water and oxygen can soak in, the embryo is roused from its dormancy, and the seed germinates with the first rains after the fire.

Passing through a cow does the same work in a different way. As the seed travels through the animal's gut, the digestive juices and the grinding action wear away and weaken the hard coat, so that when the seed is dropped in the dung it can take in water and germinate; the dung also leaves it in a moist, well-manured place.

False Confidence Alert
Students often think the fire or the cow gives the seed food or warmth that makes it grow. The real effect is mechanical: both break the hard, water-tight coat, letting in the water and oxygen that the dormant embryo needs.

Question 89

In an experiment, dormant barley seeds treated with gibberellin germinate quickly, while untreated seeds from the same batch stay dormant. Explain the role of gibberellins in breaking dormancy and starting germination, and state what the treated-against-untreated comparison shows.

Model Answer

Gibberellins are the hormones that break a seed's dormancy and switch on germination. When the seed takes in water, the embryo releases gibberellin, which passes to the aleurone layer around the food store and ends the dormancy; there it switches on the making of enzymes such as amylase, which digest the stored starch into sugars, and these sugars feed the growing embryo so that it can begin to germinate.

The treated-against-untreated comparison shows that the gibberellin is the cause of this change. Because the two sets of seeds come from the same batch and differ only in the gibberellin given to them, the fact that the treated seeds germinate while the untreated ones stay dormant shows that it is the gibberellin, and nothing else, that has broken the dormancy and started germination.

False Confidence Alert
Students often say the gibberellin simply feeds the seed. It does not feed it; it acts as a chemical signal that switches on the enzymes which digest the seed's own stored food, and it is this that ends the dormancy and starts germination.

Question 90

Kipanga argues: *'A dormant seed is really a dead seed; and in any case any seed will sprout the moment it is given water.'* Point out the mistakes in his statement and give the correct account.

Model Answer

Kipanga is wrong that a dormant seed is a dead seed: a dormant seed is alive but resting, with its life processes slowed almost to a standstill. It is still viable and is merely waiting for the right conditions; a dead seed cannot germinate at all, whereas a dormant one will germinate once its dormancy is broken, which is the very opposite of being dead.

He is also wrong that any seed will sprout the moment it is watered: water alone is not always enough. A seed in true dormancy will not germinate even when watered until its dormancy is first broken, for instance by the wearing away of a hard coat, by a spell of cold, or by the right hormone; only a non-dormant, viable seed given water, oxygen and warmth will sprout at once.

> **False Confidence Alert**
> Students often confuse dormancy with death and assume water alone always starts germination. A dormant seed is alive but resting; its dormancy must be broken first, and germination also needs oxygen and a suitable temperature, not water alone.

Question 91

A goat gives birth to a kid that already looks like a small goat, while a frog lays eggs that hatch into tadpoles quite unlike the adult. Contrast direct development with indirect development, and explain what each kind demands of the parent.

Model Answer

In direct development the young is born already resembling the adult and grows straight into it, whereas in indirect development the young hatches as a larva unlike the adult and must change into it by metamorphosis. The kid of a goat, or the chick of a bird, is a small copy of its parent and simply grows larger; the tadpole of a frog, or the caterpillar of a butterfly, is a larva that lives and feeds quite differently and is later remodelled into the adult form.

The two patterns demand very different things of the parent. Direct development demands a heavy investment in each young: the parent produces only a few offspring, supplies them with much yolk or nourishes them inside its body, and usually cares for and protects them after birth. Indirect development demands little of the parent for each young: many small eggs are laid and left, with little or no care, and the larva must feed and fend for itself, so that large numbers make up for the many that are lost.

> **False Confidence Alert**
> Students often think every animal is born looking like its parents. Only animals with direct development are; those with indirect development hatch as larvae quite unlike the adult and reach the adult form through metamorphosis.

Question 92

Kipanga insists: *'Growth means only getting bigger; as long as an animal is increasing in size, nothing else about it is changing.'* Point out the mistakes in his statement and give the correct account.

Model Answer

Kipanga is wrong that growth means only getting bigger: growth is normally accompanied by development, which is a change in form and function, not in size alone. True growth is a permanent increase in size and dry mass, but as it takes place the body also develops, its cells becoming specialised into different tissues and its parts taking on new shapes and new roles.

Many familiar examples show this change of form and function during growth. A tadpole growing into a frog changes its whole body and its way of life; a human baby growing into an adult changes its proportions, for the head, which is large at birth, comes to make up much less of the grown body. So growth and development go hand in hand, and the animal is remodelled, not merely enlarged, as it grows.

> **False Confidence Alert**
> Students often picture growth as a simple swelling in size with the body otherwise unchanged. Growth goes hand in hand with development: cells specialise, proportions change and new functions appear, so the organism is remodelled as it grows.

Question 93

An insect larva is wrapped in a hard outer skeleton, yet it must grow much larger before it is an adult. Explain why such a larva has to moult in order to grow, and describe the hormonal events of a successful moult.

Model Answer

A larva has to moult because its exoskeleton is a hard, dead cuticle that cannot itself grow. The cuticle, made largely of chitin, cannot stretch, so the only way for the larva to enlarge is to shed the old covering and quickly expand a new, larger one beneath it before that in turn hardens; without moulting the larva would stay imprisoned in a coat it had outgrown.

A successful moult is brought about by hormones. Neurosecretory cells in the brain release a brain hormone that stimulates the prothoracic gland to produce ecdysone, the moulting hormone; ecdysone triggers the shedding of the old cuticle and the laying down of the new one, while the level of juvenile hormone from the corpus allatum decides whether the moult gives another larva or moves the insect on towards the adult.

False Confidence Alert
Students often think a larva grows steadily inside its skin like a young mammal. Its skeleton is on the outside and cannot stretch, so the insect grows only in steps, by moulting; between one moult and the next its size is fixed.

Question 94

In a butterfly the caterpillar feeds on leaves while the adult sips nectar, and the two lead quite different lives. Explain why this splitting of the larval and adult stages, with different food and different habitats, is an advantage to an insect.

Model Answer

The chief advantage is that the larva and the adult do not compete with one another, because they feed on different foods and live in different places. Since the caterpillar eats leaves while the butterfly takes nectar, the young take no food from the adults, and each stage can be specially suited to its own task: the larva to feeding and growth, and the adult to dispersal and reproduction. In this way the one species makes use of two different ways of life, the adult flying off to spread the species to new places while the larva stays and feeds, and the competition within the species is greatly reduced.

False Confidence Alert
Students often think the change of form is merely part of growing up and serves no purpose. Its real value is that the larva and adult avoid competing: they use different foods and habitats, and each stage specialises, one for feeding, the other for breeding and dispersal.

Question 95

A tadpole kept in iodine-poor water, or caught by a spell of cold weather, may fail to complete its change into a frog. Explain why a shortage of iodine, and separately a cold spell, can each stall a tadpole's metamorphosis.

Model Answer

A shortage of iodine stalls metamorphosis because the change is driven by thyroxine, and iodine is needed to make thyroxine. Metamorphosis in the amphibian is switched on by thyroxine from the thyroid gland, and this hormone cannot be made without iodine; so in iodine-poor water too little thyroxine is produced, the signal for change is too weak, and the tadpole cannot complete its transformation into a frog.

A cold spell stalls metamorphosis because temperature controls the speed of the process. Warmth speeds metamorphosis and cold slows it, since the chemical reactions of the body and the action of the hormone all go more slowly when it is cold; so during a cold spell the tadpole's development is held back, and its change into a frog is delayed until warmth returns.

False Confidence Alert
Students often name only one cause, usually the cold. Iodine matters just as much: without it the thyroid cannot make the thyroxine that drives the change, so a shortage of iodine can stall metamorphosis even in warm water.

Question 96

Kipanga claims: *'A caterpillar and the butterfly it turns into are really two different species; and in any case a nymph is just the same thing as a larva.'* Point out the mistakes in his statement and give the correct account.

Model Answer

Kipanga is wrong that a caterpillar and its butterfly are different species: they are one and the same species, two stages in the life of a single animal. The caterpillar is the larva and the butterfly is the adult of the very same insect, and metamorphosis is simply the process that remodels the one into the other; they are of the same kind, however unlike they may look.

He is also wrong that a nymph is the same as a larva: the two are different kinds of young. A nymph, found in incomplete metamorphosis, already resembles the adult and grows up gradually with no pupa; a larva, found in complete metamorphosis, is quite unlike the adult and is followed by a resting pupa in which it is rebuilt. A nymph and a larva are therefore not the same thing.

False Confidence Alert
Students often treat the caterpillar and butterfly as separate animals, and use nymph and larva to mean one thing. The caterpillar and butterfly are one species at two stages; and a nymph, which is like the adult and has no pupa, is not the same as a larva, which is unlike the adult and has a pupa.

HOT QUESTIONS

These questions go beyond single facts. They ask you to put ideas together, to weigh evidence and reach a judgment, and to reason your way through situations you have not met before. Attempt each answer yourself first, then check it against the model answer and the False Confidence Alert that follows.

Question 97

Both the copying of the DNA in the S phase and the separation of the chromatids by the spindle help to keep the chromosome set constant. Evaluate which of these two events is the true guarantee of genetic stability, weighing one against the other.

Model Answer

Genetic stability is guaranteed not by either event alone but by the two acting in turn, of which the first is the faithful copying of the DNA in the S phase. In the S phase each chromosome is copied exactly into two identical sister chromatids, so that an accurate duplicate of every gene is made ready; if this copying were careless the two copies would already differ, and no later step could put right such an error, so stability would be lost from the very start.

The second event is the exact separation of those chromatids by the spindle at anaphase. The spindle shares the identical chromatids equally, so that each daughter cell receives one complete set; without this exact separation the daughters would get the wrong number of chromosomes, and even perfect copies would be wasted. Neither event alone is therefore the guarantee: stability is secured only when accurate copying is followed by exact separation.

False Confidence Alert
Students often pick just one event, usually the spindle, as the guarantee of stability. Accurate copying in the S phase and exact separation by the spindle are both essential, and a failure in either, a wrong copy or a wrong number, destroys genetic stability.

Question 98

Suppose that in some tissue the cells entered mitosis without first carrying out the S phase that normally precedes it. Predict the consequence for that tissue, and explain your reasoning.

Model Answer

If the cells entered mitosis without a preceding S phase, each division would halve the chromosome set and leave the daughter cells with an incomplete set of genes. Normally the S phase doubles each chromosome into two identical chromatids, so that the spindle can give a full set to each of the two daughters; with no S phase there is nothing to copy, so the single, unduplicated chromosomes are merely shared out, and each daughter receives only about half of them. Such cells, missing many of their genes, cannot make all the proteins they need and soon die; as the divisions continued the tissue would lose more and more living cells and would break down.

False Confidence Alert
Students often think skipping the S phase would simply make the division quicker. It would instead halve the chromosome set at every division, leaving daughter cells short of genes and unable to survive.

Question 99

In a tumour the cells go on dividing by ordinary mitosis, and under the microscope each single division can look quite normal. Reason why such uncontrolled mitosis is nevertheless dangerous.

Model Answer

Uncontrolled mitosis is dangerous not because any single division is faulty but because the divisions no longer stop when they should. Normally cell division is held in check, so that cells divide only as much as is needed to grow or to replace what is lost; in a tumour these controls have failed, and the cells go on dividing without limit even though each division by itself looks normal. The endless divisions pile up into a growing mass that crowds, compresses and starves the healthy tissue around it, and if the tumour is malignant some of its cells may break away and start fresh growths elsewhere; it is this loss of control over how often and where the cells divide, not any fault in a single division, that makes the process deadly.

False Confidence Alert
Students often look for something wrong inside each cancer-cell division. The fault is not in the single division, which looks normal, but in the loss of control over how often the cells divide.

Question 100

Two students disagree. **Kipanga** says, *'Cytokinesis is simply the last stage of mitosis.'* **Kipute** says, *'Cytokinesis is a separate event from mitosis altogether.'* Judge which of them is correct, and justify your decision.

Model Answer

Kipute is the nearer to the truth: cytokinesis is best counted as a separate event from mitosis, not a part of it. Mitosis, strictly, is the division of the nucleus, the sharing out of the chromosomes into two identical nuclei; cytokinesis is the division of the cytoplasm that comes after it, splitting the one cell into two. They are two distinct processes, the first dividing the nucleus and the second dividing the cell.

Kipanga's view is understandable but mistaken. Because cytokinesis follows mitosis so closely and completes the division, it is easy to lump the two together as one; but they can be separated, for a nucleus can divide without the cytoplasm following, giving a single cell with two nuclei. This shows that nuclear division and cytoplasmic division are not the same event, so cytokinesis is rightly judged a separate process that normally accompanies mitosis.

False Confidence Alert
Students often call cytokinesis the final phase of mitosis. Mitosis is the division of the nucleus, while cytokinesis is the separate division of the cytoplasm that follows, as is shown when a nucleus divides but the cell itself does not.

Question 101

Two populations are plotted against time: one gives an S-shaped (sigmoid) curve, the other a J-shaped curve. Compare and contrast the two curves, and judge which of them fits a population whose growth is checked by its resources.

Model Answer

The two curves agree at the start but differ in how they end: both begin with slow and then rapid growth, but the S-shaped curve levels off while the J-shaped curve does not. In the S-shaped curve the rapid rise gives way to a plateau, where the numbers steady; in the J-shaped curve the rapid rise simply continues, climbing ever more steeply until the population suddenly crashes when its resources give out.

It is the S-shaped curve that fits a population checked by its resources. Its leveling-off is the very mark of resources running short: as food, space and other needs become limiting, the death rate rises to meet the birth rate and growth slows to a halt, so the population settles at the level its resources can support. The J-shaped curve, by contrast, is the pattern of a population still growing unchecked, with nothing yet holding it back.

> **False Confidence Alert**
>
> Students often say a resource-limited population follows the J-shaped curve because it grows fast. The J-shaped curve is unchecked growth that ends in a crash; a population held in check by its resources follows the S-shaped curve, leveling off at what those resources can support.

Question 102

Ecdysone is the hormone that triggers each moult of an insect. Predict how blocking ecdysone would affect an insect's growth and its final size, and explain your reasoning.

Model Answer

If ecdysone were blocked the insect could not moult, and so it could not grow any larger or reach the adult stage. Ecdysone is the hormone that sets off each moult, and an insect can grow only in steps, by moulting, since its rigid cuticle must be shed and a new, larger one expanded before it hardens. With no ecdysone there would be no moult, so the larva would be trapped in its present cuticle, unable to increase in size and frozen at its current stage; it would never moult into the adult, but would stay small and at last die without reaching its full size.

> **False Confidence Alert**
>
> Students often think blocking the moulting hormone would simply slow the insect down. With no ecdysone it cannot moult at all, so it cannot grow in size or become an adult; it is frozen at its present stage.

Question 103

A fish goes on growing throughout its life, while a bird reaches a fixed adult size and grows no more. Reason why such indeterminate (continuous) growth can suit a fish but would not suit a bird.

Model Answer

Indeterminate growth suits a fish because the water it lives in supports its ever-increasing weight. Buoyed up by the water, a fish can go on growing all its life without its size becoming a burden, and being larger brings real advantages: it can escape more predators, take larger prey and produce more eggs. There is therefore nothing to stop continuous growth from paying off in a fish.

The same growth would not suit a bird, because flight demands a fixed and light body. A bird must keep its weight low and its body of the right size and shape to fly; if it went on growing without limit it would soon become too heavy to leave the ground, and its wings and skeleton, built for one size, could no longer lift it. A bird must therefore stop growing at a fixed adult size, so that determinate growth suits it far better.

False Confidence Alert

Students often assume any animal could grow for ever if only it had enough food. A bird could not: endless growth would make it too heavy to fly, so it must reach a fixed size, while a fish, held up by water, can keep on growing.

Question 104

Two students disagree. **Kipanga** says, *'Moulting cannot be called growth, because the animal's mass does not rise during the moult.'* **Kipute** says, *'Moulting is part of how an insect grows.'* Judge which of them is correct, and justify your decision.

Model Answer

Kipute is the nearer to the truth: moulting is best counted as part of the way an insect grows, even though no new tissue is laid down during the moult itself. The real growth, the building up of new living material, goes on steadily between the moults as the larva feeds; the moult is the step that lets this hidden gain show itself, for only by shedding the rigid old cuticle and expanding a new one can the insect actually increase in size. Moulting is thus the means by which an animal with a hard exoskeleton achieves its growth in size.

Kipanga is right only in a narrow sense. It is true that the animal's mass does not rise during the moult itself, when the swelling is caused by taking in air or water rather than by new tissue; but to conclude from this that moulting is not growth is to mistake the moult for the whole process. The growth of an insect is the gain in tissue between the moults together with the increase in size at each moult, and moulting is a necessary part of it.

False Confidence Alert

Students often decide that moulting is not growth simply because mass does not rise during the moult. The true gain in tissue happens between the moults, by feeding, and the moult is the step that lets that growth show itself as an increase in size.

Question 105

In a plant, a mutation causes the cells of its meristems to form large vacuoles very early, while they are still in the growing point. Explain how such a mutation would affect the plant's growth and development.

Model Answer

If the meristem cells formed large vacuoles early, they would stop dividing too soon, and the plant's growth would be badly stunted. A meristematic cell is normally small and packed with cytoplasm, with little or no vacuole, and it is this state that lets it go on dividing; the forming of a large vacuole is the very change that turns a dividing cell into an enlarging, maturing one. An early large vacuole would therefore push the cells out of division before their time: the meristem would soon be used up, far fewer cells would be made, and although the few cells present might still enlarge, the plant would end up small and poorly formed.

False Confidence Alert

Students often think a large vacuole would help a cell divide faster. The opposite is true: a meristematic cell stays small, with little vacuole, so that it can keep dividing, and forming a large vacuole is the change that ends division and begins enlargement.

Question 106

A complete ring of bark is cut from around the stem of a tree, removing the phloem but leaving the xylem intact. Predict what happens to the parts above and below the ring, reasoning from which tissue the bark has carried away.

Model Answer

Above the ring the parts go on thriving at first, and sugar piles up there, because the xylem is untouched while the phloem is cut. Removing the bark takes away the phloem but leaves the xylem, so water still rises freely to the leaves and they go on making sugar; but that sugar, unable to travel down past the cut, gathers above the ring, where the bark swells and any fruit grows especially large.

Below the ring the parts are starved, and in time the whole tree may die. Cut off from the sugar coming down from the leaves, the stem below the ring and the roots are left without food; the roots, unable to feed, slowly die, and once they have failed they can no longer take up water, so at last the tree above dies too. This is why ring-barking can kill a tree, and why it shows that the phloem carries food downward.

> **False Confidence Alert**
> Students often expect the leaves above the ring to wilt at once. They do not, because the xylem is left intact and water still rises; it is the food, carried in the phloem, that is cut off, so it is the parts below that starve.

Question 107

A young tree has grown to only a fraction of its expected height, yet its trunk has thickened into wood quite normally. Identify which meristem is most likely impaired, and defend your conclusion.

Model Answer

The meristem most likely impaired is the apical meristem, while the lateral meristem is working normally. Growth in length, which makes a tree taller, is the work of the apical meristems at the shoot tips, whereas growth in girth, which thickens the trunk into wood, is the work of the lateral cambium. Since this tree has thickened normally, its lateral cambium must be sound; but since it has failed to reach its proper height, the fault must lie in the apical meristems, whose task is exactly the growth in length that is missing. The pattern, normal thickening but stunted height, points to the apical meristem and to it alone.

> **False Confidence Alert**
> Students often blame poor soil or too little water for stunted height. Here the normal thickening shows the supply lines are working, so the stunting points specifically to the apical meristem, the seat of growth in length.

Question 108

The coming of woody secondary growth is often called a turning point in the history of large land plants. Evaluate why this was so, weighing its contributions to support, to transport, and to survival.

Model Answer

Woody secondary growth was a turning point because the wood it laid down gave land plants support, transport and survival all at once. The secondary xylem is strong, rigid and lignified, so it gives the mechanical support that holds a tall plant upright against its own weight and the wind; it also adds many new vessels that carry water and minerals up to a large crown of leaves, so that transport keeps pace with the greater size; and the woody, perennial body, clothed in protective bark, survives drought, fire and the passing years, living on where a soft herb would die.

Weighing the three, it is the support that was decisive. Transport and survival both mattered, but it was the strength of wood that first allowed plants to grow tall, and height is what won them the competition for light; the better transport and the longer survival followed from, and served, that new power to stand tall. Woody growth was therefore a turning point above all because it let plants become large, upright trees.

False Confidence Alert
Students often say wood mattered only for transport. Its first and greatest gift was support, the strength to stand tall, which is what let plants win the race for light, with better transport and longer survival following from it.

Question 109

It is sometimes claimed that the intercalary meristems of grasses make them just as advanced as woody plants. Evaluate this claim.

Model Answer

There is something in the claim, for the intercalary meristems are a real advantage to grasses. These meristems lie low down, at the bases of the leaves and internodes, so that when a grass is grazed, cut or burnt at the top it can grow again from below; this is why a lawn or a pasture recovers so quickly, and it fits grasses superbly to a life of being eaten and trampled.

But the claim goes too far, because advancement is the wrong measure. Intercalary meristems give a grass no secondary growth: a grass forms no wood, cannot thicken into a trunk, and cannot grow tall or live on for many years as a tree does. The grass and the tree are not one more advanced than the other; each is simply fitted to its own way of life, the grass to swift regrowth after grazing, the tree to height and long survival. The intercalary meristem makes grasses highly successful, then, but not as advanced as woody plants in the sense the claim intends.

False Confidence Alert
Students often treat advanced as a single ladder with woody plants at the top. Grasses are not backward but differently adapted: their intercalary meristems suit grazing and regrowth, while wood suits height and long life.

Question 110

After the short rains at Morogoro a farmer's amaranthus seeds came up at once, but his sorghum seeds did not germinate at all. Explain why the amaranthus germinated while the sorghum did not, propose two causes of the sorghum's dormancy, and give a practical way to break it.

Model Answer

The amaranthus germinated because its seeds were not dormant, while the sorghum did not because its seeds were still in dormancy, so the rain alone could not rouse them. The amaranthus seeds were ready to grow and needed only water, warmth and air, all of which the short rains supplied, so they came up at once; the sorghum seeds, by contrast, were held in dormancy, and a dormant seed will not germinate when merely wetted until its dormancy has first been broken.

Two likely causes of the sorghum's dormancy are a hard, water-tight seed coat and a chemical inhibitor within the seed, and either can be overcome by the farmer. A hard coat keeps out the water and oxygen the embryo needs, while a chemical inhibitor holds the embryo in check until it is removed; in practice the farmer can break such dormancy by scratching or rubbing the seed coats to let water in, or by soaking the seeds beforehand so that the inhibitor is washed out, after which they will germinate.

False Confidence Alert
Students often say the sorghum failed because the rain was too little. The amaranthus grew on that same rain; the sorghum failed because its seeds were dormant, and water alone cannot rouse a dormant seed until its dormancy is broken.

Question 111

Seed dormancy helps a wild plant survive in a climate of wet and dry seasons, but it is a nuisance to a farmer who wants all his seed to come up together. Evaluate why dormancy is an advantage in a seasonal climate yet a problem for such a farmer.

Model Answer

In a seasonal climate dormancy is an advantage because it holds the seed back until conditions are right, and spreads germination over time. By staying dormant through the dry season a seed avoids germinating when there is no water to support the seedling, and waits instead for the rains; and because the seeds do not all break dormancy at once, germination is staggered, so that if one flush of seedlings is killed by a late drought, others remain to carry the plant on. Dormancy thus times germination to the favourable season and spreads the risk.

For the farmer, though, that same staggering is a problem, because he wants an even crop. A farmer needs his seeds to come up together, quickly and uniformly, so that the crop can be weeded, watered and harvested all at one time; but dormant seed germinates unevenly and over a long period, some early and some late, giving a patchy stand that is hard to manage and that ripens unevenly. What protects the wild plant therefore frustrates the farmer, which is why seed for sowing is bred or treated to have little dormancy.

False Confidence Alert
Students often see dormancy as simply a fault that delays the crop. For a wild plant it is a survival device, timing germination to the rains and spreading risk; it troubles only the farmer, who wants every seed up at once.

Question 112

A hard seed coat can protect a wild seed, but it can also stop the seed from germinating. Evaluate whether, on balance, a hard seed coat is a help or a hindrance to a wild plant.

Model Answer

A hard seed coat is chiefly a help to a wild plant, for it protects the seed and times its germination. The tough coat shields the embryo from drought, from damage and from being eaten or digested, and it lets the seed survive a passage through an animal or a bush fire; it also enforces a dormancy that holds the seed back until the coat is broken by weathering, fire or an animal's gut, so that the seed germinates only when conditions are likely to favour the seedling, and germination is spread over time rather than all at once.

It is a hindrance only in a narrow sense, and that very drawback is part of its value. A coat so hard that water and oxygen cannot enter may delay germination, or hold it back until the coat is worn down, which can look like a disadvantage; but for a wild plant in an unpredictable climate this enforced waiting is exactly what improves survival, spreading germination and matching it to the good times. On balance, then, the hard coat is far more a help than a hindrance to a wild plant; it is a hindrance mainly from the impatient farmer's point of view.

False Confidence Alert
Students often judge the hard coat a hindrance because it can block germination. For a wild plant the coat's protection, and the enforced, staggered dormancy it gives, are a great advantage; the blocking is the very mechanism that times germination well.

Question 113

A whole animal, with its muscle, nerve, bone and blood, grows by mitosis from a single fertilised cell, and yet mitosis makes genetically identical cells. Reason how one cell, dividing in this way, can give rise to so many different tissues.

Model Answer

Although mitosis makes genetically identical cells, the body comes to have many different tissues because the cells differentiate, each switching on a different part of the same set of genes. Every cell formed by mitosis from the one fertilised egg carries the same full set of genes; but as the cells grow they differentiate, which means that different cells use, or switch on, different genes while keeping the rest silent. So a muscle cell and a nerve cell, though they hold identical genes, express different ones and so take on different shapes and different jobs. Division by mitosis provides the many cells, differentiation makes them different, and the two together build a body of many tissues from a single cell.

> **False Confidence Alert**
> Students often reason that because mitosis copies the genes exactly, all the body's cells must be the same. They do carry the same genes, but they differ because they switch on different genes; identical genes can still give different cells, through differentiation.

Question 114

The metamorphosis of an insect is governed not by one factor alone but by several acting together. Explain how temperature, hormones and nutrients interact to regulate metamorphosis in insects.

Model Answer

Hormones are the master controllers of metamorphosis, but they act only within the limits set by temperature and nutrients. The hormones run the programme: ecdysone from the prothoracic gland triggers each moult, and the level of juvenile hormone from the corpus allatum decides whether that moult gives another larva, a pupa or the adult. The hormones thus determine what happens and when.

Temperature sets the pace of the process, and nutrients supply the means to carry it out. Warmth speeds the hormone-driven reactions while cold slows them, so the same insect changes faster in warm weather than in cold; and a good supply of food provides the materials and energy to rebuild the body at each stage, while a starved larva develops slowly or stalls. Metamorphosis therefore goes forward only when the hormones give the signal, the temperature is warm enough and the food is sufficient; a shortage of any one of the three holds it back even when the others are favourable.

> **False Confidence Alert**
> Students often name only the hormones. Hormones do control metamorphosis, but temperature sets its speed and nutrients supply the means, and a lack of warmth or of food can stall the process even while the hormones are signalling.

Question 115

In an insect the corpus allatum produces juvenile hormone. Predict the effect on the insect of removing the corpus allatum early in its larval life, reasoning from what juvenile hormone does.

Model Answer

If the corpus allatum were removed early, the insect would lose its juvenile hormone and would metamorphose too soon, turning into a miniature adult. The corpus allatum makes juvenile hormone, and it is the presence of this hormone that keeps each moult producing another larva; while juvenile hormone is high the insect stays larval, and only when it falls does the insect move on to the pupa and the adult. Remove the corpus allatum early and the juvenile hormone is gone before its time, so at the very next moult, with nothing left to hold it back, the larva would change straight into the adult form, giving a tiny, premature adult far smaller than normal.

> **False Confidence Alert**
> Students often think removing the corpus allatum would simply stop the insect growing or kill it. It does not stop the moult; with no juvenile hormone the next moult jumps straight to the adult form, giving a miniature, premature adult.

Question 116

Two students disagree. **Kipanga** says, *'Complete metamorphosis is more advanced than incomplete metamorphosis.'* **Kipute** says, *'Neither is more advanced; they are merely different.'* Judge which of them is nearer the truth, and justify your decision.

Model Answer

Kipanga is the nearer to the truth, provided that more advanced is taken to mean more derived and conferring greater advantage. In complete metamorphosis the larva is utterly unlike the adult and there is a pupal stage in which the body is wholly rebuilt; this completely separates the feeding, growing larva from the breeding, dispersing adult, so that the two never compete for food or living space, and the pupa lets the insect pass the hard seasons. It is no accident that the most successful insect groups, the beetles, the flies, the bees and the butterflies, all undergo complete metamorphosis.

Kipute is right, however, to enter a caution. Incomplete metamorphosis is not a failure or a mere primitive leftover; it serves locusts and cockroaches perfectly well, and advanced must not be taken to mean better in every way. The fair judgment is therefore that complete metamorphosis is the more advanced, because of the full separation of larva from adult and the rebuilding pupa, while incomplete metamorphosis remains a successful way of life in its own right.

False Confidence Alert
Students often dismiss incomplete metamorphosis as simply primitive and therefore poor. More advanced here means more derived and more advantageous, not better in every way; incomplete metamorphosis still serves many insects very well.

Chapter 4

REPRODUCTION

BINDER QUESTIONS

Work through each question in order: attempt your own answer first, then check it against the model answer and against the False Confidence Alert that follows, which warns of the mistake that most often costs marks.

Question 1

Meiosis is often called a reduction division. Explain why it is described in this way, and state where and when it takes place in a mammal and in a flowering plant.

Model Answer

Meiosis is called a reduction division because it halves the chromosome number, turning one diploid (2n) cell into haploid (n) cells. It does this through two divisions that follow only a single replication of the DNA, so each gamete ends with one set of chromosomes instead of two.

In a mammal, meiosis occurs in the gonads, that is the testes and the ovaries, during the formation of the gametes. In a flowering plant it occurs in the anther, where it forms the pollen, and in the ovule, where it forms the embryo sac.

The halving matters because fertilisation later fuses two haploid gametes, which restores the full diploid number in the zygote and so keeps the chromosome number of the species steady from one generation to the next.

False Confidence Alert
Asked why meiosis is a reduction division, many candidates instead describe the stages of meiosis. The mark is for stating that the number is halved from diploid (2n) to haploid (n), so an answer that never says the number is halved scores nothing, however detailed its account of the stages.

Question 2

If gametes were made by ordinary cell division instead of meiosis, the chromosome number would double in every generation. Explain how meiosis and fertilisation together keep the chromosome number of a species constant.

Model Answer

Meiosis halves the chromosome number so that each gamete is haploid, and fertilisation then restores the diploid number when two gametes fuse. Because meiosis reduces 2n to n before the gametes are formed, the sperm and the egg each carry only one set of chromosomes.

At fertilisation the two haploid sets combine, so the zygote becomes diploid once more, carrying the same number its parents had.

Consequently the chromosome number stays constant from one generation to the next, because meiosis takes it down by half and fertilisation builds it back up, which in turn keeps the species stable while still mixing the genes of the two parents.

False Confidence Alert
Many candidates explain meiosis and then stop. The question asks how the number stays constant, so an answer that leaves out fertilisation restoring the diploid number cannot earn the marks, because it is the two processes working together that hold the number steady.

Question 3

During meiosis the chromosomes first pair up in a way that never happens in mitosis. Explain what a homologous pair is, and why this pairing is essential to meiosis.

Model Answer

A homologous pair is two chromosomes that carry the same genes in the same order, one inherited from each parent, so that they match in length and shape. They are not identical, because the alleles (the versions of those genes) they carry may differ.

In meiosis the homologues pair side by side, forming a bivalent made of four chromatids. This close pairing, called synapsis, has no counterpart in mitosis.

The pairing is essential because it allows the homologues to be separated into different cells at anaphase I, which is what halves the chromosome number; it also brings non-sister chromatids together so that crossing over can occur, creating new combinations of alleles.

False Confidence Alert
The trap here is describing sister chromatids instead of a homologous pair. Sister chromatids are the two identical copies of one chromosome joined at a centromere, whereas homologues are two different chromosomes, one from each parent; answer for the wrong pair and the mark is lost.

Question 4

Every chromosome must be copied before a cell can divide. Draw a labelled diagram to show a single chromosome before and after the S phase of interphase, and use it to explain what the cell must do before meiosis can begin.

Model Answer

Before meiosis can begin, the cell must replicate its DNA in the S phase, so that each chromosome is copied into two identical sister chromatids joined at a centromere, as shown in Figure 4.1. Before the S phase the chromosome is a single chromatid, that is one DNA molecule; after the S phase it consists of two sister chromatids held together at the centromere.

This copying is essential because meiosis then divides twice. The replication provides the four chromatids in each homologous pair that the two divisions will share out, ending in four haploid cells.

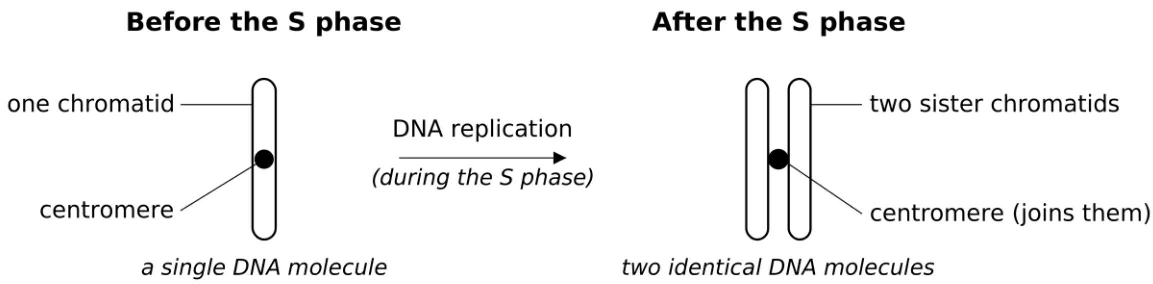


Figure 4.1: *A chromosome before and after the S phase of interphase.*

False Confidence Alert
In a draw question the marks are on the labels, not on the artwork. The usual loss here is an unlabelled centromere, or drawing the sisters as two separate chromosomes; the examiner must see two chromatids joined at one centromere, since that is what shows the chromosome has been copied.

Question 5

Prophase I is the longest and most eventful stage of meiosis. Describe, in order, what happens to the chromosomes through its five sub-stages.

Model Answer

Prophase I is divided into five sub-stages, in which the homologous chromosomes pair, cross over and then begin to separate:

1) **Leptotene:** the chromosomes condense from the chromatin and appear as long, thin threads.

2) **Zygotene:** the homologous chromosomes pair exactly along their length, a process called synapsis, forming bivalents.
3) **Pachytene:** the chromosomes shorten and thicken, each is now seen as two chromatids, and crossing over takes place between non-sister chromatids.
4) **Diplotene:** the paired homologues begin to pull apart but stay joined at points called chiasmata, where crossing over has occurred.
5) **Diakinesis:** the chromosomes coil tightly and shorten further, the chiasmata move towards the ends, the nucleolus disappears and the nuclear envelope breaks down, ready for metaphase I.

False Confidence Alert
Asked for the sub-stages in order, candidates often jump straight to crossing over and lose the sequence marks. Synapsis (in zygotene) must be named before crossing over (in pachytene), because the homologues cannot cross over until they have first paired.

Question 6

Prophase I is the stage in which the homologous chromosomes pair and exchange material. Draw a series of simple labelled diagrams to show its five sub-stages, following one homologous pair and marking where crossing over takes place.

Model Answer

The five sub-stages are shown in Figure 4.2, which follows one homologous pair from separate threads to a paired, crossed-over bivalent. In leptotene the chromosomes appear as long, thin threads; in zygotene the homologues pair by synapsis; in pachytene each chromosome is now seen as two chromatids and crossing over occurs between non-sister chromatids; in diplotene the homologues begin to separate but stay joined at the chiasmata; and in diakinesis they coil tightly as the nuclear envelope breaks down.

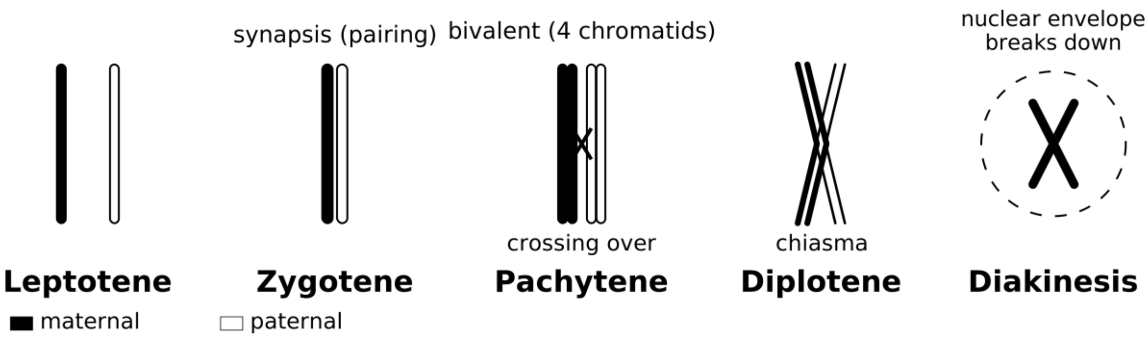


Figure 4.2: *The five sub-stages of prophase I, following one homologous pair.*

False Confidence Alert
The mark-bearing labels here are synapsis, the bivalent, the chiasma and the crossing-over point. The commonest loss is showing crossing over between the two sister chromatids of one chromosome; the examiner must see it between non-sister chromatids of the two different homologues, because only that exchanges alleles.

Question 7

Crossing over is the event in prophase I that helps make every gamete genetically unique. Explain how crossing over takes place, and why it is a source of variation.

Model Answer

Crossing over is the exchange of corresponding segments between non-sister chromatids of a homologous pair, taking place at the chiasmata during pachytene. While the homologues lie paired as a bivalent, a chromatid of the maternal chromosome and one of the paternal chromosome break at the same point and rejoin with each other's segment.

It is a source of variation because it produces recombinant chromatids that carry new combinations of alleles, combinations found on neither original chromosome, so the gametes formed afterwards are genetically varied. The point at which the chromatids cross and stay joined is called the chiasma.

False Confidence Alert
Asked how crossing over creates variation, candidates often say only that it mixes the chromosomes. The mark is for the exchange between non-sister chromatids producing new combinations of alleles; an answer that mentions neither non-sister chromatids nor new allele combinations misses the reason it matters.

Question 8

After prophase I, the first meiotic division is completed in three further stages. Describe what happens in metaphase I, anaphase I and telophase I, and state what each new cell contains at the end.

Model Answer

The first division lines up the homologous pairs and then separates them, which is what halves the chromosome number:

Metaphase I: the bivalents line up at the equator of the spindle, the two homologues of each pair lying on either side; which way each pair faces is random, and this is independent assortment.

Anaphase I: the spindle fibres pull the whole homologues, each still made of two chromatids, to opposite poles, so one chromosome of each pair goes to each end; the centromeres do not split.

Telophase I: the chromosomes reach the poles, the cytoplasm divides, and two cells form, each with half the original number of chromosomes.

Each new cell is now haploid, but every chromosome in it still consists of two sister chromatids, which the second meiotic division will later separate.

False Confidence Alert
The trap here is writing that the centromeres split in anaphase I. They do not: in anaphase I whole chromosomes, each still two chromatids, are pulled apart, and the centromeres split only in anaphase II; getting this the wrong way round loses the mark, because it is exactly what makes meiosis I the reduction division.

Question 9

The first meiotic division is the one that halves the chromosome number. Draw labelled diagrams of metaphase I, anaphase I and telophase I in a cell with two pairs of homologous chromosomes, and use them to explain how the chromosome number is halved.

Model Answer

The three stages are shown in Figure 4.3, which follows two homologous pairs through the first division. At metaphase I the bivalents line up at the equator, the two homologues of each pair on opposite sides of the plate, and the pairs are arranged independently of one another. At anaphase I the spindle pulls the whole homologues, each still two chromatids, to opposite poles. At telophase I the cell divides in two, each daughter receiving only one chromosome of each pair.

The number is halved because it is the homologous pairs, not the chromatids, that are separated: each daughter cell ends with one chromosome of each pair, so one diploid cell becomes two haploid cells.

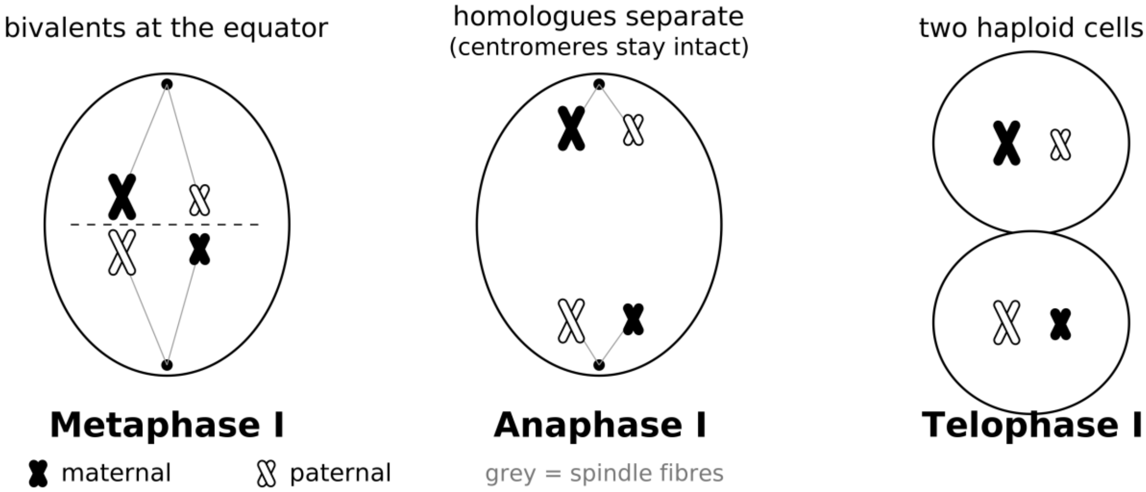


Figure 4.3: *Metaphase I, anaphase I and telophase I in a cell with two homologous pairs.*

False Confidence Alert
The marks here are for showing whole chromosomes, each still two chromatids, moving to the poles at anaphase I, and the bivalents arranged independently at the equator. The usual loss is drawing single chromatids separating, as in mitosis; that does not halve the number and earns nothing on a meiosis I diagram.

Question 10

Both meiotic divisions use a spindle, yet they separate different things. Explain how the behaviour of the chromosomes and their centromeres in anaphase I differs from that in anaphase II, and why this order matters.

Model Answer

In anaphase I whole homologous chromosomes are separated, each still made of two sister chromatids joined at an undivided centromere, so one chromosome of each homologous pair is pulled to each pole; the centromeres do not split.

In anaphase II the centromeres split, and the sister chromatids of each chromosome are pulled to opposite poles, exactly as in mitosis, so each pole now receives single chromatids.

This order matters because the first division is the one that halves the number, while the second only separates the chromatids; if the centromeres split in the first division, the homologues would not be parted and the chromosome number would not be halved.

False Confidence Alert
Asked to contrast the two anaphases, candidates often describe both as chromatids separating. Only anaphase II separates chromatids; anaphase I separates whole homologues with their centromeres intact, and an answer that misses this distinction cannot score, because it is the very reason meiosis needs two divisions.

Question 11

After a short interphase in which no DNA is replicated, the second meiotic division takes place. Describe what happens in its four stages, and state how many cells result and what each contains.

Model Answer

Meiosis II resembles mitosis and separates the sister chromatids of each haploid cell, with no fresh replication of DNA beforehand:

1) **Prophase II:** the nuclear envelope breaks down again and a new spindle forms in each of the two haploid cells.

2) **Metaphase II:** the chromosomes, each still two chromatids, line up singly at the equator of the spindle.
3) **Anaphase II:** the centromeres split and the sister chromatids are pulled to opposite poles as separate chromosomes.
4) **Telophase II:** nuclei re-form and the cells divide, giving four cells in total.

The result is four haploid cells, each carrying a single set of chromosomes that are now single chromatids, and each genetically different from the others because of crossing over and independent assortment.

False Confidence Alert
The trap here is writing that the DNA is copied again before meiosis II. It is not: the chromosomes still carry the two chromatids made in the single S phase before meiosis I, so an answer that inserts a second replication is wrong and misses why meiosis ends with haploid cells rather than diploid ones.

Question 12

The two cells from the first division each divide again, this time without copying their DNA. Draw labelled diagrams of metaphase II, anaphase II and telophase II, and show the four haploid cells that result.

Model Answer

The second division is shown in Figure 4.4, in which each of the two cells from meiosis I divides again to give four cells in all. At metaphase II the chromosomes, each still two chromatids, line up singly at the equator. At anaphase II the centromeres split and the sister chromatids are pulled to opposite poles. At telophase II the cells divide, leaving four haploid cells, each chromosome now a single chromatid.

The four cells are not identical, because the crossing over and independent assortment of the first division have given each a different combination of alleles.

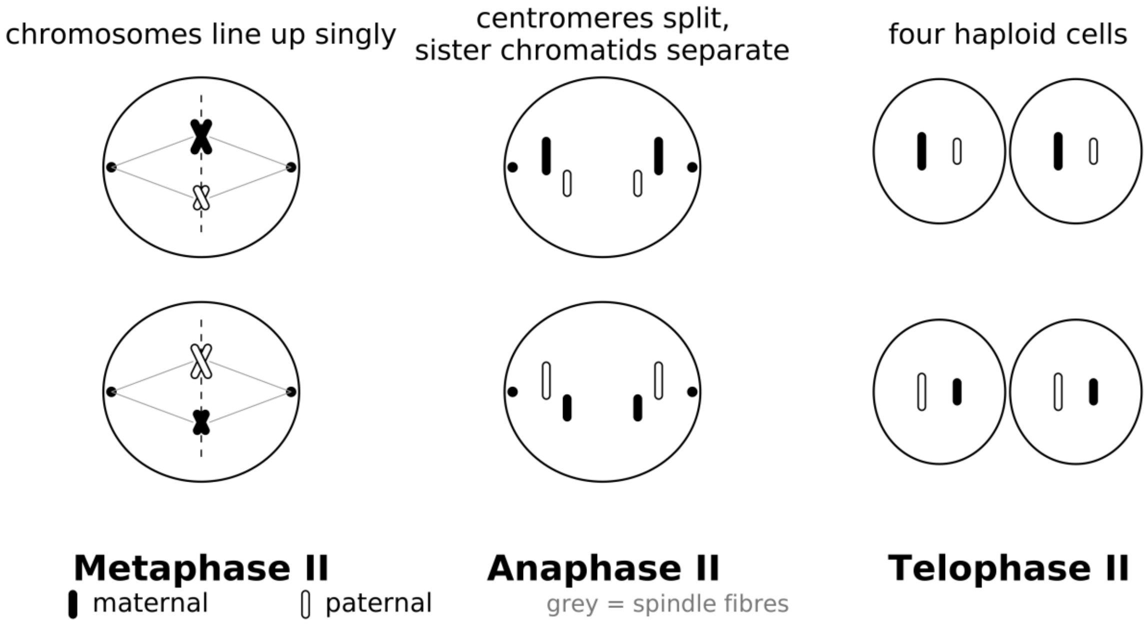


Figure 4.4: *Metaphase II, anaphase II and telophase II, giving four haploid cells.*

False Confidence Alert
The marks here are for showing single chromatids separating at anaphase II and four cells at the end, each chromosome now a single chromatid. The usual loss is leaving the chromosomes drawn as two chromatids in the final cells; meiosis II must reduce each to a single chromatid, or the division is not finished.

Question 13

Meiosis copies the DNA only once but divides twice. Explain how this arithmetic turns one diploid cell into four haploid cells.

Model Answer

Because the DNA is replicated only once but the cell then divides twice, the chromosomes are shared out among four cells and the number is halved. After the single S phase, every chromosome is two sister chromatids and the diploid cell still holds its full number of chromosomes.

The first division separates the homologous pairs, halving the number to give two haploid cells, each chromosome still two chromatids.

The second division then separates the sister chromatids, with no fresh copying, so the two cells become four, each with a single set of single-chromatid chromosomes.

One round of replication followed by two divisions is therefore exactly what is needed to turn one diploid cell into four haploid cells.

> **False Confidence Alert**
> Asked about the arithmetic, candidates often say the DNA is copied before each division. It is copied only once, before meiosis I; an answer that adds a second copying would give diploid, not haploid, products, and so misses the very reason meiosis divides twice on one replication.

Question 14

Meiosis I is called the reductional division and meiosis II the equational division. Using the chromosome number at each stage, explain why these names are deserved.

Model Answer

Meiosis I is reductional because it halves the chromosome number, taking the cell from diploid (2n) to haploid (n). It does this by separating the homologous pairs, so each daughter cell receives only one chromosome of each pair, that is n chromosomes.

Meiosis II is equational because it leaves the number unchanged, keeping each cell haploid (n); it separates only the sister chromatids of each chromosome, so the number of chromosomes stays the same, even though each is now a single chromatid.

So the number falls from 2n to n in the first division and stays at n in the second: the reduction happens once, in meiosis I, which is why that division alone is called reductional.

> **False Confidence Alert**
> The trap is calling meiosis II reductional because the chromatids separate or the chromosomes look smaller. The chromosome number does not fall in meiosis II, it stays at n; reduction means a fall in number, which happens only in meiosis I, so naming the second division reductional loses the mark.

Question 15

Crossing over is not the only way meiosis shuffles the genes. Explain what independent assortment is, and how it adds to the variety of gametes a parent can make.

Model Answer

Independent assortment is the random way the homologous pairs line up at the equator in metaphase I, so that which homologue of a pair faces which pole is settled by chance, and separately for every pair. Because the pairs orient at random, the maternal and paternal chromosomes are mixed freely among the gametes.

It adds to variety because each pair can face either way, so the number of possible combinations doubles with every pair; a cell with n pairs can make 2 to the power n different arrangements, which for a human, with 23 pairs, is over eight million.

Together with crossing over, independent assortment means that almost no two gametes carry the same set of alleles, which is why the offspring of the same two parents still differ from one another.

False Confidence Alert
Asked about independent assortment, candidates often describe crossing over instead. They are different sources of variation: crossing over swaps segments within a pair in prophase I, while independent assortment is the random orientation of whole pairs at metaphase I; answering for the wrong one loses the mark even though both create variety.

Question 16

Meiosis is essential to every organism that reproduces sexually. Outline the importance of meiosis to such organisms.

Model Answer

Meiosis matters to a sexually reproducing organism in three main ways:

1) **It halves the chromosome number:** by reducing the diploid number to the haploid number in the gametes, it allows fertilisation to restore the diploid number, so the number stays constant from one generation to the next.
2) **It generates variation:** crossing over and independent assortment give each gamete a fresh combination of alleles, so the offspring differ from their parents and from one another.
3) **It makes sexual reproduction possible:** without the haploid gametes that meiosis produces, two parents could not combine their genes to form a new individual.

This variation is also the raw material on which natural selection acts, so meiosis underlies the long-term survival and the evolution of the species.

False Confidence Alert
Asked for the importance of meiosis, candidates often write only that it produces gametes and stop. The marks are spread across the separate points, so naming the halving of the number, the creation of variation and the basis of sexual reproduction each earns credit; a one-line answer cannot reach the marks available.

Question 17

Both mitosis and meiosis are forms of nuclear division, yet they serve very different purposes. Distinguish between mitosis and meiosis.

Model Answer

Mitosis and meiosis differ in several clear ways:

1) **Number of divisions:** mitosis is a single division, whereas meiosis is two successive divisions.
2) **Number of daughter cells:** mitosis gives two cells, whereas meiosis gives four.
3) **Chromosome number:** mitosis keeps the number the same, diploid to diploid, whereas meiosis halves it, diploid to haploid.
4) **Genetic make-up:** the cells from mitosis are genetically identical to the parent, whereas those from meiosis are genetically different, through crossing over and independent assortment.
5) **Pairing of homologues:** homologous chromosomes do not pair in mitosis, whereas in meiosis they pair and cross over.
6) **Role:** mitosis serves growth, repair and asexual reproduction, whereas meiosis forms the gametes for sexual reproduction.

False Confidence Alert
In a distinguish question the marks are for paired points, not for two separate descriptions. Writing a paragraph on mitosis and then a paragraph on meiosis scores poorly; each difference must set the two side by side, for example mitosis keeps the chromosome number constant whereas meiosis halves it.

Question 18

A student looks down a microscope at a dividing cell and sees the chromosomes behaving in a particular way. Explain how their behaviour would let the student decide whether the cell is undergoing mitosis or meiosis.

Model Answer

The deciding clue is whether the homologous chromosomes pair up, because pairing happens only in meiosis. If the student sees homologues lying together as bivalents, with chiasmata between them, the cell is in meiosis, in prophase I or metaphase I.

If the chromosomes are arranged singly and never pair, the division is mitosis. Two further signs confirm meiosis: whole homologues, each still two chromatids, separating at anaphase rather than single chromatids points to anaphase I; and a final product of four cells, or cells with half the chromosome number, also shows meiosis.

In short, paired homologues, chiasmata and a halving of the number mean meiosis, while single chromosomes, no pairing and an unchanged number mean mitosis.

False Confidence Alert
Asked to tell the two apart, candidates often rely on counting chromatids, which look the same in both divisions. The reliable sign is the pairing of homologous chromosomes into bivalents, seen only in meiosis; an answer that does not use pairing as the test has no sure way to decide and loses the mark.

Question 19

A growing child makes new body cells by mitosis, but makes sperm or eggs by meiosis. Explain why each process suits its own purpose.

Model Answer

Growth needs cells that are identical to the parent cell and that keep the full chromosome number, which is exactly what mitosis provides. Mitosis copies the cell faithfully, so every new body cell carries the same diploid set, letting tissues grow and repair without altering the genetic instructions.

Gamete formation needs the opposite, cells with half the chromosome number and with new combinations of alleles, which is what meiosis provides. If gametes were made by mitosis they would be diploid, and fertilisation would then double the number every generation; meiosis halves it first, so the diploid number is restored, not doubled, when the gametes fuse.

Meiosis also mixes the alleles, giving the variation on which sexual reproduction depends, whereas mitosis deliberately keeps the cells unchanged.

False Confidence Alert
Asked why each process suits its job, candidates often just define the two divisions. The marks are for linking the outcome to the need, identical diploid cells for growth and halved, varied cells for gametes; an answer that describes mitosis and meiosis without tying each to its purpose does not answer the question.

Question 20

Before fertilisation can take place, each parent must first make its sex cells. Explain what gametogenesis is, why the gametes it makes must be haploid, and how the process differs between the two sexes.

Model Answer

Gametogenesis is the formation of the gametes, the sex cells, from special diploid cells in the gonads by meiosis followed by maturation. In the male it is called spermatogenesis and occurs in the testes; in the female it is called oogenesis and occurs in the ovaries.

The gametes must be haploid so that fertilisation restores the diploid number rather than doubling it. Each gamete carries only one set of chromosomes, so when two fuse the zygote regains the full diploid set of the species.

The two processes differ mainly in their products: spermatogenesis makes four small, motile sperm from each parent cell, while oogenesis makes one large, non-motile egg together with small polar bodies.

False Confidence Alert
Asked what gametogenesis is, candidates often answer only that it is the making of gametes, without naming meiosis. The mark depends on stating that meiosis is the step that halves the number, so an answer that leaves it out cannot explain why the gametes are haploid, which is the point of the question.

Question 21

Whether it makes sperm or eggs, gametogenesis passes through the same three phases. Describe these phases and what the cell does in each.

Model Answer

Gametogenesis passes through three phases, the same in both sexes:

1) Multiplication phase: the diploid germ cells divide repeatedly by mitosis to increase their number, so that many gamete-forming cells are produced.
2) Growth phase: each cell grows larger and stores food and other materials, becoming a primary spermatocyte or a primary oocyte ready to divide by meiosis.
3) Maturation phase: the cell divides by meiosis, halving the chromosome number, and the haploid products mature into the finished gametes.

It is the maturation phase that makes the gametes haploid, because that is the phase in which meiosis takes place.

False Confidence Alert
The trap here is calling every division in gametogenesis meiosis. Only the maturation phase is meiotic; the multiplication phase is mitosis, so an answer that makes the whole process meiosis is wrong and cannot explain how the numbers of gamete-forming cells are first built up.

Question 22

In the testis, a single stem cell gives rise to four sperm. Trace the stages of spermatogenesis from the spermatogonium to the spermatozoa, saying which divisions are mitotic and which are meiotic.

Model Answer

Spermatogenesis runs through the following stages in the wall of the seminiferous tubule:

1) **Spermatogonium (2n):** the diploid stem cell divides by mitosis during the multiplication phase to produce more spermatogonia.
2) **Primary spermatocyte (2n):** a spermatogonium grows during the growth phase to become a primary spermatocyte.
3) **Secondary spermatocytes (n):** the primary spermatocyte divides by meiosis I to give two haploid secondary spermatocytes.
4) **Spermatids (n):** each secondary spermatocyte divides by meiosis II to give two spermatids, so four spermatids form from one primary spermatocyte.
5) **Spermatozoa (n):** the four spermatids mature, by spermiogenesis, into four spermatozoa.

So mitosis multiplies the stem cells, while meiosis I and meiosis II together turn one primary spermatocyte into four haploid sperm.

False Confidence Alert
Asked which divisions are mitotic and which meiotic, candidates often call the whole sequence meiosis. The spermatogonia multiply by mitosis; only the two divisions of the primary spermatocyte are meiotic, and an answer that does not separate the two cannot show where the chromosome number is halved.

Question 23

A clear diagram makes the count of sperm easy to follow. Draw a labelled flow diagram of spermatogenesis, showing the cells at each stage, the divisions between them, and where the chromosome number is halved.

Model Answer

Spermatogenesis is shown in Figure 4.5, in which one spermatogonium gives rise to four spermatozoa. The spermatogonium (2n) multiplies by mitosis and grows into a primary spermatocyte (2n); meiosis I then halves the number to give two secondary spermatocytes (n); meiosis II gives four spermatids (n); and these mature by spermiogenesis into four spermatozoa (n).

The chromosome number is halved at meiosis I, where the diploid primary spermatocyte gives rise to the haploid secondary spermatocytes.

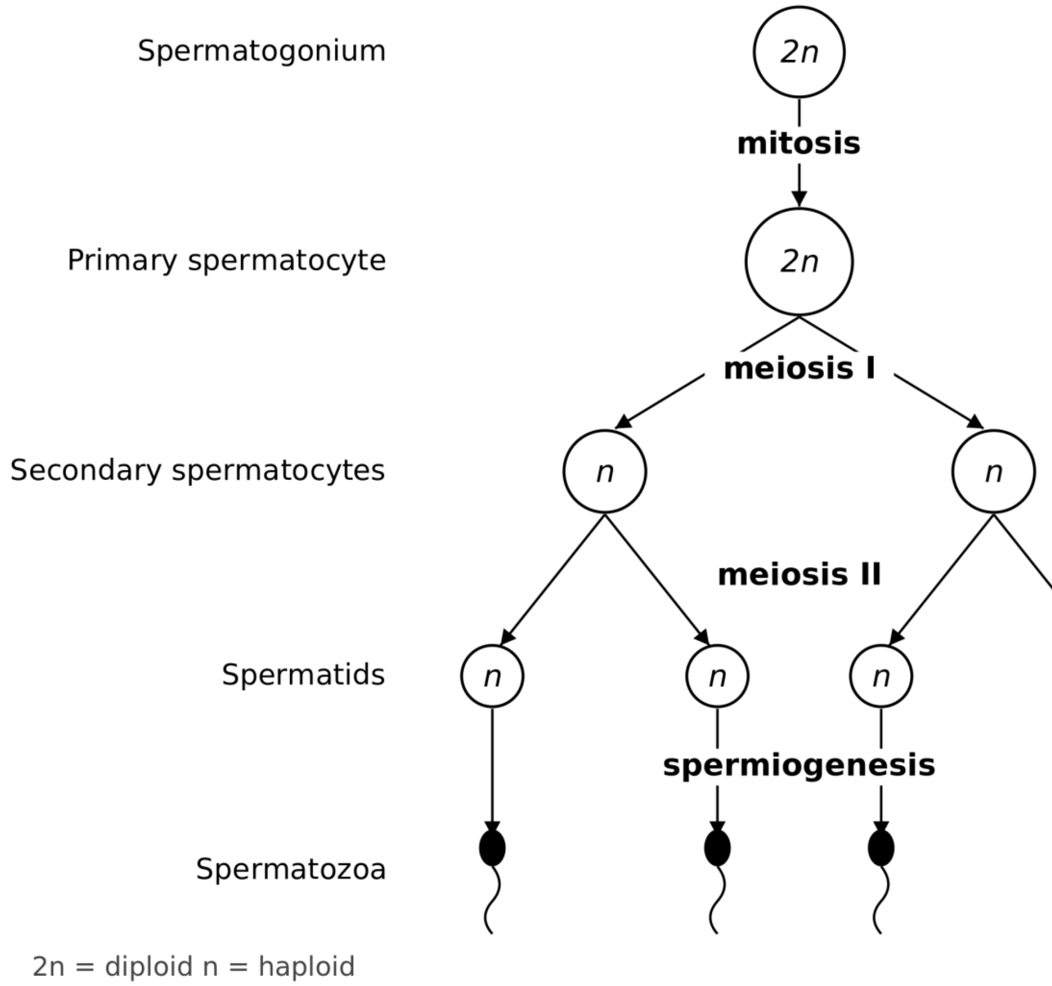


Figure 4.5: *Spermatogenesis, from one spermatogonium to four spermatozoa.*

False Confidence Alert
The mark-bearing labels are the named stages, the type of each division (mitosis, meiosis I, meiosis II) and the change from 2n to n. The usual loss is marking the halving at meiosis II; the reduction to haploid happens at meiosis I, so a diagram that shows it at the wrong division loses the mark.

Question 24

Spermatogenesis does not happen just anywhere in the testis, but in a particular place and direction. Explain where in the testis sperm are made, and why the process runs from the wall of the tube towards its centre.

Model Answer

Spermatogenesis takes place in the walls of the seminiferous tubules, the long coiled tubes that fill the testis. The dividing cells lie in layers across the tubule wall, with the earliest stages at the outer edge and the maturing sperm nearest the central space, the lumen.

The process runs from the wall inwards because the cells move towards the lumen as they mature. The spermatogonia lie against the outer wall; as they become spermatocytes, then spermatids and finally spermatozoa, they are moved inwards, so the finished sperm are released into the lumen.

This orderly arrangement keeps the stages in sequence and delivers the mature sperm straight into the space that carries them out of the testis.

False Confidence Alert
Asked where spermatogenesis occurs, candidates often answer just the testis or the scrotum. The mark is for the seminiferous tubules within the testis; naming only the organ, or confusing the testis with the scrotum that holds it, does not give the precise site the question asks for.

Question 25

The developing sperm cannot finish their journey alone; they depend on a supporting cell. Explain the role of the Sertoli cells, and what happens during spermiogenesis.

Model Answer

The Sertoli cells are large cells in the wall of the seminiferous tubule that nourish and protect the developing sperm. The spermatocytes and spermatids are embedded in the Sertoli cells, which supply them with food, remove their waste, and form a barrier that shields them as they develop.

Spermiogenesis is the final reshaping of each spermatid into a streamlined spermatozoon, guided by the Sertoli cells. The spare cytoplasm is stripped away, the acrosome forms over the front of the nucleus, the mitochondria gather in the mid-piece, and the tail grows.

This remoulding gives the sperm its swimming shape, so that it can reach and penetrate the egg.

False Confidence Alert
The trap here is treating spermiogenesis as another cell division. It is not a division at all; it is the shaping of a spermatid, already made by meiosis, into a spermatozoon, so an answer that calls it meiosis III or a further split is wrong.

Question 26

Every part of a sperm cell is built for one job, reaching and fertilising the egg. Explain how the structure of a spermatozoon fits it for this task.

Model Answer

A spermatozoon is adapted, part by part, for reaching and entering the egg:

Acrosome: a cap over the front of the head holding digestive enzymes, which break down the layers around the egg so the sperm can penetrate it.

Nucleus: the haploid nucleus in the head carries the father's single set of chromosomes, to combine with the egg's set at fertilisation.

Mid-piece: packed with mitochondria, it releases the ATP that powers the beating of the tail on the long journey to the egg.

Tail (flagellum): a long flagellum that beats from side to side to drive the sperm forward, making it motile.

The whole cell is small and streamlined, carrying very little cytoplasm, so that it can swim quickly, and in large numbers, towards the egg.

False Confidence Alert
Asked how the sperm is adapted, candidates often just name the parts without giving each a job. The marks are for linking each structure to its function, for example the mitochondria of the mid-piece providing energy for swimming; a labelled list with no functions does not answer a how question.

Question 27

A labelled diagram shows the adaptations of the sperm at a glance. Draw a labelled diagram of a mammalian spermatozoon, marking the acrosome, the nucleus, the mid-piece and the tail.

Model Answer

A mammalian spermatozoon is shown in Figure 4.6, with its three regions: the head, the mid-piece and the tail. The head carries the acrosome as a cap over the haploid nucleus; the mid-piece behind it is packed with mitochondria; and the long tail, or flagellum, trails behind.

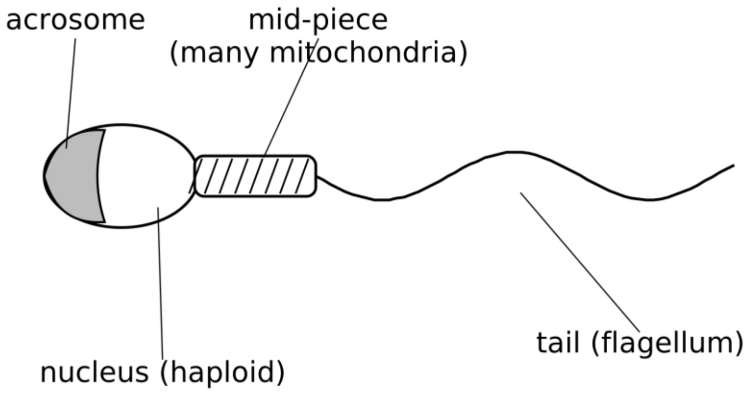


Figure 4.6: *The structure of a mammalian spermatozoon.*

> **False Confidence Alert**
> In a draw question the marks are on the labels. The commonest loss is leaving out the acrosome or the mid-piece, or labelling the whole front simply as the head; the examiner needs the acrosome, the nucleus, the mid-piece and the tail each named, since these are the adaptive features the diagram is meant to show.

Question 28

In the ovary the making of an egg follows the same meiotic plan as in the male, but shares out the cytoplasm very differently. Trace the stages of oogenesis from the oogonium to the ovum, naming the cells and the polar bodies formed.

Model Answer

Oogenesis runs through the following stages in the ovary:

1) **Oogonium (2n):** the diploid stem cell divides by mitosis in the multiplication phase to produce more oogonia.
2) **Primary oocyte (2n):** an oogonium grows during the growth phase, storing food, to become a primary oocyte.
3) **Secondary oocyte (n) and first polar body (n):** the primary oocyte divides by meiosis I, but unequally, giving one large secondary oocyte and a small first polar body.
4) **Ovum (n) and second polar body (n):** the secondary oocyte divides by meiosis II, again unequally, giving one large ovum and a small second polar body; the first polar body may also divide.

So one primary oocyte yields a single functional ovum, while the small polar bodies degenerate.

> **False Confidence Alert**
> Asked to trace oogenesis, candidates often copy the sperm pattern and write that four eggs are formed. Oogenesis gives only one ovum, the rest being polar bodies that degenerate; an answer that ends with four equal eggs has missed the unequal divisions the question is really testing.

Question 29

A diagram makes the unequal sharing of cytoplasm clear at a glance. Draw a labelled flow diagram of oogenesis, showing the cells at each stage, the polar bodies, and where the chromosome number is halved.

Model Answer

Oogenesis is shown in Figure 4.7, in which one oogonium gives rise to a single ovum. The oogonium (2n) multiplies by mitosis and grows into a primary oocyte (2n); meiosis I divides it unequally into a large secondary oocyte (n) and a small first polar body (n); and meiosis II divides the secondary oocyte unequally into a large ovum (n) and a second polar body (n).

The chromosome number is halved at meiosis I, where the diploid primary oocyte gives the haploid secondary oocyte; the polar bodies are small and degenerate.

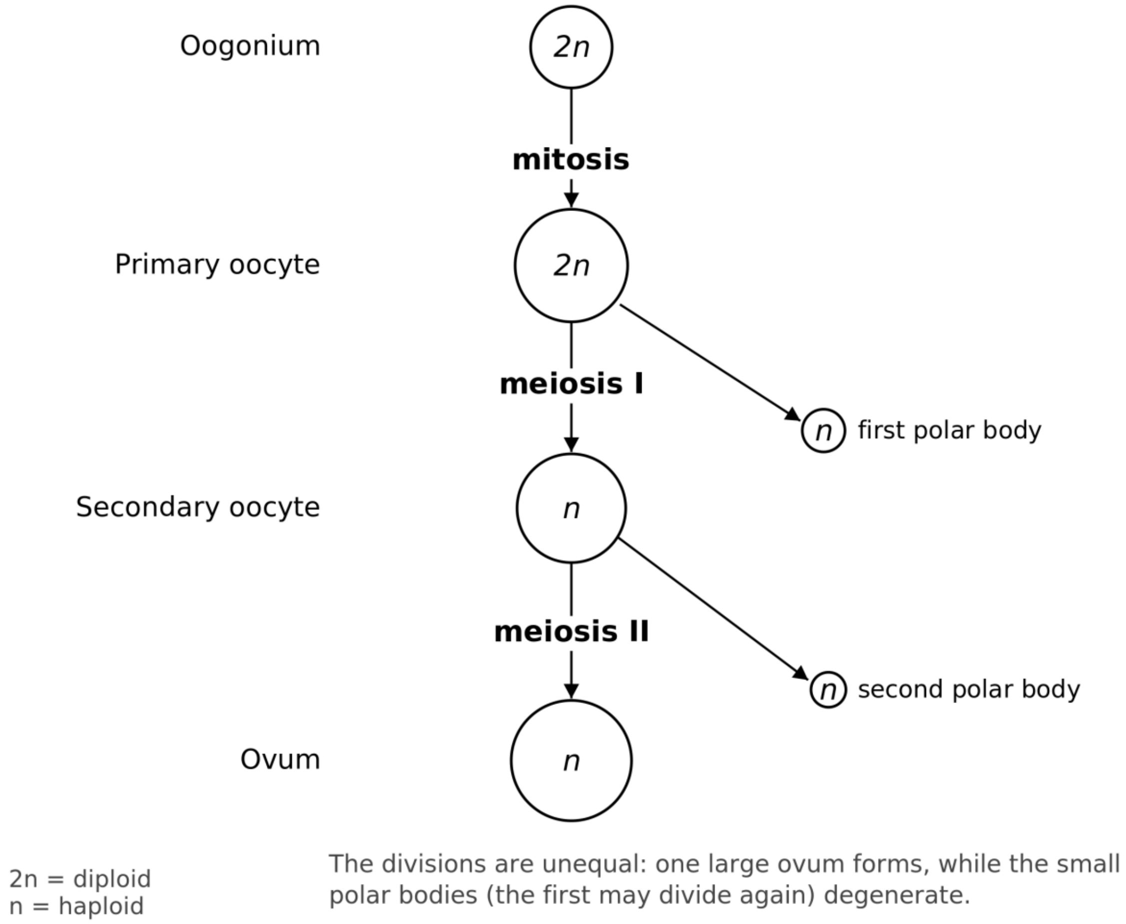


Figure 4.7: *Oogenesis, from one oogonium to a single ovum.*

False Confidence Alert
The mark-bearing labels are the named cells, the two polar bodies, the type of each division, and the change from 2n to n. The usual loss is drawing the divisions as equal, with four same-sized cells; the examiner must see the unequal split, one large cell and a small polar body at each division, since that is the point of an oogenesis diagram.

Question 30

Unlike sperm, which a man makes continuously, a woman's eggs begin forming before she is even born. Explain the timing of oogenesis and how it differs from that of spermatogenesis.

Model Answer

Oogenesis begins before birth: the oogonia multiply and enter meiosis I in the ovaries of the female fetus, then arrest as primary oocytes that wait, sometimes for decades. From puberty onwards, one primary oocyte completes meiosis I in each cycle, and meiosis II is finished only if and when the egg is fertilised.

Spermatogenesis, by contrast, begins at puberty and then runs continuously, the male making fresh sperm throughout his reproductive life, each one carried through both meiotic divisions without a long pause.

So the female's gametes are started early and finished slowly, one at a time, while the male's are made afresh, and in huge numbers, throughout life.

> **False Confidence Alert**
> Asked about the timing, candidates often say a woman makes brand-new eggs each month just as a man makes new sperm. She does not: her primary oocytes are all present before birth and merely complete their division later, so an answer that has the ovary making eggs from scratch each cycle is wrong.

Question 31

The unequal divisions of oogenesis are not a mistake but an advantage. Explain why the oocyte divides unequally to give one large ovum and small polar bodies.

Model Answer

The oocyte divides unequally so that almost all the cytoplasm, with its food store and organelles, is kept in one cell, the ovum. At each meiotic division the cytoplasm is shared out very unequally: one cell keeps nearly all of it while the other becomes a tiny polar body.

This matters because the ovum must supply the early embryo. After fertilisation the zygote divides many times before it can feed itself, so the egg needs a large store of nutrients; sharing the cytoplasm equally among four cells would leave none big enough to support development.

The polar bodies, having served only to carry off the spare sets of chromosomes, then degenerate, so the female makes one well-provisioned egg rather than four poorly provisioned ones.

> **False Confidence Alert**
> Asked why the division is unequal, candidates often say the polar bodies are simply waste or mistakes. They are not errors: they are the way the spare chromosome sets are discarded while the cytoplasm is kept in one egg, so an answer that calls them pointless misses the reason the ovum is large.

Question 32

Spermatogenesis and oogenesis are versions of the same process, yet their products are strikingly different. Compare the two.

Model Answer

Spermatogenesis and oogenesis differ in several ways:

1) **Number of gametes:** one parent cell gives four sperm in spermatogenesis, whereas it gives only one ovum in oogenesis.
2) **Division of cytoplasm:** the divisions are equal in spermatogenesis, whereas they are unequal in oogenesis, giving polar bodies.
3) **Size and motility:** the sperm is small and motile, whereas the ovum is large and non-motile.
4) **Timing:** spermatogenesis is continuous from puberty, whereas oogenesis begins before birth and is completed one egg at a time.
5) **Completion:** every spermatid matures into a sperm, whereas meiosis II of the egg is completed only if fertilisation occurs.

Both, however, use meiosis to make haploid gametes, so that fertilisation can restore the diploid number.

> **False Confidence Alert**
> In a compare question the marks are for paired points. Writing all about sperm and then all about eggs scores poorly; each difference must set the two side by side, for example spermatogenesis gives four equal sperm whereas oogenesis gives one large ovum and polar bodies.

Question 33

In the anther, special diploid cells give rise to the pollen. Trace the process of microsporogenesis, naming the cells formed and the divisions involved, from the pollen mother cell to the pollen grain.

Model Answer

Microsporogenesis takes place in the anther and runs as follows:

Pollen mother cell (2n): a diploid cell in the anther, also called a microspore mother cell, prepares to divide.

Four microspores (n): the pollen mother cell divides by meiosis to give a tetrad of four haploid microspores.

Pollen grain (n): each microspore then divides by mitosis and develops a tough wall, becoming a pollen grain that contains a tube nucleus and a generative cell.

So one pollen mother cell yields four pollen grains, and the chromosome number is halved at the meiosis that forms the microspores.

False Confidence Alert
Asked to trace microsporogenesis, candidates often stop at the four microspores and call them the pollen. A microspore is not yet a pollen grain; it must first divide by mitosis and form its wall, so an answer that ends at the tetrad has missed the step that actually makes the pollen.

Question 34

A flow diagram makes the halving and the count of pollen grains easy to see. Draw a labelled diagram of microsporogenesis, showing the pollen mother cell, the microspores, the divisions, and the structure of a pollen grain.

Model Answer

Microsporogenesis is shown in Figure 4.8, in which one pollen mother cell gives rise to four pollen grains. The pollen mother cell (2n) divides by meiosis into a tetrad of four haploid microspores (n); each microspore then divides by mitosis and develops a wall to become a pollen grain (n), containing a tube nucleus and a generative cell.

The chromosome number is halved at meiosis, where the diploid mother cell gives the haploid microspores.

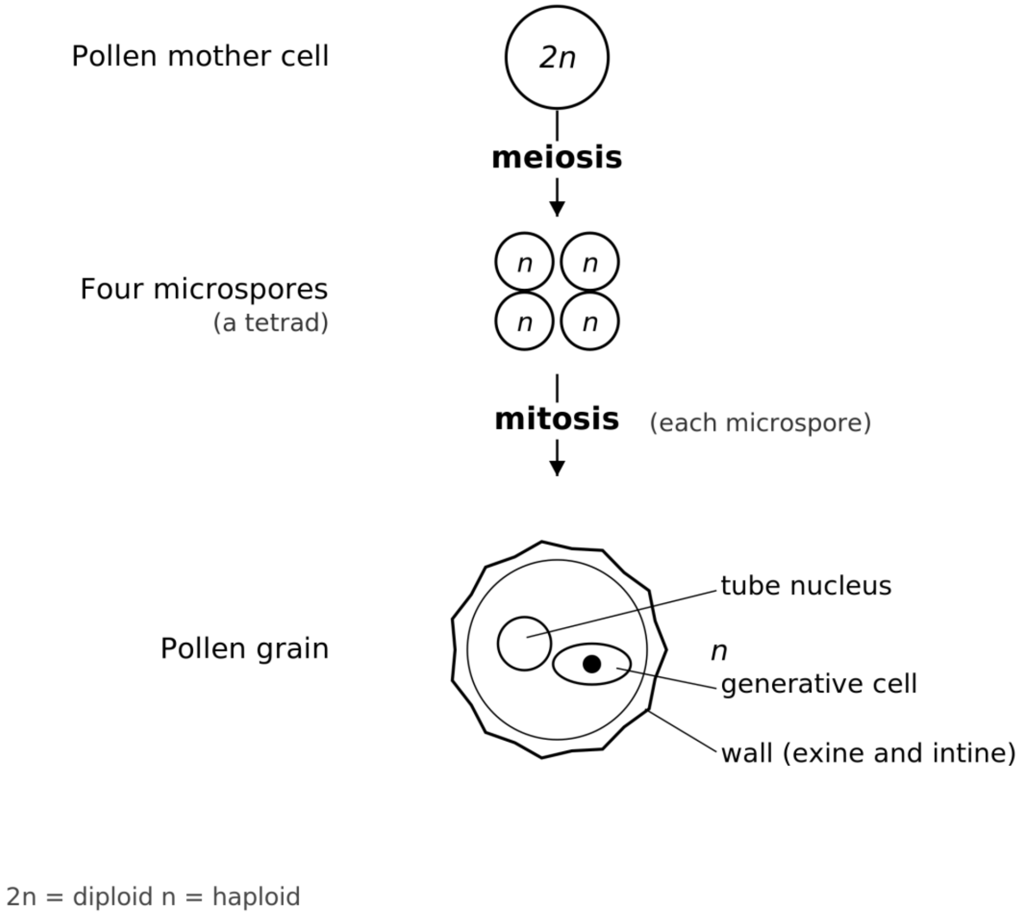


Figure 4.8: *Microsporogenesis, from one pollen mother cell to four pollen grains.*

False Confidence Alert
The mark-bearing labels are the pollen mother cell, the tetrad of microspores, the two divisions (meiosis then mitosis), and inside the grain the tube nucleus and generative cell. The usual loss is labelling both divisions meiosis; only the first is meiotic, and the mitosis that follows is what builds the pollen grain.

Question 35

A pollen grain is more than a single cell waiting to be carried to a stigma. Describe the structure of a mature pollen grain, and explain why it contains two nuclei.

Model Answer

A mature pollen grain is a small haploid structure with a tough double wall enclosing two cells, a tube cell and a generative cell. The outer wall, the exine, is hard and often patterned and protects the grain during dispersal, while the inner wall is the intine.

It contains two nuclei because each has a different job at fertilisation. The tube cell, with its tube nucleus, will grow the pollen tube down to the ovule; the generative cell will divide to form the two male gametes that double fertilisation needs.

So the grain carries both the means of delivery and the gametes themselves, ready for when it lands on a compatible stigma.

False Confidence Alert
Asked why the pollen grain has two nuclei, candidates often say one is a spare. Neither is spare: the tube nucleus controls the growth of the pollen tube, while the generative cell forms the two male gametes, so an answer that does not give each nucleus its own role misses the point.

Question 36

In the ovule, a single diploid cell gives rise to the female gamete and its companions. Trace the process of megasporogenesis, from the megaspore mother cell to the mature embryo sac.

Model Answer

Megasporogenesis takes place inside the ovule and runs as follows:

1) **Megaspore mother cell (2n):** a diploid cell within the ovule, also called the megasporocyte, prepares to divide.
2) **Four megaspores (n):** it divides by meiosis to give four haploid megaspores, but three of them degenerate and only one survives.
3) **Embryo sac (n):** the surviving megaspore divides three times by mitosis, giving the embryo sac with its eight nuclei.
4) **The eight nuclei:** these organise into the egg cell and two synergids at the micropylar end, three antipodal cells at the chalazal end, and two polar nuclei in the central cell.

So one megaspore mother cell gives a single embryo sac, and the chromosome number is halved at the meiosis that forms the megaspores.

False Confidence Alert
Asked to trace megasporogenesis, candidates often say all four megaspores form embryo sacs, copying the four pollen grains of the male. Only one megaspore survives, the other three degenerate, so an answer that keeps all four has missed the key difference from microsporogenesis.

Question 37

The mature embryo sac has a precise arrangement of cells. Draw a labelled diagram of the mature embryo sac, marking its eight nuclei and the micropyle.

Model Answer

The mature embryo sac is shown in Figure 4.9, with its eight nuclei arranged in seven cells. At the micropylar end lies the egg apparatus, the egg cell flanked by two synergids; at the chalazal end are three antipodal cells; and in the centre, in the large central cell, are two polar nuclei.

The eight nuclei are therefore the egg, two synergids, three antipodals and two polar nuclei. The micropyle, the small opening at the micropylar end, is where the pollen tube will later enter.

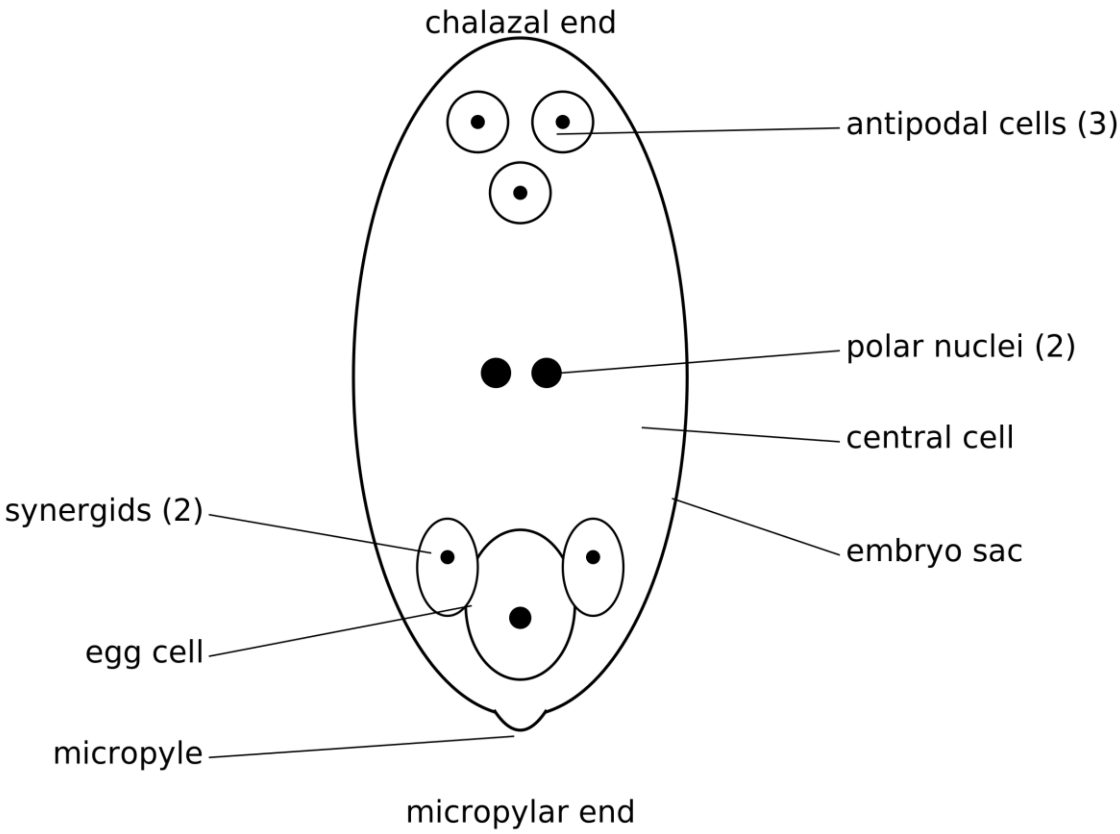


Figure 4.9: *The mature embryo sac (the female gametophyte).*

False Confidence Alert
The mark-bearing labels are the egg cell, the two synergids, the three antipodal cells, the two polar nuclei and the micropyle. The usual loss is drawing only the egg and forgetting the polar nuclei; without the two polar nuclei the diagram cannot show how double fertilisation will form the endosperm.

Question 38

The embryo sac does not sit on its own but is enclosed and protected within the ovule. Describe the structure of the ovule, naming its main parts and what each becomes after fertilisation.

Model Answer

The ovule lies inside the ovary and is made up of the following parts:

1) **Nucellus:** the central tissue that nourishes and surrounds the developing embryo sac.
2) **Integuments:** one or two protective coats around the nucellus, which become the seed coat, or testa, after fertilisation.
3) **Micropyle:** a small gap in the integuments through which the pollen tube enters to reach the egg.
4) **Embryo sac:** the female gametophyte, embedded in the nucellus, holding the egg and the other seven nuclei.
5) **Funicle:** the stalk that attaches the ovule to the wall of the ovary and carries food to it.

After fertilisation the whole ovule becomes the seed, the integuments forming the testa and the fertilised egg the embryo.

False Confidence Alert
Asked to describe the ovule, candidates often confuse it with the ovary. The ovule is the small body inside the ovary that becomes the seed, while the ovary is the larger structure that becomes the fruit; mixing the two loses the marks, because the question is about the ovule and its parts.

Question 39

The two kinds of gamete-forming tissue sit in different parts of the same flower. Explain where in the flower microsporogenesis and megasporogenesis take place, and name the floral structures involved.

Model Answer

Microsporogenesis takes place in the anthers of the stamens, the male parts that together form the androecium. Inside each anther are pollen sacs, where the pollen mother cells divide to make the pollen.

Megasporogenesis takes place in the ovules, inside the ovary of the carpel, the female part that forms the gynoecium. Within each ovule the megaspore mother cell divides to make the embryo sac.

So the two processes are kept apart in the same flower: the male gametes form in the androecium and the female gamete in the gynoecium, an arrangement that helps a flower control whether it self- or cross-pollinates.

False Confidence Alert
Asked where each process occurs, candidates often place megasporogenesis in the ovary rather than the ovule. The ovary holds the ovules, but the embryo sac forms inside the ovule itself; naming only the ovary, or putting pollen formation in the filament instead of the anther, loses the precise site the question wants.

Question 40

A moss or a fern releases swimming sperm, but a flowering plant does not. Explain why the male gametes of a flowering plant are non-motile, and how they still reach the egg.

Model Answer

The male gametes of a flowering plant are non-motile because they are delivered inside the pollen tube rather than having to swim. They have no flagella; instead the pollen grain, once on the stigma, grows a pollen tube that carries the two male gametes down to the ovule.

This frees fertilisation from a film of external water. A moss or fern needs surface water for its flagellated sperm to swim to the egg, but the flowering plant carries its gametes there directly, so it can reproduce even in dry conditions.

This is a major advantage on land, and is one reason the flowering plants are so successful away from water.

False Confidence Alert
Asked why the gametes are non-motile, candidates often answer simply that they have no tails. That is the observation, not the reason; the mark is for explaining that the pollen tube delivers them, which removes the need to swim and so frees the plant from depending on external water.

Question 41

For all their differences, the male and female sides of the flower share one key event. Explain how meiosis underlies both microsporogenesis and megasporogenesis, and what is meant by heterospory.

Model Answer

Meiosis underlies both processes because it is the division that makes the spores haploid in each. In the anther, meiosis of the pollen mother cell makes the haploid microspores; in the ovule, meiosis of the megaspore mother cell makes the haploid megaspores. Both depend on the same reduction division.

Heterospory means producing two different kinds of spore. The plant makes small microspores, which become the pollen, and larger megaspores, which become the embryo sac, rather than one kind of spore serving both sexes.

So a single mechanism, meiosis, serves both sides of the flower, but it acts on two kinds of spore-mother-cell to build the male and the female gametophytes.

False Confidence Alert
Asked about heterospory, candidates often describe it as making two kinds of gamete. It is two kinds of spore, the microspore and the megaspore, not the gametes themselves; the gametes form later as each spore develops, so an answer that confuses spores with gametes misses what heterospory names.

Question 42

Having two sizes of spore was an important advance in the history of land plants. Explain why heterospory can be seen as a step on the road to the seed.

Model Answer

Heterospory is a step towards the seed because the large megaspore is kept and nourished within the parent plant rather than being released. The megaspore stays inside the ovule, where it develops into the embryo sac and is protected and fed by the surrounding tissue.

This retention sets up everything the seed needs. Because the female spore is held on the parent, fertilisation can take place there, the embryo can develop in position, and the whole ovule can then be packaged, with a food store and a protective coat, as a seed.

So heterospory begins the shift from scattering spores to producing protected, well-provisioned seeds, which is one of the reasons the seed plants came to dominate the land.

False Confidence Alert
Asked how heterospory leads to the seed, candidates often say only that it makes male and female spores. The key point is that the large megaspore is retained and nourished on the parent plant; an answer that does not mention keeping the megaspore in the ovule misses why heterospory, and not mere spore production, points towards the seed.

Question 43

Plants and animals both use meiosis to make their gametes, yet a plant inserts an extra stage that an animal does not. Compare gametogenesis in a flowering plant with that in an animal.

Model Answer

Gametogenesis in a flowering plant and in an animal differ in several ways:

1) **Direct or indirect:** in an animal, meiosis makes the gametes directly, whereas in a plant, meiosis makes spores that first develop into gametophytes, which then make the gametes.
2) **Motility of the male gamete:** the animal sperm is motile and swims, whereas the plant's male gametes are non-motile and are carried in the pollen tube.
3) **Where it happens:** animal gametogenesis occurs in the gonads, the testes and ovaries, whereas plant gametogenesis occurs in the anther and the ovule of the flower.
4) **The female products:** in animals one ovum forms together with polar bodies, whereas in plants the megaspore forms an embryo sac of several cells, only one of which is the egg.

Both, however, use meiosis to halve the chromosome number, so that fertilisation can restore the diploid number, the point shared by all sexual reproduction.

> **False Confidence Alert**
> In a compare question the marks are for paired points. The deeper difference candidates miss is the gametophyte stage: an animal's meiosis gives gametes straight away, while a plant's meiosis gives spores that must grow into gametophytes first; an answer that lists only surface sperm-versus-pollen points, without this, misses the key contrast.

Question 44

Before a flowering plant can be fertilised, its pollen must first be moved to the right place. Explain what pollination is, and distinguish between self-pollination and cross-pollination.

Model Answer

Pollination is the transfer of pollen from the anther of a stamen to the stigma of a carpel. It is the first step that brings the male and female sides together, and it must happen before a pollen tube can grow and fertilisation occur.

In self-pollination the pollen lands on the stigma of the same flower, or of another flower on the same plant. The offspring are then less varied, because both gametes come from one parent.

In cross-pollination the pollen is carried to the stigma of a flower on a different plant of the same species. This brings together the genes of two parents, giving more varied offspring.

> **False Confidence Alert**
> Asked to define pollination, candidates often describe it as the joining of the male and female gametes. That is fertilisation, a later event; pollination is only the transfer of pollen to the stigma, so confusing the two loses the mark.

Question 45

Pollination and fertilisation are often muddled, yet they are two separate events. Explain how they differ, and why one can happen without the other.

Model Answer

Pollination is the transfer of pollen from anther to stigma, while fertilisation is the fusion of a male gamete with the egg inside the ovule. Pollination simply delivers the pollen to the right surface; fertilisation is the union of the gametes that follows.

One can happen without the other because a gap of time and distance separates them. Pollen may land on a stigma, which is pollination, and yet fail to fertilise if it is incompatible or its tube does not reach the egg, so a flower can be pollinated without being fertilised.

Fertilisation only follows a successful pollination, once the pollen tube has grown down and delivered the male gametes to the embryo sac.

> **False Confidence Alert**
> The trap is treating pollination and fertilisation as the same step. Pollination is the transfer of pollen and fertilisation is the fusion of gametes; an answer that uses the two words interchangeably cannot earn the marks for telling them apart.

Question 46

Flowers are shaped and coloured to suit the way their pollen is carried. Explain how a flower is adapted for either wind pollination or insect pollination.

Model Answer

A flower's features match its pollinating agent:

Insect-pollinated flowers: are large, brightly coloured and scented, with nectar to attract insects, and have sticky or spiky pollen and a sticky stigma so the pollen clings to the visiting insect.

Wind-pollinated flowers: are small, dull and unscented, with no nectar, but carry large anthers hanging outside to release clouds of light, smooth pollen, and large feathery stigmas to catch pollen from the air.

So each flower's structure fits its agent: colour, scent and nectar to draw insects, or exposed anthers and feathery stigmas to use the wind.

> **False Confidence Alert**
> Asked for adaptations, candidates often list the parts of a flower without linking them to the agent. The marks are for the match, for example feathery stigmas for catching wind-borne pollen; a plain description with no link to wind or insects does not answer a how question.

Question 47

Landing on a stigma is not the end of the pollen grain's journey but the start of a new stage. Explain what happens when a compatible pollen grain germinates on a stigma.

Model Answer

When a compatible pollen grain lands on a ripe stigma, it absorbs water and nutrients and germinates, putting out a pollen tube. The tube emerges through a pore in the pollen wall and grows down into the style.

The tube nucleus controls the growth of the pollen tube, leading it down through the style towards the ovary, while the generative cell follows and divides into the two male gametes.

So germination turns the resting grain into a growing tube that will carry the male gametes down to the embryo sac.

> **False Confidence Alert**
> Asked what happens at germination, candidates often jump straight to fertilisation. Germination is only the growth of the pollen tube from the grain; the gametes have not yet reached the egg, so an answer that skips the tube and its nuclei misses the stage in question.

Question 48

Once the pollen tube starts to grow, it must travel a long way to deliver its gametes. Describe how the pollen tube grows from the stigma to the embryo sac, and what it carries.

Model Answer

The pollen tube grows from the germinating pollen grain down through the style towards the ovary, guided by the tube nucleus at its tip. It secretes enzymes that digest a path through the tissues of the style, and grows towards chemicals released by the ovule.

It carries the two male gametes down to the ovule. Behind the tube nucleus travel the two male gametes, formed when the generative cell divides; the tube grows until it reaches an ovule and enters it through the micropyle.

At the embryo sac the tip of the tube bursts, releasing the two male gametes so that double fertilisation can take place.

False Confidence Alert
Asked what the tube carries, candidates often say it carries the pollen grain or just one sperm. The tube carries two male gametes to the embryo sac; an answer that gives only one cannot explain double fertilisation, which needs both.

Question 49

A diagram of the carpel shows the whole route the male gametes travel. Draw a labelled diagram of a carpel to show the pollen tube growing from the stigma to the ovule, and the embryo sac it reaches.

Model Answer

The pollen tube's route is shown in Figure 4.10, from the pollen grain on the stigma to the embryo sac within the ovule. The tube grows down the style, through the ovary, and enters the ovule by the micropyle; at its tip it carries the two male gametes to the egg cell and the two polar nuclei of the embryo sac.

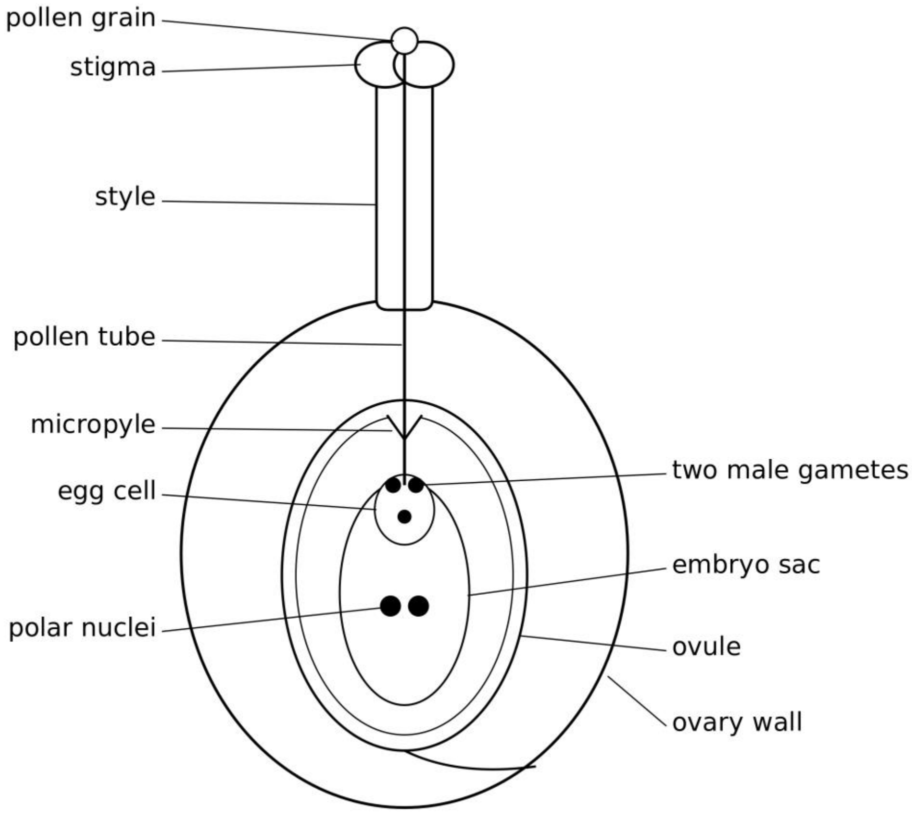


Figure 4.10: *The pollen tube growing from the stigma to the ovule, delivering the two male gametes.*

False Confidence Alert
The mark-bearing labels are the stigma, style, ovary, ovule, micropyle, embryo sac and the two male gametes at the tube tip. The usual loss is stopping the tube at the ovary wall; the examiner must see it enter the ovule through the micropyle and reach the embryo sac.

Question 50

Flowering plants carry out not one but two fusions when they are fertilised. Explain what double fertilisation is, naming the products of each fusion.

Model Answer

Double fertilisation is the fusion of the two male gametes with two different cells of the embryo sac, in two separate fusions. Both male gametes, delivered by the pollen tube, take part.

The first fusion is with the egg cell and forms the zygote. One male gamete (n) fuses with the egg (n) to give a diploid (2n) zygote, which develops into the embryo.

The second fusion is with the two polar nuclei and forms the endosperm. The other male gamete (n) fuses with the two polar nuclei to give a triploid (3n) cell, which develops into the endosperm, the food store of the seed.

> **False Confidence Alert**
> Asked what double fertilisation is, candidates often describe only the egg being fertilised. The mark needs both fusions, forming the zygote and the endosperm; an answer that leaves out the fusion forming the endosperm has described single, not double, fertilisation.

Question 51

The word double in double fertilisation is precise, and the process is found in only one group of plants. Explain why it is called double, and why it is unique to flowering plants.

Model Answer

It is called double because two fusions take place, not one: one male gamete fuses with the egg to form the zygote, and the other fuses with the two polar nuclei to form the endosperm, so two fertilisation events happen in the same embryo sac.

It is unique to flowering plants (angiosperms) because only they have an embryo sac with polar nuclei and deliver two male gametes for each fertilisation. Other seed plants, such as conifers, fertilise only the egg and lay down their food store before fertilisation, so they have just one fusion.

So double fertilisation ties the making of the food store to the act of fertilisation, which is one of the features that sets the flowering plants apart.

> **False Confidence Alert**
> Asked why it is called double, candidates often say it is because two pollen grains or two ovules are involved. It is double because one pollen tube delivers two male gametes that make two fusions, the zygote and the endosperm; an answer about two grains or two ovules misses the point.

Question 52

Once double fertilisation is over, every part of the ovule and ovary has a destiny. Explain what each of the following becomes after fertilisation: the zygote, the primary endosperm nucleus, the integuments, the ovule and the ovary.

Model Answer

After fertilisation each part develops into a particular structure:

The zygote: the diploid zygote divides by mitosis to become the embryo, with its plumule, radicle and cotyledon or cotyledons.

The primary endosperm nucleus: this triploid nucleus divides to form the endosperm, the food store of the seed.

The integuments: the protective coats of the ovule harden into the testa, the seed coat.

The ovule: the whole ovule becomes the seed.

The ovary: the ovary wall develops into the fruit, which encloses and protects the seed.

So the products of double fertilisation, the embryo and the endosperm, are packaged inside the seed, and the seed inside the fruit.

> **False Confidence Alert**
> Asked for the fates, candidates often swap the ovule and the ovary. The ovule becomes the seed and the ovary becomes the fruit; getting these the wrong way round loses two easy marks.

Question 53

After fertilisation the ovule grows into a seed and the ovary into a fruit. Explain how the seed and the fruit develop, and the part the endosperm plays.

Model Answer

After fertilisation the fertilised ovule develops into the seed, while the ovary grows into the fruit around it. Inside the seed, the zygote becomes the embryo and the integuments become the testa; the seed then dries out and becomes dormant, ready for dispersal.

The endosperm is the food store that feeds the growing embryo. It forms from the triploid cell of double fertilisation and stores starch, protein and oil; in some seeds it is used up by the cotyledons before the seed is shed, and in others it stays until germination.

So fruit and seed development turns the fertilised flower into a dispersal package, an embryo with a food store, wrapped in a testa, inside a protective fruit.

> **False Confidence Alert**
> Asked about development, candidates often say the fruit grows from the seed. The fruit develops from the ovary wall, not from the seed; the seed develops from the ovule inside the fruit, so an answer that confuses their origins cannot score.

Question 54

Seeds store their food in different places, and a diagram shows this clearly. Draw and label a maize grain and a bean seed in section, and use them to show the difference between an endospermic and a non-endospermic seed.

Model Answer

The two seeds are shown in Figure 4.11. In the maize grain, which is endospermic, the food is stored in a large endosperm, with a small embryo and its single cotyledon, the scutellum, lying against it. In the bean seed, which is non-endospermic, there is no endosperm at maturity; the food has been moved into two large cotyledons that fill most of the seed.

Both seeds are enclosed by a testa and contain an embryo with a plumule and a radicle. The key difference is where the food is stored: in the endosperm in maize, but in the cotyledons in the bean.

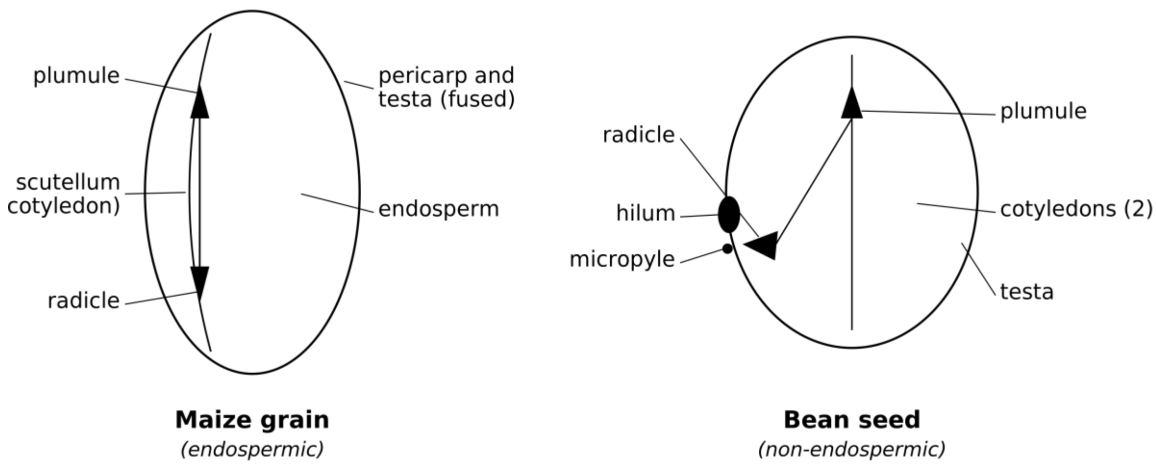


Figure 4.11: *An endospermic seed (maize grain) and a non-endospermic seed (bean) in section.*

False Confidence Alert
The mark-bearing labels are the testa, the food store (the endosperm in maize, the cotyledons in the bean), the plumule and the radicle. The usual loss is drawing an endosperm in the bean; at maturity the bean has none, because its food is already in the cotyledons.

Question 55

The wall of the ovary does not simply disappear after fertilisation but becomes an important structure. Explain what the pericarp is, and how the fruit helps the plant.

Model Answer

The pericarp is the wall of the fruit, formed from the wall of the ovary after fertilisation. It surrounds the seed or seeds and may be dry or fleshy, depending on the kind of fruit.

The fruit helps the plant chiefly by protecting and dispersing the seeds. The pericarp shields the developing seeds, and when ripe it aids dispersal: a fleshy fruit attracts animals that eat it and carry the seeds away, while a dry fruit may split open or bear wings, hooks or hairs.

So the fruit turns the ripened ovary into a means of spreading the seeds, carrying the next generation away from the parent plant.

False Confidence Alert
Asked what the pericarp is, candidates often call it the seed coat. The seed coat is the testa, formed from the integuments; the pericarp is the fruit wall, formed from the ovary wall, so confusing the two loses the mark.

Question 56

Maize and bean both store food for the new plant, but in different places. Compare an endospermic seed with a non-endospermic seed, and say what the difference means for the young seedling.

Model Answer

In an endospermic seed, such as maize, the food is stored in the endosperm, and the cotyledon, the scutellum, stays thin and absorbs that food at germination. In a non-endospermic seed, such as a bean, the endosperm is used up as the seed matures and the food is stored instead in two thick cotyledons.

The difference shows at germination, in where the seedling draws its food. The maize seedling digests and absorbs the endosperm through its scutellum, while the bean seedling draws on the food already packed in its cotyledons.

Either way the embryo is well supplied until it can photosynthesise, the food simply being held in the endosperm in the one and in the cotyledons in the other.

False Confidence Alert
Asked to compare the two, candidates often say a non-endospermic seed never had an endosperm. It did; the endosperm formed at double fertilisation but was absorbed into the cotyledons as the seed matured, so it is absent at maturity, not never formed.

Question 57

Reproducing by seed has made the flowering plants enormously successful, though it is not without cost. Outline the merits and the demerits of reproduction by seed in angiosperms.

Model Answer

Reproduction by seed brings several merits:

1) **Protection:** the embryo is enclosed in a tough testa, and often a fruit, which shield it from drought, damage and being eaten.

2) **Stored food:** the seed carries its own food store, so the seedling can establish itself before it is able to photosynthesise.
3) **Dispersal:** fruits and seeds are adapted to spread far from the parent, reducing competition and reaching new ground.
4) **Variation:** because seeds form by sexual reproduction, the offspring are varied and better able to meet a changing environment.
5) **Dormancy:** a seed can stay dormant and survive an unfavourable season, germinating only when conditions are right.

It also brings a few demerits:

1) **Slow and less certain:** reproduction by seed is slower and less reliable than vegetative methods, since each seed must be pollinated, fertilised, dispersed and then germinate before a new plant is established.
2) **Heavy losses:** many seeds are eaten or fall in unsuitable places and never germinate, so a great many must be produced for only a few to succeed.
3) **Less predictable offspring:** because the offspring are varied, a few may be less well suited to the parent's successful surroundings than the parent itself.

False Confidence Alert
Asked to outline merits and demerits, candidates often list only the advantages and stop. The question asks for both, so naming at least one genuine demerit, such as the heavy loss of seeds or the slowness of the method, is needed to reach full marks.

Question 58

A conifer builds its seed's food store before fertilisation, but a flowering plant waits until after. Explain why making the endosperm only after fertilisation is an economical strategy.

Model Answer

Making the endosperm only after fertilisation is economical because the plant invests food in an ovule only once it is certain to become a seed. The endosperm forms from the second fusion of double fertilisation, so it is built only where a male gamete has actually fertilised the egg.

A conifer, by contrast, lays down a food store in every ovule before fertilisation, so any ovule that is not fertilised has wasted the food already stored in it.

By tying the food store to fertilisation, the flowering plant avoids that waste, spending its resources only on the ovules that will actually grow into seeds.

False Confidence Alert
Asked why it is economical, candidates often answer that the endosperm is just a food store, without the timing. The economy is in the timing: the endosperm is made only after fertilisation, so food is not wasted on ovules that are never fertilised.

Question 59

Plants do not pass straight from one adult to the next, but alternate between two different forms. Explain what is meant by the alternation of generations, and where meiosis and fertilisation fit into it.

Model Answer

The alternation of generations is the regular alternation, in a plant's life cycle, between a diploid sporophyte generation and a haploid gametophyte generation. The sporophyte (2n) is the spore-producing plant; the gametophyte (n) is the gamete-producing plant; each gives rise to the other in turn.

Meiosis and fertilisation are the two switches between the generations. Meiosis in the sporophyte halves the number to make haploid spores, which grow into the gametophyte; fertilisation then fuses the gametophyte's gametes into a diploid zygote, which grows into the sporophyte.

So the cycle turns through two phases, the diploid sporophyte and the haploid gametophyte, linked by meiosis one way and fertilisation the other.

False Confidence Alert
Asked about the alternation of generations, candidates often say it is the alternation of male and female plants. It is the alternation of the diploid sporophyte and the haploid gametophyte, not of the sexes, so an answer about male and female plants misses what the term means.

Question 60

A single diagram can capture the whole alternation of generations. Draw a labelled diagram of the generalised plant life cycle, marking the sporophyte and gametophyte, the spores and gametes, and where meiosis and fertilisation occur.

Model Answer

The generalised life cycle is shown in Figure 4.12, turning between the diploid and the haploid generations. The sporophyte (2n) undergoes meiosis to form haploid spores (n); the spores grow into the gametophyte (n); the gametophyte forms gametes (n) by mitosis; the gametes fuse at fertilisation to form the zygote (2n); and the zygote grows into the sporophyte once more.

Meiosis and fertilisation mark the two switch points. Meiosis turns the cells of the diploid sporophyte into haploid spores, and fertilisation turns the haploid gametes back into a diploid zygote.

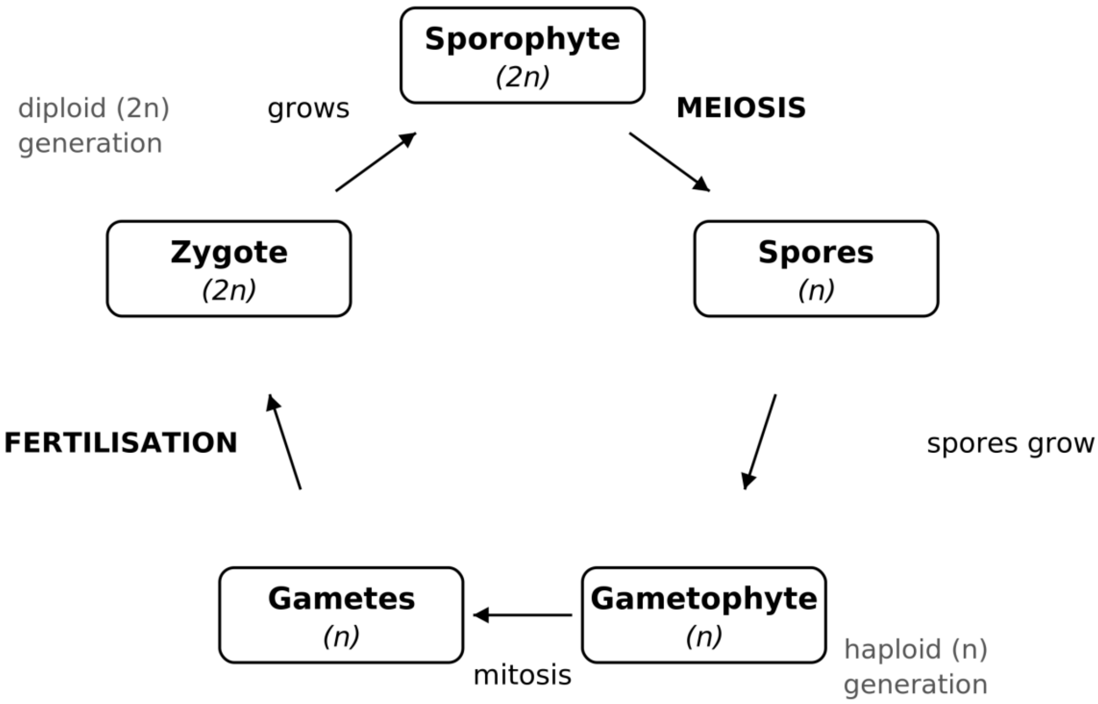


Figure 4.12: *The generalised plant life cycle, showing the alternation of generations.*

False Confidence Alert
The mark-bearing labels are the sporophyte and the gametophyte, the spores and gametes with their ploidy, and the points of meiosis and fertilisation. The usual loss is placing meiosis at the wrong step; meiosis makes the spores from the sporophyte, not the gametes, which are made by mitosis.

Question 61

In a moss, the green plant we see is only one of its two generations. Trace the life cycle of a moss, naming its generations and saying which one dominates.

Model Answer

In a moss the dominant generation is the gametophyte, the green leafy plant we see. It bears the sex organs: antheridia, which make the male gametes, and archegonia, which make the egg.

Fertilisation needs water, and produces a sporophyte that grows on the gametophyte. The male gametes swim through a film of water to the egg in the archegonium; the zygote (2n) then grows into a sporophyte, a stalk with a capsule, which stays attached to and is fed by the gametophyte.

The capsule makes spores by meiosis, and these grow into new gametophytes. Inside the capsule, meiosis forms haploid spores; these are scattered, germinate, and grow into new moss gametophytes, completing the cycle.

False Confidence Alert
Asked which generation dominates in a moss, candidates often pick the sporophyte, as in a fern. In bryophytes the gametophyte dominates, the leafy green plant, while the sporophyte is only the small dependent stalk and capsule; getting this the wrong way round loses the mark.

Question 62

A cycle diagram brings the moss's two generations together. Draw a labelled diagram of the life cycle of a moss, marking both generations, the gametes and spores, and where meiosis and fertilisation occur.

Model Answer

The moss life cycle is shown in Figure 4.13, turning between the dominant gametophyte and the small dependent sporophyte. The leafy gametophyte (n) forms gametes by mitosis; the sperm and egg fuse at fertilisation, which needs water, to give the zygote (2n); the zygote grows into a sporophyte (2n) on the gametophyte; the sporophyte's capsule makes spores (n) by meiosis; and the spores germinate into new gametophytes.

Meiosis and fertilisation are the two switches. Meiosis in the capsule makes the haploid spores and fertilisation makes the diploid zygote; in a moss the gametophyte is the dominant generation.

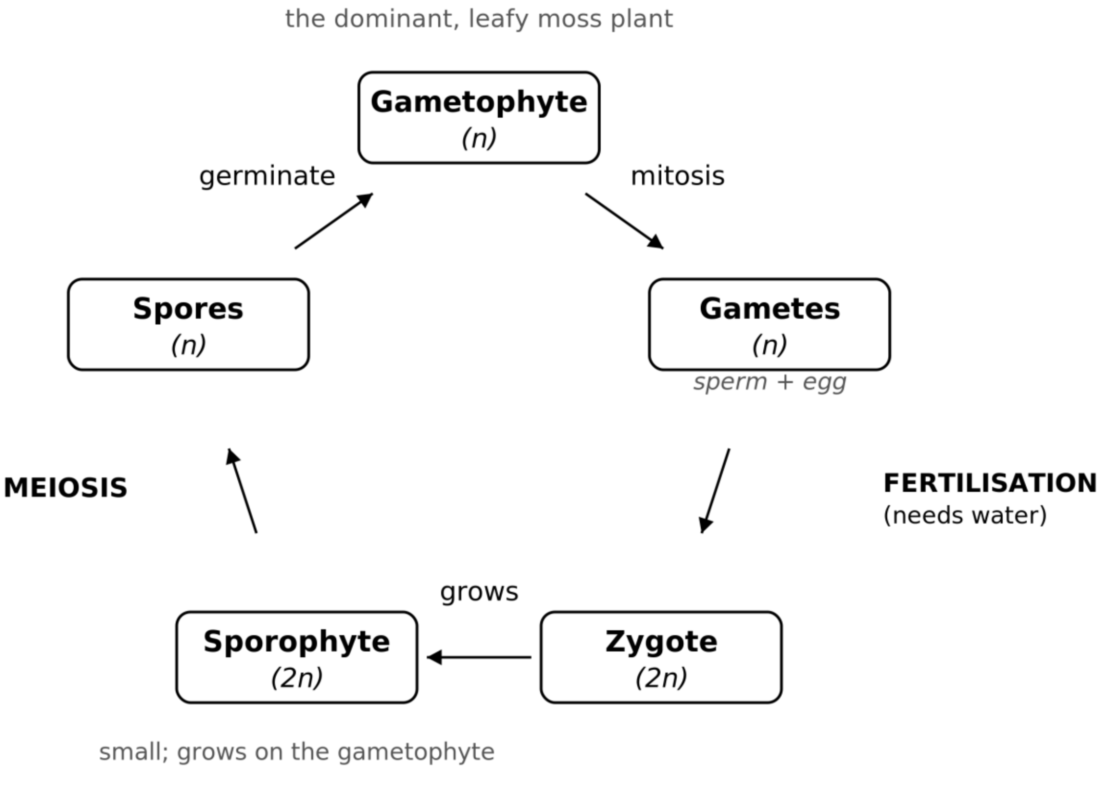


Figure 4.13: *The life cycle of a moss (a bryophyte).*

False Confidence Alert
The mark-bearing labels are the gametophyte and sporophyte with their ploidy, the gametes and spores, and the points of meiosis and fertilisation. The usual loss is showing the sporophyte as a separate free plant; in a moss it grows on, and is fed by, the gametophyte.

Question 63

You will only find mosses growing in damp, shaded places, never out in the dry sun. Explain why bryophytes are confined to moist habitats.

Model Answer

Bryophytes are tied to water mainly because their male gametes must swim to the egg, and they can only do so through a film of water. The sperm are flagellated and need a continuous layer of surface water to swim from the antheridium to the egg in the archegonium; without it, fertilisation cannot happen.

They also lack the features that let other plants resist drying. Mosses have no true roots to draw up water, no waterproof cuticle to slow water loss, and no vascular tissue to carry water far, so their thin bodies dry out quickly in the open.

For both reasons they are confined to damp, shaded places, where there is enough surface water for fertilisation and little risk of drying out.

False Confidence Alert
Asked why mosses need water, candidates often mention only photosynthesis or general thirst. The key reason is reproduction: the sperm must swim through water to reach the egg, so an answer that does not mention the swimming gametes misses the main point.

Question 64

In a fern, the large leafy plant is the opposite generation to the one that dominates in a moss. Trace the life cycle of a fern, naming its generations and saying which one dominates.

Model Answer

In a fern the dominant generation is the sporophyte, the large leafy plant with fronds that we recognise as the fern. On the underside of its fronds are sori, clusters of sporangia in which meiosis forms haploid spores.

The spores grow into a small, separate gametophyte called the prothallus. Each spore germinates into a tiny, heart-shaped prothallus (n) that lives on its own on the damp soil and bears the antheridia and archegonia.

Fertilisation still needs water, and produces a new sporophyte. The male gametes swim through a film of water to the egg; the zygote (2n) then grows into a new fern sporophyte, while the prothallus withers away.

False Confidence Alert
Asked which generation dominates in a fern, candidates often say the gametophyte, confusing it with a moss. In a fern the sporophyte, the leafy plant, dominates, while the gametophyte is only the tiny prothallus; getting this the wrong way round loses the mark.

Question 65

A diagram shows how the fern's dominant generation differs from the moss's. Draw a labelled diagram of the life cycle of a fern, marking both generations, and where meiosis and fertilisation occur.

Model Answer

The fern life cycle is shown in Figure 4.14, in which the dominant generation is the sporophyte. The leafy sporophyte (2n) forms spores (n) by meiosis in the sori on its fronds; the spores germinate into a small, free-living prothallus (n), the gametophyte; the prothallus makes gametes by mitosis; the sperm and egg fuse at fertilisation, which still needs water, to give the zygote (2n); and the zygote grows into a new fern sporophyte.

The gametophyte is now small but independent, unlike the dependent sporophyte of the moss; in a fern it is the sporophyte that dominates.

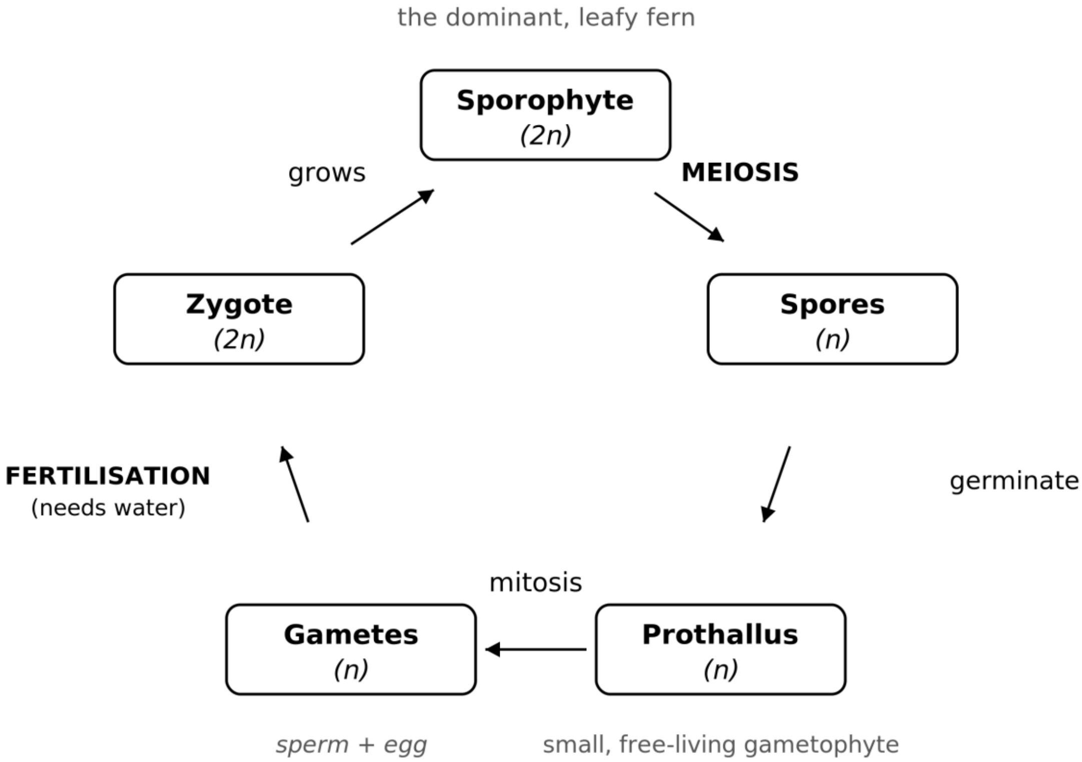


Figure 4.14: *The life cycle of a fern (a pteridophyte).*

False Confidence Alert
The mark-bearing labels are the sporophyte and the prothallus with their ploidy, the spores and gametes, and the points of meiosis and fertilisation. The usual loss is forgetting the prothallus, or making it dependent; in a fern the prothallus is a separate, free-living gametophyte.

Question 66

In a flowering plant, you never see the gametophyte as a separate plant at all. Explain how the life cycle of a seed plant continues the alternation of generations, and what has happened to the gametophyte.

Model Answer

A seed plant still alternates between a sporophyte and a gametophyte, but the gametophyte is now tiny and enclosed within the sporophyte. The flowering plant we see is the diploid sporophyte; meiosis in its anthers and ovules makes spores, which develop into the gametophytes.

The gametophytes are reduced to the pollen grain and the embryo sac. The pollen grain is the male gametophyte and the embryo sac the female gametophyte; each makes gametes by mitosis, and both are nourished inside the parent sporophyte rather than living on their own.

Fertilisation no longer needs water, because the pollen tube carries the male gametes to the egg. The zygote then grows into a new sporophyte, completing the cycle, so the alternation continues with the gametophyte almost hidden.

False Confidence Alert
Asked about the seed plant's gametophyte, candidates often say it has none. It does: the pollen grain and the embryo sac are the gametophytes, only much reduced and enclosed, so an answer that says the gametophyte has disappeared is wrong.

Question 67

A diagram of the angiosperm cycle shows just how reduced the gametophyte has become. Draw a labelled diagram of the life cycle of a flowering plant, marking the sporophyte, the much-reduced gametophytes, and where meiosis and fertilisation occur.

Model Answer

The angiosperm life cycle is shown in Figure 4.15, dominated by the sporophyte, the flowering plant. Meiosis in the anthers and ovules makes microspores and a megaspore (n); these develop into the much-reduced gametophytes, the pollen grain and the embryo sac; these make the gametes by mitosis; double fertilisation gives the zygote (2n); and the zygote grows into a new flowering plant.

The gametophytes are so reduced that they are no longer separate plants. They are tiny and enclosed within the sporophyte, and fertilisation needs no water because the pollen tube delivers the male gametes.

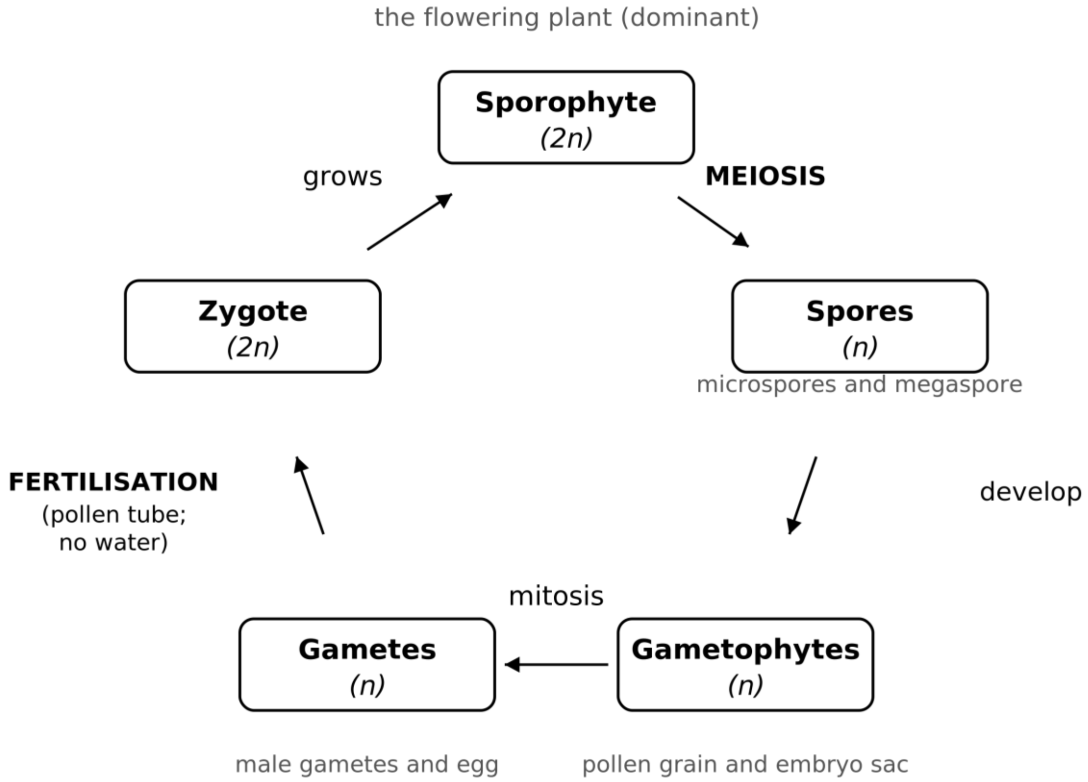


Figure 4.15: *The life cycle of a flowering plant (an angiosperm).*

False Confidence Alert
The mark-bearing labels are the sporophyte, the pollen grain and embryo sac as the gametophytes, the gametes, and the points of meiosis and fertilisation. The usual loss is leaving the gametophyte off entirely; the examiner must see the pollen grain and embryo sac marked as the reduced gametophytes.

Question 68

Between the ferns and the flowering plants sit the conifers, the first plants to make seeds. Explain the main features of the gymnosperm life cycle, and how it differs from that of a flowering plant.

Model Answer

In a gymnosperm, such as a pine, the dominant generation is the sporophyte, the cone-bearing tree, and the gametophytes are tiny and enclosed, as in the flowering plants. Meiosis in the cones makes spores that develop into the reduced gametophytes: pollen grains as the male, and the female gametophyte inside the ovule.

Pollen is carried to the ovule by the wind, and fertilisation does not need water. The pollen grows a tube to the egg, so the gymnosperm, like the flowering plant, is free of the need for surface water; the fertilised ovule then becomes a seed.

It differs from a flowering plant in two main ways. Its ovules and seeds are naked, borne exposed on the scales of a cone rather than enclosed in an ovary; and it has no double fertilisation, so its food store is laid down before fertilisation, not after, and it forms no fruit.

False Confidence Alert
Asked how a gymnosperm differs from an angiosperm, candidates often say only that it has cones. The deeper differences are that its seeds are naked, not enclosed in an ovary or fruit, and that it has no double fertilisation; an answer that stops at cones misses the marks.

Question 69

Looking across the mosses, ferns, conifers and flowering plants, a clear trend appears. Describe how the two generations change across these four groups, and why the trend suits life on land.

Model Answer

Across the four groups the sporophyte becomes more dominant and the gametophyte becomes more reduced. In mosses the gametophyte is the dominant plant and the sporophyte depends on it; in ferns the sporophyte dominates but the gametophyte is still a free-living prothallus; in conifers and flowering plants the sporophyte is the whole plant and the gametophyte is reduced to a few cells enclosed within it.

Alongside this, the plants free themselves from water for reproduction. Mosses and ferns still need a film of water for their swimming sperm, but the seed plants replace the swimming sperm with pollen and a pollen tube, so they no longer depend on surface water.

The trend suits life on land because the dominant, vascular sporophyte and the protected, water-independent gametophyte cope far better with dry conditions. A large sporophyte with roots, vascular tissue and a waterproof surface can grow tall and survive drought, while enclosing the gametophyte and using a pollen tube lets fertilisation happen without standing water, which is why the seed plants came to dominate the land.

False Confidence Alert
Asked for the trend, candidates often describe each group separately without naming the direction. The marks are for the trend itself, the sporophyte becoming dominant and the gametophyte reduced, and the move away from water; an answer that lists the groups but never states the direction of change misses the point.

Question 70

Each month a non-pregnant woman's body runs through a cycle that readies it for a possible pregnancy. Explain what the menstrual cycle is, and how its two parts, the ovarian and the uterine cycles, work together.

Model Answer

The menstrual cycle is the roughly 28-day cycle in which a woman's body ripens an egg and readies the uterus to receive it, each month from puberty to menopause. If no pregnancy follows, the cycle repeats.

It is made of two linked cycles that run together. The ovarian cycle, in the ovary, ripens and releases an egg and then forms the corpus luteum; the uterine cycle, in the uterus, builds up and then sheds the lining of the womb.

The two are kept in step by hormones, so that the lining is thickest and ready just as the egg is released and could be fertilised; the day the egg is released is ovulation, at about day 14.

False Confidence Alert
Asked what the menstrual cycle is, candidates often describe only the bleeding. Menstruation is just one part of the uterine cycle; the menstrual cycle as a whole is the monthly ripening of an egg and the building of the womb lining, so an answer that mentions only the period misses most of it.

Question 71

Within the ovary, the cycle moves through three clear phases each month. Describe the ovarian cycle through its follicular, ovulation and luteal phases.

Model Answer

The ovarian cycle passes through three phases:

1) **Follicular phase, days 1 to 14:** several follicles begin to grow under FSH, and one becomes the mature Graafian follicle, which produces oestrogen as it ripens the egg.
2) **Ovulation, about day 14:** a surge of LH makes the Graafian follicle burst and release its secondary oocyte from the ovary.
3) **Luteal phase, days 14 to 28:** the empty follicle becomes the corpus luteum, which secretes progesterone; if no pregnancy occurs, the corpus luteum breaks down and the cycle begins again.

So the ovary first ripens and releases an egg, then prepares for a possible pregnancy, all within about 28 days.

False Confidence Alert
Asked for the ovarian cycle, candidates often describe the bleeding and the womb lining instead. Those belong to the uterine cycle; the ovarian cycle is about the follicle, ovulation and the corpus luteum, so an answer about the lining has answered the wrong cycle.

Question 72

A single diagram can line up the hormones, the ovary and the womb lining across one cycle. Draw a labelled diagram of the menstrual cycle, marking the ovarian events, the lining of the uterus, and the day of ovulation.

Model Answer

The menstrual cycle is shown in Figure 4.16, with the ovary, the uterine lining and the hormones all set against the days of the cycle. In the ovary a follicle grows to a Graafian follicle, ovulation releases the egg at about day 14, and the corpus luteum then forms and later degenerates.

The uterine lining builds up to match. It is shed at menstruation in the first few days, thickens through the follicular phase, and is kept thick through the luteal phase, ready for a fertilised egg; if none arrives, it breaks down and the cycle repeats.

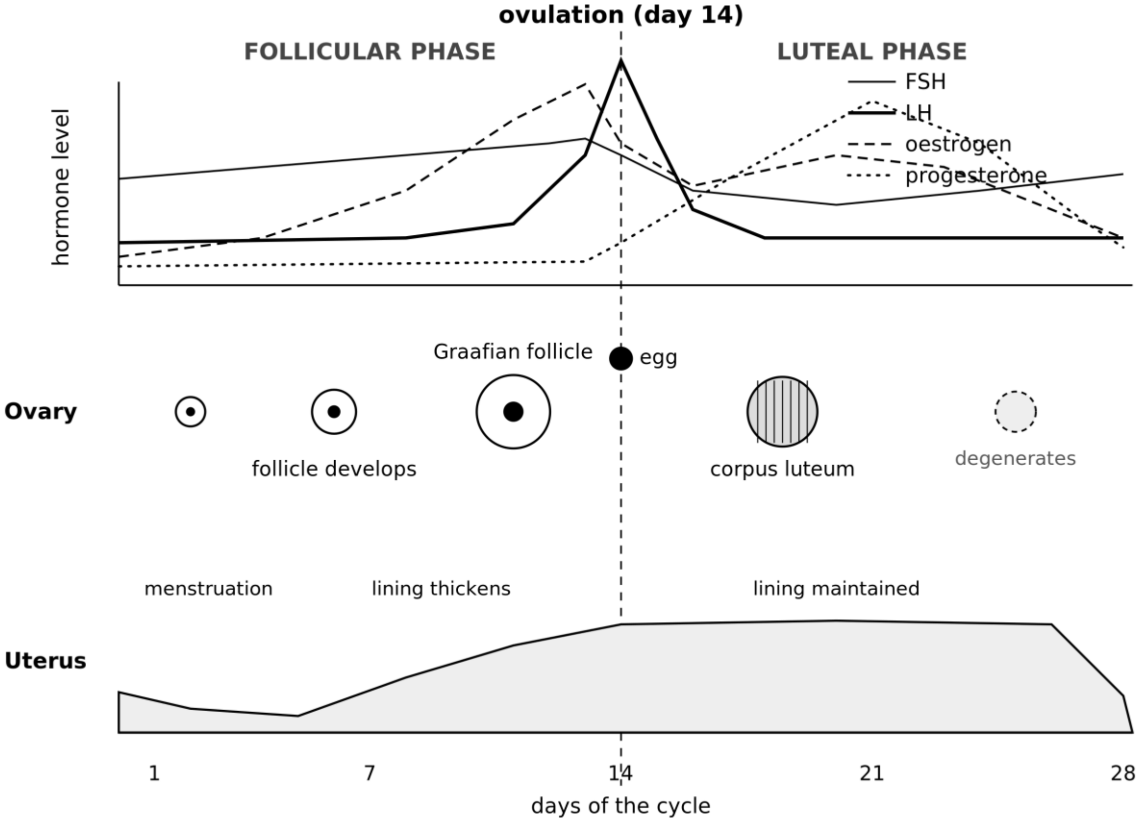


Figure 4.16: *The menstrual cycle, showing the ovarian cycle, the uterine lining and the hormone levels.*

> **False Confidence Alert**
> The mark-bearing labels are ovulation at about day 14, the Graafian follicle and the corpus luteum in the ovary, and the thickening and shedding of the uterine lining. The usual loss is putting ovulation at the wrong time; it falls at about day 14, midway through the cycle, not at the start with the bleeding.

Question 73

Four hormones, from two glands, drive the whole menstrual cycle. Name the four main hormones of the cycle, say where each is made, and give the chief effect of each.

Model Answer

Four hormones run the cycle, two from the anterior pituitary and two from the ovary:

1) **FSH (follicle-stimulating hormone):** made by the anterior pituitary; it stimulates the follicles in the ovary to grow.
2) **LH (luteinising hormone):** made by the anterior pituitary; its mid-cycle surge triggers ovulation and then forms the corpus luteum.
3) **Oestrogen:** made by the growing follicle in the ovary; it repairs and thickens the uterine lining and, at its peak, triggers the LH surge.
4) **Progesterone:** made by the corpus luteum in the ovary; it maintains the thickened uterine lining, ready for a fertilised egg.

So the pituitary hormones act on the ovary, and the ovarian hormones act back on the uterus and the pituitary.

> **False Confidence Alert**
> Asked for the sources, candidates often place all four hormones in the ovary. FSH and LH come from the anterior pituitary, and only oestrogen and progesterone from the ovary; an answer that makes the ovary the source of all four loses the marks for the pituitary hormones.

Question 74

The rise and fall of the four hormones explains the timing of the whole cycle. Using the hormone curves of Figure 4.16, explain how the levels of the four hormones change through the cycle and what each change brings about.

Model Answer

The hormone curves of Figure 4.16 show how the four hormones rise and fall in turn to drive the cycle. FSH rises early and stimulates the follicles to grow; as a follicle grows it secretes more and more oestrogen, which peaks just before day 14.

The oestrogen peak triggers a sharp surge of LH, which causes ovulation at about day 14. After ovulation the corpus luteum forms and pours out progesterone, which rises through the luteal phase while FSH and LH fall.

If no pregnancy follows, the corpus luteum dies and progesterone falls, and this fall lets menstruation begin and FSH rise again, starting the next cycle.

False Confidence Alert
Asked to read the graph, candidates often just list the hormones without linking them to events. The marks are for the cause and effect: the oestrogen peak triggers the LH surge, which causes ovulation; an answer that does not tie the curves to ovulation and the lining misses the point of the graph.

Question 75

The pituitary does not act on its own but takes its orders from the brain. Explain how the brain and the pituitary control the ovary, and how the ovary signals back.

Model Answer

The cycle is run by an axis that links the brain, the pituitary and the ovary. The hypothalamus in the brain releases a hormone (GnRH) that tells the anterior pituitary to release FSH and LH; these travel in the blood to the ovary.

FSH and LH then act on the ovary, which sends its own hormones back. FSH and LH make the follicle grow and ovulate, and the ovary releases oestrogen and progesterone, which travel back to the pituitary and the hypothalamus.

This feedback keeps the cycle turning. The ovarian hormones tell the brain and the pituitary to raise or lower FSH and LH, so the whole cycle is controlled by signals passing up and down this brain-to-ovary axis.

False Confidence Alert
Asked how the cycle is controlled, candidates often name only the ovary's hormones. The control begins in the brain: the hypothalamus and the pituitary drive the ovary through FSH and LH, so an answer that leaves out the brain and pituitary has missed where the orders come from.

Question 76

While the ovary runs its cycle, the lining of the womb runs one of its own. Describe the changes in the lining of the uterus through the uterine cycle, and how they match the ovarian cycle.

Model Answer

The lining of the uterus, the endometrium, passes through three phases that match the ovarian cycle:

Menstruation, days 1 to 5: the thickened lining of the previous cycle breaks down and is shed as the menstrual flow, because the corpus luteum has died and progesterone has fallen.

Proliferative phase, days 5 to 14: the lining is repaired and thickens again, driven by the oestrogen from the growing follicle; this matches the follicular phase of the ovary.

Secretory phase, days 14 to 28: after ovulation the lining is kept thick and enriched with glands and blood vessels by the progesterone of the corpus luteum, ready to receive a fertilised egg; this matches the luteal phase.

So the lining is built up and held ready around ovulation, and shed again only if no fertilised egg arrives.

False Confidence Alert
Asked about the uterine cycle, candidates often describe the ovary and the egg instead. The uterine cycle is about the lining of the womb, its shedding, repair and thickening; an answer about the follicle and ovulation has described the ovarian cycle, not the uterine one.

Question 77

Ovulation does not just happen on its own but is set off by a sudden hormonal signal. Explain how the LH surge brings about ovulation, and why it is an example of positive feedback.

Model Answer

Ovulation is brought about by a sudden surge of LH from the pituitary, which makes the mature Graafian follicle burst and release its egg. The LH surge happens at about day 14 and causes the follicle wall to rupture, freeing the secondary oocyte into the oviduct.

The surge is triggered by the peak of oestrogen from the follicle, and this is positive feedback. As the follicle ripens it secretes more and more oestrogen; when oestrogen reaches its peak it stimulates the pituitary to release a burst of LH, rather than holding it back.

It is positive feedback because the response increases the original signal rather than damping it. High oestrogen drives a large release of LH, the opposite of the usual negative feedback that keeps hormone levels steady.

False Confidence Alert
Asked why the LH surge is positive feedback, candidates often call it negative feedback because hormones are involved. It is positive because high oestrogen increases LH, amplifying the signal; an answer that calls it negative feedback has the direction of the effect backwards.

Question 78

After the egg is gone, the empty follicle does not simply disappear but takes on a new role. Explain what the corpus luteum is, what it secretes, and what happens to it if no pregnancy occurs.

Model Answer

The corpus luteum is the yellowish body that forms from the empty follicle after ovulation, under the influence of LH. It is an endocrine structure, and its main job is to secrete the hormone progesterone, with some oestrogen.

Its progesterone maintains the thickened uterine lining, ready for a fertilised egg. Progesterone keeps the endometrium thick and well supplied with blood, and holds back FSH and LH so that no new follicle starts while the body waits to see whether a pregnancy has begun.

If no pregnancy occurs, the corpus luteum breaks down after about ten days. Progesterone then falls, the lining can no longer be maintained, so menstruation begins and FSH rises to start the next cycle.

False Confidence Alert
Asked what the corpus luteum does, candidates often say it releases the egg. The follicle releases the egg at ovulation; the corpus luteum is what is left afterwards, and its job is to secrete progesterone, so an answer that has it releasing the egg confuses it with the follicle.

Question 79

The hormones of the cycle do not act in one direction only, but constantly adjust one another. Explain how negative feedback between the ovarian hormones and the pituitary keeps the menstrual cycle turning.

Model Answer

Negative feedback between the ovary and the pituitary keeps the cycle turning by switching the pituitary hormones up and down at the right times. For most of the cycle the ovarian hormones, oestrogen and progesterone, act back on the pituitary to hold down the release of FSH and LH.

When the ovarian hormones are high, FSH and LH are kept low. In the luteal phase the progesterone of the corpus luteum suppresses FSH and LH, so no new follicle starts to grow while the body waits to see whether a pregnancy has begun.

When the ovarian hormones fall, FSH and LH rise again. If no pregnancy occurs the corpus luteum dies, oestrogen and progesterone fall, the suppression is lifted, and FSH rises to start a new follicle and a new cycle.

False Confidence Alert
Asked about feedback, candidates often say the pituitary simply runs the cycle one way. The control runs both ways: the ovary's hormones feed back on the pituitary to raise or lower FSH and LH, and an answer that leaves out this return signal cannot explain why the cycle repeats.

Question 80

Oestrogen has a surprising double role in the cycle, acting on the pituitary in opposite ways at different times. Explain how oestrogen can both suppress and stimulate the release of FSH and LH.

Model Answer

Oestrogen acts on the pituitary in two opposite ways, depending on its level. At low to moderate levels, through most of the follicular phase, oestrogen suppresses FSH and LH by negative feedback, which keeps their levels low and limits how many follicles grow.

But when oestrogen reaches a high peak just before ovulation, it switches to positive feedback. The high oestrogen from the ripe follicle now stimulates the pituitary to release a sudden surge of LH, and some FSH, and this surge triggers ovulation.

So the same hormone first holds the pituitary back, then drives it. Low oestrogen damps FSH and LH, while peak oestrogen triggers the LH surge, which is why ovulation happens just after oestrogen peaks.

False Confidence Alert
Asked how oestrogen can both lower and raise the pituitary hormones, candidates often pick only one effect. Oestrogen does both: it suppresses FSH and LH at low levels but triggers the LH surge at its peak, so an answer that gives only one role misses the switch from negative to positive feedback.

Question 81

Most mammals do not have a menstrual cycle like a woman's, but an oestrous cycle. Explain what the oestrous cycle is, and how it differs from the menstrual cycle.

Model Answer

The oestrous cycle is the reproductive cycle of most non-primate mammals, such as cattle and dogs, in which the female is sexually receptive only during a short period called oestrus, or heat. Like the menstrual cycle, it is run by the same hormones and includes the growth of a follicle, ovulation and a corpus luteum.

It differs from the menstrual cycle chiefly in what happens to the lining of the uterus. In the oestrous cycle the thickened lining is reabsorbed by the body if there is no pregnancy, rather than being shed as a bleed, so there is no menstruation.

Mating is also restricted to oestrus. The female will only accept the male during oestrus, around the time of ovulation, whereas a woman has no such restricted period; many animals also have only one or a few oestrous cycles a year, not a regular monthly one.

False Confidence Alert
Asked to distinguish the two cycles, candidates often say they are the same thing. The key differences are that in the oestrous cycle the lining is reabsorbed rather than shed, so there is no menstruation, and mating is confined to oestrus; an answer that treats them as identical loses the marks for the distinction.

Question 82

If the egg is fertilised, the cycle must not be allowed to continue, or the new embryo would be lost. Explain how an early pregnancy is maintained and the menstrual cycle is stopped.

Model Answer

If fertilisation occurs, the early embryo keeps the corpus luteum alive, so that its progesterone continues and the lining is not lost. The young embryo, once it implants, releases a hormone (hCG) that signals the corpus luteum to survive and keep secreting progesterone, instead of dying as it would in an ordinary cycle.

The continued progesterone maintains the uterine lining and stops a new cycle. Progesterone keeps the endometrium thick to nourish the embryo, and it goes on suppressing FSH and LH, so no new follicle grows, there is no ovulation and no menstruation.

Later the placenta takes over this job. As the pregnancy goes on, the placenta itself secretes progesterone, and oestrogen, so the pregnancy is maintained even after the corpus luteum eventually fades.

False Confidence Alert
Asked how pregnancy stops the cycle, candidates often say the hormones simply switch off. The opposite is true: the embryo keeps the corpus luteum and its progesterone going, and it is this continued progesterone that holds the lining and prevents a new cycle, so an answer about hormones switching off has it backwards.

Question 83

Fertilisation may take place outside or inside the body of the female, and the place where it happens shapes the whole breeding habit of the animal. Distinguish between external and internal fertilisation, and give one example of an animal that uses each.

Model Answer

Fertilisation is external when the gametes are shed and meet outside the body, and internal when the sperm is placed inside the female so that fusion happens within her body. The difference lies in where the sperm and egg actually meet, and this in turn decides how many gametes are needed and how safe the young are.

External fertilisation: the female sheds her eggs into water and the male sheds sperm over them, so fusion occurs outside the body, as in most bony fish and in frogs and toads.

Internal fertilisation: the male passes sperm directly into the body of the female during mating, so fusion occurs inside her, as in mammals, birds, reptiles and insects.

The trade off: external fertilisation needs water and wastes huge numbers of gametes because few survive, while internal fertilisation frees the animal from water and protects the gametes, so far fewer eggs are needed.

False Confidence Alert
The command word is distinguish, so a one sided answer that describes only fishes, or that just defines fertilisation, throws away the marks. Both kinds must be named and set against each other by the place where the gametes meet, with an example of each.

Question 84

When a sperm finally reaches the secondary oocyte, a precise sequence of events lets just one sperm fuse with it. With the help of the diagram, describe how a sperm reaches and fertilises the egg in a mammal.

Model Answer

Fertilisation is reached by the sperm digesting its way through the coats of the oocyte and then fusing its membrane with that of the egg. Many sperm swim up to the secondary oocyte, but only one completes the steps that follow.

1) **Reaching the egg:** the sperm push through the corona radiata, the loose ring of follicle cells, until they meet the thick zona pellucida around the oocyte.
2) **The acrosome reaction:** the acrosome at the tip of the sperm head bursts and releases digestive enzymes that make a narrow path through the zona pellucida.
3) **Membrane fusion:** the head of the first sperm to get through touches the plasma membrane of the oocyte and the two membranes fuse, so the sperm nucleus passes into the cytoplasm.
4) **Forming the zygote:** the entry of the sperm makes the oocyte finish meiosis II, and the haploid sperm nucleus then joins the haploid egg nucleus, restoring the diploid number and forming the zygote.

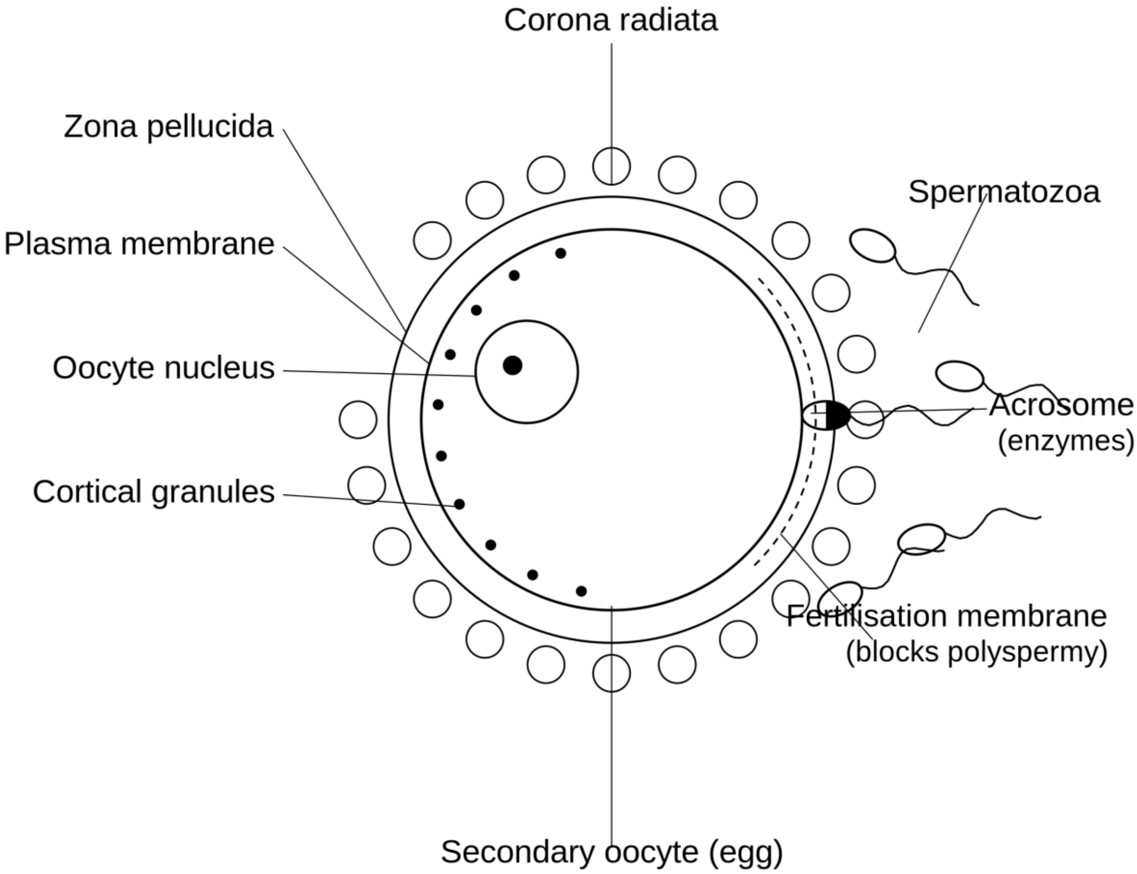


Figure 4.17: *Fertilisation in a mammal.*

False Confidence Alert
Asked for the mechanism, candidates often retell the whole menstrual cycle or simply write that the sperm meets the egg. The marks here are for the acrosome enzymes opening the zona pellucida and for the fusion of the two membranes, so those steps must appear.

Question 85

Although many sperm reach the egg at the same time, only one is allowed to fertilise it. Explain how the entry of more than one sperm, a condition called polyspermy, is prevented once the first sperm has fused with the oocyte.

Model Answer

Polyspermy is prevented because the first fusion makes the oocyte change its surface at once so that no second sperm can enter. The block is set up in two steps, one very fast and one slower but lasting.

The fast block: the moment the first sperm fuses, the charge across the oocyte membrane changes, and this brief electrical change stops further sperm fusing for a few seconds.

The cortical reaction: tiny cortical granules lying just under the membrane pour their contents outside, and these make the zona pellucida harden and lift away as a tough fertilisation membrane that no other sperm can bind or pierce.

Why it matters: letting in two sperm would give the zygote three sets of chromosomes instead of two, which is fatal, so the block keeps the diploid number correct.

False Confidence Alert
A common answer says the egg simply picks the strongest sperm, which is not biology and earns nothing. The question is about a barrier, so the answer must name the cortical reaction and the hardened fertilisation membrane that seals the egg.

Question 86

Fertilisation is far more than the joining of two cells, for it sets several biological processes in motion at once. Outline the biological importance of fertilisation.

Model Answer

Fertilisation matters because it restores the species number, mixes the genes of two parents, switches on development and starts a new life. Each of these follows from the fusion of the two haploid gametes.

1) **Restoring the diploid number:** two haploid gametes join, so the zygote and the whole new individual regain the full chromosome number of the species.
2) **Creating variation:** the genes of the mother and the father are brought together in one cell, so the offspring differ from the parents and from one another.
3) **Activating the egg:** the entry of the sperm rouses the resting oocyte to complete meiosis and to begin cleavage, so development starts.
4) **Beginning a new individual:** the zygote is the first cell of a new diploid organism and the point from which its whole life begins.

False Confidence Alert
Because the word is outline, one line saying that fertilisation forms a zygote cannot score the several marks on offer. At least the restoring of the diploid number, the mixing of parental genes and the starting of development should each be given as a separate point.

Question 87

After fertilisation the zygote does not grow larger but instead divides over and over again. With the help of the diagram, describe how the zygote develops by cleavage into a blastocyst.

Model Answer

Cleavage is a run of quick mitotic divisions that splits the zygote into many small cells without any growth, ending in a hollow ball called the blastocyst. Because there is no growth between divisions, the cells simply become smaller and more numerous while the whole structure stays the same size.

1) **Repeated cleavage:** the zygote divides into two, then four, then eight smaller cells called blastomeres, all still held within the zona pellucida as they pass down the oviduct.
2) **The morula:** continued division gives a solid ball of cells that looks like a mulberry and is called the morula.
3) **The blastocyst:** fluid then gathers in the middle of the ball to make a cavity, the blastocoel, so the morula becomes a hollow blastocyst.

4) **Two parts:** the wall of the blastocyst is a thin outer layer, the trophoblast, which will help form the placenta, while a clump of cells inside, the inner cell mass, will form the embryo itself.

Dashed ring = zona pellucida: it stays the same size while the cells inside divide and get smaller.

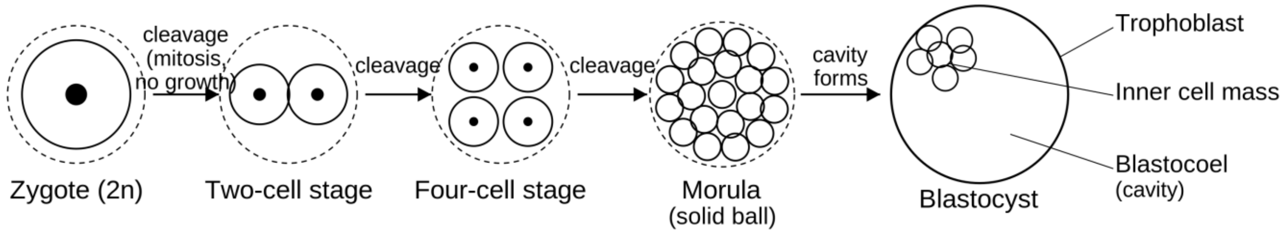


Figure 4.18: *Cleavage of the zygote.*

> **False Confidence Alert**
> Many candidates write that the zygote grows into a ball of cells, which is the very mistake the question tests. Cleavage divides the cell without growth, so the blastomeres get smaller, and that point must be made plainly.

Question 88

Once the blastocyst reaches the uterus it cannot develop further until it becomes anchored to the mother. Describe what happens during implantation.

Model Answer

Implantation is the sinking and fixing of the blastocyst into the thick lining of the uterus so that it can draw food from the mother. It takes place about a week after fertilisation, once the blastocyst has reached the uterus.

Attachment: the blastocyst loses its zona pellucida and settles against the endometrium, which has already grown thick and rich in blood vessels under the action of oestrogen and progesterone.

Embedding: the outer trophoblast cells grow into the lining and sink the blastocyst into it, so the embryo becomes buried in the wall of the uterus.

Early nourishment: the trophoblast forms finger like villi that reach into the mother's tissue and absorb food and oxygen, and these villi will later build the placenta.

> **False Confidence Alert**
> A frequent slip is to treat implantation as the same event as fertilisation. Fertilisation is the fusion of sperm and egg in the oviduct, whereas implantation is the later fixing of the blastocyst into the uterus lining, and the answer must keep the two apart.

Question 89

The hollow blastula soon rearranges itself into an embryo built of three layers. With the help of the diagram, explain how gastrulation forms the three germ layers.

Model Answer

Gastrulation is a set of cell movements that folds the single layered blastula into a three layered embryo called the gastrula. The three layers it lays down are the germ layers, the starting sheets from which all later organs are built.

The first two layers: some surface cells move inward, so the embryo comes to have an outer layer, the ectoderm, and an inner layer, the endoderm, which lines a new central cavity.

The new gut: this central cavity is the archenteron, the early gut, and it opens to the outside through a hole called the blastopore.

The third layer: a further sheet of cells, the mesoderm, then forms in the space between the ectoderm and the endoderm, completing the three layered gastrula.

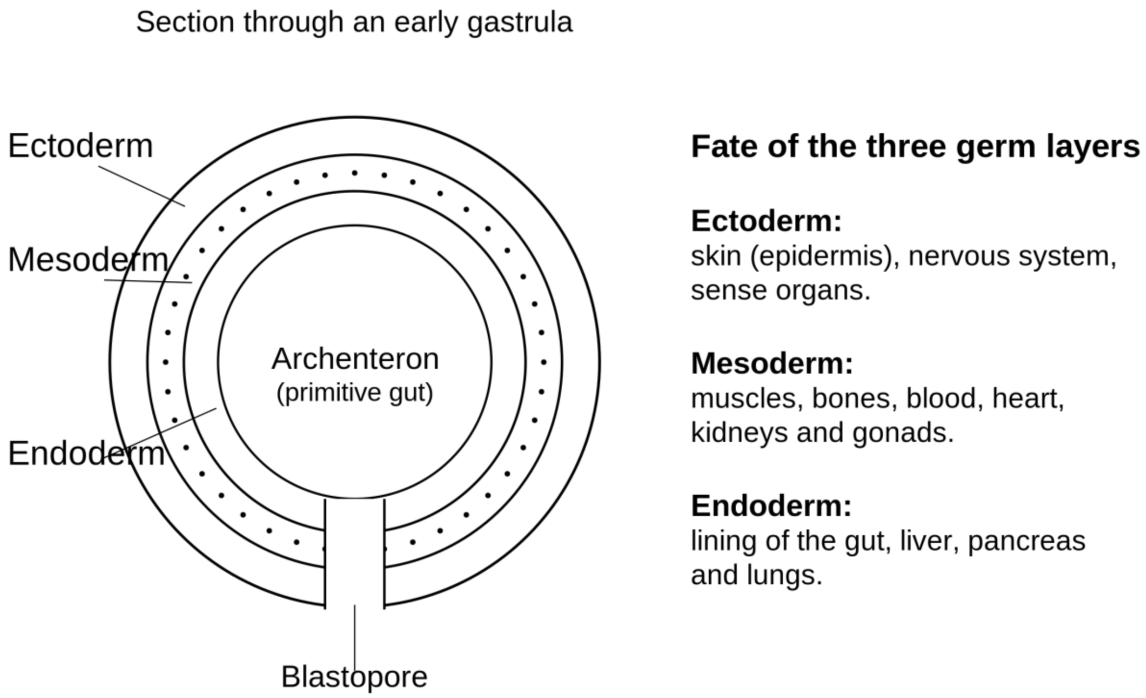


Figure 4.19: *A section through an early gastrula, showing the three germ layers, the archenteron and the blastopore, with the fate of each layer.*

> **False Confidence Alert**
> Because the question asks how gastrulation forms the layers, simply naming ectoderm, mesoderm and endoderm earns little. The movement of cells inward to build the layers, and the forming of the archenteron, are what carry the marks and must be described.

Question 90

Each of the three germ layers is the source of particular tissues and organs of the finished body. State the main structures that develop from the ectoderm, the mesoderm and the endoderm.

Model Answer

Each germ layer keeps to a fixed task: the outer ectoderm makes coverings and nerves, the middle mesoderm makes the supporting and transporting organs, and the inner endoderm makes the linings of the gut and lungs. A simple guide is that the position of the layer matches the position of what it forms.

Ectoderm: forms the epidermis of the skin with its hair and nails, and the whole nervous system together with the sense organs.

Mesoderm: forms the muscles, the skeleton, the blood and heart, the kidneys and the reproductive organs.

Endoderm: forms the lining of the gut and its glands, the liver and pancreas, and the lining of the lungs.

> **False Confidence Alert**
> The common error is to swap the layers, for example placing muscle under the ectoderm. The answer is kept right by the rule that the outer ectoderm gives outer covering and nerves, the inner endoderm gives the inner gut and lung linings, and the bulky mesoderm gives the muscle, bone and blood in between.

Question 91

As the embryo develops, four membranes grow around it, each doing a different job in its protection and feeding. With the help of the diagram, name the four embryonic membranes and state the function of each.

Model Answer

The four embryonic membranes are the amnion, the chorion, the yolk sac and the allantois, and together they cushion, enclose and nourish the embryo. Each membrane is a thin sheet that grows out from the embryo and takes on its own task.

1) **Amnion:** the inner membrane that encloses the embryo in a fluid filled bag, and the amniotic fluid in it cushions the embryo against knocks and stops it drying out.
2) **Chorion:** the outermost membrane around the whole conceptus, which grows the chorionic villi and so takes the chief part in exchange between the embryo and the mother.
3) **Yolk sac:** a small sac that in mammals holds little yolk but is an early site where blood cells are made and helps feed the young embryo.
4) **Allantois:** an outgrowth of the embryo's hindgut that stores waste in egg laying animals, while in mammals its blood vessels join the chorion to build the placenta and the umbilical cord.

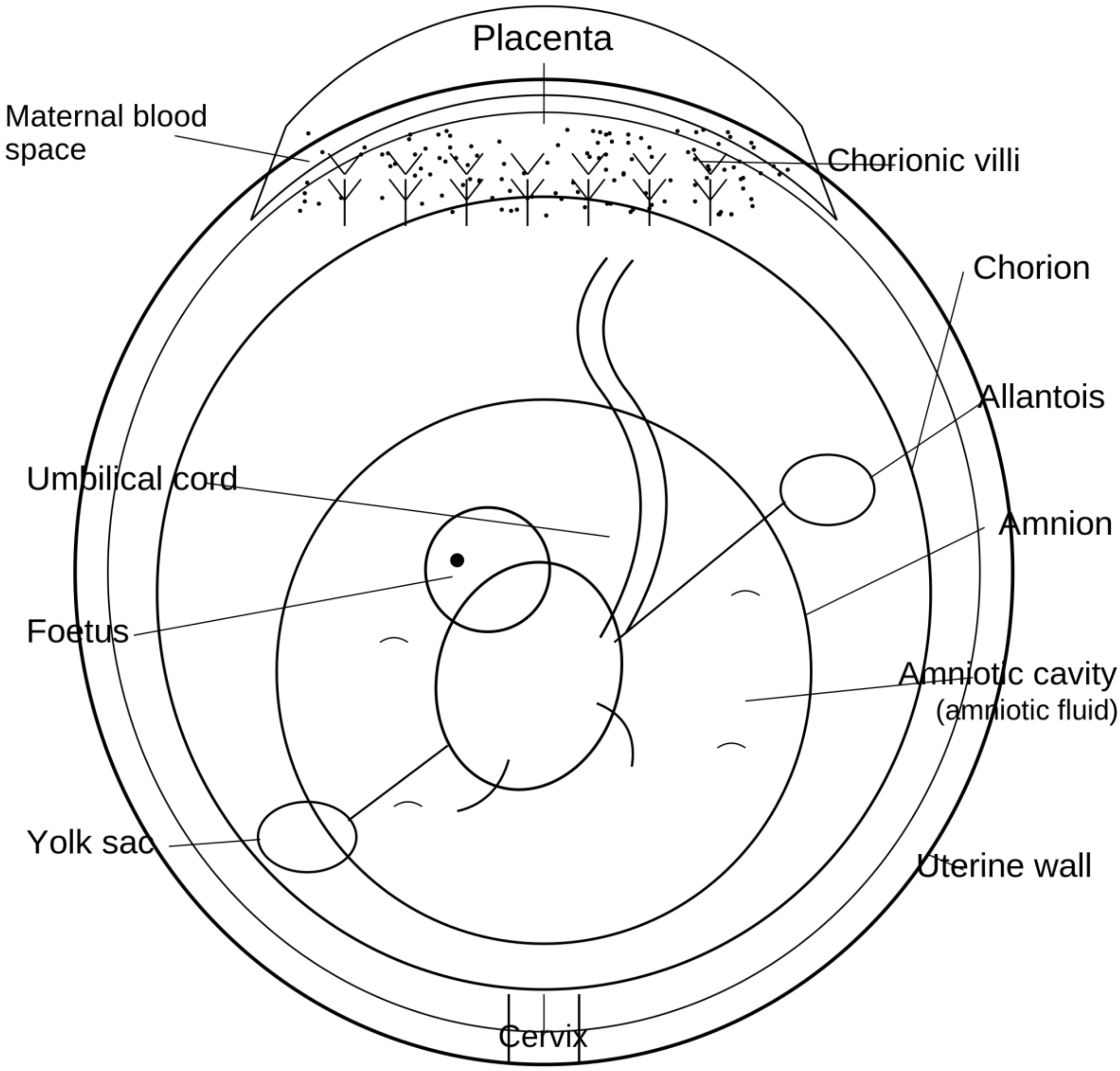


Figure 4.20: *The embryonic membranes and the placenta in a mammal.*

False Confidence Alert
The question says name and state the function, so a bare list of the four names throws away half the marks. Each membrane must be given its own job, and the amnion, which lies close around the embryo, must not be muddled with the chorion, which lies outermost.

Question 92

The placenta is the organ that links the unborn mammal to its mother and lets the two exchange materials. Describe the structure of the placenta.

Model Answer

The placenta is a disc of tissue in the wall of the uterus built from both foetal and maternal tissue, in which the two blood supplies lie close together but never mix. Its structure is suited to bringing the blood of the foetus very near to the blood of the mother.

The foetal part: it is made of chorionic villi, finger like outgrowths of the chorion that contain the foetal blood capillaries and give a very large surface for exchange.

The maternal part: these villi dip into blood spaces in the lining of the uterus that are filled with the mother's blood, so foetal villi are bathed in maternal blood.

The thin barrier: the foetal and maternal bloods are kept apart by only a thin layer of cells, across which materials pass, so the two never actually mix.

The umbilical cord: the foetus is joined to the placenta by the umbilical cord, which carries umbilical arteries to the placenta and an umbilical vein back to the foetus.

False Confidence Alert
A very common error is to write that the mother's blood and the foetal blood join together in the placenta. They stay in separate vessels and only dissolved substances cross the thin barrier between them, and an answer that lets the bloods mix is marked wrong.

Question 93

The placenta does far more than simply hold the foetus in place during pregnancy. Outline the functions of the placenta.

Model Answer

The placenta feeds the foetus, exchanges its gases, carries away its waste, guards it and makes hormones that hold the pregnancy. All of these depend on the close contact between the two bloodstreams without their mixing.

1) **Nutrition:** glucose, amino acids, fatty acids, vitamins and mineral salts pass from the mother's blood to the foetus.
2) **Gaseous exchange:** oxygen passes from the mother to the foetus, and carbon dioxide passes back from the foetus to the mother.
3) **Excretion:** wastes from the foetus, chiefly urea, pass across into the mother's blood to be removed by her kidneys.
4) **Protection:** it holds back many harmful germs and lets some of the mother's antibodies through to the foetus, giving it early immunity.
5) **Making hormones:** it secretes progesterone and oestrogen, which maintain the lining of the uterus and keep the pregnancy going.

False Confidence Alert
Because the command is outline the functions, an answer that only says the placenta feeds the baby cannot earn the several marks. At least nutrition, gaseous exchange, the removal of waste and the making of hormones should each be set down as a separate function.

Question 94

Sometimes a mother gives birth to more than one young at a single birth, and such twins are not all of one kind. Distinguish between identical and fraternal twins, and explain how each kind arises.

Model Answer

Identical twins come from one fertilised egg that splits in two, while fraternal twins come from two separate eggs each fertilised by its own sperm. The difference in how they begin decides how alike the two young will be.

Identical (monozygotic) twins: one egg is fertilised by one sperm, and the early embryo then splits into two, so the two young carry exactly the same genes, are always of the same sex, and closely resemble each other.

Fraternal (non-identical) twins: two eggs are released and each is fertilised by a different sperm, so the two young carry different genes, may be of different sexes, and are no more alike than ordinary brothers and sisters.

False Confidence Alert
A common slip is to think that all twins are identical, or to say that identical twins come from two eggs. The dividing point is the number of eggs and sperm: one egg and one sperm splitting gives identical twins, whereas two eggs and two sperm give fraternal twins.

Question 95

At the end of pregnancy the fully grown foetus is pushed out of the uterus in a process driven by hormones. Describe the process of parturition, and explain the part played by oxytocin.

Model Answer

Parturition is the birth of the young at the end of gestation, brought about by strong contractions of the uterus that are driven by the hormone oxytocin. The change is set off by a shift in the balance of hormones as the pregnancy reaches its end.

Getting ready: near the end of pregnancy the level of progesterone falls while oestrogen rises, and this makes the muscle of the uterus able to contract once again.

The work of oxytocin: the posterior pituitary releases oxytocin, which makes the muscular wall of the uterus contract and press the foetus down against the cervix.

Positive feedback: the stretching of the cervix sends signals back to the posterior pituitary to release still more oxytocin, so the contractions grow stronger and more frequent until the baby is pushed out through the widened cervix and vagina.

The afterbirth: soon after the birth, further contractions expel the placenta and membranes as the afterbirth.

False Confidence Alert
Many answers wrongly call this a negative feedback or leave out the stretching of the cervix altogether. Parturition is driven by positive feedback, in which cervical stretch brings yet more oxytocin and ever stronger contractions, and this build up must be made clear.

Question 96

Developing inside the body of the mother gives the mammalian embryo several advantages over an embryo left to develop in the open. Outline the advantages of internal development to a mammal.

Model Answer

Internal development protects the embryo, feeds it steadily, holds it in stable conditions, and so raises its chances of survival. Each gain follows from the embryo being kept within the body of the mother.

1) **Protection:** the embryo is sheltered inside the mother from predators, from drying out and from physical injury.
2) **Steady supply of food and oxygen:** through the placenta the embryo receives a constant supply of nutrients and oxygen and has its wastes carried away, so its growth is never interrupted.

3) **Stable conditions:** the embryo develops at the steady warm temperature of the mother and in the constant watery cushion of the amniotic fluid.
4) **Higher survival:** because each young is so well protected and fed, the mother needs to produce only a few at a time, yet a far greater share of them survive to birth.

False Confidence Alert
Since the command is outline the advantages, an answer that only says the embryo is protected cannot reach the several marks on offer. At least the protection, the steady nourishment through the placenta and the resulting high survival should each be given as a separate advantage.

REAL QUESTIONS

These questions test whether you can take the biology of reproduction and use it in real situations. Attempt each answer yourself first, then check it against the model answer and the False Confidence Alert that follows, which names the mistake that most often costs marks.

Question 97

In Tanzania the common goat has 60 chromosomes in each of its body cells. Using this fact, work out, with a reason in each case, the number of chromosomes in (a) a goat's sperm, (b) a cell in the testis just before it begins meiosis, and (c) a body cell of the goat's new kid.

Model Answer

The body cells are diploid with 60 chromosomes, so the gametes must carry half that number and fertilisation then restores 60 in the kid. The whole answer turns on remembering that meiosis, and nothing earlier, does the halving.

(a) **The sperm:** 30 chromosomes, because meiosis halves the diploid number when the gametes are formed.
(b) **The cell before meiosis:** 60 chromosomes, because it is still an ordinary diploid body cell that has not yet divided.
(c) **A body cell of the kid:** 60 chromosomes, because the 30 from the sperm join the 30 from the egg at fertilisation.

False Confidence Alert
The trap is to halve too early and write 30 for the cell before meiosis. That cell is still a normal diploid body cell with 60 chromosomes, because the number is halved only by meiosis itself, not before it begins.

Question 98

Two children of the same mother and father are never exactly alike, unless they happen to be identical twins. Explain, using the events of meiosis, why the children of one couple all turn out different from each other.

Model Answer

The children differ because meiosis reshuffles the parents' genes in a fresh way for every gamete, and chance decides which sperm meets which egg. Two separate shuffling events take place each time gametes are made.

Crossing over in prophase I exchanges matching pieces between the homologous chromosomes, so the chromosomes that go into the gametes carry new mixtures of genes. No two gametes are likely to receive the same recombined chromosomes.

Independent assortment at metaphase I lets the maternal and paternal chromosome of each pair line up and pass to the gametes at random, giving an enormous number of possible combinations. Added to this, which one sperm out of millions fertilises the egg is itself a matter of chance, so each child receives a different mixture.

False Confidence Alert
A weak answer says the children differ simply because they share their parents' features. The marks are for the reshuffling done inside meiosis, namely crossing over and independent assortment, together with the chance of fertilisation, and these must be named.

Question 99

A farmer notices that his banana plants, grown from suckers off the parent, are all exactly like the parent, while his maize, grown from seed, shows much variation from plant to plant. Explain this difference in terms of the kind of cell division involved.

Model Answer

The bananas are alike because they are made by mitosis, while the maize varies because it is made through meiosis and fertilisation. The kind of division decides whether the offspring are copies or a fresh mixture.

Suckers grow by mitosis, an asexual or vegetative process that copies the parent exactly, so every banana plant is a genetic copy, or clone, of the parent and of the others. No new gene combinations are made, so there is nothing to vary.

Seed is the product of sexual reproduction, in which meiosis forms gametes with reshuffled genes and fertilisation joins gametes from two parents, so each maize plant carries a new combination of genes and they differ. Variation is therefore the natural result of the sexual route.

False Confidence Alert
It is tempting to blame the difference on the soil or the quality of the seed. The real cause is the type of division, mitosis giving identical suckers and meiosis with fertilisation giving varied seed, and the answer must rest on that.

Question 100

Suppose that the gametes of an animal were formed by mitosis instead of by meiosis. Explain what would happen to the chromosome number of the species in each new generation, and why this shows that meiosis is essential for sexual reproduction.

Model Answer

If gametes were made by mitosis they would stay diploid, and fertilisation would then double the chromosome number every generation. The number would climb instead of holding steady.

A diploid gamete of 2n fusing with another diploid gamete would give a zygote of 4n, whose gametes would give 8n in the next round, and so on without end. Such a runaway rise would soon make normal development impossible and the species could not continue.

Meiosis prevents this by halving the number to the haploid n when gametes are made, so that fertilisation restores exactly the diploid 2n each time. Keeping the number constant from generation to generation is why meiosis is essential.

False Confidence Alert
Many answers describe the halving but forget that fertilisation adds chromosomes back. The key point is that without meiotic halving every fertilisation would double the number, so meiosis is needed precisely to keep the species number constant.

Question 101

A baby is born with three copies of chromosome 21, a condition known as Down syndrome. Explain how a mistake during meiosis can produce a gamete with an extra chromosome and so lead to this condition.

Model Answer

Down syndrome arises when chromosomes fail to separate properly in meiosis, so a gamete is made with an extra chromosome 21. This failure of separation is called non-disjunction.

Normally the members of each chromosome pair separate so that every gamete receives just one copy of chromosome 21. In non-disjunction the pair fails to part, so one gamete receives both copies of chromosome 21 while another receives none.

If the gamete carrying two copies is then fertilised by a normal gamete carrying one, the zygote ends up with three copies of chromosome 21, and this extra chromosome produces Down syndrome. The fault therefore lies in the unequal sharing during meiosis.

False Confidence Alert
The trap is to call this the copying of one chromosome by mistake. Non-disjunction is a failure of separation, in which one gamete gains a whole extra chromosome and its partner loses one, and the explanation must be put in those terms.

Question 102

When a disease sweeps through a herd of cattle, a few animals survive because they happen to carry resistance to it. Explain how the variation first produced by meiosis allows a species to survive such a challenge and to change over time.

Model Answer

Because meiosis and fertilisation make every animal genetically a little different, a few will by chance already carry resistance and survive to breed. Variation is the raw material that natural selection works upon.

Meiosis reshuffles the genes so that a herd is never all alike, and when the disease strikes, the resistant animals live while the rest die. Survival is decided by variation that was present beforehand, not created by the disease.

The survivors pass their resistance genes to their offspring, so over many generations resistance becomes common and the species has adapted, which is evolution in action. Without the variation from meiosis the whole herd would be alike and one disease could destroy it entirely.

False Confidence Alert
A common error is to write that the cattle developed resistance because of the disease. The resistance was already present from the variation made in meiosis, and the disease merely selected the animals that happened to carry it.

Question 103

In a mammal, meiosis makes the gametes directly, but in a flowering plant the gametes are made by mitosis and meiosis happens at an earlier point. Explain where meiosis fits into the life of (a) a mammal and (b) a flowering plant, and why the plant still ends up with haploid gametes.

Model Answer

Meiosis must happen once in every sexual life cycle to halve the chromosome number, but the mammal and the plant place that single halving at different points. Knowing where it sits explains why the plant can use mitosis for its gametes.

(a) **In a mammal:** meiosis takes place in the testis and the ovary and forms the gametes directly, so the haploid cells it produces then simply mature into the sperm and the eggs with no further division in between.

(b) **In a flowering plant:** meiosis takes place earlier and forms spores, the microspore that becomes pollen and the megaspore in the ovule, and these spores then divide by mitosis to make the gametes.

The plant's gametes are still haploid because the spore from which they are made was already halved to haploid by meiosis, so mitosis simply copies that haploid number. One meiosis early in the cycle is enough to keep every later gamete haploid.

> **False Confidence Alert**
> The trap is to assume that meiosis always makes gametes. In a flowering plant meiosis makes spores, and the gametes are made from those spores by mitosis, yet they remain haploid because the spore was already haploid.

Question 104

A man releases hundreds of millions of sperm at a single mating, while a woman usually releases only one egg in a month. Explain, in terms of the structure and the role of each gamete, why so many sperm but so few eggs are produced.

Model Answer

So many sperm are made because most are lost on the way, while so few eggs are made because each egg is large and costly and only one is needed. The numbers follow from a division of labour between the two gametes.

The sperm is tiny and carries almost no food, so it is cheap to make in huge numbers, and since most never reach the egg, vast numbers raise the chance that at least one arrives and fertilises it. Quantity makes up for the heavy losses on the journey.

The egg is large and packed with cytoplasm and food for the early embryo, so it is expensive to make and the body forms only a few, releasing one at a time because one is enough to be fertilised. Oogenesis even sacrifices the polar bodies so that this single egg is well stocked.

> **False Confidence Alert**
> It is wrong to put the difference down to the female being weaker or less fertile. The reason is the division of labour, many small mobile sperm produced to find the egg against heavy losses, and a few large food filled eggs produced to nourish the embryo.

Question 105

During oogenesis the nucleus divides equally but the cytoplasm is shared out very unequally, so that one large egg and two or three tiny polar bodies are formed. Explain why this unequal sharing is an advantage to the developing embryo.

Model Answer

The unequal sharing pours almost all the cytoplasm and food into one egg, so the embryo has a good store of nourishment before it can feed itself. Meiosis must still halve the chromosomes, but the cytoplasm need not be split evenly.

At each division of oogenesis nearly all the cytoplasm passes to one cell while the other receives a set of chromosomes with almost no cytoplasm and becomes a polar body that soon dies. In this way the chromosome number is halved without dividing the precious food store four ways.

The result is a single egg holding the yolk, organelles and cytoplasm that the young embryo will live on during its first divisions, before the placenta or other supply takes over. Four equal small cells would each be too poorly stocked to support an embryo.

> **False Confidence Alert**
> The trap is to treat the polar bodies as spare eggs that were wasted. They are the means of throwing away the extra sets of chromosomes while keeping all the cytoplasm in one well stocked egg, and they normally degenerate.

Question 106

The spermatozoon is one of the most specialised cells in the whole body, shaped entirely for one task. Explain how three features of its structure fit it for reaching and fertilising the egg.

Model Answer

Every part of the sperm is shaped to help it travel light, swim far and break into the egg. Three features show this fitness for the task especially clearly.

1) **The acrosome:** the cap over the head holds digestive enzymes that bore a path through the corona radiata and zona pellucida so the sperm can reach the egg membrane.
2) **The midpiece packed with mitochondria:** the many mitochondria release the energy as ATP that drives the long swim to the egg.
3) **The tail or flagellum:** it lashes from side to side to propel the sperm forward, while the small streamlined head and scanty cytoplasm keep the cell light enough to move quickly.

False Confidence Alert
Listing the parts of the sperm without saying what each one does cannot answer this question. Because it asks how the features fit the task, every part named must be tied to reaching the egg or to entering it.

Question 107

Sperm are made in the testes, which in many mammals hang outside the body wall in the scrotum. Explain (a) the part played by the nurse cells in sperm formation, and (b) why the testes are kept a little cooler than the rest of the body.

Model Answer

The nurse cells feed and protect the forming sperm, while the cooler position of the testes keeps sperm formation healthy. Both arrangements serve the making of good sperm.

(a) **The nurse cells:** the Sertoli or nurse cells surround the developing sperm, supporting, protecting and nourishing them as they mature, and helping to move them on once they are formed.
(b) **The cooler temperature:** sperm form best a few degrees below the core body temperature, so the scrotum holds the testes outside the body to keep them cool, and if they become too warm sperm production falls.

False Confidence Alert
A common slip is to say the testes lie outside merely to make room or for no clear reason. They are held cooler than the body because healthy sperm formation needs that slightly lower temperature.

Question 108

Spermatogenesis and oogenesis are both forms of gametogenesis carried out by meiosis, yet they differ in several important ways. State three differences between the two processes.

Model Answer

The two processes differ chiefly in how many gametes they yield, how they share the cytoplasm, and when and how steadily they work. Each difference sets one process plainly against the other.

1) **Number of gametes:** spermatogenesis makes four working sperm from each parent cell, whereas oogenesis makes only one working egg, the other products being polar bodies that die.
2) **Sharing of cytoplasm:** in spermatogenesis the cytoplasm is divided equally among the four cells, whereas in oogenesis it is divided unequally so that one cell keeps nearly all of it.
3) **Timing and output:** spermatogenesis runs without pause from puberty and pours out sperm in huge numbers, whereas oogenesis begins before birth, halts for years, and releases only one egg at a time from a fixed store.

False Confidence Alert
Since the command is to state differences, an answer that lists how the two are alike, or that describes only one of them, earns nothing. Each point must set the two side by side, such as four sperm against a single egg.

Question 109

In a flowering plant both the pollen grains and the embryo sac are made by meiosis, yet the two processes do not end in the same way. Compare microsporogenesis and megasporogenesis, noting where each takes place and what each finally produces.

Model Answer

Both begin with a mother cell dividing by meiosis, but microsporogenesis keeps all four products while megasporogenesis keeps only one. The place of each process and the fate of its products set them apart.

Microsporogenesis: takes place in the anther, where each microspore mother cell divides by meiosis into four microspores, and all four survive and ripen into pollen grains.

Megasporogenesis: takes place in the ovule, where each megaspore mother cell divides by meiosis into four megaspores, but three of them die and only one survives to grow into the embryo sac.

False Confidence Alert
The trap is to say that both processes give four working products, matching them too neatly. In megasporogenesis three of the four megaspores degenerate and only one goes on to form the embryo sac, and that loss must be stated.

Question 110

After the surviving megaspore divides three times, the mature embryo sac comes to hold eight nuclei in seven cells. State the parts of the mature embryo sac, and identify the two of them that take part in double fertilisation.

Model Answer

The mature embryo sac holds the egg apparatus, the antipodal cells and a central cell, and double fertilisation involves the egg cell and the central cell. Its seven cells are arranged from one end of the sac to the other.

The egg apparatus: at the micropylar end lies the egg cell flanked by two helper cells called synergids.

The antipodal cells: at the far, chalazal end lie three antipodal cells that simply degenerate.

The central cell: in the middle lies one large central cell holding two polar nuclei.

The two parts that take part in double fertilisation are the egg cell, which one male gamete fertilises to form the diploid zygote, and the central cell, whose two polar nuclei the second male gamete fertilises to form the triploid endosperm. One fertilisation makes the new plant, the other makes its food store.

False Confidence Alert
A common error is to name only the egg as being fertilised. Double fertilisation means two fusions, one with the egg cell and one with the polar nuclei of the central cell, so both must be identified.

Question 111

A fern and a flowering plant each produce two different kinds of spore, a condition called heterospory. Explain what heterospory is, and why it is regarded as an important step on the way to the seed habit.

Model Answer

Heterospory is the making of two kinds of spore, small microspores and larger megaspores, and it matters because the retained, nourished megaspore is the starting point from which the seed evolved. It is a move away from the single kind of spore of simpler plants.

In heterospory the small microspores grow into male gametophytes while the larger megaspores grow into female gametophytes, so the sexes are separated at the spore stage instead of one spore serving both. The larger megaspore carries a food store for the female line.

This is a step towards the seed because the megaspore is kept and fed on the parent plant rather than shed, the gametophytes shrink and become dependent, and a protected, nourished female line is exactly what the seed later provides. The seed habit grew out of this retaining and protecting of the megaspore.

False Confidence Alert
Calling heterospory simply the having of two spores, without the split into male and female, misses the point the question wants. The marks lie in the separation into microspore and megaspore and in the retaining and feeding of the megaspore that leads towards the seed.

Question 112

In an animal the products of meiosis are the gametes themselves, but in a flowering plant meiosis gives spores that must first grow into tiny gametophytes. Explain how gamete formation in a flowering plant differs from that in an animal.

Model Answer

In an animal meiosis makes the gametes directly, whereas in a plant meiosis makes spores that grow into gametophytes which then make the gametes by mitosis. The plant inserts a whole extra stage that the animal does not have.

In an animal: meiosis in the testis or ovary yields the gametes themselves, so the haploid products of meiosis become the sperm and the eggs with only maturation to follow.

In a flowering plant: meiosis yields spores, the microspores and megaspores, and each spore divides by mitosis to form a small gametophyte, the pollen grain or the embryo sac, which then produces the gametes by mitosis.

So in the plant there is an extra haploid generation, the gametophyte, standing between meiosis and the gametes, and the gametes themselves are made by mitosis rather than by meiosis. This gametophyte stage is the heart of the difference.

False Confidence Alert
The trap is to write that plants make their gametes by meiosis just as animals do. In a flowering plant meiosis makes only spores, and the gametes are produced later by mitosis within the gametophyte, so the answer must keep meiosis and gamete formation as separate steps.

Question 113

Many flowering plants carry features that make cross pollination far more likely than self pollination. Explain the difference between self pollination and cross pollination, and give two ways in which a plant encourages cross pollination.

Model Answer

Self pollination drops pollen on the stigma of the same flower or plant, while cross pollination carries it to a different plant of the same kind, and plants favour crossing because it brings variation. The two ways below both work by keeping a flower from pollinating itself.

Self versus cross: in self pollination pollen reaches the stigma of the same flower or the same plant, whereas in cross pollination pollen is carried to the stigma of a different plant of the same species.

First way, different ripening times: the anthers and the stigma of one flower ripen at different times, so the pollen is shed before or after its own stigma is ready, and it must go to another plant.

Second way, separate sexes: the plant bears separate male and female flowers, or even separate male and female plants, so that pollen cannot fall on a stigma of the same flower.

False Confidence Alert
The trap is to confuse the kind of pollination with the agent that carries the pollen. Self and cross pollination are about where the pollen lands, the same plant or a different one, not about whether wind or an insect carries it.

Question 114

A maize plant is pollinated by the wind, while a hibiscus is pollinated by insects, and their flowers are built quite differently. Compare the features of an insect pollinated flower with those of a wind pollinated flower.

Model Answer

An insect pollinated flower is built to attract and dust an insect, while a wind pollinated flower is built to shed and catch pollen on moving air. The petals, the pollen and the stamens and stigma differ in matching ways.

Petals and attractants: the insect flower has large, bright, scented petals with nectar to draw insects, whereas the wind flower has small, dull petals or none, with no scent and no nectar.

The pollen: the insect flower makes a little heavy, sticky or spiky pollen that clings to the insect, whereas the wind flower makes much light, smooth pollen that blows easily.

Stamens and stigma: the insect flower keeps its stamens and its sticky stigma inside the flower, whereas the wind flower hangs its anthers outside and spreads a large feathery stigma to catch drifting pollen.

> **False Confidence Alert**
> Because the command is compare, an answer that describes only the maize or only the hibiscus cannot score. Each feature must be set against its opposite, such as sticky pollen in the insect flower against light pollen in the wind flower.

Question 115

After a pollen grain lands on a ripe stigma it does not simply stay where it falls. Describe how the pollen tube grows and what it carries down to the embryo sac.

Model Answer

The pollen grain grows a pollen tube that bores down through the style to the ovule and delivers the two male gametes into the embryo sac. The grain itself stays on the stigma while only the tube travels.

On the ripe stigma the pollen grain germinates and pushes out a pollen tube that grows down through the tissue of the style towards the ovary, its growth led by the tube nucleus. The tube is guided to an ovule and enters it through the small opening called the micropyle.

Inside the tube travel the two male gametes, and when the tube reaches the embryo sac it bursts and releases them for double fertilisation. One gamete then fuses with the egg and the other with the polar nuclei.

> **False Confidence Alert**
> A common mistake is to write that the pollen grain itself travels down to the egg. It is the pollen tube that grows down the style carrying the two male gametes, while the grain remains on the stigma.

Question 116

Flowering plants are unique in the living world in carrying out double fertilisation. Explain what is meant by double fertilisation, and why it is an advantage to the plant.

Model Answer

Double fertilisation is the fusing of one male gamete with the egg and of a second male gamete with the polar nuclei, and its advantage is that the food store is only built once fertilisation has succeeded. Two fusions happen in the one embryo sac.

The first male gamete fuses with the egg cell to form the diploid zygote, which grows into the new plant, while the second male gamete fuses with the two polar nuclei to form the triploid endosperm, the food store. So both the new plant and its food are started together.

The advantage is that the endosperm is made only when an egg has actually been fertilised, so the plant does not waste materials stocking food around an egg that was never going to grow. The food store is then on hand to feed the developing embryo.

False Confidence Alert
The trap is to read double fertilisation as two sperm fertilising the egg, or as two eggs being fertilised. It means one fusion with the egg to give the zygote and a separate fusion with the polar nuclei to give the endosperm.

Question 117

Once fertilisation is over, the flower is transformed part by part into a fruit holding seeds. State what each of the following becomes after fertilisation: the ovule, the ovary wall, the zygote, and the primary endosperm nucleus.

Model Answer

After fertilisation the ovule becomes the seed within the ovary, which itself becomes the fruit holding it. Each part has a fixed fate.

The ovule: becomes the seed, with its outer coats hardening into the seed coat.

The ovary wall: becomes the wall of the fruit, the pericarp that encloses and protects the seeds.

The zygote: grows by mitosis into the embryo, with its young root, young shoot and seed leaves.

The primary endosperm nucleus: divides to form the endosperm, the food store of the seed.

False Confidence Alert
The usual slip is to swap the ovary and the ovule. The ovule becomes the seed, while the whole ovary becomes the fruit, and these two must not be interchanged.

Question 118

A maize grain and a bean seed both store food for the young plant, but they keep it in different places. Distinguish between an endospermic and a non-endospermic seed, and give one example of each.

Model Answer

An endospermic seed keeps its food in the endosperm, while a non-endospermic seed has moved its food into the cotyledons. Where the food finally lies is what separates the two.

Endospermic seed: the food store stays in the endosperm of the ripe seed, the cotyledons remaining thin, as in the maize grain and the castor seed.

Non-endospermic seed: the endosperm is used up while the seed is forming and the food is stored instead in the swollen cotyledons, as in the bean and the pea.

False Confidence Alert
The trap is to say that a non-endospermic seed never had any endosperm. It did form endosperm, but the food was drawn out of it into the cotyledons as the seed ripened, leaving little or none behind.

Question 119

The fruit around a seed and the food store within it each serve the new plant in their own way. Explain how the fruit and the food store of the seed help the new plant to survive and spread, and why this matters to a farmer.

Model Answer

The fruit protects the seeds and helps to scatter them away from the parent, while the food store feeds the seedling until it can make its own food. Together they give the next generation a safe start in a new place.

The fruit shields the seeds as they ripen and aids dispersal, for fleshy fruits are eaten and carried by animals, winged or hairy fruits drift on the wind, and hooked fruits cling to fur, so the seeds are spread away from the crowded parent. Spreading out lessens the competition between parent and offspring.

The food store, whether endosperm or cotyledon, nourishes the young seedling until its leaves open and it can photosynthesise, giving it a strong beginning. This matters to a farmer because well filled seeds germinate and establish far better, and knowing how seeds are spread guides how a crop is stored, planted and spaced.

False Confidence Alert
The trap is to answer only about dispersal or only about the food store. The question asks how both the fruit and the food store help the new plant, so the scattering by the fruit and the feeding by the store must each be covered.

Question 120

In the life of a moss a haploid plant and a diploid plant follow one another in turn. Explain what is meant by alternation of generations, naming the two generations and saying which cells link one to the other.

Model Answer

Alternation of generations is a life cycle in which a haploid gametophyte generation and a diploid sporophyte generation follow one another, joined by gametes at one step and by spores at the other. Neither generation stands alone, for each gives rise to the other.

The gametophyte is the haploid generation, and it makes gametes by mitosis which fuse at fertilisation to form a diploid zygote that grows into the sporophyte. Fertilisation is therefore the bridge from gametophyte to sporophyte.

The sporophyte is the diploid generation, and it makes haploid spores by meiosis which grow into new gametophytes. Meiosis and the spore are the bridge back from sporophyte to gametophyte.

False Confidence Alert
The trap is to imagine the two generations are different plants or that one simply changes into the other. They are two phases of a single life cycle, linked one way by fertilisation and the other way by meiosis, and that linkage is what the question wants.

Question 121

In a moss the green plant we see is the gametophyte, but in a fern the green plant we see is the sporophyte. Compare the dominant generation in a moss with that in a fern, and explain what is meant by calling a generation dominant.

Model Answer

The dominant generation is the larger, longer lived and self supporting one, and it is the gametophyte in a moss but the sporophyte in a fern. So the very generation we notice changes between the two plants.

In a moss: the leafy green plant is the gametophyte and is dominant, while the sporophyte is only a stalk and capsule that grows on the gametophyte and depends on it for food.

In a fern: the large leafy plant with fronds is the sporophyte and is dominant, while the gametophyte is a tiny short lived prothallus that soon withers.

To call a generation dominant means it is the bigger, more lasting and independent phase that we recognise as the plant, while the other phase is small and often dependent. Dominance is judged by size, life span and independence.

False Confidence Alert
A common error is to assume the bigger plant is always the sporophyte. In a moss the dominant green plant is the gametophyte, so dominance must be judged plant by plant from size and independence, not taken for granted.

Question 122

Setting mosses, ferns and flowering plants side by side, a clear trend runs through their alternation of generations. Describe how the gametophyte and the sporophyte generations change from mosses to flowering plants, and state one advantage this trend brings.

Model Answer

As we move from mosses to flowering plants the gametophyte grows ever smaller and more dependent while the sporophyte grows larger and takes over the life cycle. The same two generations simply shift in their relative size and importance.

In mosses the gametophyte is dominant and the sporophyte depends on it, in ferns the sporophyte is dominant but the gametophyte is still a separate small plant, and in flowering plants the gametophyte shrinks to a few cells held and protected inside the sporophyte. The diploid sporophyte therefore becomes the plant we know in the higher groups.

One advantage is that the tiny enclosed gametophyte no longer needs external water for its gametes, since pollen carries the male gamete, so the seed plants can live and reproduce in dry places. Freedom from standing water greatly widens where the plant can grow.

False Confidence Alert
The trap is to describe the trend the wrong way round, with the gametophyte growing larger. As plants advance it is the sporophyte that enlarges and dominates while the gametophyte is reduced, and stating it backwards loses the marks.

Question 123

Mosses and ferns are nearly always found in damp, shady places, while flowering plants flourish far from any water. Explain, in terms of their life cycles, why mosses and ferns are tied to moist places but flowering plants are not.

Model Answer

Mosses and ferns need a film of water because their male gametes must swim to the egg, while flowering plants do not because pollen carries the male gamete dry. The difference lies in how the male gamete reaches the egg.

In a moss or a fern the male gametes have whip like flagella and can only reach the egg by swimming through a film of water on the plant, so without moisture fertilisation cannot happen and the plants are confined to damp, shady places. Their reproduction is held hostage to rain and dew.

In a flowering plant the male gametes are carried inside a pollen grain that is taken to the stigma and then grows a pollen tube to the egg, so no external water is needed for fertilisation and the plant is free to live in dry ground. Pollen has replaced the swimming gamete.

False Confidence Alert
The trap is to blame the dampness on small size or on having no proper roots. The real reason is the swimming, flagellated male gametes that need water in mosses and ferns, against the dry pollen of flowering plants.

Question 124

Following the life cycle of a fern, state whether each of the following is haploid or diploid, giving a reason in each case: the spore, the prothallus, the gametes, and the young fern plant.

Model Answer

The spore, prothallus and gametes are all haploid, while the young fern plant is diploid, because meiosis lies between the fern plant and the spore. Tracing each part back to meiosis or to fertilisation settles its number.

The spore: haploid, because it is made by meiosis in the sporangia of the fern plant.

The prothallus: haploid, because it grows by mitosis from the haploid spore.

The gametes: haploid, because they are made by mitosis from the haploid prothallus.

The young fern plant: diploid, because it grows from the diploid zygote formed when two haploid gametes fuse.

False Confidence Alert
The trap is to assume the large fern must be haploid like the spore, or that its gametes are made by meiosis. The fern plant is diploid because it grows from the zygote, and its gametes are made by mitosis from the haploid prothallus, not by meiosis.

Question 125

A graph of a woman's hormones over twenty eight days shows FSH and LH each rising to a sharp peak at about day fourteen, while oestrogen and progesterone change through the month. Using your knowledge of the menstrual cycle, explain (a) what the LH peak at day fourteen brings about, and (b) what the rise in progesterone after day fourteen does.

Model Answer

The day fourteen LH peak triggers ovulation, while the progesterone that rises afterwards prepares and holds the uterine lining for a possible pregnancy. Each hormone on the graph marks a precise event in the cycle.

(a) **The LH peak:** the sudden surge of LH at about day fourteen makes the ripe follicle burst and release its egg, which is ovulation.
(b) **The progesterone rise:** the progesterone released by the corpus luteum after ovulation thickens and maintains the lining of the uterus, readying it for implantation, and at the same time holds FSH and LH down so that no new follicle starts.

False Confidence Alert
The trap is to read the LH peak as the cause of menstruation or of the thickening of the lining. The LH surge brings about ovulation in particular, so reading the graph means tying each hormone to its own exact event.

Question 126

When the egg released at ovulation is not fertilised, the woman menstruates about two weeks later. Explain the chain of events that leads to menstruation when fertilisation does not take place.

Model Answer

Menstruation follows because, with no fertilisation, the corpus luteum dies, its progesterone falls, and the lining it was supporting then breaks down. The whole chain is set off by the loss of the corpus luteum.

If the egg is not fertilised, the corpus luteum is no longer kept alive and degenerates after about ten to fourteen days, so the oestrogen and progesterone it was making fall sharply. There is then nothing to hold the thickened lining in place.

Without progesterone the swollen lining of the uterus cannot be maintained, so it breaks down and is shed with some blood as the menstrual flow, while the fall in hormones lets FSH rise and begin a new cycle. The bleeding is therefore the end of one cycle and the start of the next.

False Confidence Alert
The trap is to say that menstruation is caused by the egg leaving the body or by a rise in hormones. It is caused by the fall in progesterone when the unsupported corpus luteum dies, and that fall must be the centre of the answer.

Question 127

Many contraceptive pills contain hormones similar to oestrogen and progesterone. Explain how taking these hormones can prevent pregnancy, using what you know about feedback in the menstrual cycle.

Model Answer

The pill keeps oestrogen and progesterone high, and by negative feedback these hold down FSH and LH so that no egg is ever released. It works on the cycle, not on the sperm or the egg.

The steady high level of oestrogen and progesterone from the pill feeds back on the pituitary and suppresses the release of FSH and LH throughout the month. The pituitary is kept quiet as though a pregnancy were already under way.

With FSH held down no follicle ripens, and with no LH surge there is no ovulation, so no egg is released and fertilisation cannot happen. The thickened cervical mucus the hormones cause makes it harder still for sperm to pass.

False Confidence Alert
The trap is to write that the pill kills the sperm or destroys the egg. It works by feedback, holding FSH and LH down so that ovulation never happens, and with no egg released there is nothing to fertilise.

Question 128

A home pregnancy test works by detecting a hormone called hCG in the woman's urine. Explain where hCG comes from in early pregnancy, and why its presence shows that a woman is pregnant.

Model Answer

The hCG comes from the young embryo itself, and because only an implanted embryo makes it, finding it proves a pregnancy has begun. The hormone is a signal sent out by the new life.

Soon after the blastocyst implants, its chorion begins to release hCG into the mother's blood, from where some passes into her urine. The hormone keeps the corpus luteum alive so that its progesterone continues and the lining is not shed.

Because hCG is produced only when an embryo has implanted, its presence in the urine is a sure sign that fertilisation and implantation have taken place. A test that finds hCG therefore reports a pregnancy.

False Confidence Alert
The trap is to say that hCG is made by the mother's ovary or pituitary. It is made by the embryo, through its chorion, which is exactly why its presence points to a pregnancy and not merely to a stage of the ordinary cycle.

Question 129

Through the whole of pregnancy a woman neither ovulates nor menstruates. Explain why the menstrual cycle stops while she is pregnant.

Model Answer

The cycle stops because progesterone stays high all through pregnancy, holding FSH and LH down so that no new egg ripens and holding the lining so that there is no bleeding. Pregnancy keeps the hormones at levels that freeze the cycle.

At first the corpus luteum, kept alive by the embryo's hCG, kept progesterone high, and later the placenta takes over and makes progesterone and oestrogen in plenty. So the high progesterone never falls away as it would at the end of an ordinary cycle.

This steady high progesterone suppresses FSH and LH by negative feedback, so no follicle ripens and no ovulation occurs, while it also keeps the lining in place so there is no menstruation. Only after birth, when these hormones fall, does the cycle start again.

False Confidence Alert
The trap is to say the cycle stops because there is no room in the uterus or because the eggs have run out. It stops because the high progesterone of pregnancy holds FSH and LH down by feedback, preventing any new follicle and any ovulation.

Question 130

A cow comes on heat, or oestrus, only at intervals and will mate only then, while a woman has no such restricted time. Compare the oestrous cycle of the cow with the menstrual cycle of the woman.

Model Answer

Both cycles are run by the same hormones and pass through the same stages, but they differ in the time of mating and in what becomes of the unused lining. The likenesses are as important as the differences.

Time of mating: the cow will accept the bull only during the short oestrus, or heat, around ovulation, whereas the woman has no such restricted period.

Fate of the lining: in the cow the thickened lining is reabsorbed quietly if there is no pregnancy, so there is no bleeding, whereas in the woman it is shed as the menstrual flow.

Frequency: many animals come on heat only once or a few times a year, often by season, whereas the woman cycles at about monthly intervals through the year.

False Confidence Alert
The trap is to treat the two cycles as wholly the same or as wholly different. They run on the same hormones and stages, yet differ in the restricted heat period and in whether the lining is shed or reabsorbed, and a good answer holds both points together.

Question 131

Although many follicles begin to grow at the start of each cycle, normally only one ripens fully and releases a single egg. Explain how the hormones make sure that, as a rule, just one egg is released.

Model Answer

Only one egg is released because, as the follicles grow, their own oestrogen lowers FSH so that just the leading follicle survives to ovulate. The selection is done by the falling level of FSH.

At the start of the cycle FSH stimulates several follicles to start growing, and as they enlarge they secrete oestrogen into the blood. The more they grow, the more oestrogen they make.

Rising oestrogen feeds back to lower the FSH, and as FSH falls only the largest and most developed follicle can carry on, while the smaller ones, starved of FSH, degenerate. This single dominant follicle then meets the LH surge and releases its one egg.

False Confidence Alert
The trap is to say the ovary simply picks one egg to release. The single egg is the follicle that survived the fall in FSH brought on by oestrogen feedback, while the rest died back for want of FSH, and that mechanism is what the question asks for.

Question 132

A frog lays several thousand eggs in a pond, while a woman usually releases only one egg in a month. Relate the very different numbers of eggs to whether fertilisation is external or internal, and to the care the young receive.

Model Answer

The frog lays thousands because its eggs are fertilised and left in the open with heavy losses, while the woman needs only one because her young is fertilised and reared safely inside her. The number of eggs matches the dangers each faces.

In the frog fertilisation is external, so eggs and sperm are shed into the water where many are eaten, swept away or never meet, and the eggs are then left to develop with no parental care. Only a few of the thousands will ever become adult frogs, so large numbers make up for the losses.

In the woman fertilisation is internal and the embryo develops protected and fed inside her body, so each has a high chance of surviving and very few need be produced. The safer the fertilisation and the care, the fewer eggs a species need make.

False Confidence Alert
The trap is to say the frog lays many eggs merely because it is larger or a lower animal. It lays many because external fertilisation and the lack of parental care bring heavy losses, so great numbers are needed to ensure a few survive.

Question 133

Hundreds of sperm may reach an egg together, yet a healthy embryo forms from only one of them. Explain what would go wrong if two sperm fertilised a single egg, and how the egg prevents this from happening.

Model Answer

If two sperm fertilised one egg the zygote would carry three sets of chromosomes and could not develop, so the egg seals itself after the first sperm enters. The danger is a wrong chromosome number, and the guard against it is the cortical reaction.

A normal zygote has two sets of chromosomes, one from the egg and one from the sperm, but if two sperm entered it would have three sets, a faulty number that cannot develop and the embryo would die. So letting in a second sperm would ruin the new individual.

The egg prevents this by the cortical reaction, in which granules beneath the surface release their contents the instant the first sperm fuses, hardening the coat into a fertilisation membrane that no other sperm can pierce. A swift electrical change across the membrane blocks further sperm in the first seconds while this membrane forms.

False Confidence Alert
The trap is to treat the extra sperm as simply going to waste. The real danger is the abnormal three set chromosome number that two sperm would give, and the cortical reaction hardening the egg coat is what prevents it.

Question 134

A serious burn destroys a patch of a person's skin together with the nerve endings within it. From which germ layer did these damaged structures develop, and name two other structures of the body that arise from the same layer.

Model Answer

Both the skin surface and the nerve endings develop from the ectoderm, the outermost germ layer. The same layer that forms the body's covering also forms its nerves.

The epidermis of the skin and the nerves are both products of the ectoderm, which gives rise to the outer covering of the body and to the whole nervous system. That is why a burn can damage skin and nerve endings together.

Two other ectoderm structures: the brain and spinal cord, which make up the central nervous system, and the hair and nails of the skin.

False Confidence Alert
The trap is to assume that skin and nerves must come from different layers because they seem so unlike. Both arise from the ectoderm, the outer layer that forms the covering of the body and the nervous system alike.

Question 135

Doctors point out that a mother and her unborn baby may safely have different blood groups. Explain how the placenta manages to feed the baby and yet keep the mother's blood and the baby's blood from mixing.

Model Answer

In the placenta the two bloods are brought very close but kept apart by a thin barrier, across which food and oxygen pass while the blood itself does not. Nearness without mixing is the whole secret of the placenta.

The baby's blood flows in the capillaries of the chorionic villi, and these villi dip into spaces filled with the mother's blood, so the two supplies lie side by side separated only by a thin layer of cells. The villi give a large surface over which exchange can happen.

Across that thin barrier dissolved substances such as glucose and oxygen diffuse from mother to baby and wastes pass the other way, but the blood cells themselves are too large to cross, so the two bloods never mix. Because they stay separate, different blood groups in mother and baby do not clash.

False Confidence Alert
The trap is to think the two bloods must mix for food to reach the baby. Only dissolved substances cross the thin barrier while the bloods stay apart, and that very separation is why mother and baby can have different blood groups in safety.

Question 136

Throughout pregnancy the foetus floats in a bag of amniotic fluid, and near birth people speak of the waters breaking. State two functions of the amniotic fluid, and explain why the foetus is not harmed by the everyday movements of the mother.

Model Answer

The amniotic fluid cushions the foetus and keeps it in a moist, even surrounding, so the mother's movements do not jolt it. The fluid works as a protective water cushion all around the unborn young.

First function: it absorbs shocks and knocks, cushioning the foetus against blows and against the movements of the mother.

Second function: it keeps the foetus moist and at a steady temperature, and lets it move and grow freely without being squeezed.

The foetus is not harmed by the mother's movements because the surrounding fluid spreads any push or jolt evenly around it, soaking up the force the way water cushions an object floating in it. A sudden knock is shared out through the fluid instead of striking the foetus directly.

False Confidence Alert
The trap is to say the amniotic fluid feeds the foetus. Feeding is the work of the placenta, while the fluid's task is to cushion the foetus and hold it in a steady, moist surrounding.

Question 137

A mother gives birth to two boys who look exactly alike and who shared a single placenta in the womb. State whether they are identical or fraternal twins, and give the reasons for your answer.

Model Answer

They are identical twins, shown by their being the same sex, their close likeness, and their sharing of one placenta. All three signs point back to a single fertilised egg.

Identical twins arise when one egg fertilised by one sperm splits into two embryos, so the two share exactly the same genes and are always of the same sex and alike in looks. Two boys who are alike fit this origin precisely.

Their sharing of one placenta also shows they began as one embryo that divided, whereas fraternal twins come from two eggs and two sperm, may differ in sex, and usually have separate placentas. The single placenta is the clinching clue.

> **False Confidence Alert**
> The trap is to judge the twins only by their being born together. Twins born together may be of either kind, and what marks these as identical is their shared genes, seen in the same sex, the close likeness and the one shared placenta.

Question 138

When a labour is slow, doctors sometimes give the mother extra oxytocin to bring it on. Explain, using the idea of positive feedback, why oxytocin strengthens labour and hastens the birth.

Model Answer

Oxytocin makes the uterus contract, and through positive feedback each contraction calls forth more oxytocin and a stronger contraction until the baby is born. The hormone drives a loop that builds upon itself.

Oxytocin makes the muscle of the uterus contract and press the baby down onto the cervix, stretching it. The stretching of the cervix is the signal that keeps the loop turning.

That stretch sends signals to release yet more oxytocin, which makes the contractions stronger and stretches the cervix further still, so the contractions grow and grow until birth, and the extra oxytocin a doctor gives starts or reinforces this very loop. Because the response feeds back to increase its own cause, it is positive feedback.

> **False Confidence Alert**
> The trap is to call this negative feedback or to treat oxytocin as acting once and alone. It works by positive feedback, in which the stretching of the cervix brings ever more oxytocin and ever stronger contractions until the baby is delivered.

Question 139

Internal development gives the young mammal a high chance of survival, yet a mammal can bring forth only a few young at a time. Explain this trade off between the number of young produced and the care each one is given.

Model Answer

A mammal spends so much on each of its young that it can afford only a few, but in return each has a high chance of living, which is the trade off. An animal must choose between many cheap young and few costly ones.

The mammal carries each young inside the body, feeds it through the placenta and later with milk, and guards it after birth, and all this is so costly in food and effort that only a few can be reared at once. The heavy investment is what limits the number.

An animal with external development, such as a fish, takes the opposite course, making thousands of young but giving them no care, so that most die young. Both routes can keep a species going, one by protecting a few, the other by flooding the water with many.

> **False Confidence Alert**
> The trap is to say that mammals are simply better at reproducing than fish. It is a trade off, not a matter of better or worse, for the mammal protects a few young at great cost while the fish leaves many to chance, each strategy balancing its losses against its effort.

Question 140

Starting with the release of an egg and ending with the birth of a baby, outline the main events in their correct sequence, naming the key event that occurs at each stage.

Model Answer

The journey runs from ovulation through fertilisation, cleavage and implantation to development and at last birth, each step leading on to the next. Following the order is itself the heart of the answer.

1) **Ovulation:** the ovary releases an egg into the oviduct.
2) **Fertilisation:** a sperm fuses with the egg in the oviduct to form a diploid zygote.
3) **Cleavage:** the zygote divides again and again as it travels down to the uterus, becoming a hollow blastocyst.
4) **Implantation:** the blastocyst sinks into the thick lining of the uterus and draws food from the mother.
5) **Development:** the embryo lays down its germ layers and organs while the placenta and the membranes grow around it.
6) **Birth:** after about nine months of growth, oxytocin drives the contractions that push the baby out through the cervix and vagina.

False Confidence Alert
The trap is to jumble the order, for instance placing implantation before fertilisation. The sequence must run ovulation, fertilisation, cleavage, implantation, development and birth, and keeping the steps in that order is what the question rewards.

HOT QUESTIONS

These questions go beyond single facts. They ask you to put the ideas of the chapter together, to weigh evidence and reach a judgement, and to carry your understanding of meiosis into situations you have not met before.

Question 141

Meiosis is often called the one event that makes sexual reproduction possible. Drawing on what you know of gametes, fertilisation and variation, evaluate this claim.

Model Answer

The claim is largely justified, for meiosis does the two things sexual reproduction cannot do without, yet it works only hand in hand with fertilisation. A fair judgement must weigh what meiosis achieves against what it still depends on.

In its favour, meiosis halves the chromosome number so that fertilisation can restore it, without which the number would double every generation, and it shuffles the genes by crossing over and independent assortment, which is the very source of the variation that sexual reproduction exists to create. These are exactly the demands that mark sex off from simple copying.

Against the claim, meiosis alone produces nothing new until fertilisation brings two gametes together, so the halving and the reshuffling only bear fruit when a sperm meets an egg. Weighing the two, meiosis is indeed the central and indispensable event, provided we remember it acts as one half of a partnership with fertilisation.

False Confidence Alert
The command is evaluate, so simply agreeing that meiosis is essential is not enough. The marks come from setting its achievements, the halving and the variation, against its dependence on fertilisation before reaching a judgement.

Question 142

In a rare plant the cells that ought to undergo meiosis to form spores instead divide by mitosis. Predict the effect on the chromosome number of the spores, of the gametophyte that grows from them, and of the next sporophyte generation, and say whether such a plant could reproduce sexually in the normal way.

Model Answer

Every stage would be left with twice the proper number, and at the next fertilisation the number would double again, so normal sexual reproduction would break down. The fault is that the one halving step has been skipped.

Because mitosis copies the chromosome number rather than halving it, the spores would be diploid instead of haploid, the gametophyte growing from a diploid spore would be diploid, and the gametes it made by mitosis would be diploid too. Nothing in the cycle would now reduce the number.

When two such diploid gametes fused, the new sporophyte would be tetraploid, and the number would keep doubling in every following generation. A plant whose chromosome number cannot be held steady cannot reproduce sexually in the normal way.

False Confidence Alert
The trap is to halve the number at some later step out of habit. Once meiosis is replaced by mitosis nothing halves the number, so every stage is diploid and each fertilisation doubles it further.

Question 143

Crossing over and independent assortment both create variation during meiosis, and random fertilisation adds still more. Compare how much variation each can produce, and judge whether they should be seen as adding together or as multiplying.

Model Answer

Each source multiplies the variety the others make, so they should be seen as multiplying together rather than as merely adding up. Their powers compound, which is why no two people are ever quite the same.

Independent assortment alone, with its random lining up of each pair of chromosomes, gives over eight million different gametes in a human, and crossing over multiplies this still further by making each chromosome itself a fresh mixture of genes. Already the number of possible gametes is beyond counting.

Random fertilisation then takes any one of these countless eggs and joins it to any one of countless sperm, squaring the variety again, so the three sources multiply rather than add and together they make each new individual effectively unique. Trying to rank one above the others misses the point that each depends on and amplifies the rest.

False Confidence Alert
The trap is to treat the three sources as a sum, adding their effects. They multiply together, so the total variation is vastly greater than any one of them could give alone, and the judgement must say so.

Question 144

A student argues that, because identical twins come from a single zygote, meiosis plays no part in making them, and that they therefore show meiosis is not always needed for reproduction. Evaluate this argument.

Model Answer

The student is right that the splitting which makes identical twins is mitotic, but wrong to conclude that meiosis was bypassed, so the argument fails. The mistake is to look only at the twinning step and forget how the zygote arose.

It is true that one zygote divides by mitosis into two embryos, which is why identical twins carry the same genes, and no meiosis takes place at that splitting. So far the student has a point.

But that single zygote was itself made by the fusion of an egg and a sperm, and both of those gametes were produced by meiosis, so meiosis was needed before the twinning ever began. The mitotic split merely copies an individual that meiosis and fertilisation had already created, and the argument therefore does not hold.

False Confidence Alert
The trap is to accept the claim because the twinning step really is mitotic. Meiosis was not bypassed, for the zygote that split was the product of gametes made by meiosis, so the argument overlooks the step that came before.

Question 145

Two fields of cassava are struck by a new disease. One field was grown from cuttings taken off a single healthy plant, the other from seed. Predict which field is more likely to have surviving plants, and explain your reasoning from the way each crop was produced.

Model Answer

The field grown from seed is more likely to have survivors, because its plants vary while those grown from cuttings are all alike. How each crop was produced decides how much variation it holds.

The cuttings were made by mitosis, so every plant in that field is a genetic copy of the one parent, and if the disease can kill that type it can kill them all alike. Uniformity that looked like an advantage becomes a fatal weakness.

The seed field was produced through meiosis and fertilisation, so its plants differ from one another, and some may by chance carry resistance and live through the outbreak. The variation that meiosis builds into a seed crop is exactly the insurance a clone lacks.

False Confidence Alert
The trap is to pick the cutting field because its parent was healthy and strong. A clone's sameness is its weakness against a new disease, while the varied seed crop is far more likely to contain a few resistant plants.

Question 146

It is sometimes said that the difference in size and number between sperm and eggs lies at the root of many differences between the sexes. Using what you know of gametogenesis, evaluate how far this contrast in gametes can explain why the female so often gives the greater share of parental care.

Model Answer

The contrast goes a long way towards explaining the pattern, because the female has invested far more in each egg, but it does not explain every case. A fair judgement must hold the rule and its exceptions together.

Oogenesis pours all the cytoplasm and food into one large egg, made slowly from a fixed store, while spermatogenesis turns out tiny cheap sperm in their millions, so the female has put far more into each offspring before it is even born. Having more to lose, it often pays her to stay and protect that costly investment, while the male may gain more by seeking further matings.

Yet this cannot be the whole story, for in some animals it is the male that guards the young, so factors such as which parent is better placed to help, or how sure each is of being the parent, must also weigh in. The gamete difference is therefore a major part of the explanation, but not the only cause.

False Confidence Alert
The trap is to take the gamete contrast as a complete and fixed rule. It is a strong tendency that grows out of the unequal investment, but the cases where males give the care show that other factors act as well.

Question 147

A woman is born with all her egg cells already begun and then held part way through meiosis, some of them for more than forty years before they finish dividing. Suggest why this very long pause might make errors such as non-disjunction more likely in the eggs of older mothers.

Model Answer

Because an egg may be held part way through meiosis for decades, the machinery that should separate its chromosomes has long to weaken, making a failure to separate more likely. The danger lies in the length of the pause, not in age by itself.

The egg cells are arrested before birth and wait, half way through meiosis, until they are one day released, so an egg shed late in life has sat in that paused state for forty years or more. Over such a span the structures that hold the chromosomes together and pull them apart can wear out or be damaged.

When meiosis at last finishes in such an old egg, its worn machinery is more likely to let a pair of chromosomes fail to separate, so the egg ends with one too many or one too few, as in Down syndrome. Sperm, made fresh and quickly throughout life, are never held in this risky pause.

False Confidence Alert
The trap is to blame the mother's age in a vague, general way. The specific reason is the decades long pause part way through meiosis, which gives the chromosome separating machinery time to fail.

Question 148

Biologists often hold up the sperm as the clearest example of how a cell's whole structure is shaped by a single job. Using its parts, evaluate how completely the sperm has been specialised for its task, and what it has had to give up to achieve this.

Model Answer

The sperm is specialised about as completely as a cell can be, but only by surrendering almost everything that lets an ordinary cell live on its own. Its fitness for one task is bought at the price of all others.

Every part serves the single aim of reaching and entering the egg, the acrosome holding just the enzymes to bore in, the midpiece packed with mitochondria for the swim, and the tail to drive it, while all else has been stripped away. Little is left that does not help it travel and penetrate.

That stripping is the cost, for the sperm has shed most of its cytoplasm, its food store and many organelles, so it cannot grow, repair itself or live long, and it carries almost nothing but its nucleus to the zygote. The sperm is thus a model of specialisation won at the price of independence and survival.

False Confidence Alert
The trap is to praise the sperm's adaptations and stop there. Because the command is evaluate, the answer must also weigh the cost, the cytoplasm, food and long life the sperm gave up to become so specialised.

Question 149

A child receives chromosomes equally from both parents, yet almost all of the cytoplasm it starts life with comes from the mother. Explain how the events of oogenesis bring about this uneven result.

Model Answer

Oogenesis divides the chromosomes evenly but the cytoplasm very unevenly, so the egg matches the sperm in chromosomes yet far outweighs it in cytoplasm. Two different sharings in oogenesis explain the two different outcomes.

Meiosis halves the chromosomes fairly, so the egg keeps a single haploid set just as the sperm does, and at fertilisation the child receives one set from the egg and one from the sperm, equally from both parents. In their chromosomes the two gametes are evenly matched.

But at each division of oogenesis nearly all the cytoplasm is kept in the egg while the polar bodies are cast off with almost none, and the sperm itself brings hardly any cytoplasm, so the egg supplies almost all the cytoplasm and the organelles, such as mitochondria, within it. This is why features carried in the cytoplasm pass from the mother, while those carried on the chromosomes come from both parents.

False Confidence Alert
The trap is to assume that because the chromosomes are shared equally, everything in the child is. The chromosomes are equal, but oogenesis keeps almost all the cytoplasm in the egg, so the cytoplasm and its organelles are very nearly all the mother's.

Question 150

In both oogenesis in animals and megasporogenesis in plants, the four products of meiosis are cut down to a single working cell. Compare the two processes, and explain why plants and animals arrive at the same arrangement of one survivor on the female side.

Model Answer

Both processes end with one well provided female cell and three that perish, and both do so for the same reason, that the food cannot be shared four ways and still feed an embryo. The likeness is no accident but a shared answer to a shared need.

In oogenesis one egg keeps nearly all the cytoplasm while three polar bodies are cast off and die, and in megasporogenesis one megaspore survives to form the embryo sac while the other three degenerate. Each female line is reduced from four meiotic products to a single functional cell.

The reason is the same in both kingdoms, for the female cell must carry the cytoplasm and food that will support the new embryo, and a store split four ways could nourish nothing. So plant and animal alike, and quite separately, pour their resources into one female product rather than spreading them thinly.

False Confidence Alert
The trap is to treat the plant and the animal cases as having nothing to do with each other. Both cut four meiotic products down to one because the female cell must be large and well stocked to feed the embryo, so in each the resources are gathered into a single survivor.

Question 151

One student says that double fertilisation wastes a whole male gamete on the endosperm; another says that it actually saves the plant resources. Evaluate these two views, and say which is the better supported.

Model Answer

The second student is the better supported, because the saving from feeding only fertilised ovules outweighs the small cost of the extra gamete. Both views see one side of the truth, but only one weighs the whole.

The first student is right that a second male gamete is spent not on the embryo itself but only on its food store, which at first glance looks like a waste. Taken alone, that is a real cost.

But the endosperm is built only after fertilisation has actually succeeded, so the plant never wastes food stocking ovules that are never fertilised, and that saving is large against the small price of one extra gamete. Weighing the two, double fertilisation is economical, for it times the making of the food store to real success.

False Confidence Alert
The trap is to look only at the extra gamete spent and call the process wasteful. The deeper saving is that the food store is committed only once an egg has truly been fertilised, and that economy outweighs the cost of the second gamete.

Question 152

A botanist finds that in a certain plant the pollen grain, though alive and healthy, fails to grow a pollen tube after it lands on the stigma. Predict the effect on fertilisation and seed set, and explain, using the idea of the gametophyte, why a living pollen grain is still useless if its tube will not grow.

Model Answer

With no tube there can be no fertilisation and no seeds, because the grain cannot deliver its gametes to the egg. A living grain is not enough if it cannot complete its one delivery.

The pollen grain is the male gametophyte, but its task is not finished when it lands, for it must grow a tube down through the style to carry the two male gametes to the embryo sac. The gametes have no way of travelling there by themselves.

If the tube never grows, the gametes never reach the egg or the polar nuclei, so no zygote and no endosperm form, and the ovules wither instead of ripening into seeds. The plant is left without seed however alive its pollen may look.

False Confidence Alert
The trap is to assume that a living, healthy looking pollen grain must be able to fertilise. The grain is only the carrier of the gametes, and without a growing tube to deliver them it can fertilise nothing.

Question 153

Cross pollination brings variation but leans on an outside agent to carry the pollen, while self pollination is reliable but brings no variation. Evaluate the advantages and disadvantages of each, and explain why so many plants keep the power to do both.

Model Answer

Each kind of pollination trades one good thing for another, so many plants keep both to enjoy variation when they can and certain seed when they must. Neither is simply better, for each answers a different need.

Cross pollination gives variation, so some offspring may meet new conditions or resist a disease, but it depends on wind or an insect that may not come, and then the seed may fail to set. Its strength and its weakness are two sides of the same dependence.

Self pollination is sure, needing no carrier and setting seed even when the plant stands alone, but it gives no new variation, so the line stays uniform and exposed to a single threat. By keeping both, a plant crosses when partners and carriers are plentiful and falls back on selfing to guarantee some seed, balancing variation against security.

False Confidence Alert
The trap is to crown one kind of pollination the better and leave it there. Each carries a cost and a benefit, and a sound answer weighs the security of selfing against the variation of crossing, which is the very reason many plants keep both.

Question 154

A wind pollinated grass is moved into a still, enclosed greenhouse where the air never moves. Predict what will happen to its seed set, and explain how the flower structure that suits it to wind now works against it.

Model Answer

Its seed set will fall steeply or fail, because the features that fit it for wind are useless where no wind blows and no insects come. A flower built for one carrier is helpless without that carrier.

The grass has small, dull flowers with no scent and no nectar, so they offer nothing to attract an insect to carry the pollen in the wind's place. Nothing about the flower can draw a substitute carrier.

Its light, smooth pollen and dangling anthers are made to release pollen into moving air, and its feathery stigma to strain pollen from the breeze, so in still air the pollen merely falls beside the plant and the stigma catches almost nothing. Fertilisation then rarely happens and few seeds form.

False Confidence Alert
The trap is to suppose the plant will simply switch to insect pollination instead. Its wind adapted flowers have no scent, colour or nectar to attract insects, so in still air with no insects it is left with no carrier at all.

Question 155

Trace how a single successful fertilisation in a flower leads, step by step, to a seed reaching new ground far from the parent, and judge at which step the plant has the least control over what happens.

Model Answer

The plant controls the building of the seed and its fruit, but has least control over where the seed finally comes to rest. It can shape the journey's start far better than its end.

Fertilisation forms the zygote and the endosperm, then the ovule ripens into a seed and the ovary grows into a fruit around it, and the fruit is at last dispersed by being eaten, blown or carried away. Each step follows surely from the one before as far as the leaving of the parent.

From there the plant has least control, for where the seed lands depends on the wind, the animal or sheer chance, none of which it can direct. It can only load the odds, by making the fruit tasty or light or hooked, while the final resting place stays out of its hands.

False Confidence Alert
The trap is to treat the whole chain as equally in the plant's hands. The plant shapes the seed and the fruit, but the step it controls least is where the seed finally lands, for that is left to outside agents and chance.

Question 156

A student claims that a bean seed, having no endosperm, must be a more primitive seed than a maize grain, which keeps its endosperm. Evaluate this claim.

Model Answer

The claim is mistaken, for the difference is only in where the food is stored, not in how advanced the seed is. Both seeds are made in the same modern way.

Both the bean and the maize formed endosperm after double fertilisation, but as the bean ripened it drew the food out of the endosperm and into its cotyledons, while the maize left the food in the endosperm. So the bean did have endosperm, and merely moved its store.

Moving the food into the cotyledons is just another way of storing it, not a sign of being primitive, and both plants are flowering plants using the same double fertilisation. The student has confused a difference in food storage with a difference in advancement.

False Confidence Alert
The trap is to read no endosperm in the ripe seed as never having had any, or as a mark of being primitive. Both seeds make endosperm, and the bean simply shifts its food into the cotyledons, which is no sign of being less advanced.

Question 157

A farmer wants seedless fruit and is told that this can happen when a fruit forms without fertilisation. Using what you know of how fruit and seed normally form, explain how a fruit could form without seeds, and weigh what the farmer gains and loses.

Model Answer

A fruit can form from the ovary without fertilisation, giving seedless fruit, which brings the farmer an easier crop to eat and sell but no seed for the next planting. The gain and the loss both flow from the missing fertilisation.

Normally the ovary becomes the fruit and the ovule becomes the seed only after fertilisation, but in some cases the ovary can swell into a fruit on its own, and since no ovules were fertilised that fruit holds no seeds. The fruit forms while the seeds do not.

The farmer gains a seedless fruit that is often nicer and easier to eat and to sell, but he loses the seeds, so he cannot raise the next crop from them and must propagate the plant another way, such as by cuttings, and such fruit brings no new variation. The convenience of seedless fruit is paid for by the loss of seed.

False Confidence Alert
The trap is to think that no fertilisation must mean no fruit at all. The fruit can still grow from the ovary without fertilisation, but because no ovules were fertilised it contains no seeds.

Question 158

It is often said that the reduction of the gametophyte was the key change that allowed plants to conquer the land. Drawing on the moss, the fern and the flowering plant, evaluate this claim.

Model Answer

The claim is well supported but overstated, for the shrinking gametophyte was one key change among several that together won the land. Tracing the three groups shows both its strength and its limits.

In its favour, the moss keeps a dominant gametophyte and needs water for its swimming gametes, so it stays small and damp bound, the fern has a dominant sporophyte yet still a delicate free prothallus tied to moisture, and the seed plant shrinks its gametophyte to a few protected cells and replaces the swimming gamete with pollen, so it is free of standing water. The reduction of the gametophyte does indeed track the move onto dry land.

But it was not the only change, for the seed, the vascular tissue that carries water and gives support, and the waterproof cuticle were all needed as well. So the shrinking gametophyte was a key part of conquering the land, but it worked hand in hand with these other adaptations.

False Confidence Alert
The trap is to accept or dismiss the claim whole. The reduction of the gametophyte is genuinely important, yet it must be weighed alongside the seed, the vascular tissue and the cuticle rather than treated as the single cause.

Question 159

A newly found plant has a large, independent green gametophyte, and a small sporophyte that grows upon it and cannot live on its own. To which of the groups you have studied is this plant most similar, and what does this tell you about where water fits into its life?

Model Answer

The plant is most like a moss, and its dominant gametophyte tells us it almost certainly needs external water for fertilisation. The pattern of which generation is dominant is the clue that places it.

In a moss the gametophyte is the large, independent generation while the sporophyte is small and grows upon it, depending on it for food, which is exactly the arrangement described. So the plant belongs with the mosses and their kind.

Because a dominant gametophyte of this sort makes flagellated male gametes that must swim to the egg through a film of water, the plant is almost certainly tied to damp, shady places and cannot complete its life cycle without moisture. Where the gametophyte rules, water is still needed for fertilisation.

False Confidence Alert
The trap is to place the plant by the size of the whole thing rather than by which generation is dominant. A large gametophyte carrying a dependent sporophyte is the moss pattern, whatever the plant's overall size.

Question 160

A student says that, because the fern we see is diploid while the moss we see is haploid, ferns and mosses must reproduce in completely different ways. Evaluate this statement.

Model Answer

The student is mistaken, for the two plants follow the very same alternation of generations and differ only in which generation we happen to see. A difference in the visible stage has been taken for a difference in the whole method.

It is true that the fern we look at is the diploid sporophyte while the moss we look at is the haploid gametophyte, so the student has noticed a real fact. But that fact is about which generation is large, not about how each reproduces.

Both plants have a haploid gametophyte and a diploid sporophyte, linked by gametes at fertilisation and by spores at meiosis, so their life cycles share one and the same plan and differ only in which generation dominates. The student has confused a difference in dominance with a difference in method.

False Confidence Alert
The trap is to conclude from the ploidy of the visible plant that the whole life cycle differs. Moss and fern share the same two generation cycle, and differ only in whether the gametophyte or the sporophyte is the one we see.

Question 161

Mosses and ferns scatter vast numbers of tiny spores, while a coconut palm makes only a few very large seeds. Compare these two ways of starting new plants, and judge which suits a stable forest floor and which suits reaching far off new ground.

Model Answer

The many tiny spores are built for spreading far in great numbers, while the few large seeds are built to establish a strong seedling, so each suits a different need. Numbers and dispersal stand against provisioning and establishment.

A spore is tiny and carries almost no food, but it is made in huge numbers and blows far on the wind, though most land where they cannot grow, whereas a seed is large and well stocked with food, few in number and unable to travel far, but able to give its seedling a strong start. The two strategies spend their effort in opposite ways.

The light, numerous spores therefore suit reaching far off or newly opened ground, where dispersal and sheer numbers let a few find a place, while the few well fed seeds suit a stable, shaded forest floor, where a seedling must live on its reserve while it establishes under competition. Neither is better in itself, for each fits the ground it must colonise.

False Confidence Alert
The trap is to call one strategy simply better than the other. The tiny spores win at spreading and at numbers while the large seeds win at establishing under competition, so each suits a different situation.

Question 162

For medical reasons a woman has her ovaries removed, so that she no longer makes oestrogen or progesterone. Predict what would happen to the levels of FSH and LH in her blood, and explain your answer using the idea of feedback.

Model Answer

Her FSH and LH would rise and stay high, because the ovarian hormones that normally hold them down are no longer there. Removing the brake lets the pituitary run on unchecked.

In the normal cycle the oestrogen and progesterone from the ovaries feed back on the pituitary to suppress FSH and LH, keeping them in check. Take the ovaries away and that negative feedback is lost.

With no ovarian hormones to suppress it, the pituitary keeps pouring out FSH and LH, which climb and remain high as it goes on calling to ovaries that are no longer there to answer. So the loss of the ovaries raises FSH and LH rather than lowering them.

False Confidence Alert
The trap is to think that with the ovaries gone everything must shut down, so FSH and LH fall. Removing the ovaries removes the source of the negative feedback, so FSH and LH rise instead, climbing because nothing now holds them back.

Question 163

It is sometimes said that the contraceptive pill works by fooling the body into behaving as though it were already pregnant. Evaluate how good this description is.

Model Answer

The description is apt as far as the blocking of ovulation goes, but it should not be taken to mean the body is pregnant in every way. It captures the mechanism while overstating the likeness.

In pregnancy the high oestrogen and progesterone suppress FSH and LH so that no new follicle ripens and no ovulation happens, and the pill keeps these same hormones high to bring about the very same suppression and the same lack of ovulation. In this, the central trick, the pill truly does copy the signal of pregnancy.

But the likeness stops there, for a woman on the pill is not actually pregnant, carries no embryo or placenta, and usually still has a monthly bleed, so the pill mimics only the feedback that stops ovulation, not the whole state of pregnancy. Judged fairly, it is a good and useful picture of the mechanism, provided we remember it copies only the ovulation blocking signal.

False Confidence Alert
The trap is to take the as if pregnant picture literally, or else to dismiss it as wrong. It rightly captures the feedback that stops ovulation, but not the rest of pregnancy, so it should be judged a partial but apt description.

Question 164

A woman who wishes to have a child is found to have follicles that grow in her ovary each month but never release their eggs. Using the hormones of the cycle, suggest which step is most likely failing, and how a doctor might help.

Model Answer

The step most likely failing is the LH surge, since it is the sudden rise of LH at mid cycle that makes the ripe follicle release its egg. The follicles grow, so the fault lies at the moment of release.

Because the follicles develop normally, the early FSH and the oestrogen it raises must be working, so the making of follicles is not the problem. What is missing is the trigger that bursts the ripe follicle.

Without a proper surge of LH the follicle is never made to release its egg, so a doctor might help by giving a hormone treatment that supplies or sets off that LH surge, or drugs that raise the hormones which bring it on, so that ovulation can at last occur. Restoring the surge restores the release.

False Confidence Alert
The trap is to blame the ovary or the egg itself. Since the follicles grow normally, the fault is in the trigger for release, the LH surge, and not in the making of the follicles or the eggs.

Question 165

A student calls menstruation a pointless waste of blood and tissue every month. Using what you know of why the lining is built up and then shed, evaluate this view.

Model Answer

The view is too harsh, for the lining is built with a clear purpose and menstruation is only the clearing away of it when that purpose is not met. What looks like waste is really the cost of monthly readiness.

Each cycle the uterus prepares a thick, blood rich lining so that, if an egg is fertilised, the embryo can sink into it and be nourished. The building of the lining is an act of preparation, not of waste.

When no pregnancy occurs that lining is no longer needed, so it is shed as menstruation and a fresh one is built next cycle, ready once more, which means the loss is the price of being prepared for pregnancy every month rather than a pointless waste. One might still call the monthly rebuilding costly, but it is a cost with a purpose.

> **False Confidence Alert**
> The trap is to judge menstruation on its own as mere loss of blood and tissue. It makes sense only as the discarding of a lining built each month to receive an embryo, so it is the cost of monthly readiness, not a pointless waste.

Question 166

The placenta has been called the organ that makes mammalian life possible, and yet it also brings dangers of its own. Evaluate the placenta by weighing what it does for the foetus against the risks it carries.

Model Answer

On balance the placenta earns its high reputation, for the good it does the foetus far outweighs the real dangers that come with it. Its benefits and its risks spring from the very same closeness of the two bloods.

In its favour, the placenta feeds the foetus, supplies it with oxygen, carries away its wastes and makes the hormones that hold the pregnancy, so that the young can develop safely inside the mother, and without it the whole mammalian way of breeding would be impossible. It is, in plain terms, the foetus's lifeline.

Against this, the thin barrier that lets food and oxygen across also lets some harmful things through, for certain germs, alcohol and other drugs can reach the foetus and harm it. Weighing the two, the placenta is indeed what makes mammalian life possible, its benefits clearly the greater, though its dangers are real and are why a mother must take care in pregnancy.

> **False Confidence Alert**
> The trap is to praise the placenta's feeding and protection and stop there. A full evaluation must add that the same openness which lets food across also lets some germs and drugs through, so the barrier is not complete.

Question 167

Suppose a fault stopped the mesoderm from forming properly in an early embryo. Predict which kinds of organ would be the most affected, and explain why, using what you know of the germ layers.

Model Answer

The organs most affected would be the muscles, the skeleton, the blood and heart, the kidneys and the reproductive organs, because all of these arise from the mesoderm. A fault in one germ layer strikes every organ that layer was to build.

Since the mesoderm gives rise to the body's framework, its muscles, its transport and its excretory and reproductive systems, an embryo whose mesoderm failed could not build the means to support

itself, to move, to carry materials or to clear its waste. So many vital systems would be missing at once that the embryo would almost certainly die.

The skin and nerves from the ectoderm and the gut and lung linings from the endoderm might still begin to form, but without the mesoderm between them the body could neither be filled out nor held together. The damage is so wide because the mesoderm builds so much.

False Confidence Alert
The trap is to name only one organ from the mesoderm, such as muscle. The mesoderm gives rise to a whole set of organs, the muscles, bones, blood, heart and kidneys, so a fault in it strikes many systems together, and that breadth is the point.

Question 168

A student believes that as soon as a sperm meets an egg, the embryo is at once fixed in the womb and the pregnancy is established. Using the events between fertilisation and implantation, evaluate this view.

Model Answer

The student is wrong, for several days and several steps separate the meeting of the gametes from the fixing of the embryo in the womb. Fertilisation and implantation are two events, not one.

Fertilisation happens in the oviduct, not the uterus, and forms a zygote, which then divides by cleavage as it travels down towards the uterus, becoming a hollow blastocyst on the way. The new life is on a journey during this time, not yet fixed anywhere.

Only when the blastocyst reaches the uterus, about a week after fertilisation, does it sink into the lining and implant, and only then is the pregnancy truly established. The student has collapsed a journey of several days into a single instant.

False Confidence Alert
The trap is to treat fertilisation and implantation as the same moment. Fertilisation in the oviduct forms the zygote, but the embryo must cleave and travel for about a week before it implants in the uterus, so the two are days and a journey apart.

Question 169

Compare the way a flowering plant and a mammal each protect and feed their developing young, and judge which of the two faces the greater problem in doing so.

Model Answer

Both guard and feed their young, but the mammal faces the harder problem, since it must care for a living embryo within its own body for a long time. The plant solves the problem once, while the mammal solves it continuously.

The plant seals its embryo in a seed, with a food store of endosperm or cotyledons and a tough protective coat, and then sets it loose to wait and to travel, needing no further care once the seed is made. Everything the young plant needs is packed in advance into the seed.

The mammal instead keeps its embryo inside the mother, feeding it through the placenta, sheltering it in the membranes and clearing its waste until birth, which means carrying and serving a growing young for months and bringing two bloodstreams close together without letting them mix. Judged by this, the mammal meets the greater and more continuous problem, while the plant meets it once and for all by stocking and sealing the seed.

False Confidence Alert
The trap is to compare only the structures, the seed against the womb, without judging the problem each one solves. Because the question asks which faces the greater problem, the long, continuous care of the mammal must be set against the once for all packing of the seed.

Question 170

Looking back over the whole chapter, from meiosis through to birth, explain how the single aim of producing a new and varied individual links all of its parts together.

Model Answer

Every part of the chapter serves one aim, the making of a new individual that carries a fresh mixture of its parents' genes, and it is this aim that ties the parts into a whole. Each topic is a step on the same single road.

Meiosis halves the chromosome number and shuffles the genes, so that the gametes are varied and the full number can be restored later, and gametogenesis then shapes those gametes, stocking the egg with food and building the sperm or the pollen to deliver its nucleus. The early chapters thus prepare varied gametes and ready them for their meeting.

Fertilisation brings two gametes together, restoring the full chromosome number and combining the genes of two parents into a new, varied zygote, and the life cycles, the cleavage, the implantation and the development that follow grow that zygote into a new individual, while the reproductive cycles, the placenta and birth, or else the seed and its dispersal, see the young safely made and set on its way. So from the first halving in meiosis to the cry of birth or the sprouting of a seed, every step works towards one end, a new and varied life.

False Confidence Alert

The trap is to see the chapter as a string of separate topics learned one by one. Meiosis, gametogenesis, fertilisation, the life cycles and development all serve the single linked aim of producing a new and varied individual, and grasping that thread is what makes sense of the whole.

Chapter 5

GENETICS

BINDER QUESTIONS

Work through each question in order: attempt your own answer first, then check it against the model answer and against the False Confidence Alert that follows, which warns of the mistake that most often costs marks.

Question 1

Before a maize plant can pass its grain colour to the next generation, something inside its cells must carry that instruction. Explain what the hereditary material is, and why a living cell relies on the nucleic acids, DNA and RNA, rather than on any ordinary chemical, to store and hand on this information.

Model Answer

The hereditary material is the chemical substance in the chromosome that carries coded information from one generation to the next. It is not the whole cell or the whole chromosome but one kind of molecule, a nucleic acid, whose sequence of bases spells out the instructions for the organism's characteristics.

Two nucleic acids share the work: deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). DNA is the stable, long-term store of the information in most organisms, while RNA carries that information and helps put it to use, and RNA even serves as the hereditary material in some viruses. An ordinary chemical cannot do this because the carrier of inheritance must be able to be copied exactly and to code for traits, and only the nucleic acids meet both of these demands.

False Confidence Alert
A tempting but costly answer is to name the gene or the chromosome and stop there. The question asks for the chemical that carries the information, so the credit hangs on identifying the nucleic acid itself rather than the structure that holds it.

Question 2

In a human cheek cell seen under the microscope, the genetic material is tucked away inside a clear central body. Describe where and how the hereditary material is stored in a eukaryotic cell, and explain why it appears as loose threads for most of the cell's life but as separate chromosomes only when the cell is about to divide.

Model Answer

In a eukaryotic cell the hereditary material is held inside the nucleus, a compartment bounded by a double membrane. This membrane protects the DNA and controls the exchange of materials between the nucleus and the cytoplasm, and within it the DNA lies in a semi-fluid nucleoplasm.

For most of the cell's life the DNA is wound around proteins called histones to form long, thin threads of chromatin. When the cell prepares to divide, the chromatin coils and condenses tightly into the shorter, thicker bodies we can see and count as chromosomes, so that the copied DNA can be shared out exactly between the two daughter cells. A human body cell holds 46 such chromosomes arranged in 23 pairs.

False Confidence Alert
Watch the wording on chromatin and chromosomes: they are not two substances but the same DNA in an uncoiled and a coiled state. An answer that treats them as separate, or that has chromosomes sitting ready-made in the resting nucleus, forfeits the mark for that change of state.

Question 3

A cholera bacterium has no nucleus, yet it still inherits its features and passes them to its offspring. Explain where a prokaryotic cell keeps its hereditary material and how that arrangement differs from a eukaryote's, including the part played by plasmids.

Model Answer

A prokaryotic cell keeps its hereditary material in the cytoplasm, in a region called the nucleoid that has no surrounding membrane. Lying free in this region is a single, large, circular DNA molecule that carries most of the genes the cell needs.

Unlike eukaryotic DNA, the prokaryote's DNA is not wound on histones, so it is more loosely and freely arranged. Many prokaryotes also carry small, separate rings of DNA called plasmids, which hold a few extra genes, such as those for antibiotic resistance, and can be copied and passed on independently of the main chromosome.

False Confidence Alert
The word nucleoid is doing real work here, naming an organised region of DNA and not the absence of one. Candidates who read 'no nuclear membrane' as 'no proper genetic material', or who forget the plasmids, give away easy marks.

Question 4

Both an Acacia tree and the bacteria in the soil around its roots store their information in DNA, yet they package it very differently. Compare how the hereditary material is organised in a eukaryotic and in a prokaryotic cell, and explain why, in spite of these differences, the DNA itself is the same kind of molecule in both.

Model Answer

The two cell types differ in where and how they house the same molecule:

1) **Location:** in a eukaryote the DNA is shut inside a membrane-bound nucleus, whereas in a prokaryote it lies free in the cytoplasm in the nucleoid.
2) **Shape:** eukaryotic DNA is carried in several long, linear chromosomes, while the prokaryote has one circular chromosome.
3) **Packaging:** eukaryotic DNA is wound on histone proteins to form chromatin, but prokaryotic DNA has no histones and is loosely arranged.
4) **Extra DNA:** many prokaryotes also carry plasmids, which eukaryotes usually lack.

In spite of this, the DNA is chemically identical in both: the same nucleotides, the same double helix and the same base-pairing rule, so the difference between the cells is one of packaging and not of the molecule itself.

False Confidence Alert
In a compare answer the marks come from pairing the two cells feature against feature, not from listing facts about each in turn. The decisive point is the one most often missed, that the DNA molecule is the same in both, so it is only the packaging being compared and not the chemistry.

Question 5

Not every molecule in a cell could serve as the carrier of inheritance; the job makes strict demands. Explain the main properties a substance must have to act as the genetic material, showing in each case why the property matters.

Model Answer

A genetic material must meet several demands, and the nucleic acids meet them all:

1) **Coded storage:** the instructions are written in the sequence of bases, so one molecule can carry the plan for the whole organism.
2) **Exact replication:** the cell must copy it before dividing, so that every daughter cell and every offspring receives a faithful set.
3) **Stability with repair:** the information must survive unchanged for the life of the cell, yet any damage must still be put right.
4) **Controlled expression:** different cells use different genes, so the material must let some instructions be read and others kept silent.
5) **Capacity to mutate:** a rare, heritable change creates the variation on which evolution depends.

DNA, and RNA in some viruses, satisfy every one of these, which is why a nucleic acid and not an ordinary chemical carries inheritance.

False Confidence Alert
This question rewards the reason as much as the property, so a bare list of qualities leaves the explanation marks untouched. An answer that offers only replication is also too thin, because coded storage, controlled expression and the capacity to mutate are each being counted.

Question 6

Just as a long word is built from a few repeated letters, the giant DNA and RNA molecules are built from one kind of repeating unit. Explain what a single nucleotide is made of, and how nucleotides are joined to build a complete nucleic acid.

Model Answer

A nucleotide is the repeating unit, or monomer, from which the nucleic acids are built, and each one is made of three parts joined together. These are a pentose (five-carbon) sugar, a phosphate group and a nitrogenous base, with both the base and the phosphate attached to the sugar.

Many nucleotides are then linked into a long, unbranched chain called a polynucleotide, the phosphate of one nucleotide joining to the sugar of the next so that the sugars and phosphates form a continuous backbone with the bases projecting from it. A DNA or RNA molecule is simply a very long polynucleotide, which is why the order of its bases can store so much information.

False Confidence Alert
A frequent slip is to call the base alone, or the sugar alone, the nucleotide. The nucleotide is all three parts together, sugar with phosphate and base, so an answer that names only one of them describes a fragment and not the unit.

Question 7

A nucleotide is built from three distinct components, each with a specific role. Draw a simple labelled diagram of a single nucleotide, and beneath it state briefly what each of the three labelled parts contributes.

Model Answer

A single nucleotide is drawn in Figure 5.1, with its three parts labelled.

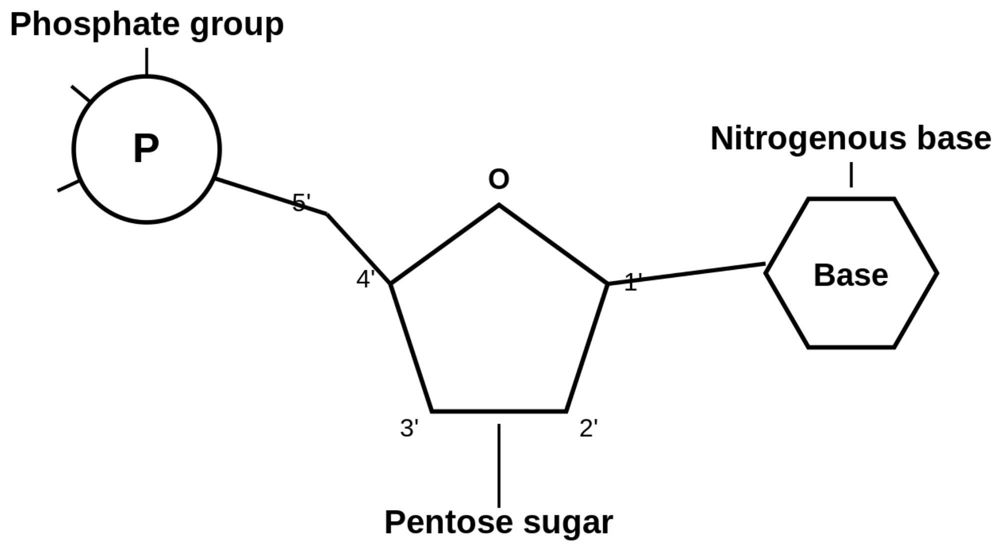


Figure 5.1: *A nucleotide, made of a pentose sugar, a phosphate group and a nitrogenous base.*

Each part has its own contribution:

1) **Pentose sugar:** the five-carbon sugar is the central framework to which the other two parts attach, and it links to the next nucleotide to help build the backbone.
2) **Phosphate group:** it joins the sugar of one nucleotide to the sugar of the next, and it gives the molecule its acidic, negatively charged nature.
3) **Nitrogenous base:** it is the information-carrying part, because it is the order of the bases along the chain that spells out the genetic message.

> **False Confidence Alert**
> The commonest way to lose marks here is a diagram with no functions, or with the phosphate and base attached at the wrong points. The phosphate joins at the 5' carbon and the base at the 1' carbon of the sugar, and each label should carry its job and not just its name.

Question 8

The letter D in DNA and the letter R in RNA point to the one difference in their sugars. Explain how ribose differs from deoxyribose, and why this small difference decides which sugar builds DNA and which builds RNA.

Model Answer

Ribose and deoxyribose are both five-carbon pentose sugars, and they differ at a single position, the second (2') carbon. Ribose carries a hydroxyl (-OH) group on its 2' carbon, whereas deoxyribose has only a hydrogen there, that is, one fewer oxygen atom, which is what the prefix deoxy means.

This single difference decides each sugar's role: ribose builds RNA while deoxyribose builds DNA. The missing oxygen makes deoxyribose, and therefore DNA, more chemically stable, which suits DNA to the long-term storage of information, while the reactive hydroxyl of ribose leaves RNA less stable and shorter-lived.

> **False Confidence Alert**
> The wrong place to look for the difference is the number of carbons. Both are five-carbon sugars, and the real difference is a single oxygen on the 2' carbon, so naming the wrong feature loses the mark.

Question 9

Two kinds of bond hold a nucleic acid together, and they do very different jobs. Explain the part played by the phosphate group, and distinguish the phosphodiester bond from the hydrogen bond in a nucleic acid.

Model Answer

The phosphate group links the nucleotides into a chain and gives the molecule its character. It is attached to the 5' carbon of one sugar and joins to the 3' carbon of the next, and because it comes from phosphoric acid it makes the nucleic acid acidic and strongly negatively charged.

The two bonds differ in strength and in what they hold together:

1) **Phosphodiester bond:** a strong bond that joins the sugar of one nucleotide to the phosphate of the next, building the sugar-phosphate backbone that runs the length of a single strand.
2) **Hydrogen bond:** a much weaker bond that forms between the bases, holding the two strands of DNA to each other yet allowing them to be parted for copying.

False Confidence Alert
A tempting mistake is to treat the two bonds as equally strong or interchangeable. The phosphodiester bonds are strong and hold one strand together, whereas the hydrogen bonds are weak and hold two strands to each other, and confusing them muddles how DNA is both stable and able to unzip.

Question 10

The five bases of the nucleic acids fall into two families of unequal size. Explain how the purines differ from the pyrimidines, naming the bases in each group and saying which base belongs only to DNA and which only to RNA.

Model Answer

The nitrogenous bases are divided into two groups by the number of rings in each:

1) **Purines:** the larger bases, each built from two rings (a double-ring structure); they are adenine (A) and guanine (G).
2) **Pyrimidines:** the smaller bases, each built from a single ring; they are cytosine (C), thymine (T) and uracil (U).

Two of the bases are restricted to one nucleic acid: thymine occurs only in DNA and uracil only in RNA, while adenine, guanine and cytosine occur in both.

False Confidence Alert
It is easy to muddle which bases are the two-ringed ones. Adenine and guanine are the larger, double-ring purines, so calling cytosine or thymine a purine reverses the families and loses the mark.

Question 11

Suppose you are shown the five bases as ring structures, some with one ring and some with two. Using the number of rings, classify each base, and explain why, on a rung of the DNA ladder, a purine must always pair with a pyrimidine.

Model Answer

By counting rings, the five bases sort at once into the two families. Adenine and guanine, with two rings each, are purines; cytosine, thymine and uracil, with one ring each, are pyrimidines.

On a rung of the DNA ladder a large purine must always pair with a small pyrimidine, because two purines would make the rung too wide and two pyrimidines too narrow; only a purine with a pyrimidine keeps the two strands an even, constant distance apart. This is why adenine pairs with thymine and guanine with cytosine.

False Confidence Alert
It is a common belief that any base can pair with any other. The fixed width of the ladder forces a purine to pair with a pyrimidine, so allowing a purine-purine or pyrimidine-pyrimidine rung ignores the geometry that keeps DNA uniform.

Question 12

Along a single strand the sugar-phosphate backbone never changes, yet one gene differs from another. Explain why it is the sequence of bases, and not the backbone, that carries the genetic information.

Model Answer

The sugar-phosphate backbone is the same all along the chain and the same in every nucleic acid, so it cannot tell one gene from another. It simply repeats the same sugar and phosphate over and over, and a repeating, unchanging structure can carry no message.

The bases, by contrast, vary from one position to the next, and it is their order that spells out the information, in the same way that a few letters arranged in different orders spell different words. A change in the base sequence changes the instruction, which is the basis of both inheritance and mutation.

False Confidence Alert
A common error is to credit the backbone, or the sugar, with storing the information. The backbone is identical in every nucleic acid and only the order of the bases differs, so only the base sequence can carry the genetic message.

Question 13

Although every plant and animal stores its inheritance in DNA, a few viruses break the rule. Explain why DNA is the genetic material of almost all organisms while some viruses use RNA instead, relating the choice to the properties of the two molecules.

Model Answer

DNA is the genetic material in the great majority of organisms because it is chemically stable and can be replicated and repaired with great accuracy. That stability lets it store information faithfully for the whole life of the cell and pass it unchanged to the next generation.

RNA serves as the genetic material in some viruses only, because RNA is chemically less stable, shorter-lived and harder to copy without error. A small, fast-replicating virus can manage with a short-lived RNA genome, but a long-lived organism needs the dependable store that only DNA provides.

False Confidence Alert
The wrong conclusion to draw is that RNA cannot be a genetic material at all. It clearly can, since some viruses depend on it, but its instability is exactly why it is confined to them and not trusted by whole organisms.

Question 14

Hold a strand of RNA beside a strand of DNA and the differences begin at the building blocks. Describe the structure of an RNA molecule, naming its bases, and explain why RNA is far less stable than DNA.

Model Answer

RNA is a single-stranded polynucleotide, a single chain of nucleotides that is not normally paired with a partner strand. Its four nitrogenous bases are adenine, guanine, cytosine and uracil, and uracil takes the place that thymine holds in DNA.

RNA is unstable mainly because its ribose sugar carries a reactive hydroxyl (-OH) group on the 2' carbon. This group makes the chain prone to hydrolysis and easily broken, so RNA is short-lived and unsuited to long-term storage, a task left to the more stable DNA whose deoxyribose lacks that group.

False Confidence Alert
It is wrong to picture RNA as a double helix like DNA. RNA is normally a single strand, although it can fold back on itself, and treating it as routinely double-stranded confuses it with DNA.

Question 15

The instructions for a protein are locked in the DNA of the nucleus, yet proteins are built out in the cytoplasm. Explain how messenger RNA is made and the job it does, and why the cell needs it at all.

Model Answer

Messenger RNA (mRNA) is made in the nucleus by copying one strand of a DNA gene, a process called transcription, so its base sequence is a complementary copy of the DNA strand that was read.

Its job is to carry the genetic message from the DNA in the nucleus to the ribosomes in the cytoplasm, where the protein is assembled. The cell needs mRNA because the DNA does not leave the nucleus and cannot be decoded into protein directly, so the mRNA acts as a portable working copy. It carries coding stretches that specify the amino acids and untranslated stretches that help control where translation starts and stops.

> **False Confidence Alert**
> A frequent error is to say that the DNA itself travels to the ribosome to make protein. DNA stays in the nucleus and it is the mRNA copy that carries the message out, so sending the DNA to the cytoplasm loses the mark.

Question 16

Every protein in your body is assembled on a tiny structure built largely from one kind of RNA. Explain what ribosomal RNA is and the part it plays in the cell.

Model Answer

Ribosomal RNA (rRNA) is the RNA that, with protein, builds the ribosome, the structure on which proteins are made. It makes up more than half the mass of a ribosome and forms the framework of the ribosome's two parts, the large subunit and the small subunit.

Its part is therefore structural and functional at once: by forming the body of the ribosome it provides the very site where the mRNA is read and the amino acids are joined into a polypeptide. Without rRNA there would be no ribosome and so no protein synthesis.

> **False Confidence Alert**
> Do not confuse rRNA with the messenger that carries the code. rRNA builds the ribosome where translation happens, whereas mRNA brings the instructions to it, and swapping the two roles costs the mark.

Question 17

A small, cloverleaf-shaped molecule does the delicate job of matching each codon to its amino acid. Describe the structure of a transfer RNA molecule and explain how its shape lets it recognise both an amino acid and a codon.

Model Answer

Transfer RNA (tRNA) is a small single strand of about 80 nucleotides folded back on itself into a cloverleaf shape held together by hydrogen bonds. At one end is the acceptor stem, ending in the bases C-C-A, to which a particular amino acid is attached; on the loop at the opposite end is a triplet of bases called the anticodon.

This two-ended shape is exactly what lets tRNA act as an adaptor: the acceptor end carries a specific amino acid while the anticodon recognises and pairs with the matching codon on the mRNA. In this way each tRNA brings the right amino acid to the right place as the message is read.

> **False Confidence Alert**
> A common slip is to call the triplet on the tRNA a codon. The triplet on the tRNA is the anticodon, which pairs with the codon on the mRNA, and mixing the two terms reverses the matching.

Question 18

A clear diagram makes the work of tRNA obvious. Draw a labelled diagram of a transfer RNA molecule, then state what happens at the two ends that do the molecule's work.

Model Answer

A transfer RNA molecule is drawn in Figure 5.2, with its cloverleaf shape and working parts labelled.

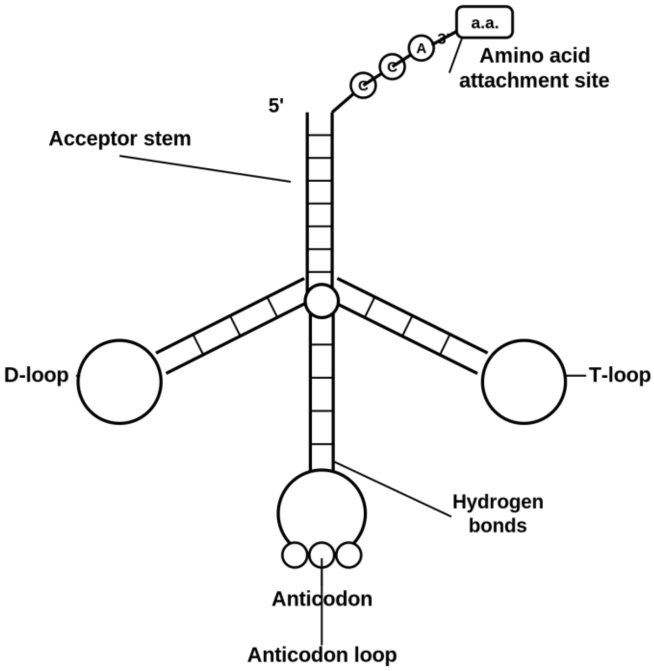


Figure 5.2: *A transfer RNA (tRNA) molecule, showing the amino-acid (CCA) end and the anticodon.*

The two working ends do the following:

The acceptor stem (3' end): ends in the bases C-C-A and is where the specific amino acid that the tRNA carries becomes attached.

The anticodon: is the triplet of bases on the loop at the far end, and it pairs with the complementary codon on the mRNA, so that the correct amino acid is delivered to the correct point in the chain.

False Confidence Alert
The marks slip away when the two ends are labelled but their jobs are left out. The diagram should show that one end holds the amino acid and the other reads the codon, because it is this pairing of the two ends that the question is really about.

Question 19

The viruses that cause influenza and AIDS store their genes not in DNA but in RNA. Explain how some viruses use RNA as their genetic material, what is special about a retrovirus, and why RNA viruses change so quickly.

Model Answer

Some viruses carry their genes as RNA instead of DNA, and this RNA holds all the instructions the virus needs to reproduce inside a host cell. A retrovirus is special because it carries an enzyme, reverse transcriptase, that copies its RNA back into DNA, the reverse of the usual flow of information from DNA to RNA.

RNA viruses change very quickly because they copy their genomes with enzymes that lack a proofreading step, so copying errors, that is, mutations, are frequent and are kept. This rapid change lets such viruses adapt to new hosts or escape drugs and vaccines, which is why a fresh influenza vaccine is needed each year.

False Confidence Alert
It is a mistake to think every virus must turn its RNA into DNA. Only the retroviruses do that, using reverse transcriptase, while many other RNA viruses copy RNA straight from RNA, so the retrovirus route is the exception and not the rule.

Question 20

Watson and Crick's famous model pictured DNA as a twisted ladder of two strands running in opposite directions. Describe the structure of a DNA molecule, and explain what is meant by saying that its two strands are antiparallel.

Model Answer

DNA is a double helix made of two polynucleotide strands wound around each other, like a twisted ladder. Each strand has a backbone of alternating deoxyribose sugars and phosphate groups, with the nitrogenous bases projecting inwards and pairing with the bases of the other strand to form the rungs.

The two strands are antiparallel, which means they run in opposite directions: one strand runs in the 5' to 3' direction while its partner runs 3' to 5'. This head-to-tail arrangement is what lets the bases pair correctly across the helix, and it becomes important when the molecule is copied.

False Confidence Alert
A frequent mistake is to draw the two strands running the same way. The strands are antiparallel, one 5' to 3' and the other 3' to 5', and a model with both pointing the same way could not base-pair correctly.

Question 21

The rungs of the DNA ladder are never random; each base will join only one partner. Explain the rule of complementary base pairing in DNA, including the number of hydrogen bonds in each pair and why this makes one pair stronger than the other.

Model Answer

In DNA the bases pair by a fixed rule: adenine always pairs with thymine, and guanine always pairs with cytosine. A large purine always pairs with a small pyrimidine, so the two strands stay an even distance apart, and each pair is held together by hydrogen bonds.

The two kinds of pair differ in the number of hydrogen bonds: an adenine-thymine pair is held by two hydrogen bonds, while a guanine-cytosine pair is held by three. The G-C pair is therefore the stronger, so a stretch of DNA rich in G-C is harder to pull apart than a stretch rich in A-T.

False Confidence Alert
The pairing is often half-remembered as adenine with cytosine, or guanine with thymine. Adenine pairs only with thymine (two bonds) and guanine only with cytosine (three bonds), and any other pairing breaks the rule that keeps the strands a constant width apart.

Question 22

A straightened diagram shows the pairing rule at a glance. Draw a short labelled diagram of a base-paired stretch of DNA, marking the two backbones, the base pairs, the hydrogen bonds and the 5' and 3' ends, then state what the diagram shows about how the two strands are held together.

Model Answer

A short, straightened stretch of DNA is drawn in Figure 5.3, with its parts labelled.

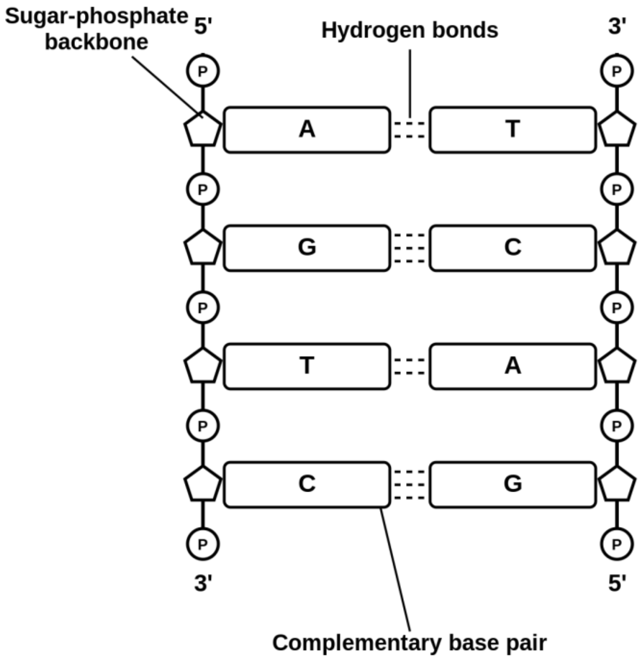


Figure 5.3: *A straightened stretch of DNA, showing the antiparallel strands, the complementary base pairs and the hydrogen bonds.*

The diagram shows two things about how the strands are held together:

The backbones run in opposite directions: the left strand is 5' at the top and 3' at the bottom, while the right strand is 3' at the top and 5' at the bottom, so the two are antiparallel.

The strands are joined only at the bases: each rung is a complementary base pair, adenine with thymine and guanine with cytosine, held by hydrogen bonds, two for A-T and three for G-C, which hold the helix yet are weak enough to be unzipped for copying.

> **False Confidence Alert**
> A diagram loses marks when the 5' and 3' ends are left off, or are drawn the same way up on both strands. The ends must run opposite each other, because the antiparallel arrangement is the very point the diagram is meant to make.

Question 23

The pairing rule does more than hold the ladder together; it is the secret of accurate copying. Explain why complementary base pairing allows one strand of DNA to act as a faithful template for building a new strand.

Model Answer

Because each base pairs with only one partner, the order of bases on one strand fixes the order on the other. Wherever there is an adenine on one strand there must be a thymine opposite it, and wherever there is a guanine there must be a cytosine, so the two strands carry the same information in complementary form.

This is why one strand can serve as a template for a faithful copy: if the strands are separated, each exposed base calls up only its correct partner, so a new strand built against it must repeat the original sequence exactly. In this way the pairing rule lets DNA be copied with very few errors, which is the basis of replication and of inheritance.

> **False Confidence Alert**
> It is tempting to say the two strands are identical. They are not identical but complementary, each the negative of the other, and it is this complementarity, not sameness, that lets either strand rebuild the whole molecule.

Question 24

The DNA helix has the same precise measurements in every organism, and it is remarkably hard-wearing. Give the main dimensions of the DNA double helix, and explain why DNA is so chemically stable.

Model Answer

The DNA double helix has fixed dimensions: neighbouring base pairs lie 0.34 nm apart, one complete turn of the helix measures 3.4 nm and contains ten base pairs, and the helix is about 2 nm wide.

DNA is chemically stable because several features work together: its deoxyribose sugar lacks the reactive hydroxyl group that makes RNA fragile, the bases are stacked closely inside the helix where they are shielded from water, and the two strands hold each other along their whole length. This stability is why DNA can store genetic information safely for the whole life of a cell.

> **False Confidence Alert**
> It is easy to credit the hydrogen bonds alone for DNA's stability. Each hydrogen bond is weak and easily broken, so it is really the stable deoxyribose backbone and the stacking of the bases that make DNA hard-wearing, and naming only the bonds misses the main reason.

Question 25

Although DNA and RNA are close chemical cousins, several clear differences set them apart. Compare DNA and RNA, and explain how each is suited to its own job.

Model Answer

DNA and RNA differ in five main ways:

1) **Strands:** DNA is double-stranded as a double helix, whereas RNA is single-stranded.
2) **Sugar:** DNA contains deoxyribose, while RNA contains ribose, which carries an extra, reactive hydroxyl group.
3) **Bases:** both use adenine, guanine and cytosine, but DNA uses thymine where RNA uses uracil.
4) **Stability:** DNA is chemically stable and long-lived, while RNA is less stable and short-lived.
5) **Role:** DNA is the permanent store of genetic information, whereas RNA is a working copy used in making proteins.

Each is suited to its job by these very properties: the stable, double-stranded DNA is ideal for storing information safely and for being copied accurately, while the short-lived, single-stranded RNA is ideal as a disposable messenger and worker in protein synthesis.

> **False Confidence Alert**
> The temptation in a comparison is to describe DNA fully and then RNA fully, in two separate blocks. The marks come instead from pairing the two point by point, strand against strand and sugar against sugar, so that each line is a true comparison.

Question 26

Before a cell can divide into two, it must first make a second, identical copy of all its DNA. Explain what is meant by DNA replication, when in the life of a cell it happens, and why it must happen before division.

Model Answer

DNA replication is the process by which a DNA molecule makes an exact copy of itself, producing two identical molecules from one original. Each new molecule carries the same sequence of bases as the original, so the genetic information is doubled.

Replication takes place during interphase (specifically the S phase), the stage before the cell divides, so that the DNA is copied while the cell is still preparing to divide. It must happen first because each daughter cell has to receive a complete and identical set of DNA; without copying, each would get only half the information. This is why replication is the foundation of inheritance.

False Confidence Alert
A common confusion is to place replication during the actual division of the cell. The DNA is copied earlier, in interphase, so that division can then simply share out the ready-made copies, and putting replication inside mitosis itself loses the mark.

Question 27

The two strands of DNA are wound tightly together, so copying must begin by prising them apart. Explain how the DNA double helix is unwound at the start of replication, naming the enzyme involved and the proteins that keep the strands apart.

Model Answer

Replication begins when the enzyme helicase unwinds the double helix and breaks the weak hydrogen bonds that hold the two strands together. This separates the strands and creates a Y-shaped region called the replication fork, where the copying takes place.

Once the strands are apart, single-strand binding proteins attach to them and hold them open. These proteins stop the separated strands from simply zipping back together before they have been copied, so that each strand stays exposed and ready to act as a template.

False Confidence Alert
It is wrong to say the strands are cut apart. Helicase only breaks the weak hydrogen bonds between the bases, leaving each sugar-phosphate backbone whole, so describing the strands as cut or broken loses the mark.

Question 28

DNA polymerase can build a new strand in one direction only, yet the two template strands point opposite ways. Explain why this forces one new strand to be made continuously and the other in pieces, naming the two strands.

Model Answer

DNA polymerase can add new nucleotides only in the 5' to 3' direction, but the two template strands are antiparallel and run in opposite directions. This means the enzyme can follow one template smoothly toward the fork yet must work in steps along the other.

As a result the two new strands are made differently: the leading strand is built continuously, in one unbroken piece, as the fork opens, while the lagging strand is built discontinuously, in a series of short pieces, because its template runs the wrong way. The antiparallel arrangement is therefore the whole reason for the difference.

False Confidence Alert
The trap is to blame the difference on two different enzymes rather than on the antiparallel strands. The same rule, synthesis only 5' to 3', acts on both strands, and it is only because their templates point opposite ways that one is continuous and the other in fragments.

Question 29

DNA polymerase cannot start a new strand from nothing; it needs a short length to build on. Explain how synthesis of the leading strand begins and why it can then proceed continuously.

Model Answer

Before DNA polymerase can begin, a short piece of RNA called a primer is laid down by the enzyme primase. The primer gives DNA polymerase a starting point, a free end onto which it can add the first DNA nucleotides.

On the leading strand only one primer is needed, because its template runs in the right direction for the polymerase to follow the fork as it opens. The enzyme can therefore add nucleotides without interruption, building the whole leading strand as one continuous piece.

> **False Confidence Alert**
> A frequent slip is to say DNA polymerase starts the new strand by itself. It cannot begin on a bare template and must first be given an RNA primer by primase, so leaving out the primer loses the mark.

Question 30

On one of the two strands the new DNA appears not as one piece but as a string of short segments. Explain why the lagging strand is built in fragments, what these fragments are called, and how each one is started.

Model Answer

The lagging strand is built in short pieces called Okazaki fragments because its template runs in the opposite direction to the fork's movement. As the fork opens and exposes more template, the polymerase can only work away from the fork, so it must keep starting again and make a new short fragment each time.

Each fragment is started in the same way as the leading strand, with its own RNA primer laid down by primase. Many such primers are placed along the lagging-strand template and a separate Okazaki fragment is built from each, so the lagging strand ends up as a series of pieces that must later be joined.

> **False Confidence Alert**
> Watch the direction on the lagging strand, since it is easy to draw its fragments running the same way as the leading strand. Each Okazaki fragment is in fact made away from the fork, which is exactly why the strand cannot be built in one continuous piece.

Question 31

The new strands are first built with RNA primers in them, but the finished DNA must be pure DNA and error-free. Explain how the RNA primers are dealt with and how the accuracy of the new DNA is checked.

Model Answer

The RNA primers are removed by a second enzyme, DNA polymerase I, which strips them out and fills the gaps with the correct DNA nucleotides. In this way every piece of RNA primer is replaced by DNA, so the finished strand is made entirely of DNA.

The accuracy of the copy is checked by proofreading. The DNA polymerases read back over the new strand and correct any wrongly paired base they find, so that very few mistakes are left. This proofreading is why replication is so faithful and why mutations are rare.

> **False Confidence Alert**
> It is tempting to think the RNA primer simply stays in the finished strand. The primer is removed and replaced with DNA, so a finished molecule contains no RNA, and an answer that leaves the primer in place misses the final tidying step.

Question 32

After the lagging strand has been built and tidied, it is still a row of separate pieces with breaks between them. Explain how these pieces are finally joined into one continuous strand, and name the enzyme responsible.

Model Answer

The separate Okazaki fragments are joined together by the enzyme DNA ligase. It seals the breaks by joining the sugar-phosphate backbone of one fragment to the next, so the gaps between them are closed.

The result is one continuous, unbroken strand, turning the string of fragments on the lagging strand into a single complete strand like the leading strand. With this step the two new DNA molecules are finished, each a faithful copy of the original.

False Confidence Alert
Be careful not to say ligase makes the base pairs, or joins the two strands of the helix. Ligase joins fragments end to end along one strand's backbone, not the two strands across the helix, and confusing the two roles loses the mark.

Question 33

When a DNA molecule has been copied, each of the two new molecules is found to contain one old strand and one new one. Explain what is meant by semi-conservative replication and why this name is used.

Model Answer

Semi-conservative replication means that each new DNA molecule is made of one original (old) strand and one newly built strand. When the helix unwinds, each of the two old strands acts as a template for a new partner, so every daughter molecule keeps half of the original.

The name says exactly this: semi means half and conservative means kept, so half of each new molecule is conserved from the parent. This was confirmed by the Meselson and Stahl experiment, which showed that copied DNA is indeed a hybrid of one old and one new strand, not two completely new strands.

False Confidence Alert
Do not picture replication making two brand-new molecules while leaving the original whole. Each daughter molecule is a mix of one old and one new strand, so saying the parent strands stay together while two fresh copies form describes the wrong, conservative model.

Question 34

Replication is the work of a team of enzymes, each with its own task at the fork. Outline the part played by each of the main enzymes and proteins of DNA replication.

Model Answer

Several enzymes and proteins work together at the replication fork:

1) **Helicase:** unwinds the double helix and breaks the hydrogen bonds to open the replication fork.
2) **Single-strand binding proteins:** hold the separated strands apart so they cannot rejoin before they are copied.
3) **Primase:** lays down the short RNA primer that gives DNA polymerase a starting point.
4) **DNA polymerase III:** adds new DNA nucleotides 5' to 3', building the bulk of each new strand.
5) **DNA polymerase I:** removes the RNA primers and fills the gaps with DNA.
6) **DNA ligase:** joins the Okazaki fragments into one continuous strand.

A further enzyme, topoisomerase, relaxes the coiling ahead of the fork, so that the helix does not become over-twisted as helicase unwinds it.

False Confidence Alert
The marks are lost when the two polymerases are treated as the same enzyme. DNA polymerase III builds the new strand while DNA polymerase I removes the primers and fills the gaps, and blurring their two jobs leaves the account incomplete.

Question 35

A single diagram can hold the whole process together. Draw a labelled diagram of a replication fork, then state the overall direction in which the fork moves and what is happening on each of the two new strands.

Model Answer

A replication fork is drawn in Figure 5.4, with its enzymes and strands labelled.

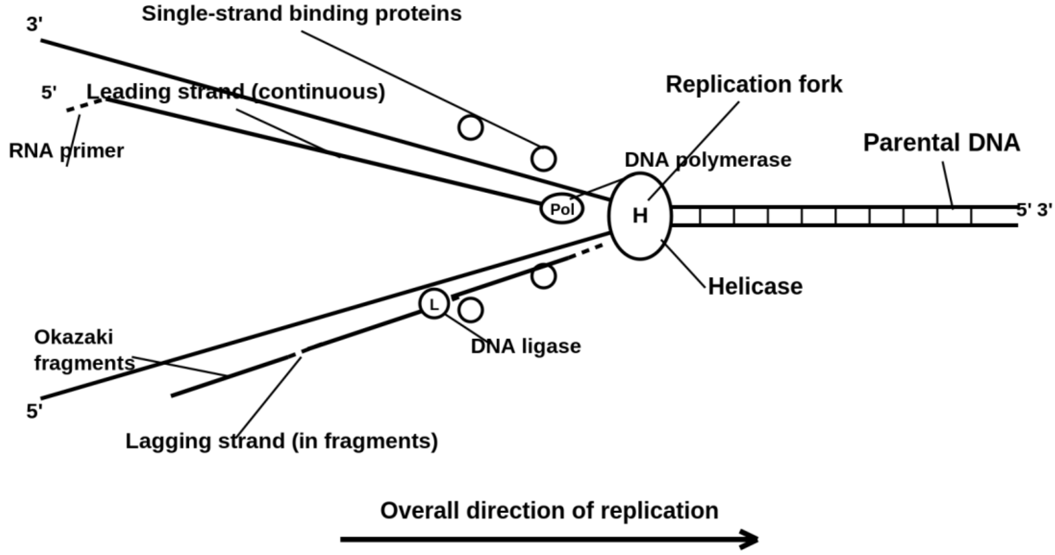


Figure 5.4: *A replication fork, showing helicase, the leading and lagging strands, the Okazaki fragments and the enzymes.*

The diagram shows the following:

1) **The fork and its direction:** helicase opens the parental DNA at the replication fork, and the fork moves along the molecule in the overall direction of replication, unwinding more DNA as it goes.
2) **The leading strand:** is built continuously toward the fork from a single RNA primer by DNA polymerase.
3) **The lagging strand:** is built away from the fork as short Okazaki fragments, each from its own primer, which DNA ligase later joins into one strand.

False Confidence Alert
A diagram earns little if the two new strands are drawn the same. The leading strand must be shown as one continuous piece and the lagging strand as separate fragments, because that contrast is the main thing the diagram has to teach.

Question 36

There are twenty amino acids to be specified but only four bases to do it with, so the code cannot simply read the bases one at a time. Explain why the genetic code must be read in groups of three bases.

Model Answer

The genetic code is a triplet code, which means the bases are read in groups of three, and each group of three codes for one amino acid. It must be a triplet because twenty different amino acids have to be specified using only the four bases.

Reading the bases in ones or twos does not give enough combinations: a single base gives only four codes and two bases give only sixteen, both fewer than the twenty amino acids needed. Three bases give sixty-four different combinations, which is more than enough to specify all twenty amino acids, with codes to spare.

False Confidence Alert
A neat-sounding but wrong answer is that two bases would do, since four times four is sixteen. Sixteen is still short of the twenty amino acids, so only a triplet, giving sixty-four codes, has enough room.

Question 37

Each triplet of bases on the mRNA has both a name and a meaning. Explain what a codon is, and why having sixty-four codons for only twenty amino acids is useful rather than wasteful.

Model Answer

A codon is a group of three bases on the mRNA that codes for one particular amino acid. Because each of the three positions can be any of the four bases, there are sixty-four possible codons in all.

Having sixty-four codons for twenty amino acids is useful, not wasteful, because the spare codes allow most amino acids to be specified by more than one codon, and they provide separate codons to mark where a chain should start and stop. This spare capacity also softens the effect of some mistakes in the code.

False Confidence Alert
It is wrong to assume that sixty-four codons must mean sixty-four amino acids. There are only twenty amino acids, and the extra codons are shared among them or used as start and stop signals, so matching the codon number to the amino-acid number is a mistake.

Question 38

Out of the sixty-four codons, a few do not stand for an amino acid at all but act as punctuation. Explain the part played by the start codon and the stop codons in protein synthesis.

Model Answer

One codon, AUG, is the start codon: it marks the point where reading of the message begins, and it also codes for the amino acid methionine. Reading always begins at this codon, so it sets the frame in which all the following triplets are read.

Three codons, UAA, UAG and UGA, are stop codons: they do not code for any amino acid but mark the end of the chain, so the ribosome stops and releases the finished polypeptide. Because they carry no amino acid, the stop codons are also called nonsense codons.

False Confidence Alert
Beware the idea that the stop codons code for some unusual amino acid. They code for no amino acid at all and simply signal the end of the chain, which is exactly why they are called nonsense codons.

Question 39

The meaning of every codon can be set out in a single table for reference. Study the genetic code table below, then work out the amino acids coded by the mRNA sequence AUG GUU CCA UAA.

1st \ 2nd	U	C	A	G
U	**UUU** Phe **UUC** Phe **UUA** Leu **UUG** Leu	**UCU** Ser **UCC** Ser **UCA** Ser **UCG** Ser	**UAU** Tyr **UAC** Tyr **UAA** Stop **UAG** Stop	**UGU** Cys **UGC** Cys **UGA** Stop **UGG** Trp
C	**CUU** Leu **CUC** Leu **CUA** Leu **CUG** Leu	**CCU** Pro **CCC** Pro **CCA** Pro **CCG** Pro	**CAU** His **CAC** His **CAA** Gln **CAG** Gln	**CGU** Arg **CGC** Arg **CGA** Arg **CGG** Arg
A	**AUU** Ile **AUC** Ile **AUA** Ile **AUG** Met (start)	**ACU** Thr **ACC** Thr **ACA** Thr **ACG** Thr	**AAU** Asn **AAC** Asn **AAA** Lys **AAG** Lys	**AGU** Ser **AGC** Ser **AGA** Arg **AGG** Arg
G	**GUU** Val **GUC** Val **GUA** Val **GUG** Val	**GCU** Ala **GCC** Ala **GCA** Ala **GCG** Ala	**GAU** Asp **GAC** Asp **GAA** Glu **GAG** Glu	**GGU** Gly **GGC** Gly **GGA** Gly **GGG** Gly

Model Answer

Reading the sequence in triplets against the table: AUG codes for methionine and is the start codon, GUU codes for valine, CCA codes for proline, and UAA is a stop codon.

The sequence therefore codes for three amino acids, methionine, valine and proline, and then stops.

> **False Confidence Alert**
> A frequent error is to read the bases one or two at a time instead of in fixed groups of three. The table gives the right answer only when the mRNA is split into non-overlapping triplets beginning at the start codon.

Question 40

Once reading of an mRNA begins, the bases are taken three at a time and never shared between codons. Explain what is meant by saying the genetic code is non-overlapping, and why the starting point matters.

Model Answer

A non-overlapping code is one in which each base belongs to only one codon, so the bases are read in fixed, separate groups of three. For example, the sequence AUGCUA is read as AUG then CUA, and the same bases are never reused in a neighbouring codon.

The starting point matters because it sets the reading frame: if reading began one base too early or too late, every triplet after it would be different and the wrong amino acids would be assembled. This is why a single base added or lost can change the whole message from that point onward.

> **False Confidence Alert**
> It is tempting to imagine the codons sharing bases, as in AUG, then UGC, then GCA. In a non-overlapping code each base is used only once, so the codons are AUG and then the next three bases, and overlapping them misreads the message.

Question 41

Most of the twenty amino acids can be called up by more than one codon. Explain what is meant by saying the genetic code is degenerate, and name the two amino acids that are exceptions.

Model Answer

A degenerate code is one in which most amino acids are coded by more than one codon. For example, the amino acid threonine is specified by four codons, ACU, ACC, ACA and ACG, which differ only in the third base; such alternatives are called synonymous codons.

Two amino acids are exceptions to this: methionine and tryptophan are each coded by a single codon only, AUG and UGG. The degeneracy is useful because a change in the third base of a codon often makes no difference to the amino acid, so some mutations have no effect at all.

> **False Confidence Alert**
> Degenerate is sometimes wrongly taken to mean the code is faulty or wasteful. It simply means several codons can stand for the same amino acid, which actually protects the organism by making many third-base changes harmless.

Question 42

A codon that means valine in a bacterium means valine in a human being too. Explain what is meant by saying the genetic code is universal, and why this matters for genetic engineering.

Model Answer

A universal code is one that is the same in almost all living things, so a given codon stands for the same amino acid in a bacterium, a maize plant and a human being. This shared code is strong evidence that all life has a common origin.

Its universality is what makes genetic engineering possible: because the code is read the same way everywhere, a human gene placed into a bacterium produces the same protein, such as human insulin. A few minor exceptions exist, for instance in mitochondria, where UGA codes for tryptophan instead of acting as a stop codon.

False Confidence Alert
It is a mistake to claim the code is identical in absolutely every organism without exception. It is very nearly universal, but a few exceptions exist, such as in mitochondria, so the safe statement is that the code is almost universal.

Question 43

The instructions for a protein are written in the DNA of the nucleus, but the protein is built on a ribosome out in the cytoplasm, and the two are never in the same place. Explain why protein synthesis must happen in two stages, and name them.

Model Answer

Protein synthesis happens in two stages because the DNA that holds the instructions cannot leave the nucleus or be read directly by the ribosome. A working copy of the instructions must first be made and carried out to where the protein is built.

The two stages are transcription and translation: in transcription the base sequence of a gene is copied from DNA into a molecule of messenger RNA inside the nucleus; in translation that mRNA is read at the ribosome in the cytoplasm and its message is used to join amino acids into a protein. The mRNA is therefore the link that carries the message from the gene to the ribosome.

False Confidence Alert
A common misconception is that a protein is built straight from the DNA. The DNA stays in the nucleus and its message must first be copied into mRNA, so an account that skips transcription and reads protein directly off the DNA loses marks.

Question 44

When a gene is switched on, only one of its two DNA strands is actually copied. Explain how messenger RNA is built during transcription, naming the enzyme and saying how its bases are chosen.

Model Answer

In transcription the enzyme RNA polymerase unwinds the gene and copies just one of the two DNA strands, called the template strand. It moves along the template in the 3' to 5' direction and builds the new mRNA in the 5' to 3' direction, and it needs no primer to start.

The bases of the new mRNA are chosen by complementary base pairing with the template: each template base calls up its RNA partner, so guanine pairs with cytosine and cytosine with guanine, a thymine on the template calls up adenine, and an adenine on the template calls up uracil, since RNA carries uracil in place of thymine. The finished mRNA is therefore a complementary copy of the template strand.

False Confidence Alert
A frequent slip is to pair adenine with thymine when building the mRNA. RNA carries no thymine, so an adenine on the template calls up uracil, and writing thymine into an RNA strand loses the mark.

Question 45

A diagram makes the two roles of the DNA strands clear at once. Draw a labelled diagram of transcription, then state what RNA polymerase is doing and which strand becomes the pattern for the mRNA.

Model Answer

Transcription is drawn in Figure 5.5, with the DNA strands, the enzyme and the new mRNA labelled.

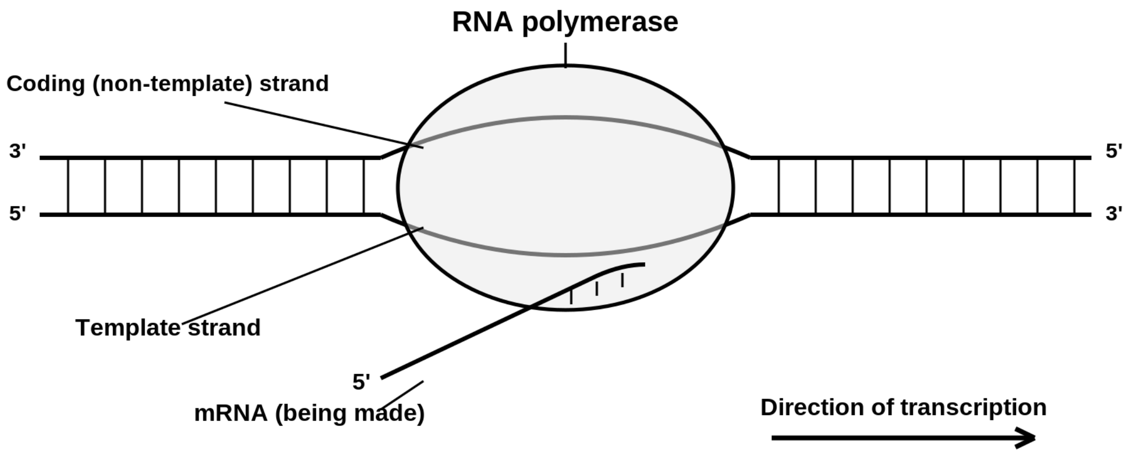


Figure 5.5: *Transcription. RNA polymerase reads the template strand and builds a complementary mRNA copy.*

The diagram shows the following:

1) **RNA polymerase:** unwinds the DNA and moves along it, building the new mRNA from free RNA nucleotides as it goes.
2) **The template strand:** is the one strand that is read, and the mRNA is built as a complementary copy of it, while the other strand, the coding strand, is not read.

> **False Confidence Alert**
> A diagram earns little if both DNA strands are shown being copied. Only the template strand is read, so a correct drawing shows one new mRNA forming against one strand, not two new strands forming against both.

Question 46

Transcription does not happen all at once but moves through three clear phases. Outline the three stages of transcription and say what happens in each.

Model Answer

Transcription passes through three stages:

1) Initiation: RNA polymerase recognises and binds a special sequence at the start of the gene called the promoter, and the DNA unwinds so that copying can begin.
2) Elongation: the enzyme moves along the template strand, adding RNA nucleotides one by one to build the growing mRNA by complementary base pairing.
3) Termination: when the enzyme reaches a stop signal at the end of the gene it stops, the finished mRNA is released, and the DNA re-forms its double helix.

> **False Confidence Alert**
> It is easy to forget the promoter and let RNA polymerase start just anywhere on the DNA. The enzyme must first bind the promoter, which marks where the gene begins and fixes which strand is read, so leaving it out loses the initiation mark.

Question 47

Both DNA replication and transcription copy DNA, yet they are quite different processes with different ends. Compare transcription with DNA replication.

Model Answer

Transcription and replication differ in several ways:

1) **How much is copied:** replication copies both strands of the whole DNA molecule, whereas transcription copies just one strand of a single gene.
2) **The enzyme:** replication is carried out by DNA polymerase, transcription by RNA polymerase.
3) **The product:** replication makes a new DNA strand, transcription makes a molecule of mRNA.
4) **Bases and primer:** replication uses thymine and needs an RNA primer to start, while transcription uses uracil in place of thymine and needs no primer.

The purposes differ too: replication makes a complete second copy of all the DNA before a cell divides, while transcription makes a short, disposable working copy of one gene so that its protein can be built.

False Confidence Alert
The trap is to treat the two as the same copying process. Replication duplicates the whole genome in DNA for the next cell, whereas transcription copies one gene into RNA for immediate use, and blurring the two misses the point of each.

Question 48

In a eukaryotic cell the first mRNA made is not yet ready to be used; it must be tidied up before it leaves the nucleus. Explain the main changes made to the new mRNA before it is translated, and why they are useful.

Model Answer

The newly made mRNA of a eukaryote is modified in three main ways before it leaves the nucleus. A protective cap is added to one end and a tail of many adenine nucleotides, the poly-A tail, is added to the other; these protect the mRNA from being broken down and help it to be recognised at the ribosome.

The third change is splicing: non-coding stretches called introns are cut out and the remaining coding pieces, the exons, are joined together. This makes a shorter, finished mRNA, and because the exons can sometimes be joined in different ways, one gene can give rise to more than one protein.

False Confidence Alert
It is a mistake to think the first mRNA made is ready to use straight away. In eukaryotes it must first be capped and tailed, and then spliced to cut out the introns, so describing the raw transcript as the finished message loses the mark.

Question 49

Before amino acids can be joined into a protein, each one must be picked up and carried to the ribosome by the right tRNA. Explain how the ribosome and the tRNAs are made ready for translation, including how each amino acid is matched to its tRNA.

Model Answer

Translation begins when the small subunit of the ribosome attaches to the mRNA and the large subunit joins it, so the ribosome can hold the mRNA and read it three bases at a time. The ribosome, built largely of rRNA, is the machine on which the amino acids are joined.

Each amino acid is matched to its own tRNA by an enzyme called aminoacyl-tRNA synthetase, which uses energy from ATP to attach the correct amino acid to the tRNA that carries the matching anticodon. This activation step makes sure that every tRNA reaches the ribosome already bearing the right amino acid for its codon.

False Confidence Alert
A common error is to think the ribosome itself chooses which amino acid goes where. Each amino acid is matched to its tRNA beforehand by aminoacyl-tRNA synthetase, and the ribosome only joins whatever the correctly loaded tRNAs deliver.

Question 50

Like transcription, translation moves through three stages as the message is read. Outline the three stages of translation and say what happens in each.

Model Answer

Translation passes through three stages:

1) **Initiation:** the small ribosomal subunit binds the mRNA and finds the start codon AUG, the first tRNA pairs with it, and the large subunit joins to complete the ribosome.
2) **Elongation:** the ribosome moves along the mRNA codon by codon, each new tRNA pairs its anticodon with the codon, and a peptide bond joins its amino acid to the growing chain.
3) **Termination:** when the ribosome reaches a stop codon no tRNA fits it, so a release factor ends the process and the finished polypeptide is set free.

False Confidence Alert
It is tempting to say the chain grows simply because the amino acids line up along the mRNA. They are brought one at a time by tRNAs whose anticodons must pair the codons, and a peptide bond must form each time, so leaving out the tRNAs and the bonds loses marks.

Question 51

A diagram shows at a glance how the codon, the anticodon and the growing chain fit together. Draw a labelled diagram of translation at a ribosome, then state how the correct amino acid is chosen and how the chain grows.

Model Answer

Translation is drawn in Figure 5.6, with the ribosome, the mRNA, the tRNAs and the growing chain labelled.

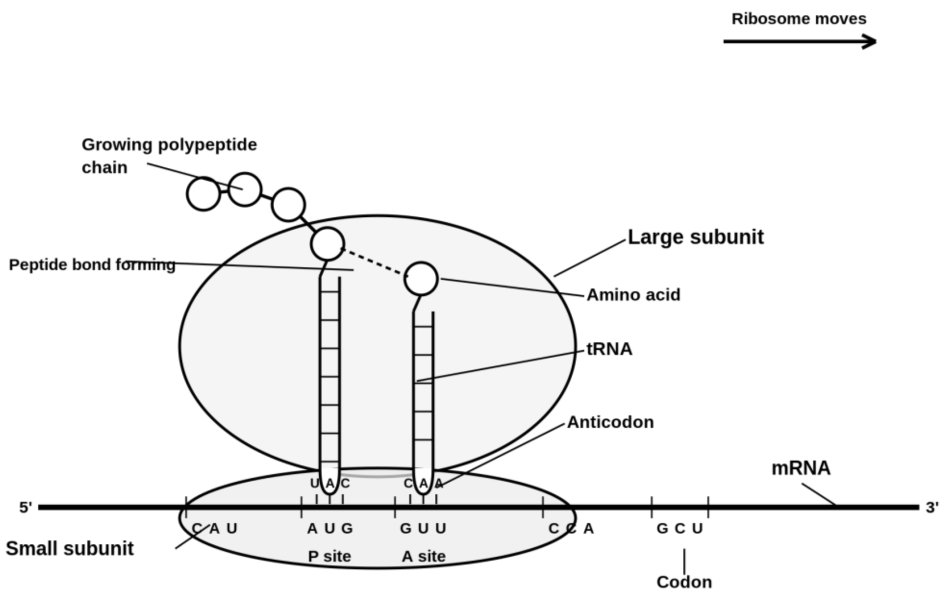


Figure 5.6: ***Translation***. *The ribosome reads the mRNA codon by codon; each tRNA pairs its anticodon with a codon and a peptide bond adds its amino acid to the growing chain.*

The diagram shows two things:

1) **How the correct amino acid is chosen:** each tRNA carries an anticodon that pairs only with the matching codon on the mRNA, so only the tRNA bearing the right amino acid can fit at that position.

2) **How the chain grows:** a peptide bond forms between the chain already held in the ribosome and the new amino acid just brought in, adding it to the growing polypeptide, and the ribosome then moves on to the next codon.

False Confidence Alert
A drawing earns little if the anticodon is left off the tRNA. It is the pairing of anticodon with codon that selects the right amino acid, so a diagram without it cannot show how the message is read.

Question 52

The chain that leaves the ribosome is not yet a working protein, and a single mRNA is rarely read by just one ribosome. Explain what the immediate product of translation is and what becomes of it, and what a polysome is.

Model Answer

The immediate product of translation is a chain of amino acids joined in a particular order, which is only the primary structure of the protein. This chain must then fold into its three-dimensional shape, and may be modified further, before it can work.

A single mRNA is usually read by several ribosomes at the same time, each at a different point along the message and each building its own copy of the protein. A group of ribosomes translating one mRNA together in this way is called a polysome, and it lets the cell make many copies of a protein quickly from a single message.

False Confidence Alert
It is a mistake to treat the chain released from the ribosome as the finished, working protein. It is only the primary structure and must still fold into its proper shape, so calling the raw chain a functional protein loses the mark.

Question 53

Long before genes were seen, a monk named Gregor Mendel worked out the rules of inheritance by breeding pea plants in a monastery garden. Explain why the garden pea was such a good choice for his experiments, and what made his method succeed where earlier breeders had failed.

Model Answer

The garden pea (*Pisum sativum*) was an ideal choice for several reasons that made clear results possible:

1) **Pure-breeding varieties:** the pea had many varieties that bred true, such as tall and short, giving reliable starting material.
2) **Clearly contrasting characters:** each character came in two sharply different forms, such as round or wrinkled seeds, that were easy to tell apart and to count.
3) **Controlled mating:** the flowers normally self-pollinate but can also be cross-pollinated by hand, so Mendel could choose exactly which plants to cross.
4) **Quick and fertile:** the pea grows fast, gives many offspring and produces fertile hybrids, so large numbers could be counted over several generations.

His method succeeded because he followed one character at a time and counted the offspring, using large numbers so that the ratios stood out clearly, instead of trying to follow many features at once as earlier breeders had done. This careful, mathematical approach let him see the simple ratios that revealed the rules of inheritance.

False Confidence Alert
It is not enough to say Mendel simply chose the pea plant. The marks come from the reasons the pea suited him, pure-breeding and contrasting characters with controlled pollination, together with his one-character-at-a-time counting method.

Question 54

Genetics has its own precise language, and using the right word in the right place is half the battle in a cross. Explain the terms gene, allele, dominant, recessive, homozygous, heterozygous, genotype and phenotype, and show how they fit together in deciding a trait.

Model Answer

These terms build on one another to describe how a trait is decided:

1) **Gene:** a length of DNA that carries the instruction for one character, such as seed shape.

2) **Allele:** one of the alternative forms of a gene, such as the allele for round or the allele for wrinkled seed.

3) **Dominant:** an allele that shows its effect even when only one copy is present, written with a capital letter, R.

4) **Recessive:** an allele whose effect is hidden when a dominant allele is present and shows only when two copies are present, written with a small letter, r.

5) **Homozygous:** having two identical alleles of a gene, such as RR or rr.

6) **Heterozygous:** having two different alleles of a gene, such as Rr.

7) **Genotype:** the alleles an organism carries, such as Rr.

8) **Phenotype:** the visible character that results, such as a round seed.

Together they explain a trait: the alleles of a gene make up the genotype, and the genotype, through dominance, decides the phenotype that is seen.

> **False Confidence Alert**
> The common mix-up is between genotype and phenotype. The genotype is the alleles carried, such as Rr, while the phenotype is the visible result, a round seed, and using one word for the other throws away easy marks.

Question 55

When you set out a genetic cross, following a fixed order keeps the working clear and prevents mistakes. Explain how a genetic cross should be laid out, naming each line you would write.

Model Answer

A genetic cross is set out in a fixed order, one line beneath the next:

1) **Parental phenotypes:** the visible characters of the two parents being crossed.

2) **Parental genotypes:** the alleles each parent carries, written beneath its phenotype.

3) **Gametes:** the alleles each parent passes on, each circled and kept separate, since a gamete carries only one allele of the gene.

4) **Fertilisation:** the gametes are combined, usually in a Punnett square, to show every possible pairing.

5) **Offspring genotypes and phenotypes:** the genotypes produced and the visible characters and ratio that result.

Keeping to this order matters because each line follows from the one above, so the working can be checked step by step and the final ratio can be trusted.

> **False Confidence Alert**
> Marks are often lost by jumping straight from the parents to the offspring. The gametes must be shown separately, each carrying only one allele, because it is the random pairing of these single-allele gametes that gives the offspring ratio.

Question 56

When Mendel crossed a tall pea with a short one, all the offspring were tall, yet short plants reappeared in the next generation. Explain how a monohybrid cross gives a uniform first generation and then a 3:1 ratio, and why the short character disappears and then returns.

Model Answer

A monohybrid cross follows a single character, here height, controlled by one gene with a dominant allele (T) and a recessive allele (t). When a pure tall plant (TT) is crossed with a pure short one (tt), every offspring receives one allele from each parent and so is Tt; because tall is dominant, the whole first generation (F1) is tall, and the short character seems to disappear.

The short character returns in the second generation because the recessive allele has only been hidden, not lost. When two F1 plants (Tt) are crossed, their gametes combine at random to give offspring in the ratio 1 TT : 2 Tt : 1 tt, which shows as 3 tall : 1 short. The short plants reappear wherever two recessive alleles happen to come together.

> **False Confidence Alert**
> A frequent error is to think the short character is lost in the F1. It is only hidden, because the recessive allele is carried unseen in the heterozygous F1 and reappears in the F2 whenever two recessive alleles meet.

Question 57

A clear genetic diagram shows exactly where each ratio comes from. Set out a full monohybrid cross for pea seed shape, in which round (R) is dominant to wrinkled (r), from pure-breeding parents through to the F2, showing the gametes, a Punnett square and the F2 ratio.

Model Answer

The cross is set out below, from the parents through to the second generation.

Parents, phenotype: round seed × wrinkled seed

Parents, genotype: RR × rr

Gametes: all R × all r

F1 generation: all Rr (all round)

F1 self-pollinated: Rr × Rr (each parent gives gametes R and r)

Punnett square:

	R	**r**
R	RR	Rr
r	Rr	rr

F2 genotype: 1 RR : 2 Rr : 1 rr

F2 phenotype: 3 round : 1 wrinkled

> **False Confidence Alert**
> The diagram loses marks if the gametes are written as pairs such as RR instead of single alleles. Each gamete carries only one allele, R or r, and it is the pairing of these single alleles in the Punnett square that produces the 3:1 ratio.

Question 58

The familiar 3:1 ratio of the F2 hides a more detailed pattern underneath. Explain why the 3:1 ratio of phenotypes is really a 1:2:1 ratio of genotypes, and why this matters when you look at the dominant offspring.

Model Answer

The three round plants of the F2 are not all the same underneath, but a mixture of two genotypes. The F2 genotypes come in the ratio 1 RR : 2 Rr : 1 rr, and because both RR and Rr look round, the three round plants are one RR and two Rr, while the single wrinkled plant is rr. So the visible 3:1 hides a genotype ratio of 1:2:1.

This matters because the round plants cannot be told apart just by looking, since a pure RR and a heterozygous Rr have exactly the same round phenotype. To find out which is which, the plant must be crossed with a wrinkled (rr) plant, which is the test cross.

False Confidence Alert
It is wrong to assume that every round F2 plant is pure-breeding. Two of every three round plants are heterozygous (Rr) and carry a hidden wrinkled allele, so treating them all as RR is a costly mistake.

Question 59

Mendel's first law explains why each parent passes on only one of its two alleles. State Mendel's law of segregation, and explain it by what happens to the chromosomes during meiosis.

Model Answer

Mendel's law of segregation, the first law, states that the two alleles of a gene separate during the formation of gametes, so each gamete carries only one allele of the gene. The two alleles are then brought together again at fertilisation, one coming from each parent.

This is explained by the behaviour of the chromosomes in meiosis: the two alleles of a gene lie on the two homologous chromosomes of a pair, and when these homologous chromosomes separate at anaphase I of meiosis, the alleles are carried apart into different gametes. The law of segregation is therefore simply the result of homologous chromosomes parting during meiosis.

False Confidence Alert
Stating the law as a bare rule about alleles earns only half the marks. The explanation marks come from linking it to meiosis, where the two alleles separate because the homologous chromosomes carrying them separate at anaphase I.

Question 60

In mice, a cross between a pure black mouse and a pure brown mouse gave all black offspring. When two of these offspring were later mated, they produced young in the ratio of about 3 black to 1 brown. From these results, deduce which character is dominant, give the genotypes of all the mice mentioned, and explain the 3:1 ratio.

Model Answer

Because the first cross of pure black with pure brown gave all black offspring, black is the dominant character. If brown were dominant, some brown young would have appeared in that first cross, so the all-black result shows that the black allele masks the brown one.

Writing black as B and brown as b, the genotypes are:

1) Pure black parent: BB.

2) Pure brown parent: bb.

3) First-generation offspring: all Bb, which look black because B is dominant.

4) The mating of two offspring: Bb × Bb.

The 3:1 ratio arises because the first-generation mice are all heterozygous (Bb): each carries a hidden brown allele, so when two are mated their B and b gametes combine at random to give 1 BB : 2 Bb : 1 bb, which shows as 3 black : 1 brown.

> **False Confidence Alert**
> The reasoning is incomplete if you name the dominant character without showing how the results prove it. The proof is that a cross of two pure lines gave only black offspring, so black must be dominant, and stating dominance without this evidence loses the reasoning marks.

Question 61

An organism showing a dominant character may be pure-breeding, or it may carry a hidden recessive allele, and the two cannot be told apart just by looking. Explain what a test cross is and how it reveals the unknown genotype.

Model Answer

A test cross is a cross between an organism that shows the dominant character but whose genotype is unknown, and an organism that is homozygous recessive. The homozygous recessive partner can pass on only recessive alleles, so the offspring reveal what alleles the unknown parent was carrying.

The offspring show which genotype the unknown parent had: if all of them show the dominant character, the unknown parent was homozygous dominant, because it had no recessive allele to pass on; but if about half of them show the recessive character, the unknown parent was heterozygous, because half of its gametes carried the hidden recessive allele.

> **False Confidence Alert**
> It is a mistake to test the unknown organism by crossing it with another that shows the dominant character. Only a homozygous recessive partner works, because a dominant partner would mask the recessive alleles and the result could not be read.

Question 62

Whether a tall pea plant is pure-breeding can only be settled by a cross. Work a test cross for a tall pea plant, where tall (T) is dominant to short (t), showing what the offspring would be if the plant were homozygous (TT) and if it were heterozygous (Tt).

Model Answer

The tall plant of unknown genotype is crossed with a short plant, which must be homozygous recessive (tt). There are two possible results.

If the tall plant is homozygous (TT):

Cross: TT (tall) × tt (short)

Gametes: all T × all t

Offspring: all Tt, all tall

If the tall plant is heterozygous (Tt):

Cross: Tt (tall) × tt (short)

Gametes: T and t × t and t

Punnett square:

	t	**t**
T	Tt	Tt
t	tt	tt

Offspring: 2 Tt : 2 tt, that is 1 tall : 1 short

So the result tells you the genotype: an all-tall offspring means the parent was homozygous (TT), while a 1 tall : 1 short result means it was heterozygous (Tt).

> **False Confidence Alert**
> The slip here is to expect a 3:1 ratio from a test cross. A test cross uses a homozygous recessive partner, so a heterozygous plant gives a 1:1 ratio, not 3:1, and quoting 3:1 shows the test cross has been confused with an F1 self-cross.

Question 63

Once a cross has been worked out, the chance that any one offspring shows a particular feature can be read straight from it. Explain how the probability of an offspring's genotype or phenotype is found from a cross, using the cross Rr × Rr as your example.

Model Answer

The probability of an outcome is read from the proportion of the offspring that show it, written as a fraction or a percentage. In the cross Rr × Rr, where R stands for round seed and r for wrinkled, the Punnett square gives four equally likely offspring: RR, Rr, Rr and rr.

From these four boxes the chances are read directly: three of the four are round, so the chance of a round offspring is 3 in 4, or 3/4 (75%), while one of the four is wrinkled, so the chance of a wrinkled offspring is 1 in 4, or 1/4 (25%). In the same way the chance of the RR genotype is 1/4, of Rr is 2/4 (a half), and of rr is 1/4.

> **False Confidence Alert**
> A common error is to think that because the last offspring was round, the next must be wrinkled. Each offspring is an independent event, so the chance stays 3 in 4 round every time, whatever came before.

Question 64

Mendel did not stop at one character; he followed two at once, such as the shape and the colour of pea seeds, and found a new ratio. Explain how a dihybrid cross gives a 9:3:3:1 ratio in the F2, and why this ratio is really two 3:1 ratios combined.

Model Answer

A dihybrid cross follows two characters at the same time, here seed shape (round R, dominant to wrinkled r) and seed colour (yellow Y, dominant to green y). When a plant pure for both dominants (RRYY) is crossed with one pure for both recessives (rryy), all the F1 are RrYy and show both dominant characters, round and yellow.

When the F1 are crossed, the F2 appears in the ratio 9 round yellow : 3 round green : 3 wrinkled yellow : 1 wrinkled green. This 9:3:3:1 is really two separate 3:1 ratios combined, because each character on its own still gives 3 round : 1 wrinkled and 3 yellow : 1 green. The two characters are inherited independently, so their ratios multiply together.

> **False Confidence Alert**
> It is wrong to expect a dihybrid cross to give a simple 3:1. Following two characters at once gives 9:3:3:1, because the two 3:1 ratios combine, and quoting 3:1 here shows that only one character has been considered.

Question 65

The 9:3:3:1 ratio is easiest to see when the whole cross is set out. Work a dihybrid cross between two pea plants heterozygous for both seed shape (round R, wrinkled r) and seed colour (yellow Y, green y), showing the gametes, a Punnett square and the F2 phenotype ratio.

Model Answer

Both parents are RrYy, round and yellow, and each one makes four kinds of gamete.

Parents: RrYy (round yellow) × RrYy (round yellow)

Gametes from each parent: RY, Ry, rY and ry

Punnett square:

	RY	**Ry**	**rY**	**ry**
RY	RRYY	RRYy	RrYY	RrYy
Ry	RRYy	RRyy	RrYy	Rryy
rY	RrYY	RrYy	rrYY	rrYy
ry	RrYy	Rryy	rrYy	rryy

Reading the sixteen boxes by phenotype gives the F2 ratio: nine round yellow (with at least one R and one Y), three round green (R but yy), three wrinkled yellow (rr but Y), and one wrinkled green (rryy), that is 9 : 3 : 3 : 1.

> **False Confidence Alert**
> The usual mistake is to give each parent only two kinds of gamete, such as R and Y. A plant that is RrYy makes four kinds, RY, Ry, rY and ry, carrying one allele of each gene, and missing this gives the wrong ratio.

Question 66

Mendel's second law explains why the two characters in a dihybrid cross are inherited independently of each other. State Mendel's law of independent assortment, and explain it by what happens to the chromosomes during meiosis.

Model Answer

Mendel's law of independent assortment, the second law, states that the alleles of different genes are passed into the gametes independently of one another, so the way one pair of alleles separates has no effect on how another pair separates. This is why a parent RrYy can make all four kinds of gamete, RY, Ry, rY and ry, in equal numbers.

This is explained by the random arrangement of the chromosomes in meiosis: at metaphase I each pair of homologous chromosomes lines up at the equator independently of the other pairs, so the maternal and paternal chromosomes are shuffled at random before they separate. Because the two genes lie on different chromosome pairs, their alleles are dealt into the gametes in every possible combination.

> **False Confidence Alert**
> Independent assortment is not the same as segregation. Segregation is the separation of the two alleles of one gene, while independent assortment is the random combining of the alleles of different genes, and confusing the two laws is a common error.

Question 67

Independent assortment holds only when the two genes lie on different chromosomes; when they lie on the same chromosome, the rule breaks down. Explain what is meant by linkage, why it makes a dihybrid cross depart from the 9:3:3:1 ratio, and how crossing over partly overcomes it.

Model Answer

Two genes are said to be linked when they lie on the same chromosome, so their alleles tend to be inherited together rather than independently. Because linked genes travel together into the same gamete, the parental combinations appear far more often than expected, and the offspring do not show the 9:3:3:1 ratio that independent assortment would give.

Crossing over partly overcomes the linkage: during meiosis the homologous chromosomes can exchange segments at the chiasmata, so a few gametes carry new, recombined combinations of the linked alleles. These recombinants appear in small numbers, and the closer together the two genes lie, the fewer recombinants there are, a fact used to map genes along a chromosome.

False Confidence Alert
It is a mistake to think linked genes can never be separated. Crossing over does separate them in a few gametes, so linkage makes the parental types common but does not make them the only possibility.

Question 68

Sometimes an organism carries an allele for a character yet does not show it, and sometimes the same allele shows much more strongly in one individual than in another. Explain what is meant by penetrance and by expressivity, giving an example of each.

Model Answer

Penetrance is the proportion of the individuals carrying an allele who actually show its effect in the phenotype. If every carrier shows the character the allele is fully penetrant, but if some carriers do not show it the allele has reduced penetrance; for example, the dominant allele for polydactyly (extra fingers or toes) is not always expressed, so a few people who carry it have the normal number of digits.

Expressivity is the degree to which the allele's effect shows in those who do express it. The same allele may give a strong effect in one individual and a weak one in another; for example, polydactyly may show as one extra finger on a single hand, or as extra digits on both hands and feet. Both penetrance and expressivity are influenced by other genes and by the environment.

False Confidence Alert
Penetrance and expressivity are easy to swap. Penetrance is whether the allele shows at all (how many carriers express it), while expressivity is how strongly it shows in those who do, and using one term for the other loses the mark.

Question 69

When a red-flowered snapdragon is crossed with a white one, the offspring are neither red nor white but pink. Explain what incomplete dominance is, and why it gives a 1:2:1 ratio in the F2 that differs from Mendel's 3:1.

Model Answer

Incomplete dominance is when neither allele is fully dominant, so the heterozygote shows a blended phenotype that lies between the two homozygotes. A red snapdragon (RR) crossed with a white one (rr) gives an F1 that is all Rr and pink, because one red allele on its own cannot make a fully red flower.

The F2 shows a 1:2:1 ratio because the blended heterozygote can now be seen: crossing two pink F1 plants (Rr × Rr) gives 1 RR : 2 Rr : 1 rr, which shows as 1 red : 2 pink : 1 white. The phenotype ratio equals the genotype ratio here, unlike Mendel's 3:1, because each genotype has its own distinct appearance.

False Confidence Alert
It is wrong to expect the usual 3:1 from incomplete dominance. Because the heterozygote looks different from both homozygotes, the F2 is 1:2:1, with the phenotype ratio matching the genotype ratio exactly.

Question 70

A genetic diagram makes the pink generation easy to follow. Set out a full cross for flower colour in snapdragons, where red (R) and white (r) show incomplete dominance, from the pure-breeding parents to the F2, showing the gametes and the F2 ratio.

Model Answer

The cross is set out below; the heterozygote Rr is pink because neither allele is fully dominant.

Parents, phenotype: red × white

Parents, genotype: RR × rr

Gametes: all R × all r

F1 generation: all Rr, all pink

F1 crossed: Rr × Rr (each gives gametes R and r)

Punnett square:

	R	**r**
R	RR	Rr
r	Rr	rr

F2 genotype: 1 RR : 2 Rr : 1 rr

F2 phenotype: 1 red : 2 pink : 1 white

False Confidence Alert
The diagram is spoiled if the F1 is written as red just because R is a capital letter. The capital does not mean full dominance here, since Rr is pink, so the heterozygote must be shown as the blended colour and not as red.

Question 71

In some cattle a cross between a red animal and a white one gives offspring that are roan, with red and white hairs mixed together rather than a single blended colour. Explain what co-dominance is, and how it differs from incomplete dominance.

Model Answer

Co-dominance is when both alleles of the heterozygote are fully expressed at the same time, so both characters appear together instead of blending. In roan cattle the heterozygote shows patches of red hairs and white hairs side by side, because both the red allele and the white allele have their full effect.

It differs from incomplete dominance in how the heterozygote looks: in incomplete dominance the two alleles blend into a new, intermediate phenotype such as pink, whereas in co-dominance there is no blend and both parental characters are seen together, such as red and white hairs in the one animal. Both, however, still give a 1:2:1 ratio in the F2.

False Confidence Alert
Co-dominance and incomplete dominance are often confused. In co-dominance both alleles show fully and separately, as red and white hairs together, while in incomplete dominance they blend into something new such as pink, so the test is whether the heterozygote blends or shows both.

Question 72

The human ABO blood group system is decided by a gene that has not two but three alleles, and two of those alleles are co-dominant. Explain how the ABO blood groups show both multiple alleles and co-dominance.

Model Answer

The ABO blood group gene has three alleles, written I^A, I^B and I^O, although any one person carries only two of them. A gene with more than two possible alleles in the population in this way is said to show multiple alleles.

The alleles also show co-dominance: I^A and I^B are co-dominant, so a person who is I^AI^B has blood group AB and makes both the A and the B antigen, while I^O is recessive to both. This gives the four blood groups: A (I^AI^A or I^AI^O), B (I^BI^B or I^BI^O), AB (I^AI^B) and O (I^OI^O).

> **False Confidence Alert**
> A common slip is to think a person can carry all three ABO alleles at once. There are three alleles in the population, but each individual has only two, one inherited from each parent, so writing a genotype with three alleles is impossible.

Question 73

In sweet peas, two different pure-white varieties, when crossed, give purple-flowered offspring, and the next generation shows purple and white in a 9:7 ratio. Explain how complementary genes work and why this cross gives a 9:7 ratio.

Model Answer

Complementary genes are two different genes that must both be present in their dominant form for a character to appear; if either one is missing, the character does not show. In sweet peas, purple colour needs a dominant allele of both gene C and gene P, so one pure-white line is CCpp and the other is ccPP, each lacking one of the two dominants and therefore white.

When the two whites are crossed, the F1 (CcPp) has both dominants and is purple, and crossing two such F1 plants gives an F2 in which only the nine plants carrying at least one C and one P (C_P_) are purple, while the other seven, which lack one dominant or the other, are white. The usual 9:3:3:1 framework collapses to 9 purple : 7 white because those last three classes all look the same.

> **False Confidence Alert**
> The error is to expect colour whenever a dominant allele appears. With complementary genes both dominants are needed together, so a plant with only one of them (C_pp or ccP_) is still white, which is why the ratio is 9 purple : 7 white and not 9:3:3:1.

Question 74

Sometimes one gene can hide the effect of a completely different gene, just as a switch turned off stops a lamp working however good the bulb. Explain what is meant by epistasis, naming the two kinds of gene involved, and how it changes the result of a dihybrid cross.

Model Answer

Epistasis is when one gene masks or hides the effect of a different gene at another locus, so the hidden gene cannot show in the phenotype. The gene that does the masking is called the epistatic gene, and the gene whose effect is hidden is called the hypostatic gene.

Epistasis changes a dihybrid cross by altering the usual 9:3:3:1 ratio: because one gene hides the other, some of the four phenotype classes Mendel would expect are merged together, giving modified ratios such as 9:3:4, 12:3:1 or 15:1 instead of 9:3:3:1. Which ratio appears depends on which gene masks which and on whether the masking allele is dominant or recessive.

False Confidence Alert
A common mistake is to think epistasis always produces one fixed ratio. Which modified ratio appears (9:3:4, 12:3:1 or 15:1) depends on which gene masks which and on whether the masking allele is dominant or recessive, so the ratio is not fixed.

Question 75

In Labrador dogs, coat colour depends on two genes, and a dog that cannot lay down any pigment is yellow whatever its other colour gene says. Using gene B (black B, brown b) and gene E (pigment allowed E, no pigment e), work the cross between two black dogs heterozygous for both genes, and explain the 9:3:4 ratio.

Model Answer

Both parents are BbEe and black, and each one makes four kinds of gamete: BE, Be, bE and be.

Parents: BbEe (black) × BbEe (black)

Gametes from each: BE, Be, bE and be

The key is that ee masks gene B: a dog needs at least one E to make any pigment, so any ee dog is yellow whatever its B/b genotype. The sixteen offspring fall into three colour classes:

1) Black (9): B_E_, with at least one B and one E, so black pigment is made and shown.

2) Brown (3): bbE_, brown pigment is made (E present) but it is brown because there is no B.

3) Yellow (4): every ee dog, that is B_ee (3) and bbee (1), because no pigment can be laid down at all.

So the ratio is 9 black : 3 brown : 4 yellow. The usual 9:3:3:1 has become 9:3:4 because the two ee classes, which would have been 3 and 1, are merged into one yellow class of 4.

False Confidence Alert
The trap is to give a 9:3:3:1 answer because two genes are involved. Here gene E is epistatic, so every ee dog is yellow whatever gene B says, and the two recessive-ee classes merge to give 9:3:4, not 9:3:3:1.

Question 76

In summer squash, a single dominant allele of one gene gives white fruit no matter what a second colour gene says, and only plants without that allele show any colour. Explain how this dominant epistasis gives a 12:3:1 ratio.

Model Answer

In dominant epistasis a single dominant allele of the epistatic gene hides the second gene completely. In summer squash a dominant allele W gives white fruit whatever the colour gene says, so any plant with at least one W is white.

Only plants that are ww can let the colour gene show: among these, wwG_ are yellow and wwgg are green. In the F2 of a WwGg × WwGg cross, the 12 plants with at least one W (the 9 W_G_ plus the 3 W_gg) are all white, 3 (wwG_) are yellow and 1 (wwgg) is green, giving 12 white : 3 yellow : 1 green.

False Confidence Alert
It is easy to forget that one dominant allele is enough to mask the other gene here. Because a single W makes the fruit white, the 9 and the 3 of the 9:3:3:1 merge into 12 white, so expecting four separate classes loses the mark.

Question 77

When two genes do the same job, the F2 can show one of two strikingly different ratios depending on how they share the work. Explain duplicate recessive epistasis, which gives a 9:7 ratio, and duplicate dominant epistasis, which gives a 15:1 ratio.

Model Answer

In duplicate recessive epistasis the character appears only when both genes carry at least one dominant allele, so being recessive at either gene blocks it. This is like complementary genes: only the 9 individuals that are A_B_ show the character, while the other 7, which are recessive at one gene or the other, do not, giving a 9:7 ratio.

In duplicate dominant epistasis a dominant allele of either gene is enough to produce the character, so it fails to appear only when both genes are fully recessive (aabb). The 15 individuals that carry a dominant allele of either gene all look the same, and only the 1 that is aabb differs, giving a 15:1 ratio.

> **False Confidence Alert**
> The two duplicate ratios are easy to muddle. Duplicate recessive needs a dominant allele of both genes (9:7), while duplicate dominant needs a dominant allele of just one gene (15:1), so check whether the trait needs both genes or only one.

Question 78

Both dominance and epistasis involve one thing hiding another, yet they are not the same. Distinguish clearly between dominance and epistasis.

Model Answer

Dominance and epistasis differ in what does the hiding and what is hidden:

1) **Dominance:** is the interaction between the two alleles of the same gene, where the dominant allele hides the recessive allele at that one locus, for example R hiding r.
2) **Epistasis:** is the interaction between two different genes at different loci, where one gene hides the effect of the other, for example gene E hiding gene B.

In short, dominance is one allele over its partner at the same gene, while epistasis is one gene over a different gene, which is why epistasis changes the dihybrid ratio away from 9:3:3:1 while simple dominance does not.

> **False Confidence Alert**
> Saying epistasis is just a strong form of dominance is wrong. Dominance acts within a single gene, but epistasis acts between two different genes, and only epistasis collapses the 9:3:3:1 dihybrid ratio.

Question 79

In poultry, two genes for comb shape work together so that the offspring include two comb shapes that neither parent had. Explain collaborative gene interaction using the comb shapes of fowls, and why its 9:3:3:1 ratio is still non-Mendelian.

Model Answer

Collaborative gene interaction is when two genes work together so that their combination produces a phenotype that neither gene gives on its own. In fowls the rose-comb gene (R) alone gives a rose comb (R_pp) and the pea-comb gene (P) alone gives a pea comb (rrP_), but when both dominants are present (R_P_) the two combs collaborate to give a new shape, the walnut comb, while birds recessive for both (rrpp) have yet another shape, the single comb.

The F2 of a walnut × walnut cross gives 9 walnut : 3 rose : 3 pea : 1 single, which looks like Mendel's 9:3:3:1 but is still non-Mendelian, because two of the four classes, walnut and single, are brand-new phenotypes produced by the interaction and not just the parental characters reshuffled.

> **False Confidence Alert**
> Because the numbers are 9:3:3:1, it is tempting to call this an ordinary Mendelian dihybrid cross. The ratio is the same, but two of the phenotypes (walnut and single) are new and appear only through the interaction of the two genes, which is what makes it non-Mendelian.

Question 80

Following on from the comb shapes of fowls, you are given four birds: a rose comb, a pea comb, a walnut comb and a single comb. Using gene R (rose) and gene P (pea), give the possible genotype of each comb shape and explain your reasoning.

Model Answer

Each comb shape matches a particular pattern of dominant and recessive alleles at the two genes:

1) Walnut comb: R_P_, with at least one dominant of each gene, so it may be RRPP, RRPp, RrPP or RrPp.

2) Rose comb: R_pp, dominant at gene R but recessive at gene P, so it is RRpp or Rrpp.

3) Pea comb: rrP_, recessive at gene R but dominant at gene P, so it is rrPP or rrPp.

4) Single comb: rrpp, recessive at both genes, which is the only genotype that gives a single comb.

So walnut and single each appear only when the two genes act together, walnut needing a dominant allele of both genes and single needing neither, which is why these two shapes are the new ones produced by the interaction.

> **False Confidence Alert**
> A rose or pea comb is sometimes given a single fixed genotype. Each can be homozygous or heterozygous at its dominant gene (rose is RRpp or Rrpp, pea is rrPP or rrPp), so giving only one genotype misses the possibilities.

Question 81

Human skin colour and height do not fall into a few sharp classes like Mendel's tall and short peas, but vary smoothly from one extreme to the other. Explain what polygenic inheritance is and why it gives this continuous variation.

Model Answer

Polygenic inheritance is when a single character is controlled by many genes acting together, each adding a small effect to the phenotype. Skin colour, for example, is decided by several genes, and the more dominant (darkening) alleles a person inherits across these genes, the darker the skin.

This control by many genes is what gives continuous variation: because the small effects of many genes add up, and each person inherits a different number of the darkening alleles, the phenotypes grade smoothly from very light to very dark instead of falling into a few sharp classes. The environment, such as exposure to sunlight, blurs the range still further.

> **False Confidence Alert**
> A common error is to look for a clean 3:1 or 9:3:3:1 in a polygenic character. Because many genes each add a small amount, the phenotypes form a continuous range rather than a few discrete classes, so a simple Mendelian ratio cannot be found.

Question 82

When two yellow mice are crossed, the offspring are not the expected 3 yellow to 1 of another colour, but 2 yellow to 1 agouti, because some die before birth. Explain how a lethal allele changes the ratio, and work the cross to show the 2:1 result.

Model Answer

The yellow-coat allele is dominant for colour but lethal when homozygous, so a mouse with two yellow alleles dies before birth. Writing the yellow allele Y and the agouti allele y, every living yellow mouse is heterozygous (Yy), because the homozygous YY never survives.

Parents: Yy (yellow) × Yy (yellow)

Gametes: Y and y × Y and y

Punnett square:

	Y	**y**
Y	YY	Yy
y	Yy	yy

Offspring expected: 1 YY : 2 Yy : 1 yy

But the YY mice die before birth, so they are not among the living young: this leaves 2 Yy (yellow) : 1 yy (agouti), a 2:1 ratio instead of the usual 3:1. The lethal allele removes one quarter of the offspring and so changes the ratio seen at birth.

> **False Confidence Alert**
> It is tempting to read the 2:1 as a new kind of dominance. The genotype ratio is still the Mendelian 1:2:1, but the lethal YY class dies, so only 2 yellow : 1 agouti are born, which is why the living ratio is 2:1.

Question 83

In humans and many animals, whether an offspring is male or female is settled at fertilisation by a pair of special chromosomes. Explain how sex is determined by the XY system, and why the ratio of males to females is about 1:1.

Model Answer

In the XY system sex is decided by the sex chromosomes: a female has two X chromosomes (XX) and a male has one X and one Y (XY). The female is homogametic, making only X-bearing eggs, while the male is heterogametic, making half X-bearing and half Y-bearing sperm.

The 1:1 sex ratio follows from this: an X egg fertilised by an X sperm gives a girl (XX), while an X egg fertilised by a Y sperm gives a boy (XY); since half the sperm carry X and half carry Y, the two outcomes are equally likely, so about half the offspring are male and half female.

> **False Confidence Alert**
> It is a mistake to say the mother decides the sex of the child. The mother gives only X, so it is the father's sperm, X or Y, that settles the sex, and the equal numbers of X and Y sperm give the 1:1 ratio.

Question 84

The XY system is not the only way to decide sex; birds and some insects do it differently, and in a few reptiles the temperature of the nest decides. Outline the other main systems of sex determination, and how each differs from the XY system.

Model Answer

Several other systems decide sex, differing in which sex is heterogametic or in what signal is used:

1) **The ZW system (birds, some insects):** the male has two of the same sex chromosome (ZZ) and the female has two different ones (ZW), so here it is the female that is heterogametic and the egg that decides the offspring's sex.

2) **The XO system (some insects):** the female is XX but the male has a single X with no partner (XO), so sex depends on the number of X chromosomes rather than on a Y.

3) **The X-to-autosome balance (Drosophila):** sex is set not by the Y but by the ratio of X chromosomes to the sets of autosomes, so two X with the normal autosomes give a female and one X gives a male.

4) Temperature (some reptiles): in some turtles and crocodiles there are no sex chromosomes at all, and the temperature at which the eggs are incubated decides whether the young are male or female.

In each case the principle is the same as in the XY system, that an inherited or an environmental difference sends development down the male or the female path, but the chromosome arrangement or the signal used is different.

False Confidence Alert
Do not assume the male is always the heterogametic sex. In birds (ZW) it is the female that is heterogametic, and in some reptiles sex is set by temperature with no sex chromosomes at all, so the XY pattern is only one of several.

Question 85

Genes that lie on the same chromosome do not always follow Mendel's rule of independent assortment, and one special case of this involves the sex chromosomes. Explain what is meant by linkage and by sex linkage.

Model Answer

Linkage is when two or more genes lie on the same chromosome, so they tend to be inherited together rather than independently. Because linked genes travel together into the same gamete, they do not assort independently the way genes on different chromosomes do.

Sex linkage is the special case where the gene lies on a sex chromosome, almost always the X. A sex-linked gene is one carried on the X chromosome (rarely the Y), and although it controls an ordinary body character, its pattern of inheritance is tied to sex because it travels with the sex chromosome. The X carries many such genes, while the much shorter Y carries very few.

False Confidence Alert
Sex linkage does not mean a gene that decides sex. A sex-linked gene simply sits on a sex chromosome and controls an ordinary character such as colour vision, so it is linked to sex only in how it is inherited, not in what it does.

Question 86

Part of the X chromosome has no matching partner on the much shorter Y, and this is why sex-linked recessive conditions strike males far more often than females. Explain why a recessive allele on the X chromosome shows up more readily in males than in females.

Model Answer

The X chromosome is much longer than the Y, so part of the X has no homologous region on the Y to pair with. A gene in this non-homologous part of the X has no matching allele on the Y, so a male, being XY, carries only the single copy on his one X.

This is why a recessive allele shows up more readily in a male: because he has only one X, a single recessive allele on it has nothing to mask it and is expressed at once, whereas a female, being XX, would need the recessive allele on both of her X chromosomes before it could show. Since the recessive allele is rare, it is far less likely to come together twice in a female.

False Confidence Alert
It is wrong to say males inherit these conditions more often because they are somehow weaker. A male shows a sex-linked recessive simply because his single X has no second allele to mask it, whereas a female needs the recessive allele on both X chromosomes.

Question 87

A woman can pass a sex-linked disease such as haemophilia to her sons while showing no sign of it herself. Explain what a carrier is, and why carriers of sex-linked conditions are usually female.

Model Answer

A carrier is an individual who carries a recessive allele without showing its effect, yet can still pass it on to offspring. For a sex-linked recessive the carrier is a heterozygous female, for example X^HX^h, in whom the normal dominant allele on one X masks the recessive allele on the other, so she stays healthy.

Carriers of sex-linked conditions are usually female because only a female, with two X chromosomes, can hold a recessive allele on one X while the other X hides it. A male, with a single X, cannot be a carrier: if he has the recessive allele he simply shows the condition. This is why the allele is handed down through healthy female carriers from one generation to the next.

> **False Confidence Alert**
> It is a mistake to think a carrier must be unwell, or that a male can be a carrier. A carrier is a healthy heterozygous female whose second X hides the allele, while a male has only one X, so he either has the condition or does not.

Question 88

Red-green colour blindness is a sex-linked recessive condition, and writing out its genotypes shows at once why men are affected more often than women. Using B for normal vision and b for colour blindness, give the possible genotypes for colour vision in males and in females, and state the phenotype of each.

Model Answer

Because the gene is on the X chromosome, the alleles are written as superscripts on the X, and there are five possible genotypes:

1) X^BX^B: a normal-sighted female.

2) X^BX^b: a normal-sighted female who is a carrier.

3) X^bX^b: a colour-blind female.

4) X^BY: a normal-sighted male.

5) X^bY: a colour-blind male.

A female is colour-blind only when she has the recessive allele on both X chromosomes (X^bX^b), but a male is colour-blind with the single allele X^bY, which is why the condition is far commoner in men.

> **False Confidence Alert**
> A common mistake is to write a male genotype with two X alleles, such as X^bX^b for a man. A male has one X and one Y, so his genotype must be X^BY or X^bY, and giving him two X alleles is wrong.

Question 89

The criss-cross way that colour blindness passes from a carrier mother to her sons is clearest in a genetic diagram. Work the cross between a normal-sighted carrier woman and a normal-sighted man, showing the gametes, a Punnett square and the children's phenotypes.

Model Answer

The carrier mother is X^BX^b and the normal father is X^BY.

Parents, phenotype: normal carrier woman × normal man

Parents, genotype: $X^BX^b \times X^BY$

Gametes: X^B and X^b × X^B and Y

Punnett square:

	X^B	Y
X^B	X^BX^B	X^BY
X^b	X^BX^b	X^bY

Children: X^BX^B normal girl, X^BY normal boy, X^BX^b carrier girl, X^bY colour-blind boy

So all the daughters are normal-sighted (one of them a carrier), while the sons are half normal and half colour-blind. No daughter is colour-blind, but a colour-blind son appears, which is the criss-cross pattern by which the allele passes from the carrier mother to her son.

> **False Confidence Alert**
> The trap is to expect colour-blind daughters from this cross. Every daughter receives a normal X^B from her father, so no daughter can be colour-blind here; only the sons, who get their single X from the carrier mother, can be colour-blind.

Question 90

Haemophilia is another sex-linked recessive condition, in which the blood fails to clot properly, and it comes in two forms. Explain what haemophilia is, and distinguish between haemophilia A and haemophilia B.

Model Answer

Haemophilia is a sex-linked recessive disorder in which the blood clots very slowly or not at all, so that even a small injury can cause prolonged bleeding. It is caused by a recessive allele on the X chromosome, so it is inherited just like colour blindness and affects mainly males.

The two forms differ in which clotting factor is missing:

1) Haemophilia A (classic haemophilia): caused by a lack of clotting factor VIII (factor 8).

2) Haemophilia B (Christmas disease): caused by a lack of clotting factor IX (factor 9).

Both forms show the same sex-linked pattern of inheritance and the same prolonged bleeding, and differ only in which clotting protein the faulty gene fails to make.

> **False Confidence Alert**
> Do not treat haemophilia A and B as having different inheritance. Both are X-linked recessive and passed on in the same way, differing only in the clotting factor that is missing, factor VIII in A and factor IX in B.

Question 91

Tracing a genetic condition through a family is made clear by a chart called a pedigree, which uses a few simple symbols. Explain how a pedigree is set out, naming the symbols used and how individuals are connected.

Model Answer

A pedigree is a family tree that shows how a character is passed down the generations, drawn with a fixed set of symbols.

1) **Squares and circles:** a square stands for a male and a circle for a female.
2) **Shading:** a shaded (filled) symbol shows an individual who has the condition, and an open symbol one who does not.
3) **Lines:** a horizontal line joins the two parents, and a vertical line drops to their children, who hang from a horizontal sibship line.

The generations are numbered with Roman numerals down the side, so that any individual can be named by its generation and position and the path of an allele can be traced from parents to offspring.

> **False Confidence Alert**
> A pedigree is not the same as a Punnett square. A pedigree records the real members of a family and who is affected, whereas a Punnett square predicts the offspring of a single cross, so the two answer different questions.

Question 92

The pedigree in Figure 5.7 below shows haemophilia, a sex-linked recessive condition, in one family, with the affected boy (II-1) shaded. From the pedigree, work out which individuals must carry the haemophilia allele, and explain how the affected boy inherited it.

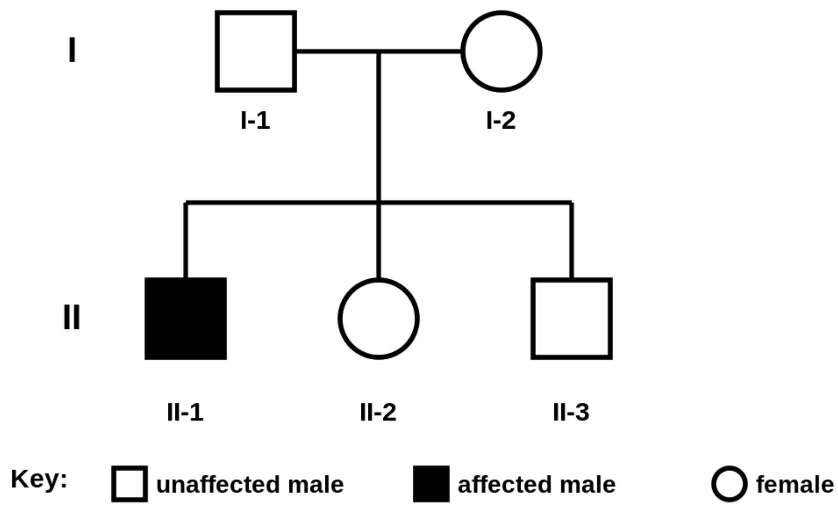


Figure 5.7: *A pedigree showing haemophilia in one family. The shaded square (II-1) is an affected male.*

Model Answer

The affected boy II-1 has haemophilia, so his genotype is X^hY, carrying the recessive allele on his single X. A boy receives his Y from his father and his single X from his mother, so the haemophilia allele on his X must have come from his mother, I-2.

This shows that the mother I-2 must be a carrier (X^HX^h), although she is healthy, because she is the only parent who could have passed the allele to her son; the father I-1 is unaffected (X^HY) and gave his son only a Y. The daughter II-2 looks normal but has a one-in-two chance of being a carrier like her mother, while the unaffected son II-3 is X^HY.

False Confidence Alert
It is wrong to think the affected boy got the allele from his unaffected father. A father gives his son only a Y, so the X carrying the haemophilia allele must have come from the mother, which is why she must be a carrier.

Question 93

Not every sex-linked condition is recessive; a few are dominant, and these break the usual rule that males are the ones most affected. Explain what an X-linked dominant condition is, and why some of them are more serious in males than in females.

Model Answer

An X-linked dominant condition is caused by a dominant allele on the X chromosome, so a single copy of the allele is enough to show the condition. Because only one copy is needed, a female with the allele on just one of her X chromosomes is affected, so these conditions can affect females as often as, or more than, males.

Some X-linked dominant conditions are more serious in males, and can even be fatal to them, because a male has only one X and so no second, normal allele to soften the effect. Examples are incontinentia pigmenti, a skin disorder that often causes the loss of affected male babies, and Rett syndrome, which affects nervous development mainly in girls because affected boys rarely survive.

False Confidence Alert
It is a mistake to assume every sex-linked condition is recessive and commoner in males. Some are X-linked dominant, affecting females from a single allele and sometimes lethal in males, so the male-mostly pattern is not a universal rule.

Question 94

Most genes we have met so far have just two alleles, but some have three or more, even though any one individual still carries only two. Explain what is meant by multiple alleles, using the ABO blood group gene as an example.

Model Answer

Multiple alleles means that a gene has more than two possible alleles in the population, although any one individual carries only two of them, one on each of the paired chromosomes.

The ABO blood group gene is a clear example: it has three alleles, I^A, I^B and I^O, so there are more than the usual two forms of the gene in the population, yet each person inherits just two, one from each parent. This is why several genotypes, and several blood groups, are possible from a single gene.

False Confidence Alert
A common error is to think multiple alleles means one person has many alleles of the gene. The population has three or more alleles, but each individual still carries only two, so a single genotype never holds more than two alleles.

Question 95

A person's ABO blood group is decided by which antigens sit on the surface of the red cells, and this in turn depends on the alleles inherited. Give the genotype of each of the four ABO blood groups, and explain how the alleles decide which antigens are present.

Model Answer

The four groups arise from the three alleles, with I^A and I^B co-dominant and I^O recessive:

1) Group A: I^AI^A or I^AI^O, with the A antigen on the red cells.

2) Group B: I^BI^B or I^BI^O, with the B antigen on the red cells.

3) Group AB: I^AI^B, with both the A and the B antigen, because both alleles are expressed.

4) Group O: I^OI^O, with neither antigen, because I^O makes no antigen.

Each allele decides which antigen is made: I^A makes the A antigen, I^B makes the B antigen, and I^O makes none, so the antigens on the red cells, and therefore the blood group, follow directly from the two alleles a person carries.

False Confidence Alert
The trap is to forget that group O makes no antigen at all. The I^O allele produces neither the A nor the B antigen, so a group O person (I^OI^O) has red cells with no ABO antigen, the opposite of group AB.

Question 96

A surprising result of blood-group genetics is that two parents can have children whose blood groups match neither parent. Work the cross between a group AB parent and a group O parent, showing the gametes and the children's possible blood groups.

Model Answer

The group AB parent is I^AI^B and the group O parent is I^OI^O.

Parents, phenotype: group AB × group O

Parents, genotype: $I^AI^B \times I^OI^O$

Gametes: I^A and $I^B \times I^O$ and I^O

Punnett square:

	I^O	I^O
I^A	I^AI^O	I^AI^O
I^B	I^BI^O	I^BI^O

Children: I^AI^O (group A) and I^BI^O (group B), in a 1:1 ratio

So the children are group A or group B, and none is group AB or group O like the parents, which shows how blood-group genetics can give children different from both parents.

False Confidence Alert
Do not expect a group AB and group O cross to give any AB or O children. The AB parent passes only I^A or I^B and the O parent only I^O, so every child is I^AI^O or I^BI^O, that is group A or group B, never AB or O.

Question 97

When both parents are heterozygous, an ABO cross can produce children of all four blood groups from just two people. Work the cross between a heterozygous group A parent and a heterozygous group B parent, showing the children's possible blood groups.

Model Answer

The heterozygous group A parent is I^AI^O and the heterozygous group B parent is I^BI^O.

Parents, phenotype: group A × group B

Parents, genotype: $I^AI^O \times I^BI^O$

Gametes: I^A and $I^O \times I^B$ and I^O

Punnett square:

	I^B	I^O
I^A	I^AI^B	I^AI^O
I^O	I^BI^O	I^OI^O

Children: I^AI^B (AB), I^AI^O (A), I^BI^O (B), I^OI^O (O)

So the four children are 1 AB : 1 A : 1 B : 1 O, meaning a group A and a group B parent can together have a child of any of the four blood groups, including group O, which neither parent shows.

False Confidence Alert
Because the parents are group A and group B, it is tempting to expect only A and B children. Since each parent also carries a hidden I^O allele, a child can be I^OI^O (group O) or I^AI^B (group AB), so all four groups are possible.

Question 98

Now and then the genetic material is changed, and the change is copied when the cell divides. Explain what a mutation is, and why a mutation in a body cell affects only the individual while a mutation in a sex cell can be passed to the offspring.

Model Answer

A mutation is a change in the DNA sequence, or in the structure or number of the chromosomes, of an organism. Because it changes the genetic material itself, a mutation alters the genotype and is copied into all the cells that descend from the mutated cell.

Where the mutation happens decides whether it is inherited: a mutation in a somatic (body) cell is passed only to that cell's descendants within the same body, so it affects only that individual and dies with it; but a mutation in a germ cell, one that forms gametes, can be carried in the sperm or egg into the next generation and become part of the offspring. This is why only germ-line mutations are inherited.

False Confidence Alert
It is wrong to think every mutation is passed to the children. Only a mutation in the cells that make gametes can be inherited; a mutation in an ordinary body cell, such as a skin cell, stays in that body and is not handed on.

Question 99

Although mutations can happen by chance when DNA is copied, certain agents in the environment make them far more likely. Explain how mutations arise, naming the main types of mutagen.

Model Answer

Mutations arise partly on their own, as rare mistakes made when DNA is copied during replication, and partly because of agents called mutagens that damage the DNA. A mutagen is any agent that raises the rate of mutation above its natural background level.

The main mutagens fall into a few groups:

1) **Ionising radiation:** such as X-rays and gamma rays, which carry enough energy to break or alter the DNA.
2) **Ultraviolet (UV) light:** from the sun, which damages the DNA of exposed cells such as those of the skin.
3) **Chemical mutagens:** such as the tar in tobacco smoke and aflatoxin from mouldy food, which react with the DNA and change its bases.

The more an organism is exposed to these mutagens, the higher its rate of mutation, which is why such exposure raises the risk of conditions like cancer.

False Confidence Alert
A common slip is to treat all radiation and chemicals as mutagens. Only those with enough energy or the right chemistry to damage DNA, such as ionising radiation, UV light and certain chemicals, are mutagens, not every kind of light or substance.

Question 100

A mutation is often pictured as something purely harmful, yet its effect depends entirely on what it changes. Explain why a mutation may be harmful, neutral or even beneficial, giving an example of a harmful one.

Model Answer

The effect of a mutation depends on where in the DNA it falls and what it changes, so it may be harmful, neutral or beneficial.

1) **Harmful:** it may spoil a gene so that a needed protein is faulty or missing, as in sickle-cell anaemia or cancer.
2) **Neutral:** it may fall in a part of the DNA that does not matter, or change a codon to another for the same amino acid, so the organism is unaffected.
3) **Beneficial:** it may, rarely, give a useful new feature that helps the organism survive, which is the raw material on which natural selection acts.

So a mutation is not always bad: most are neutral or harmful, but the rare beneficial ones are the source of the variation that drives evolution.

> **False Confidence Alert**
> It is a mistake to say all mutations are harmful. Many are harmful and most are neutral, but a rare mutation can be beneficial, and without such beneficial changes there would be no new variation for evolution to act on.

Question 101

Sexual reproduction shuffles existing alleles into new combinations, but it cannot make a brand-new allele; only one process can do that. Explain why mutation is described as the ultimate source of all genetic variation.

Model Answer

Mutation is the only process that creates entirely new alleles, because it changes the DNA sequence to produce a version of a gene that did not exist before. Other processes, such as crossing over and the independent assortment of chromosomes in meiosis, and the random fusion of gametes at fertilisation, only shuffle alleles that already exist into new combinations.

This is why mutation is called the ultimate source of variation: all the alleles that meiosis and fertilisation rearrange must first have been made by mutation at some time in the past. Without mutation there would be nothing new to shuffle, and evolution would have no raw material to act upon.

> **False Confidence Alert**
> Crossing over is sometimes wrongly called the source of new alleles. Crossing over and assortment only rearrange alleles that already exist, whereas mutation alone creates new ones, so it is mutation that is the ultimate source of variation.

Question 102

A change to even a single base of a gene can alter the protein it codes for, and such changes come in several recognised forms. Explain what a gene (point) mutation is, and describe its main types.

Model Answer

A gene mutation, or point mutation, is a change in the DNA at a single gene, affecting one or a few of its bases, which can change the sequence of amino acids in the protein the gene codes for.

Its main types are:

1) **Substitution:** one base is replaced by a different one; this may be silent (the new codon still codes the same amino acid), missense (it codes a different amino acid) or nonsense (it becomes a stop codon).
2) **Deletion:** one or more bases are lost from the sequence.
3) **Insertion (addition):** one or more extra bases are added to the sequence.
4) **Duplication:** a part of the sequence is copied and repeated.
5) **Inversion:** a short stretch of bases is reversed, so its order runs back to front.

A deletion or insertion of a single base is especially serious, because it shifts the reading frame, so that every codon after it is misread, a change called a frameshift.

> **False Confidence Alert**

Every substitution is too readily assumed to wreck the protein. A substitution can be silent and change nothing, or missense, or nonsense, so it is the kind of substitution, not merely the fact of one, that decides the effect.

Question 103

A short DNA sequence can be tested against the genetic code to see what a single base change would do. In the triplet that gives the mRNA codon GAG (glutamic acid), the middle base is changed so that the codon becomes GUG (valine). Classify this mutation, and explain its effect on the protein.

Model Answer

This is a substitution, because one base has simply been replaced by another, here the middle A of GAG by a U to give GUG. It is a missense substitution, because the new codon GUG codes for a different amino acid, valine, in place of the original glutamic acid.

Its effect is to change one amino acid in the protein: wherever glutamic acid should have been placed, valine is put instead, which alters the structure of the protein at that point. This single change is the very one that turns normal haemoglobin into the sickle-cell form.

False Confidence Alert
The mistake is to call a single-base change a frameshift. Replacing one base by another is a substitution, which alters only that one codon, whereas a frameshift comes only from adding or losing bases and shifts every codon after it.

Question 104

Sickle-cell anaemia provides a clear example of how a single base change can cause a serious disease. Explain the mutation that causes sickle-cell anaemia, and how it affects the red blood cells and the person.

Model Answer

Sickle-cell anaemia is caused by a substitution mutation in the gene for the beta-chain of haemoglobin, in which one base is changed so that the codon GAG becomes GUG. This puts the amino acid valine in place of glutamic acid at one point in the chain, producing an abnormal haemoglobin called haemoglobin S (HbS).

This faulty haemoglobin changes the shape of the red cells: when oxygen is low, HbS makes the red cells collapse into a stiff, crescent or sickle shape instead of the normal disc. The sickled cells carry less oxygen and block small blood vessels, causing the anaemia, pain and tissue damage of the disease in a person who is homozygous (Hb^SHb^S).

False Confidence Alert
A common belief is that sickle-cell anaemia comes from a large or complicated change. It is a single base substitution, putting one wrong amino acid, valine for glutamic acid, into haemoglobin, and that one change is enough to deform the whole red cell.

Question 105

Two parents who each carry the sickle-cell trait but are healthy can still have a child with the full disease. Work the cross between two carriers, using Hb^A for the normal allele and Hb^S for the sickle allele, and explain why the carrier is protected against malaria.

Model Answer

Each carrier parent is heterozygous, Hb^AHb^S, and healthy, because the normal allele still makes enough good haemoglobin.

Parents, phenotype: carrier × carrier

Parents, genotype: $Hb^AHb^S \times Hb^AHb^S$

Gametes: Hb^A and Hb^S × Hb^A and Hb^S

Punnett square:

	Hb^A	**Hb^S**
Hb^A	Hb^AHb^A	Hb^AHb^S
Hb^S	Hb^AHb^S	Hb^SHb^S

Children: 1 Hb^AHb^A (normal) : 2 Hb^AHb^S (carrier) : 1 Hb^SHb^S (sickle-cell anaemia)

The carrier is protected against malaria, which is why the allele stays common in malarial areas: the Hb^AHb^S carrier has some sickle haemoglobin, which makes the red cells a poorer home for the malaria parasite, so the carrier survives malaria better than a normal Hb^AHb^A person. This survival advantage of the heterozygote is called heterozygote advantage, and it keeps the sickle allele in the population in spite of the death of Hb^SHb^S homozygotes.

> **False Confidence Alert**
> The trap is to give a 3:1 ratio because the cross looks Mendelian. The genotypes are 1:2:1, and so are the phenotypes, 1 normal : 2 carrier : 1 affected, because the carrier is a distinct, healthy but malaria-resistant phenotype and not simply normal.

Question 106

An albino animal or person cannot make the dark pigment melanin, and this too comes down to a single faulty gene. Explain the cause of albinism and how it is inherited.

Model Answer

Albinism is caused by a recessive mutation in the gene for the enzyme tyrosinase, which is needed to make the pigment melanin from the amino acid tyrosine. Without working tyrosinase no melanin can be made, so the skin, hair and eyes lack their normal colour.

Albinism is inherited as a simple autosomal recessive condition, so it shows only in a person with two copies of the faulty allele (aa), while a person with one normal allele (Aa) makes melanin normally and is an unaffected carrier. Two carrier parents (Aa × Aa) can therefore have an albino child in the usual 3 normal : 1 albino ratio.

> **False Confidence Alert**
> It is a mistake to think an albino simply has white pigment. An albino makes no melanin at all, because the tyrosinase enzyme that should make it is missing, so there is an absence of pigment rather than a white one.

Question 107

Besides changes to single genes, whole sections of a chromosome can be altered during meiosis, changing many genes at once. Describe the main types of change in chromosome structure.

Model Answer

A change in chromosome structure alters a whole section of a chromosome, and there are four main types:

1) **Deletion:** a section of the chromosome breaks off and is lost, taking its genes with it.
2) **Duplication:** a section is copied, so that a block of genes is repeated.
3) **Inversion:** a section breaks off, turns through 180 degrees and rejoins, so the order of its genes is reversed.

4) **Translocation:** a section breaks off and joins a different chromosome, or a different part of the same chromosome.

Even when no genes are lost, changing their order or position can alter the phenotype, an effect called the position effect, because where a gene sits can change how it works.

> **False Confidence Alert**
> It is wrong to think a chromosome mutation must always lose genes. A deletion does lose genes, but an inversion or a translocation can move genes to a new place without losing any, yet still change the phenotype through the position effect.

Question 108

Sometimes a cell ends up with one chromosome too many or too few, because the chromosomes failed to separate properly during meiosis. Explain what aneuploidy is and how non-disjunction causes it.

Model Answer

Aneuploidy is a condition in which a cell has one or a few chromosomes more or fewer than the normal number, such as 2n + 1 or 2n - 1, rather than a whole extra set. It usually arises during the formation of gametes.

Aneuploidy is caused by non-disjunction, the failure of a pair of homologous chromosomes (in meiosis I) or of sister chromatids (in meiosis II) to separate, so that both go to the same pole. This gives one gamete an extra chromosome and another a missing one; when such a gamete joins a normal one at fertilisation, the zygote has an abnormal chromosome number. A change involving whole extra sets of chromosomes, by contrast, is called polyploidy.

> **False Confidence Alert**
> Aneuploidy and polyploidy are easily confused. Aneuploidy is a few chromosomes too many or too few from non-disjunction, while polyploidy is one or more complete extra sets, so the difference is between a few chromosomes and whole sets.

Question 109

In humans, the failure of chromosomes to separate during meiosis produces several well-known disorders, each with its own abnormal chromosome number. Describe the chromosome cause of Down syndrome, Klinefelter syndrome and Turner syndrome.

Model Answer

Each of these disorders is caused by non-disjunction, which leaves the person with an abnormal number of chromosomes:

1) **Down syndrome:** an extra copy of chromosome 21, giving 47 chromosomes (2n + 1, a trisomy); the chance of it rises with the mother's age.
2) **Klinefelter syndrome:** an extra X chromosome in a male, genotype XXY, giving 47 chromosomes; such men are usually sterile.
3) **Turner syndrome:** a missing X chromosome in a female, genotype XO, giving 45 chromosomes (2n - 1); such women are short and infertile.

In each case the extra or missing chromosome upsets the balance of genes, which is why an abnormal chromosome number produces these distinct sets of features.

> **False Confidence Alert**
> Do not give Down, Klinefelter and Turner the same chromosome number. Down syndrome and Klinefelter both have 47 chromosomes (an extra one), but Turner has only 45 (one missing), so check whether a chromosome is gained or lost.

Question 110

Genetic engineering lets scientists move a gene from one organism into a completely different one, even across the boundaries between species. Explain what genetic engineering is, and what is meant by recombinant DNA and by a genetically modified organism.

Model Answer

Genetic engineering, also called genetic modification, is the deliberate changing of an organism's genetic material, by adding, removing or altering genes, in order to give it a wanted characteristic. It is made possible by recombinant DNA technology, in which genes from different sources are cut out and joined together.

Two key terms follow from this:

Recombinant DNA: DNA made by joining together pieces of DNA from different organisms, a combination that would not be found in nature.

Genetically modified organism (GMO), or transgenic organism: an organism that has had a gene from another organism added to it by genetic engineering.

> **False Confidence Alert**
> It is wrong to confuse genetic engineering with ordinary selective breeding. Selective breeding only chooses among genes the organism already has, whereas genetic engineering moves a particular gene from one species into another, which breeding cannot do.

Question 111

To be useful, a single gene often has to be copied into many millions of copies, and bacteria are enlisted to do the copying. Explain what gene cloning is and the part played by the plasmid.

Model Answer

Gene cloning is the process of making many identical copies of a particular gene, usually by putting the gene into bacteria that then copy it as they multiply. A clone is a set of genetically identical copies, so the cloned gene is produced in very large numbers.

The plasmid is the carrier that gets the gene into the bacterium: a plasmid is a small circle of DNA, separate from the main bacterial chromosome, that can be cut open and have the gene inserted into it. Once the plasmid carrying the gene is taken up by a bacterium, every time the bacterium divides it copies the plasmid, and so the gene, along with itself.

> **False Confidence Alert**
> A common slip is to think the gene copies itself once it is inside the bacterium. It is copied only because the plasmid carrying it is copied each time the bacterium divides, so it is the dividing of the bacteria that multiplies the gene.

Question 112

Cloning a gene follows a clear sequence of steps, each done by a particular tool or enzyme. Outline the steps by which a gene is cloned in bacteria.

Model Answer

A gene is cloned in bacteria by the following steps:

1) **Cut out the gene:** the gene of interest is cut from the source DNA using a restriction enzyme.
2) **Cut open the plasmid:** a bacterial plasmid is cut open with the same restriction enzyme, so that its ends match those of the gene.
3) **Join them:** the gene is joined into the plasmid by the enzyme DNA ligase, making a recombinant plasmid.

4) **Insert into bacteria:** the recombinant plasmid is taken up by bacteria, a step called transformation.
5) **Grow the bacteria:** the bacteria are grown in large numbers, and as each divides it copies the plasmid and the gene, producing many clones.

False Confidence Alert
A frequent error is to cut the gene and the plasmid with different enzymes. The same restriction enzyme must cut both, so their cut ends match and DNA ligase can join them, and different enzymes would leave ends that do not fit.

Question 113

A flow diagram makes the cloning process easy to follow from start to finish. Draw a labelled diagram of gene cloning, then state the job done by the restriction enzyme and by DNA ligase.

Model Answer

Gene cloning is drawn in Figure 5.8, with each step labelled.

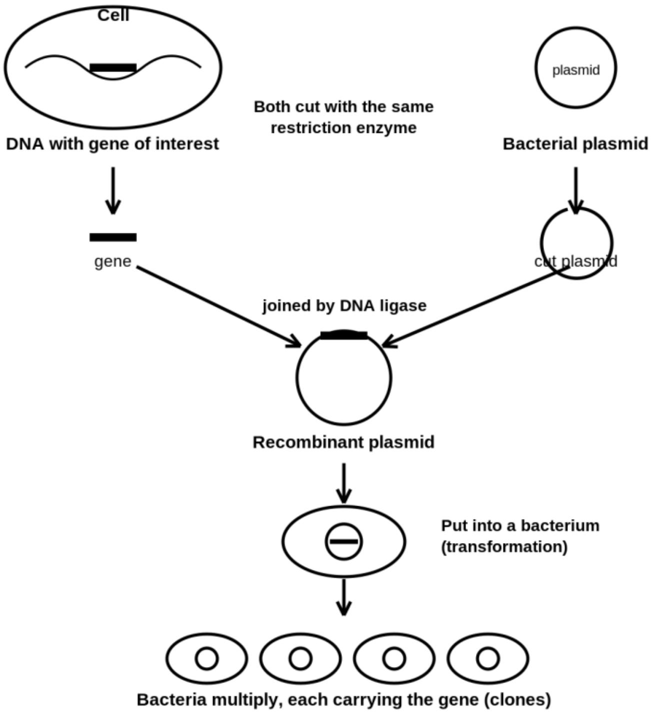


Figure 5.8: ***Gene cloning.*** *A gene is cut out and joined into a plasmid, which is put into bacteria that multiply to make many copies of the gene.*

Two enzymes do the cutting and joining:

1) **The restriction enzyme:** cuts the gene out of the source DNA and cuts the plasmid open, leaving matching ends on both.
2) **DNA ligase:** joins the gene into the cut plasmid, sealing it into one recombinant plasmid ready to be put into bacteria.

False Confidence Alert
A diagram earns little if the restriction enzyme and DNA ligase are left unnamed. The cut is made by a restriction enzyme and the join by DNA ligase, so naming the two enzymes is the heart of what the diagram has to show.

Question 114

Cloning is not limited to genes; a whole animal can be cloned, as the famous sheep Dolly showed. Explain what is meant by cloning a whole organism, and distinguish reproductive cloning from therapeutic cloning.

Model Answer

Cloning a whole organism means making a new individual that is genetically identical to an existing one, by a technique called somatic-cell nuclear transfer. In this technique the nucleus from a body cell of the donor is placed into an egg cell whose own nucleus has been removed, and the egg then develops into a copy of the donor; the first mammal cloned this way was Dolly the sheep.

Reproductive and therapeutic cloning differ in their purpose:

Reproductive cloning: is done to produce a whole new animal genetically identical to the donor, as with Dolly.

Therapeutic cloning: is done to produce stem cells for treating disease or for research, rather than a whole animal, and is now often replaced by reprogramming ordinary body cells into induced pluripotent stem cells.

> **False Confidence Alert**
> It is a mistake to think reproductive and therapeutic cloning aim at the same thing. Reproductive cloning makes a whole new organism, whereas therapeutic cloning makes stem cells for medical use, so their goals are quite different.

Question 115

Genetic engineering is already at work in medicine, agriculture and industry, making products that were once hard or impossible to obtain. Outline the main uses of genetic engineering, giving examples.

Model Answer

Genetic engineering is used in several fields:

1. Making medicines and hormones

Engineered bacteria or yeast make human hormones such as insulin for diabetics and human growth hormone, and vaccines such as the hepatitis-B vaccine; other proteins, such as erythropoietin, are made in the same way in cultured animal cells.

2. Improving crops

Plants are engineered to resist pests and herbicides, to tolerate drought, and to give a higher yield or better-quality food.

3. Improving animals and treating wastes

The quality of animal products such as meat and milk can be improved, and engineered microbes can be used to break down environmental wastes.

> **False Confidence Alert**
> Genetic engineering is too often thought to be only about crops. Its first and most important use was medical, making human insulin and other proteins in bacteria, so medicine is as important a field as agriculture.

Question 116

Supporters of genetic engineering point to real benefits for health and for farming, especially in a country like Tanzania. Outline the main advantages of genetic engineering.

Model Answer

Genetic engineering brings several advantages:

1) **Cheap, pure medicines:** hormones such as insulin, and vaccines, can be made in large amounts, cheaply and free of the diseases that animal-sourced products once carried.

2) **Better food security:** crops engineered to resist pests, drought and disease can give higher and more reliable yields, which matters most where harvests are uncertain.
3) **Improved quality and clean-up:** foods can be made more nutritious and animal products improved, while engineered microbes help break down wastes.

For a Tanzanian farmer in particular, a drought-tolerant or pest-resistant maize could mean a more dependable harvest in a difficult and changing climate.

> **False Confidence Alert**
> Listing only medical benefits sells the advantages short. Crops engineered to resist drought and pests are a major advantage too, especially for food security in regions with an unreliable climate.

Question 117

Genetic engineering also raises real worries, which is why its use is debated and regulated around the world. Outline the main disadvantages and risks of genetic engineering.

Model Answer

Genetic engineering carries several risks and objections:

1) **Antibiotic resistance:** the marker genes used in engineering often carry antibiotic resistance, which could spread to harmful bacteria and make infections hard to treat.
2) **Loss of local varieties:** a few highly engineered crops or animals could replace the many local varieties, reducing biodiversity and harming farmers who depend on those varieties.
3) **Ethical and safety concerns:** some object on moral or religious grounds to humans altering life in this way, and there is a fear that the technology could be misused, for example to make biological weapons.

> **False Confidence Alert**
> The risks of genetic engineering are too easily dismissed as imaginary. Real concerns, such as the spread of antibiotic-resistance genes and the loss of local crop varieties, are exactly why the technology is carefully regulated.

REAL QUESTIONS

These questions test whether you can take the biology of this chapter and use it in real situations. Attempt each answer yourself first, then check it against the model answer and the False Confidence Alert that follows, which names the mistake that most often costs marks.

Question 118

A student in a laboratory is given two specimens under the microscope: a cell from the lining of a human cheek, and a Salmonella bacterium from a sample of contaminated food. For each, state where its genetic material is found and how its arrangement differs, and justify your answer from the kind of cell each one is.

Model Answer

In the human cheek cell, which is a eukaryotic cell, the genetic material is held inside a membrane-bound nucleus. The DNA is wound on histone proteins as chromatin and kept apart from the cytoplasm by the nuclear membrane; we can be sure of this because an animal cell is eukaryotic and so has a true nucleus.

In the Salmonella bacterium, which is a prokaryotic cell, the genetic material lies free in the cytoplasm in a region called the nucleoid, with no surrounding membrane, as a single circular DNA molecule that carries no histones, often with small extra plasmids beside it; we can be sure of this because a bacterium is prokaryotic and so has no nucleus. The same molecule, DNA, is therefore housed quite differently in the two cells.

False Confidence Alert
It is wrong to say the bacterium simply keeps its DNA in a smaller nucleus. A bacterium has no nucleus at all, its DNA lying free in the nucleoid, while only the eukaryotic cheek cell has a true membrane-bound nucleus.

Question 119

Asked in an examination what the genetic material is and why DNA is so well suited to the role, a candidate simply wrote *'DNA is the genetic material'.* Write a fuller answer, explaining what is meant by the genetic material and giving the properties that make DNA suited to the job.

Model Answer

The genetic material is the chemical substance in the chromosome that carries the coded instructions for an organism's characteristics from one generation to the next, and in nearly all organisms this material is DNA.

DNA is well suited to the role for several reasons:

1) **It stores information in code:** the order of its bases spells out the instructions, so a single molecule can carry the whole plan of the organism.

2) **It can be copied exactly:** its base-pairing rule lets it be replicated faithfully before every cell division, so each new cell gets a true copy.

3) **It is chemically stable:** its deoxyribose backbone makes it long-lasting, so the information survives unchanged for the life of the cell.

4) **It can mutate:** rare changes in its sequence give the new variation on which evolution depends.

False Confidence Alert
Simply naming DNA as the genetic material, as the candidate did, earns very little. The marks come from saying what the genetic material does, carry coded information from generation to generation, and giving the properties, stable storage, exact copying and the capacity to mutate, that fit DNA for the job.

Question 120

A short length of one DNA strand has the base sequence A-T-G-C-C-A. Write the base sequence of the complementary strand, and then work out how many hydrogen bonds in total hold this six-base-pair stretch together.

Model Answer

Each base pairs with its fixed partner, A with T and G with C, so the complementary strand reads T-A-C-G-G-T. Set against the given strand, A pairs with T, T with A, G with C, C with G, C with G, and A with T.

The hydrogen bonds are found by counting 2 for each A-T pair and 3 for each G-C pair: there are three A-T pairs (the 1st, 2nd and 6th), giving $3 \times 2 = 6$ bonds, and three G-C pairs (the 3rd, 4th and 5th), giving $3 \times 3 = 9$ bonds, so the total is $6 + 9 = 15$ hydrogen bonds.

False Confidence Alert
A common mistake is to count two hydrogen bonds for every base pair. An A-T pair has two bonds but a G-C pair has three, so the two kinds must be added separately, here 6 from the A-T pairs and 9 from the G-C pairs.

Question 121

A nerve cell and a skin cell from the same person look completely different and do completely different jobs, yet both contain exactly the same DNA. Explain how this is possible.

Model Answer

Every body cell of a person carries the same complete set of DNA, because all of them arose by mitosis from the one fertilised egg, which copies its DNA exactly at each division. So a nerve cell and a skin cell really do hold an identical set of genes.

They look and work differently because different genes are switched on in each: a cell uses only the genes it needs for its own job and keeps the rest switched off, so a nerve cell expresses the genes for carrying impulses while a skin cell expresses the genes for making a tough, protective surface. The difference between the two cells is therefore one of which genes are used, not of which genes are present.

> **False Confidence Alert**
> The two cells are too easily imagined to carry different genes. They carry exactly the same genes and differ only in which genes are switched on, so it is gene expression, not gene content, that makes them different.

Question 122

A sample of DNA is analysed and found to contain 30% adenine among its bases. Work out the percentage of each of the other three bases it must contain, and state the rule you have used.

Model Answer

Because the two strands of DNA are paired with adenine always opposite thymine, the amount of adenine equals the amount of thymine, so thymine is also 30%. Adenine and thymine together therefore make up 30% + 30% = 60% of the bases.

The remaining 40% must be guanine and cytosine, and since guanine always pairs with cytosine their amounts are equal, so each is 40% / 2 = 20%. The sample is thus 30% adenine, 30% thymine, 20% guanine and 20% cytosine. The rule used is Chargaff's rule, that in DNA the amount of A equals T and the amount of G equals C, which follows from complementary base pairing.

> **False Confidence Alert**
> Finding that thymine equals adenine is only half the work. The remaining 40% must be shared equally between guanine and cytosine to give 20% each, not left out or guessed at.

Question 123

In a practical, two nucleic-acid samples are tested. Sample X is found to contain thymine and the sugar deoxyribose; sample Y contains uracil and the sugar ribose. Identify each sample, and give three structural differences between DNA and RNA.

Model Answer

Sample X is DNA, because it contains the base thymine and the sugar deoxyribose, both of which belong to DNA. Sample Y is RNA, because it contains the base uracil and the sugar ribose, both of which belong to RNA.

Three structural differences between DNA and RNA are:

1) **The sugar:** DNA contains deoxyribose, while RNA contains ribose, which has one more oxygen atom.

2) **The bases:** DNA uses thymine, while RNA uses uracil in its place; the other three bases are the same.

3) **The number of strands:** DNA is a double strand twisted into a helix, while RNA is usually a single strand.

> **False Confidence Alert**
> A frequent error is to separate DNA from RNA only by their bases. The sugar (deoxyribose against ribose) and the number of strands differ too, so an answer that gives the base difference alone is incomplete.

Question 124

The two strands of a DNA molecule are described as antiparallel. Explain what this means, and why this arrangement matters when the molecule is copied during replication.

Model Answer

Antiparallel means the two strands run in opposite directions: one strand runs in the 5' to 3' direction while the other runs 3' to 5', so they lie head-to-tail rather than side by side the same way. This lets the bases of the two strands face each other and pair correctly, A with T and G with C.

It matters in replication because new nucleotides can be added only to the 3' end, that is, in the 5' to 3' direction. So as the fork opens, one new strand (the leading strand) is built continuously towards the fork, while the other (the lagging strand) must be built in short pieces away from the fork and then joined up. The antiparallel arrangement is the very reason the two new strands are copied in these two different ways.

False Confidence Alert
Antiparallel does not just mean the two strands lie alongside each other. It means they point in opposite directions, one 5' to 3' and the other 3' to 5', and missing this direction is what loses the mark.

Question 125

When a cell makes a protein such as the enzyme amylase, three kinds of RNA each play a part. State the job of messenger RNA, transfer RNA and ribosomal RNA in making the protein.

Model Answer

The three RNAs divide the work of protein synthesis between them:

1) **Messenger RNA (mRNA):** carries the coded instructions, copied from the gene in the nucleus, out to the ribosome where they are read three bases at a time.

2) **Transfer RNA (tRNA):** brings the amino acids one by one to the ribosome, each tRNA matching its anticodon to the codon so that the correct amino acid is added.

3) **Ribosomal RNA (rRNA):** makes up the ribosome, the structure on which the protein is built, and helps to join the amino acids by peptide bonds.

In this way the message of the gene is turned into the ordered chain of amino acids that forms the amylase, with each kind of RNA doing a job that the others cannot.

False Confidence Alert
It is wrong to let the three RNAs merge into a single 'RNA that makes protein'. Each has a distinct role, and an answer that names only the messenger leaves out the transfer and ribosomal RNA that actually build the chain.

Question 126

In a test, Kipanga writes: *'DNA has four bases, adenine, thymine, guanine and uracil, which pair up as A with U and G with C.'* Identify the two mistakes in his statement and correct them.

Model Answer

Kipanga's first mistake is to list uracil as a base of DNA. Uracil is a base of RNA, not DNA; the four bases of DNA are adenine, thymine, guanine and cytosine, so his fourth base should be cytosine, not uracil.

His second mistake is the pairing 'A with U'. In DNA adenine pairs with thymine, not uracil, so the correct pairing is A with T and G with C. The pairing A with U occurs only when RNA is involved, as when mRNA is made on a DNA template.

False Confidence Alert
Listing uracil among the DNA bases feels right because uracil is certainly a base, but it belongs to RNA. DNA uses thymine, and writing A to U for DNA simply carries the same slip one step further.

Question 127

When a DNA molecule is copied, it gives two molecules that are exact copies of the original. Explain what is meant by saying that DNA replication is semiconservative, and why this way of copying produces such a faithful copy.

Model Answer

Replication is semiconservative because each new double helix is made of one original (parent) strand and one newly built strand. The two strands of the parent molecule first unwind and separate; each then acts as a template on which a new partner strand is built, so each daughter molecule conserves one half of the original. This is why it is called 'semi' (half) conservative.

The copy is faithful because the new strand is built by complementary base pairing: adenine can only pair with thymine and guanine only with cytosine, so each template strand dictates exactly the sequence of its new partner. The copying enzyme, DNA polymerase, also checks and corrects mistakes as it works, which makes replication extremely accurate.

False Confidence Alert
It is tempting to picture replication as building two brand-new molecules from nothing. In fact each daughter keeps one original strand, which is exactly why the copy can be so faithful.

Question 128

In a famous investigation, a DNA molecule whose two strands were both made with 'heavy' nitrogen was allowed to replicate once in a medium that supplied only 'light' nitrogen. Predict the make-up of each of the two daughter molecules, and explain your prediction.

Model Answer

Each of the two daughter molecules will contain one heavy strand and one light strand, that is, both daughters will be hybrid molecules of equal heavy and light content. None of them will be wholly heavy, and none will be wholly light, after this single round of replication.

This follows from semiconservative replication: the two heavy parent strands separate and are conserved, and each one serves as a template for a new strand. Because the new strands are built from light nitrogen only, each old heavy strand ends up paired with a new light strand, giving two hybrid molecules. This is exactly the result that Meselson and Stahl observed, and it is what proved replication to be semiconservative.

False Confidence Alert
After one round of copying in light nitrogen it is wrong to expect a fully light molecule. Each daughter must keep one heavy parent strand, so both come out as hybrids of one heavy and one light strand.

Question 129

Before a body cell divides to form two new cells, it first copies all of its DNA. Explain why the DNA must be copied before the cell divides, and what would happen to the daughter cells if it were not.

Model Answer

The DNA must be copied first so that there is a complete set of genes for each of the two daughter cells. Replication is carried out during interphase, before the cell divides, so that when division comes each new cell receives a full and identical copy of all the genetic instructions.

If the DNA were not copied before division, the single set would simply be shared out between the two cells, so each daughter cell would get only part of the genetic information. Such a cell would be missing many of its genes, could not make all the proteins it needs, and would not survive or work properly. Copying the DNA first is therefore what allows both daughter cells to be complete and identical to the parent cell.

False Confidence Alert
Copying the DNA is not part of the dividing stage itself; it is completed beforehand, in interphase. A cell that divided without first copying its DNA would hand each daughter only half a set of genes.

Question 130

Two students argue about replication. **Kipanga** says *the original DNA molecule stays whole and acts as a mould for two brand-new molecules.* **Kipute** says *each new molecule is made of one old strand and one new strand.* State who is correct, and explain why the other is wrong.

Model Answer

Kipute is correct. Replication is semiconservative, so each new molecule is built from one old strand kept from the parent and one newly made strand, just as Kipute describes.

Kipanga is wrong because he is describing the conservative model, in which the parent molecule would stay intact and a wholly new molecule would be made beside it. In reality the two strands of the parent molecule separate, and each goes into a different daughter molecule, so the original double helix does not survive as one whole piece. Experiments on DNA copied in heavy and light nitrogen showed the semiconservative pattern and ruled out Kipanga's conservative one.

False Confidence Alert
The idea that the original molecule stays intact is the conservative model, which experiment ruled out. The parent strands actually separate, so the original double helix does not survive as a single piece.

Question 131

A short length of the template (transcribed) strand of a gene reads 3'-TAC-AAA-CGG-ATT-5'. Using the codon meanings given below, work out (a) the sequence of the mRNA made from this strand, and (b) the amino acids it codes for.

Codon meanings: AUG = methionine (start); UUU = phenylalanine; GCC = alanine; UAA = stop.

Model Answer

(a) The mRNA is built as the complement of the template, with uracil replacing thymine, so reading 5' to 3' the mRNA is AUG-UUU-GCC-UAA. Against the template 3'-TAC-AAA-CGG-ATT-5', each base pairs T to A, A to U, C to G and so on, giving these four codons.

(b) Reading the codons against the key gives the amino acids: AUG codes for methionine and is the start, UUU codes for phenylalanine, GCC codes for alanine, and UAA is a stop codon that ends the chain. The polypeptide made is therefore methionine - phenylalanine - alanine, after which translation stops.

False Confidence Alert
The mRNA is not a direct copy of the template strand but its complement, with uracil in place of thymine. Copying the template's own bases straight across, or forgetting that UAA is a stop, is the commonest way this question is lost.

Question 132

Using the idea that the genetic code is degenerate, explain why a change in the third base of a codon often has no effect on the protein, while a change in the first or second base usually does.

Model Answer

The code is degenerate, meaning that most amino acids are coded by more than one codon, and these codons usually differ only in their third base. For example, the four codons GGU, GGC, GGA and GGG all code for glycine, differing only in the last base.

This is why the position of the change matters:

1) **A third-base change is often silent:** it frequently turns a codon into another codon for the same amino acid, so the protein is unchanged.

2) **A first- or second-base change usually counts:** it almost always gives a codon for a different amino acid, so the protein is altered at that point.

So degeneracy gives the code a built-in protection at the third base, which is why changes there often pass without harm while changes earlier in the codon usually show up in the protein.

> **False Confidence Alert**
> Degeneracy makes many third-base changes silent, but it does not make the code error-proof. A change in the first or second base usually does alter the amino acid, so 'degenerate' must never be read as 'a mutation cannot matter'.

Question 133

Human insulin is now made by putting the human insulin gene into bacteria, which then produce the human protein. Explain how the fact that the genetic code is virtually universal makes this possible.

Model Answer

The genetic code is virtually universal, which means that nearly all living things use the same codons to stand for the same amino acids. A codon such as GCC means alanine in a human cell and also in a bacterium.

Because of this, a bacterium can read a human gene in exactly the same way the human cell would: it translates the human codons into the very same sequence of amino acids, and so builds genuine human insulin rather than some different protein. If the code were not shared, the bacterium would read the inserted gene by different rules and make the wrong protein. The universal code is therefore the property that allows a gene to be moved from one species to another and still work.

> **False Confidence Alert**
> It is not the bacterium's own machinery that makes the protein human; it is that the bacterium reads the human codons by the very same code. Without a near-universal code, the inserted gene would be translated into a different sequence of amino acids.

Question 134

Part of the coding (sense) strand of a gene reads 5'-ATG-GTT-CCA-3'. Using the codon meanings given below, work out (a) the mRNA codons made from this gene, (b) the tRNA anticodons that pair with them, and (c) the amino acids the tRNAs carry.

Codon meanings: AUG = methionine; GUU = valine; CCA = proline.

Model Answer

(a) The mRNA has the same sequence as the coding strand but with uracil in place of thymine, so the mRNA codons are AUG, GUU and CCA. (The coding strand already matches the mRNA, so only T is changed to U.)

(b) Each anticodon is the complementary, antiparallel partner of its codon, so the anticodons are: UAC pairing with AUG, CAA pairing with GUU, and GGU pairing with CCA.

(c) Reading the codons against the key, the amino acids carried are methionine, valine and proline, so the order built into the growing chain is methionine - valine - proline.

> **False Confidence Alert**
> The anticodon is not a copy of the codon but its complementary, antiparallel partner. Writing the anticodon identical to the codon, instead of base-pairing it, is the usual error here.

Question 135

The chain of amino acids that comes off the ribosome is not yet a working protein, and surprisingly the same gene can give rise to more than one form of a protein. Explain both of these statements.

Model Answer

The chain leaving the ribosome is only the primary structure of the protein, the amino acids in their correct order. Before it can work, this chain must fold into its particular three-dimensional shape, and it may be modified further, for example by adding other groups; only then does it have the shape on which its job depends.

The same gene can give more than one protein because of alternative splicing: when the first mRNA is processed, the non-coding introns are cut out and the coding exons are joined, but the exons can be joined in different combinations. Each combination gives a slightly different mRNA, and so a different version of the protein, which is how one gene can serve more than one purpose.

> **False Confidence Alert**
> The chain leaving the ribosome is only the primary structure and must still fold before it can work. Assuming as well that one gene can make only one protein overlooks alternative splicing.

Question 136

Both transcription and translation are steps of protein synthesis, but they are not the same process. Give three differences between them.

Model Answer

Transcription and translation differ in several ways:

1) **What is made:** transcription makes a molecule of mRNA, while translation makes a chain of amino acids (a polypeptide).

2) **Where it happens:** transcription takes place in the nucleus, where the DNA is, while translation takes place at the ribosomes in the cytoplasm.

3) **The language:** transcription copies the message from one nucleic acid to another (DNA bases to mRNA bases), while translation changes the language from bases to amino acids.

A further difference is in what carries out each step: transcription is done by the enzyme RNA polymerase, while translation is done by the ribosome together with the tRNAs.

> **False Confidence Alert**
> Transcription and translation are easily treated as two names for one process. They differ in what is made, where it happens, and the language used, so blurring them together is a common loss of marks.

Question 137

In an examination, **Kipanga** writes that *during translation the DNA itself moves out to the ribosome, where it is read directly to make the protein.* Identify what is wrong with this, and give the correct account.

Model Answer

Kipanga is wrong because the DNA does not leave the nucleus and is never read directly at the ribosome. The DNA is far too large and too valuable to leave, so it stays safely in the nucleus at all times.

The correct account has two stages: first, in the nucleus, the gene is transcribed into a molecule of mRNA, which is a working copy of that one gene. The mRNA then passes out of the nucleus to a ribosome in the cytoplasm, where it, not the DNA, is translated into the protein. So it is the messenger copy that travels and is read, while the DNA remains in the nucleus.

> **False Confidence Alert**
> Kipanga's picture of the DNA travelling to the ribosome feels direct and simple. But DNA never leaves the nucleus; it is the mRNA copy that carries the message, and letting the DNA itself be read skips the whole purpose of transcription.

Question 138

In cattle, the polled (hornless) condition is dominant to horned. A polled bull is mated with several horned cows, and although many of the calves are polled, some are born horned. Using a genetic diagram, deduce the genotype of the bull and show the expected ratio of polled to horned calves.

Model Answer

Because some calves are horned, the bull must carry the recessive horned allele. A horned calf is pp and must receive one p from each parent; the horned cows (pp) supply one p, so the bull must supply the other. The bull therefore cannot be pure polled (PP) but must be heterozygous, Pp.

Parents: polled bull Pp × horned cow pp

Gametes: P and p × p only

	P	**p**
p	Pp	pp

Calves: 1 Pp (polled) : 1 pp (horned)

The expected ratio is therefore 1 polled : 1 horned. This 1:1 result is the mark of a cross between a heterozygote and a homozygous recessive, and it confirms the bull is Pp.

False Confidence Alert
A polled bull need not be pure-breeding. Because polled is dominant, a Pp bull also looks polled, and only the appearance of horned calves reveals the hidden recessive allele.

Question 139

A true-breeding black guinea pig is crossed with a true-breeding white one, and all the offspring are black. These offspring are then crossed among themselves. Work out the expected ratio of coat colour in the second generation, and explain it using Mendel's first law.

Model Answer

Since all the offspring of the first cross are black, black (B) is dominant to white (b), and the true-breeding parents are BB (black) and bb (white).

Parents (P): BB (black) × bb (white)

Gametes: all B × all b

First generation (F1): all Bb (black)

F1 crossed: Bb (black) × Bb (black)

	B	**b**
B	BB	Bb
b	Bb	bb

Second generation (F2): 1 BB : 2 Bb : 1 bb = 3 black : 1 white

The expected ratio in the second generation is 3 black : 1 white. By Mendel's first law of segregation, the two alleles of each Bb parent separate during gamete formation, so half the gametes carry B and half carry b; their random combination at fertilisation gives the 3:1 ratio.

False Confidence Alert
The 3:1 ratio appears in the second generation, not the first. The first cross gives offspring that are all black, and only when these are crossed together does the hidden white reappear in about one quarter.

Question 140

A breeder has a black guinea pig but cannot tell whether it is pure-breeding (BB) or a carrier (Bb), since both look exactly the same. Explain the test cross she should use to find out, and how the appearance of the offspring would reveal the genotype.

Model Answer

She should perform a test cross, mating the black animal with a white one (bb), which is homozygous recessive. The white partner can pass on only b, so the offspring reveal which alleles the black animal is carrying.

There are two possible results:

1) If the black animal is BB: all its gametes carry B, so every offspring is Bb and black, and no white offspring appear.

2) If the black animal is Bb: half its gametes carry b, so about half the offspring are bb and white, giving a ratio of about 1 black : 1 white.

The carrier case: Bb (black) × bb (white)

	B	**b**
b	Bb	bb

Offspring: 1 Bb (black) : 1 bb (white)

So the appearance of even one white offspring shows the black animal is a carrier (Bb), while a good number of offspring that are all black indicates that it is pure-breeding (BB).

False Confidence Alert
Testing the unknown against another black animal would not work, because a dominant phenotype hides the genotype. Only a cross to the homozygous recessive lets the hidden allele show itself in the offspring.

Question 141

In humans, the ability to roll the tongue (R) is dominant to the inability to roll it (r). A man and a woman are both able to roll their tongues and are both heterozygous. Work out (a) the probability that a child of theirs cannot roll its tongue, and (b) the probability that their first two children can both roll their tongues.

Model Answer

The cross is Rr×Rr, which gives offspring in the ratio 3 rollers : 1 non-roller (1 RR : 2 Rr : 1 rr).

Cross: Rr × Rr

	R	**r**
R	RR	Rr
r	Rr	rr

(a) A child who cannot roll the tongue must be rr, which is one of the four equally likely outcomes, so the probability is 1/4.

(b) The births are independent events, so the chance that both children are rollers is found by multiplying their separate chances: each child has a 3/4 chance of being a roller, so the chance that the first two are both rollers is 3/4 × 3/4 = 9/16.

False Confidence Alert
The chance of two rollers in a row is not 3/4 again, nor 3/4 added to 3/4. Because each birth is independent, the separate probabilities are multiplied, giving 3/4 × 3/4 = 9/16.

Question 142

In tomato plants, tall stem (T) is dominant to dwarf (t), and round fruit (R) is dominant to pear-shaped fruit (r). A plant heterozygous for both characters is crossed with another that is also heterozygous for both. Work out the expected ratio of phenotypes among the offspring.

Model Answer

Each parent has the genotype TtRr, and because the two genes assort independently each makes four kinds of gamete in equal numbers: TR, Tr, tR and tr.

Cross: TtRr (tall round) × TtRr (tall round)

Gametes (each parent): TR, Tr, tR, tr

	TR	**Tr**	**tR**	**tr**
TR	TTRR	TTRr	TtRR	TtRr
Tr	TTRr	TTrr	TtRr	Ttrr
tR	TtRR	TtRr	ttRR	ttRr
tr	TtRr	Ttrr	ttRr	ttrr

Collected by phenotype: 9 tall round : 3 tall pear : 3 dwarf round : 1 dwarf pear

The expected phenotype ratio is therefore 9 tall round : 3 tall pear : 3 dwarf round : 1 dwarf pear, the classic dihybrid ratio that appears whenever two double heterozygotes are crossed and the genes lie on different chromosomes.

False Confidence Alert
A double heterozygote does not make only two kinds of gamete such as TR and tr. Because the two genes assort independently it makes four, TR, Tr, tR and tr, and forgetting the mixed gametes Tr and tR destroys the 9:3:3:1 ratio.

Question 143

A cross between two pea plants produced offspring in the ratio 1 tall round : 1 tall wrinkled : 1 dwarf round : 1 dwarf wrinkled. Using T and t for height and R and r for seed shape, work out the genotypes of the two parents.

Model Answer

An equal 1:1:1:1 ratio in a two-character cross is the result of a test cross, in which a parent heterozygous for both genes is crossed with one that is homozygous recessive for both.

The genotypes of the parents must therefore be:

1) **One parent TtRr:** heterozygous for both genes (tall and round in appearance), making four kinds of gamete, TR, Tr, tR and tr.

2) **The other parent ttrr:** homozygous recessive for both genes (dwarf and wrinkled), making only one kind of gamete, tr.

Cross: TtRr (tall round) × ttrr (dwarf wrinkled)

	TR	**Tr**	**tR**	**tr**
tr	TtRr	Ttrr	ttRr	ttrr

Offspring: 1 tall round : 1 tall wrinkled : 1 dwarf round : 1 dwarf wrinkled

The equal 1:1:1:1 ratio confirms that one parent was the double heterozygote TtRr and the other the double recessive ttrr.

False Confidence Alert
An equal 1:1:1:1 ratio does not come from crossing two double heterozygotes, which would give 9:3:3:1. It is the signature of a test cross, so one of the parents must be the double recessive ttrr.

Question 144

In rats, black coat (B) is dominant to brown (b), and short hair (S) is dominant to long hair (s). Two rats each heterozygous for both genes (BbSs) are crossed. Without drawing the full sixteen-box square, use the fact that the two genes assort independently to work out the fraction of the offspring expected to be (a) brown with long hair, and (b) black with short hair.

Model Answer

Because the genes assort independently, each character can be worked out on its own and the separate chances multiplied. Taking each gene by itself, Bb × Bb gives 3/4 black and 1/4 brown, and Ss × Ss gives 3/4 short and 1/4 long.

(a) Brown with long hair (bbss): the chance of brown is 1/4 and the chance of long hair is 1/4, so the chance of both together is 1/4 × 1/4 = 1/16.

(b) Black with short hair: the chance of black is 3/4 and the chance of short hair is 3/4, so the chance of both together is 3/4 × 3/4 = 9/16.

False Confidence Alert
These fractions come from multiplying the separate chances, not adding them. Because the two genes are inherited independently, 1/4 × 1/4 gives the 1/16 of brown long-haired rats directly, without drawing the whole square.

Question 145

Kipanga is told that when a pure tall pea plant is crossed with a dwarf one, all the offspring are tall. He concludes that the dwarf allele has disappeared and can never be seen again. Explain why Kipanga is wrong.

Model Answer

Kipanga is wrong because the dwarf allele has not disappeared; it is only hidden in the tall offspring. Each tall offspring has the genotype Tt, carrying one tall allele and one dwarf allele; the dwarf allele is recessive, so it does not show while the dominant tall allele is present, but it is still there.

The hidden dwarf allele can reappear in the next generation, if two of these tall (Tt) plants are crossed:

Tall offspring crossed: Tt × Tt $\rightarrow$ 3 tall : 1 dwarf

About one quarter of the new plants will be dwarf (tt), because the alleles of each Tt parent separate and can pair together again. The dwarf allele is therefore masked, not lost, which is exactly what Mendel's first law shows.

> **False Confidence Alert**
> A recessive allele is never lost simply because it cannot be seen. It is hidden whenever the dominant allele is present, and it returns in any offspring that inherit two copies of it.

Question 146

In Andalusian fowls, a cross between a black bird and a white (splashed-white) bird gives offspring that are all blue. When two of these blue Andalusians are crossed together, work out the ratio of colours expected, and explain why no single colour is dominant.

Model Answer

Colour here shows incomplete dominance, so the blue bird is the heterozygote C^BC^W, carrying one black allele and one white allele. The pure black parent is C^BC^B and the pure white parent is C^WC^W, and their cross gives offspring that are all C^BC^W, which appear blue because one black allele on its own cannot make the bird fully black.

Blue × blue: $C^BC^W \times C^BC^W$

	C^B	C^W
C^B	C^BC^B	C^BC^W
C^W	C^BC^W	C^WC^W

Offspring genotype: 1 C^BC^B : 2 C^BC^W : 1 C^WC^W

Offspring phenotype: 1 black : 2 blue : 1 white

The expected ratio is therefore 1 black : 2 blue : 1 white. No single colour is dominant because the heterozygote is blue, a colour of its own, rather than taking after either parent; since neither allele masks the other, the phenotype ratio (1:2:1) equals the genotype ratio.

> **False Confidence Alert**
> Because the parents are black and white, it is tempting to treat blue as a separate pure-breeding colour. But the blue bird is a heterozygote, so blue crossed with blue always throws back some black and some white in a 1:2:1 ratio.

Question 147

In shorthorn cattle, a red bull crossed with a white cow gives roan calves, whose coats carry red hairs and white hairs mixed together. A roan bull is now crossed with a roan cow. Work out the expected ratio of the offspring, and explain how this codominance differs from the incomplete dominance seen in the blue Andalusian.

Model Answer

Coat colour here shows codominance, so a roan animal is the heterozygote C^RC^W, in which both the red allele and the white allele have their full effect. A red animal is C^RC^R and a white one is C^WC^W, so red crossed with white gives all roan, C^RC^W.

Roan × roan: $C^RC^W \times C^RC^W$

	C^R	C^W
C^R	C^RC^R	C^RC^W
C^W	C^RC^W	C^WC^W

Offspring: 1 red (C^RC^R) : 2 roan (C^RC^W) : 1 white (C^WC^W)

The expected ratio is 1 red : 2 roan : 1 white. It differs from the Andalusian only in the heterozygote: in codominance the roan shows red and white hairs side by side, both alleles fully expressed, whereas in the Andalusian's incomplete dominance the two alleles blend into a single new colour, blue. The 1:2:1 ratio, however, is the same in both.

False Confidence Alert
Roan is not a blended colour in the way blue is. It is a true mix of separate red and white hairs, so it shows codominance, where both alleles are seen in full, not the blending of incomplete dominance.

Question 148

A baby of blood group O is born to a mother of blood group A. Three men, of blood groups O, AB and B, are each said to be the possible father. Using genetics, decide which of the men could be the father and which can be ruled out.

Model Answer

The baby is group O, so its genotype is I^OI^O, and it must have received one I^O allele from each parent. The mother is group A but must carry a hidden I^O to have passed one on, so her genotype is I^AI^O. The father, too, must be able to supply an I^O allele.

Testing each man against this requirement:

1) **The group O man (I^OI^O):** can pass on I^O, so he could be the father.

2) **The group AB man (I^AI^B):** has no I^O allele to give, so he is ruled out.

3) **The group B man:** could be the father only if he is I^BI^O, carrying a hidden I^O; if he is I^BI^B he could not, so he remains a possibility.

So the group O man and the group B man could be the father, while the group AB man cannot. Blood groups can only rule a man out or leave him possible; they can never prove on their own that a particular man is the father.

False Confidence Alert
A man of a matching blood group is too quickly assumed to be the father. Blood groups can only exclude a man or leave him possible, so here the group AB man is firmly ruled out, but neither of the others is proved.

Question 149

Two pure-breeding white-flowered sweet pea plants, when crossed, surprisingly give offspring that are all purple. Explain this result, and predict the ratio of colours when these purple offspring are crossed among themselves.

Model Answer

Purple colour needs a dominant allele of two different genes, C and P, working together; this is called complementary gene action. Each white parent is pure-breeding but lacks one of the two dominants: one is CCpp and the other is ccPP. Crossed together, every offspring receives a C from one parent and a P from the other, so all are CcPp and therefore purple.

When these purple CcPp plants are crossed among themselves, each gene gives a 3/4 chance of the dominant form, so the chance of having both a C and a P together (and so being purple) is $3/4 \times 3/4 = 9/16$. The other 7/16 lack a C, or a P, or both, and so are white, giving a ratio of 9 purple : 7 white.

False Confidence Alert
Two white parents giving all-purple offspring looks impossible until you notice that two genes are involved. Purple needs a dominant of both genes, so the 9:7 ratio, rather than 3:1, is the signature of complementary genes.

Question 150

In mice, coat colour depends on two genes. Gene A gives agouti (A) or black (a), but gene C must carry a dominant allele for any colour to show at all: a mouse that is cc is albino whatever its A genes. Two agouti mice, each AaCc, are crossed. Work out the expected ratio of agouti : black : albino offspring, and explain how the usual 9:3:3:1 is changed.

Model Answer

A cross of AaCc × AaCc would, on its own, give the four genotype classes in the familiar 9 : 3 : 3 : 1 pattern: 9 A_C_, 3 A_cc, 3 aaC_ and 1 aacc. The epistasis of gene C now changes how these appear.

Because any mouse that is cc is albino whatever its A genes, the two cc classes are masked and merge:

1) **Agouti (9):** the 9 A_C_ mice have a dominant A and a dominant C, so they show agouti.

2) **Black (3):** the 3 aaC_ mice have a dominant C but are aa, so they show black.

3) **Albino (4):** the 3 A_cc and the 1 aacc all lack a dominant C, so all four are albino regardless of their A genes.

The expected ratio is therefore 9 agouti : 3 black : 4 albino. The recessive cc is epistatic: by hiding gene A whenever colour cannot be deposited, it merges the 3 and 1 classes into a single group of 4, turning 9:3:3:1 into 9:3:4.

False Confidence Alert
A 9:3:4 ratio is easily mistaken for a faulty 9:3:3:1. The two missing classes have not vanished but merged, because the recessive cc makes the mouse albino whatever its other gene, joining the A_cc and aacc classes into one albino group of 4.

Question 151

Human skin colour and height vary smoothly, from very light to very dark and from short to tall, instead of falling into a few sharp classes. Explain why such characters show continuous variation, and how this differs from a character like the ABO blood group.

Model Answer

Skin colour and height show continuous variation because they are polygenic, controlled by many genes together, each adding a small effect. The many genes can combine in a great number of ways, and the environment (such as diet for height, or sunlight for skin colour) adds further small effects, so the character grades smoothly from one extreme to the other rather than falling into separate classes.

The ABO blood group is different because it is controlled by a single gene, so it falls into a few clear-cut categories (A, B, AB and O) with nothing in between, and it is almost unaffected by the environment. This is discontinuous variation, in contrast to the continuous variation of the polygenic characters.

False Confidence Alert
Continuous variation is wrongly thought to mean no genes are involved. Characters like skin colour are still inherited, but through many genes of small effect together with the environment, so it is the adding-up of many contributions, not the absence of genes, that gives the smooth range.

Question 152

When two yellow mice are crossed, the offspring are always about 2 yellow : 1 non-yellow, and yellow mice can never be made to breed true however often they are crossed. Explain both of these observations.

Model Answer

Yellow coat is caused by an allele (Y) that is dominant for colour but lethal when homozygous, so every living yellow mouse is the heterozygote Yy. A pure yellow YY dies before birth, which is the key to both observations.

Cross: Yy (yellow) × Yy (yellow)

	Y	**y**
Y	YY	Yy
y	Yy	yy

Offspring: 1 YY (dies) : 2 Yy (yellow) : 1 yy (non-yellow)

The 2:1 ratio appears because the YY class dies, leaving the survivors as 2 Yy (yellow) : 1 yy (non-yellow) instead of the usual 3:1. Yellow can never breed true because a yellow mouse is always Yy; crossing two of them must give the lethal YY, the yellow Yy and the non-yellow yy every time, so a pure-breeding all-yellow stock can never be obtained.

False Confidence Alert
Yellow mice are expected to breed true like any other colour. They cannot, because every yellow mouse is the heterozygote Yy and the pure YY dies before birth, so a yellow stock always carries the non-yellow yy as well and throws the 2:1 ratio.

Question 153

Kipanga sees a cross that gives offspring in a 1 : 2 : 1 ratio of phenotypes and at once concludes that the gene must show incomplete dominance. Explain why he cannot be sure, and what else could give a 1:2:1 ratio.

Model Answer

Kipanga is too quick, because a 1:2:1 phenotype ratio does not by itself prove incomplete dominance. Codominance gives exactly the same 1:2:1 ratio, as in roan cattle (1 red : 2 roan : 1 white), and so the ratio alone cannot tell the two apart.

To decide between them, Kipanga must look at the heterozygote itself, not just the ratio: if the heterozygote is a blend of the two parental forms, such as pink or blue, the gene shows incomplete dominance; if instead it shows both parental characters together, such as red and white hairs side by side, the gene shows codominance. Only the appearance of the heterozygote settles the matter.

False Confidence Alert
A 1:2:1 ratio does not by itself prove incomplete dominance. Codominance gives the very same ratio, so only looking at the heterozygote, a blend on one hand or both characters shown on the other, can decide which is at work.

Question 154

A colour-blind man marries a woman who has normal colour vision and is not a carrier. Work out the colour vision of their sons and daughters, and explain why none of the children is colour-blind yet the condition can appear among their grandsons.

Model Answer

The colour-blind man is X^bY and the woman, being a normal non-carrier, is X^BX^B, so she can pass on only X^B. The man passes X^b to his daughters and his Y to his sons.

Cross: X^bY (colour-blind father) × X^BX^B (normal mother)

	X^b	Y
X^B	X^BX^b	X^BY

Children: daughters all X^BX^b (carriers, normal vision); sons all X^BY (normal vision)

None of the children is colour-blind: every daughter receives the father's X^b but also the mother's X^B, which masks it, so she is a carrier with normal vision; every son receives the mother's X^B and is normal.

The condition reappears in the grandsons because the allele is carried on by the daughters, for a carrier daughter (X^BX^b) can pass X^b to half her sons, who, having no second X to mask it, will be colour-blind. This is why a sex-linked condition often seems to skip a generation, passing from a man to his grandsons through his unaffected daughters.

> **False Confidence Alert**
> Although none of the children is colour-blind, the allele has not gone, because every daughter is a carrier. It travels silently through the daughters and reappears in their sons, which is why the condition seems to skip a generation.

Question 155

A woman whose father was a haemophiliac marries a man who does not have haemophilia. Work out the chance that a son of theirs has haemophilia, explaining first what the woman's genotype must be.

Model Answer

The woman must be a carrier, X^HX^h. Her father was a haemophiliac (X^hY) and gave his only X, the X^h, to all his daughters; since the woman herself has normal blood clotting, her other X (from her mother) must carry the normal allele X^H, making her X^HX^h.

Cross: X^HX^h (carrier mother) × X^HY (normal father)

	X^H	Y
X^H	X^HX^H	X^HY
X^h	X^HX^h	X^hY

Children: daughters X^HX^H and X^HX^h; sons X^HY (normal) and X^hY (haemophiliac)

Among the sons, half are X^HY (normal) and half are X^hY (haemophiliac), so the chance that a son has haemophilia is 1/2. (Counting all the children, one in four is an affected son, but the question asks only about the sons.) None of the daughters is affected, though half of them are carriers like their mother.

> **False Confidence Alert**
> Having a haemophiliac father does not make the woman a haemophiliac. She receives his single X but her other X carries the normal allele, so she is a carrier, and the risk then falls on her sons, half of whom may be affected.

Question 156

About 8 in every 100 men, but fewer than 1 in 100 women, are red-green colour-blind. Using genetics, explain why the condition is so much more common in men than in women.

Model Answer

Colour blindness is caused by a recessive allele carried on the X chromosome, and men and women differ in how many X chromosomes they have. A man has only one X (he is XY), so a single colour-blind allele on that X is enough to make him colour-blind, with no second X to mask it.

A woman has two X chromosomes (she is XX), so she is colour-blind only if both of her X chromosomes carry the allele, which is far less likely than carrying just one when the allele is uncommon. A woman with only one copy is a carrier with normal vision. This is why the condition shows up in many more men than women, even though the same allele is involved.

False Confidence Alert
It is wrong to think men simply catch colour blindness more easily. A man shows it whenever his single X carries the allele, while a woman shows it only if both of her X chromosomes do, so the difference is the number of X chromosomes, not any difference in exposure.

Question 157

It is sometimes said that girls can never be colour-blind. By working out the cross between a carrier woman and a colour-blind man, show that a colour-blind daughter is in fact possible, and say what is needed for it to happen.

Model Answer

The carrier woman is X^BX^b and the colour-blind man is X^bY, so the woman can pass on X^B or X^b, while the man passes X^b to his daughters and Y to his sons.

Cross: X^BX^b (carrier mother) × X^bY (colour-blind father)

	X^b	**Y**
X^B	X^BX^b	X^BY
X^b	X^bX^b	X^bY

Children: daughters X^BX^b (carrier) and X^bX^b (colour-blind); sons X^BY (normal) and X^bY (colour-blind)

Half of the daughters are X^bX^b and are therefore colour-blind, so a colour-blind daughter is clearly possible. What it requires is that both alleles reach her: the father must be colour-blind (to give an X^b) and the mother must carry the allele as well, so that the daughter can receive two copies. Because both parents must supply the allele, colour-blind girls are uncommon but not impossible.

False Confidence Alert
Colour-blind girls are often thought impossible, but they are only uncommon. An affected father and a carrier mother can together give a daughter two colour-blind alleles, which is exactly what is needed for a girl to be colour-blind.

Question 158

A husband and wife are both of blood group AB. Work out the ratio of blood groups expected among their children, and explain why they can never have a child of group O.

Model Answer

Each AB parent has the genotype I^AI^B and so passes on either I^A or I^B, never an I^O, because neither parent carries that allele.

Cross: I^AI^B (group AB) × I^AI^B (group AB)

	I^A	I^B
I^A	I^AI^A	I^AI^B
I^B	I^AI^B	I^BI^B

Children: 1 I^AI^A (A) : 2 I^AI^B (AB) : 1 I^BI^B (B)

The expected ratio is 1 group A : 2 group AB : 1 group B. No child can be group O, because a group O child would need to be I^OI^O, and neither AB parent has an I^O allele to pass on. The codominance of I^A and I^B is why the middle class shows as a third group, AB, rather than blending.

False Confidence Alert
Two group AB parents are expected to have only AB children. In fact AB crossed with AB gives A, AB and B in a 1:2:1 ratio, and no child is group O because neither parent carries an I^O allele to pass on.

Question 159

In one family a trait appears only in males. It is seen in a grandfather, is absent from all his children, and then reappears in some of his grandsons, the sons of his daughters. Kipanga says the trait is Y-linked; Kipute says it is X-linked recessive. Decide who is correct and explain why the other is wrong.

Model Answer

Kipute is correct: the trait is X-linked recessive. The grandfather (X^aY) passes his X^a to all his daughters, who become carriers (X^AX^a) without showing the trait; each carrier daughter then passes X^a to about half of her sons, who show the trait because they have no second X to mask it. This gives exactly the pattern described, with the trait skipping the daughters and reappearing in the grandsons.

Kipanga is wrong because a Y-linked trait could not behave this way. A gene on the Y chromosome passes straight from a father to every one of his sons and is never carried by a daughter, since daughters have no Y. A Y-linked trait could therefore not pass through the unaffected daughters to the grandsons, so the route through the daughters rules out Kipanga's idea.

False Confidence Alert
A trait limited to males is too quickly called Y-linked. Passing through unaffected daughters to grandsons rules out Y-linkage, since a Y-linked gene would go straight from father to every son, so the pattern instead fits an X-linked recessive carried silently by the daughters.

Question 160

In parts of Tanzania where malaria is common, the sickle-cell allele stays surprisingly frequent, even though people with sickle-cell anaemia often die young. Using the idea of heterozygote advantage, explain why the allele is not eliminated by natural selection.

Model Answer

The key is that the heterozygote, the carrier, is fitter than either pure type in a malarial area. The three genotypes fare very differently:

1) Hb^AHb^A (normal): has normal blood but no protection, so is at full risk from malaria.

2) Hb^AHb^S (carrier): has mostly normal blood, so is healthy, and is also protected against severe malaria.

3) Hb^SHb^S (sickle-cell anaemia): suffers severe anaemia and often dies young.

Because the carrier survives both dangers better than the others, natural selection favours the heterozygote where malaria is common. Selection for the carrier keeps passing on both alleles, so the Hb^S allele cannot be removed even though it is harmful in the double dose. This balance, in which selection maintains a harmful allele because the heterozygote is favoured, explains why the sickle-cell allele stays common just where malaria is common.

> **False Confidence Alert**
> The sickle-cell allele is wrongly expected to die out simply because it can be deadly. In a malarial area the carrier is fitter than either pure type, so selection keeps the allele common by favouring the very carriers who pass it on.

Question 161

Albinism, in which the skin and hair lack the pigment melanin, is an autosomal recessive condition that is relatively common in Tanzania. A couple who both have normal skin colour have an albino child. Explain how this happened, give the genotypes of the parents, and state the chance that their next child is also albino.

Model Answer

Both parents must be carriers, each with the genotype Aa. Albinism is recessive, so an albino child must be aa and must have received one a allele from each parent; since both parents have normal skin colour but have passed on a, each must carry a hidden a behind a dominant A, making them Aa.

Cross: Aa (normal carrier) × Aa (normal carrier)

	A	**a**
A	AA	Aa
a	Aa	aa

Children: 1 AA : 2 Aa : 1 aa = 3 normal : 1 albino

The chance that the next child is albino is 1/4 (one in four). Each pregnancy is an independent event, so this 1/4 chance applies again to the next child whatever the earlier children were; having already had one albino child does not change it.

> **False Confidence Alert**
> Two normal parents are often thought unable to have an albino child. Because albinism is recessive, each can carry a hidden a allele without showing it, and when both pass it on the child is aa and albino though neither parent is.

Question 162

A gene can be altered either by the substitution of one base for another or by the insertion of one extra base near its start. Explain why the insertion is likely to be far more damaging to the protein than the substitution.

Model Answer

A substitution changes only the single codon in which it falls, so it alters at most one amino acid. It may even be silent, if the new codon still codes the same amino acid, or it may change just one amino acid; either way the rest of the protein is read normally.

An insertion of one base is far worse because it causes a frameshift. Since the bases are read in threes from a fixed starting point, adding one extra base near the start pushes every later base into the wrong triplet, so every codon after the insertion is misread. The whole sequence of amino acids beyond that point is therefore wrong, and the protein is almost always made useless. This is why a one-base insertion usually does much more damage than a one-base substitution.

> **False Confidence Alert**
> A single inserted base can look as harmless as a single swapped one. A substitution changes at most one codon, but an insertion shifts the whole reading frame so that every later codon is misread, which is why it usually ruins the protein.

Question 163

A baby is born with Down syndrome and is found to have three copies of chromosome 21 instead of two. Explain how a fault in cell division produces this condition, and why the chance of it rises with the mother's age.

Model Answer

Down syndrome arises from non-disjunction, a failure of chromosome 21 to separate properly during meiosis. Normally the two copies of chromosome 21 move to opposite ends and each gamete gets one; if they fail to separate, one gamete receives two copies of chromosome 21 and another receives none. When the gamete carrying two copies is fertilised by a normal one, the baby has three copies in all, a total of 47 chromosomes instead of 46.

The risk rises with the mother's age because of the way her eggs are formed. A woman's eggs begin meiosis before she is even born and are then held part-way through it for years, finishing only when each is released; the longer they are held, the more likely the chromosomes are to fail to separate. So an older mother's eggs are more prone to non-disjunction, and the chance of a Down syndrome baby increases with her age.

False Confidence Alert
Down syndrome is sometimes thought to be inherited from an affected parent. It usually arises fresh, from a failure of chromosome 21 to separate in egg formation, and the risk rises with the mother's age because her eggs have been held part-way through division since before her own birth.

Question 164

Kipanga says that *all mutations are harmful, and that mutation is therefore always a bad thing for a species.* Explain why Kipanga is wrong.

Model Answer

Kipanga is wrong because mutations are not all harmful. Many mutations are neutral, falling in parts of the DNA that make no difference, and a rare few are beneficial, giving a useful new feature; even the sickle-cell mutation, harmful in the double dose, protects carriers from malaria.

More importantly, mutation is the only source of completely new alleles, and so it is the ultimate source of the variation on which natural selection acts. Without mutation there would be no new variety for selection to choose between, and a species could never adapt to a changing environment. Mutation is therefore essential to life, not simply a bad thing, even though many individual mutations are harmful.

False Confidence Alert
Branding every mutation as harmful forgets that mutation is the source of all genetic novelty. The same process that causes some diseases also produces the beneficial variants on which natural selection works, so a species with no mutation could never adapt.

Question 165

Before genetic engineering, people with diabetes used insulin taken from the pancreases of pigs and cattle. Explain how human insulin is now made using bacteria, and give two advantages of this method over using animal insulin.

Model Answer

Human insulin is now made by putting the human insulin gene into bacteria so that the bacteria make the hormone for us. The gene for human insulin is cut out and joined into a bacterial plasmid to form recombinant DNA; the plasmid is taken up by bacteria, which are then grown in huge numbers in fermenters, where they read the human gene and produce human insulin that is collected and purified.

Two advantages over animal insulin are:

1) It is an exact human match: the product is true human insulin, so it works better and causes fewer allergic or immune reactions than pig or cattle insulin, which differ slightly from the human form.

2) It gives a large, reliable supply: bacteria multiply very fast and can be grown in great quantity, so insulin can be made cheaply and in bulk without depending on the pancreases of slaughtered animals, and it is acceptable to people who avoid pig or cattle products.

False Confidence Alert
Bacterial insulin is sometimes thought to be only an imitation of the real thing. In fact it is true human insulin, because the bacteria follow a human gene, so it matches the body better than pig or cattle insulin; the bacterium is merely the factory.

Question 166

A Tanzanian farmer is offered genetically modified maize that has been engineered to resist drought and insect pests. Explain two ways in which such a crop could benefit the farmer, and give one genuine concern about growing it.

Model Answer

Two ways the crop could benefit the farmer are:

1) Better survival in drought: because the maize resists drought, it is more likely to survive a poor rainy season, reducing the risk of crop failure and helping to secure the family's food supply.

2) Less loss to pests: because the maize resists insect pests, less of the crop is eaten or destroyed and less money need be spent on pesticides, so the yield and the farmer's income should rise.

One genuine concern is the loss of local varieties and independence: if many farmers grow the one engineered variety, the traditional local maize varieties may be lost, reducing the diversity that protects against future diseases, and the farmer may become dependent on buying new seed each season from the company that supplies it. A fair view therefore weighs the clear benefits against such real concerns rather than treating the crop as simply good or simply bad.

False Confidence Alert
Genetically modified crops are too easily judged either all good or all bad. A drought- and pest-resistant maize can genuinely raise a farmer's yield and food security, yet real concerns such as the loss of local varieties remain, so a fair answer weighs both sides.

Question 167

Kipanga says that *because a whole animal can be cloned, as was done with Dolly the sheep, people should be free to clone human beings in the same way*. Outline how such cloning would be carried out, and give the main arguments on each side of whether it should be done.

Model Answer

Cloning a whole individual is done by somatic-cell nuclear transfer. The nucleus is taken from a body cell of the individual to be copied and placed into an egg cell whose own nucleus has been removed; the egg is stimulated to divide and is implanted into a surrogate mother, and the offspring is genetically identical to the body-cell donor, as Dolly was to the sheep that supplied her nucleus.

Those who argue for allowing it say:

It could help in some cases: it might let an infertile couple have a genetically related child, or be used in medical research and to make tissues for treating disease.

Those who argue against it say:

It is unsafe and raises deep ethical concerns: the success rate is very low and many clones are born with abnormalities, and many people hold strong moral and religious objections about human dignity, identity and consent; a clone would in any case be a separate person, not a true copy of the original.

So the science makes human cloning conceivable, but it does not settle whether it should be done, which is why human reproductive cloning is at present banned or condemned in most countries. Kipanga's step from 'we can' to 'we may' is the weak point: being able to do a thing does not by itself make it right.

> **False Confidence Alert**
> Being able to clone an animal is wrongly taken to settle whether we should clone people. What is technically possible is a separate question from what is ethically acceptable, and human cloning raises safety and moral objections that the science alone cannot answer.

HOT QUESTIONS

The questions that follow are the most demanding in the chapter. They do not call for new facts but ask you to connect the ideas of the chapter, to weigh evidence, and to carry your reasoning into unfamiliar situations. Take your time over each one, think it through, and set out your reasoning clearly.

Question 168

Long before the structure of DNA was known, scientists reasoned that whatever the genetic material was, it had to be able to do three things: store information, copy itself exactly, and occasionally change. Explain how the structure of DNA, once it was discovered, was found to meet all three of these requirements.

Model Answer

The discovery that DNA is a double helix of two base-paired strands explained, in one structure, how it can do all three jobs.

Storing information: the four bases can follow one another in any order along a strand, and this sequence acts as a code, so a single molecule can hold a vast amount of information in the order of its bases.

Copying itself exactly: because A always pairs with T and G with C, each strand carries the exact information needed to rebuild its partner, so when the strands separate each acts as a template for a faithful new copy.

Changing occasionally: a rare error in the base sequence, a mutation, alters the stored information and is then copied like any other sequence, giving the new variation on which evolution depends.

So the very same feature, the ordered sequence of paired bases, accounts for all three demands at once: the sequence stores the message, the pairing rule copies it, and a rare change in the sequence varies it. This is why the structure, once seen, was so convincing as the genetic material.

> **False Confidence Alert**
> It is tempting to praise the structure of DNA for storage alone. Storing the code is only one of the three demands, for the same base pairing also allows exact copying, and rare errors in the sequence allow change, so a full answer must link the structure to all three.

Question 169

A newly discovered microbe is found to carry its genetic information in single-stranded RNA rather than in double-stranded DNA. Using what you know about the structure of the two molecules, predict two ways in which its heredity might differ from that of a DNA-based organism, giving your reasoning for each.

Model Answer

Two likely differences follow from the single strand and the chemistry of RNA:

1) **A higher rate of mutation:** a single strand has no paired partner to check it against, so errors made when the RNA is copied cannot be caught and corrected by comparison with a complementary strand; the microbe would therefore tend to mutate faster and change more quickly than a DNA organism.

2) **Less durable information:** RNA, with its ribose sugar and uracil base, is chemically less stable than DNA, so the genetic message would break down more easily and be less reliably preserved over time.

Both predictions come from the same reasoning used for DNA, carried into a new case: the second strand of DNA gives it both a template for accurate repair and a stable, lasting store, and an organism lacking that second strand, and built of the less stable RNA, would be expected to copy less accurately and to keep its information less securely. This is in fact why many RNA-based viruses mutate so rapidly.

> **False Confidence Alert**
> An RNA-based organism is wrongly assumed to behave just like a DNA one. Its single strand leaves errors unchecked and its chemistry is less stable, so it should be expected to mutate faster and to hold its information less durably.

Question 170

A sample of DNA from an unknown organism is analysed and found to contain 28% adenine, 28% thymine, 22% guanine and 22% cytosine. A second sample, said to be the genetic material of the same organism, gives 31% adenine, 19% thymine, 26% guanine and 24% cytosine. Using Chargaff's rule, judge whether the second sample can really be normal double-stranded DNA, explaining your reasoning.

Model Answer

The first sample behaves as normal double-stranded DNA, but the second does not. Chargaff's rule says that in double-stranded DNA the amount of adenine equals that of thymine and the amount of guanine equals that of cytosine, because A pairs with T and G with C across the two strands.

Testing each sample against the rule:

First sample: A = T (28% and 28%) and G = C (22% and 22%), so it obeys Chargaff's rule and is consistent with ordinary double-stranded DNA.

Second sample: A = 31% but T = 19%, so adenine and thymine are far from equal; the rule is broken, and the sample cannot be normal double-stranded DNA.

Because base pairing forces A to equal T in a double strand, a large mismatch between them shows the second sample is not double-stranded; it is more likely a single-stranded nucleic acid, in which the bases are not paired and so need not be present in equal amounts. The closeness of G and C in that sample does not rescue it, since both halves of the rule must hold.

> **False Confidence Alert**
> Matching G to C in the second sample is not enough to call it normal DNA. Double-stranded DNA must obey both halves of Chargaff's rule, and here A and T are far apart, so the sample cannot be ordinary double-stranded DNA however close G and C may be.

Question 171

A good genetic store must be very stable, so that the information is kept safe, yet it must also be easy to open up whenever the cell needs to copy or read it. Explain how the structure of DNA manages to meet these two seemingly opposite demands at once.

Model Answer

Both demands are met by the same feature of the structure: the two strands are held together by many hydrogen bonds, which are strong in total but weak one at a time. Added up along the whole molecule, the great number of these bonds, together with the stacking of the bases inside the helix and the strong sugar-phosphate backbones on the outside, makes the double helix very stable, so the stored information is well protected.

Yet because each individual hydrogen bond is weak, the strands can be separated easily and locally, so an enzyme can unzip a short stretch of the helix to copy or read it without breaking the strong backbone, and the bonds simply re-form afterwards. The same many-but-weak hydrogen bonding therefore gives overall stability and easy local opening together, rather than these being a contradiction.

False Confidence Alert
Stability and easy opening sound like opposite demands that one molecule could not meet. They are met by the same feature, since the many hydrogen bonds are strong in total but weak one by one, so the helix holds firmly yet can be unzipped locally.

Question 172

In the cell, DNA serves as the permanent store of genetic information while RNA serves as a short-lived working copy. Explain how the differences in the structures of the two molecules suit each one to its particular role.

Model Answer

DNA's structure suits a permanent store because it is built for stability. Its two strands protect the information by holding a complementary backup of every base, so damage can be repaired from the other strand; its deoxyribose sugar is chemically more stable, and its use of thymine adds to that stability, so the message can be kept safely for the life of the cell.

RNA's structure suits a temporary working copy because it is built to be made and removed quickly. It is usually a single strand, so it is quick to make and easy to break down once used; its ribose sugar makes it less stable and therefore shorter-lived, and a single copy can be read many times and then destroyed when no longer needed. So the very features that would be weaknesses in a permanent store, single strand and a less stable sugar, are exactly what suit RNA to a disposable copy.

False Confidence Alert
The differences between DNA and RNA are often listed without saying why they matter. Each difference fits the molecule to its job: DNA's double strand and stable sugar make it a lasting store, while RNA's single strand and less stable sugar suit a copy that is made and destroyed quickly.

Question 173

A student argues that, *because both DNA and proteins are long chains found in chromosomes and proteins are built from twenty different amino acids, a protein could just as well have been the genetic material.* Evaluate this argument, explaining what a molecule must be able to do to act as the genetic material and why DNA, not protein, is used.

Model Answer

The student is right that a protein could store information, but wrong to conclude it could serve as the genetic material. To act as the genetic material, a molecule must do three things: store information in a code, be copied exactly so that the information passes on, and be stable while still able to change. A protein's twenty amino acids could indeed spell out a code, so the storing requirement is met.

The argument fails on the requirement to be copied exactly. A protein has no rule by which one chain can act as a template for an identical new chain, so there is no simple way to replicate it. DNA, by contrast, has complementary base pairing: each strand templates its partner, so the molecule copies itself faithfully. It is this built-in copying mechanism, which protein lacks, that makes DNA and not protein the genetic material.

False Confidence Alert
A long chain with great variety, such as protein, looks like a strong candidate for the genetic material. But variety alone is not enough, because the material must also copy itself exactly, and protein has no pairing rule to template a copy whereas DNA's base pairing provides one.

Question 174

DNA made entirely of heavy nitrogen is allowed to replicate in a medium of light nitrogen only. After one round of replication all the DNA is of intermediate, hybrid density. Predict the densities of the DNA after a second round of replication in the light medium, and explain how the whole result rules out the conservative model of replication.

Model Answer

After the second round, half of the DNA will be hybrid and half will be fully light, that is, a 1 hybrid : 1 light mixture. This is because each hybrid molecule from the first round has one heavy strand and one light strand; when these separate, the heavy strand templates a new light strand (giving another hybrid) while the light strand templates a new light strand (giving a fully light molecule).

The result rules out the conservative model, in which the original double helix would stay whole and a brand-new molecule would be made beside it. The conservative model predicts that after the first round there would be only heavy and light DNA, with no intermediate at all; instead, every molecule was hybrid. The semiconservative pattern, with hybrid appearing first and then a growing share of light DNA, is exactly what is seen, so the conservative model is excluded.

> **False Confidence Alert**
> The first round alone is sometimes thought to settle the matter. It is the second round that is most telling, for the hybrid molecules give half hybrid and half fully light DNA, a pattern the conservative model can never produce because it makes no hybrid at all.

Question 175

DNA polymerase can add new nucleotides only to the 3' end of a growing strand, and the two strands of a DNA molecule are antiparallel. Explain how these two facts together make it necessary for one new strand to be built continuously and the other in short pieces.

Model Answer

The two facts act together: synthesis can run in one direction only (5' to 3'), and the two template strands point in opposite directions, so the same enzyme cannot copy both templates the same way.

As the fork opens, the two new strands are therefore built differently:

The leading strand: its template runs so that the new strand can be made continuously towards the fork, adding to its 3' end as the fork opens, in one smooth piece.

The lagging strand: its template runs the opposite way, so a new strand added 5' to 3' must be made away from the fork; it can only be built in short pieces, each started as a new length of template is exposed, and the pieces are later joined.

So the discontinuous copying of one strand is not a fault but a necessity, forced by combining the rule that synthesis goes only 5' to 3' with the fact that the strands are antiparallel. If either were not true, both strands could be copied in the same continuous way.

> **False Confidence Alert**
> It is easy to blame the lagging strand on the enzyme being clumsy. The discontinuous copying is forced, not careless, because synthesis runs only 5' to 3' while the strands are antiparallel, so one template can only be copied away from the fork in short pieces.

Question 176

Human DNA has billions of base pairs, yet replication copies it with very few mistakes. Explain the features that make replication so accurate, and predict what would happen to a line of cells whose DNA polymerase lost its proofreading ability.

Model Answer

Replication is accurate because of several checks working together:

1) Complementary base pairing: each base on the template accepts only its correct partner, A with T and G with C, so most wrong bases are never added in the first place.

2) Proofreading by DNA polymerase: as it works, the enzyme checks the base it has just added and removes it if it is wrong before moving on, correcting most of the errors that slip past pairing.

3) Repair after replication: other enzymes scan the new DNA and mend remaining mismatches, lowering the error rate still further.

If the polymerase lost its proofreading ability, the cells would suffer a much higher mutation rate, because errors that base pairing missed would no longer be removed and would be copied into all later cells. Many more faulty proteins would be made, harmful mutations would build up with every division, and the cells would be far more likely to malfunction or die; if the damaged genes included those controlling cell division, the line could become cancerous. This shows how much of replication's reliability rests on proofreading, not on base pairing alone.

> **False Confidence Alert**
> Base pairing alone is often credited for the accuracy of replication. Pairing is only the first check, for the polymerase also proofreads and removes wrong bases and further repair follows, so removing proofreading would let many missed errors pass and raise the mutation rate sharply.

Question 177

There are 20 amino acids to be coded for, using an 'alphabet' of only four bases. By working out how many amino acids could be specified if the code used one, two or three bases per 'word', explain why the code has to be a triplet code, and say what the cell does with the codes that are left over.

Model Answer

The number of possible 'words' is found by raising 4 (the number of bases) to the power of the word length:

One base per word: gives 4 to the power 1 = 4 possible words, enough for only 4 amino acids, far too few for 20.

Two bases per word: gives 4 to the power 2 = 16 possible words, still fewer than the 20 amino acids needed, so a doublet code cannot work.

Three bases per word: gives 4 to the power 3 = 64 possible words, which is more than enough to specify all 20 amino acids.

So three is the smallest word length that can cover all twenty amino acids, because two bases give only 16 and that is fewer than 20; this is why the code has to be a triplet code.

The 64 codes far outnumber the 20 amino acids, and the cell puts the surplus to use: most amino acids are given more than one codon (the code is degenerate), and a few codes are set aside as signals, one start codon and three stop codons, to mark where reading begins and ends. So none of the spare capacity is wasted.

> **False Confidence Alert**
> A triplet code is sometimes accepted simply because 64 is more than 20. The sharper argument is that a doublet code gives only 16, fewer than the 20 amino acids needed, so three is the smallest word length that can possibly work.

Question 178

Suppose the genetic code were not degenerate: that each amino acid had exactly one codon, and all the remaining codons were stop codons. Predict how this would change the effect of point mutations, and say whether organisms would be better or worse off than they are with the real, degenerate code.

Model Answer

With such a code, almost every base substitution would damage the protein, so organisms would be worse off. In the real degenerate code a change, especially in the third base of a codon, often gives another codon for the same amino acid, so the mutation is silent and harmless.

If each amino acid had only one codon, that safety would be gone: any base change would turn the codon either into the single codon for a different amino acid, changing the protein, or into one of the many stop codons, cutting the protein short. There would be no silent changes left at all, so nearly every point mutation would be harmful. This shows that degeneracy, far from being wasteful repetition, protects organisms by absorbing many mutations without effect.

False Confidence Alert
Degeneracy is easily dismissed as wasteful, since several codons can do the same job. In fact it is protective, because without it almost every base change would alter an amino acid or create a stop codon, so far more mutations would damage the protein.

Question 179

Follow a single wrong base in a gene all the way to the organism. Explain, step by step, how one changed base in the DNA can end up altering a visible feature of the whole organism, using sickle-cell anaemia as your example.

Model Answer

A single base change is turned into a visible feature through a chain of steps, each passing the change on to the next:

1) **In the DNA:** one base of the haemoglobin gene is changed, so the triplet on the template strand that read CTC now reads CAC.

2) **In transcription:** the changed gene is copied into mRNA, so the codon that should have been GAG is now GUG.

3) **In translation:** the tRNA that reads GUG brings valine instead of the glutamic acid that GAG would have brought, so one amino acid in the haemoglobin chain is wrong.

4) **In the protein:** this single wrong amino acid changes the shape and behaviour of the haemoglobin, making it clump together when oxygen is low.

5) **In the cell and body:** the clumped haemoglobin pulls the red blood cells into a sickle shape, and these sickled cells block vessels and break down, causing the anaemia and pain that can be seen and felt in the person.

So a change far too small to see, one base in the DNA, is magnified step by step into a feature of the whole organism, because each level faithfully passes its change to the next: base to codon, codon to amino acid, amino acid to protein, protein to cell, and cell to body.

False Confidence Alert
A single base change is often thought too small to matter to the whole organism. Yet the steps magnify it, one base changing one codon, one codon one amino acid, and one amino acid a protein's shape and so a visible feature, which is how a tiny change becomes a large effect.

Question 180

In a eukaryotic cell the mRNA is processed, by adding a cap and a tail and by splicing, after it is made and before it is translated. Explain how this processing both protects the message and lets one gene make more than one protein, and why a prokaryote, which has no nucleus, cannot process its mRNA in the same way.

Model Answer

The cap and tail protect the message. The cap added to one end and the tail added to the other guard the mRNA against being broken down too quickly and help it to leave the nucleus and be translated, so the message lasts long enough to be used.

Splicing lets one gene make more than one protein. During splicing the non-coding introns are cut out and the coding exons are joined together, and because the exons can be joined in different combinations, one gene's mRNA can be edited in more than one way to give different proteins.

A prokaryote cannot do this because it has no nucleus to separate the two stages. In a prokaryote transcription and translation happen together in the cytoplasm, with ribosomes attaching to the mRNA and translating it while it is still being made, so there is no separate stage, between making the mRNA and using it, in which the message could be capped, tailed and spliced. The nucleus of the eukaryote provides exactly that separate stage.

> **False Confidence Alert**
> mRNA processing is easily seen as mere tidying-up. In fact the cap and tail protect the message while splicing joins exons in different ways to let one gene make several proteins, which is why a prokaryote translating its mRNA as it is made cannot process it the same way.

Question 181

A cell sometimes needs to make thousands of copies of a particular protein quickly, yet it has only one or two copies of the gene for it. Explain the features of transcription and translation that let a cell produce a protein in large amounts and at speed from just one gene.

Model Answer

The output is multiplied at two separate stages, which together turn one gene into a flood of protein.

1) **One gene makes many mRNA copies:** the gene can be transcribed over and over again, each time producing another mRNA molecule, so a single gene quickly gives rise to many messages.

2) **Each mRNA makes many protein copies:** a single mRNA can be translated by many ribosomes at the same time, forming a polysome, and each ribosome builds its own copy of the protein; the mRNA can also be read again and again before it is broken down.

Because the amplification happens at both stages, the numbers multiply: one gene gives many mRNAs, and each mRNA gives many proteins, so a cell can make thousands of copies of a protein rapidly even though it holds only one or two copies of the gene. This two-level multiplication is the key to producing proteins in bulk and at speed.

> **False Confidence Alert**
> It is tempting to think one gene can make only one protein molecule at a time. In fact the gene is transcribed many times and each mRNA is read by many ribosomes at once, so the output is multiplied at two stages rather than one.

Question 182

Mendel knew nothing of chromosomes, yet his two laws are now explained by the way chromosomes behave during meiosis. Explain how the behaviour of chromosomes in meiosis accounts for both the Law of Segregation and the Law of Independent Assortment.

Model Answer

Both laws follow from how chromosomes move in meiosis, because the alleles Mendel followed are carried on the chromosomes.

The Law of Segregation: the two alleles of a gene sit at the same place on a pair of homologous chromosomes; during meiosis the homologous chromosomes are pulled to opposite ends and so end up in different gametes, so each gamete carries only one allele of the gene. The separation of the homologues is the segregation of the alleles.

The Law of Independent Assortment: genes on different chromosome pairs are sorted separately, because each pair of homologues lines up at the middle of the cell on its own and quite at random, so the way one pair faces does not affect the way another faces. The alleles of one gene therefore pass into the gametes independently of the alleles of a gene on a different chromosome.

So the two laws are not separate rules to be learned by heart but direct results of meiosis: homologues separating gives segregation, and homologous pairs lining up at random gives independent assortment. This is why the laws hold, and also why genes on the same chromosome (which cannot assort independently) are an exception to the second law.

False Confidence Alert
Mendel's laws are sometimes treated as rules quite separate from cell division. In truth each is simply the behaviour of chromosomes in meiosis, since homologues separating gives segregation and pairs lining up at random gives independent assortment.

Question 183

A student crosses two heterozygous tall pea plants (Tt x Tt) and, among just 8 offspring, counts 5 tall and 3 dwarf rather than the expected 6 tall and 2 dwarf. The student concludes that the 3:1 ratio is wrong. Evaluate this conclusion, explaining the part played by chance and by sample size in genetic ratios.

Model Answer

The student's conclusion is not justified, because a count of 5 tall and 3 dwarf does not disprove the 3:1 ratio. A genetic ratio is a statement of probability, not a promise that exact numbers will appear; each seed has a 3/4 chance of being tall and a 1/4 chance of being dwarf, and chance alone makes the actual count vary about the expected one.

The smaller the sample, the larger this chance variation is, in proportion. With only 8 offspring, getting 5 and 3 instead of 6 and 2 is an easily expected swing of chance, far too small to overturn the ratio. Only when hundreds or thousands of offspring are counted do the proportions settle close to 3:1, which is exactly why Mendel worked with very large numbers of plants rather than a handful. So the ratio stands; it is the smallness of the sample, not the ratio, that explains the figures.

False Confidence Alert
A result close to but not exactly 3:1 is wrongly taken to disprove the ratio. Genetic ratios are probabilities, so small samples scatter around them by chance, and only large numbers settle close to the predicted figure.

Question 184

A dihybrid cross between two double heterozygotes is expected to give a 9:3:3:1 ratio of phenotypes. In one such cross, however, most of the offspring are of the two parental types, with only a few showing the other two combinations. Explain what this result tells you about the two genes, and why the few non-parental offspring appear at all.

Model Answer

The result shows that the two genes are linked, that is, they lie on the same chromosome. Because they are on one chromosome, they tend to be passed on together rather than assorting independently, so the offspring mostly resemble the parental combinations instead of being shared out into the 9:3:3:1 pattern that independent genes would give.

The few non-parental offspring appear because of crossing over during meiosis. When homologous chromosomes exchange segments, the linked alleles are occasionally separated and recombined into new combinations, producing a small number of recombinant offspring. The rarer these recombinants are, the closer together the two genes must lie, since closely linked genes are seldom separated by crossing over. So the result both reveals the linkage and hints at how close the genes are.

False Confidence Alert
A ratio far from 9:3:3:1 is easily read as a mistake in the cross. More often it is a clue that the genes are linked on one chromosome, with the few non-parental types made only when crossing over separates them.

Question 185

Two parents are each heterozygous for albinism (Aa x Aa). Their first child has normal skin colour. Work out the probability that this normal child is a carrier (Aa), and explain why the answer is 2/3 and not 1/2.

Model Answer

The cross Aa x Aa gives offspring in the ratio 1 AA : 2 Aa : 1 aa.

Cross: Aa × Aa

	A	**a**
A	AA	Aa
a	Aa	aa

We are told the child is not an albino, so it cannot be aa, and the aa outcome must be left out of the counting. That leaves three equally likely normal outcomes, 1 AA and 2 Aa; of these, two are carriers (Aa). The probability that the normal child is a carrier is therefore 2 out of 3, or 2/3.

The answer is 2/3, not 1/2, because the extra information that the child is normal changes the odds. Before knowing the child's appearance the carrier chance would be 2/4 = 1/2, but ruling out the one albino class removes a quarter of the outcomes and leaves the carriers as two out of the three that remain. Using the information given is what turns 1/2 into 2/3.

False Confidence Alert
It is tempting to call a normal child a one-in-two chance of being a carrier. Once the albino class is ruled out, only three equally likely normal genotypes remain, two of them carriers, so the chance is 2/3, not 1/2.

Question 186

When two double heterozygotes are crossed, the offspring sometimes appear not in the usual 9:3:3:1 ratio but in ratios such as 9:3:4, 12:3:1, 9:7 or 15:1. Explain what all of these modified ratios have in common, and show how each one arises from the basic 9:3:3:1.

Model Answer

All of these ratios are really the same 9:3:3:1, but with some of its four classes merged because one gene affects the other, a situation called gene interaction (epistasis). The four parts 9, 3, 3 and 1 always add up to 16, and in every modified ratio the same sixteen offspring are simply grouped differently, so each modified ratio also adds up to 16.

Each modified ratio comes from merging particular classes:

1) **9:3:4:** the 3 and the 1 merge into 4, when a recessive condition of one gene hides the other (recessive epistasis).

2) **12:3:1:** the 9 and a 3 merge into 12, when a dominant allele of one gene masks the other (dominant epistasis).

3) 9:7: the two 3s and the 1 merge into 7, when both genes are needed together for the feature to show (complementary genes).

4) 15:1: the 9 and both 3s merge into 15, when either gene alone is enough to give the feature (duplicate dominant genes).

So none of these is a new or separate ratio to be memorised on its own: each is the ordinary 9:3:3:1 with classes combined according to how the two genes interact, which is why all of them still total sixteen.

False Confidence Alert
The modified ratios look like a confusing list to be memorised separately. They are really one ratio, 9:3:3:1, with classes merged whenever one gene masks or depends on another, which is why every one of them still adds up to sixteen.

Question 187

The ABO blood-group system shows both codominance and complete dominance at the same time, within a single gene that has three alleles. Explain how one gene can show both relationships, and predict the blood groups possible among the children of a group A parent and a group B parent who each carry a hidden O allele.

Model Answer

One gene can show both because the relationship depends on which pair of alleles is present. The alleles I^A and I^B are codominant to each other, so when both are present (I^AI^B) both show and the person is group AB; but both I^A and I^B are completely dominant to the recessive I^O, which shows only when no other allele is present (I^OI^O, group O). So the same gene shows codominance between two of its alleles and complete dominance over the third.

The group A parent carrying a hidden O is I^AI^O, and the group B parent carrying a hidden O is I^BI^O.

Cross: I^AI^O (group A) × I^BI^O (group B)

	I^B	I^O
I^A	I^AI^B	I^AI^O
I^O	I^BI^O	I^OI^O

All four blood groups are possible among the children, in the ratio 1 AB : 1 A : 1 B : 1 O. It is the codominance of I^A and I^B that produces the AB child, and the recessiveness of I^O that allows a group O child from two parents who are neither group O, so both kinds of dominance show up together in the one family.

False Confidence Alert
It seems impossible for a single gene to be both codominant and completely dominant. Yet the ABO gene is, because the A and B alleles are codominant to each other while both are completely dominant over the recessive O allele.

Question 188

Identical twins have exactly the same genes, yet if they are raised apart they can grow to noticeably different heights. Explain how this is possible for a polygenic character such as height, and what it shows about the parts played by genes and environment in continuous variation.

Model Answer

Height is a polygenic character, set by many genes together, but it is also strongly affected by the environment, especially by diet and health in childhood. Identical twins share all their genes, so they have the same genetic potential for height; but if they are raised apart, with different diets and conditions, they may not reach the same actual height.

This shows that genes and environment work together to shape a continuous character: the genes set the range of heights a person could reach, while the environment decides where, within that range, the person actually ends up. Continuous variation arises from this combination, the many small genetic effects together with the environment, which is why such characters grade smoothly and why even genetically identical people are not bound to be identical in them.

> **False Confidence Alert**
> Identical genes are wrongly expected to give an identical height. The genes set the possible range, but the environment, especially childhood diet, decides where in that range a person ends up, so twins raised apart can differ.

Question 189

A breeder finds that a certain coat colour in cattle can never be made to breed true, and that crossing two animals of this colour always gives offspring in a ratio of about 2 of that colour to 1 of another, instead of the usual 3:1. Explain what these two observations, taken together, reveal about the allele for that colour.

Model Answer

The two observations together point to a lethal allele: one that is dominant for the colour but kills the animal when it is present in double dose. If the colour allele is lethal when homozygous, then every living coloured animal must be a heterozygote, because the homozygous-coloured embryos die before birth.

This single idea explains both observations at once:

1) **Why it cannot breed true:** a true-breeding coloured animal would have to be homozygous for the colour allele, but such animals die, so only heterozygotes survive and the colour can never be fixed.

2) **Why the ratio is 2:1:** crossing two heterozygotes gives 1 homozygous coloured : 2 heterozygous coloured : 1 of the other type; the homozygous coloured die, leaving the survivors as 2 coloured : 1 other instead of 3:1.

So a ratio of 2:1 in place of 3:1, together with a colour that cannot be made pure-breeding, is the classic signature of a dominant allele that is lethal in the homozygous state.

> **False Confidence Alert**
> A 2:1 ratio is easily mistaken for a miscounted 3:1. Taken with the fact that the colour can never breed true, it instead reveals a lethal allele whose homozygotes die, leaving 2 heterozygotes to 1 of the other type.

Question 190

Kipanga is shown two crosses: a red-flowered plant crossed with a white one gives all pink flowers, and a red cow crossed with a white one gives roan calves with red and white hairs. He says both are examples of 'blending inheritance', in which the parents' characters mix together permanently. Explain why Kipanga is wrong about both, and what is really happening in each case.

Model Answer

Kipanga is wrong because in neither case do the alleles truly blend; the old idea of blending inheritance, in which characters mix and cannot be recovered, is disproved by what happens in the next generation.

The pink flowers show incomplete dominance: the heterozygote looks intermediate, but the red and white alleles are unchanged; crossing two pink plants gives 1 red : 2 pink : 1 white, so the original colours reappear undiluted.

The roan cattle show codominance: the heterozygote shows red hairs and white hairs separately, not a true mix, and crossing two roans likewise brings back pure red and pure white animals.

In both cases the alleles stay separate and reappear unchanged in later generations, which is exactly the evidence that overturned blending inheritance: if characters truly blended, red and white could never come back once pink or roan had formed. So the appearances may look like a mixture, but the underlying alleles do not blend at all.

False Confidence Alert
Pink and roan look like the parents' colours blended together. But the alleles do not blend, because crossing two of the in-between offspring brings the original red and white back, which is just what disproves old blending inheritance.

Question 191

A condition is studied in several families and is found to follow different patterns in different families. In some it passes from affected fathers to all of their sons but to none of their daughters; in others it appears in every generation and affects both sexes about equally; in others it skips generations and affects mainly males. For each of these three patterns, name the most likely mode of inheritance and explain your reasoning.

Model Answer

Each pattern points to a different mode of inheritance:

Father to all sons, no daughters: most likely Y-linked. A gene on the Y chromosome is passed from a father to every son (who receives his Y) and to no daughter (who receives his X), which is exactly this pattern.

Every generation, both sexes about equally: most likely autosomal dominant. A dominant allele on an ordinary (non-sex) chromosome shows in anyone who carries even one copy, so it appears in each generation and affects males and females alike.

Skips generations, mainly males: most likely X-linked recessive. A recessive allele on the X chromosome shows in males with their single X, but is usually hidden in female carriers, so it passes silently through carrier daughters and reappears in their sons a generation later.

So the key is to read the exact pattern rather than to note only that males are affected: whether the condition passes through daughters, whether it skips generations, and whether it ever goes from father straight to son together pin down which chromosome and which kind of allele are involved.

False Confidence Alert
A condition that affects mainly males is too quickly called the same thing every time. The exact pattern decides the mode, for father-to-all-sons points to Y-linkage, every-generation-in-both-sexes to autosomal dominant, and skipping-generations-mainly-males to X-linked recessive.

Question 192

Two newborn babies in a hospital have been mixed up, and it must be worked out which baby belongs to which mother. One baby is blood group O and the other is group B; the two mothers are blood group AB and blood group O. Using blood groups, decide which baby belongs to which mother as far as you can, and explain why blood groups can sometimes exclude a relationship but rarely prove one.

Model Answer

The group O baby cannot be the child of the group AB mother. A group AB mother is I^AI^B and can pass on only I^A or I^B, never I^O, so every child of hers must carry an I^A or an I^B and so be group A, B or AB, but never group O. The group O baby must therefore belong to the group O mother, and by elimination the group B baby belongs to the group AB mother.

This shows how blood groups exclude rather than prove. They let us say with confidence that a particular child cannot belong to a particular mother, as here for the O baby and the AB mother; but had both babies been group B, blood groups alone could not have told which was which, since a group B child is consistent with more than one mother. Blood groups narrow the possibilities, and can sometimes settle a case by elimination, but on their own they rarely prove a relationship.

False Confidence Alert
A matching blood group is wrongly taken to prove which baby belongs to which mother. Blood groups can firmly exclude a pairing, as the AB mother is excluded from the group O baby, but on their own they rarely prove a match.

Question 193

A harmful X-linked recessive condition is so severe that affected boys die before they are old enough to have children, removing their copy of the allele from the population each generation. Yet the condition keeps appearing in generation after generation. Explain how the allele survives despite being lost every time from the boys who show it.

Model Answer

The allele survives because most copies of it are not in affected boys at all, but hidden in healthy female carriers. A carrier girl is X^HX^h: she has one copy of the allele but does not show the condition, because her other X carries the normal allele; she is perfectly healthy and can grow up and have children, passing the allele on.

So while each affected boy does take his copy out of the population, this removes only a small share of all the copies present, because far more copies are being carried safely and silently by unaffected women. These carriers pass the allele to the next generation, where about half of their sons will show the condition again, so it keeps reappearing. (New cases can also arise by fresh mutation.) The reservoir of hidden copies in carriers is what keeps the allele in the population despite the loss from affected boys.

False Confidence Alert
A harmful allele that kills affected boys is expected to die out quickly. It survives because most of its copies are hidden in healthy female carriers, who never show the condition yet keep passing the allele on.

Question 194

A person is found to have three sex chromosomes for the colour-vision gene: X^bX^bY, that is, two X chromosomes each carrying the colour-blind allele, together with a Y chromosome. Predict whether this person is colour-blind and what their sex is likely to be, explaining your reasoning.

Model Answer

The person is most likely male and is colour-blind. The sex is decided by the Y chromosome, not by the number of X chromosomes: the Y carries the genes that start male development, so an individual with a Y is male even when two X chromosomes are present. Such a person (XXY) is in fact an example of a known condition, Klinefelter's syndrome, which arises when an extra X is present alongside the XY.

The person is colour-blind because neither X carries a normal allele. Both X chromosomes carry the colour-blind allele (X^b), so there is no dominant normal allele anywhere to give normal colour vision, and the colour-blind phenotype must show. This question shows how the rules of sex determination and of sex linkage can both be applied together to an unusual chromosome make-up.

False Confidence Alert
Two X chromosomes are wrongly assumed to mean the person must be female. It is the Y that sets male development, so an XXY individual is male, and with both X chromosomes carrying the colour-blind allele he is colour-blind as well.

Question 195

The sickle-cell allele causes a serious disease, so it might seem that a programme to remove it from a population would be a clear and simple benefit. Evaluate this idea for a region where malaria is common, weighing the likely consequences of removing the allele.

Model Answer

In a malarial region, removing the allele would not be the simple benefit it first appears, because the allele has two opposite effects. Taking it away would indeed end sickle-cell anaemia, sparing the suffering of those born with two copies; but it would also take away the protection against severe malaria that the carriers (with one copy) enjoy.

The two effects must be weighed against each other:

1) **The gain:** no more children would be born with sickle-cell anaemia, removing that disease and its early deaths.

2) **The cost:** the whole population would lose the carriers' resistance to malaria, so more people would suffer and die from severe malaria, which in a malarial region is itself a major killer.

So in a region where malaria is common the idea is not a clear benefit but a trade-off, exchanging the burden of one disease for a greater burden of another; the allele stays common precisely because, on balance, carriers are favoured there. In a region without malaria the calculation would be different, since there would be no protection to lose, and removing the allele would then be more clearly beneficial. A fair evaluation therefore depends on the setting and weighs both effects rather than looking only at the disease.

False Confidence Alert
Removing the sickle-cell allele sounds like an unmixed good. In a malarial region it would also strip away the carriers' protection from malaria, so the gain against one disease could be paid for in more deaths from another.

Question 196

Three different single-base changes occur in the same gene. The first changes one codon into another codon for the same amino acid. The second changes a codon, early in the gene, into a stop codon. The third inserts a base near the start of the gene. Rank these three mutations from least to most damaging to the protein, explaining your ranking.

Model Answer

From least to most damaging, the order is: the silent change first, then the early stop, then the insertion.

1) **Least damaging - the silent substitution:** the new codon still codes for the same amino acid, so the protein is made exactly as before and nothing is lost.

2) **More damaging - the early stop codon:** translation halts near the start, so only a short, incomplete piece of the protein is made and it almost always cannot work.

3) **Most damaging - the insertion near the start:** adding a base shifts the reading frame, so every codon after it, almost the whole gene, is misread; the entire amino-acid sequence beyond the insertion is wrong, and a premature stop usually appears as well.

So the ranking follows how much of the protein each change spoils: the silent change spoils none of it, the early stop loses everything after an early point but at least misreads nothing, and the frameshift both misreads and loses the whole stretch after the start, making it the worst of the three.

False Confidence Alert
A silent change and a frameshift are too easily lumped together as simply 'mutations'. A silent substitution leaves the protein unchanged, while a frameshift near the start corrupts every codon that follows, so their effects are worlds apart.

Question 197

During the formation of a woman's eggs, non-disjunction can produce some eggs that carry two X chromosomes and some that carry none. Predict the possible sex-chromosome make-ups of the children produced when such faulty eggs are fertilised by a normal sperm (carrying either an X or a Y), and name the conditions that result.

Model Answer

A normal egg carries one X, but after non-disjunction some eggs carry XX and some carry no sex chromosome at all; each kind may be fertilised by an X-bearing or a Y-bearing sperm. The four combinations give:

1) XX egg + X sperm gives XXX: a female with three X chromosomes (triple-X).

2) XX egg + Y sperm gives XXY: a male with an extra X, the condition called Klinefelter's syndrome.

3) No-X egg + X sperm gives XO: a female with a single X, the condition called Turner's syndrome.

4) No-X egg + Y sperm gives YO: an embryo with a Y but no X at all; because the X chromosome carries genes essential to life, this cannot survive and is lost.

So three of the four combinations give living individuals, XXX, XXY (Klinefelter's) and XO (Turner's), while the fourth, a Y with no X, is not viable. All of them arise from the same fault, the failure of the sex chromosomes to separate properly when the eggs were formed.

False Confidence Alert
It is tempting to list all four combinations as living conditions. An embryo that ends up with a Y but no X cannot survive, because the X chromosome carries genes essential to life, so that combination is lost.

Question 198

It is said that without mutation there could be no evolution, yet most mutations are harmful, and organisms have repair systems that correct many of them. Explain how these facts fit together, and why a moderate mutation rate, neither zero nor very high, is the best for a species in the long run.

Model Answer

The facts fit together once it is seen that mutation is both a danger to the individual and a necessity for the species. Mutation is the only source of completely new alleles, so it provides the variation that natural selection needs; without any mutation a species would have no new variety and could never adapt to a changing world. Yet most single mutations are harmful to the individual that carries them, which is why repair systems exist to remove many of them.

A moderate mutation rate balances these two pressures:

1) Not zero: if the rate were zero, no new alleles would ever arise, and the species could not adapt when its environment changed, so it would be at great risk in the long run.

2) Not too high: if the rate were very high, harmful mutations would pile up faster than selection or repair could deal with them, so individuals would be damaged and the species could not survive.

So the best rate is a middle one: low enough that most offspring are healthy and the repair systems can cope, but not so low that the rare beneficial mutations, the raw material of evolution, never appear. A moderate rate protects the individual now while still supplying the variation the species will need in the future.

False Confidence Alert
A very low mutation rate is wrongly assumed to be always best. Too low and a species gains no new variation to adapt with, too high and harmful mutations overwhelm it, so a moderate rate serves best in the long run.

Question 199

Genetic engineering works only because several discoveries from earlier in this chapter are all true at the same time. Explain how the universal genetic code, the complementary base pairing of DNA, and the existence of enzymes that cut and join DNA together make it possible to put a human gene into a bacterium and have the bacterium make a human protein.

Model Answer

Genetic engineering is really the practical pay-off of the whole chapter, because it relies on three of its ideas working together:

1) **The universal genetic code:** because nearly all organisms read the same codons as the same amino acids, a bacterium reads a human gene by exactly the same rules as a human cell, and so builds the same protein chain rather than a different one.

2) **Complementary base pairing:** when a restriction enzyme cuts the DNA it leaves short single-stranded ends, and because bases pair only A with T and G with C, the cut ends of the human gene and of the plasmid match and join correctly; the same pairing then lets the gene be copied faithfully each time the bacterium divides.

3) **Enzymes that cut and join:** restriction enzymes cut the DNA at particular sequences to release the gene and open the plasmid, and DNA ligase seals the gene into the plasmid, producing the recombinant DNA that is put into the bacterium.

So no single trick makes genetic engineering work; it is possible only because the code is universal, because bases pair in a fixed way, and because enzymes can cut and seal DNA, all of which were established earlier in the chapter. Genetic engineering brings these threads together into one powerful technique.

> **False Confidence Alert**
> Genetic engineering can seem like a trick that stands on its own. In truth it works only because the code is universal, because bases pair to join the cut DNA, and because enzymes can cut and seal it, all discoveries from earlier in this chapter.

Question 200

Genetic engineering offers great benefits but also raises serious concerns. Using examples, evaluate whether its benefits outweigh its risks, and explain why decisions about its use cannot be made on the science alone.

Model Answer

Genetic engineering brings real and large benefits, but also genuine risks, and a fair judgement must weigh both.

The benefits: it gives cheap, pure medicines such as human insulin and vaccines, and crops that resist drought and pests and so improve food security, which matters greatly in countries such as Tanzania; it can also help clean up waste and may one day treat inherited disease directly.

The risks: engineered genes might spread to wild relatives or to harmful bacteria, local crop and animal varieties could be lost, farmers may become dependent on buying seed, and there are ethical and religious objections as well as fears of misuse.

On balance the benefits are substantial, and many of the risks can be reduced by careful regulation, testing and monitoring, so in many uses the benefits can be judged to outweigh the risks; but this is a judgement, not a fixed fact, and it depends on the particular use and how well it is controlled.

The decision cannot rest on the science alone because science answers a different question. Science can tell us what genetic engineering is able to do and how likely each outcome is, but it cannot by itself say what we ought to value, how to weigh a benefit to some against a risk to others, or where ethical limits should lie. Those are questions of values and of society, so deciding how genetic engineering should be used needs both the science and a careful, open weighing of its costs, benefits and ethics.

False Confidence Alert
The benefits of genetic engineering are wrongly thought to settle the matter by themselves. Whether they outweigh the risks depends on values, regulation and setting as well as on data, because the science shows what can be done but not what should be.

Chapter 6

EVOLUTION

BINDER QUESTIONS

Work through each question in order: attempt your own answer first, then check it against the model answer and against the False Confidence Alert that follows, which warns of the mistake that most often costs marks.

Question 1

Long before laboratories existed, people everywhere asked where the first living things came from, and several theories grew up in answer, some resting on belief and others on evidence. Explain what makes an explanation of the origin of life scientific rather than mere speculation, and why this distinction matters when the theories are judged.

Model Answer

A scientific theory of the origin of life is one that can be tested against evidence, while speculation cannot be tested and so can only be believed or doubted. A theory becomes scientific when it makes claims that observation or experiment could support or overturn, such as whether life can arise from non-living matter.

This matters because the theories of the origin of life are judged by this very standard. Special creation and the steady-state idea place the origin outside what can be observed, so science can neither prove nor disprove them; spontaneous generation, by contrast, could be tested in the laboratory and was shown to be false, while the biochemical theory is supported by experiments that reproduce the building blocks of life. **Testability is therefore the line that separates a scientific explanation from a belief.**

False Confidence Alert
A tempting answer is to call a theory scientific simply because many people accept it. Acceptance is not the test; an explanation earns the name scientific only when evidence could confirm or refute it, which is why special creation, however widely held, lies outside science.

Question 2

Many Tanzanian families hold, on religious grounds, that all living things were made by God. Explain what the special creation theory claims about the origin of species and whether they change, and explain why science is able neither to prove nor to disprove it.

Model Answer

The special creation theory holds that the Earth and all its living things were brought into being by a supernatural creator, God, and that each kind of organism has remained unchanged since it was created. On this view there has been no real change in living things over time, since species were made complete and fixed.

Science can neither prove nor disprove this claim because creation is said to have happened only once, in a way that cannot be observed, repeated or tested. Since science deals only with what can be observed and tested, an event placed outside that reach falls outside science altogether, so it can be neither confirmed nor refuted by experiment. Its lasting value was to set people thinking about the origin of life.

False Confidence Alert
Students often try to attack or defend special creation with scientific evidence. The mark here is the opposite point: the theory makes no testable prediction, so science simply cannot reach it, neither to support nor to deny.

Question 3

For centuries people believed that maggots simply appeared in rotting meat and that the mud of a river could give rise to frogs. Explain what the theory of spontaneous generation claimed, using examples such as these, and why the idea seemed so convincing before the seventeenth century.

Model Answer

The theory of spontaneous generation claimed that living things could arise directly from non-living matter, without any parent, whenever conditions were favourable; this forming of life from lifeless material is called abiogenesis. Aristotle taught that dead leaves falling into water turned into fish, and that worms and insects formed from soil and decaying matter, while the ancient Egyptians believed the mud of the Nile gave rise to many forms of life, even frogs.

The idea was convincing because people saw maggots appear on uncovered meat and small creatures seem to spring from mud and decay, with no parent in sight. Since the true cause, the eggs laid by flies, was far too small to be noticed, it was natural to conclude that the living things had formed from the lifeless material itself.

False Confidence Alert
It is easy to confuse spontaneous generation with the modern biochemical theory, since both speak of life from non-living matter. The difference that earns the mark is that spontaneous generation claimed whole organisms appeared ready-made and repeatedly, not that simple molecules slowly combined over a vast span of time.

Question 4

When Francesco Redi covered one piece of meat and left another exposed, only the exposed meat bred maggots. Explain how Redi's experiment overturned the theory of spontaneous generation, and state the principle it established in its place.

Model Answer

Redi's experiment showed that maggots come from the eggs laid by flies, not from the meat itself, and so disproved spontaneous generation. He placed meat in two sets of jars, leaving one set open and covering the other so that flies could not reach the meat inside.

Maggots appeared only on the meat that flies could settle on and lay their eggs on, while the covered meat produced none, even though it decayed in just the same way. This proved that the maggots had living parents and did not arise from the lifeless meat. In its place Redi's work supported the principle of biogenesis, which states that living things arise only from other living things.

False Confidence Alert
A common slip is to say the covered meat did not rot, so no maggots formed. The covered meat did decay; the decisive point is that flies could not reach it to lay their eggs, which is why no maggots appeared and life was shown to come only from life.

Question 5

Some scientists have suggested that life did not begin on Earth at all but arrived ready-made from space. Explain what the cosmozoic (panspermia) theory proposes, naming the scientists who shaped it, and explain why it is not accepted as a true theory of the origin of life.

Model Answer

The cosmozoic or panspermia theory proposes that life did not originate on Earth but reached it from elsewhere in the universe as ready-made spores or simple living particles. Richter suggested that life came drifting in with cosmic dust, Helmholtz that it arrived on meteorites, and Arrhenius that resistant spores could travel through space from one world to another.

It is not accepted as a true theory of the origin of life because it does not actually explain how life first began; it only moves the question to another place in the universe. Furthermore, living matter is unlikely to survive the extreme cold, dryness and radiation of space, and the idea cannot be tested by experiment, so it accounts for neither the origin nor the journey of life.

False Confidence Alert
The trap is to treat panspermia as the answer to where life came from. It only shifts the problem elsewhere, so the mark depends on seeing that a theory of the origin of life must explain how life first arose, which panspermia never does.

Question 6

One old idea held that the Earth and its life never had a beginning, but have always existed. Explain what the steady-state theory claims, and explain why it conflicts both with the fossil record and with the principle of biogenesis.

Model Answer

The steady-state theory claims that the Earth had no origin and has always existed and supported life, undergoing only slight changes, so that life too had no beginning and species merely rise and fall in number. On this view organisms were never created; they only increase, decrease or become extinct.

It conflicts with the fossil record because fossils show that different forms of life appeared, changed and died out at different times, which points to the origin of new species and the extinction of others rather than an unchanging living world. It also runs against the principle of biogenesis, since if every organism arises from a pre-existing one, the chain of life traced backwards must have had a beginning, yet the steady-state theory denies that life ever began.

False Confidence Alert
Students sometimes credit the steady-state theory for rejecting a sudden creation and stop there. The mark-dropping error is to miss its central flaw, that the fossil record and the principle of biogenesis both point to a beginning for life, which this theory refuses to allow.

Question 7

The modern scientific account holds that the first life was built up gradually from simple chemicals on the early Earth. Using Oparin's ideas, explain how the conditions of the primitive Earth allowed simple molecules to form and then combine, step by step, towards the first living cell.

Model Answer

Oparin proposed that life arose on the early Earth by chemical evolution, as simple molecules slowly combined into more complex ones under the conditions of the primitive planet. The young Earth was intensely hot and its atmosphere held hydrogen, ammonia, methane and water vapour but no free oxygen, so it was a reducing atmosphere in which such reactions could occur.

As the Earth cooled, the water vapour condensed into heavy rain that formed the early seas, and energy from sunlight, lightning and the Earth's own heat drove the dissolved gases to react, producing simple organic molecules such as amino acids and sugars. These in turn joined into larger molecules, including proteins and nucleic acids, which gathered into tiny droplets called coacervates. The coacervates took in further substances and slowly gained the ability to copy themselves, and so gave rise to the first simple, self-feeding (heterotrophic) cell.

False Confidence Alert
A frequent error is to picture the early atmosphere as rich in oxygen like today's. It was the opposite, a reducing atmosphere with no free oxygen, which is exactly what allowed the delicate organic molecules to form instead of being broken down.

Question 8

In a famous experiment, a mixture of gases thought to resemble the early atmosphere was sealed in glassware and sparked with electricity, and amino acids were formed. Explain how an experiment of this kind supports the biochemical theory of the origin of life.

Model Answer

An experiment of this kind supports the biochemical theory by showing that the building blocks of life can form from simple gases under conditions like those of the early Earth. A mixture of methane, ammonia, hydrogen and water vapour, standing for the early reducing atmosphere, was supplied with energy as an electric spark, which stood for lightning.

After the mixture had been left to react, it was found to contain amino acids, fatty acids and nitrogenous bases, the very molecules from which proteins and nucleic acids are built. This is important because it demonstrates that the first stage of Oparin's scheme, the making of organic molecules from non-living gases, can actually happen, and so gives experimental weight to the idea that life began through ordinary chemical reactions.

False Confidence Alert
It is a costly overstatement to say this experiment created life. It produced only the building blocks, such as amino acids, not a living cell, so its support for the theory reaches only as far as that first chemical step.

Question 9

The five theories of the origin of life do not all stand on the same footing, for some can be tested and others cannot. Outline the five theories, and for each show whether it can be tested scientifically.

Model Answer

The five theories differ above all in whether they can be tested:

1) **Special creation:** holds that a supernatural creator made all life, and cannot be tested, since the event is placed beyond observation.

2) **Spontaneous generation:** held that organisms arose ready-made from non-living matter, and could be tested, but was disproved by Redi.

3) **Cosmozoic (panspermia):** holds that life arrived from space, cannot be tested, and does not even explain how life first began.

4) **Steady-state:** holds that the Earth and life never began, is untestable, and is contradicted by the fossil record.

5) **Biochemical (naturalistic):** holds that life arose by chemical evolution on the early Earth, can be tested, and is supported by laboratory experiments.

Only the spontaneous-generation and biochemical theories can be put to the test, and of these only the biochemical theory still stands.

False Confidence Alert
Listing the theories without judging them leaves the real marks untouched. The question turns on testability, so each theory must be marked as testable or not, with the biochemical theory identified as the one scientific account that still survives.

Question 10

Living things today show enormous variety, yet the fossil record suggests they descend from far simpler ancestors. Draw a simple branching (phylogenetic) tree of living things, and use it to explain what organic evolution means and the overall direction of the change it describes.

Model Answer

Organic evolution is the gradual change in the genetic make-up of a population of living things over many generations, by which new species arise from pre-existing ones. It is a slow change that builds up over a very long time, and its overall direction is from simple, primitive forms towards more complex and varied ones.

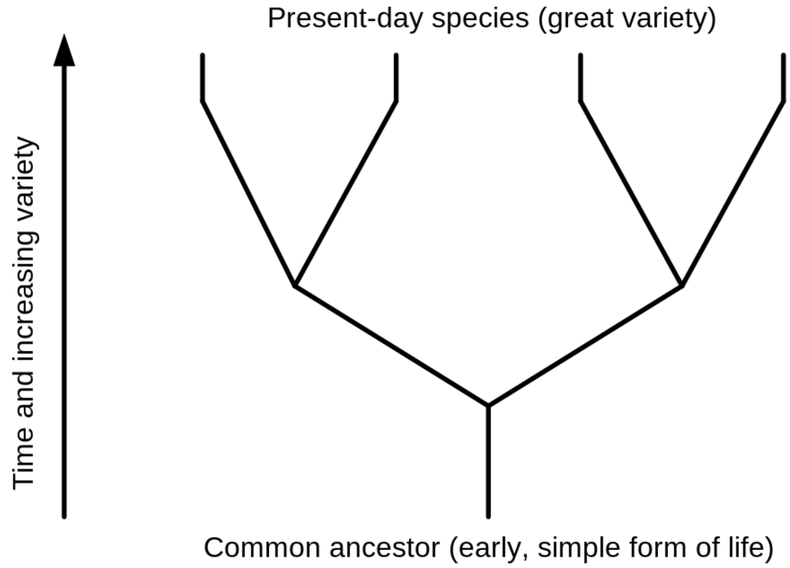


Figure 6.1: *A phylogenetic tree, showing descent from a common ancestor.*

The branching tree shows this clearly: a single common ancestor at the base gives rise, through repeated branching over time, to the many different species living today. Each fork marks a point at which one kind of organism gave rise to two, so the great variety at the top has all descended, with modification, from the simple form at the bottom.

False Confidence Alert
A common slip is to call evolution a change in an individual during its life. It is not; evolution is a change in the inherited make-up of a whole population across generations, which is why a single growing organism is never an example of it.

Question 11

The first full explanation of how evolution might work was put forward by the French biologist Jean Baptiste de Lamarck in 1809. Explain the two ideas on which Lamarck built his theory of evolution.

Model Answer

Lamarck built his theory on two linked ideas: the law of use and disuse, and the inheritance of acquired characters. He proposed that a changing environment creates new needs in an organism, and that the organism responds by using some body parts more and others less.

By the law of use and disuse, a part that is used a great deal becomes larger and more efficient, while a part that is little used gradually weakens and may disappear. By the inheritance of acquired characters, any such change gained during the organism's lifetime is then passed on to its offspring, so that, over many generations, these accumulated changes were thought to produce a new kind of organism.

False Confidence Alert
Naming only one of the two ideas is a frequent cause of lost marks. Lamarck's theory needs both pillars together: use and disuse changes the body, and the inheritance of acquired characters is what carries the change to the next generation.

Question 12

A duck spends its life paddling in water, and over generations, Lamarck believed, its feet became webbed. Explain, using the idea of use and disuse, how Lamarck accounted for a structure like the webbed foot, and what he supposed happened to parts that fell out of use.

Model Answer

By the law of use and disuse, Lamarck held that the constant use of a part strengthens and develops it, so a structure such as the webbed foot was built up by repeated use. As ducks spread their toes again and again to push against the water in search of food, the skin between the toes was stretched and enlarged, generation after generation, until a full web was formed.

A part that fell out of use met the opposite fate. Because it was no longer exercised, it would gradually weaken, shrink and in time disappear, just as the eyes of some burrowing animals are said to have dwindled through disuse. In Lamarck's scheme, therefore, the environment shapes the body by deciding which parts are used and which are left idle.

False Confidence Alert
It is wrong to picture the duck deliberately growing webs because it wanted them. Lamarck claimed only that constant use enlarged the part, not that the animal willed the change, so reading purpose into it misstates his theory.

Question 13

A blacksmith who works at the forge all his life develops large, strong arm muscles, and Lamarck would expect such a gain to appear in the blacksmith's children. Explain what Lamarck meant by the inheritance of acquired characters, and the part it played in his theory.

Model Answer

The inheritance of acquired characters is Lamarck's idea that a feature an organism gains during its own lifetime, as it adapts to its surroundings, becomes part of its heredity and is handed on to its offspring. On this view the blacksmith's enlarged muscles, built up by years of work, would be passed to his children, who would begin life already strong in the arm.

This idea was essential to Lamarck's theory because it provided the bridge between one generation and the next. Use and disuse could change a single body, but only if those changes were inherited could they build up over many generations into a new species; the inheritance of acquired characters was therefore the step that turned a lifetime's change into lasting evolution.

False Confidence Alert
Students often confuse an acquired character with an inherited one. An acquired character is gained during life, such as muscles built by work or a scar from an injury; Lamarck's mistake was to assume these reach the offspring, when only changes in the genes carried in the gametes can be inherited.

Question 14

The long neck of the giraffe is the most famous example used to illustrate Lamarck's theory. Using a labelled diagram, show how Lamarck explained the giraffe's long neck and legs, and name one other example he accounted for in the same way.

Model Answer

Lamarck explained the giraffe's long neck and legs as the inherited result of generations of stretching to reach food. He supposed that the ancestors of the giraffe had short necks and legs and fed on ground plants, but that when grass became scarce they were forced to stretch upward to reach the leaves of tall trees.

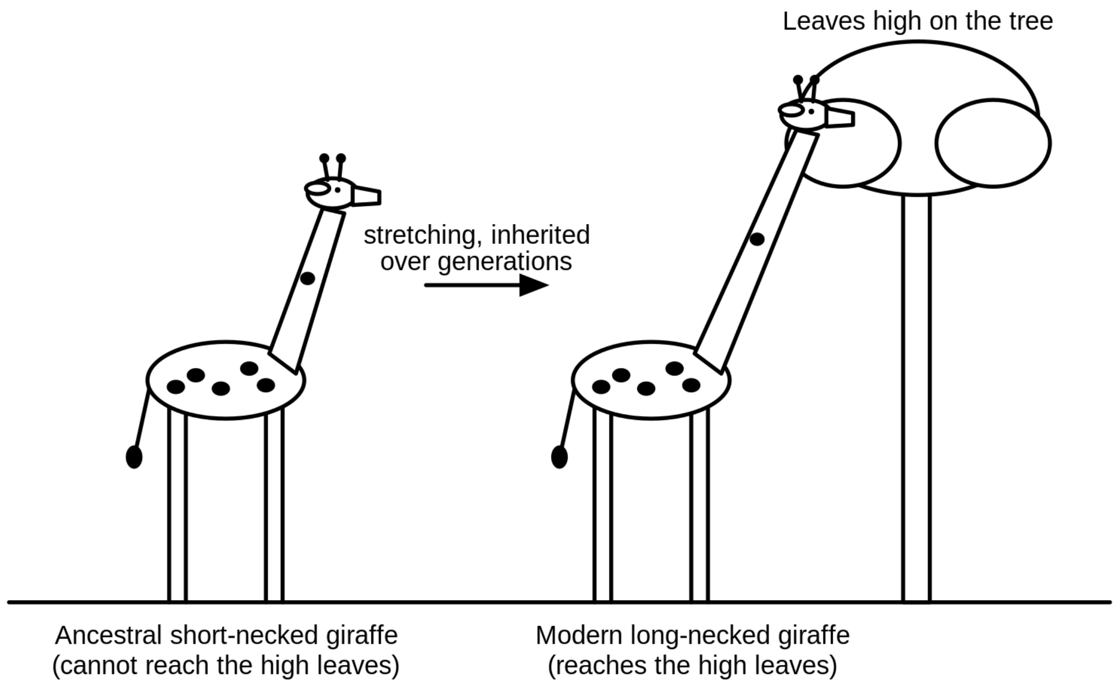


Figure 6.2: *Lamarck's explanation of the evolution of the long-necked giraffe.*

By the law of use and disuse, this constant stretching slightly lengthened the neck and front legs of each animal, and by the inheritance of acquired characters the small gain was passed to the offspring, which stretched in turn; over many generations the neck and legs grew into those of the modern giraffe. Lamarck accounted for the flat shape of bottom-living fish in the same way, as a feature built up by use and then inherited.

False Confidence Alert
The mark-dropping move is to offer Lamarck's giraffe as the correct explanation. It is the discredited account; Darwin's explanation, that long-necked giraffes already varied and were then selected, is the accepted one, so Lamarck's version must be given as his claim and not as fact.

Question 15

Although Lamarck's theory was later rejected, it was an important step in the history of biology. Explain the strengths of Lamarck's contribution to the study of evolution.

Model Answer

Lamarck's chief strength was that he offered the first complete, natural explanation of evolution, and so opened the subject to serious scientific study. Before him the fixity of species was widely assumed; by proposing a mechanism of change, Lamarck encouraged other scientists to think, study and argue about how and why living things evolve.

A second strength was that he rightly recognised the part played by the environment. He saw that an organism's surroundings can shape its form, an insight that survives today in the knowledge that the conditions of life do influence the body, even though the changes he described are not in fact inherited.

False Confidence Alert
Praising Lamarck only for being first is too thin for the marks. Credit must also go to his real insight, that the environment shapes living things, which is the part of his thinking that modern biology has kept.

Question 16

When August Weismann cut off the tails of mice for many generations, their offspring were still born with normal tails. Explain why this result, together with the modern understanding of inheritance, reveals the central weakness of Lamarck's theory.

Model Answer

The central weakness of Lamarck's theory is that characters acquired during an organism's lifetime are not inherited, because they do not change the genes carried in the gametes. A trait gained by use or disuse affects only the body, the somatic cells, and does not alter the hereditary material passed on in the sex cells, so it cannot reach the offspring.

Weismann's experiment demonstrated this directly. He removed the tails of mice for many successive generations, yet every new generation was still born with a full tail, showing that the acquired loss was never inherited. Since the gametes were unchanged by what had happened to the body, the enforced disuse had no effect on the offspring, and so Lamarck's idea of the inheritance of acquired characters could not be correct.

> **False Confidence Alert**
> A common error is to say Weismann's mice kept their tails by chance or because the cut simply healed. The point is deeper: cutting the tail changed only the body and never the gametes, so there was no route by which the change could be inherited, which is exactly what sinks Lamarck's theory.

Question 17

In 1831 the young Charles Darwin set sail on HMS Beagle for a five-year voyage that would change biology. Explain how his observations during and after this voyage led him towards the theory of evolution by natural selection.

Model Answer

Darwin's theory grew out of the evidence he gathered on the five-year voyage of HMS Beagle and from his later study of breeding. Sailing round the coasts of South America, and especially during five weeks on the Galapagos Islands, he was struck by the way the tortoises and finches differed from one island to the next, yet still resembled the species of the nearby mainland.

These observations convinced him that species are not fixed but change over time to suit their surroundings. On his return he studied how breeders improve livestock by choosing which animals reproduce, a process he called artificial selection, and he saw that nature might select in a similar way. In 1859 he published On the Origin of Species, and because Alfred Russel Wallace had reached the same idea independently, the theory is known as the Darwin-Wallace theory of natural selection.

> **False Confidence Alert**
> It is not enough to say Darwin simply observed animals on a voyage. The marks lie in what the observations showed him, that island species varied yet resembled the mainland, and in his link to artificial selection, which suggested nature could select too.

Question 18

At the heart of Darwin's theory is the idea of natural selection. Explain what is meant by natural selection, and why variation among the members of a population is necessary for it to act.

Model Answer

Natural selection is the process by which the organisms best adapted to their environment survive and reproduce, while the less well adapted fail to do so. The survivors pass their favourable characteristics to their offspring, so that, over many generations, these characteristics become more common in the population.

Variation is necessary because selection can only choose between differences that already exist. Since the members of a population are not identical, some happen to carry features that suit the environment better than others; nature then acts on this variation, favouring the well adapted and removing the rest. Without inherited variation there would be nothing for selection to act upon, and the population could not change.

False Confidence Alert
A loose answer says the strongest or biggest organisms survive. Natural selection favours the best ADAPTED, not the strongest, so a smaller organism that is better suited to its surroundings will be selected over a larger one that is not.

Question 19

Darwin built his theory on a small number of everyday observations about living things and their resources. State and explain the three observations from which he began.

Model Answer

Darwin began from three observations about populations and their resources:

1) **Overproduction:** every kind of organism produces far more offspring than can ever survive to maturity, so numbers could in theory rise enormously.

2) **Constancy of population size:** despite this huge potential increase, the number of individuals in a natural population stays more or less steady from year to year.

3) **Limited resources:** the food, space and other resources of any habitat are limited, and cannot support all the offspring that are produced.

Taken together, these three observations mean that far more individuals are born than the environment can ever support, which sets the stage for the struggle that follows.

False Confidence Alert
Listing the observations without the tension between them loses the point. The force of Darwin's argument is that overproduction meets steady numbers and limited resources, so most of the offspring produced must die before they breed.

Question 20

From his three observations Darwin drew two logical conclusions, or deductions, that together explain how species change. Explain the struggle for existence and the survival of the fittest, and show how they lead to new species.

Model Answer

The first deduction is the struggle for existence: because far more offspring are produced than the resources can support, the members of a population must compete in order to survive. This struggle is sharpest between members of the same species (intraspecific competition), which need exactly the same resources, but it also occurs between different species (interspecific competition), and many individuals die or fail to breed before they reproduce.

The second deduction is the survival of the fittest, which is natural selection itself: in this struggle the individuals carrying variations that suit them best to the environment are the most likely to survive and reproduce, an outcome Herbert Spencer called the survival of the fittest. They pass their favourable traits to their offspring, while the less well adapted are selected against; over many generations these advantages accumulate until the descendants differ so much from their ancestors that a new species has arisen.

False Confidence Alert
The fittest does not mean the strongest or fiercest. In Darwin's sense the fittest are those best adapted to the environment and so able to leave the most offspring, which a small, well-camouflaged animal may do better than a large, conspicuous one.

Question 21

Darwin's theory of natural selection can be summed up in a few essential features that build on one another. Outline the essential features of natural selection as Darwin put them forward.

Model Answer

Natural selection rests on six features that each lead into the next:

1) **Overproduction:** organisms produce many more offspring than can survive.

2) **Constant population size:** numbers nevertheless stay roughly steady, so many individuals must die.

3) **Struggle for existence:** with resources limited, individuals compete to survive.

4) **Variation:** the members of a population vary, and some of the variation is inherited.

5) **Survival of the fittest:** those best adapted survive, reproduce and pass on their favourable variations.

6) **Formation of new species:** over many generations the favourable variations accumulate until the descendants form a new species.

Each feature leads into the next, so that overproduction in a world of limited resources ends, through the selection of the best adapted, in the origin of new species.

> **False Confidence Alert**
> A bare list of the six features earns only part of the marks. The examiner rewards the thread that joins them, that overproduction and limited resources force a struggle in which inherited variation is selected, building new species over time.

Question 22

The giraffe's long neck was explained by Lamarck through stretching; Darwin explained it quite differently. Explain how Darwin's theory of natural selection accounts for the evolution of the giraffe's long neck.

Model Answer

Darwin explained the giraffe's long neck not by stretching but by the selection of inherited variation that was already present. Among the ancestral giraffes some, by chance, had longer necks and legs than others, and this variation could be passed on to the offspring.

When food near the ground became scarce, the longer-necked giraffes could reach the leaves high on the trees, so they were better fed, survived and reproduced, while many shorter-necked giraffes failed to compete and died without offspring. Because the long-necked giraffes left more young, which inherited the long neck, each generation contained a greater proportion of long-necked animals, until the modern giraffe was produced. The key difference from Lamarck is that the variation came first and was then selected, rather than being created by the animal's own efforts.

> **False Confidence Alert**
> It is a serious error to mix the two theories by saying giraffes stretched their necks and then passed the longer necks on. That is Lamarck; Darwin's account requires the long necks to exist as variation first, with selection merely favouring them.

Question 23

When the environment consistently favours one extreme of a character, the whole population shifts towards it. Using a labelled diagram of the distribution of a character, show and explain directional selection, and give one example.

Model Answer

Directional selection occurs when one extreme of a character is favoured while the opposite extreme is selected against, so that the average of the population shifts towards the favoured extreme.

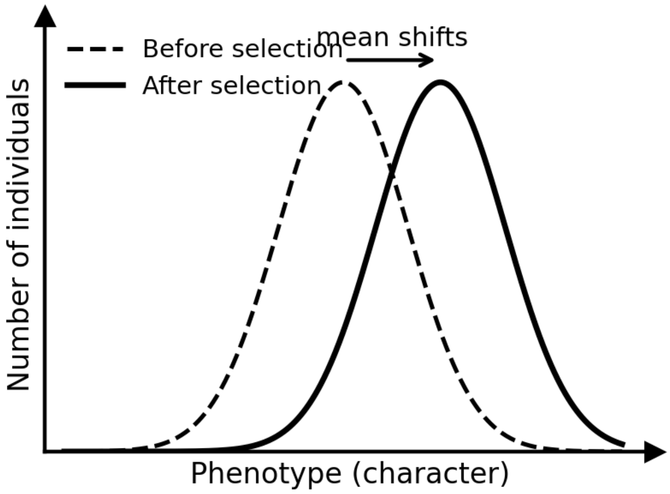


Figure 6.3: *Directional selection, in which the mean shifts towards one extreme.*

The diagram shows the original distribution as a bell-shaped curve; selection removes the individuals at one end, so the curve, and with it the mean, moves across to the favoured side over the generations. A clear example is neck length in giraffes: the short-necked individuals were selected against when high leaves were the only food, so the population shifted steadily towards longer necks.

> **False Confidence Alert**
> A common mistake is to describe the curve as merely getting taller or shorter. In directional selection the whole curve MOVES to one side, because one extreme is favoured and the mean shifts towards it.

Question 24

In a stable environment, the common middle form of a character is often the most successful. Using a labelled diagram, show and explain stabilising selection, and give one example.

Model Answer

Stabilising selection occurs when both extremes of a character are selected against and the intermediate form is favoured, so the population becomes more uniform around its average.

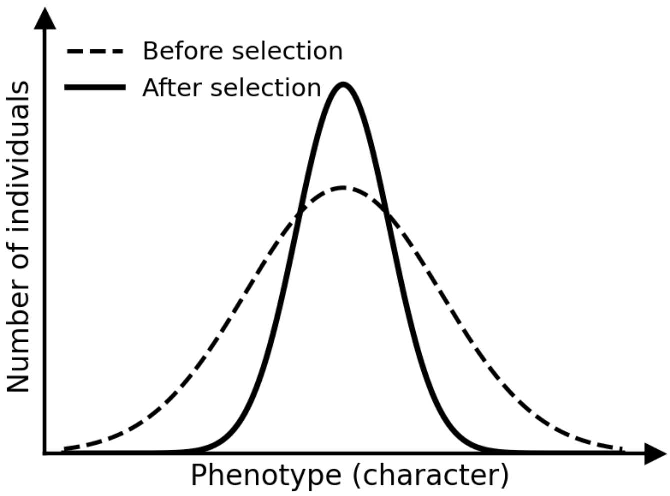


Figure 6.4: *Stabilising selection, in which the extremes are removed and the mean is unchanged.*

The diagram shows the spread of the character narrowing: the original curve is broad, but after selection it becomes taller and narrower about the same mean, because the extreme types are removed while the middle type survives best. A good example is plant height in maize, where very short plants are shaded out and very tall plants are easily broken by wind, so the medium-sized plants are favoured. In animals the best-known example is human birth weight, where very small and very large babies have historically had the lowest survival, so the intermediate weight is favoured.

False Confidence Alert
Students often confuse stabilising with directional selection. In stabilising selection the mean does NOT move; the curve stays centred on the same value but becomes narrower as the two extremes are removed.

Question 25

Sometimes conditions favour both extremes of a character at once and turn against the middle. Using a labelled diagram, show and explain disruptive selection, and state how it can eventually give rise to two species.

Model Answer

Disruptive (diversifying) selection occurs when both extremes of a character are favoured while the intermediate form is selected against, so a single population begins to split into two distinct groups.

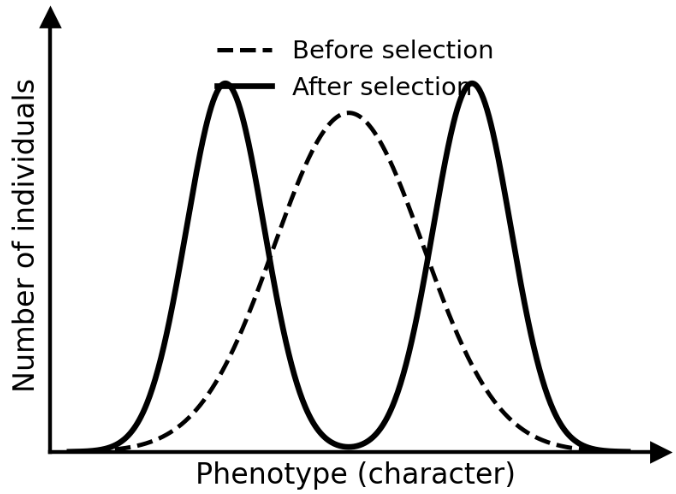


Figure 6.5: *Disruptive selection, in which both extremes are favoured and the middle declines.*

The diagram shows the original single-peaked curve becoming two-peaked: the individuals at each extreme survive and reproduce, while those in the middle are at a disadvantage and decline. If the two favoured groups go on to breed mainly among themselves and the gap between them widens, they may in time become so different that they can no longer interbreed, and two new species arise. An example is the range of beak sizes in the Galapagos finches, where the intermediate beaks were the least suited to the available food.

False Confidence Alert
The error here is to treat disruptive selection as simply two directional selections. Its distinctive feature is that the intermediate type is selected AGAINST, leaving two peaks, which is what allows it to split one population into two.

Question 26

Darwin's theory of natural selection transformed biology and is still the foundation of evolutionary thought. Explain the main strengths of Darwin's theory.

Model Answer

Darwin's theory was a major advance for several reasons:

1) **A natural mechanism:** it explained evolution by an observable, natural process, natural selection, without appeal to the supernatural.

2) **The role of environment and competition:** it showed clearly how the struggle for limited resources drives change.

3) **The importance of variation:** it recognised that inherited variation within a population is the raw material on which selection works.

4) **The origin of species:** it explained how new species can arise from pre-existing ones, directly opposing the older belief that species are fixed.

Together these strengths gave biology its first testable, evidence-based account of how living things change over time.

> **False Confidence Alert**
> Saying only that Darwin explained evolution is too vague for the marks. Credit comes from naming specific strengths, above all that he gave a natural, testable mechanism, natural selection acting on inherited variation.

Question 27

Powerful though it was, Darwin's theory left important questions unanswered, largely because the science of genetics did not yet exist. Explain the main weaknesses or limitations of Darwin's theory of natural selection.

Model Answer

Darwin's theory had several limitations, most of them traceable to his ignorance of genetics:

1) **No source of variation:** Darwin saw that variation existed but could not explain where it came from, since mutation and genetic recombination were unknown to him.

2) **No mechanism of inheritance:** he could not explain how favourable variations were passed on, because Mendel's work on genes was not yet known to him.

3) **The origin of life:** the theory explains how new species arise from existing ones, but not how life itself first began.

These gaps do not overturn the theory but show where it was incomplete; they were later filled by genetics, giving rise to the modern, or Neo-Darwinian, theory of evolution.

> **False Confidence Alert**
> It is wrong to say Darwin was simply mistaken. His limitations were gaps, not errors, chiefly that he could not explain the origin or the inheritance of variation; genetics later supplied exactly what he lacked.

Question 28

After Mendel's work on genes became known, Darwin's theory was rebuilt on a genetic foundation and renamed Neo-Darwinism. Explain what Neo-Darwinism is, and how it describes evolution in terms of genes.

Model Answer

Neo-Darwinism, or the modern theory of evolution, is the theory of evolution by natural selection acting on genetically determined variation. It keeps Darwin's central idea of natural selection but explains it using the knowledge of genetics that Darwin did not have.

In this modern view, evolution is described as a change in the frequency of genes (alleles) in a population from one generation to the next. The variation on which selection acts arises from mutation and the reshuffling of genes, and selection then increases the frequency of the favourable alleles while the unfavourable ones become rarer. The word Neo means new, marking this as Darwinism brought up to date by genetics, molecular biology and ecology.

False Confidence Alert
It is wrong to think Neo-Darwinism replaces Darwin's theory. It keeps natural selection at its centre and simply adds the genetics Darwin lacked, recasting evolution as a change in gene frequency.

Question 29

Darwin's theory had two great gaps: he could not say where variation came from, nor how it was passed on. Explain how Neo-Darwinism fills these two gaps.

Model Answer

Neo-Darwinism fills Darwin's two gaps with the findings of genetics, explaining both the source of variation and the way variation is inherited. Darwin could only observe that variation existed; the modern theory shows where it comes from and how it is passed on.

First, the source of variation is now known to be mutation, which creates new alleles, together with the reshuffling of existing alleles by genetic recombination during meiosis. Second, the mechanism of inheritance is explained by Mendel's genes: the variations are carried on the chromosomes as alleles and passed to the offspring in the gametes. With these two additions, natural selection can be seen clearly as the sorting of inherited genetic variation.

False Confidence Alert
A thin answer simply repeats that Darwin lacked genetics. The marks come from naming both gaps and their fillers: mutation and recombination as the source of variation, and Mendelian genes carried in the gametes as the means of inheritance.

Question 30

Sexual reproduction shuffles the genes of two parents into new combinations in their offspring. Explain how genetic recombination acts as a source of the variation on which natural selection works.

Model Answer

Genetic recombination is the mixing of alleles into new combinations during sexual reproduction, and it is a major source of the variation that selection acts upon. It does not create new alleles, but it brings existing alleles together in fresh arrangements, so that offspring differ from their parents and from one another.

The reshuffling happens chiefly during meiosis: in prophase I, crossing over exchanges segments between homologous chromosomes, and the independent assortment of the chromosomes mixes the parents' alleles further; the random joining of gametes at fertilisation then adds yet more variety. Because each offspring receives a new combination of alleles, the population contains the differences on which natural selection can act.

False Confidence Alert
It is a common error to say recombination creates new genes. It only rearranges existing alleles into new combinations; the source of genuinely new alleles is mutation, not recombination.

Question 31

In a small population, chance alone can change how common a gene is, even when no selection is taking place. Explain genetic drift, and why its effect is greater in a small population than in a large one.

Model Answer

Genetic drift is a change in the frequency of genes in a population brought about by chance rather than by selection. When only some individuals happen to survive or reproduce, the alleles they carry become more common in the next generation, while others may be lost altogether, regardless of whether they were favourable.

Its effect is far greater in a small population because chance has more influence on small numbers. In a large population a few accidental deaths or births make little difference to the overall proportions, but in a small one, for example a group cut off by a flood or by migration, the loss of a few individuals can sharply change, or even remove, an allele. The recognition of this chance effect is credited to Sewall Wright.

False Confidence Alert
Drift is easily confused with natural selection. Selection changes gene frequency because some alleles are favourable, whereas drift changes it purely by chance, so even a useful allele can be lost from a small population.

Question 32

Alongside recombination and drift, natural selection remains central to Neo-Darwinism, but it is now understood in terms of genes. Explain how natural selection brings about evolution in the modern, genetic view.

Model Answer

In the modern view, natural selection brings about evolution by changing the frequency of alleles in a population, favouring those that suit the environment and removing those that do not. The variation it acts on is supplied by mutation and recombination, so selection itself does not create variation but sorts it.

When the environment exerts a selection pressure, the individuals carrying favourable alleles survive and reproduce more, so they pass on more copies of those alleles; the frequency of the favourable alleles therefore rises generation by generation, while the unfavourable alleles become rarer. Over time this steady change in gene frequency adapts the population to its environment and can lead to new species, which is natural selection expressed in the language of genetics.

False Confidence Alert
Saying that selection creates adaptations overstates it. Selection only changes the frequency of alleles that already exist; the favourable alleles arise first by mutation and recombination, and selection then increases their share.

Question 33

Before the factories of England blackened the tree trunks, the pale form of the peppered moth was the common one; afterwards the dark form took over. Using a labelled diagram, explain how industrial melanism in the peppered moth (*Biston betularia*) shows natural selection in action.

Model Answer

Industrial melanism in the peppered moth shows natural selection because a change in the environment changed which moth colour survived, and so changed the proportions of the two forms. The moth occurs as a pale, speckled form and a dark (melanic) form, and birds hunt them by sight.

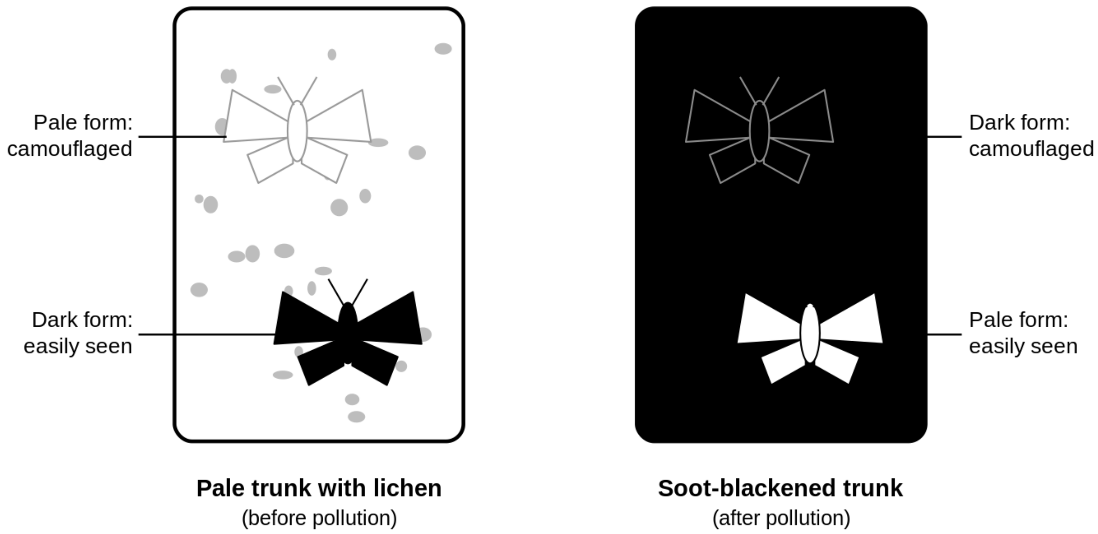


Figure 6.6: *Industrial melanism in the peppered moth: each form is hidden on one background but conspicuous on the other.*

Before industrialisation, the tree trunks were covered with pale lichens, so the pale moths were camouflaged while the dark moths were easily seen and eaten; the pale form was therefore common. When soot from the factories killed the lichens and blackened the trunks, the situation reversed: the dark moths were now camouflaged and survived, while the pale moths were eaten, so the dark form became common in the polluted areas. Bird predation was the selection pressure, and the change was studied by Kettlewell.

False Confidence Alert
A frequent mistake is to say the moths changed colour to match the trees. They did not change; both colour forms already existed, and the pollution simply altered which form the birds could see and eat, shifting the balance between them.

Question 34

When DDT was first sprayed against mosquitoes it killed almost all of them, but after a few years it had become almost useless. Explain how the rise of DDT-resistant mosquitoes is an example of natural selection, sometimes called evolution in action.

Model Answer

The rise of DDT-resistant mosquitoes is natural selection because the insecticide acted as a selection pressure that favoured the few resistant individuals already present in the population. Among the mosquitoes, a small number happened to carry alleles giving resistance to DDT, while the great majority did not.

When DDT was sprayed, it killed the non-resistant mosquitoes but the resistant ones survived and bred, passing the resistance alleles to their offspring. Generation after generation the proportion of resistant mosquitoes rose, until most of the population was resistant and DDT no longer worked. Because this change can be seen within a few years, the emergence of resistance is often called evolution in action.

False Confidence Alert
It is wrong to say the mosquitoes became resistant because DDT was used, as though the spray created the resistance. The resistance alleles were already present in a few mosquitoes; DDT merely selected them by killing the rest.

Question 35

Neo-Darwinism is the accepted modern theory of evolution, but it too has its limits. Explain the main strengths and weaknesses of Neo-Darwinism.

Model Answer

The chief strength of Neo-Darwinism is that it explains evolution completely, by joining Darwin's natural selection to the genetics of variation and inheritance that Darwin lacked. It accounts for the source of variation through mutation and recombination, shows how variation is inherited through genes, and is strongly supported by observed cases such as industrial melanism and the spread of pesticide resistance, in which evolution is seen in action.

Its main weakness is that it explains small-scale change, the shift of gene frequencies within a population, far better than it explains the origin of large and complex new groups of organisms. Critics note that natural selection can favour variations but does not by itself create the wholly new structures that major evolution requires, so some regard the theory as a strong but still incomplete account.

> **False Confidence Alert**
> It is too easy to present Neo-Darwinism as beyond criticism. Its strength is the union of selection with genetics, but its weakness is that it explains small changes in gene frequency better than the origin of wholly new and complex forms.

Question 36

No single observation proves that evolution has happened, but many separate lines of evidence point the same way. Outline the main lines of evidence that support organic evolution.

Model Answer

Several independent lines of evidence all point to the same conclusion, that today's species have descended with change from common ancestors:

1) **Palaeontology (fossils):** fossils in the rocks show that life has changed over time, from simple early forms to complex modern ones.

2) **Comparative anatomy:** the shared basic structure of different organisms, such as the limbs of vertebrates, points to a common ancestry.

3) **Comparative embryology:** the early embryos of different vertebrates are strikingly alike, suggesting a common origin.

4) **Comparative biochemistry:** organisms share the same basic molecules, such as DNA, cytochrome and haemoglobin, which traces them to one stem.

5) **Geographical distribution:** the way species are spread over the continents and islands reflects how they evolved and dispersed.

6) **Selective breeding:** the way breeders create new varieties shows that selection really can change living things.

Because these separate lines of evidence all agree, together they make a strong case for evolution.

> **False Confidence Alert**
> It is weak to rest the whole case for evolution on fossils alone. The strength of the argument is that several independent lines of evidence agree, so a good answer names and uses more than one.

Question 37

The rocks beneath our feet hold the remains of organisms that lived long ago. Explain what a fossil is, how fossils are formed, and why the position of a fossil in the rock layers matters.

Model Answer

A fossil is the preserved remains, trace or impression of an organism that lived in the geological past, and palaeontology is the study of such fossils. Most fossils form when an organism is quickly buried in sediment such as mud or silt; the soft parts usually decay, but the hard parts, such as bones, teeth and shells, are preserved as the sediment hardens into rock, a process called fossilisation.

The position of a fossil in the rock layers matters because sedimentary rock is laid down in layers, or strata, one on top of another over time. The lowest layers are the oldest and those above them are progressively younger, so the fossils deep down are the most ancient and simple, while those nearer the surface are more recent and complex. The order of the fossils therefore records the order in which living things appeared.

False Confidence Alert
A common slip is to say that all dead organisms become fossils. Very few do; the soft-bodied usually decay away completely, so the fossil record favours organisms with hard parts and is for that reason incomplete.

Question 38

Fossils are preserved in several different ways, depending on the conditions in which the organism was buried. Describe the main types of fossils, giving an example of each.

Model Answer

Fossils are preserved in several forms, according to how the remains were treated by the surrounding conditions:

1) **Whole-organism fossils:** the entire organism is preserved, for example an insect trapped in amber or a mammoth frozen in ice.

2) **Petrified fossils:** minerals slowly replace the hard tissues and turn them to stone, as in petrified wood and bone.

3) **Moulds and casts:** a buried hard part such as a shell dissolves away to leave a hollow mould, which may later fill with minerals to form a cast, as in the moulds and casts of ancient shells.

4) **Impressions:** a print left in soft sediment that then hardens, such as the impressions of leaves or feathers, or the footprints preserved in volcanic ash at Laetoli in Tanzania.

5) **Carbonised fossils:** the soft tissue is reduced to a thin film of carbon, as in many plant fossils and in the formation of coal.

These different forms together preserve a wide range of past life for the palaeontologist to study.

False Confidence Alert
It is not enough to say a fossil is simply a buried bone. The marks come from naming distinct types, such as whole-organism remains, petrified remains, moulds and casts, impressions and carbonised films, each formed in a different way.

Question 39

The fossil record does more than show that old organisms existed; it shows the order in which life changed. Using the evolution of the horse as an example, explain how fossils provide evidence for evolution.

Model Answer

Fossils provide evidence for evolution because, read from the oldest layers upward, they show a clear change from simple, ancient forms to complex modern ones. The horse is a famous example, traced through a series of fossils recovered from the rocks of North America.

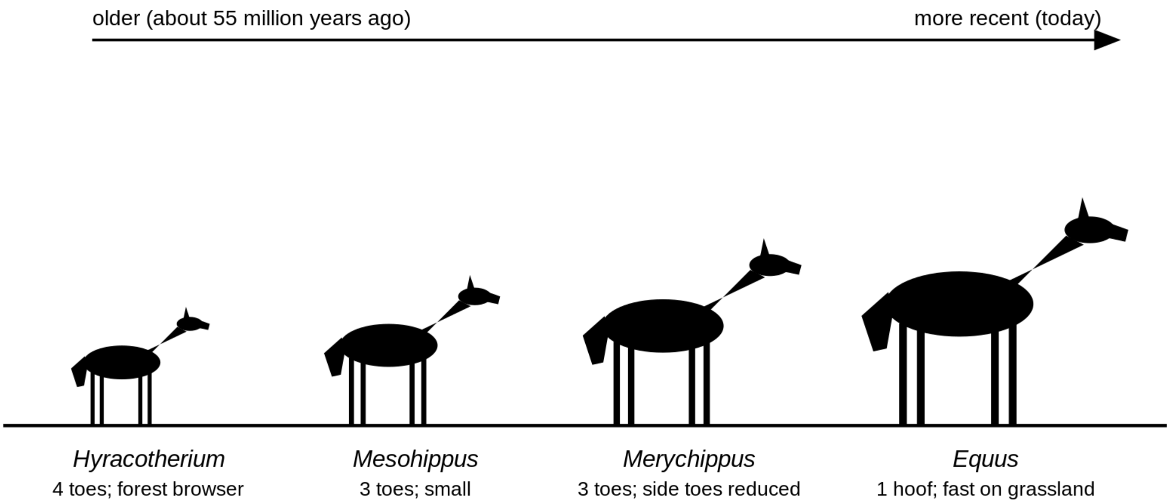


Figure 6.7: *The evolution of the horse, showing the overall trend from a small many-toed browser to the large single-hoofed grazer.*

The earliest horse, *Hyracotherium*, was a small, dog-sized animal with several toes on each foot that browsed in forests; later fossils show a steady increase in size, a lengthening of the legs and a reduction in the number of toes, until the modern horse, *Equus*, stands on a single hoofed toe suited to running fast over open grassland. Because each stage is found in successively younger rock, the series records the actual course the horse's evolution took.

False Confidence Alert
It is a mistake to read the horse series as a single straight ladder of ancestors. It is better described as a branching history in which the overall trend was towards larger size and fewer toes, not a simple straight line.

Question 40

The fossil record, though powerful, is full of gaps, and these gaps are often called missing links. Explain what is meant by a missing link, and give reasons why the fossil record is incomplete.

Model Answer

A missing link is a gap in the fossil record where the intermediate forms connecting one group to another have not been found, so the line of descent cannot be followed completely. Such gaps are common because only a tiny fraction of living things ever become fossils.

The record is incomplete for several reasons: most organisms decay or are eaten before they can be buried, so they leave no trace; soft-bodied organisms fossilise very poorly; many fossils that did form have since been destroyed by erosion or by movements of the Earth's crust; and the fossils that survive are often broken and hard to interpret. For these reasons the fossil record can show the general course of evolution without preserving every single step.

False Confidence Alert
A missing link is wrongly taken by some to mean that evolution is false. The gaps reflect how rarely fossils form and survive, not an absence of evolution, and many supposed missing links have in fact later been found.

Question 41

The forelimbs of a human, a bat, a whale and a horse look very different and do very different jobs, yet they are built to the same plan. Using a labelled diagram of the pentadactyl limb in different mammals, explain what homologous structures are and how they provide evidence for divergent evolution.

Model Answer

Homologous structures are organs in different species that have the same basic structure and developmental origin but are adapted to perform different functions. The classic example is the pentadactyl (five-fingered) limb of vertebrates, which is built from the same set of bones, the humerus, the radius and ulna, the wrist bones and the five digits, in every case.

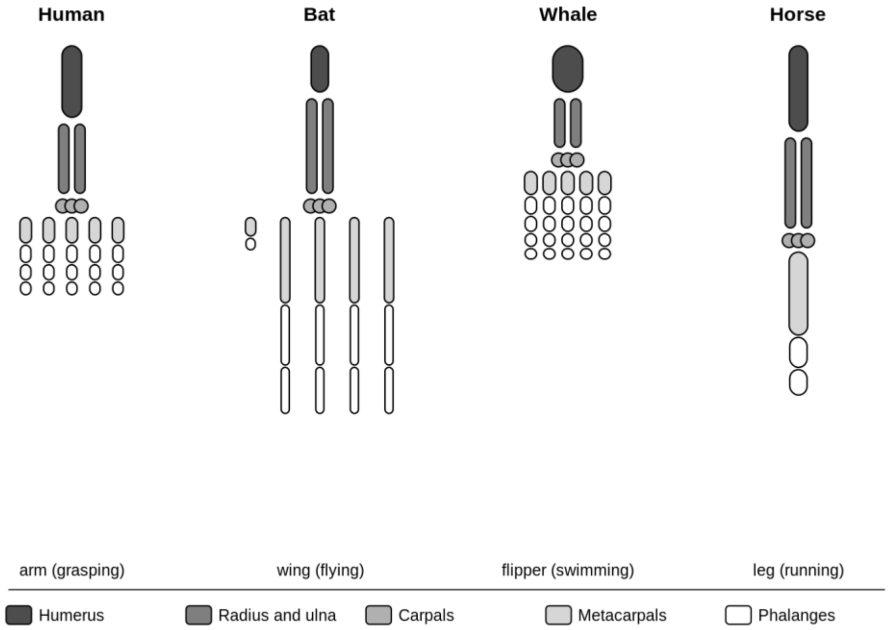


Figure 6.8: *The pentadactyl limb of four mammals, built from the same bones but adapted to different uses.*

Although the underlying plan is the same, the limb is modified for different ways of life: a wing for flight in the bat, a flipper for swimming in the whale, a running leg in the horse and a grasping hand in the human. This adaptation of one ancestral structure to many different uses is called adaptive radiation, and because the shared plan is best explained by descent from a common ancestor, homologous structures are strong evidence for divergent evolution, in which related groups grow more and more different over time.

False Confidence Alert

It is wrong to call structures homologous just because they do the same job. Homology is about a shared basic plan and origin, not shared function, which is why a bat's wing and a whale's flipper are homologous even though their jobs are completely different.

Question 42

The wing of an insect and the wing of a bird both allow flight, yet they are built in completely different ways. Explain what analogous structures are, and how they provide evidence for convergent evolution.

Model Answer

Analogous structures are organs in different species that perform the same function but have a different basic structure and a different evolutionary origin. They resemble one another only on the surface, because they do the same job, and not because they were inherited from a common ancestor.

The wings of an insect and the wings of a bird are a good example: both are used for flight, but the insect wing is a thin extension of the body wall while the bird wing is a modified pentadactyl limb supported by bones, so the two are built quite differently. Such structures are evidence for convergent evolution, in which unrelated or distantly related organisms, living in similar conditions, independently evolve similar features to meet the same need.

False Confidence Alert
The trap is to confuse analogous with homologous structures. Analogous structures share a function but not an origin (insect and bird wings), whereas homologous structures share an origin but not always a function, so mixing the two up loses the mark.

Question 43

Some organisms carry reduced, apparently useless structures that were fully working in their ancestors. Explain what vestigial structures are, and how they support the idea of evolution, giving examples.

Model Answer

Vestigial structures are reduced, degenerate organs that have little or no function in an organism but were well developed and useful in its ancestors. Their presence makes sense only if the organism has descended, with change, from an ancestor in which the structure was fully working.

Examples include the appendix in humans, which is reduced but is large and functional in plant-eating mammals that digest cellulose; the halteres of houseflies, which are the shrunken remains of the second pair of wings (the hindwings); and the reduced, spiny leaves of desert plants such as the cactus. Because these structures are best explained as left-over remnants of once-useful organs, they are good evidence that today's species have evolved from different ancestral forms.

False Confidence Alert
It is a mistake to say a vestigial structure has never had any use. The point is the opposite: it was fully functional in the ancestor and has since been reduced, which is exactly why it stands as evidence for evolution.

Question 45

Beneath their outward differences, living things are built from a surprisingly small set of the same chemicals. Explain how the biochemistry shared by different organisms provides evidence for evolution.

Model Answer

Living things share the same basic molecules and the same chemical machinery, and this biochemical similarity is strong evidence that they descend from a common ancestor. As a rule, the more alike the molecules of two organisms, the more closely they are related.

For example, the respiratory pigment cytochrome c is almost identical in all aerobically respiring organisms, from bacteria to humans, and the haemoglobin of humans, gorillas and chimpanzees is very nearly the same; above all, the genetic code, by which DNA spells out proteins, is universal, read in the same way by almost every living thing. Such deep chemical unity could only arise if these organisms inherited their biochemistry from one ancient stem, which also points to an evolutionary link between the prokaryotes and the eukaryotes.

False Confidence Alert
It is not enough to say living things are merely similar. The mark lies in the depth of the likeness, that molecules such as cytochrome c, and the genetic code itself, are shared, which only common ancestry can explain.

Question 46

Not only the structures but also the workings of different animals are often alike, and this too points to common ancestry. Explain how similarities in physiology, such as the actions of hormones, provide evidence for evolution.

Model Answer

The physiological processes of related animals are often so similar that the hormones of one species can work in the body of another, which is evidence that they share a common ancestor. Because the chemical messengers, and the systems they control, were inherited from the same stem, they remain interchangeable across species.

For example, insulin taken from cattle or pigs is so like human insulin that it was long used to treat diabetes in people; thyroxine from one vertebrate will bring about metamorphosis in a frog tadpole whose own thyroid has been removed; and the hormone prolactin controls broadly similar processes in many different vertebrates. Such shared physiology, working across the species lines, is best explained by descent, with modification, from common ancestors.

False Confidence Alert
A weak answer just says that animals have hormones. The evidence is that a hormone from one species actually works in another, such as cattle insulin in humans, which shows how closely their physiology has been inherited from a shared ancestor.

Question 47

The animals of Australia, such as the kangaroo and the platypus, are found almost nowhere else on Earth. Explain how the geographical distribution of organisms provides evidence for evolution.

Model Answer

The way living things are spread over the Earth reflects their evolutionary history and the way the land has changed, which makes their distribution evidence for evolution. Each group of organisms arose in a particular place and then spread only as far as barriers such as oceans, mountains and deserts would allow.

Australia is the clearest example: because it became separated from the other continents long ago, its mammals evolved in isolation, so it is home to pouched mammals (marsupials) such as the kangaroo, and to the egg-laying monotremes, the platypus and the echidna, a fauna found almost nowhere else. These animals are best explained as the descendants, with modification, of ancestors that were cut off and evolved on their own, rather than as separate creations placed there.

False Confidence Alert
It is wrong to treat each animal's location as a mere accident. The point is that isolation shaped the distribution, which is why an isolated land such as Australia evolved its own marsupials and monotremes, a fauna found almost nowhere else.

Question 48

Fossils of the same ancient animals are found on continents now separated by wide oceans, and remote islands have their own peculiar species. Explain how continental drift and the life of oceanic islands add to the evidence from geographical distribution.

Model Answer

The matching of fossils across now-distant continents, and the unique life of remote islands, both add to the evidence that today's species evolved from earlier ones in step with the movement of the land. The continents have not always been where they are now.

Fossils of the same ancient amphibians, reptiles and ferns are found in South America, Africa, India and Australia, which only makes sense if these lands were once joined in a single great continent, Gondwana, that has since drifted apart. On oceanic islands, which were built by volcanoes and never joined to a mainland, the plants and animals are peculiar but clearly related to those of the nearest land, because their ancestors crossed the sea by wind, water or flight and then evolved into new forms in isolation.

False Confidence Alert
Students often forget that the land itself has moved. The shared fossils of Gondwana are evidence not only for evolution but also for continental drift, and the two together explain the puzzling distribution of life across the continents.

Question 49

Farmers and breeders have produced many different kinds of cattle, maize and dogs from a few wild ancestors. Explain how selective breeding, or artificial selection, provides evidence that living things can be changed by selection.

Model Answer

Selective breeding, also called artificial selection, is the process by which humans choose which organisms shall reproduce in order to develop desirable traits, and its success is direct evidence that selection really can change living things. By breeding only from the individuals with the wanted features, generation after generation, the breeder gradually reshapes the population.

In this way many breeds of cattle, varieties of maize and breeds of dog have been produced from a few wild ancestors, the breeder using methods such as inbreeding (mating close relatives to fix a desired trait) and outbreeding (crossing unrelated stock to combine traits and add vigour). Darwin used artificial selection as a model for natural selection: if a breeder can reshape a species so quickly by choosing the parents, then nature, selecting over far longer periods, can do the same and more, so the new varieties produced show that species are not fixed but can be changed by selection.

> **False Confidence Alert**
> It is a mistake to think artificial selection is unrelated to evolution. Darwin used it as direct evidence: if a breeder can reshape a species in a few generations by choosing the parents, nature can do the same over far longer stretches of time.

Figure 6.9: *The early embryos of four vertebrates, alike in showing pharyngeal pouches and a tail.*

At an early stage they all show features such as a tail and a series of pharyngeal (gill) pouches in the neck region, even in those animals that never breathe by gills; in the fish these pouches develop into gills, while in the others they are put to other uses or disappear. The general rule is that the more alike the embryos of two species, the more closely they are related, so this shared early plan points to descent from a common ancestor.

> **False Confidence Alert**
> A common error is to claim that the human embryo passes through an adult fish or adult reptile stage. It does not; it is the early EMBRYOS that resemble one another, sharing features such as gill pouches and a tail, not the adult forms.

Question 50

Over time, one species can give rise to two. Using a simple diagram, explain what speciation is and how a single ancestral species can split into two separate species.

Model Answer

Speciation is the formation of new and distinct species, in which a single ancestral lineage splits into two or more separate lineages that can no longer interbreed. It is the process that turns the variation within one species into two genetically independent species.

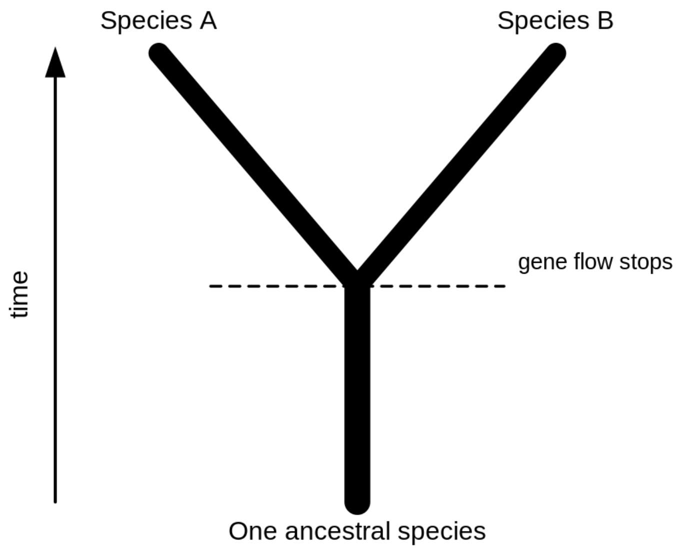


Figure 6.10: *Speciation, in which one ancestral species splits into two once gene flow between them stops.*

The diagram shows how it happens: a single ancestral population is divided, the two parts stop exchanging genes, and over many generations each part accumulates its own changes through selection, drift and mutation. When the two have become so different that they can no longer interbreed and produce fertile offspring, even if they meet again, they are separate species. Speciation is therefore the branching point at which one line of descent becomes two.

False Confidence Alert
It is wrong to say that a species changing over time is by itself speciation. Speciation requires a lineage to SPLIT into two that can no longer interbreed, not merely to change, so one line becoming two is the essential point.

Question 51

Biologists recognise four types of speciation, according to how the diverging populations are arranged in space. Using a diagram, describe the four types of speciation, giving an example of each.

Model Answer

The four types of speciation are distinguished by how far apart the diverging populations are, from complete separation to none at all:

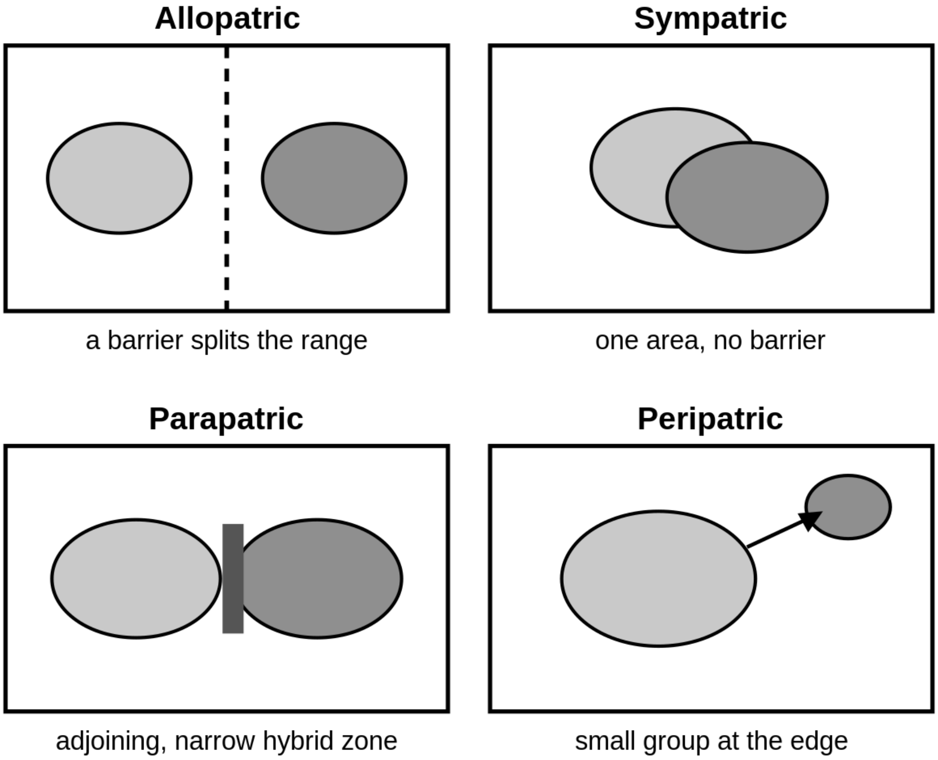


Figure 6.11: *The four types of speciation, set apart by how the populations are arranged in space.*

1) **Allopatric:** the population is split by a geographical barrier such as a sea or a mountain range, as in the finches of the Galapagos Islands.

2) **Sympatric:** a population splits into two within the same area, with no barrier between them, as in the apple maggot fly.

3) **Parapatric:** two populations occupy adjoining areas and diverge across a narrow zone of overlap, where a few hybrids form.

4) **Peripatric:** a small group at the edge of the main population becomes isolated and diverges, largely through genetic drift.

In every case the result is the same, two species where there was one, but the geographical setting in which they arise is different.

False Confidence Alert
Students often think speciation always needs a geographical barrier. Only allopatric and peripatric speciation depend on physical separation; sympatric speciation happens within one area, so a barrier is not always required.

Question 52

On the Galapagos Islands a single kind of finch gave rise to many species, each on its own island. Explain how allopatric speciation produces new species, using this kind of example.

Model Answer

Allopatric speciation is the formation of new species when a population is divided by a geographical barrier, so that the separated groups can no longer exchange genes. The word allopatric means in different homelands.

When the ancestral finches reached the separate islands of the Galapagos, the sea between the islands acted as a barrier that stopped the groups from interbreeding. Cut off from one another, each island group met its own conditions and food supply, and over many generations natural selection and genetic drift changed each group in its own way, for example giving it a different beak shape. In time the groups became so different that they could no longer interbreed even if brought back together, and so separate species had formed. Allopatric speciation is the commonest route to new species.

> **False Confidence Alert**
> It is not enough to say the islands simply had different finches. The mark lies in the mechanism: the sea barrier stopped gene flow, and the isolated groups then diverged under their own selection and drift until they could no longer interbreed.

Question 53

Sometimes a population splits into two species while living in the same place, with no barrier between them. Explain how sympatric speciation can occur, using a named example.

Model Answer

Sympatric speciation is the formation of new species from a population living in the same area, where reproductive isolation arises without any geographical barrier. The word sympatric means in the same homeland.

It can happen when part of a population begins to use a different resource or habitat and to breed separately. In the apple maggot fly of North America, for example, some flies began to lay their eggs on introduced apple trees instead of the native hawthorn; because the flies tend to mate on the fruit they grew up on, the apple-feeders and the hawthorn-feeders increasingly breed among themselves, so gene flow between them is reduced even though they share the same area. The cichlid fishes of Lake Nyasa show the same pattern, having split into many species within a single lake.

> **False Confidence Alert**
> A common error is to think sympatric speciation needs no isolation at all. It still needs reproductive isolation, the cutting of gene flow; what it does without is the geographical barrier, the isolation arising instead from differences in breeding or habitat.

Question 54

Besides the two main types, speciation can also occur in populations that lie side by side, or in a small group at the edge of a species' range. Explain parapatric and peripatric speciation.

Model Answer

Parapatric speciation is the formation of new species in two populations that occupy neighbouring areas and meet along a common boundary. There is no complete barrier between them, but each population lives under different conditions across a habitat gradient, so the two diverge; where they meet, a narrow hybrid zone forms, and because the hybrids are less fit, the separation is reinforced until two species result.

Peripatric speciation is the formation of a new species from a small group isolated at the edge, or periphery, of the main population. Because the founding group is small, chance changes in gene frequency, that is genetic drift, have a strong effect, and together with selection in the new surroundings this small group can diverge quickly into a separate species. Both types, like the others, end in two species where there was one.

> **False Confidence Alert**
> The trap is to treat parapatric and peripatric speciation as the same thing. Parapatric populations lie side by side and meet in a hybrid zone, whereas peripatric speciation begins from a small group budded off at the edge, where drift plays the leading part.

Question 55

Allopatric and sympatric speciation are the two main routes to new species, but they differ in one key respect. Explain the difference between allopatric and sympatric speciation.

Model Answer

The key difference is that allopatric speciation requires a geographical barrier, while sympatric speciation does not. In allopatric speciation a physical barrier, such as a sea, a mountain range or a river, splits the population so that the two groups cannot meet to interbreed; the isolation is geographical.

In sympatric speciation, by contrast, the diverging groups stay in the same area, and their gene flow is cut not by distance but by differences in their breeding, such as using different food plants or breeding at different times. So both routes require gene flow to be cut, which is what lets the groups diverge, but they differ in how that gene flow is stopped: by a barrier in allopatric speciation, and by reproductive differences within one area in sympatric speciation.

> **False Confidence Alert**
> It is wrong to say the two differ in whether isolation occurs. Both need reproductive isolation; the difference is in the cause, a geographical barrier in allopatric speciation against reproductive differences within one area in sympatric speciation.

Question 56

Whatever the route, speciation cannot happen while two groups freely interbreed. Explain why a reduction in gene flow is necessary for speciation, and what is meant by reproductive isolation.

Model Answer

Speciation needs the gene flow between the diverging groups to be reduced or stopped, because as long as the groups freely interbreed their genes are mixed back together and they cannot become different species. Cutting gene flow allows each group to accumulate its own changes independently.

Reproductive isolation is the condition in which the members of two populations are prevented from interbreeding successfully, so that their genes no longer mix. The factors that bring it about are called isolating mechanisms, recognised by Dobzhansky, and they fall into two groups: pre-zygotic mechanisms, which act before fertilisation to stop a zygote forming, and post-zygotic mechanisms, which act after fertilisation by making the hybrid offspring fail. Once reproductive isolation is complete, the two groups are separate species.

> **False Confidence Alert**
> A weak answer treats isolation as merely living apart. Reproductive isolation is specifically the failure to interbreed successfully, by whatever means, which is what stops the two gene pools mixing and lets the groups become separate species.

Question 57

Some isolating mechanisms work by preventing two species from ever forming a zygote together. Describe the main pre-zygotic isolating mechanisms, giving an example of each.

Model Answer

Pre-zygotic isolating mechanisms prevent mating or fertilisation, so that no zygote is ever formed; they take several forms:

1) **Ecological isolation:** the two groups live in different habitats within the area, so they rarely meet to mate.

2) **Behavioural isolation:** their courtship behaviour differs, such as different bird songs or frog calls, so the opposite sex is not attracted.

3) **Mechanical isolation:** differences in the reproductive structures, or in plants the failure of the pollen tube to grow on the wrong stigma, make mating or fertilisation impossible.

4) **Temporal (seasonal) isolation:** the two groups breed or flower at different times, so their gametes never meet.

5) **Spatial isolation:** the groups are separated in space, as in plants that have separate male and female individuals (dioecy).

Because they all act before fertilisation, these mechanisms prevent any hybrid from being formed at all.

False Confidence Alert
It is a mistake to lump all isolating mechanisms together. Pre-zygotic mechanisms stop a zygote from ever forming, by preventing mating or fertilisation, which is quite different from the post-zygotic mechanisms that act only after a hybrid has been made.

Question 58

Other isolating mechanisms allow a hybrid to be formed, but make sure it is a dead end. Describe the post-zygotic isolating mechanisms, using the mule as an example.

Model Answer

Post-zygotic isolating mechanisms act after fertilisation, allowing a hybrid to form but preventing it from passing on its genes; there are three main kinds:

1) **Hybrid inviability:** the hybrid offspring is formed but is weak and dies before it can reach maturity and breed.

2) **Hybrid sterility:** the hybrid survives but cannot make functional gametes, so it leaves no offspring. The classic example is the mule, the offspring of a horse (2n = 64) and a donkey (2n = 62); the mule (2n = 63) is healthy but sterile, because its odd, unmatched set of chromosomes cannot pair properly at meiosis.

3) **Hybrid breakdown:** the first-generation hybrids are fertile, but their own offspring, the second generation, are weak or sterile.

Because they prevent the hybrid from reproducing, these mechanisms keep the two gene pools separate.

False Confidence Alert
A common slip is to think the mule shows that hybrids cannot be formed. They can: the mule is a healthy hybrid, but it is sterile because its unmatched chromosomes cannot pair at meiosis, so it is a post-zygotic, not a pre-zygotic, barrier.

Question 59

Once two groups are isolated, what actually drives them apart into separate species? Explain the parts played by natural selection and by genetic drift in speciation.

Model Answer

Once gene flow is cut, natural selection and genetic drift are the forces that drive the isolated groups apart until they become separate species. Each works on the variation within the groups, but in a different way.

Natural selection drives divergence when the two groups live under different conditions: each is selected for the features that suit its own environment, so they steadily become more different, a process called divergent selection. Genetic drift drives divergence by chance, and it matters most when a group is small, as in a peripheral or founding population, where the random loss or fixing of alleles can change the group quickly, even without selection. Working together, selection and drift accumulate the differences that finally make the groups distinct species.

False Confidence Alert
It is wrong to credit speciation to selection alone. Genetic drift also drives divergence, especially in small isolated groups, where chance changes in gene frequency can be as important as selection in making the groups distinct.

Question 60

Beyond selection and drift, the raw material and the fine-tuning of new species come from mutation and from adaptation to different environments. Explain the parts played by mutation and by adaptation in speciation.

Model Answer

Mutation supplies the new genetic variation on which speciation ultimately depends, while adaptation to different environments shapes that variation into the differences that separate the new species. Without mutation there would be no genuinely new alleles for the other forces to act on.

Mutation is the original source of the new alleles that arise, by chance, in the isolated groups; because the groups no longer share genes, the unique mutations that appear in one are not passed to the other, so the groups grow apart. Adaptation then follows as natural selection favours, in each group, the variations that best suit its particular surroundings, so that populations in different environments, such as the Galapagos finches feeding on different foods, develop different traits, reduce their interbreeding and finally become separate species.

False Confidence Alert
A weak answer treats mutation as a force that directs speciation. Mutation only supplies random new alleles; it is selection, acting on those alleles as each group adapts to its environment, that gives speciation its direction.

REAL QUESTIONS

These questions take the biology of evolution into real situations, and into claims you must weigh for yourself. As before, attempt each question first, then check your answer against the model answer and the False Confidence Alert that follows.

Question 61

In a Tanzanian kitchen, a piece of meat left uncovered on the table soon swarms with maggots, while meat kept in a closed pot stays free of them. Explain what this everyday observation shows about the origin of living things, and how it settles the old argument of spontaneous generation.

Model Answer

This everyday observation shows that the maggots come from the eggs that flies lay on the exposed meat, and not from the meat itself, so it supports the principle of biogenesis, that living things arise only from other living things. It is, in effect, Redi's experiment repeated in the kitchen.

The uncovered meat is reached by flies, which lay their eggs on it, and the eggs hatch into maggots; the meat in the closed pot decays in just the same way but breeds no maggots, because no fly can reach it to lay its eggs. This settles the old argument of spontaneous generation, for life did not arise from the lifeless meat: when the living parents, the flies, were kept away, no new life appeared.

False Confidence Alert
Students often answer that the closed pot kept the meat from rotting, so no maggots formed. The meat in the pot does rot; the real reason is that flies could not reach it to lay their eggs, so the maggots had no parents.

Question 62

In a Form Six debate, one group argues that the special creation theory should be taught as science, while another argues that only the biochemical theory belongs in a science lesson. Using the idea of testability, explain which view a scientist would support and why.

Model Answer

A scientist would support teaching the biochemical theory as science, because it can be tested against evidence, while keeping special creation out of the science lesson, because it cannot. The dividing line is testability, not belief.

The biochemical theory makes claims that experiments can check, for example that simple gases can form the building blocks of life, and such experiments have actually been carried out; this makes it a scientific theory, whether or not it is finally confirmed. Special creation, by contrast, describes a single, unrepeatable act that no experiment can observe, support or overturn, so science can neither prove nor disprove it, and it therefore lies outside the science lesson. This does not declare the belief false; it only places it beyond the reach of science.

> **False Confidence Alert**
> It is a costly mistake to argue that special creation should be excluded because it is false. A scientist does not call it false; the point is only that it cannot be tested, which is what places it outside science.

Question 63

Kipanga writes: *"The biochemical theory and the old theory of spontaneous generation are really the same thing, because both say that life came from non-living matter; and since Miller's experiment made amino acids, it proved that life was created in the laboratory."* Identify the mistakes in Kipanga's statement and correct them.

Model Answer

Kipanga has made two clear mistakes, one about the theories and one about the experiment:

1) **The theories are not the same:** spontaneous generation claimed that whole, ready-made organisms appeared suddenly from rotting matter, whereas the biochemical theory says that simple molecules combined slowly, over a vast time, into the first cell; one was disproved by Redi, while the other is the accepted modern account.

2) **The experiment did not create life:** Miller's experiment produced only the building blocks of life, such as amino acids, not a living cell, so it supports the first chemical step of the biochemical theory but does not show the step from molecules to a living organism.

So Kipanga is wrong both to treat the two theories as one and to say that life was made in the laboratory.

> **False Confidence Alert**
> Students often half-correct Kipanga, fixing the Miller claim but letting the 'same theory' error stand. Both must be named: the two theories differ in how life arose, and the experiment made only building blocks, not life.

Question 64

Kipanga says, *"The cosmozoic theory answers where life came from, because it tells us that life arrived from space."* Kipute replies, *"No, it does not really answer the question at all."* Decide who is right, and give the reason.

Model Answer

Kipute is right: the cosmozoic theory does not really answer where life came from; it only moves the question to another place in the universe. Saying that life arrived from space is not the same as saying how life began.

The cosmozoic theory proposes that life reached the Earth ready-made, as spores from space, but this assumes that life already existed somewhere else and never explains how it first arose. A true theory of the origin of life must explain how living things first formed from non-living matter, which the cosmozoic theory never does, and it cannot even be tested. Kipanga has mistaken a theory about how life reached the Earth for a theory of how life began, which is why Kipute is correct.

False Confidence Alert
It is tempting to side with Kipanga because the cosmozoic theory sounds like an answer. The mark depends on seeing that explaining how life ARRIVED is not the same as explaining how life BEGAN, so the theory leaves the real question untouched.

Question 65

A Tanzanian porter spends years carrying heavy loads and develops very strong shoulder and back muscles. His children, however, are born no stronger than other children. Explain why the strength he gained during his life is not passed on to his children.

Model Answer

The strength the porter gained is an acquired character, built up in his body cells during his life, and acquired characters are not inherited because they do not change the genes carried in his gametes. Only a change in the genes of the sex cells can pass to the offspring.

The hard work of carrying loads enlarged the muscles of the porter's body, but it made no change to the DNA in his sperm, which carry the instructions his children inherit. Since the children receive only the genes in the gametes, and these were left unaltered by his labour, they are born with ordinary muscles and must build their own strength if they wish to. This is exactly why Lamarck's idea of the inheritance of acquired characters was rejected.

False Confidence Alert

Students often say the children inherit some of the strength because the father worked so hard. Effort changes only the body, never the genes in the gametes, so not even a little of an acquired character is passed on.

Question 66

Kipanga explains the giraffe's long neck like this: "The ancestors of the giraffe stretched their necks to reach high leaves, their necks grew longer with the stretching, and they passed these longer necks on to their young, until the modern giraffe was formed." Identify what is wrong with Kipanga's explanation, and give the correct one.

Model Answer

Kipanga has given Lamarck's discredited explanation, which is wrong because stretching cannot lengthen the inherited neck: a neck stretched during life is an acquired character that does not change the genes passed to the young. The error is to suppose that the use of a part during an animal's life can be inherited.

The correct, Darwinian explanation is that the ancestral giraffes already varied, some having longer necks than others by chance, and that this variation could be inherited. When the low food grew scarce, the longer-necked giraffes could reach the high leaves, so they were better fed, survived and left more offspring, which inherited the long neck, while the shorter-necked ones died out. Over many generations the population shifted towards long necks. The variation came first and was then selected, and was not created by stretching.

False Confidence Alert

Students often correct only half of this, replacing 'stretching' with 'selection' but still letting the necks lengthen during life. The key fix is that the long necks must already exist as inherited variation before selection can act; nothing is lengthened by use.

Question 67

A farmer cuts the tails of his sheep for hygiene, generation after generation, yet the lambs are always born with full tails. Kipanga says, "In time the lambs will be born with short tails, because the tail is no longer used." Kipute says, "They will always be born with full tails, however long the practice continues." Decide who is right, and explain why.

Model Answer

Kipute is right: the lambs will always be born with full tails, no matter how many generations have their tails cut. Cutting the tail is done to the body and never reaches the genes in the gametes, so it cannot be inherited.

This is exactly what Weismann showed when he cut the tails off mice for many generations and found that every new generation was still born with a full tail. The tail removed from the parent is an acquired change to the body, that is to the somatic cells, but the sperm and egg that form the lamb carry unchanged genes for a full tail. Since the offspring inherit only what is in the gametes, the cutting has no effect on them, and Kipanga's Lamarckian expectation is wrong.

False Confidence Alert

It is tempting to agree with Kipanga that disuse will shorten the tail in time. The tail is cut from the body, not from the gametes, so no change reaches the offspring, which is the very point that Weismann's experiment proved.

Question 68

In a Tanzanian hospital, an antibiotic that once cured an infection in a few days slowly stops working as more and more patients use it. Explain, using natural selection, how the bacteria become resistant, and why a patient is told to finish the full course of treatment.

Model Answer

The bacteria become resistant by natural selection: a few in the population already carry, by chance, an allele that resists the antibiotic, and when the drug is used it kills the non-resistant bacteria and leaves these resistant ones to multiply. The antibiotic acts as a selection pressure; it does not itself create the resistance.

Generation after generation the survivors pass on the resistance allele, so the proportion of resistant bacteria rises until the drug no longer works. A patient is told to finish the full course because stopping early leaves alive the hardier bacteria that the drug had not yet killed; these are exactly the ones most able to resist, and if they survive and breed the infection returns in a more resistant form. Completing the course kills them before they can be selected.

False Confidence Alert

Students often write that the antibiotic taught the bacteria to resist, or made them stronger. The resistant bacteria were already present by chance, and the antibiotic only selected them by killing the rest; it created nothing new.

Question 69

The sickle-cell allele causes a serious anaemia, yet it remains common in the malarial regions of Tanzania. Explain, using natural selection, why this harmful allele is not removed from the population.

Model Answer

The sickle-cell allele remains common because, in malarial areas, the people who carry a single copy of it are protected against malaria, so natural selection favours these carriers and keeps the allele in the population. Selection acts through survival and breeding, and here the carrier has the advantage.

A person with two sickle-cell alleles suffers a severe anaemia and often dies young, while a person with none is fully vulnerable to malaria; but the carrier, with one normal allele and one sickle allele, is both reasonably healthy and resistant to malaria, so carriers survive and reproduce best of all. Because the carriers pass on both kinds of allele, the sickle allele is preserved wherever malaria is common. Where malaria is absent, this advantage disappears and the allele becomes rare.

False Confidence Alert

It is tempting to say that natural selection should simply remove a harmful allele. It is kept because the carrier, with one copy, is protected against malaria and so survives best, so selection actually favours the carrier and preserves the allele in malarial regions.

Question 70

A single female tilapia can lay many hundreds of eggs, yet the number of tilapia in a fish pond stays roughly the same from year to year. Use Darwin's three observations and two deductions to explain what happens to all the offspring that are produced.

Model Answer

By Darwin's reasoning, far more tilapia are produced than the pond can support, so most must die in a struggle for existence, and only the best-adapted survive to breed. The three observations and two deductions follow one from another.

The observations are that the tilapia overproduce, laying hundreds of eggs each; that their numbers nevertheless stay roughly constant; and that the food, space and oxygen of the pond are limited. From these it is deduced, first, that there must be a struggle for existence, in which most of the young die or are eaten before they can breed; and second, that the few survivors are those whose inherited variations best suit them to the pond, so it is these fittest fish that reproduce and pass on their features. In this way the population stays steady while slowly becoming better adapted.

False Confidence Alert

A thin answer just says that many fish die. The marks come from the whole chain: overproduction meeting steady numbers and limited resources forces a struggle, in which the best-adapted survive and breed, which is Darwin's argument in full.

Question 71

In Region A a malaria drug is used carelessly, with patients often stopping treatment early, while in Region B the same drug is used correctly under supervision. After some years, drug-resistant malaria parasites are far more common in Region A than in Region B. Explain this difference, and predict what will happen to the drug's usefulness in Region A if nothing changes.

Model Answer

The difference arises because the careless use in Region A applies natural selection for resistance far more strongly than the correct use in Region B. When treatment is stopped early, the hardier, partly resistant parasites are left alive to breed, so the resistance allele spreads quickly.

In Region B, by contrast, the correct full course kills the parasites before the resistant ones can be selected, so resistance spreads only slowly. Because Region A keeps selecting the resistant parasites generation after generation, their proportion will go on rising; the prediction, therefore, is that if nothing changes the drug will steadily lose its power in Region A until it no longer cures malaria there, while it stays useful for much longer in Region B.

> **False Confidence Alert**
>
> Students often blame the difference on the drug being weaker in Region A. The drug is the same in both regions; it is the careless use that selects the resistant parasites more strongly, which is why resistance rises faster there.

Question 72

Kipanga explains natural selection like this: "Natural selection means that the strongest and biggest animals always survive, and that when an animal needs a new feature, it develops it and passes it on." Identify the mistakes in Kipanga's explanation and correct them.

Model Answer

Kipanga has made two mistakes, one about what fittest means and one that confuses Darwin with Lamarck:

1) **The fittest are not the strongest or biggest:** in natural selection the fittest are those best adapted to their environment, which may be a small, well-camouflaged or fast-breeding animal rather than a large, strong one, because what matters is leaving the most offspring, not winning a fight.

2) **Animals do not develop features because they need them:** that is Lamarck's discredited idea; in Darwin's theory the variation arises first, by chance, and natural selection then favours whichever variations happen to suit the environment, so the need does not create the feature.

So Kipanga is wrong to equate fitness with strength and wrong to think that a need can produce a new feature.

> **False Confidence Alert**
>
> Students often catch the 'strongest' error but let the 'develops what it needs' error stand, or the reverse. Both must be corrected: fitness is being best adapted, and variation comes first by chance, not because the animal needs it.

Question 73

After rats survive a poisoning, Kipanga says, "The poison made the rats resistant, by forcing their bodies to get used to it." Kipute says, "No, a few rats were already resistant before the poison was used, and only those survived." Decide who is right, and explain why.

Model Answer

Kipute is right: a few rats were already resistant before the poison was used, and the poison merely selected them by killing the rest. The poison did not make the rats resistant; it acted as a selection pressure.

In any large population of rats there is inherited variation, and by chance a few carry alleles that make them resistant to the poison. When the poison is spread, it kills the non-resistant rats, but the resistant ones survive and breed, passing the resistance to their young, so the resistant kind becomes common. Kipanga's idea, that the poison forced the rats' bodies to get used to it and that this was then inherited, is Lamarck's discredited notion of acquired characters; the resistance was present first and was selected, not built up by exposure during life.

False Confidence Alert

It is tempting to side with Kipanga because the rats clearly changed after the poison was used. The population changed only because the already-resistant rats were selected; no individual rat's body got used to the poison and passed that on.

Question 74

When a new insecticide is used against mosquitoes in Tanzania, scientists can watch the mosquito population become resistant within only a few years, something they call evolution in action. Explain, in terms of gene frequency, why this change can be seen so quickly, while the evolution of large new animals cannot.

Model Answer

The change can be seen so quickly because evolution, in the modern view, is simply a change in the frequency of genes in a population, and in fast-breeding insects the frequency of a resistance allele can rise very rapidly. Each new generation gives selection another chance to act.

The mosquitoes breed in huge numbers and pass through many generations in a single year, so once the insecticide selects the few mosquitoes that already carry a resistance allele, that allele can spread through almost the whole population within a few years; this small but real change in gene frequency is what is meant by evolution in action. The evolution of large new animals cannot be watched in the same way, because such animals breed slowly, with many years to a generation, so the build-up of large differences takes thousands of generations.

False Confidence Alert
Students often say the insects evolve fast because they need to. The speed comes from their short generations and huge numbers, which let the frequency of an already-present resistance allele climb quickly, not from any extra urgency.

Question 75

After a severe drought, only a few cattle survive in a herd, and they happen to be mostly of one coat colour. When the herd builds up again, that colour is now far more common than it was before the drought. Explain this change using the idea of genetic drift.

Model Answer

This change is an example of genetic drift: the drought killed most of the herd by chance rather than by selection, and the few survivors happened to carry mostly the alleles for one coat colour, so when they bred, that colour became common in the new herd. The shift was due to chance, not to any advantage of that colour.

Because only a small number of cattle survived, the alleles they carried were a chance sample of the original herd, so any colour that was common among the survivors was passed on out of all proportion, while colours that the drought happened to remove may have disappeared altogether. Such a strong effect of chance is typical of a small population, and it shows that the frequency of genes can change without natural selection playing any part.

> **False Confidence Alert**
> Students often assume the common colour must have been the fittest. Here it spread purely by chance, because the cattle that survived the drought happened to carry it; this is genetic drift, not selection.

Question 76

Kipanga writes: *"When a crop is sprayed with a pesticide, the insects on it mutate in order to become resistant, because they need to survive the poison."* Identify what is wrong with Kipanga's statement, and give the correct explanation.

Model Answer

Kipanga is wrong because mutation is not produced by need: the resistant mutations arise by chance, on their own, before and independently of the spraying, and the pesticide does not cause them. The error is to suppose that the insects mutate because they need to.

The correct, Neo-Darwinian explanation is that mutation happens at random in the population all the time, so that a few insects already carry a resistance allele before the pesticide is ever used. When the crop is sprayed, the pesticide kills the non-resistant insects and selects these already-present resistant ones, which then survive and breed, until over a few generations the resistance allele becomes common. So the pesticide selects existing variation; it does not call new mutations into being to meet a need.

> **False Confidence Alert**
> Students often half-correct this, allowing that selection acts but still letting the insects mutate in response to the spray. The key fix is that the mutations are random and already present before spraying, and the pesticide only selects them.

Question 77

Kipanga says, *"Crossing over during meiosis creates brand-new genes, and that is where all new variation comes from."* **Kipute** says, *"No, crossing over only shuffles the genes that are already there; the truly new alleles come from mutation."* Decide who is right, and explain why.

Model Answer

Kipute is right: crossing over does not create new genes; it only rearranges the existing alleles into new combinations, while the truly new alleles arise from mutation. Recombination and mutation are both sources of variation, but they work in different ways.

During meiosis, crossing over exchanges segments between homologous chromosomes, which brings the parents' existing alleles together in fresh combinations, so the offspring differ from the parents and from one another; but no allele in these combinations is new, for each one was already present in the population. A genuinely new allele can appear only when the base sequence of a gene is changed, which is a mutation. So Kipute is correct: recombination shuffles, and only mutation creates the new variation on which the shuffling, and then selection, can work.

> **False Confidence Alert**
> It is tempting to credit crossing over with new variation, because it produces offspring unlike the parents. Those offspring carry only new COMBINATIONS of old alleles; the new alleles themselves come only from mutation.

Question 78

Tanzania is famous for the fossil sites of Olduvai Gorge and Laetoli, where ancient bones and even footprints have been found. Explain how fossils such as these provide evidence for the evolution of humans and of other organisms.

Model Answer

Fossils such as those of Olduvai Gorge and Laetoli provide evidence for evolution because they preserve the remains and traces of organisms that lived long ago, showing that earlier, simpler forms existed and gradually changed into later ones. The deeper, older rock layers hold the more ancient forms, while the layers above them hold more recent ones.

At Laetoli, a set of footprints preserved in hardened volcanic ash shows that human-like ancestors already walked upright on two legs about three and a half million years ago, long before modern humans appeared, while the bones found at Olduvai record a series of forms leading towards the human of today. Because these fossils are found in datable rock layers and form an ordered series from older to younger, they give direct evidence that humans and other organisms have evolved over a very long time.

False Confidence Alert
Students often treat a single fossil as proof on its own. Its value comes from its place in the dated rock layers and in an ordered series running from older, simpler forms to younger ones, which is what shows change over time.

Question 79

A bat's wing, a bird's wing and a butterfly's wing all serve for flight. Classify these wings as homologous or analogous structures, and explain what each kind of likeness tells us about how the animals are related.

Model Answer

The wings of the bat and the bird are homologous structures, built on the same bony (pentadactyl) plan inherited from a common ancestor, whereas the butterfly's wing is only analogous to them, doing the same job but built quite differently. The two kinds of likeness tell us opposite things about relationship.

The homology of the bat and bird wings, both modified vertebrate forelimbs with the same bones, shows that the two share a common ancestor from which the basic plan was inherited and then adapted for flight. The analogy of the insect wing, a thin extension of the body wall with no bones, shows only that an unrelated animal met the same need and solved it independently, so it is no sign of close relationship. Homology therefore points to shared ancestry, while analogy points only to a shared way of life.

False Confidence Alert
Students often assume that sharing a feature such as wings means close relationship. Only homologous features, with a shared plan and origin, show relationship; analogous features, like an insect's and a bird's wing, show only a shared function.

Question 80

A Tanzanian surgeon sometimes has to remove a patient's appendix, a small blind-ended tube off the gut that seems to do no useful work in humans. Explain what kind of structure the appendix is, and what its presence tells us about our ancestors.

Model Answer

The appendix is a vestigial structure, a reduced remnant of an organ that was large and useful in our plant-eating ancestors but has lost its function in humans. Its presence is best explained by descent, with change, from such ancestors.

In many plant-eating mammals the matching structure is a large pouch that holds bacteria for digesting the cellulose of their plant food; in humans, whose diet is different, it has shrunk to the small, almost functionless appendix. The fact that we still carry this reduced remnant, which does little of its original work and may even become infected, makes sense only if we have inherited it from ancestors in which it was a working organ. The appendix is therefore evidence that humans have evolved from earlier forms with a different way of life.

False Confidence Alert
It is wrong to say a vestigial organ proves we never needed it. The opposite is true: it was useful in our ancestors and has since been reduced, which is exactly why it stands as evidence of our evolution.

Question 81

When scientists compare the DNA and proteins of different animals, they find that a human is far more like a chimpanzee than like a fish. Explain how such biochemical comparisons are used as evidence for evolution and for working out how closely animals are related.

Model Answer

Biochemical comparisons are used as evidence for evolution because organisms that share more of their DNA and proteins are more closely related, having branched more recently from a common ancestor. The degree of chemical likeness is a measure of the closeness of relationship.

All living things use the same DNA and the same genetic code, which by itself points to a single common origin; and when the actual sequences are compared, those of a human and a chimpanzee are found to be far more alike than those of a human and a fish, because the human and the chimpanzee shared a common ancestor much more recently. In the same way, the near-identity of molecules such as insulin and haemoglobin among related mammals shows their close kinship. The smaller the chemical difference between two animals, the closer and more recent their shared ancestry.

False Confidence Alert
Students often say only that animals share the same chemicals. The evidence lies in the amount shared: the more alike the DNA and proteins of two animals, the more recently they branched from a common ancestor, which is how relationship is measured.

Question 82

A Tanzanian student travelling to Australia is surprised to find that almost all the native mammals there, such as kangaroos and koalas, are pouched mammals quite unlike the mammals of Tanzania. Explain how the geographical distribution of these animals provides evidence for evolution.

Model Answer

The strange Australian mammals are evidence for evolution because they show that, once a land is cut off, its organisms evolve on their own into forms found nowhere else, exactly as descent with modification predicts. Distribution follows evolutionary history, not a chance placing of animals.

Australia became separated from the other continents long ago, before the ordinary placental mammals had spread there, so its early pouched mammals (marsupials) were left to evolve in isolation and filled the land with their own kinds, such as the kangaroo and the koala, while Tanzania and the other continents came to be dominated by placental mammals. The two faunas are so different because they descended from different ancestors and evolved apart after the lands were divided. This is far better explained by evolution in isolation than by each animal being separately created where it now lives.

False Confidence Alert
Students often treat the odd Australian animals as a mere curiosity. The point for the marks is that isolation let them evolve on their own into unique forms, which is evidence for descent with modification rather than separate creation.

Question 83

Tanzanian farmers have, over many years, produced higher-yielding maize and better milk cattle by always breeding from their best plants and animals. Explain how this selective breeding supports the theory of evolution, and how it differs from natural selection.

Model Answer

Selective breeding supports evolution because it shows, within a human lifetime, that choosing which organisms reproduce can change a species and produce new varieties from the original stock, which is exactly the kind of change that evolution holds to be possible. Darwin himself used it as a model for natural selection.

By always breeding from the maize plants with the largest cobs, or from the cattle that give the most milk, the farmer raises those features generation after generation, so the crop or the herd is gradually changed into a new and better variety. The difference from natural selection lies in who does the choosing: in selective breeding it is the farmer who decides which individuals reproduce, choosing the features useful to people, whereas in natural selection it is the environment that decides, favouring the features that help the organism survive and breed. In both, however, selection acting on variation changes the population over generations.

False Confidence Alert
A weak answer just says that farmers breed good animals. The evidence is that selecting the best parents changes the species into new varieties, and the only real difference from nature is that the farmer, not the environment, does the choosing.

Question 84

Kipanga argues: *"A bat, a bird and a butterfly all have wings, and an octopus and a person both have eyes, so these animals must all be closely related."* Identify the mistake in Kipanga's reasoning, and explain it correctly.

Model Answer

Kipanga's mistake is to treat every shared feature as a sign of close relationship, when wings and eyes of this kind are analogous structures, which arise independently and show only a shared way of life, not common ancestry. A likeness counts as evidence of relationship only when it is homologous, built on a shared plan inherited from a common ancestor.

The wing of a butterfly is built quite differently from the wing of a bird or a bat, and the eye of an octopus is built differently from the eye of a person; in each case the resemblance arose because unrelated animals met the same need and solved it in similar ways, which is convergent evolution. Such analogous features tell us nothing about close kinship. So Kipanga is wrong, because a shared function does not mean a shared ancestry, and only homologous structures reveal how closely animals are truly related.

False Confidence Alert
Students often repeat Kipanga's error in reverse, dismissing all shared features as meaningless. The rule is exact: homologous features, with a shared plan and origin, show relationship, while analogous features, with a shared function only, do not.

Question 85

Kipanga says, *"Evolution means that humans came from the monkeys we see today."* **Kipute** says, *"No, humans and monkeys both descended from a common ancestor that lived long ago."* Decide who is right, and explain why.

Model Answer

Kipute is right: humans did not come from the monkeys alive today; instead, humans and monkeys both descended from a shared ancestor that lived long ago, from which the two lines have since evolved separately. The monkeys of today are our cousins, not our ancestors.

The evidence of anatomy and biochemistry shows that humans and monkeys are closely related, but it points to a common ancestor in the distant past, not to humans arising from present-day monkeys. From that ancestor, one line led, over millions of years, to the modern monkeys and another led to modern humans, so the two are branches of the same tree rather than one being the parent of the other. Kipanga has misread a shared ancestry as a direct descent, which is why Kipute is correct.

False Confidence Alert
It is a very common error to say that humans came from today's monkeys. Evolution says only that the two share a distant common ancestor; the monkeys we see now are themselves modern, evolved cousins, and not our forebears.

Question 86

The lakes of the East African Rift Valley, such as Lake Victoria and Lake Nyasa, each contain hundreds of species of cichlid fish found nowhere else, most of which arose within a single lake. Explain how so many new species could form within one lake.

Model Answer

So many cichlid species could form within one lake by sympatric speciation, in which groups of fish became reproductively isolated from one another without any geographical barrier dividing the lake. Different groups came to use different foods, depths and breeding sites, and to choose mates of their own kind, so that gene flow between them was cut even though they shared the same water.

Once a group bred mainly among itself, it began to diverge, building up its own differences in feeding structures, colour and behaviour, until it could no longer interbreed with the others and had become a separate species. Because the rich and varied conditions of a large lake offered many different ways of life, this happened again and again, producing the great flock of cichlid species seen today. The lake has acted like a natural laboratory of rapid speciation.

False Confidence Alert
Students often assume the lake must have been divided by a barrier. These cichlids speciated within one undivided lake, their gene flow cut by differences in feeding and in mate choice, which is sympatric speciation.

Question 87

A wide river cuts through a forest, leaving a population of monkeys on each bank, and over a very long time the two populations become separate species. Explain, using the idea of speciation, how the river brings this about.

Model Answer

The river brings about new species by allopatric speciation: it acts as a geographical barrier that stops the monkeys on the two banks from meeting and interbreeding, so their gene flow is cut and the two groups evolve apart. Once separated, each group goes its own evolutionary way.

On its own side of the river, each group meets its own conditions, food and dangers, and over many generations natural selection and genetic drift change the two groups in different directions, so they steadily build up their own differences. After a very long time the two have become so different that, even if the river dried and they met again, they could no longer interbreed and produce fertile young; at that point they are separate species. The river, by cutting the gene flow, was the first and necessary step.

False Confidence Alert
Students often say the river itself turned one monkey into another. The river only stops the groups breeding together; it is selection and drift, acting separately on each side over a long time, that actually make them into different species.

Question 88

In some parts of Tanzania a horse is crossed with a donkey to produce a mule, a strong animal used to carry loads, but a mule cannot have young of its own. Explain why the horse and the donkey are regarded as two separate species, even though they can produce a mule together.

Model Answer

The horse and the donkey are regarded as separate species because, although they can mate and produce a mule, the mule is sterile, so the two kinds are kept apart by a post-zygotic isolating mechanism, hybrid sterility. A true species must be able to breed and produce fertile offspring of its own kind.

The horse and the donkey have different numbers of chromosomes, so when they cross, the mule inherits an odd, unmatched set that cannot pair properly during meiosis; the mule therefore cannot make working gametes and leaves no offspring. Because the mule is a dead end, no genes flow from horse to donkey through it, and the two populations stay genetically separate. It is this failure of the hybrid to reproduce, and not any failure to mate, that makes the horse and the donkey two distinct species.

> **False Confidence Alert**
> Students often think that because a horse and a donkey can produce a mule, they must be one species. The opposite is true: the mule is sterile, so no genes pass between the two through it, which is exactly why they remain separate species.

Question 89

Kipanga writes: *"When a horse is crossed with a donkey, the mule that results is a brand-new species formed by people, which proves that we can make new species whenever we like."* Identify what is wrong with Kipanga's statement, and explain it correctly.

Model Answer

Kipanga is wrong because the mule is not a new species at all: it is a sterile hybrid that cannot reproduce, and a new species must be able to breed and produce fertile offspring of its own kind. A single sterile animal can never make up a species.

A species is a group of organisms that can interbreed among themselves to produce fertile young, generation after generation. The mule fails this test completely, because its unmatched chromosomes cannot pair at meiosis, so it leaves no offspring and the line ends with it. Far from showing that we can make new species at will, the mule shows the opposite, that crossing two species usually gives only a sterile dead end, and that forming a true new species needs a whole population that can go on breeding, not a single hybrid.

> **False Confidence Alert**
> Students often correct Kipanga only halfway, agreeing the mule is unusual but still calling it a new species. The decisive point is that the mule is sterile, so it can never form a breeding population, and therefore is not a species at all.

Question 90

A new dam splits a river, leaving one fish population in the upper part and another in the lower part. **Kipanga** says, *"They are now two different species, because they are separated and can no longer mix."* **Kipute** says, *"They are not yet two species; they will be only when they can no longer interbreed."* Decide who is right, and explain why.

Model Answer

Kipute is right: separating the fish by a dam does not by itself make them two species; they become two species only when they have diverged so far that they can no longer interbreed and produce fertile young. Geographical separation is the start of speciation, not the finish of it.

When the dam first splits the river, the two groups are still the same species, merely living apart; if the dam were removed at once, they would mix and breed freely again. Only if they stay separated for a very long time, and natural selection and genetic drift change them in different ways until they can no longer interbreed even when reunited, will they have become two species. So Kipanga has mistaken the first step, isolation, for the whole of speciation, which is why Kipute is correct.

False Confidence Alert
It is tempting to agree with Kipanga that being separated already makes two species. Separation only begins the process; the groups are not separate species until they can no longer interbreed, which takes a long time of evolving apart.

HOT QUESTIONS

These final questions ask you to put the whole chapter to work: to weigh competing theories, to judge what a piece of evidence really shows, and to reason your way through situations you have not met before. The facts you need are already in the earlier questions; what is tested now is how well you connect and apply them. As before, attempt each question fully before reading the model answer and the False Confidence Alert that follows.

Question 91

Scientists treat the biochemical theory as the most satisfactory account of the origin of life, while setting the others aside. A sound scientific explanation must meet two demands: it must be open to testing, and it must actually account for how life first began on Earth. Using these two demands, evaluate the main theories and justify why the biochemical theory is preferred.

Model Answer

The biochemical theory is preferred because it is the only account that satisfies both demands together: it can be tested against evidence, and it sets out how life itself first arose from non-living matter on the early Earth. The other theories each fail one demand or the other.

Special creation fails the first demand, for it describes a single, unrepeatable act that no experiment can support or overturn, so it lies outside science altogether. Spontaneous generation did meet the first demand and was duly tested, by Redi and others, and it failed the test, because no life appeared from non-living matter once living parents were shut out. The cosmozoic and steady-state theories fail mainly on the second demand: the cosmozoic idea only moves the problem elsewhere, telling us how life might have reached the Earth from space but not how it first began, while the steady-state view, that life has simply always existed, dodges the question of a beginning and conflicts with the fossil record. The biochemical theory alone proposes a definite, testable sequence, from simple gases to building blocks to the first cell, and its early steps have actually been reproduced in the laboratory, which is why it stands as the soundest scientific account.

False Confidence Alert
A common error is to dismiss every rival theory as simply false. In fact each is set aside for its own reason: creation for being untestable, spontaneous generation for being tested and disproved, cosmozoic and steady-state for never explaining the actual beginning. Naming that exact reason, rather than calling them all wrong, is what earns the marks.

Question 92

A space probe reports that amino acids and other building-block molecules have been found inside a meteorite. A newspaper announces that this proves life exists out in space, and that life on Earth must therefore have come from there. Evaluate this claim.

Model Answer

The newspaper has read far more into the find than the evidence allows, because building-block molecules are not themselves living, and even if such molecules did reach the Earth from space, that

would explain only how life might have arrived, not how it first began. Two separate over-claims are tangled together here.

Amino acids are merely the raw materials from which living matter can be assembled; on their own they are lifeless chemicals, just as a pile of bricks is not a house. Miller-type experiments showed long ago that such building blocks form readily from simple gases with no life present, so finding them in a meteorite shows only that the same ordinary chemistry occurs elsewhere in the universe, not that organisms live there. The second claim fares no better: even if molecules, or spores, did travel here on meteorites, that is simply the cosmozoic idea, which shifts the question to another place and still leaves unanswered how life first arose, wherever it did. A careful scientist would therefore welcome the discovery as support for the chemical steps of the biochemical theory, not as proof of life in space or of the origin of life on Earth.

False Confidence Alert
It is tempting to read the phrase building blocks of life as life itself. The two are quite different: amino acids are non-living raw materials, and showing that they occur in space says nothing about whether living cells do. Claiming more than the evidence will bear is the trap to avoid.

Question 93

The biochemical theory holds that the first living things arose from non-living chemicals under the conditions of the early Earth. Explain why life is not arising from such chemicals in the same way on Earth today.

Model Answer

Life is not arising from non-living chemicals today because the special conditions that made it possible on the early Earth have gone, and because any building-block molecules that did form would now be destroyed or consumed long before they could ever build up into life. Two great changes since that time block the path.

The early atmosphere held no free oxygen and was a reducing one, so the delicate building blocks could form and slowly accumulate over an immense stretch of time without being broken apart. The atmosphere today is rich in oxygen, which is highly reactive and would quickly oxidise and destroy such molecules before they could ever join into larger ones. Just as decisive, the early Earth carried no life at all, so molecules could gather undisturbed, whereas the present world already teems with living things, and any nourishing molecule that happened to form would at once be absorbed or decomposed by existing bacteria and other organisms. With both the life-free setting and the oxygen-free atmosphere gone, the slow chemical build-up can no longer happen, which is exactly why, in the world of today, living things arise only from other living things, as biogenesis states.

False Confidence Alert
Students often answer only that the origin of life was a once-only event, which earns little. The marks lie in the two concrete reasons it cannot repeat now: today's oxygen would destroy the building blocks, and the life already present would consume them before they could accumulate.

Question 94

Although Lamarck's theory of evolution is rejected today, biologists still regard him as having made an important contribution to the subject. Evaluate this view, making clear both what modern biology rejects in his theory and what it nevertheless credits him with.

Model Answer

The view is fair, because modern biology rejects the mechanism by which Lamarck said evolution works, yet rightly credits him with being among the first to give a natural explanation for how living things change, and with seeing that the environment plays a part. The rejection and the credit fall on different parts of his work.

What is rejected is the core of his mechanism, the inheritance of acquired characteristics through use and disuse. A feature that an organism develops during its own lifetime, such as the muscles built by effort or the neck supposedly stretched by reaching, is a change in the body cells only; it is not written into the sex cells, and so it cannot be handed on, as Weismann showed by cutting the tails of mice for many generations without ever producing a tailless one. What is credited to him is real and lasting: at a time when most people held that species were fixed and specially created, Lamarck argued boldly that species are not fixed but change over time, and he proposed a natural process, rather than a miracle, to bring this about. He also drew attention to the influence of the environment on living things, an idea that Darwin later placed on a firm footing by replacing use and disuse with variation and natural selection. Lamarck was therefore wrong about how evolution happens, but right that it happens and that the environment matters, which is why he is honoured as a pioneer.

False Confidence Alert
It is a mistake to treat the words Lamarck was wrong as the whole answer and dismiss him outright. The marks lie in the balance: his mechanism, the inheritance of acquired traits, is rejected, while his insight that species change and that the environment is involved was a genuine step forward.

Question 95

Two parents are both strong weightlifters with well-built muscles. Their child is not born with big muscles, but after years of the same training the child also becomes strongly built. A neighbour says this shows that the parents passed their big muscles on to the child. Using the difference between body cells and sex cells, explain why the child's muscles are not inherited in Lamarck's sense, and say what the child could really have inherited.

Model Answer

The neighbour is mistaken, because the parents' big muscles are an acquired feature of their body cells, built up by training during their own lives, and such a feature cannot be passed on; what the child can truly inherit is not the muscles themselves but a genetic make-up that responds well to training. The case therefore gives no support to Lamarck.

Muscles enlarge in the body, or somatic, cells of a person who exercises, but the sex cells that go on to form the child carry only the parents' genes, which the training does not alter; this is exactly why an acquired character is not inherited, as Weismann's mouse-tail experiment demonstrated. The child is therefore born with ordinary muscles and becomes strong only by doing the training afresh, just as each parent once had to. What can pass from parent to child is the underlying inheritance: genes for a build, a bone frame and a muscle type that take well to exercise, so that a tendency towards athletic ability can indeed run in a family. The key point is that the child inherits a **potential**, which must still be developed by effort, and not the finished, acquired trait.

False Confidence Alert
The trap is to reason that because athletic ability seems to run in families, the muscles themselves must have been inherited. They were not: what is passed on is a genetic potential that still has to be built up by training, while the parents' actual muscles, an acquired trait, die with their body cells.

Question 96

Some students object that the phrase "survival of the fittest" explains nothing, since the fittest are simply those that survive, and those that survive are then called the fittest. Evaluate this objection, and explain what "fitness" really means in Darwin's theory.

Model Answer

The objection has force only while fitness is left undefined; it fails once we see that fitness can be described independently of mere survival, for the fittest are those whose inherited features best suit them to their surroundings and which therefore leave the most fertile offspring. So the phrase is not the empty circle it first appears.

It would indeed say nothing to claim only that the survivors survive. But Darwin's claim is not empty, because the features that make an organism fit can be pointed out in advance of any dying: a faster antelope, a better-camouflaged moth, or a plant that holds water through a drought each carries an advantage we can identify before we know its fate. The theory then predicts that such individuals will, on average, survive and breed more than their rivals, so that their helpful inherited features spread through the population. Fitness, properly understood, is therefore not just being alive but being well-adapted and, above all, leaving many offspring that themselves survive to breed. Measured in this way, survival of the fittest makes a real and testable claim, namely that heritable advantages tend to become more common in a population over the generations.

False Confidence Alert
The careless reply is to agree that the phrase is a meaningless circle. Avoid this: fitness is defined by adaptation and reproductive success, which can be judged separately from who happens to survive, so the statement does carry real, testable content.

Question 97

On an island, a bird species normally has medium-sized beaks suited to medium seeds. A long drought then kills off the plants with medium seeds, leaving only plants with very large, hard seeds and plants with very small seeds. Using the correct type of natural selection, predict and explain what is likely to happen to the beaks in this population over many generations.

Model Answer

This is a case of disruptive selection, in which the two extreme forms are favoured while the middle form is selected against; so over many generations the population is likely to split into one group with large, strong beaks and another with small beaks, while medium beaks grow rare. Both ends of the range are favoured at once.

With only large hard seeds and very small seeds left to eat, the birds with the largest, strongest beaks can crack the hard seeds, and those with the smallest beaks can deal neatly with the tiny ones, but the medium-beaked birds are now suited to neither food and tend to go hungry, so they leave fewer offspring. Because beak size is inherited, each succeeding generation carries a higher proportion of the two extremes and fewer of the middle, until the single original range is pulled apart into two distinct beak types. If, in time, the large-beaked and small-beaked birds also came to feed, settle and breed apart, and ceased to interbreed, this disruptive selection could even be the first step towards splitting the one species into two.

False Confidence Alert
A common slip is to call this directional selection merely because the beaks change. Directional selection shifts a population towards one extreme, whereas here BOTH extremes are favoured at the expense of the middle, which is the mark of disruptive selection.

Question 98

It has been said that Darwin's theory could explain the survival of the fittest, but not the arrival of the fittest. Explain what this criticism means, and show how the later science of genetics answered it.

Model Answer

The criticism means that Darwin could explain how, once different forms exist, the better-adapted ones survive and spread, but he could not explain where those different forms first came from, nor how they were passed on; the science of genetics later supplied both answers. His theory dealt with the survival of variation, not its arrival.

Natural selection acts only on variation that is already present, choosing among the differences between individuals, and so it accounts well for the survival of the fittest. But Darwin did not know the source of that variation, nor the mechanism of inheritance, and the blending idea of his day even threatened to dilute any new advantage away within a few generations; this unexplained gap is the arrival of the fittest. Genetics closed it on both counts: mutation was found to be the origin of genuinely new variation, with recombination reshuffling it into fresh combinations, while Mendel's particulate genes showed that an advantage is carried whole in the gametes and handed on, not blended away. Uniting this genetics with natural selection gives Neo-Darwinism, which explains both the arrival of the fittest, by mutation and recombination, and their survival, by selection.

False Confidence Alert
Students often answer only that Darwin did not know about genes, which is too vague to score. Be precise: he could not explain the SOURCE of new variation, now known to be mutation, nor how it is INHERITED, now explained by Mendelian genes, and these are exactly the two pieces Neo-Darwinism supplies.

Question 99

Kipanga says, *"Natural selection is what produces the variations in a population, because it makes each animal develop the features it needs to survive."* **Kipute** says, *"No, natural selection does not produce the variations; they are already present in the population, and selection only decides which of them survive."* Decide who is right, and explain why.

Model Answer

Kipute is right: natural selection does not produce variation, it only sorts the variation that is already present, letting the better-adapted forms survive and breed while the rest are weeded out. Variation and selection are two separate steps, in that order.

In any population the individuals already differ from one another, and these inherited differences arise on their own, by mutation and the reshuffling of genes, before and independently of any need. When the environment then presses on the population, selection acts upon this ready-made variety: it does not call new features into being to meet a need, but simply favours whichever existing forms happen to be best suited, so that their genes grow more common over the generations. Kipanga's version, in which the animal develops the features it needs, is really the discarded Lamarckian idea of acquired characters dressed up in Darwinian words; the modern view keeps the two steps firmly apart, with variation arising first by chance and selection doing the choosing afterwards. That is why Kipute, and not Kipanga, has stated the theory correctly.

False Confidence Alert
It is easy to be half-swayed by Kipanga, since selection clearly does shape a population in the end. The decisive point is the order of events: variation comes first, by chance, and selection only sorts it afterwards, for selection never creates a feature simply because it is needed.

Question 100

Most mutations are harmful or have no effect, and they occur at random, without regard to what an organism needs. Yet biologists insist that mutation is essential to evolution. Explain how both of these statements can be true.

Model Answer

Both statements are true because mutation and natural selection play different parts: mutation is the only source of genuinely new variation, supplying the raw material at random, while selection, acting afterwards, keeps the rare useful mutations and discards the harmful ones, and so gives evolution its direction. The randomness lies in the supply, the direction comes from the sorting.

It is quite correct that most mutations are harmful or neutral and that they arise by chance, not to order, for a mutation does not appear because an organism needs it. But evolution cannot go forward without a supply of new variation, and mutation is the one process that creates entirely new alleles, which recombination cannot do, since recombination only reshuffles alleles that mutation has already produced. The harmfulness and randomness are not a fatal objection, because selection does the sorting: in each generation the many harmful mutations are weeded out along with their carriers, while the occasional beneficial one is preserved and spreads. Over an immense span of time, even very rare useful mutations, sieved and built up by selection, are enough to produce the adaptations we see. Mutation therefore supplies the raw material blindly, selection shapes it, and evolution needs both.

False Confidence Alert
It is tempting to conclude that because most mutations are harmful, mutation cannot be the engine of evolution. The resolution is the division of labour: mutation only supplies new variation at random, while selection, not mutation, provides the direction by keeping the rare useful changes.

Question 101

Two small island populations of the same beetle each begin with equal numbers of green and brown individuals. On Island A, birds prey on the beetles, and green ones show up clearly against the brown soil. On Island B there are no predators at all. After many generations, Island A is almost all brown, while Island B has become almost all green. Naming the process at work on each island, explain why the colour changed in each case.

Model Answer

On Island A the change is due to natural selection, while on Island B, where there is no predator to do any selecting, the change is due to genetic drift, the chance alteration of gene frequencies in a small population. The same outcome, a shift in colour, has arisen from two quite different causes.

On Island A the birds eat the conspicuous green beetles more often than the well-hidden brown ones, so the brown beetles survive and breed more successfully; because colour is inherited, the brown allele grows commoner each generation until the population is almost all brown. This is natural selection, for the environment, acting through predation, is favouring one form over the other. On Island B no such pressure exists, since nothing hunts the beetles and neither colour carries any advantage; yet in a small population the proportions of the two colours can still drift by pure chance, as only some individuals happen to breed and pass on their colour, and here that chance has carried the green form to near-fixation. The contrast shows the key difference: selection changes a population in a direction set by the environment, whereas drift changes it at random and matters most when the population is small.

False Confidence Alert
A frequent error is to assume the green beetles on Island B must somehow be fitter. With no predator and no advantage to either colour, the shift cannot be selection; it is genetic drift, the working of chance in a small population, where no form is being favoured at all.

Question 102

Neo-Darwinism explains small-scale changes very well, such as a moth becoming darker or bacteria becoming resistant to a drug, but some argue that it is less able to explain the origin of whole new major groups of living things. Evaluate Neo-Darwinism in the light of this objection, making clear what it accounts for well and where the difficulty lies.

Model Answer

Neo-Darwinism is on its strongest ground with small-scale, or micro-, evolution, which can actually be observed, and its account of large-scale, or macro-, evolution rests on the very same processes extended over an immense time; the real difficulty is one of direct observation, not of a missing mechanism. Its strength and the objection point to different time scales.

The strength is plain in cases such as industrial melanism in the peppered moth and the rise of drug-resistant bacteria, where a measurable change in gene frequency takes place within a human lifetime, exactly as the theory predicts, with mutation and recombination supplying variation and selection sorting it. The objection is that the origin of major groups, such as the first mammals or the flowering plants, cannot be watched in this way, because it unfolds over millions of years. But Neo-Darwinism answers that macro-evolution is simply the same micro-evolutionary processes continued and added up over geological time, and that this large-scale picture, though not directly visible, is strongly supported by other evidence: the fossil record, comparative anatomy and the molecular likenesses between groups. The fair verdict is therefore that Neo-Darwinism is a powerful and well-supported theory whose small-scale claims are directly demonstrated and whose large-scale claims rest on sound inference from converging evidence, rather than on direct sight.

> **False Confidence Alert**
> Be careful not to treat the macro-evolution objection as proof that Neo-Darwinism has failed. The honest position is that large-scale change is harder to observe directly, not that a different mechanism is required, and the fossil and molecular evidence supports the same processes acting over a far longer time.

Question 103

No single line of evidence proves evolution by itself, yet taken together the different kinds of evidence make an overwhelming case. Explain how the separate lines of evidence support and strengthen one another.

Model Answer

The separate lines of evidence strengthen one another because they are independent, yet they all point to the same conclusion, common descent, and even agree on the same pattern of relationships, which is far more than coincidence could explain. Their power lies in their agreement, not in any one of them alone.

Taken singly, each line could be questioned: a doubter might call a single fossil a one-off, or a shared bone plan a mere accident. But the lines do not stand singly. The fossils show life changing in an ordered sequence through the rock layers; comparative anatomy shows living groups built on shared plans, as in the pentadactyl limb; embryology shows related animals passing through similar early stages; biochemistry shows the same basic molecules and genetic code throughout life, with the closest molecules in the most alike animals; geographical distribution shows related species clustered where their ancestors once lived; and selective breeding shows that selection really can reshape a population. Above all, these independent lines agree, the family tree drawn from bones matching the one drawn from molecules. Because separate and unconnected kinds of evidence converge on the very same story, the case for evolution becomes overwhelming, much as many independent witnesses telling one account leave little room for doubt.

> **False Confidence Alert**
> A weak answer simply lists the kinds of evidence one after another. The marks come from the link between them: each line is independent, yet all point the same way and even agree on the same relationships, and it is this convergence, not the length of the list, that makes the case strong.

Question 104

The fossil record is known to be incomplete, with many gaps and missing links. Some people use this to argue that evolution is therefore unproven. Evaluate this argument.

Model Answer

The argument is weak, because the gaps in the fossil record are exactly what we should expect from the way fossils form, the record is steadily being filled, and in any case evolution does not rest on fossils alone but on several independent lines of evidence. An expected gap is not a disproof.

Fossils form only under special conditions, when a dead organism is buried quickly before it decays, so the great majority of living things leave no fossil at all; soft-bodied creatures are rarely preserved, and later earth movements destroy much of what does form. Gaps are therefore inevitable, and to expect a complete record is to misunderstand how rare fossilisation is. Moreover the so-called missing links are being found: the horse series, and intermediate forms such as the feathered, part-reptile early bird, show smooth transitions where gaps once stood. Most important of all, even if no fossils existed, the evidence from comparative anatomy, embryology, biochemistry and geographical distribution would still point firmly to evolution. The incompleteness of one line of evidence cannot overturn a conclusion that several independent lines support, and so the argument fails.

> **False Confidence Alert**
> It is a mistake to grant that an incomplete fossil record leaves evolution unsupported. Gaps are expected because fossilisation is rare, the record is being filled by transitional forms, and the other lines of evidence stand on their own even where fossils are missing.

Question 105

A bird's wing and a bat's wing are used alike for flight, and biologists treat them as evidence that the two are related. A bird's wing and a whale's flipper look quite different and do quite different jobs, yet biologists treat these as evidence of relationship as well. A bird's wing and an insect's wing look alike and share a job, yet these are **not** taken as evidence of relationship. Explain the principle that makes sense of all three judgements.

Model Answer

The principle is that relationship is shown by a shared underlying plan and common origin, the mark of homologous structures, and not by outward likeness or by doing the same job, which is the mark of merely analogous structures. We must look at how a structure is built, not at what it looks like or does.

The wings of a bird and a bat, and the flipper of a whale, however different they look or whatever they are used for, are all built on the same plan of bones, the pentadactyl limb inherited from a common vertebrate ancestor and only modified for flying or swimming; this shared inner structure, not the outward shape, is what marks them as homologous, and so as evidence of relationship. The wing of an insect, by contrast, resembles a bird's wing only on the surface and in its use, for inside it has no bones at all and develops in quite a different way; it is analogous, the product of unrelated animals meeting the same need independently, and so it shows no relationship. The lesson is that to test relationship we must look beneath the surface at how a structure is built and where it comes from, because likeness of plan reveals shared ancestry while likeness of mere appearance or function does not.

> **False Confidence Alert**
> The trap is to judge relationship by how alike two structures look, or by what they are used for. Homology, the test that really counts, looks at the shared plan and common origin beneath the surface, which is why differently shaped limbs can be related while similar-looking wings need not be.

Question 106

Scientists can work out a family tree of animals from comparing their skeletons, and quite separately work out a family tree from comparing their proteins or DNA. When this is done, the two trees agree closely. Explain why this agreement is such powerful evidence for evolution.

Model Answer

The agreement is powerful evidence because the two trees are built from completely independent kinds of information, bones on the one hand and molecules on the other, and there is no reason for them to match unless the relationships they show are real, the result of true common descent. Independent methods that agree are hard to doubt.

When animals are grouped by their skeletons, the most alike are placed closest together; when they are grouped instead by how similar their proteins or DNA are, the most alike molecules again place the same animals closest together. These two methods share nothing, one looking at outward bony structure and the other at the chemistry hidden inside the cells, so they could easily have told different stories. That they tell the same story, placing a human nearest the apes by its bones and equally nearest the apes by its molecules, is very hard to explain by chance, or by separate creation, under which the two need not agree at all. It is exactly what evolution predicts, for if living things have descended with modification from common ancestors, then both their structure and their molecules carry the same record of that descent, and so must agree. The matching of two independent family trees is therefore strong confirmation that the relationships, and the common ancestry behind them, are real.

False Confidence Alert
A thin answer just repeats that molecules and bones are alike in related animals. The real force lies in independence: two unconnected methods need not agree, so their close agreement is powerful precisely because only genuine common descent would make both carry the same pattern.

Question 107

If every kind of animal had been created independently and simply placed where the climate suited it, we might expect the same kinds to appear on every continent with a similar climate. Instead, an isolated land such as Australia has its own peculiar mammals, the marsupials, found almost nowhere else, while well-suited placental mammals are largely absent. Explain why this pattern of distribution is better explained by evolution than by independent creation.

Model Answer

This pattern is better explained by evolution because the animals of a region are not those best suited to its climate from anywhere on Earth, but the descendants, with modification, of the ancestors that happened to live there, so it is isolation and ancestry, not mere suitability of climate, that decide what is found where. Distribution follows history, not just habitat.

Australia became separated from the other land masses long ago, carrying its early marsupials with it; cut off from the placental mammals that were evolving elsewhere, these marsupials diversified in isolation into the many forms now found there and nowhere else, filling the ways of life that placentals fill on other continents. Independent creation cannot easily explain this, for if animals had simply been placed where the climate suited them, the grasslands and forests of Australia, so like those of Africa or America, ought to hold the same well-adapted placental mammals, yet they do not. The same reasoning explains why remote oceanic islands carry only the descendants of the few chance arrivals that managed to reach them, rather than a full and fitting set of animals. It is the link between distribution and ancestry, rather than between distribution and climate alone, that gives the pattern away, and only descent with modification from regional ancestors accounts for it.

False Confidence Alert
Students often explain Australia's animals by saying they are simply suited to its conditions. That cannot be the whole story, since placental mammals would suit those same conditions too; the deciding factor is history and isolation, the marsupials being the modified descendants of the ancestors stranded there.

Question 108

Kipanga says, *"Selective breeding by farmers has nothing to teach us about evolution, because the farmer deliberately chooses which animals breed, whereas in nature nobody chooses."* **Kipute** says, *"Selective breeding is in fact strong evidence for evolution, because it shows that choosing which individuals breed really can transform a population."* Decide who is right, and explain why.

Model Answer

Kipute is right: selective breeding is valuable evidence for evolution, because it shows directly that choosing which individuals breed, generation after generation, can reshape a population, which is exactly the kind of change evolution claims; the only difference is who, or what, does the choosing. The selector differs, but the process is the same.

In selective breeding a farmer keeps the individuals with the wanted features, a higher milk yield or a larger cob, and breeds only from them, so that over many generations the whole stock is changed, as the great variety of cattle, dogs and crop plants bred from wild ancestors plainly shows. This proves, before our eyes and within a short time, that selection acting on inherited variation has the power to transform living things.

Natural selection works in just the same way, except that the environment, rather than a farmer, decides which individuals survive and breed; artificial selection is therefore a working model of the natural process, sped up and made visible. Kipanga is wrong to dismiss it, for the fact that the selector is a person and not the environment does not weaken the demonstration; it merely lets us watch in a few years what nature does over ages. That is why Kipute has judged the matter correctly.

False Confidence Alert
It is easy to side with Kipanga, since a farmer choosing the parents does seem unlike wild nature. But the lesson holds: selective breeding shows that choosing which individuals breed can remake a population, and whether the selector is a farmer or the environment, the power of selection on inherited variation is the same.

Question 109

Describe and explain the complete sequence of events by which a single species can split into two separate species, making clear why each stage in the sequence is necessary.

Model Answer

A single species splits into two through a sequence of necessary stages: the population must first contain inherited variation, its gene flow must then be cut so that one group stops interbreeding with the other, the separated groups must diverge under selection and drift, and finally reproductive isolation must build up so that the two can no longer interbreed even if they meet again. Remove any one stage and the split fails.

The starting point is variation, for without inherited differences there would be nothing for the groups to diverge in. The first essential step is then the cutting of gene flow, usually by a barrier such as a river, sea or mountain that divides the population, because as long as the two groups keep interbreeding their genes are shared and mixed, and any new differences are swamped before they can build up. Once gene flow is stopped, the separated groups meet different conditions, and natural selection and genetic drift change them in different directions, so that over many generations they steadily accumulate their own distinct features. The final and decisive stage is the build-up of reproductive isolation, by pre-zygotic or post-zygotic mechanisms, for only when the two groups can no longer interbreed to produce fertile offspring, even if they are brought back together, have they truly become two species rather than two varieties. Each stage thus plays its part: variation gives the raw material, isolation protects the differences, divergence creates them, and reproductive isolation makes the split permanent.

False Confidence Alert
A common weakness is to stop at the idea that the groups were separated and became different. That alone leaves them as two varieties; the stage that actually completes speciation is reproductive isolation, the point at which they can no longer interbreed even when reunited.

Question 110

The usual test of whether two organisms belong to the same species is whether they can interbreed to produce fertile offspring. Explain why this test is hard or impossible to apply to (a) organisms that reproduce only asexually, such as many bacteria, and (b) organisms known only from fossils, and say what this difficulty tells us about the idea of a species.

Model Answer

The interbreeding test cannot be applied in either case, because it depends on sexual reproduction between living organisms, and neither an asexual organism nor a long-dead fossil can be made to breed; this shows that the interbreeding definition, useful as it is, is not a universal one. The two parts fail the test for related but distinct reasons.

(a) Asexual organisms, such as many bacteria: they reproduce only by dividing to make copies of themselves, so they never interbreed at all, and the question whether two of them could produce fertile offspring together cannot even arise; biologists must instead group them by their structure, biochemistry and genes.

(b) Organisms known only from fossils: they are long dead and so cannot be bred to find out whether they would have produced fertile young, which means they too can be judged only by their preserved form and structure.

What this difficulty tells us is that the interbreeding test, valuable as it is for living, sexually reproducing organisms, cannot be the whole definition of a species. Where it cannot be applied, biologists fall back on close similarity of structure and other features as the practical mark of one kind, so that a species is best seen as a powerful but not perfectly sharp idea, to be tested in whatever way suits the organisms in hand.

False Confidence Alert
It is tempting to treat being able to interbreed and produce fertile offspring as the one and only definition of a species. It is the best test for living, sexual organisms, but it simply cannot be applied to asexual forms or to fossils, for which similarity of structure must serve instead.

Question 111

Two populations of a fish have been separated by a large waterfall for a very long time, and have become somewhat different in colour and size. A flood then destroys the waterfall, bringing the two groups back into contact. Describe the two different outcomes that are now possible, and explain what each outcome would tell us about whether speciation had been completed.

Model Answer

Two outcomes are now possible: either the two groups interbreed freely and merge back into one population, or they fail to interbreed and stay separate; the first would show that speciation had not yet been completed, while the second would show that it had. The reunion is, in effect, the test of how far speciation had gone.

If, on meeting again, the two groups still accept one another as mates and breed together to produce fertile offspring, then their differences in colour and size were merely those of two varieties of one species; gene flow is restored, the groups blend back together, and speciation, though it had begun, was never finished. If instead the two groups no longer interbreed, because they will not accept one another as mates or because any hybrids they form are sterile or die, then reproductive isolation has already been achieved, and they are two separate species that will remain distinct even though the barrier is gone. The reunion therefore works as the true test of speciation, revealing whether the long separation had only made the groups different or had carried them all the way to reproductive isolation. Where that isolation is nearly but not quite complete, selection may even strengthen it, since fish that waste breeding on weak or sterile hybrids leave fewer offspring, so the two kinds are pushed further apart.

False Confidence Alert
Students often assume that because the two groups had grown different, they must already be separate species, so that bringing them together changes nothing. In truth the reunion is the test: only if they fail to interbreed were they truly two species, otherwise they simply merge back into one.

Question 112

Explain how the very same processes that bring about small changes within a species, such as a change in colour or in beak size, can, given enough time and repeated isolation, account for the millions of different species that live on Earth.

Model Answer

The same processes account for the whole diversity of life because speciation is the bridge between them: the small changes produced within a population by mutation, recombination, selection and drift become, once gene flow is cut and reproductive isolation builds up, the differences between

separate species, and this splitting, repeated again and again over an immense time, multiplies one ancestral species into many. Nothing new has to be added, only more time and more splitting.

Within any population, mutation and recombination supply variation while selection and drift change the proportions of that variation, producing the small shifts in colour, size or beak that we can actually observe. When a population becomes divided and its parts are kept from interbreeding, these same small changes accumulate separately in each part until the parts can no longer interbreed, and one species has become two. No new or special process is needed to go further, for each daughter species can itself later be divided and diverge again, so that branching is piled upon branching. Repeated over millions of years, this steady splitting turns a few early ancestors into an ever-spreading tree of descendants, which is why the living world now holds millions of species, all related through common ancestors yet separated by countless speciation events. Large-scale diversity is therefore simply small-scale change, made permanent by reproductive isolation and multiplied by time.

False Confidence Alert
It is a mistake to imagine that producing a whole new species, or a great new group, must require some powerful extra process beyond ordinary variation and selection. The same everyday processes, once locked in by reproductive isolation and repeated over vast time, are enough to build all the diversity of life.

Chapter 7

ECOLOGY

BINDER QUESTIONS

Work through each question in order. Try your own answer first, then read the Model Answer beneath it. The bold opening sentence of each answer is the single point an examiner most wants to see; the lines that follow show the reasoning that earns the rest of the marks. The boxed False Confidence Alert names the trap that quietly costs marks even when a student feels sure.

Question 1

When people first meet the word "ecology", many picture a list of plants and animals to be named and learnt by heart. Walking through a patch of *miombo* woodland near home, a student is told that an ecologist sees something different in the very same scene. Explain what ecology actually studies, and how its view of the living world differs from a mere catalogue of organisms.

Model Answer

Ecology is the study of the interactions between living organisms and one another, and between those organisms and their non-living surroundings. An ecologist looking at the miombo woodland does not stop at naming the trees, grasses, insects and birds; she asks how each one depends on the others and on the soil, water, light and air around it. The woodland is read as a working system of relationships, not a shelf of separate species.

Naming is only the starting point, because ecology begins where the connections are traced: which organism feeds which, which returns nutrients to the soil, and how the non-living factors set the stage. **The living world, to an ecologist, is a web of give-and-take rather than a list of names.**

> **False Confidence Alert**
> A tempting answer is to define ecology simply as "the study of living things", which is just biology. The marks are earned by naming the two relationships ecology adds, namely organism with organism and organism with its non-living environment, not by listing creatures.

Question 2

An ecology lesson lists six words in a fixed order: organism, population, community, ecosystem, biome and biosphere. A classmate wants to know why they are always given in that sequence and not jumbled. Explain how these levels of organisation are related, and why each is said to contain the one before it.

Model Answer

The levels of ecological organisation form a nested ladder, in which each higher level includes everything below it. A single zebra is an organism; all the zebra of one area make a population; the populations of every species living together, among them zebra, grasses, lions and bacteria, make a community; that community together with its non-living surroundings of soil, water and climate is an ecosystem; a large region of similar ecosystems, such as the savanna, is a biome; and all the biomes together form the biosphere, the whole living skin of the Earth.

Each step up adds something the step below does not contain, so the order follows the inclusion and cannot be jumbled. **Read the ladder either way: every level is built from the one beneath it and is part of the one above it.**

> **False Confidence Alert**
> Students often swap "population" and "community", calling a mixed group of different species a population. A population is one species only; the moment more than one species is counted, the level has become a community.

Question 3

Two terms that learners often treat as the same are "habitat" and "niche". Using a familiar savanna animal such as the African elephant, explain how a habitat differs from an ecological niche.

Model Answer

A habitat is the place where an organism lives, while its niche is the role it plays there, that is, how it makes its living rather than merely where it lives. The elephant's habitat is the savanna woodland and grassland it moves through, its address on the land. Its niche is everything it does there: a giant mixed feeder that strips leaves and bark, crops the grasses, pushes over trees and so opens the canopy, scatters seeds in its dung, and as an adult is taken by no predator.

Two species may share the same habitat, yet each keeps its own niche, because they cannot all make a living in exactly the same way. **Habitat is the address; niche is the occupation carried on at that address.**

> **False Confidence Alert**
> A common slip is to describe the niche as just "where the animal is found", which only repeats the habitat. The niche must say what the organism does: what it eats, how it changes its surroundings and how it is affected by them, not merely where it sits.

Question 4

In a single pond at the edge of a village, an ecologist speaks of both "the population of tilapia" and "the pond community". A learner is puzzled that two different level-names are used for organisms living in the very same pond. Explain why population and community sit at different levels even though they share one place.

Model Answer

Population and community sit at different levels because they differ not in place but in the number of species each one counts. A population is all the members of one species in an area, that is, all the tilapia of the pond. A community is all the populations of different species living and interacting in that area: the tilapia together with the frogs, water snails, algae, insects and bacteria. The one pond therefore holds many populations, one for each species, and those populations together make up its single community.

Sharing a place does not make them the same level, since the level is fixed by how many species are included, not by where they are. **One species is a population; all the species together are the community.**

> **False Confidence Alert**
> It is tempting to think a larger area means a community and a smaller one a population. The size of the area is irrelevant; the distinction is one species (a population) against many interacting species (a community).

Question 5

The largest level of ecological organisation is the biosphere. Hearing the word, a student imagines it must be some separate region of the Earth set aside for life. Explain what the biosphere actually is, and how it relates to all the ecosystems and biomes beneath it.

Model Answer

The biosphere is the thin global layer of the Earth in which all life exists, the sum of every ecosystem and biome on the planet. It is not a region apart but the whole living shell, reaching from the deep oceans and the soil where organisms live up into the lower air through which birds, insects and spores travel. Every biome, whether savanna, forest, desert or ocean, lies within it, and so does every ecosystem inside those biomes.

Because it gathers up all life together with the air, water and land that support that life, the biosphere is the single largest ecological unit there is. **It is one continuous skin of life wrapped around the Earth, not a place separate from the rest of it.**

> **False Confidence Alert**
> A frequent error is to rank the biosphere as one biome among others, or to imagine it out in space. The biosphere contains every biome, and nothing living lies outside it.

Question 6

Ecologists speak of a "balance of nature" in which the numbers of organisms stay within limits over time. Using cooperation, competition, predation and parasitism, explain how the interactions among organisms help to keep this balance.

Model Answer

The balance of nature is held by a set of opposing interactions that each stop some population from rising or falling without limit. Competition for food, water and space means that as a resource grows scarce no single species can take everything, and crowded numbers are pressed back down. Predation removes the surplus of prey, and because predators in turn run short when prey is few, the two rise and fall together. Parasitism thins or weakens a host population when it becomes too dense, while cooperation and mutualism let species support one another and steady the whole.

Acting together, these push-and-pull forces return a community toward a working level after any disturbance. **No single force rules the balance; the balance is the running total of them all.**

> **False Confidence Alert**
> Students sometimes describe the balance of nature as a fixed, unchanging state. It is a dynamic balance, with numbers rising and falling around a level, maintained by these interactions, not a frozen, permanent stillness.

Question 7

A maize plant standing in a field is constantly trading materials and energy with its non-living surroundings. Explain how a green plant and its abiotic environment give to and take from each other in both directions.

Model Answer

A green plant and its abiotic surroundings exchange matter and energy in both directions, the plant drawing materials in and giving others back. Into the plant pass light energy from the sun, carbon dioxide from the air, and water and mineral salts from the soil. Out of it pass oxygen, released to the air during photosynthesis, and water vapour, lost by transpiration; and when the plant dies its organic matter and nutrients are returned to the soil by decomposers. The energy taken in as sunlight is fixed into food and later leaves the system as heat.

The traffic therefore runs two ways: the environment supplies raw materials and energy, and the plant returns gases, water and, in time, nutrients. **Neither the plant nor its surroundings is left unchanged by the other.**

> **False Confidence Alert**
> A one-sided answer says only that the plant "takes in" water, light and carbon dioxide. Half the marks lie in what the plant gives back: oxygen, water vapour and, after death, nutrients to the soil.

Question 8

A district facing the loss of a nearby forest asks why an understanding of ecology should guide how that forest is used. Taking a Tanzanian forest as your example, explain how ecological knowledge helps people use such a natural resource without destroying it.

Model Answer

Ecological knowledge guides the sustainable use of a forest by showing how its parts depend on one another, so that the forest can be used at a rate which still lets it renew itself. Ecology shows the forest to be a working system: the trees hold and feed the soil with their leaf litter, shelter the animals that pollinate flowers and scatter seeds, and draw up water that returns to the air and the rivers. Knowing this, people can fell timber selectively instead of clearing everything, leave seed trees and young stock to regrow, protect the pollinators and seed-carriers, and avoid cutting on steep slopes where the soil would wash away.

The forest then keeps yielding wood, water and habitat instead of collapsing into bare ground. **Understanding the connections is what separates using a forest from using it up.**

False Confidence Alert
It is not enough to answer "so that we protect the trees". The marks come from linking the forest's parts (soil, water, animals and regrowth) and showing how that understanding sets a rate of use the forest can sustain.

Question 9

An ecology class studying a stretch of grassland is told to record two kinds of information: numbers, such as how many plants of each species there are, and descriptions, such as the colour and the general condition of the vegetation. Explain the difference between quantitative and qualitative data in an ecological study, and why both are worth collecting.

Model Answer

Quantitative data are measurements written as numbers, while qualitative data are descriptions of qualities that are not counted, and an ecological study collects both because each captures what the other misses. Quantitative data, such as counts of individuals, the area sampled, the density of a species or its percentage cover, allow populations to be compared and any change to be measured exactly. Qualitative data, such as the colour of the leaves, the texture of the soil, signs of grazing or the general health of the plants, describe conditions that figures alone cannot show.

A count tells you how much is there; a description tells you what kind it is and in what state. **Numbers measure the community, descriptions characterise it, and a thorough study needs both.**

False Confidence Alert
It is tempting to dismiss qualitative observations as unscientific because they carry no figures. They are a proper part of ecological data, since the colour, condition and signs left by organisms often reveal what the bare counts cannot.

Question 10

When estimating how much of the ground a plant species covers, one student counts the cover directly within marked squares while another simply judges it as abundant or rare on a fixed scale. Explain the difference between objective and subjective methods of collecting ecological data, and why the objective method is generally trusted more.

Model Answer

Objective methods record what is actually measured or counted, while subjective methods rest on the observer's personal judgement, and the objective method is trusted more because its result does not depend on who carries it out. An objective method, such as direct counting, photography or readings taken from a quadrat, gives the same value whoever does the work, so it can be repeated and checked by others. A subjective method, such as judging cover as abundant, frequent or rare on a scale, is quicker and useful over very large or rough ground, but two observers may rate the same patch differently, so it is open to bias.

The objective count can be repeated and defended, whereas the subjective estimate is faster but only as reliable as the eye behind it. **Where results must be trusted by others, the objective method is preferred wherever it is practical.**

False Confidence Alert
Students sometimes treat a subjective estimate as worthless. It has a real place where direct counting is impossible, over a huge area or rugged ground, provided its limits are understood; the mistake is to quote it as though it were an exact count.

Question 11

An ecologist who wishes to know how many trees of one species grow in a large miombo woodland does not try to count every single tree. Explain why ecologists study a sample rather than counting every individual, and what a sample is meant to represent.

Model Answer

An ecologist studies a sample because counting every individual across a large area would take more time, money and effort than any study can afford, and a sample is a small part chosen to stand for the whole. A miombo woodland may stretch over many square kilometres and hold uncountable trees, herbs and animals, some of which move or hide, so a complete census would be impossibly slow and costly. Instead the ecologist examines a number of small, carefully placed plots and uses them to estimate the features of the whole area, such as its density of trees and the species present and their abundance.

Because the sample is made to represent the whole, the estimate is only as good as the sample is fair. **A well chosen sample lets a small amount of work speak for a very large area.**

> **False Confidence Alert**
> A common error is to think a sample gives the exact total. It gives an estimate, and its worth depends entirely on how well the sample represents the whole area, which is why the plots are placed with care and not just wherever is convenient.

Question 12

Before laying out any plots for a detailed study, an experienced ecologist first walks over the whole site to gain a general impression of it. Explain what a reconnaissance survey is, and how this preliminary walk makes the main sampling that follows more efficient.

Model Answer

A reconnaissance survey is a preliminary, general inspection of the study area, carried out before detailed sampling begins, and it makes the main work efficient by showing the lie of the land in advance. Walking the site, the ecologist sees how the vegetation changes, where woodland gives way to grassland and where a stream or a rocky patch lies, and gathers a rough idea of which species are present and how large the area is. With that knowledge the main sampling can be planned sensibly: a suitable method and quadrat size are chosen, each distinct part of the site is given its fair share of plots, and effort is spent where it is actually needed.

In this way the survey turns blind sampling into planned sampling. **A short walk beforehand saves a great deal of wasted or lopsided work later.**

> **False Confidence Alert**
> It is tempting to skip the reconnaissance and start placing quadrats at once. Without it the sampling may miss a distinct part of the site or settle on an unsuitable quadrat size, so the brief preliminary survey usually saves time rather than wasting it.

Question 13

Three field groups sample the same grassland in three different ways. The first places its quadrats at positions chosen by chance; the second places them at fixed, regular intervals along a line; the third divides the field into its woodland and its open patches and samples each in proportion to its size. Explain how random, systematic and stratified sampling differ in where the plots are placed, and when each is useful.

Model Answer

The three designs differ in how the position of each plot is decided, and each suits a different kind of site.

Random sampling: the plots fall at positions fixed purely by chance, for example by using pairs of random numbers as coordinates, so that every part of the area has an equal chance of being picked and personal bias is removed; it suits a fairly uniform site.

Systematic sampling: the plots are placed at regular, fixed intervals, often along a line or a grid, which is quick and gives even coverage; it suits a site that changes gradually from one side to the other, as along a slope.

Stratified sampling: the area is first divided into its distinct parts, or strata, such as woodland and open grassland, and each part is then sampled, usually in proportion to its size, so that no important part of a mixed site is left out.

Which design is best therefore depends on whether the ground is uniform, gradually changing, or made of clearly different patches.

> **False Confidence Alert**
> Students often confuse systematic sampling with random because both feel fair. In systematic sampling the spacing is fixed and regular, not left to chance, so a repeating pattern in the vegetation could bias it in a way that true random sampling would avoid.

Question 14

Where the vegetation changes steadily from the edge of a pond up a gentle slope, an ecologist records the plants along a single measured line rather than in scattered quadrats. With the help of a labelled diagram, explain how a line transect and a belt transect each record the way a community changes along an environmental gradient.

Model Answer

A transect is a measured line laid across a changing environment so as to record how the community changes along that gradient; a line transect records what touches the line, while a belt transect records everything within a strip beside it. In a line transect a tape is stretched across the gradient, for example from the edge of the pond up the slope, and the species touching the line, or those at marked points along it, are noted (see the labelled diagram), which shows the order in which one plant replaces another. A belt transect widens this into a strip of fixed width, a row of quadrats laid side by side along the line, so that the abundance of each species can be counted as well as its position.

Because both follow one line across the change, they reveal the zonation that scattered quadrats would blur. **A transect trades the wide coverage of random quadrats for a clear picture of how a community is arranged along a gradient.**

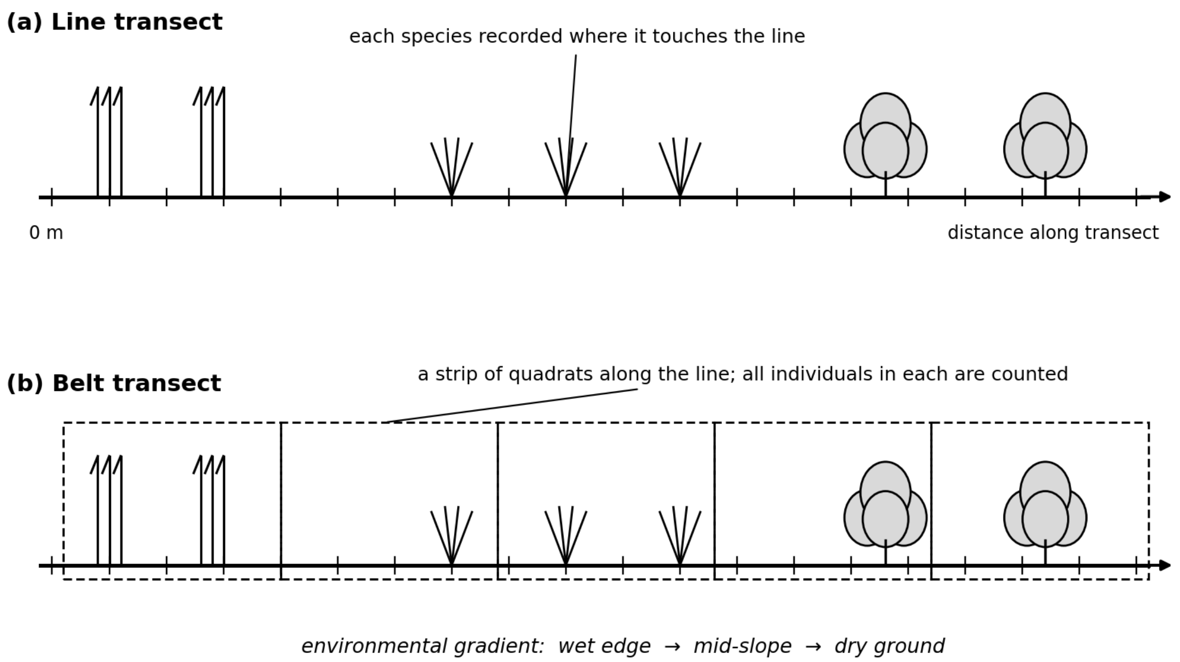


Figure 7.1: *Recording change along an environmental gradient with a line transect (a) and a belt transect (b).*

> **False Confidence Alert**
> A frequent slip is to choose a transect where random quadrats are really wanted, or the reverse. A transect is the right tool only when there is a gradient or zonation to follow; for a uniform area, scattered quadrats give a fairer sample.

Question 15

To find out how a grassland is shared among its plant species, an ecologist drops a square wire frame onto the ground at chosen points and records only what lies inside it. With the help of a labelled diagram, explain what a quadrat is and how it lets an ecologist estimate what a whole area holds from a few small samples.

Model Answer

A quadrat is a frame of known area, usually a square, placed on the ground so that the organisms inside it can be counted or estimated, and it lets a whole area be judged from a few small samples. The frame, often one metre square and sometimes divided by wires into a hundred small squares, marks off a known patch of ground. Within it the ecologist records what is present: the number of each species, the fraction of the small squares a species occupies, or the share of the ground it covers. Several quadrats are placed at chosen points across the site, and their readings are averaged and then scaled up to stand for the whole area.

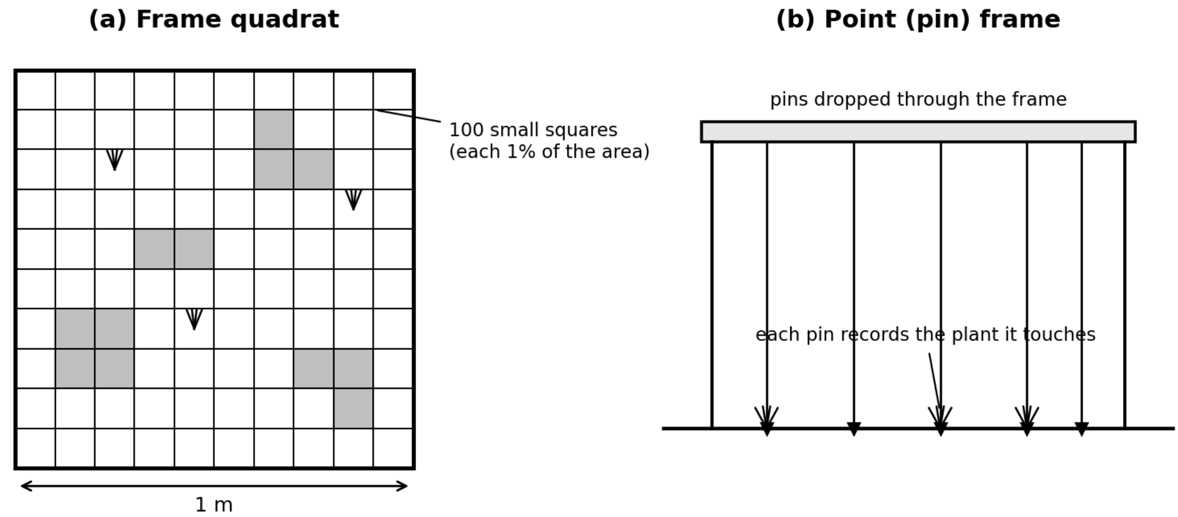


Figure 7.2: *Two kinds of quadrat: a gridded frame quadrat (a) and a point or pin frame (b).*

Because each frame encloses a known area, the readings from a handful of them can be turned into an estimate for the entire site. **The quadrat makes a large area measurable by sampling it a small, known piece at a time.**

False Confidence Alert
A common mistake is to place the quadrat where the plants look interesting or plentiful. That biases the result, and the whole value of the known frame is lost unless its positions are chosen without favour, so that the samples fairly represent the site.

Question 16

An ecologist would use a frame the size of a dinner plate to study lichens on a rock, a one-metre square to study grasses, but a frame ten or twenty metres across to study the trees of a miombo woodland. Explain why the size of the quadrat must be matched to the kind of organism being studied.

Model Answer

The size of a quadrat must match the size and the spacing of the organism being studied, so that each frame holds enough individuals to be representative without being needlessly large. Lichens and mosses are tiny and tightly packed, so a small frame a few centimetres across already contains many of them and is easy to read. Grasses and herbs are larger and more spread out, so a one-metre square is needed to catch a fair number. Trees in a miombo woodland stand metres apart, so a small frame might enclose no tree at all, or only one; a plot ten or twenty metres across is needed before the count means anything.

Too small a frame for a large, scattered organism gives wild and unreliable counts, while a needlessly huge frame for tiny plants wastes effort. **The right quadrat is the smallest one that still captures the organism fairly.**

False Confidence Alert
Students sometimes assume that one standard quadrat size, such as the familiar one-metre square, will suit everything. A frame that works well for grasses would enclose too few trees to be reliable, so the size must always be matched to the organism.

Question 17

From the same set of quadrats an ecologist can work out three different measures of a plant species: its density, its frequency and its cover. Explain how density, frequency and cover each describe a different thing about a population.

Model Answer

Density, frequency and cover are three measures read from quadrats, and each describes a different feature of a species in the area.

Density: the number of individuals of a species per unit area, found by counting how many fall in the quadrats and dividing by the area sampled; it tells you how crowded the species is.

Frequency: how often a species turns up, given as the percentage of the quadrats in which it occurs at all; it tells you how widely the species is spread, whether it is present as one plant or as many.

Cover: the proportion of the ground a species occupies, usually read as the percentage of the quadrat shaded by its leaves when seen from above; it tells you how much space the species takes, which matters most for low, spreading plants that are hard to count as separate individuals.

A species may score high on one measure yet low on another, so the three together describe a population more fully than any one of them alone.

False Confidence Alert
It is easy to confuse density with frequency. Density counts how many individuals there are, while frequency only records whether a species is present in a quadrat, so a single plant and a hundred plants both count just once towards frequency.

Question 18

In a survey of a *miombo* woodland, ten quadrats each ten metres by ten metres were placed at random, and a chosen tree species was counted in each. Over the ten quadrats, twenty-four trees of that species were found in all. Explain how a count from a few small plots is scaled up to a density per hectare, and work out the density for this survey.

Model Answer

A per-plot count is scaled up to a density per hectare by first finding the number of individuals per unit area in the sample and then multiplying up to the area of one hectare. The total area sampled is found by multiplying the area of one quadrat by the number of quadrats. The total count is then divided by this sampled area to give the density per square metre. Finally, because one hectare is ten thousand square metres, the density per square metre is multiplied by ten thousand to give the density per hectare.

Area of one quadrat = $10 \text{ m} \times 10 \text{ m} = 100 \text{ m}^2$.

Total area sampled = $100 \text{ m}^2 \times 10$ quadrats = $1\,000 \text{ m}^2$.

Density = 24 trees / $1000 \text{ m}^2 = 0.024$ trees per m^2.

Per hectare = $0.024 \times 10\,000 = 240$ trees per hectare.

So the ten small plots, holding only twenty-four trees between them, give an estimate of 240 trees of that species in every hectare of the woodland.

False Confidence Alert
A frequent error is to forget the area and simply multiply the count by the number of hectares, or to mix up the units. Always work to a density per square metre first, then multiply by ten thousand, since one hectare is ten thousand square metres.

Question 19

When an ecologist samples larger and larger areas of a community and keeps a running total of the species found, the count climbs quickly at first and then almost stops rising. With the help of a labelled graph, explain what the minimal area of a community is and how the species-area curve is used to find it.

Model Answer

The minimal area is the smallest area that must be sampled to include almost all the species of a community, and it is found from the species-area curve, the graph of the running total of species against the area sampled. As the sampled area grows, the common species appear at once and the count rises steeply; as sampling continues, fewer and fewer new species are added, so the curve bends over and flattens. The area at which the curve levels off, beyond which doubling the area adds hardly any new species, is taken as the minimal area, and sampling that area, or a little more, is enough to represent the community without wasted effort.

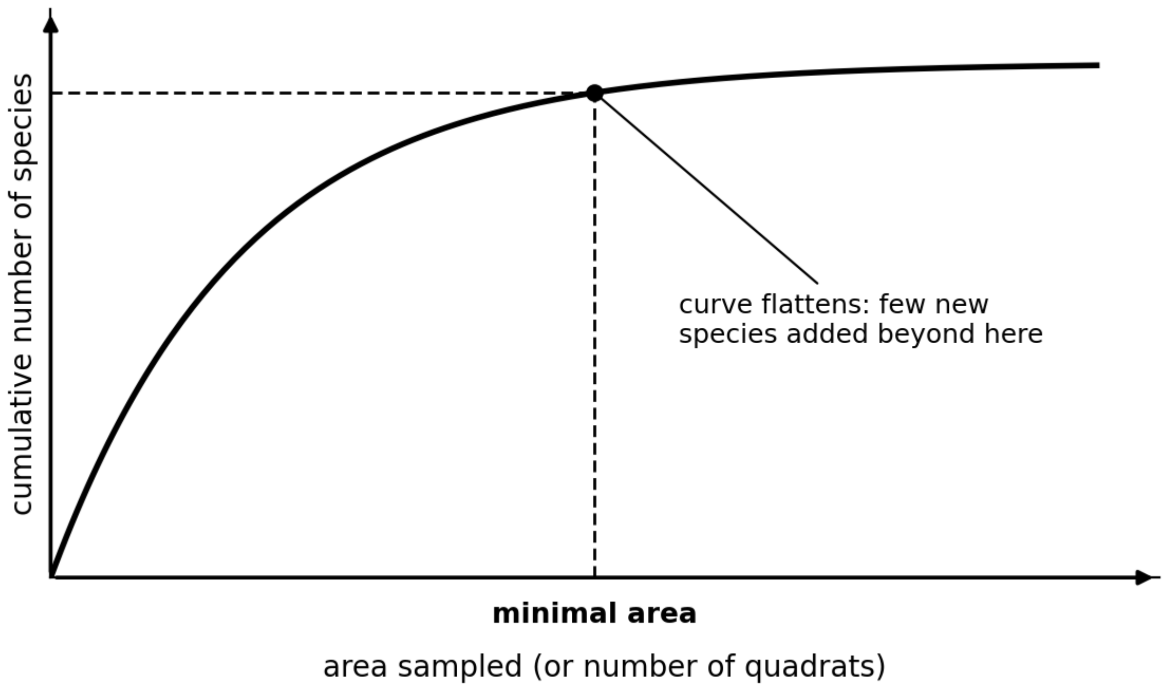


Figure 7.3: *The species-area curve, used to find the minimal area of a community.*

The curve therefore tells the ecologist how large a sample must be: large enough to reach the flat part, but no larger.

False Confidence Alert
A tempting mistake is to think that a bigger sample is always better. Past the minimal area the extra work adds almost no new species, while sampling below it misses species and underestimates how rich the community really is.

Question 20

Animals such as fish or grasshoppers cannot easily be counted one by one, because they move and hide. To estimate the number of tilapia in a village pond, an ecologist caught, marked and released fifty fish; a week later she caught eighty fish, of which twenty carried the mark. Explain how the capture-mark-recapture method estimates a population, and use the Lincoln index to estimate the number of tilapia in the pond.

Model Answer

Capture-mark-recapture estimates a moving population by marking a known number of animals, releasing them to mix back in, and then seeing what fraction of a second catch carries the mark; the smaller that fraction, the larger the population must be. The reasoning is that the proportion of marked animals in the second catch should match the proportion of marked animals in the whole pond. This gives the Lincoln index, N = ($n_1 \times n_2$) / n_3, where n_1 is the number first marked, n_2 is the size of the second catch, and n_3 is the number of marked animals caught again.

n_1 = 50 fish marked and released.

n_2 = 80 fish in the second catch, of which n_3 = 20 were marked.

$$\mathbf{N} = \frac{\mathbf{n_1 \times n_2}}{\mathbf{n_3}} = \frac{\mathbf{50 \times 80)}}{\mathbf{20}} = \mathbf{200\ tilapia}.$$

The pond is therefore estimated to hold about 200 tilapia, far more than the few dozen ever held in the hand at one time.

False Confidence Alert
A common error is to add the figures, or to put the wrong one on top. The number first marked times the second catch goes on top, divided by the number caught again; and the estimate is trustworthy only if the marks stay on, the animals mix back in, marking does not change their chance of being caught, and few are born, die or move away in between.

Question 21

A school garden, a pond and the whole Serengeti plain are each called an ecosystem, though they differ enormously in size. Explain what an ecosystem is, and how it joins living things to their non-living surroundings into a single working unit.

Model Answer

An ecosystem is a community of living organisms together with the non-living surroundings they interact with, joined into one working unit by the flow of energy through it and the cycling of materials within it. The living, or biotic, part is the community of plants, animals and microbes; the non-living, or abiotic, part is the soil, water, air, light and climate. The two are bound together: energy from the sun enters through green plants and passes along the feeding chain, while materials such as carbon and nitrogen pass from the surroundings into living bodies and back again when those bodies are broken down. Size does not matter, for a pond and the whole Serengeti are each a unit because each holds both parts working together.

What makes an ecosystem is not its size but the joining of a community to its surroundings through one flow of energy and one cycling of matter.

False Confidence Alert
It is tempting to call only the plants and animals the ecosystem. The non-living surroundings belong to it too, for without the soil, water, air and sunlight there is no ecosystem, only a list of organisms with nowhere to live.

Question 22

Every animal in a grassland, from the grasshopper to the lion, depends in the end on the grass. Explain how the producers of an ecosystem turn the sun's energy into the food on which every other trophic level depends.

Model Answer

Producers are green plants and other autotrophs that capture the sun's radiant energy and use it, in photosynthesis, to build energy-rich food from simple inorganic raw materials, and this food is the starting point for every other organism. Using the light trapped by chlorophyll, a plant combines carbon dioxide from the air with water from the soil to make glucose, locking the sun's energy into chemical bonds. From this glucose the plant builds the leaves, stems, roots, fruits and seeds that herbivores eat. The herbivores are in turn eaten by carnivores, so the energy first fixed by the grass passes up through the grasshopper to the lion.

Because only producers can capture sunlight and turn it into food, every consumer above them is living, at one remove or another, on the energy the producers fixed.

False Confidence Alert
A common slip is to say that plants get their food from the soil. Plants take only water and mineral salts from the soil; their actual food, the energy-rich sugar, is built in the leaves from carbon dioxide and water using sunlight.

Question 23

Most producers use sunlight, yet certain bacteria deep in the soil or in dark places build their own food with no light at all. Explain how chemoautotrophic bacteria make food without sunlight, and why they still count as producers.

Model Answer

Chemoautotrophic bacteria make their own food using energy released by chemical reactions instead of energy from sunlight, and they still count as producers because they build energy-rich food from simple inorganic materials. Rather than trapping light, these bacteria obtain energy by oxidising simple inorganic substances around them, such as compounds of iron, sulphur or nitrogen. The energy released in those reactions is then used to combine carbon dioxide into organic food, just as light energy is used in photosynthesis. Because they manufacture their food from inorganic raw materials and do not feed on other organisms, they are autotrophs.

What makes an organism a producer is that it builds its own food from inorganic matter, whether the energy for the task comes from light or from chemical reactions.

False Confidence Alert
Students often assume that all producers must be green and must use sunlight. Chemoautotrophic bacteria are colourless and use no light, yet they are true producers because they still make their food from inorganic materials.

Question 24

In a grassland the zebra eats grass and the lion eats the zebra; nearby, a lizard eats a grasshopper and an eagle eats the lizard. Explain how consumers are placed into trophic levels by what they eat rather than by how large they are.

Model Answer

Consumers are heterotrophs that feed on other organisms, and they are placed into trophic levels by what they eat, not by their size, counting up from the producers.

Primary consumers: the herbivores that eat the producers directly, such as the zebra cropping the grass or the grasshopper chewing a leaf.

Secondary consumers: the carnivores that eat primary consumers, such as the lion that eats the zebra or the lizard that eats the grasshopper.

Tertiary consumers: the carnivores that eat secondary consumers, such as the eagle that eats the lizard, sitting near the top of the chain.

Size does not fix the level: the tiny grasshopper and the large zebra are both primary consumers because both eat plants, while an omnivore such as a human, eating both plants and animals, feeds at more than one level.

False Confidence Alert
It is tempting to rank consumers by size, putting the lion above the zebra because it is fiercer. Trophic level is set only by what an organism eats, so a large grazer is a primary consumer while a small insect-eating bird is a secondary one.

Question 25

When a tree falls or an animal dies in the forest, it does not pile up forever; in time it disappears and the soil around it grows richer. Explain how decomposers and detritivores return the nutrients locked in dead matter to the soil for plants to use again.

Model Answer

Decomposers and detritivores feed on dead organisms and waste, breaking the complex matter down and releasing the nutrients locked inside it back into the soil, where plants can take them up once more. Detritivores, such as earthworms, millipedes and termites, swallow dead leaves and wood and break them into small pieces, exposing far more surface. Decomposers, chiefly fungi and bacteria, then digest these remains by releasing enzymes onto them, absorbing the simple products and freeing mineral salts such as nitrates and phosphates into the soil. Plants absorb these salts through their roots and use them to grow, so the same nutrients are used over and over.

Without decomposers and detritivores the nutrients would stay locked in dead bodies, the soil would grow poorer, and the plants would in time run short.

False Confidence Alert
A common mistake is to think decomposers simply make dead matter disappear. They do not destroy the matter, but release its trapped nutrients back to the soil, which is why decomposition keeps an ecosystem fertile rather than merely tidy.

Question 26

Why a hillside carries forest on its damp lower slopes but only thin grass on its dry, rocky top is decided not by the plants themselves but by their surroundings. Explain how the climatic and the edaphic factors of a place together set which species can live there.

Model Answer

The abiotic factors of a place, which fall into a climatic group and an edaphic group, together decide which species can survive there, because each species can live only within the range of conditions its body can tolerate.

Climatic factors: the conditions of the atmosphere, such as temperature, light, rainfall, wind and humidity; these set how much warmth and water are available and so decide, for instance, whether trees or only grasses can grow.

Edaphic factors: the conditions of the soil, such as its pH, texture, depth, air content, humus and mineral salts; these decide whether roots can anchor and find enough water and nutrients.

Where the climate is moist and the soil deep, forest can grow; where the rain is scarce and the soil thin and rocky, only drought-tolerant grasses survive, so the one hillside carries different communities at different points.

False Confidence Alert
It is tempting to explain where a plant grows by the plant alone. A species grows where it does because the climate and soil there fall within the range it can tolerate; change those conditions and a different community takes over.

Question 27

Two cocks in one yard fight over the same hens, while a herd of buffalo and a herd of zebra graze down the same grass. Explain how intraspecific competition differs from interspecific competition in who is doing the competing.

Model Answer

Competition is the struggle between organisms for a resource that is in short supply, and it is called intraspecific when the competitors belong to the same species and interspecific when they belong to different species. In intraspecific competition the rivals are members of one species needing exactly the same things, as when two cocks of one flock compete for the same hens, or maize plants in a row compete with one another for light and water; because their needs are identical, this competition is especially fierce. In interspecific competition the rivals belong to different species that happen to share a resource, as when buffalo and zebra graze the same grass, or weeds compete with a crop for soil nutrients.

The resource fought over may be the same in both cases; what differs is whether the competitors are of one species or of two.

> **False Confidence Alert**
> Students sometimes decide the type of competition by how hard the struggle looks. It is decided only by who the competitors are: the same species means intraspecific, different species means interspecific, however gentle or fierce the struggle.

Question 28

Where lions are many the zebra grow few, and where the zebra then grow scarce the lions in turn go hungry and decline. Explain how a predator and its prey regulate each other's numbers over time.

Model Answer

A predator and its prey hold each other's numbers in check through a feedback that runs both ways, so that neither population can rise or fall without limit. When prey are plentiful the predators are well fed and breed successfully, so their numbers rise; but as the predators increase they kill more prey, and the prey numbers fall. With prey now scarce, the predators go hungry and their own numbers drop; the easing of hunting then lets the prey recover, and the cycle begins again. So the two populations rise and fall in turn, each lagging a little behind the other.

Predator and prey are tied together in a balance, each keeping the other from growing unchecked or from vanishing altogether.

> **False Confidence Alert**
> A common error is to think a predator would do best by eating all of its prey. If it did, it would then starve; predators thrive only as long as their prey survive, which is why the two persist together rather than one wiping out the other.

Question 29

Close partnerships between two different species are common in nature, but they do not all share their benefits equally. Explain how mutualism, commensalism and parasitism differ in who gains and who loses from the partnership.

Model Answer

Symbiosis is a close, lasting association between two different species, and its three kinds differ in how the benefit is shared between the partners.

Mutualism: both partners gain, as when bacteria in a cow's stomach are given food and shelter while they digest the cow's grass for it, or a flower feeds a bee while the bee carries its pollen.

Commensalism: one partner gains while the other is neither helped nor harmed, as when an epiphytic orchid grows high on the branch of a tree, gaining a place in the light without taking anything from the tree.

Parasitism: one partner, the parasite, gains while the other, the host, is harmed, as when a tapeworm lives in the gut of a person and robs them of food, or ticks suck the blood of cattle.

The three form a scale of give-and-take, from a partnership that helps both, through one that helps one and ignores the other, to one that helps one at the other's expense.

> **False Confidence Alert**
> It is tempting to call any two species living together mutualism. The test is who benefits: both partners in mutualism, only one with no effect on the other in commensalism, and one at the host's cost in parasitism.

Question 30

A cow lives on grass, yet no mammal can make the enzyme needed to digest the cellulose that grass is largely made of. Explain how the partnership between a cow and the bacteria in its gut is a worked example of mutualism in which both partners gain.

Model Answer

The cow and the cellulose-digesting bacteria in its stomach form a mutualism because each does for the other something it cannot do for itself, and both gain from the arrangement. The cow cannot make cellulase, the enzyme that breaks down the cellulose of grass, so by itself it could not release the energy in its food. The bacteria living in a special chamber of its stomach do make cellulase; they digest the cellulose and release sugars, some of which the cow then absorbs and uses. In return the cow gives the bacteria a warm, moist home and a constant supply of grass to work on.

Neither partner could prosper alone on grass; together the cow gains digestible food and the bacteria gain shelter and a steady food supply.

> **False Confidence Alert**
> A common slip is to picture the gut bacteria as germs harming the cow. These bacteria are helpful partners, not parasites, since without them the cow could not live on grass at all.

Question 31

Unlike the carbon or the nitrogen in an ecosystem, the energy that enters it is never used twice; it passes through once and is gone. Explain how energy enters an ecosystem and flows one way through it, rather than cycling as materials do.

Model Answer

Energy enters an ecosystem as sunlight captured by the producers and then flows one way along the feeding chain, being spent as heat at every step until none is left to pass on. Green plants fix a small part of the sunlight as chemical energy in their food. When a herbivore eats the plant it gains some of that energy, but it uses most of it for movement, warmth and other life processes, and this energy leaves its body as heat. The carnivore that eats the herbivore receives only the small amount left, and again loses most of it as heat. Because heat cannot be recaptured and refixed by the ecosystem, the flow is one way and the energy is steadily drained away.

Materials cycle and are used again, but energy makes a single one-way journey from the sun, through the living things, and out as heat.

> **False Confidence Alert**
> It is tempting to think energy cycles round an ecosystem as nitrogen does. It does not, for once energy leaves an organism as heat it cannot be reused, so an ecosystem needs a constant fresh supply of sunlight to keep going.

Question 32

Of all the energy a field of maize captures from the sun in a season, only part is left stored in the crop, because the plants spend some of it simply staying alive. Explain how gross primary productivity differs from net primary productivity, and why the difference matters to the animals that feed on the plants.

Model Answer

Gross primary productivity is the total amount of energy that producers capture and fix in a given area and time, while net primary productivity is what remains after the producers have used some of that energy in their own respiration. A green plant fixes a certain total of energy in photosynthesis, which is the gross primary productivity; but the plant is alive and must respire to power its own growth and upkeep, and respiration uses up part of the energy fixed. What is left, the net primary productivity, is the energy actually stored in new plant material. Only this net amount is available to be eaten by the herbivores and passed on up the chain.

Gross productivity is what the plants capture; net productivity is what they bank after paying their own running costs, and it is the net amount that feeds everything above them.

False Confidence Alert
A common error is to assume the animals can use all the energy the plants capture. They cannot, because the plants spend a share on their own respiration first, so only the net productivity, the part left over, is available to the consumers.

Question 33

In the last questions you saw that energy makes a one-way journey through an ecosystem and is lost as heat. Yet the carbon, nitrogen and other materials an ecosystem contains are never used up in the same way. Explain how matter cycles within an ecosystem while energy flows through it, and why the two behave so differently.

Model Answer

Matter cycles within an ecosystem, being used over and over, while energy flows through it once and is lost, because matter can be reused but the energy that drives life is spent as heat at every step. The atoms of carbon, nitrogen, oxygen and the mineral elements pass from the non-living surroundings into living bodies, move along the feeding chain, and are returned to the surroundings by respiration, excretion and decay, ready to be taken up again; the same atom may belong to a plant, then an animal, then the air, and then a plant once more. Energy, by contrast, enters only as sunlight, is passed on in food, and leaves as heat that cannot be recaptured, so a fresh supply of sunlight is always needed.

Matter goes round in a loop and is endlessly recycled; energy travels a one-way street and must be constantly renewed.

False Confidence Alert
It is tempting to treat energy and matter the same way because both are passed along the food chain. They part company at the end: matter is returned to the surroundings and reused, while energy is lost as heat and gone for good.

Question 34

Every nutrient cycle, whatever element it follows, turns on one group of organisms working quietly in the soil and the litter. Explain why the decomposers are the hinge on which every nutrient cycle turns.

Model Answer

Decomposers are the hinge of every nutrient cycle because they break down the dead bodies and wastes in which nutrients are locked, releasing those nutrients in simple forms that producers can take up again. When a plant or animal dies, the carbon, nitrogen and minerals it contains are bound up in complex molecules that no plant can absorb. The decomposers, chiefly bacteria and fungi, digest these molecules and free the elements as simple substances such as carbon dioxide, ammonium and mineral salts.

These return to the air and the soil, from which producers draw them once more to build new living matter. Without this step the cycle would be broken at the very point where dead matter must become available again.

Whichever element the cycle follows, it must pass back through the decomposers to be returned to the living world; remove them and every cycle stalls.

False Confidence Alert
Students often think of decomposers as mere cleaners that clear away dead matter. Their real importance is the opposite end of the job: they unlock the nutrients and hand them back to the producers, so without them the soil would soon be stripped of nourishment.

Question 35

A single nitrogen atom in the protein of your body may once have been part of a bean plant, the air, and a soil bacterium, and may yet belong to a tree. The energy that built that same protein, however, can never be used a second time. Explain why a nutrient atom can be used again and again while a unit of energy is spent only once.

Model Answer

A nutrient atom can be used again and again because matter is conserved and merely changes hands, while a unit of energy is spent only once because at each transfer most of it is turned into heat and lost from the living world. An atom of nitrogen is not destroyed when an organism dies; it is simply passed on, from soil to plant to animal to air and back to soil, taking part in one body after another without ever being used up. Energy, by contrast, is downgraded each time it is passed on: a plant or animal converts most of the energy it receives into heat as it lives and works, and that heat escapes into the surroundings and cannot be gathered back to do biological work again.

Atoms are passed round and conserved; energy is passed on and steadily downgraded to useless heat, which is why one is recycled and the other is not.

False Confidence Alert
It is tempting to imagine that energy, like matter, must go somewhere and so could be collected and reused. It does go somewhere, as heat, but heat spread through the surroundings can no longer power life, so for the ecosystem it is as good as lost.

Question 36

Nitrogen makes up most of the air, yet plants cannot use it in that form and depend instead on several kinds of bacteria to make it available and to return it. With the help of a labelled diagram, explain how nitrogen-fixing, nitrifying and denitrifying bacteria move nitrogen between its different forms.

Model Answer

The nitrogen cycle is driven by three groups of bacteria that move nitrogen between the unusable gas in the air and the soluble forms plants can use: nitrogen-fixing bacteria bring it in, nitrifying bacteria convert it to nitrate, and denitrifying bacteria return it to the air.

Nitrogen-fixing bacteria, such as *Rhizobium* in the root nodules of legumes and the free-living *Azotobacter*, combine nitrogen gas into ammonium, which plants can take up, and lightning fixes a little as well. Decomposers add more ammonium by breaking down dead matter, a step called ammonification. Nitrifying bacteria then oxidise this ammonium to nitrate in two stages, *Nitrosomonas* turning ammonium into nitrite and *Nitrobacter* turning nitrite into nitrate, the form most readily absorbed by roots. Finally, denitrifying bacteria in waterlogged soil break nitrate back down to nitrogen gas, completing the cycle.

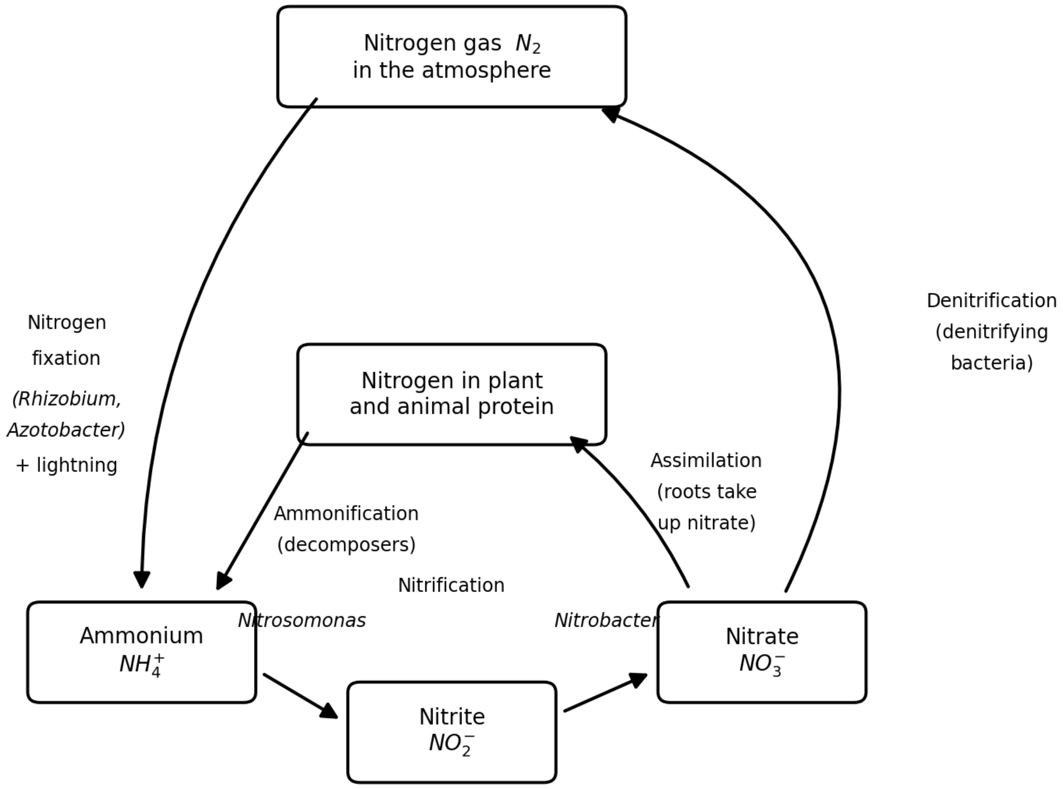


Figure 7.4: *The nitrogen cycle, in which bacteria move nitrogen between the air and the soluble forms that plants can use.*

Between them the fixing, nitrifying and denitrifying bacteria carry nitrogen from the air into living things and back to the air again.

False Confidence Alert
A common error is to say that plants absorb nitrogen straight from the air. Plants cannot use nitrogen gas at all; they take it up only as nitrate, or as ammonium, prepared for them by the soil bacteria.

Question 37

Farmers in many parts of Tanzania grow beans or groundnuts in rotation with maize, and find that the maize which follows grows better even without added fertiliser. Explain how a legume and the Rhizobium bacteria in its root nodules enrich the soil with nitrogen.

Model Answer

A legume enriches the soil with nitrogen through a mutualism with *Rhizobium* bacteria living in swellings, called nodules, on its roots, where the bacteria fix nitrogen gas into a form the plant, and later the soil, can use.

The *Rhizobium* bacteria in the nodules take nitrogen gas from the air spaces of the soil and combine it into ammonium and then into amino acids, which the legume uses to build its proteins; in return the plant supplies the bacteria with sugars and shelter. When the legume dies, or when its nitrogen-rich roots and nodules are left in the ground after harvest, decomposers release this nitrogen into the soil as ammonium and nitrate. A crop such as maize planted afterwards then finds the soil already richer in nitrogen.

By housing nitrogen-fixing bacteria, a legume leaves the soil more fertile than it found it, which is why rotating beans with maize repays the farmer.

False Confidence Alert
A common mistake is to think the legume itself fixes the nitrogen. The plant cannot fix nitrogen; it is the *Rhizobium* bacteria in its root nodules that do the work, the plant and the bacteria each giving the other what it cannot make alone.

Question 38

The same carbon atoms move endlessly between the air, the bodies of living things, and the soil. Explain how the carbon cycle moves carbon between the atmosphere, the producers and the decomposers, and what adds carbon dioxide back to the air.

Model Answer

The carbon cycle moves carbon between the carbon dioxide of the air and the bodies of living things, the producers taking it out of the air while respiration and decay return it. Green plants remove carbon dioxide from the air in photosynthesis and fix its carbon into sugars and then into all their other tissues; the animals that eat the plants take this carbon into their own bodies. Carbon returns to the air as carbon dioxide in three main ways: through the respiration of plants, animals and decomposers as they release energy from food; through the decomposers breaking down dead bodies and waste; and through the burning of wood and fossil fuels. So the carbon taken out by the producers is balanced by the carbon dioxide put back by respiration, decay and combustion.

Photosynthesis draws carbon out of the air and respiration, decay and burning return it, keeping the same carbon atoms in endless circulation.

False Confidence Alert
It is tempting to think that only animals add carbon dioxide to the air and only plants remove it. Plants respire too, and the decomposers and the burning of fuels are major sources of carbon dioxide, while photosynthesis is the one process that takes it out.

Question 39

In the laboratory a barnacle species can live across a wide band of the seashore, yet on a real shore it is found only on a narrow strip, kept off the rest by other barnacles. Explain the difference between the fundamental niche and the realised niche of a species, and what shrinks the one to the other.

Model Answer

The fundamental niche is the full range of conditions and resources within which a species could in principle live, while the realised niche is the smaller part it actually occupies once competition and other species are taken into account. On its own, with no rivals, a species could spread across every place whose physical conditions it can tolerate, and this whole potential range is its fundamental niche. In the real world, however, other species compete with it for space and food, while predators and parasites attack it, and these pressures push it out of part of that range. What is left, the strip it can hold in the face of all this, is its realised niche. The seashore barnacle could survive across a wide band, but competition from stronger barnacles confines it to a narrow one.

The fundamental niche is what a species could occupy if it were alone; the realised niche is the smaller share that competition and other species actually leave it.

False Confidence Alert
It is tempting to think a species lives wherever its body can cope with the conditions. It could, were it alone; but competition and enemies cut its fundamental niche down to the narrower realised niche in which it is actually found.

Question 40

When two species of *Paramecium* that feed in exactly the same way are grown together in one culture, one always dies out while the other survives, although each does perfectly well when grown on its own. Explain the principle of competitive exclusion, and how this *Paramecium* experiment demonstrates it.

Model Answer

The competitive-exclusion principle states that two species which need exactly the same resources cannot go on living together in the same place indefinitely, because the better competitor will in time drive the other out.

Where two species have the same niche, every scrap of food or space taken by one is denied to the other, so they cannot share the habitat for long; the one that is even slightly more efficient secures more of the resource, leaves more offspring, and steadily replaces its rival. Gause showed this by growing two species of *Paramecium*, *Paramecium aurelia* and *Paramecium caudatum*, first separately and then together. Each thrived when alone, but grown together in the same tube on the same food, *P. aurelia* multiplied faster while *P. caudatum* dwindled and died out.

Because no two species can occupy exactly the same niche for long, one must either be excluded or come to use the resource in a slightly different way.

False Confidence Alert
Students sometimes expect that two species needing the same thing will simply share it. They cannot share it indefinitely; the more efficient competitor takes a growing share until the other is excluded, which is why each *Paramecium* survives alone but not together.

Question 41

Not every food chain begins with a living green plant being eaten; some begin instead with dead leaves and other remains. With the help of labelled diagrams, explain how a grazing food chain and a detritus food chain differ in where they begin, and how energy passes along each.

Model Answer

A food chain is a sequence that shows how energy passes from one organism to the next as each is eaten, and the two kinds differ in their first link: a grazing food chain begins with a living producer, while a detritus food chain begins with dead organic matter. In a grazing food chain the first link is a green plant, which is eaten by a herbivore, which is eaten by a carnivore, and so on; for example grass is eaten by a grasshopper, the grasshopper by a toad, the toad by a snake, and the snake by a hawk. In a detritus food chain the first link is detritus, the dead leaves, wood and remains lying on the ground, which is fed on by detritivores and decomposers, and these in turn are eaten by larger animals; for example leaf litter is eaten by an earthworm, the earthworm by a sparrow, and the sparrow by a hawk.

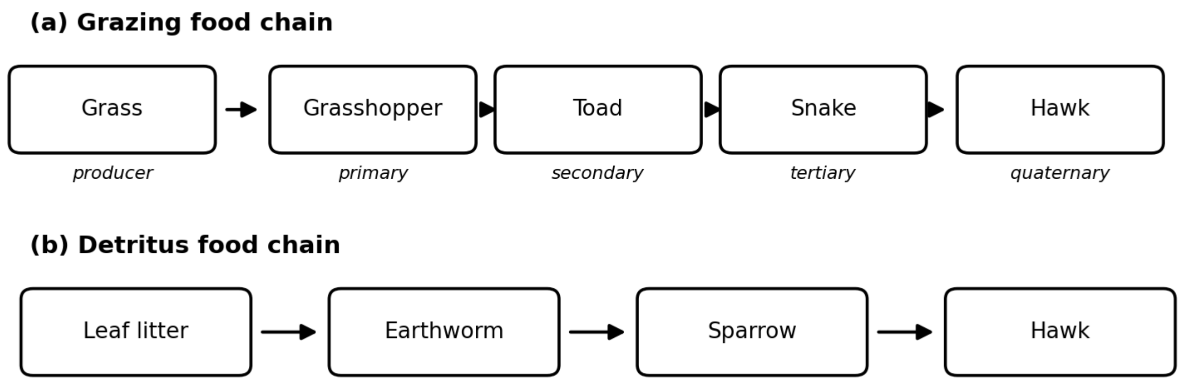


Figure 7.5: *A grazing food chain (a) and a detritus food chain (b).*

The two chains differ only in their starting point, a living plant or dead matter; from there energy flows along each in the same one-way fashion, lost as heat at every step.

False Confidence Alert
A common mistake is to think every food chain must start with a green plant. Many start instead with detritus, the dead matter that decomposers and detritivores feed on, although the energy held in that dead matter came from producers in the first place.

Question 42

A single food chain suggests that each animal eats only one kind of food and is eaten by only one kind of predator, but real ecosystems are not so simple. With the help of a labelled diagram, explain how a food web differs from a food chain, and why that difference makes an ecosystem more stable.

Model Answer

A food web is a set of many food chains linked together, showing the real feeding relationships of a community in which most organisms eat several kinds of food and are eaten by several kinds of predator, whereas a single food chain shows only one straight path. A food chain follows one line, as if grass led only to a grasshopper, the grasshopper only to a lizard, and so on; but in nature the grass is also eaten by zebra and antelope, the lizard is taken by both a snake and a hawk, and the lion preys on both zebra and antelope. Drawing all these crossing links together gives a food web. Because each species then has more than one source of food and more than one predator, the loss of any one species need not break the whole system, since the animals that fed on it can turn to other foods.

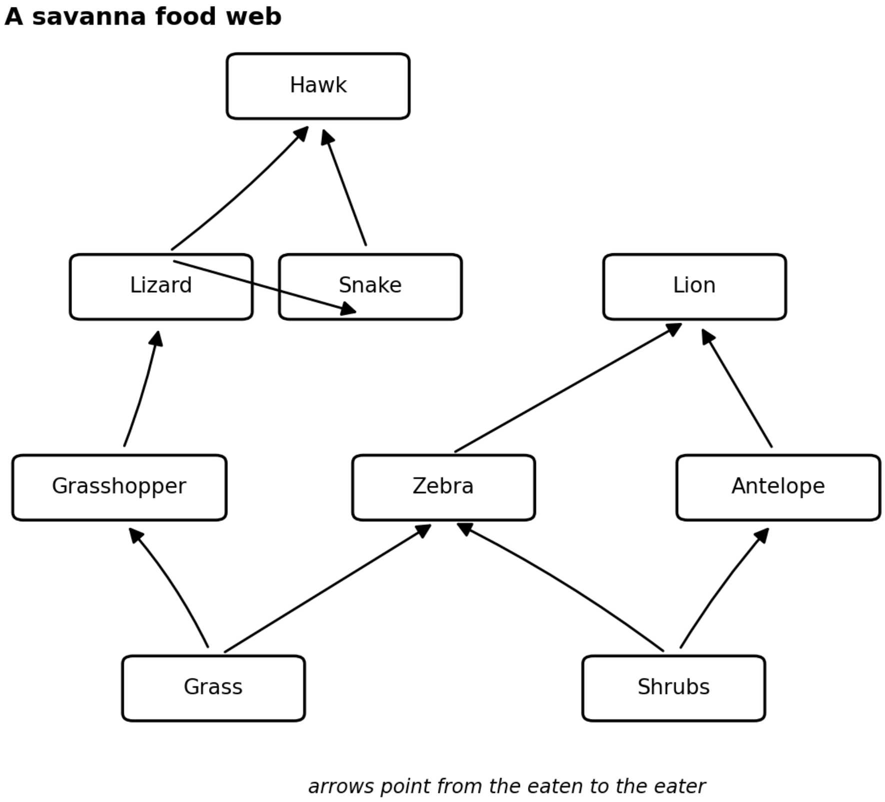


Figure 7.6: *A savanna food web, made of many food chains linked together.*

A food chain is a single thread, a food web the whole fabric; the many alternative links of the web are what give a community its stability.

False Confidence Alert
It is tempting to treat a food chain as the full picture of who eats whom. It shows only one path, whereas the food web shows that most organisms have several foods and several enemies, which is exactly why a community does not collapse when one link is lost.

Question 43

When an ecologist wants to show at a glance how a community is built up from its producers to its top carnivores, the figures are often drawn as a stack of bars, one above another. With the help of a labelled diagram, explain what an ecological pyramid is and what each of its bars represents.

Model Answer

An ecological pyramid is a diagram in which the trophic levels of a community are drawn as horizontal bars stacked one above another, the length of each bar showing the amount of something, the number of organisms, their biomass, or their energy, at that level. The bottom bar stands for the producers, the bar above it for the primary consumers or herbivores, the next for the secondary consumers or carnivores, and so on up to the top carnivores. Because there is usually less of the measure at each higher level, the bars grow shorter towards the top, which gives the figure its pyramid shape. These diagrams were first used by Charles Elton, and so are also called Eltonian pyramids.

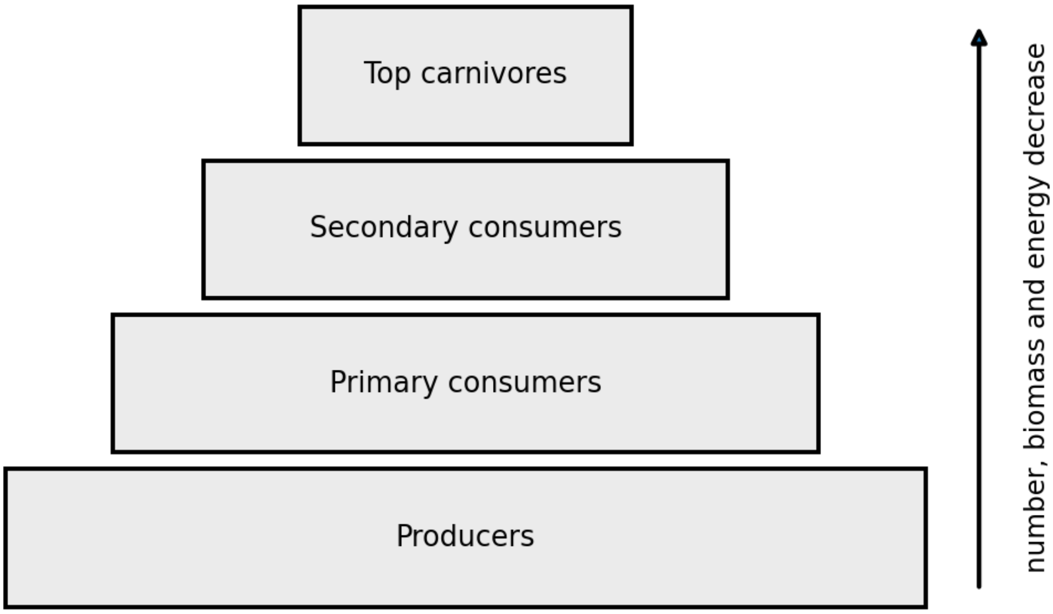


Figure 7.7: *An upright ecological pyramid: the trophic levels drawn as stacked bars that narrow towards the top.*

An ecological pyramid is therefore a picture of how much of each trophic level a community holds, drawn so that the whole feeding structure can be read at a glance.

False Confidence Alert
A common mistake is to read the height of the pyramid as the important thing. It is the length of each bar that carries the meaning, showing how much is found at that trophic level; the bars are simply stacked in feeding order from the producers upward.

Question 44

In most ecological pyramids each bar is shorter than the one below it, so the figure narrows towards the top. Explain why a pyramid usually tapers upward, linking the narrowing to what happens to energy at each step of the food chain.

Model Answer

A pyramid usually tapers upward because most of the energy is lost at each step of the food chain, so each higher trophic level holds far less energy, and can therefore support far less living matter, than the one below it. When one organism is eaten by another, only a small part of the energy in its body, on average about a tenth, is passed on and built into the body of the feeder; the rest is lost as heat in respiration or passes out in undigested waste. Because each level receives only a fraction of the energy of the level below, it can support only a fraction of the biomass, and usually far fewer or smaller organisms. Level by level the amount falls away, and so the bars grow shorter towards the top.

The taper is the visible sign of the energy lost at every transfer: less energy at each level means less life that level can support.

False Confidence Alert
It is tempting to say the pyramid narrows simply because predators are fewer. The deeper reason is energy: because only about a tenth of it passes up at each step, each level can support less than the one below, and that is what makes the figure taper.

Question 45

Both a food chain and an ecological pyramid arrange the organisms of a community by trophic level, yet they tell you different things. Explain how an ecological pyramid differs from a food chain, even though both are built on the same trophic levels.

Model Answer

A food chain shows the pathway along which energy passes, naming which organism eats which, while an ecological pyramid shows the quantity at each trophic level, measuring how much there is; so one gives the route and the other the amounts. A food chain is a line of named organisms, grass to grasshopper to bird, telling you the order of feeding but nothing about how many or how much. A pyramid takes those same trophic levels and draws a bar for each, the length of the bar giving the number of organisms, their biomass, or their energy, so that the levels can be compared. A food chain therefore answers who eats whom, while a pyramid answers how much is present at each step.

The food chain traces the path of energy; the pyramid measures the amount of life found at each level along that path.

> **False Confidence Alert**
> Students sometimes treat a pyramid as just a food chain stood upright. A food chain names the feeding sequence only; a pyramid adds the information a plain chain never carries, namely the quantity at each level.

Question 46

The simplest ecological pyramid is the pyramid of numbers. Explain how a pyramid of numbers is built, and what its usual shape tells you about a community.

Model Answer

A pyramid of numbers is built by counting the individual organisms at each trophic level in a given area and drawing, for each level, a bar whose length stands for that count, with the producers at the base and the consumers above. The ecologist counts how many producers there are, how many primary consumers feed on them, how many secondary consumers feed on those, and so on, and draws each count as a bar. In a typical grassland the producers are by far the most numerous, so the base is the longest bar, and the numbers fall away upward, giving an upright pyramid. This shows that the community rests on a broad base of many plants supporting fewer and fewer animals towards the top.

The pyramid of numbers shows, level by level, how many individuals a community holds, and its usual upright shape reflects the many producers needed to support the few top consumers.

> **False Confidence Alert**
> A common error is to assume the pyramid of numbers always comes out upright. It often does, but because it counts individuals without regard to their size, it can be turned upside down, as the next question shows.

Question 47

Unlike the other pyramids, a pyramid of numbers is sometimes drawn upside down, with a short bar at the bottom and longer bars above. With the help of a labelled diagram, explain why a pyramid of numbers can be inverted, using the example of a single large tree and of parasites.

Model Answer

A pyramid of numbers can be inverted because it counts individuals without regard to their size, so a few very large producers, or a few large hosts, can support a far greater number of small consumers above them. Take one large tree, such as a baobab or a mango: it is a single producer, so the bottom bar is very short, yet it feeds hundreds of caterpillars and other insects, which makes the bar above it much longer, and the figure stands upside down. The same happens with parasites: one host animal, drawn as a single individual at the lower level, may carry thousands of fleas, ticks or lice above it, so the numbers rise up the pyramid instead of falling.

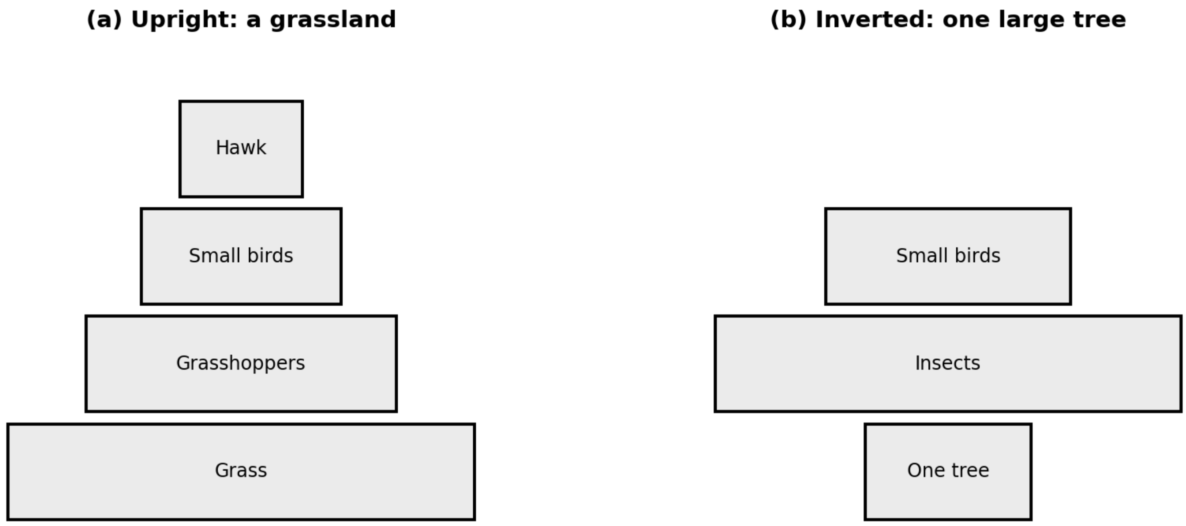


Figure 7.8: *The pyramid of numbers: usually upright (a), but inverted (b) where a few large organisms support many small ones. Bar length shows the number of individuals.*

Because it ignores size, the pyramid of numbers inverts whenever a few large organisms support many small ones, as with one tree and its insects, or one host and its parasites.

False Confidence Alert
It is tempting to think an inverted pyramid means the community is failing. It does not; the inversion only shows that the pyramid of numbers ignores the size of organisms, which is the very weakness the pyramids of biomass and energy were designed to overcome.

Question 48

Because the pyramid of numbers ignores the size of organisms, ecologists often use a pyramid of biomass instead. Explain how a pyramid of biomass is built and how it improves on the pyramid of numbers, and, with the help of a labelled diagram, say why it too can sometimes be inverted.

Model Answer

A pyramid of biomass is built by measuring the total dry mass of the living material at each trophic level in a given area, rather than counting individuals, and it improves on the pyramid of numbers because it takes the size of the organisms into account. Biomass is the mass of living matter, usually given as the dry mass per unit area, so a single large tree contributes a great deal while a tiny insect contributes very little. Because it weighs the organisms instead of merely counting them, the pyramid of biomass comes out upright even in cases where the pyramid of numbers does not, such as one tree feeding many small insects. It can still be inverted, however, in open water, where the producers are microscopic phytoplankton that are eaten and replaced so quickly that, at any one moment, their standing biomass is smaller than that of the zooplankton feeding on them, so the base becomes the shortest bar.

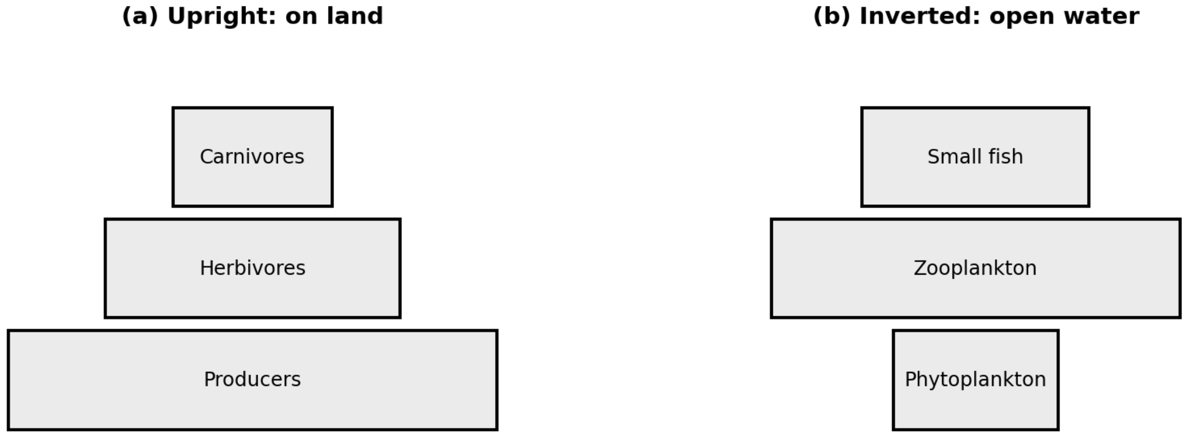


Figure 7.9: *The pyramid of biomass: upright on land (a), but inverted in open water (b), where the tiny, fast-eaten phytoplankton hold little biomass at any one moment. Bar length shows the biomass.*

By measuring mass rather than number, the pyramid of biomass corrects the size problem of the numbers pyramid, though in fast-turnover water communities it too can stand upside down.

False Confidence Alert
A common mistake is to think the pyramid of biomass can never be inverted. It is usually upright, but in open water the rapidly eaten phytoplankton hold so little biomass at any instant that the pyramid inverts, the very weakness the pyramid of energy finally overcomes.

Question 49

The most useful of the three pyramids is the pyramid of energy. Explain how a pyramid of energy is measured, and why it gives a truer picture of a community than a pyramid of numbers or of biomass.

Model Answer

A pyramid of energy is measured not by a single count or weighing but by the rate at which energy flows through each trophic level, that is, the amount of energy fixed or passed on per unit area in a given time, for example in kilojoules per square metre per year. Instead of recording how many organisms there are, or how much they weigh at one moment, it records how much energy passes through each level over a period of time. This takes account both of the size of the organisms and of how fast they live and reproduce, so it is not misled by a few large producers, nor by tiny producers that are eaten and replaced quickly. Because every level is measured in the same units of energy flow, the levels can be compared directly and fairly.

By measuring the flow of energy through each level over time, the pyramid of energy captures what the other two miss, and so gives the truest picture of how a community is supported.

False Confidence Alert
Students sometimes describe the pyramid of energy as just another way of weighing the organisms. It does not measure the mass present at one moment but the energy flowing through each level over time, which is why it succeeds where the biomass pyramid can fail.

Question 50

Unlike the pyramids of numbers and of biomass, a pyramid of energy can never be drawn upside down. Explain why a pyramid of energy is always upright.

Model Answer

A pyramid of energy is always upright because energy is lost at every transfer along the food chain, so each trophic level always receives less energy than the level below it and can never receive more. When energy passes from one level to the next, only a small part of it, on average about a tenth, is built into the bodies of the feeders; the rest is lost as heat in respiration and in undigested waste. This loss happens at every step without exception, so the energy flowing through any level is always smaller than the energy flowing through the level beneath it. A higher level can therefore never carry more energy than a lower one, which is exactly what an inverted pyramid would require.

Because energy always decreases up the chain and can never increase, the pyramid of energy can only taper upward, never invert.

False Confidence Alert
It is tempting to think that, like biomass, energy might sometimes build up at a higher level. It cannot: some energy is always lost as heat at each step, so a higher level can never hold more energy than the one below, and the pyramid stays upright.

Question 51

An ecologist must often choose between the pyramid of numbers, the pyramid of biomass and the pyramid of energy. Explain how the three pyramids compare in what each one shows and what each one hides, and say which gives the most reliable picture.

Model Answer

The three pyramids measure a community in three different ways, and each reveals something that the simpler one hides, with the pyramid of energy being the most reliable of all.

Pyramid of numbers: counts the individuals at each level; it is the quickest to make, but because it ignores the size of organisms it is easily inverted, as by one large tree or by a host carrying many parasites.

Pyramid of biomass: weighs the living material at each level; by taking size into account it corrects the numbers pyramid and is usually upright, but because it records the mass present at only one moment it can still invert in fast-turnover water, where the phytoplankton are quickly eaten.

Pyramid of energy: measures the energy flowing through each level over time; it allows for both size and rate of living, is always upright, and lets different ecosystems be compared, although it is the hardest and slowest to measure.

Because it alone is never inverted and takes everything into account, the pyramid of energy gives the most reliable picture, even though the pyramid of numbers is the easiest to draw.

False Confidence Alert
It is tempting to treat the three pyramids as equally good. They are not: the pyramid of numbers is the simplest but the most easily misled, the biomass pyramid is better but can still invert, and only the pyramid of energy is always upright and fully reliable.

Question 52

After a volcanic eruption leaves bare lava, or after a field is abandoned, the site does not stay empty; over time it is colonised by one community after another until a stable community is reached. Explain what ecological succession is.

Model Answer

Ecological succession is the gradual, orderly and directional change in the community of organisms occupying an area over time, one community replacing another until a stable, self-maintaining community called the climax is reached. A bare or disturbed site is first colonised by a few hardy pioneer species; these change the conditions, making the site fit for other species, which move in and replace them; those in turn alter the site further, so that a series of communities follows one after another. Each stage prepares the way for the next, and the process continues until a community is reached that can maintain itself and changes no further, the climax community.

Succession is therefore the replacement of one community by another in a regular sequence, running from the first pioneers to a stable climax.

False Confidence Alert
A common mistake is to picture succession as the same plants simply growing bigger. It is not growth but replacement: each community is made of different species from the one before, until the climax community is reached.

Question 53

Ecologists describe the course of a succession as passing through several named phases, from the first bared ground to the final stable community. Explain the six phases through which a typical succession passes.

Model Answer

A succession passes through six phases, each one preparing the ground for the next, from the bared site to the climax.

1) **Nudation**: the making of a bare, lifeless surface, by an event such as a volcanic eruption, a landslide or a fire, on which no community yet lives.
2) **Migration**: the arrival of the seeds, spores and other reproductive bodies of the pioneer species, carried in by wind, water or animals.
3) **Ecesis**: the successful germination, growth and establishment of these pioneers on the bare site, the first organisms to take hold.
4) **Competition**: as the colonisers multiply and crowd the site, they begin to compete with one another, and with newcomers, for light, water and space.
5) **Reaction**: the organisms change the site itself, building soil, adding humus and altering moisture and shade, so that it becomes less suitable for themselves but more suitable for other species.
6) **Stabilisation**: the site reaches a final, stable community, the climax, which is in balance with the climate and changes no further.

Through these six phases the bare ground is turned, step by step, into a settled climax community.

False Confidence Alert
Students sometimes leave out reaction, the phase in which the organisms change their own surroundings. It is the key phase, because by altering the soil and shade each community makes way for the next, which is what drives the whole succession forward.

Question 54

Succession is often described as directional and cumulative rather than random. Explain why the changes in a succession are said to be directional and cumulative.

Model Answer

Succession is directional because the communities follow one another in a regular, predictable order towards a climax, and cumulative because each community builds on the changes made by the one before, so that the effects add up over time. The order is not haphazard: the pioneers must come first because only they can survive the bare conditions, and the later, more demanding species can move in only after the earlier ones have improved the site. Each stage leaves the site richer, with more soil, humus, moisture and shelter than before, and the next stage begins from that improved condition rather than from scratch. So the changes head steadily in one direction, towards the climax, and the gains are passed on and added to from stage to stage.

Because each community both follows a set order and builds on the work of the last, succession moves in one direction and its effects accumulate, rather than changing at random.

False Confidence Alert
It is tempting to think any community could appear at any stage. It cannot: the demanding climax species could not survive on bare rock and arrive only once the earlier communities have built the soil, which is why the order is fixed and not random.

Question 55

On a surface that has never borne life, such as bare rock or fresh volcanic lava, succession must begin by building the very soil that plants need. With the help of a labelled diagram, explain how primary succession proceeds on bare rock, naming its main stages.

Model Answer

Primary succession is the succession that begins on a bare surface which has never been colonised before and carries no soil, such as bare rock or new lava, so that it must first build soil from nothing before larger plants can grow. The pioneers are lichens and mosses, which can cling to bare rock and survive drought; as they grow and die, and as their acids and the weather crumble the rock, a thin layer of soil and humus slowly forms. This soil lets small grasses and herbs take root, and these add more organic matter and hold moisture, so that shrubs and then trees can follow. The whole process is very slow, taking hundreds of years in the tropics, because the soil must be made before each larger kind of plant can establish.

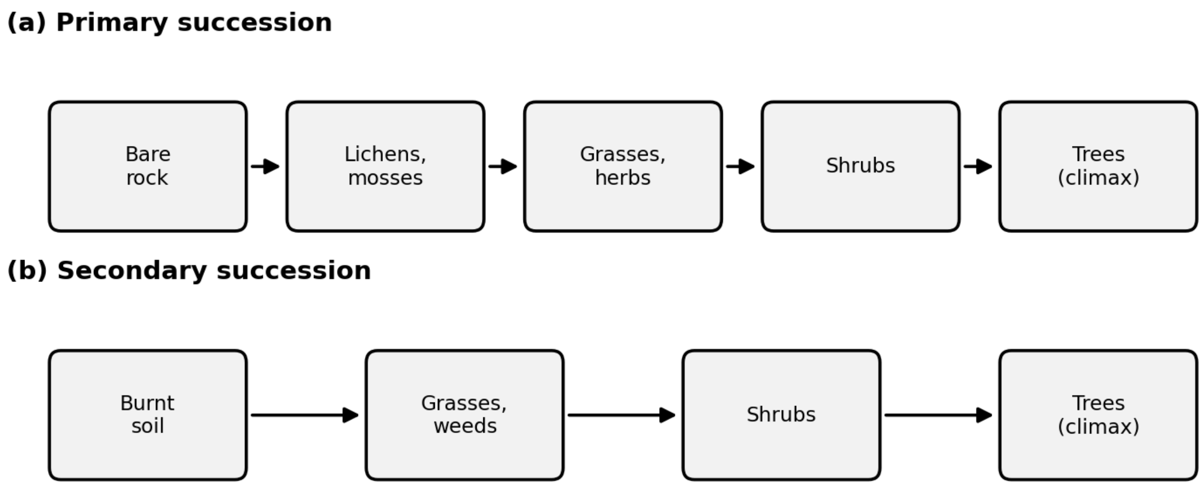


Figure 7.10: *Primary succession on bare rock (a) and secondary succession on existing soil (b); secondary succession skips the soil-building stage and is much faster.*

Primary succession therefore starts from bare, lifeless rock and, through lichen and moss pioneers that build the first soil, works its way up to a forest climax.

False Confidence Alert
A common mistake is to start primary succession with grasses or seedlings. Nothing with roots can grow on bare rock; the true pioneers are lichens and mosses, which make the first soil that everything after them depends on.

Question 56

When a forest is cleared or a grassland is burnt, the land that is left is very different from bare rock, and the community returns far more quickly. Explain how secondary succession differs from primary succession, especially in where it begins.

Model Answer

Secondary succession is the succession that takes place on land where a community has been destroyed or removed but the soil is left behind, such as a burnt grassland or a cleared field, and it differs from primary succession chiefly in that it does not have to build soil from nothing. Because the soil already exists, complete with its humus, its buried seeds and living roots, the slow first stage of soil-making is skipped. Fast-growing grasses and weeds spring up at once from the seeds and roots already in the ground, and these are followed by shrubs and then trees, leading back to a climax community much like the one before. For the same reason secondary succession is far faster than primary, taking decades rather than centuries to reach its climax.

Secondary succession begins on ready-made soil rather than bare rock, so it skips the soil-building stage and reaches the climax far sooner than primary succession.

> **False Confidence Alert**
> It is tempting to think secondary succession also starts with lichens. It does not, because the soil is already present; it begins with the grasses and weeds that grow straight from the seeds and roots left in that soil.

Question 57

Every succession ends in a community that, unlike the stages before it, stays much the same year after year. Explain what a climax community is, how it is recognised, and why it is relatively stable.

Model Answer

A climax community is the final, stable community reached at the end of a succession, one that maintains itself and changes no further for as long as the climate and conditions stay the same. It is recognised because it is the last stage, in which the community stops being replaced and remains steady over time, and because it is the community best suited to the climate of the region, such as tropical rain forest in a warm, wet climate or savanna grassland in a drier one. It is relatively stable because its species are well adapted to the conditions and to one another, it is rich in species, and its many feeding links let it absorb small disturbances and recover, so that it tends to return to the same state after minor upsets.

The climax community is the settled end-point of succession, in balance with the climate, that renews itself and so persists with little further change.

> **False Confidence Alert**
> Students sometimes call any tall, tree-covered stage the climax. The climax is not simply the tallest stage but the one that no longer changes and is in balance with the climate; a young woodland that is still being replaced is not yet a climax.

Question 58

Primary and secondary succession both end in a climax community, yet they differ in important ways at the start. Contrast primary succession with secondary succession.

Model Answer

Primary and secondary succession differ mainly in where they start, in their pioneers, and in how long they take.

1) **Starting surface**: primary succession begins on a bare, lifeless surface with no soil, such as rock or new lava, while secondary succession begins on land that already carries soil left from a previous community.
2) **Pioneers**: the pioneers of primary succession are lichens and mosses, which must first build the soil, whereas the pioneers of secondary succession are fast-growing grasses and weeds that grow straight from seeds and roots in the soil that is already there.
3) **Speed**: primary succession is very slow, taking hundreds of years because the soil must be made first, while secondary succession is much faster, taking only decades because the soil is ready.

Both arrive at a similar climax community in the end, but secondary succession reaches it far sooner because it is spared the long task of building soil.

> **False Confidence Alert**
> It is tempting to think the two are completely different processes. They follow the same general path to a climax; the difference lies only in the starting point, the pioneers and the speed, all of which follow from whether soil is present at the start.

Question 59

The number of elephants in Mikumi National Park rises and falls from one year to the next. Explain what a population is, and how natality, mortality, immigration and emigration together decide whether such a population grows or shrinks.

Model Answer

A population is a group of organisms of the same species living together in the same area at the same time and able to interbreed, and its size is set by the balance between the numbers added to it and the numbers lost from it. Two processes add individuals: natality, the birth of new young, and immigration, the arrival of individuals from elsewhere. Two processes remove them: mortality, death, and emigration, the departure of individuals to other areas. When births and immigration together exceed deaths and emigration, the population grows; when deaths and emigration are the greater, it shrinks; and when the two sides balance, its size stays steady. So the elephant numbers in Mikumi rise in years of plentiful births and arrivals, and fall in years of heavy death or departure.

A population therefore grows or shrinks according to the simple sum of what is added by birth and immigration against what is lost by death and emigration.

False Confidence Alert
A common mistake is to think only births and deaths change a population. Movement matters too: immigration adds individuals and emigration removes them, so a population can grow even when births are few if enough animals move in from outside.

Question 60

Ecologists, and students of evolution, study populations rather than single organisms. Explain why the population, and not the individual, is treated as the real unit on which ecology and evolution act.

Model Answer

The population, not the individual, is the real unit of ecology and evolution because it is the population that persists, changes and adapts over time, while a single organism merely lives and dies without itself evolving. An individual organism is born with a fixed set of genes and cannot change them; it cannot evolve, and when it dies its line may end. A population, however, carries a pool of varied genes shared among its members, and over the generations the make-up of that pool changes as some individuals leave more offspring than others. It is the population whose numbers rise and fall, whose gene frequencies shift under natural selection, and which can adapt to a changing environment. Ecology too measures births, deaths and density at the level of the population, not of the single animal.

Because only a population can persist across generations and change its genetic make-up, it, and not the individual, is the true unit of both ecology and evolution.

False Confidence Alert
It is tempting to think evolution happens to individuals. An individual cannot evolve, since its genes are fixed for life; evolution is a change in a population over the generations, which is why the population is the unit that matters.

Question 61

No population can go on growing forever; sooner or later its growth slows and levels off at a ceiling set by its surroundings. Explain what the carrying capacity of an environment is, and how environmental resistance bends a population's growth towards it.

Model Answer

The carrying capacity is the largest population that a given environment can support indefinitely with the resources it has, and environmental resistance is the sum of all the factors that hold a population back, bending its growth towards that ceiling. While a population is small and resources are plentiful, it grows quickly; but as it becomes larger, food, water and space begin to run short, while predators, disease and competition increase. These checks together make up the environmental resistance, and they grow stronger as the population grows. The resistance slows the rate of increase more and more, until births and deaths come into balance and the population levels off at the carrying capacity, the most the environment can sustain.

Environmental resistance is the brake that strengthens as a population grows, steadying it at the carrying capacity, the ceiling the environment can support.

False Confidence Alert
Students sometimes treat the carrying capacity as a fixed, exact number. It is the level the environment can sustain, but it rises and falls as conditions change, climbing in a good rainy season and falling in a drought.

Question 62

When a population grows faster than its environment can support, the result is a population explosion that cannot last. Explain what a population explosion is, and what happens when a population overshoots its carrying capacity.

Model Answer

A population explosion is a sudden, very rapid increase in the numbers of a population, often carrying it beyond the carrying capacity of its environment, and when a population overshoots that ceiling it cannot be sustained and must fall back. An explosion can occur when conditions are unusually favourable, when a species enters a new area that has no predators, or when humans remove the natural checks. The swollen population then demands more food, water and space than the environment can provide; resources are used up faster than they can renew, waste builds up, and disease and hunger spread. Deaths rise sharply and the population crashes back to, or below, the carrying capacity. In human terms, an explosion brings overpopulation, with shortages of food, land, water, jobs and services.

A population explosion carries numbers above what the environment can support, and the overshoot is followed by a crash as resources fail and deaths rise.

False Confidence Alert
It is tempting to think a population can simply stay at its peak after an explosion. It cannot: once it has overshot the carrying capacity the resources can no longer support it, so the boom is followed by a crash.

Question 63

Across the world the land falls into great regions, each with its own kind of vegetation and animal life, called biomes. With the help of a labelled diagram, explain how the climate, especially temperature and rainfall, decides which biome occupies a region.

Model Answer

A biome is a large region of the Earth with a characteristic climate, vegetation and animal life, and which biome occupies a region is decided chiefly by its climate, above all by its temperature and its rainfall. Temperature and rainfall together set what kind of plants can grow, and the plants in turn set what animals can live there. Where it is hot and wet all year, dense tropical rainforest grows; where it is hot but the rain is seasonal, the trees thin out into tropical savanna grassland; and where it is hot and very dry, only desert plants survive. Cooler regions carry temperate grassland or temperate forest according to the rainfall, while the cold far north bears coniferous forest and, colder still, treeless tundra.

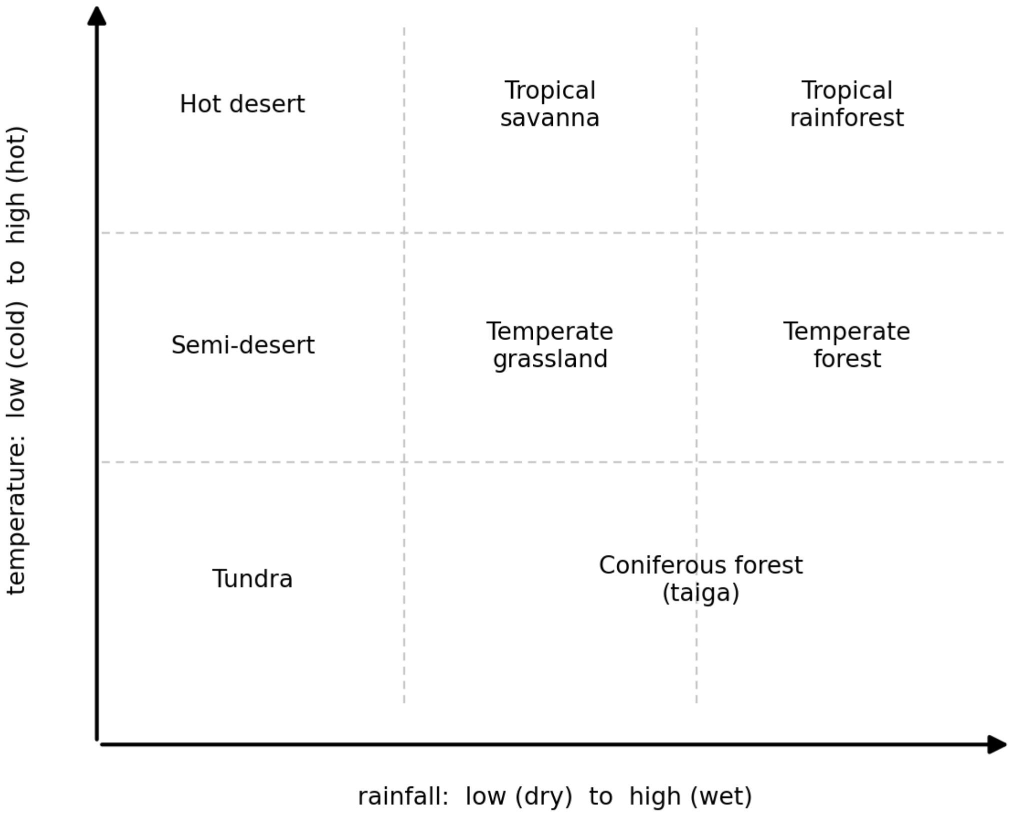


Figure 7.11: *How climate sets the biome: each biome occupies a region of a particular temperature and rainfall.*

Because temperature and rainfall decide which plants, and so which animals, can live in a place, the climate of a region settles which biome it will bear.

False Confidence Alert
A common mistake is to think the soil alone decides the biome. Climate is the master factor: temperature and rainfall set the vegetation type over whole regions, while soil only varies the detail within a climate's biome.

Question 64

Two biomes common in and around Tanzania are the tropical savanna and the hot desert, yet they support very different life. Contrast the tropical savanna and the hot desert in their rainfall, their vegetation and their animal life.

Model Answer

The tropical savanna and the hot desert differ above all in how much rain they receive, and this one difference shapes the vegetation and the animals that each can support.

Rainfall: the savanna has a moderate but strongly seasonal rainfall, with a clear wet season and dry season, while the hot desert receives very little rain at all, often less than 250 mm a year, and may go for years with almost none.

Vegetation: the savanna is grassland dotted with scattered drought-resistant trees such as acacia and baobab, whereas the desert has only sparse, specially adapted plants such as succulents and thorny scrub, with much bare ground between them.

Animal life: the savanna supports great herds of grazing herbivores, such as zebra, wildebeest and antelope, and the carnivores that hunt them, while the desert holds only a few small animals adapted to go without water and active mostly at night.

In short, the savanna's seasonal rain supports rich grassland and abundant large animals, while the desert's near-absence of rain allows only sparse, specially adapted life.

False Confidence Alert
It is tempting to picture the savanna as almost a desert because both are dry for part of the year. The savanna's seasonal rains make it green and grassy in the wet season and able to feed huge herds, which a true desert, with almost no rain, can never do.

Question 65

Most of Tanzania, including its famous national parks, is covered by tropical savanna. Explain why the tropical-savanna biome dominates the Tanzanian landscape.

Model Answer

The tropical-savanna biome dominates Tanzania because the climate over most of the country is exactly the climate that produces savanna: warm temperatures all year together with a moderate, strongly seasonal rainfall. Lying near the equator, Tanzania is warm throughout the year, and most of it receives a moderate amount of rain that falls in distinct wet and dry seasons rather than evenly or in great abundance. This seasonal rainfall is too little to support continuous rainforest, yet far too much for desert, and it is just the pattern that favours grassland scattered with drought-resistant trees, which is savanna. Only small parts of the country differ: the wet slopes of the high mountains carry forest, while a few very dry corners approach semi-desert.

Tanzania's warm, seasonally wet climate over most of its land is the very climate that produces savanna, which is why the savanna biome covers so much of the country.

False Confidence Alert
A common mistake is to credit the savanna to its animals, as though the herds make the grassland. It is the climate that makes the savanna: the warm, seasonally dry rainfall produces the grassland, and the grassland then supports the herds, not the other way round.

Question 66

Where one biome or community meets another, there is often a band that is richer in species than either side. Explain what an ecotone is, and why it usually holds more species than the communities on either side of it.

Model Answer

An ecotone is the transitional zone where two different communities or biomes meet and overlap, such as the strip where a forest gives way to grassland, and it usually holds more species than either community alone. In the ecotone the conditions are intermediate between those of the two neighbouring communities, so it offers a wider range of habitats than either pure community does. Species from both sides can live there, the forest species reaching in from one side and the grassland species from the other, and in addition there are species especially suited to the edge itself. This crowding-together of organisms from both communities, plus the edge specialists, makes the ecotone unusually rich, an effect known as the edge effect.

Because an ecotone gathers species from both neighbouring communities and adds its own edge species, it is usually richer in life than either community beside it.

False Confidence Alert
It is tempting to think the boundary between two communities must be poorer in life, a kind of no-man's-land. The opposite is usually true: the overlap of the two communities, together with the edge specialists, makes the ecotone richer, not poorer, which is the edge effect.

Question 67

The factors that limit a population may act between members of the same species or between members of different species. Explain how intraspecific factors differ from interspecific factors in the way they act on a population.

Model Answer

Intraspecific factors act between members of the same species, while interspecific factors act between members of different species, so the two differ in whether the pressure comes from a population's own kind or from other kinds. Intraspecific factors arise within the population itself, as when its own members compete with one another for the same food, water, mates and space; because they all need exactly the same things, this pressure grows fierce as the population becomes crowded. Interspecific factors come from other species sharing the area, such as a competing species, a predator, a parasite or a disease, and these act on the population from outside it. Both can hold a population in check, but one works among a species' own members and the other between different species.

Intraspecific factors are the pressures a population puts on itself; interspecific factors are the pressures that other species put on it.

> **False Confidence Alert**
> Students sometimes decide the type by how strong the effect is. It is decided only by who is involved: the same species means intraspecific, different species means interspecific, however gentle or fierce the effect.

Question 68

Apart from the climate and the soil, the living things in an area also decide where a population can live and how dense it can become. State four biotic factors that influence the distribution and density of a population, and say briefly how each one acts.

Model Answer

Four biotic factors that influence where a population lives and how dense it becomes are the food supply, predation, competition, and disease and parasitism.

1) **Food supply**: the amount of food available sets how many individuals an area can feed, so where food is plentiful the population can grow dense, and where it is scarce the population is thin or absent.
2) **Predation**: predators kill members of the population and so keep its numbers down, and a heavy weight of predators can confine a prey species to places where it can hide or escape.
3) **Competition**: other organisms competing for the same food, water or space reduce what is left for the population, limiting both where it can live and how dense it can grow.
4) **Disease and parasitism**: diseases and parasites weaken and kill members of the population, especially where it is crowded, and so hold its numbers and its spread in check.

Together these living factors, alongside the climate and the soil, decide the distribution and the density of a population.

> **False Confidence Alert**
> It is tempting to list only the non-living factors, such as rainfall and temperature. The living, or biotic, factors, food, predators, competitors and disease, are just as important, and often it is these that set a population's density.

Question 69

A cold night that kills many young of one species may barely affect another species living in the same place. Explain why the same factor can be a powerful limit on one population yet have little effect on another.

Model Answer

The same factor can limit one population strongly yet hardly touch another because each species has its own range of tolerance and its own adaptations, so a condition that lies outside one species' limits may lie comfortably within another's. Every species can survive only within a certain range of each condition, such as temperature, and is adapted to cope with some pressures but not others. A cold night that falls below the lower limit of one species, killing its young, may still be well within the tolerance of a hardier species adapted to the cold, so the same night barely affects it. In the same way a drought, a predator or a disease may be deadly to a species poorly suited to it but almost harmless to one that is well adapted.

A factor limits a population only when it pushes beyond that species' particular range of tolerance, which is why the very same condition can cripple one species and leave another untouched.

> **False Confidence Alert**
> It is tempting to assume a harsh factor must affect every species in a place equally. It does not: each species has its own tolerances and adaptations, so the same cold, drought or predator weighs heavily on one and lightly on another.

Question 70

Some of the factors that limit a population act more and more strongly as the population grows denser. Explain what is meant by a density-dependent factor, and how its effect changes as a population becomes more crowded.

Model Answer

A density-dependent factor is one whose effect on a population grows stronger as the population becomes denser and weaker as it becomes sparser, so that it presses hardest just when the population is most crowded. Such factors are mostly the living ones: competition for food and space, predation, and the spread of disease and parasites. When a population is sparse, food goes round easily, predators meet prey only rarely, and disease passes slowly, so these factors take little toll. As the population grows crowded, food runs short, predators gather where prey is plentiful and take more, and disease spreads quickly from one close-packed individual to the next. The denser the population, the harder these factors bite, so they tend to push a growing population back towards the carrying capacity.

Because its grip tightens with crowding and loosens with sparseness, a density-dependent factor acts as a self-correcting brake that holds a population near its carrying capacity.

> **False Confidence Alert**
> A common mistake is to think a density-dependent factor acts at a fixed strength. Its very nature is that its strength rises and falls with the population's density, biting hardest when the population is most crowded.

Question 71

Other limiting factors strike a population with much the same force whether it is crowded or sparse. Explain what is meant by a density-independent factor, and give examples of such factors.

Model Answer

A density-independent factor is one whose effect on a population does not depend on how dense the population is, striking with much the same force whether the population is crowded or sparse. Such factors are mostly the non-living ones, the sudden events of weather and physical disturbance. A severe frost, a drought, a flood, a wildfire or a volcanic eruption kills a similar proportion of the population, or sweeps away whole numbers, regardless of how many there were to begin with, for a flood drowns the crowded and the sparse alike. Human actions such as an oil spill or the clearing of a forest act in the same way, striking the population whatever its density.

A density-independent factor, usually a climatic or physical event, falls on a population with a force unrelated to its density, harming the crowded and the sparse alike.

> **False Confidence Alert**
> Students sometimes expect every limiting factor to depend on density. The density-independent ones, chiefly weather and disasters such as drought, frost or fire, do not: they strike with the same force however many or few the organisms are.

Question 72

When a few organisms enter a new, rich and empty habitat, their numbers may rise faster and faster, tracing a J-shaped curve. With the help of a labelled graph, explain how the J-shaped growth curve rises, and why it cannot continue for long.

Model Answer

The J-shaped, or exponential, growth curve shows a population whose numbers rise faster and faster with time, slowly at first while the population is small, then ever more steeply, giving the sharp upward sweep of the letter J. When resources are unlimited and nothing holds the population back, each generation leaves more offspring than the one before, so the more individuals there are, the faster new ones are added. The curve therefore climbs gently at first, then with increasing steepness as the growing numbers breed. But no real habitat has unlimited resources: sooner or later food, water and space run short, while waste and disease build up, and the growth can no longer be sustained, so the population crashes steeply downward instead of rising for ever.

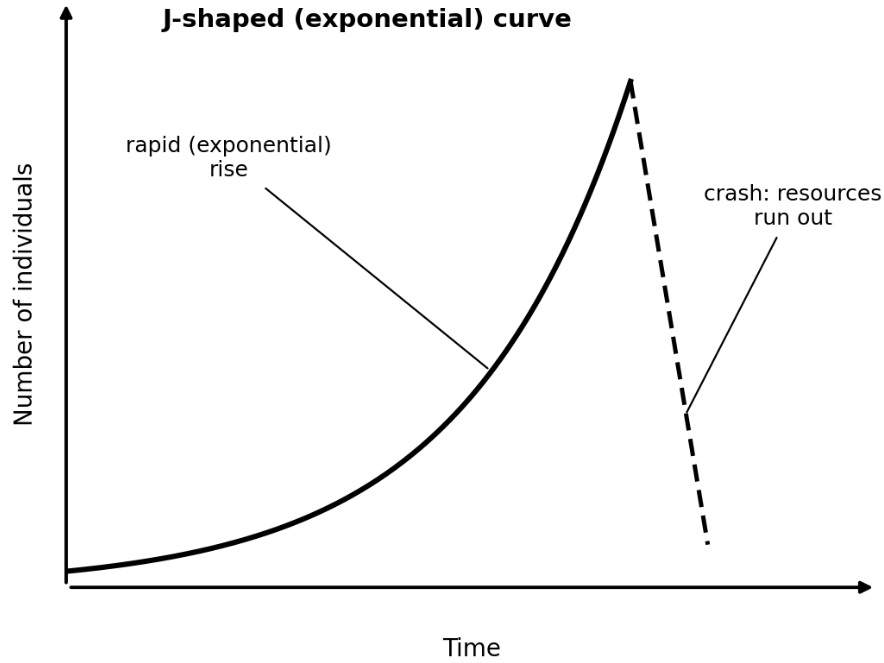


Figure 7.12: *The J-shaped (exponential) growth curve: unchecked growth that rises ever more steeply and then crashes.*

The J-shaped curve is the runaway growth of a population with no checks, and because no environment can feed such growth for long, it always ends in a sudden crash.

False Confidence Alert
It is tempting to think a J-shaped curve can simply level off into an S. It does not: a true J-curve has no brake, so instead of levelling it overshoots and crashes; only a checked population traces the levelling S-curve.

Question 73

Most real populations, growing where resources are limited, trace an S-shaped curve that rises and then levels off. With the help of a labelled graph, explain the four phases of the S-shaped growth curve and how they lead to a stable population at the carrying capacity.

Model Answer

The S-shaped, or sigmoid, growth curve shows a population growing where resources are limited, rising through four phases until it levels off and holds steady at the carrying capacity.

1) **Lag phase**: at the start the few individuals are still settling in and finding mates, so the numbers rise only slowly.
2) **Exponential (log) phase**: once established, the population grows faster and faster while resources are still plentiful, the numbers climbing steeply.
3) **Deceleration phase**: as the population becomes crowded, environmental resistance grows, food and space run short and deaths rise, so the growth slows.
4) **Stationary (plateau) phase**: births and deaths come into balance and the population levels off, holding steady at the carrying capacity.

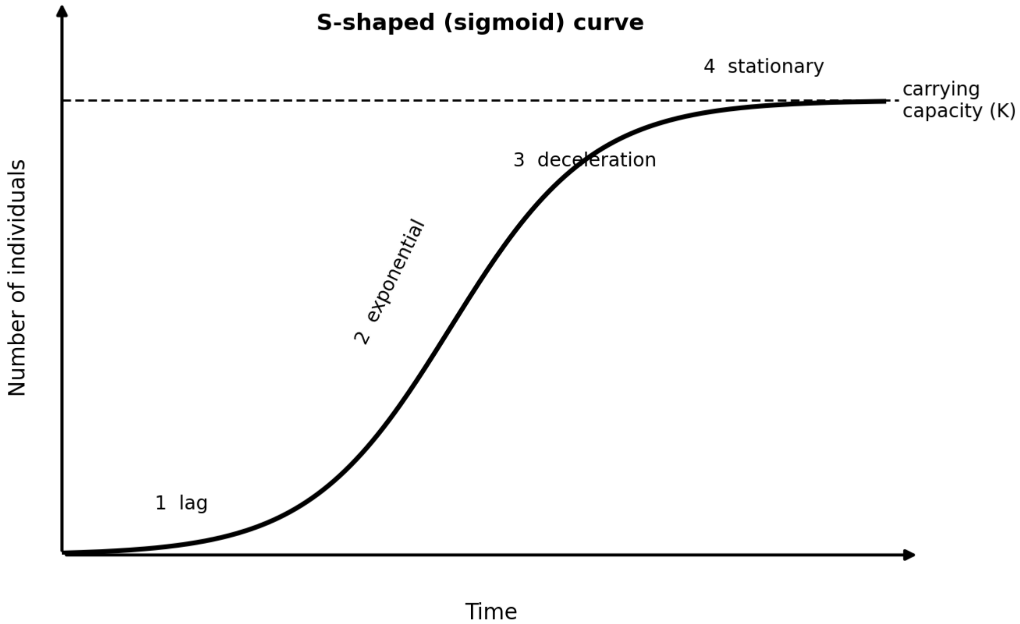


Figure 7.13: *The S-shaped (sigmoid) growth curve and its four phases, levelling off at the carrying capacity (K).*

So the S-curve rises slowly, then steeply, then more gently, and finally flattens at the carrying capacity, where the population stays in balance with its environment.

False Confidence Alert
Students sometimes forget that the S-curve levels off because of environmental resistance, not because the organisms stop breeding. They go on breeding, but the rising deaths from crowding, shortage and disease come to match the births, holding the population steady at the carrying capacity.

Question 74

Biodiversity is more than just the number of different animals and plants in a place; ecologists recognise it at three different levels. Explain what biodiversity is, and describe its three levels: genetic, species and ecosystem diversity.

Model Answer

Biodiversity, or biological diversity, is the whole variety of living things, and it is measured at three levels, ranging from the genes inside a species, through the species in a community, to the ecosystems of a region.

Genetic diversity: the variety of genes, and so of inherited characters, among the individuals within a single species; for example the many varieties of maize, or of cattle, which differ in their genes while all belonging to one species.

Species diversity: the variety of different species living together in a community or area; a patch of forest holding many kinds of tree, bird, insect and mammal has a high species diversity, a maize field a very low one.

Ecosystem diversity: the variety of different ecosystems or habitats found within a region; a country with forests, grasslands, wetlands, lakes and coral reefs has a high ecosystem diversity.

Together these three levels, from the genes within a species to the ecosystems of a whole landscape, make up the biodiversity of a place.

False Confidence Alert
A common mistake is to think biodiversity means only the number of species. Species variety is just one of its three levels; the variety of genes within a species, and the variety of ecosystems in a region, are part of biodiversity too.

Question 75

Two woodlands may each hold the same number of species, yet one strikes an ecologist as far more diverse than the other. Explain how species richness and species evenness together measure the diversity of a community.

Model Answer

The species diversity of a community depends on two things together: its species richness, the number of different species present, and its species evenness, how equally the individuals are shared among those species. Species richness simply counts how many different species there are, so the more species, the richer the community. But richness alone can mislead, because a community in which one species makes up almost all the individuals, with the rest very rare, feels far less diverse than one in which the individuals are spread evenly across the species. Species evenness measures this balance. A truly diverse community is therefore both rich, with many species, and even, with no single species overwhelmingly dominating the rest.

A community is most diverse when it is both rich in species and even in their numbers, so richness and evenness must always be read together.

False Confidence Alert
Students often judge diversity by the number of species alone. Two woodlands with the same number of species can still differ greatly in diversity: the one in which the individuals are more evenly shared among the species is the more diverse, because of its greater evenness.

Question 76

The biodiversity of a country is valuable to its people in two different kinds of way: some of its benefits can be counted in goods and money, while others cannot. Explain how the tangible and the intangible values of biodiversity differ, giving examples of each.

Model Answer

The values of biodiversity fall into two kinds: tangible, or direct, values that can be counted as goods and money, and intangible, or indirect, values that cannot easily be counted but are real all the same.

Tangible (direct) values: the material goods that biodiversity provides and that can be measured or sold, such as food crops and livestock, timber and firewood, fibres, medicines obtained from plants, and the income earned from fishing and from tourism.

Intangible (indirect) values: the benefits that cannot easily be counted in money but on which life depends, such as the pollination of crops, the cleaning of water and air, the cycling of nutrients, the holding of the soil and the regulation of climate, together with the cultural, spiritual, scientific and beauty value of nature.

Biodiversity is therefore worth keeping both for the goods it yields directly and for the unseen services and meanings it provides.

False Confidence Alert
It is tempting to value biodiversity only for the goods that can be sold. Its intangible services, such as pollination, clean water and the cycling of nutrients, are worth even more, for without them no crop, fishery or city could survive.

Question 77

The biodiversity of Tanzania, and of the world, is now being lost faster than ever before. Explain how each of four main threats, habitat loss, overexploitation, pollution and climate change, erodes biodiversity.

Model Answer

Biodiversity is eroded by four main threats, each of which destroys, removes or weakens the living things of a place.

Habitat loss: when forests are cleared for farmland, wetlands are drained or land is built over, the homes of countless species are destroyed and the species are lost with them; this is the single greatest cause of loss.

Overexploitation: when species are taken faster than they can breed, as in overfishing, the hunting of animals for meat or ivory, and the felling of valuable trees such as *mpingo*, their numbers fall and some are driven towards extinction.

Pollution: poisons, sewage and fertilisers released into the air, water and soil kill organisms outright or upset the conditions they need, as when fertiliser washing into a lake causes the choking growth of algae.

Climate change: as the climate warms and the rainfall patterns shift, the conditions a species is adapted to may move or disappear, so that species which cannot move or adapt fast enough are lost, while coral reefs are bleached and killed.

Most often these threats act together, and human activity drives them all, which is why biodiversity is now being lost so rapidly.

False Confidence Alert
It is tempting to blame the loss of biodiversity on hunting alone. Hunting, as one form of overexploitation, is a real cause, but the destruction of habitat is the greatest of all, and pollution and climate change add further to the loss.

Question 78

Biodiversity can be conserved either in the wild, where the species naturally live, or away from it, in special collections. Explain how in-situ conservation differs from ex-situ conservation, and what each does best.

Model Answer

Conservation may be in-situ, protecting species in their natural surroundings, or ex-situ, protecting them in collections away from the wild, and each does best in different circumstances.

In-situ conservation: protecting species where they naturally live, in national parks, game reserves, forest reserves and marine protected areas; it keeps whole communities and their habitats together and lets species go on evolving in the wild, and it is the better method wherever the habitat still survives.

Ex-situ conservation: protecting species away from their natural home, in zoos, botanical gardens, aquaria and seed or gene banks; it is used to save species whose wild habitat has been destroyed, to breed rare species in safety so as to return them to the wild, and to store seeds and genes against future loss.

In-situ conservation is preferred wherever the wild habitat remains, while ex-situ conservation is the safeguard for species that cannot yet be protected in the wild.

False Confidence Alert
Students sometimes treat zoos and seed banks as the main way to save biodiversity. Ex-situ methods are only a backstop; in-situ conservation, which keeps species in their living habitats, is the better and the main approach wherever the habitat can be saved.

Question 79

A natural resource such as a forest or a fishery can be used by people for ever, or used up within a single generation, depending on how it is managed. Explain what is meant by the sustainable management of a natural resource, and how it allows a resource to be used and yet still renew itself.

Model Answer

Sustainable management is the use of a natural resource at a rate that allows it to renew itself, so that it can go on yielding to people indefinitely instead of being used up. A living resource such as a forest or a fish stock can replace what is taken from it, by growth and breeding, but only up to a point; if it is harvested faster than it can renew, it dwindles and is destroyed. Sustainable management keeps the harvest within that limit: in a fishery, by setting catch limits, closed seasons and net mesh sizes that let the young fish escape and breed; in a forest, by felling only selected trees and replanting, and by leaving the soil and the seed trees intact. The resource is then never taken faster than it can recover.

Sustainable management means taking no more than a resource can replace, so that it renews itself and keeps yielding for generation after generation.

False Confidence Alert
It is tempting to think that using a resource sustainably means not using it at all. It does not: a sustainably managed forest or fishery is used, and used continually, but only at a rate slow enough for it to renew what is taken.

Question 80

When a species is brought, by accident or on purpose, into an area where it does not belong, it sometimes spreads out of control and does great harm. Explain what an alien invasive species is, and how it harms the community it enters, using a Tanzanian example.

Model Answer

An alien invasive species is a species introduced, deliberately or by accident, into an area outside its natural range, which then spreads rapidly and harms the native community, because it has arrived without the predators, parasites and competitors that held it in check at home. Freed from its natural enemies, the invader multiplies unchecked and crowds out the native species, competing with them for light, space, food or water, and sometimes preying on them or bringing new disease. A clear Tanzanian example is the water hyacinth, an alien floating plant that choked the surface of Lake Victoria: its dense mats shut out the light and used up the oxygen, killing the fish and the native water plants beneath them, and blocking boats, fishing and water intakes. In this way a single invader can upset and impoverish a whole community.

An alien invasive species, freed from the enemies that controlled it at home, spreads unchecked and drives out or harms the native species, reducing the diversity of the community it enters.

False Confidence Alert
It is tempting to think any newly arrived species is invasive. A species is invasive only when it spreads aggressively and harms the native community; many introduced species settle in quietly, and it is the few that escape all control, such as the water hyacinth, that do the damage.

REAL QUESTIONS

The questions in this tier put the ideas to work. They set real situations, many of them drawn from Tanzanian farms, lakes, forests and reserves, and ask you to reason rather than recall. Work each question yourself before reading the Model Answer; the bold opening sentence is the single point an examiner most wants to see, and the boxed False Confidence Alert names the trap that quietly costs marks even when a student feels sure.

Question 81

On the open grassland of the central plateau near Dodoma, where the seasonal rains bring up a fresh flush of grass, a student watches a single grasshopper feeding on a blade. Her teacher asks her to place this one grasshopper on the full ladder of ecological organisation, from organism all the way up to the biosphere, giving a reason for each rung from the grassland in front of her. Show how the levels build up from one grasshopper to the biosphere, justifying each step.

Model Answer

Each level of organisation is reached by widening the circle drawn around the level below it, so the single grasshopper can be followed step by step all the way up to the biosphere.

1) **Organism**: the one grasshopper itself, a single living individual feeding on the grass.
2) **Population**: all the grasshoppers of that grassland together, because a population is all the members of one species living in the same area.
3) **Community**: those grasshoppers together with every other species sharing the grassland, the grasses, the herbs, the birds, the lizards, the soil insects and the bacteria, all interacting with one another.
4) **Ecosystem**: that whole community together with its non-living surroundings, the soil, the rain water, the air, the mineral salts and the sunlight, working as one system.
5) **Biome**: the wide belt of savanna grassland that stretches across the region beyond this one field, sharing the same warm, seasonally dry climate and the same kind of life.
6) **Biosphere**: all such ecosystems and biomes of the whole Earth added together, the single thin layer of land, water and air within which every living thing exists, of which this grassland is one small patch.

Read either way, the ladder is one of inclusion: each rung is built from the rung beneath it and is itself a part of the rung above. **From one grasshopper to the whole living Earth, every step simply takes in more than the last.**

> **False Confidence Alert**
> It is tempting to call the grassland an ecosystem the moment its plants and animals are listed. A community of living things only becomes an ecosystem when the non-living surroundings, the soil, water, air and sunlight, are counted in with it; leave those out and the level is still only a community.

Question 82

After harvest, a maize farmer in the Southern Highlands sets fire to the dry stalks and leaves left standing in his field, sure that the ash will feed next season's crop. An ecologist who understands the soil advises him to stop and to dig the residues back in instead. Reasoning from the soil organisms through to the final harvest, explain why burning the crop residues year after year tends to lower rather than raise the farmer's yield.

Model Answer

Burning the crop residues destroys the organic matter and starves the soil organisms that release nutrients, so season after season the soil grows poorer and the yield falls. The dead stalks and leaves are not rubbish but food for the decomposers, the bacteria, fungi and small animals of the soil, which break them down and return their nitrogen, phosphorus and other nutrients to the ground in a form that roots can take up. Burning turns this organic matter to smoke in minutes: the carbon and most of the nitrogen escape into the air as gases, while the micro-organisms at the surface and the cover that shaded them are scorched away. The little ash that remains holds some minerals such as potassium, but it is a small return for a large loss, and the bare blackened soil is now easily washed off by the rains or blown away by the wind.

Year upon year the store of organic matter and the living population that recycles it both dwindle, the soil loses its crumb structure and its hold on water, and the maize has less and less to draw upon. **Digging the residues back, or composting them first, feeds the soil organisms instead of killing them, and it is they who keep the land yielding.**

> **False Confidence Alert**
> It is tempting to think the ash left after burning is a good fertiliser. The ash returns only a little mineral; the burning has already sent most of the nitrogen up as gas and killed the soil organisms that recycle nutrients, so the field is left poorer, not richer.

Question 83

A farmer notices that a plot sown with maize every single year gives a smaller harvest each season, while a neighbour who rotates her crops and digs in farmyard manure keeps her yields steady on soil that is no better than his. Using your understanding of nutrient cycling, explain why returning nutrients to the soil allows the same farmland to stay productive year after year.

Model Answer

Every harvest carries nutrients out of the soil inside the crop, so the same land can stay productive only if those nutrients are put back, which is exactly what nutrient cycling does. When maize grows it draws nitrogen, phosphorus, potassium and other mineral salts out of the soil and locks them into its grain and stalk. If the whole crop is then carried away at harvest and nothing is returned, the soil is steadily mined: each season a little more leaves than comes back, and the yield falls, just as it does on the plot cropped with maize every year. Nutrient cycling is the natural return of these same elements to the soil, and a farmer can work with it rather than against it.

Digging in manure and crop residues feeds the decomposers, which release their nutrients back into the ground; growing a legume such as beans or groundnuts in rotation lets the bacteria in its roots fix nitrogen from the air into the soil; and resting the land under fallow lets the cycle catch up. The neighbour who does these things replaces what her crops remove, and so her soil does not run down. **Understanding the cycle gives the farmer one simple rule: put back what the harvest takes out, and the same land will go on yielding.**

> **False Confidence Alert**
> Students sometimes assume the soil holds an endless supply of nutrients, so a field can be cropped forever with nothing added. The store is limited; each harvest removes part of it, and unless those nutrients are returned the soil is mined and the yield steadily falls.

Question 84

A student is asked to survey the plants of a small reserve that is half dense woodland and half open grassland. To save effort she plans to lay all her quadrats in the grassland, where walking is easy. Explain why this would give a biased picture of the reserve, and how she should choose her sample so that it fairly represents the whole site.

Model Answer

A sample represents a site fairly only when every part of that site has had a fair chance of being included, so the woodland and the grassland must both be sampled, not just the half that is easy to reach. If the student lays all her quadrats in the open grassland, she measures the grassland alone and then reports it as the whole reserve; every species that lives only under the trees is missed, and her figures are biased towards grassland plants. To represent the whole site she should first walk over it in a reconnaissance to see how it is divided, then sample both the woodland and the grassland, fixing the position of each quadrat with random numbers so that her own preference for the easy ground cannot creep in, and taking enough quadrats in each part to even out chance variation.

A fair sample is the site in miniature: every habitat present, in proportion, with positions set by chance rather than by convenience. **The aim is a small picture that looks like the whole reserve, not like its easiest corner.**

False Confidence Alert
It is tempting to think that simply taking more quadrats makes a sample representative. A thousand quadrats all thrown in the open grassland still describe only the grassland; representativeness comes from covering every part of the site, not from sample size alone.

Question 85

An ecologist must survey a site that falls into three clearly different patches: a block of woodland, an area of open grassland and a narrow strip of riverbank. A colleague suggests scattering quadrats at random over the whole site in one go. Explain why stratified sampling is the better technique for ground like this, and how it is carried out.

Model Answer

Stratified sampling suits such a site because it divides the ground into its distinct patches and samples each one separately, so that no patch is missed or swamped by the others. A site that falls into clear blocks of woodland, grassland and a thin riverbank strip is not uniform, and a single set of quadrats scattered across the whole could by chance land mostly in the large blocks and barely touch the narrow riverbank, which might then carry species found nowhere else. In stratified sampling the ecologist first treats each patch as a separate stratum; then places quadrats within each stratum, their positions fixed at random; shares the total number of quadrats among the strata in proportion to the area of each; and finally combines the results into one picture of the site.

Every patch, even the smallest, is then certain to be sampled and to count for its fair share. **By matching the sampling to the real structure of the ground, stratified sampling captures the whole patchy site where a single blanket method might not.**

False Confidence Alert
Stratified sampling does not mean placing the same number of quadrats in every patch. The quadrats are shared out in proportion to each patch's area, so a large woodland receives more than a thin riverbank strip; equal numbers would over-weight the small patches.

Question 86

Two field workers planning a vegetation survey disagree: one wants to fix every quadrat position by random numbers, the other wants to place the quadrats at regular intervals along a measured grid. Compare the advantages and limitations of random and systematic sampling for a survey like this.

Model Answer

Random and systematic sampling both spread quadrats across a site, but random sampling fixes their positions by chance to avoid bias, while systematic sampling spaces them at fixed intervals to guarantee even coverage; each gains one thing at the cost of the other.

Where the plots fall: in random sampling each position is fixed by random numbers, so it cannot be foreseen; in systematic sampling the plots sit at regular intervals, such as every ten metres along a grid or line.

Freedom from bias: random sampling removes the surveyor's unconscious choice of where to put a quadrat, which is its chief strength; systematic sampling can by bad luck fall into step with a regular pattern in the vegetation, such as planted rows or ridges and furrows, and so build a bias into the result.

Evenness of cover: systematic sampling covers the ground evenly and reaches every corner of the site; random sampling can by chance leave some areas crowded with plots and other areas empty.

Speed and ease: systematic plots are quick and simple to lay out from a tape measure; random plots take longer, because each position must first be generated as a pair of coordinates and then found on the ground.

Neither is best for every survey: random sampling is the safer choice where hidden bias must be avoided, while systematic sampling is preferred where even coverage of a large or banded area matters and no regular pattern is feared. **Many surveys take the best of both, placing random plots within a systematic framework.**

False Confidence Alert
Random sampling does not mean tossing the quadrat over your shoulder and walking to where it lands. That is haphazard, not random, and lets unconscious bias slip in; true random sampling fixes each position from random numbers before anyone goes into the field.

Question 87

On short grassland where the plants form a low, tangled mat, estimating how much ground each species covers by eye is difficult and two observers rarely agree. Explain how a pin-frame (point-frame) quadrat is used to measure cover, and why it suits low ground vegetation of this kind.

Model Answer

A pin-frame quadrat measures plant cover by lowering thin pins vertically onto the vegetation and recording which species each pin touches, which turns a vague visual judgement into an objective count. The frame is a bar or small stand carrying a row of holes, through each of which a long pin is dropped straight down to the ground. Every species that a pin touches on its way down is recorded as a hit, and a single pin may strike more than one species where leaves overlap in layers. When all the pins have been lowered, the cover of each species is worked out as the number of pins that touched it, taken as a fraction of the total number of pins and expressed as a percentage.

It suits low, close vegetation such as grassland, lawn and creeping herbs, where the plants are short enough for the vertical pins to reach the ground and too intermingled to judge by eye, but it is impractical for tall plants or trees. **For low ground cover it gives cover figures that two different workers would arrive at alike.**

False Confidence Alert
A pin frame measures cover, not the number of plants. Each pin only records whether a species is touched at that one point, so the result is the percentage of points covered; it is wrong to report the pin hits as a head count of individual plants.

Question 88

A student lays a quadrat of 0.25 square metres ten times across a grassland and records a star grass. The grass is present in six of the ten quadrats, and the total number of its plants counted over all ten quadrats is forty-five. Work out the frequency and the density of the star grass, and say what each figure tells the ecologist.

Model Answer

Frequency and density are worked from the same quadrat records but answer different questions: frequency from how many quadrats held the species, and density from how many individual plants were counted in all.

Frequency = (number of quadrats in which the species occurs / total quadrats) × 100

Frequency = (6 / 10) × 100 = 60%

Density = total individuals counted / total area sampled

Total area sampled = 10 × 0.25 m^2 = 2.5 m^2

Density = 45 / 2.5 m^2 = 18 plants per m^2

The frequency of 60% says the star grass is well spread, turning up in more than half of the quadrats; it measures how widely the species occurs across the site. The density of 18 plants per square metre says how thickly it grows where the ground is measured; it measures true abundance. A species could score a high frequency yet a low density, or the reverse, which is why an ecologist reads the two together. **Frequency tells you how widespread a species is; density tells you how many there are.**

False Confidence Alert
A high frequency is often mistaken for a high density. Frequency counts only the quadrats a species appears in, not how many plants are in them; a grass found in every quadrat but as a single blade each time is highly frequent yet very sparse.

Question 89

Frogs cannot be lined up and counted, so to estimate how many live around a pond a student catches forty-eight of them one evening, marks each with a dab of harmless paint and releases them. The next evening she catches sixty-four frogs, of which twelve already carry the mark. Use the Lincoln index to estimate the number of frogs around the pond, and explain the reasoning behind the figure.

Model Answer

The Lincoln index estimates a population that cannot be counted directly by marking some animals, then seeing what fraction of a second catch carries the mark.

$N = \frac{n_1 \times n_2}{n_3}$ (n_1 = first catch marked, n_2 = second catch, n_3 = marked in the second catch)

$$N = \frac{48 \times 64)}{12}$$

N = 256 frogs

The pond holds about 256 frogs. The reasoning is that the marked share of the second catch, 12 out of 64, should match the marked share of the whole population, 48 out of N; setting those two shares equal and solving for N gives the estimate. **The fewer of the marked frogs you meet again, the larger the population the index reports.**

False Confidence Alert
It feels as though recapturing only a few marked frogs must mean there are few frogs in all. It is the other way round: the smaller the marked fraction in the second catch, the more the marks have been diluted among unmarked frogs, and so the larger the population the index gives.

Question 90

People often hear that a growing forest helps to cool the planet by locking up carbon. Using what you know about producers and respiration, explain why an ecosystem with a healthy, growing producer layer acts as a carbon sink rather than a carbon source.

Model Answer

An ecosystem is a carbon sink when its producers take in more carbon dioxide by photosynthesis than the whole community returns by respiration and decay, so that, on balance, carbon is stored rather than released. Green producers draw carbon dioxide from the air and fix its carbon into sugars, and from these into the wood, leaves and roots of their bodies. At the same time every organism, the plants included, releases some carbon dioxide back to the air in respiration, and the decomposers release more as they break down dead matter. While the producer layer is healthy and growing, the carbon it fixes and stores in new wood, deepening soil and accumulating litter outweighs the carbon breathed back out, and the surplus is locked away in the living and dead organic matter of the ecosystem.

Such a system is a net store of carbon, a sink. **Clear or burn the producers, and the stored carbon is released while little new carbon is fixed, so the same ground turns from a sink into a source.**

False Confidence Alert
It is tempting to say a forest is a sink simply because its plants photosynthesise. The plants and the soil also respire and decay, returning carbon to the air; the ecosystem is a sink only while the carbon fixed and stored exceeds the carbon released, which is why a young growing forest takes up more than an old, unchanging one.

Question 91

An examiner gives a list of familiar Tanzanian animals and asks candidates to sort them by what they eat. Classify each of the following as a herbivore, a carnivore or an omnivore, giving a reason for each: the zebra, the lion, the baboon, the fish eagle and the domestic fowl.

Model Answer

An animal is placed by what it eats, not by its size or family: a herbivore eats plants, a carnivore eats other animals, and an omnivore eats both.

Zebra: herbivore, because it feeds only on plant material, grazing the grasses of the plains.

Lion: carnivore, because it lives by killing and eating the flesh of other animals, such as zebra and wildebeest.

Baboon: omnivore, because it takes both plant food (fruits, seeds and roots) and animal food (insects, eggs and small animals).

Fish eagle: carnivore, because it feeds on the flesh of animals, snatching fish from the water.

Domestic fowl: omnivore, because it pecks both grain and green shoots and also insects and worms.

What an animal eats, and nothing else, fixes its feeding class. **An animal that takes both plants and flesh is an omnivore, whatever its size or family.**

> **False Confidence Alert**
> Students often guess from size or fierceness rather than diet, calling any large animal a carnivore. The elephant is huge yet a pure herbivore, while a small insect-eating bird is a carnivore; only the diet decides.

Question 92

Imagine a soil in which every decomposer, the bacteria and fungi of decay, has been killed, while the green plants are left untouched. Explain why, before long, those plants would begin to starve, by tracing the loop that the decomposers normally complete.

Model Answer

Without decomposers the nutrients taken up by plants would stay locked inside dead bodies and never return to the soil, so the soil would run out of the minerals the living plants need and they would starve. Plants draw nitrogen, phosphorus and other mineral salts out of the soil and build them into their tissues. Normally, when leaves fall and plants and animals die, the decomposers break this dead organic matter down and release those same minerals back into the soil in a form the roots can take up again, closing the loop. Kill the decomposers and the loop is broken: dead leaves, wood and bodies pile up undecayed, and the nutrients held inside them are never freed. The soil, still giving up minerals to the growing plants but receiving none back, is steadily stripped of them.

As the store of nitrogen and other salts in the soil falls, the plants can no longer make the proteins and other materials they need, and growth fails. **The decomposers are the return half of the nutrient cycle; remove them and the one-way drain on the soil soon starves the very plants that seemed to manage without them.**

> **False Confidence Alert**
> It is easy to think that plants, making their own food, do not depend on decomposers. Plants make their own food, but not their own mineral nutrients; those must come from the soil, and it is the decomposers that keep returning them to it.

Question 93

Two fields a short distance apart carry quite different wild plants, although they share the same climate. The difference lies in their soils. Analyse how three edaphic (soil) factors, namely soil pH, soil air and humus, each help to decide what will grow on a site.

Model Answer

Edaphic factors are the properties of the soil itself, and pH, soil air and humus each set conditions that suit some plants and bar others.

Soil pH: the acidity or alkalinity of the soil decides which minerals dissolve and can be taken up, so each plant grows best within its own range; tea and many forest plants favour acid soils, while others fail there and need near-neutral ground.

Soil air: the air held in the spaces between the soil particles supplies oxygen to the roots for respiration, so a well-aerated soil supports vigorous root growth, while a waterlogged soil, its spaces filled with water, suffocates most roots and admits only specially adapted plants such as rice or swamp species.

Humus: the dark, decayed organic matter in the soil stores nutrients and water and binds the soil into crumbs, so a soil rich in humus is fertile and moist and carries lush growth, while a humus-poor soil is thin and hungry and supports little.

Because each soil offers its own combination of pH, aeration and humus, two sites under one climate can carry quite different plants. **The soil is a control in its own right, set apart from the weather above it.**

> **False Confidence Alert**
> It is tempting to put every difference in vegetation down to climate, the rain and the heat. Two sites under the very same climate can carry different plants because their soils differ; the edaphic factors are a separate control, not a part of the weather.

Question 94

Three partnerships are often confused. A lichen on a rock, a tick on a dog, and an orchid perched high on a forest tree each involve two organisms living together, yet the dealings between them are not the same. Place each partnership in its correct type of symbiosis, that is mutualism, commensalism or parasitism, and justify your choice.

Model Answer

The three types of symbiosis differ in who gains and who loses, and each of these partnerships falls clearly into one of them.

The lichen: mutualism, because it is a partnership of a fungus and an alga in which both gain: the alga makes food by photosynthesis for both, while the fungus gives anchorage, water and shelter, so neither is harmed and each benefits.

The tick on a dog: parasitism, because the tick gains by sucking the blood of the dog while the dog loses, being weakened and perhaps infected; one benefits at the expense of the other.

The epiphytic orchid: commensalism, because the orchid gains a high, lit perch on the tree and so reaches the sunlight, while the tree, merely carrying it, is neither helped nor harmed; one gains and the other is unaffected.

Name the gainer and the loser in each case, and the type names itself: both gain in mutualism, one gains while the other is unharmed in commensalism, and one gains while the other suffers in parasitism.

> **False Confidence Alert**
> An epiphytic orchid is often mistaken for a parasite because it grows on another plant. It only perches on the tree for light and takes no food or sap from it; a true parasite, such as mistletoe, draws nourishment from its host, which the orchid does not.

Question 95

A top carnivore such as a lion or a fish eagle is supported by a vast base of plants below it, yet there can only ever be a few of them. Explain, in five points, why so little of the energy captured by the plants ever reaches a top carnivore.

Model Answer

So little energy reaches a top carnivore because energy is lost at every step of the food chain, and only a small fraction, about a tenth, passes from each level to the next.

1) **Loss in respiration**: at every level most of the energy taken in is spent on the organism's own life processes and lost to the air as heat, so it cannot be passed on.
2) **Loss in waste**: some of the food eaten is never digested and leaves the body in faeces, carrying its energy away with it.
3) **Uneaten parts**: not all of one level is eaten by the next; roots, bones, hair and many whole individuals die and pass to the decomposers instead of to the carnivore.
4) **The ten per cent step**: because of these losses only about one tenth of the energy at one level is built into the level above, so roughly nine tenths is gone at every transfer.
5) **Several steps multiply the loss**: from plant to herbivore to small carnivore to top carnivore a tenth is taken of a tenth of a tenth, so by the top only a tiny share of the original energy is left.

Each link in the chain keeps most of the energy for itself and loses far more, so the few links that the energy can stretch to leave almost nothing for the animal at the top. **The top carnivore is rare because energy, not hunting skill, runs short at the summit.**

False Confidence Alert
It is tempting to blame the small number of top carnivores on a shortage of prey to hunt. The real limit is energy: so much is lost at each step that the higher levels simply cannot be fed in large numbers, however much prey may seem to be about.

Question 96

A maize farmer near a lake spreads nitrate fertiliser on his field to green his crop. After the heavy rains, the lake beside his farm turns thick and green with a bloom of algae, and before long the fish begin to die. Using your knowledge of the nitrogen cycle, explain how nitrate meant to feed the maize ends up destroying life in the lake.

Model Answer

The nitrate that was meant to feed the maize is washed by the rain into the lake, where it fertilises the algae instead, setting off a runaway growth and decay that robs the water of oxygen and kills the fish; this damage is called eutrophication. Nitrate is the soluble form of nitrogen that roots take up, and it is exactly because it dissolves so readily that the rain washes the surplus off the field and into the lake. There it acts as a fertiliser for the lake's own tiny plants, the microscopic algae, which multiply into a dense green bloom across the surface. The bloom shades the water beneath it so that the plants there die, and when the short-lived algae themselves die in their millions the decomposer bacteria that rot them multiply too. As these bacteria respire they use up the oxygen dissolved in the water, and as the oxygen falls the fish and other animals suffocate.

So the very nitrate that greens a crop on land can, once washed into water, green it to death. **A nutrient is a benefit only while it stays where it is wanted; carried into a lake, the same nitrate becomes a destroyer by feeding the wrong plants.**

False Confidence Alert
It is tempting to think more fertiliser can only mean more growth and therefore more good. Washed into a lake, the same nitrate does harm, feeding an algal bloom whose decay strips the water of the oxygen that fish need; the fault is not in the nitrate but in its reaching where it was never meant to be.

Question 97

Newspapers blame both the burning of fuels and the clearing of forests for a warming world. Using the carbon cycle, explain how burning fossil fuels and clearing forest each tilt the balance of carbon dioxide in the air towards warming.

Model Answer

Both burning fossil fuels and clearing forest raise the carbon dioxide in the air, the first by releasing long-buried carbon and the second by both releasing carbon and removing the trees that would take it back, and more carbon dioxide traps more heat. In the carbon cycle, carbon dioxide is taken from the air by photosynthesis and returned by respiration, decay and burning, while over the ages some carbon was locked away underground as coal, oil and gas. Burning these fossil fuels takes that ancient buried carbon and pours it back into the air as carbon dioxide far faster than the cycle can remove it, so the amount in the air climbs. Clearing forest tilts the balance twice over: the felled trees, burnt or left to rot, release the carbon stored in their wood, and, once gone, they no longer photosynthesise, so the forest that used to draw carbon dioxide out of the air can no longer do so.

Carbon dioxide is a greenhouse gas that holds in the heat of the Earth, so as both actions push its level in the air upward, the world grows warmer. **One action adds carbon, the other adds carbon and removes the sink; both ends of the cycle are pushed the same way.**

> **False Confidence Alert**
> It is easy to see clearing a forest only as the loss of a carbon store. It does two things at once: it releases the carbon held in the trees and it removes the living sink that was pulling carbon dioxide out of the air, so its push towards warming is double.

Question 98

The competitive-exclusion principle says that two species with exactly the same needs cannot live together for long, yet on the savanna the zebra, the wildebeest and the gazelle graze the same plains side by side. Explain how resource partitioning allows close competitors to share one habitat.

Model Answer

Close competitors can share a habitat by resource partitioning, that is by dividing the shared resource so that each uses a slightly different part of it, so that their niches no longer overlap completely. Competitive exclusion forces one species out only when two need exactly the same thing in exactly the same way. If instead each comes to use the resource a little differently, the competition between them eases and both can persist. On the plains the grazers divide the grass between them: the zebra takes the tall, coarse tops of the grasses, the wildebeest crops the medium leafy middle, and the gazelle nibbles the short, tender new growth near the ground. Each feeds on the same grass but at a different level, so none strips all the food from the others.

The same partitioning can be made in other ways, two birds feeding at different heights in one tree, or two animals feeding at different times of day. **By splitting the resource rather than each taking all of it, the competitors carve out separate niches and so escape the exclusion that complete overlap would bring.**

> **False Confidence Alert**
> It is tempting to think two species sharing a habitat must be breaking the exclusion principle. They are not competing for exactly the same thing: resource partitioning has given each a slightly different niche, which is precisely what lets them live together.

Question 99

Using named organisms from the African savanna, build a grazing food chain of at least four links, and label the trophic level of each organism in it.

Model Answer

A grazing food chain begins with a living green plant and passes energy from it to a herbivore and then on through a series of carnivores, each step a higher trophic level.

$$\textbf{Grass} \rightarrow \textbf{mouse} \rightarrow \textbf{snake} \rightarrow \textbf{mongoose} \rightarrow \textbf{eagle}$$

1) **Grass**: producer, the first trophic level; the green plant that makes its own food and captures the energy that feeds the whole chain.

2) **Mouse**: primary consumer, the second trophic level; a herbivore that eats the grass and its seeds.
3) **Snake**: secondary consumer, the third trophic level; a carnivore that eats the mouse.
4) **Mongoose**: tertiary consumer, the fourth trophic level; a carnivore that hunts and eats the snake.
5) **Eagle**: top carnivore, the fifth trophic level; it eats the mongoose and is itself eaten by nothing.

Each arrow points from the organism eaten to the one that eats it, and the chain climbs one trophic level at every step, from the producer grass to the top carnivore eagle.

False Confidence Alert
The arrows in a food chain are often drawn the wrong way round. Each arrow points from the organism that is eaten to the one that eats it, showing the direction in which energy flows, not the direction in which a hunter reaches for its meal.

Question 100

A single chain cannot show all the feeding links in a real grassland, where most animals eat more than one kind of food. Draw a simple savanna food web, then trace two different routes by which energy can pass from the grass to a top carnivore.

Model Answer

A food web joins several food chains together, showing that one kind of organism may be eaten by more than one feeder, so that energy can travel from the grass to a top carnivore by more than one route.

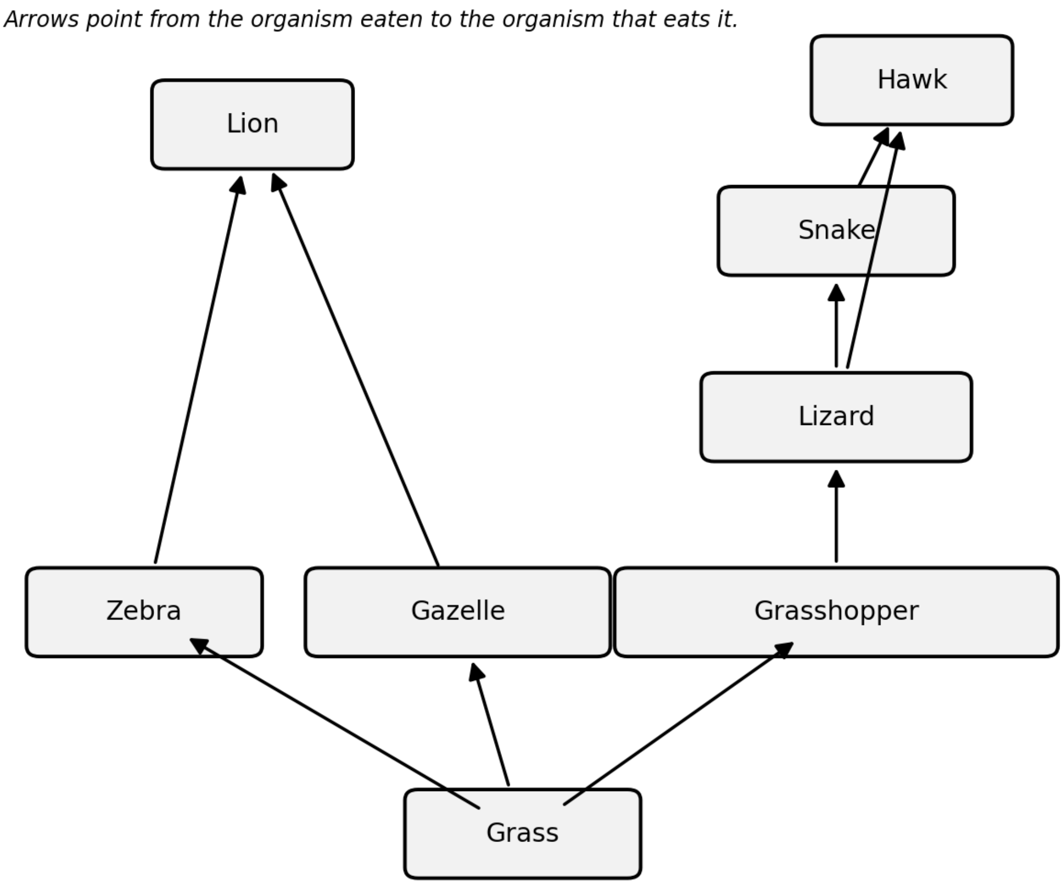


Figure 7.14: *A simple savanna food web; energy can pass from the grass to a top carnivore by several routes.*

Two routes by which energy passes from the grass to a top carnivore are these.

1) **Grass to lion**: the grass is grazed by the zebra, and the zebra is killed and eaten by the lion.
2) **Grass to hawk**: the grass is eaten by the grasshopper, the grasshopper by the lizard, the lizard by the snake, and the snake by the hawk.

Because the web offers several such paths, the loss of any one link need not cut a top carnivore off from the grass. **That overlap of many chains is exactly what makes a food web more stable than any single chain.**

False Confidence Alert
A food web is sometimes read as a set of separate chains that happen to share a page. It is one connected network: the same grass and the same animals belong to several chains at once, and that overlap is what gives the web its many routes and its resilience.

Question 101

An ecologist surveys one hectare of grassland and counts, at each feeding level, about 60 000 grass plants, 9 000 grasshoppers that feed on them, 300 lizards that eat the grasshoppers, and 6 hawks at the top. Using these figures, describe the pyramid of numbers you would draw from them, and explain what its shape tells you about the grassland.

Model Answer

Drawn to these figures, as in Figure 7.15, the pyramid of numbers is upright and narrows very steeply, each bar far shorter than the one below it, because the number of organisms falls sharply at every step up the chain.

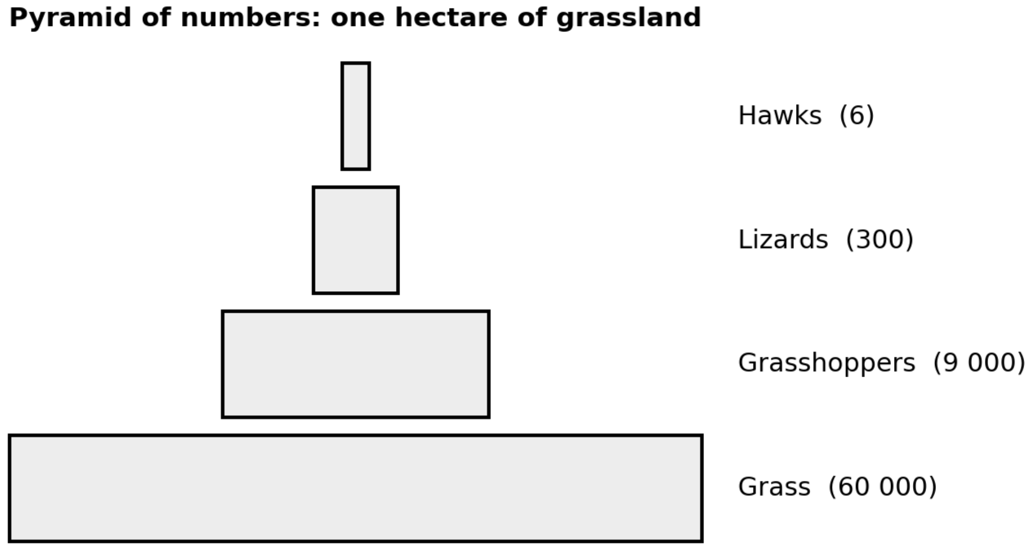


Figure 7.15: *The pyramid of numbers for one hectare of grassland; the count falls steeply from a broad base of grass to only a few hawks.*

In the pyramid above, each bar is drawn to the count at its level, with the producers at the base and the top carnivores at the top: the 60 000 grass plants make a broad base, the 9 000 grasshoppers a much narrower bar above it, the 300 lizards a far narrower one again, and the 6 hawks only a thin sliver at the very top.

The steepness of the narrowing is the message. Because only about a tenth of the energy passes from one level to the next, each level can support far fewer organisms than the one below, so a single hectare that carries tens of thousands of grass plants can keep only a handful of hawks. **The shape says at a glance that top predators must always be few, for the chain beneath them can spare only a tiny share of its numbers.**

False Confidence Alert
It is tempting to read the mere six hawks as a sign that the grassland is poor or failing. A healthy chain always tapers to a few top predators, because energy is lost at every step; the small number at the top is normal, not a warning.

Question 102

An ecologist draws a pyramid of numbers for a single large fig tree, placing the one tree at the base, the thousands of leaf-eating insects above it, and the still greater number of tiny parasites above them, so that the pyramid is widest at the top. Kipanga says the drawing must be wrong, because a pyramid can only ever be widest at the bottom. Kipute says it is perfectly correct. Judge who is right, and explain.

Model Answer

Kipute is right: a pyramid of numbers can indeed be inverted, widest at the top, and the fig-tree drawing, shown in Figure 7.16, is a correct example of it.

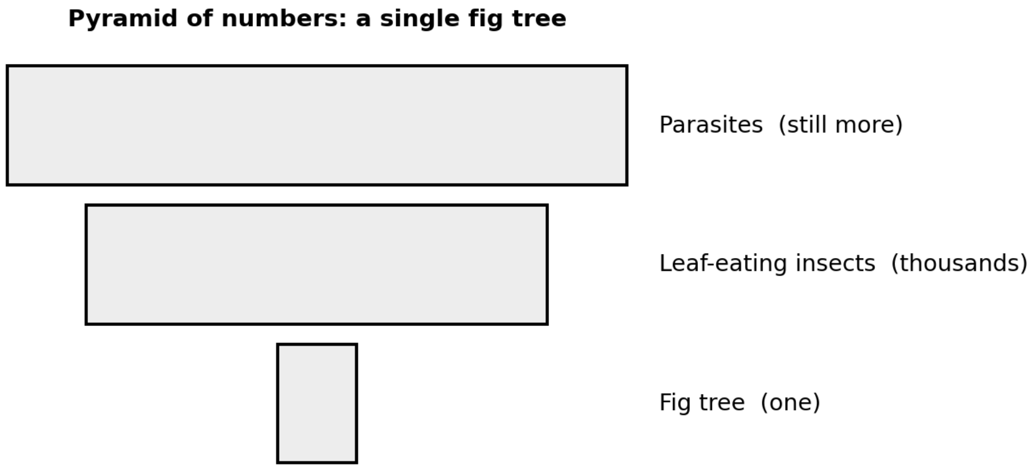


Figure 7.16: *An inverted pyramid of numbers: one large fig tree supports thousands of insects, and those in turn still more parasites.*

A pyramid of numbers counts only the individuals at each level and takes no account of their size. When one very large producer, a single fig tree, feeds a huge number of small consumers, the base bar of one tree is tiny while the bar of thousands of insects above it is enormous, so the pyramid turns upside down; and it widens again where each insect carries many smaller parasites. Kipanga's rule that a pyramid must be widest at the bottom holds only for the pyramid of energy, not for numbers.

Because the pyramid of numbers ignores the size of the organisms, one big plant feeding many small animals stands it on its head. **The inverted drawing is not a mistake but exactly what such a community looks like when its individuals are counted.**

False Confidence Alert
Kipanga's error is to treat 'widest at the bottom' as a law for every pyramid. It is a law only for the pyramid of energy; pyramids of numbers, and of biomass, can and do invert whenever a few large organisms support many small ones.

Question 103

In a sample from Lake Victoria the mass of the floating phytoplankton present at one moment is about 4 grams beneath each square metre, while the zooplankton and small fish that feed on them come to about 6 grams beneath the same square metre. Drawn as a pyramid of biomass the base is therefore lighter than the level it feeds. Explain how the producers can weigh less than the consumers they support.

Model Answer

The phytoplankton can weigh less than the animals they feed because they are eaten and replaced so quickly that only a small mass of them is ever present at one moment, even though the total mass they produce over time is very large. A pyramid of biomass drawn from a single sample shows only the standing crop, the mass present at that instant, and not the mass produced over the whole season. The phytoplankton are tiny, short-lived plants that grow, reproduce and are grazed within days, so at any one moment only a thin layer of them is in the water; but they are renewed again and again, and that steady stream of new growth is more than enough to feed the longer-lived zooplankton and fish above them, whose own bodies build up and linger in the water.

So at the instant of sampling the consumers outweigh the producers, and the pyramid stands on its head. **It is the rapid turnover of the phytoplankton, not any shortage of food, that inverts the pyramid: a small standing crop can still feed a larger one above it when it is replaced fast enough.**

False Confidence Alert
An inverted biomass pyramid looks as though the chain is breaking the rule that energy must dwindle upward. It is not: measured over a whole season the producers still make far more than the consumers; only the snapshot of standing mass is inverted, because the tiny producers are renewed so fast.

Question 104

Kipanga proudly shows a pyramid of energy he has drawn for a pond, and in his drawing the top carnivores hold more energy than the producers, so that the pyramid is upside down. Without even seeing his pond, explain how you can be sure he has made a mistake, and say what he has most likely done wrong.

Model Answer

Kipanga must have made a mistake, because a true pyramid of energy can never be inverted: each level passes on only part of the energy it receives, so every level above must hold less energy, not more. Energy enters a community at the producers and flows one way up the chain, and at every step most of it is lost as heat in respiration and carried off in waste, so only about a tenth reaches the next level. A higher level therefore cannot possibly contain more energy than the one beneath it, and the pyramid of energy is always broad at the base and narrows upward. If Kipanga's drawing shows more energy at the top, his figures cannot be true energy figures.

Most likely he has plotted the wrong measure, the numbers of organisms or their standing biomass at one moment, either of which can invert, and has labelled it energy by mistake. **A genuine pyramid of energy is upright by the very law of energy loss; an inverted one is a sure sign that numbers or biomass, and not energy, were measured.**

False Confidence Alert
It is tempting to accept any neatly drawn pyramid at face value. A pyramid of energy that comes out inverted is impossible by the law of energy loss; whenever you meet one, the measure plotted was numbers or biomass, not the rate of energy flow.

Question 105

A development worker argues that a given piece of land can feed many more people if they eat its maize directly than if the maize is fed to cattle and the people eat the beef. Using the idea of energy loss along a food chain, explain why eating crops directly feeds more people than eating the meat of animals raised on those crops.

Model Answer

Eating the maize directly feeds more people because each extra step in a food chain wastes most of the energy, so feeding the maize to cattle first throws away about nine tenths of its food energy before it ever reaches a person. The maize plants capture the energy of the Sun and store it as food. If people eat the maize, they stand only one short step from the producer and receive most of that stored energy. If instead the maize is fed to cattle and the people eat the beef, a whole extra level has been added: the cattle spend most of the maize's energy on their own respiration, movement and warmth, and lock only about a tenth of it into the meat that the people finally eat.

The same field of maize therefore yields far less human food as beef than as grain, because the animal step has burned most of the energy away. **Every trophic level added between the crop and the plate wastes most of the energy, so a land short of food feeds the most people when they eat low on the chain, close to the plants themselves.**

False Confidence Alert
It is tempting to think that meat, being the richer food, must feed more people from the same land. The opposite is true: raising animals adds a step that loses about nine tenths of the energy, so the same land feeds far fewer people through meat than through the crop eaten directly.

Question 106

Succession is often said to be driven by the organisms themselves: each community changes its own surroundings until it can no longer thrive there, while the next community can. Taking a bare rock surface through to woodland, explain how each stage alters the site so that the stage after it is able to move in.

Model Answer

Each stage of a succession changes the site, above all by building and enriching the soil and by altering the shade and moisture, in ways that make the ground less suitable for itself but more suitable for the larger plants that follow. The first colonisers of bare rock, the lichens and then the mosses, cling where nothing else can; as they grow, die and decay they slowly etch the rock and add the first scraps of organic matter, beginning a thin skin of soil that holds a little moisture. On this thin soil small grasses and herbs can at last root, and these add far more dead matter, deepen the soil and shade the ground, so that the place is no longer the bare, dry, sunlit rock the pioneers needed but a richer, moister, shadier one. Shrubs and small trees then take hold in the deeper soil, casting heavier shade and dropping still more litter, until the soil is deep and rich enough to carry the tall trees of the woodland.

At every step the residents improve the soil and soften the conditions near the ground, and in doing so they prepare the way for taller plants that will shade them out. **Succession advances because each community, by changing the site, makes it fit for its own successor and unfit for itself.**

False Confidence Alert
It is tempting to picture succession as merely new plants arriving and winning by being stronger. The deeper cause is that each stage changes the site itself, building soil and shade, so it engineers the very conditions its successors need while undermining its own; the change in the ground drives the change in the community.

Question 107

On the slopes of a Tanzanian volcano such as Kilimanjaro, old lava flows once hardened into bare rock, and ecologists say it can take centuries for such bare rock to come to carry mature woodland. Explain why primary succession on a bare lava flow is so slow.

Model Answer

Primary succession on bare lava is so slow because there is no soil to begin with, and the making of soil from naked rock, the step on which all the later stages wait, takes a very long time. A hardened lava flow offers no soil, no nutrients in a form a plant can use, little hold for water and no seed bank, only hard rock baked in the sun, so nothing with roots can grow on it. The first colonisers must therefore be lichens and mosses, which can live on bare rock, and they begin the slow work of breaking it down: their action together with the sun, rain and frost cracks and crumbles the surface, while their dead remains add the first traces of organic matter. Soil forms only a little at a time in this way, and until enough of it has gathered to hold water and nutrients, no grass, shrub or tree can root and the succession cannot move on.

Because every later stage must wait on this slow deepening of the soil, the whole sequence from bare rock to woodland is stretched across centuries. **It is the building of soil from solid rock, grain by grain, that sets the pace.**

False Confidence Alert
It is tempting to think the lava is slow to green because seeds are slow to arrive. Seeds may blow in at any time; what they lack is soil to root in. The long wait is for the pioneers to weather the rock into enough soil, not for the seeds to come.

Question 108

After a dry-season fire sweeps through a miombo woodland, the blackened ground is green again within a few seasons, far sooner than bare rock could ever come to carry woodland. Explain how a burnt *miombo* woodland regrows, and why this secondary succession is so much faster than primary succession.

Model Answer

A burnt miombo woodland regrows quickly because the fire destroys only the plants standing above the ground, not the soil beneath them, so the succession begins again on ready-made fertile ground instead of having to build soil from nothing. When fire passes through miombo it scorches the leaves and grass, but the soil survives, and with it the seeds lying in the ground and, above all, the living roots and underground stems of the trees and grasses. Within a season the grasses and herbs spring up again from these surviving rootstocks and seeds, while the miombo trees themselves resprout from their unburnt roots and stumps rather than having to grow afresh from seed. Because the soil, the seed bank and the rootstocks are all still in place, the long, slow stages of weathering rock and forming soil are skipped entirely, and the community rebuilds itself from a far advanced starting point.

Secondary succession is fast because it begins with the soil already made and life already present in the ground. **Primary succession is slow for the opposite reason: it must first create the very soil that secondary succession inherits.**

> **False Confidence Alert**
> It is tempting to credit the quick recovery to kinder weather or richer rainfall. The real reason is the starting point: the soil, its seed bank and the living rootstocks all survive the fire, so secondary succession leaps over the soil-building stages that make primary succession so slow.

Question 109

In one year a colony of 4000 weaver birds has 1200 chicks hatch and 700 adults die, while 300 birds fly in from neighbouring colonies and 500 leave to settle elsewhere. Work out whether the colony is growing or shrinking over the year, and by how much, and explain which processes you have weighed against which.

Model Answer

A population grows when its births and arrivals together outnumber its deaths and departures; weighed out here, the weaver-bird colony grows by 300 over the year.

Gains = births + immigration = 1200 + 300 = 1500

Losses = deaths + emigration = 700 + 500 = 1200

Change = gains − losses = 1500 − 1200 = +300 birds

Four processes set the size of any population: natality (births) and immigration (arrivals) add to it, while mortality (deaths) and emigration (departures) take from it. Here the 1200 chicks and 300 incomers make 1500 added, against the 700 deaths and 500 leavers that make 1200 lost. Because the gains outweigh the losses, the colony rises, from 4000 to 4300 by the end of the year. **It is the balance of all four, not births alone, that decides whether a population climbs or falls.**

> **False Confidence Alert**
> It is tempting to weigh only births against deaths and forget the movement of individuals. Immigration and emigration count just as much; a population with more births than deaths can still shrink if enough of its members leave it.

Question 110

A junior student watches the tilapia in a fish pond multiply quickly at first and then level off, and asks you why they have stopped increasing even though the fish are plainly still breeding. Explain, as you would to that student, why a growing population settles at a steady level instead of rising forever.

Model Answer

The population levels off not because breeding has stopped but because the pond can feed and hold only so many fish, so that, as it fills, deaths rise until they match births and the numbers hold steady. At first a few fish have plenty of food, space and oxygen, so most of the young survive and the numbers shoot up. But the pond is only so big: as the fish grow crowded, food runs short, waste builds up, and disease and competition take a heavier toll, so more of the young now die. This growing push-back from the crowded surroundings is the environmental resistance, and the largest number the pond can support for good is its carrying capacity.

The fish go on breeding as briskly as ever; it is simply that, in the crowded pond, as many now die as are born, so the population stops climbing and holds level. It is like a daladala filling up: people keep trying to board, but once it is full, one can get on only as another gets off, so the number inside stays the same although people are always coming and going. **A population steadies when births and deaths come into balance at the carrying capacity, not because its members have stopped breeding.**

False Confidence Alert
The natural guess, and the junior student's, is that the animals must have stopped breeding. They have not: breeding goes on, but the crowded surroundings now kill as many as are born, and it is that balance, not any halt in breeding, that holds the numbers level.

Question 111

Tanzania's 2022 census counted about 61.7 million people, up from about 34 million only twenty years before. Analyse the main causes of so rapid a rise in human numbers, and the problems it can bring if the resources of the country do not grow as fast.

Model Answer

Numbers rise so fast mainly because births far outnumber deaths, as a high birth rate meets a falling death rate, and the rise brings hardship when many more people must be fed, housed and employed from a resource base that grows far more slowly.

The main causes are these:

A high birth rate: large families are still common, many people marry young, and a large share of the people are themselves young and of child-bearing age.

A falling death rate: better health care, vaccination, cleaner water and more reliable food have cut deaths, above all of infants, so far more children now survive to grow up and have children of their own.

The problems it can bring include:

Pressure on food and land: more mouths to feed push farming onto poorer ground and clear forests, while family plots are divided into ever smaller pieces.

Strain on services: schools, clinics, housing and water supplies must serve far more people, and may fall short.

Too few jobs: the economy may not create enough work for the swelling number of young people reaching working age.

Damage to the environment: heavier demand for firewood, grazing and water brings deforestation, soil erosion and overgrazing.

When people multiply faster than the food, land and work that must support them, the rising numbers press ever harder on a resource base that cannot keep pace.

False Confidence Alert
It is tempting to blame a population explosion on a high birth rate alone. The surge comes from the GAP between births and deaths: birth rates stayed high while death rates fell sharply, so it is the widening gap, not a high birth rate by itself, that drives the numbers up.

Question 112

The chaparral and the tropical savanna are two distinctive biomes found in different regions of the world. Describe each of these biomes by its climate, its plants and its animals, and say where in the world each is found.

Model Answer

Each biome is set by its own pattern of temperature and rainfall: the chaparral is a dry, shrubby biome of mild Mediterranean climates, while the tropical savanna is a warm grassland of strongly seasonal tropical rains.

The chaparral: its climate is Mediterranean, with hot dry summers and mild wet winters; its plants are low, tough, evergreen shrubs with small, hard, leathery leaves that resist drought and fire; its animals include browsing deer, rodents, lizards, snakes and many birds. It is found around the Mediterranean Sea and in similar climates in California, central Chile, the Cape of South Africa and south-western Australia.

The tropical savanna: its climate is warm all year, with a marked wet season and a long dry season; its vegetation is tall grasses dotted with scattered drought-resistant trees such as the acacia and the baobab; its animals include great herds of grazing herbivores, among them zebra, wildebeest and antelope, and the lions, cheetahs and hyenas that hunt them. It is found across tropical Africa, including Tanzania, and in parts of South America, northern Australia and India.

Each biome is the living signature of its climate: the fire-hardened evergreen shrubs of the dry-summer chaparral, and the grass-and-acacia plains of the wet-and-dry tropical savanna.

False Confidence Alert
It is tempting to expect the chaparral, being dry in summer, to look like a desert. It is not a desert but a dense shrubland; its mild, wet winters give it enough rain for a thick cover of evergreen bushes, far more plant life than a true desert can carry.

Question 113

Density-dependent factors are said to regulate a population from within, tightening their hold as it grows more crowded and easing as it thins. Explain how predation, parasitism and competition each work in this self-regulating way.

Model Answer

Each of these factors bites harder as a population grows denser and slackens as it thins, so that each pushes a crowded population down and lets a sparse one recover, holding the numbers around a steady level.

Predation: as prey grow numerous they are easier for predators to find and catch, and predators gather and breed where prey are plentiful, so a denser prey population loses a greater share to them; as the prey thin, the predators take fewer and the prey can recover.

Parasitism and disease: parasites and the diseases they carry pass most easily where hosts are crowded and often in contact, so a dense population suffers heavier infection and death, while in a sparse one the parasite spreads slowly and does far less harm.

Competition: where the population is dense each individual wins a smaller share of the limited food, water and space, so more starve or fail to breed; where it is sparse the same resources go round easily and more survive.

Because all three press hardest just when the population is largest and relax when it is small, they act as a brake that keeps the numbers near the level the surroundings can support.

False Confidence Alert
It is tempting to think these factors simply kill a fixed number of animals. What makes them regulating is that they take a greater share as the population grows denser; it is this changing grip, tightening with crowding and loosening without it, that steadies the numbers.

Question 114

An examiner lists three events that have struck different populations: a severe drought, a sweeping wildfire and an oil spill along a coast. Classify each as a density-dependent or a density-independent factor, and justify your choice.

Model Answer

All three are density-independent factors, because each strikes with a force that owes nothing to how crowded the population is: a sparse population suffers as surely as a dense one.

The drought: density-independent, because the failure of the rains parches the land and kills whether the animals are few or many; the size of the population does nothing to bring on the drought or to soften it.

The wildfire: density-independent, because the fire sweeps through and destroys what lies in its path regardless of how dense the population is; being few in number is no protection from it.

The oil spill: density-independent, because the spreading oil poisons and smothers the shore life it reaches whatever its density; the disaster comes from outside and bears no relation to the population's own size.

Each is an abiotic blow from outside that falls regardless of crowding, which is just what marks a factor as density-independent. **A density-dependent factor, by contrast, such as disease or competition, would bite harder only as the population grew dense.**

False Confidence Alert
It is tempting to call a wildfire density-dependent because thick vegetation burns more fiercely. The test is whether the effect depends on the density of the affected population, and it does not: the fire kills the crowded and the scattered alike, so it is density-independent.

Question 115

A few yeast cells are added to a fresh, sugar-rich solution and counted each hour. The counts run 100, 200, 400, 800, 1600, 3200, and onward in the same way. Describe the pattern of growth these figures show, name it, and explain both why it arises and why it cannot continue for long.

Model Answer

The numbers double every hour, so the population grows by an ever-larger amount at each step; this is exponential, or J-shaped, growth, shown in Figure 7.17, and it cannot last because the yeast soon use up the very conditions that allow it.

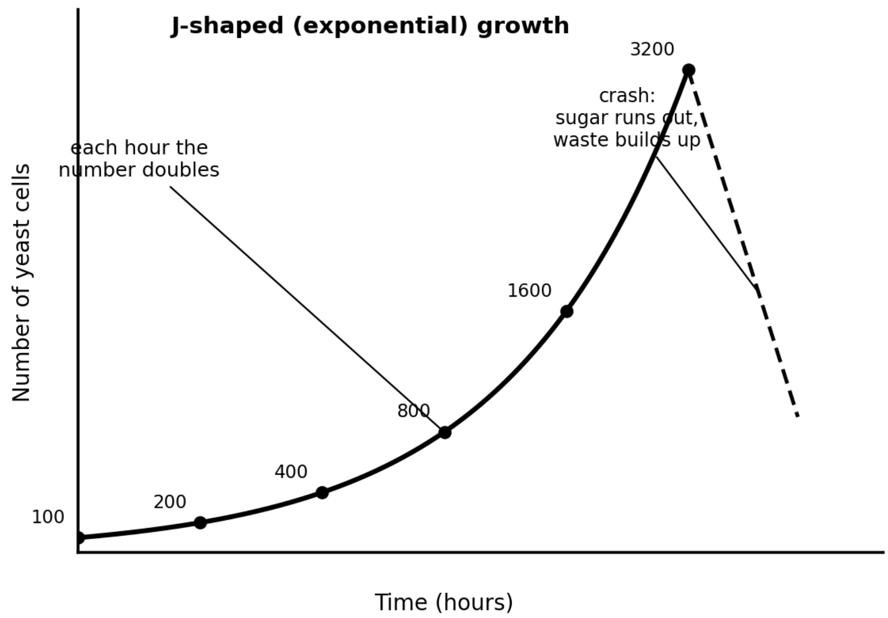


Figure 7.17: *The J-shaped (exponential) growth of the yeast: the number doubles each hour, then crashes once the sugar runs out and waste builds up.*

Each figure is twice the one before, 100 to 200 to 400 and so on, so although the population starts small it climbs faster and faster; plotted against time, as the curve shows, it sweeps upward in the shape of the letter J. Growth like this arises whenever conditions are ideal and unchecked: every cell divides to give two, those two give four, and with plenty of sugar, ample room and nothing to hold them back the doubling simply repeats.

But a closed solution holds only so much sugar and can take up only so much waste. Before long the sugar runs low while the yeast's own waste, including alcohol, builds up and poisons them, so the rise halts and the population crashes. **Exponential growth is the runaway doubling of a population set free of limits; it is always brief, because the population soon exhausts or poisons its surroundings and collapses.**

False Confidence Alert
It is tempting to read steady doubling as a population that will simply go on rising. None can: exponential growth always outruns its resources, and the J-shaped climb ends in a sharp crash once food runs out or waste builds up.

Question 116

Both the J-shaped and the S-shaped curve describe how a population can grow over time, yet they end quite differently. Give two clear differences between the S-shaped (sigmoid) curve and the J-shaped (exponential) curve.

Model Answer

The two curves differ above all in how they end, and in whether the environment is allowed to check the growth along the way.

How each ends: the J-shaped curve rises faster and faster without check and then crashes suddenly when its resources fail, whereas the S-shaped curve rises steeply at first but then levels off and settles at a steady plateau, its carrying capacity.

The action of environmental resistance: in the J-shaped curve the surroundings put up no brake until the abrupt collapse, while in the S-shaped curve environmental resistance builds up steadily as the population grows, slowing the rise smoothly until births and deaths come into balance.

In short, the J-curve is unchecked growth that ends in a crash, while the S-curve is growth brought gently to a stable ceiling by the resistance of the environment.

False Confidence Alert
It is tempting to think the two curves differ only in their shape. The deeper difference is what happens at the top: the J-curve overshoots and crashes because nothing slowed it, while the S-curve levels off because environmental resistance checked it in good time.

Question 117

A community living beside one of the Eastern Arc forests is asked to set down what the forest is worth to them. Set out, with Tanzanian examples, both the direct (tangible) and the indirect (intangible) benefits that such a forest provides.

Model Answer

A forest gives direct benefits, the material goods that can be taken from it and counted in money, and indirect benefits, the services it quietly performs that are never bought or sold yet are just as vital.

The direct (tangible) benefits include:

1) **Timber and wood**: hardwoods such as mpingo and mninga for carving and furniture, poles for building, and firewood and charcoal for fuel.
2) **Food and medicine**: wild fruits, honey, mushrooms and game meat, and the many plants gathered for traditional medicine.

The indirect (intangible) benefits include:

1) **Water catchment**: the Eastern Arc forests catch and store the rain and release it steadily to the rivers and dams that supply towns and farms below.
2) **Soil protection**: the tree roots and the leaf litter bind the steep slopes and stop the soil being washed away.
3) **Air and climate**: the trees take in carbon dioxide and give out oxygen, store carbon, and cool and moisten the climate around them.
4) **Habitat and tourism**: the forest shelters rare plants and animals found nowhere else on Earth, drawing scientists and visitors.

The timber and food can be counted in shillings, but the water, the soil and the climate the forest guards are worth far more. **A forest is worth most left standing and used with care, for its hidden services outlast and outvalue anything cut from it.**

False Confidence Alert
It is tempting to value a forest only by the timber and firewood that can be sold from it. Its greatest worth is often the indirect services, the water it stores and the soil it holds, which cost nothing yet would be ruinously dear to replace once the forest is gone.

Question 118

Two of Tanzania's living treasures, the *mpingo tree* (African blackwood) and the black rhinoceros, are under heavy pressure. Explain why each is threatened, and what the loss of each would cost the country.

Model Answer

Both are under pressure because they are being taken faster than they can replace themselves, the mpingo felled for its prized timber and the rhinoceros poached for its horn, and the loss of either would rob Tanzania of something it could never easily recover.

The mpingo: it is a slow-growing hardwood whose dark, dense timber is prized for carvings and musical instruments and sells for high prices abroad, so it is cut far faster than the slow trees can grow back; losing it would end a valuable timber and carving trade, take away a tree of deep cultural use, and strip a species from the woodland it belongs to.

The black rhinoceros: it is hunted illegally for its horn, which fetches huge sums overseas, and because it breeds slowly its numbers have already crashed to a few; losing it would erase a unique animal, cut off the tourist income that living rhinos bring, and break a strand of the savanna community it helps to shape.

In each case a slow-breeding species is being harvested faster than it can renew itself. **Once gone, neither the blackwood tree nor the rhinoceros could be brought back, and its money value and its place in nature would vanish with it.**

False Confidence Alert
It is tempting to weigh such a loss only in lost trade or tourist money. The deeper cost is that it cannot be undone: a species taken to extinction is gone forever, and with it a store of genes and a part in its ecosystem that no amount of money can rebuild.

Question 119

Tanzania protects its plants and animals both in great national parks and, increasingly, in seed and gene banks. Explain why a national park (in-situ) and a seed bank (ex-situ) are complementary strategies that work best together, rather than competing alternatives.

Model Answer

The park and the seed bank protect biodiversity in opposite ways, each able to do what the other cannot, so that together they guard against dangers that neither could meet alone.

What the national park does: it conserves species in-situ, in their own wild home, so that whole communities of plants and animals live on together, keep their natural relationships, and go on adapting and evolving in the wild; but a park can be struck by fire, drought, disease, poaching or war that may destroy what it holds.

What the seed bank does: it conserves species ex-situ, away from the wild, storing seeds or other living material safely so that they survive even if the wild population is lost, and can later be grown to restock a park or restore a habitat; but it cannot keep a living community or let it evolve, and not every species can be banked.

Because the park keeps life living and evolving while the seed bank keeps a safe copy in reserve, the one insures the other. **Used together they protect biodiversity far better than either could alone, which is why they are complementary and not competing.**

False Confidence Alert
It is tempting to treat in-situ and ex-situ conservation as rival choices, one right and one wrong. They guard against different dangers: the park preserves the living, evolving community, the seed bank preserves a backup against its destruction, and biodiversity is safest when both are used.

Question 120

When the alien water hyacinth choked the shores of Lake Victoria, several ways of fighting it were tried before biological control was finally chosen. Describe how the water hyacinth was controlled on the lake, and explain why biological control was preferred.

Model Answer

The water hyacinth was fought by pulling it out by hand and machine, by spraying it with chemicals, and at last by releasing weevils that feed only on it; this last way, biological control, was chosen because it proved cheaper, lasting and safe for the lake.

Mechanical removal: the weed was dragged out by hand and by machines, but it grew back faster than it could be cleared, and the work was endless and costly.

Chemical control: herbicides could kill the weed, but spraying poisons over a lake that people drink from and fish in risked harming the fish, the people and the other life of the water.

Biological control: small weevils that feed only on the water hyacinth were bred and released onto the floating mats; they multiplied, ate into the plants, and brought the weed down to a level that could be lived with.

Biological control was preferred because, once the weevils were established, they spread and went on working by themselves at no further cost, they attacked only the water hyacinth and so spared the fish and other plants, and they gave a lasting check rather than the brief relief of cutting or spraying. **By setting the weed's own natural enemy upon it, biological control gave a cheap, self-sustaining and lake-safe answer where cutting was endless and poisons were dangerous.**

False Confidence Alert
It is tempting to think the surest cure for a weed is to spray it with a strong chemical. On a lake that feeds and waters people, poisons threaten the fish and the community; the weevil, which eats only the hyacinth, removes the weed without poisoning the water.

HOT QUESTIONS

These are the most demanding questions in the chapter, and they cannot be answered by recall alone. Each one asks you to weigh a claim, judge between views, predict a consequence or carry your reasoning into an unfamiliar situation, drawing together ideas from across the whole of ecology. Work slowly and set your reasoning out step by step, and where a question asks for a verdict, give one plainly. As before, the bold opening sentence carries the heart of the answer, and the boxed False Confidence Alert names the trap that catches even strong students.

Question 121

A student reads that nature is held in a balance and concludes that a natural community, once settled, stays fixed and unchanging, the very same species in the very same numbers for ever. Evaluate this claim, and say what the balance of nature really means.

Model Answer

The claim is mistaken: the balance of nature is not a fixed, frozen state but a dynamic balance, in which numbers, and over time even the species present, rise and fall around a working level while the community as a whole holds roughly steady. It is true that a settled community can look much the same from one year to the next, and that is what tempts the student to call it fixed. But nothing in it is actually still: predator and prey numbers rise and fall together in a linked cycle, each tracking the other with a lag, populations climb after good rains and shrink in drought, individuals are born and die without pause, and over longer spans succession and a shifting climate replace one community with another. What stays steady is not the exact count of each species but the overall working of the system, held near a level by the give-and-take of competition, predation, parasitism and cooperation.

The balance is therefore a moving one, restored after each disturbance rather than never disturbed at all, more like a standing person who sways and corrects than like a stone lying at rest. **So the balance of nature is real but dynamic: a community in constant small change, held around a steady level, not a fixed picture that never alters.**

> **False Confidence Alert**
> It is tempting to take the word 'balance' to mean 'unchanging'. The balance of nature is dynamic, a running equilibrium of births, deaths and shifting numbers held near a level by opposing forces; a community that truly stopped changing would be a dead one, not a balanced one.

Question 122

It is sometimes said that ecology is only about protecting wild animals. Judge this claim against what the science of ecology actually covers, and reach a clear verdict.

Model Answer

The claim is far too narrow to stand: protecting wild animals is one application of ecology, but ecology itself is the much wider study of how all living things interact with one another and with their non-living surroundings. It is fair to grant that conservation, the protection of wildlife, draws heavily on ecology and is the part of it the public sees most often. But ecology reaches far beyond animals and far beyond protection. It studies plants, fungi and microbes as fully as animals; it studies the non-living world of soil, water, air and climate and how organisms trade matter and energy with it; and it traces food chains, nutrient cycles, populations and whole ecosystems. Its findings guide farming, fisheries, forestry, pest control, pollution management and public health, not only the running of game parks.

To shrink all of this down to protecting wild animals is to mistake one fruit for the whole tree. **The verdict is that the claim is wrong: wildlife protection is a valuable use of ecology, but ecology is the broad study of the relationships of all life with its environment, of which conservation is only one branch.**

> **False Confidence Alert**
> It is tempting to equate ecology with wildlife conservation, because that is its most visible face. Ecology is the whole study of living things and their environment, plants and microbes included, and it underpins farming, fisheries and pollution control as much as the protection of animals.

Question 123

A hillside runs from a wet streambank at its foot to a dry, rocky ridge at its top, and you are asked to record how the plant community changes up the slope. Justify the sampling design you would choose for this site, and defend your choice against one alternative design.

Model Answer

Because the task is to record how the vegetation changes along the wet-to-dry gradient of the slope, the right design is a transect run straight up the hillside and sampled at intervals, for a transect is made to capture change along a gradient. I would lay a line from the streambank to the ridge and, at marked intervals up it, record the plants in a quadrat placed beside the line, making a belt transect, so that each step up the slope, and so each change in moisture, is sampled in order. This keeps the gradient itself as the backbone of the survey and shows exactly how the community shifts from the damp-loving plants at the foot to the drought-resistant plants at the top.

The obvious alternative, scattering quadrats at random over the whole hillside, would be worse here. Random sampling is meant to remove bias when an area is fairly uniform, but it would mix together plots from the wet foot, the middle slope and the dry ridge with no order, so the very pattern we are after, the change up the slope, would be blurred and lost. **For a site whose whole point is a gradient, a transect is the better design because it follows and reveals that gradient, whereas random sampling, blind to position, would scatter the plots and hide the trend.**

> **False Confidence Alert**
> It is tempting to reach for random sampling every time, because it is the standard cure for bias. On a clear gradient it is the wrong tool: the question is about change with position, and random sampling throws position away, while a transect, which keeps the order up the slope, is exactly what the gradient demands.

Question 124

Two woodland plots are surveyed. In plot A the crown cover (the ground shaded by the tree canopies) is 80 per cent and the ground-layer cover is 25 per cent; in plot B the crown cover is 40 per cent and the ground-layer cover is 70 per cent. From these figures, reason which community is the more closed, and explain why the two sets of figures fit together.

Model Answer

Plot A is the more closed community, because its crown cover of 80 per cent shows that the tree canopies nearly meet overhead and shut the woodland in, whereas plot B, with only 40 per cent crown cover, has an open, broken canopy. Crown cover measures how much of the ground lies under the shade of the tree canopies, so it is the direct measure of how closed the canopy is: the higher the crown cover, the more the crowns touch and the less sky shows through. Plot A at 80 per cent is therefore a closed woodland, and plot B at 40 per cent an open one.

The ground-layer figures fit this exactly and confirm it. In closed plot A the dense canopy lets little light reach the floor, so the ground layer is sparse, only 25 per cent; in open plot B much more light comes through the broken canopy, so a thick ground layer of grasses and herbs grows, 70 per cent. **A community is closed when its canopy is closed, which the crown cover reports directly; the bare floor of plot A is the shadow of its closed canopy, while the rich ground layer of plot B is the sign of the light let in by its open one.**

> **False Confidence Alert**
> It is tempting to judge how closed a community is by how much plant cover lies on the ground, and so to call leafy plot B the more closed. It is the crown cover that measures closure; a high ground cover usually means an open canopy that has let the light in, not a closed one.

Question 125

An ecologist in a hurry samples a smaller area than the species-area curve shows to be the minimal area, and reports the number of species he finds as the diversity of the site. Explain why sampling below the minimal area would mislead his estimate of the site's biodiversity.

Model Answer

Sampling below the minimal area misleads because such a small area has not yet taken in all the species of the community, so it yields too low a count and understates the true diversity. The species-area curve rises steeply at first, as each fresh patch of ground turns up species not seen before, and it levels off only once the area is large enough that almost no new species are added; that levelling-off point is the minimal area, the smallest area that holds a fair sample of the community. Below it the curve is still climbing, which means species are still being missed, in particular the rarer and patchier ones that a small area happens not to include.

An ecologist who stops short therefore counts only the commoner species and reports a diversity lower than the site really holds. Worse, if he compares two sites each sampled below their minimal areas, the comparison is unfair, because the counts then depend as much on how much ground was searched as on the sites themselves. **Below the minimal area the species are still being discovered, so any count taken there is an underestimate, and counts from different-sized scraps of ground cannot fairly be set side by side.**

> **False Confidence Alert**
> It is tempting to think any sample, if taken carefully, gives a fair count of species. The area itself matters: below the minimal area the rarer species are simply not yet included, so the diversity is undercounted, and samples of different sizes cannot fairly be compared.

Question 126

The Lincoln index trusts that the marked animals released back into a population behave just like the rest. Reason through what happens to the estimate if, instead, the marks are lost, or the marked animals do not mix back among the others, or the marking itself shortens their lives.

Model Answer

Each of these breaks an assumption the Lincoln index depends on, and each throws the estimate out, because the index works only if the share of marked animals in the second catch truly mirrors the share of marked animals in the whole population.

If the marks are lost: some animals that were marked are counted as unmarked in the second catch, so the number of recaptures recorded is too small; since the estimate is the first catch times the second divided by the recaptures, too few recaptures make the estimate too large, and the population is overstated.

If the marked animals do not mix back: when the marked animals keep to one area or shun the traps that caught them, the second catch is no longer a fair sample of the whole population, so the proportion of marked animals in it is wrong and the estimate cannot be trusted, coming out too high or too low according to how they have separated.

If the marking shortens their lives: should the mark make the animals easier for predators to spot, or weaken them, more of the marked ones die before the second catch, so once again too few are recaptured and the population is overestimated.

In every case the recaptured fraction no longer matches the true fraction of marked animals, and the Lincoln estimate, which rests entirely on that fraction, is thrown off, usually too high whenever marked animals go missing from the second catch.

> **False Confidence Alert**
> It is tempting to treat the Lincoln figure as a hard count of the population. It is only an estimate, and a fragile one: it holds only if no marks are lost, the marked animals mix back freely, and marking neither helps nor harms survival; break any one of these and the number is wrong.

Question 127

Acid rain, or the heavy use of certain fertilisers, can slowly lower the pH of a soil over the years. Predict how such a drop in soil pH would reshape the community of plants and animals living on that soil, reasoning through the changes step by step.

Model Answer

A drop in soil pH would reshape the community by driving out the plants that need near-neutral soil and favouring the few that tolerate acid, and the change would then pass up the food chain and slow the recycling of nutrients, so that in time a different and poorer community would replace the first. The first to feel it are the plants, for each kind grows only within a certain range of pH. As the soil turns acid, the plants that need neutral or alkaline ground weaken and die out, while acid-tolerant plants spread to take their places, and the mix of species shifts. The change does not stop there: as particular plants vanish, the animals that fed on them or sheltered among them lose their food and homes and must move away or dwindle, so the animal community shifts too.

Meanwhile the falling pH harms the soil itself. Many decomposer bacteria work poorly in acid ground, so dead matter breaks down more slowly and nutrients are released and recycled less freely; and at low pH some nutrients are locked up out of reach while aluminium becomes more soluble and poisons the roots that meet it. **Step by step, then, the acid soil would replace a rich, mixed community with a sparser one of acid-tolerant species fed by a slower nutrient cycle: a single change in one abiotic factor reshaping the whole living community above it.**

False Confidence Alert
It is tempting to think a change in soil pH would touch only the plants. Because the plants feed and shelter the animals, and the soil organisms recycle their remains, a fall in pH ripples through the whole community, animals and decomposers included, and not the plants alone.

Question 128

The competitive-exclusion principle says that when two species compete for exactly the same resource, one is driven out. Yet in nature close competitors very often end up living side by side, each using the resource a little differently. Explain why competition can drive two species apart, into different ways of life, rather than always driving one of them to extinction.

Model Answer

Competition drives two species apart because, where their needs overlap, it is the individuals that differ most from their rivals that compete least and survive best, so over the generations natural selection pushes each species toward a slightly different way of life and the two diverge instead of one dying out. When two species overlap, the fiercest competition falls exactly where they are most alike, on the resource they both want most. Within each species, an individual that happens to take a slightly different food, or to feed at a different height or a different time, escapes some of that competition, finds more to eat and leaves more offspring. Generation after generation, then, selection favours the members of each species that differ most from the other, and the two are slowly driven apart, the one perhaps taking the larger seeds and the other the smaller, until their niches no longer overlap.

This gradual divergence, called character displacement, lets both species persist where complete overlap would have forced one out; exclusion follows only when neither can shift, when the resource cannot be divided and there is nowhere else to go. **So competition does not always end in a single winner: more often it is the very force that separates close species into different niches, and the result is not extinction but coexistence through divergence.**

False Confidence Alert
It is tempting to read competitive exclusion as a law that one competitor must always die out. Exclusion follows only when the species cannot diverge; far more often competition itself drives them apart into separate niches, so that both survive side by side.

Question 129

Food chains in nature rarely have more than four or five links. A student suggests this is simply because the top predators run out of prey to eat. Explain why the real cap on the length of a food chain is the one-way loss of energy at each step, and not a shortage of food.

Model Answer

A food chain is capped at four or five links not because prey run out but because so much energy is lost at every step that, after a few steps, too little is left to support another level of life at all. At each link only about a tenth of the energy is passed on, while the other nine tenths is lost as heat in respiration and carried off in waste. So the energy reaching the second level is about a tenth of the producers', the third level a tenth of that, and by the fourth or fifth level only a tiny fraction of the original energy remains, far too little to feed a population of still higher predators large enough to survive and breed.

The chain ends, then, not for want of animals to be eaten but for want of energy to support an animal that could eat them: a sixth-level predator simply could not gather enough food to live on, because the energy it would need is no longer there. Were energy passed on without loss, chains could run far longer; it is the steady one-way drain that sets the limit. **The length of a food chain is fixed by energy, not by appetite: each step keeps most of the energy and passes on little, so after four or five steps there is not enough left to build another link.**

False Confidence Alert
It is tempting to say chains are short because the top predators run out of prey. The deeper limit is energy: after four or five steps so little of the original energy remains that no further level could gather enough to survive, however much lower-level life there might seem to be.

Question 130

If an ecosystem had to lose one whole trophic level, which could it least afford to lose? Arguing from the way energy flows through an ecosystem, judge which trophic level is the most indispensable, and defend your verdict.

Model Answer

An ecosystem could least afford to lose its producers, because they are the level at which energy enters the system, so that without them every level above would be cut off from its only source of energy and would collapse. Energy flows one way through an ecosystem: it enters only at the producers, the green plants that capture sunlight and fix it into food, and from them it passes up to the herbivores, the carnivores and the top carnivores in turn. Every level above the producers depends entirely on the energy they supply. Remove the top carnivores and the ecosystem is harmed but survives, for the levels below still have their energy and may even flourish; remove the herbivores and the carnivores starve, yet the producers live on and could support a new community.

But remove the producers and there is no longer any way for energy to enter at all: the herbivores starve, and with them everything above, and the whole system falls, for no other level can take the producers' place since none of them can make food from sunlight. **The verdict is clear: the producers are the one level an ecosystem cannot do without, for they are the gateway through which all its energy enters, and every level above is only living on what they first capture.**

False Confidence Alert
It is tempting to name the top carnivore as the most important level, because it seems to rule the others. In terms of energy it is the most dispensable: lose it and the system goes on. Lose the producers, through which all energy enters, and nothing above them can survive.

Question 131

Nitrifying bacteria are a small, unseen part of the soil, yet a poison that killed every one of them would in time ruin the fertility of that soil. Predict and explain the effect on soil fertility of a biocide that wiped out all the nitrifying bacteria.

Model Answer

Killing every nitrifying bacterium would, before long, starve the plants of usable nitrogen and so ruin the soil's fertility, because nitrification is the step that turns ammonia into the nitrate that plant roots mainly take up. In the nitrogen cycle the decomposers break the nitrogen of dead matter and waste down into ammonia, but plants cannot use most of that ammonia directly; it is the nitrifying bacteria that convert it, first into nitrite and then into nitrate, and nitrate is the form the roots chiefly absorb. Remove the nitrifying bacteria and this conversion stops: ammonia builds up in the soil while the supply of nitrate dries away.

Although decay still goes on, the nitrogen it releases can no longer be turned into the usable form, so the plants, however much dead matter lies around them, are left short of the nitrogen they need to make proteins, and their growth fails; and as the plants suffer, so does the whole community that feeds on them. **The soil would not lose its nitrogen, but it would lose the power to make that nitrogen available: with nitrification broken, the nitrate that crops live on is no longer formed, and fertility collapses.**

> **False Confidence Alert**
> It is tempting to think that as long as dead matter keeps rotting the soil stays fertile. Rotting only releases ammonia; without the nitrifying bacteria to turn it into nitrate, the nitrogen sits in a form most plants cannot use, and the soil grows barren in the midst of plenty.

Question 132

Two species may compete fiercely and yet often survive together by coming to use a resource differently. But suppose two species had exactly the same niche, needing precisely the same things in precisely the same way, with no room to differ. Reasoning from competition, explain why the two could not go on sharing the habitat for long.

Model Answer

Two species with exactly the same niche cannot coexist for long because one of them is bound to be even slightly the better competitor, and that small advantage, repeated generation after generation, must in time drive the other out altogether. When two species need precisely the same resource in the same way, every scrap of food or space that one takes is denied to the other, so they are locked in direct and total competition. No two species are ever exactly equal: one will be a little more efficient at finding food, or breed a little faster, or survive a little better. That species therefore secures a slightly larger share of the resource, leaves slightly more offspring, and comes to the next generation a little more numerous; with its greater numbers it takes a still larger share, and the advantage compounds.

The weaker competitor, left with an ever-smaller share, dwindles steadily until it is gone, and because the niche cannot be divided and the loser has no other way to make a living, there is no escape from this slow defeat. **So where the niches are truly identical, coexistence is impossible: competition magnifies the smallest difference in fitness into the complete exclusion of one species, which is the competitive-exclusion principle at work.**

> **False Confidence Alert**
> It is tempting to think two evenly matched species could simply share a resource for ever. They cannot if their niches are identical: no two species are ever exactly equal, and competition turns the slightest edge into a growing advantage that ends in the other's exclusion.

Question 133

An ecologist argues that a food web with many cross-links is far more stable than a single, simple food chain. Explain why a community whose feeding links form a richly connected web is better able to withstand the loss of a species than one whose organisms are strung along a single chain.

Model Answer

A richly connected web is more stable because its many cross-links give each feeder more than one source of food, so the loss of any one species can be made good by others, whereas in a single chain every organism has only one food and one feeder, so one break destroys everything above it. In a single food chain each link depends utterly on the one below it: if the one prey species of some animal dies out, that animal has nothing else to turn to and starves, and so does everything that fed on it, so the whole chain above the broken link collapses. In a food web the same animal eats several kinds of prey and is itself eaten by several kinds of predator. If one of its prey species is lost, it simply takes more of the others; if one of its predators disappears, the prey it would have eaten are shared among the rest.

These alternative routes mean that energy can still flow from the producers to the top even when a species is removed, because the web simply reroutes around the gap. **The web survives a loss that would break a chain because it offers detours the chain does not: many links mean many ways for the energy to keep flowing, so no single loss brings the whole community down.**

False Confidence Alert
It is tempting to think a simpler chain is somehow sturdier. The opposite is true: a single chain is fragile because each organism has just one food source, while a web, with its many alternative links, can absorb a loss and reroute the flow of energy around it.

Question 134

In a savanna where lions are the top predators, suppose the lions were all removed, by hunting or by disease. Predict the train of effects this single loss could set off through the community, and explain why removing a top predator can disturb far more than the predator itself.

Model Answer

Removing the lions would let the herbivores they once held in check multiply unchecked, and the swollen herds would then overgraze the grassland, so that in time the loss of the predator could damage the plants, the soil and even, by destroying their own food, the herbivores themselves. The lions normally crop the numbers of the grazing animals, the zebra, wildebeest and antelope, keeping them within what the grassland can feed. Take the lions away and nothing checks the grazers, so their numbers climb. The growing herds eat the grasses faster than the grasses can recover, and the grassland is stripped and begins to fail, while the bared soil, no longer held by plant cover, may start to erode.

As their food collapses, the over-large herds in turn starve and their numbers crash, and the other animals that depended on the grassland, from insects to ground-nesting birds, are struck as their habitat is destroyed. A change aimed at one species has run right through the community. **So a top predator does far more than feed itself: by holding the herbivores in check it guards the plants beneath them, and removing it can unleash a cascade of overgrazing, erosion and collapse, a knock-on through the levels that ecologists call a trophic cascade.**

False Confidence Alert
It is tempting to think removing a predator simply means more of its prey, which sounds harmless or even welcome. The prey boom overgrazes and wrecks the vegetation that feeds them and shelters others, so the loss of one predator can ripple down into a collapse far larger than the predator itself.

Question 135

An ecologist samples a pond and finds, to her surprise, that the total mass of the tiny floating plants at the base is less than the mass of the animals that feed on them. Without taking any further measurements, what can she infer from this inverted pyramid of biomass about the rate at which the plants at the base reproduce?

Model Answer

From the inverted pyramid alone she can infer that the plants at the base must reproduce and be replaced extremely fast, far faster than the animals above them, because that is the only way so small a standing mass could feed so large a one. A pyramid of biomass shows only the standing crop, the mass present at the moment of sampling, and not the mass made over time. For the base to weigh less than the level it feeds and yet still feed it, the base cannot merely be sitting there; it must be turning over rapidly, growing, breeding and being eaten and then growing again, so that a small mass present at any instant yields, over days and weeks, far more living material than its size suggests. The animals above, being larger and longer-lived, breed and turn over slowly, so their mass piles up and lingers.

The inverted shape is therefore a direct sign of a fast-breeding, short-lived, high-turnover base holding up a slow, long-lived top. **An upside-down biomass pyramid is the fingerprint of rapid reproduction at**

the base: only producers that renew themselves very quickly can support a greater mass of consumers on a smaller mass of their own.

False Confidence Alert
It is tempting to read the small plant mass as a sign that food is scarce and the pond unproductive. It means the opposite: the base is so productive, breeding and being eaten so fast, that only a little of it is ever present at once, yet it makes more than enough to feed the animals above.

Question 136

A true pyramid of energy can never be inverted. Suppose, then, that an ecologist measured the actual energy flow at each level of a community and the pyramid still came out inverted, with more energy above than below. Taking the figures as genuine, what would such an inverted energy pyramid tell you about the state of that community?

Model Answer

Taken as genuine, an inverted energy pyramid would be a danger sign: it would mean the producers are no longer capturing enough energy to support the levels above them, so the community is living beyond its means, drawing on a falling store or on energy brought in from outside, and is heading for collapse. In a healthy, self-supporting community energy enters at the producers and dwindles upward, so the base always carries the most, which is why a true energy pyramid cannot invert. If the measured energy at the base is really less than that above, the base is no longer doing its work: the producers may have been struck down by pollution, drought or overgrazing, so that they now fix far less energy than the consumers are using.

The consumers can keep going for a while only by eating into the standing stock faster than it is renewed, or by feeding on dead matter and energy washed or blown in from elsewhere, and neither can last: a community spending energy faster than its producers can capture it is running down. **An inverted energy pyramid, if the figures are sound, marks a community out of balance, its producer base failing and its consumers living on borrowed or imported energy: a system in trouble that must recover its producers or collapse.**

False Confidence Alert
It is tempting to treat an inverted energy pyramid as just another shape a pyramid might take, like the inverted pyramid of numbers. Energy is different: it cannot truly invert in a healthy system, so a genuine inverted energy pyramid is not a curiosity but a warning that the community's energy base is failing.

Question 137

When ecologists wish to compare two very different ecosystems, a forest and a lake for instance, they prefer the pyramid of energy to the pyramids of numbers or of biomass. Explain why energy, rather than the number of organisms or their mass, is the truest common currency for comparing ecosystems.

Model Answer

Energy is the truest currency because, unlike the number of organisms or their mass, it measures the actual flow that drives every ecosystem, in the same units everywhere, and it never inverts or misleads, so it lets two quite different systems be compared on a single fair scale. Counting numbers is the crudest measure, for it treats every organism as equal, a single tree weighed against a single bacterium, so that the same community can look upright or upside-down according only to the sizes of its members; numbers cannot fairly compare a forest of a few huge trees with a lake of countless tiny plants. Biomass is better, for it weighs the living material, but it captures only the standing crop at one moment and so can itself invert where a small, fast-breeding base supports a larger top, again misleading the comparison.

Energy escapes both faults: measured as the rate of energy flow through each level, in units of energy per area per year, it records what every ecosystem actually runs on, it is the same measure in a forest and a lake alike, and because energy is always lost upward it never inverts. **Numbers ignore size and mass ignores time, and both can stand on their heads; energy, the common fuel of all life, measured in the same**

units and always dwindling upward, is the one currency on which any two ecosystems can be fairly weighed.

> **False Confidence Alert**
> It is tempting to compare ecosystems by how many organisms or how much life they carry. Those measures depend on the sizes and the timing of the organisms and can mislead; only energy, the flow that every ecosystem depends on, gives a fair and fixed scale for comparing systems as unlike as a forest and a lake.

Question 138

You are asked to choose one kind of ecological pyramid with which to compare a *miombo* woodland and a lake, and to defend your choice against the other two, given that the pyramid you favour may also be the hardest of the three to measure. Which would you choose, and how would you defend it?

Model Answer

I would choose the pyramid of energy, because it alone compares the two ecosystems fairly, and although it is the hardest to measure, that extra effort is the price of an honest comparison the other two cannot give. The pyramid of numbers I would reject at once, for counting heads weighs a miombo tree against a water flea as equals, and so could never sensibly compare a woodland of a few great trees with a lake of countless tiny ones. The pyramid of biomass is better, and far easier to gather, since one need only weigh the standing crop; but its snapshot of mass can invert in the lake, where a small, fast-breeding plant base feeds a larger mass of animals, so it too would compare the two systems unfairly.

The pyramid of energy avoids both traps: by measuring the rate of energy flow through each level it captures what each system truly runs on, in the same units, and it never inverts. Its drawback is real, that energy flow is laborious to measure, needing the productivity at each level over time rather than a simple count or weighing. **Still I would choose energy and bear the labour, for a comparison worth making must be a fair one: numbers and biomass are easier but can deceive, while the pyramid of energy, hard-won though it is, is the only one that lets a woodland and a lake be set honestly side by side.**

> **False Confidence Alert**
> It is tempting to pick the pyramid of biomass because it is so much easier to measure than energy. Ease is not accuracy: biomass can invert and mislead, so for a fair comparison of two unlike ecosystems the harder pyramid of energy is worth the extra work.

Question 139

In much of the Tanzanian savanna the climate could support woodland or forest, yet the land stays open grassland with only scattered trees, and year after year fires sweep through it in the dry season. Predict how this repeated burning would hold the community short of the woodland climax its climate could otherwise reach, and name what such a held-back community is called.

Model Answer

Repeated burning would hold the community at an open, grassy stage well short of its woodland climax by killing the young trees before they can grow up, so that the succession toward forest is checked again and again and never completed; a community held below its climatic climax in this way by a recurring factor is a deflected climax or plagioclimax, sometimes also called a subclimax. Left alone, the succession on this land would move on through grasses and shrubs toward the woodland or forest its climate can support, as young trees established themselves and slowly shaded out the grasses. But each dry-season fire cuts this short. The grasses survive easily, for they resprout from their roots and underground stems below the soil and are green again within a season; the tree seedlings and saplings, with their growing tips held up in the open, are scorched and killed before they are large enough to withstand a fire.

So the trees can never get away, the closed canopy that would shade out the grasses never forms, and the land is thrown back to grassland each time it burns; as long as the fires keep returning, the community is pinned at this fire-checked grassy stage. **The climate sets one endpoint, but the recurring fire sets another and lower one: the grassland is a fire-maintained plagioclimax, a community held below the woodland it could become because a repeated disturbance keeps resetting its succession.**

> **False Confidence Alert**
> It is tempting to assume a community always reaches the climax its climate allows. A recurring factor such as fire, heavy grazing or cultivation can hold it permanently short of that climax, at a plagioclimax (deflected climax); the open savanna is kept treeless by fire, not because the climate forbids trees.

Question 140

A climax community is often described as the stable, final, self-maintaining end of a succession. From this, a student concludes that a climax community, once reached, never changes again. Evaluate this conclusion.

Model Answer

The conclusion goes too far: a climax community is relatively stable and self-renewing, so it does not advance to some further stage as the earlier seres did, but it is not frozen and unchanging, for it turns over within itself, shifts with the climate over long spans, and can be thrown back by disturbance. It is true that a climax is the self-maintaining end of a succession: it renews itself, the same kinds of plants and animals persisting generation after generation, and it does not give way to a later community as a seral stage does. That is the sense in which it is rightly called stable. But the words never changes again are false on three counts.

First, even at the climax nothing truly stands still: individual trees die and are replaced, gaps open and close, and numbers rise and fall, so the climax is a dynamic balance, steady only in its overall make-up. Second, a community is the climax only for the climate that shapes it, so that over centuries, as the climate slowly warms or dries, the climax shifts with it and one type of climax gives way to another. Third, a large disturbance, a fire, a clearing or a disease, can destroy the climax outright and send the succession back to an earlier stage to start again. **So the climax is stable in the way the student means, that it advances no further to a new stage; but it is not changeless, for it lives by constant internal renewal, it tracks the climate over the long run, and it can be reset by disturbance, and so never changes again is too strong a claim.**

> **False Confidence Alert**
> It is tempting to read stable, final climax as fixed for ever. The climax is stable only in that it keeps its overall character and advances no further; within it life turns over constantly, and over long times, or after a disturbance, even the climax itself changes.

Question 141

A population is often said to settle at the carrying capacity of its habitat, as though that were a fixed number written into the land. Explain why the carrying capacity is better thought of as a moving ceiling that rises and falls than as a fixed number.

Model Answer

The carrying capacity is a moving ceiling because it is set by the resources and conditions of the habitat, and those themselves change from season to season and year to year, so that the greatest number the habitat can support rises when conditions are good and falls when they are poor. The carrying capacity is simply the largest population the habitat can feed, water and shelter for good, and that depends on how much food, water and space the habitat is actually providing at the time, none of which stays constant. A good rainy season brings a flush of grass, so more grazers can be fed and the ceiling rises; a drought withers the grass, so the same land can support far fewer and the ceiling drops. Fire, disease, the coming and going of competitors and predators, and the slow enriching or wearing-out of the land all push it up or down as well.

So a population does not climb to a fixed line and stop there; it chases a ceiling that is forever shifting, rising toward it in the good times and being cut back whenever the ceiling falls. **Carrying capacity is**

therefore not a fixed number but a moving level, the changing balance between a population and a habitat whose richness is never the same for long.

False Confidence Alert
It is tempting to treat the carrying capacity as a single fixed number for a habitat. It is not: it rises and falls with the rains, the seasons and the state of the land, so a population always tracks a moving ceiling rather than resting at a permanent one.

Question 142

In a fenced wildlife reserve the grassland cannot be enlarged, yet through a run of good years the grazing herds double in number while the area of grass stays the same. Predict the ecological problems this doubling would bring, and what would most likely happen to the herds in the end.

Model Answer

With twice as many mouths on the same grass, each animal would get only half the share, so competition would sharpen, the grassland would be overgrazed and damaged, and in the end the swollen herds would overshoot what the land can feed and crash back to, or below, its carrying capacity. When the population doubles but the resources do not, those resources must be divided among twice as many, so each individual gets less food, water and space. Competition for the dwindling grass grows fierce, and the weakest, often the very young and the old, begin to starve. The crowded, hungry herds press on the grassland harder than it can bear, cropping and trampling it faster than it can regrow, so the grass is stripped, the bared soil begins to erode, and the habitat itself is degraded; the crowding also lets disease and parasites spread the more easily through the close-packed animals.

Having climbed above what the land can support, the population cannot be held there: deaths come to outnumber births, and the herds crash steeply, sometimes falling below the number the now-damaged land could once have fed. **A population that doubles against a fixed resource base does not simply settle at a new, higher level; it overshoots, damages the very resources it lives on, and then collapses, the classic overshoot and crash of numbers pushed beyond a carrying capacity that cannot grow with them.**

False Confidence Alert
It is tempting to think a doubled population just settles at a new, higher level. If the resources have not grown with it there is no room at a higher level: the surplus animals overgraze and degrade the habitat, so the population overshoots and crashes rather than holding steady.

Question 143

Two ecologists surveying the same stretch of country, where grassland gives way to woodland, draw the boundary between the two communities in different places, and neither has made a mistake. Explain why the boundary of a community can reasonably be drawn in different places by different observers.

Model Answer

The boundary can reasonably be drawn in different places because one community does not stop and the next begin at a sharp line; they grade into each other gradually through a zone of overlap, the ecotone, so exactly where the line is placed becomes a matter of judgement. Communities are not sealed boxes with clean edges. Where grassland meets woodland the grasses do not end all at once; rather, scattered trees appear and grow steadily more numerous across a broad band until grassland has become woodland, and within that band of change, the ecotone, the two communities mingle. Because the change is gradual, there is no single natural point that must be the boundary: one ecologist may set the line where the last continuous grass gives out, another where the trees first close into a canopy, a third where some chosen indicator species appears or vanishes.

Different species, moreover, change over at different points across the band, so no one line marks the change for all of them at once, and each observer draws a defensible boundary by a different reasonable rule. **The boundary is uncertain not because the ecologists disagree about the facts but because nature**

itself draws no sharp line: communities blend through ecotones, and just where to cut the boundary is a reasonable choice rather than a single fixed truth.

False Confidence Alert
It is tempting to think every community has one true, sharp boundary waiting to be found. Communities usually grade into one another through an ecotone, so the boundary is partly a matter of where the observer reasonably chooses to draw it, and two equally careful ecologists may place it differently.

Question 144

A population regulated by density-dependent factors is said to be self-correcting, able to return toward a steady level after it is pushed away from it. Explain how density-dependent factors give a population this self-correcting, feedback character.

Model Answer

Density-dependent factors make a population self-correcting because they act as a negative feedback: their grip tightens when numbers rise and loosens when numbers fall, so they always push the population back toward a steady level, whichever way it has strayed. A density-dependent factor, such as competition, disease or predation, presses harder the more crowded a population becomes. So when numbers rise above the level the habitat can comfortably support, these factors strengthen: food grows short, disease spreads, predators gather, and deaths climb until the increase is halted and turned back, and the numbers fall again. When instead numbers drop too low, the same factors slacken: food is plentiful, disease and predators take a smaller share, more survive and breed, and the numbers climb once more.

The factor therefore opposes change in either direction, damping a rise and lifting a fall, much as a thermostat cools a room that has grown too warm and warms one that has grown too cold. **This two-way correction is what is meant by feedback: because density-dependent factors automatically resist any move away from the sustainable level, the population is held, self-correcting, around its carrying capacity.**

False Confidence Alert
It is tempting to think density-dependent factors only ever cut a population down. They work both ways: they ease when numbers are low and let the population recover, and it is this loosening, as much as the tightening, that makes the regulation self-correcting rather than merely destructive.

Question 145

However fast a species can breed, no population in nature goes on growing at an unlimited rate for long. Explain why unlimited growth is impossible for any population, however great its power to multiply.

Model Answer

Unlimited growth is impossible because every population lives in a finite world of limited food, water and space, so however fast it can breed, its rising numbers must sooner or later meet a resistance that checks them. The power of living things to multiply is enormous: left wholly unchecked, a single pair, with their offspring breeding in turn, would in time give numbers beyond counting, enough to cover the Earth, as Darwin showed even the slow-breeding elephant would in a few hundred years. Yet this never happens, because the world that must feed and hold them does not grow with them. As a population swells, its members press ever harder on a fixed supply of food, water and space; competition sharpens, food runs short, waste and disease build up in the crowding, and predators and parasites thrive on the abundance.

This rising environmental resistance lifts the death rate and lowers the birth rate until the growth is brought to a stop, and no population can outrun it, for to grow without limit it would need limitless resources, and the Earth has none to give. **Every population sooner or later runs into the limits of its world: unlimited multiplication is a power on paper only, always cancelled in nature by the finite resources on which all life depends.**

False Confidence Alert
It is tempting to think a fast-enough breeder could simply keep on multiplying. No rate of breeding can escape a finite world: the faster a population grows, the sooner it exhausts its resources, and the resistance that its own rising numbers create always brings the growth to an end.

Question 146

In the laboratory, or in a newly opened habitat, a population may for a time show the soaring J-shaped curve of unchecked growth, yet most populations in nature follow the S-shaped curve instead. Explain why the S-shaped curve, and not the J-shaped one, is the pattern most real populations follow.

Model Answer

Most real populations follow the S-shaped curve because in a real habitat the environmental resistance does not hold off and then strike all at once, as the J-curve would have it, but builds up gradually as the population grows, bending the rise over smoothly into a plateau instead of letting it soar and then crash. The J-shaped curve is what growth looks like only while a population is still small in rich, near-empty surroundings, with food and space to spare and little to hold it back, as when a few organisms are first placed in a fresh culture or reach a new land. But this cannot last. As the population grows and begins to fill its habitat, the pressures of crowding come on little by little: food grows scarcer, competition stiffens, waste and disease increase, and the death rate slowly rises while the birth rate slowly falls.

Because this resistance increases steadily with the numbers, it slows the growth gently and ever more, so the curve eases off and settles at the carrying capacity rather than shooting past it, and that gradual, self-limiting approach to a ceiling is the S shape. **The S-curve is the realistic pattern because real environments push back harder as they fill; the J-curve is only the brief opening burst before that growing resistance bends the same growth over into the levelling S.**

False Confidence Alert
It is tempting to think the J-curve and the S-curve describe two different kinds of population. They are the same growth seen under different conditions: the J is the early, unchecked phase, and as environmental resistance builds with crowding it turns that same growth into the S; only where resistance never gets the chance to build does growth stay J-shaped, and then it ends in a crash.

Question 147

The Eastern Arc Mountains of Tanzania are a world biodiversity hotspot, home to many plants and animals found nowhere else on Earth, yet they face several threats at once: the clearing of their forest, the over-harvesting of valuable species, pollution, and climate change. Judge which of these threats is the most urgent for the Eastern Arc, and defend your ranking.

Model Answer

Of these threats the most urgent for the Eastern Arc is the clearing of its forest, that is, habitat loss, because the hotspot's whole value lies in species confined to small patches of forest, and destroying those patches wipes such species out at once and for ever, faster and more surely than any of the other threats. The Eastern Arc matters because so many of its species are endemic, living only in these few isolated mountain forests and nowhere else, and each often clings to a small fragment of habitat. That is exactly why habitat loss is the gravest danger here: when a patch of forest is cleared for farming, timber or settlement, or swept by fire, the species that lived only in it lose everything at a stroke, and an endemic species so lost is gone from the world. The other threats, though real, rank below it: over-harvesting strikes only the particular species that are hunted or felled, not the whole community; pollution, though harmful, is more local and often reversible; and climate change, grave as it is over decades, acts more slowly and leaves a little room to respond.

Habitat loss alone is at once immediate, total and irreversible, and it is happening now, which is what lifts it above the rest. **So I would rank habitat loss first, then over-harvesting, then pollution, with climate**

change the gravest in the long run but the slowest to bite: for a hotspot of forest-bound endemics, the swift and complete destruction of the forest itself is the threat that must be met first.

False Confidence Alert
It is tempting to name climate change as the most urgent threat everywhere, because it is the largest in scale. For a hotspot of endemics in small forest patches, the immediate and irreversible clearing of those patches destroys species faster than the slower-acting climate, so for the Eastern Arc habitat loss is the more pressing danger.

Question 148

Gold mining brings Tanzania jobs and revenue, but it can scar the land and poison rivers. Taking gold mining as your example, evaluate how such an economic-development activity can be carried out with the least possible damage to the surrounding ecosystem.

Model Answer

Gold mining can be carried out with far less damage if it is planned to disturb as little land as possible, kept from poisoning the water and soil, and followed by restoring the land afterwards; but because mining must dig up the ground, some damage cannot be avoided, only reduced and repaired, so its gains must be weighed against the harm that remains. The chief harms of mining are plain: land is cleared and dug up, destroying habitat; the waste rock and tailings, and chemicals such as mercury, can wash into rivers and poison the water and the life in it; and loose dust and bared soil bring erosion. Each can be lessened. Before any work begins, an environmental impact study should place the mine away from the most sensitive habitats and protected areas, and the pit should be kept as small as the work allows, so that little ground is disturbed. During mining, the tailings and chemicals must be held in proper ponds and treated, never let run into the streams, while water sources and dust are guarded.

When the gold is worked out, the land should be rehabilitated: the pit refilled, the topsoil that was set aside spread back, and native plants replanted, so that the ecosystem can recover in time. With these measures the damage is greatly reduced and partly undone, yet some loss of habitat and some risk always remain. **Mining is therefore justified only where its benefits clearly outweigh that residual harm and where the safeguards are truly enforced: the honest aim is least damage and full restoration, never no damage at all.**

False Confidence Alert
It is tempting to think an activity like mining can be made completely harmless if only it is done carefully. Care can reduce and repair the damage but not abolish it, since the ground must still be dug; the realistic goal is least damage with restoration afterward, not a mine that harms nothing.

PART TWO
EXAMINATIONS

GENERAL INSTRUCTIONS

These instructions apply to all five Form Five examination papers (Papers 1 to 5). Read them once, before you begin; they are not repeated on the individual papers.

1. Each paper consists of three sections: A, B and C, with a total of ten (10) questions.
2. Answer seven (7) questions in all: three (3) from Section A, two (2) from Section B and two (2) from Section C.
3. Section A carries 30 marks, Section B carries 30 marks and Section C carries 40 marks; each paper totals 100 marks.
4. The marks for each question, or part of a question, are shown in brackets beside it.
5. Each paper is to be completed in three (3) hours.
6. All diagrams must be drawn in pencil and clearly labelled; non-programmable calculators may be used.
7. Cellular phones and any other unauthorised materials are not allowed in the examination room.

How each paper is built

Section	Question type	Printed	Answer	Each	Section marks
A	Short-answer	4	3	10	30
B	Structured	3	2	15	30
C	Essay	3	2	20	40
Total		**10**	**7**		**100**

Two ways to use a paper. To sit it as a timed examination, answer the seven questions above in three hours for 100 marks. To revise the whole syllabus instead, answer all ten questions, untimed; the solutions cover every question.

ENJOY & MASTER ADVANCED BIOLOGY

Paper 1

FORM SIX EXAMINATION

Biology Time: 3 Hours

SECTION A (30 Marks)

Answer THREE (3) questions from this section. Each question carries 10 marks.

Question 1

A tall tree must carry water up from its roots to leaves many metres above, and at the same time carry the sugars made in its leaves down to its roots. Two different tissues, the xylem and the phloem, do these two jobs.

(a) Giving three points, distinguish between the structure of the xylem and that of the phloem. ***(06 marks)***

(b) Explain how the structure of a xylem vessel suits it to the carrying of water. ***(04 marks)***

Question 2

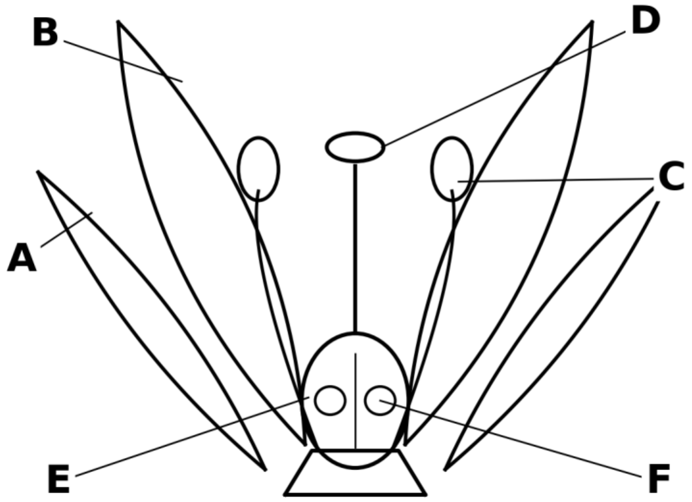
Blood is the body's great transport system, a tissue that flows. In an adult it amounts to about five litres, and it is far more than a simple red liquid.

(a) Name the four main components of blood, and state one function of each. ***(08 marks)***

(b) Explain why a person whose diet is short of iron may become anaemic and feel tired. ***(02 marks)***

Question 3

The flower is the reproductive organ of a flowering plant, built to bring the male and the female gametes together and to form seeds. The diagram below shows a section through a typical insect-pollinated flower.



(a) Name the parts labelled A to F. ***(06 marks)***

(b) State the function of each of the following: ***(03 marks)***

(i) the anther;

(ii) the stigma;

(iii) the ovary.

(c) Name the part that develops into the seed after fertilisation. ***(01 mark)***

Question 4

In maize, the allele for purple grain (R) is dominant to the allele for white grain (r). The terms a geneticist uses can all be seen at work in the grains of a single cob.

(a) Using grain colour in maize, state the genotype and the phenotype of: ***(06 marks)***

(i) a plant carrying two R alleles;

(ii) a plant carrying one R allele and one r allele;

(iii) a plant carrying two r alleles.

(b) Explain why a plant with the genotype Rr has purple grain, and not white grain or an in-between colour. ***(04 marks)***

SECTION B (30 Marks)

Answer TWO (2) questions from this section. Each question carries 15 marks.

Question 5

A seedling grows taller at its tips and its roots push deeper, all from special regions where the cells are always dividing. This lengthening of the plant body is called primary growth.

(a) Name the regions of a plant where primary growth takes place, and state the kind of cells they contain. ***(03 marks)***

(b) Describe the three zones found just behind a root tip, and what happens in each. ***(06 marks)***

(c) Explain the importance to a growing root of: ***(06 marks)***

(i) the root cap;

(ii) the root hairs.

Question 6

Before a flower can make seeds, pollen must be carried from the anther to the stigma. Some plants, such as the maize in a Tanzanian field, use the wind to carry their pollen, while others, such as the hibiscus, use insects.

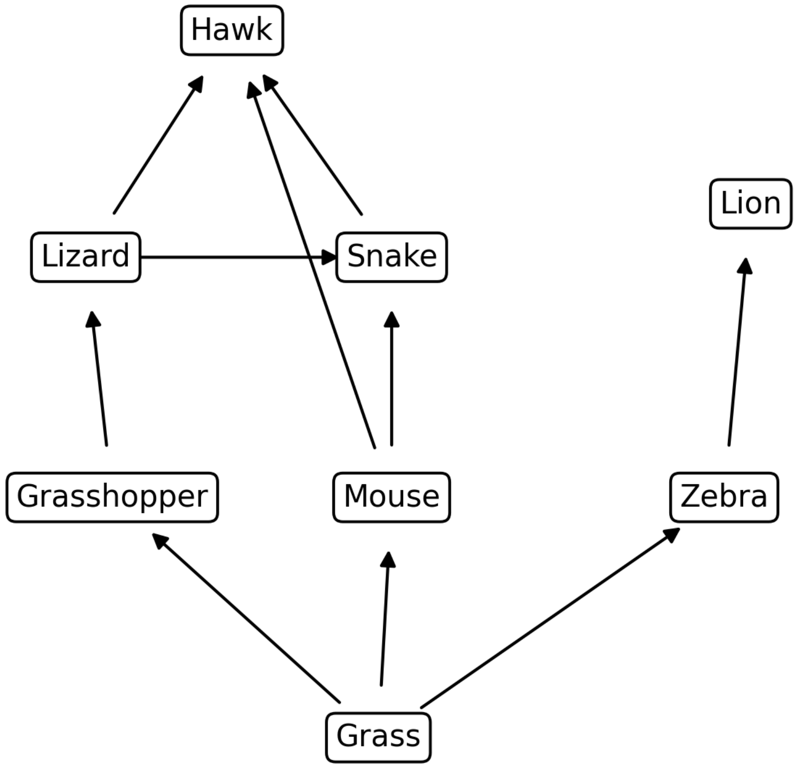
(a) Explain two advantages that cross-pollination gives to a plant species. ***(04 marks)***

(b) Describe four features by which a wind-pollinated flower, such as that of maize, is adapted to pollination by the wind. ***(06 marks)***

(c) Explain how, after pollination, the male gamete reaches the egg cell so that fertilisation can take place. ***(05 marks)***

Question 7

In the savanna of Tanzania, grass is eaten by grasshoppers and zebra, which in turn are eaten by other animals. The feeding relationships of a community can be drawn as a food web. The following web shows part of such a community.



(a) From the web, write out one food chain that has four trophic levels. ***(03 marks)***

(b) Name the trophic level occupied by each of the following: ***(03 marks)***

(i) the grass;

(ii) the grasshopper;

(iii) the hawk.

(c) Explain what would happen to the other organisms in the web if all the grasshoppers were killed by a pesticide. ***(05 marks)***

(d) Explain why a food web gives a truer picture of feeding relationships than a single food chain.

(04 marks)

SECTION C (40 Marks)

Answer TWO (2) questions from this section. Each question carries 20 marks.

Question 8

The instructions for making every protein in the body are written in the DNA of the genes, yet the proteins are built on the ribosomes out in the cytoplasm. The cell copies the instruction and carries it out in two stages, transcription and translation.

(a) Describe what happens during transcription. ***(08 marks)***

(b) Describe what happens during translation. ***(12 marks)***

Question 9

Living things today are different from those that lived long ago, and the many kinds now on Earth are thought to have arisen from earlier, simpler ones. Several quite separate lines of evidence support this idea of evolution, among them the famous early-human fossils unearthed at Olduvai Gorge in Tanzania.

(a) Explain how each of the following provides evidence for evolution: ***(16 marks)***

(i) fossils;

(ii) comparative anatomy (homologous structures);

(iii) embryology;

(iv) biochemistry.

(b) Using the forelimbs of a human, a whale and a bat as your example, explain what makes them homologous structures. ***(04 marks)***

Question 10

An ecosystem, such as Lake Victoria or the Serengeti plain, is made up of living organisms together with their non-living surroundings, all linked together. Through it flows a one-way stream of energy that comes, in the end, from the Sun.

(a) Name the two main parts of an ecosystem, and give two examples of each. ***(04 marks)***

(b) Describe how energy enters an ecosystem and flows through it from one trophic level to the next.

(10 marks)

(c) Explain why a food chain rarely has more than four or five links. ***(06 marks)***

ENJOY & MASTER ADVANCED BIOLOGY

Paper 2

FORM SIX EXAMINATION

Biology Time: 3 Hours

SECTION A (30 Marks)

Answer THREE (3) questions from this section. Each question carries 10 marks.

Question 1

On a hot, dry, windy afternoon a maize plant loses water vapour from its leaves faster than its roots can replace it, and it wilts. This loss of water vapour from the leaves is called transpiration.

(a) Name the part of the leaf through which most water vapour is lost, and explain why water is lost there. ***(03 marks)***

(b) Explain how each of the following increases the rate of transpiration: ***(06 marks)***

(i) a rise in temperature;

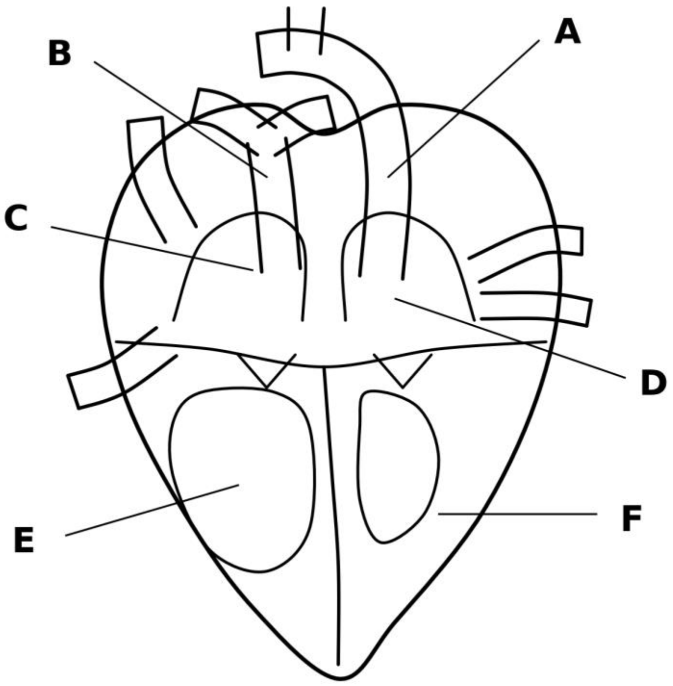
(ii) an increase in wind (moving air);

(iii) a fall in humidity.

(c) State one way in which transpiration is useful to the plant. ***(01 mark)***

Question 2

The mammalian heart is a double pump that drives blood twice round the body, once to the lungs and once to the rest of the body. The diagram below shows the heart in section, seen from the front.



(a) Name the parts labelled A to F. ***(06 marks)***

(b) Explain why the wall of the left ventricle is much thicker than that of the right ventricle. ***(02 marks)***

(c) Name the blood vessel that carries oxygenated blood from the heart to the body, and the vessel that carries deoxygenated blood from the heart to the lungs. ***(02 marks)***

Question 3

Inside the anther of a flower, special cells divide to form the pollen grains that will carry the male gametes. The making of pollen is called microsporogenesis.

(a) State where in the flower pollen grains are made. ***(01 mark)***

(b) Describe how pollen grains are formed in the anther, starting from the pollen mother cells. ***(06 marks)***

(c) Explain why meiosis is important in the formation of pollen. ***(03 marks)***

Question 4

When a pure-breeding tall pea plant is crossed with a pure-breeding short one, all the offspring are tall; but when these are bred together, short plants reappear. Mendel explained this with a single pair of factors, what we now call alleles.

(a) Using the symbols T for tall and t for short, show the cross between a pure-breeding tall plant (TT) and a pure-breeding short plant (tt), giving the genotype and phenotype of the F1 generation. ***(04 marks)***

(b) The F1 plants are then crossed together. Using a Punnett square, show the genotypes of the F2 generation and give the phenotype ratio. ***(06 marks)***

SECTION B (30 Marks)

Answer TWO (2) questions from this section. Each question carries 15 marks.

Question 5

A young stem is soft and thin, but over the years a tree trunk grows thick and woody, adding a new ring of wood each year. This thickening of the stem is called secondary growth.

(a) Name the meristem responsible for the secondary growth of a stem, and state what it produces on each side. ***(04 marks)***

(b) Explain how the annual rings seen in the cut trunk of a tree are formed, and how they can be used to find the age of the tree. ***(06 marks)***

(c) Describe the economic importance of wood (timber) to the people of Tanzania. ***(05 marks)***

Question 6

Flowering plants are unusual in that fertilisation happens twice over in each ovule, a thing found nowhere else in the living world and called double fertilisation. From it come both the embryo and its food store.

(a) Describe what happens during double fertilisation. ***(06 marks)***

(b) State what each of the following develops into after fertilisation: ***(04 marks)***

(i) the zygote;

(ii) the ovule;

(iii) the ovary;

(iv) the integuments.

(c) Explain how seeds and fruits are adapted for dispersal, giving two examples, and why dispersal is an advantage to the plant. ***(05 marks)***

Question 7

When the energy held by the living things at each feeding level of a community is measured and drawn as bars one above another, the result is usually a pyramid, broad at the base and narrow at the top. For a grassland in Tanzania the following figures, in kilojoules per square metre per year, were obtained: producers (grass) 20 000; primary consumers (grasshoppers) 2 000; secondary consumers (lizards) 200; tertiary consumers (birds) 20.

(a) Calculate the percentage of the energy that is passed on from the producers to the primary consumers, and from the primary consumers to the secondary consumers. ***(04 marks)***

(b) Using your answers, state the approximate percentage of energy that passes from one trophic level to the next, and explain what happens to the rest of the energy. ***(05 marks)***

(c) Explain why a pyramid of energy is always broad at the base and narrow at the top, and can never be turned upside down. ***(06 marks)***

SECTION C (40 Marks)

Answer TWO (2) questions from this section. Each question carries 20 marks.

Question 8

When Mendel followed two characters at once, the shape and the colour of his pea seeds, he found that the two were inherited independently of each other, and in the second generation they appeared in a ratio of 9:3:3:1.

(a) In peas, round seed (R) is dominant to wrinkled (r), and yellow seed (Y) is dominant to green (y). A pure-breeding round yellow plant (RRYY) is crossed with a pure-breeding wrinkled green plant (rryy). State the genotype and phenotype of the F1 generation. ***(04 marks)***

(b) The F1 plants are crossed together. Using a Punnett square, work out the F2 generation and give the phenotype ratio. ***(12 marks)***

(c) State the law of inheritance that this dihybrid cross illustrates. ***(04 marks)***

Question 9

Darwin and Wallace explained how living things change over time by a process they called natural selection, the survival of those best suited to their surroundings. The rise of malaria parasites resistant to drugs, and of mosquitoes resistant to insecticides in Tanzania, shows it still at work today.

(a) Outline the main steps of Darwin and Wallace's theory of evolution by natural selection. ***(12 marks)***

(b) Using the example of mosquitoes becoming resistant to an insecticide, explain how natural selection brings this about. ***(08 marks)***

Question 10

Living things need nitrogen to make their proteins, yet they cannot use the vast amount of it in the air directly. Instead the nitrogen is passed round and round between the air, the soil and living things in the nitrogen cycle.

(a) Describe how nitrogen from the air is made available to plants, and how it is eventually returned to the air, in the nitrogen cycle. ***(12 marks)***

(b) Explain why farmers in Tanzania often grow leguminous crops, such as beans, in rotation with other crops. ***(04 marks)***

(c) State two ways, other than by growing leguminous plants, in which the nitrogen content of the soil can be increased. ***(04 marks)***

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Paper 3

FORM SIX EXAMINATION

Biology Time: 3 Hours

SECTION A (30 Marks)

Answer THREE (3) questions from this section. Each question carries 10 marks.

Question 1

When a plant cell is placed in pure water it swells and becomes firm, but when it is placed in a strong sugar or salt solution it shrinks and its lining pulls away from the wall. Both changes are brought about by osmosis.

(a) Explain how water moves into or out of a plant cell by osmosis. ***(03 marks)***

(b) State, in terms of water potential, the direction in which water moves during osmosis, and explain why a plant cell does not burst when it takes in water. ***(04 marks)***

(c) Describe, and account for, what happens to a plant cell when it is placed in a strong salt solution.

(03 marks)

Question 2

Blood travels round the body in three kinds of vessel: the arteries that carry it away from the heart, the capillaries where it does its work, and the veins that bring it back. Each is built differently for its job.

(a) Giving three points, compare the structure of an artery with that of a vein. ***(06 marks)***

(b) Explain how the structure of a capillary suits it to the exchange of materials between the blood and the tissues. ***(04 marks)***

Question 3

Just as pollen is made in the anther, the female gamete is made deep inside the ovule, where a single cell divides to form the embryo sac that holds the egg.

(a) State where in the flower the embryo sac is formed. ***(01 mark)***

(b) Describe how the embryo sac is formed, starting from the megaspore mother cell. ***(06 marks)***

(c) Name the two nuclei of the embryo sac that take part in double fertilisation, and state what each forms. ***(03 marks)***

Question 4

The instructions for building and running every living thing are written in the long, twisted ladder of the DNA molecule, in an alphabet of just four bases.

(a) Name the three parts that make up a single DNA nucleotide. ***(03 marks)***

(b) State the rule of base pairing in DNA, naming which base pairs with which. ***(03 marks)***

(c) One strand of a piece of DNA has the base sequence A T G C C A G T. Write down the base sequence of the strand that pairs with it. ***(04 marks)***

SECTION B (30 Marks)

Answer TWO (2) questions from this section. Each question carries 15 marks.

Question 5

When the height or the mass of a growing organism, such as a maize plant or a locust, is plotted against time, the line is not straight but S-shaped: slow at first, then rapid, then slowing again. This is the sigmoid growth curve.

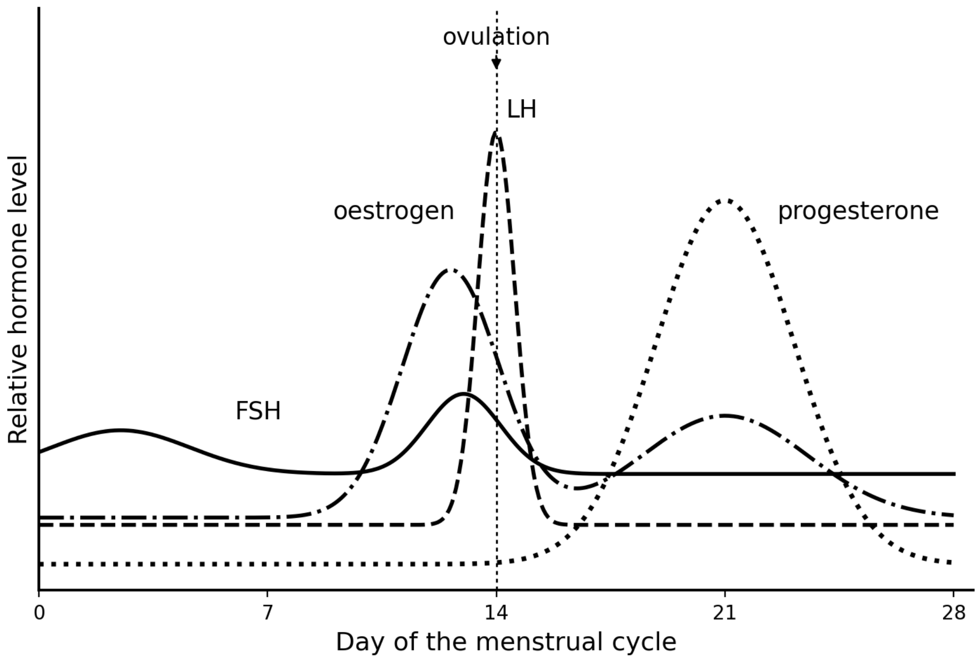
(a) Describe the shape of the sigmoid growth curve, and explain what is happening to the organism in each of its three phases. ***(08 marks)***

(b) Describe two ways in which the growth of a plant can be measured. ***(04 marks)***

(c) Explain why dry mass is a better measure of growth than fresh mass. ***(03 marks)***

Question 6

About once a month the lining of the womb is prepared to receive an embryo, and if none arrives it is shed. This menstrual cycle is controlled by hormones whose levels rise and fall as the graph below shows.



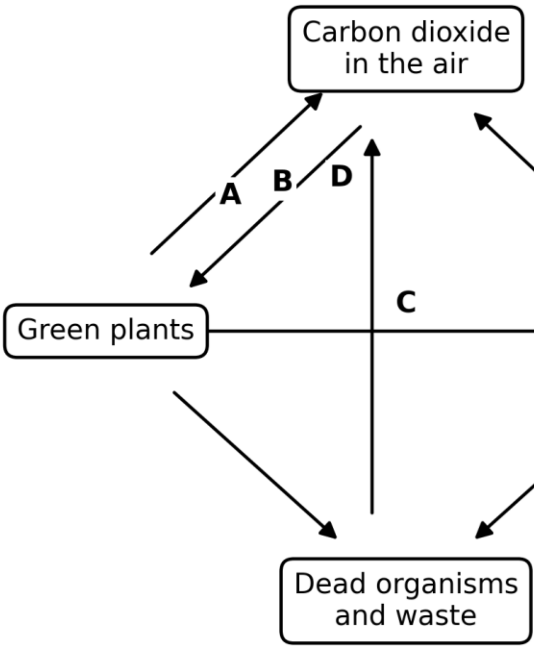
(a) State on which day of the cycle ovulation occurs, and name the hormone whose sudden surge triggers it. ***(03 marks)***

(b) Describe the part played by oestrogen and by progesterone in the menstrual cycle. ***(06 marks)***

(c) Explain what happens to the hormone levels, and to the lining of the womb, if the egg is not fertilised. ***(06 marks)***

Question 7

The carbon in the body of every living thing has been round a great cycle, passing between the air, the green plants, the animals and the soil. The following diagram shows this carbon cycle.



(a) Name the processes labelled A to D on the diagram. ***(04 marks)***

(b) Describe how the carbon locked up in a dead plant or animal can be returned to the air. ***(05 marks)***

(c) Explain how the burning of fossil fuels and the cutting down of forests in Tanzania can raise the amount of carbon dioxide in the air, and why this matters. ***(06 marks)***

SECTION C (40 Marks)

Answer TWO (2) questions from this section. Each question carries 20 marks.

Question 8

Before a cell divides, every one of its DNA molecules must be copied exactly, so that each new cell receives a complete set of instructions. This copying is called DNA replication, and it is wonderfully accurate.

(a) Describe how a molecule of DNA is replicated. ***(14 marks)***

(b) Explain why DNA replication is described as semi-conservative. ***(06 marks)***

Question 9

How did the giraffe come to have such a long neck? Lamarck and Darwin gave two very different answers, and the way biologists decided between them shows how science tests its ideas.

(a) Explain how Lamarck, and then how Darwin, would account for the long neck of the giraffe. ***(12 marks)***

(b) Explain why Lamarck's theory is now rejected, while Darwin's is accepted. ***(08 marks)***

Question 10

As Tanzania's towns and farms grow, human activities put more and more pressure on the natural world: the air, the water and the soil are polluted, forests are cleared and wildlife is lost.

(a) Describe three types of pollution, naming a cause and an effect of each. ***(12 marks)***

(b) Explain how the cutting down of forests (deforestation) in Tanzania harms the environment. ***(04 marks)***

(c) Suggest two ways in which the people of Tanzania can reduce the damage done to their environment. ***(04 marks)***

ENJOY & MASTER ADVANCED BIOLOGY

Paper 4

FORM SIX EXAMINATION

Biology Time: 3 Hours

SECTION A (30 Marks)

Answer THREE (3) questions from this section. Each question carries 10 marks.

Question 1

A tall mvule tree in a Tanzanian forest lifts water from its roots to leaves more than thirty metres above the ground, yet it has no pump and uses no living energy to raise it.

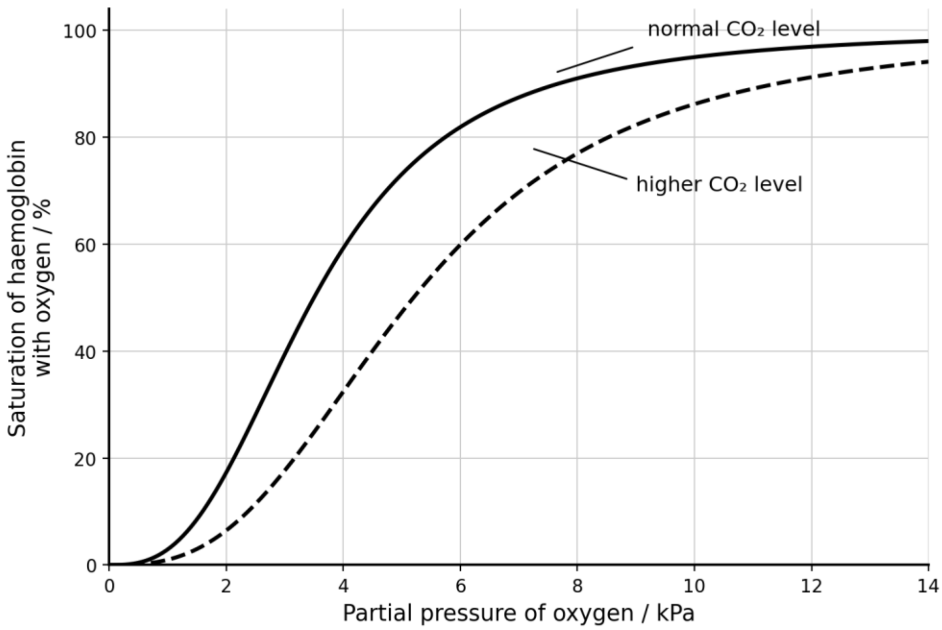
(a) Name the tissue through which this water is carried, and state one feature of that tissue which suits it to the task. ***(02 marks)***

(b) Explain how water is pulled all the way up to the leaves of such a tall tree. ***(05 marks)***

(c) Explain why this column of water may fail to rise if an air bubble forms in it. ***(03 marks)***

Question 2

Haemoglobin in the red blood cells must pick up oxygen where it is plentiful, in the lungs, and release it where it is scarce, in the respiring tissues. The graph below shows how the saturation of haemoglobin with oxygen changes with the partial pressure of oxygen around it.



(a) Using the graph, state the percentage saturation of the haemoglobin in the lungs, where the partial pressure of oxygen is about 13 kPa, and in an actively respiring muscle, where it is about 3 kPa.

(02 marks)

(b) Explain how the shape of the curve allows haemoglobin to load oxygen in the lungs and to unload it in the tissues. ***(05 marks)***

(c) The dashed curve shows the effect of a higher level of carbon dioxide. Explain how this change helps an actively respiring muscle to obtain more oxygen. ***(03 marks)***

Question 3

A man releases many millions of sperm at one time, each one a tiny cell stripped down to little more than a package of DNA and a tail, and built for a single journey.

(a) State where in the body the sperm are made. ***(01 mark)***

(b) Describe how sperm are formed, from the dividing cells of the testis to the finished sperm. ***(05 marks)***

(c) Name three parts of a mature sperm, and give the work done by each. ***(04 marks)***

Question 4

In Tanzania, as everywhere, about as many boys are born as girls. Whether a child is a boy or a girl is settled at the very moment of fertilisation.

(a) Explain how the sex of a child is determined. ***(03 marks)***

(b) Using a genetic diagram, show why boys and girls are produced in roughly equal numbers. ***(04 marks)***

(c) Explain why it is the father, and not the mother, who determines the sex of the child. ***(03 marks)***

SECTION B (30 Marks)

Answer TWO (2) questions from this section. Each question carries 15 marks.

Question 5

The mosquito that spreads malaria in Tanzania begins life as a wriggling larva in water and ends it as a flying adult, changing completely along the way. A cockroach, by contrast, hatches as a small copy of its parent and changes only by degrees.

(a) Distinguish between complete and incomplete metamorphosis. ***(04 marks)***

(b) Describe the stages in the complete metamorphosis of a mosquito. ***(06 marks)***

(c) Explain how a knowledge of the mosquito's life cycle helps in the control of malaria in Tanzania. ***(05 marks)***

Question 6

Inside the womb the growing baby cannot breathe, feed, or get rid of its wastes for itself. All of these are done for it across the placenta, which brings its blood close to its mother's.

(a) State two substances that pass from the mother to the baby across the placenta, and two that pass from the baby to the mother. ***(04 marks)***

(b) Explain how the placenta is suited to the exchange of these substances. ***(06 marks)***

(c) Explain why it is important that the blood of the mother and the blood of the baby do not actually mix. ***(05 marks)***

Question 7

In a stretch of Tanzanian grassland the grass is eaten by grasshoppers, and the grasshoppers are eaten by lizards. In one square metre the dry mass of living material is found to be 1000 g of grass, 250 g of grasshoppers and 50 g of lizards.

(a) Name the trophic level occupied by the grass, by the grasshoppers, and by the lizards. ***(03 marks)***

(b) Using a scale of 1 cm to represent 100 g of dry mass per square metre, draw a pyramid of biomass for this grassland. ***(06 marks)***

(c) Explain why the dry mass becomes smaller at each higher level, and why a pyramid of biomass usually gives a truer picture than a pyramid of numbers. ***(06 marks)***

SECTION C (40 Marks)

Answer TWO (2) questions from this section. Each question carries 20 marks.

Question 8

Red green colour blindness, which makes it hard to tell red from green, is far commoner in men than in women. It is carried on the X chromosome, and so runs through families in a telling pattern.

(a) Explain why a character such as colour blindness is described as sex linked, and why it appears more often in men than in women. ***(08 marks)***

(b) A woman who is a carrier of colour blindness marries a man with normal vision. Using a genetic diagram, work out the chances that their sons, and their daughters, will be colour blind. ***(12 marks)***

Question 9

Every kind of living thing alive today is thought to have arisen from an earlier kind. Sometimes a single species gives rise to two new ones that can no longer breed together.

(a) Explain how, beginning from a single species, the action of variation, isolation and natural selection over a long time can give rise to two separate species. ***(14 marks)***

(b) The cichlid fishes of the East African lakes, such as Lake Victoria and Lake Tanganyika, have formed hundreds of different species. Suggest how this great variety may have come about. ***(06 marks)***

Question 10

When a piece of bare ground is left alone, whether a cleared and abandoned field or a fresh bank of sand by a river, it does not stay bare. It is taken over by one community of living things after another until a stable community is reached.

(a) Describe how an ecological succession proceeds, from the first pioneer species to a stable climax community. ***(12 marks)***

(b) Explain why the later communities are more stable and richer in species than the pioneer community, and suggest why an abandoned farm regains its plant cover faster than a bare rock surface. ***(08 marks)***

ENJOY & MASTER ADVANCED BIOLOGY

Paper 5

FORM SIX EXAMINATION

Biology Time: 3 Hours

SECTION A (30 Marks)

Answer THREE (3) questions from this section. Each question carries 10 marks.

Question 1

The sugar made in the green leaves of a sugarcane plant ends up stored in its stem, and the food a cassava plant makes is carried down to its swelling root. Food made in one part of a plant is moved to another through the phloem.

(a) Name the tissue that carries food in a plant, and the living cells through which the food actually moves. ***(02 marks)***

(b) Explain how sugars are moved from a leaf, where they are made, to the parts of the plant where they are used or stored. ***(04 marks)***

(c) Describe how a ringing experiment, in which a ring of bark is removed from a stem, can show that the phloem carries the sugars. ***(04 marks)***

Question 2

The heart beats about seventy times a minute, every beat a set sequence of squeezes that drives the blood the right way through its chambers, and it beats on its own without waiting to be told to by the brain.

(a) Describe the events of one heartbeat (one cardiac cycle), naming what the atria and the ventricles do. ***(05 marks)***

(b) Explain how the valves of the heart make sure that the blood flows in one direction only. ***(03 marks)***

(c) Explain why the heartbeat is described as myogenic, and name the part of the heart that sets its rhythm. ***(02 marks)***

Question 3

While a man makes millions of sperm, a woman usually ripens and releases just one egg each month, a large cell stocked with food for the new life it may begin.

(a) State where in the body the eggs are made. ***(01 mark)***

(b) Describe how an egg is formed and then released from the ovary. ***(06 marks)***

(c) Explain two ways in which an egg is suited to its task of starting a new individual. ***(03 marks)***

Question 4

Human blood comes in four groups, A, B, AB and O, decided by three forms of a single gene. Knowing a person's group can be a matter of life and death when blood must be given.

(a) Explain how three alleles of one gene give rise to the four blood groups, and why groups A and B are said to be codominant. ***(04 marks)***

(b) A man of group A, whose mother was group O, marries a woman of group B whose father was group O. Using a genetic diagram, work out the blood groups their children could have. ***(06 marks)***

SECTION B (30 Marks)

Answer TWO (2) questions from this section. Each question carries 15 marks.

Question 5

A dry bean seed can lie still in a packet for a year, seeming quite lifeless, and yet spring into growth within days of being sown in the right surroundings.

(a) State the external conditions a seed needs in order to germinate. ***(03 marks)***

(b) Describe what happens inside and outside the seed as it germinates. ***(07 marks)***

(c) Describe an experiment to show that one of these conditions is necessary for germination. ***(05 marks)***

Question 6

A Tanzanian farmer often grows a new crop without any seed at all, planting a cassava stem cutting, a banana sucker, or a piece of sweet potato, each of which grows into a whole new plant.

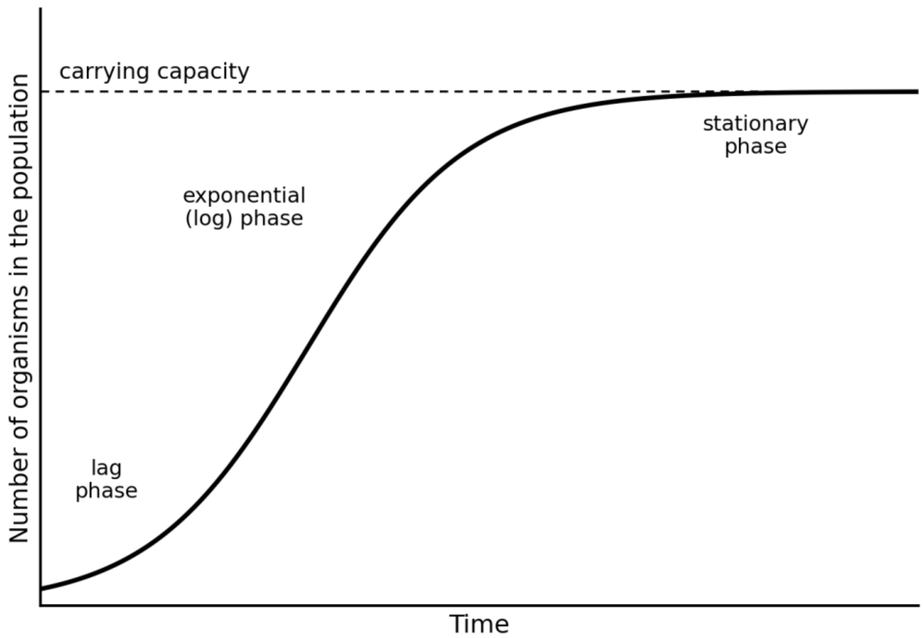
(a) Explain how a whole new plant can arise by vegetative propagation, and why the new plant is exactly like its parent. ***(03 marks)***

(b) Describe three natural methods of vegetative propagation, giving a named Tanzanian plant for each. ***(06 marks)***

(c) Give two advantages, and one disadvantage, to the farmer of raising crops in this way. ***(06 marks)***

Question 7

When a few organisms reach a new and favourable place, such as the water hyacinth weed that arrived in Lake Victoria, they multiply fast at first and then more slowly, until their numbers level off. The graph below shows this growth of a population.



(a) Using the graph, describe how the size of the population changes with time, naming the phases that are shown. ***(05 marks)***

(b) Explain what brings the rapid growth to an end and holds the population steady at its carrying capacity. ***(06 marks)***

(c) Explain why the water hyacinth was able to grow so explosively when it first reached Lake Victoria. ***(04 marks)***

SECTION C (40 Marks)

Answer TWO (2) questions from this section. Each question carries 20 marks.

Question 8

Most of the variety among living things comes from the reshuffling of genes that already exist, but now and then a wholly new form of a gene appears by mutation. A change in a single one of the chemical letters of the DNA can have effects out of all proportion to its size.

(a) Explain how a mutation arises, and distinguish between a gene mutation and a chromosome mutation. ***(08 marks)***

(b) Using sickle cell anaemia as your example, explain how the change of a single base in the DNA can affect the whole body, and why the sickle cell allele stays common in the parts of Tanzania where malaria is found. ***(12 marks)***

Question 9

Long before there were any living things, the Earth was a lifeless place of rock, water and gases. How the first living things arose from such beginnings is one of the great questions of biology.

(a) Outline how, according to the chemical theory, the first simple living things could have arisen from non living matter on the early Earth. ***(12 marks)***

(b) Explain how, once the first living things existed, natural selection could lead to the great variety of life seen today. ***(08 marks)***

Question 10

Tanzania is rich in wild life, from the great herds of the Serengeti to its forests and coral reefs. But this wealth is under threat, and once a kind of living thing is lost it is gone for ever.

(a) Explain why it is important to conserve natural resources and wild life. ***(08 marks)***

(b) Describe the main threats to wild life in Tanzania, and the steps that can be taken to conserve it.

(12 marks)

PART THREE

MODEL SOLUTIONS TO THE EXAMINATIONS

How to use these solutions. *Each answer is written exactly as it should be set down in the examination room. It opens with the mark-bearing point stated plainly and in bold, and then develops that point in connected scientific English, in which one idea is joined to the next by linking words such as because, which in turn, consequently, as a result of which, leading to and whereas. Read every answer not only for what it states, but for the way its statements are reasoned into a single chain of cause and effect; notice, too, how each answer keeps strictly to what its question asks, and matches its length to the marks.*

ENJOY & MASTER ADVANCED BIOLOGY

Paper 1

FORM SIX EXAMINATION

Solutions

SECTION A

Question 1

(a) The xylem and the phloem differ in structure in three main ways:

1) **Living state of the cells:** the xylem is made of dead, empty cells, whereas the phloem is made of living cells.
2) **The cells and their walls:** the xylem is built of vessels and tracheids whose walls are thickened with lignin, and whose end walls have broken down so that the cells join into continuous open tubes; in contrast, the phloem is built of living sieve tubes whose end walls remain as perforated sieve plates, each sieve tube being kept alive by a companion cell beside it.
3) **What is carried, and in which direction:** the xylem carries water and dissolved mineral salts in one direction only, upward from the roots to the leaves, whereas the phloem carries dissolved food, chiefly sucrose, in either direction, both up and down the plant.

(b) **A xylem vessel is a dead, hollow tube, so that water can pass through it without obstruction.** Because the cells are dead and empty, they hold no cytoplasm or cross-walls to impede the flow, and because their end walls have dissolved away, the cells join into one long continuous pipe along which water moves freely from root to leaf.

The wall is thickened with lignin, which is both strong and waterproof. This thickening enables the vessel to withstand the great tension of the rising water column without collapsing inward, while the waterproofing prevents water from leaking out sideways, as a result of which the whole column is drawn upward unbroken.

Question 2

(a) Blood has four main components:

1) **Red blood cells:** they are packed with the pigment haemoglobin, which binds oxygen in the lungs and releases it in the tissues, whereby oxygen is carried from the lungs to every respiring cell of the body.
2) **White blood cells:** they defend the body against disease, some by engulfing and digesting invading germs and others by making antibodies, consequently protecting the body against infection.
3) **Platelets:** they bring about the clotting of the blood at a wound, because they help to form the mesh that seals the cut, thereby stopping the bleeding and keeping germs out.
4) **Plasma:** the pale, straw-coloured liquid in which the cells are carried, and in which dissolved foods, salts, hormones, wastes, carbon dioxide and heat are all transported about the body.

(b) **Iron is needed to make haemoglobin, the red pigment that carries oxygen in the red blood cells.** Consequently, when the diet is short of iron, too little haemoglobin can be made, so the blood carries less oxygen to the tissues; because the tissues then receive less oxygen, they release less energy in respiration, as a result of which the person feels weak and easily tired. This condition, due to the shortage of haemoglobin, is called anaemia.

Question 3

(a) The labelled parts are:

A: sepal.

B: petal.

C: anther.

D: stigma.

E: ovary.

F: ovule.

(b)

(i) **The anther:** it makes and holds the pollen grains, within which the male gametes are carried.

(ii) **The stigma:** it receives the pollen grains at pollination, its sticky surface holding them so that each may grow a pollen tube.

(iii) **The ovary:** it encloses and protects the ovules and, after fertilisation, it develops into the fruit.

(c) **The ovule** develops into the seed after fertilisation.

Question 4

(a)

(i) **Two R alleles:** the genotype is RR, and the phenotype is purple grain.

(ii) **One R and one r allele:** the genotype is Rr, and the phenotype is also purple grain.

(iii) **Two r alleles:** the genotype is rr, and the phenotype is white grain.

(b) **The allele R is dominant and the allele r is recessive.** A dominant allele expresses its effect whenever it is present, whereas a recessive allele expresses its effect only when no dominant allele is there to mask it.

In the plant Rr the single R allele is enough to produce the full purple colour. This is because R directs the making of the purple pigment, and one dose of the allele makes enough pigment to colour the grain completely, while the recessive r makes no pigment and its presence is therefore hidden. Because the effect of R does not blend with that of r, the grain is not an in-between shade, and because R completely masks r, it is not white either.

SECTION B

Question 5

(a) **Primary growth takes place at the apical meristems,** which lie at the tip of the shoot and at the tip of the root. These regions consist of small, thin-walled cells that divide again and again, and it is the new cells produced by this division that make the plant grow longer.

(b) Just behind the root tip lie three zones:

1) **The zone of cell division:** here, immediately behind the tip, the meristem cells divide repeatedly, consequently producing a steady supply of new cells.

2) **The zone of elongation:** here the newly formed cells absorb water and grow longer, and this lengthening causes the root tip to be pushed forward, driving it deeper into the soil.

3) **The zone of differentiation (maturation):** here the cells stop lengthening and become specialised into the various tissues of the root, whereby the xylem, the phloem and the root hairs are formed.

(c)

(i) **The root cap** protects the delicate meristem at the very tip as the root is forced through the rough, abrasive soil. Because its outer cells are continually worn away by friction, they are steadily replaced from within, and many of them give out a slime that lubricates the tip, as a result of which the growing point is shielded from damage.

(ii) **The root hairs** are long, thin outgrowths of the surface cells that greatly increase the surface area of the root. Because of this enlarged surface, water and dissolved mineral salts are absorbed from the soil far more rapidly, which in turn supplies the whole plant with the water it needs for support, for transport and for photosynthesis.

Question 6

(a) Cross-pollination gives a plant species two main advantages:

1) **It brings variation into the offspring:** because the two gametes come from different parent plants, the offspring inherit a fresh mixture of characters and are not all alike, leading to a population whose members differ from one another.

2) **This variation makes the species stronger and more adaptable:** since the offspring vary, there is a far better chance that some of them will be suited to new or changing conditions, whereas the loss of vigour that tends to follow repeated self-fertilisation is avoided.

(b) A wind-pollinated flower is adapted to the wind in four ways:

1) **The flowers are small, dull-coloured and without scent or nectar,** because they have no need to attract insects and depend upon the wind instead.

2) **The anthers are large and hang outside the flower on long, slender filaments,** so that the wind can easily shake the loose pollen out of them.

3) **The stigmas are large and feathery and also hang outside the flower,** whereby they present a wide, net-like surface that catches the pollen grains drifting in the air.

4) **The pollen is produced in great quantity and is small, light, smooth and dry,** consequently it is carried far and easily by the wind, which makes up for the large amount that never reaches a stigma.

(c) After pollination, the male gamete reaches the egg in the following way:

1) **The pollen grain on the stigma absorbs moisture and grows a pollen tube,** which pushes its way down through the tissue of the style towards the ovary.

2) **The pollen tube grows down to an ovule and enters it through a tiny opening called the micropyle,** its growth being guided there by chemical signals given out by the ovule.

3) **The tip of the tube then bursts and releases the male gamete, which fuses with the egg cell inside the ovule.** This fusion of the male and the female gamete is fertilisation, as a result of which a zygote is formed that afterwards grows into the embryo of the new seed.

Question 7

(a) **A food chain with four trophic levels is:** grass → grasshopper → lizard → hawk, in which the grass is eaten by the grasshopper, the grasshopper by the lizard, and the lizard by the hawk.

(b)

(i) **The grass** is a producer, and so occupies the first trophic level.

(ii) **The grasshopper** is a primary consumer, a herbivore, and so occupies the second trophic level.

(iii) **The hawk** is a tertiary consumer, a top carnivore, and so occupies the fourth trophic level.

(c) **The animals that feed on the grasshopper would lose a major source of food.** The lizard, which depends upon the grasshopper, would consequently fall in number, or else be forced to turn to other prey in order to survive.

The effect would then pass on up the web. Because the lizards had become fewer, the snakes and hawks that feed on them would in turn find their own food scarcer, leading to a decline in these predators as well.

The grass, on the other hand, would at first flourish. Since one of the animals that grazes it had been removed, the grass would for a time grow more thickly, until the other plant-eaters increased and grazed it down again. This shows that the organisms in a web are all linked together, so that the removal of a single kind of organism sends its effects, through one feeding link after another, throughout the whole community.

(d) **A single food chain shows only one straight line of feeding,** as though each animal ate just one kind of food and was itself eaten by only one kind of predator.

In nature, however, feeding is far more tangled than this. Most animals eat several different foods and are themselves eaten by several different predators, whereas a single chain can show none of these cross-links. A food web joins many separate food chains together, and because it shows all these interconnected feeding relationships at once, it gives a far truer picture of how the community really feeds.

SECTION C

Question 8

(a) Transcription copies the gene into a molecule of messenger RNA:

1) **Transcription takes place in the nucleus, and it begins when the DNA double helix unwinds over the length of the gene.** The two strands separate in this region, whereby the bases of the gene are exposed and made ready to be copied.
2) **One of the two exposed strands now serves as the template.** Free RNA nucleotides line up along it, each one pairing with its complementary base; because the new strand is RNA, the base adenine on the DNA pairs with uracil rather than with thymine, while cytosine pairs with guanine.
3) **The enzyme RNA polymerase joins the lined-up nucleotides together** into a single continuous strand, consequently building a molecule of messenger RNA (mRNA) whose sequence of bases is a faithful copy of the gene.
4) **When the gene has been copied, the messenger RNA peels away from the DNA,** and the helix zips up again behind it. The messenger RNA then passes out of the nucleus through a pore in the nuclear membrane and into the cytoplasm, where it carries the gene's instructions to a ribosome.

(b) Translation builds the protein from the message carried by the messenger RNA:

1) **Translation takes place on a ribosome in the cytoplasm.** The messenger RNA becomes attached to the ribosome, which will move along the molecule and read its coded message.
2) **The ribosome reads the messenger RNA in groups of three bases.** Each group of three bases is called a codon, and because each codon stands for one particular amino acid, the order of the codons fixes the order of the amino acids in the protein that is to be built.
3) **The amino acids are brought to the ribosome by transfer RNA (tRNA) molecules.** Each transfer RNA carries one particular amino acid at one end, and bears three exposed bases, called an anticodon, at the other.
4) **Each transfer RNA pairs its anticodon with the matching codon on the messenger RNA.** Because an anticodon can pair only with its own complementary codon, every amino acid is delivered to exactly the place fixed by the messenger RNA, whereby the amino acids are brought into their correct order.
5) **The ribosome then joins each newly arrived amino acid to the growing chain by a peptide bond.** As the ribosome moves on from one codon to the next, the chain of amino acids, a polypeptide, lengthens steadily, while the emptied transfer RNAs are released to collect fresh amino acids.
6) **When the ribosome reaches a stop codon, no further amino acid is added and the chain is complete.** The finished polypeptide is then released, and it folds up into its particular three-dimensional shape, consequently becoming the working protein that the gene encoded.

Question 9

(a)

(i) **Fossils are the preserved remains or traces of organisms that lived long ago,** and they give direct evidence of evolution. Because the simpler kinds of organism are found in the older, deeper rocks and the more complex kinds in the newer rocks above, the fossil record shows that living things have changed gradually over a vast span of time; some fossils, moreover, are intermediate in form and link one group to another, whereby a line of descent can be traced. The early-human fossils unearthed at Olduvai Gorge in Tanzania are a famous example of such evidence.

(ii) **Comparative anatomy reveals the same basic plan of structure beneath organs that look quite different.** The forelimb of a human, the flipper of a whale and the wing of a bat are all built to the same arrangement of bones, the pentadactyl (five-fingered) limb, even though each is put to a different use. Because so close a likeness of plan is most simply explained by inheritance from a shared ancestor, these homologous structures point clearly to common descent.

(iii) **Embryology shows that related animals pass through similar stages early in their development.** The young embryos of fishes, amphibians, reptiles, birds and mammals closely resemble one another, and all, for instance, bear gill-pouches at an early stage. Because such likeness is found even where the adult animals differ greatly, it suggests that they have all descended from a common ancestor whose pattern of development they still share.

(iv) **Biochemistry reveals a deep chemical unity among all living things.** Every organism uses DNA as its hereditary material and reads it by the same genetic code, which is most simply explained by descent from a common origin. Furthermore, when the same protein, such as haemoglobin, is compared between species, closely related species differ in fewer of its amino acids than distantly related ones, whereby the degree of chemical difference measures how long ago two groups last shared an ancestor.

(b) **The forelimbs of a human, a whale and a bat are homologous because they are built to the same underlying plan of bones, the pentadactyl limb, inherited from a common ancestor.** Although the human arm is used for handling, the whale flipper for swimming and the bat wing for flying, the same set of bones, a single upper-arm bone, two forearm bones, the wrist bones and five digits, can be recognised in each, merely altered in size and shape to suit its work. Because this one ancestral plan has been adapted in different directions to perform different tasks, the three limbs are homologous, and their shared structure is exactly what descent from a common ancestor would produce.

Question 10

(a) An ecosystem has two main parts:

1) **The biotic (living) part:** all the living organisms of the area, for example the green plants, which act as producers, and the animals, which act as consumers; the decomposers, such as bacteria and fungi, also belong here.

2) **The abiotic (non-living) part:** the physical surroundings in which they live, for example the sunlight and the temperature, and the water, the air and the soil.

(b) Energy enters an ecosystem and flows through it in the following way:

1) **Energy enters the ecosystem from the Sun, and it is captured by the green plants.** The producers absorb sunlight and, by photosynthesis, convert it into the chemical energy of the food they manufacture, whereby light energy is locked into the ecosystem in a usable form.

2) **The energy is then passed along the food chain from one trophic level to the next.** When a herbivore eats a plant the stored energy passes to the primary consumer, and when a carnivore eats the herbivore it passes on to the secondary and then the tertiary consumers.

3) **At every transfer, however, most of the energy is lost.** A large part is released as heat in respiration and escapes from the body, while more is lost in undigested remains and in parts that are not eaten, as a result of which only a little of the energy reaches the next level.

4) **Because of these losses, only about one-tenth of the energy at one trophic level is passed on to the level above it.** Consequently the quantity of energy grows smaller and smaller at each step along the chain, which is why the organisms at the higher levels are always so few.

5) **The decomposers finally release the energy still held in dead bodies and in waste,** and this too is given off as heat. Because all the captured energy is in the end lost from the ecosystem as heat, and none of it is recycled, a fresh supply of sunlight is always needed; the flow of energy is therefore one-way.

(c) **A food chain is short because so much energy is lost at every link.** Since only about one-tenth of the energy at each trophic level is passed on to the next, while the other nine-tenths is lost chiefly as heat in respiration, the energy available dwindles rapidly as it moves along the chain.

After only four or five transfers there is too little energy left to support a further level. Because each level can capture only a tenth of what the level below it held, a fifth or a sixth consumer would find far too little food energy to sustain it, which is why the chain comes to an end.

This same loss of energy explains why the top carnivores are so few. The producers at the base hold the most energy and are therefore very numerous, whereas the animals at the top, drawing on the little energy that remains, must always be few in number.

ENJOY & MASTER ADVANCED BIOLOGY

Paper 2

FORM SIX EXAMINATION

Solutions

SECTION A

Question 1

(a) **Most water vapour is lost through the stomata, the tiny pores in the surface of the leaf, which are most numerous on the lower side.** The stomata are open by day to let carbon dioxide in for photosynthesis, and because they are open, water vapour escapes through them by diffusion, passing from the moist air spaces inside the leaf to the drier air outside.

(b)

(i) **A rise in temperature:** it warms the leaf, so that water evaporates faster from the moist cell surfaces inside, and the warmed molecules diffuse out more quickly, consequently the rate of transpiration rises.

(ii) **An increase in wind:** moving air blows away the humid layer of water vapour that gathers just outside the stomata, whereby the air there is kept dry and the diffusion gradient steep, as a result of which water is lost faster.

(iii) **A fall in humidity:** drier air outside the leaf makes the difference in water-vapour concentration between the inside and the outside greater, so that water vapour diffuses out more quickly, leading to a higher rate of transpiration.

(c) **Transpiration is useful because it draws up the transpiration stream,** which carries water and the dissolved mineral salts up from the roots to the leaves, and which also cools the leaf as the water evaporates from it.

Question 2

(a) The labelled parts are:

A: aorta.

B: pulmonary artery.

C: right atrium.

D: left atrium.

E: right ventricle.

F: left ventricle.

(b) **The left ventricle has a much thicker, more muscular wall because it must pump blood all the way round the body.** Since it drives the blood over a long distance and against a high resistance, it has to develop a high pressure, whereas the right ventricle pumps blood only the short way to the nearby lungs and at a much lower pressure; consequently the left ventricle needs the greater force that only a thicker wall can provide.

(c) **The aorta carries oxygenated blood from the heart to the body,** whereas **the pulmonary artery carries deoxygenated blood from the heart to the lungs.**

Question 3

(a) **Pollen grains are made in the pollen sacs, the lobes of the anther.**

(b) Pollen grains are formed in the anther in the following way:

1) **The anther contains pollen sacs filled with many pollen mother cells,** each of which is diploid.
2) **Each pollen mother cell then divides by meiosis,** and because meiosis halves the chromosome number, it produces a group of four haploid cells, a tetrad of microspores.
3) **Each microspore rounds off and lays down a tough, protective wall,** thereby becoming a pollen grain.
4) **The nucleus of each pollen grain afterwards divides by mitosis** into a tube nucleus and a generative nucleus, and the generative nucleus later gives rise to the two male gametes that the pollen grain will carry to the ovule.

(c) **Meiosis is important because it halves the chromosome number, so that the pollen grain, and the male gamete it carries, is haploid.** This matters because, when the haploid male gamete later fuses with the haploid female gamete at fertilisation, the normal diploid number is restored, as a result of which the chromosome number is kept constant from one generation to the next. Meiosis also reshuffles the genes, whereby it brings new variation into the offspring.

Question 4

(a)

Parents: TT (tall) × tt (short).

Gametes: one parent forms gametes carrying only T, the other only t.

F1 generation: every offspring is Tt, and because T is dominant to t, all of them are tall.

(b)

The F1 plants are crossed: Tt × Tt.

Each F1 plant forms two kinds of gamete: T and t.

Gametes	**T**	**t**
T	TT	Tt
t	Tt	tt

F2 genotypes: one TT to two Tt to one tt.

F2 phenotype ratio: 3 tall : 1 short, because every plant carrying at least one T allele is tall, whereas only the tt plants are short.

SECTION B

Question 5

(a) **The meristem responsible for secondary growth is the vascular cambium.** It is a ring of dividing cells lying between the xylem and the phloem, and it produces new xylem (wood) on its inner side and new phloem on its outer side, whereby the stem grows thicker year by year.

(b) The annual rings are formed, and used to find the age, in this way:

1) **In the wet, growing season the cambium makes large, wide xylem vessels,** which together form a band of pale, open wood.
2) **In the dry season it makes only small, narrow vessels,** which form a band of darker, denser wood.
3) **One pale band and one dark band together make up a single year's growth, seen as one ring,** so that a fresh ring is added each year because growth is fast in one season and slow in the other.

4) **The age of the tree can therefore be found by counting the rings,** since each ring stands for one year of growth.

(c) Wood is of great economic importance to the people of Tanzania:

1) **Timber for building and furniture:** hardwoods such as mninga and *mvule* are sawn into planks for houses, doors and furniture, which gives the wood great value.
2) **Fuel:** much wood is burned directly as firewood, and a great deal is turned into charcoal, which is the chief cooking fuel of many Tanzanian homes.
3) **Poles and fencing:** straight poles are used for building, for scaffolding and for fencing.
4) **Paper and employment:** wood is also pulped to make paper, and the timber trade gives work and income to many people, thereby supporting the wider economy.

Question 6

(a) Double fertilisation takes place in the following way:

1) **The pollen tube grows down the style and enters the ovule through the micropyle,** carrying two male gametes into the embryo sac.
2) **One male gamete fuses with the egg cell** to form a diploid zygote, which afterwards grows into the embryo of the seed.
3) **The other male gamete fuses with the two polar nuclei of the central cell,** thereby forming a triploid cell.
4) **This triploid cell then grows into the endosperm, the food store of the seed.** Because two separate fusions take place within each ovule, the whole process is called double fertilisation.

(b)

(i) **The zygote** develops into the embryo.

(ii) **The ovule** develops into the seed.

(iii) **The ovary** develops into the fruit.

(iv) **The integuments** develop into the seed coat, the testa.

(c) Seeds and fruits are adapted for dispersal in several ways:

1) **Dispersal by wind:** some seeds and fruits are very light, or bear wings or parachutes of fine hairs, so that the wind carries them far from the parent, as in the grasses and in the dandelion.
2) **Dispersal by animals:** some fruits carry hooks that catch in an animal's fur, whereas others are fleshy and brightly coloured, so that animals eat them and later pass the hard seeds out elsewhere.

Why dispersal is an advantage: it carries the seeds away from the parent plant, so that the seedlings need not compete with the parent or crowd one another for light, water and minerals, and fresh ground is colonised as a result.

Question 7

(a) The percentages passed on are worked out as follows:

From the producers to the primary consumers: (2 000 ÷ 20 000) × 100 = 10 per cent.

From the primary consumers to the secondary consumers: (200 ÷ 2 000) × 100 = 10 per cent.

(b) **About one tenth, that is roughly 10 per cent, of the energy at one trophic level is passed on to the next.** The remaining nine tenths is lost: most of it escapes as heat given out in respiration, while some is lost in undigested food (faeces), in the parts that are not eaten, and in the bodies of organisms that die and are taken by the decomposers. Because this lost energy cannot be passed on, less and less of it remains at each higher level.

(c) **The pyramid is broad at the base because energy is lost at every transfer from one level to the next.** Since each level can capture only about a tenth of the energy held by the level below, every level contains far less energy than the one beneath it, which in turn means that the producers at the base hold by far the most.

Each level above therefore holds less energy than the one below, so that the bars grow shorter towards the top, which gives the pyramid its broad base and its narrow apex.

It can never be turned upside down, because no level can ever hold more energy than the level that feeds it; there is simply too little energy left higher up to support a greater amount above, and so a pyramid of energy is never inverted.

SECTION C

Question 8

(a)

Parents: RRYY (round, yellow) × rryy (wrinkled, green).

Gametes: one parent forms gametes carrying only RY, the other only ry.

F1 generation: every offspring is RrYy, and because round and yellow are dominant, all are round and yellow.

(b)

The F1 plants are crossed: RrYy × RrYy.

Each F1 plant forms four kinds of gamete: RY, Ry, rY and ry.

When these gametes combine at random, the Punnett square below shows the sixteen possible offspring:

Gametes	**RY**	**Ry**	**rY**	**ry**
RY	RRYY	RRYy	RrYY	RrYy
Ry	RRYy	RRyy	RrYy	Rryy
rY	RrYY	RrYy	rrYY	rrYy
ry	RrYy	Rryy	rrYy	rryy

Counting the offspring gives a phenotype ratio of 9 : 3 : 3 : 1, that is 9 round yellow : 3 round green : 3 wrinkled yellow : 1 wrinkled green, because the two characters are inherited independently of each other.

(c) **This dihybrid cross illustrates Mendel's law of independent assortment.** The law states that, when two pairs of alleles are inherited together, each allele of one pair may pass into a gamete with either allele of the other pair, so that the two characters are inherited independently. It is for this reason that the new combinations, round green and wrinkled yellow, appear in the F2 alongside the parental types.

Question 9

(a) The theory of evolution by natural selection has the following main steps:

1) **Overproduction:** living things produce far more offspring than can ever survive to grow up.
2) **Variation:** the members of a species are not all alike, but differ from one another in many of their features.

3) **Struggle for existence:** because food, space and the other needs of life are limited, the offspring must compete, and many of them die before they can breed.
4) **Survival of the fittest:** those whose variations happen to make them best suited to their surroundings are the most likely to survive this struggle, whereas the less suited tend to die.
5) **Inheritance of the favourable variations:** the survivors live on to breed, whereby they pass their helpful features to their offspring.
6) **Change over time:** because this is repeated generation after generation, the helpful features become steadily more common, so that over a long time the species changes and becomes better adapted, and in the end new species may arise.

(b) Natural selection brings about insecticide resistance in the following way:

1) **There is variation in the mosquito population,** and a few mosquitoes happen to carry a gene that makes them resistant to the insecticide.
2) **When the insecticide is sprayed, the ordinary non-resistant mosquitoes are killed,** whereas the few resistant ones survive.
3) **These survivors breed and pass the resistance gene on to their offspring,** consequently the next generation contains a greater proportion of resistant mosquitoes.
4) **Generation after generation the resistant mosquitoes are favoured in this way, until most of the population is resistant** and the insecticide no longer kills them. This is natural selection at work.

Question 10

(a) Nitrogen is passed round the nitrogen cycle in the following way:

1) **Nitrogen fixation:** nitrogen gas from the air is turned into nitrogen compounds by nitrogen-fixing bacteria, such as *Rhizobium* in the root nodules of legumes and free-living bacteria in the soil, and also by lightning, whereby nitrates are added to the soil.
2) **Uptake and protein-making:** plants absorb these nitrates from the soil through their roots and build them into amino acids and proteins, and animals obtain their nitrogen in turn by eating the plants.
3) **Decay (ammonification):** when plants and animals die, and from their droppings, decomposer bacteria and fungi break down the proteins, consequently setting ammonia free into the soil.
4) **Nitrification:** nitrifying bacteria then change this ammonia first into nitrites and afterwards into nitrates, which the plants can take up once more.
5) **Denitrification:** in waterlogged soil, denitrifying bacteria change nitrates back into nitrogen gas, which escapes into the air, thereby completing the cycle.

(b) **Leguminous plants such as beans carry nitrogen-fixing bacteria in the nodules on their roots,** and these bacteria, of the genus *Rhizobium*, turn nitrogen from the air into nitrogen compounds in the soil. Consequently, growing a crop of legumes enriches the soil with nitrogen, so that a crop grown after them finds the soil already fertile; because of this, the farmer needs to buy far less nitrogen fertiliser.

(c) The nitrogen content of the soil can also be increased in two other ways:

1) **By adding manure or compost:** the rotted remains of plants and animals return nitrogen compounds to the soil as they decay.
2) **By adding artificial nitrogen fertilisers:** these supply the soil directly with nitrates or ammonium salts.

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Paper 3

FORM SIX EXAMINATION

Solutions

SECTION A

Question 1

(a) **Osmosis is the movement of water across a partially permeable membrane, from a region of higher water potential to a region of lower water potential.** When the solution outside the cell is more dilute than the cell sap, its water potential is higher, so that water passes into the cell; in contrast, when the solution outside is more concentrated, its water potential is lower, and consequently water passes out of the cell.

(b) **Water always moves by osmosis from a region of higher water potential to one of lower water potential.**

A plant cell does not burst because it is enclosed by a strong cellulose wall. As water enters and the cell swells, the wall resists and pushes back, whereby a turgor pressure is set up; this pressure rises until it prevents any more water from entering, so that the cell becomes firmly turgid instead of bursting.

(c) **In a strong salt solution the cell loses water by osmosis, because the solution has a lower water potential than the cell sap.** As a result of which the cytoplasm and the cell membrane shrink and pull away from the cell wall, whereby the cell is said to be plasmolysed.

Question 2

(a) The artery and the vein differ in three main ways:

1) **An artery has a thick, muscular and elastic wall,** whereas a vein has a much thinner wall.
2) **An artery has a narrow lumen and, except at the heart, no valves,** whereas a vein has a wide lumen and bears valves along its length that stop the blood from flowing backwards.
3) **An artery carries blood at high pressure away from the heart,** whereas a vein carries it at low pressure back towards the heart.

(b) **The wall of a capillary is only one cell thick,** so that the distance over which materials must diffuse between the blood and the tissues is very short, which in turn makes the exchange rapid.

The capillaries are also very narrow and form a vast branching network, whereby a large surface area is provided for exchange; and because these narrow vessels slow the blood down, there is ample time for substances to pass through the thin, permeable wall.

Question 3

(a) **The embryo sac is formed inside the ovule,** within the ovary of the flower.

(b) The embryo sac is formed in the following way:

1) **The ovule contains a single diploid cell, the megaspore mother cell,** where the process begins.
2) **This cell divides by meiosis to form four haploid megaspores,** three of which then break down, so that only one survives.
3) **The surviving megaspore divides by mitosis three times in succession,** consequently producing eight haploid nuclei within the growing sac.

4) **These eight nuclei then arrange themselves** as the egg cell with two synergids at the micropyle end, three antipodal cells at the far end, and two polar nuclei in the centre.

(c) The two nuclei that take part in double fertilisation are:

1) **The egg cell, which fuses with one male gamete to form the zygote,** which afterwards grows into the embryo.
2) **The two polar nuclei, which fuse with the other male gamete to form the endosperm,** the tissue that nourishes the embryo.

Question 4

(a) A single DNA nucleotide is made of three parts:

1) **A deoxyribose sugar.**
2) **A phosphate group.**
3) **A nitrogenous base,** which is adenine, thymine, guanine or cytosine.

(b) **In DNA, adenine always pairs with thymine, and guanine always pairs with cytosine.** The bases of each pair are held together by hydrogen bonds, and it is this complementary pairing that holds the two strands of the molecule together.

(c)

Given strand: A T G C C A G T

Complementary strand: **T A C G G T C A**

SECTION B

Question 5

(a) **The curve is S-shaped, rising slowly at first, then steeply, and finally levelling off,** which marks out its three phases:

1) **In the slow lag phase growth is gradual,** because the organism is still small, with few cells, and is only becoming established.
2) **In the rapid exponential (log) phase growth is fast,** because the cells are now dividing quickly while food and other resources are plentiful, consequently the organism increases greatly in size.
3) **In the final plateau (stationary) phase growth slows and then stops,** as the organism reaches its full size and is checked by its own limits and by competition for resources.

(b) The growth of a plant can be measured in two ways:

1) **By its increase in length or height,** measured with a ruler on a shoot or a root at intervals over time.
2) **By its increase in mass,** weighing the plant at intervals, of which the dry mass is the more reliable.

(c) **Dry mass is the better measure because it records only the actual organic material the organism has built up.** The fresh mass changes from hour to hour as the plant takes in or loses water, and because this water is not new growth, the fresh mass gives an unreliable figure; the one drawback of dry mass is that the plant must be killed and dried in order to find it.

Question 6

(a) **Ovulation occurs at about day 14 of the cycle.** It is triggered by the sudden surge of luteinising hormone (LH), which is seen as the tall peak on the graph at about that day.

(b) **Oestrogen, made by the developing follicle, repairs and thickens the lining of the womb after menstruation,** and when it reaches a high level it triggers the surge of LH that brings about ovulation.

Progesterone, made by the corpus luteum after ovulation, keeps the lining thick and richly supplied with blood, ready to receive an embryo; it also holds back the making of FSH and LH, whereby no new follicle is allowed to develop.

(c) **If the egg is not fertilised, the corpus luteum breaks down, so that the levels of progesterone and then of oestrogen fall.** Because progesterone is no longer present to maintain it, the thickened lining of the womb can no longer be held in place, consequently it breaks down and is shed, together with some blood, as the menstrual flow. This fall in progesterone also lets FSH rise once more, which in turn starts a new follicle growing and so begins the next cycle.

Question 7

(a) The processes labelled on the diagram are:

A: photosynthesis.
B: respiration.
C: feeding (the animal eating the plant).
D: decomposition (decay brought about by decomposers).

(b) **The carbon locked in dead matter is returned to the air mainly by the decomposers.** Bacteria and fungi feed on the dead bodies and the waste and respire, whereby the carbon is set free as carbon dioxide. Some dead matter, however, is buried before it can decay and is turned, over millions of years, into fossil fuels such as coal and oil; the carbon held in these is returned to the air as carbon dioxide only when they are burned.

(c) **Burning fossil fuels releases large amounts of extra carbon dioxide into the air,** far faster than the natural processes can remove it.

Clearing the forests removes the trees that would otherwise have taken carbon dioxide out of the air by photosynthesis, so that less of it is removed.

The amount of carbon dioxide in the air therefore rises, and because the gas traps heat, the climate grows warmer; this is the greenhouse effect. For Tanzania the consequences are serious, because the warming can change the pattern of the rains, harm the crops and raise the level of the sea, thereby threatening farms and coastal towns alike.

SECTION C

Question 8

(a) A molecule of DNA is replicated (copied) in the following way:

1) **The copying takes place in the nucleus, before the cell divides,** so that each of the two cells later formed can be given a complete and exact copy of the instructions.
2) **The two strands of the double helix first unwind and then separate,** as the enzyme helicase breaks the weak hydrogen bonds that hold the paired bases together, so that the strands unzip and come apart, laying their bases bare.
3) **Each of the old strands then serves as a template, or pattern, on which a new strand is built,** because the order of the bases along the old strand fixes the order along the new one.
4) **Free DNA nucleotides, which are present in the nucleus, line up against the exposed bases of each template,** each pairing with its complementary base by the base-pairing rule, adenine with thymine and guanine with cytosine, and held there by hydrogen bonds.
5) **The enzyme DNA polymerase then joins these lined-up nucleotides together into a continuous new strand,** linking their sugars and phosphates into a backbone alongside each template.

6) **In this way each old strand gains a new partner strand,** so that where there was a single double-stranded molecule there are now two.

7) **Each new molecule is therefore made of one old strand and one newly built strand,** and the two are exactly alike and identical to the molecule from which they were copied.

8) **Because each base can pair with one kind of base only, the copying is extremely accurate,** consequently, when the cell at last divides, each daughter cell receives a perfect copy of the genetic instructions.

(b) **Replication is called semi-conservative because each new molecule is built from one old strand and one new strand.** When the helix is copied, the two original strands separate and each acts as a template for a new partner, so that one strand of every new molecule is conserved from the parent while the other is freshly made. Because exactly half of each new molecule is thus kept from the original, the copying is described as semi-conservative.

Question 9

(a) **Lamarck explained the long neck by the inheritance of acquired characters, which rests on his law of use and disuse.** By this law a part of the body that is used a great deal becomes better developed, whereas a part that is little used dwindles away. He supposed that the short-necked ancestors of the giraffe reached up to browse on the leaves of tall trees, and that, by stretching constantly, each animal lengthened its neck a little during its own lifetime; because he held that such an acquired character could be passed on, the slightly longer neck was inherited by the offspring, consequently the neck grew longer and longer over many generations until the giraffe of today was reached.

Darwin explained the same long neck instead by natural selection. He pointed out that the giraffe's ancestors already varied, some having longer necks than others, and that this variation was inherited; because far more young are born than the food can ever support, the animals had to struggle to survive, especially once the lower leaves had been stripped and food grew short. In that struggle the animals with longer necks could reach the leaves that lay beyond the rest, so that they were the better fed and the more likely to survive, which is the survival of the fittest; consequently these longer-necked animals lived to breed and passed the long-neck character to their young, and as this was repeated generation after generation the long-necked type grew ever more common, until at last it was the only one.

(b) **Lamarck's theory is now rejected because characters acquired during life are not inherited.** A change brought about in the body during an animal's life affects only its body cells, and because it does not alter the genes carried in the sex cells, it cannot be handed on to the offspring; the children of a blacksmith, for example, are not born with the great muscles he has built up. The matter was settled by Weismann, who cut off the tails of mice generation after generation, yet the young were always born with full tails, which showed plainly that an acquired change is never inherited.

Darwin's theory is accepted because it rests on inherited variation and is borne out by the evidence. The variation on which it depends is real and is truly inherited, as the science of genetics has since confirmed, and the better-suited individuals are indeed the ones that survive and pass on their genes. The theory is supported, moreover, by the fossils, by comparative anatomy and by the way living things may be classified into related groups; and natural selection has actually been seen at work in our own day, as when mosquitoes become resistant to insecticides and bacteria to antibiotics. Because it fits, too, all that is now known of genes, DNA and mutation as the source of variation, Darwin's explanation is the one that biologists accept.

Question 10

(a) Three types of pollution may be described as follows:

1) **Water pollution is caused by sewage, factory waste and the run-off of fertilisers into rivers and lakes,** and it kills fish and other water life, spreads diseases such as cholera, and, where fertilisers are washed in, causes the over-growth of algae that robs the water of its oxygen.

2) **Air pollution is caused by the smoke and gases from vehicles, factories and the burning of wood and rubbish,** and it brings on diseases of the lungs, helps to form acid rain, and adds the carbon dioxide that warms the climate.

3) **Land pollution is caused by rubbish, plastics and the careless use of pesticides and other chemicals,** and it poisons the small living things of the soil, harms the crops and the animals that feed on them, and spoils the look of the land.

(b) **Cutting down the forests removes the trees that take in carbon dioxide and give out oxygen,** so that the air gains more carbon dioxide and the climate warms.

It also leaves the soil bare, so that the rain washes away the fertile topsoil and chokes the rivers with silt; the clearing destroys, too, the homes of countless wild plants and animals.

(c) The damage can be reduced in two main ways:

1) **By planting trees and protecting the forests,** cutting no more than is needed and replacing whatever is taken.

2) **By treating sewage and factory waste before it is released,** using fewer chemicals on the land, reducing, reusing and recycling rubbish, and protecting wildlife in national parks and reserves.

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Paper 4

FORM SIX EXAMINATION

Solutions

SECTION A

Question 1

(a) **The water is carried up through the xylem,** in particular through its vessels. These vessels are dead, hollow and open-ended, and are joined end to end into continuous tubes, so that water can pass freely up them without obstruction.

(b) **Water is pulled up the tree by the transpiration stream, which is driven by evaporation from the leaves.** As water vapour is lost from the leaf cells by transpiration, these cells draw water from the xylem to replace it, whereby a pull, or tension, is set up at the top of the water column.

This pull is passed all the way down the column because the water molecules cling together. The molecules are held to one another by cohesion, owing to the hydrogen bonds between them, so that the water forms one continuous thread; consequently the tension at the top draws the whole column upward, while the molecules also cling to the walls of the narrow xylem vessels by adhesion, which helps to hold the column in place. In this way water is raised to the top of even a tall mvule tree without any pump and without the use of living energy.

(c) **The water can be drawn up only while the column is unbroken, so an air bubble stops it rising.** Because the molecules must cling together in one continuous thread in order to pass the tension downward, an air bubble (an embolism) snaps that thread; as a result of which the tension can no longer be carried across the gap, and the broken column of water can no longer be pulled up that vessel.

Question 2

(a) **In the lungs, where the partial pressure of oxygen is about 13 kPa, the haemoglobin is about 97 per cent saturated;** in an actively respiring muscle, where the partial pressure is only about 3 kPa, it is about 40 per cent saturated.

(b) **The curve is S-shaped, and it is this shape that lets haemoglobin both load oxygen in the lungs and unload it in the tissues.** At the high partial pressure found in the lungs the curve is almost flat and near the top, so that the haemoglobin becomes very nearly fully saturated and takes up its maximum load of oxygen; and because the curve is flat here, the saturation stays high even if the oxygen pressure falls a little.

At the low partial pressures found in the respiring tissues, however, the curve is steep, so that a small fall in oxygen pressure brings about a large fall in saturation; consequently the haemoglobin gives up a great deal of its oxygen just where the tissues need it, whereas in the lungs it had held firmly on to it.

(c) **A higher level of carbon dioxide shifts the curve to the right, so that at any given oxygen pressure the haemoglobin holds less oxygen.** This is the Bohr effect, whereby carbon dioxide lowers the affinity of haemoglobin for oxygen. An actively respiring muscle gives out a great deal of carbon dioxide, and because this shifts the curve to the right, the haemoglobin passing through the muscle releases even more of its oxygen than it otherwise would, as a result of which the hard-working muscle is supplied with the extra oxygen it needs.

Question 3

(a) **The sperm are made in the testes,** within the walls of the seminiferous tubules.

(b) Sperm are formed in the following way:

1) **The wall of the seminiferous tubule contains diploid germ cells, the spermatogonia, which divide again and again by mitosis,** so keeping up a constant supply of cells.
2) **Some of these grow into primary spermatocytes, which then divide by meiosis.** The first meiotic division produces two haploid secondary spermatocytes, whereby the chromosome number is halved.
3) **The second meiotic division follows,** so that from each primary spermatocyte four haploid spermatids are formed.
4) **Each spermatid then changes shape to become a mature sperm,** growing a long tail and packing its head with the nucleus, consequently the finished sperm is stripped down and built for its single journey to the egg.

(c) Three parts of a mature sperm, and the work of each, are:

1) **The head, which carries the haploid nucleus** with the father's genes, and is tipped by the acrosome, a cap of enzymes that digests a way into the egg.
2) **The middle piece, which is packed with mitochondria** that release the energy, as ATP, needed to drive the tail.
3) **The tail, which lashes from side to side** and so propels the sperm forward towards the egg.

Question 4

(a) **The sex of a child is determined by the sex chromosomes, X and Y.** A female has two X chromosomes (XX), whereas a male has one X and one Y (XY); consequently, when a sperm carrying a Y chromosome fertilises the egg the child is a boy, whereas when a sperm carrying an X chromosome fertilises it the child is a girl.

(b)

Parents: mother XX × father XY.

Gametes: the mother forms only X eggs, whereas the father forms X and Y sperm in equal numbers.

Gametes	X	Y
X	XX	XY
X	XX	XY

Offspring: two XX (girls) to two XY (boys), that is one girl to one boy; because the father makes equal numbers of X and Y sperm, boys and girls are produced in roughly equal numbers.

(c) **It is the father who determines the sex of the child, because only the father can provide a Y chromosome.** The mother, being XX, can pass on nothing but an X chromosome, whereas the father, being XY, passes on either an X or a Y; consequently it is which of the father's two kinds of sperm fertilises the egg that decides the sex, so that the deciding chromosome always comes from the father.

SECTION B

Question 5

(a) Complete and incomplete metamorphosis differ in two main ways:

In complete metamorphosis the young is utterly unlike the adult, and the change passes through four stages, egg, larva, pupa and adult, whereas in incomplete metamorphosis the young, called a nymph, already resembles the adult and passes through three stages only, egg, nymph and adult.

In complete metamorphosis there is a resting pupal stage in which the body is wholly rebuilt, whereas in incomplete metamorphosis there is no pupa; the nymph simply grows and moults, changing little by little until it becomes an adult.

(b) The complete metamorphosis of a mosquito passes through four stages:

1) **The egg:** the female lays her eggs on the surface of still water, and from each egg a larva hatches.
2) **The larva:** the larva is an active, wriggling creature that lives in the water, feeding and growing and breathing air through a tube at its tail, and it moults several times as it enlarges.
3) **The pupa:** the larva then becomes a comma-shaped pupa, which still lives in the water but does not feed; within it the body is broken down and rebuilt into the adult form.
4) **The adult:** at last the pupal skin splits and the winged adult emerges, rests on the water until its wings harden, and then flies away, consequently completing the cycle when the female lays eggs of her own.

(c) **Because both the larva and the pupa live in water, the life cycle shows that the mosquito is most easily struck while it is still in the water.** This knowledge guides the control of malaria in Tanzania in several ways:

1) **Draining or filling stagnant pools and clearing blocked drains** takes away the standing water in which the female must lay her eggs, so that the larvae have nowhere to develop.
2) **Spreading a thin film of oil, or a larvicide, over standing water** blocks the breathing tubes of the larvae and pupae, consequently suffocating them before they can become biting adults.
3) **Knowing that the adult female bites mainly at night** also explains why sleeping under treated nets and spraying the walls of houses protect people, because these measures strike the adult as it comes to feed.

Question 6

(a) **From the mother to the baby pass food and oxygen:** dissolved foods such as glucose and amino acids, and the oxygen that the baby needs but cannot yet breathe for itself.

From the baby to the mother pass its wastes: the carbon dioxide and the urea made by the baby, which the mother's own organs then remove.

(b) The placenta is suited to this exchange in three ways:

1) **It has a very large surface area,** because it is drawn out into many finger-like villi that dip into the mother's blood, whereby a wide area is provided over which materials can be exchanged.
2) **The barrier between the two bloods is very thin,** so that the substances have only a short distance to diffuse across, which in turn makes the exchange rapid.
3) **The mother's blood and the baby's blood are brought very close together but kept in separate vessels,** and because a steep concentration gradient is maintained between them, oxygen and food diffuse steadily towards the baby while wastes diffuse the other way.

(c) **It is important that the two bloods do not mix because they may differ in ways that would harm the baby.** The mother and the baby may belong to different blood groups, so that if their blood were to mix the mother's antibodies could attack and destroy the baby's red cells; the baby's delicate vessels could not, moreover, withstand the mother's higher blood pressure, which would damage them. Keeping the bloods apart also helps to prevent germs and harmful substances in the mother's blood from passing straight to the baby, and so exchange takes place safely by diffusion across the thin barrier, without the two bloods ever joining.

Question 7

(a) **The grass** is a producer, occupying the first trophic level.

The grasshoppers are primary consumers, occupying the second trophic level.

The lizards are secondary consumers, occupying the third trophic level.

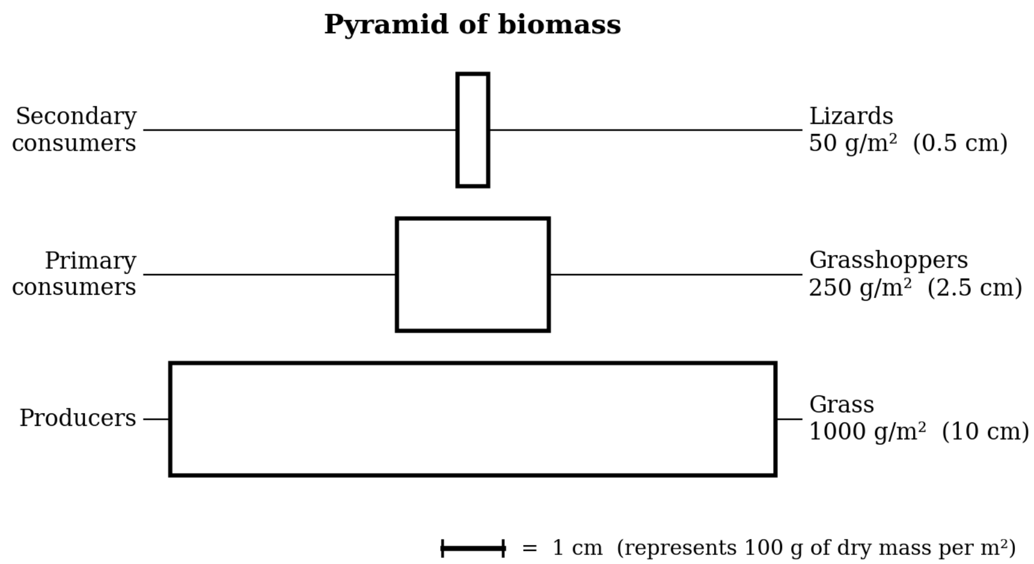
(b) **First the dry mass at each level is turned into a bar length, using the scale that 1 cm represents 100 g of dry mass per square metre:**

Grass: 1000 g ÷ 100 = a bar 10 cm long.

Grasshoppers: 250 g ÷ 100 = a bar 2.5 cm long.

Lizards: 50 g ÷ 100 = a bar 0.5 cm long.

The three bars are then drawn one above another and centred, the widest at the base, to give the pyramid of biomass shown below.



(c) **The dry mass becomes smaller at each higher level because so much material is lost at every step.** Much of what an animal eats is never built into its body, since some passes out undigested while a great deal is broken down in respiration to release energy and is lost as carbon dioxide and water; consequently each level can build up far less living material than the level below it fed upon, which is why the biomass falls as one goes up.

A pyramid of biomass usually gives a truer picture than a pyramid of numbers because it measures the amount of living material, and not merely the number of organisms. A pyramid of numbers can mislead, for a single large producer, such as one tree, counts as just one organism yet may feed a great many insects, so that the pyramid appears upside down; in contrast, weighing the living material at each level shows its true mass, and so keeps the proper pyramid shape.

SECTION C

Question 8

(a) **A character is described as sex linked when the gene that controls it is carried on a sex chromosome, here the X chromosome.** The gene for colour vision lies on the X chromosome and has no place on the much shorter Y chromosome, so that the character is inherited together with sex.

Colour blindness appears more often in men than in women because a man has only one X chromosome. Since the colour-blindness allele is recessive, a woman, who has two X chromosomes, is colour blind only if she carries the allele on both of them, whereas if she carries it on just one she has normal vision and is merely a carrier. A man, however, has only a single X chromosome, so that one recessive allele upon it is enough to make him colour blind, there being no second X to mask it; consequently colour blindness is far commoner in men.

(b) Let X^B stand for the X chromosome carrying the normal allele, and X^b for the X chromosome carrying the colour-blindness allele.

Parents: carrier mother X^BX^b × normal father X^BY.

Gametes: the mother forms X^B and X^b eggs, whereas the father forms X^B and Y sperm.

Gametes	$\mathbf{X^B}$	**Y**
$\mathbf{X^B}$	X^BX^B	X^BY
$\mathbf{X^b}$	X^BX^b	X^bY

The daughters are either X^BX^B (normal) or X^BX^b (carriers with normal vision); consequently none of the daughters is colour blind, though half of them are carriers.

The sons are either X^BY (normal) or X^bY (colour blind); consequently half of the sons are expected to be colour blind.

In summary, there is a one-in-two (50 per cent) chance that any son will be colour blind, whereas no daughter will be colour blind, although half of the daughters will be carriers and may pass the allele to their own children.

Question 9

(a) A species is a group of organisms that can interbreed to produce fertile offspring. Beginning from one such species, two separate species can arise as follows:

1) **Variation:** the members of the original species are not all alike, but vary; this variation arises in the first place from mutation, which creates new alleles, and is increased by the reshuffling of genes during meiosis and sexual reproduction.
2) **Isolation:** the species becomes divided into two populations that are kept apart by a barrier, such as a river, a mountain range or a stretch of sea; because the barrier prevents the two groups from meeting, they can no longer interbreed, so that the flow of genes between them is stopped.
3) **Different conditions:** the two separated areas usually differ in climate, in food and in predators, so that the two populations are exposed to different pressures of survival.
4) **The struggle for existence:** in each population far more young are produced than the food and space can support, so that the members must compete, and many die before they are able to breed.
5) **Natural selection acts differently on each population:** in each place it is the individuals best suited to the local conditions that survive and breed, whereby different variations are favoured in the two populations.
6) **The two gene pools change independently:** because the survivors pass on their favourable alleles, those alleles grow more common, and since selection works in different directions in the two places, the gene pools of the two populations change in different ways.
7) **The populations diverge:** generation after generation, as different features are selected and fresh mutations accumulate, the two populations grow more and more unlike each other in structure, in habits and in their genes.
8) **Reproductive isolation completes speciation:** in time the two have come to differ so greatly that, even if the barrier were removed and they met once more, they could no longer interbreed to produce fertile offspring; consequently they are now two separate species, and speciation is complete.

(b) **The great variety of cichlids is thought to have arisen by repeated speciation within the lakes.** The large lakes, such as Lake Victoria and Lake Tanganyika, offer many different habitats, some rocky, some sandy, some deep and some shallow, and groups of fish became isolated in them, for example around separate rocky shores, or when a falling lake level divided the water into smaller pools.

Once isolated, each group was shaped by natural selection to suit its own habitat and its own food, some becoming fitted to scrape algae from rocks, others to crush snails, and others to take insects or even the scales of other fish; consequently, as each isolated group diverged, it became a separate species, until the lakes came to hold hundreds of kinds, each suited to its own way of life.

Question 10

(a) An ecological succession proceeds from bare ground to a climax community as follows:

1) **Pioneer species colonise the bare ground first.** The first to arrive are tough, simple plants such as lichens and mosses, which can grow on bare rock or sand where little else will live, and as they grow and die they begin to make a thin soil.

2) **The new soil allows small plants to take over.** As the pioneers add dead material, the soil deepens and holds more water, whereby it becomes able to support grasses and small herbs, which then crowd the pioneers out.

3) **Larger plants follow in their turn.** The deepening soil and the shelter of the smaller plants now let shrubs, and later small trees, take root, and these in turn shade out and replace the plants that went before, so that each community changes the conditions and makes way for the next.

4) **A stable climax community is reached at last.** In the end a community is formed, such as a forest, that is in balance with the climate and the soil and gives way to no other; this final, stable community is called the climax, and the whole orderly series of changes from bare ground to climax is an ecological succession.

(b) **The later communities are richer in species and more stable because they offer far more ways of living than the bare pioneer stage did.** As the soil deepens and plants of many sizes grow, they create many different habitats and sources of food, so that a great variety of animals and plants can live together; and because the food webs are then woven of many interlinking strands, the loss of any one species matters less, whereby the whole community is the better able to withstand change and is therefore more stable.

An abandoned farm regains its plant cover faster than a bare rock surface because the hardest work has already been done. The farm already has a deep, fertile soil, full of water, minerals, seeds and roots, so that new plants can spring up almost at once; a bare rock, in contrast, has no soil at all, and soil must first be made, very slowly, by pioneer species over a long time, which is why succession upon bare rock is so much the slower.

ENJOY & MASTER ADVANCED BIOLOGY

Paper 5

FORM SIX EXAMINATION

Solutions

SECTION A

Question 1

(a) **Food is carried in the phloem,** and it moves through the living conducting cells of the phloem, the sieve tubes, each of which is helped by a companion cell beside it.

(b) **The movement of food from the leaf to the rest of the plant is called translocation, and it takes place along the sieve tubes of the phloem.** In the leaf, where photosynthesis makes the sugar, the sugar is actively loaded into the sieve tubes, so that water follows it in by osmosis and a high pressure is built up at that end; because this source end is at high pressure while the parts that use or store the sugar are at low pressure, the sugary sap is pushed along the sieve tubes from the leaf to the roots, the stem and the fruits, where the sugar is unloaded to be used in respiration or laid down as a store. In this way food can be carried either up or down the plant, in whatever direction it is needed.

(c) **A complete ring of bark, which contains the phloem, is cut away from round a woody stem, while the xylem deeper in the wood is left untouched.** After some weeks the bark swells into a bulge just above the ring, because the sugars travelling down the phloem are halted at the cut and gather there, whereas below the ring, cut off from their supply of food, the stem and roots are starved and may in time die. Because the water in the xylem still rises freely past the ring, so that the leaves stay alive, the experiment shows that it is the phloem of the bark, and not the xylem, that carries the sugars downward.

Question 2

(a) One heartbeat, or cardiac cycle, passes through these events:

1) **Atrial systole, when the atria contract:** the two atria contract together, so that the blood they hold is forced down through the open valves to fill the two ventricles.
2) **Ventricular systole, when the ventricles contract:** the two ventricles then contract, and because the rising pressure shuts the valves between the atria and the ventricles, the blood cannot go back but is driven out into the arteries, to the lungs and to the body.
3) **Diastole, when the heart relaxes:** the whole heart then relaxes, whereby the chambers fill once more with blood returning along the veins, and the cycle begins again.

(b) **The valves of the heart open one way only, so that blood can pass forward but never back.** When the ventricles contract, the atrioventricular valves between the atria and the ventricles are pushed shut, which stops the blood from flowing back into the atria, so that it must leave by the arteries instead; and when the ventricles relax, the semilunar valves in the mouths of the aorta and the pulmonary artery are pushed shut by the blood already in the arteries, consequently that blood cannot fall back into the ventricles. Because each valve closes the moment the pressure behind it would drive the blood the wrong way, the blood is kept moving in one direction only.

(c) **The heartbeat is described as myogenic because it arises in the heart muscle itself, and not from any nerve of the brain, so that the heart goes on beating even when its nerves are cut.** The rhythm is set by the sino-atrial node, the pacemaker, a patch of special muscle in the wall of the right atrium.

Question 3

(a) **The eggs are made in the ovaries.**

(b) An egg is formed and released in the following way:

1) **The ovary contains diploid germ cells, the oogonia, which divide by mitosis** and grow into primary oocytes.

2) **Each primary oocyte then begins meiosis, but the cytoplasm is divided unequally,** so that the first division gives one large secondary oocyte, which keeps almost all the food, and a tiny polar body, which is cast aside.

3) **The secondary oocyte, wrapped in a ball of cells called a follicle, grows and ripens,** as the follicle fills with fluid and moves to the surface of the ovary.

4) **At ovulation the ripe follicle bursts and sets the secondary oocyte free from the ovary** into the funnel of the oviduct, whereby the egg begins its journey towards the womb; its second meiotic division is completed only if a sperm later enters it.

(c) An egg is suited to its task of starting a new individual in two main ways:

1) **It is stocked with food (yolk),** which nourishes the new embryo in its earliest stages, until it can feed itself or, in a mammal, until it embeds in the wall of the womb.

2) **It is large and still, and the moment one sperm enters, its membrane changes so as to shut out all the others,** consequently the egg is fertilised by a single sperm only, and the proper chromosome number of the new individual is kept.

Question 4

(a) **The blood group is controlled by a single gene that has three alleles, namely I^A, I^B and i.** The alleles I^A and I^B are each dominant to i, while i is recessive, so that group A is I^AI^A or I^Ai, group B is I^BI^B or I^Bi, group O is ii, and group AB is I^AI^B. **Groups A and B are said to be codominant because, when I^A and I^B are present together, neither one masks the other but both are fully expressed,** consequently such a person shows the A and the B character at the same time and belongs to group AB.

(b) **The man is group A, but his mother was group O (ii), so she must have passed him an i allele; the man is therefore I^Ai. In the same way the woman is group B but her father was group O, so she is I^Bi.**

Parents: father I^Ai (group A) × mother I^Bi (group B).

Gametes: the father forms I^A and i, whereas the mother forms I^B and i.

Gametes	**I^A**	**i**
I^B	I^AI^B (AB)	I^Bi (B)
i	I^Ai (A)	ii (O)

The children could be of any of the four groups, with one chance in four of each: group AB (I^AI^B), group A (I^Ai), group B (I^Bi) or group O (ii).

SECTION B

Question 5

(a) In order to germinate, a seed needs three external conditions:

1) **Water,** which is taken in to soften the seed coat, to set the enzymes working and to carry the dissolved food to the growing parts.

2) **Oxygen,** which the living seed needs for the respiration that releases the energy for growth.

3) **A suitable warmth,** because the enzymes that bring about germination can work only within a certain range of temperature.

(b) As the seed germinates the following happens, within it and without:

1) **The seed takes in water and swells,** so that its coat, the testa, is softened and splits open.
2) **The water sets the enzymes of the seed working,** and these enzymes begin to digest the food stored in the seed.
3) **The stored starch is digested to sugar, and the stored protein to amino acids,** so that these soluble foods can be carried to the growing points and there used for energy and for building new cells.
4) **The young root, the radicle, is the first to emerge,** growing downward into the soil, anchoring the seedling and taking up water and mineral salts.
5) **The young shoot, the plumule, then grows upward** towards the light, pushing up through the soil.
6) **Until its first green leaves open, the seedling lives on the food stored in the seed,** whereby it respires and grows; once the leaves expand in the light, the seedling makes its own food by photosynthesis and so becomes self-supporting.

(c) An experiment to show that water is necessary for germination may be set up as follows:

1) **Set up three boiling tubes of bean seeds side by side,** so that the seeds in them can be given different conditions and compared.
2) **Give each tube different conditions:** in the first the seeds are kept dry; in the second they rest on moist cotton wool with air above them; in the third they are covered completely with water that has been boiled to drive out its air, with a film of oil on top to keep air out. In this way only the first tube lacks water, while the second has water, air and warmth together.
3) **Leave all three tubes for several days in the same warm place,** so that the warmth, which every seed needs, is kept the same in each and is not the thing being tested.
4) **Observe which seeds germinate:** those in the second tube, with water, air and warmth, germinate, whereas those in the first tube, with air and warmth but no water, do not.
5) **Draw the conclusion:** because the only difference between the first tube and the second is the water, and only the watered seeds grew, water must be necessary for germination; the third tube, which had water and warmth but no air and also failed, serves as a control showing that oxygen too is needed.

Question 6

(a) **In vegetative propagation a new plant grows from a part of the parent, such as a stem, a root or a leaf, without any seed and without the fusion of gametes.** The new plant is produced by ordinary mitosis from the cells of the one parent, and because mitosis copies the genes exactly, the offspring receives the very same genes as the parent; consequently it is genetically identical to the parent, one of a group called a clone, and resembles it in every inherited feature.

(b) Three natural methods of vegetative propagation, each with a Tanzanian plant, are:

1) **By rhizomes:** a rhizome is an underground stem that grows sideways and sends up new shoots, as in the banana, whose suckers spring up from the rhizome beside the parent and grow into new plants.
2) **By tubers:** a tuber is a swollen underground store of food bearing buds that grow into new plants, as in the sweet potato, whose tubers sprout into fresh plants, and the round (Irish) potato, whose 'eyes' grow into shoots.
3) **By bulbs:** a bulb is a short underground stem swollen with stored food, as in the onion, which forms new bulbs at its base, each of which grows into a separate plant.

(c) **Advantages:**

The crop comes true to type: because the new plants are genetically identical to the parent, a good parent, such as a sweet, heavy-yielding cassava, gives offspring exactly as good, without the variation that seed would bring.

The crop is quicker and more certain: a cutting or a sucker grows into a mature plant far sooner than a seed would, and it establishes more reliably, so that the farmer harvests sooner and need not depend on the setting of seed.

Disadvantage:

The whole crop is at the same risk: because every plant is genetically the same, the crop has no variation, consequently if one plant is struck by a particular disease or drought, all the others, being identical, are equally vulnerable, and the whole crop may be lost at once.

Question 7

(a) **The graph is S-shaped (sigmoid), and it shows the population passing through three phases:**

1) **The lag phase:** at first the few founding organisms increase only slowly, because they are still few in number and are settling into the new place.
2) **The exponential (log) phase:** the population then grows rapidly, doubling again and again, because food and space are plentiful and there is as yet little to check it, so that the numbers climb steeply.
3) **The stationary phase:** at last the growth slows and the numbers level off, holding roughly steady about a ceiling called the carrying capacity, the largest population that the place can support.

(b) **The rapid growth is brought to an end by environmental resistance, the whole set of factors that check a population as it grows denser.** As the numbers rise, these checks come into play:

1) **Food and space run short:** the crowding organisms compete for a limited supply of food, water and room, so that many can no longer get enough and fewer survive to breed.
2) **Wastes, predators and disease increase:** wastes pile up, predators gather where the prey is plentiful, and disease spreads easily through the crowd, consequently the death rate rises.
3) **Birth rate and death rate come to balance:** because of these checks the population can grow no larger, the number being born coming to equal the number dying, whereby it is held steady at the carrying capacity.

(c) **The water hyacinth grew explosively because, in Lake Victoria, it met ideal conditions and almost nothing to check it.** The warm tropical water and the plentiful nutrients, especially where sewage and the run-off of fertilisers had enriched the lake, gave it abundant food and room to spread; and because it was a newcomer, it had in the lake no natural enemies, no insects, diseases or animals that fed on it, to hold it back, so that, multiplying fast both by seed and by vegetative budding, it spread unchecked across the water until it covered great stretches of the lake.

SECTION C

Question 8

(a) **A mutation is a sudden change in the genetic material, the DNA, of a cell.** It may happen by chance when the DNA is being copied before a cell divides, a base being put in wrongly or left out altogether, and such changes are made more frequent by mutagens, such as certain chemicals, X-rays and other ionising radiation, and ultraviolet light.

A gene mutation is a change within a single gene, that is, in the sequence of bases of its DNA, for example one base being replaced by another, so that the gene now codes for a slightly altered protein. **A chromosome mutation, in contrast, is a change in the structure or the number of whole chromosomes,** as when a piece of a chromosome is lost, doubled or turned around, or when a cell comes to have a whole chromosome too many or too few, as in the extra chromosome that causes Down's syndrome. The two therefore differ in their scale: a gene mutation alters the letters within one gene, whereas a chromosome mutation rearranges or miscounts the chromosomes, each of which carries many genes.

(b) **In sickle cell anaemia a single base in the gene for haemoglobin is changed, so that one wrong amino acid is built into the haemoglobin.** Where the normal gene carries one base the sickle gene carries another, consequently in the protein the amino acid glutamic acid is replaced by valine at one point along the haemoglobin chain.

This one change alters the way the haemoglobin behaves. When it has given up its oxygen, the faulty haemoglobin molecules stick together into long fibres that pull the red cell out of shape, so that the round cell collapses into a stiff, curved sickle.

The sickled cells then harm the whole body. Because they are stiff and pointed, they cannot pass easily through the narrow capillaries, consequently they block the small vessels and cut off the blood supply, which causes pain and damages the organs; and because the sickled cells are fragile and are quickly destroyed, the person is left short of red cells, that is to say anaemic. Thus a change in a single base, through its effect on one protein, makes itself felt throughout the whole body.

The sickle cell allele stays common in the malarial parts of Tanzania because, in a single dose, it gives protection against malaria. A person who inherits the allele from both parents has the disease and often dies young, whereas a person who inherits it from one parent only, together with a normal allele from the other, is a carrier who is healthy and yet resists malaria, because the malaria parasite fares badly in his slightly sickle-prone red cells.

This carrier therefore has the advantage where malaria is rife. The carriers survive malaria better than people with two normal alleles, who are vulnerable to it, and they live longer than people with two sickle alleles, who suffer the anaemia; consequently the carriers are the most likely to survive and to breed, and so they keep handing on the sickle allele, which is why it stays common just where malaria is found. This is the heterozygous advantage.

Question 9

(a) According to the chemical theory, put forward by Oparin and Haldane, the first living things arose from non-living matter through a series of steps:

1) **The early atmosphere held the raw materials but no oxygen.** It is thought to have contained gases such as water vapour, ammonia, methane and hydrogen, and to have had no free oxygen, so that conditions were reducing and did not destroy the substances that formed.
2) **There was plenty of energy to drive the reactions.** Lightning, the Sun's strong ultraviolet rays (then unscreened, for there was no ozone) and the heat of volcanoes supplied the energy that made these gases react together.
3) **Simple organic molecules were formed.** Under this energy the gases combined into small organic molecules, such as amino acids and simple sugars; the experiment of Miller and Urey, who passed electric sparks through such a mixture of gases and obtained amino acids, shows that this could indeed happen.
4) **The molecules collected in the seas and joined into larger ones.** Washed by the rain into the early seas, the small molecules grew so concentrated, in what is called the primordial soup, that they joined together into larger molecules, among them proteins and nucleic acids.
5) **These large molecules gathered into droplets marked off from the water.** Bounded by a thin film, such a droplet could take in materials and grow, and so behaved a little like a very simple cell.
6) **At last a droplet arose that could copy itself.** Once a molecule able to reproduce itself had appeared within such a droplet, it could pass on its own make-up, whereby the first simple living things had come into being, and from then on life could go on reproducing and changing.

(b) **Once the first living things existed, natural selection could turn them, over an immense span of time, into the great variety of life we see today.** The steps are these:

1) **The first organisms varied,** because mutation kept giving rise to new forms of their genes, and later the reshuffling of genes in sexual reproduction added still more variation.
2) **More were produced than could survive,** so that the organisms had to struggle for the limited food and space, and many died before they could breed.

3) **The best-suited survived and bred:** in each kind of surroundings the individuals whose variations fitted them best were the most likely to survive and to pass those features on, which is natural selection.

4) **As living things spread into different habitats, selection shaped them in different directions,** so that each group became adapted to its own way of life, and groups that were isolated and selected differently diverged until they could no longer interbreed and so were separate species.

5) **Repeated over thousands of millions of years, this slow change and splitting produced, from the first simple cells, the millions of different kinds of living thing,** each suited to its place, that make up the variety of life today.

Question 10

(a) It is important to conserve natural resources and wild life for several reasons:

1) **They are a source of useful things:** wild plants and animals give us food, timber, medicines and materials, and many medicines still undiscovered may lie in species not yet studied, so that to lose them is to lose riches we can never regain.

2) **They keep the natural balance on which we ourselves depend:** living things recycle the gases of the air, build and hold the soil, pollinate the crops and keep one another's numbers in check, whereby the whole web of life, ourselves included, is kept in working order.

3) **They bring the country income through tourism:** Tanzania's wild herds, parks and coral reefs draw visitors from all over the world, consequently the wild life earns the nation a great deal of money and gives work to many people.

4) **They are a heritage with a worth of their own:** each kind of living thing is the unique product of a long history and, once lost, is gone for ever, so that we hold it in trust for our children, and many believe that living things have a right to exist for their own sake.

(b) The main threats to wild life in Tanzania, and the steps that can be taken against them, are these. First, the threats:

1) **The destruction of habitats:** as forests are cleared for farmland, timber and charcoal, and wetlands are drained, the wild plants and animals lose the very places in which they live, which is the greatest threat of all.

2) **Poaching and over-hunting:** animals are killed faster than they can breed, the elephant for its ivory and the rhinoceros for its horn, so that their numbers fall steeply.

3) **Pollution and over-use:** the poisoning of rivers and lakes, over-fishing and over-grazing by too many cattle spoil the habitats and exhaust the living resources.

And the steps that can be taken:

1) **Setting aside protected areas:** national parks and game reserves, such as the Serengeti and the Ngorongoro, are kept as places where the wild life is safe and may be neither farmed nor hunted.

2) **Making and enforcing laws:** the hunting of protected animals and the trade in ivory and other wild products are forbidden or controlled by law, and rangers are employed to guard the animals against poachers.

3) **Replacing what is taken and teaching the people:** trees are replanted, fishing and grazing are kept within what the land can bear, and the people are taught the value of wild life and are helped to share in the income from tourism, so that they too wish to protect it.

INDEX