EXAMINATION QUESTIONS ON MEASUREMENT AND MOTION

Question 1

(a) A student claims: *"Weight is a fundamental physical quantity because every object has weight and it can be measured directly on a scale."* Explain why this claim is incorrect.

(b) Work and torque both have the same dimensional formula ML^2T^{-2}, yet they are physically different quantities. Explain how two quantities can share the same dimensions but differ physically. Give one other pair of quantities with this property.

(c) The frequency f of a vibrating string depends on its length l, the tension T (force), and the linear mass density μ (mass per unit length). Use dimensional analysis to derive an expression for f in terms of l, T, and μ.

Question 2

(a) A student says: *"The number of students in a classroom is a physical quantity because it has a numerical value."* Explain clearly why this reasoning is flawed and why the number of students is not a physical quantity.

(b) Angles measured in radians are dimensionless, yet they represent a physical rotation. Explain why angles are treated as dimensionless in dimensional analysis and state one consequence this has for deriving formulas that contain angles.

(c) The Bernoulli equation for fluid flow is $P + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}$, where P is pressure, ρ is density, v is velocity, g is acceleration due to gravity, and h is height. Verify that the equation is dimensionally homogeneous.

Question 3

(a) A student repeats a measurement twenty times to reduce the error. Explain why this strategy reduces random errors but has no effect on systematic errors.

(b) Explain the physical mechanism by which parallax error arises when reading a scale. Describe how it can be eliminated.

(c) A student times 50 complete oscillations of a simple pendulum three times and obtains: 98.4 s, 98.0 s, 98.8 s. The pendulum length is $l = (0.950 \pm 0.002)$ m.

(d) Calculate the period T with its uncertainty.

(i) Calculate g using $g = 4\pi^2 l/T^2$ with its percentage and absolute uncertainty.

(ii) Identify the dominant source of error.

Question 4

(a) Explain why the international scientific community adopted a single system of units (SI) rather than allowing each country to use its own system.

(b) In 1999, the Mars Climate Orbiter spacecraft was destroyed during its approach to Mars. The root cause was a unit mismatch between two engineering teams. What lesson does this incident teach about measurement discipline?

(c) Convert a pressure of 760 mmHg into Nm^{-2} by using the method of dimensions. The density of mercury is $13.6 gcm^{-3}$.

Question 5

(a) Explain why averaging repeated measurements reduces random error. State clearly the condition under which this strategy works.

(b) Seven measurements of the thickness of a glass plate are recorded (in mm): 3.52, 3.48, 3.55, 3.50, 3.53, 4.21, 3.49. Examine the data carefully and explain your treatment of any suspect reading.

(c) Using the data from (b), after any necessary treatment, calculate the mean thickness with its absolute and percentage uncertainty. Express the result in standard notation.

Question 6

(a) Explain why the percentage error in a quantity raised to a power n is n times the percentage error in the original measurement.

(b) The period of a compound pendulum is given by:

$$T = 2\pi\sqrt{\frac{k^2 + h^2}{gh}}$$

where k is the radius of gyration and h is the distance from the pivot to the centre of mass. The measurements are $k = (0.200 \pm 0.001)$ m, $h = (0.300 \pm 0.001)$ m, and $g = 9.8\text{ms}^{-2}$ (exact). Calculate the percentage error in T.

Question 7

(a) Explain what is meant by catastrophic cancellation in measurement. State the condition under which it occurs and give one practical example.

(b) Explain how an experiment can be redesigned to avoid catastrophic cancellation. Give one specific example.

(c) The difference in gravitational potential energy between two points at distances r_1 and r_2 from the centre of the Earth is:

$$\Delta PE = GMm\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

Given $r_1 = (6400 \pm 10)$ km, $r_2 = (6800 \pm 10)$ km, and GMm is exact, find the percentage error in ΔPE.

Question 8

(a) Distinguish between the resolution of a measuring instrument and its sensitivity. Explain why a highly sensitive instrument is not necessarily accurate.

(b) A student says: *"I obtained the textbook value of $g = 9.8ms^{-2}$, so my experiment has zero error."* Identify two things wrong with this reasoning.

(c) In an experiment, the refractive index of glass is determined from $n = \sin i/\sin r$ where $i = (45.0 \pm 0.5)°$ and $r = (28.0 \pm 0.5)°$. Calculate the percentage uncertainty of n and its value in the standard notation.

(Hint: for a small change $\Delta\theta$ in an angle, the change in its sine is approximately $\Delta(\sin\theta) \approx \cos\theta \times \Delta\theta$, where $\Delta\theta$ must be in radians.)

Question 9

(a) In a pendulum experiment, explain why plotting T^2 against l is preferred over plotting T against l.

(b) A student draws a best-fit line through all the data points on a graph and forces it through the origin. Explain two things wrong with this approach.

(c) In a simple pendulum experiment, a student measures the period by timing 20 oscillations for six different lengths. The results are:

l (m)	0.40	0.50	0.60	0.70	0.80	0.90
T^2 (s^2)	1.58	2.05	2.48	2.78	3.22	3.60

The best-fit gradient is $4.05 s^2 m^{-1}$, the maximum gradient is $4.32 s^2 m^{-1}$, and the minimum gradient is $3.80 s^2 m^{-1}$. Using the relationship $T^2 = (4\pi^2/g)l$, determine g with its absolute and percentage uncertainty.

Question 10

(a) A student writes: "The mass of the Earth is 6×10^{24}." Explain what is wrong with this statement.

(b) A student measures the period of a simple pendulum by timing 20 oscillations and obtains $T = (2.01 \pm 0.01)$ s. The pendulum length is $l = (1.000 \pm 0.002)$ m. Using this value of g, the student then calculates the escape velocity from the Earth's surface using $v_e = \sqrt{2gR}$ where $R = 6.4 \times 10^6$ m (exact). Find percentage error in g and v_e.

Question 11

(a) Distinguish between accuracy and precision using a specific example from a school laboratory.

(b) A student claims: *"Random errors always cancel out when you take the mean, so the mean is always equal to the true value."* Explain why this is an oversimplification and state the conditions under which the claim approximately holds.

(c) A student determines g using a simple pendulum of length $l = (0.900 \pm 0.002)$ m. They time 30 complete oscillations three times and record: 57.24 s, 57.48 s, 57.12 s.

(i) Calculate the period T with its uncertainty.

(ii) Calculate g with its percentage and absolute uncertainty.

(iii) The accepted value of g at the location is $9.81 ms^{-2}$. Comment on whether the student's result is consistent with the accepted value.

Question 12

(a) A vehicle travels along a straight horizontal road for several minutes while its velocity remains constant. During this interval, fuel consumption continues and engine sound remains noticeable. Give a physical account of the force situation consistent with this observation.

(b) When the same vehicle enters dense traffic, passengers experience repeated forward and backward jolts even though the average velocity of the journey is not high. Account for these sensations using principles of motion.

(c) A car of mass 1400kg moving at 28m/s on a level road is brought uniformly to rest after travelling 84m. Determine:

(i) the braking force acting on the car and

(ii) the time taken to stop.

Question 13

(a) A small object released inside a smoothly moving train appears to fall vertically to a passenger inside, while an observer beside the track describes its path differently. Account for this difference without assuming either observation is incorrect.

(b) A cyclist maintains nearly the same pedalling effort but notices increasing difficulty in sustaining the same velocity when facing a strong headwind. Explain.

(c) A body of mass 3.0kg moves along a straight line under a constant driving force of 18N. A resistive force R = 3v acts simultaneously, where R is in Newton and v in m/s. Determine the acceleration at the instant when v = 4m/s.

Question 14

(a) A puck set in motion on a nearly frictionless horizontal surface continues moving for a long time after the initial push has ceased. Account for this observation.
(b) A passenger in a lift experiences brief changes in apparent weight when the lift starts moving upward and again when it slows near the top. Give an account of these sensations.
(c) A lift of mass 800kg carries a passenger of mass 70kg. At a certain instant, the lift is moving upward but slowing uniformly at $1.5 m/s^2$. Determine the normal reaction on the passenger.

(Take $g = 9.8 m/s^2$)

Question 15

(a) Two skaters initially at rest on frictionless ice push apart. The lighter skater is observed to gain velocity more rapidly. Account for this observation.
(b) A runner accelerates forward while pushing backward on the ground. Give a physical explanation of how forward motion arises in this situation.
(c) On frictionless ice, Kipute (55kg) and Kipanga (75kg) are initially at rest. Kipute pushes Kipanga for 0.40s. Immediately after the interaction, Kipute moves backward at 2.5m/s. Determine:
 (i) Kipanga's velocity and
 (ii) the magnitude of the force exerted during the push.

Question 16

(a) A ball projected vertically upward eventually returns to its starting level. Give a physical account of this motion.
(b) Athletes landing on sand often bend their knees, whereas landing stiffly on rigid ground frequently causes injury. Account for this difference.
(c) A ball is projected vertically upward from the ground at 26m/s. At the same instant, another ball is released from rest from a point 35m directly above the ground. Determine:
 (i) the time and
 (ii) height at which the two balls are at the same level.

(Take $g = 9.8 m/s^2$)

Question 17

(a) A ball is released from a moving vehicle travelling along a straight road. Relative to the ground, the ball lands some distance ahead of the point vertically below where it was released. Explain this observation.
(b) A runner on a smooth surface finds it difficult to accelerate compared with running on rough ground. Explain this observation.
(c) A body of mass 5.0kg initially at rest is acted upon by a constant horizontal force of 20N while a resistive force of 4N opposes the motion. Calculate the velocity attained after 5.0s and the displacement during this time.

Question 18

(a) During circular motion at constant speed, an object is still described as accelerating. Explain how this statement is physically consistent.
(b) When a car rounds a bend at steady speed, passengers tend to lean sideways. Discuss the physical reason for this behaviour.
(c) A car of mass 1200kg travels at 18m/s along a straight horizontal road. A constant braking force brings it to rest in 9.0s. Calculate the braking force and obtain the stopping distance.

Question 19

(a) A vehicle moves along a straight horizontal road while its engine power remains roughly constant, yet its velocity gradually approaches a steady value instead of increasing indefinitely. Explain physically why continuous acceleration does not persist.
(b) A crate is pushed across a warehouse floor. Initially it resists motion strongly, but once moving it slides more easily even though the applied push is unchanged. Discuss the physical reasons behind this behaviour.

(c) A car of mass 1200kg accelerates uniformly from 12m/s to 30m/s while travelling 270m along a straight level road. Calculate the resultant force acting on the car.

Question 20

(a) Two observers describe the same moving object but assign different velocities to it. Clarify how both descriptions can remain physically valid.
(b) A passenger standing in a bus notices that when the driver suddenly changes lanes, unsecured objects inside the bus shift sideways. Give a physical explanation for this effect.
(c) A ball is projected vertically upward from the edge of a 40m-high cliff with velocity 18m/s. Calculate the time taken to reach the ground below.

(Take $g = 9.8m/s^2$)

Question 21

(a) A student claims that whenever a body is moving, some net force must be acting in the direction of its motion. Explain why this claim is not generally valid.
(b) A box is pushed along a rough floor at constant velocity by a person whose push remains steady. Explain what must be true about the horizontal forces during the motion.
(c) A 0.25kg ball strikes a wall normally with velocity 10m/s and rebounds with velocity 8m/s in the opposite direction. The contact time is 0.030s. Calculate:
   (i) the change in momentum of the ball and
   (ii) the average force exerted on the ball by the wall.

Question 22

(a) A body can be accelerating even when its velocity magnitude remains constant. Explain how this can occur.
(b) A passenger standing in a daladala feels a sideways "pull" when the vehicle turns suddenly at a junction. Explain why this sensation is experienced.
(c) A stone is projected vertically upward from the ground with velocity 24m/s. Find:
   (i) the time when it is at a height of 20m on its way downward and
   (ii) its velocity at that instant.

(Take $g = 9.8m/s^2$)

Question 23

(a) Two forces can be equal in magnitude and opposite in direction yet fail to cancel. Explain why this can happen.
(b) When walking on a slippery surface, a person struggles to move forward effectively. Explain this observation using force ideas.
(c) On a smooth horizontal surface, two blocks A and B of masses 3kg and 5kg are in contact. A horizontal force of 16N is applied to block A, pushing both blocks together. Neglect friction. Calculate:
   (i) the common acceleration and
   (ii) the force exerted by A on B.

Question 24

(a) A body may momentarily have zero velocity without being at rest for any finite time. Explain this statement.
(b) A passenger inside a bus feels pressed sideways when the bus negotiates a roundabout at nearly constant velocity magnitude. Explain the sensation.
(c) A stone is projected vertically upward from ground level with velocity 22m/s. Calculate the time interval during which the stone is above a height of 15m. (Take $g = 9.8m/s^2$)

Question 25

(a) Explain why a constant resultant force does not always imply constant acceleration for every possible situation.
(b) A driver applies the brakes on a wet road and notices the stopping distance becomes much longer than on a dry road at the same initial velocity. Explain why.

(c) A car of mass 1200kg is moving at 20m/s on a straight road. The driver notices danger and reacts for 0.70s before braking begins. During braking, the resultant retarding force is constant at 3600N until the car stops. Calculate:
   (i) the braking time after braking begins,
   (ii) the braking distance,
   (iii) the total stopping distance from the instant the danger is noticed.

Question 26

(a) Explain why two bodies in collision experience equal and opposite forces yet can undergo different accelerations.
(b) A person in a moving vehicle is safer wearing a seatbelt during sudden braking. Explain why this is physically expected.
(c) A ball is projected vertically upward from the ground with velocity 28m/s. Exactly 1.2s later, a second ball is projected vertically upward from the same point with velocity 34m/s. Calculate:
   (i) the time after the first launch when the two balls meet,
   (ii) the height above the ground at which they meet.

(Take $g = 9.8m/s^2$)

Question 27

(a) A student claims that *if two forces are equal in magnitude and opposite in direction, then they must form a Newton's third-law pair*. Explain why this is not necessarily true.
(b) In many road accidents, two drivers claim they were travelling at the "same velocity" because their speedometers showed the same reading. Explain why this claim can still be wrong in physics terms.
(c) A car of mass 1000kg moves along a straight road with velocity 12m/s. The engine provides a constant driving force of 2200N. The resistive force is given by $R = 400 + 50v$, where R is in N and v is in m/s. Calculate:
   (i) the acceleration at $v = 12m/s$,
   (ii) the velocity at which acceleration becomes zero.

Question 28

(a) Two different force descriptions are proposed for a moving body: *"forces are absent"* and *"forces balance."* Explain why only one of these descriptions matches ordinary motion on Earth most of the time.
(b) A form five student claims that in any interaction, the "bigger force" must act on the object that accelerates more. Explain why this claim is not compatible with Newton's third law.
(c) A motorcycle and a car move along the same straight road. At a certain instant the motorcycle has velocity 18m/s and the car has velocity 30m/s in the same direction. The motorcycle begins to accelerate uniformly at $2m/s^2$ at that instant, while the car begins to decelerate uniformly at $3m/s^2$ at the same instant. Find:
   (i) the time after that instant when their velocities become equal,
   (ii) the separation between them at that instant if they were at the same point initially.

Question 29

(a) Kipute argues that *if two opposing forces act on a body and the body moves, then those forces cannot be equal in magnitude*. Explain why her reasoning can fail even when the body is moving.
(b) A diver steps off a platform into water. The diver comes to rest, yet serious injury is uncommon when the water is deep. Explain the physical reason using force and motion ideas.
(c) A stone is projected vertically upward from ground level with velocity 28m/s. Calculate the time interval during which the stone is below a height of 18m. (Take $g = 9.8m/s^2$)

SOLUTIONS

Question 1

(a) Weight is not a fundamental quantity. It is a force: $W = mg$. Force is derived from mass (fundamental), length (fundamental), and time (fundamental) through $F = MLT^{-2}$. The fact that weight can be measured directly on a scale does not make it fundamental.

Many derived quantities can be measured directly (velocity with a speedometer, pressure with a barometer), but they remain derived because they can be expressed in terms of simpler quantities.

(b) Work is a scalar defined as the product of force and displacement in the direction of the force: $W = Fd\cos\theta$. Torque is a vector defined as the product of force and the perpendicular distance from the pivot: $\tau = Fr\sin\theta$. Both involve force times distance, giving the same dimensions ML^2T^{-2}, but they describe entirely different physical effects. Work is energy transferred; torque is a turning effect. Dimensional analysis cannot distinguish them because it sees only dimensions, not physical meaning.

Another pair: pressure ($ML^{-1}T^{-2}$) and stress ($ML^{-1}T^{-2}$).

(c) Assume $f = kl^aT^b\mu^c$

Dimensions: $[f] = T^{-1}$, $[l] = L$, $[T] = MLT^{-2}$, $[\mu] = ML^{-1}$

$$T^{-1} = L^a(MLT^{-2})^b(ML^{-1})^c = M^{b+c}L^{a+b-c}T^{-2b}$$

For M: $0 = b + c$ … (i)

For T: $-1 = -2b$, giving $b = 1/2$ … (ii)

For L: $0 = a + b - c$ … (iii)

From (i): $c = -1/2$. From (iii): $a = c - b = -1/2 - 1/2 = -1$.

$$f = \frac{k}{l}\sqrt{\frac{T}{\mu}}$$

Question 2

(a) A physical quantity is a property that can be measured on a continuous scale and expressed as a number with a unit. The number of students is obtained by counting, not measuring. It is a discrete integer with no unit and no uncertainty. You cannot have 32.7 students. A physical quantity like length can take any value on a continuous scale (2.35 m, 2.351 m, 2.3517 m…) and always requires a unit to have meaning. Counting produces a pure number; measuring produces a physical quantity.

(b) An angle in radians is defined as arc length divided by radius: $\theta = s/r$. Both s and r have dimensions of length, so $[\theta] = L/L = 1$ (dimensionless). In dimensional analysis, angles are invisible: they contribute no powers of M, L, or T. The consequence is that dimensional analysis cannot discover that a formula contains an angle. For example, the formula $x = A\sin(\omega t + \phi)$ cannot be derived by dimensional analysis because sin and the angle ϕ are dimensionless and undetectable.

(c) First term: $[P] = ML^{-1}T^{-2}$

Second term: $\left[\frac{1}{2}\rho v^2\right] = ML^{-3} \times (LT^{-1})^2 = ML^{-3} \times L^2T^{-2} = ML^{-1}T^{-2}$

Third term: $[\rho gh] = ML^{-3} \times LT^{-2} \times L = ML^{-1}T^{-2}$

All three terms have dimensions $ML^{-1}T^{-2}$. The equation is dimensionally homogeneous.

Question 3

(a) Random errors vary unpredictably in direction: some readings are too high, others too low. When many readings are averaged, the positive deviations tend to cancel the negative ones, and the mean converges toward the true value. Systematic errors shift every reading in the same direction by the same amount. Averaging twenty shifted readings gives a mean that is shifted by exactly the same amount as any single reading. Repetition adds no new information about the systematic shift; only recalibration or a change of technique can remove it.

(b) Parallax occurs when the observer's eye is not perpendicular to the scale. If a pointer sits a small distance above the scale markings, viewing from an angle causes the line of sight to pass through the pointer and hit the scale at the wrong position. The pointer appears to align with a mark that is to the left or right of the true reading. The error is always in the same direction for a given viewing angle, making it systematic. It is eliminated by positioning the eye directly in front of and perpendicular to the scale at the point of reading.

(c)(i) Mean total time for 50 oscillations:

$$\bar{t} = \frac{98.4s + 98.0s + 98.8s}{3} = \frac{295.2s}{3} = 98.4s$$

Individual absolute errors: $|98.4 - 98.4| = 0.0$ s, $|98.0 - 98.4| = 0.4$ s, $|98.8 - 98.4| = 0.4$ s

Mean absolute error in total time: $\Delta\bar{t} = \frac{(0.0+0.4+0.4)s}{3} = 0.27s$

Period: $T = \frac{98.4s}{50} = 1.968s$

Uncertainty in period: $\Delta T = \frac{0.27s}{50} = 0.005s$

Result: $T = (1.968 \pm 0.005)$ s

(c)(ii)

$$g = \frac{4\pi^2 \times 0.950m}{(1.968s)^2} = 9.69ms^{-2}$$

$$\frac{\Delta g}{g} = \frac{\Delta l}{l} + 2\frac{\Delta T}{T} = \frac{0.002m}{0.950m} + 2 \times \frac{0.005s}{1.968s} = 0.21\% + 0.51\% = 0.72\%$$

$$\Delta g = 0.0072 \times 9.69ms^{-2} = 0.07ms^{-2}$$

Result: $g = (9.69 \pm 0.07)ms^{-2}$

(c)(iii) The period T dominates, contributing 0.51% out of the total 0.72%.

Question 4

(a) Different unit systems make communication between scientists, engineers, and trading partners unreliable. A measurement in one system cannot be compared with a measurement in another without conversion, and every conversion is an opportunity for error. A single international system ensures that a kilogram in one place means the same as a kilogram in any other place, enabling science, engineering, and commerce to operate without ambiguity.

(b) The lesson: every number must carry its unit, and every interface between systems must include a unit check.

(c) The pressure exerted by a column of liquid is $P = h\rho g$.

In CGS units: $h = 76cm$, $\rho = 13.6gcm^{-3}$, $g = 980cms^{-2}$

$$P = 76 \times 13.6 \times 980 = 1.013 \times 10^6 \quad gcm^{-1}s^{-2}$$

The dimensional formula of pressure is $ML^{-1}T^{-2}$, so $a = 1$, $b = -1$, $c = -2$.

Converting to SI using the method of dimensions:

$$n_{SI} = n_{CGS} \times \left(\frac{M_{CGS}}{M_{SI}}\right)^1 \times \left(\frac{L_{CGS}}{L_{SI}}\right)^{-1} \times \left(\frac{T_{CGS}}{T_{SI}}\right)^{-2}$$

$$= 1.013 \times 10^6 \times \left(\frac{1g}{1kg}\right)^1 \times \left(\frac{1cm}{1m}\right)^{-1} \times \left(\frac{1s}{1s}\right)^{-2}$$

$$= 1.013 \times 10^6 \times (10^{-3})^1 \times (10^{-2})^{-1} \times 1$$

$$= 1.013 \times 10^5 Nm^{-2}$$

The pressure is $1.013 \times 10^5 Nm^{-2}$.

Question 5

(a) Random errors vary unpredictably: some readings are too high, others too low. When many readings are averaged, the positive deviations tend to cancel the negative ones, so the mean converges toward the true value. This works on the condition that the errors are truly random (equally likely to be positive or negative) and that no systematic error is present. If a systematic error exists, every reading is shifted in the same direction, and averaging cannot remove the shift.

(b) Six of the seven readings cluster between 3.48 and 3.55 mm, a spread of 0.07 mm. The reading 4.21 mm lies 0.66 mm above the next highest value, far outside the cluster. This is almost certainly a blunder (a severe mistake such as misreading the scale or recording the wrong digit). It is discarded before further analysis. Including it would contaminate the mean and inflate the uncertainty with a single human error rather than reflecting the genuine measurement uncertainty.

(c) Using the six valid readings: 3.52, 3.48, 3.55, 3.50, 3.53, 3.49

Mean: $\bar{t} = (3.52 + 3.48 + 3.55 + 3.50 + 3.53 + 3.49)/6 = 21.07/6 = 3.512$ mm

Individual absolute errors: $|3.52 - 3.512| = 0.008$, $|3.48 - 3.512| = 0.032$, $|3.55 - 3.512| = 0.038$, $|3.50 - 3.512| = 0.012$, $|3.53 - 3.512| = 0.018$, $|3.49 - 3.512| = 0.022$

Mean absolute error:

$\Delta\bar{t} = \frac{(0.008+0.032+0.038+0.012+0.018+0.022)\text{m}}{6} = 0.022 \text{ mm} \approx 0.02 \text{ mm}$

Percentage error: $\left(\frac{0.02}{3.512}\right) \times 100\% = 0.6\%$

Result: $t = (3.51 \pm 0.02)$ mm

Question 6

(a) If $x = a^n$, then x is the product of n factors of a. By the multiplication rule, the relative error of a product is the sum of the relative errors of each factor. Since each factor is a with relative error $\Delta a/a$, the total relative error is $\Delta a/a$ added n times: $\Delta x/x = n(\Delta a/a)$. The power acts as a multiplier on the relative error.

(b) The question involves error propagation. So it requires all three rules:

Powers:

$k^2 = 0.0400\text{m}^2$. Percentage error: $2 \times \frac{0.001}{0.200} \times 100\% = 1.0\%$. Absolute error: $0.01 \times 0.0400 = 0.0004\text{m}^2$.

$h^2 = 0.0900\text{m}^2$. Percentage error: $2 \times \frac{0.001}{0.300} \times 100\% = 0.67\%$. Absolute error: $0.0067 \times 0.0900 = 0.0006\text{m}^2$.

Addition: $k^2 + h^2 = 0.1300\text{m}^2$. Absolute error: $0.0004\text{m}^2 + 0.0006\text{m}^2 = 0.0010\text{m}^2$.

Percentage error in *numerator* $(k^2 + h^2)$: $\left(\frac{0.0010}{0.1300}\right) \times 100\% = 0.77\%$

Division: The expression inside the square root is $\frac{k^2+h^2}{gh}$. Since g is exact, the *denominator* contributes only the error from h: $\frac{0.001}{0.300} \times 100\% = 0.33\%$.

Percentage error inside the square root: $0.77\% + 0.33\% = 1.10\%$

Square root: The square root applies a power of $1/2$:

$$\%\text{ error in T} = \frac{1}{2} \times 1.10\% = 0.55\%$$

The percentage error in T is 0.55%.

Question 7

(a) Catastrophic cancellation occurs when two nearly equal measured quantities are subtracted. The absolute errors add (Rule 1), but the result of the subtraction is small, so the relative error of the difference becomes much larger than the relative errors of the individual measurements. Example: if $a = (50.0 \pm 0.5)$ and $b = (49.0 \pm 0.5)$, each has 1% relative error, but the difference $a - b = (1.0 \pm 1.0)$ has 100% percentage error.

(b) The experiment should be redesigned to measure the small difference directly, rather than obtaining it by subtracting two large numbers. Example: to find the temperature rise of water during heating, use the same thermometer to read both temperatures (the change is read directly from the scale) rather than using two separate thermometers and subtracting. Alternatively, use instruments with much higher precision so that the absolute errors are small compared to the expected difference.

(c) First compute $\frac{1}{r_1}$ and $\frac{1}{r_2}$:

$$\frac{1}{r_1} = \frac{1}{6400\text{km}} = 1.5625 \times 10^{-4}\text{km}^{-1}$$

Error: $\frac{\Delta\left(\frac{1}{r_1}\right)}{\left(\frac{1}{r_1}\right)} = \frac{\Delta r_1}{r_1} = \frac{10}{6400} = 0.156\%$

$$\Delta\left(\frac{1}{r_1}\right) = 0.00156 \times 1.5625 \times 10^{-4} = 2.44 \times 10^{-7}\text{km}^{-1}$$

$$\frac{1}{r_2} = \frac{1}{6800\text{km}} = 1.4706 \times 10^{-4}\text{km}^{-1}$$

Error: $\frac{\Delta\left(\frac{1}{r_2}\right)}{\left(\frac{1}{r_2}\right)} = \frac{10}{6800} = 0.147\%$

$$\Delta\left(\frac{1}{r_2}\right) = 0.00147 \times 1.4706 \times 10^{-4} = 2.16 \times 10^{-7}\text{km}^{-1}$$

The difference:

$$\frac{1}{r_1} - \frac{1}{r_2} = 1.5625 \times 10^{-4} - 1.4706 \times 10^{-4} = 0.0919 \times 10^{-4} = 9.19 \times 10^{-6}\text{km}^{-1}$$

Absolute error:

$$\Delta = 2.44 \times 10^{-7} + 2.16 \times 10^{-7} = 4.60 \times 10^{-7}\text{km}^{-1}$$

Percentage error:

$$\frac{4.60 \times 10^{-7}}{9.19 \times 10^{-6}} \times 100\% = 5.0\%$$

Since GMm is exact, this is also the percentage error in ΔPE: **5.0%**.

Note: The individual measurements of r_1 and r_2 each have only about 0.15% error, but the subtraction of two close reciprocals amplifies this to 5.0%.

Question 8

(a) Resolution (least count) is the smallest change in a quantity that an instrument can detect. It equals the smallest division on the scale. Sensitivity is how much the instrument's output changes per unit change in the measured quantity. A thermometer where the mercury moves 3 cm per °C is more sensitive than one where it moves 0.5 cm per °C.

A highly sensitive instrument responds strongly to small changes, but if it has a systematic calibration error, all its readings are shifted from the true value. It detects changes precisely but reports values inaccurately. Sensitivity measures the fineness of the response; accuracy measures the correctness.

(b) First thing: Getting the textbook value does not mean the error is zero. The measurement still carries uncertainty from the instrument resolution, reaction time, and other sources. The uncertainty exists whether or not the mean happens to match the accepted value.

Second thing: The "textbook value" of $g = 9.8\text{ms}^{-2}$ is itself rounded. The actual value varies with location (latitude, altitude, local geology). A more precise accepted value for a specific location might be 9.812ms^{-2}. Comparing with a rounded reference value proves nothing about the quality of the measurement.

(c) $n = \sin 45.0°/\sin 28.0° = 0.7071/0.4695 = 1.506$

For the error, using $\Delta(\sin\theta) \approx \cos\theta \times \Delta\theta$ where $\Delta\theta$ is in radians:

$\Delta\theta = 0.5° = 0.5 \times \frac{\pi}{180} = 0.00873$ rad

Error in numerator:

$$\Delta(\sin 45.0°) = \cos 45.0° \times 0.00873 = 0.7071 \times 0.00873 = 0.00617$$

Relative error in numerator: $\frac{0.00617}{0.7071} = 0.872\%$

Error in denominator:

$$\Delta(\sin 28.0°) = \cos 28.0° \times 0.00873 = 0.8829 \times 0.00873 = 0.00771$$

Relative error in denominator: $\frac{0.00771}{0.4695} = 1.642\%$

Total percentage error in n (division rule):

$$0.872\% + 1.642\% = \mathbf{2.5}\%$$

$$\Delta n = 0.025 \times 1.506 = 0.038 \approx 0.04$$

Value: $n = 1.51 \pm 0.04$

Question 9

(a) The relationship $T = 2\pi\sqrt{l/g}$ is not linear: T is proportional to $\sqrt{l}$, not to l. Plotting T against l produces a curve, and drawing a straight line through a curve is unreliable and gives an imprecise gradient. Squaring both sides gives $T^2 = (4\pi^2/g)l$, which is a straight line through the origin with gradient $4\pi^2/g$. A straight-line graph is easier to draw accurately, the gradient can be measured precisely using two well-separated points, and deviations from linearity are immediately visible.

(b) First: The best-fit line should be drawn so that data points are distributed as evenly as possible above and below it. Drawing through every point follows the random scatter of individual readings, amplifying noise rather than averaging it out.

Second: The line should not be forced through the origin unless there is a physical reason and experimental confirmation. Even if the theory predicts the line passes through the origin, the data may indicate a small systematic offset (such as a zero error in the length measurement). Forcing the line through the origin hides this information and may distort the gradient.

(c) Gradient $m = \frac{4\pi^2}{g}$, so $g = \frac{4\pi^2}{m}$.

Best estimate: $g = \frac{4\pi^2}{4.05 s^2 m^{-1}} = 9.75 ms^{-2}$

From maximum gradient: $g_{min} = \frac{4\pi^2}{4.32 s^2 m^{-1}} = 9.14 ms^{-2}$

From minimum gradient: $g_{max} = \frac{4\pi^2}{3.80 s^2 m^{-1}} = 10.39 ms^{-2}$

$$\Delta g = \frac{g_{max} - g_{min}}{2} = \frac{10.39 ms^{-2} - 9.14 ms^{-2}}{2} = 0.6 ms^{-2}$$

Percentage uncertainty: $\left(\frac{0.6}{9.75}\right) \times 100\% = 6.2\%$

Result: $g = (9.8 \pm 0.6) ms^{-2}$

Question 10

(a) The statement is missing the unit. "6×10^{24}" is a pure number with no physical meaning. It could be 6×10^{24} kg, 6×10^{24} grams, or 6×10^{24} atoms. A physical quantity must always include its unit. Without the unit, the number communicates nothing.

(b) Percentage error in g:

$$\frac{\Delta g}{g} = \frac{\Delta l}{l} + 2\frac{\Delta T}{T} = \frac{0.002 m}{1.000 m} + 2 \times \frac{0.01 s}{2.01 s} = 0.2\% + 1.0\% = 1.2\%$$

Percentage error in v_e:

Since $v_e = \sqrt{2gR}$ and R is exact, v_e depends on g with a power of $1/2$:

$$\frac{\Delta v_e}{v_e} = \frac{1}{2} \times \frac{\Delta g}{g} = \frac{1}{2} \times 1.2\% = 0.6\%$$

Question 11

(a) Accuracy describes how close measurements are to the true value. Precision describes how closely repeated measurements agree with each other. Example: a student measures the boiling point of water five times using a thermometer and gets 101.2°C, 101.3°C, 101.1°C, 101.2°C, 101.3°C. The readings are precise (spread of only 0.2°C) but inaccurate (the true value at standard pressure is 100°C). A systematic calibration error of about +1.2°C is present.

(b) Random errors cancel only on average and only approximately. For a finite number of readings, the cancellation is incomplete. The mean of 5 readings may still differ from the true value by a small amount due to chance. As the number of readings increases, the mean approaches the true value more closely, but it reaches it exactly only in the limit of infinitely many readings. Furthermore, the claim assumes no systematic error is present. If a systematic error exists, the mean is displaced from the true value no matter how many readings are taken.

(c)(i) Mean total time for 30 oscillations:

$$\bar{t} = \frac{57.24 s + 57.48 s + 57.12 s}{3} = 57.28 s$$

Individual absolute errors: $|57.24 - 57.28| = 0.04$ s, $|57.48 - 57.28| = 0.20$ s, $|57.12 - 57.28| = 0.16$ s

Mean absolute error: $\Delta\bar{t} = \frac{(0.04 + 0.20 + 0.16) s}{3} = 0.13 s$

Period: $T = \frac{57.28 s}{30} = 1.909 s$

Uncertainty: $\Delta T = \frac{0.13 s}{30} = 0.004 s$

Result: $T = (1.909 \pm 0.004)$ s

(c)(ii)

$$g = \frac{4\pi^2 \times 0.900\text{m}}{(1.909\text{s})^2} = \frac{35.53\text{m}}{3.644\text{s}^2} = 9.75\text{ms}^{-2}$$

$$\frac{\Delta g}{g} = \frac{\Delta l}{l} + 2\frac{\Delta T}{T} = \frac{0.002\text{m}}{0.900\text{m}} + 2 \times \frac{0.004\text{s}}{1.909\text{s}} = 0.22\% + 0.42\% = 0.64\%$$

$$\Delta g = 0.0064 \times 9.75\text{ms}^{-2} = 0.06\text{ms}^{-2}$$

Result: $g = (9.75 \pm 0.06)\text{ms}^{-2}$

(c)(iii) The accepted value $9.81ms^{-2}$ lies at the upper boundary of the student's range $(9.75 \pm 0.06)ms^{-2}$, which spans from 9.69 to $9.81ms^{-2}$. The result is therefore consistent with the accepted value, though only marginally so. The fact that the accepted value falls at the extreme edge rather than near the centre suggests a possible small systematic error, such as measuring the length slightly too long or a slight timing bias.

Question 12

(a) Constant velocity means acceleration is zero. By Newton's second law, zero acceleration implies the resultant force on the vehicle is zero. Fuel is still consumed because the engine must provide a forward driving force to balance resistive forces such as air resistance and rolling friction. The engine sound and fuel consumption therefore indicate that forces are present but balanced, giving zero resultant force.

(b) In dense traffic the vehicle repeatedly accelerates and decelerates, so its velocity changes frequently. Because of inertia, passengers' bodies tend to maintain their previous state of motion while the vehicle's velocity changes. When the vehicle accelerates forward, passengers tend to lag behind relative to the vehicle; when it brakes, they tend to continue forward. These effects are felt as repeated forward and backward jolts.

(c) Given: $m = 1400\text{kg}, u = 28\text{m/s}, v = 0\text{m/s}, s = 84\text{m}$.

Using $v^2 = u^2 + 2as$:

$0 = (28\text{m/s})^2 + 2a(84\text{m})$

$a = -4.67\text{m/s}$

(i) Braking force: $F = ma$

$F = 1400\text{kg}\left(-\frac{4.67\text{m}}{\text{s}^2}\right) = -6.54 \times 10^3\text{N}$

The braking force has magnitude $6.54 \times 10^3\text{N}$ and acts opposite the motion.

(ii) Time to stop: $v = u + at$

$0 = 28\text{m/s} + (-4.67\text{m/s}^2)t;\ t = 6.0\text{s}$

The time to stop is 6.0s.

Question 13

(a) The difference arises because motion is described relative to a reference frame. The passenger inside the train shares the train's horizontal motion, so relative to the passenger the object has no horizontal velocity and appears to fall straight down under gravity. To the observer beside the track, the object retains the train's horizontal velocity at the moment of release while also accelerating downward due to gravity, so the path is curved. Both descriptions are correct in their own reference frames.

(b) A headwind increases the resistive force due to air resistance acting opposite to the cyclist's motion. If the cyclist's driving force (from pedalling) remains nearly the same while the opposing resistive force increases, the resultant forward force decreases. With a smaller resultant force, acceleration reduces and sustaining the previous velocity becomes more difficult.

(c) At v = 4m/s, resistive force: $R = 3v = 3(4) = 12\text{N}$.

Resultant force: $F = 18\text{N} - 12\text{N} = 6\text{N}$ (forward).

Acceleration: $a = \frac{F}{m} = \frac{6\text{N}}{3.0\text{kg}} = 2.0\text{m/s}^2$.

The acceleration is 2.0m/s^2.

Question 14

(a) With negligible friction, the horizontal resistive force is very small, so after the push there is approximately zero resultant horizontal force. By Newton's first law, the puck continues moving with constant velocity due to inertia. It is not kept moving by a continuing push; it continues because no significant resultant force acts to change its motion.

(b) Apparent weight depends on the normal reaction between the lift floor and the passenger. When the lift accelerates upward, the passenger must accelerate upward, requiring a larger upward normal reaction than weight, so the passenger feels heavier. When the lift slows while moving upward, its acceleration is downward; the required normal reaction becomes smaller than weight, so the passenger feels lighter.

(c) The lift is moving upward but slowing at 1.5m/s^2, so its acceleration is downward with magnitude 1.5m/s^2.

So $a = -1.5\text{m/s}^2$.

For the passenger: $N - W = ma$ or $N - mg = ma$

$N = mg + ma = m(g + a) = 70\text{kg}(9.8\text{m/s}^2 - 1.5\text{m/s}^2) = 581\text{N}$

The normal reaction on the passenger is 581N.

Question 15

(a) During the push, each skater experiences an interaction force equal in magnitude and opposite in direction. However, acceleration depends on mass through $a = F/m$. The lighter skater has smaller mass, so the same force produces a larger acceleration, causing the lighter skater to gain velocity more rapidly.

(b) When the runner's foot pushes backward on the ground, the ground exerts an equal and opposite frictional force forward on the foot. That forward force acts on the runner's body and produces forward acceleration. Without this forward force from the ground, forward acceleration would not occur.

(c) During the push, the interaction forces on the two skaters are equal in magnitude (Newton's third law). But since force is equal to the momentum change divided by time taken and they act for the same time interval (0.40s), the change in momentum on the two skaters are also equal in magnitude.

$|\Delta p|$ in Kipute $= m(v - u) = 55kg(2.5m/s - 0) = 55 \times 2.5kgm/s$

$|\Delta p|$ in Kipanga $= m(v - u) = 75kg(v - 0) = 75kg(v)$

$|\Delta p|$ in Kipute $= |\Delta p|$ in Kipanga or $55 \times 2.5kgm/s = 75kg(v);\ v = 1.83m/s$

(i) The Kipanga's velocity is 1.83m/s.

Kipute changes from 0 to 2.5m/s in 0.40s.

It follows that:

$$a = \frac{\Delta v}{\Delta t} = \frac{2.5m/s}{0.40s} = 6.25m/s^2$$

Magnitude of force: $F = ma = 55kg(6.25m/s^2) = 344N$

(ii) The magnitude of the force exerted during the push is 344N.

Question 16

(a) The ball is projected upward with an initial upward velocity. Gravity provides a constant downward acceleration throughout the motion. While the ball moves upward, its upward velocity decreases because the acceleration due to gravity is opposite to the motion. At the highest point the velocity becomes momentarily zero, but the acceleration remains downward, so the ball then gains downward velocity and returns to its starting level.

(b) The change in momentum needed to come to rest is fixed, but the average force depends on the stopping time: $F = \Delta p/\Delta t$. Bending the knees increases the time over which the body is brought to rest, reducing the average force during the impact. A smaller force reduces the risk of injury, while a stiff landing produces a shorter stopping time and therefore a larger force.

(c) Using $s = ut + \frac{1}{2}at^2 = ut + \frac{1}{2} \times (-9.8)t^2 = ut - 4.9t^2$

Ball A (projected upward from ground): $s = 26t - 4.9t^2$

The two balls will be at the same level after ball B travelling a distance of $35 - s$.

So, for ball B (released from rest 35m above ground): $35 - s = \frac{1}{2}at^2 = \frac{1}{2} \times (9.8)t^2 = 4.9t^2$

From which:

$$s = 35 - 4.9t^2$$

It follows that:

$$26t - 4.9t^2 = 35 - 4.9t^2$$
$$26t = 35;\ t = 1.35s$$

(i) The time is 1.35s.

Height: substitute into s for ball A:

$$s = 26(1.35) - 4.9(1.35)^2$$
$$s = 35.1 - 8.93 = 26.2m$$

(ii) The height is 26.2m above the ground.

Question 17

(a) The ball already has the forward velocity of the moving vehicle at the instant it is released. After release it continues moving forward due to inertia while gravity pulls it downward. Hence, relative to the ground it travels forward as it falls and lands ahead of the release point.

(b) On a smooth surface the frictional force between the runner's foot and the ground is small, so the ground cannot provide a large forward reaction force on the runner. Since forward acceleration requires a forward resultant force, the runner cannot accelerate effectively. On rough ground, greater friction allows a larger forward reaction force, making acceleration easier.

(c) Resultant force: $F = 20N - 4N = 16N$

Acceleration: $a = \frac{F}{m} = \frac{16N}{5.0kg} = 3.2m/s^2$

Velocity after 5.0s: $v = u + at = 0 + (3.2m/s^2)(5.0s) = 16m/s$

Displacement in 5.0s: $s = ut + 1/2at^2 = 0 + 1/2(3.2m/s^2)(5.0s)^2 = 40m$

Question 18

(a) Acceleration depends on change of velocity, and velocity changes if either magnitude or direction changes. In circular motion, the direction of velocity changes continuously even when speed is constant, so the object has acceleration directed toward the centre of the circle.

(b) Passengers tend to continue in their original straight-line motion due to inertia while the car changes direction. Relative to the turning car, this gives the sideways leaning effect. The actual resultant force required for turning is directed toward the centre of the bend, and the passenger's body must be forced sideways to follow the curved path.

(c) Acceleration: $a = \frac{v - u}{t} = \frac{(0 - 18m/s)}{9.0s} = -2.0m/s^2$
Braking force: $F = ma = 1200kg(-2.0m/s^2) = -2400N$
Magnitude of braking force = $2400N$ (opposite to the motion)
Stopping distance: $s = ut + 1/2at^2 = (18m/s)(9.0s) + 1/2(-2.0m/s^2)(9.0s)^2 = 81m$

Question 19

(a) As velocity increases, resistive forces (especially air resistance and rolling resistance) increase. With roughly constant engine power, the driving force available at higher velocity does not keep increasing, while the opposing forces grow. The resultant force therefore decreases and may reach zero, so acceleration reduces and eventually becomes zero, giving a steady (terminal) velocity on the road.

(b) Before motion begins, static friction adjusts up to a maximum value and can be large, so the crate strongly resists starting. Once the crate is moving, kinetic friction acts and is typically smaller and more nearly constant. With the same applied push, the resultant forward force becomes larger after slipping begins, so the crate moves more easily.

(c) Using $v^2 = u^2 + 2as$; where: $u = 12m/s, v = 30m/s, s = 270m$
$a = (v^2 - u^2)/(2s) = ((30)^2 - (12)^2)/(2 \times 270)$
$a = (900 - 144)/540 = 756/540 = 1.40m/s^2$
Resultant force: $F = ma = 1200kg \times 1.40m/s^2 = 1.68 \times 10^3$ N

Question 20

(a) Velocity is defined relative to a reference frame. Different observers may use different frames (ground, vehicle, train etc), so they can assign different velocities to the same object without contradiction. Each velocity is correct within its own chosen reference frame.

(b) When the bus changes lanes, it accelerates sideways. Unsecured objects tend to continue in their original straight-line motion due to inertia. Relative to the bus, they appear to shift sideways opposite to the bus's sideways acceleration. The sideways shift is therefore a consequence of inertia during change of direction.

(c) Initial velocity: $u = +18m/s$, Acceleration: $a = -9.8m/s^2$, Displacement to ground: $s = -40m$
Using $s = ut + \frac{1}{2}at^2$
$-40 = 18t + \frac{1}{2}(-9.8)t^2$
$-40 = 18t - 4.9t^2$

Rearrange: $4.9t^2 - 18t - 40 = 0$; $t = 5.23s$

The time taken to reach the ground is 5.23s.

Question 21

(a) Motion does not require a net force; only a change in motion (acceleration) requires a net force. A body can move with constant velocity while the resultant force is zero. Net force is linked to acceleration, not to the existence of velocity.

(b) Constant velocity means zero acceleration, so resultant horizontal force must be zero. Therefore, the forward push must be equal in magnitude to the frictional (and any other resistive) force acting backward.

(c) Take initial direction toward the wall as positive: $m = 0.25kg, u = +10m/s, v = -8m/s, t = 0.030s$

(i) Change in momentum:

$$\Delta p = m(v - u) = 0.25(-8 - 10) = 0.25(-18) = -4.5kgm/s$$

The change in momentum of the ball is $4.5kgm/s$ opposite to the initial motion's direction.

(ii) Average force:

$$F = \Delta p/\Delta t = (-4.5)/0.030 = -150N$$

The average force exerted on the ball by the wall is 150N opposite to the initial motion's direction (away from the wall).

Question 22

(a) Acceleration depends on change of velocity, and velocity changes if direction changes even when magnitude is constant. Thus, an object moving with constant speed in a curved path can still accelerate because its direction of motion changes continuously.

(b)

Reason:
A change in direction of motion requires a resultant force toward the centre of the turn.

Explanation:
When the daladala turns, it accelerates sideways toward the centre of the curve. The passenger's body tends to continue moving in a straight line due to inertia. Relative to the turning vehicle, this makes the passenger appear to be pushed sideways outward.

(c) Using $s = ut + 1/2at^2$; where: $u = 24m/s, a = -9.8m/s^2, s = 20m$
$20 = 24t - 4.9t^2$ or $4.9t^2 - 24t + 20 = 0$
Solving the quadratic equation gives: $t = 1.07s$ or $t = 3.83s$
(i) On the way downward → larger time: $t = 3.83s$
(ii) Velocity then: $v = u + at = 24 - 9.8(3.83) = -13.5m/s$ (downward)

Question 23

(a)
Reason:
Forces cancel only when they act on the same body.

Explanation:
Equal and opposite forces can act on different bodies as part of a Newton's third-law interaction pair. Since these forces act on separate objects, they do not combine to give zero resultant force on any single body. Cancellation occurs only when opposite forces act on the same object.

(b) Forward motion while walking requires a forward frictional force from the ground. On a slippery surface, friction is too small, so the ground cannot provide a strong forward force on the foot. The foot slips backward and the person cannot generate sufficient forward acceleration.

(c) Total mass $= 3kg + 5kg = 8kg$
(i) Common acceleration: $a = \frac{F}{m_{total}} = \frac{16N}{8kg} = 2.0m/s^2$
(ii) Force exerted by A on B is the one that makes B to accelerates. Thus;
$F_{AB} = m_B a = 5kg(2.0m/s^2) = 10N$

Question 24

(a) In motions such as a vertical throw, the body slows down as it rises because acceleration remains downward. At the highest point the velocity becomes zero only momentarily (instantaneous), but acceleration is still present, so the velocity immediately changes again and the body continues moving in the opposite direction. Hence zero velocity at an instant does not mean the body is at rest for a finite time.

(b) As the bus goes around the roundabout, its velocity direction changes continuously even if the magnitude stays nearly constant. The passenger's body tends to continue in a straight line due to inertia, so relative to the turning bus the passenger feels pushed sideways. The actual force required is inward (toward the centre) to make the passenger follow the curved path.

(c) Given: $u = 22m/s, a = -9.8m/s^2$, height $h = 15m$.

Solve for times when $s = 15m$ using: $s = ut + \frac{1}{2}at^2$

$$15 = 22t - 4.9t^2 \text{ or } 4.9t^2 - 22t + 15 = 0$$

Solving the quadratic equation gives two values of t which are:

$t_1 = 0.84s$ (on the way upward)

$t_2 = 3.65s$ (on the way downward)

Time interval above $15m = t_2 - t_1 = 3.65s - 0.84s = 2.81s$

So the stone is above 15m for **2.81s**.

Question 25

(a)
Reason:
A constant resultant force does not always guarantee constant acceleration unless the mass of the body remains constant.

Explanation:
Newton's second law in its most general form states that the resultant force equals the rate of change of momentum. If the mass of a body changes with time (for example, systems losing mass), a constant force can produce a non-uniform change in velocity. Therefore, constant force implies constant acceleration only when the mass of the body is constant.

(b)
Reason:
The maximum braking force depends on the friction between the tyres and the road.

Explanation:
On a wet road, the friction between tyres and the road surface is reduced. This limits the maximum braking force that can act on the vehicle. With a smaller braking force, the deceleration is smaller ($a = F/m$), so the vehicle takes more time and travels a longer distance before stopping. Hence the stopping distance increases on wet roads.

(c) Reaction distance: $s = vt$

$$s = (20\ m/s)(0.70\ s) = 14m$$

Braking acceleration: $a = \frac{F}{m} = -\frac{3600}{1200} = -3m/s^2$

(i) Using $v = u + at$

$$0 = 20 - 3t;\ t = 6.67s$$

The braking time is 6.67s.

(ii) Using $v^2 = u^2 + 2as$

$$0 = 20^2 + 2(-3)s;\ s = 66.7m$$

The braking distance is 66.7m.

(iii) Total distance = Reaction distance + Braking distance = $(14 + 66.7)m$
The total stopping distance is 80.7m.

Question 26

(a)
Reason:
Acceleration depends on both force and mass.

Explanation:
During a collision, the two bodies exert equal and opposite forces on each other according to Newton's third law. However, acceleration is given by force divided by mass. **If the masses of the two bodies are different**, the same force produces different accelerations. Therefore, equal and opposite forces do not always lead to equal accelerations.

(b)
Reason:
A seatbelt increases the time over which a passenger's momentum changes.

Explanation:
When a vehicle brakes suddenly, the passenger tends to continue moving forward due to inertia. A seatbelt applies a stopping force over a longer time and distance compared with an abrupt stop against the dashboard or seat. Since average force equals change in momentum divided by time, increasing the stopping time reduces the force on the passenger, lowering the risk of injury.

(c) Using $s = h = ut - \frac{1}{2}gt^2 = ut - 4.9t^2$
If t is the time from the first launch.

Height of first ball: $h = 28t - 4.9t^2$

Height of second ball (launched 1.2 s later): $h = 34(t - 1.2) - 4.9(t - 1.2)^2$

Equating heights and simplifying gives: $t = 2.69s$

(i) Time after first launch is 2.69s.
(ii) Height: $h = 28(2.69) - 4.9(2.69)^2 = 39.9m$

Question 27

(a)
Reason:
Equal and opposite forces can act on the same body.

Explanation:

A Newton's third-law pair must act on two different bodies. Two forces can be equal and opposite yet both act on the same object (balanced forces). In that case they are not a third-law pair.

(b)
Reason:

Velocity includes direction as well as magnitude.

Explanation:

Two bodies can have the same speedometer reading yet have different velocities if their directions differ. Even if directions are opposite, the magnitudes can match but velocities are not the same

(c) Resistive force: R = 400 + 50v
(i) At $v = 12\ m/s; R = 400 + 50(12) = 1000\ N$

Resultant force: $F = 2200N - 1000N = 1200N$

Acceleration: $a = \frac{F}{m} = \frac{1200N}{1000kg} = 1.2\ m/s^2$

The acceleration is $1.2\ m/s^2$.

(ii) Acceleration becomes zero when driving force equals resistance:

$$2200 = 400 + 50v;\ v = 36m/s$$

The velocity is $36m/s$.

Question 28

(a) **Choice:** Forces balance

Reason:

On Earth, resistive forces and contact forces are almost always present.

Explanation:

In ordinary motion, forces are rarely absent because bodies interact with the ground, air, and other surfaces. What commonly happens is that several forces act but balance so that the resultant force is zero, giving constant velocity or rest. Therefore "forces balance" matches ordinary motion more often than "forces are absent".

(b)

Reason:

Newton's third law requires interaction forces to be equal and opposite.

Explanation:

In an interaction, the force on A by B equals the force on B by A in magnitude. Therefore, there is no "bigger force" between the two interacting bodies. The body that accelerates more does so because it has smaller mass, not because it experiences a bigger interaction force.

(c) Velocities become equal when; $v_{motorcycle} = v_{car}$

For motorcycle: $v = u + at$

$$v = 18m/s + (2m/s^2)t$$

For car: $v = u + at$

$$v = 30m/s + (-3m/s^2)t$$

If velocities become equal:

$$18 + 2t = 30 - 3t;\ t = 2.4s$$

(i) Time when velocities become equal is 2.4s.

Motorcycle displacement: $s = ut + ½at^2$

$$s_m = (18m/s)(2.4s) + ½(2m/s^2)(2.4s)^2 = 48.96m$$

Car displacement: $s = ut + ½at^2$

$$s_c = (30m/s)(2.4s) + ½(-3m/s^2)(2.4s)^2 = 63.36m$$

$\text{Separation} = s_c - s_m = 63.36m - 48.96m = 14.4m$

(ii) The separation between them is 14.4m.

Question 29

(a)

Reason:

Motion does not require a non-zero resultant force.

Explanation:

A body can move with constant velocity when the resultant force is zero. If two forces on the body are equal in magnitude and opposite in direction, the resultant force is zero, so the body does not accelerate but it can still continue moving if it already had velocity. Therefore, movement does not imply unequal forces; unequal forces are required only for changing velocity.

(b)

Reason:

Injury risk depends on the size of the stopping force, which depends on how quickly velocity is reduced.

Explanation:

When the diver enters deep water, the diver is brought to rest over a longer time and distance because the water yields and allows the body to decelerate gradually. Since the change in momentum is spread over a longer time, the average resultant force is smaller. A smaller stopping force reduces the likelihood of serious injury compared with coming to rest in a very short time on a rigid surface.

(c) Use vertical motion equation: $s = ut - \frac{1}{2}gt^2$ (From $s = ut + \frac{1}{2}at^2$; where $a = -g$)
Substituting:

$$18 = 28t - \frac{1}{2}(9.8)t^2 \text{ or } 18 = 28t - 4.9t^2$$

Rearranging:

$$4.9t^2 - 28t + 18 = 0$$

Solving the quadratic equation gives two values of t which are:

$t_1 = 0.74s$ (on the way upward)

$t_2 = 4.98s$ (on the way downward)

Time interval above $15m = t_2 - t_1 = 4.98s - 0.74s = 4.24s$

So the stone is above 18m for 4.24s.

Total time of flight: $T = \frac{2u}{g} = \frac{2 \times 28m/s}{9.8m/s^2} = 5.71s$

Time interval below given height = Total time of flight − Time interval above the height

Time interval below $18m = (5.71 - 4.24)s = 1.47s$

The stone is below the height of 18m for $\mathbf{1.47s}$ in total.