MODULE 18
FREE-BODY DIAGRAMS (FBDs)

Before applying equilibrium equations, we need a clear picture of what forces are actually acting on a body. In real situations, forces often come from different sources: gravity pulls downward, surfaces push upward, strings pull at angles, and friction resists motion. To analyse such situations properly, Physics isolates the body from its surroundings and represents all the forces acting on it in a simple sketch called a **free-body diagram (FBD)**. This diagram acts as the bridge between the physical situation and the mathematical equations used to analyse equilibrium. It is a bit like cooking **pilau** without the spices; you may still call it pilau, but everyone knows something important is missing. In the same way, solving equilibrium problems without a free-body diagram often produces an answer, but it often lacks balance, clarity, and sometimes correctness.

Concisely, a free-body diagram *is a diagram of a body isolated from its surroundings, showing **only the forces acting on it***. It is the bridge between the real situation and the equilibrium equations: $\Sigma F_x = 0$ and $\Sigma F_y = 0$.

Is a Free-Body Diagram Always Necessary?

It is not always necessary to draw a free-body diagram before solving equilibrium problems, especially in very simple situations where the forces are obvious and act along a single straight line. In such cases, the equilibrium equations can sometimes be written directly without first sketching a diagram.

However, as soon as forces act in different directions, particularly at angles, drawing a free-body diagram becomes extremely important. The diagram helps to:

- Identify all forces acting on the body.

- Show their correct directions.

- Avoid missing or inventing forces.

- Guide the correct resolution of forces into components.

Without a proper free-body diagram, mistakes often occur not in algebra but in identifying forces and their directions.

For this reason, although not always compulsory, drawing a free-body diagram is considered best practice in A-Level Physics and is strongly recommended before applying the equilibrium equations.

How to Draw a Free-Body Diagram (Step-by-Step)

Step 1: Choose the body

Decide exactly what you are analysing (a block, a ring, a hanging load, a trolley, etc.). Treat it as a **particle** (a point).

Step 2: Isolate it

Imagine the body is cut free from contact surfaces, strings, and supports. The surroundings are removed, but the **forces they exert remain**.

Step 3: Replace each interaction by a force arrow

Draw arrows starting from the particle. Each arrow represents a force on the body.

Step 4: Label every force

Use standard symbols (**W** for weight, **R** for normal reaction, **T** for tension, **f** for friction force). If a force is at an angle, show the angle clearly.

Step 5: Choose axes

Usually: **x** for horizontal, **y** for vertical. Choose positive directions. If an incline is involved, you may choose axes parallel and perpendicular to the plane (later in the chapter).

What to Include (and What NOT to Include) in FBDs

A correct free-body diagram includes only the relevant forces acting on the body and nothing more. The following guidelines help ensure clarity and accuracy.

Include:

- Forces **acting on** the body (pushes, pulls, weight, contact forces).

- Directions of forces.

- Angles where needed.

Do NOT include:

- Motion arrows (velocity) as if they were forces.

- Forces exerted **by** the body on other objects (unless that other object is your chosen body).

- Extra forces invented to "make it balance."

Always obey the following **rule:** *Every force must have a clearly identifiable source (agent). If you cannot say what is causing the force, you should question whether it really exists.*

Common FBD Mistakes

Errors in equilibrium analysis frequently originate from incorrect free-body diagrams rather than algebraic mistakes. The following are common pitfalls students should avoid.

- **Mixing action and reaction on the same diagram**

Example: If you draw forces on a block resting on a table, include the weight of the block and the upward reaction from the table. Do not include the force the block exerts on the table, because that force acts on the table, not on the block.

So, *always draw only forces acting on the object you are analysing, not the forces it exerts on other bodies.*

- **Friction drawn in the wrong direction**

Friction opposes motion: it acts opposite to actual movement or to the direction an object is trying to move.

- **Assuming the Normal Reaction Is Always Vertical**

The normal reaction force acts perpendicular (at right angle) to the contact surface and is therefore **vertical only when the surface is horizontal** (the normal reaction is not necessarily vertical).

- **Leaving out one force**

In equilibrium problems, missing a force is the fastest way to destroy the conditions $\Sigma F_x = 0$ and $\Sigma F_y = 0$.

Before these ideas start colliding in our heads, let us calm them down with a few useful worked examples.

BINDER Example 6

A small metal ball of mass 0.50kg is released and allowed to fall freely through the air (air resistance neglected).

(a) Draw the free-body diagram of the ball.
(b) State the resultant force on the ball.
(c) Show that the acceleration of the ball is equal to the acceleration due to gravity, g.

Solution

(a)
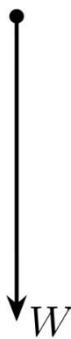
(b) Resultant force is downward and equals the weight, $W = 0.5N \times 9.8N/kg = 4.9N$ downward.

(c) Using Newton's second law in the vertical direction:

$$\Sigma F_y = ma_y$$

$$W = ma_y$$

But $W = mg$

$$mg = ma_y$$

So: $a_y = g$

Making Sense of the Answer: The ball accelerates because there is no other force to cancel its weight.

Thinking Like a Physicist: If you cannot name the agent producing a force (string, surface, air), do not draw it.

BINDER Example 7

A particle is acted on by two horizontal forces: 20N to the right and 12N to the left.

(a) Draw the free-body diagram.
(b) Find the resultant force.
(c) A student adds an extra 8N force to the left on the diagram and says, *"The particle must be in equilibrium."* Explain what is wrong with this thinking.
(d) State the equilibrant force for the given forces.

Solution

(a) FBD

12N ⟵————————•————————⟶ 20N
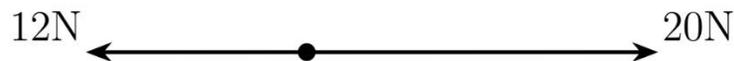
(b) Taking right as positive:

$$F_R = 20N - 12N = 8N$$

The resultant force is 8N to the right.

(c) The extra 8N force has no physical source (no agent). Forces cannot be added simply because we want equilibrium; they must come from a real interaction (a string, a push, contact, etc.). The particle is not automatically in equilibrium; it accelerates if the resultant is not zero.

(d) The equilibrant is the single force that would cancel the resultant: $F_E = 8N$ to the left

Making Sense of the Answer: *Equilibrium is a condition produced by real forces, not a wish added to the diagram.*

Thinking Like a Physicist: *Never "repair" a diagram by inventing forces. First ask: what object could apply that force?*

BINDER Example 8

Three coplanar forces act on a small ring at rest at a junction of light cords. Force $F_1 = 100N$ acts horizontally to the right. Force $F_2 = 80N$ acts at **60° above the horizontal** (measured counterclockwise from the positive x-axis). Force F_3 has unknown magnitude and unknown direction.

(a) Determine the **magnitude** of F_3 required for equilibrium.
(b) Determine the **direction** of F_3 (measured counterclockwise from the positive x-axis).

Solution

Since F_1 and F_2 together act generally northeast, the equilibrant force F_3 must act generally southwest. So, the free body diagram for the example 8 will be as follows:
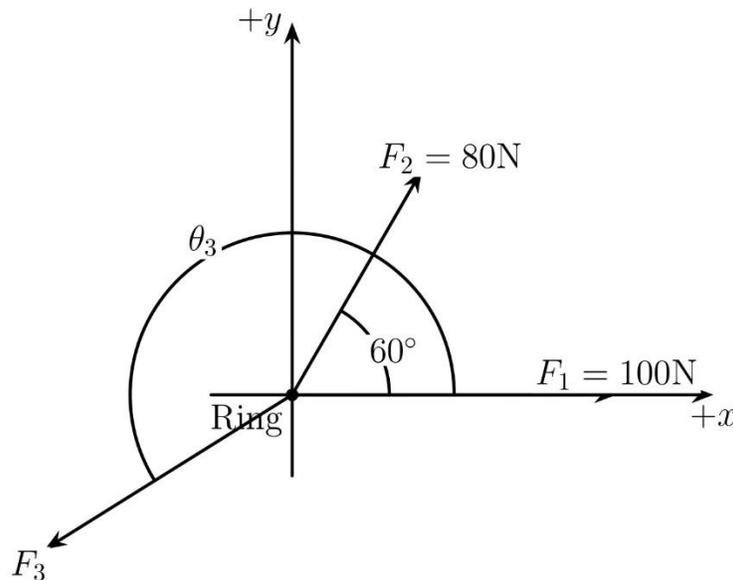
Resolving F_1 and F_2 into components

$F_1 = \textbf{100N to the right}$ (0° from the positive $x-$ axis)

- $(F_1)_x = 100N$ (By using formula it is $100N\cos0° = 100N$)

- $(F_1)_y = 0$ (By using formula it is $100N\sin0° = 0N$)

$F_2 = \textbf{80N at 60°}$

- $(F_2)_x = 80\cos60 = 40N$

- $(F_2)_y = 80\sin60 = 69.3N$

The equilibrium condition: $\Sigma F_x = 0$ and $\Sigma F_y = 0$

Then;

$$\Sigma F_x = 100N + 40N + (F_3)_x = 0; \; \mathbf{(F_3)_x = -140N}$$

And;

$$\Sigma F_y = 0N + 69.3N + (F_3)_y = 0; \; \mathbf{(F_3)_y = -69.3N}$$

The magnitude of F_3 is given by the following relationship:

$$F_3 = \sqrt{((F_3)_x)^2 + ((F_3)_y)^2} = \sqrt{(-140)^2 + (-69.3)^2} = 156.21N$$

(a) The magnitude is 156.21N.

From geometry of free body diagram;

$$\tan(\theta_3 - 180) = \frac{(F_3)_y}{(F_3)_x} = \frac{-69.3}{-140} = 0.495$$

$$\theta_3 - 180 = \tan^{-1} 0.495 = 26.33°; \; \theta_3 = 26.33° + 180° = 206.33°$$

(b) The direction of F_3 is 206.33° from the positive x-axis (counterclockwise).

Making Sense of the Answer: *Since F_1 and F_2 together act generally northeast, the equilibrant F_3 must act generally southwest to maintain equilibrium. Its magnitude simply matches the resultant of F_1 and F_2, but its direction is opposite.*

Thinking Like a Physicist: *Before calculating, always predict the direction. If the combined forces point northeast, the equilibrant must point southwest. This quick check helps prevent sign and angle mistakes.*

As the worked examples quietly leave the table, the next subtopic arrives; not to overwhelm us, but to be understood and enjoyed!