

Chapter 1: Mechanics

1.1 Physical Quantities & Measurement · 1.2 Motion · 1.3–1.8 Forces, Energy & Pressure

Scalars

Magnitude only – no direction.

- Distance
- Speed
- Time
- Mass
- Energy
- Temperature

Vectors

Both magnitude **and** direction.

- Force & Weight
- Velocity
- Acceleration
- Momentum
- Electric field strength
- Gravitational field strength

To find the resultant of two perpendicular vectors, apply Pythagoras' theorem: $a^2 = b^2 + c^2$. For example, if $b = 3\text{ N}$ and $c = 3\text{ N}$, then $a = \sqrt{18} \approx 4.24\text{ N}$.



Fig. 1: Measuring cylinders used to measure volume accurately.

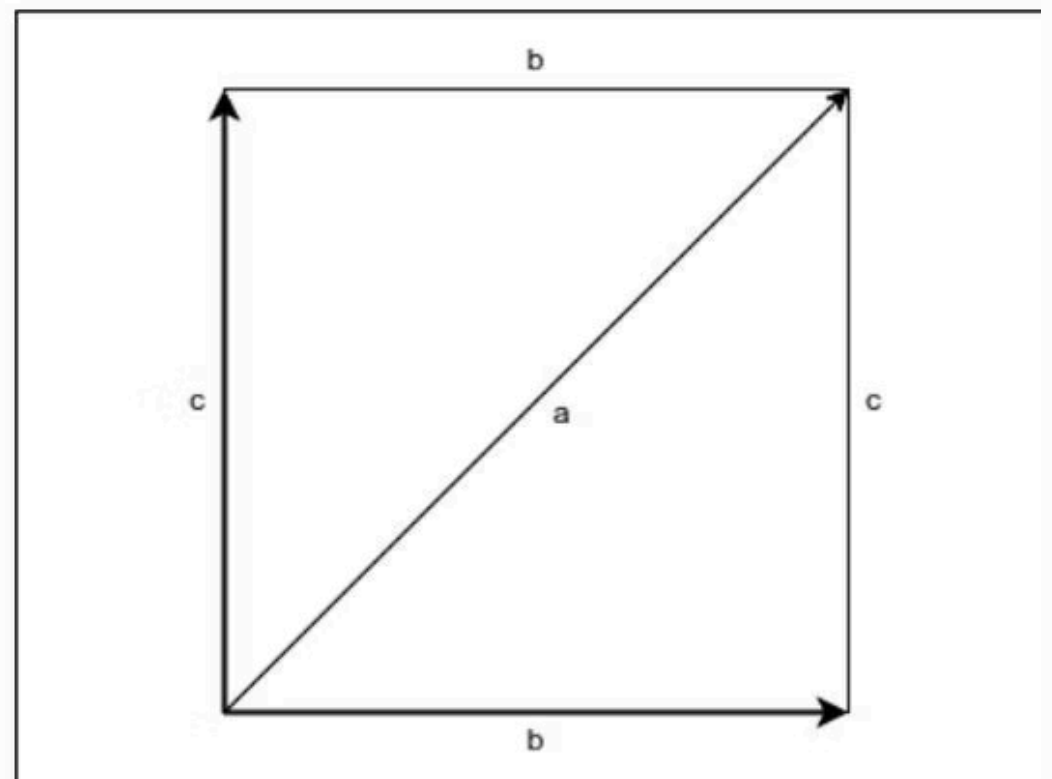


Fig. 2: Resultant of two perpendicular vectors using Pythagoras.

1.2 Motion: Speed, Velocity & Acceleration

Key Formulas

Velocity

$$v = \frac{s}{t}$$

Average Speed

$$\text{avg speed} = \frac{\text{total distance}}{\text{total time}}$$

Acceleration

$$a = \frac{\Delta v}{\Delta t}$$

ⓘ The symbol Δ means "change in". So Δv = final velocity - initial velocity ($v - u$).

Three Equations of Motion

Use these symbols: v = final velocity, u = initial velocity, a = acceleration, t = time, s = distance, $g = 9.8 \text{ m/s}^2$

1st

$$v = u + at$$

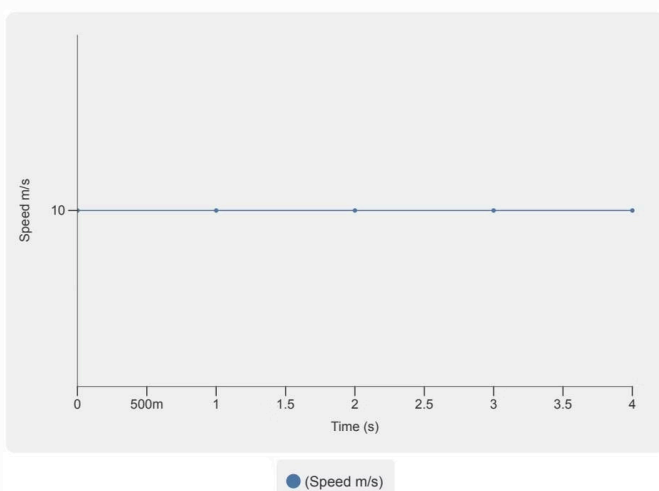
2nd

$$s = ut + \frac{1}{2}at^2$$

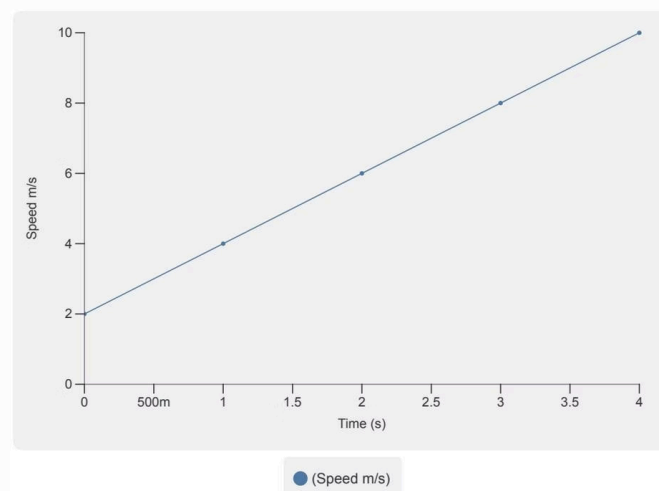
3rd

$$v^2 - u^2 = 2as$$

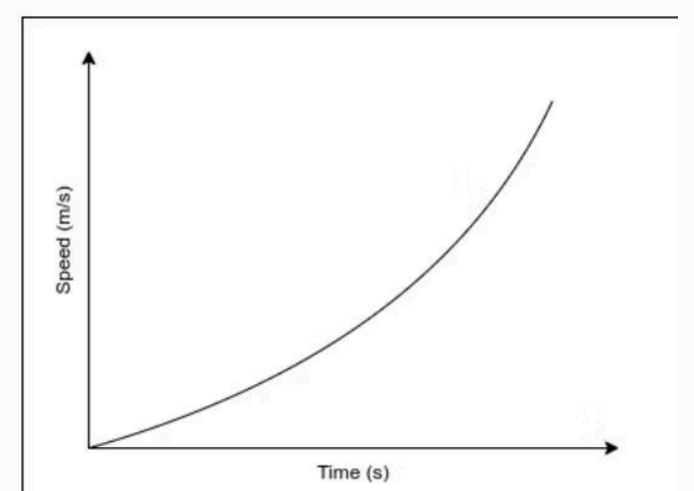
Speed-Time Graphs



Constant speed – horizontal straight line.



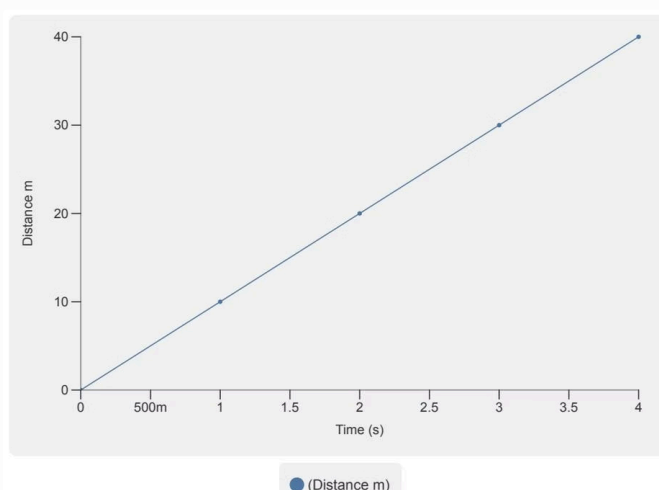
Constant acceleration – straight line with positive gradient.



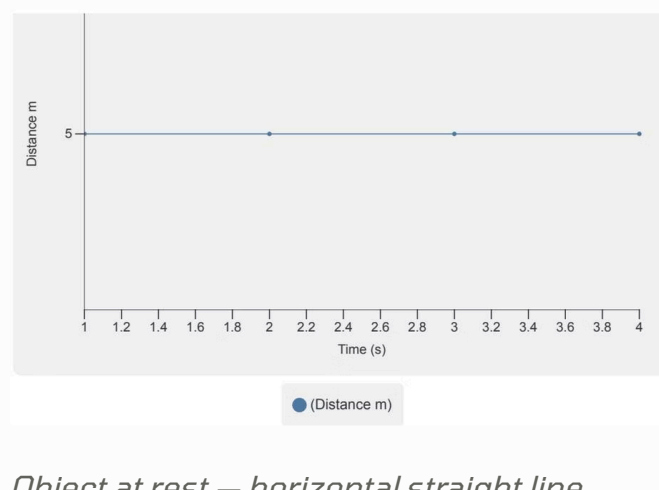
Changing acceleration – curved line (Fig. 3).

📌 **Calculating distance from a speed-time graph:** Find the **area under the graph**. Divide the shape into triangles and rectangles, calculate each area, then add them together. For example, a triangle of base 1 s and height 4 m/s gives area = $1 \times 4 \times \frac{1}{2} = 2 \text{ m}$, and a rectangle of $4 \times 4 = 16 \text{ m}$, giving a total distance of 18 m.

Distance-Time Graphs



Constant speed – slanted straight line.



Object at rest – horizontal straight line.

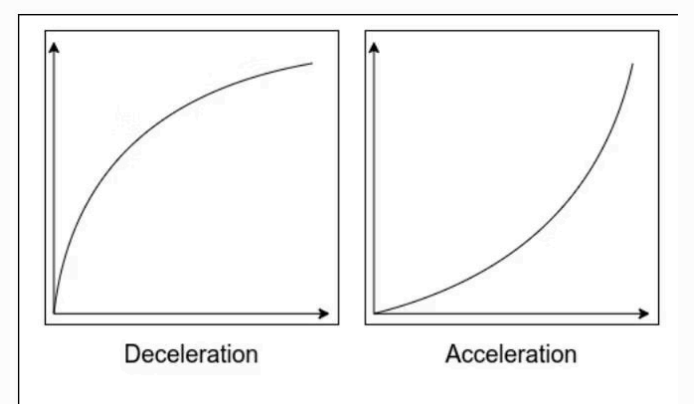


Fig. 5: Acceleration (concave up) and deceleration (concave down).

ⓘ **Calculating speed from a distance-time graph:** Use the gradient of the line. Pick two points, e.g. (1, 2) and (2, 6), then apply $\frac{y_2 - y_1}{x_2 - x_1} = \frac{6 - 2}{2 - 1} = 4 \text{ m/s}$. **Deceleration** is negative acceleration: if deceleration = 2 m/s^2 , then acceleration = -2 m/s^2 .

Free Fall

Free fall is when an object falls freely under gravity alone, with no other forces. Acceleration = 9.8 m/s^2 (or 10 m/s^2 as specified). With air resistance, objects eventually reach **terminal velocity** – a constant speed where drag equals gravity. A heavier and lighter object dropped from the same height reach the ground at the same time (when air resistance is ignored), because the acceleration of free fall does not depend on mass.

1.3–1.6: Mass, Density, Forces & Momentum

Mass vs. Weight

Mass is the amount of matter in an object. Weight is the gravitational force on that mass.

$$g = \frac{W}{m}$$

Note: g also equals the acceleration of free fall.

Density

$$\rho = \frac{m}{V}$$

If an object's density is **lower** than the liquid it's in, it floats. If **higher**, it sinks.

Measuring Density

01

Regular Solids

Use a ruler to measure dimensions, calculate volume ($l \times w \times h$), then use a balance for mass.

02

Liquids

Weigh empty measuring cylinder, add liquid, find change in mass and read volume from markings.

03

Irregular Solids

Measure mass with balance. Drop object into known volume of water; volume change = object's volume.

Forces, Hooke's Law & Spring Constant

Hooke's Law states that extension is directly proportional to the stretching force – up to the **limit of proportionality**. Beyond this point, the graph is no longer linear.

$$F = kx \quad \Rightarrow \quad k = \frac{F}{x}$$

The **spring constant** k is the force per unit extension. Note: extension \neq total length of spring.

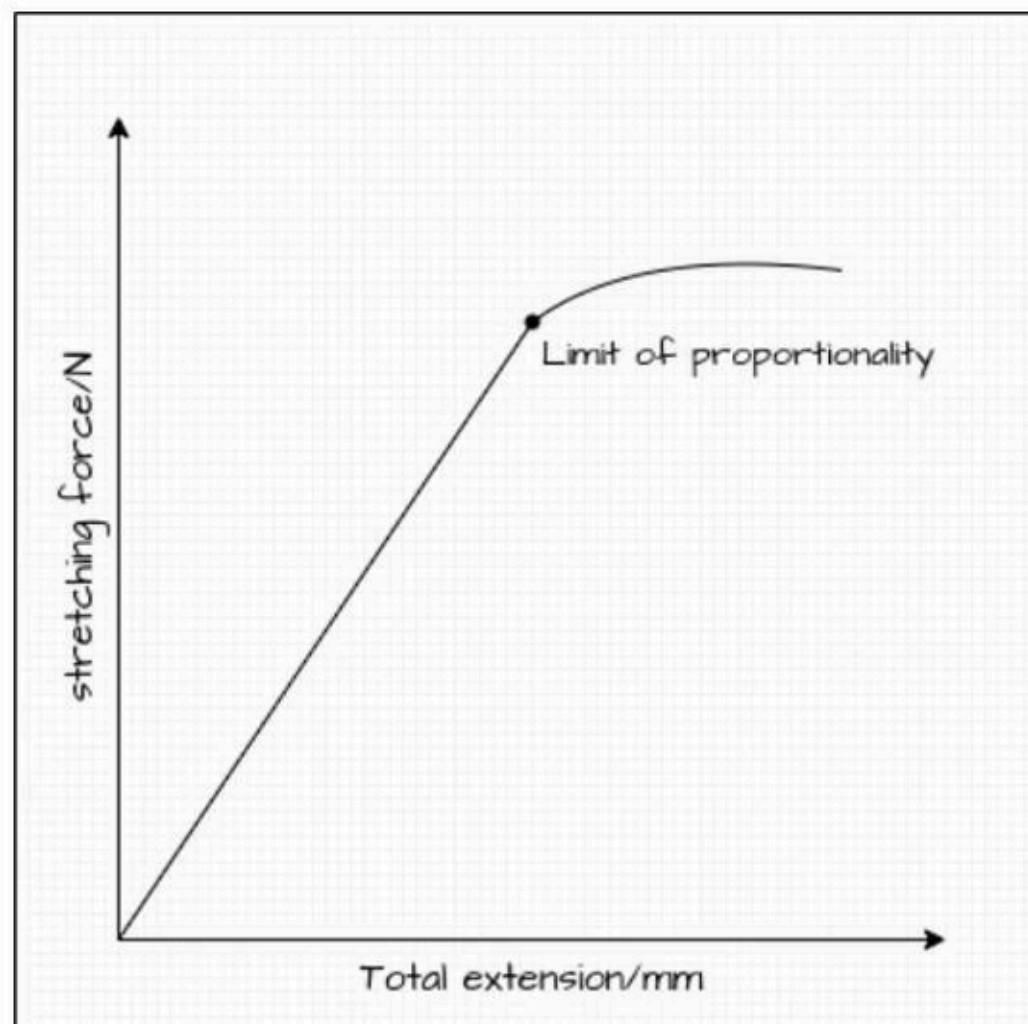


Fig. 6: Hooke's Law load-extension graph. Load (N) on y-axis, extension (mm) on x-axis.

Momentum

$$p = mv$$

Units: kg m/s or N s. Momentum is conserved in collisions when no external forces act.

✔ **Example:** Train (10 kg, 5 m/s) hits stationary cart (1 kg). They move together. Initial momentum = 50 kg m/s. Final velocity = $50 \div 11 = 4.55$ m/s.

Impulse & Resultant Force

$$\text{Impulse} = F \times t = \Delta p$$

$$F = \frac{\Delta p}{\Delta t}$$

Resultant force is the change in momentum per unit time.

1.5 Forces: Newton's Laws, Friction & Circular Motion

Newton's 1st Law

An object remains at rest or moves at constant speed in a straight line unless acted on by a resultant force. A resultant force may change velocity by changing speed or direction.

$F = ma$

Force = mass \times acceleration. Units: force in N, mass in kg, acceleration in m/s^2 . Force and acceleration must be in the same direction.

Friction

Friction opposes motion and acts in the opposite direction to the applied force. Drag in liquids and air works the same way – e.g. air resistance on a plane.

Circular Motion & Centripetal Force

An object moving in a circle has a changing velocity (direction changes) even if speed is constant – so it is always accelerating. The **centripetal force** acts at 90° to the velocity, pulling toward the center.

More force

Faster circular motion (same mass & radius)

More force (constant speed & mass)

Smaller radius (tighter circle)

Heavier object

Needs more force for same radius & speed

Turning Effect of Forces & Moments

moment = force \times perpendicular distance from pivot

Unit: Nm. A door is easier to open at the handle (far from pivot) than near the hinge.

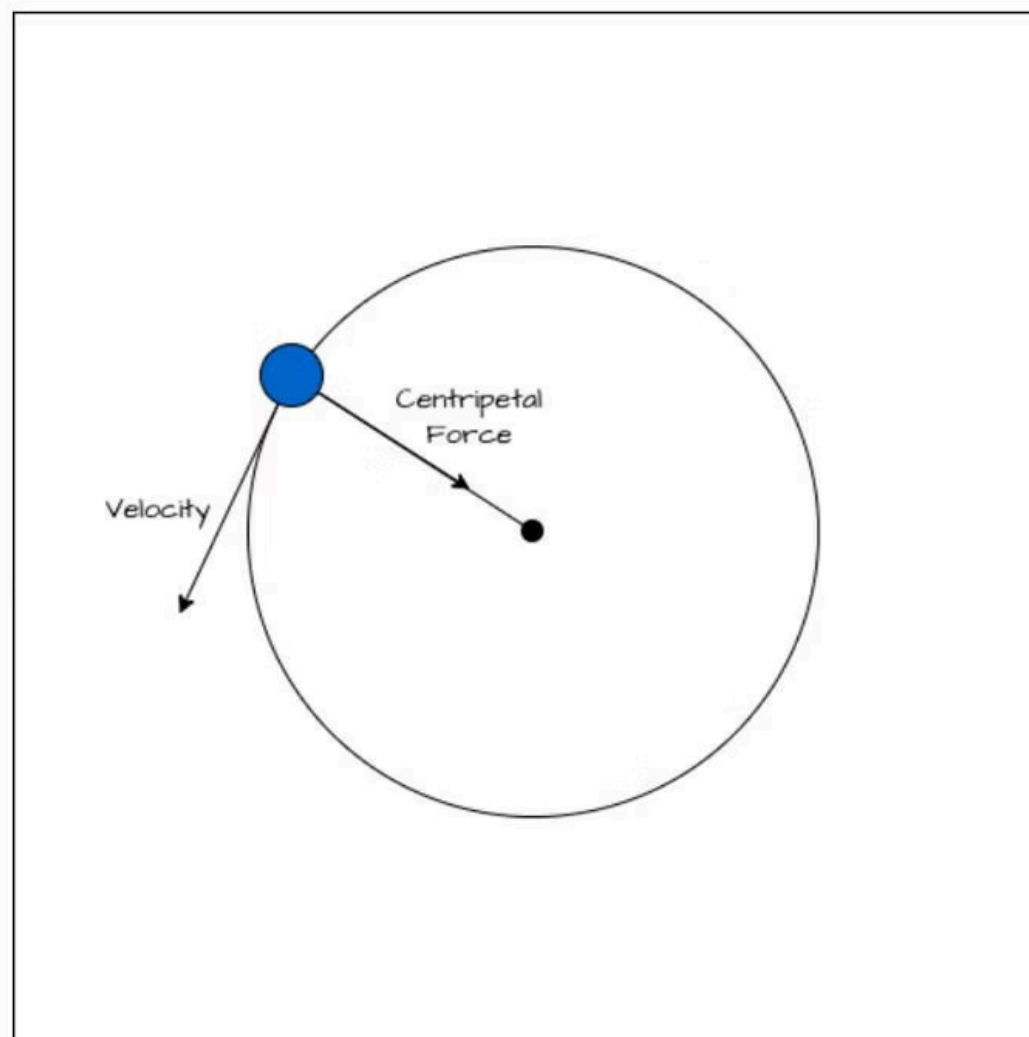


Fig. 9: Centripetal force always points toward the center of the circle.

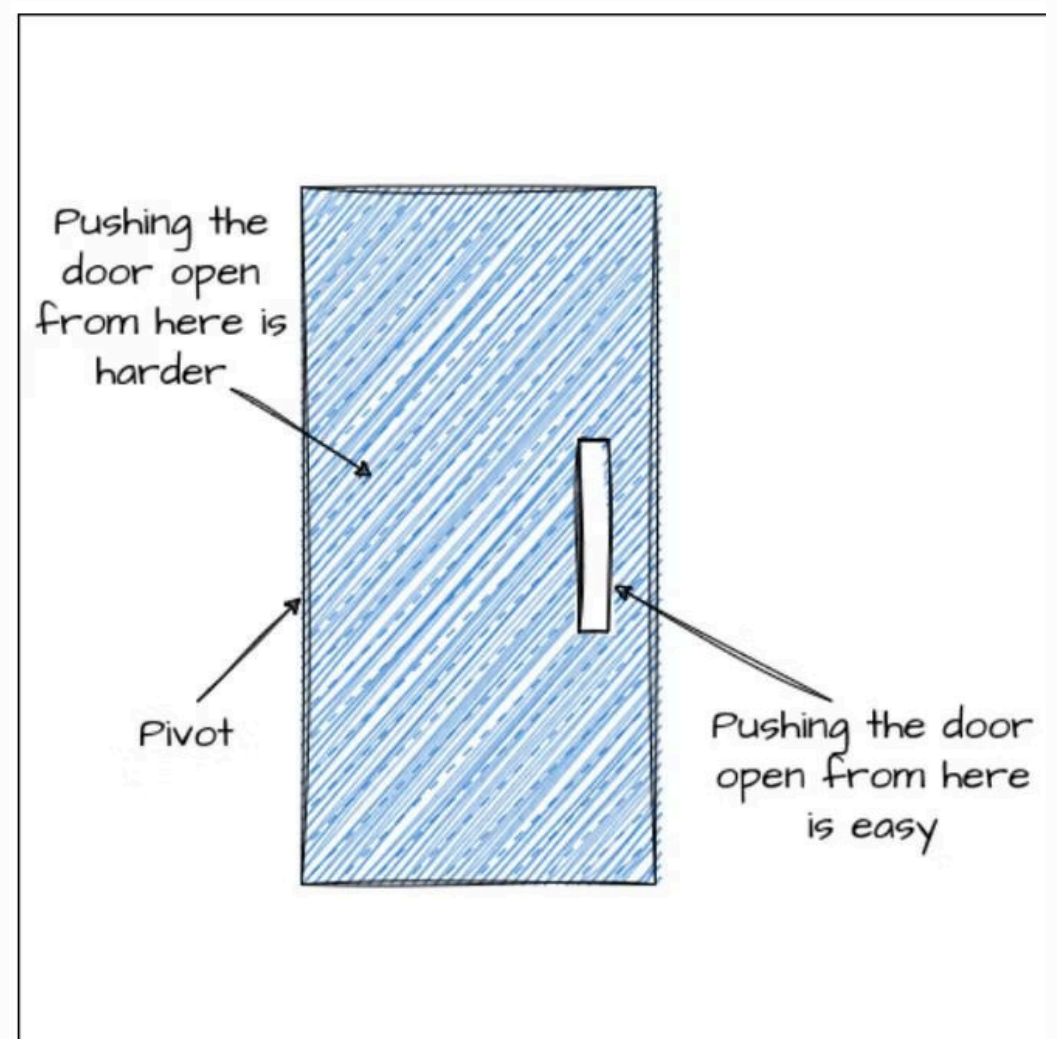


Fig. 10: Turning effect – pushing near the pivot requires more force.

Equilibrium

An object is in equilibrium when: (1) no resultant force, and (2) no resultant moment. Clockwise moments = anticlockwise moments.

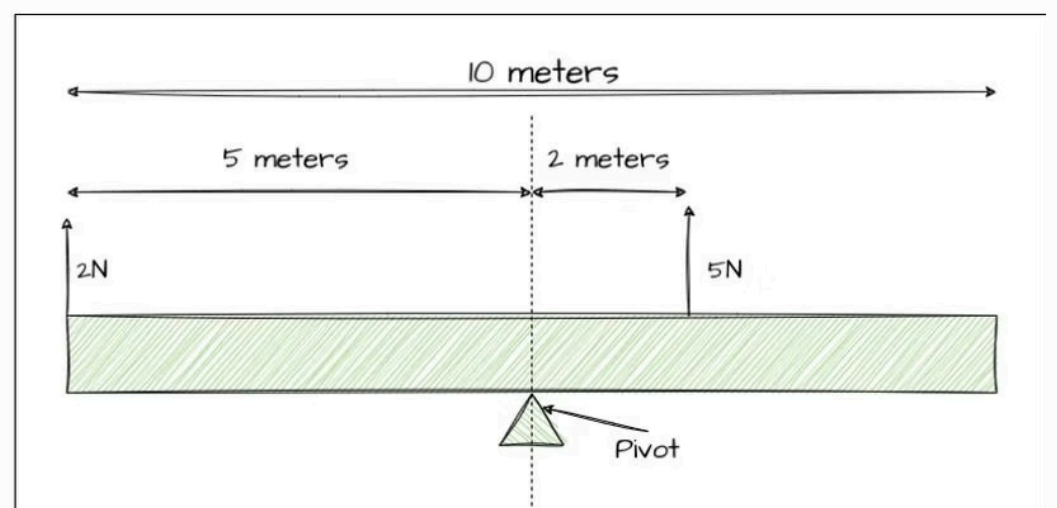


Fig. 11: $5N \times 2m = 2N \times 5m = 10 Nm$ each side \rightarrow equilibrium.

Centre of Gravity & Stability

The centre of gravity is the point where all of an object's weight is considered to act. A **lower** centre of gravity = more stable. A **higher** centre of gravity = more likely to topple. To find the centre of gravity of an irregular lamina, suspend it from two holes and use a plumb line – the intersection of the two lines is the centre of gravity.

1.7 Energy, Work & Power



Kinetic Energy

$$E_k = \frac{1}{2}mv^2$$

Energy of a moving object. m in kg, v in m/s, E in Joules.



Gravitational P.E.

$$\Delta E_p = mg\Delta h$$

Energy due to position above Earth's surface. Also known as g.p.e.



Work Done

$$W = Fd = \Delta E$$

Distance d must be in the direction of the force. 1 J = 1 Nm.



Power

$$P = \frac{W}{t} = \frac{\Delta E}{t}$$

Rate of energy transfer. Unit: Watts (W). 1 kW = 1000 W, 1 MW = 10⁶ W.



Efficiency

$$\text{efficiency} = \frac{\text{useful output}}{\text{total input}} \times 100$$

Can be calculated using energy or power values.

- ❑ **Principle of Conservation of Energy:** Energy cannot be created or destroyed – it can only change form or be transferred. Forms include: kinetic, gravitational potential, chemical, elastic/strain, nuclear, electrostatic, and internal/thermal energy.

Energy Resources

Source	Type	Advantages	Disadvantages
Fossil Fuels	Non-renewable	High energy density; established infrastructure	Polluting; finite supply
Biofuels	Renewable	Renewable; less CO ₂	Low energy; can be unstable
Hydroelectric	Renewable	Low emissions; reliable	High construction cost; harms aquatic life
Geothermal	Renewable	Low emissions; renewable	Location-dependent; high drilling cost
Solar	Renewable	Clean; renewable	Expensive; weather-dependent
Wind	Renewable	No greenhouse gases	Noisy; land-intensive; expensive
Nuclear	Non-renewable	Large power output; low emissions	Radioactive waste; disaster risk

- ❗ The **Sun** is the primary source of almost all energy on Earth, except geothermal, nuclear, and tidal. The Sun's energy comes from **nuclear fusion**.

1.8 Pressure

$$p = \frac{F}{A}$$

Unit: Pascal (Pa). 1 Pa = 1 N/m². Pressure and area are inversely proportional (constant F). Pressure and force are directly proportional (constant A).

Pressure in Liquids

$$\Delta p = \rho g \Delta h$$

Pressure increases with depth due to the weight of liquid above. The greater the depth, the greater the pressure.

Chapter 2: Thermal Physics

2.1 Kinetic Particle Model · 2.2 Thermal Properties · 2.3 Transfer of Thermal Energy

States of Matter

Property	Solid	Liquid	Gas
Volume	Fixed	Fixed	Indefinite
Shape	Fixed	Takes shape of container	Takes shape of container
Compressible?	∞	√ (very little)	√

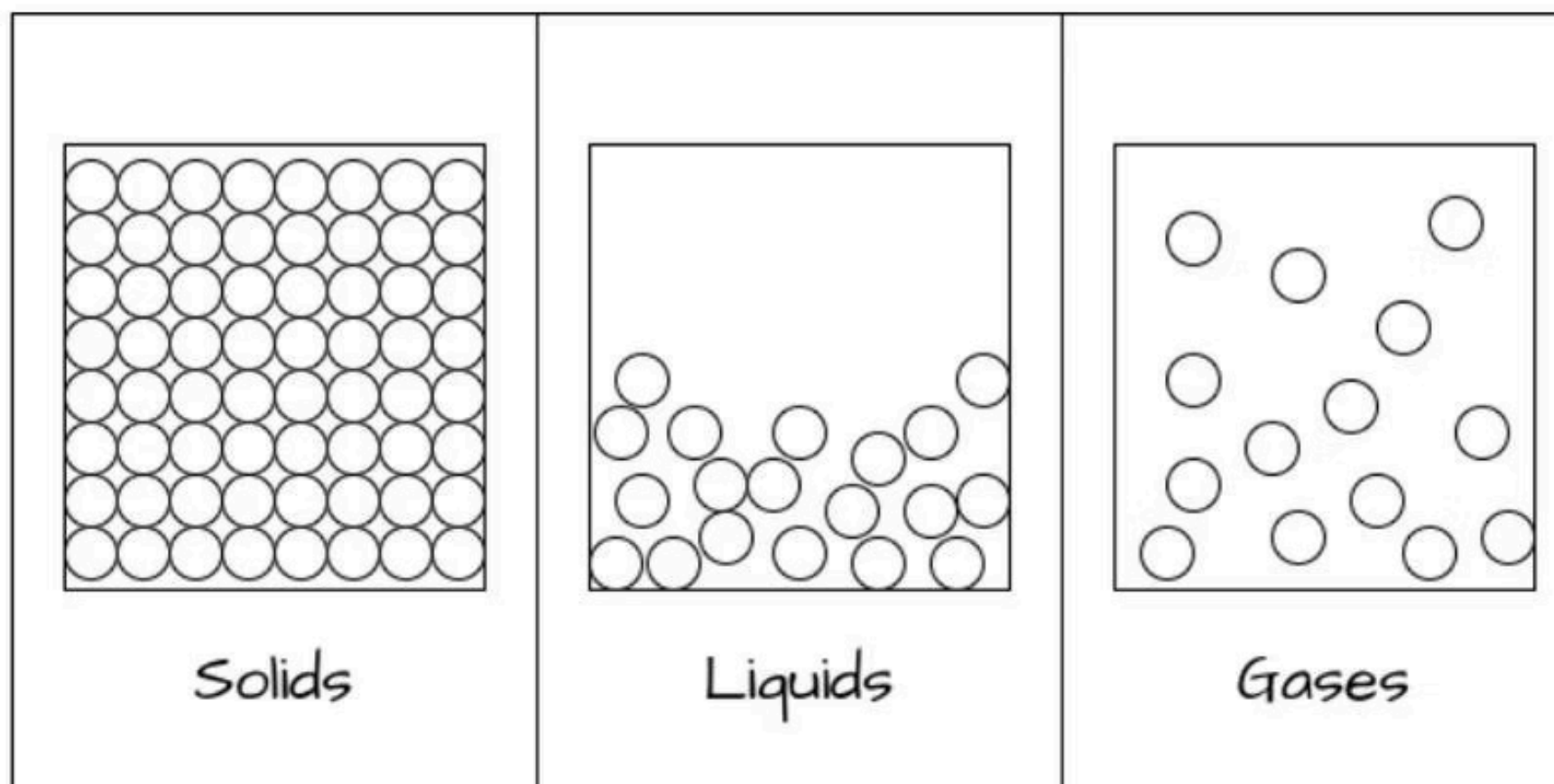


Fig. 2: Particle arrangement – solids (tightly packed lattice), liquids (close but mobile), gases (widely spaced and random).

Solids

Particles packed tightly in fixed positions. Can only vibrate. Strong intermolecular forces → fixed shape and volume. Expand very little when heated.

Liquids

Particles slightly further apart; can move past each other. Weaker forces → flow and take container shape. Expand more than solids when heated.

Gases

Particles far apart; very weak forces. Can flow easily and fill any container. Expand the most when heated.

Temperature, Kinetic Energy & Pressure

Temperature measures the **average kinetic energy** of particles. At **absolute zero** ($-273^{\circ}\text{C} = 0\text{ K}$), kinetic energy = 0 and particles stop moving. Gas particles hitting container walls cause pressure. Faster particles → more collisions → higher pressure.

Boyle's Law

At constant temperature, pressure of a fixed mass of gas is inversely proportional to its volume:

$$p_1 V_1 = p_2 V_2$$

Temperature Conversion

$$T (\text{K}) = \theta (^{\circ}\text{C}) + 273$$

Key values: $-273^{\circ}\text{C} = 0\text{ K}$ and $0^{\circ}\text{C} = 273\text{ K}$.

Brownian Motion