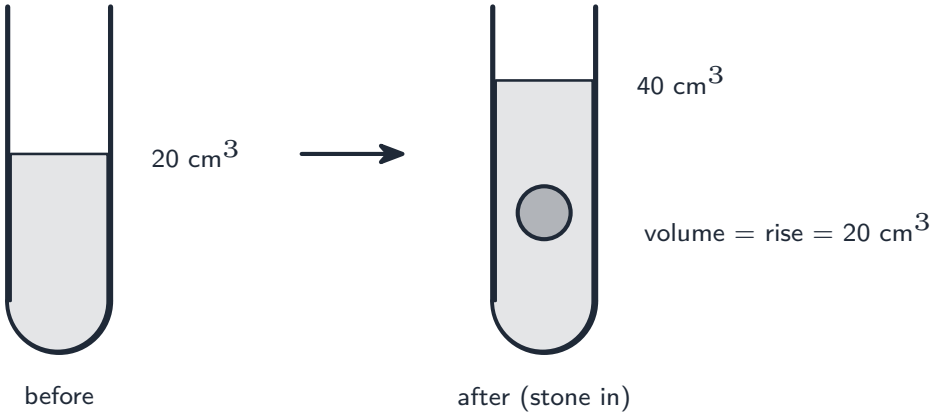
Motion, forces and energy

IGCSE Physics

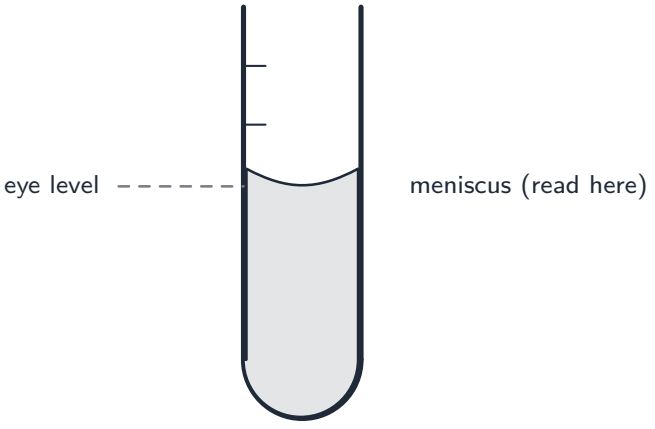
Measurement

■ Length and volume

Use a **ruler** to measure length. Read the scale with your eye straight in front of the mark to avoid a reading error.



The water an irregular solid pushes up gives its volume



Read a measuring cylinder at the bottom of the meniscus, with your eye level

Use a **measuring cylinder** to measure the volume of a liquid. Read the scale at the bottom of the curved surface (the **meniscus**), with your eye level with

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it.

■ Measuring time

Use a **stopwatch** or a **digital timer** to measure a time interval. A clock is fine for long times (minutes or hours). Starting and stopping by hand introduces **reaction time** error; its size depends on the operator and method. To make this error matter less, time a long interval, or time many repeats and divide (see below).

■ Measuring small amounts

A single small length or a short time is hard to measure well. The trick is to **measure many and divide** :

- To find the average thickness of one sheet, measure a stack of 100 sheets and divide by 100. Count sheets, not printed page numbers.
- To find the time for one swing of a **pendulum** , measure the time for 20 swings and divide by 20. The time for one complete oscillation is called the **period** .

This reduces the effect of a fixed reading or timing **uncertainty** on the average value. It does not remove systematic errors or a miscount.

Worked measurement comparison. A stack of 100 sheets without covers is 10.0 mm thick. Count the sheets, align the stack, avoid gaps or uneven compression, and read at eye level. The thickness is an average, not a precise measurement of every sheet.

$$\text{mean thickness} = \frac{\text{stack thickness}}{N} = \frac{10.0\ \text{mm}}{100} = 0.100\ \text{mm}$$

Three timings of 20 complete pendulum oscillations are 31.8 s, 32.2 s and 32.0 s. Start and finish at a marked position with the pendulum moving in the same direction; count complete cycles.

$$\text{mean time} = \frac{t_1 + t_2 + t_3}{3} = \frac{31.8\ \text{s} + 32.2\ \text{s} + 32.0\ \text{s}}{3} = 32.0\ \text{s}$$

$$T = \frac{\text{mean time}}{N} = \frac{32.0\ \text{s}}{20} = 1.60\ \text{s}$$

Timing multiples reduces the effect of a similar start/stop error per oscillation; repeated trials help check consistency. Neither corrects a wrong cycle count.

■ Practical skills: readings, results and graphs

The practical paper rewards the same few habits in every experiment:

- **Read at eye level.** Looking at a scale from above or below gives a **parallax** error. Put your eye level with the pointer, the liquid surface or the mark.

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- **Check for a zero error.** A **zero error** is a reading the instrument gives when it should read zero, such as a newton meter showing 0.2 N with nothing on it. Subtract it from every reading, or reset the instrument to zero first.
- **Record to the instrument's precision.** A ruler marked in millimetres gives readings such as 23 mm, or 2.3 cm. Give every value in a column to the same number of decimal places, and put the unit in the column heading, for example *extension / mm*.
- **Repeat and spot anomalies.** An **anomalous result** does not fit the pattern of the others. Repeat that reading, and leave it out when you calculate a mean.
- **Draw a line of best fit.** A **line of best fit** is one smooth straight line (or curve) with the points spread evenly on both sides; never join the points dot to dot. To find its gradient, use a triangle that covers more than half of the line.

Worked example. A student hangs loads on a spring and measures its extension with a millimetre ruler.

load / N	0	1.0	2.0	3.0	4.0	5.0
extension / mm	0	8	16	29	32	40

(a) *Identify the anomalous result.* The extension goes up by 8 mm for each extra 1.0 N, except at 3.0 N: 29 mm instead of the expected 24 mm.

(b) *Find the gradient of the line of best fit.* The line through the other points passes through (0, 0) and (5.0 N, 40 mm), so the gradient is $\frac{40\ \text{mm}}{5.0\ \text{N}} = 8.0\ \text{mm/N}$.

(c) *Suggest one precaution.* Fix a pointer to the bottom of the spring and read the ruler with the eye level with the pointer, to avoid parallax error. Check that the spring returns to its original length after the loads are removed: if it does not, it has gone past its limit of proportionality.

■ Scalars and vectors

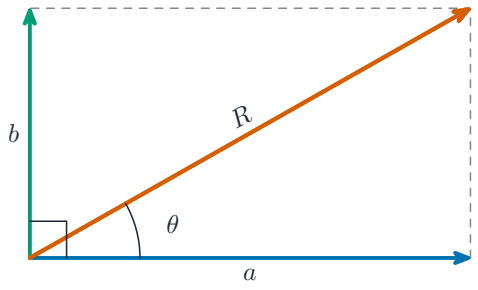
A **scalar quantity** has size (**magnitude**) only. A **vector quantity** has size **and** direction.

- Scalars: distance, speed, time, mass, energy, temperature.
- Vectors: force, weight, velocity, acceleration, momentum, **electric field strength**, **gravitational field strength**.

To add two vectors at right angles (90°), draw them as two sides of a rectangle. The **resultant** is the diagonal. Find its size with Pythagoras and its direction with trigonometry.

$$R = \sqrt{a^2 + b^2}$$

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$R = \sqrt{a^2 + b^2}$

Two vectors at right angles add to a resultant R, the diagonal of the rectangle

Motion

■ Speed and velocity

Speed is the distance travelled per unit time.

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

Velocity is speed in a stated direction. So velocity is a vector but speed is a scalar.

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

> **Worked example.** A cyclist rides 3.6 km to school. The ride takes 10 minutes, plus 2 minutes waiting at traffic lights. Find the average speed in m/s.

Change to SI units first: 3.6 km = 3600 m and 12 min = $12 \times 60 = 720$ s. The waiting time counts, because it is part of the total time.

$$\text{average speed} = \frac{3600 \text{ m}}{720 \text{ s}} = 5.0 \text{ m/s}$$

■ Acceleration

Acceleration is the change in velocity per unit time.

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

Here Δv means "the change in velocity". A **deceleration** reduces speed: the acceleration is opposite to the velocity. Its sign depends on the chosen positive direction.

> **Worked example.** A car speeds up from 8 m/s to 20 m/s in 4.0 s. Find its acceleration.

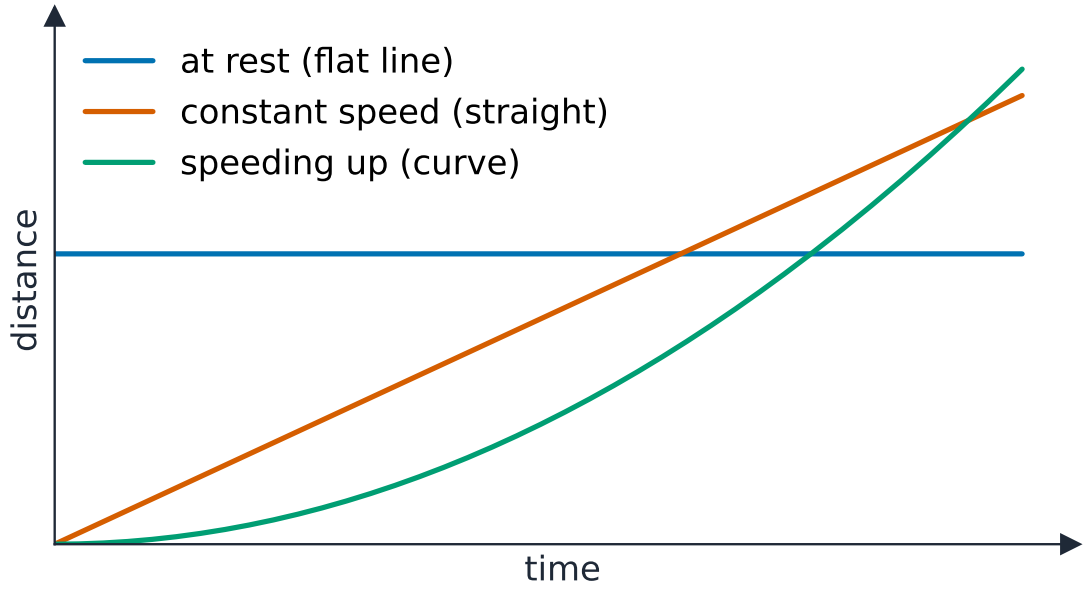
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$$a = \frac{\Delta v}{\Delta t} = \frac{20 - 8}{4.0} = 3.0 \text{ m/s}^2$$

Motion graphs

A **distance–time graph** - shows how far an object has gone:

- A flat (horizontal) line means the object is **at rest** .
- A straight slope means constant speed. The **gradient** (steepness) is the speed.
- A curve that gets steeper means the object is speeding up.

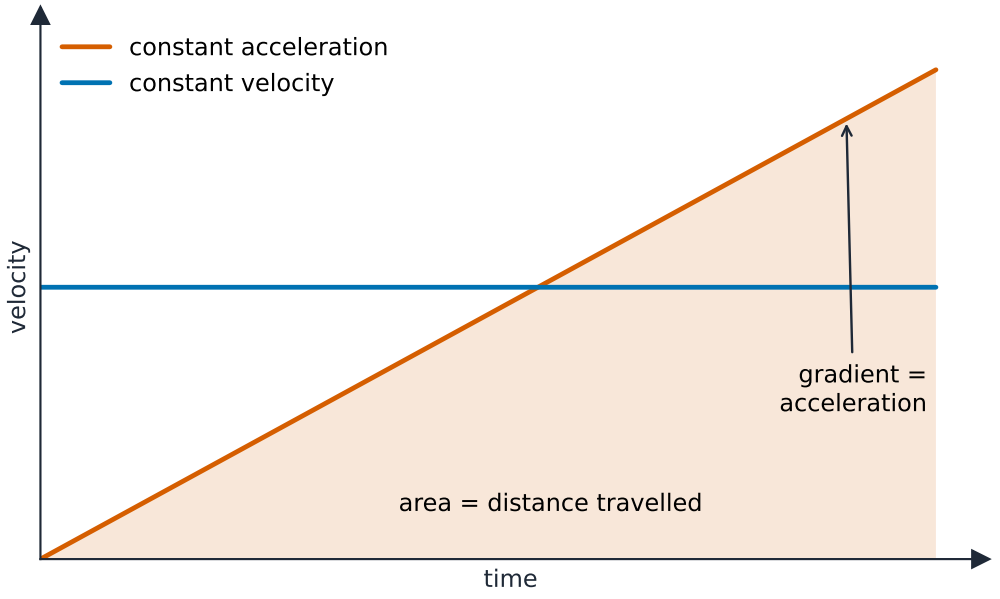


The shape of a distance–time line: flat is at rest, a straight slope is constant speed, a rising curve is speeding up

A **speed–time graph** - shows how fast an object is going:

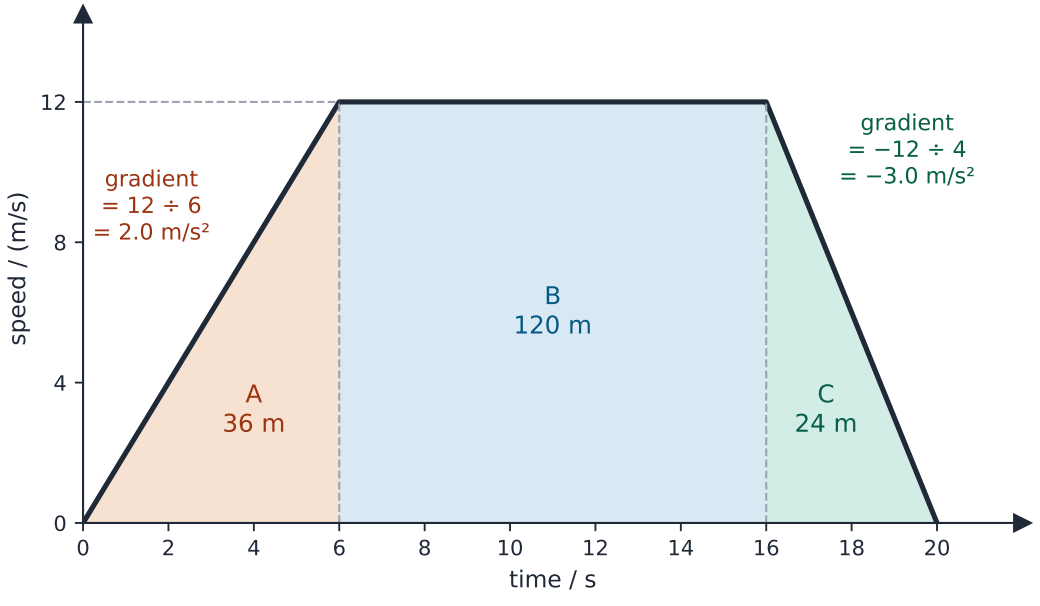
- A flat line means constant speed.
- A straight slope means constant acceleration. The gradient is the acceleration.
- The **area under the line** is the distance travelled.

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On a velocity–time graph the gradient is the acceleration and the area under the line is the distance travelled

Worked example (reading a graph). The graph shows a bus moving between two stops. Find (a) the acceleration in the first 6 s, (b) the acceleration in the last 4 s, (c) the distance between the stops and (d) the average speed.



Split the area into a triangle, a rectangle and a triangle, and add the three parts

(a) Gradient of the first part: $a = \dfrac{12 - 0}{6 - 0} = 2.0\ \text{m/s}^2$.

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(b) Gradient of the last part: $a = \dfrac{0 - 12}{20 - 16} = -3.0$ m/s^2. The minus sign shows the bus is slowing down: a deceleration of 3.0 m/s^2.

(c) Distance = total area under the line:

$$\text{A} = \tfrac{1}{2} \times 6 \times 12 = 36 \text{ m} \qquad \text{B} = 10 \times 12 = 120 \text{ m} \qquad \text{C} = \tfrac{1}{2} \times 4 \times 12 = 24 \text{ m}$$

$$\text{distance} = 36 + 120 + 24 = 180 \text{ m}$$

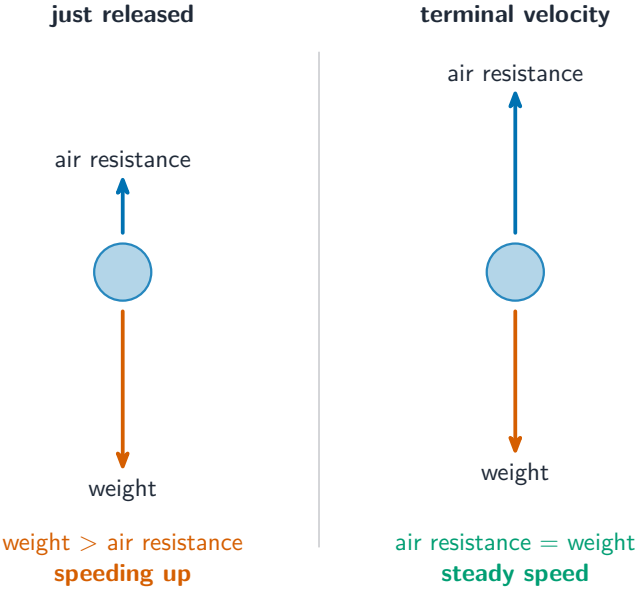
(d) Average speed $= \dfrac{180 \text{ m}}{20 \text{ s}} = 9.0$ m/s. This is less than the top speed of 12 m/s, because the bus is slower while it speeds up and slows down.

Read the time for each part from the time axis: part B lasts $16 - 6 = 10$ s, not 16 s.

■ Falling objects

Near the Earth the gravitational field is **uniform** (the same strength everywhere), so objects in free fall have the same acceleration when air resistance is negligible. This is the **acceleration of free fall** , $g \approx 9.8$ m/s^2.

When an object falls through air, **air resistance** (a drag force) acts upward. As it speeds up, air resistance grows. When air resistance equals the weight, the resultant force is zero and the object stops speeding up. It then falls at a steady **terminal velocity** .



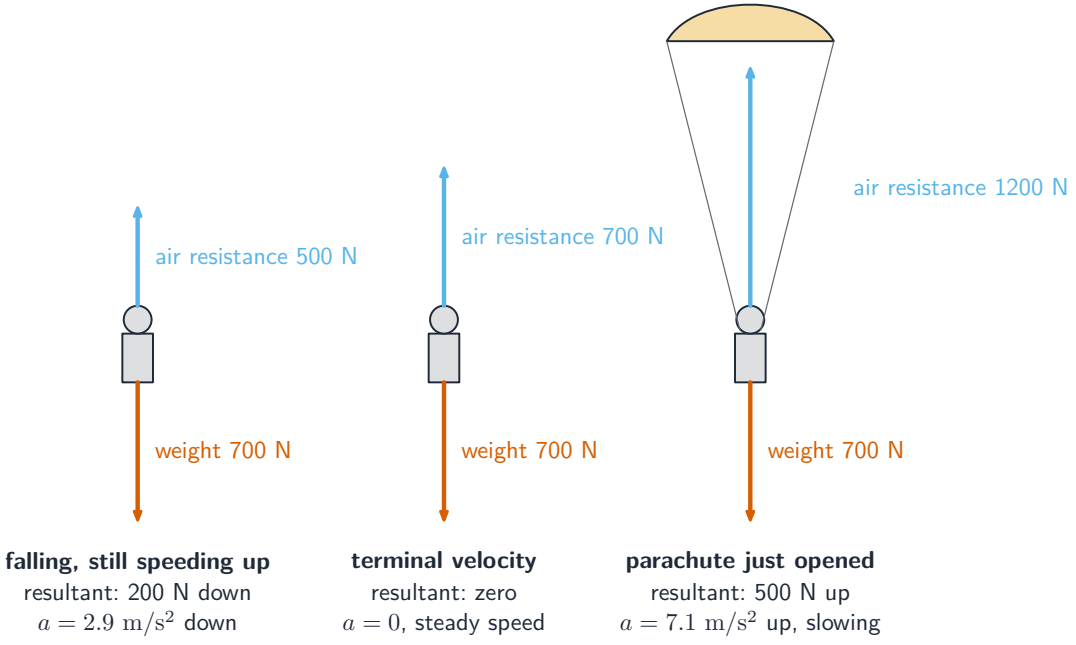
At first the weight is bigger than the air resistance, so the object speeds up; at terminal velocity the two are equal and the speed is steady

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Worked example. A skydiver of mass 70 kg falls through the air ($g = 10$ N/kg, so the weight is 700 N).

- When the air resistance is 500 N: resultant force $= 700 - 500 = 200$ N downwards, so $a = \dfrac{F}{m} = \dfrac{200}{70} = 2.9$ m/s^2 downwards. The skydiver is still speeding up, but less quickly than at the start.
- At terminal velocity the air resistance is 700 N, equal to the weight. Resultant force $= 0$, so $a = 0$.
- The parachute opens and the air resistance jumps to 1200 N. Resultant force $= 1200 - 700 = 500$ N **upwards**, so $a = \dfrac{500}{70} = 7.1$ m/s^2 upwards. The skydiver is still moving down but slows down, until the air resistance falls back to 700 N at a new, lower terminal velocity.

An upward resultant force does not make the skydiver go up. It makes the downward speed get smaller.



Arrows drawn to scale: the weight stays 700 N while the air resistance changes, so the resultant force changes

Mass and weight

Mass is the amount of **matter** in an object. It is measured in kilograms (kg) and does not change when you move the object.

Weight is the force of gravity on a mass. It is measured in newtons (N). Weight can

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change: it is smaller on the Moon because the Moon's gravity is weaker.

Gravitational field strength is the force per unit mass:

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

This g has the same value as the acceleration of free fall (≈ 9.8 N/kg).

> **Worked example.** An astronaut has a mass of 60 kg. Find the weight on the Earth ($g = 9.8$ N/kg) and on the Moon ($g = 1.6$ N/kg).

$$W_{\text{Earth}} = mg = 60 \times 9.8 = 590 \text{ N} \qquad W_{\text{Moon}} = 60 \times 1.6 = 96 \text{ N}$$

The mass is 60 kg in both places. Only the weight changes. You can compare masses with a **balance** .



A laboratory balance measures mass; weight is the gravitational force on that mass

Density

Density is the mass per unit volume.

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

The symbol ρ is the Greek letter "rho". The unit is kg/m^3 or g/cm^3.

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To find density: measure the mass with a balance, find the volume, then divide.

- **Regular solid** (like a box): measure the sides and calculate the volume.
- **Irregular solid** (a strange shape): lower it into water in a measuring cylinder. The rise in water level is its volume. This is the **displacement method** .
- **Liquid**: put an empty measuring cylinder on the balance and read its mass. Pour in the liquid, read the volume on the cylinder, and read the mass again. The mass of the liquid is the difference between the two mass readings.

An object **floats** if its density is less than the density of the liquid. It sinks if its density is greater. In the same way, one liquid floats on top of another (if the two do not mix) when its density is lower: oil floats on water.

> **Worked example.** A stone of mass 54 g is lowered into a measuring cylinder. The water level rises from 20 cm^3 to 40 cm^3. Find the density of the stone.

The volume of the stone is the rise in water level, $40 - 20 = 20$ cm^3, so

$$\rho = \frac{m}{V} = \frac{54}{20} = 2.7 \text{ g/cm}^3$$



An iceberg floats with most of its volume hidden: ice is slightly less dense than water

Forces

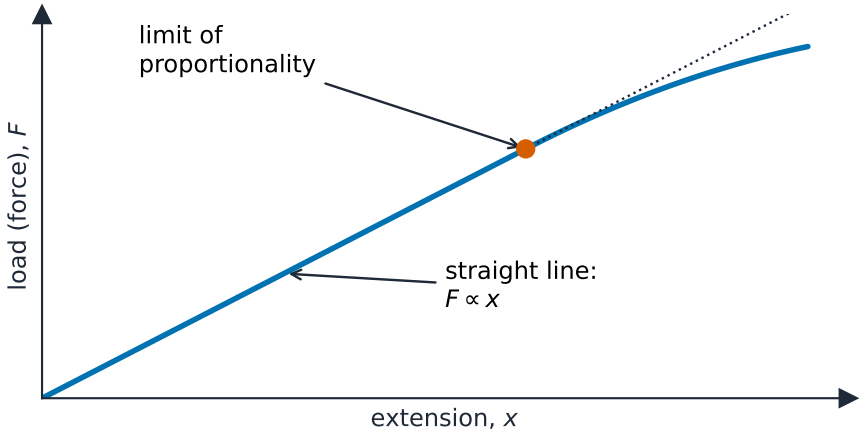
A force is a push or a pull. A force can change the **shape** , the speed, or the direction of an object.

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■ Stretching (Hooke's law)

When you hang a load on a spring, it stretches. The stretch is called the **extension** .

On a **load–extension graph** - the line is straight at first: extension is proportional to load. The point where the line stops being straight is the **limit of proportionality** .



$F = kx$ (straight section)
$k =$ gradient

Load is proportional to extension until the limit of proportionality, then the line curves

The experiment. Hang the spring from a clamp and stand a ruler beside it. Read the position of the bottom of the spring with no load: this is the original length. Add loads one at a time (for example 1 N each) and record the new length each time. The extension is the new length minus the original length. Plot load on the y-axis against extension on the x-axis.

Within the linear range, the **spring constant** is force divided by extension:

$$k = \frac{F}{x}$$

A large k means a stiff spring.

> **Worked example.** A spring is 12.0 cm long with no load. With a 6.0 N load it is 15.0 cm long. Find (a) the spring constant and (b) the length with a 4.0 N load (the limit of proportionality is not reached).

(a) Extension $x = 15.0 - 12.0 = 3.0$ cm $= 0.030$ m, so

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$$k = \frac{F}{x} = \frac{6.0}{0.030} = 200 \text{ N/m}$$

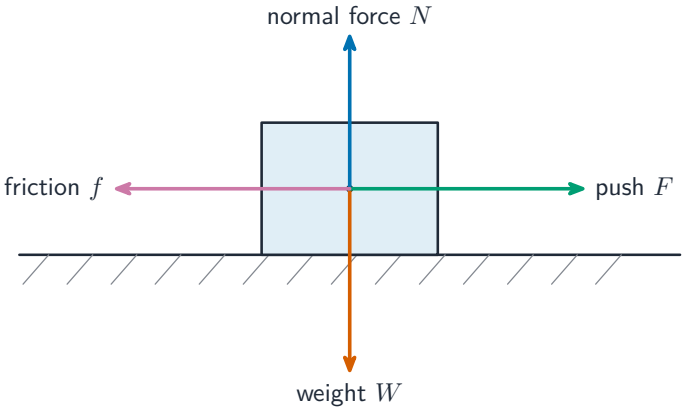
(b) Extension $= \dfrac{F}{k} = \dfrac{4.0}{200} = 0.020$ m $= 2.0$ cm, so the length is $12.0 + 2.0 = 14.0$ cm. Use the extension in $k = F/x$, never the whole length: $6.0 \div 0.150$ gives a wrong answer.

■ Resultant force and Newton's laws

Add forces on a straight line to get the **resultant force** (forces one way are positive, the other way negative).

- If the resultant force is zero, the object stays at rest **or** keeps moving in a straight line at constant speed. (Newton's first law.)
- If the resultant force is not zero, the object accelerates in the direction of the force:

$$F = ma$$



A free-body diagram shows every force on the box as a labelled arrow

> **Worked example.** A 1200 kg car has a 3000 N driving force and 600 N of friction. Find its acceleration.

First find the resultant force: $3000 - 600 = 2400$ N. Then

$$a = \frac{F}{m} = \frac{2400}{1200} = 2.0 \text{ m/s}^2$$

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Motion in a circle

A resultant force at right angles to the motion does not change the speed. It changes the direction, so the object moves in a circle at a steady speed. This is **circular motion** . The force always points towards the centre of the circle: the pull of the string on a whirling ball, or the gravity of the Sun on a planet.

For an object moving in a circle:

- a bigger force is needed to keep the same mass moving at a higher speed in a circle of the same **radius** ;
- a bigger force makes the same mass at the same speed move in a smaller circle (a smaller radius);
- a bigger mass needs a bigger force to keep the same speed and the same radius.

Friction

Friction is the force between two surfaces that touch. It opposes relative sliding or the tendency to slide, and can cause heating. Drag opposes an object's motion relative to the surrounding fluid.

Moments – the turning effect

The **moment** of a force is its turning effect about a **pivot** .

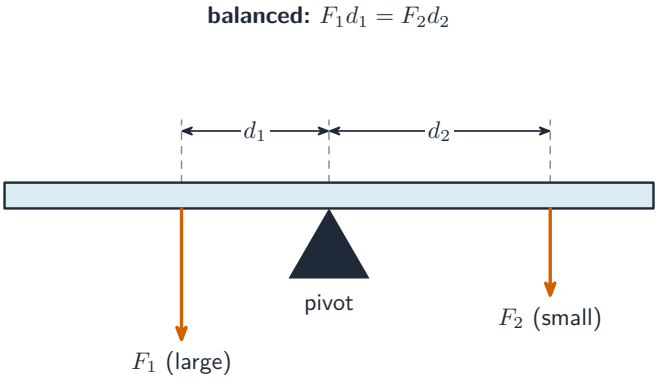
$$\text{moment} = \text{force} \times \text{perpendicular distance from the pivot}$$

The unit is the newton metre (N m).

Principle of moments : when an object is balanced (in **equilibrium**),

$$\text{total clockwise moment} = \text{total anticlockwise moment}$$

An object is in equilibrium when there is no resultant force **and** no resultant moment.



The beam balances when the clockwise moment equals the anticlockwise moment

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Worked example. A 30 N weight sits 0.20 m to the left of a pivot. How far to the right must a 20 N weight sit to balance the beam?

Balanced, so anticlockwise moment = clockwise moment:

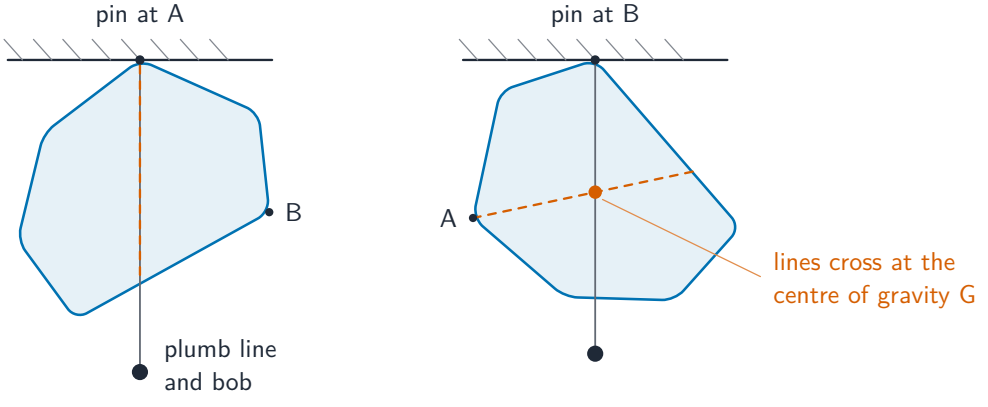
$$30 \times 0.20 = 20 \times d \quad \Rightarrow \quad d = \frac{6.0}{20} = 0.30 \text{ m}$$

Checking the principle by experiment. Balance a metre rule at its centre on a pivot. Hang a known weight on each side and move them until the rule balances again. Measure each distance from the pivot. Force × distance on the left equals force × distance on the right, within the small errors of measurement, so there is no resultant moment on a balanced object.

Centre of gravity

The **centre of gravity** is the single point where all the weight of an object seems to act.

For a flat shape (**lamina**), hang it from a pin and let it settle; draw a vertical line down from the pin using a plumb line. Repeat from another point. The centre of gravity is where the lines cross.



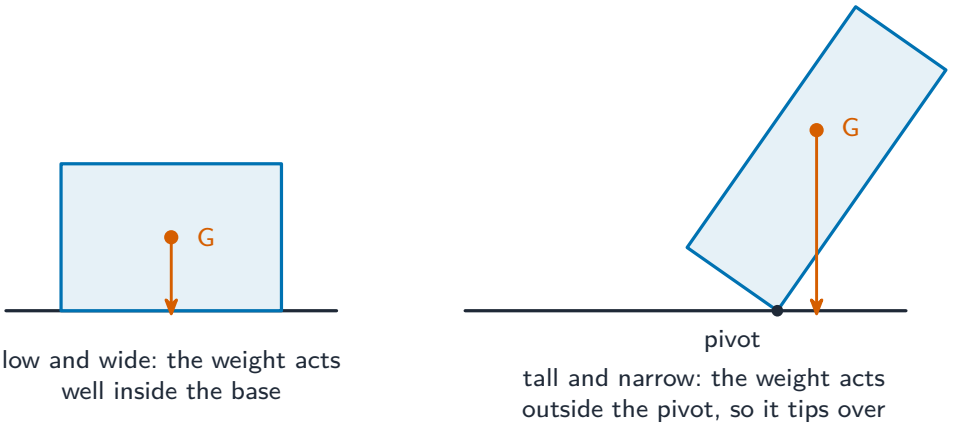
(1) hang from A; draw along the plumb line

(2) hang from B: the new plumb line crosses it at G

Hang the lamina from two points: the plumb lines cross at the centre of gravity

The **stability** of an object depends on where its centre of gravity is. An object is more **stable** when its centre of gravity is low and its base is wide. It tips over when a vertical line down from the centre of gravity passes outside the base.

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A low centre of gravity and a wide base keep the weight acting inside the base

Momentum

Momentum is mass times velocity. It is a vector.

$$p = mv$$

Impulse is the force times the time it acts, and it equals the change in momentum:

$$\text{impulse} = F\,\Delta t = \Delta(mv)$$

So the resultant force is the change in momentum per unit time:

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

> **Worked example.** A 0.40 kg ball hits a wall at 10 m/s and bounces straight back at 8.0 m/s. It touches the wall for 0.050 s. Find the impulse and the average force on the ball.

Take towards the wall as positive, so the velocity after is -8.0 m/s.

$$\Delta p = m(v - u) = 0.40 \times (-8.0 - 10) = -7.2 \text{ kg m/s}$$

The impulse is 7.2 N s away from the wall, and

$$F = \frac{\Delta p}{\Delta t} = \frac{7.2}{0.050} = 140 \text{ N}$$

away from the wall. If you forget the change of direction you get $0.40 \times (10 - 8.0) = 0.80$ N s, which is far too small.

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Conservation of momentum : when objects collide and no outside force acts, the total momentum before equals the total momentum after.

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

(Here u is a velocity before and v is a velocity after.)

> **Worked example.** A 2.0 kg trolley moving at 3.0 m/s hits a stationary 1.0 kg trolley and they stick together. Find their common velocity afterwards.

Total momentum is conserved, so

$$(2.0 \times 3.0) + (1.0 \times 0) = (2.0 + 1.0)\,v \quad \Rightarrow \quad v = \frac{6.0}{3.0} = 2.0 \text{ m/s}$$

Energy, work and power

Energy stores

Energy can be **stored** in different ways: kinetic , gravitational potential , chemical , elastic (strain) , nuclear , electrostatic , and internal (thermal) .

Energy is **transferred** between stores by forces (mechanical work), by electric currents, by heating, and by waves (such as light and sound).



Wind turbines transfer energy from the kinetic store of the moving air to electricity

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■ Kinetic and potential energy

Kinetic energy is the energy of a moving object:

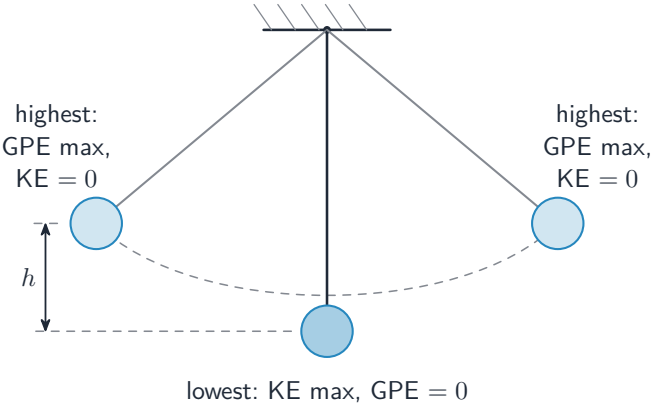
$$E_k = \frac{1}{2}mv^2$$

The change in **gravitational potential energy** when an object goes up or down by a height Δh:

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

■ Conservation of energy

The **principle of conservation of energy** says energy is never made or destroyed; it only moves between stores. A falling object turns gravitational potential energy into kinetic energy. A **Sankey diagram** shows how the input energy splits into useful energy and **wasted** energy.



Energy moves between gravitational potential energy (at the highest points) and kinetic energy (at the lowest point)

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On a roller-coaster, gravitational potential energy stored at the top of the hill becomes kinetic energy as the cars speed down

> **Worked example.** A 0.50 kg ball is dropped from a height of 1.8 m. Ignoring air resistance, find its speed just before it lands. (Take $g = 10$ m/s^2.)

All the gravitational potential energy becomes kinetic energy, so $\frac{1}{2}mv^2 = mg\,\Delta h$. The mass cancels, leaving $v^2 = 2g\,\Delta h$:

$$v = \sqrt{2 \times 10 \times 1.8} = \sqrt{36} = 6.0 \text{ m/s}$$

Because the mass cancels, every object dropped from this height would land at the same speed.

■ Work

Work done equals the energy transferred. For a constant force, use the displacement in the direction of that force:

$$W = Fd = \Delta E$$

The unit of work and energy is the **joule** (J).

The distance d must be in the direction of the force. When you lift something, use the vertical height, not the length of a slope or a staircase.

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■ Power

Power is the work done (or energy transferred) per unit time.

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

The unit is the **watt** (W). 1 W = 1 J/s.

> **Worked example.** A student of weight 500 N runs up a staircase. The stairs rise 3.0 m vertically and are 5.0 m long along the slope. The climb takes 6.0 s. Find the work done against gravity and the power.

The force (the weight) acts vertically, so use the vertical height 3.0 m:

$$W = Fd = 500 \times 3.0 = 1500 \text{ J} \qquad P = \frac{W}{t} = \frac{1500}{6.0} = 250 \text{ W}$$

A student who walks up the same stairs in 15 s does the same work, 1500 J, but with a smaller power, 100 W.

■ Efficiency

Efficiency tells you how much of the input energy becomes useful energy.

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

Real devices usually transfer some input energy to less useful stores, so their useful efficiency is below 100%. An ideal model can use 100% efficiency; wasted energy is transferred, not destroyed. The same idea works with power:

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

> **Worked example.** A motor is supplied with 200 J of electrical energy and lifts a load, giving it 150 J of gravitational potential energy. Find its efficiency.

$$\eta = \frac{E_{\text{useful}}}{E_{\text{in}}} \times 100\% = \frac{150 \text{ J}}{200 \text{ J}} \times 100\% = 75\%$$

Comparing energy and power. Suppose the same motor transfers this energy in 5.0 s. Use the same interval for both average powers.

$$P_{\text{in}} = \frac{E_{\text{in}}}{t} = \frac{200 \text{ J}}{5.0 \text{ s}} = 40 \text{ W}$$

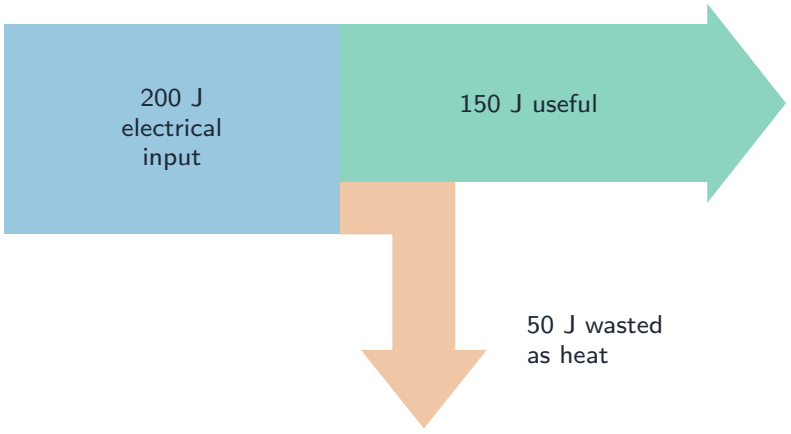
$$P_{\text{useful}} = \frac{E_{\text{useful}}}{t} = \frac{150 \text{ J}}{5.0 \text{ s}} = 30 \text{ W}$$

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$$\eta = \frac{P_{\text{useful}}}{P_{\text{in}}} \times 100\% = \frac{30\ \text{W}}{40\ \text{W}} \times 100\% = 75\%$$

$$E_{\text{wasted}} = E_{\text{in}} - E_{\text{useful}} = 200\ \text{J} - 150\ \text{J} = 50\ \text{J}$$

The power and energy ratios agree because the same time interval applies. Wasted energy is transferred to less useful stores, not destroyed.



A Sankey diagram for this motor: the band widths are proportional to the energy, so the 200 J input splits into 150 J useful and 50 J wasted as heat

■ Energy resources

We generate electricity from many **energy resources**. Most spin a **turbine** that drives a **generator** – often by boiling water to make steam (**fossil fuels**, **nuclear fuel**, **geothermal**, **biofuels**), or directly by moving water or air (**hydroelectric**, **waves**, **tides**, **wind**). **Solar cells** make electricity from sunlight directly; **solar panels** heat water.

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Resource	Renewable?	Notes
fossil fuels (coal, oil, gas)	no	reliable, high output, but CO_2 and pollution
nuclear fuel	no	no CO_2 from reactor operation; waste
biofuels	yes	replanting absorbs CO_2; production emits CO_2
hydroelectric	yes	water supply matters; dams flood land
wind	yes	no fuel burned; output varies
solar	yes	no fuel burned; needs daylight
geothermal / tidal	yes	site-limited; tidal output is not continuous

The nuclear reactor does not emit carbon dioxide while operating, but fuel supply and construction can cause emissions. Biofuel crops can absorb carbon dioxide as they regrow; emissions from growing, processing and transporting the fuel also matter, so replanting alone does not guarantee zero net emissions.

When you compare resources, use these five ideas: **renewability** (will it run out?), **availability** (is it always there? the wind can drop and the Sun sets), **reliability** (does it give a steady output?), **scale** (how much energy can it supply?) and **environmental impact** (pollution, carbon dioxide, land flooded by a dam).

Most of these trace back to the **Sun** (fossil fuels are ancient stored sunlight; wind and waves come from solar heating) – the exceptions are **geothermal**, **nuclear**, and **tidal** energy. The Sun itself is powered by **nuclear fusion**, joining hydrogen nuclei into helium. The syllabus includes research into using energy released by fusion to generate electrical power on a large scale.

Worked energy routes. A school wants electric lighting and hot water. Solar cells supply electrical energy directly; solar water-heating panels transfer energy from solar radiation to the internal energy of water. Neither needs a steam turbine for its stated function. In a fuel-fired power station, a boiler heats water, steam turns a turbine and the turbine drives a generator. Wind or moving water can turn turbines directly. Identify the energy route before naming the components.

Exam transfer. In 0625/22 May/June 2025 Q9, wind is the only one of wind, geothermal and nuclear fuel that gets its energy from the Sun (official answer D). Solar heating helps drive movement of air. Geothermal energy comes from inside the Earth; nuclear fuel supplies energy through nuclear changes. Renewability is a separate test.

Worked resource comparison. A remote clinic needs electricity day and night.

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Solar cells without a battery, backup or grid connection cannot meet its night demand. A hydroelectric scheme may supply at night if suitable flow or stored water is available, but seasonal flow and scheme capacity must be checked. Compare each supply with the clinic's power requirement and assess site, land and habitat effects, especially if a dam is needed. Renewable alone does not mean continuous, adequate or environmentally harmless. Use availability, reliability, scale and environmental impact to explain the choice.

Pressure

Pressure is the perpendicular force per unit surface area.

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

The unit is the **pascal** (Pa). 1 Pa = 1 $\mathrm{N/m^2}$.

A small area gives a large pressure (a sharp knife cuts well). A large area gives a small pressure (snowshoes stop you sinking).

> **Worked example.** A 600 N student stands on both feet. Each shoe touches the floor over 200 $\mathrm{cm^2}$. Find the pressure on the floor.

The total area is 400 $\mathrm{cm^2}$. Change it to $\mathrm{m^2}$: 1 $\mathrm{m^2}$ = 100 × 100 = 10 000 $\mathrm{cm^2}$, so 400 $\mathrm{cm^2}$ = 0.040 $\mathrm{m^2}$.

$$p = \frac{F}{A} = \frac{600}{0.040} = 15\,000 \text{ Pa}$$

Standing on one foot halves the area, so the pressure doubles to 30 000 Pa.

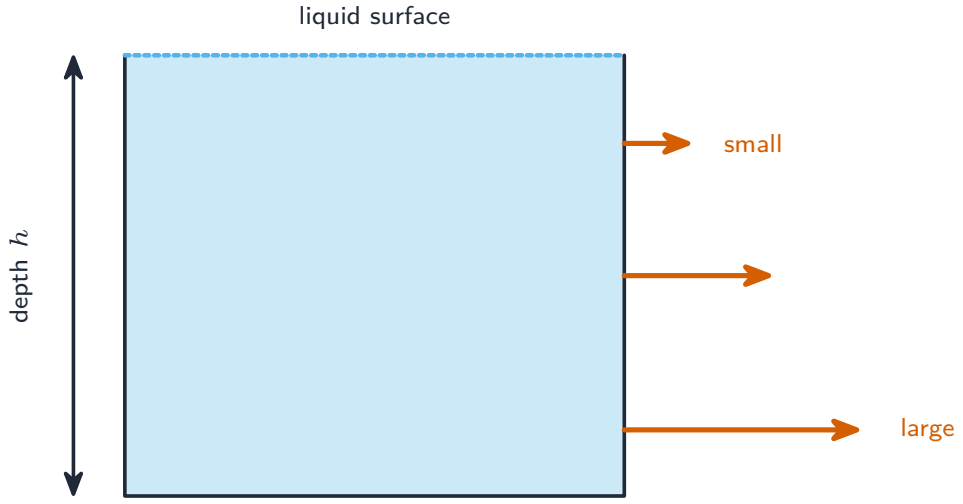
■ Pressure in a liquid

In a liquid, pressure increases with **depth** and with the liquid's density:

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

This is why a dam is built thicker at the bottom, where the water pressure is greatest. Pressure in a liquid acts in all directions.

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The deeper the liquid, the greater the pressure, so the outward push on the wall grows with depth



A real dam is built much thicker at the bottom, because the water pushes hardest where it is deepest

Worked example. Find the extra pressure at a depth of 2.0 m in water (density 1000 kg/m^3, $g = 10$ N/kg).

$$\Delta p = \rho g \, \Delta h = 1000 \times 10 \times 2.0 = 20\,000 \text{ Pa}$$

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Exam tips

- On a **distance–time** graph the gradient is the speed; on a **speed–time** graph the gradient is the acceleration and the *area* under the line is the distance travelled. Never read one graph as if it were the other.
- **Mass** (kg) is the amount of matter and is the same everywhere; **weight** (N) is the force of gravity, $W = mg$. On the Moon your mass is unchanged but your weight is smaller.
- **Speed** is a scalar; **velocity** is a vector. Something moving at steady speed around a curve is still accelerating, because its direction keeps changing.
- In **Hooke's law**, load is proportional to extension only up to the **limit of proportionality**. Use the *extension* (stretched length − original length), never the whole length.
- Total **momentum** is conserved in a collision when the resultant external force is negligible. Give each velocity a + or − sign for its direction *before* you add them.
- Check that units are consistent. $p = F/A$ defines pressure; $\Delta p = \rho g\,\Delta h$ gives the change in pressure between depths in a liquid.

■ Common mistakes

- Joining the points on a graph dot to dot. Draw one line of best fit, and leave out an anomalous point.
- Averaging two speeds to get the average speed. Use total distance ÷ total time, and include the time spent stopped.
- Saying "no forces act" at terminal velocity. The weight and the air resistance both act; they are equal and opposite, so the *resultant* force is zero.
- Writing a weight in kilograms. Weight is a force, measured in newtons; mass is in kilograms.
- Using the whole length of a spring in $k = F/x$. Use the extension (new length − original length), in metres.
- Forgetting the minus sign when an object bounces back. The change in velocity from +10 to −8 m/s is −18 m/s, not −2 m/s.
- Dividing by an area in cm^2 in $p = F/A$. Change to m^2 first: $1\ \text{cm}^2 = 0.0001\ \text{m}^2$.
- Using the slope length to find the work done in lifting. Use the vertical height, because the weight acts vertically.

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