

5 • Forces

AQA • GCSE • Physics

Forces: pushes, pulls and their effects

A bridge, a brake, a bungee cord, a planet in orbit: engineers analyse them all with forces. This reference covers **AQA GCSE Physics 8463, topic 4.5 Forces** – the largest topic of Paper 2.

How the exam treats this topic:

- Paper 2 (4.5–4.8) carries this topic, and it may also draw on energy and electricity ideas. Equation-sheet support depends on the examination series. Practise choosing an equation, rearranging it and using SI units; check the sheet supplied for your examination.
- Moments, levers and gears and fluid pressure are **physics only**. Interpreting terminal-velocity graphs is also physics only. Momentum is **Higher Tier**; collision calculations and changes in momentum are physics only.
- Free-body diagrams, vector diagrams (scale drawing) and resolution of forces are **HT only**.
- Required practicals: RP6 (force–extension of a spring) and RP7 (force and mass effect on acceleration).

Scalars, vectors and forces

Scalar : magnitude only – distance, speed, mass, energy. **Vector** : magnitude **and** direction – displacement, velocity, force, weight, momentum. A vector is drawn as an arrow: length = magnitude, direction = direction.

A **force** is a push or pull from the interaction with another object:

- **contact** forces (touching): friction, air resistance, tension, normal contact force;
- **non-contact** forces (separated): gravitational, electrostatic, magnetic.

Gravity: weight of mass is the force on an object due to gravity; it acts at the **centre** and is measured with a calibrated spring-balance (newtonmeter):

$$W = mg$$

- W weight in N; m mass in kg; g gravitational field strength in N/kg (given, usually 9.8 near Earth).
- Weight and mass are directly proportional ($W \propto m$).

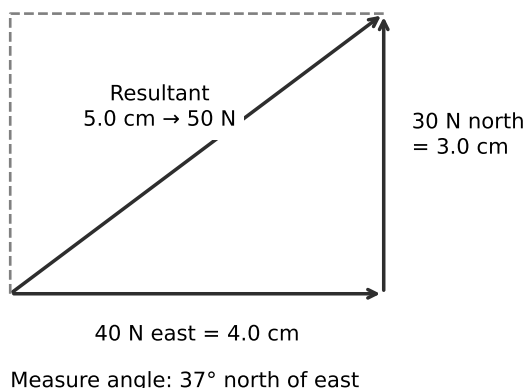
Resultant force : the single force replacing several forces with the same effect. Collinear: add same-direction forces, subtract opposite ones. (HT) Use **free-body**

diagrams (only the forces on the chosen object), resolve a force into perpendicular components, and find resultants by **scale drawing**.

Worked example. A 65 kg person stands on Mars where $g = 3.7 \text{ N/kg}$.

$$W = mg = 65 \times 3.7 = 240 \text{ N (2 s.f.)}$$

Scale: 1.0 cm represents 10 N



HT scale diagram with explicit magnitude, direction and scale.

Worked scale drawing (HT; teacher-written). Use 1 cm for 10 N. Draw 4.0 cm east, then 3.0 cm north. The resultant joins the first tail to the last head: 5.0 cm represents 50 N, about 37° north of east. The equilibrant has equal magnitude in the opposite direction.

Exam demand. AQA June 2025 8463/2H Q05.5 uses 240 N upwards and 200 N left. A scale triangle or parallelogram gives about 310 N, 40° left of vertical (official ranges 300–320 N and $38\text{--}42^\circ$). The diagram, arrow directions and scale are part of the method.

Work done and energy transfer

A force does **work** when it moves its point of application through a distance:

$$W = Fs$$

- W work done in J; F force in N; s distance **moved along the line of action of the force**, in m.
- **1 J = 1 N · m**: one joule is the work of one newton over one metre.

- Work done against friction raises the object's temperature – the energy transfers to thermal stores.

Worked example. A child pushes a baby walker 2.8 m with a horizontal force of 25 N.

$$W = Fs = 25 \text{ N} \times 2.8 \text{ m} = 70 \text{ J}$$

Forces and elasticity (RP6)

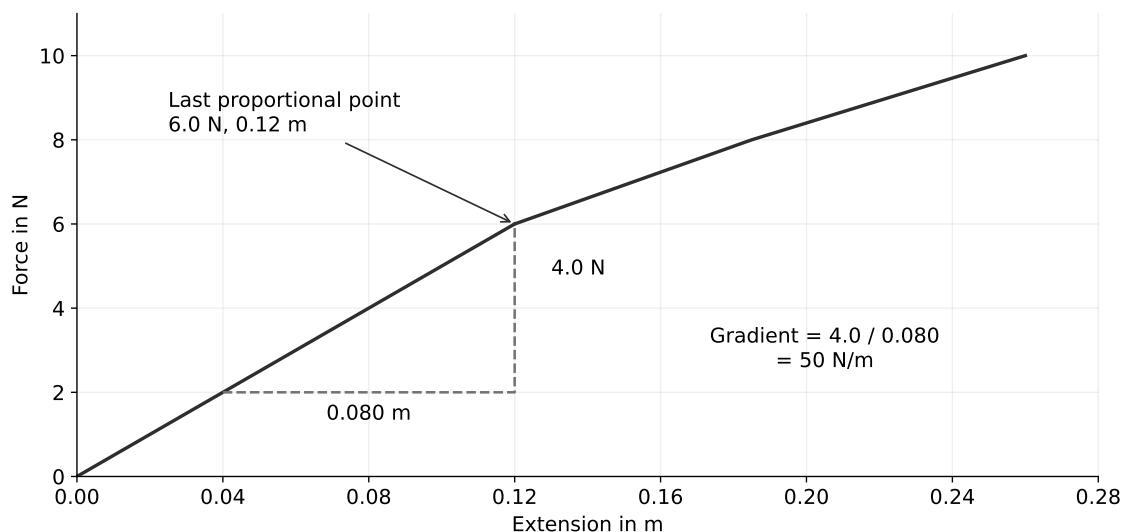
More than one force is needed to stretch, bend or compress a **stationary** object (a single force would just move it). **Elastic** deformation is recovered when the forces are removed; **inelastic** is not.

Below the **limit of proportionality**:

$$F = ke \quad E_e = \frac{1}{2}ke^2$$

- k spring constant in N/m (stiff spring $\rightarrow$ large k); e extension = stretched length – original length (or compression).
- Work done on the spring = elastic energy stored (if not inelastically deformed).

Required practical 6: hang masses on a spring, measure extension for each (ruler at eye level), plot force against extension. The linear section's **gradient is k** ; beyond the limit of proportionality the line curves. Hooke's-law reasoning: doubling the force doubles the extension only below the limit.



RP6: force against extension for a spring, linear then curving past the limit of proportionality.

Worked example (AQA June 2025 Q02.7). A force of 4.0 N produces extension 0.064 m. Choose $F = ke$ in the proportional region, then rearrange:

$$k = \frac{F}{e} = \frac{4.0 \text{ N}}{0.064 \text{ m}} = 62.5 \text{ N/m}$$

A plot of total **length** has a non-zero intercept because the unloaded spring has a non-zero length. A curve away from the proportional line means F and e are no longer proportional; unload the spring to test for permanent deformation. Secure the stand, limit loading, keep the ruler vertical and close, and use a pointer at eye level.

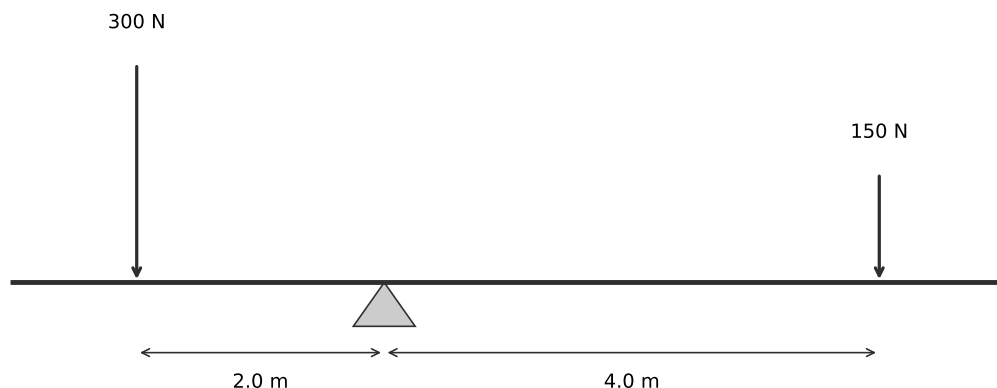
Moments, levers and gears (physics only)

$$M = Fd$$

- M moment in $\text{N} \cdot \text{m}$; d is the **perpendicular distance from the pivot to the line of action** of the force.
- **Balance:** total clockwise moment = total anticlockwise moment.

Levers and **gears** transmit the rotational effect of a force. A longer lever arm produces a larger moment for the same perpendicular force. In an ideal pair of meshed gears, the teeth exert equal forces at the contact: a larger driven gear turns more slowly with a larger moment. The meshed gears turn in opposite directions.

$$\text{Balanced: } 300 \text{ N} \times 2.0 \text{ m} = 150 \text{ N} \times 4.0 \text{ m}$$



A balanced beam: two weights on opposite sides of a pivot with their distances marked.

Worked example. Choose the pivot and equate clockwise and anticlockwise moments:

$$F_R d_R = F_L d_L$$

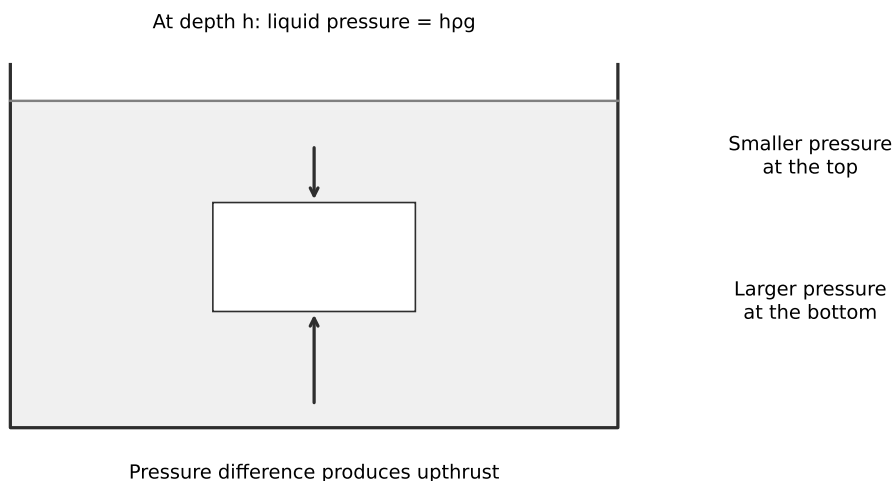
$$F_R = \frac{F_L d_L}{d_R} = \frac{300 \text{ N} \times 2.0 \text{ m}}{4.0 \text{ m}} = 150 \text{ N}$$

For AQA June 2024 Q02.6, convert the perpendicular distance 7.5 cm to 0.075 m: $M = Fd = 2.0 \text{ N} \times 0.075 \text{ m} = 0.15 \text{ N m}$. In a pair of meshed gears, the teeth produce a force and moment on the other gear; adjacent gears rotate in opposite directions.

Pressure and fluids (physics only)

$$p = \frac{F}{A} \quad (\text{HT only}) \quad p = h\rho g$$

- p pressure in Pa; F force **normal** to the surface; A area in m^2 .
- (HT) h column height in m, ρ liquid density in kg/m^3 . Pressure grows with depth and density.
- A submerged object feels greater pressure on its bottom than its top $\rightarrow$ a resultant **upthrust**. Floating at rest: upthrust = weight. If weight initially exceeds upthrust, a released object accelerates downwards; a sinking object can later move at constant speed when upthrust plus drag balances its weight.
- **Atmospheric pressure** decreases with height: fewer air molecules above a surface as you climb, so less weight of air; the atmosphere gets less dense with altitude.



Pressure difference between top and bottom produces upthrust.

Worked example (teacher-written; HT). A 2.0 m water column has density 1000 kg/m^3 ; $g = 9.8 \text{ N/kg}$. Its pressure, additional to that at the free surface, is:

$$p = h\rho g = 2.0 \text{ m} \times 1000 \text{ kg/m}^3 \times 9.8 \text{ N/kg} = 19600 \text{ Pa}$$

Floating at rest requires a complete force balance. A sinking object can reach constant velocity when **upthrust + drag = weight**; sinking does not always mean downward acceleration.

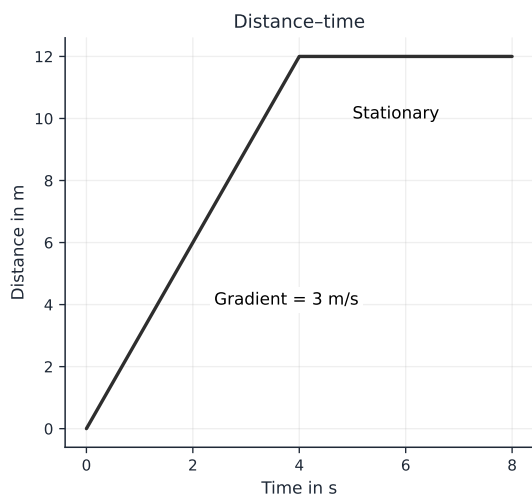
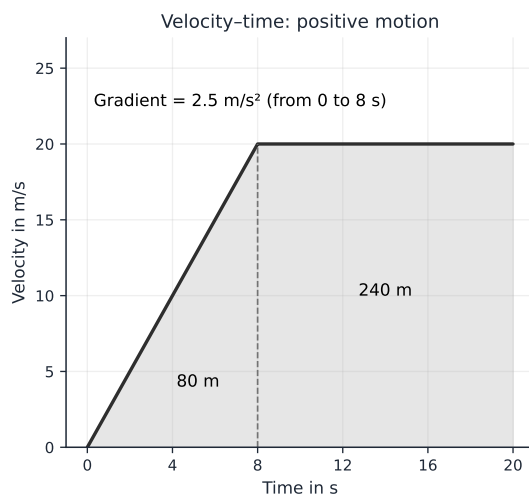
Describing motion along a line

- **Distance** (scalar): how far. **Displacement** (vector): straight-line distance **and direction**.
- **Speed** (scalar) – typical values: walking ≈ 1.5 m/s, running ≈ 3 m/s, cycling ≈ 6 m/s, sound in air ≈ 330 m/s. **Velocity** (vector): speed in a given direction.
- $s = vt$ (constant speed); average speed = total distance $\div$ total time.
- **Distance–time graph**: gradient = speed; (HT) a tangent gives instantaneous speed of an accelerating object.
- **Acceleration** : $a = \Delta v/t$, in m/s^2 ; deceleration means slowing down. With the initial direction chosen positive, its acceleration is negative. Estimate everyday accelerations.
- **Velocity–time graph**: gradient = acceleration; (HT) signed area gives displacement. Add the magnitudes of areas above and below zero to find total distance. If velocity stays positive, area also gives distance.
- Uniform acceleration: $v^2 - u^2 = 2as$. Free fall near Earth: $a \approx 9.8$ m/s^2 .

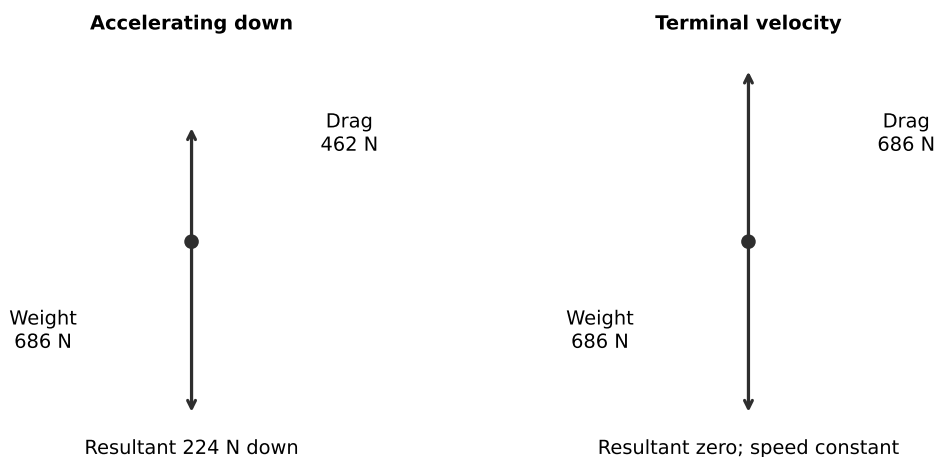
Worked example (graph). A v – t graph rises straight from 0 to 20 m/s in 8 s, then stays flat for 12 s.

- Acceleration (gradient): $a = \Delta v/\Delta t = (20 - 0)/8 = 2.5$ m/s^2 .
- (HT) Positive-velocity areas: $s = s_1 + s_2 = \frac{1}{2}\Delta t_1 v + v\Delta t_2 = \frac{1}{2} \times 8 \times 20 + 20 \times 12 = 320$ m.

Terminal velocity : a falling object accelerates (weight > drag); as speed grows, drag grows until resultant force = 0 – constant speed = **terminal velocity**. Skydiver: fast terminal before the chute, slow after; interpret the v – t curve shape.



A distance-time graph and a velocity-time graph with the gradient and area meanings.



A free-body diagram of a skydiver with weight and drag, beside the terminal-velocity story.

Worked tangent example (HT; teacher-written). At a chosen instant, a tangent to a distance–time curve passes through (2 s, 3 m) and (6 s, 15 m):

$$v = \frac{\Delta s}{\Delta t} = \frac{(15 - 3) \text{ m}}{(6 - 2) \text{ s}} = 3.0 \text{ m/s}$$

This is instantaneous speed at the point of tangency. A chord over a time interval instead gives an average rate.

Exam demand. AQA June 2025 Q05.2 gives mean acceleration 0.64 m/s^2 from rest for 2.5 minutes. Convert time to 150 s, then:

$$v = u + a\Delta t = 0 + 0.64 \text{ m/s}^2 \times 150 \text{ s} = 96 \text{ m/s}$$

Q05.3 needs the linked terminal-velocity explanation: speed rises $\rightarrow$ drag rises $\rightarrow$ drag equals weight $\rightarrow$ resultant and acceleration become zero. On opening a parachute, drag initially exceeds weight: upward acceleration slows the still downward-moving skydiver.

Newton's laws (RP7)

- **First law:** zero resultant force $\rightarrow$ stationary stays stationary; moving keeps the same velocity. For motion in a straight line at steady speed, driving force = resistive forces. (HT) **Inertia** : the tendency to keep the state of motion.
- **Second law:** $a \propto F$, $a \propto 1/m$, so:

$$F = ma$$

(HT) **Inertial mass** = force $\div$ acceleration – resistance to change of velocity.

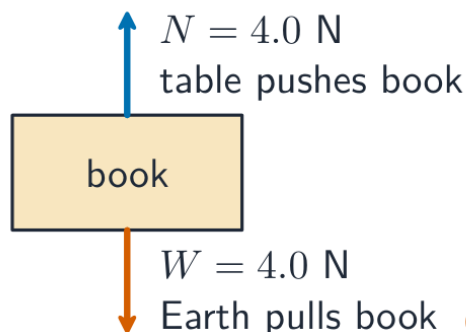
Required practical 7: trolley on a runway – vary the driving force by transferring masses from the trolley to its hanging holder, keeping the **total moving mass** constant. For the combined trolley–hanger system, the driving force is the hanger's weight when resistance is negligible or compensated; the string tension on the trolley is a different force. Then keep hanger mass constant and add mass to the trolley. Measure acceleration with light gates; plot a against driving force at fixed total mass, or a against $1/m$ where m is total moving mass.

- **Third law:** two interacting objects exert **equal and opposite** forces **on each other** – same type, opposite directions, on different objects.

Worked example (third law in an equilibrium situation). A book of weight 4.0 N rests on a table.

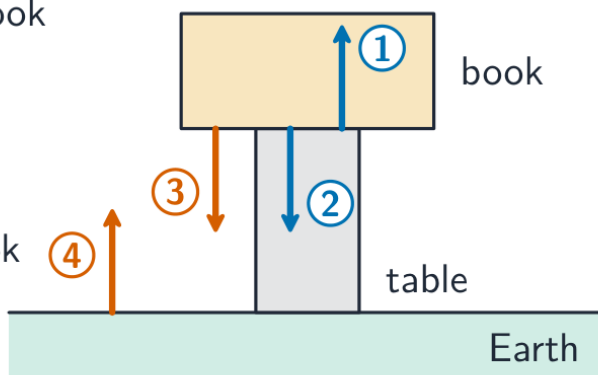
- Forces **on the book**: the weight, 4.0 N down (the Earth pulls the book), and the normal contact force, 4.0 N up (the table pushes the book). They balance because the book is in equilibrium: that is the first law, zero resultant force.
- These two are **not** a third-law pair. They act on the same object, and they are different types of force (one gravitational, one contact).
- The real pairs: the table pushes the book up (1) and the book pushes the table down with 4.0 N (2); the Earth pulls the book down (3) and the book pulls the Earth up with 4.0 N (4).

forces on the book



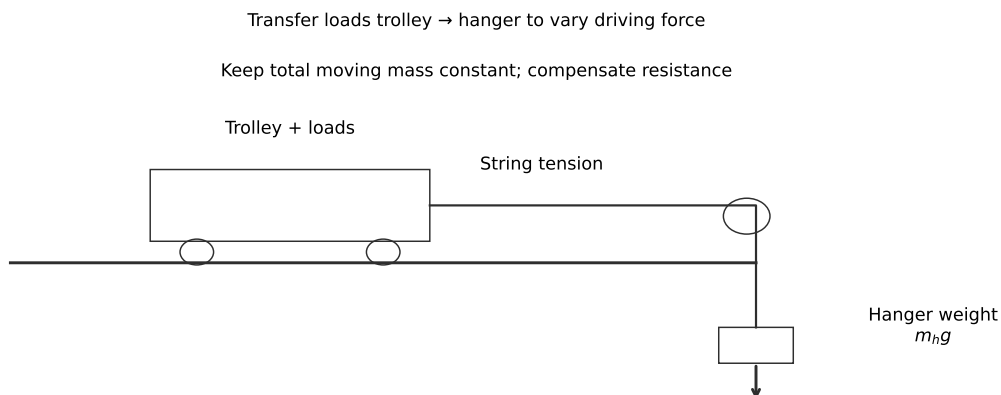
balanced: first law

two third-law pairs



The weight and the normal force on the book balance, but they are not a pair: each third-law pair acts on two different objects

Test any claimed pair: same type of force, equal size, opposite directions, acting on two different objects.



RP7 combined trolley-hanger system and total moving mass.

Worked uncertainty example (AQA June 2024 Q05.4). Three accelerations are 1.36, 1.39 and 1.33 m/s². The range is 0.06 m/s²; using half the range, report uncertainty ± 0.03 m/s². Repeats reveal spread; a mean reduces random variation but does not remove a common calibration error.

From rest under uniform acceleration, acceleration can also be found from distance and time: average speed is s/t , final speed is twice the average, and acceleration is final speed divided by time. State the rest/uniform-acceleration assumptions.

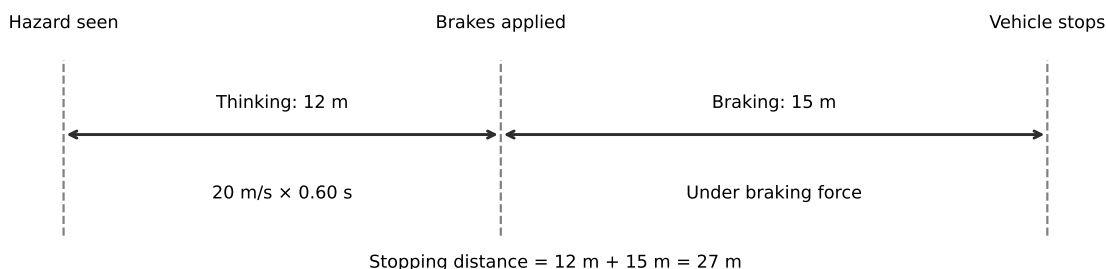
Forces and braking

Stopping distance = thinking distance + braking distance.

- **Thinking** (reaction) distance = reaction time $\times$ speed. Reaction time 0.2–0.9 s typically; affected by tiredness, drugs, alcohol, distractions. Measure it: drop a ruler between a partner's fingers – distance fallen $\rightarrow$ time from $s = \frac{1}{2}at^2$ (or electronic timers).
- **Braking distance:** grows with speed (for a given braking force); wet or icy roads, worn brakes or tyres lengthen it.
- Braking physics: friction between brake and wheel does work on the kinetic energy store; the brakes' temperature rises; a higher speed or shorter stop $\rightarrow$ larger force needed $\rightarrow$ larger deceleration $\rightarrow$ **overheating brakes, loss of control**. (HT) Estimate deceleration forces with $F = ma$.

Worked example. A 1500 kg car brakes from 30 m/s to rest in 60 m.

- Choose initial motion positive. From $v^2 - u^2 = 2as$, $a = (v^2 - u^2)/(2s) = (0 - 30^2)/(2 \times 60) = -7.5$ m/s².
- Braking-force magnitude: $|F| = m|a| = 1500 \times 7.5 = 11250 \approx 11000$ N, opposite the initial motion.



A car braking: thinking distance then braking distance add to the stopping distance.

Worked exam example (AQA June 2025 Q06.3). A 1400 kg car slows uniformly from 18 m/s to rest over 24 m of **braking**. Choose the initial direction positive:

$$a = \frac{v^2 - u^2}{2s} = \frac{0 - (18 \text{ m/s})^2}{2 \times 24 \text{ m}} = -6.75 \text{ m/s}^2$$

$$F = ma = 1400 \text{ kg} \times (-6.75 \text{ m/s}^2) = -9450 \text{ N}$$

The force has magnitude 9450 N, opposite the initial motion. Do not insert thinking distance into the braking equation.

Momentum (HT; calculations physics only)

$$p = mv \quad F = \frac{m\Delta v}{\Delta t}$$

- p momentum in kg m/s (a vector); conservation: in a **closed system**, total momentum before = total momentum after an event (collisions).
- $F = m\Delta v/\Delta t$: force = **rate of change of momentum** (this is $F = ma$ restated).
- Safety features explained by it: air bags, seat belts, crash mats, cycle helmets, cushioned playgrounds – all **increase the time** over which momentum changes, so $\Delta v/\Delta t$ falls and the force falls.

Worked example. A 1000 kg car at 20 m/s hits a barrier and stops in 0.25 s.

- Magnitude of momentum change: $|\Delta p| = m|\Delta v| = 1000 \times 20 = 20\,000 \text{ kg m/s}$.
- Mean force magnitude: $|\bar{F}| = |\Delta p|/\Delta t = 20\,000/0.25 = 80\,000 \text{ N}$, opposite the motion. With a crumple zone ($\Delta t = 0.50 \text{ s}$), the mean force magnitude halves to 40 000 N for the same momentum change.

Worked collision example (sheet 5.9). A 2.0 kg trolley moving right at 3.0 m/s sticks to a stationary 1.0 kg trolley. With negligible external horizontal impulse, take right positive:

$$p_i = m_A u_A + m_B u_B = 2.0 \times 3.0 + 1.0 \times 0 = 6.0 \text{ kg m/s}$$

$$v = \frac{p_i}{m_A + m_B} = \frac{6.0 \text{ kg m/s}}{3.0 \text{ kg}} = 2.0 \text{ m/s right}$$

Momentum conservation does not require kinetic energy conservation. For a rebound, keep signed velocities: a 0.16 kg ball changes from +12 to −8.0 m/s, so $\Delta p = m(v - u) = -3.2 \text{ kg m/s}$. Over 0.020 s, mean force is $\bar{F} = \Delta p / \Delta t = -160 \text{ N}$ (160 N left). The wall experiences the equal, opposite mean force.

Air-bag explanation (AQA June 2025 Q06.2). For the same driver and momentum change, the bag lengthens stopping time, reducing the rate of momentum change and mean force. This reduces injury risk; it does not guarantee a harmless collision.

Checklist before you call this topic done

- Classify scalar/vector, contact/non-contact; compute $W = mg$; find collinear resultants; (HT) draw free-body and scale-diagram resultants.
- $W = Fs$ with energy transfer story; $F = ke$, $E_e = \frac{1}{2}ke^2$; RP6 with gradient = k .
- (physics only) Moments balance; levers and gears trade force for distance; $p = F/A$, (HT) $p = h\rho g$; upthrust and floating; atmospheric pressure vs height.
- Distance vs displacement; typical speeds; read d–t and v–t graphs (gradient, tangent, area); $v^2 - u^2 = 2as$; terminal velocity story.
- Newton’s three laws with examples; RP7 method and graphs.
- Stopping distance split; reaction-time measurement; braking energy and deceleration dangers.
- (HT) $p = mv$, conservation in collisions, $F = m\Delta v / \Delta t$, safety features via longer Δt .

■ Common mistakes

- Giving weight in kilograms. Mass is in kg; weight is a force in N, $W = mg$.
- Using the wrong distance for a moment. Use the **perpendicular** distance from the pivot to the line of the force, in metres.
- Reading the wrong feature of a motion graph. Gradient of distance–time = speed; gradient of velocity–time = acceleration; area under velocity–time = distance.
- Saying zero resultant force means the object is stationary. It may also move at constant velocity.
- Putting a Newton’s third law pair on the same object. The two forces act on **different** objects, so they never cancel each other.
- Putting the stretched length into $F = ke$. Use the extension, and only in the proportional region.
- Mixing up the two parts of stopping distance. Tiredness, drugs and distraction lengthen the thinking distance; wet or icy roads and worn tyres or brakes lengthen the braking distance.

- Ignoring direction in momentum. Choose a positive direction; a velocity the other way is negative.