

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 ($W \propto m$).

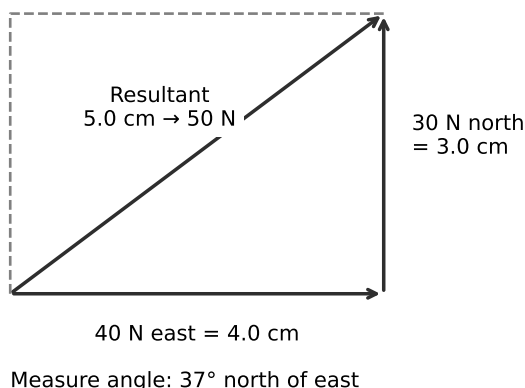
Resultant force : the single force replacing several forces with the same effect. Collinear: add same-direction forces, subtract opposite ones. (HT) Use **free-body**

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



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 June2025 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)

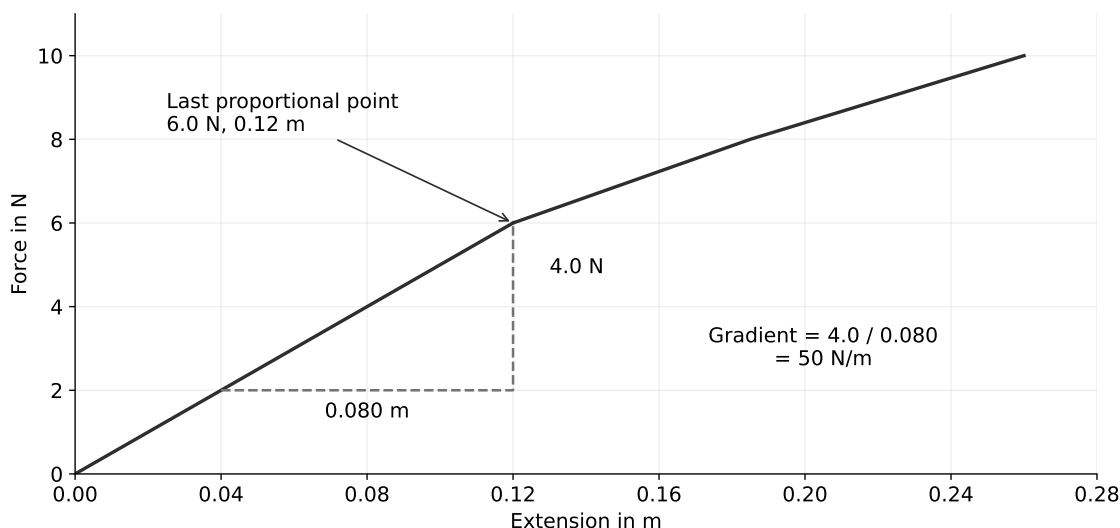
More than one force is needed to stretch, bend or compress a **stationary** object (a single force would just move it). **Elastic** deformation is recovered when the forces are removed; **inelastic** is not.

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.



Worked example (AQA June2025 Q02.7). A force of 4.0 N produces extension 0.064 m. Choose $F = ke$ in the proportional region, then rearrange:

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

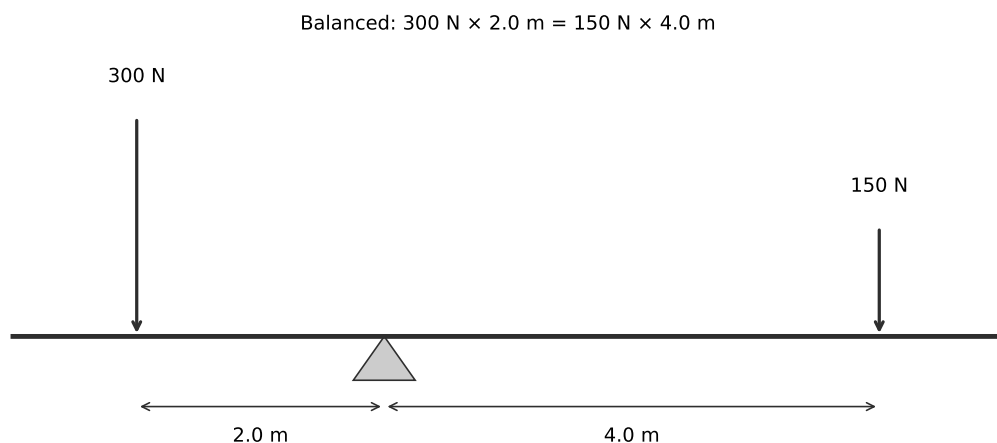
A plot of total **length** has a non-zero intercept because the unloaded spring has a non-zero length. A curve away from the proportional line means F and e are no longer proportional; unload the spring to test for permanent deformation. Secure the stand, limit loading, keep the ruler vertical and close,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



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

$$F_R d_R = F_L d_L$$

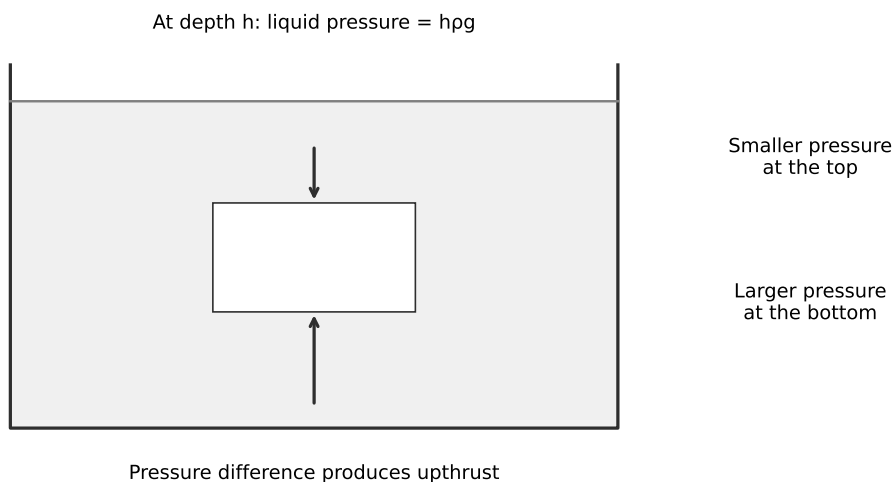
$$F_R = \frac{F_L d_L}{d_R} = \frac{300 \text{ N} \times 2.0 \text{ m}}{4.0 \text{ m}} = 150 \text{ N}$$

For AQA June2024 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.



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

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

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

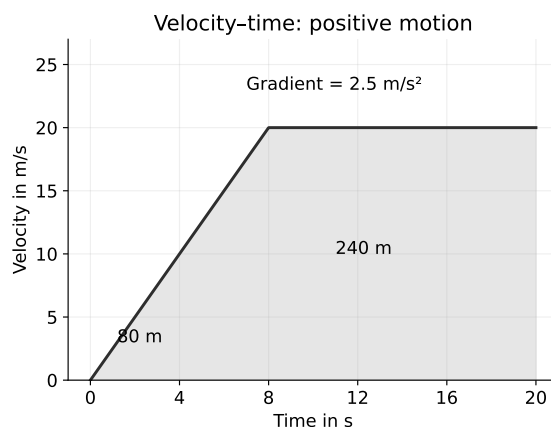
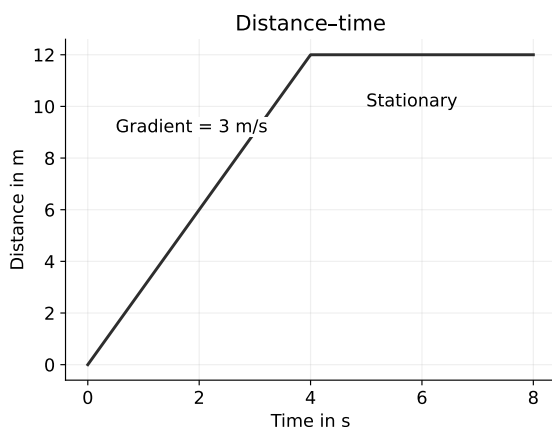
- **Distance** (scalar): how far. **Displacement** (vector): straight-line distance **and direction**.

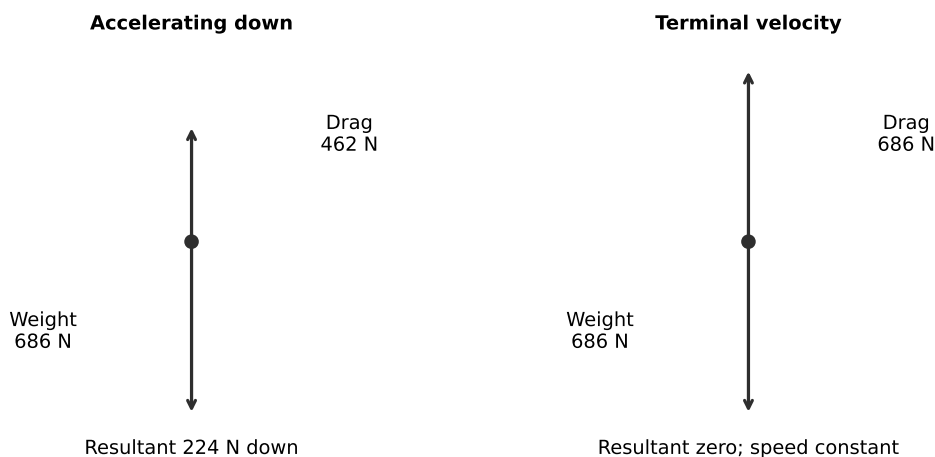
- **Speed** (scalar) – typical values: walking ≈ 1.5 m/s, running ≈ 3 m/s, cycling ≈ 6 m/s, sound in air ≈ 330 m/s. **Velocity** (vector): speed in a given direction.
- $s = vt$ (constant speed); average speed = total distance $\div$ total time.
- **Distance–time graph**: gradient = speed; (HT) a tangent 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.





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 June2025 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:

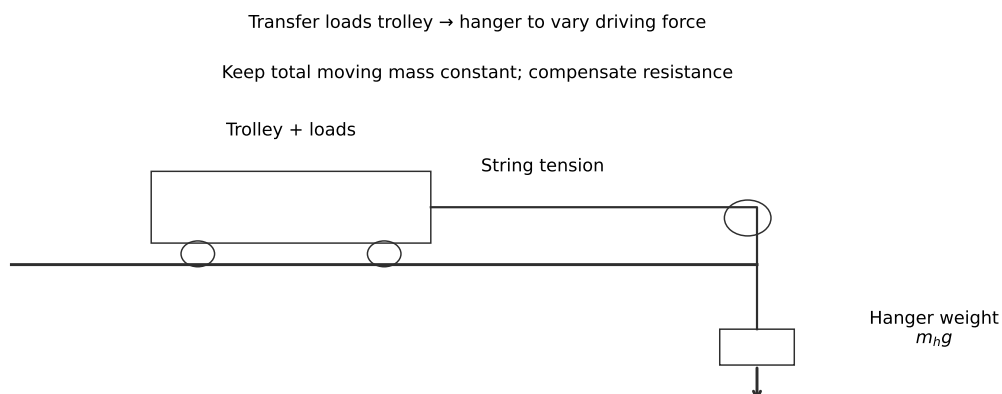
$$F = ma$$

(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 uncertainty example (AQA June2024 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.

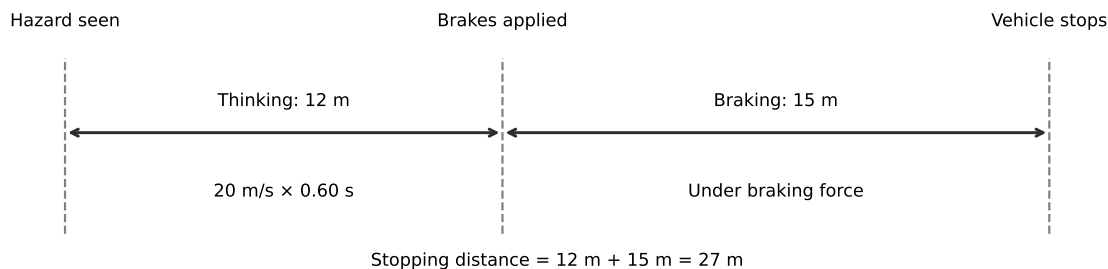
Forces and braking

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



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 June2025 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 .