

1 • Mechanics and Materials

Pearson Edexcel • International A-Level • Physics

What this unit covers

Edexcel IAL Physics Unit 1 (paper **WPH11**) is **Mechanics and Materials** : how things move, what forces do, how momentum and energy behave, and how solid and liquid materials respond to forces.

- The paper is 1 hour 30 minutes, 80 marks, every question compulsory. It mixes multiple-choice, short answers, calculations and one or two extended-writing answers marked with an asterisk (*).
- At least 32 of the 80 marks test Level-2 mathematics: reading graphs, rearranging equations, trigonometry and areas.
- A formula list is printed at the back of the paper. Learn what each symbol means and **when** each equation is allowed – the list gives formulas, not understanding.
- Use $g = 9.81 \text{ m s}^{-2}$. The paper requires this value; using $g = 10$ can lose accuracy marks. Give final answers with a **unit** and a sensible number of significant figures (usually 2–3, matching the data).

A speedometer shows speed at one moment; a journey can still hide stops and bursts. This unit replaces one number with the full picture: graphs, vectors, forces, momentum, energy and the strength of materials.

Motion: quantities and graphs

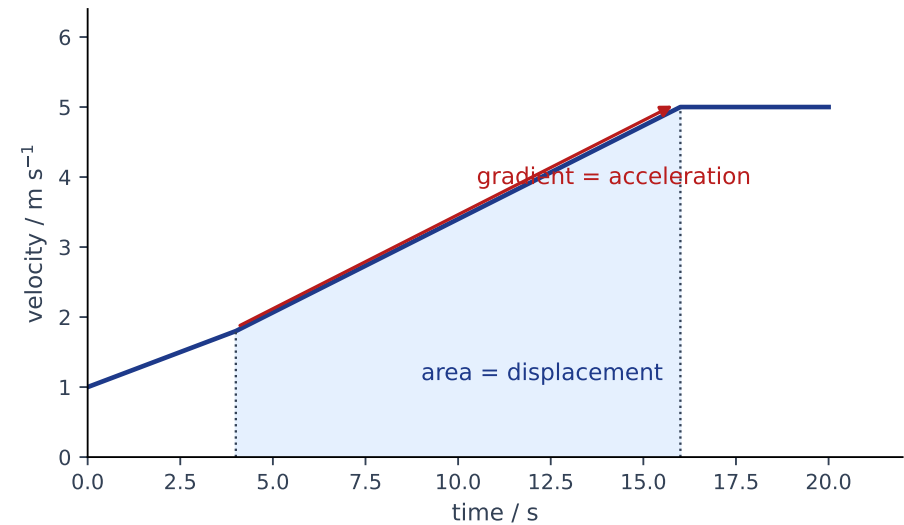
- **displacement** – straight-line change of position, with direction (a vector). **distance** – the total path length (a **scalar**, no direction).
- **velocity** – rate of change of displacement. **speed** – rate of change of distance.
- **acceleration** – rate of change of velocity: $a = \frac{\Delta v}{\Delta t}$, unit m s^{-2} .

Because displacement is the straight line from start to finish, a curved path always gives **distance** > **magnitude of displacement** – the examiner asks for exactly this comparison.

■ Reading motion graphs

- On a displacement–time graph, the **gradient** is the velocity. A curved line means changing velocity; take the gradient of a **tangent** at the point.
- On a velocity–time graph, the gradient is the acceleration, and the **area** between the line and the time axis is the displacement. Area below the axis is negative displacement (motion backwards); distance adds the sizes of all the areas.
- On an acceleration–time graph, the area under the line is the **change in velocity**.

- Constant non-zero acceleration bends a displacement–time graph into a parabola; a straight line on that graph means zero acceleration.



Worked example (June 2025 style). A velocity–time line rises straight from 1.8 m s^{-1} at $t = 4 \text{ s}$ to 5.0 m s^{-1} at $t = 16 \text{ s}$.

- Known: two (t, v) pairs on the straight part. Why: acceleration is the gradient of a velocity–time graph.

$$a = \frac{\Delta v}{\Delta t}$$
$$a = \frac{5.0 \text{ m s}^{-1} - 1.8 \text{ m s}^{-1}}{16 \text{ s} - 4 \text{ s}} = \frac{3.2 \text{ m s}^{-1}}{12 \text{ s}} = 0.27 \text{ m s}^{-2}$$

- Check: the line rises gently, so a small acceleration is sensible.

■ The four suvat equations

For **uniform acceleration** (constant acceleration) in one dimension, with s displacement, u initial velocity, v final velocity, a acceleration, t time:

$$v = u + at \quad s = \frac{(u + v)t}{2} \quad s = ut + \frac{1}{2}at^2 \quad v^2 = u^2 + 2as$$

- Choose the equation that contains your known quantities and the one you want – and nothing you do not know. No t ? Use $v^2 = u^2 + 2as$. No a ? Use $s = \frac{(u+v)}{2}t$.
- These equations are valid **only** while the acceleration is constant. A curved velocity–time graph shows changing acceleration; a curved displacement–time graph can still represent constant acceleration.
- Free fall is uniform acceleration with $a = g = 9.81 \text{ m s}^{-2}$ downwards (air resistance negligible).

Worked example (deduce-and-compare, June 2025 Q13). A basketball is thrown from 1.7 m above the floor with initial vertical velocity 5.1 m s^{-1} upwards, and enters the hoop moving downwards at 2.1 m s^{-1} . Is the hoop 3.0 m above the floor?

- Known: $u = +5.1 \text{ m s}^{-1}$, $v = -2.1 \text{ m s}^{-1}$ (downwards is negative), $a = -9.81 \text{ m s}^{-2}$. Wanted: the rise Δs . No time given, so use $v^2 = u^2 + 2a\Delta s$.

$$v^2 = u^2 + 2a\Delta s \Rightarrow \Delta s = \frac{v^2 - u^2}{2a}$$

$$\Delta s = \frac{(-2.1 \text{ m s}^{-1})^2 - (5.1 \text{ m s}^{-1})^2}{2 \times (-9.81 \text{ m s}^{-2})} = \frac{4.41 - 26.01}{-19.62} \text{ m} = 1.1 \text{ m}$$

- Hoop height = $1.7 \text{ m} + 1.1 \text{ m} = 2.8 \text{ m} \neq 3.0 \text{ m}$, so the hoop was **not** at the regulation height. A "deduce whether" question earns its last mark only when the comparison and conclusion are stated.

■ Core practical 1: measuring g

Drop an object and measure it: with a light gate or video of known frame rate, get s and t (or velocities at two points) and use a suvat equation. Cleaner: plot s against t^2 for $s = \frac{1}{2}gt^2$ – a straight line through the origin with gradient $g/2$. A straight line that misses the origin reveals a systematic offset, for example a fixed offset in the measured distance. A timing delay can also distort the relationship; automatic timing reduces reaction-time error. In a strobe photograph, the object moves during each flash. A shorter flash produces a sharper image and a smaller range of possible positions, reducing the uncertainty in the distance reading if the scale and image resolution are unchanged.

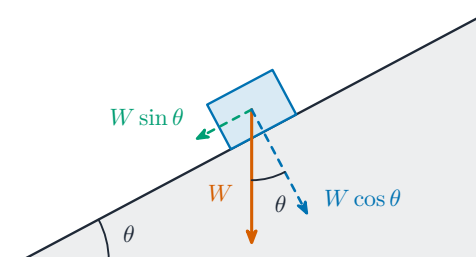
Scalars, vectors and projectile motion

A **vector** has magnitude and direction (displacement, velocity, acceleration, force, momentum); a **scalar** has magnitude only (distance, speed, work, energy). Vector notation in the paper is an arrow above the symbol, $\vec{F}$.

■ Resolving and combining

- Resolving splits one vector into two perpendicular components: the component of force F at angle θ along a direction is $F \cos \theta$ if θ is measured from that direction, $F \sin \theta$ from the perpendicular. Choose by drawing the right triangle, not by habit.
- Combining two perpendicular components rebuilds the vector: magnitude $R = \sqrt{F_x^2 + F_y^2}$, direction from $\tan \theta = F_y/F_x$.
- Combine before squaring.** The resultant of 500 N and 200 N at right angles is $\sqrt{500^2 + 200^2} \text{ N}$, not $\sqrt{500^2} + \sqrt{200^2}$.
- At any angle, add vectors by drawing a scale diagram (a vector triangle, nose to tail) or by resolving each vector into components first. In equilibrium, the vector triangle closes: $\vec{W} + \vec{T}_1 + \vec{T}_2 = 0$.

Worked example. A box sits on a ramp at angle θ to the horizontal, weight W acting vertically down.



- Why: the sliding direction is along the ramp, so resolve W into components along and perpendicular to the ramp.

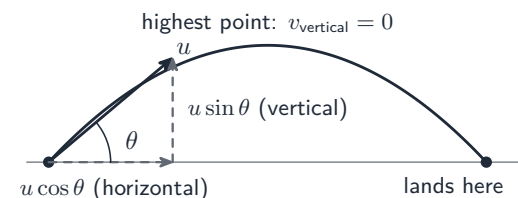
$$W_{\text{along}} = W \sin \theta \quad W_{\text{perp}} = W \cos \theta$$

- At constant speed the resultant force is zero, so the friction $F = W \sin \theta$ exactly. ($W \cos \theta$ acts into the ramp and is balanced by the normal contact force.)

■ Projectile motion

A projectile moving freely under gravity is **two independent motions**: horizontal velocity constant (no horizontal force), vertical velocity changing under g .

- The time to fall depends only on the vertical motion. Two balls leaving a table at different speeds – or with different masses – land after the **same** time: mass and horizontal speed do not appear in $s = ut + \frac{1}{2}gt^2$.
- Method: resolve the launch velocity into $u_h = u \cos \theta$ and $u_v = u \sin \theta$; run suvat separately for each direction; time links the two.



Worked example (January 2025 Q19). A projectile launches at 500 m s^{-1} , 22° above the horizontal, from 2.0 km above the sea. Show it passes over a ship 15 km away after about 30 s.

- Known: u , θ , horizontal distance s_h . Horizontal motion has $a = 0$, so use $s_h = u_h t$.

$$u_h = u \cos \theta = 500 \text{ m s}^{-1} \times \cos 22^\circ = 464 \text{ m s}^{-1}$$

$$s_h = u_h t \quad \Rightarrow \quad t = \frac{s_h}{u_h} = \frac{15\,000 \text{ m}}{464 \text{ m s}^{-1}} = 32 \text{ s} \approx 30 \text{ s}$$

- The vertical height at that time uses $s_v = u_v t - \frac{1}{2}gt^2$ with $u_v = u \sin \theta = 187 \text{ m s}^{-1}$:

$$s_v = 187 \text{ m s}^{-1} \times 32 \text{ s} - \frac{1}{2} \times 9.81 \text{ m s}^{-2} \times (32 \text{ s})^2 = 5\,984 \text{ m} - 5\,023 \text{ m} = 961 \text{ m}$$

$$h = 2.0 \text{ km} + 0.96 \text{ km} = 3.0 \text{ km above sea level}$$

- Why a maximum range exists: raising the launch angle raises u_v (more time in the air) but lowers u_h ; range = $u_h \times t$ peaks between the two effects.

Forces and Newton's laws

- A **free-body diagram** shows only the forces acting **on** the chosen object – never forces the object applies to other things. On an extended body, the weight acts at the **centre of gravity**.
- Newton's first law** : zero resultant force means no change in motion – at rest or moving at constant velocity. Constant velocity is not “no forces”; it is balanced forces.
- Newton's second law** : $\sum F = ma$. The resultant force causes the acceleration; list every force, choose a positive direction, then apply.
- Newton's third law** : when body A exerts a force on body B, B exerts an equal, opposite force **on A**. The pair acts on **different bodies**, is the same type of force, and acts along the same line. A book's weight and the table's normal contact force are **not** a third-law pair: they act on the same body.
- weight** $W = mg$; **gravitational field strength** $g = \frac{F}{m}$, so $g = 9.81 \text{ N kg}^{-1}$.
- Terminal velocity** : as a falling object speeds up, drag grows until drag (+ upthrust) equals weight; the resultant force is then zero and the velocity stops changing. “Terminal” describes the force balance, not a speed limit printed in nature.

Worked example (June 2025 Q11). A resultant force of 4800 N accelerates a boat at 0.31 m s^{-2} . Find the boat's weight.

- Known: $\sum F$, a . Why: $\sum F = ma$ links them to the mass; $W = mg$ links mass to weight.

$$\sum F = ma \quad \Rightarrow \quad m = \frac{\sum F}{a} = \frac{4800 \text{ N}}{0.31 \text{ m s}^{-2}} = 15\,500 \text{ kg}$$

$$W = mg = 15\,500 \text{ kg} \times 9.81 \text{ N kg}^{-1} = 1.5 \times 10^5 \text{ N}$$

- Check: the answer needs two equations chained; the unit is newtons, not kilograms.

Momentum

- momentum** $p = mv$, a vector, unit kg m s^{-1} .
- Conservation of linear momentum** : when the resultant external force is zero (or its impulse during a short interaction is negligible), total momentum before an event equals total momentum after. Give velocities signs: choose one direction as positive and keep it.
- Momentum conservation follows from Newton's second and third laws: the forces between the two bodies are equal and opposite, act for the same time, so the changes of momentum are equal and opposite.
- Kinetic energy need not survive a collision; momentum always does (in an isolated system).

Worked example (June 2025 Q10). A train of mass $3m$ at speed v meets a truck of mass m at speed $2v$ the other way; they couple. Find the new speed.

- Known: masses, velocities in opposite directions. Why: an isolated pair, so conserve momentum with signs. Take the train's direction as positive.

$$p_{\text{before}} = p_{\text{after}}$$

$$3m \times v + m \times (-2v) = (3m + m)V$$

$$mv = 4mV \quad \Rightarrow \quad V = \frac{v}{4}$$

- Check: the momenta nearly cancel, so a small combined speed in the train's direction is sensible.

Moments and equilibrium

- The **moment of a force** about a pivot is moment = Fx , where x is the **perpendicular distance** from the pivot to the force's line of action. If the force meets the lever at angle θ , use the perpendicular component $F \sin \theta$ or the perpendicular distance – never both.
- Principle of moments** : in equilibrium, total clockwise moment = total anti-clockwise moment (resultant moment is zero).
- Full equilibrium needs **both**: resultant force zero and resultant moment zero. A seesaw with equal children at equal distances has both; the same children at unequal distances still balance forces but not moments.
- For a uniform beam, the weight acts at its centre.

Worked example (June 2025 Q19). A uniform rail, length 1.40 m, weight 95 N, lies at 42° to the vertical, pivoted at one end. A piston pushes with 160 N at 18° to the rail, 0.37 m from the pivot. What perpendicular force F at the handle end just lifts the rail?

- Known: geometry, both forces, both angles. Why: just lifting means equilibrium at the pivot, so apply the principle of moments with perpendicular parts.

$$\text{moment of piston} = (160 \text{ N} \times \sin 18^\circ) \times 0.37 \text{ m} = 18.3 \text{ N m}$$

$$\text{moment of weight} = (95 \text{ N} \times \cos 42^\circ) \times 0.70 \text{ m} = 49.4 \text{ N m}$$

$$18.3 \text{ N m} + F \times 1.40 \text{ m} = 49.4 \text{ N m} \Rightarrow F = \frac{49.4 \text{ N m} - 18.3 \text{ N m}}{1.40 \text{ m}} = 22 \text{ N}$$

- A vertical pull at the handle instead: its perpendicular distance to the pivot is shorter than the rail's length, so a **larger** force would be needed for the same moment.

Work, energy, power and efficiency

- work** $\Delta W = F\Delta s$ when the force acts along the motion; if the force is at angle θ to the motion, only the component along the motion works: $\Delta W = F\Delta s \cos \theta$.
- kinetic energy** $E_k = \frac{1}{2}mv^2$ – doubling speed quadruples the energy.
- gravitational potential energy** $\Delta E_{\text{grav}} = mg\Delta h$ near the Earth's surface.
- Conservation of energy** : energy is transferred or transformed, never created or destroyed. In a fall with drag, ΔE_{grav} becomes E_k **plus** work done against air resistance; at terminal velocity E_k is constant, so *all* of the ΔE_{grav} goes to work against drag.
- power** $P = \frac{E}{t} = \frac{W}{t}$ – energy transferred per unit time.
- efficiency** $= \frac{\text{useful energy output}}{\text{total energy input}} = \frac{\text{useful power output}}{\text{total power input}}$.

Worked example (June 2025 Q14). An electric car of 1800 kg at 14 m s⁻¹ brakes to rest on a hill, gaining 0.76 m of height; the battery gains 45 kJ. Find the efficiency of the braking.

- Known: m , v , Δh , battery gain. Why: the total input is the energy the brakes remove – kinetic energy lost **minus** the gravitational energy the car keeps by ending higher.

$$E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 1800 \text{ kg} \times (14 \text{ m s}^{-1})^2 = 1.76 \times 10^5 \text{ J}$$

$$\Delta E_{\text{grav}} = mg\Delta h = 1800 \text{ kg} \times 9.81 \text{ N kg}^{-1} \times 0.76 \text{ m} = 1.34 \times 10^4 \text{ J}$$

$$\text{efficiency} = \frac{\text{useful output}}{\text{total input}} = \frac{45 \times 10^3 \text{ J}}{1.76 \times 10^5 \text{ J} - 1.34 \times 10^4 \text{ J}} = 0.28$$

- Check: $0.28 < 1$ – required. The common error is dividing by E_k alone and forgetting the height gain.

Materials: density, upthrust and viscous drag

- density** $\rho = \frac{m}{V}$. For a sphere, $V = \frac{4}{3}\pi r^3$.
- upthrust** = weight of the fluid displaced – the displaced *weight*, not its volume or its mass.
- Stokes' law** : viscous drag on a small sphere at low speed in laminar flow is $F = 6\pi\eta rv$, with η the viscosity, r the radius, v the speed. It is valid only for small spheres moving slowly without turbulence, and η falls as the liquid warms in this experiment; gases do not generally follow this trend.

Core practical 2: viscosity by the falling-ball method

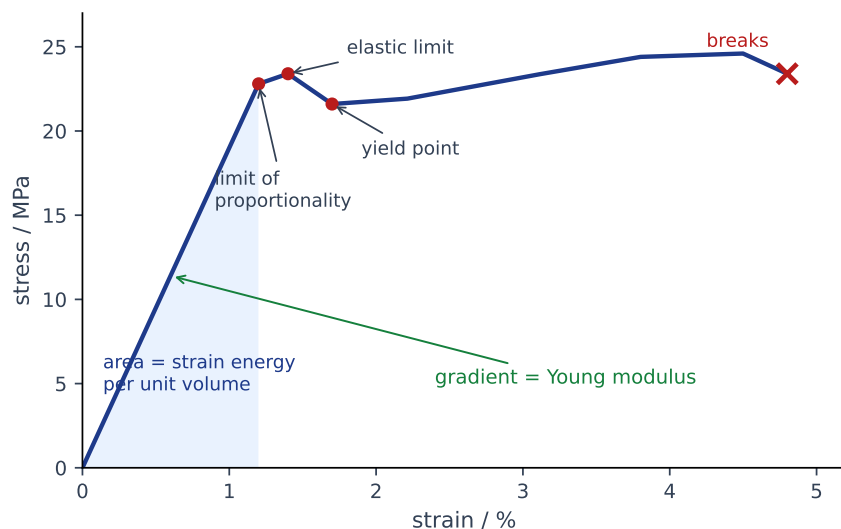
Drop a ball-bearing into a measuring cylinder of the liquid. Wait until it falls at terminal velocity, then time it over a marked distance. At terminal velocity, the forces balance: weight = upthrust + drag, so

$$6\pi\eta rv = \frac{4}{3}\pi r^3(\rho_{\text{ball}} - \rho_{\text{oil}})g$$

You need the ball's radius and mass (or its density), the oil's density, the fall distance and the time. Warm oil is less viscous, so the ball falls faster and the measured time is shorter.

Materials: stretching solids

- Hooke's law** : $\Delta F = k \Delta x$ while the material behaves proportionally; k is the **stiffness** (spring constant), the gradient of the force–extension graph.
- stress** $\sigma = \frac{F}{A}$ (unit Pa), **strain** $\varepsilon = \frac{\Delta x}{x}$ (no unit), **Young modulus** $E = \frac{\sigma}{\varepsilon}$. Stress and strain describe the *material*; force and extension describe the *sample*.
- On a force–extension or stress–strain graph: the straight part ends at the **limit of proportionality**; beyond the **elastic limit** the sample no longer returns to its original length (**elastic deformation** = it does return; **plastic deformation** = it stays stretched); a material with a distinct **yield point** can stretch substantially with little increase in force at yield; other ductile materials yield gradually. The **yield point** marks the onset of substantial plastic flow; the **breaking stress** is the stress at fracture.
- elastic strain energy** : $\Delta E_{\text{el}} = \frac{1}{2}F\Delta x$ for a linear spring – the area under the force–extension graph. For a non-linear graph, estimate the area by squares. The area under a loading *stress–strain* graph is the work done **per unit volume**, because $\frac{F}{A} \times \frac{\Delta x}{x} = \frac{F\Delta x}{V}$. In the elastic region this is stored recoverably as elastic strain energy; work beyond the elastic limit is not all recoverable.



Worked example (June 2025 Q17b). A violin string of original length 0.750 m and radius 0.85×10^{-3} m stretches to 0.752 m under 36 N. Find the Young modulus.

- Known: F , x , Δx , r . Why: $E = \sigma/\epsilon$ needs stress and strain; stress needs the cross-sectional area.

$$A = \pi r^2 = \pi \times (0.85 \times 10^{-3} \text{ m})^2 = 2.27 \times 10^{-6} \text{ m}^2$$

$$\sigma = \frac{F}{A} = \frac{36 \text{ N}}{2.27 \times 10^{-6} \text{ m}^2} = 1.59 \times 10^7 \text{ Pa} \quad \epsilon = \frac{\Delta x}{x} = \frac{0.002 \text{ m}}{0.750 \text{ m}} = 2.67 \times 10^{-3}$$

$$E = \frac{\sigma}{\epsilon} = \frac{1.59 \times 10^7 \text{ Pa}}{2.67 \times 10^{-3}} = 6.0 \times 10^9 \text{ Pa}$$

- Check: a metal-wire modulus is 10^9 – 10^{12} Pa; 6 GPa sits in range.

■ Core practical 3: the Young modulus of a wire

Hang known weights on a long wire and measure the extension with a marker against a scale; keep the wire long and the extensions small for precision, add loads in steps within the proportional region, and measure the diameter in several places with a micrometer. Then E comes from the gradient of the stress–strain line, or from σ/ϵ point by point within the proportional region.

Exam craft for WPH11

- Show every step.** "Use of $F = ma$ " earns a mark before any number appears – write the equation in symbols, then substitute.
- Units and g .** A missing unit usually loses the final mark; $g = 10 \text{ m s}^{-2}$ can lose accuracy marks; "show that" questions need one more significant figure than the target value.

- Command words:** *state* = a short precise answer; *calculate/determine* = numbers with working and a unit; *deduce* = working plus a compared conclusion; *explain* = linked physics reasons; *describe* = what happens, in order.
- The asterisk (*) answer is marked for linked, logical reasoning as well as content: order the points, then link them.
- The formula list is at the back – know where, so you never memorise what you can look up in two seconds.

Check yourself

- On a velocity–time graph, what do the gradient and the area give? – **acceleration; displacement.**
- Which suvat equation finds a height from two velocities without time? – $v^2 = u^2 + 2as$.
- A projectile's horizontal acceleration in free flight? – **zero** (only gravity acts, vertically).
- A book rests on a table: are its weight and the table's normal force a Newton's-third-law pair? – **No: they act on the same body.**
- Two trolleys collide and stick. Which quantity is always conserved? – **total momentum** (kinetic energy need not be).
- A force at an angle to a lever: which distance goes into the moment? – **the perpendicular distance from the pivot to the line of action.**
- A car brakes uphill: what is the input energy for the efficiency? – **the kinetic energy lost minus the gravitational energy gained.**
- Upthrust equals the weight of what? – **the fluid displaced.**
- Stokes' law needs which three conditions? – **small sphere, low speed, laminar flow** (and η is temperature-dependent).
- On a stress–strain graph, what is the gradient of the straight part, and what is the area beneath it? – **the Young modulus; the elastic strain energy per unit volume.**