

Unit 1: Mechanics and Materials

WPH11 · Issue 3 specification · teach with sheets 1.1–1.8

From observations to models

- Unit 1 connects motion, forces, momentum, energy and material response.
- The handout is the reference; sheets 1.1–1.8 develop skills before authentic questions.
- State the model and conditions before choosing an equation.

What WPH11 asks you to do

Paper feature	Preparation consequence
90 min / 80 marks	All questions compulsory; use the provided formula list with understanding of its symbols and conditions.
At least 32 maths marks	Practise graph gradients/areas, rearrangement, trigonometry and units.
Required g	Use $g = 9.81 \text{ m s}^{-2}$ and retain guard digits before final rounding.

Distance is a path; displacement is a change

Distance and speed

Distance adds the path lengths; speed measures the rate of covering that path.

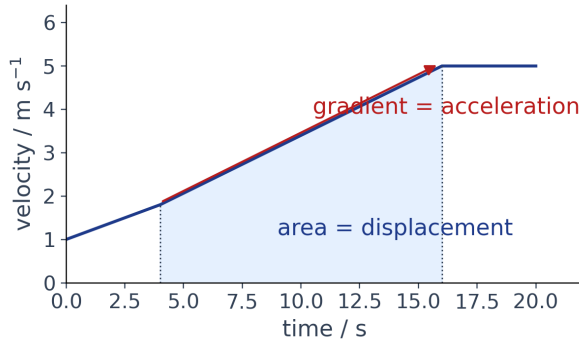
A complete return journey has positive distance.

Displacement and velocity

Displacement is the directed change from start to finish; velocity is its rate of change.

Returning to the start gives zero displacement, even though motion occurred.

Observe the motion graph



Read the axes and locate the named features before explaining them.

Read the axes before the curve

Graph	Gradient / signed area
Displacement–time	Gradient gives velocity; use a tangent for instantaneous velocity on a curve.
Velocity–time	Gradient gives acceleration; signed area gives displacement. Add area magnitudes for distance.
Acceleration–time	Signed area gives change in velocity.

Worked gradient: use changes, not coordinates

- 1 **Known** The straight velocity–time line passes through (4 s, 1.8 m/s) and (16 s, 5.0 m/s).
- 2 **Why this equation** Acceleration is the graph gradient: $a = \Delta v / \Delta t$.
- 3 **Substitute** $a = \frac{5.0 \text{ m/s} - 1.8 \text{ m/s}}{16 \text{ s} - 4 \text{ s}} = 0.267 \text{ m/s}^2$
- 4 **Check** The positive gradient agrees with increasing velocity. Use two differences, not v/t from a single point.

Choose a suvat equation with a reason

Known / missing quantity	Choose under constant acceleration
No time supplied	$v^2 = u^2 + 2as$ avoids t .
No acceleration supplied	$s = (u + v)t/2$ avoids a .
Initial velocity, time and acceleration	$s = ut + \frac{1}{2}at^2$ finds displacement.
Model boundary	One-dimensional constant acceleration; a curved velocity–time graph does not fit.

Use the evidence

A parabolic displacement–time graph can represent constant acceleration. Check which axes the curve uses.

Your turn: a basketball changes direction

- Take upward as positive: $u = 5.1$, $v = -2.1$, $a = -9.81$, in SI units.
- The ball starts 1.7 m above the floor. Is the hoop at 3.0 m?
- Pause and write an equation, a height and a compared conclusion.

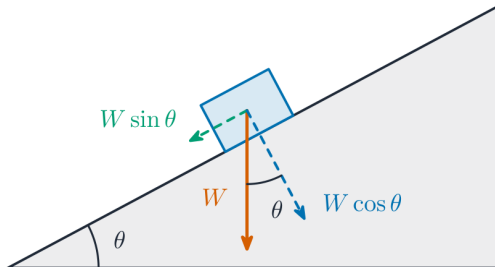
Basketball: calculate, then deduce

- 1 Model and signs** Upward positive: $u = +5.1 \text{ m/s}$, $v = -2.1 \text{ m/s}$,
 $a = -9.81 \text{ m/s}^2$; start height 1.7 m.
- 2 Equation and rearrangement** $v^2 = u^2 + 2as \Rightarrow s = (v^2 - u^2)/(2a)$
- 3 Substitute** $s = \frac{(-2.1 \text{ m/s})^2 - (5.1 \text{ m/s})^2}{2(-9.81 \text{ m/s}^2)} = 1.10 \text{ m}$
- 4 Deduce** $h = h_0 + s = 1.7 \text{ m} + 1.10 \text{ m} = 2.80 \text{ m}$. The hoop is lower than 3.0 m.

Core practical 1: determine g

Practical choice	Reason / model
Fall from rest	Measure s and t with automatic timing to reduce reaction-time error.
Linear plot	$s = \frac{1}{2}gt^2$: plot s against t^2 ; gradient is $g/2$.
Repeated readings	Reveal variation; a distance offset changes the intercept, while a timing offset can distort the relationship.

Resolve from the marked angle



- Draw a right triangle: the adjacent component uses cosine, the opposite uses sine.
- For a slope at angle θ :
 $W_{\parallel} = W \sin \theta$, $W_{\perp} = W \cos \theta$.
- Combine perpendicular components with Pythagoras and give a direction.

Equilibrium closes the vector triangle

Choose the force scale and directions;
draw the three vectors nose to tail.



$$\text{In equilibrium, } \vec{W} + \vec{T}_1 + \vec{T}_2 = \vec{0}.$$

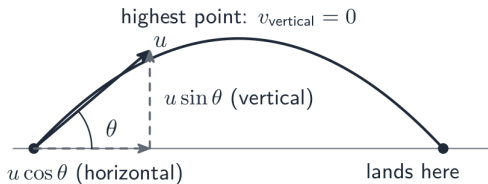


The vector triangle closes, representing zero resultant force.



Individual forces still act. A closed triangle describes their combined effect, not their absence.

One projectile, two motions



- Neglect drag: horizontal acceleration is zero; vertical acceleration is $-g$ upward-positive.
- $u_h = u \cos \theta$, $u_v = u \sin \theta$; time links the two directions.
- At the highest point only the vertical velocity is zero.

Projectile method: horizontal time, vertical height

- 1 Known and model** Launch 500 m/s at 22° from 2000 m; horizontal target distance 15000 m. Neglect drag.
- 2 Horizontal component** $u_h = u \cos \theta = 500 \text{ m/s} \cos 22^\circ = 463.592 \text{ m/s}$
- 3 Time from horizontal motion** $s_h = u_h t \Rightarrow t = \frac{15000 \text{ m}}{463.592 \text{ m/s}} = 32.356 \text{ s}$
- 4 Vertical component** $u_v = u \sin \theta = 500 \text{ m/s} \sin 22^\circ = 187.303 \text{ m/s}$

Decision

Keep guard digits. Only vertical velocity becomes zero at the top; horizontal motion continues.

Projectile height: retain the guard digits

- 1 **Known** Initial height 2000 m; vertical launch velocity 187.303 m/s; time 32.356 s; upward positive.
- 2 **Vertical equation** $h = h_0 + u_v t - \frac{1}{2}gt^2$
- 3 **Substitute** $h = 2000 \text{ m} + (187.303 \text{ m/s})(32.356 \text{ s}) - \frac{1}{2}(9.81 \text{ m/s}^2)(32.356 \text{ s})^2$
- 4 **Calculate and compare** $h \approx 2925 \text{ m} = 2.93 \text{ km}$ above sea level. The projectile is above the ship at that horizontal position.

Choose the body before drawing forces

Force-analysis step	What to put in the model
Choose the body	Draw only forces acting on that body, not forces it exerts elsewhere.
Choose positive direction	Add signed components to form the resultant $\sum F$.
Apply Newton's second law	$\sum F = ma$; zero resultant means constant velocity, including rest.

Third-law pairs act on different bodies

Third-law interaction

Earth pulls the book downward; the book pulls Earth upward with an equal opposite gravitational force.

The pair acts on different bodies and belongs to the same interaction.

Balance on one body

The book's weight and the table's normal force both act on the book.

They can balance without forming a third-law pair. Terminal speed similarly means drag plus upthrust balance weight.

Your turn: boat mass and weight

Your turn

A resultant force of 4800 N accelerates a boat at 0.31 m/s^2 . Use $g = 9.81 \text{ N/kg}$ to calculate its mass and then its weight. Show the two symbolic equations and units.

Attempt the complete task before advancing. Show the method and interpret the result.

Two equations: boat mass to weight

- 1 **Known** Resultant boat force 4800 N; acceleration 0.31 m/s^2 . Find weight using $g = 9.81 \text{ N/kg}$.
- 2 **Mass equation** $\sum F = ma \Rightarrow m = \sum F/a$
- 3 **Calculate mass** $m = \frac{4800 \text{ N}}{0.31 \text{ m/s}^2} = 1.548 \times 10^4 \text{ kg}$
- 4 **Calculate weight** $W = mg = 1.548 \times 10^4 \text{ kg} \times 9.81 \text{ N/kg} = 1.52 \times 10^5 \text{ N}$

Momentum: define the system and signs

Momentum model	Condition / consequence
Definition	$p = mv$; a vector with unit kg m/s.
System boundary	Total momentum is conserved when net external impulse is negligible.
Collision reasoning	Internal third-law forces act for the same time, giving equal opposite momentum changes.
Energy comparison	Kinetic energy can decrease while total system momentum is conserved.

Your turn: coupled train

Your turn

A train of mass $3m$ moves at $+v$; a truck of mass m moves at $-2v$. They couple with negligible external impulse. Find their final velocity and explain its sign.

Attempt the complete task before advancing. Show the method and interpret the result.

A coupled train: cancellation matters

- 1 **Known and signs** Train mass $3m$ moves at $+v$; truck mass m moves at $-2v$. They couple; external impulse is negligible.
- 2 **Conservation** $p_{\text{before}} = p_{\text{after}}$
- 3 **Apply to both bodies** $3mv + m(-2v) = (3m + m)V$
- 4 **Rearrange and interpret** $mv = 4mV \Rightarrow V = v/4$. Positive V means motion in the original train direction.

Equilibrium needs two tests

Translational equilibrium

$\sum F = 0$: no translational acceleration.

Include all forces on the chosen body.

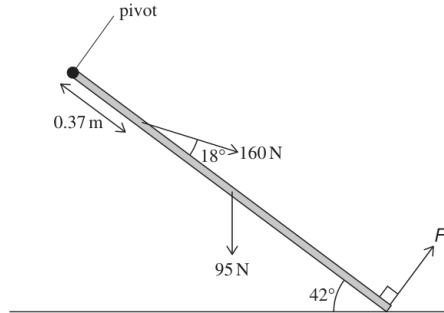
Rotational equilibrium

$\sum M = 0$: no angular acceleration.

Moment = force $\times$ perpendicular distance from pivot to line of action.

Full equilibrium requires both tests.

Locate the rail's perpendicular lever arms



- The 42° angle is measured from the horizontal.
- Weight acts at the midpoint; F is perpendicular to the rail.

A lifting rail: compare the moments

- 1 **Geometry** Uniform rail: length 1.40 m, weight 95 N, 42° to horizontal. Piston: 160 N, at 18° to rail, 0.37 m from pivot.
- 2 **Piston moment** $M_p = F_p r_p \sin 18^\circ = 160 \text{ N} \times 0.37 \text{ m} \times \sin 18^\circ = 18.3 \text{ N m}$
- 3 **Weight moment** $M_W = W(L/2) \cos 42^\circ = 95 \text{ N} \times 0.70 \text{ m} \times \cos 42^\circ = 49.4 \text{ N m}$
- 4 **Solve for perpendicular pull** $M_p + FL = M_W \Rightarrow F = \frac{49.4 - 18.3}{1.40} \text{ N} = 22.2 \text{ N}$

Decision

A vertical handle pull has a shorter perpendicular lever arm and needs a larger force. The original paper marks 42° to horizontal.

Draw the energy boundary

Quantity	Relation and boundary
Kinetic / potential energy	$E_k = \frac{1}{2}mv^2$; $\Delta E_{\text{grav}} = mg\Delta h$ near Earth.
Work / power	$W = Fs \cos \theta$ for a constant force; $P = E/t$ over the stated interval.
Efficiency	Useful output $\div$ total input for the same system and interval.

Use the evidence

Energy transfers and transforms. Dissipation does not mean energy disappears from existence.

Your turn: braking uphill

Your turn

An 1800 kg car moving at 14 m/s brakes to rest while rising 0.76 m. Its battery gains 45000 J. Calculate braking efficiency using $g = 9.81 \text{ N/kg}$, and explain the energy input you choose.

Attempt the complete task before advancing. Show the method and interpret the result.

Regenerative braking uphill

- 1 Known and boundary** Car mass 1800 kg, initial speed 14 m/s, final speed zero, height gain 0.76 m; battery gains 45000 J.
- 2 Kinetic energy lost** $E_k = \frac{1}{2}mv^2 = \frac{1}{2}(1800 \text{ kg})(14 \text{ m/s})^2 = 176400 \text{ J}$
- 3 Gravitational gain** $\Delta E_{\text{grav}} = mg\Delta h = 1800 \text{ kg} \times 9.81 \text{ N/kg} \times 0.76 \text{ m} = 13420 \text{ J}$
- 4 Braking efficiency** $\eta = \frac{E_{\text{battery}}}{E_k - \Delta E_{\text{grav}}} = \frac{45000}{176400 - 13420} = 0.276 \approx 28\%$

Decision

Height gain retains part of the initial kinetic energy. Subtract it before treating the remainder as braking input.

Upthrust and Stokes' law

Fluid relation	Meaning / conditions
Density	$\rho = m/V$; sphere volume $V = 4\pi r^3/3$.
Upthrust	Weight of displaced fluid, not its volume or mass alone.
Stokes' drag	$F_d = 6\pi\eta rv$ for a small sphere at low speed in laminar flow.
Terminal speed	Weight = upthrust + drag; resultant force and acceleration are zero.

Core practical 2: viscosity from a falling ball

Measure sphere radius, ball and fluid densities, and the distance between timing marks.



Allow terminal speed before timing; find $v = s/t$ from repeated readings.



Use $6\pi\eta rv = 4\pi r^3(\rho_{\text{ball}} - \rho_{\text{fluid}})g/3$.



Rearrange: $\eta = 2r^2(\rho_{\text{ball}} - \rho_{\text{fluid}})g/(9v)$;
control temperature and avoid wall effects.

Explain the cable tension with links

Steady lifting gives zero acceleration: cable tension plus upthrust balance weight, $T + U = W$.



As the submarine emerges, its submerged volume decreases.



The weight of water displaced decreases, so upthrust U decreases.

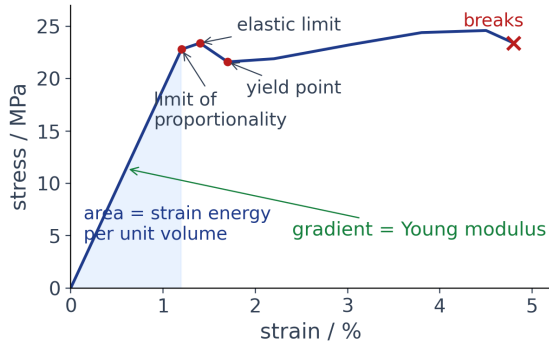


From $T = W - U$, tension increases and reaches W when no water is displaced.

Sample quantities and material quantities

Sample or material quantity	Relation / interpretation
Force and extension	$F = k\Delta x$ in the proportional region; stiffness k describes this sample.
Stress / strain	$\sigma = F/A$ in Pa; $\varepsilon = \Delta x/L$ has no unit.
Young modulus	$E = \sigma/\varepsilon$ in the linear region; describes material response.

Observe the material response



Read the axes and locate the named features before explaining them.

Read the stages of a stress–strain curve

Graph feature	Interpretation
Proportional limit	End of the straight region.
Elastic limit	Beyond it, some deformation remains after unloading.
Yield / fracture	Yield behaviour depends on material; breaking stress is stress at fracture.
Initial straight gradient	Young modulus E on the stress–strain graph.

Your turn: modulus of the string

Your turn

A 0.750 m string stretches to 0.752 m under 36 N. Its radius is 0.85 mm. Calculate cross-sectional area, stress, strain and Young modulus. Show each denominator and unit.

Attempt the complete task before advancing. Show the method and interpret the result.

A violin string: check each denominator

1 **Known** Original length 0.750 m; final length 0.752 m; radius 0.85 mm; force 36 N.

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

3 **Stress** $\sigma = \frac{F}{A} = \frac{36 \text{ N}}{2.27 \times 10^{-6} \text{ m}^2} = 1.59 \times 10^7 \text{ Pa}$

4 **Strain** $\varepsilon = \frac{\Delta x}{L} = \frac{0.752 - 0.750}{0.750} = 2.67 \times 10^{-3}$

5 **Young modulus** $E = \frac{\sigma}{\varepsilon} = \frac{1.59 \times 10^7 \text{ Pa}}{2.67 \times 10^{-3}} \approx 6.0 \times 10^9 \text{ Pa}$

Core practical 3: Young modulus of a wire

Practical measurement	Purpose / check
Original length and diameter	Use a long wire; measure diameter at several positions and orientations with a micrometer.
Force and extension	Add loads in steps within the proportional region; check zero offsets and repeat readings.
Stress-strain gradient	Calculate each stress and strain, plot the linear region and find E ; unload to check recovery.

Two graph areas, two meanings

Force–extension area

Gives work in joules for the sample.

For a linear elastic spring, $E_{\text{el}} = \frac{1}{2}F\Delta x$.

Loading stress–strain area

Gives work per unit volume, in J/m^3 ; multiply by sample volume for total work.

In the elastic region this is recoverable strain energy. Work beyond the elastic limit is not all recoverable.

Write evidence the command word requests

Command	Evidence to show
Calculate	Symbolic equation, substitution, result and unit.
Deduce	Use working to make an explicit comparison and conclusion.
Explain	Link the model to causes and effects.
Show that / rounding	Retain guard digits and follow the question's precision instructions.

Retrieval before authentic practice

- What do velocity–time gradient and signed area represent?
- Why are balanced forces on one object not automatically a third-law pair?
- Which graph area gives joules, and which gives joules per cubic metre?

Check yourself

Graph meanings

Velocity–time gradient gives acceleration; signed area gives displacement.

Force–extension area gives joules; stress–strain area gives joules per cubic metre.

Force meanings

Third-law partners act on different bodies.

Balanced forces concern the resultant on one chosen body; individual forces can still act.