

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.

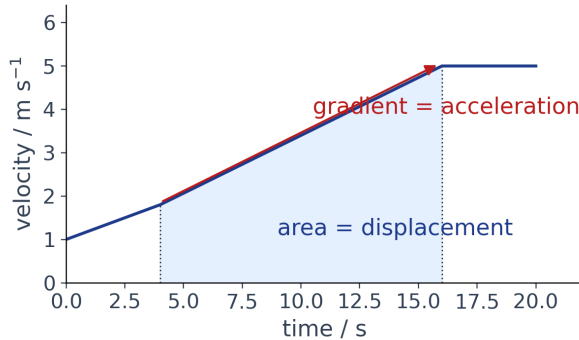
What WPH11 asks you to do

- 90 minutes; 80 marks; all questions compulsory; a formula list is provided.
- At least 32 marks assess Level-2 mathematics; use $g = 9.81 \text{ m s}^{-2}$.
- Calculations, graphs and explanations require different kinds of evidence.

Distance is a path; displacement is a change

- Distance adds the path lengths; displacement points from start to finish.
- Velocity is the rate of change of displacement; speed uses distance.
- A return trip can have positive distance and zero displacement.

Observe the motion graph



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

Read the axes before the curve

- Displacement–time gradient gives velocity; velocity–time gradient gives acceleration.
- Signed velocity–time area gives displacement; add area magnitudes for distance.
- Acceleration–time area gives the change in velocity.

Worked gradient: use changes, not coordinates

- $a = \Delta v / \Delta t$: a gradient requires two differences.
- $a = (5.0 - 1.8) / (16 - 4) = 0.267 \text{ m s}^{-2}$.
- The positive gradient agrees with the increasing velocity.

Choose a suvat equation with a reason

- These equations require constant acceleration in one dimension.
- No time given? $v^2 = u^2 + 2as$ avoids an unnecessary unknown.
- A curved velocity–time graph breaks this model; a parabolic displacement–time graph need not.

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.

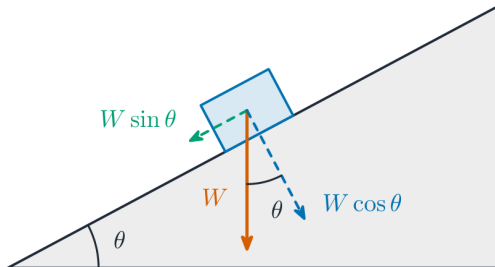
Basketball: calculate, then deduce

- $s = (v^2 - u^2)/(2a) = (4.41 - 26.01)/(-19.62) = 1.10 \text{ m}.$
- $h = 1.7 + 1.10 = 2.80 \text{ m}$ above the floor.
- 2.80 m differs from 3.0 m: the hoop is lower than the stated regulation height.

Core practical 1: determine g

- Measure fall distance and time from rest; automatic timing reduces reaction-time error.
- Plot s against t^2 : $s = \frac{1}{2}gt^2$, so $g = 2 \times \text{gradient}$.
- Repeat readings; a distance offset affects the intercept; a timing offset can distort the relationship.

Resolve from the marked angle

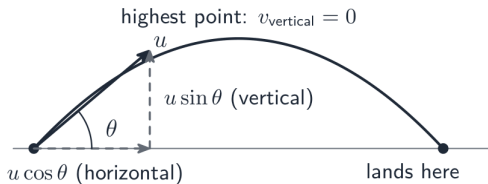


- Draw a right triangle: the adjacent component uses cosine, the opposite uses sine.
- For a slope at angle θ :
 $W_{\parallel} = W \sin \theta$, $W_{\perp} = W \cos \theta$.
- Combine perpendicular components with Pythagoras and give a direction.

Equilibrium closes the vector triangle

- Draw force arrows nose to tail to the chosen scale.
- Three forces in equilibrium satisfy $\vec{W} + \vec{T}_1 + \vec{T}_2 = \vec{0}$.
- A closed triangle represents zero resultant; forces still act.

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

- $t = s_h / (u \cos \theta)$ from the horizontal model.
- $h = h_0 + (u \sin \theta)t - \frac{1}{2}gt^2$ from the vertical model.
- For the handout's 500 m/s, 22° , 15 km example: $t \approx 32.4$ s and $h \approx 2.93$ km.

Choose the body before drawing forces

- A free-body diagram contains only forces acting on the selected body.
- $\sum F = ma$ uses the resultant, not whichever force is mentioned first.
- Zero resultant means constant velocity, including rest.

Third-law pairs act on different bodies

- A pushes B; B pushes A equally and oppositely, with the same interaction type.
- A book's weight and normal force both act on the book: they are not a third-law pair.
- At terminal velocity, weight equals drag plus upthrust; acceleration is zero.

Two equations: boat mass to weight

- $m = \sum F/a = 4800/0.31 \approx 1.55 \times 10^4 \text{ kg}.$
- $W = mg \approx 1.55 \times 10^4 \times 9.81 = 1.52 \times 10^5 \text{ N}.$
- Mass and weight differ: kilograms describe mass; newtons describe force.

Momentum: define the system and signs

- $p = mv$ is a vector; unit kg m s^{-1} .
- Total momentum is conserved when the system's net external impulse is negligible.
- Kinetic energy can decrease in a collision even when momentum is conserved.

A coupled train: cancellation matters

- Choose the train's direction positive: masses $3m$, m ; velocities v , $-2v$.
- $3mv - 2mv = (3m + m)V$, so $V = v/4$.
- The combined train moves slowly in the original train direction.

Equilibrium needs two tests

- $\text{Moment} = \text{force} \times \text{perpendicular distance from pivot to line of action}.$
- Resultant force zero prevents translational acceleration.
- Resultant moment zero prevents angular acceleration: both are required.

A lifting rail: compare the moments

- Piston moment: $160 \sin 18^\circ \times 0.37 = 18.3 \text{ N m}$.
- Weight moment: $95 \cos 42^\circ \times 0.70 = 49.4 \text{ N m}$.
- $F = (49.4 - 18.3)/1.40 = 22.2 \text{ N}$; a vertical pull has a shorter lever arm.

Draw the energy boundary

- $E_k = \frac{1}{2}mv^2$; $\Delta E_{grav} = mg\Delta h$.
- Work by a constant force: $W = Fs\cos\theta$; power is energy transferred per unit time.
- Efficiency = useful output / total input, for the same system and interval.

Regenerative braking uphill

- $E_k = \frac{1}{2}(1800)(14)^2 = 176400 \text{ J}.$
- $\Delta E_{grav} = (1800)(9.81)(0.76) = 13420 \text{ J}.$
- $\eta = 45000/(176400 - 13420) = 0.276 \approx 28\%.$

Upthrust and Stokes' law

- $\rho = m/V$; upthrust equals the weight of fluid displaced.
- $F_d = 6\pi\eta rv$ for a small sphere moving slowly in laminar flow.
- At terminal speed: weight = upthrust + viscous drag.

Core practical 2: viscosity from a falling ball

- Measure radius, ball density, fluid density, timed distance and time after terminal speed is reached.
- $v = s/t$ and $\eta = 2r^2(\rho_{ball} - \rho_{fluid})g/(9v)$.
- Control temperature, repeat timings and avoid wall effects; warmer oil is less viscous.

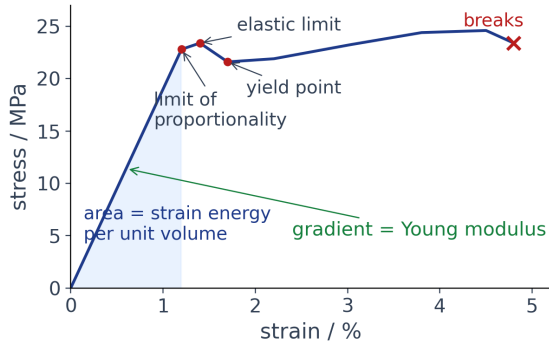
Explain the cable tension with links

- Submarine lifted steadily: $T + U = W$, so $T = W - U$.
- As it emerges, less water is displaced, so upthrust decreases.
- Therefore tension increases, reaching weight when the submarine leaves the water.

Sample quantities and material quantities

- $F = k\Delta x$ in the proportional region; stiffness describes the sample.
- $\sigma = F/A$, $\varepsilon = \Delta x/L$, $E = \sigma/\varepsilon$ in the linear region.
- Stress and Young modulus use pascals; strain has no unit.

Observe the material response



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

Read the stages of a stress–strain curve

- Proportional limit ends the straight region; elastic limit ends fully recoverable deformation.
- Yield behaviour varies by material; beyond the elastic limit there is permanent strain.
- Gradient of the initial straight region gives Young modulus; fracture sets breaking stress.

A violin string: check each denominator

- $A = \pi r^2 = 2.27 \times 10^{-6} \text{ m}^2$ for $r = 0.85 \text{ mm}$.
- $\sigma = 36/A = 1.59 \times 10^7 \text{ Pa}$; $\varepsilon = (0.752 - 0.750)/0.750 = 0.00267$.
- $E = \sigma/\varepsilon = 5.95 \times 10^9 \text{ Pa} \approx 6.0 \text{ GPa}$.

Core practical 3: Young modulus of a wire

- Measure original length; measure diameter at several positions and orientations with a micrometer.
- Add loads in steps; measure extensions and plot stress against strain in the proportional region.
- Use the gradient for E ; repeat/unload to check elastic behaviour and control zero errors.

Two graph areas, two meanings

- Force–extension area gives work done; for a linear spring $E_{el} = \frac{1}{2}F\Delta x$.
- Loading stress–strain area gives work per unit volume; in the elastic region this is recoverable strain energy.
- Multiply by sample volume for total work; plastic deformation makes part of that work unrecoverable.

Write evidence the command word requests

- Calculate: equation, substitution, result and unit. Deduce: add a comparison and conclusion.
- Explain: link the model to causes and effects; a list of terms is insufficient.
- Keep guard digits; follow the question's rounding and "show that" 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

- Gradient: acceleration. Signed area: displacement, including direction.
- Third-law partners act on different bodies; balance concerns a single body.
- Force–extension area: joules. Stress–strain area: joules per cubic metre.