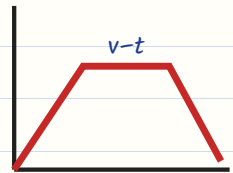


Measurement and Motion



Syllabus topics 1.1 Physical quantities and measurement techniques · 1.2 Motion

For the Cambridge IGCSE Physics 0625 syllabus, exams in 2026, 2027 and 2028 (Core and Extended)

Syllabus statements covered in this chapter

Syllabus ref.	What you must be able to do	Level
1.1 statements 1-3	Measure lengths and volumes (rulers, measuring cylinders) and time intervals (clocks, digital timers); find an average small distance or short time by measuring multiples, including the period of a pendulum	C
1.1 statements 4-7	Scalars and vectors; the two lists of named scalars and vectors; resultant of two vectors at right angles, by calculation and by scale drawing (forces or velocities only)	S
1.2 statements 1-8	Speed, velocity, average speed; distance-time and speed-time graphs: sketch, plot, interpret; speed from a gradient; distance from an area; $g \approx 9.8 \text{ m/s}^2$	C
1.2 statements 9-13	Acceleration $a = \frac{\Delta v}{\Delta t}$; constant and changing acceleration from a speed-time graph; acceleration from a gradient; deceleration as negative acceleration; falling with and without air resistance, terminal velocity	S

What is inside

1. Concept notes, 8 worked examples
2. Practical skills (Paper 5 / 6); common mistakes
3. 20 MCQs (Paper 1/2 style), explained
4. 4 Extended (Paper 4) + 2 Core (Paper 3) theory questions and 1 Alternative to Practical (Paper 6), all with full mark schemes
5. Quick-reference sheet, "I can" checklist

How to read these notes

- C** = Core: every candidate must know it
S = Supplement: Extended candidates only (Papers 2 and 4)
red = key term **green** = definition
1 = one mark in the mark scheme

★ **Exam tip:** No formula sheet in Physics: learn every equation with its units.

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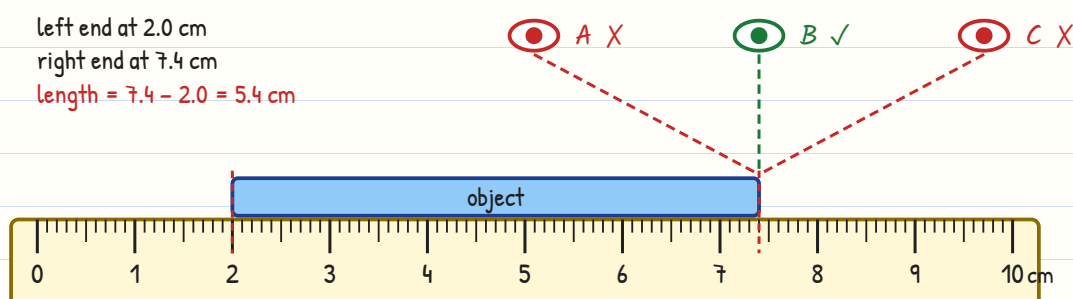
1.1 Physical quantities and measurement techniques

A **physical quantity** is anything that can be measured and written as a **number × unit**, for example 5.4 cm or 36 cm³. Physics uses SI units: metre (m) for length, kilogram (kg) for mass and second (s) for time. You must be able to convert between the common metric units:

Quantity	Conversions you will use
length	1 m = 100 cm = 1000 mm; 1 km = 1000 m; 1 cm = 10 mm
volume	1 cm ³ = 1 ml; 1 dm ³ = 1000 cm ³ = 1 litre; 1 m ³ = 1 000 000 cm ³ (= 10 ⁶ cm ³)
time	1 minute = 60 s; 1 hour = 3600 s; 1 ms = 0.001 s
mass	1 kg = 1000 g; 1 g = 1000 mg

Measuring length with a ruler

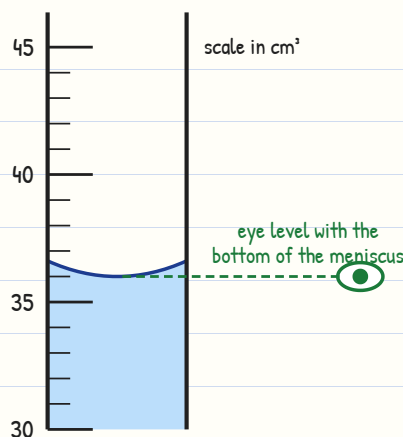
- A metre rule or 30 cm ruler has millimetre divisions, so a length is recorded to the nearest **millimetre** (0.1 cm), e.g. 5.4 cm, not 5 cm.
- Do not start from the very end of the ruler: the end may be worn. Line one end of the object up with a clear mark (or read both ends) and **subtract**: length = final reading – initial reading.
- Put the ruler right against the object and look with your eye **directly above** (perpendicular to) the mark you are reading. Looking from an angle gives a **parallax error**.



Eye B, directly above the mark, reads the correct value; eyes A and C give parallax errors.

Measuring volume with a measuring cylinder

- Choose a cylinder whose capacity is a little larger than the volume, so that the scale divisions are small (a 50 cm³ cylinder for about 40 cm³, not a 250 cm³ one).
- Stand the cylinder on a level bench. The water surface curves down in the middle (the **meniscus**). Read the scale at the **bottom of the meniscus**, with your eye level with it.
- Read to the nearest scale division (or half a division where you can), and record the unit: cm³.
- Volume of an irregular solid (link to 1.4 Density): read the water level, lower the solid in gently on a thread until it is completely covered, and read again. Volume of the solid = second reading – first reading.



The reading here is 36 cm³: eye level with the bottom of the meniscus.

Measuring time intervals C

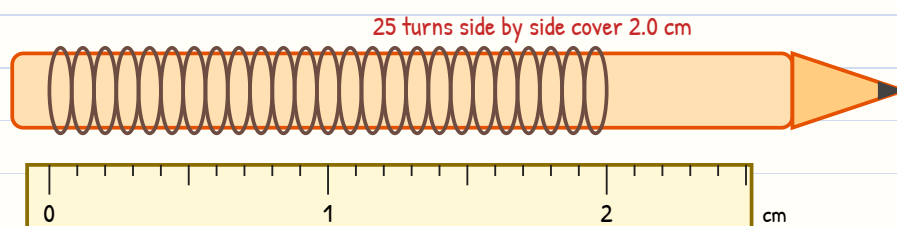
Instrument	Typical use	Points to remember
clock or watch	long intervals (minutes, hours), e.g. a cooling experiment	read to the nearest second
stopwatch (hand-operated, digital)	intervals of a few seconds or more, e.g. timing oscillations	displays 0.01 s, but your reaction time (about 0.2–0.3 s) at the start and at the stop makes the reading much less certain than that
digital timer with light gates	very short intervals, e.g. a trolley passing a gate	started and stopped electronically when a card cuts the light beam, so there is no reaction time

With light gates the speed of a trolley can be found: a card of length 5.0 cm cuts the beam for 0.25 s, so the speed is $\frac{0.050 \text{ m}}{0.25 \text{ s}} = 0.20 \text{ m/s}$.

Measuring multiples to find a small distance or a short time C

A single small distance or short time cannot be measured accurately: the ruler's 1 mm divisions or your reaction time are too large compared with it. So measure **many** of them together and **divide**.

- **Thickness of one sheet of paper:** measure the thickness of a stack of, say, 200 sheets with a ruler and divide by 200.
- **Diameter of a thin wire:** wind it in tight turns, side by side, around a pencil; measure the length of the coil and divide by the number of turns.
- **Period of a pendulum:** time 20 complete oscillations and divide by 20.



Diameter of the wire = $2.0 \text{ cm} \div 25 = 0.080 \text{ cm} = 0.80 \text{ mm}$.

Worked example 1: measuring multiples

A student winds 25 turns of wire side by side around a pencil. The coil is 2.0 cm long. Calculate the diameter of the wire in mm.

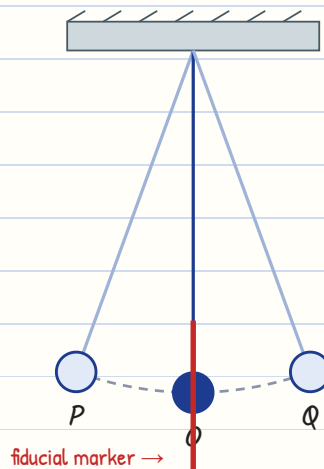
$$\text{diameter} = \frac{\text{length of coil}}{\text{number of turns}} = \frac{2.0 \text{ cm}}{25} = 0.080 \text{ cm} = \mathbf{0.80 \text{ mm}}$$

Why not measure one turn? 0.8 mm is less than one division on the ruler; across 25 turns the same ± 1 mm reading uncertainty is shared by 25 diameters.

The simple pendulum C

Definition  The **period** of a pendulum is the time for one complete oscillation.

One **complete oscillation** is from one end of the swing to the other end and back again ($P \rightarrow Q \rightarrow P$ in the diagram). Going only from P to Q is half an oscillation.



one oscillation: $P \rightarrow Q \rightarrow P$ (or $O \rightarrow Q \rightarrow O \rightarrow P \rightarrow O$)

Time 20 oscillations, starting and stopping as the bob passes the fiducial marker at the centre O.

1. Set the pendulum swinging with a **small** swing (amplitude).
2. Put a **fiducial marker** (a pin, or a vertical line on card) behind the centre of the swing. Start the stopwatch as the bob passes it, counting "zero".
3. Count 20 complete oscillations and stop the stopwatch as the bob passes the marker, going the same way, on "twenty".
4. Repeat the timing, find the **mean** time for 20 oscillations, and divide by 20.

Why the centre? The bob moves fastest there, so the moment it passes the marker is easy to judge. At the ends it is nearly stationary, so it is hard to tell exactly when it turns round.

Scalars and vectors S

Extended (Supplement) only

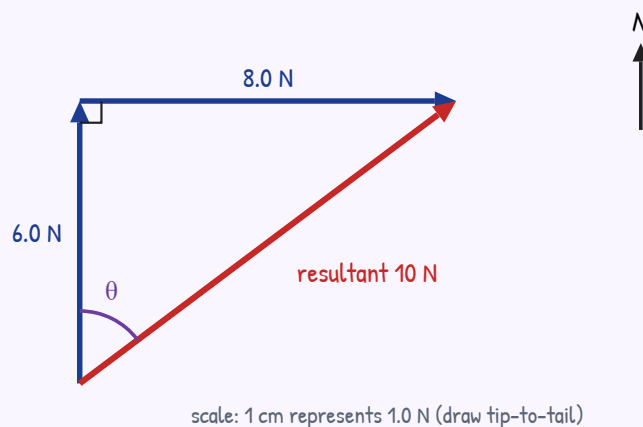
Definition  A **scalar** quantity has magnitude (size) only. A **vector** quantity has magnitude and direction.

Scalars (learn this list)	Vectors (learn this list)
distance, speed, time, mass, energy, temperature	force, weight, velocity, acceleration, momentum, electric field strength, gravitational field strength

A vector is drawn as an arrow: its length shows the magnitude (to scale) and it points in the direction of the quantity. The **resultant** of two vectors is the single vector that has the same effect as both together.

Two vectors at right angles (the syllabus limits this to forces or velocities):

- **By calculation:** draw the two vectors tip-to-tail; the resultant is the hypotenuse. Magnitude by Pythagoras: $R = \sqrt{F_1^2 + F_2^2}$. Direction from trigonometry, e.g. $\tan \theta = \frac{\text{opposite}}{\text{adjacent}}$. Always say which direction the angle is measured from.
- **Graphically (scale drawing):** choose a scale (e.g. 1 cm represents 1.0 N); draw the first vector to scale with a ruler and protractor; draw the second from its tip; join the start of the first to the tip of the second. Measure the length of this line and convert with the scale; measure the angle with a protractor.



6.0 N north and 8.0 N east, tip-to-tail: the resultant is 10 N at $\theta = 53^\circ$ east of north.

Worked example 2: resultant of two forces at right angles

Forces of 6.0 N due north and 8.0 N due east act on a box. Determine the resultant force.

magnitude: $R = \sqrt{6.0^2 + 8.0^2} = \sqrt{36 + 64} = \sqrt{100} = 10 \text{ N}$

direction: $\tan \theta = \frac{8.0}{6.0} = 1.33$, so $\theta = 53^\circ$ (53.1°) **east of north**.

Answer: **10 N at 53° east of north**. By scale drawing (1 cm : 1.0 N) the resultant line is 10.0 cm long and the angle measured is 53° : the same answer, within drawing accuracy.

Worked example 3: resultant velocity

A swimmer swims at 1.2 m/s straight across a river (due north). The river flows due east at 0.50 m/s. Calculate the swimmer's resultant velocity.

$v = \sqrt{1.2^2 + 0.50^2} = \sqrt{1.44 + 0.25} = \sqrt{1.69} = 1.3 \text{ m/s}$; $\tan \theta = \frac{0.50}{1.2} = 0.417$,
 $\theta = 23^\circ$ (22.6°).

Answer: **1.3 m/s at 23° east of north** (the direction must be given: velocity is a vector).

1.2 Motion

Speed, velocity and average speed

Definition  **Speed** is the distance travelled per unit time.

$$v = \frac{s}{t} \quad v = \text{speed (m/s)}, s = \text{distance (m)}, t = \text{time (s)}; \text{rearranged: } s = vt, t = \frac{s}{v}$$

Definition  **Velocity** is speed in a given direction.

Two cars at 20 m/s, one going north and one going south, have the same speed but different velocities. A car going round a bend at a steady 20 m/s has a constant speed but a changing velocity.

Speed usually changes during a journey, so we use the **average speed**:

$$\text{average speed} = \frac{\text{total distance travelled}}{\text{total time taken}}$$

Units: m/s, or km/h for journeys. To change km/h into m/s divide by 3.6 (because 1 km/h = 1000 m ÷ 3600 s): 72 km/h = 20 m/s.

Worked example 4: average speed

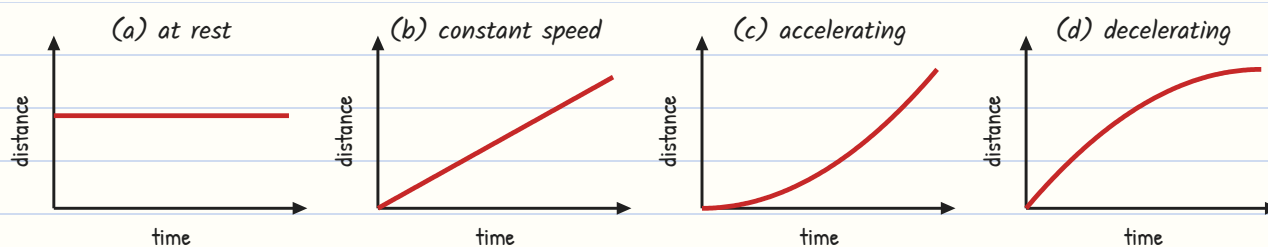
A bus travels 12 km in 15 minutes, waits at a stop for 5.0 minutes, and then travels 18 km in 20 minutes. Calculate the average speed for the whole journey (a) in km/h, (b) in m/s.

total distance = 12 + 18 = 30 km; total time = 15 + 5.0 + 20 = 40 minutes = $\frac{40}{60}$ h = 0.667 h (the time at the stop counts: it is part of the total time taken).

$$(a) \text{ average speed} = \frac{30 \text{ km}}{0.667 \text{ h}} = 45 \text{ km/h} \quad (b) \frac{30\,000 \text{ m}}{2400 \text{ s}} = 12.5 \text{ m/s (or } 45 \div 3.6 = 12.5 \text{ m/s)}$$

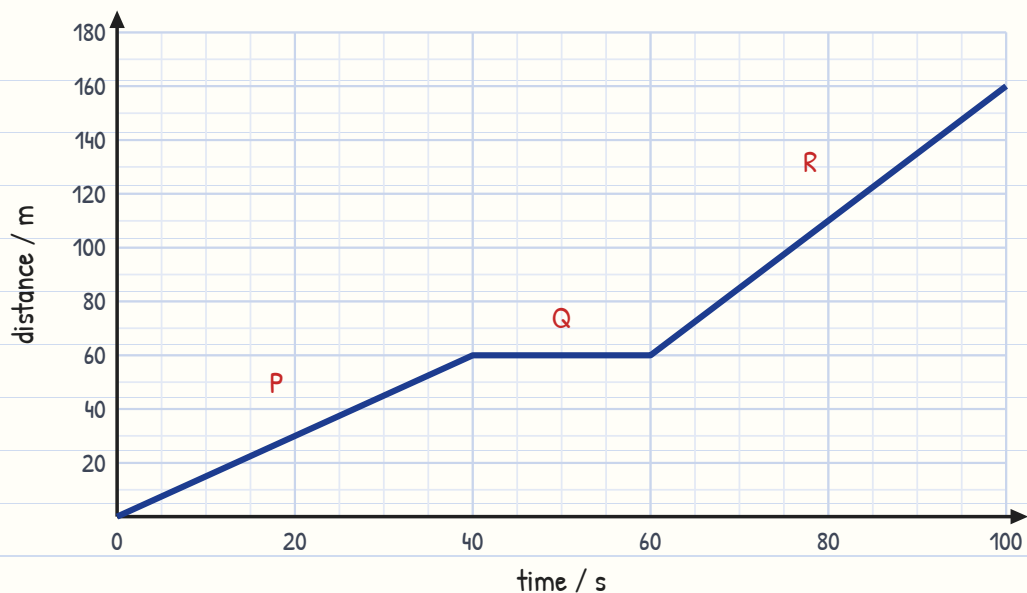
Distance-time graphs

The **gradient** (slope) of a distance-time graph is the **speed**. A steeper line means a greater speed.



Shape of the distance-time graph	Motion
horizontal line (gradient zero)	at rest (stationary): the distance is not changing
straight sloping line (constant gradient)	moving with constant speed
curve getting steeper	accelerating (speed increasing)
curve getting less steep	decelerating (speed decreasing)

Speed from the gradient of a straight section: $\text{speed} = \frac{\text{change in distance}}{\text{change in time}} = \frac{\text{rise}}{\text{run}}$. Read two points far apart on the line.



Distance-time graph for a walk: sections P, Q and R.

Worked example 5: reading a distance-time graph

Use the graph above.

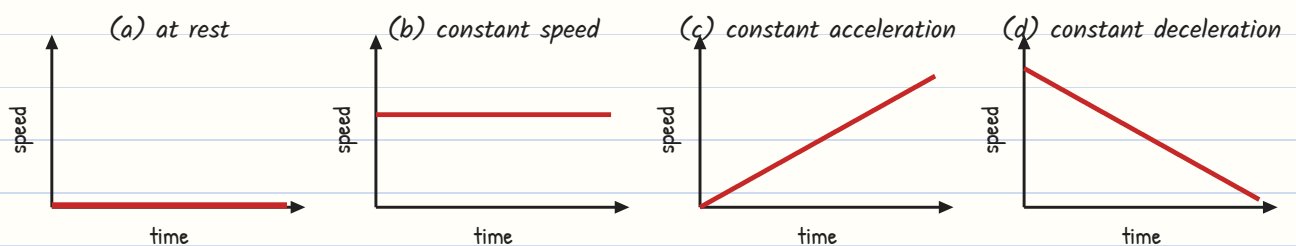
P (0–40 s): speed = $\frac{60 \text{ m}}{40 \text{ s}} = 1.5 \text{ m/s}$. Q (40–60 s): the line is horizontal, so the walker is **at rest**

(speed 0). R (60–100 s): speed = $\frac{160 - 60}{100 - 60} = \frac{100 \text{ m}}{40 \text{ s}} = 2.5 \text{ m/s}$ (steepest section, so fastest).

Average speed for the whole walk = $\frac{160 \text{ m}}{100 \text{ s}} = 1.6 \text{ m/s}$. Note this is not the average of 1.5, 0 and 2.5.

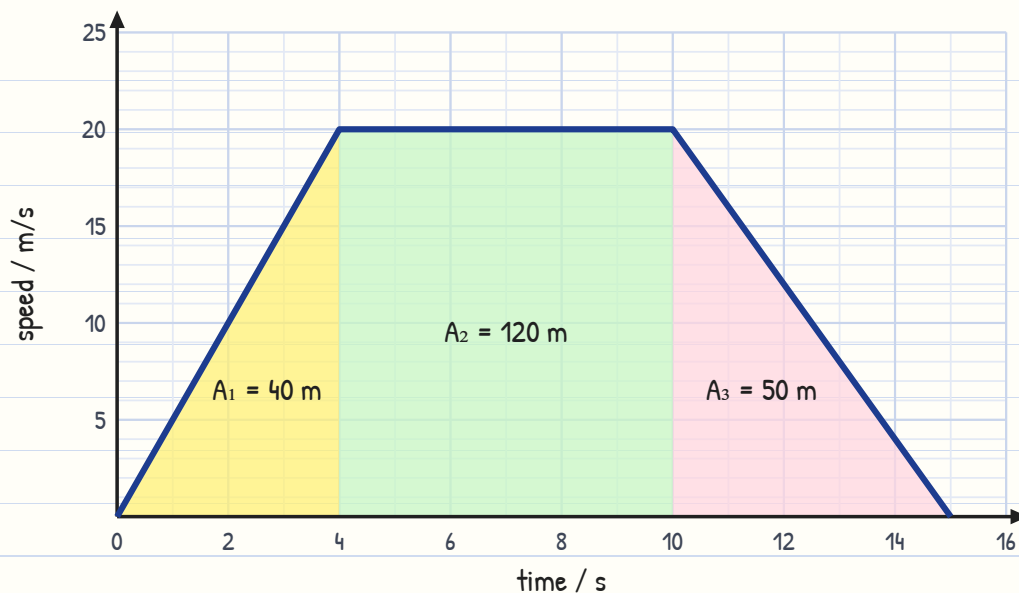
Speed-time graphs

Look at the label on the vertical axis before you answer anything: on a **speed-time** graph a horizontal line means **constant speed**, not "at rest".



Shape of the speed-time graph	Motion
horizontal line on the time axis (speed = 0)	at rest
horizontal line above the axis	constant speed
straight line sloping up	accelerating (constant acceleration)
straight line sloping down	decelerating (constant deceleration)

The area under a speed-time graph is the distance travelled. Split the area into rectangles (area = base $\times$ height) and triangles (area = $\frac{1}{2} \times$ base $\times$ height). The syllabus asks for this for constant speed and constant acceleration (straight-line sections).



Speed-time graph for a car: accelerating 0–4 s, constant speed 4–10 s, decelerating 10–15 s.

Worked example 6: distance and acceleration from a speed-time graph

Use the car graph above. (a) Calculate the total distance travelled. (b) **S** Calculate the acceleration in the first 4.0 s and the deceleration in the last 5.0 s.

(a) $A_1 = \frac{1}{2} \times 4.0 \times 20 = 40 \text{ m}$; $A_2 = 6.0 \times 20 = 120 \text{ m}$; $A_3 = \frac{1}{2} \times 5.0 \times 20 = 50 \text{ m}$. Total distance = $40 + 120 + 50 = 210 \text{ m}$.

(b) $a = \frac{\Delta v}{\Delta t} = \frac{20 - 0}{4.0} = 5.0 \text{ m/s}^2$. In the last 5.0 s: $a = \frac{0 - 20}{5.0} = -4.0 \text{ m/s}^2$, a deceleration of 4.0 m/s^2 .

Average speed = $210 \text{ m} \div 15 \text{ s} = 14 \text{ m/s}$.

Acceleration **S**

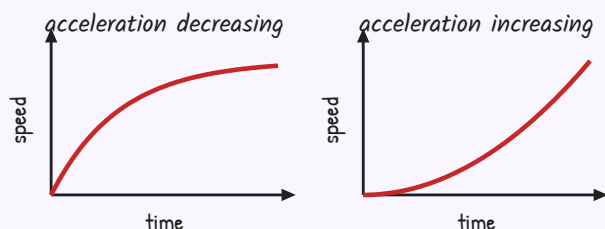
Extended (Supplement) only

Definition Acceleration is the change in velocity per unit time.

$$a = \frac{\Delta v}{\Delta t} \quad a = \text{acceleration (m/s}^2\text{)}, \Delta v = \text{change in velocity (m/s)} = \text{final} - \text{initial}, \Delta t = \text{time taken (s)}$$

- The unit m/s^2 means "metres per second, every second": an acceleration of 5.0 m/s^2 adds 5.0 m/s to the velocity each second.
- The **gradient of a speed-time graph is the acceleration**. A steeper line means a greater acceleration.
- A **deceleration is a negative acceleration**. If the speed falls, Δv is negative and so a is negative: a car slowing from 30 m/s to rest in 6.0 s has $a = \frac{0 - 30}{6.0} = -5.0 \text{ m/s}^2$, i.e. a deceleration of 5.0 m/s^2 . In calculations keep the minus sign; in words say "deceleration of 5.0 m/s^2 ".

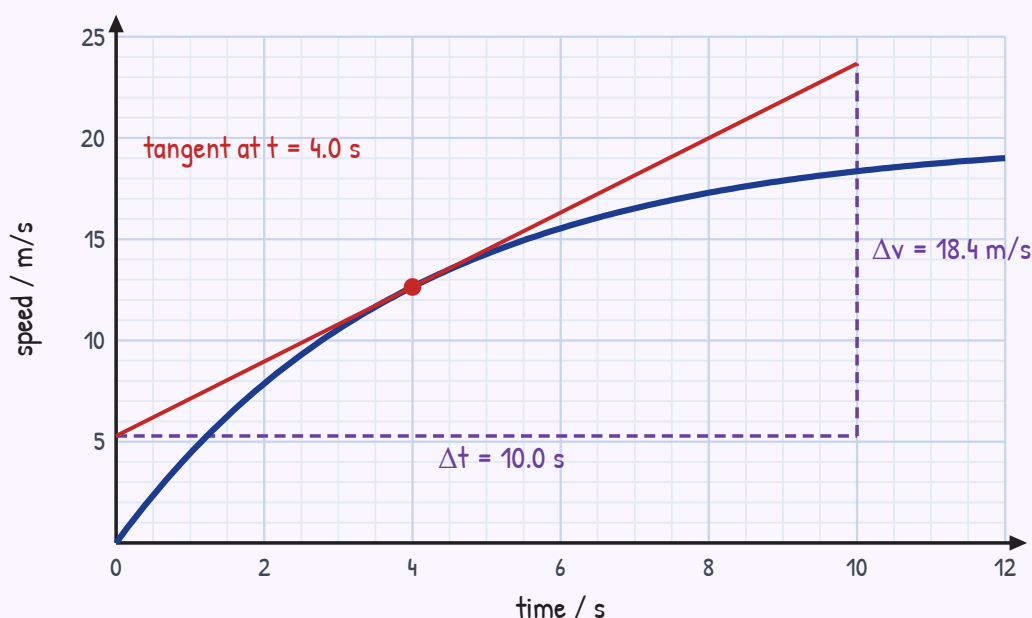
Constant or changing acceleration from the shape of a speed-time graph:



- straight line: **constant** acceleration (the gradient does not change);
- curve getting less steep: acceleration **decreasing** (still speeding up, but more slowly);
- curve getting steeper: acceleration **increasing**.

From data: if the speed rises by the same amount in each equal time interval (e.g. 0, 4, 8, 12 m/s at 1 s intervals) the acceleration is constant; if the rises change (0, 6, 10, 12 m/s) the acceleration is changing (here decreasing).

Acceleration on a curved speed-time graph: draw a **tangent** to the curve at the time asked for, with a sharp pencil, touching the curve at just that point. Then find the gradient of the tangent with a large triangle.



Tangent at $t = 4.0$ s: gradient = $\Delta v \div \Delta t$.

Worked example 7: acceleration from a tangent

From the graph above, determine the acceleration of the object at $t = 4.0$ s.

The tangent at $t = 4.0$ s passes through (0, 5.3) and (10.0, 23.7). Gradient = $\frac{23.7 - 5.3}{10.0 - 0} = \frac{18.4}{10.0}$, so $a = 1.8 \text{ m/s}^2$ (an answer between about 1.6 and 2.1 m/s^2 is acceptable from a hand-drawn tangent).

Do not divide the speed at 4.0 s by 4.0 s ($12.6 \div 4.0 = 3.2 \text{ m/s}^2$ is wrong): that is the average acceleration from the start, not the acceleration at 4.0 s.

Free fall

The **acceleration of free fall**, g , for an object near the surface of the Earth is approximately constant and is approximately **9.8 m/s^2** . Without air resistance, every object (a feather and a hammer, a large and a small

stone) falls with this same acceleration: its speed increases by 9.8 m/s every second. Its speed-time graph is a straight line through the origin with gradient 9.8 m/s^2 .

Worked example 8: falling stone

A stone is dropped from rest and falls for 2.0 s . Air resistance is negligible. Calculate (a) its speed after 2.0 s , (b) the distance it falls.

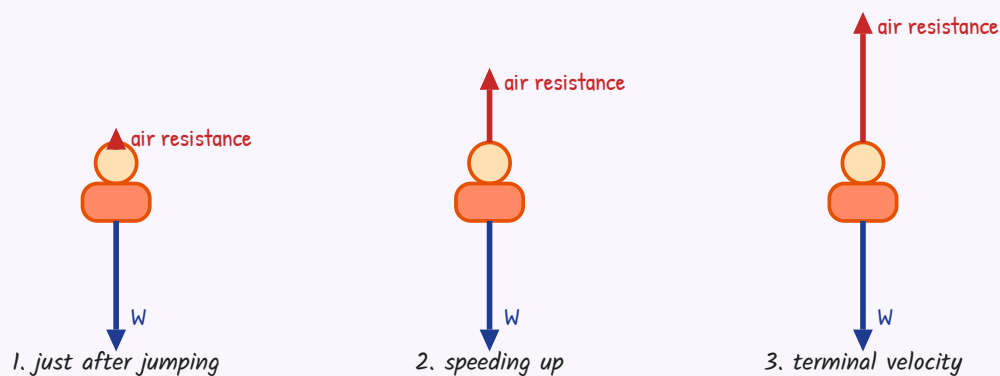
(a) speed gained = $9.8 \text{ m/s}^2 \times 2.0 \text{ s} = 19.6 \text{ m/s}$ (20 m/s to 2 s.f.)

(b) The speed-time graph is a triangle: distance = area = $\frac{1}{2} \times 2.0 \times 19.6 = 19.6 \text{ m}$ (20 m to 2 s.f.).

Falling with air (or liquid) resistance: terminal velocity S

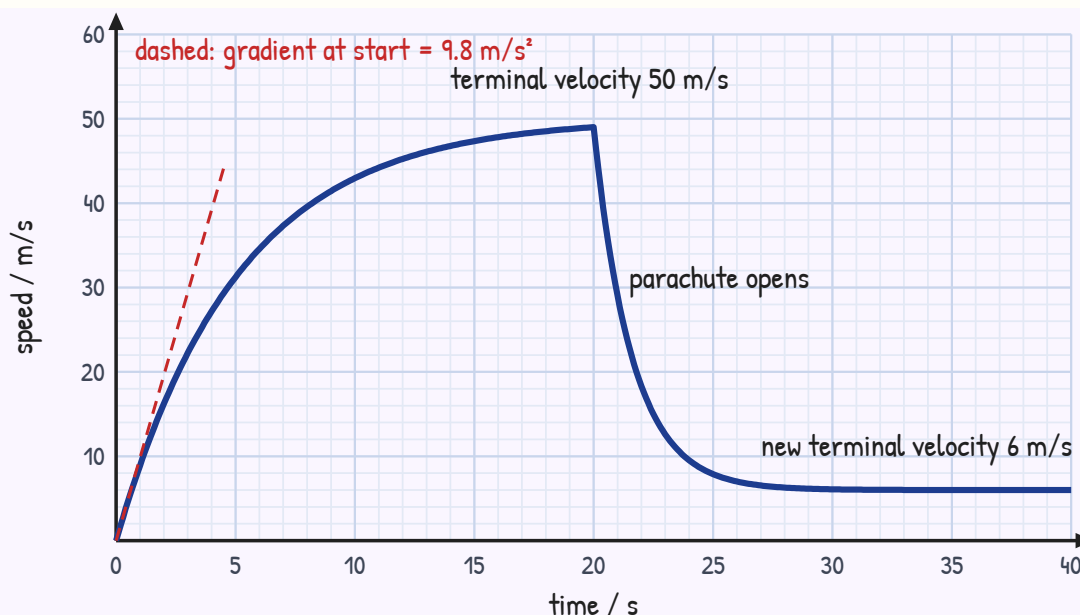
Extended (Supplement) only

In air, a falling object has two forces on it: its **weight** W (downwards, constant) and **air resistance** (upwards, which increases as the speed increases).



The weight stays the same; the air resistance grows with speed until the two forces are equal.

1. At the start the speed is zero, so there is no air resistance: the only force is the weight and the acceleration is $g = 9.8 \text{ m/s}^2$.
2. As the speed increases, the air resistance increases. The resultant (downward) force = $W - \text{air resistance}$ becomes smaller, so the **acceleration decreases**. The object is still speeding up, but more slowly.
3. Eventually the air resistance equals the weight. The resultant force is zero, so the acceleration is zero and the object falls at a constant speed: the **terminal velocity**.
4. If a parachute opens, the air resistance suddenly becomes much larger than the weight. The resultant force is upwards, so the parachutist **decelerates**. As the speed falls the air resistance falls, until it equals the weight again at a new, lower terminal velocity.



Speed-time graph for a skydiver: gradient 9.8 m/s^2 at the start, falling to zero at terminal velocity; deceleration after the parachute opens; a lower terminal velocity.

The same happens to a ball bearing falling through oil or another liquid: the liquid's resistance increases with speed, and the ball soon reaches a (small) terminal velocity.

X Don't do this: At terminal velocity the object is **not** at rest and has **not** stopped accelerating "because of gravity". It moves at a constant (maximum) speed because the resultant force is zero. Also, the air resistance does not exceed the weight while the skydiver is still speeding up.

Practical skills for Paper 5 and Paper 6

The practical paper and the Alternative to Practical test the same skills. These are the rules examiners apply to every table, reading and graph.

Recording results

- Head each column with the quantity and its unit separated by a solidus: **L / m, t / s, T / s**. Do not write units in the body of the table.
- Record every reading to the precision of the instrument: a metre rule to the nearest mm (0.452 m, not 0.45 m), a stopwatch to 0.01 s or 0.1 s as shown.
- Read a scale to the nearest half of its smallest division.
- A calculated value should have the same number of significant figures as the least precise raw data (usually 2 or 3).
- Repeat readings and take the mean; identify any anomalous value and leave it out of the mean.

Drawing a graph

- Label both axes with quantity / unit, the same as the table headings. Put the independent variable (the one you changed) on the x-axis.
- Choose scales that use more than half of the grid in each direction, with simple steps (1, 2 or 5 units per 2 cm square; never 3).
- Plot each point to half a small square, as a small cross (x) or a circled dot.

- Draw one thin best-fit line, straight or a smooth curve, with points spread evenly on both sides. Do not join the dots.
- For a gradient, draw a triangle covering at least half the line, mark it on the graph, and show the values you read.

Experiment 1: period of a simple pendulum

Apparatus: clamp and stand, thread, pendulum bob, metre rule, stopwatch, fiducial marker, protractor.

Method: measure the length l from the point of suspension to the centre of the bob; displace the bob through a small angle (about 10°); time 20 oscillations from the fiducial marker; repeat and average; $T = \text{mean time} \div 20$. Change l and repeat for at least five lengths across a wide range (e.g. 0.200 m to 1.000 m).

Variables: independent: length l ; dependent: period T ; controlled: mass of bob, amplitude (small, same each time), same pendulum and stopwatch.

Errors and improvements: reaction time (time more oscillations, use a fiducial marker, repeat and average); parallax when measuring l (eye level with the scale; set square to the centre of the bob); a large amplitude changes the period (keep it small); counting mistakes (count "zero" at the start).

Experiment 2: speed of a trolley or a walker

Mark a distance (e.g. 10.00 m with a tape measure or trundle wheel). Time the trolley or person over that distance with a stopwatch; repeat three times and average. $\text{speed} = \text{distance} \div \text{mean time}$. For a trolley on a ramp, light gates with a digital timer remove reaction time; with two gates and a timer you can also find the acceleration **S** from the change in speed $\div$ time between the gates.

Language of measurement (use these words correctly)

accurate: close to the true value · **precise:** repeated values close to each other · **anomalous:** a value well outside the pattern · **independent variable:** the one you change · **dependent variable:** the one you measure · **controlled variables:** kept the same for a fair test. Two results agree "within the limits of experimental accuracy" if they differ by less than about 10%.

Common mistakes that lose marks

- **Reading the wrong graph.** A horizontal line means "at rest" on a distance-time graph, but "constant speed" on a speed-time graph. Read the axis label first.
- **"Constant" on its own.** Write "constant speed of 20 m/s" or "constant acceleration", never just "constant", and never "constant motion".
- **Area means acceleration?** No: the area under a speed-time graph is the distance; the gradient is the acceleration.
- **Averaging speeds.** Average speed = total distance $\div$ total time, including stops. It is not the mean of the separate speeds.
- **One oscillation.** It is a complete swing out and back ($P \rightarrow Q \rightarrow P$), not $P \rightarrow Q$.
- **Vector without a direction.** A resultant force or velocity needs magnitude and direction, and the angle must say what it is measured from (" 53° east of north"). A compass point alone (e.g. "east") only earns credit if the diagram shows which way north is.
- **Using sin or cos instead of tan.** With two perpendicular vectors you know the two shorter sides, so the angle comes from $\tan \theta = \text{opposite} \div \text{adjacent}$.

- **Tangent in the wrong place.** Draw it at the time asked for, thin and long, and use a large triangle. Speed $\div$ time from the origin is not the acceleration at that instant.
- **Terminal velocity explanations.** Say: air resistance increases with speed $\rightarrow$ resultant force decreases $\rightarrow$ acceleration decreases $\rightarrow$ air resistance = weight $\rightarrow$ resultant force zero $\rightarrow$ constant speed. Do not write "it decelerates" while it is still speeding up.
- **Units and rounding.** Write the equation, substitute, give the answer with its unit. Round only the final answer, normally to 2 or 3 significant figures. Change minutes to seconds and km to m when the answer is wanted in m/s.

Exam-style multiple-choice questions (Paper 1/2 style)

20 questions, 1 mark each. Choose one answer, A, B, C or D. Questions marked **S** are Extended only. Take $g = 9.8 \text{ m/s}^2$. Answers with full explanations follow the questions.

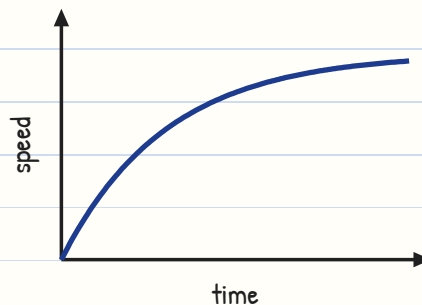
1. A student needs to measure about 40 cm^3 of water as precisely as possible. Which piece of apparatus should she use?
 - A a 250 cm^3 beaker with 50 cm^3 markings
 - B a 1 dm^3 measuring jug with 100 cm^3 markings
 - C a 50 cm^3 measuring cylinder with 1 cm^3 markings
 - D a 10 cm^3 measuring cylinder with 0.2 cm^3 markings
2. A stack of 250 identical sheets of paper is 2.5 cm thick. What is the thickness of one sheet?

A 0.1 mm	B 1 mm
C 0.01 mm	D 10 mm
3. A pendulum makes 20 complete oscillations in 36.0 s . What is its period?

A 0.56 s	B 3.6 s
C 18 s	D 1.8 s
4. Why does a student time 20 oscillations of a pendulum instead of timing one oscillation?
 - A so that the pendulum swings with a constant speed
 - B to reduce the effect of her reaction time on the result
 - C to make the period of the pendulum longer
 - D so that the amplitude of the swing stays large
5. **S** Which list contains only vector quantities?
 - A distance, force, mass
 - B acceleration, momentum, weight
 - C energy, velocity, temperature
 - D speed, time, gravitational field strength
6. **S** Two forces act on an object: 5.0 N due east and 12 N due north. What is the magnitude of the resultant force?

A 7.0 N	B 8.5 N
C 17 N	D 13 N

13. A ball is dropped from rest and falls freely, with no air resistance, for 1.5 s. What is its speed after 1.5 s?
- A 6.5 m/s
B 15 m/s
C 9.8 m/s
D 29 m/s
14. **S** A car slows down uniformly from 24 m/s to 6.0 m/s in 3.0 s. What is its acceleration?
- A +6.0 m/s²
B -10 m/s²
C -6.0 m/s²
D -8.0 m/s²
15. **S** A skydiver is falling at terminal velocity. Which statement is correct?
- A The air resistance on the skydiver is zero.
B The weight of the skydiver is greater than the air resistance.
C The acceleration of the skydiver is 9.8 m/s².
D The air resistance on the skydiver is equal to the weight.
16. **S** The speed-time graph is for an object moving in a straight line. Which statement describes its motion?



- A Its speed increases and its acceleration decreases.
B Its speed increases with constant acceleration.
C Its speed increases and its acceleration increases.
D Its speed decreases and its acceleration is constant.
17. Which statement defines velocity?
- A speed in a given direction
B distance travelled per unit time
C change of speed per unit time
D distance travelled in a given direction
18. An athlete runs one lap of a 400 m track in 80 s and finishes where she started. What is her average speed?
- A 0 m/s
B 0.20 m/s
C 320 m/s
D 5.0 m/s
19. A student measures an object with a ruler marked in millimetres. The left end of the object is at the 1.0 cm mark and the right end is at the 8.3 cm mark. What is the length of the object?
- A 8.3 cm
B 7.3 cm
C 9.3 cm
D 7.0 cm

20. A ball is thrown vertically upwards. Air resistance is negligible. Which row describes the ball at the highest point of its flight?

	velocity	acceleration
A	zero	zero
B	9.8 m/s upwards	zero
C	zero	9.8 m/s ² downwards
D	9.8 m/s downwards	9.8 m/s ² downwards

Answers and explanations

1 C · 2 A · 3 D · 4 B · 5 B · 6 D · 7 A · 8 C · 9 D · 10 B · 11 C · 12 A · 13 B · 14 C · 15 D · 16 A · 17 A · 18 D · 19 B · 20 C

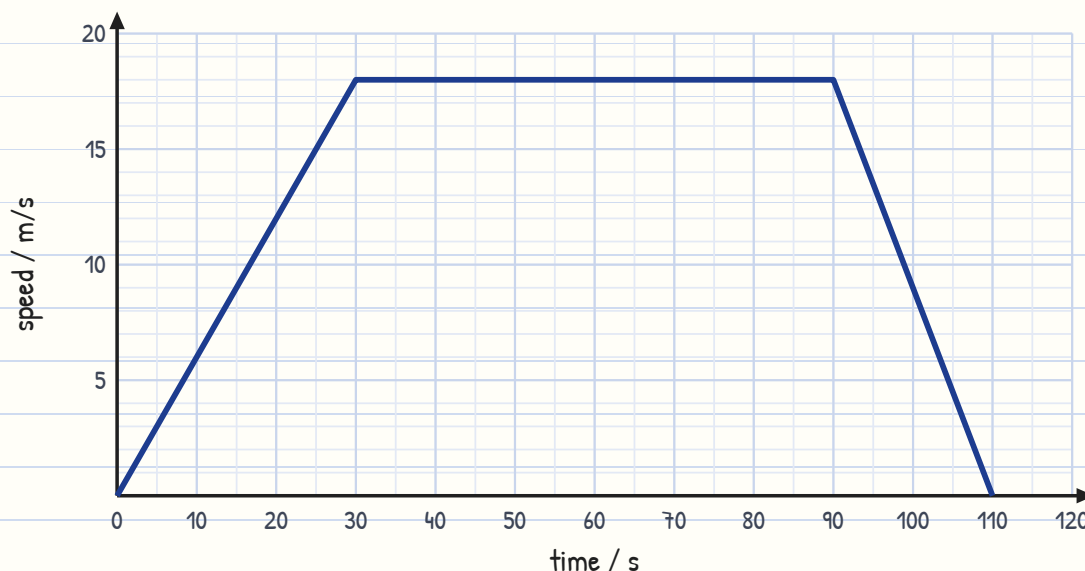
- C.** The 50 cm³ cylinder holds 40 cm³ and its 1 cm³ divisions give the most precise reading of that volume. The beaker and jug have divisions far too large; the 10 cm³ cylinder is too small and would need four fillings, adding four sets of reading errors.
- A.** 2.5 cm = 25 mm; 25 mm ÷ 250 = 0.1 mm.
- D.** period = time for one oscillation = 36.0 s ÷ 20 = 1.8 s.
- B.** The reaction-time error (a few tenths of a second) is the same whether you time 1 or 20 oscillations, so over 20 oscillations it is a much smaller fraction of the measured time. Timing does not change the pendulum's speed, period or amplitude.
- B.** Acceleration, momentum and weight all have direction. Distance, mass, energy, temperature, speed and time are on the syllabus list of scalars.
- D.** $R = \sqrt{(5.0^2 + 12^2)} = \sqrt{(25 + 144)} = \sqrt{169} = 13$ N. Adding (17 N) or subtracting (7.0 N) is only correct for forces along the same line.
- A.** magnitude $\sqrt{(3.0^2 + 4.0^2)} = 5.0$ m/s; $\tan \theta = 4.0 \div 3.0$, $\theta = 53^\circ$ from north towards east. The 37° answer is the angle measured from east, so it is not "east of north".
- C.** 2 hours 30 minutes = 2.5 h; 150 km ÷ 2.5 h = 60 km/h.
- D.** The gradient (speed) of graph D increases with time. Graph A is at rest, B has constant speed, and C becomes less steep (decelerating).
- B.** distance = area under the graph = triangle $\frac{1}{2} \times 5 \times 10 = 25$ m, plus rectangle $10 \times 10 = 100$ m: total 125 m.
- C.** $a = \Delta v \div \Delta t = (10 - 0) \div 5.0 = 2.0$ m/s². 0.50 m/s² comes from dividing the wrong way; 50 m/s² is the area.
- A.** gradient = change in distance ÷ change in time = speed.
- B.** speed gained = $9.8 \times 1.5 = 14.7$ m/s, which is 15 m/s to 2 significant figures. 29 m/s is twice this; 9.8 m/s is the speed after 1.0 s.
- C.** $a = (6.0 - 24) \div 3.0 = -18 \div 3.0 = -6.0$ m/s². The minus sign shows a deceleration.
- D.** At terminal velocity the resultant force is zero, so the air resistance (upwards) equals the weight (downwards) and the acceleration is zero.
- A.** The speed keeps rising but the gradient (acceleration) gets smaller: the curve becomes less steep.
- A.** Velocity is speed in a given direction (syllabus definition). "Distance per unit time" is speed; "change per unit time" describes acceleration.
- D.** average speed = total distance ÷ total time = 400 m ÷ 80 s = 5.0 m/s. Speed is a scalar; the fact that she ends where she started would only make her average *velocity* zero.
- B.** length = 8.3 cm – 1.0 cm = 7.3 cm.
- C.** At the top the ball stops for an instant (velocity zero), but gravity still acts, so its acceleration is still 9.8 m/s² downwards.

Exam-style Extended theory questions (Paper 4 style)

Answer all parts. Show your working. Take $g = 9.8 \text{ m/s}^2$. Total: 39 marks. Full mark schemes follow each question.

Question 1 [11 marks]

A train starts from rest at a station and travels along a straight, level track to the next station. The speed-time graph for the journey is shown.



Speed-time graph for the train (Question 1).

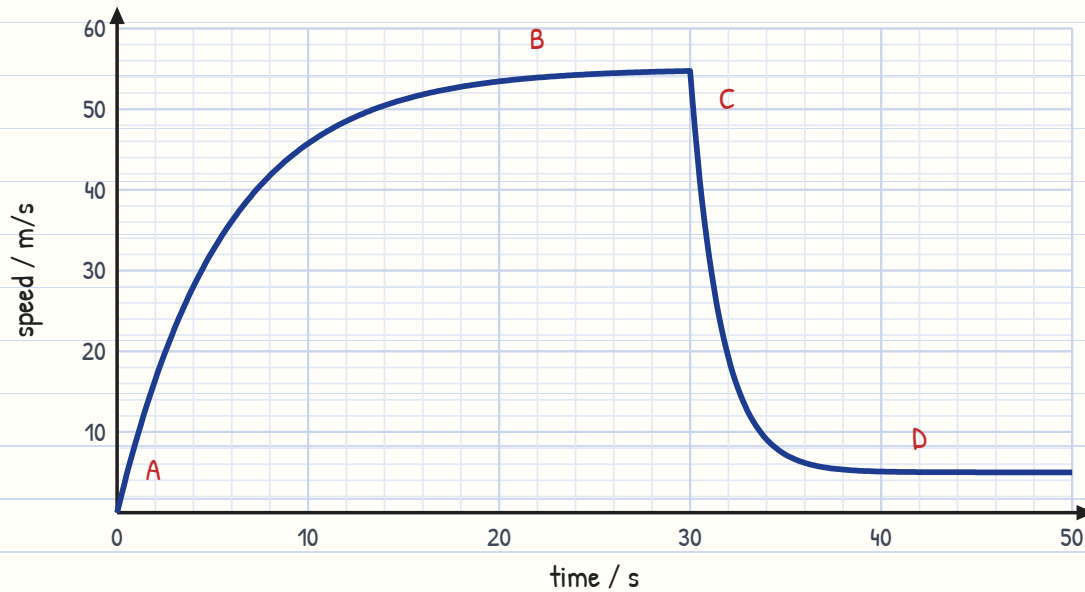
- Describe the motion of the train between $t = 30 \text{ s}$ and $t = 90 \text{ s}$. [1]
- Calculate the acceleration of the train during the first 30 s. [2]
- Calculate the deceleration of the train between $t = 90 \text{ s}$ and $t = 110 \text{ s}$. [2]
- Calculate the total distance between the two stations. [4]
- Calculate the average speed of the train for the whole journey. [2]

Mark scheme

- (a) constant speed 1 of 18 m/s (both needed for the mark: "constant" alone scores 0)
- (b) $a = \frac{\Delta v}{\Delta t} = \frac{18 - 0}{30}$ 1 = 0.60 m/s² 1
- (c) $a = \frac{0 - 18}{110 - 90} = \frac{-18}{20}$ 1; deceleration = 0.90 m/s² 1 (accept -0.90 m/s² given as an acceleration)
- (d) distance = area under the graph 1; $\frac{1}{2} \times 30 \times 18 = 270 \text{ m}$ and $60 \times 18 = 1080 \text{ m}$ 1; $\frac{1}{2} \times 20 \times 18 = 180 \text{ m}$ 1; total = 1530 m 1 (alternative: area of trapezium = $\frac{1}{2} \times (60 + 110) \times 18 = 1530 \text{ m}$ scores all four marks)
- (e) average speed = total distance $\div$ total time = $1530 \div 110$ 1 = 13.9 m/s (14 m/s) 1 (allow their (d) $\div$ 110)

Question 2 [10 marks]

A parachutist jumps from a helicopter that is hovering at rest. The graph shows how her speed changes with time. A, B, C and D mark four stages of the motion. She opens her parachute at $t = 30$ s.



Speed-time graph for the parachutist (Question 2).

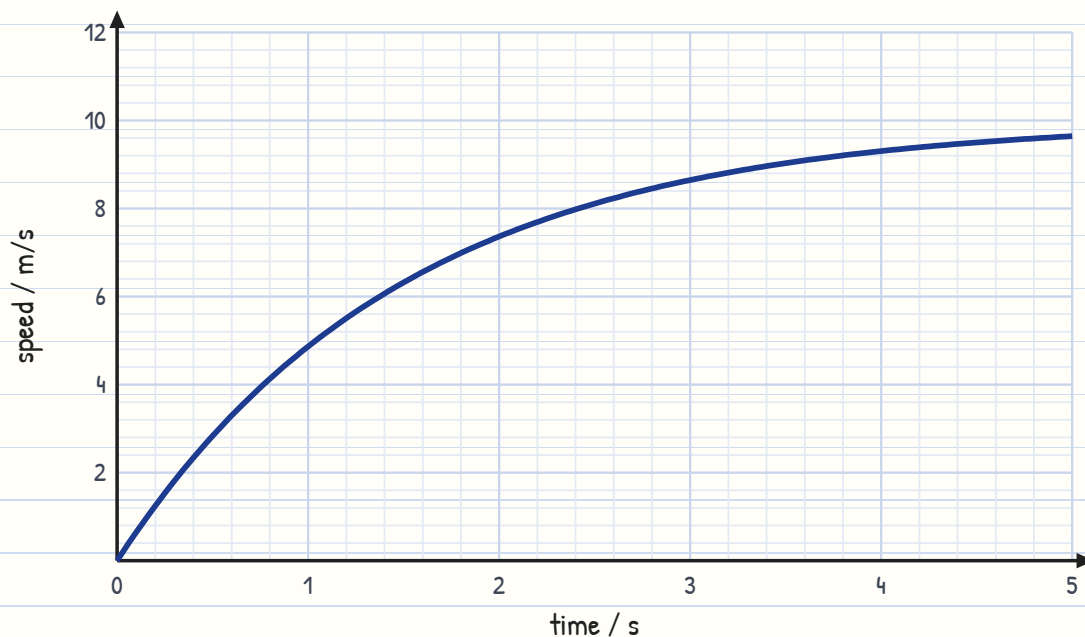
- (a) State the value of her acceleration at the instant she leaves the helicopter (point A), and explain why it has this value. [2]
- (b) Describe and explain, in terms of the forces acting on her, how her motion changes between A and B. [4]
- (c) At C she opens her parachute. Explain why her speed decreases. [2]
- (d) Explain why she then reaches a new, constant speed at D, which is lower than her speed at B. [2]

Mark scheme

- (a) 9.8 m/s^2 1; her speed is zero, so there is no air resistance and the only force on her is her weight 1
- (b) any four from: her speed increases 1; air resistance increases as speed increases 1; the resultant (downward) force decreases 1; so her acceleration decreases (the gradient of the graph decreases) 1; at B the air resistance equals her weight / the resultant force is zero 1; she moves at constant speed: terminal velocity (55 m/s) 1 (contradictions such as "she decelerates" before B lose a mark)
- (c) the air resistance increases (suddenly) and becomes greater than her weight 1; the resultant force is upwards, so she decelerates 1
- (d) as her speed falls, the air resistance falls 1; until air resistance equals weight again / resultant force zero, at a lower speed because the parachute's large area gives the same air resistance at a lower speed 1

Question 3 [9 marks]

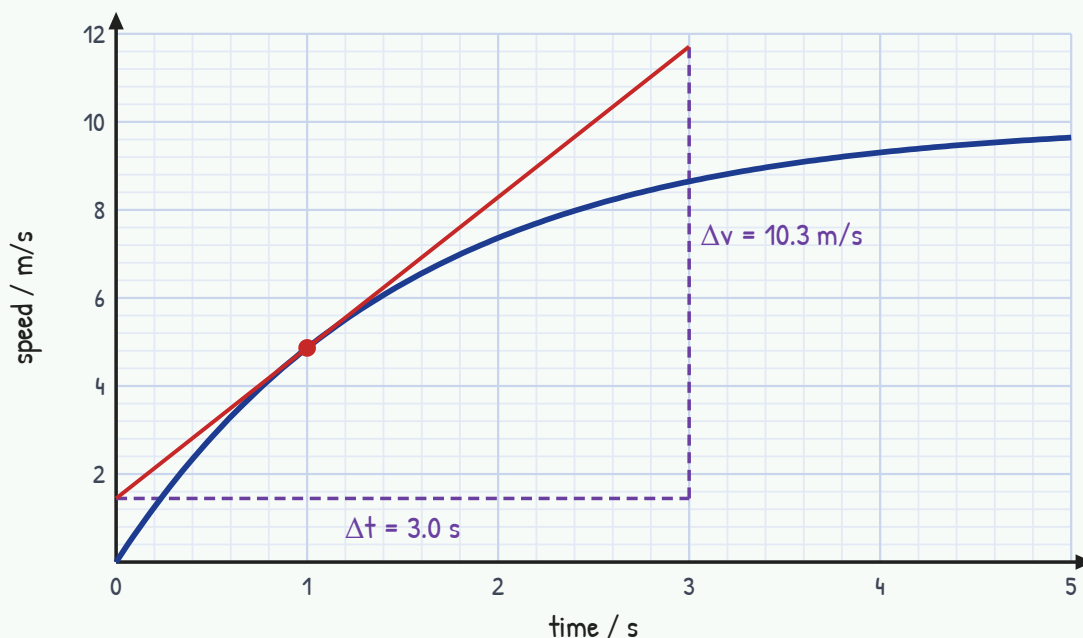
A sprinter starts a race from rest. The speed-time graph shows her motion for the first 5.0 s.



Speed-time graph for the sprinter (Question 3).

- (a) State how the graph shows that her acceleration is decreasing. [1]
- (b) By drawing a tangent to the graph, determine her acceleration at $t = 1.0$ s. [3]
- (c) Estimate the distance she runs in the first 4.0 s. Explain your method. [3]
- (d) Calculate her average speed during the first 4.0 s. [2]

Mark scheme



Mark-scheme figure: tangent at $t = 1.0$ s.

- (a) the gradient (slope) of the graph decreases / the curve gets less steep 1
- (b) tangent drawn touching the curve at $t = 1.0$ s 1; gradient calculated from a large triangle, e.g. $\Delta v \div \Delta t = 10.3 \div 3.0$ 1; acceleration = 3.4 m/s^2 1 (accept 2.9 to 3.9 m/s^2 ; $v \div t = 4.9 \div 1.0$ does not score)
- (c) distance = area under the graph 1; counting squares (or splitting into strips) between $t = 0$ and $t = 4.0$ s 1; distance = 26 m 1 (accept 24 to 28 m)

- (d) average speed = distance $\div$ time = $26 \div 4.0$ 1 = 6.5 m/s 1 (allow their (c) $\div$ 4.0)

Question 4 [9 marks]

An aircraft is flying with a velocity of 240 m/s due north relative to the air. A wind blows the air due east at 70 m/s.

- State why velocity is a vector quantity. [1]
- Calculate the magnitude and the direction of the resultant velocity of the aircraft. [3]
- Describe how the resultant velocity could be found by a scale drawing. State a suitable scale. [3]
- The aircraft keeps this resultant velocity for 2.0 hours. Calculate the distance it travels, in km. [2]

Mark scheme

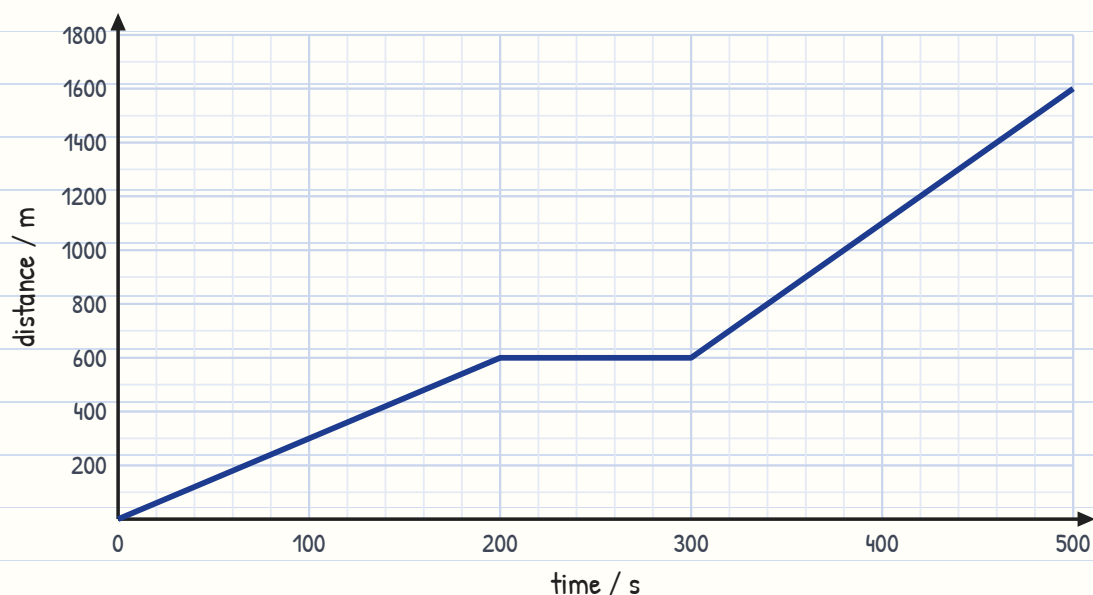
- (a) it has magnitude (size) and direction 1
- (b) $v = \sqrt{240^2 + 70^2} = \sqrt{62\,500}$ 1 = 250 m/s 1; $\tan \theta = \frac{70}{240}$, $\theta = 16^\circ$ east of north 1
(accept 74° north of east; a direction must say what it is measured from)
- (c) choose a scale, e.g. 1 cm represents 20 m/s 1; draw 12.0 cm north and, from its tip, 3.5 cm east, at right angles (tip-to-tail) 1; draw the resultant from the start to the end, measure its length (12.5 cm) and convert with the scale (250 m/s), and measure the angle from north with a protractor (16°) 1
- (d) distance = speed $\times$ time = 250 m/s $\times$ 7200 s 1 = 1 800 000 m = 1800 km 1 (or 900 km/h $\times$ 2.0 h)

Exam-style Core theory questions (Paper 3 style)

Total: 16 marks. Full mark schemes follow each question.

Question 5 [8 marks]

A girl cycles from home to school. The distance-time graph shows her journey. She stops at a red traffic light on the way.



Distance-time graph for the journey (Question 5).

- State what the girl is doing between $t = 200$ s and $t = 300$ s. Explain how the graph shows this. [2]
- Calculate her speed during the first 200 s. [3]

(c) State the section of the journey in which she cycles fastest. Give a reason for your answer. [1]

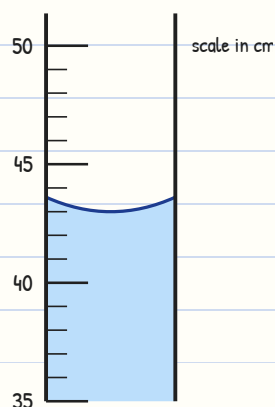
(d) Calculate her average speed for the whole journey from home to school. [2]

Mark scheme

- (a) she is at rest / stationary (waiting at the traffic light) 1; the line is horizontal / the distance does not change 1
- (b) $v = \frac{s}{t}$ (in any form) 1; $= \frac{600}{200}$ 1; $= 3.0 \text{ m/s}$ 1
- (c) between 300 s and 500 s, because the gradient (slope) is steepest 1 (5.0 m/s compared with 3.0 m/s)
- (d) average speed $= \frac{1600}{500}$ 1 $= 3.2 \text{ m/s}$ 1

Question 6 [8 marks]

(a) The diagram shows part of a measuring cylinder containing water.



Measuring cylinder (Question 6).

(i) State the volume of the water. [1]

(ii) State where the student's eye should be when taking this reading. [1]

(b) A student has 10 identical coins and a 30 cm ruler marked in millimetres. Describe how he can find the thickness of one coin as accurately as possible. [3]

(c) The stack of 10 coins is 18 mm high.

(i) Calculate the thickness of one coin. [1]

(ii) Suggest why this method gives a more accurate value than measuring one coin. [2]

Mark scheme

- (a)(i) 43 cm^3 1 (unit needed)
- (a)(ii) level with the bottom of the meniscus (looking horizontally at the scale) 1
- (b) stack all 10 coins on top of each other (on a flat surface) 1; measure the height of the stack with the ruler, reading with the eye directly above / level with the mark, or using a set square / blocks at the ends 1; divide the height by 10 1
- (c)(i) $18 \text{ mm} \div 10 = 1.8 \text{ mm}$ 1
- (c)(ii) one coin (about 2 mm) is only a few divisions on the ruler, so the reading error is large compared with it 1; the same reading error is shared over 10 coins, so it is a smaller fraction of the measurement 1

Exam-style Alternative to Practical question (Paper 6 style)

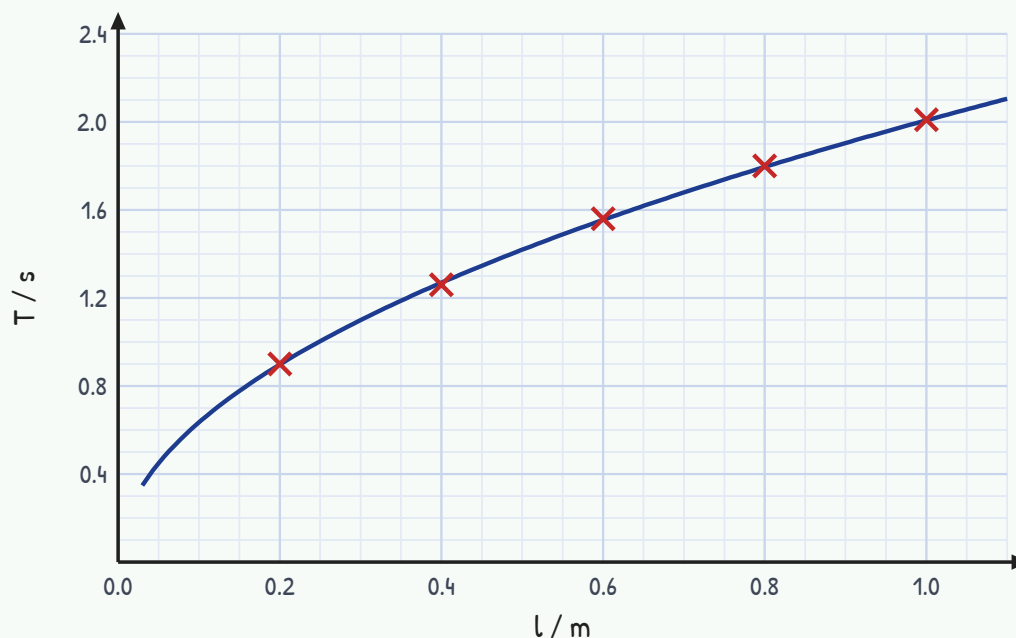
Question 7 [11 marks]

A student investigates how the period T of a simple pendulum depends on its length l . For each length, she times 10 complete oscillations. Her results are shown in the table.

l / m	t / s	T / s
0.200	9.0	
0.400	12.6	
0.600	15.6	
0.800	18.0	
1.000	20.1	

- Complete the table by calculating the period T for each length. [2]
- Plot a graph of T / s (y-axis) against l / m (x-axis). Start both axes at the origin. Draw the best-fit line. [4]
- The student suggests that T is directly proportional to l . State whether her results support this suggestion. Justify your answer by reference to the results. [2]
- Suggest one way of making the timings more reliable, and one precaution when measuring the length l . [2]
- State one variable that she should keep constant in this experiment. [1]

Mark scheme



Mark-scheme figure: points plotted as crosses with a smooth best-fit curve.

- (a) $T = t \div 10$ used 1; 0.90, 1.26, 1.56, 1.80, 2.01 s, all correct, all to 2 decimal places (consistent with t to 0.1 s) 1
- (b) axes labelled with quantity and unit (T / s , l / m) the right way round 1; suitable scales using more than half the grid in each direction 1; all five points plotted correctly to half a small square 1; a single thin, smooth best-fit curve (not dot-to-dot, not forced to be straight) 1

- (c) no (not supported) **I**; the graph is a curve and not a straight line through the origin, OR doubling l from 0.400 m to 0.800 m increases T from 1.26 s to 1.80 s, not to 2.52 s **I**
- (d) timings: time more oscillations (e.g. 20) / repeat each timing and find the mean / use a fiducial marker at the centre of the swing **I**; length: measure to the centre of the bob / eye level with the mark on the rule to avoid parallax / use a set square **I**
- (e) the mass of the bob, or the amplitude (keep it small) **I**

Quick-reference sheet

Item	Statement / equation	Unit	Level
speed	distance travelled per unit time; $v = \frac{s}{t}$	m/s	C
velocity	speed in a given direction	m/s	C
average speed	total distance travelled $\div$ total time taken	m/s	C
acceleration	change in velocity per unit time; $a = \frac{\Delta v}{\Delta t}$; deceleration = negative acceleration	m/s ²	S
free fall	$g \approx 9.8 \text{ m/s}^2$, approximately constant near the Earth's surface	m/s ²	C
distance-time graph	gradient = speed; horizontal = at rest		C
speed-time graph	area = distance travelled; horizontal = constant speed; gradient = acceleration S		C
resultant (right angles)	$R = \sqrt{F_1^2 + F_2^2}$, $\tan \theta = \frac{\text{opp}}{\text{adj}}$, or scale drawing tip-to-tail	N or m/s	S
scalars	distance, speed, time, mass, energy, temperature		S
vectors	force, weight, velocity, acceleration, momentum, electric field strength, gravitational field strength		S
period	time for one complete oscillation; time 20, divide by 20	s	C
terminal velocity	air resistance = weight, resultant force = 0, constant speed	m/s	S

"I can" checklist

- ☐ use a ruler (avoiding parallax and zero errors) and a measuring cylinder (bottom of the meniscus, eye level)
- ☐ choose a clock, a stopwatch or a digital timer with light gates for a time interval, and explain reaction time
- ☐ find a small distance or a short time by measuring multiples, including the period of a pendulum
- ☐ **S** define scalar and vector, and list the syllabus scalars and vectors
- ☐ **S** find the resultant of two perpendicular forces or velocities by calculation and by scale drawing, with its direction
- ☐ define speed and velocity; use $v = \frac{s}{t}$ and average speed = total distance $\div$ total time
- ☐ sketch, plot and interpret distance-time and speed-time graphs; say when an object is at rest, at constant speed, accelerating or decelerating
- ☐ find speed from the gradient of a distance-time graph, and distance from the area under a speed-time graph
- ☐ **S** define acceleration; use $a = \frac{\Delta v}{\Delta t}$; find acceleration from a gradient or a tangent; treat deceleration as negative acceleration

- ☐ **S** tell constant from changing acceleration, from data or the shape of a speed-time graph
- ☐ state that $g \approx 9.8 \text{ m/s}^2$ near the Earth
- ☐ **S** describe falling with and without air or liquid resistance, and explain terminal velocity in terms of forces

★ **Exam tip:** Next chapter: 1.3 Mass and weight and 1.4 Density. Weight is a force (a vector), mass is a scalar, and the measuring-cylinder method above is used again for the volume of irregular solids.