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A.1 Kinematics

Space, time and motion: describing motion with position, velocity and acceleration

Standard Level and Higher Level (9 hours; there is no additional HL content in A.1)

What you must be able to do

Idea	You must be able to...	Level
Position, displacement, distance	Describe motion with position, velocity and acceleration; tell displacement from distance	SL HL
Velocity and acceleration	Use velocity = rate of change of position and acceleration = rate of change of velocity; average versus instantaneous values, found from graphs	SL HL
Equations of motion	Solve uniform-acceleration problems with the four *suvat* equations; handle non-uniform acceleration graphically	SL HL
Projectiles	Resolve into horizontal and vertical components; horizontal launches, launches above and below the horizontal (constant g, no fluid resistance)	SL HL
Fluid resistance	Qualitative effect on time of flight, trajectory, velocity, acceleration, range and terminal speed	SL HL

What is inside

1. Concept notes with 7 worked examples
2. Graph skills: gradient, area, tangent
3. Common mistakes; investigation (IA) tips
4. 15 Paper 1A-style MCQs, explained
5. 3 Paper 2-style structured questions with mark schemes
6. Quick-reference sheet and "I can" checklist

How to read these notes

SL = Standard Level content

HL = needed at Higher Level only

red = key term green = definition

1 = one mark in the mark scheme

★ **Exam tip:** The Physics data booklet is allowed in every paper. Equations marked *data booklet* are given to you; the others you must remember.

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Position, displacement, velocity, acceleration

Kinematics describes **how** bodies move, without asking what causes the motion. We always measure from a chosen **origin** along a chosen direction, and call one direction positive. Position x is the location relative to the origin. A **vector** has size and direction; a **scalar** has size only.

Quantity	Type	Meaning	Unit
distance d	scalar	total length of the path travelled	m
displacement s	vector	straight-line change in position, from start to finish: $s = x_{\text{final}} - x_{\text{initial}}$	m
speed	scalar	distance travelled per unit time	m s^{-1}
velocity v	vector	rate of change of position (displacement per unit time)	m s^{-1}
acceleration a	vector	rate of change of velocity	m s^{-2}

Definition **Velocity** is the rate of change of position: $v = \dfrac{\Delta s}{\Delta t}$. **Acceleration** is the rate of change of velocity: $a = \dfrac{\Delta v}{\Delta t}$.

Average and instantaneous values

- **Average velocity** over an interval $= \dfrac{\text{total displacement}}{\text{total time}}$. **Average speed** $= \dfrac{\text{total distance}}{\text{total time}}$. They differ whenever the path turns back or curves.
- **Instantaneous velocity** is the velocity at one moment: the limit of $\dfrac{\Delta s}{\Delta t}$ as $\Delta t \to 0$. On a position–time graph it is the gradient of the tangent at that moment.
- **Instantaneous acceleration** is the gradient of the tangent on a velocity–time graph.
- A body can have zero velocity and non-zero acceleration (for an instant, at the top of a throw). Speed can rise while acceleration shrinks (see terminal speed, later).

Worked example 1: distance, displacement, average speed and velocity

A runner starts at the west end of a straight 100 m path, runs east to the far end in 14 s, then walks back 40 m west in 20 s. Find (a) the distance, (b) the displacement, (c) the average speed, (d) the average velocity for the whole trip.

(a) $d = 100 + 40 = 140$ m. (b) $s = 100 - 40 = 60$ m east. (c) average speed $= 140/34 = 4.1$ m s^{-1}. (d) average velocity $= 60/34 = 1.8$ m s^{-1} east.

Direction matters: speed has none, velocity needs one.

✗ Don't do this: Writing "the velocity is 5 m s^{-1}" with no direction when the question asks for a vector. Write "5 m s^{-1} north", or give the sign (+5) after stating which direction is positive.

Reading motion graphs

Three graphs describe one motion. Each is linked to the next by a gradient (going right) or an area (going left).

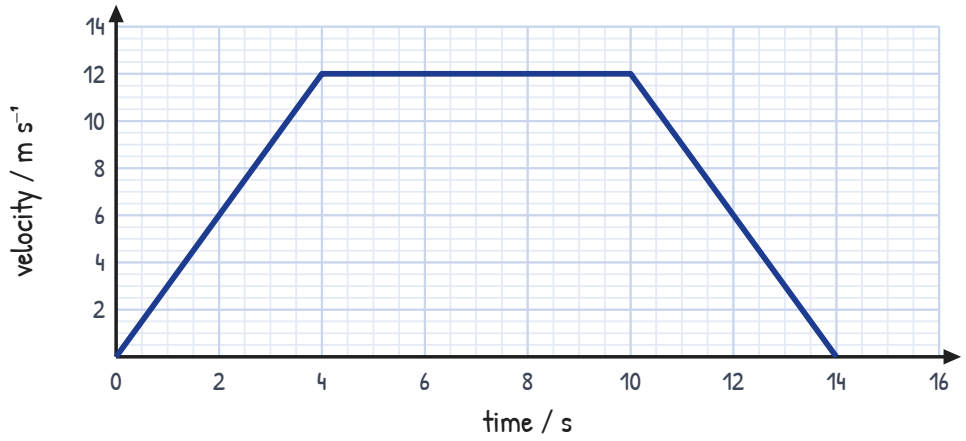
Graph	Gradient gives	Area under graph gives

position (or displacement) – time	velocity	(nothing useful)
velocity – time	acceleration	change in displacement
acceleration – time	(rate of change of acceleration)	change in velocity

- A **straight** line on a velocity–time graph means **uniform** acceleration; a curve means non-uniform acceleration.
- Areas **below** the time axis are negative displacement (motion in the negative direction). For the **distance** travelled, add the sizes of all areas.
- A horizontal line on a position–time graph: at rest. A horizontal line on a velocity–time graph: constant velocity, zero acceleration.

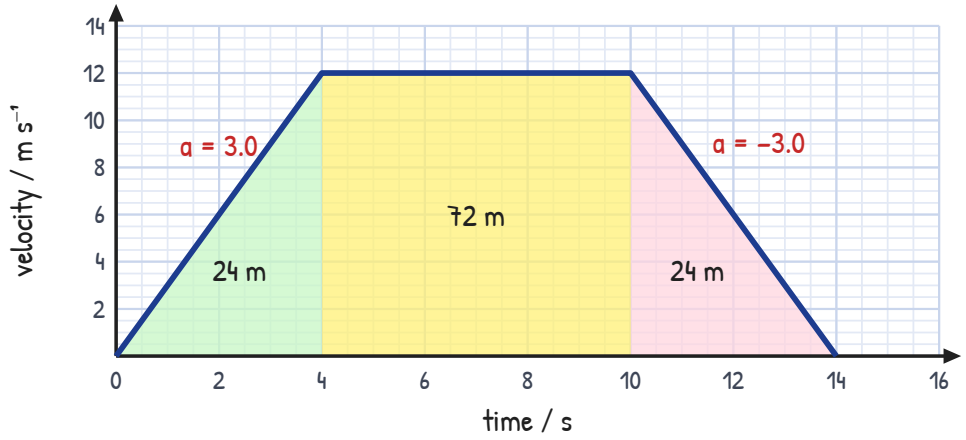
Worked example 2: a journey graph

A trolley's velocity is shown against time. Find its acceleration in each stage and the total displacement.



0–4 s: $a = \dfrac{12-0}{4} = 3.0\ \text{m s}^{-2}$. **4–10 s:** $a = 0$. **10–14 s:** $a = \dfrac{0-12}{4} = -3.0\ \text{m s}^{-2}$.

Displacement = area $= \frac{1}{2}(4)(12) + (6)(12) + \frac{1}{2}(4)(12) = 24 + 72 + 24 = 120$ m (the area of a trapezium: $\frac{1}{2}(6+14) \times 12$).



The same graph with each area marked and each acceleration (m s⁻²) shown.

★ ***Exam tip:*** To find an area under a curve, count squares, state the area of one square, and give the answer with a sensible number of significant figures.

Uniformly accelerated motion

When the acceleration is **constant** along a straight line, five variables are linked: s (displacement), u (initial velocity), v (final velocity), a (acceleration), t (time). Each equation leaves one variable out. *(All four are in the data booklet.)*

$$v = u + at \qquad s = \tfrac{1}{2}(u + v)\,t \qquad s = ut + \tfrac{1}{2}at^2 \qquad v^2 = u^2 + 2as$$

Missing variable: $v = u + at$ has no s; $s = \frac{1}{2}(u + v)t$ has no a; $s = ut + \frac{1}{2}at^2$ has no v; $v^2 = u^2 + 2as$ has no t.

Where they come from. The definition $a = \dfrac{v - u}{t}$ gives $v = u + at$. On a velocity–time graph from u to v the displacement is the area of a trapezium: $s = \frac{1}{2}(u + v)t$. Putting $v = u + at$ into this gives $s = ut + \frac{1}{2}at^2$. Eliminating t gives $v^2 = u^2 + 2as$.

Method for every suvat question

1. Draw a sketch; choose the positive direction (up, or the direction of motion) and keep it.
2. List the values you know with **signs** and the one you want. Remember hidden values: "starts from rest" means $u = 0$; "comes to rest" means $v = 0$; free fall near Earth gives $a = \pm 9.81\ \text{m s}^{-2}$.
3. Pick the equation that contains your four variables, rearrange, then substitute.

Worked example 3: braking

A car travelling at $25\ \text{m s}^{-1}$ brakes uniformly at $6.0\ \text{m s}^{-2}$ until it stops. Find the braking distance and time.

Take the direction of motion as positive: $u = 25$, $v = 0$, $a = -6.0$. Distance: $v^2 = u^2 + 2as \Rightarrow 0 = 625 - 12s \Rightarrow s = 52\ \text{m}$. Time: $v = u + at \Rightarrow t = \dfrac{0 - 25}{-6.0} = 4.2\ \text{s}$.

Worked example 4: a ball thrown upwards

A ball is thrown vertically up at $15\ \text{m s}^{-1}$. Ignore air resistance. Find the maximum height and the total time to return to the hand.

Up is positive: $u = +15$, $a = -9.81$. At the top $v = 0$: $0 = 225 - 19.62\,s \Rightarrow s = 11.5\ \text{m}$. Time to top: $t = \dfrac{15}{9.81} = 1.53\ \text{s}$. By symmetry the whole flight is $2 \times 1.53 = 3.06\ \text{s}$. (Check with $s = ut + \frac{1}{2}at^2 = 0$: $t(15 - 4.905\,t) = 0 \Rightarrow t = 3.06\ \text{s}$.)

Worked example 5: using $s = \frac{1}{2}(u + v)t$

A train speeds up uniformly from $8.0\ \text{m s}^{-1}$ to $20\ \text{m s}^{-1}$ in $9.0\ \text{s}$. Find its acceleration and the distance covered.

$a = \dfrac{20 - 8.0}{9.0} = 1.3\ \text{m s}^{-2}$; $s = \frac{1}{2}(8.0 + 20)(9.0) = 126\ \text{m}$.

✗ Don't do this: Using suvat when the acceleration is **not constant**. If the velocity–time graph is a curve, use gradients and areas instead.

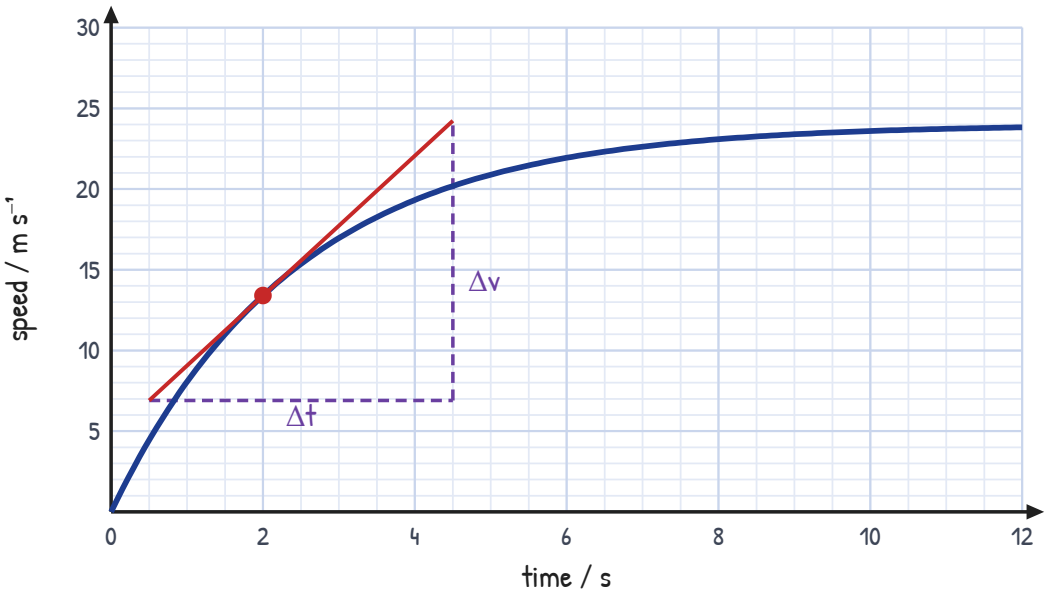
Motion with changing acceleration

When the velocity–time graph is a curve, the acceleration changes with time. The two graph tools still work:

- **Instantaneous acceleration** at time t = gradient of the **tangent** to the curve at t. Draw a long tangent, then use a large triangle: $a = \dfrac{\Delta v}{\Delta t}$.
- **Displacement** between two times = area under the curve (count squares, or split into trapeziums).
- **Average acceleration** over an interval = $\dfrac{v_{\text{final}} - v_{\text{initial}}}{\Delta t}$, the gradient of the *chord* joining the end points (not of a tangent).

Worked example 6: a tangent

A sphere falls through oil. Its speed is plotted below. Estimate the acceleration at $t = 2.0$ s.



The tangent drawn at $t = 2.0$ s passes through $(0.5\text{ s},\ 6.9\text{ m s}^{-1})$ and $(4.5\text{ s},\ 24.2\text{ m s}^{-1})$.
$a = \dfrac{\Delta v}{\Delta t} = \dfrac{24.2 - 6.9}{4.5 - 0.5} = 4.3\text{ m s}^{-2}$ (accept 4.1 to 4.5). It is less than 9.81 because the resistance from the oil has already built up.

★ **Exam tip:** In a data-based question (Paper 1B or a graph in Paper 2) the tangent must be **drawn on the graph** and the triangle must be **large**. A small triangle loses marks.

Uncertainties in graphs (for the investigation)

When you plot your own data, draw **error bars**, then draw a **best-fit line** and a **worst acceptable line** (steepest or shallowest line that still passes through all the bars). The uncertainty in the gradient is half the difference: $\Delta m = \frac{1}{2}(m_{\max} - m_{\min})$.

Projectile motion

A **projectile** moves under gravity alone. Near the Earth's surface $g = 9.81\text{ m s}^{-2}$ is constant, and in this chapter fluid resistance is ignored. The key idea: horizontal and vertical motion are independent.

Horizontal (x)

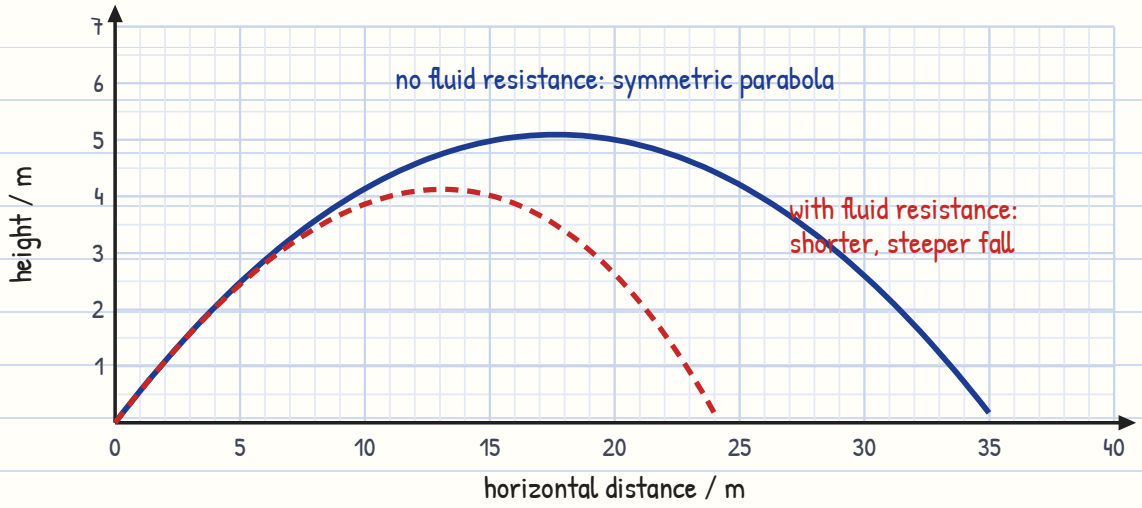
- No horizontal force, so $a_x = 0$.

- Constant velocity: $x = u_x t$.

Vertical (y, up positive)

- $a_y = -g$, constant.
- Use suvat: $v_y = u_y - gt$, $y = u_y t - \frac{1}{2}gt^2$.

For a launch at speed u and angle θ above the horizontal: $u_x = u\cos\theta$, $u_y = u\sin\theta$. The time is the same in both directions, so it links them. The speed at any moment is $\sqrt{v_x^2 + v_y^2}$ and the direction is $\tan\phi = \dfrac{|v_y|}{v_x}$.



A launch at 20 m s^{-1}, 30° above the horizontal. Blue: no fluid resistance (parabola). Red dashed: with fluid resistance (see next page).

Results without air resistance (level ground, launch angle θ)

- Time of flight $T = \dfrac{2u\sin\theta}{g}$; maximum height $H = \dfrac{(u\sin\theta)^2}{2g}$; range $R = \dfrac{u^2\sin 2\theta}{g}$.
- The path is a **parabola**. The range is greatest at $45°$, and angles θ and $90° - \theta$ give the same range.
- At the top $v_y = 0$ but $v_x \neq 0$ and the acceleration is still g downwards.

Worked example 7: horizontal launch

A ball leaves a cliff top horizontally at $12\ \text{m s}^{-1}$. The cliff is $45\ \text{m}$ high. Find the time of flight, the horizontal distance, and the speed and direction at impact.

Vertical: $u_y = 0$, $45 = \frac{1}{2}(9.81)t^2 \Rightarrow t = 3.03\ \text{s}$. Horizontal: $x = 12 \times 3.03 = 36\ \text{m}$. Vertical speed at impact $v_y = 9.81 \times 3.03 = 29.7\ \text{m s}^{-1}$, so $v = \sqrt{12^2 + 29.7^2} = 32\ \text{m s}^{-1}$ at $\tan^{-1}\left(\dfrac{29.7}{12}\right) = 68°$ below the horizontal.

Angles above and below the horizontal

Worked example 8: launch above the horizontal

A football is kicked from the ground at $25\ \text{m s}^{-1}$ at 40° above the horizontal. Find the time of flight, the maximum height and the range. Ignore air resistance.

$u_x = 25\cos 40^\circ = 19.2\ \text{m s}^{-1}$, $u_y = 25\sin 40^\circ = 16.1\ \text{m s}^{-1}$. Landing at the same height: $y = 0 \Rightarrow t = \dfrac{2u_y}{g} = 3.28\ \text{s}$. Height: $H = \dfrac{16.1^2}{2(9.81)} = 13.2\ \text{m}$. Range: $R = u_x t = 19.2 \times 3.28 = 63\ \text{m}$.

Worked example 9: launch below the horizontal

A stone is thrown from the top of a $20\ \text{m}$ cliff at $10\ \text{m s}^{-1}$, 30° **below** the horizontal. Find the time to hit the sea and the horizontal distance.

Take down as positive here: $u_y = 10\sin 30^\circ = 5.0$, $u_x = 10\cos 30^\circ = 8.66$. $20 = 5.0t + 4.905t^2 \Rightarrow 4.905t^2 + 5.0t - 20 = 0$, so $t = \dfrac{-5.0 + \sqrt{25 + 392.4}}{9.81} = 1.57\ \text{s}$ (reject the negative root). Horizontal distance $= 8.66 \times 1.57 = 13.6\ \text{m}$.

Choose one sign convention for the whole question. A launch below the horizontal has u_y in the same direction as g.

Energy method

If only the **speed** at some height is wanted, conservation of energy is quicker than components: $\frac{1}{2}v^2 = \frac{1}{2}u^2 + g\,\Delta h_{\text{down}}$ (no mass needed). For the cliff in example 7: $v^2 = 12^2 + 2(9.81)(45) = 1027$, so $v = 32\ \text{m s}^{-1}$, the same as above. The method gives speed only, not direction.

★ **Exam tip:** Questions often give a "launch speed" and an "angle" and then ask for something at the *top* of the path: use $v_y = 0$ there and v_x unchanged.

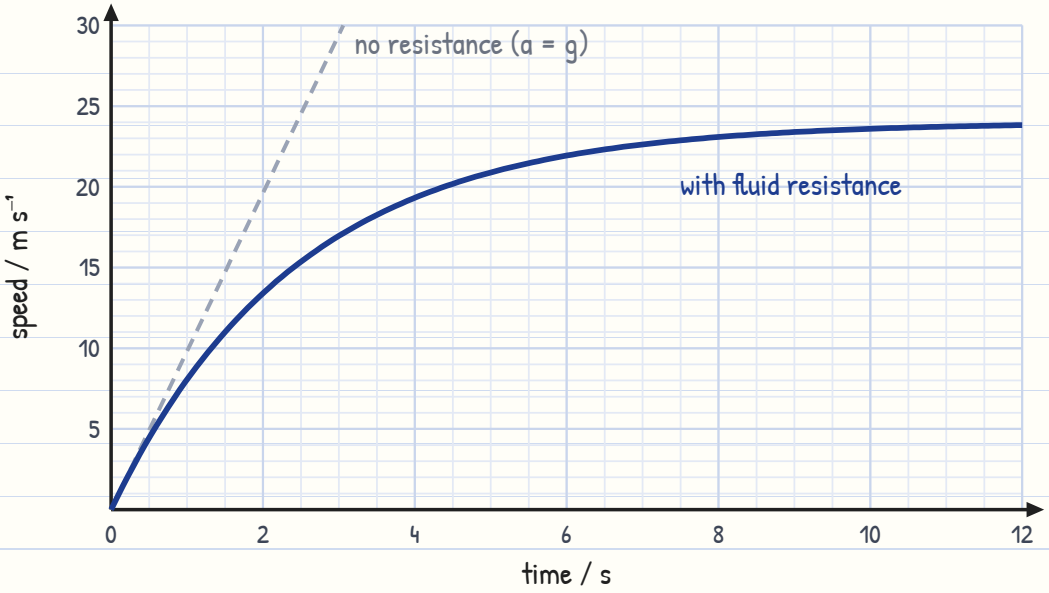
✗ **Don't do this:** Adding or "averaging" the horizontal and vertical motions into one equation. Treat them separately and join them only through time t.

The effect of fluid resistance

Fluid resistance (drag) is the force from a gas or liquid on a moving body. It acts **opposite to the velocity** and generally grows as the speed increases (and with the body's cross-section). It is not required quantitatively in this chapter; you need to describe its effects.

On a falling body: terminal speed

1. Released from rest the speed is zero, so there is no drag; $a = g$.
2. As the speed rises, so does the upward drag. The resultant force (weight − drag) falls, so the **acceleration decreases** but is still downwards; speed keeps increasing.
3. When drag = weight, the resultant force and the acceleration are **zero**. The body falls at a constant **terminal speed**.



The gradient of the curve falls from g at $t = 0$ to zero at terminal speed.

On a projectile

Quantity	Without resistance	With resistance
Horizontal velocity	constant	decreases all the way (drag has a horizontal component)
Acceleration	g downwards, constant	not constant; at the start larger than g when going up, then smaller than g as it descends
Maximum height	H	smaller
Time of flight	T	time up is shorter, time down is longer; overall usually shorter than T for a strong drag
Range	R	smaller
Trajectory	symmetric parabola	asymmetric: the descent is steeper than the ascent; the highest point is nearer the landing end
Speed on landing	equal to launch speed	less than the launch speed

★ **Exam tip:** For "explain" questions on terminal speed use this chain: resultant force → acceleration → speed change. Always say **acceleration** is zero at terminal speed, not that the speed is zero or that gravity stops acting.

Common mistakes

Mistake	Correct idea
Calling the average of two speeds the average speed of a trip	Average speed is total distance ÷ total time. For two equal distances at 50 and 100 km h^{-1} it is $\dfrac{2}{1/50 + 1/100} = 66.7$ km h^{-1}, not 75.
Using $v = s/t$ for accelerating motion	That gives the *average* velocity only.
Wrong signs for upward throws ($a = +9.81$)	If up is positive, $a = -9.81$ for the whole flight, rising and falling.

Saying acceleration is zero at the top of a throw	Velocity is zero for an instant; acceleration is still $9.81\ \text{m s}^{-2}$ downwards.
Gradient of a displacement–time graph called acceleration	It is velocity. Acceleration is the gradient of velocity–time.
Reading distance from the area when part of it is below the axis	Subtract areas for displacement; add sizes for distance.
Using the range formula for launch and landing at different heights	$R = \frac{u^2 \sin 2\theta}{g}$ is for level ground only. Otherwise solve $y(t)$ for the time.
"Terminal speed means no forces act"	Weight and drag act; they are equal and opposite.

Investigation ideas (IA)

Kinematics gives good, low-cost investigations. Pick a question with a clear independent variable and measurable dependent variable, and plan how you will reduce uncertainty:

- How does the launch angle of a ball (ramp or spring launcher) affect its range? Use video analysis for the time and the horizontal distance.
- How does the mass or the cross-section of a falling paper cone affect its terminal speed? (Control the height and the release.)
- Does a ball rolling down a ramp show uniform acceleration? Plot s against t^2 (a straight line through the origin if $s = \frac{1}{2}at^2$ and the gradient gives $a/2$).

Linking idea: graph linearisation (plotting s against t^2) turns a curve into a straight line so the gradient and its uncertainty can be found.

15 multiple-choice questions

One mark each; no marks lost for a wrong answer. Use $g = 9.81\ \text{m s}^{-2}$. Answers and explanations are on the next page.

1. A runner completes one lap of a 400 m track in 50 s. What are her average speed and average velocity for the lap?
   A 8 m s⁻¹, zero B zero, zero
   C zero, 8 m s⁻¹ D 8 m s⁻¹, 8 m s⁻¹

2. Which of these is a vector quantity?
   A displacement B speed
   C time D distance

3. The gradient of a displacement–time graph at a point gives the:
   A average speed B instantaneous velocity
   C distance travelled D acceleration

4. A car accelerates uniformly from $10\ \text{m s}^{-1}$ to $30\ \text{m s}^{-1}$ while travelling $200\ \text{m}$. Its acceleration is:
   A 0.10 m s⁻² B 4.0 m s⁻²
   C 1.0 m s⁻² D 2.0 m s⁻²

5. A stone is released from rest and falls freely for 3.0 s. The distance fallen is:
   A 44.1 m B 88.3 m
   C 29.4 m D 14.7 m

6. A projectile is at the highest point of its path. Air resistance is negligible. Which statement is correct?
   A Its vertical velocity is a maximum.
   B Its horizontal velocity is zero.
   C Its velocity is zero.
   D Its acceleration is $9.81\ \text{m s}^{-2}$ downwards.

7. Ball X is dropped from rest from a table and ball Y rolls off the table horizontally at the same instant. Ignore air resistance. Compared with X, ball Y takes:
   A the same time to land B longer to land
   C less time to land D a time depending on its mass

8. Two balls are launched with the same speed on level ground, one at 30° and one at 60° to the horizontal. Ignore air resistance. Their ranges are:

   A larger for 60° B larger for 30°

   C zero for both D equal

9. A car brakes uniformly from $20\ \text{m s}^{-1}$ to rest in $4.0\ \text{s}$. The distance it travels is:

   A 80 m B 5.0 m

   C 40 m D 20 m

10. A body's velocity changes uniformly from $+4.0\ \text{m s}^{-1}$ to $-2.0\ \text{m s}^{-1}$ in $3.0\ \text{s}$. Its acceleration is:

    A $-0.67\ \text{m s}^{-2}$ B $+0.67\ \text{m s}^{-2}$

    C $-2.0\ \text{m s}^{-2}$ D $+2.0\ \text{m s}^{-2}$

11. A sphere falls through a liquid at its terminal speed. Which statement is correct?

    A Its acceleration is $9.81\ \text{m s}^{-2}$.

    B The resultant force on it is zero.

    C No forces act on it.

    D The drag is smaller than the weight.

12. On a speed–time graph a curve rises with a gradient that decreases steadily. The motion is one in which the:

    A object is at rest

    B object is slowing down

    C acceleration is constant and positive

    D speed increases and the acceleration decreases

13. A ball rolls horizontally off a table of height $1.2\ \text{m}$ at $8.0\ \text{m s}^{-1}$. Ignore air resistance. The horizontal distance to where it lands is closest to:

    A 1.9 m B 4.0 m

    C 7.9 m D 2.4 m

14. A car covers the first 100 km at $50\ \text{km h}^{-1}$ and the next 100 km at $100\ \text{km h}^{-1}$. Its average speed is:

    A 83.3 km h⁻¹ B 66.7 km h⁻¹

    C 70.0 km h⁻¹ D 75.0 km h⁻¹

15. Compared with the same launch in a vacuum, a projectile moving through air has:

    A a longer time of flight

    B a constant horizontal velocity

    C a shorter range and a steeper descent than ascent

    D a greater maximum height

Answers and explanations

1 A	2 A	3 B	4 D	5 A	6 D	7 A	8 D
9 C	10 C	11 B	12 D	13 B	14 B	15 C	

1. **A.** Distance 400 m in 50 s gives 8 m s⁻¹. The displacement for a full lap is zero, so the average velocity is zero.

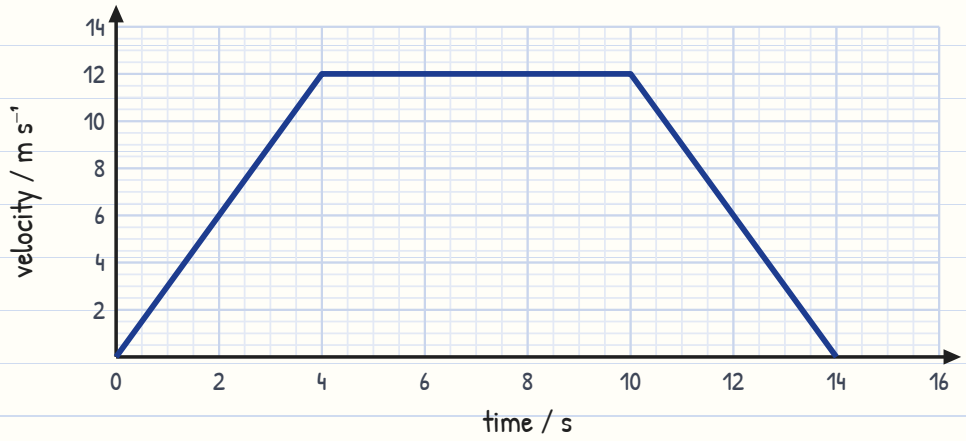
2. **A.** Displacement has direction. Distance, speed and time are scalars.

3. **B.** Gradient of s-t is $\Delta s/\Delta t$, the velocity (at a point, the instantaneous velocity).
4. **D.** $v^2 = u^2 + 2as$: $900 = 100 + 400a$, so $a = 2.0$ m s^{-2}.
5. **A.** $s = \frac{1}{2}gt^2 = 0.5 \times 9.81 \times 9.0 = 44.1$ m. D is $\frac{1}{2}gt$ (14.7); C is gt (29.4); B is gt^2 (88.3).
6. **D.** Gravity still acts, so the acceleration is 9.81 m s^{-2} downwards. The velocity is not zero (the horizontal component remains); only the vertical component is zero.
7. **A.** Vertical motion is identical (both start with zero vertical velocity), so they land together.
8. **D.** $R \propto \sin 2\theta$ and $\sin 60^\circ = \sin 120^\circ$: θ and $90^\circ - \theta$ give equal ranges.
9. **C.** $s = \frac{1}{2}(u + v)t = \frac{1}{2}(20)(4.0) = 40$ m.
10. **C.** $a = (-2.0 - 4.0)/3.0 = -2.0$ m s^{-2}.
11. **B.** Drag equals weight, so the resultant force and acceleration are zero. A, D and C are false.
12. **D.** A rising curve means increasing speed; a falling gradient means a decreasing acceleration.
13. **B.** $t = \sqrt{2(1.2)/9.81} = 0.495$ s; $x = 8.0 \times 0.495 = 3.96 \approx 4.0$ m.
14. **B.** Times: 2.0 h + 1.0 h = 3.0 h; $200/3.0 = 66.7$ km h^{-1}. D is the mean of the two speeds.
15. **C.** Drag shortens the range and makes the descent steeper. Maximum height is lower, and the horizontal velocity decreases.

Structured questions

Question 1 (8 marks)

The graph shows the velocity of a trolley moving along a straight horizontal track.



(a) Calculate the acceleration of the trolley during the first 4.0 s. [2]

(b) Determine the total distance travelled by the trolley. [3]

(c) Calculate the average speed over the whole 14 s. [2]

(d) State the direction of the resultant force on the trolley between 10 s and 14 s. [1]

Mark scheme

- (a) $a = \Delta v/\Delta t$ with $12/4.0$ (1); $= 3.0$ m s^{-2} (1)
- (b) distance = area under graph (1); $\frac{1}{2}(4)(12) + (6)(12) + \frac{1}{2}(4)(12)$ (1); $= 120$ m (1)
- (c) average speed = total distance ÷ total time (1); $120/14 = 8.6$ m s^{-1} (1)
- (d) opposite to the direction of motion (it is decelerating) (1)

Question 2 (8 marks)

A stone is thrown horizontally at $6.0\ \text{m s}^{-1}$ from a bridge $30\ \text{m}$ above a river. Ignore air resistance.

(a) Calculate the time taken for the stone to reach the water. [2]

(b) Calculate the horizontal distance from the bridge at which it lands. [1]

(c) Determine the speed of the stone as it reaches the water. [3]

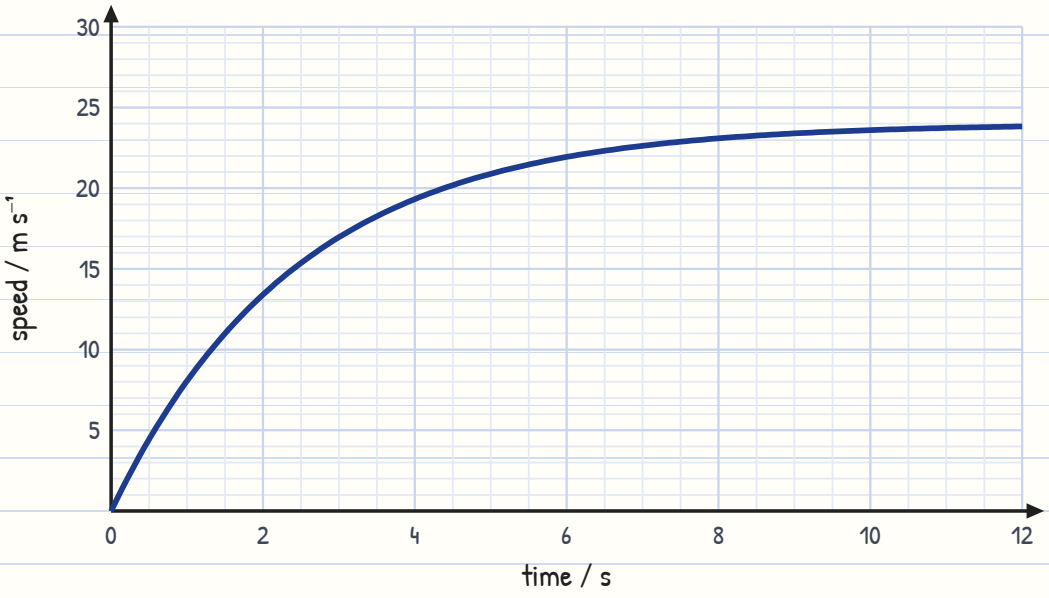
(d) State and explain the effect of air resistance on the horizontal distance. [2]

Mark scheme

- (a) $30 = \frac{1}{2}(9.81)t^2$ (1); $t = 2.5\ \text{s}$ (2.47 s) (1)
- (b) $6.0 \times 2.47 = 15\ \text{m}$ (14.8 m) (1)
- (c) $v_y = gt = 9.81 \times 2.47 = 24.3\ \text{m s}^{-1}$ (1); $v = \sqrt{6.0^2 + 24.3^2}$ (1); $= 25\ \text{m s}^{-1}$ (1)
  (energy method: $\sqrt{36 + 2 \times 9.81 \times 30} = 25$ also gains all three)
- (d) the horizontal distance would be smaller (1); drag has a horizontal component opposing the motion, so horizontal velocity decreases (1)

Question 3 (7 marks)

A steel sphere of mass $0.050\ \text{kg}$ is released from rest in a tall cylinder of oil. The graph shows its speed against time.



(a) Describe how the acceleration of the sphere changes from $t = 0$ to $t = 12$ s. [2]

(b) Explain, in terms of the forces acting, why the sphere reaches a constant speed. [3]

(c) Determine the resistive force on the sphere at the terminal speed. [2]

Mark scheme

- (a) the acceleration decreases (1); from about $9.8\ \text{m s}^{-2}$ at the start (the gradient is steepest) to zero when the speed is constant (the gradient is zero) (1)
- (b) drag increases as speed increases (1); until the drag (plus any upthrust) equals the weight (1); the resultant force is then zero so the acceleration is zero and the speed is constant (Newton's first law) (1)
- (c) at terminal speed resistive force = weight (1); $0.050 \times 9.81 = 0.49\ \text{N}$ (1)

> Note: the weight is the total downward force; any buoyant force is included in "resistive force" here.

Quick reference

Equations (data booklet)

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

Projectile (up +): $a_y = -g$, $a_x = 0$

$u_x = u\cos\theta$, $u_y = u\sin\theta$

level ground: $T = \dfrac{2u\sin\theta}{g}$, $H = \dfrac{u^2\sin^2\theta}{2g}$, $R = \dfrac{u^2\sin 2\theta}{g}$

Graphs

s-t: gradient = v

v-t: gradient = a, area = Δs

a-t: area = Δv

Drag: opposes v; terminal speed when drag = weight ($a = 0$); projectile: shorter range, steeper descent

"I can" checklist

- ☐ I can explain displacement versus distance and velocity versus speed.
- ☐ I can find acceleration from a tangent and displacement from an area.
- ☐ I can choose the correct suvat equation and use signs correctly.
- ☐ I can solve projectile problems launched horizontally, above and below the horizontal.
- ☐ I can describe the effects of fluid resistance and terminal speed.