

A.1 Kinematics

Ahmed Gomaa · IB DP Physics SL and HL · ideas explained step by step · original worked examples

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Pen colours: blue = the motion itself, red = laws, velocities and key steps, green = answers and accelerations, pencil = construction lines and side notes. Boxes: **Why?** = the reasoning, **Mistake** = what students get wrong, yellow note = exam tip.

The big picture

Kinematics describes motion: where an object is, how fast it moves and how its motion changes. It does not ask *why* the motion changes; that is the job of forces (A.2).

Everything in this topic is built from three quantities and two links between them:

position $s \rightarrow$ velocity $v \rightarrow$ acceleration a

velocity = rate of change of position · acceleration = rate of change of velocity

With these we can do three things: (1) describe a motion in words, numbers and graphs; (2) predict where an object will be and how fast it will move; (3) analyse real motions such as a car braking, a ball thrown from a cliff or a skydiver falling through air.

Why start with straight lines?

Most motions are complicated. But a projectile is just two straight-line motions happening at the same time, one across and one up and down. If you master motion in a straight line, you have already done most of the work for motion in two dimensions.

Position, displacement and distance

To describe motion along a line, choose a **zero** (origin) and a **positive direction**. Then the **position** s of an object is a number with a sign: $s = +7$ m means 7 m from the origin in the positive direction, $s = -3$ m means 3 m on the other side. The choice of origin and positive direction is yours, but you must keep it for the whole problem.

Displacement = change in position: $\Delta s = s_{\text{final}} - s_{\text{initial}}$ (a vector: it has a sign)

Distance = total length of the path travelled (a scalar: never negative)



The robot's path: 16 m out, 26 m back. Distance = 42 m, but displacement = -10 m.

Worked example 1

A delivery robot in a corridor starts at $s = +6$ m, drives to $s = +22$ m, then turns and drives to $s = -4$ m. Find (a) its displacement and (b) the distance it travels.

1. Displacement only cares about the start and the end: $\Delta s = s_{\text{final}} - s_{\text{initial}} = (-4) - (+6)$.
2. (a) $\Delta s = -10$ m: the robot ends 10 m on the negative side of where it started.
3. Distance adds up every part of the path: $22 - 6 = 16$ m out, then $22 - (-4) = 26$ m back.
4. (b) distance = $16 + 26 = 42$ m

✗ Mistake

"The robot went 42 m, so its displacement is 42 m." Distance and displacement are only equal if the object never changes direction. Here it turns round, so they are very different.

Speed and velocity

Speed tells you how fast; velocity tells you how fast **and** which way.

Average velocity = displacement / time: $\bar{v} = \Delta s / \Delta t$ (a vector)

Average speed = distance / time (a scalar)

Worked example 2

The robot trip in Worked example 1 took 14 s. Find its average speed and its average velocity.

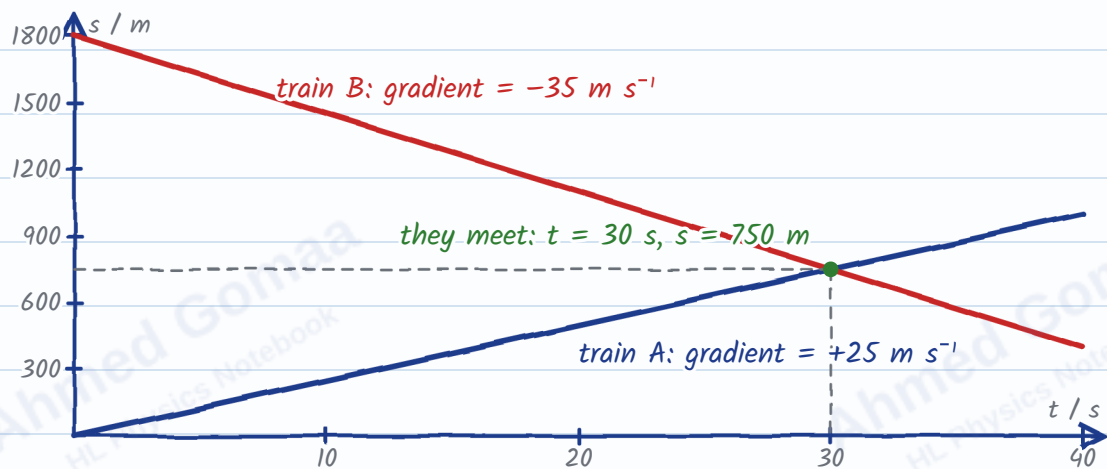
1. Average speed = distance / time = $42 / 14 = 3.0 \text{ m s}^{-1}$
2. Average velocity = displacement / time = $-10 / 14 = -0.71 \text{ m s}^{-1}$
3. The minus sign means "towards decreasing s". The two answers differ because the robot changed direction.

Uniform motion

If the velocity is constant, the position changes by the same amount every second. Starting at s_0 :

$$s = s_0 + vt \quad (\text{constant velocity only})$$

On a graph of s against t this is a straight line: the **gradient is the velocity** and the intercept is s_0 . A positive gradient means moving towards increasing s ; a negative gradient means moving the other way.



Where the two lines cross, the trains are at the same place at the same time.

Worked example 3

Train A leaves $s = 0$ at $+25 \text{ m s}^{-1}$. At the same moment train B, on a parallel track at $s = 1800 \text{ m}$, moves at -35 m s^{-1} . When and where do they pass each other?

1. Write each position: $s_A = 25t$, $s_B = 1800 - 35t$.
2. They meet when $s_A = s_B$: $25t = 1800 - 35t \rightarrow 60t = 1800 \rightarrow t = 30 \text{ s}$.
3. Position: $s = 25 \times 30 = 750 \text{ m}$. (Check with B: $1800 - 35 \times 30 = 750 \text{ m}$. ✓)

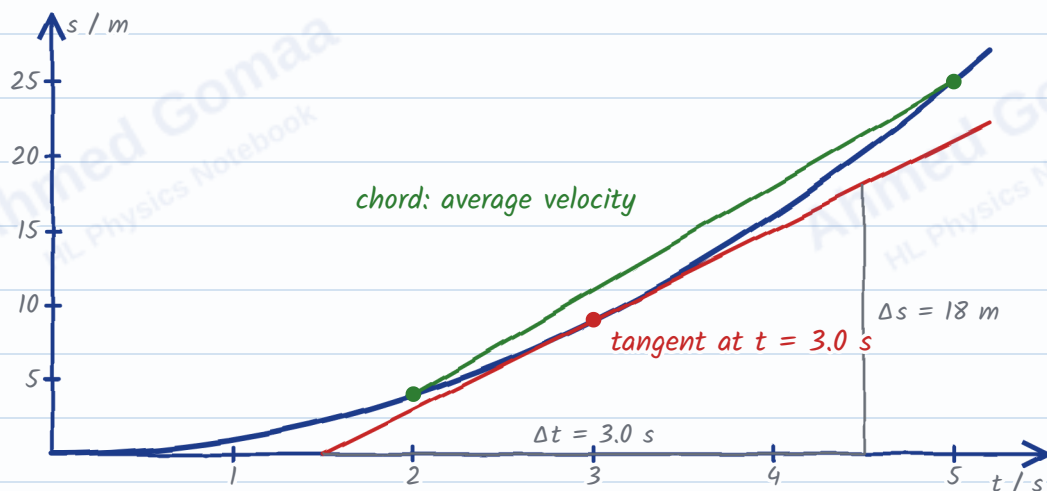
Meeting problems

Write a position equation for each object, using the same origin and the same clock. Then set the positions equal.

Instantaneous velocity

A car's speedometer does not show the average for the whole trip; it shows the velocity **now**. To get this, we take the average velocity over a shorter and shorter time interval.

Instantaneous velocity = the rate of change of position at one instant
= the **gradient of the tangent** to the s - t graph at that instant



Chord (green) $\rightarrow$ average velocity over an interval. Tangent (red) $\rightarrow$ instantaneous velocity at one time.

Worked example 4

Use the graph to find (a) the average velocity from $t = 2.0 \text{ s}$ to $t = 5.0 \text{ s}$ and (b) the instantaneous velocity at $t = 3.0 \text{ s}$.

1. (a) Chord from $(2.0 \text{ s}, 4 \text{ m})$ to $(5.0 \text{ s}, 25 \text{ m})$: $\bar{v} = \Delta s / \Delta t = (25 - 4) / (5.0 - 2.0) = 7.0 \text{ m s}^{-1}$
2. (b) Draw the tangent at $t = 3.0 \text{ s}$. Read two points far apart on the tangent: $(1.5 \text{ s}, 0)$ and $(4.5 \text{ s}, 18 \text{ m})$.
3. Gradient $= 18 / 3.0 = 6.0 \text{ m s}^{-1}$

Tangents in the exam

Use a long ruler, touch the curve at one point only, and pick two points on your line that are far apart (not points on the curve). The IB allows a range of answers because tangents are never perfect.

The size of the instantaneous velocity is the **instantaneous speed**. From now on, "velocity" means instantaneous velocity unless the word "average" is used.

Acceleration

Acceleration = rate of change of velocity: $a = \Delta v / \Delta t$ (unit m s^{-2})

Instantaneous acceleration = gradient of the tangent to the v - t graph

Average acceleration uses the velocity change over a whole interval. If the acceleration is constant, average and instantaneous acceleration are the same. For example, a cyclist who speeds up from 3.0 m s^{-1} to 9.0 m s^{-1} in 4.0 s has $a = (9.0 - 3.0) / 4.0 = 1.5 \text{ m s}^{-2}$.

Why can "negative acceleration" mean speeding up?

Acceleration is a vector. Its sign only tells you the direction of the change in velocity. If $v = -5 \text{ m s}^{-1}$ becomes $v = -9 \text{ m s}^{-1}$, then $\Delta v = -4 \text{ m s}^{-1}$; the acceleration is negative, but the object is going **faster** (in the negative direction). An object slows down when v and a have **opposite** signs and speeds up when they have the **same** sign.

✗ Mistake

"At the top of its flight a ball has zero velocity, so its acceleration is zero." No: the velocity is still changing (from up to down) at that instant, so the acceleration is still g downwards.

The equations of motion

When the acceleration is **constant** (uniform), four equations connect five quantities: displacement s , initial velocity u , final velocity v , acceleration a and time t .

$$v = u + at$$

$$s = \frac{1}{2}(u + v)t$$

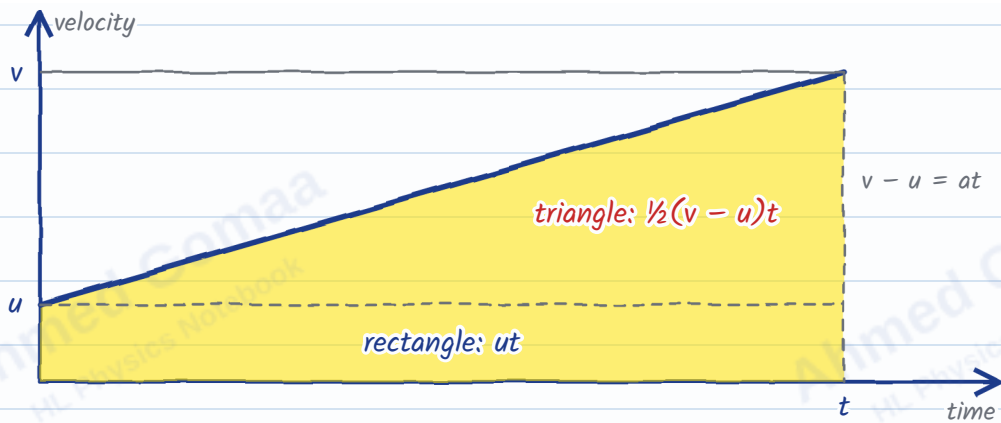
$$s = ut + \frac{1}{2}at^2$$

$$v^2 = u^2 + 2as$$

(constant acceleration only · all are in the data booklet)

The idea behind them

You do not need to derive the equations (they are in the data booklet). One idea behind them is examined again and again: **the displacement is the area under the v - t graph**. For constant acceleration that area is a rectangle (ut) plus a triangle ($\frac{1}{2}at^2$), which gives $s = ut + \frac{1}{2}at^2$.

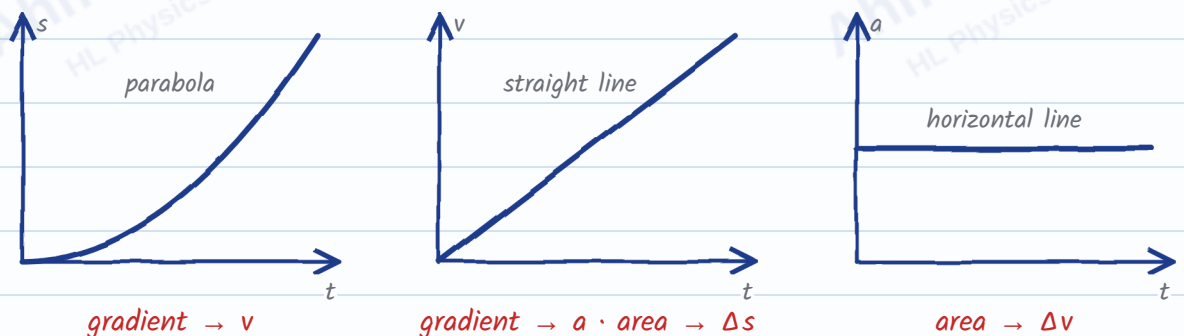


Area under a v - t graph = displacement. Rectangle + triangle gives $s = ut + \frac{1}{2}at^2$.

Why is the area the displacement?

Over a very short time δt the velocity hardly changes, so the displacement is $v \times \delta t$: the area of a thin strip under the graph. Add up all the strips and you get the whole area. This works for **any** v - t graph, even when the acceleration is not constant.

For constant acceleration, the three graphs always have the same shapes:



Constant acceleration from rest: s - t parabola, v - t straight line, a - t horizontal line.

Using the equations

Each equation leaves out one of the five quantities. So the method is always the same:

Equation	Leaves out	Use it when...
$v = u + at$	s	no distance is given or asked for
$s = \frac{1}{2}(u + v)t$	a	no acceleration is given or asked for

$$s = ut + \frac{1}{2}at^2 \quad v$$

no final velocity is given or asked for

$$v^2 = u^2 + 2as \quad t$$

no time is given or asked for

Four steps for every problem

1. Draw a sketch and choose the positive direction.
2. List s , u , v , a , t with signs. Mark the one you want with "?".
3. Pick the equation that leaves out the quantity you neither know nor want.
4. Substitute, solve, then check the sign and size make sense.

Worked example 5

A car moving at 4.0 m s^{-1} accelerates uniformly at 2.5 m s^{-2} for 6.0 s . Find its final velocity and the distance it travels.

1. $u = 4.0$, $a = 2.5$, $t = 6.0$; $v = ?$, $s = ?$
2. $v = u + at = 4.0 + 2.5 \times 6.0 = 19 \text{ m s}^{-1}$
3. $s = ut + \frac{1}{2}at^2 = 4.0 \times 6.0 + \frac{1}{2} \times 2.5 \times 6.0^2 = 24 + 45 = 69 \text{ m}$
4. Check with $s = \frac{1}{2}(u + v)t = \frac{1}{2}(4.0 + 19) \times 6.0 = 69 \text{ m} \checkmark$

Worked example 6

A train moving at 30 m s^{-1} brakes uniformly and stops in 450 m . Find its acceleration and the braking time.

1. $u = 30$, $v = 0$, $s = 450$; $a = ?$, $t = ?$ No time given $\rightarrow$ use $v^2 = u^2 + 2as$.
2. $0 = 30^2 + 2a \times 450 \rightarrow a = -900/900 = -1.0 \text{ m s}^{-2}$ (minus: opposite to the motion)
3. Time: $v = u + at \rightarrow 0 = 30 - 1.0t \rightarrow t = 30 \text{ s}$

Stopping distance

A driver needs time to react before braking starts. During this **reaction time** the car still moves at constant speed. Then it slows with constant deceleration.

Worked example 7

A driver moving at 20 m s^{-1} sees a hazard. Her reaction time is 0.70 s , and the brakes give a deceleration of 5.0 m s^{-2} . Find the total stopping distance.

1. Thinking distance (constant speed): $20 \times 0.70 = 14 \text{ m}$.
2. Braking distance: $v^2 = u^2 + 2as \rightarrow 0 = 20^2 + 2(-5.0)s \rightarrow s = 400/10 = 40 \text{ m}$.
3. Total = $14 + 40 = 54 \text{ m}$

✗ Mistake

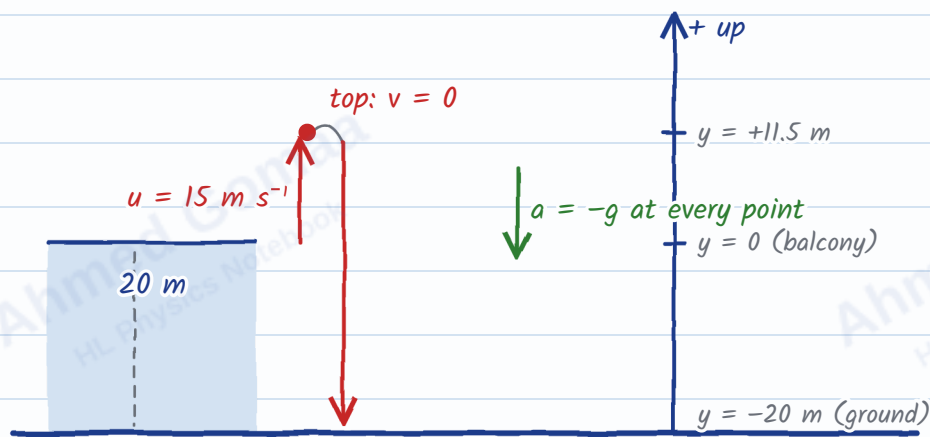
Using a suvat equation for the whole stopping distance in one go. The reaction time part has $a = 0$ and the braking part has $a = -5.0 \text{ m s}^{-2}$. Different accelerations $\rightarrow$ split the motion into stages.

Free fall and vertical throws

Near the Earth's surface, if air resistance is negligible, every object has the same acceleration, directed vertically downwards: the **acceleration of free fall**, $g = 9.8 \text{ m s}^{-2}$ (9.81 in the data booklet). This is true whether the object is going up, at the top, or coming down.

Choose up as positive $\rightarrow a = -g = -9.8 \text{ m s}^{-2}$

Then the suvat equations work for the whole flight, up and down together.



One axis, one origin (the balcony), up positive. The ground is at $y = -20 \text{ m}$.

Worked example 8

A ball is thrown vertically upwards at 15 m s^{-1} from a balcony 20 m above the ground. Find (a) the maximum height above the balcony, (b) the time to reach it, (c) the time to hit the ground, (d) the speed on hitting the ground. ($g = 9.8 \text{ m s}^{-2}$)

1. Up positive, origin at the balcony: $u = +15$, $a = -9.8$.
2. (a) At the top $v = 0$: $0 = 15^2 - 2 \times 9.8 \times s \rightarrow s = 225/19.6 = 11.5 \text{ m}$
3. (b) $0 = 15 - 9.8t \rightarrow t = 1.53 \text{ s}$
4. (c) At the ground $s = -20 \text{ m}$: $-20 = 15t - 4.9t^2 \rightarrow 4.9t^2 - 15t - 20 = 0$.
5. Quadratic formula: $t = [15 + \sqrt{(15^2 + 4 \times 4.9 \times 20)}] / 9.8 = (15 + 24.8)/9.8 = 4.07 \text{ s}$ (the negative root has no meaning here).
6. (d) $v^2 = u^2 + 2as = 15^2 + 2(-9.8)(-20) = 617 \rightarrow \text{speed} = 24.8 \text{ m s}^{-1}$ (the velocity is -24.8 m s^{-1} : downwards).

Why does the ball pass the balcony at 15 m s^{-1} ?

Without air resistance the motion is symmetric. Put $s = 0$ into $v^2 = u^2 + 2as$: $v^2 = u^2$, so $v = -15 \text{ m s}^{-1}$. It comes back down past the balcony at the same speed it went up, and the time up equals the time down.

✗ Mistake

Splitting the flight into "up" and "down" with different sign rules and then mixing them. It is fine to split, but in each stage write every quantity with the sign of **your** chosen positive direction. With up positive, a is -9.8 m s^{-2} both on the way up and on the way down.

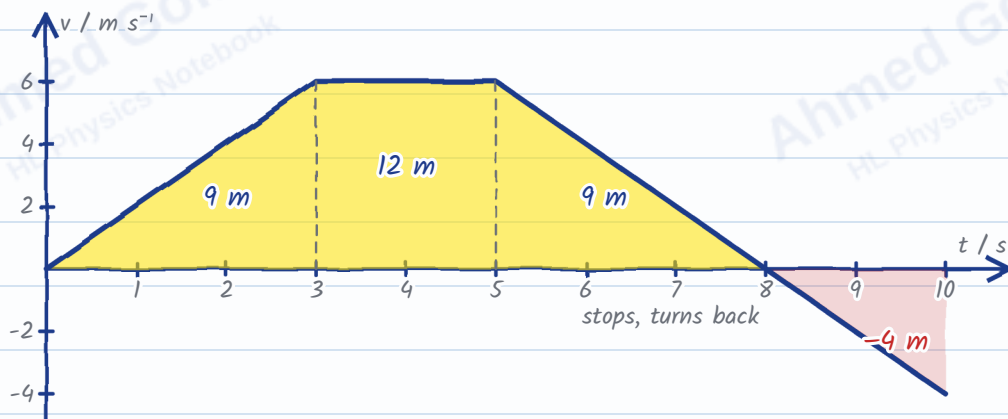
Motion graphs

Graphs work for **every** motion, even when the acceleration changes and the suvat equations cannot be used. Learn this table:

Graph	Gradient gives	Area under it gives
s against t	velocity	(nothing useful)
v against t	acceleration	displacement
a against t	(not needed)	change in velocity

Worked example 9

The v - t graph shows a toy car moving along a track. Find (a) the acceleration in the first 3.0 s, (b) the displacement after 10 s, (c) the distance travelled, (d) the average velocity and average speed.

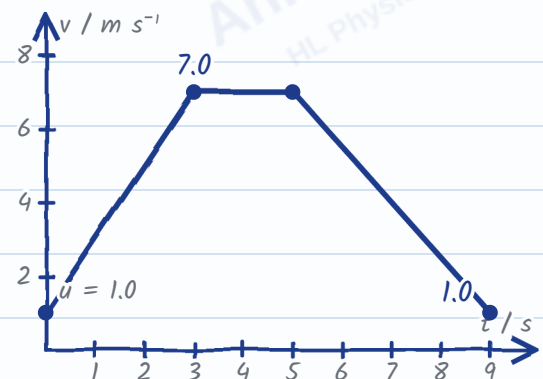
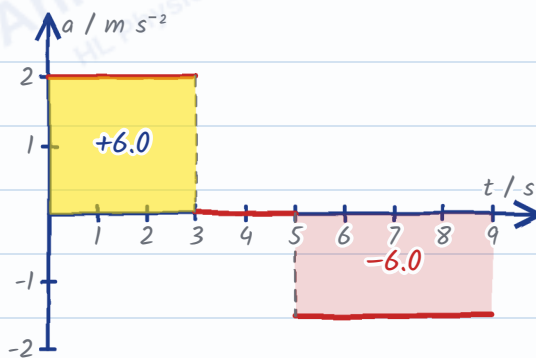


1. (a) Gradient of the first line: $a = 6.0/3.0 = 2.0 \text{ m s}^{-2}$

2. Areas: 0–3 s triangle $\frac{1}{2} \times 3 \times 6 = 9 \text{ m}$; 3–5 s rectangle $2 \times 6 = 12 \text{ m}$; 5–8 s triangle $\frac{1}{2} \times 3 \times 6 = 9 \text{ m}$; 8–10 s triangle below the axis $\frac{1}{2} \times 2 \times 4 = 4 \text{ m}$, so -4 m .
3. (b) Displacement = $9 + 12 + 9 - 4 = 26 \text{ m}$
4. (c) Distance = $9 + 12 + 9 + 4 = 34 \text{ m}$ (areas below the axis count as positive for distance)
5. (d) Average velocity = $26/10 = 2.6 \text{ m s}^{-1}$; average speed = $34/10 = 3.4 \text{ m s}^{-1}$

Reading a graph from another graph

To sketch v - t from an s - t graph, look at the **gradient** of the s - t graph at many times: steep and rising $\rightarrow$ large positive v ; flat $\rightarrow v = 0$; falling $\rightarrow$ negative v . To go the other way (a - $t \rightarrow v$ - t), add up the **area** under the a - t graph, starting from the initial velocity.



Area under a - t = change in v . Start from $u = 1.0 \text{ m s}^{-1}$: $+6.0 \rightarrow 7.0$, then 0, then $-6.0 \rightarrow 1.0 \text{ m s}^{-1}$.

✗ Mistake

Reading the height of a v - t graph as the position. The height is the velocity. A v - t line that goes down does not mean the object is moving down; it means its velocity is decreasing.

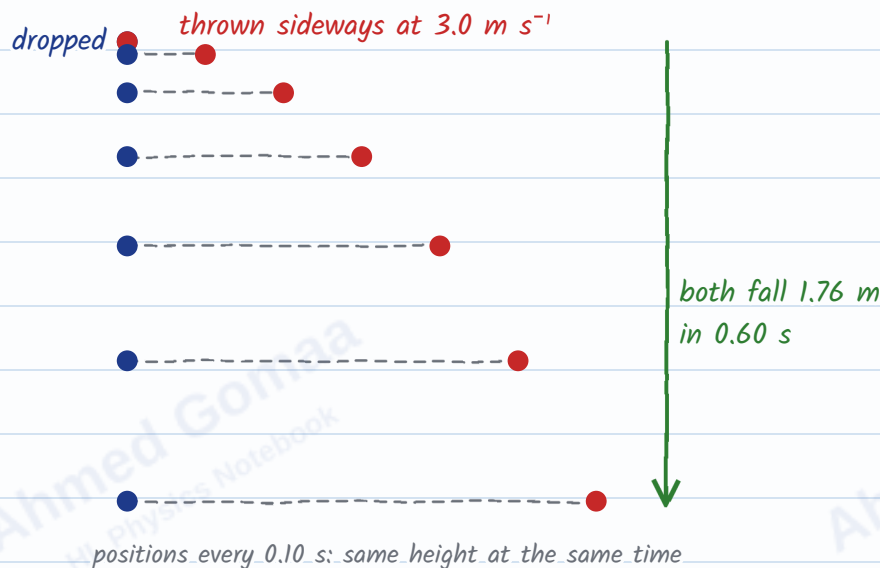
Projectiles: two motions in one

A **projectile** is an object moving freely through the air after it is launched, with only gravity acting (no air resistance in calculations). The key idea:

The horizontal and vertical motions are **independent**.

Horizontal: $a = 0 \rightarrow$ constant velocity · Vertical: $a = -g \rightarrow$ free fall

They share only one thing: the **time**.



The sideways motion does not change how fast the ball falls.

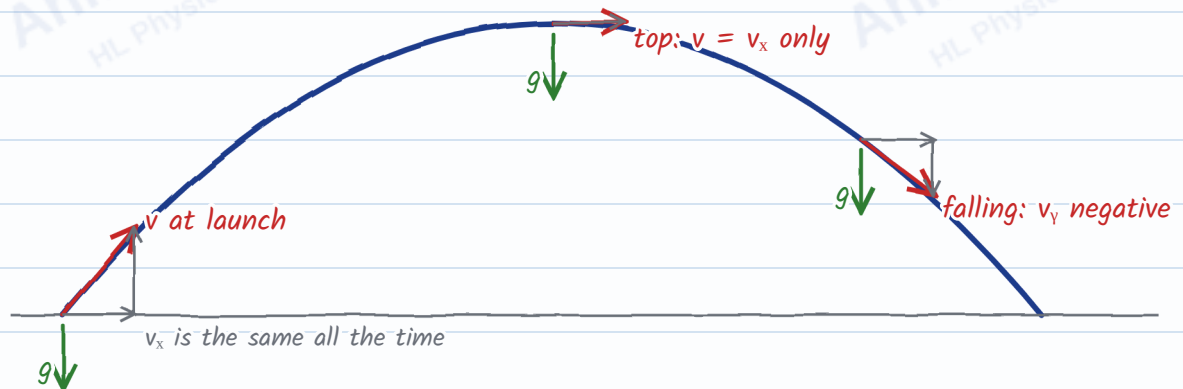
Why are the motions independent?

The only force is the weight, and it is vertical. A vertical force can change only the vertical velocity. Nothing acts horizontally, so the horizontal velocity never changes. (A.2 makes this exact with Newton's second law.)

So we split the launch velocity into components, then use straight-line kinematics in each direction separately. For launch speed u at angle θ above the horizontal (origin at the launch point, up positive):

	Horizontal (x)	Vertical (y)
initial velocity	$u_x = u \cos \theta$	$u_y = u \sin \theta$
acceleration	0	$-g$
velocity at time t	$v_x = u \cos \theta$ (constant)	$v_y = u \sin \theta - gt$
position at time t	$x = (u \cos \theta) t$	$y = (u \sin \theta) t - \frac{1}{2}gt^2$

The speed at any time is $v = \sqrt{v_x^2 + v_y^2}$ and the direction is given by $\tan \phi = v_y / v_x$. Without air resistance the path is a parabola (you do not need its equation).



v_x never changes. v_y decreases steadily, is zero at the top, then negative. The acceleration is g downwards everywhere.

Launch at an angle (level ground)

Three results come from the table. Derive them in the exam rather than learning them by heart:

1. Time to the top: $v_y = 0 \rightarrow t_{\text{top}} = u \sin \theta / g$
2. Maximum height: $0 = (u \sin \theta)^2 - 2gH \rightarrow H = (u \sin \theta)^2 / 2g$
3. Time of flight (back to the launch height): $T = 2t_{\text{top}} = 2u \sin \theta / g$,
and the range $R = (u \cos \theta) \times T$.

Worked example 10

A football is kicked from the ground at 22 m s^{-1} at 35° above the horizontal. Find (a) the components of the initial velocity, (b) the maximum height, (c) the time of flight, (d) the range. ($g = 9.8 \text{ m s}^{-2}$, no air resistance)

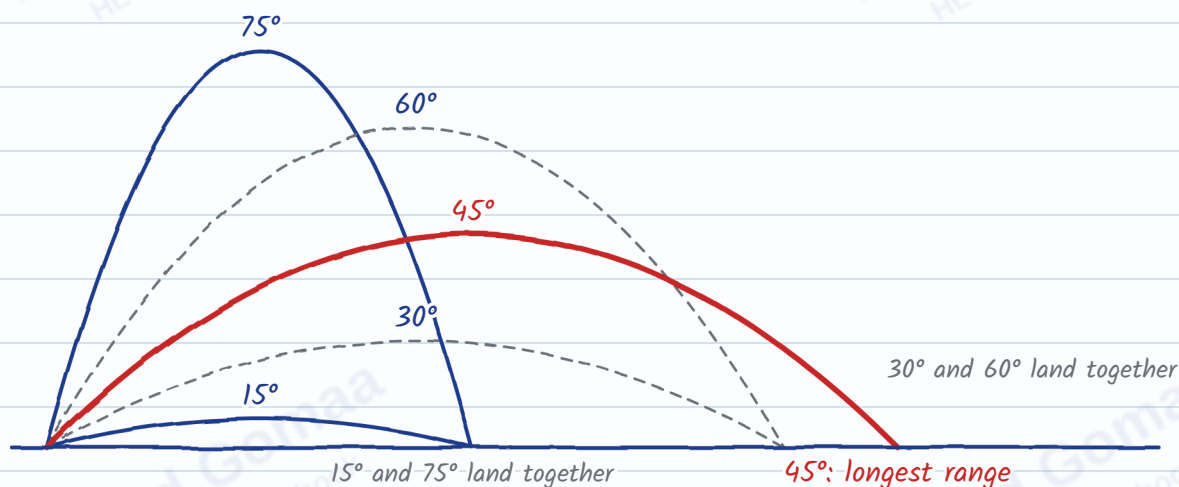
1. (a) $u_x = 22 \cos 35^\circ = 18.0 \text{ m s}^{-1}$; $u_y = 22 \sin 35^\circ = 12.6 \text{ m s}^{-1}$

2. (b) $H = u_y^2 / 2g = 12.6^2 / 19.6 = 8.1 \text{ m}$

3. (c) $T = 2u_y / g = 2 \times 12.6 / 9.8 = 2.6 \text{ s}$

4. (d) $R = u_x T = 18.0 \times 2.58 = 46 \text{ m}$ (keep unrounded values in your calculator)

45° gives the largest range on level ground, without air resistance.



Same speed, different angles: 45° goes furthest.

✗ Mistake

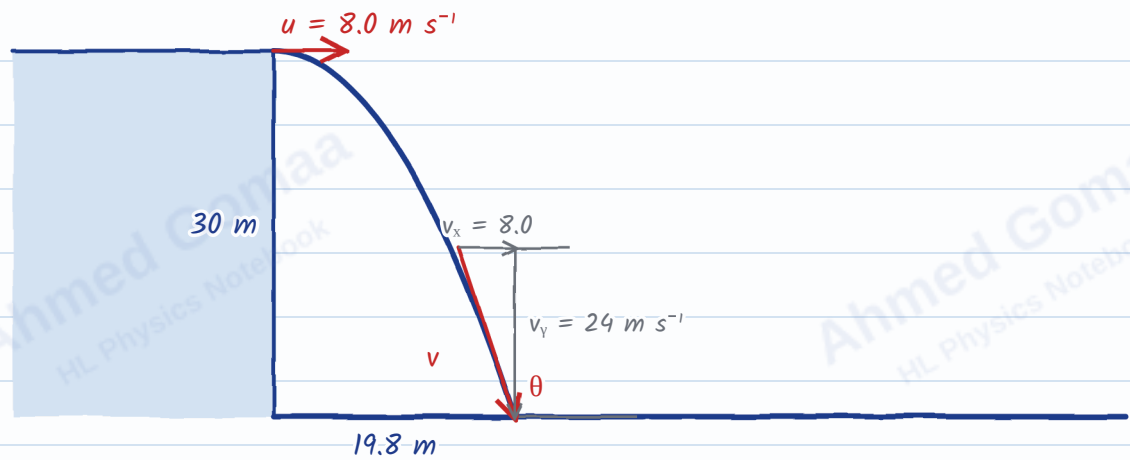
Saying the velocity at the top is zero. Only the **vertical** component is zero. The ball still moves horizontally at $u \cos \theta$, so the speed at the top is $u \cos \theta$ (its smallest value).

Launch from a height

When the launch point is above the landing point, the flight is **not** symmetric and the shortcuts $T = 2u \sin \theta / g$ and $R = u^2 \sin 2\theta / g$ do **not** work. Go back to the vertical equation with y equal to the landing height (negative).

Horizontal launch

$\theta = 0$, so $u_y = 0$ and $u_x = u$. The time of flight depends only on the height:
 $-h = -\frac{1}{2}gt^2$.



At impact: add the components like vectors to get the speed and the angle.

Worked example 11

A stone is thrown horizontally at 8.0 m s^{-1} from the top of a cliff 30 m high. Find (a) the time to reach the ground, (b) how far from the foot of the cliff it lands, (c) its speed and direction on impact.

1. (a) Vertical: $-30 = 0 - \frac{1}{2} \times 9.8 \times t^2 \rightarrow t^2 = 60/9.8 \rightarrow t = 2.47 \text{ s}$
2. (b) Horizontal: $x = 8.0 \times 2.47 = 19.8 \text{ m}$
3. (c) $v_x = 8.0 \text{ m s}^{-1}$; $v_y = 0 - 9.8 \times 2.47 = -24.2 \text{ m s}^{-1}$.
4. Speed $v = \sqrt{(8.0^2 + 24.2^2)} = 25.5 \text{ m s}^{-1}$; angle below horizontal:
 $\tan \phi = 24.2/8.0 \rightarrow \phi = 72^\circ$

Launch below the horizontal

Worked example 12

A ball is thrown from a window 15 m above the ground at 10 m s^{-1} , at 30° below the horizontal. How far from the wall does it land?

1. Up positive: $u_x = 10 \cos 30^\circ = 8.66 \text{ m s}^{-1}$; $u_y = -10 \sin 30^\circ = -5.0 \text{ m s}^{-1}$ (downwards).
2. Vertical: $-15 = -5.0t - 4.9t^2 \rightarrow 4.9t^2 + 5.0t - 15 = 0$.
3. $t = [-5.0 + \sqrt{(5.0^2 + 4 \times 4.9 \times 15)}] / 9.8 = (-5.0 + 17.9)/9.8 = 1.31 \text{ s}$.

4. Horizontal: $x = 8.66 \times 1.31 = 11 \text{ m}$

Projectile checklist

1. Origin at the launch point, up positive.
2. Split u into u_x and u_y (watch the sign of u_y).
3. Find the time from the **vertical** motion.
4. Use that time in the **horizontal** motion.
5. For the final velocity, combine v_x and v_y with Pythagoras and $\tan$.

✗ Mistake

Using the launch speed u in the vertical equation, or using g in the horizontal equation. Each direction has its own initial velocity component and its own acceleration (0 across, $-g$ vertically).

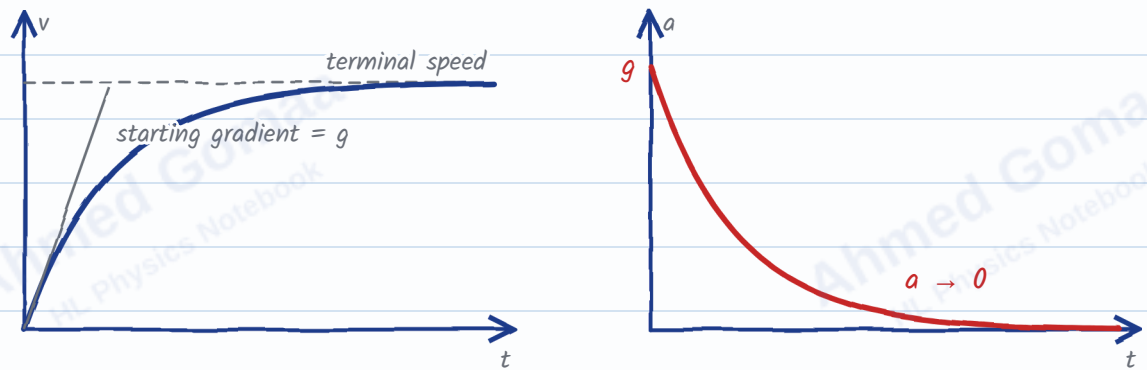
Fluid resistance and terminal speed

Any object moving through a fluid (a gas such as air, or a liquid such as water) feels a **fluid resistance** force (drag). Drag always acts **opposite to the velocity**, and it gets **larger as the speed increases**. For **projectiles**, the IB only asks for the effects of fluid resistance in words. You will still calculate with drag when a formula is given (for example $F = cv^2$) and in A.2 (Stokes's law, $F_d = 6\pi\eta rv$).

Falling with air resistance

1. At the start the speed is zero, so there is no drag: the acceleration is g .
2. As the speed grows, the drag grows. The resultant force (weight – drag) gets smaller, so the acceleration gets smaller.
3. Eventually drag = weight (in air, buoyancy is negligible). The resultant force is zero, so the acceleration is zero and the speed stays constant:

the terminal speed.

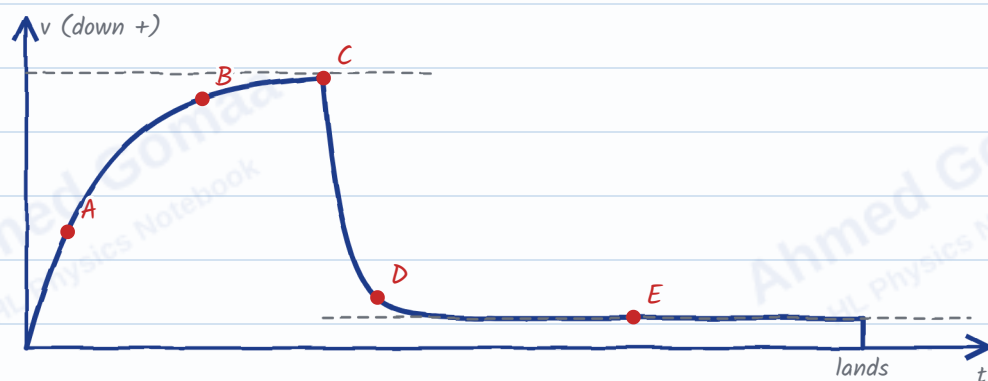


v rises and levels off at the terminal speed; a starts at g and falls to zero.

Terminal speed: the constant speed reached when the **resultant force** on the object is zero, so its acceleration is zero. For a dense object falling through air, buoyancy is tiny, so $\text{drag} \approx \text{weight}$. In a liquid, or for a balloon: falling, $\text{drag} + \text{buoyancy} = \text{weight}$; rising, $\text{buoyancy} = \text{weight} + \text{drag}$.

Worked example 13

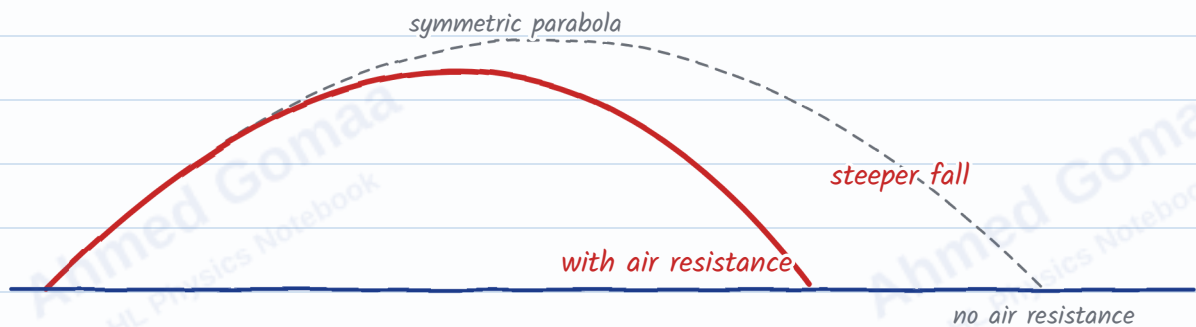
Describe the motion of a skydiver at each labelled point of the v - t graph (down positive).



1. **A:** just after jumping, speed small, drag small $\rightarrow$ acceleration close to g .
2. **B:** drag almost equal to weight $\rightarrow$ acceleration almost zero; close to the first terminal speed.

3. C: the parachute opens. The area facing the air is much larger, so drag is now much **bigger** than the weight $\rightarrow$ large acceleration **upwards**: the skydiver slows down (she does not move up).
4. D: as she slows, the drag decreases, so the deceleration decreases.
5. E: drag = weight again (resultant force zero) at a much lower terminal speed, safe for landing.

Projectiles with air resistance



Same launch velocity. Pencil: no air resistance. Red: with air resistance.

Quantity	Effect of air resistance
maximum height	smaller
range	smaller
time of flight	depends on the launch. Thrown horizontally or downwards: longer , because on the way down the drag has an upward part, so the ball falls with an acceleration less than g . Thrown upwards: it does not rise as high, so the total time is often a little shorter. Do not assume: think about the vertical forces.
trajectory	not a parabola, not symmetric: the way down is steeper than the way up
horizontal velocity	decreases during the flight (drag has a horizontal part)

acceleration not constant. Its **vertical** part is greater than g on the way up (the drag has a downward part), exactly g at the top (the drag is horizontal there), and less than g on the way down (the drag has an upward part). Its horizontal part is backwards all the time.

landing speed smaller than the launch speed (energy is transferred to the air)

terminal speed a long fall approaches a terminal speed instead of speeding up for ever

Why is the way down steeper?

Drag keeps reducing the horizontal velocity during the whole flight. On the way down the ball covers less horizontal distance for each metre it falls than it did on the way up, so the path bends down more sharply.

✗ Mistake

"When the parachute opens, the skydiver goes up." The velocity is still downwards; only the acceleration points up. She keeps falling, but more slowly.

Writing the explanations

Most A.1 marks come from calculations, but the short explanations about air resistance and graphs come up again and again, and markschemes look for the same key words every time.

"State what is meant by velocity / acceleration" (1 mark)

✓ Velocity is the **rate of change of position** (of displacement).

✓ Acceleration is the **rate of change of velocity**.

Always say "rate of change". "Speed in a direction" or "how fast it speeds up" will not get the mark.

"Explain why the falling object reaches a terminal speed"
(2-3 marks)

- ✓ A **drag force** (air resistance) acts on the object, opposite to its velocity (upwards when it falls).
- ✓ The drag **increases with speed**, so the resultant force and the acceleration get smaller.
- ✓ Drag becomes equal to the weight (in a liquid: drag + buoyancy = weight), so the **resultant force is zero**, the acceleration is zero and the speed stays constant.

Name the forces and say "resultant force is zero". The forces do not disappear; they balance.

"State the acceleration of the object at the start / at the top of its flight" (1 mark)

- ✓ It is $g = 9.8 \text{ m s}^{-2}$ (the acceleration of free fall), **vertically downwards**, with no air resistance. At the start of a fall with drag, $v = 0$, so there is no drag yet and $a = g$.
- ✓ On a drawing, the acceleration arrow is vertically down at every point; the velocity arrow is along the **tangent to the path**.

Write "g" or " 9.8 m s^{-2} ", not just "gravity". And never say the acceleration is zero at the top.

"Outline the effect of air resistance on the vertical acceleration of a projectile" (2 marks)

- ✓ Air resistance **opposes the velocity** (the direction of motion).
- ✓ On the way **up** the drag has a downward part, so the vertical acceleration is **greater than g**.
- ✓ On the way **down** the drag has an upward part, so the vertical acceleration is **less than g**. At the very top the drag is

horizontal, so the vertical part is exactly g .

Compare with g every time: "greater than g " and "less than g ".

"Describe how air resistance changes the path of a projectile" (2–3 marks)

- ✓ The **range** and the **maximum height** are smaller.
- ✓ The horizontal velocity **decreases** during the flight, so the path is **not a parabola**: it is not symmetric and the way down is steeper than the way up.
- ✓ **Time of flight**: thrown horizontally or downwards it is longer; thrown upwards, think about the vertical forces before you answer. A long fall approaches a **terminal speed**.

For each quantity, give the effect and one reason in terms of the drag force.

"Determine the distance / the acceleration from the velocity–time graph" (2–3 marks)

- ✓ Distance (displacement) = **area under the v - t graph**. For a curved line, count squares or split into simple shapes; say what one square is worth.
 - ✓ Acceleration at one instant = **gradient of the tangent** to the v - t graph at that time.
 - ✓ Show the working on the graph: the shapes you used or the tangent with two far-apart points.
- The first mark is for the method ("area" or "gradient of the tangent"), so write it down even before you calculate.

"Show that the speed (or time) is about ..." (1–2 marks)

- ✓ Write the equation you use (for example $v^2 = u^2 + 2as$) with **every number substituted**.
- ✓ Give the answer to **one more significant figure** than the

value in the question (at least 3 s.f.).

The answer is already given, so the marks are for the working. A bare " $= 4.3$ " earns nothing.

Common mistakes

✗ Ten traps in A.1

1. Writing "gravity" for the acceleration. Write g , or 9.8 m s^{-2} downwards.
2. Using $v = u + at$ or $s = ut + \frac{1}{2}at^2$ when the acceleration is **not constant** (with drag, or on a spring). These equations need uniform acceleration; otherwise use graphs or energy.
3. Saying the forces are zero at terminal speed. The **resultant** force is zero; weight and drag are both still acting.
4. Saying "air resistance increases" without saying why. Write "drag increases **with speed**".
5. Forgetting buoyancy in a liquid. Falling: drag + buoyancy = weight. Rising: buoyancy = weight + drag.
6. Drawing an extra "force of motion" on a free-body diagram. A moving object has only real forces on it: weight, drag (and buoyancy, normal force, friction if present).
7. Saying air resistance makes the vertical acceleration less than g all the time. It is greater than g going up, exactly g at the top and less than g coming down.
8. Assuming air resistance always shortens the time of flight. Thrown horizontally or downwards, the time of flight is longer.
9. Using a chord between two points to find the acceleration at one instant on a curved $v-t$ graph. Draw the tangent at that instant.
10. In a "show that", writing only the rounded answer from the question. Substitute fully and give one more significant figure.

Exam habits

Draw a sketch and mark your positive direction before you write any equation. List s , u , v , a , t with signs. In projectiles, find the time from the vertical motion first. Give final answers to 2 or 3 significant figures with units.

Practise next

You have read the notes. Now practise, in this order:

1. **Levelled practice**: first a ★ at Level 2 in every topic (the goal), then Levels 3 and 4 for a 6 or 7. Hints and worked answers help you as you go.
2. **IB-format practice** ([Paper 1A](#) · [Paper 2](#)): timed, one attempt, and your report goes to your teacher. Do these when the practice goal is reached.

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