

Kinematics

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Read first: [Differentiation](#), [Integration](#)

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What you need to know

By the end of this topic you should be able to:

1. **Use calculus on a particle moving in a straight line.** Differentiate displacement to get velocity, and velocity to get acceleration. Integrate the other way, using given facts to find each constant. This works whether the acceleration is constant or changes with time, and for any function you can differentiate or integrate (powers, e^{kt} , $\ln$, $\sin$ and $\cos$).
2. **Draw and use the five motion graphs:** displacement–time, distance–time, velocity–time, speed–time and acceleration–time. Know what the gradient of each graph and the area under it tell you, and sketch one graph from another or from a formula.

Understand it

Displacement, distance, velocity and speed

A particle moves along a straight line through a fixed point O . At time t :

- its **displacement** s is its position measured from O , with a sign: positive on one side of O , negative on the other;
- its **velocity** v is how fast s is changing, also with a sign: positive means moving in the positive direction, negative means moving the other way;
- its **acceleration** a is how fast v is changing.

Distance and **speed** have no sign. Speed is the size of the velocity, $|v|$: a velocity of -12 m s^{-1} is a speed of 12 m s^{-1} . Distance travelled counts every metre moved, forwards or backwards, so it can never go down.

Displacement only tells you where the particle has ended up.

Differentiate down, integrate up

Velocity is the rate of change of displacement, and acceleration is the rate of change of velocity:

$$v = \frac{ds}{dt}, \quad a = \frac{dv}{dt} = \frac{d^2s}{dt^2}.$$

Going the other way needs integration, and every integration brings a constant:

$$v = \int a \, dt, \quad s = \int v \, dt.$$

The question gives you a fact to find each constant, such as "starts from rest" ($v = 0$ when $t = 0$) or "passes through O when $t = 0$ " ($s = 0$ when $t = 0$). For example, if $a = 6t$ and $v = 2$ when $t = 0$, then $v = 3t^2 + c$ and $2 = 0 + c$, so $v = 3t^2 + 2$.

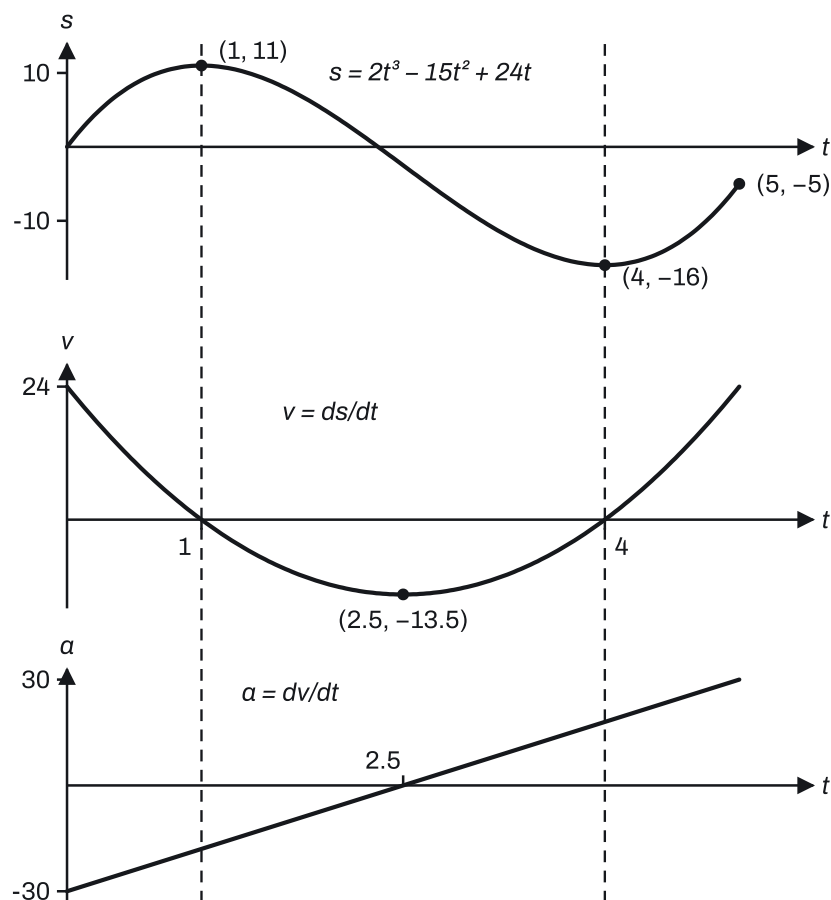
"Constant acceleration" is only a special case: the same calculus still works. You do not need any other formulas.

Key words in questions

The question says	It means
"at (instantaneous) rest"	$v = 0$
"changes direction"	$v = 0$ and v changes sign there
"initially"	$t = 0$
"returns to O " or "passes through O "	$s = 0$
"maximum or minimum velocity"	$a = 0$
"moving towards O "	s and v have opposite signs
"deceleration of 3 m s^{-2} "	$a = -3$ (or a is 3 in the direction opposite to the motion)

The three graphs together

The gradient of the displacement–time graph is the velocity, and the gradient of the velocity–time graph is the acceleration. So the turning points of s are where v crosses zero, and the turning points of v are where a crosses zero.

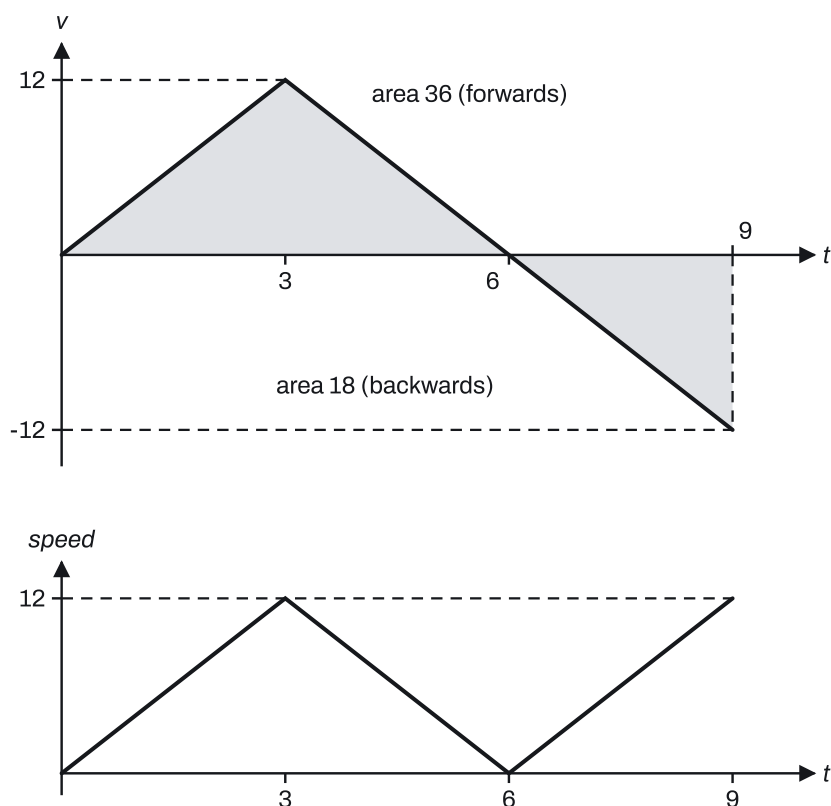


Here $s = 2t^3 - 15t^2 + 24t$, so $v = 6t^2 - 30t + 24 = 6(t - 1)(t - 4)$ and $a = 12t - 30$.

- The particle moves forwards until $t = 1$, when it is 11 m from O . It stops, turns back, and moves backwards until $t = 4$, when $s = -16$. Then it moves forwards again, reaching $s = -5$ at $t = 5$.
- At $t = 2$, $s = 4$ and $v = -12$: it is on the positive side of O and moving in the negative direction, so it is moving **towards** O at a speed of 12 m s^{-1} .
- Its displacement after 5 seconds is -5 m, but the distance it has travelled is $11 + 27 + 11 = 49$ m (out to 11, back 27 to -16 , then forwards 11 to -5).

Area under a velocity–time graph

Integrating v between two times gives the **change in displacement**, which is the area between the graph and the t -axis, counted **positive above the axis and negative below**. For the **distance**, count every area as positive.



When the graph is made of straight lines, find the areas with triangles, rectangles and trapeziums instead of integrating. The gradient of each straight piece is the (constant) acceleration during that piece.

The other graphs follow the same rules:

- **Speed–time:** reflect every part of the velocity–time graph that is below the t -axis up above it.
- **Distance–time:** the same as displacement–time until the particle first turns back; after that, every stretch where displacement goes down is drawn going up by the same amount, so the graph never falls.
- **Acceleration–time:** its gradient means nothing useful, but the area under it is the change in velocity.
- A **displacement–time graph made of straight lines** means constant velocities: each velocity is the gradient of that piece, and a horizontal piece means the particle is at rest.

Key facts and formulas

The 0606 List of formulas has nothing on kinematics or calculus, so everything here must be learnt.

Formula	Status
$v = \frac{ds}{dt}, a = \frac{dv}{dt} = \frac{d^2s}{dt^2}$	Learn it
$v = \int a \, dt, s = \int v \, dt$, each with a constant found from given values	Learn it
Displacement from t_1 to t_2 : $\int_{t_1}^{t_2} v \, dt$ (signed area under the v - t graph)	Learn it

Formula	Status
Distance: split the interval at every time where $v = 0$ and add the sizes of the pieces	Learn it
Speed $=$	v
At rest: $v = 0$; greatest or least velocity: $a = 0$	Learn it
Gradient of $s-t$ = velocity; gradient of $v-t$ = acceleration; area under $a-t$ = change in velocity	Learn it
Derivatives: $\frac{d}{dt}e^{kt} = ke^{kt}$, $\frac{d}{dt}\ln(at+b) = \frac{a}{at+b}$, $\frac{d}{dt}\sin kt = k\cos kt$, $\frac{d}{dt}\cos kt = -k\sin kt$	Learn it
Integrals: $\int e^{kt} dt = \frac{1}{k}e^{kt}$, $\int \frac{1}{at+b} dt = \frac{1}{a}\ln(at+b)$, $\int \sin kt dt = -\frac{1}{k}\cos kt$, $\int \cos kt dt = \frac{1}{k}\sin kt$ (each $+c$)	Learn it

Angles are in **radians** whenever calculus meets $\sin$ or $\cos$: put your calculator in radian mode on Paper 2.

How to do it

In the Paper 1 and Paper 2 questions we have tagged for this topic (33 questions, 2021–2025), the types came up this often. 22 of the 33 questions mix two or three types, so the counts add up to more than 33.

Question type	Questions
Velocity and acceleration by differentiating	21
Velocity and displacement by integrating	13
Sketching motion graphs	7
Distance travelled when the particle turns back	6
Straight-line velocity–time and displacement–time graphs	6
Motion in two stages	5

1. Velocity and acceleration by differentiating (21 questions)

- Differentiate s to get v , and v to get a .** Use the chain, product or quotient rule where needed, for example $\frac{d}{dt} 3 \sin 2t = 6 \cos 2t$.

- Answer the question asked:**

- a value at a given time: substitute t ;
- when the particle is at rest: solve $v = 0$, keeping only $t \geq 0$ (or t in the stated range);
- the acceleration (or displacement) at that moment: substitute the time you found into a (or s);
- greatest or least velocity: solve $a = 0$;

- when s is greatest: solve $v = 0$ and check it is a maximum.

3. **Speed** is $|v|$. If $v = -3$, the speed is 3. Never give a negative speed.

Variations you will meet:

- **"Show that the particle is never at rest"** (or "never changes direction"): show that $v = 0$ has no solution with $t \geq 0$. Useful reasons: a squared bracket is never negative; $e^{kt} > 0$; $\cos$ lies between -1 and 1 , so for example $v = 3 - 2 \cos t$ is always at least 1; or the only roots of $v = 0$ are negative. Finish with a sentence.
- **"Show that the acceleration is never zero"**: the same idea for a . Checking a single value of t proves nothing.
- **"Show that v can be written as ..."**: differentiate, then simplify (take out common factors) until your expression matches the given form exactly.
- **Moving towards or away from O** : work out s and v at that time. Opposite signs mean towards O ; the same sign means away from it.
- **Exponential or $\ln$ equations from $v = 0$** : an equation like $5e^t - 6e^{-t} = 7$ becomes a quadratic in e^t after multiplying through by e^t : $5e^{2t} - 7e^t - 6 = 0$, so $(5e^t + 3)(e^t - 2) = 0$. Reject the negative value, so $e^t = 2$ and $t = \ln 2$.
- **Trigonometric velocity**: solve in radians and take the smallest positive root if asked for "first".
- **a in terms of s** : compare the expressions. If $s = 2 \cos 3t + 5$ then $a = -18 \cos 3t$, and $2 \cos 3t = s - 5$, so $a = -9(s - 5)$.
- **Approximate change** in v for a small change in t : $\delta v \approx \frac{dv}{dt} \delta t$, as in the Applications of differentiation note.

2. Velocity and displacement by integrating (13 questions)

1. **Integrate a to get v** (or v to get s) and write $+ c$. For example $\int e^{3t} dt = \frac{1}{3}e^{3t}$ and $\int \frac{8}{2t+1} dt = 4 \ln(2t+1)$.
2. **Find the constant** by substituting the given pair of values, such as " $v = 5$ when $t = 2$ ". It is not always $t = 0$.
3. **Write out the full expression** with the constant in, before using it.
4. **Integrate again** (with a new constant) if you need s , and find that constant from a displacement fact.

Variations you will meet:

- **Definite integral instead of a constant**: the displacement between $t = t_1$ and $t = t_2$ is $\int_{t_1}^{t_2} v dt$, with no constant needed. Show the substitution of both limits.
- **"Starts from rest at O "** gives both constants: $v = 0$ and $s = 0$ when $t = 0$.
- **Distance between two positions of rest**: solve $v = 0$ for the two times, then integrate v between them and give the size.

3. Sketching motion graphs (7 questions)

1. **Find the formula for the graph asked for** by differentiating (or integrating).

2. **Find the key points:** where it meets each axis (put $t = 0$; solve the formula $= 0$), and any turning points. A repeated factor such as $(t - 4)^2$ means the graph touches the t -axis there instead of crossing it.
3. **Draw only for $t \geq 0$** (or the range given). The graph must meet the vertical axis. Draw the smooth shape first, then mark and label every intercept.
4. **Check the shapes against each other:** where s has a turning point v crosses zero, and where v has a turning point a crosses zero. A linear a is a **ruled straight line**.

Variations you will meet:

- **Speed–time from velocity–time:** reflect the parts below the axis. The speed graph touches the axis where v changes sign, with a sharp corner.
- **Acceleration–time from a velocity–time curve:** if v is a quadratic, a is a straight line; if the v curve has gradient 0 at the start, the a line starts at the origin.
- **Graph from a description:** "constant velocity" is a horizontal line on v – t ; "constant acceleration" is a sloping straight line; a velocity that changes sign crosses the t -axis. Use the fact that the signed area must match the given displacement (for example "returns to A " means the areas above and below are equal).
- **Trigonometric graphs:** sketch one full cycle and give the intercepts exactly, in terms of π .

4. Distance travelled when the particle turns back (6 questions)

1. **Find when $v = 0$** in the time interval. These are the times when the particle might turn.
2. **Find s at the start, at each turning time and at the end**, or integrate v over each piece.
3. **Add the sizes of the changes:** distance $= |s_1 - s_0| + |s_2 - s_1| + \dots$

For the particle above, $s = 11$ at $t = 1$, -16 at $t = 4$ and -5 at $t = 5$, so the distance in the first 5 seconds is $11 + 27 + 11 = 49$ m, while the displacement is only -5 m.

Variations you will meet:

- **Given a graph and no rest time:** find the maximum of s from $\frac{ds}{dt} = 0$ first; if the particle goes out and comes back to where it started, the distance is twice the distance out.
- **Returns to its starting point:** solve $s = s(0)$ algebraically. With a square root, rearrange so the root is alone, then square both sides and check your answers.
- **Never at rest in the interval:** then the distance is just $|s(t_2) - s(t_1)|$, one piece.
- **Trigonometric velocity:** the particle turns many times; if the pieces are the same size, one piece times the number of pieces is fine.

5. Straight-line velocity–time and displacement–time graphs (6 questions)

1. **Read the graph:** on a v – t graph each straight piece has a constant acceleration equal to its **gradient**; on an s – t graph each piece has a constant velocity equal to its gradient.
2. **Distance on a v – t graph = area.** Split into triangles, rectangles and trapeziums (area of a trapezium $= \frac{1}{2}(a + b)h$), or use one trapezium for the whole shape when it fits.

3. **Unknown speed or time:** write the area in terms of the unknown, set it equal to the given distance and solve. With an unknown time you usually get a quadratic; reject the root that doesn't fit the graph (for example a time longer than the stage it belongs to).

4. **Acceleration during a slowing-down stage is negative:** $\text{gradient} = \frac{\text{final } v - \text{initial } v}{\text{time taken}}$.

For example, a v - t trapezium whose parallel sides (along the t -axis and along the top) are 10 s and 5 s long and whose height is V has area $\frac{1}{2}(10 + 5)V = 7.5V$.

6. Motion in two stages (5 questions)

1. **Keep the stages apart.** Use each formula only in its own time interval.
2. **Work through the first stage** as in type 1 or 2, and find v and s at the moment the stage ends.
3. **Start the second stage from those values.** Velocity and displacement do not jump, so the end values of stage 1 are the facts that fix the constants in stage 2. (Acceleration may jump.)
4. **For the distance over both stages,** check each stage for times of rest, then add the pieces (type 4).

Variations you will meet:

- **Unknown end time k** with a given total distance: find the distance for stage 1 as a number and stage 2 in terms of k , set their sum equal to the total and solve.
- **Displacement given as two formulas:** differentiate each to sketch the v - t graph, which is made of two pieces meeting at the change-over time.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **M1** method mark: for a correct method, even if the numbers slip.
 - **A1** accuracy mark: for a correct answer; it needs the M mark before it.
 - **B1** mark for a correct result on its own, with no method needed.
-

Example 1

A particle starts from rest at a point O and moves in a straight line. It accelerates uniformly to a velocity of 12 m s^{-1} in 3 s. It then has a constant acceleration of -4 m s^{-2} for the next 6 s.

- (a) Sketch the velocity-time graph for $0 \leq t \leq 9$. **[2]**
- (b) Find the time at which the particle is at rest. **[1]**
- (c) Find the displacement of the particle from O when $t = 9$, and the total distance it has travelled by then. **[3]**

(d) After $t = 9$ the particle keeps the velocity it had at $t = 9$. Find the time at which it passes through O . **[2]**

(a) A straight line from $(0, 0)$ to $(3, 12)$. From $t = 3$ the gradient is -4 , so $v = 12 - 4 \times 6 = -12$ at $t = 9$: a straight line from $(3, 12)$ to $(9, -12)$. It is the top graph in the second diagram in "Understand it". **B1** for the first line, **B1** for the second line crossing the axis and ending at -12 .

(b) $12 - 4(t - 3) = 0$ gives $t = 6$. **B1**

(c) Area above the axis, $0 \leq t \leq 6$: $\frac{1}{2} \times 6 \times 12 = 36$. Area below, $6 \leq t \leq 9$: $\frac{1}{2} \times 3 \times 12 = 18$. **M1** for both triangle areas.

Displacement = $36 - 18 = 18$ m. **A1** Distance = $36 + 18 = 54$ m. **A1**

(d) It is 18 m from O on the positive side, moving back at 12 m s^{-1} , so it needs $\frac{18}{12} = 1.5$ s more. **M1** It passes through O at $t = 10.5$. **A1**

Example 2

No calculator. A particle moves in a straight line so that its displacement from a fixed point O at time t seconds is s metres, where

$$s = t + \frac{16}{t+1}, \quad t \geq 0.$$

(a) Find expressions for the velocity and acceleration of the particle. **[3]**

(b) Find the speed of the particle when $t = 1$. **[1]**

(c) Find the time when the particle is at rest, and its displacement and acceleration at that time. **[4]**

(d) Find the total distance travelled by the particle in the first 7 seconds. **[3]**

(a) $s = t + 16(t+1)^{-1}$, so

$$v = 1 - 16(t+1)^{-2} = 1 - \frac{16}{(t+1)^2}, \quad a = 32(t+1)^{-3} = \frac{32}{(t+1)^3}.$$

B1 for 1, **B1** for $-16(t+1)^{-2}$ (chain rule), **B1** for a .

(b) $v = 1 - \frac{16}{4} = -3$, so the speed is 3 m s^{-1} . **B1** (not -3).

(c) $1 - \frac{16}{(t+1)^2} = 0 \Rightarrow (t+1)^2 = 16 \Rightarrow t+1 = 4$ (the root $t+1 = -4$ gives $t < 0$), so $t = 3$. **M1 A1**

$s = 3 + \frac{16}{4} = 7$ m and $a = \frac{32}{64} = \frac{1}{2} \text{ m s}^{-2}$. **A1 A1**

(d) The particle turns at $t = 3$. $s = 16$ when $t = 0$, $s = 7$ when $t = 3$, and $s = 7 + \frac{16}{8} = 9$ when $t = 7$. **M1** for finding s at 0, 3 and 7.

Distance = $(16 - 7) + (9 - 7) = 9 + 2 = 11$ m. **M1 A1**

Using $s(7) - s(0) = -7$ would give the displacement, not the distance, and scores nothing.

Example 3

No calculator. A particle moves in a straight line. Its acceleration at time t seconds is $a = -8 \sin 2t \text{ m s}^{-2}$. When $t = \frac{\pi}{2}$ its velocity is 1 m s^{-1} , and when $t = 0$ it is at a fixed point O .

- (a) Find an expression for the velocity of the particle at time t . **[3]**
- (b) Show that the particle is never at rest. **[2]**
- (c) Find the exact displacement of the particle from O at the first time after $t = 0$ when its acceleration is zero. **[4]**

(a) $v = \int -8 \sin 2t \, dt = 4 \cos 2t + c$. **B1**

At $t = \frac{\pi}{2}$: $4 \cos \pi + c = 1 \Rightarrow -4 + c = 1 \Rightarrow c = 5$. **M1** for using the given values to find c .

$v = 4 \cos 2t + 5$. **A1**

(b) $\cos 2t \geq -1$, so $v \geq -4 + 5 = 1 > 0$ for every t . **M1** The velocity is never zero, so the particle is never at rest. **A1**

(c) $s = \int (4 \cos 2t + 5) \, dt = 2 \sin 2t + 5t + d$. **B1**

$s = 0$ when $t = 0$, so $d = 0$ and $s = 2 \sin 2t + 5t$. **M1**

$a = 0 \Rightarrow \sin 2t = 0 \Rightarrow 2t = \pi$ (the first positive solution), so $t = \frac{\pi}{2}$. **B1**

$s = 2 \sin \pi + \frac{5\pi}{2} = \frac{5\pi}{2} \text{ m}$. **A1**

Example 4

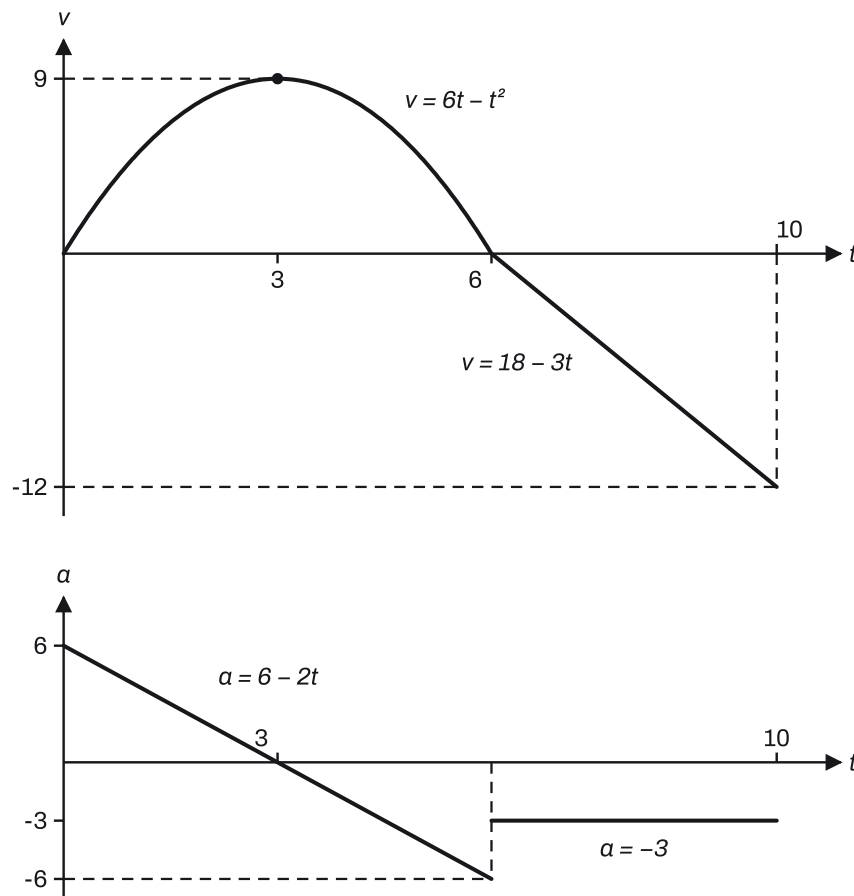
A particle P starts from rest at O and moves in a straight line. For $0 \leq t \leq 6$ its velocity is $v = 6t - t^2 \text{ m s}^{-1}$. For $6 \leq t \leq 10$ its acceleration is a constant -3 m s^{-2} .

- (a) Find the greatest velocity of P for $0 \leq t \leq 6$. **[2]**
- (b) Find an expression for v for $6 \leq t \leq 10$. **[2]**
- (c) Sketch the velocity–time and acceleration–time graphs for $0 \leq t \leq 10$. **[4]**
- (d) Find the displacement of P from O when $t = 10$, and the total distance travelled. **[4]**

(a) $a = 6 - 2t = 0$ when $t = 3$, **M1** so the greatest velocity is $18 - 9 = 9 \text{ m s}^{-1}$. **A1**

(b) $v = \int -3 \, dt = -3t + c$. At $t = 6$ the velocity must match the first stage: $6(6) - 36 = 0$. **M1** So $0 = -18 + c$, $c = 18$ and $v = 18 - 3t$. **A1**

(c)



v - t : **B1** for the arch through $(0, 0)$, $(3, 9)$, $(6, 0)$; **B1** for the line from $(6, 0)$ to $(10, -12)$. a - t : **B1** for the line from $(0, 6)$ to $(6, -6)$; **B1** for the horizontal line at -3 . The acceleration jumps at $t = 6$; the velocity does not.

(d) Stage 1: $\int_0^6 (6t - t^2) dt = \left[3t^2 - \frac{1}{3}t^3 \right]_0^6 = 108 - 72 = 36$. **M1 A1**

Stage 2: $\int_6^{10} (18 - 3t) dt = \left[18t - \frac{3}{2}t^2 \right]_6^{10} = 30 - 54 = -24$ (the particle moves backwards). **A1**

Displacement = $36 - 24 = 12$ m; distance = $36 + 24 = 60$ m. **A1**

Common mistakes

- **Mixing up velocity and speed.** Examiners see a negative "speed" every year. Speed is $|v|$, so if $v = -2$ the speed is 2.
- **Mixing up displacement and distance.** A particle that turns back has travelled further than its displacement shows. Before finding a distance, always solve $v = 0$ to see whether it turns inside the interval, and use that time to split the working.
- **Leaving out the constant of integration**, or assuming it is 0. Then the given information can't be used and later parts are lost. Find it from the values the question gives, even if they are not at $t = 0$.
- **Using the wrong pair of values for the constant**, for example using a velocity fact to find the constant in s . Match each fact to the right expression.

- **Differentiating when you should integrate** (or the other way round). From s to v to a is differentiation; from a to v to s is integration.
- **Using degrees with calculus.** With $\sin$ and $\cos$, t is in radians; a calculator in degree mode gives nonsense.
- **Stopping at $t = 0$ or keeping a negative root.** When solving $v = 0$ or $a = 0$, reject negative times and, if the question asks for the first time the particle is at rest after it starts, give the smallest positive solution.
- **Using the wrong stage.** In a two-stage question, a formula for $t \geq 3$ can't be used to answer a question about $t = 2$, and constant-acceleration formulas don't apply when the acceleration varies.
- **Reading a velocity–time graph as a displacement graph.** On a v – t graph the acceleration is the gradient, not "velocity $\div$ time"; the distance is the area, not a value read off the axis.
- **Splitting an area wrongly.** Draw the shapes on the graph first, and give a slowing-down acceleration a minus sign.
- **Sketches that go left of the vertical axis or don't reach it.** Motion graphs start at $t = 0$; the curve must meet the vertical axis, and every intercept asked for must be labelled.

How to get the marks

- **Write the calculus.** Show $v = \dots$ from differentiating, or $\int \dots dt$ with $+ c$, before substituting. Method marks need to see what you differentiated or integrated.
- **Show the constant being found**, with the numbers substituted, then write the full expression for v or s .
- **Definite integrals:** write the integral with limits, then show both limits substituted. The substitution is a method step and earns its own mark.
- **Distance questions:** state the time of rest you are using and the displacements at each end of every piece, then add their sizes.
- **Speed and distance are never negative.** A negative final answer for a speed or a distance loses the accuracy mark, even with correct working.
- **"Show that ...":** the answer is given, so every line must be there, finishing with a sentence such as " $v > 0$ for all t , and the particle never comes to rest".
- **"Use calculus" or "use algebra"** means that method must be seen; reading from a graph or trial and improvement gets no credit.
- **Sketches:** smooth curves and ruled straight lines, only for the times asked, with intercepts written on the axes (exact, in terms of π , if asked).
- **Accuracy:** "exact" means fractions, surds, $\ln$ or π . Otherwise give 3 significant figures (angles in radians to 3 s.f. too), and keep more figures in the working.
- **Paper 1 has no calculator**, so questions there have exact numbers: expect to solve $v = 0$ by factorising or with simple surds and logarithms.

Quick check

1. A particle moves so that $s = t^4 - 32t$ for $t \geq 0$. Find the time when it is at rest, and its displacement and acceleration at that time.
2. A particle starts from rest at O and has acceleration $a = 6t - 4$. Find its displacement from O when $t = 3$, and the total distance it has travelled in the first 3 seconds.
3. A particle has velocity -6 m s^{-1} at $t = 0$ and a constant acceleration of 2 m s^{-2} . Use a velocity–time graph to find when it is at rest, its displacement from its starting point at $t = 5$, and the distance it has travelled by then.
4. A particle has velocity $v = t^2 - 4t + 3$ for $0 \leq t \leq 4$. Describe the speed–time graph, and find the greatest speed for $1 \leq t \leq 3$.

Answers

1. $v = 4t^3 - 32 = 0 \Rightarrow t^3 = 8 \Rightarrow t = 2$. Then $s = 16 - 64 = -48$ m and $a = 12t^2 = 48$ m s⁻².
2. $v = 3t^2 - 4t + c$ with $v = 0$ at $t = 0$, so $c = 0$. $s = t^3 - 2t^2 + d$ with $s = 0$ at $t = 0$, so $d = 0$. $s(3) = 27 - 18 = 9$ m. The particle is at rest at $t = \frac{4}{3}$, where $s = \frac{64}{27} - \frac{32}{9} = -\frac{32}{27}$. Distance = $\frac{32}{27} + (9 + \frac{32}{27}) = \frac{307}{27} \approx 11.4$ m.
3. $v = -6 + 2t$, a straight line from $(0, -6)$ to $(5, 4)$. At rest when $t = 3$. Area below the axis = $\frac{1}{2} \times 3 \times 6 = 9$; area above = $\frac{1}{2} \times 2 \times 4 = 4$. Displacement = $-9 + 4 = -5$ m; distance = $9 + 4 = 13$ m.
4. $v = (t - 1)(t - 3)$: 3 at $t = 0$, zero at $t = 1$ and $t = 3$, -1 at $t = 2$, and 3 at $t = 4$. The speed–time graph is the same curve with the part between $t = 1$ and $t = 3$ reflected above the axis, so it touches the axis at $t = 1$ and $t = 3$ with sharp corners and has a rounded peak at $(2, 1)$. The greatest speed for $1 \leq t \leq 3$ is 1 m s⁻¹.

Past questions to try

- **0606/21/O/N/24 Q8**: a cubic displacement, when it turns, moving towards O and the distance.
- **0606/12/F/M/24 Q6**: area and gradient on a straight-line velocity–time graph, then a product-rule acceleration.
- **0606/22/F/M/23 Q10**: motion in two stages, integrating an acceleration.
- **0606/11/M/J/24 Q10**: a trigonometric velocity, the displacement and the distance over one cycle.