

2.1.3 The equations of uniformly accelerated motion

Name: _____ Class: _____ Date: _____

Total: **37 marks**

KEY WORDS uniform acceleration • velocity • deceleration
• acceleration • speed

Objective

Build the skills to answer exam questions with the **equations of uniformly accelerated motion** : deriving them, choosing the right one, using signs, and solving problems with two stages or two objects. This sheet covers syllabus 2.1, learning outcomes 6 and 7 (motion in a straight line).

You must be able to:

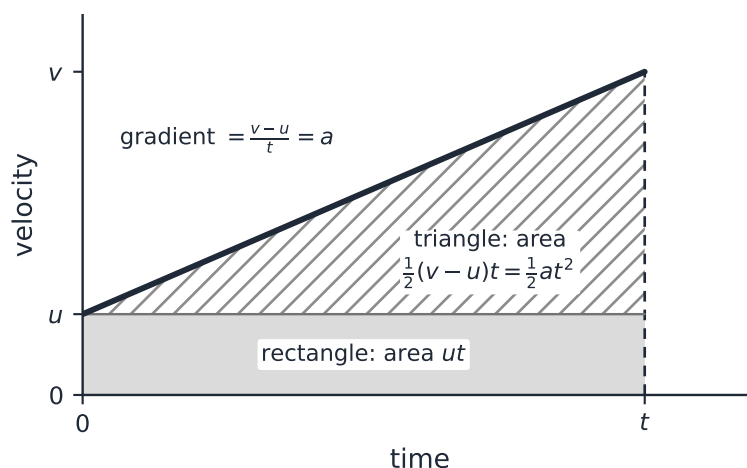
- **derive** the equations from the definition of acceleration and the area under a velocity–time graph
- state when the equations can be used
- choose the equation that links what you know to what you want
- choose a positive direction and give every vector a sign
- solve problems with two stages, or with two objects
- solve a **quadratic** with two answers, and decide which answers make sense

1 Worked examples

Study these first. Each one shows a **method** that a question later on this sheet needs.

■ Deriving the equations

An object has **uniform acceleration** a in a straight line. Its velocity changes from u to v in a time t , and its displacement is s .



- from the definition of acceleration (the gradient)

$$a = \frac{v-u}{t} \Rightarrow v = u + at$$

- displacement = area under the line, a **trapezium**

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

- put $v = u + at$ into the trapezium; this is the rectangle plus the triangle in the graph

$$s = \frac{1}{2}(u + u + at)t = ut + \frac{1}{2}at^2$$

- from the first equation $t = (v-u)/a$; put this into $s = \frac{1}{2}(u+v)t$

$$s = \frac{(v+u)(v-u)}{2a} \Rightarrow v^2 = u^2 + 2as$$

The equations work only when the acceleration is **constant** and the motion is in a **straight line**. $s = \frac{1}{2}at^2$ also needs the object to start from rest ($u = 0$).

■ Choosing an equation

Write down the five symbols s , u , v , a , t . Find the one you are not given and do not want: use the equation without it.

not given and not wanted	use
s	$v = u + at$
a	$s = \frac{1}{2}(u+v)t$
v	$s = ut + \frac{1}{2}at^2$
t	$v^2 = u^2 + 2as$

Example. A cyclist brakes uniformly from $9.0 \frac{\text{m}}{\text{s}}$ to rest in a distance of 12 m.

- $u = 9.0 \frac{\text{m}}{\text{s}}$, $v = 0$, $s = 12 \text{ m}$; to find a , there is no t

$$a = \frac{v^2 - u^2}{2s} = \frac{0 - (9.0 \frac{\text{m}}{\text{s}})^2}{2 \times 12 \text{ m}} = -3.4 \text{ m s}^{-2}$$

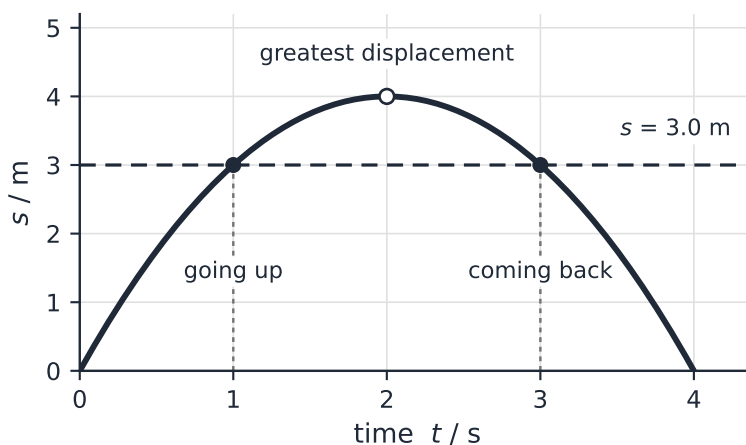
- to find t , there is no a

$$t = \frac{2s}{u + v} = \frac{2 \times 12 \text{ m}}{9.0 \frac{\text{m}}{\text{s}} + 0} = 2.7 \text{ s}$$

- the minus sign shows the acceleration is opposite to the velocity: a **deceleration** of 3.4 m s^{-2}

■ Signs, and two answers

Choose one direction as positive and keep it for the whole problem. A ball rolls up a slope at $4.0 \frac{\text{m}}{\text{s}}$. Its acceleration is 2.0 m s^{-2} down the slope, on the way up and on the way back down. Take **up the slope as positive**: $u = +4.0 \frac{\text{m}}{\text{s}}$ and $a = -2.0 \text{ m s}^{-2}$.



- when does it stop? Use $v = u + at$

$$v = u + at : \quad 0 = 4.0 \frac{\text{m}}{\text{s}} + (-2.0 \text{ m s}^{-2})t \quad \Rightarrow \quad t = 2.0 \text{ s}$$

- when is it 3.0 m up the slope? Use $s = ut + \frac{1}{2}at^2$ (values in m and s)

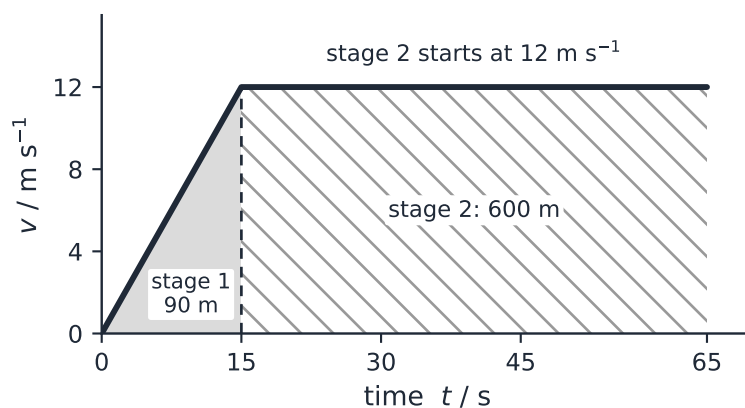
$$s = ut + \frac{1}{2}at^2 : \quad 3.0 = 4.0t - 1.0t^2 \quad \Rightarrow \quad t^2 - 4.0t + 3.0 = 0$$

$$t = 1.0 \text{ s or } 3.0 \text{ s}$$

- both answers are real: at 1.0 s the ball is going up, and at 3.0 s it is coming back down

■ Two stages

A tram starts from rest with an acceleration of 0.80 m s^{-2} for 15 s. It then keeps a steady speed for 50 s.



- stage 1: the final velocity

$$v = u + at = 0 + (0.80 \text{ m s}^{-2})(15 \text{ s}) = 12 \frac{\text{m}}{\text{s}}$$

- stage 1: the displacement

$$s_1 = \frac{1}{2}at^2 = \frac{1}{2}(0.80 \text{ m s}^{-2})(15 \text{ s})^2 = 90 \text{ m}$$

- the final velocity of stage 1 is the initial velocity of stage 2

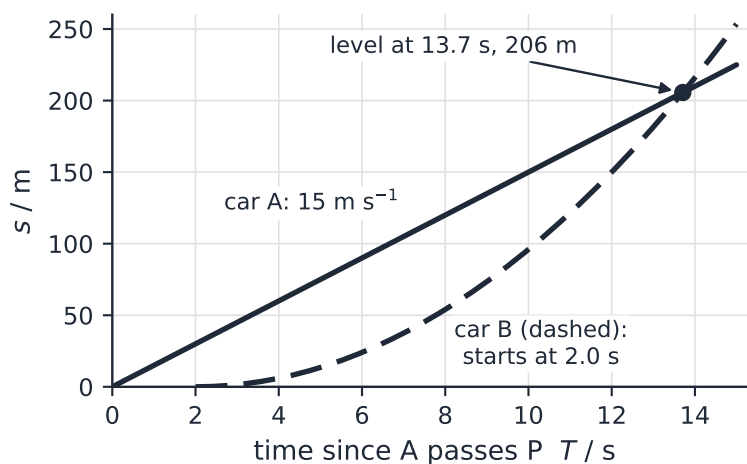
$$s_2 = vt = (12 \frac{\text{m}}{\text{s}})(50 \text{ s}) = 600 \text{ m}$$

- total displacement $s = s_1 + s_2 = 90 \text{ m} + 600 \text{ m} = 690 \text{ m}$

A driver's **reaction time** is a stage too: the car keeps its speed, so the **thinking distance** is speed $\times$ reaction time. The **braking distance** comes from $v^2 = u^2 + 2as$, and the **stopping distance** is the sum of the two.

■ Two objects

Car A passes a point P at a constant $15 \frac{\text{m}}{\text{s}}$. 2.0 s later, car B starts from rest at P with an acceleration of 3.0 m s^{-2} . Measure the time T from when A passes P.



- car A has moved for T and car B for $(T - 2.0)$, so (values in m and s)

$$s_A = v_A T = 15T$$

$$s_B = ut + \frac{1}{2}at^2 = 0 + \frac{1}{2}(3.0)(T - 2.0)^2 = 1.5(T - 2.0)^2$$

- they are level when the displacements are equal

$$s_A = s_B : \quad 15T = 1.5(T - 2.0)^2 \quad \Rightarrow \quad T^2 - 14T + 4.0 = 0$$

$$T = 13.7 \text{ s or } 0.29 \text{ s}$$

- 0.29 s is before B starts, so it is not a meeting: B catches A at $T = 13.7 \text{ s}$

$$s = vT = \left(15 \frac{\text{m}}{\text{s}}\right)(13.7 \text{ s}) = 206 \text{ m}$$

2 Practice

Now use the methods above.

2.1 Show that $s = ut + \frac{1}{2}at^2$ follows from $v = u + at$ and $s = \frac{1}{2}(u + v)t$. [2]



2.2 The equations of uniformly accelerated motion can only be used under certain conditions.

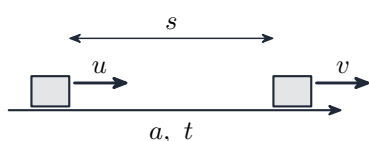
(a) State two conditions that must both be true. [2]

s u v a t

(b) State the extra condition needed to use $s = \frac{1}{2}at^2$. [1]

2.3 Choose the right equation each time.

- (a) $u = 2.0 \frac{\text{m}}{\text{s}}$, $a = 1.5 \text{ m s}^{-2}$, $t = 4.0 \text{ s}$. Find v . [1]



- (b) $u = 0$, $v = 12 \frac{\text{m}}{\text{s}}$, $s = 18 \text{ m}$. Find a . [1]

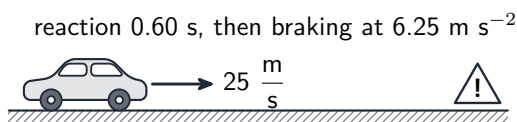
- (c) $u = 5.0 \frac{\text{m}}{\text{s}}$, $v = 15 \frac{\text{m}}{\text{s}}$, $t = 4.0 \text{ s}$. Find s . [1]

- (d) $u = 3.0 \frac{\text{m}}{\text{s}}$, $a = 2.0 \text{ m s}^{-2}$, $s = 10 \text{ m}$. Find v . [1]

2.4 A car is travelling at $25 \frac{\text{m}}{\text{s}}$ when the driver sees a hazard. The driver's reaction time is 0.60 s . The car then brakes with a constant deceleration of 6.25 m s^{-2} .

- (a) Calculate the thinking distance. [1]

- (b) Calculate the braking distance. [2]



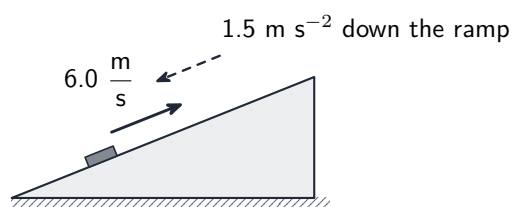
- (c) State the stopping distance. [1]

2.5 A puck slides up a smooth icy ramp at $6.0 \frac{\text{m}}{\text{s}}$. Its acceleration is 1.5 m s^{-2} down the ramp, on the way up and on the way back down. Take up the ramp as positive.

(a) Calculate the time taken for the puck to stop. [1]

(b) Calculate the greatest distance the puck travels up the ramp. [2]

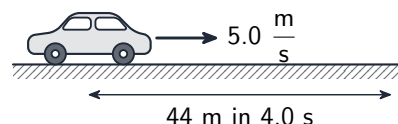
(c) Calculate the two times at which the puck is 10 m up the ramp. (*Hint: you will need to solve a quadratic.*) [3]



3 Exam-style questions

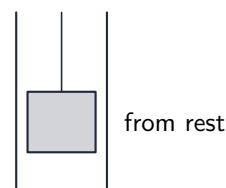
3.1 A car moving at $5.0 \frac{\text{m}}{\text{s}}$ accelerates uniformly. In the next 4.0 s it travels 44 m. What is its acceleration? [1]

- ☐ A 1.5 m s^{-2}
☐ B 3.0 m s^{-2}
☐ C 5.5 m s^{-2}
☐ D 6.0 m s^{-2}



3.2 A lift starts from rest and accelerates uniformly at 1.2 m s^{-2} for 2.5 s. It then moves at a constant velocity for 6.0 s, and finally slows uniformly to rest in 2.0 s. How far does the lift travel? [1]

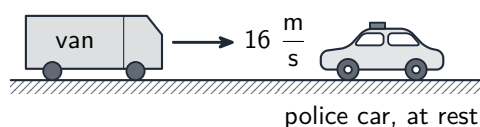
- ☐ A 18 m
☐ B 25 m
☐ C 28 m
☐ D 32 m



3.3 A delivery van travels along a straight road at a constant velocity of $16 \frac{\text{m}}{\text{s}}$. It passes a police car that is at rest. 3.0 s later, the police car sets off after the van. It accelerates uniformly at 2.5 m s^{-2} until it reaches $30 \frac{\text{m}}{\text{s}}$, and then keeps this velocity.

- (a) Calculate the time the police car takes to reach $30 \frac{\text{m}}{\text{s}}$. [1]

- (b) Calculate the distance the police car travels while it is accelerating. [2]



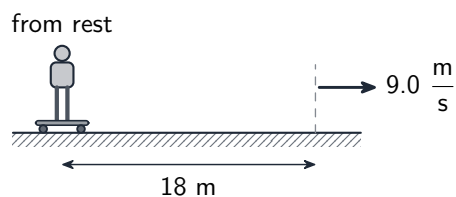
- (c) **Show that** the police car has not caught the van when it reaches $30 \frac{\text{m}}{\text{s}}$. [2]

- (d) Determine the time, measured from when the van passes the police car, at which the police car catches the van. [3]

- (e) On one set of axes, **sketch** the velocity–time graphs of the van and of the police car up to the moment the police car catches the van. Label each line. [2]

3.4 The equation $v^2 = u^2 + 2as$ links velocity and displacement.

(a) Starting from $v = u + at$ and $s = \frac{1}{2}(u + v)t$, **derive** $v^2 = u^2 + 2as$. [3]



(b) A skateboarder accelerates uniformly from rest to $9.0 \frac{\text{m}}{\text{s}}$ over a distance of 18 m. Calculate her acceleration. [2]

(c) Explain why this equation could not be used if her acceleration decreased as she sped up. [1]