

Exercise walk-through

## 2.1.3

# The equations of uniformly accelerated motion

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A-Level Physics

## Sheet 2.1.3 – what you need to know

### You must be able to:

- **derive** the four equations from a velocity–time graph
- state when they apply: **constant acceleration** in a straight line
- choose the equation, and give every vector a sign
- solve **two stages**, **two objects**, and a quadratic with two answers

### What the exam asks

“State two conditions for this equation to apply.” [2]

“Calculate the acceleration.” [2]

multiple choice: a train between two stations

*Practise on exercise sheet 2.1.3, then try the real exam questions on past-paper sheet 2.1.3.*

# The four SUVAT equations

Straight line, **uniform acceleration** : five symbols  $u$ ,  $v$ ,  $a$ ,  $s$ ,  $t$  – each equation drops one.

$$v = u + at$$

no  $s$ 

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

no  $v$ 

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

no  $a$ 

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

no  $t$ 

Pick the equation that holds your **three knowns** *and* your **unknown**. They hold only for **constant acceleration** in a straight line.

# Where SUVAT comes from

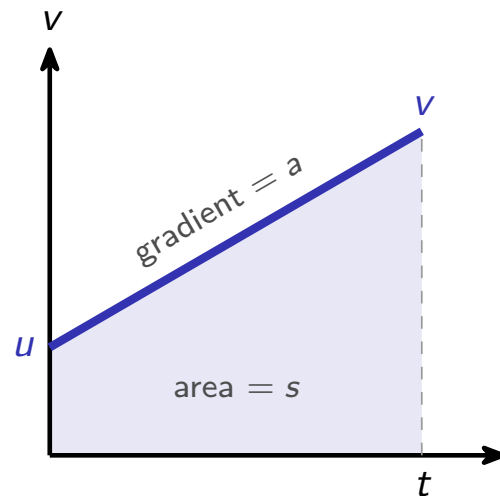
Start from the **velocity–time graph** of the motion:

1 gradient:  $a = \frac{v - u}{t}$ , so  $v = u + at$

2 area of a trapezium :  $s = \frac{1}{2}(u + v)t$

3 put  $v = u + at$  into 2:  
 $s = \frac{1}{2}(u + u + at)t = ut + \frac{1}{2}at^2$

4 put  $t = \frac{v - u}{a}$  into 2:  
 $2as = (v + u)(v - u) = v^2 - u^2$



A **derive** question wants exactly these steps, each starting from a definition or an equation already shown, with **no numbers**.

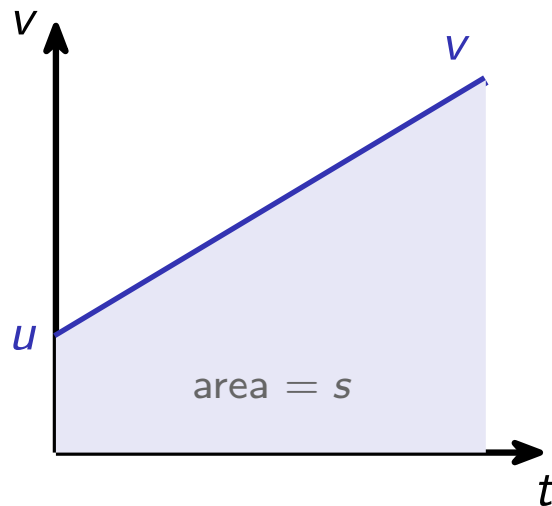
## Worked example – find the acceleration

**Car:**  $u = 8$ ,  $v = 20 \text{ m s}^{-1}$  **over**  $s = 56 \text{ m}$

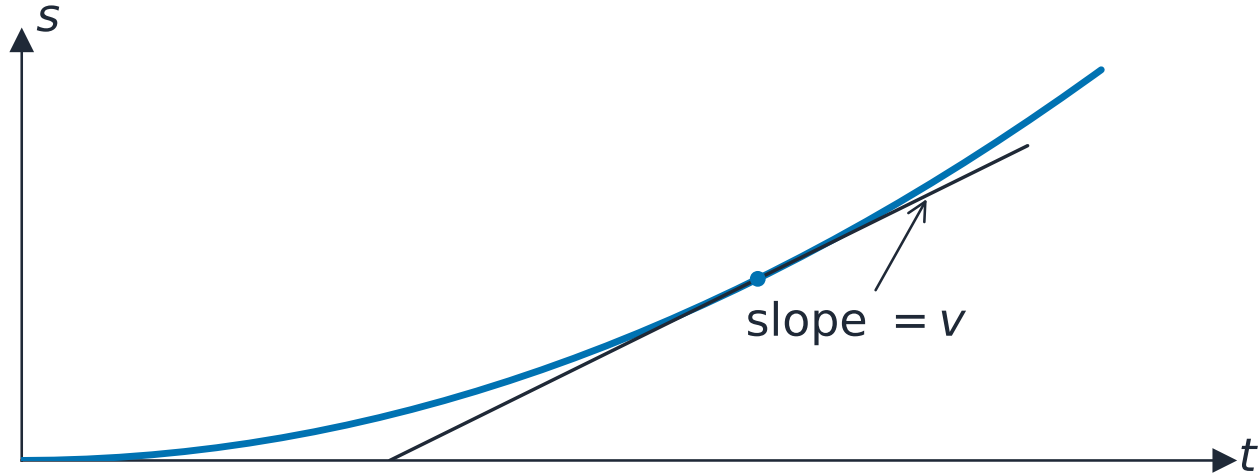
**Knowns**  $u, v, s$ ; **want**  $a$ , so use  $v^2 = u^2 + 2as$ :

$$20^2 = 8^2 + 2a(56)$$

$$336 = 112a \Rightarrow a = 3.0 \text{ m s}^{-2}.$$



# The displacement–time graph is a parabola



constant  $a \Rightarrow s-t$  is a parabola · gradient of tangent  
=  $v$

With uniform acceleration the  $s-t$  graph is a **parabola**  
the **tangent** at any point is the **velocity** at that instant.

: the gradient of

## Exercise 2.1

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**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]



## Exercise 2.1

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**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]



**2.1**

- substitute  $v = u + at$  into  $s = \frac{1}{2}(u + v)t$

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

- multiply out the bracket:  $s = ut + \frac{1}{2}at^2$

## Exercise 2.2 (a)

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**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]

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## Exercise 2.2 (a)

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**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]

$s$   $u$   $v$   $a$   $t$

---

(a) the acceleration is constant; the motion is in a straight line

## Exercise 2.2 (b)

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

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

## Exercise 2.2 (b)

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

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

(b) the object starts from rest, so  $u = 0$

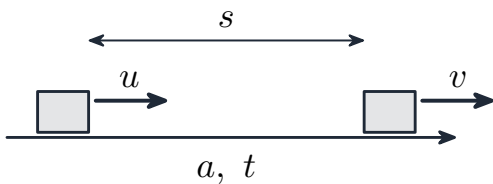
## Exercise 2.3 (a)

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**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]



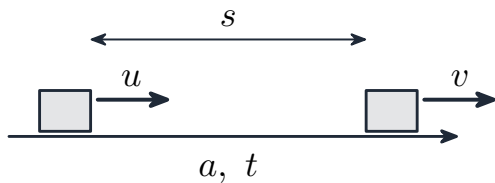
## Exercise 2.3 (a)

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

[1]



(a) no  $s$ , so  $v = u + at = 2.0 \frac{\text{m}}{\text{s}} + (1.5 \text{ m s}^{-2})(4.0 \text{ s}) = \mathbf{8.0} \frac{\text{m}}{\text{s}}$

## Exercise 2.3 (b)

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**2.3** Choose the right equation each time.

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

[1]

## Exercise 2.3 (b)

---

**2.3** Choose the right equation each time.

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

[1]

(b) no  $t$ , so use  $v^2 = u^2 + 2as$

$$a = \frac{v^2 - u^2}{2s} = \frac{(12 \frac{\text{m}}{\text{s}})^2 - 0}{2 \times 18 \text{ m}} = \mathbf{4.0 \text{ m s}^{-2}}$$

## Exercise 2.3 (c)

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**2.3** Choose the right equation each time.

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

[1]

## Exercise 2.3 (c)

---

**2.3** Choose the right equation each time.

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

(c) no  $a$ , so use  $s = \frac{1}{2}(u + v)t$

$$s = \frac{1}{2}(u + v)t = \frac{1}{2}\left(5.0 \frac{\text{m}}{\text{s}} + 15 \frac{\text{m}}{\text{s}}\right)(4.0 \text{ s}) = \mathbf{40 \text{ m}}$$

## Exercise 2.3 (d)

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**2.3** Choose the right equation each time.

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

[1]

## Exercise 2.3 (d)

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**2.3** Choose the right equation each time.

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

[1]

(d) no  $t$ , so use  $v^2 = u^2 + 2as$

$$v^2 = u^2 + 2as = \left(3.0 \frac{\text{m}}{\text{s}}\right)^2 + 2(2.0 \text{ m s}^{-2})(10 \text{ m}) = 49 \text{ m}^2 \text{ s}^{-2} \Rightarrow v = \mathbf{7.0} \frac{\text{m}}{\text{s}}$$

## Exercise 2.4 (a)

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**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  $6.25 \text{ m s}^{-2}$ .

(a) Calculate the thinking distance.

[1]

## Exercise 2.4 (a)

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**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  $6.25 \text{ m s}^{-2}$ .

(a) Calculate the thinking distance. [1]

(a) the speed is constant during the reaction time, so the thinking distance is  $s = v t$

$$s = v t = \left(25 \frac{\text{m}}{\text{s}}\right)(0.60 \text{ s}) = \mathbf{15 \text{ m}}$$

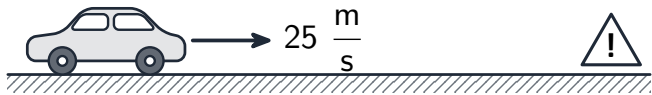
## Exercise 2.4 (b)

**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  $6.25 \text{ m s}^{-2}$ .

(b) Calculate the braking distance.

[2]

reaction 0.60 s, then braking at  $6.25 \text{ m s}^{-2}$



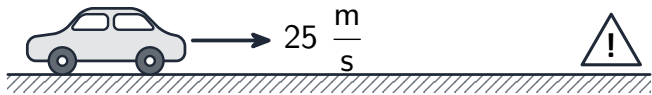
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(b) Calculate the braking distance.

[2]

reaction 0.60 s, then braking at  $6.25 \text{ m s}^{-2}$



(b)  $u = 25 \frac{\text{m}}{\text{s}}$ ,  $v = 0$ ,  $a = -6.25 \text{ m s}^{-2}$ ; use  $v^2 = u^2 + 2as$

$$s = \frac{v^2 - u^2}{2a} = \frac{0 - \left(25 \frac{\text{m}}{\text{s}}\right)^2}{2(-6.25 \text{ m s}^{-2})} = \mathbf{50 \text{ m}}$$

## Exercise 2.4 (c)

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**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  $6.25 \text{ m s}^{-2}$ .

(c) State the stopping distance.

[1]

## Exercise 2.4 (c)

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**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  $6.25 \text{ m s}^{-2}$ .

(c) State the stopping distance.

[1]

(c) stopping distance = thinking distance + braking distance

$$s = s_{\text{think}} + s_{\text{brake}} = 15 \text{ m} + 50 \text{ m} = \mathbf{65 \text{ m}}$$

## Exercise 2.5 (a)

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**2.5** A puck slides up a smooth icy ramp at  $6.0 \frac{\text{m}}{\text{s}}$ . Its acceleration is  $1.5 \text{ m s}^{-2}$  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]

## Exercise 2.5 (a)

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**2.5** A puck slides up a smooth icy ramp at  $6.0 \frac{\text{m}}{\text{s}}$ . Its acceleration is  $1.5 \text{ m s}^{-2}$  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]

(a) at the top  $v = 0$

$$t = \frac{v - u}{a} = \frac{0 - 6.0 \frac{\text{m}}{\text{s}}}{-1.5 \text{ m s}^{-2}} = \mathbf{4.0 \text{ s}}$$

## Exercise 2.5 (b)

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

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

## Exercise 2.5 (b)

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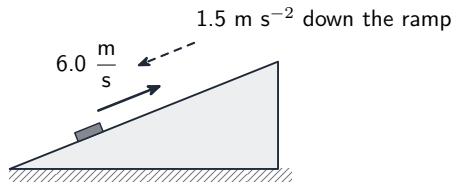
(b) at the top  $v = 0$ ; use  $v^2 = u^2 + 2as$

$$s = \frac{v^2 - u^2}{2a} = \frac{0 - (6.0 \frac{\text{m}}{\text{s}})^2}{2(-1.5 \text{ m s}^{-2})} = \mathbf{12 \text{ m}}$$

## Exercise 2.5 (c)

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

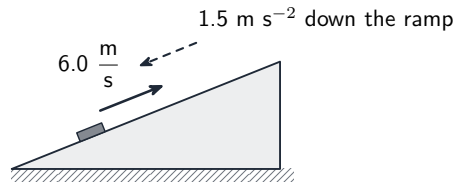
(c) Calculate the two times at which the puck is 10 m up the ramp. (*Hint: you will need to solve a quadratic.*) [3]



## Exercise 2.5 (c)

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

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



(c)  $s = ut + \frac{1}{2}at^2$  with  $s = 10$ ,  $u = 6.0$ ,  $a = -1.5$  (values in m and s)

$$s = ut + \frac{1}{2}at^2 : \quad 10 = 6.0t - 0.75t^2 \quad \Rightarrow \quad 0.75t^2 - 6.0t + 10 = 0$$

- solve  $pt^2 + qt + r = 0$  with  $p = 0.75$ ,  $q = -6.0$ ,  $r = 10$

$$t = \frac{-q \pm \sqrt{q^2 - 4pr}}{2p} = \frac{6.0 \pm \sqrt{(-6.0)^2 - 4(0.75)(10)}}{2(0.75)} = \frac{6.0 \pm \sqrt{36 - 30}}{1.5}$$

- $t = \mathbf{2.4 \text{ s}}$  (going up) and  $t = \mathbf{5.6 \text{ s}}$  (coming back down)

## Exercise 3.1

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**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]

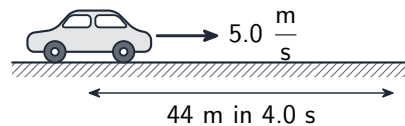
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**A**  $1.5 \text{ m s}^{-2}$

**B**  $3.0 \text{ m s}^{-2}$

**C**  $5.5 \text{ m s}^{-2}$

**D**  $6.0 \text{ m s}^{-2}$



## Exercise 3.1

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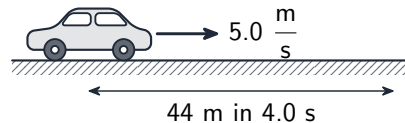


**A**  $1.5 \text{ m s}^{-2}$

**B**  $3.0 \text{ m s}^{-2}$

**C**  $5.5 \text{ m s}^{-2}$

**D**  $6.0 \text{ m s}^{-2}$



**3.1 B**

- $u = 5.0 \frac{\text{m}}{\text{s}}$ ,  $t = 4.0 \text{ s}$ ,  $s = 44 \text{ m}$ ; there is no  $v$ , so use  $s = ut + \frac{1}{2}at^2$

$$s = ut + \frac{1}{2}at^2 : \quad 44 \text{ m} = (5.0 \frac{\text{m}}{\text{s}})(4.0 \text{ s}) + \frac{1}{2}a(4.0 \text{ s})^2$$

$$a = \frac{2(s - ut)}{t^2} = \frac{2(44 \text{ m} - 20 \text{ m})}{(4.0 \text{ s})^2} = \frac{48 \text{ m}}{16 \text{ s}^2} = \mathbf{3.0 \text{ m s}^{-2}}$$

- A** leaves out the  $\frac{1}{2}$ ; **C** leaves out  $ut$ ; **D** subtracts  $u$  from the average speed but does not divide by the time

## Exercise 3.2

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**3.2** A lift starts from rest and accelerates uniformly at  $1.2 \text{ m s}^{-2}$  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]

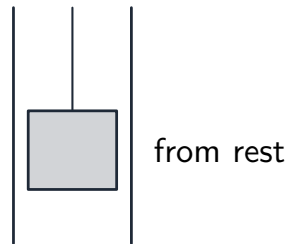
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**A** 18 m

**B** 25 m

**C** 28 m

**D** 32 m



## Exercise 3.2

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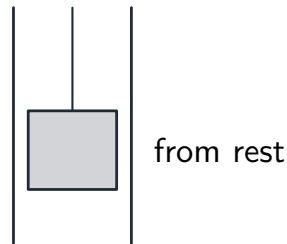


A 18 m

B 25 m

C 28 m

D 32 m



### 3.2 B

- top speed at the end of the first stage, from rest so  $u = 0$

$$v = u + at = 0 + (1.2 \text{ m s}^{-2})(2.5 \text{ s}) = 3.0 \frac{\text{m}}{\text{s}}$$

## Full solution 3.2

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### 3.2 B

- top speed at the end of the first stage, from rest so  $u = 0$

$$v = u + at = 0 + (1.2 \text{ m s}^{-2})(2.5 \text{ s}) = 3.0 \frac{\text{m}}{\text{s}}$$

- distance = area under the velocity–time graph: a triangle, a rectangle and a triangle

$$s = \frac{1}{2}t_1v + t_2v + \frac{1}{2}t_3v$$

$$s = \frac{1}{2}(2.5 \text{ s})(3.0 \frac{\text{m}}{\text{s}}) + (6.0 \text{ s})(3.0 \frac{\text{m}}{\text{s}}) + \frac{1}{2}(2.0 \text{ s})(3.0 \frac{\text{m}}{\text{s}}) = \mathbf{25 \text{ m}}$$

- **A** is the steady stage only; **C** halves only one of the two sloping stages; **D** uses the top speed for the whole 10.5 s

## Exercise 3.3 (a)

---

**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  $2.5 \text{ m s}^{-2}$  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]

## Exercise 3.3 (a)

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

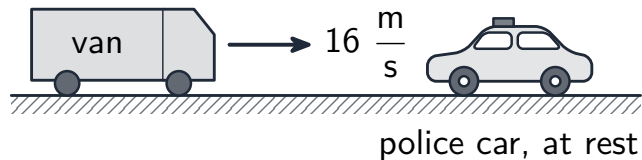
(a)

$$t = \frac{v - u}{a} = \frac{30 \frac{\text{m}}{\text{s}} - 0}{2.5 \text{ m s}^{-2}} = \mathbf{12 \text{ s}}$$

## Exercise 3.3 (b)

**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.  $3.0 \text{ s}$  later, the police car sets off after the van. It accelerates uniformly at  $2.5 \text{ m s}^{-2}$  until it reaches  $30 \frac{\text{m}}{\text{s}}$ , and then keeps this velocity.

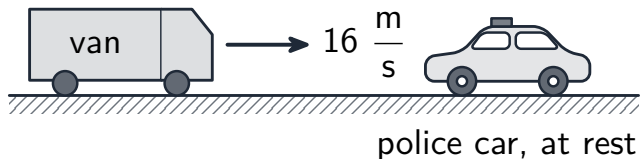
(b) Calculate the distance the police car travels while it is accelerating. [2]



## Exercise 3.3 (b)

**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.  $3.0 \text{ s}$  later, the police car sets off after the van. It accelerates uniformly at  $2.5 \text{ m s}^{-2}$  until it reaches  $30 \frac{\text{m}}{\text{s}}$ , and then keeps this velocity.

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



(b) no  $a$  needed once  $t$  is known

$$s = \frac{1}{2}(u + v)t = \frac{1}{2}(0 + 30 \frac{\text{m}}{\text{s}})(12 \text{ s}) = \mathbf{180 \text{ m}}$$

## Exercise 3.3 (c)

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**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.  $3.0 \text{ s}$  later, the police car sets off after the van. It accelerates uniformly at  $2.5 \text{ m s}^{-2}$  until it reaches  $30 \frac{\text{m}}{\text{s}}$ , and then keeps this velocity.

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

## Exercise 3.3 (c)

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

(c) the van has been moving for  $t_{\text{van}} = 3.0 \text{ s} + 12 \text{ s} = 15 \text{ s}$

$$s_{\text{van}} = v t = \left(16 \frac{\text{m}}{\text{s}}\right)(15 \text{ s}) = 240 \text{ m}$$

- 240 m is more than 180 m, so the van is still ahead

## Exercise 3.3 (d)

---

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

## Exercise 3.3 (d)

---

**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  $2.5 \text{ m s}^{-2}$  until it reaches  $30 \frac{\text{m}}{\text{s}}$ , and then keeps this velocity.

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

(d) the gap at 15 s is  $\Delta s = s_{\text{van}} - s_{\text{police}} = 240 \text{ m} - 180 \text{ m} = 60 \text{ m}$

- the police car closes it at  $\Delta v = v_{\text{police}} - v_{\text{van}} = 30 \frac{\text{m}}{\text{s}} - 16 \frac{\text{m}}{\text{s}} = 14 \frac{\text{m}}{\text{s}}$

$$\Delta t = \frac{\Delta s}{\Delta v} = \frac{60 \frac{\text{m}}{\text{s}}}{14 \frac{\text{m}}{\text{s}}} = 4.3 \text{ s} \quad \Rightarrow \quad t = 15 \text{ s} + \Delta t = \mathbf{19 \text{ s}}$$

## Exercise 3.3 (e)

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**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.  $3.0 \text{ s}$  later, the police car sets off after the van. It accelerates uniformly at  $2.5 \text{ m s}^{-2}$  until it reaches  $30 \frac{\text{m}}{\text{s}}$ , and then keeps this velocity.

(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]

## Exercise 3.3 (e)

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(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]

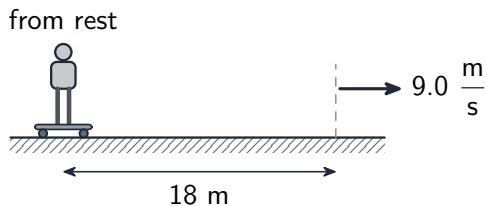
(e)

- van: a horizontal line at  $16 \frac{\text{m}}{\text{s}}$  from  $t = 0$
- police car: zero until 3.0 s, a straight line up to  $30 \frac{\text{m}}{\text{s}}$  at 15 s, then horizontal to about 19 s

## Exercise 3.4 (a)

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

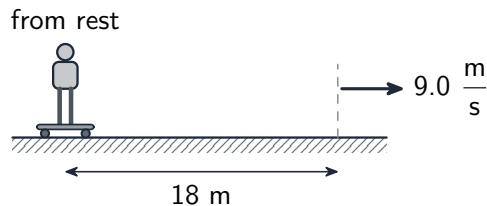
(a) Starting from  $v = u + at$  and  $s = \frac{1}{2}(u + v)t$ , **derive**  $v^2 = u^2 + 2as$ . [3]



## Exercise 3.4 (a)

**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]



(a)

- from  $v = u + at$ ,  $t = (v - u)/a$
- substitute into  $s = \frac{1}{2}(u + v)t$

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

- so  $2as = v^2 - u^2$ , which gives  $v^2 = u^2 + 2as$

## Exercise 3.4 (b)

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

(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]

## Exercise 3.4 (b)

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

(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]

(b)  $u = 0$

$$a = \frac{v^2 - u^2}{2s} = \frac{\left(9.0 \frac{\text{m}}{\text{s}}\right)^2 - 0}{2 \times 18 \text{ m}} = \mathbf{2.3 \text{ m s}^{-2}}$$

## Exercise 3.4 (c)

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

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

## Exercise 3.4 (c)

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

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

(c) the equation is true only when the acceleration is constant