

## Chapter 9 Linear motion

### Section 9.1 Displacement, speed and velocity

#### Worked example: Try yourself 9.1.1

##### AVERAGE VELOCITY AND CONVERTING UNITS

Sally is an athlete performing a training routine by running back and forth along a straight stretch of running track. She jogs 100 m west in a time of 20 s, then turns and walks 160 m east in a further 45 s before stopping.

<b>a</b> What is Sally's average velocity in $\text{m s}^{-1}$ ?	
<b>Thinking</b>	<b>Working</b>
Calculate the displacement. Remember total displacement is the sum of individual displacements. Sally's total journey consists of two displacements: 100 m west and 160 m east. Take east to be the positive direction.	$s = \text{sum of displacements}$ $= 100 \text{ m west} + 160 \text{ m east}$ $= -100 + 160$ $= +60 \text{ m or } 60 \text{ m east}$
Work out the total time taken for the journey.	Time taken $= 20 + 45 = 65 \text{ s}$
Substitute the values into the velocity equation.	$\text{average velocity } v_{av} = \frac{s}{\Delta t}$ $= \frac{60}{65}$ $= 0.92 \text{ m s}^{-1}$
Velocity is a vector, so a direction must be given.	$0.92 \text{ m s}^{-1} \text{ east}$

<b>b</b> What is the magnitude of Sally's average velocity in $\text{km h}^{-1}$ ?	
<b>Thinking</b>	<b>Working</b>
Convert from $\text{m s}^{-1}$ to $\text{km h}^{-1}$ by multiplying by 3.6.	$0.92 \times 3.6 = 3.3 \text{ km h}^{-1} \text{ east}$
As the magnitude of velocity is needed, direction is not required in this answer.	Magnitude of $v_{av} = 3.3 \text{ km h}^{-1}$

<b>c</b> What is Sally's average speed in $\text{m s}^{-1}$ ?	
<b>Thinking</b>	<b>Working</b>
Calculate the distance. Remember, distance is the length of the path covered in the entire journey. Sally travels 100 m in one direction and then 160 m the other way.	$d = 100 + 160$ $= 260 \text{ m}$
Work out the total time taken for the journey.	$20 + 45 = 65 \text{ s}$
Substitute the values into the speed equation.	$\text{Distance is } 260 \text{ m.}$ $\text{Time taken is } 65 \text{ s.}$ $\text{average speed } v_{av} = \frac{d}{\Delta t}$ $= \frac{260}{65}$ $= 4.0 \text{ m s}^{-1}$

<b>d</b> What is Sally's average speed in $\text{km h}^{-1}$ ?	
<b>Thinking</b>	<b>Working</b>
Convert from $\text{m s}^{-1}$ to $\text{km h}^{-1}$ by multiplying by 3.6.	$\text{average speed } v_{av} = 4.0 \text{ m s}^{-1}$ $= 14.4 \text{ km h}^{-1}$

## Section 9.1 Review

## KEY QUESTIONS SOLUTIONS

- 1 B and C. The distance travelled is  $25 \times 10 = 250$  m, but the displacement is zero because the swimmer starts and ends at the same place.
- 2 **a** Displacement = final position – initial position  
 $= 40 - 0$   
 $= +40$  cm  
 Distance travelled = 40 cm
- b** Displacement = final position – initial position  
 $= 40 - 50$   
 $= -10$  cm  
 Distance travelled = 10 cm
- c** Displacement = final position – initial position  
 $= 70 - 50$   
 $= 20$  cm  
 Distance travelled = 20 cm
- d** Displacement = final position – initial position  
 $= 70 - 50$   
 $= 20$  cm  
 Distance covered =  $50 + 30$   
 $= 80$  cm
- 3 **a**  $d = 50 + 30 = 80$  km
- b**  $s = 50$  km north +  $30$  km south  
 $= 50 + (-30)$   
 $= 50 - 30$   
 $= +20$  km or 20 km north
- 4 **a** The basement is 10 m downwards from the starting position on the ground floor. This can be calculated using the following equation:  
 $s = \text{final position} - \text{initial position}$   
 $= -10 - 0$   
 $= -10$  m or 10 m downwards
- b** The total displacement from the basement to the top floor is 60 m upwards. This can be calculated using the following equation:  
 $s = \text{final position} - \text{initial position}$   
 $= +50 - (-10)$   
 $= 50 + 10$   
 $= +60$  m or 60 m upwards
- c** The total distance travelled is 70 m.  
 $10 + 10 + 50 = 70$  m
- d** The top floor is 50 m upward from the starting position on the ground floor. This can be calculated using the following equation:  
 $s = \text{final position} - \text{initial position}$   
 $= 50 - 0$   
 $= 50$  m or 50 m upward
- 5 **a** average speed  $v_{av} = \frac{\text{distance travelled}}{\text{time taken}}$   
 $= \frac{400}{12}$   
 $= 33 \text{ m s}^{-1}$
- b** The car travelled 25 m. This can be calculated using the following method:  
 average speed  $v_{av} = \frac{\text{distance travelled}}{\text{time taken}}$   
 $d = v_{av} \times t$   
 $= 33 \times 0.75$   
 $= 25$  m

$$\begin{aligned}
 6 \quad a \quad 90 \text{ min} &= \frac{90}{60} \\
 &= 1.5 \text{ h} \\
 \text{average speed } v_{av} &= \frac{\text{distance travelled}}{\text{time taken}} \\
 &= \frac{25}{1.5} \\
 &= 17 \text{ km h}^{-1}
 \end{aligned}$$

b To convert from  $\text{km h}^{-1}$  to  $\text{m s}^{-1}$ , you need to divide by 3.6. So:

$$\begin{aligned}
 \text{average speed } v_{av} &= \frac{17}{3.6} \\
 &= 4.7 \text{ m s}^{-1}
 \end{aligned}$$

$$\begin{aligned}
 7 \quad a \quad \text{average speed } v_{av} &= \frac{\text{distance travelled}}{\text{time taken}} \\
 &= \frac{d}{\Delta t} \\
 &= \frac{9}{10} \\
 &= 0.9 \text{ m s}^{-1}
 \end{aligned}$$

b Displacement is 1 m east of the starting position.

$$\begin{aligned}
 \text{average velocity } v_{av} &= \frac{\text{displacement}}{\text{time taken}} \\
 &= \frac{s}{\Delta t} \\
 &= \frac{1}{10} \\
 &= 0.1 \text{ m s}^{-1} \text{ east}
 \end{aligned}$$

$$\begin{aligned}
 8 \quad a \quad \text{average speed } v_{av} &= \frac{\text{distance travelled}}{\text{time taken}} \\
 &= \frac{2.5}{0.25} \\
 &= 10 \text{ km h}^{-1}
 \end{aligned}$$

$$b \quad \frac{10 \text{ km h}^{-1}}{3.6} = 2.8 \text{ m s}^{-1} \text{ south}$$

9 a Distance travelled = 10 km north + 3 km south + x km north to finish 15 km north of the start.  
 $x = 8 \text{ km north.}$

$$\begin{aligned}
 \text{Total distance covered} &= 10 + 3 + 8 \\
 &= 21 \text{ km}
 \end{aligned}$$

b She finishes 15 km north of her starting point. This is her displacement.

$$\begin{aligned}
 c \quad \text{average speed } v_{av} &= \frac{\text{distance travelled}}{\text{time taken}} \\
 &= \frac{21}{1.5} \\
 &= 14 \text{ km h}^{-1}
 \end{aligned}$$

$$\begin{aligned}
 d \quad \text{average velocity } v_{av} &= \frac{\text{displacement}}{\text{time taken}} \\
 &= \frac{15}{1.5}
 \end{aligned}$$

## Section 9.2 Acceleration

### Worked example: Try yourself 9.2.1

#### CHANGE IN SPEED AND VELOCITY PART 1

A golf ball is dropped onto a concrete floor and strikes the floor at  $9.0 \text{ m s}^{-1}$ . It then rebounds at  $7.0 \text{ m s}^{-1}$ .

<b>a</b> What is the change in speed of the ball?		
<b>Thinking</b>	<b>Working</b>	
Find the values for the initial speed and the final speed of the ball.	$u = 9.0 \text{ m s}^{-1}$ $v = 7.0 \text{ m s}^{-1}$	
Substitute the values into the change in speed equation: $\Delta v = v - u$	$\Delta v = v - u$ $= 7.0 - 9.0$ $= -2.0 \text{ m s}^{-1}$	

Note that speed is a scalar so the negative value indicates a decrease in magnitude, as opposed to a negative direction.

<b>b</b> What is the change in velocity of the ball?		
<b>Thinking</b>	<b>Working</b>	
Apply the sign convention to replace the directions.	$u = 9.0 \text{ m s}^{-1}$ down $= -9.0 \text{ m s}^{-1}$ $v = 7.0 \text{ m s}^{-1}$ up $= +7.0 \text{ m s}^{-1}$	
Reverse the direction of $u$ to get $-u$ .	$u = -9.0 \text{ m s}^{-1}$ $-u = 9.0 \text{ m s}^{-1}$	
Substitute the values into the change in velocity equation: $\Delta v = v + (-u)$	$\Delta v = v + (-u)$ $= 7.0 + (+9.0)$ $= 16.0 \text{ m s}^{-1}$	
Apply the sign convention to describe the direction.	$\Delta v = 16 \text{ m s}^{-1}$ up	

### Worked example: Try yourself 9.2.2

#### CHANGE IN SPEED AND VELOCITY PART 2

A golf ball is dropped onto a concrete floor and strikes the floor at  $9.0 \text{ m s}^{-1}$ . It then rebounds at  $7.0 \text{ m s}^{-1}$ . The contact time with the floor is 35 ms.

What is the average acceleration of the ball during its contact with the floor?		
<b>Thinking</b>	<b>Working</b>	
Note the values you will need in order to find the average acceleration (initial velocity, final velocity and time). Convert ms into s by dividing by 1000. (Note that $\Delta v$ was calculated for this situation in the previous Worked example.)	$u = -9.0 \text{ m s}^{-1}$ $-u = 9.0 \text{ m s}^{-1}$ $v = 7.0 \text{ m s}^{-1}$ $\Delta v = 16 \text{ m s}^{-1}$ up $\Delta t = 35 \text{ ms}$ $= 0.035 \text{ s}$	
Substitute the values into the average acceleration equation.	$a_{av} = \frac{\text{change in velocity}}{\text{time taken}}$ $= \frac{\Delta v}{\Delta t}$ $= \frac{16}{0.035}$ $= 457 \text{ m s}^{-2}$ , which approximates to $460 \text{ m s}^{-2}$	
Acceleration is a vector, so you must include a direction in your answer.	$a_{av} = 460 \text{ m s}^{-2}$ up	

## Section 9.2 Review

## KEY QUESTIONS SOLUTIONS

$$\begin{aligned} 1 \quad \Delta v &= v - u \\ &= 3 - 10 \\ &= -7 \end{aligned}$$

So the change in speed is  $-7 \text{ km h}^{-1}$ .

Note that speed is a scalar so the negative value indicates a decrease in magnitude, as opposed to a negative direction.

$$\begin{aligned} 2 \quad \Delta v &= v - u \\ &= 0 + (+5) \\ &= +5 \text{ m s}^{-1} \text{ or } 5 \text{ m s}^{-1} \text{ up} \end{aligned}$$

$$\begin{aligned} 3 \quad &\text{Down is negative, so the initial velocity is } -5.0 \text{ m s}^{-1}. \\ \Delta v &= v - u = (+3.0) \pm (\pm 5.0) \\ &= +8 \text{ m s}^{-1} \\ &= 8 \text{ m s}^{-1} \text{ up} \end{aligned}$$

$$\begin{aligned} 4 \quad a_{av} &= \frac{\text{change in velocity}}{\text{time taken}} \\ &= \frac{\Delta v}{\Delta t} \\ &= \frac{0 - 7.5}{1.5} \\ &= -5.0 \text{ m s}^{-2} \\ &= 5.0 \text{ m s}^{-2} \text{ south} \end{aligned}$$

$$\begin{aligned} 5 \quad a_{av} &= \frac{\text{change in velocity}}{\text{time taken}} \\ &= \frac{\Delta v}{\Delta t} \\ &= \frac{150 - 0}{3.5} \\ &= 43 \text{ km h}^{-1} \text{ s}^{-1} \end{aligned}$$

$$\begin{aligned} 6 \quad a \quad \Delta v &= v - u \\ &= 15 - 25 \\ &= -10 \text{ m s}^{-1} \end{aligned}$$

Note that speed is a scalar so the negative value indicates a decrease in magnitude, as opposed to a negative direction.

$$\begin{aligned} b \quad \Delta v &= v - u \\ &= -15 \pm (-25) \\ &= -40 \text{ m s}^{-1} \\ &= 40 \text{ m s}^{-1} \text{ west} \end{aligned}$$

$$\begin{aligned} c \quad a_{av} &= \frac{\text{change in velocity}}{\text{time taken}} \\ &= \frac{\Delta v}{\Delta t} \\ &= \frac{40}{0.050} \\ &= 800 \text{ m s}^{-2} \end{aligned}$$

Magnitude only so direction not required.

$$\begin{aligned} 7 \quad a \quad \Delta v &= v - u \\ &= 8.0 - 0 \\ &= 8.0 \text{ m s}^{-1} \end{aligned}$$

$$\begin{aligned} b \quad \Delta v &= v - u \\ &= -8.0 - 0 \\ &= -8.0 \text{ m s}^{-1} \\ &= 8.0 \text{ m s}^{-1} \text{ south} \end{aligned}$$

$$\begin{aligned} c \quad a_{av} &= \frac{\text{change in velocity}}{\text{time taken}} \\ &= \frac{\Delta v}{\Delta t} \\ &= \frac{8.0}{1.2} \\ &= 6.7 \text{ m s}^{-2} \end{aligned}$$

## Section 9.3 Graphing position, velocity and acceleration over time

### Worked example: Try yourself 9.3.1

#### ANALYSING A POSITION–TIME GRAPH

Use the graph shown in Worked example 9.3.1 to answer the following questions.

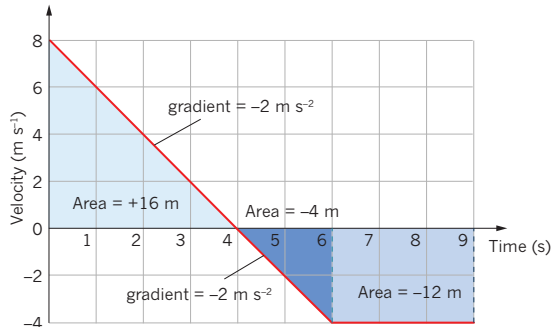
<b>a</b> What is the velocity of the cyclist between E and F?	
<b>Thinking</b>	<b>Working</b>
Determine the change in position (displacement) of the cyclist between E and F using: $s = \text{final position} - \text{initial position}$	At E, $x = 300 \text{ m}$ . At F, $x = 0 \text{ m}$ . $s = 0 - 300$ $= -300 \text{ m}$ or $300 \text{ m}$ backwards (that is, back towards the starting point)
Determine the time taken to travel from E to F.	$= 100 - 80$ $= 20 \text{ s}$
Calculate the gradient of the graph between E and F using: $\text{gradient of } x-t \text{ graph} = \frac{\text{rise}}{\text{run}} = \frac{\Delta x}{\Delta t}$ Remember that $\Delta x = s$ .	Gradient $= \frac{-300}{20}$ $= -15$
State the velocity, using: $\text{gradient of } x-t \text{ graph} = \text{velocity}$ Velocity is a vector so direction must be given.	Since the gradient is $-15$ , the velocity is $-15 \text{ m s}^{-1}$ or $15 \text{ m s}^{-1}$ backwards (towards the starting point).

<b>b</b> Describe the motion of the cyclist between D and E.	
<b>Thinking</b>	<b>Working</b>
Interpret the shape of the graph between D and E.	The graph is flat between D and E, indicating that the cyclist's position is not changing for this time. So the cyclist is not moving. If the cyclist is not moving, the velocity is $0 \text{ m s}^{-1}$ .
You may confirm the result by calculating the gradient of the graph between D and E using: $\text{gradient of } x-t \text{ graph} = \frac{\text{rise}}{\text{run}} = \frac{\Delta x}{\Delta t}$ Remember that $\Delta x = s$ .	Gradient $= \frac{0}{20}$ $= 0$

**Worked example: Try yourself 9.3.2****ANALYSING A VELOCITY–TIME GRAPH**

Use the graph shown in Worked example 9.3.2 to answer the following questions.

<b>a</b> What is the displacement of the car from 4 to 6 seconds?	
<b>Thinking</b>	<b>Working</b>
<p>Displacement is the area under the graph. So, calculate the area under the graph for the time period for which you want to find the displacement.</p> <p>Use displacement = <math>b \times h</math> for squares and rectangles.</p> <p>Use displacement = <math>\frac{1}{2} b \times h</math> for triangles.</p>	 <p>Area is triangular:</p> $\text{area} = \frac{1}{2} \times 2 \times -4$ $= -4 \text{ m}$
Displacement is a vector quantity, so a direction is needed.	displacement = 4 m west

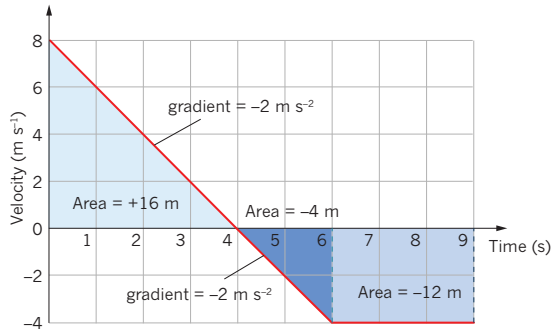
  

<b>b</b> What is the average velocity of the car from 4 to 6 seconds?	
<b>Thinking</b>	<b>Working</b>
Identify the equation and variables, and apply the sign convention.	$v = \frac{s}{\Delta t}$ $s = -4 \text{ m}$ $\Delta t = 2 \text{ s}$
Substitute values into the equation: $v = \frac{s}{\Delta t}$	$v = \frac{s}{\Delta t}$ $= \frac{-4}{2}$ $= -2 \text{ m s}^{-1}$
Velocity is a vector quantity, so a direction is needed.	$v_{\text{av}} = 2 \text{ m s}^{-1}$ west

### Worked example: Try yourself 9.3.3

#### FINDING ACCELERATION USING A V-T GRAPH

Use the graph shown in Worked example 9.3.3 to answer the following questions.

What is the acceleration of the car during the period from 4 to 6 seconds?	
<p><b>Thinking</b></p> <p>Acceleration is the gradient of a <math>v</math>-<math>t</math> graph. Calculate the gradient using:</p> $\text{gradient} = \frac{\text{rise}}{\text{run}}$	<p><b>Working</b></p>  <p>Gradient from 4 to 6 = <math>\frac{\text{rise}}{\text{run}} = \frac{-4}{2} = -2 \text{ m s}^{-1}</math></p>
<p>Acceleration is a vector quantity, so a direction is needed.</p> <p>Note: In this case, the car is moving in the negative direction and speeding up.</p>	<p>Acceleration = <math>2 \text{ m s}^{-2}</math> west.</p>

## Section 9.3 Review

### KEY QUESTIONS SOLUTIONS

- D. The gradient is the displacement over the time taken, hence velocity.
- The car initially moves in a positive direction and travels 8 m in 2 s. It then stops for 2 s. The car then reverses direction for 5 s, passing back through its starting point after 8 s. It travels a further 2 m in a negative direction before stopping after 9 s.
- Reading from graph:
  - +8 m
  - +8 m
  - +4 m
  - 2 m
- The car returns to its starting point when the position is zero again, which occurs at  $t = 8 \text{ s}$ .
- The velocity during the first 2 s is equal to the gradient of the graph during this interval.  

$$\text{velocity} = \frac{\text{rise}}{\text{run}} = \frac{8-0}{2} = +4 \text{ m s}^{-1}$$
  - After 3 s the velocity is zero, since the gradient of the graph = 0.
  - velocity = gradient of graph =  $\frac{\text{rise}}{\text{run}} = \frac{8-0}{2} = -2 \text{ m s}^{-1}$
  - The velocity at 8 s is  $-2 \text{ m s}^{-1}$ , since the car is travelling at a constant velocity of  $-2 \text{ m s}^{-1}$  between 4 s and 9 s.
  - The velocity from 8 s to 9 s =  $-2 \text{ m s}^{-1}$ , since the car is travelling at a constant velocity of  $-2 \text{ m s}^{-1}$  between 4 s and 9 s.
- Distance =  $8 + 8 + 2 = 18 \text{ m}$
  - Displacement =  $\Delta x = (-2) - 0 = -2 \text{ m}$
- Average speed = gradient of the line segment  

$$= \frac{\text{rise}}{\text{run}} = \frac{150}{30} = 5 \text{ m s}^{-1}$$

- b** Average velocity = gradient of the line segment plus direction

$$\begin{aligned}
 &= \frac{\text{rise}}{\text{run}} \\
 &= \frac{200}{10} \\
 &= 20 \text{ m s}^{-1} \text{ north}
 \end{aligned}$$

The velocity is positive so the direction of the cyclist is north.

- c** Average velocity = displacement over time

$$\begin{aligned}
 &= \frac{\text{rise}}{\text{run}} \\
 &= \frac{500}{50} \\
 &= 10 \text{ m s}^{-1} \text{ north}
 \end{aligned}$$

- 8 a** Acceleration = gradient

$$\begin{aligned}
 &= \frac{\text{rise}}{\text{run}} \\
 &= 0 \text{ m s}^{-2}
 \end{aligned}$$

- b** Acceleration = gradient

$$\begin{aligned}
 &= \frac{\text{rise}}{\text{run}} \\
 &= \frac{-3}{3} \\
 &= -1 \text{ or just } 1 \text{ m s}^{-2}
 \end{aligned}$$

Magnitude only so direction is not required.

- c** Split the area up into shapes and add the values together to get the full area under the graph.

Displacement = area under

$$\begin{aligned}
 &= (b \times h) + \left(\frac{1}{2} \times b \times h\right) + \left(\frac{1}{2} \times b \times h\right) \\
 &= (4 \times 1) + \left(\frac{1}{2} \times 2 \times 2\right) + \left(\frac{1}{2} \times 3 \times 3\right) \\
 &= 4 + 2 + 4.5 \\
 &= 10.5 \text{ m}
 \end{aligned}$$

- d** average velocity =  $\frac{\text{displacement}}{\text{time}}$

$$\begin{aligned}
 &= \frac{10.5}{7} \\
 &= 1.5 \text{ m s}^{-1}
 \end{aligned}$$

- 9 a** instantaneous velocity = gradient of the line

$$\begin{aligned}
 &= \frac{\text{rise}}{\text{run}} \\
 &= \frac{300}{15} \\
 &= 20 \text{ m s}^{-1} \text{ north}
 \end{aligned}$$

- b** instantaneous velocity = gradient of the line

$$\begin{aligned}
 &= \frac{\text{rise}}{\text{run}} \\
 &= \frac{-600}{15} \\
 &= -40 \text{ or } 40 \text{ m s}^{-1} \text{ south}
 \end{aligned}$$

- 10 a** Reading from the graph, the curve flattens out after 80 s.

- b** Draw a tangent to the graph at 10 s and determine the gradient of the tangent.

$$\begin{aligned}
 \text{gradient} &= \frac{\text{rise}}{\text{run}} \\
 &= \text{approx. } \frac{35}{30} \text{ or } \frac{53}{40} \\
 &= 1.2 \text{ or } 1.3 \text{ m s}^{-2} \text{ (answers may vary slightly)}
 \end{aligned}$$

- c** Draw a tangent to the graph at 40 s and determine the gradient of the tangent.

$$\begin{aligned}
 \text{gradient} &= \frac{\text{rise}}{\text{run}} \\
 &= \text{approx. } \frac{34}{90} \text{ or } \frac{35}{85} \\
 &= 0.38 \text{ or } 0.41 \text{ m s}^{-2} \text{ (answers may vary slightly)}
 \end{aligned}$$

- d** displacement = area under the graph

There are various methods for calculating this, but counting squares gives 49 squares, each of area  $10 \times 10$ .

$$49 \times 10 \times 10 = 4900 \text{ m or } 4.9 \text{ km}$$

**11 a** acceleration = gradient

$$\begin{aligned}
 &= \frac{\text{rise}}{\text{run}} \\
 &= \frac{8}{4} \\
 &= 2 \text{ m s}^{-1}
 \end{aligned}$$

**b** The bus will overtake the bike when they have both travelled the same distance, given by the areas under the two graphs. After 8 s, the bus has travelled 56 m and the bike 64 m. After 10 s, the bus has travelled 80 m and the bike 80 m.

Algebraically, this could be determined by:

The displacement for the bus =  $56 + 12(t - 8)$

The displacement for the bike =  $8t$

Equating these two displacements gives:

$$8t = 56 + 12t - 96$$

$$12t - 8t = 96 - 56$$

$$4t = 40$$

$$t = 10 \text{ s}$$

**c** After 10 s the bike has travelled  $10 \times 8 = 80 \text{ m}$ .

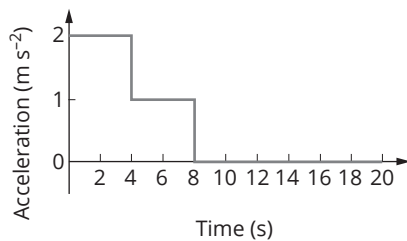
**d** average velocity  $v_{\text{av}} = \frac{\text{displacement}}{\text{time taken}}$

$$\begin{aligned}
 &= \left(\frac{1}{2} \times 4 \times 8\right) + (4 \times 8) + \left(\frac{1}{2} \times 4 \times 4\right) \\
 &= 16 + 32 + 8 \\
 &= 56 \text{ m}
 \end{aligned}$$

So

$$\begin{aligned}
 v_{\text{av}} &= \frac{56}{8} \\
 &= 7 \text{ m s}^{-1}
 \end{aligned}$$

**12 a**



**b** The change in velocity of the bus over the first 8 s is determined by calculating the area under the acceleration–time graph from  $t = 0$  to  $t = 8 \text{ s}$ , i.e.  $+12 \text{ m s}^{-1}$ .

## Section 9.4 Equations for uniform acceleration

### Worked example: Try yourself 9.4.1

#### USING THE EQUATIONS OF MOTION

A snowboarder in a race is travelling  $15 \text{ m s}^{-1}$  east as she crosses the finishing line. She then decelerates uniformly until coming to a stop over a distance of 30 m.

<b>a</b> What is her acceleration as she comes to a stop?	
<b>Thinking</b>	<b>Working</b>
Write down the known quantities as well as the quantity that you are finding. Apply the sign convention that east is positive and west is negative.	$s = +30 \text{ m}$
Identify the correct equation to use.	$v^2 = u^2 + 2as$
Substitute known values into the equation and solve for $a$ . Include units with the answer.	$v^2 = u^2 + 2as$ $0^2 = 15^2 + 2 \times a \times 30$ $a = \frac{0 - 225}{60}$ $= -3.8 \text{ m s}^{-2}$
Use the sign convention to state the answer with its direction.	$a = 3.8 \text{ m s}^{-2}$ west

<b>b</b> How long does she take to come to a stop?	
<b>Thinking</b>	<b>Working</b>
Write down the known quantities as well as the quantity that you are finding. Apply the sign convention that east is positive and west is negative.	$s = 30 \text{ m}$ $u = 15 \text{ m s}^{-1}$ $v = 0 \text{ m s}^{-1}$ $a = -3.8 \text{ m s}^{-2}$ $t = ?$
Identify the correct equation to use. Since you now know four values, any equation involving $t$ will work.	$v = u + at$
Substitute known values into the equation and solve for $t$ . Include units with the answer.	$t = \frac{0 - 15}{-3.8}$ $= 3.9 \text{ s}$

<b>c</b> What is the average velocity of the snowboarder as she comes to a stop?	
<b>Thinking</b>	<b>Working</b>
Write down the known quantities as well as the quantity that you are finding. Apply the sign convention that east is positive and west is negative.	$u = +15 \text{ m s}^{-1}$ $v = 0 \text{ m s}^{-1}$ $v_{\text{av}} = ?$
Identify the correct equation to use.	$v_{\text{av}} = \frac{1}{2}(u + v)$
Substitute known quantities into the equation and solve for $v_{\text{av}}$ . Include units with the answer.	$v_{\text{av}} = \frac{1}{2}(u + v)$ $= \frac{1}{2}(15 + 0)$ $= 7.5 \text{ m s}^{-1}$
Use the sign convention to state the answer with its direction.	$v_{\text{av}} = 7.5 \text{ m s}^{-1}$ east

## Section 9.4 Review

## KEY QUESTIONS SOLUTIONS

1 E. The chosen equation must contain  $s$ ,  $u$ ,  $v$  and  $a$ .

2 a  $u = 0$ ,  $s = 400$ ,  $t = 16$ ,  $a = ?$

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

$$400 = 0 + \frac{1}{2}a \times 16^2$$

$$a = \frac{400}{\frac{256}{2}} \times 2$$

$$= 3.1 \text{ m s}^{-2}$$

b  $u = 0$ ,  $s = 400$ ,  $t = 16$ ,  $a = 3.1$ ,  $v = ?$

$$v = u + at$$

$$= 0 + 3.1 \times 16$$

$$= 50 \text{ m s}^{-1}$$

c  $50 \text{ m s}^{-1} \times 3.6 = 180 \text{ km h}^{-1}$

3 a  $u = 0$ ,  $t = 8.0$ ,  $v = 16$ ,  $a = ?$

$$v = u + at$$

$$16 = 0 + a \times 8.0$$

$$a = \frac{16}{8.0}$$

$$= 2.0 \text{ m s}^{-2}$$

b  $v_{av} = \frac{u+v}{2}$

$$= \frac{0+16}{2}$$

$$= 8 \text{ m s}^{-1}$$

c  $u = 0$ ,  $t = 8.0$ ,  $v = 16$ ,  $a = 2.0$ ,  $s = ?$

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

$$= \frac{1}{2}(0+16) \times 8.0$$

$$= 64 \text{ m}$$

4 a  $u = 0$ ,  $v = 160$ ,  $t = 4.0$ ,  $a = ?$

$$v = u + at$$

$$160 = 0 + a \times 4.0$$

$$a = 40 \text{ m s}^{-2}$$

b In the first 4.0 s:  $u = 0$ ,  $t = 4.0$ ,  $v = 160$ ,  $a = 40$ ,  $s = ?$

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

$$= \frac{1}{2}(0+160) \times 4.0$$

$$= 80 \times 4.0$$

$$= 320 \text{ m}$$

In the last 5.0 seconds:

$$u = 160$$
,  $t = 5.0$ ,  $v = 160$ ,  $a = 0$ ,  $s = ?$

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

$$= \frac{1}{2}(160+160) \times 5.0$$

$$= 160 \times 5.0$$

$$= 800 \text{ m}$$

Total distance in 9.0 s:

$$= 320 + 800$$

$$= 1120 \text{ m}$$

$$= 1.12 \text{ or } 1.1 \text{ km}$$

c  $160 \text{ m s}^{-1} \times 3.6 = 576 \text{ or } 580 \text{ km h}^{-1}$

d  $u = 0$ ,  $v = 160$

$$v_{av} = \frac{u+v}{2}$$

$$= \frac{0+160}{2}$$

$$= 80 \text{ m s}^{-1}$$

e  $v_{av} = \frac{s}{t}$

$$= \frac{1120}{9}$$

$$= 124.4 \text{ or } 120 \text{ m s}^{-1}$$

5 a  $u = 4.2$ ,  $t = 0.5$ ,  $v = 6.7$ ,  $a = ?$

$$v = u + at$$

$$6.7 = 4.2 + a \times 0.50$$

$$a = \frac{6.7-4.2}{0.50}$$

$$= 5.0 \text{ m s}^{-1}$$

b  $u = 4.2$ ,  $t = 0.5$ ,  $v = 6.7$ ,  $a = 5.0$ ,  $s = ?$

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

$$= \frac{1}{2}(4.2+6.7) \times 0.50$$

$$= 2.725 \text{ or } 2.7 \text{ m}$$

c  $v_{av} = \frac{u+v}{2}$

$$= \frac{4.2+6.7}{2}$$

$$= 5.45 \text{ or } 5.5 \text{ m s}^{-1}$$

6 D. The stone is travelling downwards, so the velocity is downwards. As the stone strikes the water, it quickly decelerates, so the acceleration is upwards.

7 a  $u = -28$ ,  $v = 0$ ,  $s = -4.0$ ,  $a = ?$

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

$$0 = (-28)^2 + 2 \times a \times -4.0$$

$$a = \frac{-784}{-80}$$

$$= 98 \text{ m s}^{-2}$$

b  $u = -28$ ,  $v = 0$ ,  $s = -4.0$ ,  $a = 98$ ,  $t = ?$

$$v = u + at$$

$$0 = -28 + 98t$$

$$t = \frac{28}{98}$$

$$= 0.29 \text{ s}$$

c What is the speed of the diver after she has dived through 2.0 m of water?

$$u = -28$$
,  $s = -2.0$ ,  $a = 98$ ,  $v = ?$ 

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

$$= (-28)^2 + 2 \times 98 \times -2.0$$

$$= 784 - 392$$

$$v = 19.8 \text{ or } 20 \text{ m s}^{-1}$$

8 a  $\frac{75 \text{ km h}^{-1}}{3.6} = 20.83 \text{ or } 21 \text{ m s}^{-1}$

b  $u = 21, a = 0, t = 0.25, s = ?$

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

$$= 21 \times 0.25$$

$$= 5.25 \text{ or } 5.3 \text{ m}$$

c  $u = 21, a = -6.0, v = 0, t = ?$

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

$$0 = (21)^2 + 2 \times -6.0 \times s$$

$$s = \frac{(21)^2}{12}$$

$$= 36.75 \text{ or } 37 \text{ m}$$

d  $5.3 + 37 = 42.3 \text{ or } 42 \text{ m}$

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

$$= 0 + 2(2.0 \times 4.0)$$

$$v = 4.0 \text{ m s}^{-1}$$

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

$$= 0 + 2(2.0 \times 8.0)$$

$$v = 5.7 \text{ m s}^{-1}$$

c  $v = u + at$

$$4.0 = 0 + 2.0t$$

$$t = 2.0 \text{ s}$$

d  $v = u + at$

$$5.7 = 0 + 2.0t$$

$$t = 2.85 \text{ s}$$

The time taken to travel the final 4.0 m is

$$2.85 \text{ s} - 2.0 \text{ s} = 0.85 \text{ s}.$$

10 a  $v = u + at$

$$12 = 0 + 1.5t$$

$$t = 8.0 \text{ s}$$

- b The bus will catch up with the cyclist when they have each travelled the same distance from the point at which the cyclist first passes the bus.

Cyclist: constant velocity, so  $s = 12 \times t$

Bus: uniform acceleration  $u = 0, a = 1.5 \text{ m s}^{-2}, s = ?, t = ?$

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

$$= 0.75t^2$$

When the bus catches up with the cyclist, their displacements are equal, so:

$$12t = 0.75t^2$$

$$t = 16 \text{ s}$$

c  $s = 12 \times 16 = 192 \text{ m}$

## Section 9.5 Vertical motion

### Worked example: Try yourself 9.5.1

#### VERTICAL MOTION

A construction worker accidentally knocks a hammer from a building so that it falls vertically a distance of 60 m to the ground. Use  $g = -9.8 \text{ m s}^{-2}$  and ignore air resistance when answering these questions.

a How long does the hammer take to fall halfway, to 30 m?	
<b>Thinking</b>	<b>Working</b>
Write down the values of the quantities that are known and what you are finding. Apply the sign convention that up is positive and down is negative.	$s = -30 \text{ m}$ $u = 0 \text{ m s}^{-1}$ $a = -9.8 \text{ m s}^{-2}$ $t = ?$
Identify the correct equation to use.	$s = ut + \frac{1}{2}at^2$
Substitute known values into the equation and solve for t. Think about whether the value seems reasonable.	$-30 = 0 \times t + \frac{1}{2} \times -9.8 \times t^2$ $-30 = -4.9t^2$ $t = \sqrt{\frac{-30}{-4.9}}$ $= 2.5 \text{ s}$

<b>b</b> How long does it take the hammer to fall all the way to the ground?	
<b>Thinking</b>	<b>Working</b>
Write down the values of the quantities that are known and what you are finding. Apply the sign convention that up is positive and down is negative.	$s = -60 \text{ m}$ $u = 0 \text{ m s}^{-1}$ $a = -9.8 \text{ m s}^{-2}$ $t = ?$
Identify the correct equation to use.	$s = ut + \frac{1}{2}at^2$
Substitute known values into the equation and solve for $t$ . Think about whether the value seems reasonable.	$-60 = 0 \times t + \frac{1}{2} \times -9.8 \times t^2$ $-60 = -4.9t^2$ $t = \sqrt{\frac{-60}{-4.9}}$ $= 3.5 \text{ s}$

<b>c</b> What is the velocity of the hammer as it hits the ground?	
<b>Thinking</b>	<b>Working</b>
Write down the values of the quantities that are known and what you are finding. Apply the sign convention that up is positive and down is negative.	$s = -60 \text{ m}$ $u = 0 \text{ m s}^{-1}$ $v = ?$ $a = -9.8 \text{ m s}^{-2}$ $t = 3.5 \text{ s}$
Identify the correct equation to use. Since you now know four values, any equation involving $v$ will work.	$v = u + at$
Substitute known values into the equation and solve for $v$ . Think about whether the value seems reasonable.	$v = 0 + (-9.8) \times 3.5$ $= -34 \text{ m s}^{-1}$
Use the sign and direction convention to describe the direction of the final velocity.	$v = -34 \text{ m s}^{-1}$ or $34 \text{ m s}^{-1}$ downwards

### Worked example: Try yourself 9.5.2

#### MAXIMUM HEIGHT PROBLEMS

On winning a cricket match, a fielder throws a cricket ball vertically into the air at  $15 \text{ m s}^{-1}$ . In this example, air resistance can be ignored and the acceleration due to gravity will be taken as  $9.8 \text{ m s}^{-2}$ .

<b>a</b> Determine the maximum height reached by the ball.	
<b>Thinking</b>	<b>Working</b>
Write down the values of the quantities that are known and what you are finding. At the maximum height the velocity is zero. Apply the sign convention that up is positive and down is negative.	$u = 15 \text{ m s}^{-1}$ $v = 0$ $a = -9.8 \text{ m s}^{-2}$ $s = ?$
Select an appropriate formula.	$v^2 = u^2 + 2as$
Substitute known values into the equation and solve for $s$ .	$0 = (15)^2 + 2 \times (-9.8) \times s$ $s = \frac{-225}{-19.6}$ $\therefore s = +11.5 \text{ m}$ , i.e. the ball reaches a height of 11.5 m.

<b>b</b> Calculate the time that the ball takes to return to its starting position.	
<b>Thinking</b>	<b>Working</b>
To work out the time for which the ball is in the air, it is often necessary to first calculate the time that it takes to reach its maximum height. Write down the values of the quantities that are known and what you are finding.	$u = 15 \text{ m s}^{-1}$ $v = 0 \text{ m s}^{-1}$ $a = -9.8 \text{ m s}^{-2}$ $s = 11.5 \text{ m}$ $t = ?$
Select an appropriate formula.	$v = u + at$
Substitute known values into the equation and solve for $t$ .	$0 = 15 + (-9.8 \times t)$ $9.8t = 15$ $\therefore t = 1.5 \text{ s}$ The ball takes 1.5 s to reach its maximum height. It will therefore take 1.5 s to fall from this height back to its starting point and so the whole trip will last for 3.0 s.

## Section 9.5 Review

### KEY QUESTIONS SOLUTIONS

- 1** B. The acceleration of a falling object is due to gravity, so it is constant.
- 2** A and D. Acceleration due to gravity is constant (down), however, velocity changes throughout the journey as it is zero at the top of the flight.
- 3** **a**  $u = 0 \text{ m s}^{-1}$   
 $v = ?$   
 $a = -9.8 \text{ m s}^{-2}$   
 $t = 3 \text{ s}$   
 $v = u + at$   
 $= 0 + (-9.8) \times 3.0$   
 $= 29 \text{ m s}^{-1}$  (no direction required for speed)

**b**  $s = -30 \text{ m}$   
 $u = 0 \text{ m s}^{-1}$   
 $v = ?$   
 $a = -9.8 \text{ m s}^{-2}$   
 $v^2 = u^2 + 2as$   
 $= 0 + 2 \times (-9.8) \times (-30)$   
 $v = \sqrt{588}$   
 $= 24 \text{ m s}^{-1}$

**c**  $v_{\text{av}} = \frac{1}{2}(u + v)$   
 $= \frac{1}{2}(0 + 24)$   
 $= 12 \text{ m s}^{-1}$  (down)
- 4** **a** C. The acceleration of a falling object is due to gravity, so it is constant no matter the direction of vertical travel (upwards or downwards).

**b** D. The flight is symmetrical, so the starting and landing speeds are the same, but in opposite directions.
- 5** **a**  $v = 0 \text{ m s}^{-1}$ ,  $a = -9.8 \text{ m s}^{-2}$ ,  $t = 1.5 \text{ s}$ ,  $u = ?$   
 $v = u + at$   
 $0 = u - 9.8 \times 1.5$   
 $u = 14.7 \text{ or } 15 \text{ m s}^{-1}$

**b**  $u = 15 \text{ m s}^{-1}$ ,  $v = 0 \text{ m s}^{-1}$ ,  $a = -9.8 \text{ m s}^{-2}$ ,  $t = 1.5 \text{ s}$ ,  $s = ?$   
 $s = \frac{1}{2}(u + v)t$   
 $= \frac{1}{2}(15 + 0) \times 1.5$   
 $= 11.25 \text{ or } 11 \text{ m}$

- 6 a  $u = 0 \text{ m s}^{-1}$ ,  $a = -9.8 \text{ m s}^{-2}$ ,  $t = 0.40 \text{ s}$ ,  $v = ?$

$$v = u + at$$

$$= 0 - 9.8 \times 0.40$$

$$= -3.92 \text{ or } -3.9 \text{ m s}^{-1}$$

- b  $u = 0 \text{ m s}^{-1}$ ,  $a = -9.8 \text{ m s}^{-2}$ ,  $t = 0.40 \text{ s}$ ,  $v = -3.9 \text{ m s}^{-1}$ ,  $s = ?$

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

$$= \frac{1}{2}(0 + 3.9) \times 0.40$$

$$= -0.78 \text{ or } 0.78 \text{ m}$$

- c  $u = 0$ ,  $a = -9.8$ ,  $t = 0.20$ ,  $s = ?$

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

$$= 0 + \frac{1}{2} \times -9.8 \times (0.20)^2$$

$$= -0.20 \text{ or } 0.20 \text{ m}$$

- d Distance in last  $0.20 \text{ s} = 0.78 - 0.20$

$$= 0.58 \text{ m}$$

- 7 a The time to the top is half of the total time, i.e.  $2.0 \text{ s}$ .

- b  $v = 0$ ,  $a = -9.8$ ,  $t = 2$ ,  $u = ?$

$$v = u + at$$

$$0 = u + -9.8 \times 2$$

$$u = 9.8 \times 2$$

$$= 19.6 \text{ or } 20 \text{ m s}^{-1}$$

- c  $v = 0$ ,  $a = -9.8$ ,  $t = 2$ ,  $u = 19.6$ ,  $s = ?$

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

$$= 0 + \frac{1}{2} \times -9.8 \times (0.2)^2$$

$$= 19.6 \text{ or } 20 \text{ m}$$

- d The lid returns to its starting position, so the final velocity will be same as the launch velocity, but in the opposite direction, i.e.  $20 \text{ m s}^{-1}$  downwards.

- 8 a Shot-put:  $u = 0$ ,  $a = -9.8$ ,  $s = -60.0$ ,  $t = ?$

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

$$-60.0 = 0 + \frac{1}{2} \times -9.8 \times t^2$$

$$t^2 = \frac{60}{\frac{1}{2} \times 9.8}$$

$$t = 3.5 \text{ s}$$

- b 100 g mass:  $u = -10.0$ ,  $a = -9.8$ ,  $s = -70.0$ ,  $v = ?$ ,  $t = ?$

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

$$= (10.0)^2 + 2 \times (-9.8) \times (-70.0)$$

$$= 1472$$

$$v = \pm 38.4 \text{ m s}^{-1}$$

Because the mass has a downwards velocity, we use the negative value.

$$v = -38.4 \text{ m s}^{-1}$$

$$v = u + at$$

$$-38.4 = -10.0 - 9.8t$$

$$9.8t = -10.0 + 38.4$$

$$t = 2.9 \text{ s}$$

You can also solve this using the formula  $s = ut + \frac{1}{2}at^2$  and the quadratic formula.

- 9 a  $s = vt - \frac{1}{2}at^2$

$$15.0 = 0 - 0.5 \times 9.8 \times t^2$$

$$t = 1.7 \text{ s}$$

- b From maximum height of  $15.0 \text{ m}$ , the ball will fall by  $11.0 \text{ m}$ . Find how long it takes to travel this  $15.0 \text{ m}$ .

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

$$-11.0 = 0 + 0.5 \times (-9.8) \times t^2$$

$$t = 1.5 \text{ s}$$

$$\text{Total time from bounce} = 1.7 + 1.5 = 3.2 \text{ s}$$

## Chapter 9 Review

$$1 \quad \frac{95 \text{ km h}^{-1}}{3.6} = 26 \text{ m s}^{-1}$$

$$2 \quad 15 \text{ m s}^{-1} \times 3.6 = 54 \text{ km h}^{-1}$$

$$3 \quad \begin{aligned} \text{average speed} &= \frac{\text{distance}}{\text{time}} \\ &= \frac{15 \text{ km} + 5 \text{ km} + 5 \text{ km} + 5 \text{ km}}{2.0} \\ &= 15 \text{ km h}^{-1} \end{aligned}$$

$$4 \quad \begin{aligned} \text{a average velocity} &= \frac{\text{displacement}}{\text{time}} \\ &= \frac{20}{2.0} \\ &= 10 \text{ km h}^{-1} \text{ north} \end{aligned}$$

$$\begin{aligned} \text{b } 10 \text{ km h}^{-1} \text{ north} &= \frac{10 \text{ km h}^{-1} \text{ north}}{3.6} \\ &= 2.8 \text{ m s}^{-1} \text{ north} \end{aligned}$$

$$5 \quad \begin{aligned} \Delta v &= 4.0 - 6.0 \\ &= -2.0 \text{ m s}^{-1} \end{aligned}$$

The change in speed is  $-2.0 \text{ m s}^{-1}$ . That is, it has decreased by  $2.0 \text{ m s}^{-1}$ . Speed is a scalar and has no direction.

- 6 B. The car is moving in a positive direction so its velocity is positive. The car is slowing down so its acceleration is negative.

$$7 \quad \begin{aligned} a_{av} &= \frac{v - u}{t} \\ &= \frac{-15}{2.5} \\ &= -6 \text{ m s}^{-2} \end{aligned}$$

or

$$u = 15, v = 0, t = 2.5, a = ?$$

$$v = u + at$$

$$0 = 15 + a \times 2.5$$

$$\begin{aligned} a &= \frac{-15}{2.5} \\ &= -6 \text{ m s}^{-2} \end{aligned}$$

- 8 a The only positive gradient section is from 10 to 25 s.  
 b The only negative gradient section is from 30 to 45 s.  
 c The motorbike is stationary when the sections on the position–time graph are horizontal. The horizontal sections are from 0 to 10 s, from 25 to 30 s and from 45 to 60 s.  
 d The zero position is at 42.5 s or 43 s.
- 9 a Graph B is the correct answer as it shows speed decreasing to zero to show the car stopping.  
 b Graph A is the correct graph because it shows a constant value for speed. This is indicated by a straight horizontal line on a velocity–time graph.  
 c Graph C is the correct graph because it shows velocity increasing from zero in a straight line, indicating uniform acceleration.
- 10 a Displacement is the area under a velocity–time graph. Area can be determined by counting squares under the graph, then multiplying by the area of each square. This gives approximately  $57 \text{ squares} \times (2 \times 1) = 114 \text{ m}$ .  
 Alternatively, you can break the area into various shapes and find the sum of their areas:  
 $72 + 14 + 18 + 10 = 114 \text{ m}$ .  
 The result is positive, which means the displacement is north of the starting point.  
 The cyclist's displacement is 114 m north.
- b Average velocity =  $\frac{\text{displacement}}{\text{time}}$   

$$= \frac{114}{11.0}$$

$$= 10.4 \text{ m s}^{-1}$$
- c Acceleration is the gradient of the graph. At  $t = 1 \text{ s}$ , the gradient is flat and therefore zero. This could also be calculated:  
 gradient =  $\frac{\text{rise}}{\text{run}}$   

$$= 0 \text{ m s}^{-2}$$

**d** Acceleration at  $t = 10$  s is:

$$\begin{aligned}\text{gradient} &= \frac{\text{rise}}{\text{run}} \\ &= -\frac{14}{2} \\ &= -7 \text{ or } 7 \text{ m s}^{-2} \text{ south}\end{aligned}$$

**e** A. The velocity is always positive (or zero) indicating that the cyclist only travelled in one direction.

**11**  $u = 0$ ,  $a = 3.5$ ,  $t = 4.5$ ,  $v = ?$

$$\begin{aligned}v &= u + at \\ &= 0 + 3.5 \times 4.5 \\ &= 15.75 \text{ or } 16 \text{ m s}^{-1}\end{aligned}$$

**12 a**  $u = 0$ ,  $s = 2$ ,  $t = 1$ ,  $a = ?$

$$\begin{aligned}s &= ut + \frac{1}{2}at^2 \\ 2.0 &= 0 + \frac{1}{2} \times a \times (1.0)^2 \\ a &= 4.0 \text{ m s}^{-2}\end{aligned}$$

**b**  $u = 0$ ,  $t = 2$ ,  $a = 4$ ,  $v = ?$

$$\begin{aligned}v &= u + at \\ &= 0 + 4.0 \times 1.0 \\ &= 4.0 \text{ m s}^{-1}\end{aligned}$$

**c** After 2.0 s the total distance travelled:

$$\begin{aligned}u &= 0, t = 2, a = 4, s = ? \\ s &= ut + \frac{1}{2}at^2 \\ &= 0 + 0.5 \times 4.0 \times (2.0)^2 \\ &= 8.0 \text{ m}\end{aligned}$$

Distance travelled during the second second =  $8.0 \text{ m} - 2.0 \text{ m} = 6.0 \text{ m}$ .

**13 a**  $u = 10$ ,  $v = 0$ ,  $s = 10$ ,  $a = ?$

$$\begin{aligned}v^2 &= u^2 + 2as \\ 0 &= 10^2 + 2 \times a \times 10 \\ a &= -\frac{100}{20} \\ &= -5.0 \text{ m s}^{-2}\end{aligned}$$

**b**  $u = 10$ ,  $v = 0$ ,  $s = 10$ ,  $a = -5$ ,  $t = ?$

$$\begin{aligned}v &= u + at \\ 0 &= 10 - 5t \\ t &= 2.0 \text{ s}\end{aligned}$$

**14 a** She starts at + 4 m.

**b** She is at rest during section A and C.

**c** She is moving in a positive direction during section B with a velocity  $+0.8 \text{ m s}^{-1}$ .

**d** She is moving in the negative direction at  $2.4 \text{ m s}^{-1}$  during section D.

**e**  $d = 8 + 12$

$$= 20 \text{ m}$$

$$\Delta t = 25 \text{ s}$$

$$v_{av} = \frac{d}{\Delta t}$$

$$= \frac{20}{25}$$

$$= 0.8 \text{ m s}^{-1}$$

**15** The marble slows down by  $9.8 \text{ m s}^{-1}$  each second so it will take 4 seconds to stop momentarily at the top of its motion. It has a positive velocity that changes to zero on the way up. Its acceleration is constant at  $-9.8 \text{ m s}^{-2}$  due to gravity.

**16** D. The acceleration of a falling object is due to gravity, so it is constant.

**17** B. Initial velocity is upwards, it is zero at the top and downwards on the way back down. Acceleration is always downwards.

- 18 a** The area under the  $v$ - $t$  graph up to 3 s gives:

$$s = \frac{1}{2} \times 3 \times 30$$

$$= 45 \text{ m}$$

or

$$u = 30, v = 0, t = 3, s = ?$$

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

$$= \frac{1}{2}(30 + 0) \times 3$$

$$= 45 \text{ m}$$

- b** From the graph, the ball goes up for 3 s then down for 3 s, giving a total time of 6 s, or:

$$u = 30, v = -30, a = -10, t = ?$$

$$v = u + at$$

$$-30 = 30 - 10t$$

$$t = \frac{60}{10}$$

$$= 6 \text{ s}$$

- c** From the  $v$ - $t$  graph, the velocity at  $t = 5$  s is  $-20$  or  $20 \text{ m s}^{-1}$  down, or:

$$u = 30, a = -10, t = 5, v = ?$$

$$v = u + at$$

$$= 30 + (-10) \times 5$$

$$= 30 - 50$$

$$= -20 \text{ m s}^{-1}$$

A negative value indicates down, therefore the correct answer is  $20 \text{ m s}^{-1}$  down.

- d** Acceleration is always  $10 \text{ m s}^{-2}$  down.

- 19 a** Balloon:  $u = -8.0, a = 0, s = -80, t = ?$

The balloon has constant speed. Use  $v = \frac{s}{t}$  so:

$$t = \frac{s}{v}$$

$$= \frac{80}{8.0}$$

$$= 10 \text{ s}$$

- b** Coin:  $u = -8.0, a = -9.8, s = -80, v = ?$

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

$$= (-8)^2 + 2 \times -9.8 \times -80$$

$$= 64 + 1568$$

$$v = 40.4 \text{ or } 40 \text{ m s}^{-1}$$

- c** Coin:  $u = -8.0, a = -9.8, s = -80, v = -40.4, t = ?$

$$v = u + at$$

$$-40.4 = -8.0 - 9.8t$$

$$9.8t = -8.0 + 40.4$$

$$t = 3.3 \text{ s}$$

Balloon takes 10 s to land, coin takes 3.3 s, so  $10 - 3.3 = 6.7 \text{ s}$  difference.

The following information relates to questions 20 and 21.

During a game of minigolf, Renee putts a ball so that it hits an obstacle and travels straight up into the air, reaching its highest point after 1.5 s.

- 20**  $t = 1.5, v = 0, a = -9.8, u = ?$

$$v = u + at$$

$$0 = u + (-9.8 \times 1.5)$$

$$u = 15 \text{ m s}^{-1} \text{ up}$$

- 21**  $t = 1.5, v = 0, a = -9.8, u = 15, s = ?$

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

$$0 = (15)^2 + 2 \times -9.8 \times s$$

$$s = 11 \text{ m}$$