8.2 QUESTIONS

1 Estimate the speed:
   a at which you walk
   b of a snail crawling
   c of a cricket ball bowled by Shane Warne
   d of a ten-pin bowling ball.

2 Toni rides her bicycle to school and travels the 2.5 km distance in a time of 10 min.
   a Calculate her average speed in kilometres per hour (km h^{-1}).
   b Calculate her average speed in metres per second (m s^{-1}).
   c Is Toni's average speed a realistic representation of her actual speed? Explain.

3 A sports car, accelerating from rest, was timed over 400 m and was found to reach a speed of 120 km h^{-1} in 18.0 s.
   a What was the average speed of the car in m s^{-1}?
   b Calculate the average acceleration of the car in km h^{-1} s^{-1}.
   c What was its average acceleration in m s^{-2}?
   d If the driver of the car had a reaction time of 0.60 s, how far would the car travel while the driver was reacting to apply the brakes at this speed of 120 km h^{-1}?

4 Draw these vector subtractions and find the resultant vector for:
   a 10 m s^{-1} east minus 15 m s^{-1} east
   b 12 m s^{-1} west minus 8 m s^{-1} west.

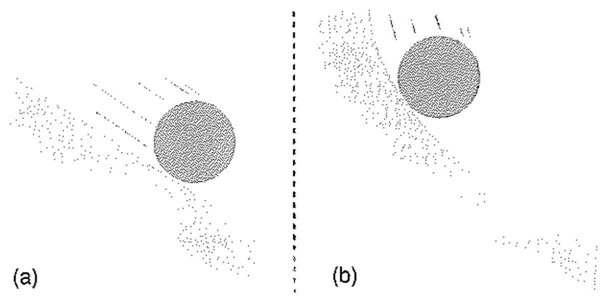
5 A squash ball travelling east at 25 m s^{-1} strikes the front wall of the court and rebounds at 15 m s^{-1} west. The contact time between the wall and the ball is 0.050 s.
   a Calculate the change in speed of the ball.
   b Calculate the change in velocity of the ball.
   c What is the acceleration of the ball during its contact with the wall?

6 A bus travelling north along a straight road at 60 km h^{-1} slows down uniformly and takes 5.0 s to stop.
   a Calculate its acceleration in km h^{-1} s^{-1}.
   b Calculate its acceleration in m s^{-2}.

7 During a world record 1500 m freestyle swim, Kieren Perkins completed 30 lengths of a 50 m pool in a time of 14 min 42 s.
   a What was his distance travelled during this race?
   b What was his average speed (in m s^{-1})?
   c What was his displacement during the race?
   d What was his average velocity during his record-breaking swim?

8 Christopher is travelling by car to a city 100 km away. For the trip, he wants to average 50 km h^{-1}. However, owing to mechanical problems, he finds that when he has travelled halfway his average speed is only 25 km h^{-1}. Which one of the following best describes the required speed for the second half of the trip for Christopher's average speed of 50 km h^{-1} to be achieved?
   A 75 km h^{-1}
   B 100 km h^{-1}
   C 150 km h^{-1}
   D It is not possible.

9 A ball rolls down an incline as shown in (a) below. Which one of the following best describes the speed and acceleration of the ball?
   A The speed and acceleration both increase.
   B The speed increases and the acceleration is constant.
   C The speed is constant and the acceleration is zero.
   D The speed and acceleration are both constant.



(a) (b)

10 A ball rolls down the slope shown in (b) above. Which one of the following best describes its speed and acceleration?
   A Its speed and acceleration both increase.
   B Its speed and acceleration both decrease.
   C Its speed increases and its acceleration decreases.
   D Its speed decreases and its acceleration increases.

Questions 11 and 12 require you to make reasonable estimates for any data that you need. You should perform these calculations without a calculator and then check them with your calculator. Assume that the speed of electromagnetic radiation is 3×10^8 m s^{-1}.

11 Estimate the number of metres in a light year. A light year is the distance that light travels in one year.

12 Suppose you are sitting on your chair in the lounge room and you press the off button on the remote control. Estimate the amount of time it takes the infrared signal to reach the television set.

8.3 Graphing motion: position, velocity and acceleration

At times, the motion of an object travelling even in a straight line can be complicated. The object may travel forwards or backwards, speed up or slow down, or even stop. Where the motion remains in one dimension, the information can be presented in graphical form. The main advantage of a graph compared with a table is that it allows the scope of the motion to be seen clearly. Information that is contained in a table is not as readily accessible and as easy to interpret as that presented graphically.

Graphing position

A *position–time* graph indicates the position of an object at any time for motion that occurs over an extended time interval. However, the graph can also provide additional information.

Consider once again Sophie swimming laps of a 50 m pool. Her position–time data are shown in Table 8.6. The starting point is treated as the origin for this motion.

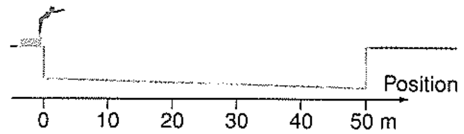


Figure 8.14 This swimmer will travel to the 50 m mark, then return to the 25 m mark. Her position is shown in Table 8.6.

Table 8.6 The positions and times of a swimmer completing one and a half lengths of a pool

Time (s)	0	5	10	15	20	25	30	35	40	45	50	55	60
Position (m)	0	10	20	30	40	50	50	50	45	40	35	30	25

An analysis of the table reveals several features of the swim. For the first 25 s, Sophie swims at a constant rate. Every 5 s she travels 10 m in a positive direction, i.e. her velocity is +2 m s^{-1}. Then from 25 s to 35 s, her position does not change; she seems to be resting, i.e. stationary, for this 10 s interval. Finally from 35 s to 60 s, she swims back towards the starting point, i.e. in a negative direction. On this return lap, she maintains a more leisurely rate of 5 metres every 5 seconds, i.e. her velocity is −1 m s^{-1}. However, Sophie does not complete this lap but ends 25 m from the start. These data can be conveniently shown on a position–time graph.

The *displacement* of the swimmer can be determined by comparing the initial and final positions. Her displacement between 20 s and 60 s is, for example:

$$s = \text{final position} - \text{initial position} = 25 - 40 = -15 \text{ m}$$

By further examining the graph in Figure 8.17, it can be seen that during the first 25 s, the swimmer has a displacement of +50 m. Thus her *average velocity* is +2 m s^{-1}, i.e. 2 m s^{-1} to the right. This value can also be obtained by finding the *gradient* of this section of the graph.

Velocity is given by the gradient of a position–time graph. A positive velocity indicates that the object is moving in a positive direction, and a negative velocity indicates motion in a negative direction.

If the position–time graph is *curved*, the velocity will be the *gradient of the tangent* to the line at the point of interest. This will be an *instantaneous velocity*. Dimensional analysis can be used to confirm that the gradient of a position–time graph is a measure of velocity:

$$\text{gradient} = \frac{\text{rise}}{\text{run}} = \frac{\Delta x}{\Delta t}$$

The units of gradient are metres per second (m s^{-1}), i.e. gradient is a measure of velocity.

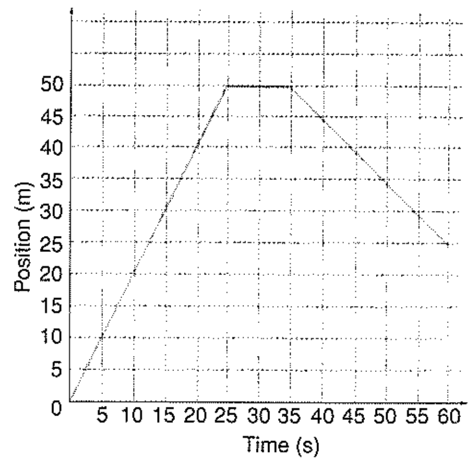


Figure 8.15 This graph represents the motion of a swimmer travelling 50 m along a pool, then resting and swimming back towards the starting position. The swimmer finishes halfway along the pool.

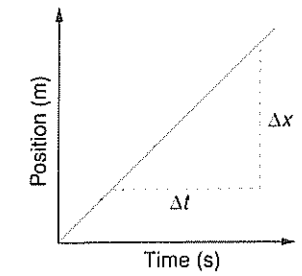
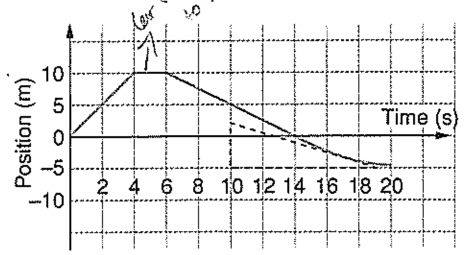


Figure 8.16 From the units of the rise and run, it can be seen that the units for the gradient are m s^{-1}, confirming that this is a measure of velocity.



Worked Example 8.3A

A car driven by a learner driver travels along a straight driveway and is initially heading north. The position of the car is shown in the graph.

- **a** Describe the general motion of the car.
- **b** What is the displacement of the car during the first 10 s of its motion?
- **c** What distance has the car travelled during the first 10 s?
- **d** Calculate the average velocity of the car during the first 4 s.
- **e** Calculate the average velocity of the car between $t = 6$ s and $t = 20$ s.
- **f** Calculate the average velocity of the car during its 20 s trip.
- **g** Calculate the average speed of the car during its 20 s trip.
- **h** Calculate the instantaneous velocity of the car at $t = 18$ s.

Solution

- **a** The car initially travels 10 m north in 4 s. It then stops for 2 s. From $t = 6$ s to $t = 20$ s, the car travels towards the south, i.e. it reverses. It passes through its starting point after 14 s, and finally stops 2 m south of this point after 20 s.
- **b** The displacement of the car is given by its change in position. From the graph, we can see that the car started from zero, and after 10 s its position is 5 m, so its displacement is +5 m or 5 m north.
- **c** The distance travelled is an indication of the ground covered by the car. During the first 10 s the car travels 10 m north, then stops and travels 5 m south. Therefore it travels a distance of 15 m.
- **d** The average velocity is given by the gradient during the first 4 s:

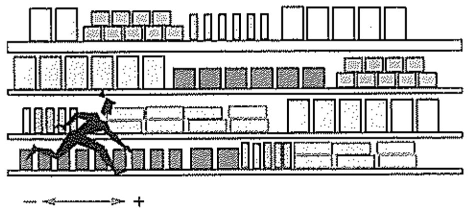
$$\text{gradient} = \frac{\text{rise}}{\text{run}} = \frac{10}{4} = +2.5 \text{ m s}^{-1} \text{ or } 2.5 \text{ m s}^{-1} \text{ north}$$

- **e** Again, the average velocity is given by the gradient:

$$\text{gradient} = \frac{\text{rise}}{\text{run}} = -\frac{15}{14} = -1.1 \text{ m s}^{-1} \text{ or } 1.1 \text{ m s}^{-1} \text{ south.}$$

- **f** To determine the average velocity for the 20 s:
  $v_{av} = s/t = -5$ m/20 s $= -0.25$ m s^{-1} or 0.25 m s^{-1} south.
  This could also be found by calculating the gradient of the line from the start to the end of the motion.
- **g** The car travels a distance of 10 m + 10 m + 5 m = 25 m in 20 s. Its average speed is:
  v_{av} = distance/time = 25/20 = 1.25 m s^{-1}.
- **h** The graph is curved at this time, so to find the instantaneous velocity it is necessary to draw a tangent to the line and calculate the gradient of the tangent:

$$\text{gradient} = \frac{\text{rise}}{\text{run}} = \frac{-5}{10} = -0.50, \text{ i.e. } v_{inst} = 0.50 \text{ m s}^{-1} \text{ south}$$



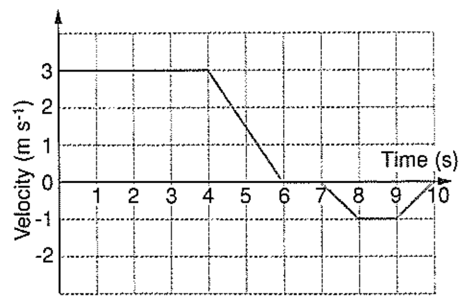


Figure 8.17 This graph shows the straight line motion of a girl running back and forth along a supermarket aisle.

Graphing velocity

A graph of *velocity against time* shows how the velocity of an object changes with time. This type of graph is useful for analysing the motion of an object moving in a complex manner, for example a ball bouncing up and down. A velocity–time graph can also be used to obtain additional information about the object.

Consider the example of a small girl, Eleanor, running back and forth along an aisle in a supermarket. A study of the velocity–time graph in Figure 8.17 reveals that Eleanor is moving with a positive velocity, i.e. in a positive direction, for the first 6 s. Between the 6 s mark and the 7 s mark, she is stationary, then she runs in the reverse direction, i.e. has negative velocity, for the final 3 s.

This graph directly shows Eleanor's velocity at each instant in time. She moves in a *positive direction* with a constant speed of 3 m s^{-1} for the first 4 s. From 4 s to 6 s, she continues moving in a positive direction but slows down, until 6 s after the start she comes to a stop. Then during the final 3 s, when the line is below the time axis, her *velocity is negative*; she is now moving in a *negative direction*.

A *velocity–time graph* can also be used to find the *displacement* of the body under consideration. In the first 6 s of Eleanor's motion she moves with a constant velocity of +3 m s^{-1} for 4 s, then slows from 3 m s^{-1} to zero in the next 2 s. Her displacement during this time can be determined from the v–t graph:

$v = s/\Delta t$, so

$s = v \times \Delta t$ = height × base = area under v–t graph.

From Figure 8.18, the *area* under the graph for the first 4 s gives the displacement of the girl during this time, i.e. +12 m. The displacement from 4 s to 6 s is represented by the area of the shaded triangle and is equal to +3 m. Thus the total displacement during the first 6 s is +12 m + 3 m = +15 m.

Displacement is given by the *area under a velocity–time graph* (or the area between the line and the time axis). It is important to note that this applies for any graph, and that an area below the time axis indicates a negative displacement, i.e. motion in a negative direction.

The *acceleration* of an object can also be found from a velocity–time graph. Consider the motion of the girl in the 2 s interval between 4 s and 6 s. She is moving in a positive direction but slowing down from 3 m s^{-1} to rest. Her acceleration is:

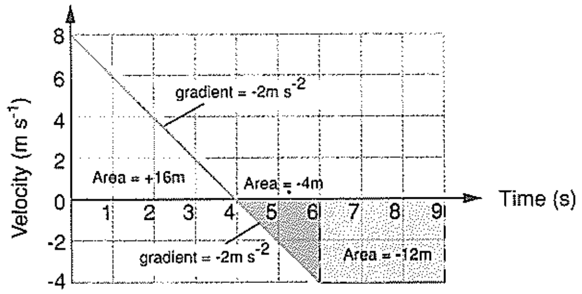
$a = \Delta v / \Delta t = (v - u)/\Delta t = (0 - 3)/2 = -1.5$ m s^{-2}

Since acceleration is the velocity change divided by time taken, it is also given by the *gradient* of the v–t graph. As can be seen from Figure 8.18 once again, the gradient of the line between 4 s and 6 s is −1.5 m s^{-2}.

The *gradient of a velocity–time* graph is the average *acceleration* of the object over the time interval. If the acceleration is changing, the velocity–time graph will be curved, and so the gradient of the tangent will give an instantaneous acceleration.

Worked Example 8.3B

The motion of a marble rolling across a floor is represented by the following graph.



Use this graph to help you to:

- **a** describe the motion of the marble
- **b** calculate the displacement of the marble during the first 4 s
- **c** determine the displacement for the 9 s shown
- **d** find the acceleration during the first 4 s
- **e** find the acceleration from 4 s to 6 s.

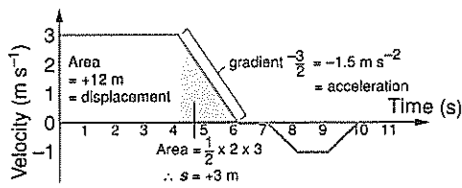


Figure 8.18 The displacement of the girl is given by the area under the graph. During the first 6 s, her displacement is +15 m.

Physics File

The *area* under a velocity–time graph is a measure of *displacement*. When the units on the axes are multiplied when finding the area, a displacement unit results. From Figure 8.19a:

area units = m s^{-1} × s = m,
i.e. a displacement

The *gradient* of a velocity–time graph is the *acceleration* of the object. When finding the gradient, the units are divided. From Figure 8.19b:

gradient units = m s^{-1}/s = m s^{-2},
i.e. an acceleration

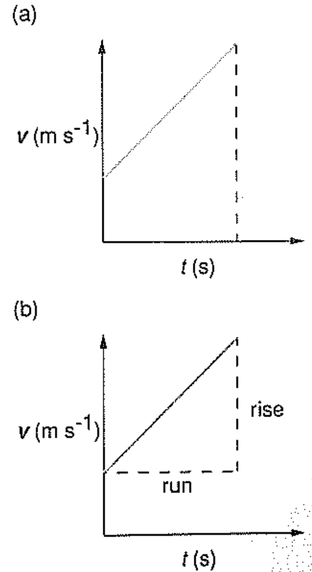


Figure 8.19 (a) The units on the axes of a v–t graph confirm that the area under the graph represents a displacement. (b) The gradient of the line is the acceleration.

Physics File

A useful and time-saving technique of finding the area under a graph is that of '*counting squares*'. To determine the area under a graph by counting squares:

- calculate the area of one grid square
- use a pencil to check off the number of complete squares under the graph
- if the graph is curved or contains part squares, estimate the combined total of these incomplete squares
- add these two amounts to determine the total number of squares
- multiply this value by the area of each square to determine the area under the graph.

For example, in the graph in Worked Example 8.3B, the area of each grid square is $2 \times 1 = 2$ m.

Up to 4 s, in the shaded triangular area, the complete and part squares combine to make 8 squares. The total displacement during this time is 8 squares $\times$ 2 m = + 16 m.

Solution

a The marble is initially moving in a positive direction at 8 m s^{-1}. It slows down and comes to a stop after 4 s, then reverses and travels in a negative direction. From 4 s to 6 s the marble gains speed in the negative direction, then maintains a constant velocity of –2 m s^{-1} for the final 3 s.

b The displacement is given by the area under the graph; in this case the triangular area as shown. The marble's displacement during the first 4 s is +16 m.

c The displacement for the complete motion is given by the total area under the graph: +16 – 4 – 12 = 0, i.e. the marble finishes where it started.

d The acceleration is given by the gradient of the line. For the first 4 s, this is –2 m s^{-2}. This indicates that the marble is slowing down by 2 m s^{-1} each second while travelling in a positive direction.

e The gradient of the line from 4 s to 6 s is also –2 m s^{-2}. This now indicates that the marble is speeding up by 2 m s^{-1} each second while travelling in a negative direction.

Graphing acceleration

An *acceleration–time graph* simply indicates the acceleration of the object as a function of time. The area under an acceleration–time graph is found by multiplying an acceleration and a time value:

$$\text{area} = a \times t = \Delta v$$

The *area* will give the *change in velocity* (Δv) of the object. In order to establish the actual velocity of the object, the initial velocity must be known.

Consider the marble from Worked Example 8.3B once again. The change in velocity during the first 6 s can be determined from the acceleration–time graph. As shown in Figure 8.20, the velocity changes by –12 m s^{-1}. This can be confirmed by looking at the velocity–time graph in Worked Example 8.3B. It shows that the marble slows down from +8 m s^{-1} to –4 m s^{-1}, a change of –12 m s^{-1}, during this time.

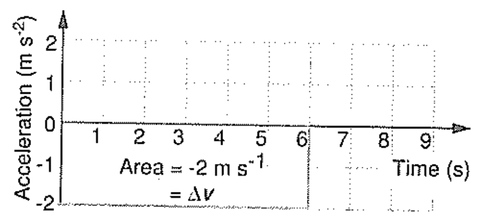


Figure 8.20 The acceleration–time graph for the marble rolling across a floor. It was drawn by taking account of the gradient values of the velocity–time graph. The marble's change in velocity is given by the area under the graph.

PHYSICS IN ACTION

Timing with precision

Until 1964, all timing of events at the Olympic Games was recorded by hand-held stopwatches. The reaction times of the judges meant an uncertainty of 0.2 s for any measurement. An electronic quartz timing system introduced in 1964 improved accuracy to 0.01 s, but in close finishes the judges still had to wait for a photograph of the finish before they could announce the placings.

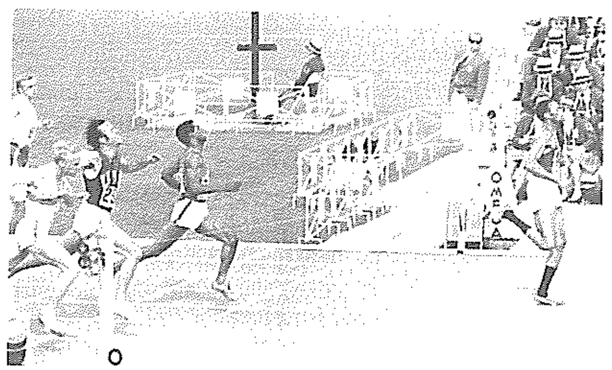


Figure 8.21 At the 1968 Mexico Olympic Games, the judges on the right used hand-held stopwatches to measure the times of the athletes.

Currently the timing system used is a vertical line-scanning video system (VLSV). Introduced in 1991, this is a completely automatic electronic timing system. The starting pistol triggers a computer to begin timing. At the finish line, a high-speed video camera records the image of each athlete and indicates the time at which the chest of each one crosses the line. This system enables the times of all the athletes in the race to be precisely measured to one-thousandth of a second.

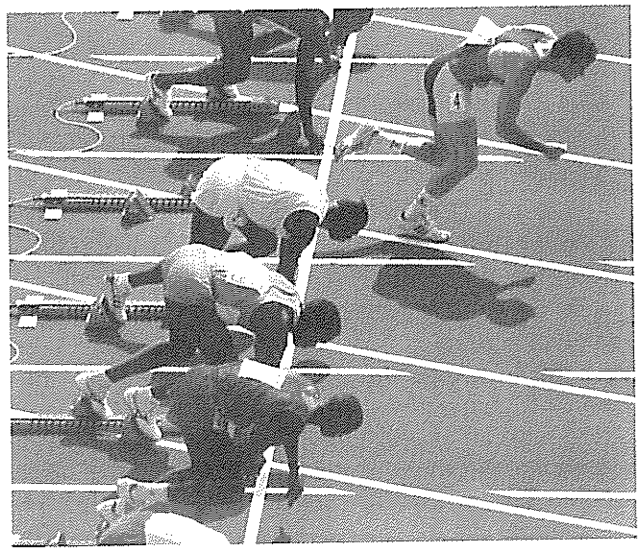


Figure 8.23 This athlete has made a false start. A pressure pad in each starting block registers the starting time of each athlete. The cable leading from each starting block connects to a computer which instantly indicates the false start.

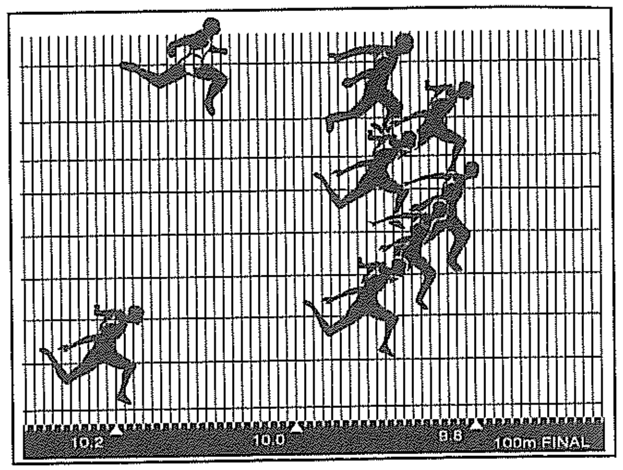
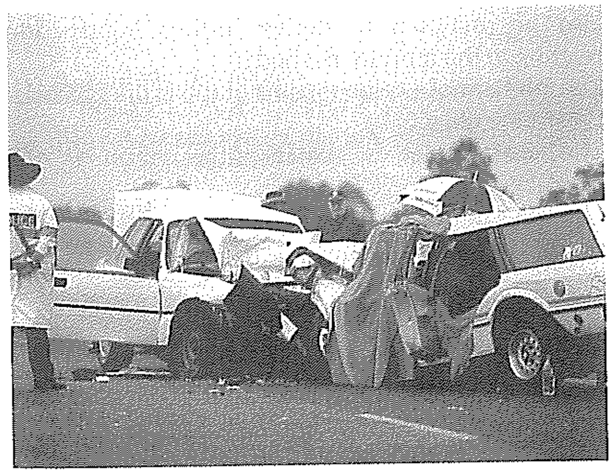


Figure 8.22 This is the finish of a world championship men's 100 m race. The time scale along the bottom of the film allows the time of each runner to be determined. The winning time here was 9.85 s and was a new world record set by Ben Johnson. He was later stripped of this record after a positive drug test.

Another feature of this system is that it indicates when a runner 'breaks' at the start of the race. Each starting block is connected by electronic cable to the timing computer and a pressure sensor indicates if a runner has left the blocks early. In fact, to ensure that a runner has not anticipated the pistol, a reaction time of 0.11 s is incorporated into the system. This means that a runner can still commit a false start even if their start was *after* the pistol. A start that is less than 0.11 s after the pistol has fired is registered as being false.

PHYSICS IN ACTION

Overtake with care!



Head-on collisions involving cars are a major cause of deaths and injuries on our roads. These accidents are often the result of a poorly judged overtaking manoeuvre. The construction of divided roads and freeways, and the increased use of right-turn arrows at intersections, has reduced the number of head-on collisions.

Figure 8.24 A head-on collision is considered to be the most serious type of car accident.

To gain an understanding of the risks associated with overtaking, consider this example. You are the driver of a car with a six-cylinder engine and you are driving behind a truck that is travelling at a constant speed of 90 km h^{-1} (25 m s^{-1}). You decide to overtake the truck but you are conscious of the speed limit and so do not travel faster than 100 km h^{-1} (28 m s^{-1}). At these speeds, your car is capable of accelerating at 3.0 m s^{-2}. This information can be represented in graphical form.

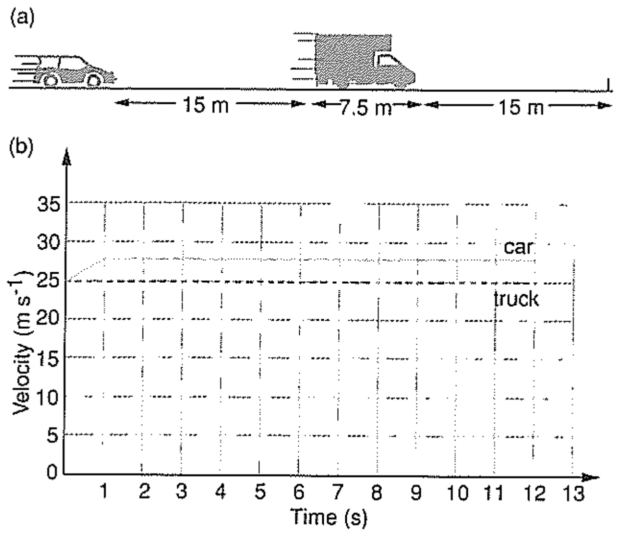


Figure 8.25 (a) The car commences its passing manoeuvre when it is 15 m behind the truck, and will overtake to a distance of 15 m ahead of the truck. (b) This velocity–time graph shows the motion of both the car and the truck. The area between the two lines represents the additional distance travelled by the car in passing the truck.

The area between the two lines is the extra distance that the car travels in passing the truck. If the truck is 7.5 m long and you start overtaking when 15 m behind and finish when 15 m ahead, then your car will have travelled 15 + 7.5 + 15 = 37.5 m further than the truck. So the area between the lines is 37.5 m, and the time needed to complete the overtaking manoeuvre can be found. From Figure 8.25, the area between the lines is equal to 37.5 m after 13 s. In other words, the car takes 13 s to overtake the truck.

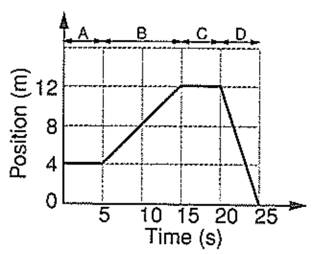
It is important to have an appreciation of the distances involved in overtaking. In the 13 s that the car takes to pass the truck, the car travels over 360 m. This is given by the area under the graph for the car. If there was an oncoming vehicle also moving at 100 km h^{-1}, then it too would travel around 360 m. Thus, including a safety margin of 100 m, the oncoming car must be at least 800 m away if you are to safely complete this overtaking manoeuvre. This is the reason that many drivers make poor decisions. They have not been aware of the large distances needed. The performance of the car and the relative speeds of the vehicles are the determining factors. How would the distances compare if a less powerful four-cylinder car was involved, or if the passing speed was only 5 km h^{-1} faster than the other vehicle?

8.3 SUMMARY Graphing motion: position, velocity and acceleration

- A position–time graph can be used to determine the location of a body directly. Additional information can also be derived in the following ways:
  - The displacement is given by the change in position.
  - The velocity of the body is given by the gradient of the position–time graph.
  - If the graph is curved, the gradient of the tangent at a point gives the instantaneous velocity.
- A velocity–time and acceleration–time graph can also be analysed to derive further information relating to the motion of a body.
- The gradient of a velocity–time graph is the acceleration of the object.
- The area under a velocity–time graph is the displacement of the object.
- The area under an acceleration–time graph is the change in velocity of the object.

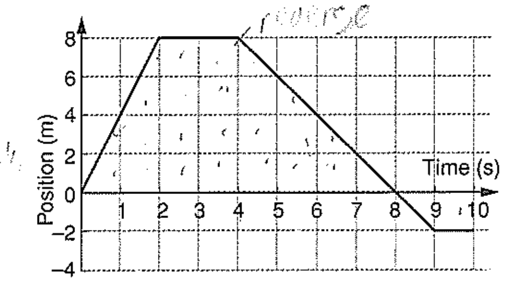
8.3 QUESTIONS

1 The graph shows the position of a dancer moving across a stage.

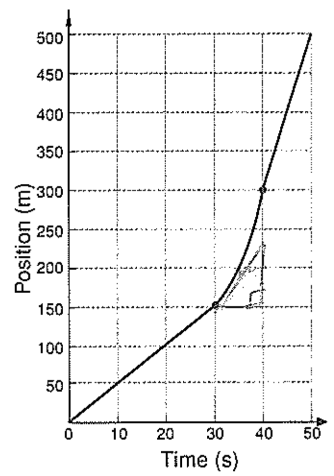


a What was the starting position of the dancer?
b In which of the sections (A–D) is the dancer at rest?
c In which of the sections is the dancer moving in a positive direction?
d In which of the sections is the dancer moving with a negative velocity?

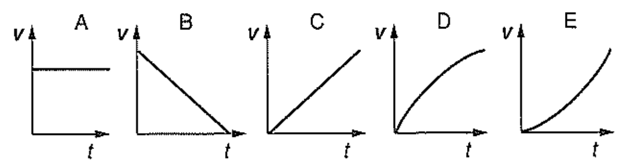
The following information relates to questions 2–6. The graph represents the straight line motion of a radio-controlled toy car.



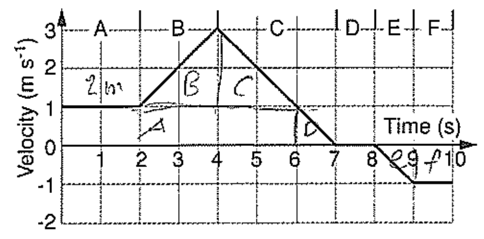
2 Describe the motion of the car.
3 What was the position of the car after:
a 2 s? **b** 4 s? **c** 6 s? **d** 10 s?
4 When did the car return to its starting point?
5 What was the velocity of the car:
a during the first 2 s? **b** after 3 s?
c from 4 s to 8 s? **d** at 8 s?
e from 8 s to 9 s?
6 During its 10 s motion, what was the car's:
a distance travelled? **b** displacement?
7 The following position–time graph is for a cyclist travelling along a straight road.



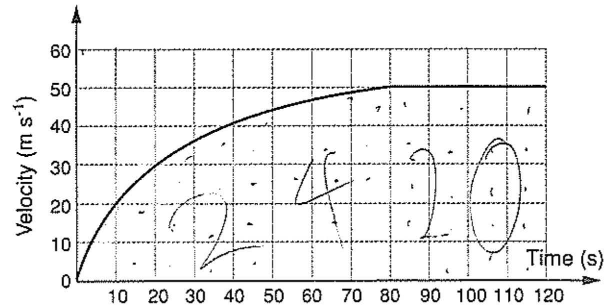
a Describe the motion of the cyclist.
b What was the velocity of the cyclist during the first 30 s?
c What was the cyclist's velocity during the final 10 s?
d Calculate the cyclist's instantaneous velocity at 35 s.
e What was the average velocity of the cyclist between 30 s and 40 s?
8 Which of the velocity–time graphs A–E best represents the motion of:
a a car coming to a stop at a traffic light?
b a swimmer moving with constant speed?
c a cyclist accelerating from rest with constant acceleration?
d a car accelerating from rest and changing through its gears?



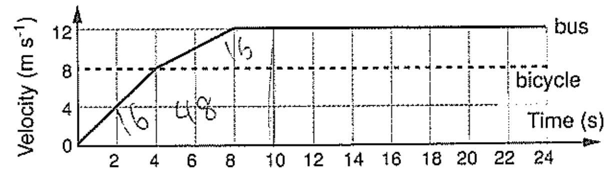
The following information relates to questions 9–11. The following graph shows the motion of a dog running along a footpath. In this problem, north is considered to be positive.



9 Describe the motion of the dog during these sections of the graph.
a A **b** B **c** C **d** D **e** E **f** F
10 Calculate the displacement of the dog after:
a 2 s **b** 7 s **c** 10 s.
11 Plot a position–time graph of the dog's motion.
12 The straight-line motion of a high speed intercity train is shown below.



a How long does it take the train to reach its cruising speed?
b What is the acceleration of the train 10 s after starting?
c What is the acceleration of the train 40 s after starting?
d What is the displacement of the train after 120 s?
13 The velocity–time graphs for a bus and a bicycle travelling along the same straight stretch of road are shown below. The bus is initially at rest and starts moving as the bicycle passes it.



a Calculate the initial acceleration of the bus.
b When does the bus first start gaining ground on the bicycle?
c At what time does the bus overtake the bicycle?
d How far has the bicycle travelled before the bus catches it?
e What is the average velocity of the bus during the first 8 s?
14 a Draw an acceleration–time graph for the bus discussed in question 13.
b Use your acceleration–time graph to determine the change in velocity of the bus over the first 8 s.

8.4 Equations of motion

Equations for uniform acceleration

A graph is an excellent way of representing motion because it provides a great deal of information that is easy to interpret. However, a graph is time-consuming to draw and, at times, values have to be estimated rather than precisely calculated. The previous section used the graph of a motion to determine the different quantities needed to describe the motion of a body. In this section, we will examine a more powerful and precise method of solving problems involving *uniform acceleration*. This method involves the use of a series of *equations* that can be derived from the basic definitions developed earlier.

Consider a body moving in a straight line with an *initial velocity* u and a *uniform acceleration* a for a time interval t. After time t, the body is travelling with a *final velocity* v. Its acceleration will be given by:

$$a = \frac{\Delta v}{\Delta t} = \frac{(v-u)}{t}$$

This can be rearranged as:

$$v = u + at \qquad \text{(i)}$$

The *average velocity* of this object is:

$$v_{av} = \frac{\text{displacement}}{\text{time taken}} = \frac{s}{t}$$

An *average velocity* v_{av} can also be found as the average of the initial and final velocities, i.e. $v_{av} = \dfrac{(u+v)}{2}$.

So: $\dfrac{s}{t} = \dfrac{(u+v)}{2}$

This gives: $$s = \frac{(u+v)t}{2} \qquad \text{(ii)}$$

A graph describing this particular motion is shown in Figure 8.26. The displacement s of the body is given by the area under the velocity–time graph. The area under the velocity–time graph in Figure 8.26 is given by the combined area of the rectangle and the triangle:

Area $= s = ut + \frac{1}{2} \times t \times \Delta v$

Since $a = \Delta v / t$ then $\Delta v = at$ and this can be substituted for Δv:

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

$$s = ut + \tfrac{1}{2}at^2 \qquad \text{(iii)}$$

Now making u the subject of equation (i) gives: $u = v - at$.

You might like to derive another equation yourself by substituting this into equation (ii). You should get:

$$s = vt - \tfrac{1}{2}at^2 \qquad \text{(iv)}$$

Rewriting equation (i) with t as the subject gives: $t = (v-u)/a$.

Now if this is substituted into equation (ii):

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

Finally, transposing this gives: $$v^2 = u^2 + 2as \qquad \text{(v)}$$

Three of these equations are commonly used to solve problems where the acceleration is constant. They are summarised below.

$$v = u + at$$
$$s = ut + \tfrac{1}{2}at^2$$
$$v^2 = u^2 + 2as$$

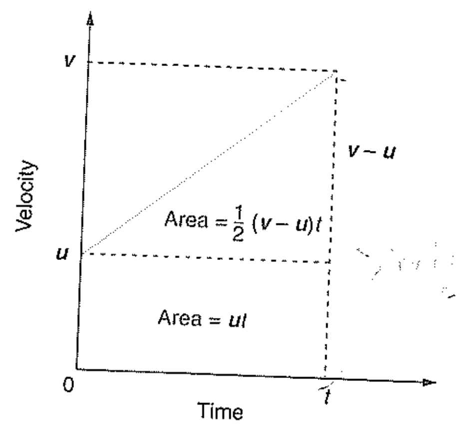


Figure 8.26 The area of the shaded rectangle and triangle represents the displacement s of the body for each time interval.

VIP. steps

These equations can also be used with the scalar quantities speed and distance.

When solving problems by using these equations, it is important that you think about the problem and try to visualise what is happening. The following steps are advisable.

Step 1 Draw a simple diagram of the situation.
Step 2 Neatly write down the information that has been given in the question, using positive and negative values to indicate directions. Convert all units to SI form. (Standard international)
Step 3 Select the equation that matches your data.
Step 4 Use the appropriate number of significant figures in your answer.
Step 5 Include units with the answer and specify a direction if the quantity is a vector.

Worked Example 8.4A

A snowboarder in a race is travelling at 10 m s^{-1} as she crosses the finishing line. She then decelerates uniformly until coming to rest over a distance of 20 m.

a What is her acceleration as she pulls up?
b How long does she take to come to rest?
c Calculate the average speed of the snowboarder as she pulls up.

Solution

a When the snowboarder stops, her velocity is zero.
$u = 10$ m s^{-1}, $v = 0$, $s = 20$ m, $a = ?$
$v^2 = u^2 + 2as$
$0 = 10^2 + 2 \times a \times 20$
$a = -2.5$ m s^{-2}

b $u = 10$ m s^{-1}, $v = 0$, $a = -2.5$ m s^{-2}, $s = 20$ m, $t = ?$
$v = u + at$
$0 = 10 - 2.5 \times t$
$t = 4.0$ s

c v_{av} = distance/time = 20/4.0 = 5.0 m s^{-1}
This could also have been determined by using: $v_{av} = (u + v)/2 = (10 + 0)/2 = 5.0$ m s^{-1}

Vertical motion under gravity

Falling bodies are an interesting example of motion with a *constant acceleration*. Consider the motion of a golfball that has been dropped. It is not greatly affected by air resistance and so *accelerates* as it falls. This is well known and explains why it would be no problem to catch a golf ball that had fallen just 1 m, but painful to catch one that had been dropped from a five-storey building. The longer the ball falls, the faster it travels. This property of falling bodies has been known since ancient times, but up until the 17th century it was thought that the acceleration depended on the mass of the body. In other words, people thought that a heavy mass would fall faster than a light mass.

Galileo Galilei changed this theory. He did a great deal of research on the motion of bodies on inclined planes—a sort of 'diluted acceleration due to gravity'. His work on these experiments laid the groundwork for Isaac Newton and his laws of motion.

Some falling objects are greatly affected by *air resistance*, for example a feather and a balloon. This is why these objects do not speed up as they fall. However, if air resistance is not significant, free-falling bodies near

Physics File

The three equations of motion
$v = u + at$
$s = ut + \frac{1}{2}at^2$
$v^2 = u^2 + 2as$
are equations that each describe the same thing—a body moving with uniform acceleration.

They all have initial velocity and acceleration since these two quantities determine what will happen to the body—they are the initial parameters. Each equation has just two of the other three quantities: v, a, t. In any situation involving constant acceleration, choose the equation that has the quantities that you need to work with.

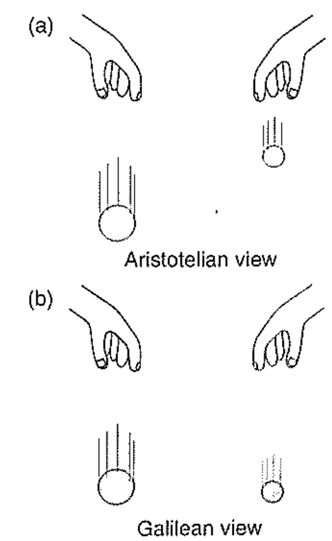


Figure 8.27 (a) Up until the 17th century, it was commonly thought that a heavy object would fall faster than a light object. (b) After research by Galileo Galilei, it was shown that, if air resistance can be ignored, all bodies fall with an equal acceleration.

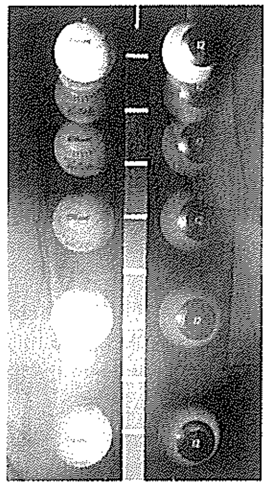


Figure 8.28 This multiflash photograph is taken with a frequency of 15 Hz and the scale markings are 10 cm apart. The photograph shows the relative motions of a baseball and a shotput in free fall. Even though the shotput is over 20 times heavier than the baseball, both objects fall with an acceleration of 9.8 m s^{-2} down.

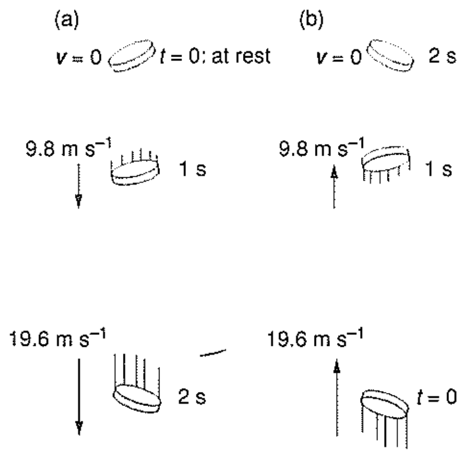


Figure 8.29 These coins are both moving with an acceleration of 9.8 m s^{-2} down. (a) The speed of a coin falling vertically *increases* by 9.8 m s^{-1} each second, i.e. it has an acceleration of 9.8 m s^{-2} down. (b) The speed of a coin thrown upwards *decreases* by 9.8 m s^{-1} each second. It too has an acceleration of 9.8 m s^{-2} down.

the Earth's surface will move with an equal downwards acceleration. In other words, the *mass of the object does not matter*. This is clearly shown in the multiflash photograph of Figure 8.28 where a baseball of mass 0.23 kg can be seen to fall at the same rate as a shotput of mass 5.4 kg. Given that the flash rate is 15 Hz and the markings are 10 cm apart, you should be able to calculate the acceleration of these objects and obtain a value close to 9.8 m s^{-2}. This value of 9.8 m s^{-2} is the *acceleration of bodies falling due to gravity* and is commonly represented as **g**.

> At the Earth's surface, the acceleration due to gravity is: g = 9.8 m s^{-2} down.

Free fall simply implies that the motion of the body is affected only by gravity, i.e. there is no air resistance and there are no rockets firing. It is also important to note that the acceleration of a freely falling body is always 9.8 m s^{-2} down, and does not depend on whether the body is falling up or down. For example, a coin that is dropped from rest will be moving at 9.8 m s^{-1} after 1 s, 19.6 m s^{-1} after 2 s, and so on. Each second, its speed increases by 9.8 m s^{-1}.

However, if the coin was launched straight up at 30 m s^{-1}, then after 1 s its speed would be 20.2 m s^{-1}, and after 2 s it would be moving at 10.4 m s^{-1}. In other words, each second it would slow down by 9.8 m s^{-1}.

Since the acceleration of a freely falling body is constant, it is appropriate to use the equations for uniform acceleration. It is often necessary to specify up or down as the positive or negative direction when doing these problems.

Worked Example 8.4B

A construction worker accidently knocks a brick from a building so that it falls vertically a distance of 50 m to the ground. Using g = 9.8 m s^{-2}, calculate:

a the time the brick takes to fall the first 25 m
b the time the brick takes to reach the ground
c the speed of the brick as it hits the ground.

Solution

Down will be treated as the positive direction for this problem since this is the direction of the displacement.

a $u = 0$, $s = 25$ m, $a = 9.8$ m s^{-2}, $t = ?$
$s = ut + \frac{1}{2}at^2$
$25 = 0 + \frac{1}{2} \times 9.8 \times t^2$
$t^2 = 5.1$
$t = 2.3$ s

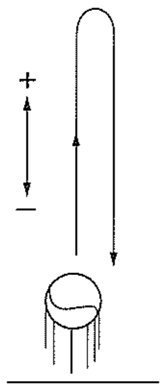
b $u = 0$, $a = 9.8$ m s^{-2}, $s = 50$ m, $t = ?$
$s = ut + \frac{1}{2}at^2$
$50 = 0 + \frac{1}{2} \times 9.8 \times t^2$
$t^2 = 10.2$
$t = 3.2$ s
Notice how the brick takes less time, only 0.9 s, to travel the final 25 m. This is because it is accelerating.

c $u = 0$, $a = 9.8$ m s^{-2}, $s = 50$ m, $t = 3.2$ s, $v = ?$
$v = u + at$
$= 0 + 9.8 \times 3.2 = 31$ m s^{-1}

Worked Example 8.4C

On winning a tennis match the victorious player, Michael, smashed the ball vertically into the air at 30 m s^{-1}. In this example, air resistance will be ignored and the acceleration due to gravity will be taken as 10 m s^{-2}.

a Determine the maximum height reached by the ball.
b Calculate the time that the ball takes to return to its starting position.
c Calculate the velocity of the ball 5.0 s after being hit by Michael.
d Determine the acceleration of the ball at its maximum height.
e Draw an acceleration–time graph of the ball's motion.
f Draw a velocity–time graph of the ball's motion.



Solution

In this problem, up will be taken as positive since it is the direction of the initial displacement.

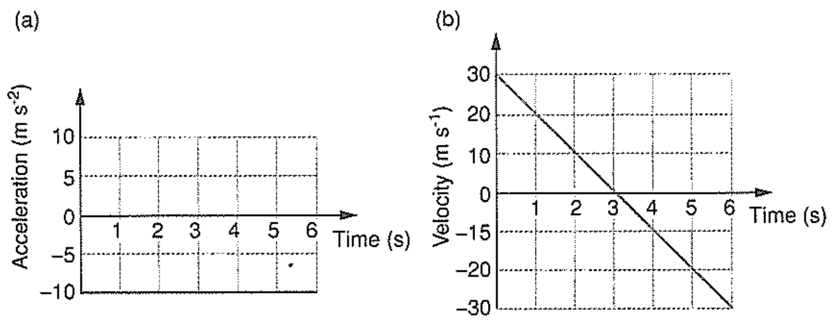
a At the maximum height, the velocity of the ball is momentarily zero.
$u = 30$ m s^{-1}, $v = 0$, $a = -10$ m s^{-2}, $s = ?$
$v^2 = u^2 + 2as$
$0 = (30)^2 + 2(-10)s$
$\therefore s = +45$ m, i.e. the ball reaches a height of 45 m.

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.
$u = 30$ m s^{-1}, $v = 0$, $a = -10$ m s^{-2}, $s = 45$ m, $t = ?$
$v = u + at$
$0 = 30 + (-10 \times t)$
$\therefore t = 3.0$ s
The ball takes 3.0 s to reach its maximum height. It will therefore take 3.0 s to fall from this height back to its starting point and so the whole trip will last for 6.0 s.

c $u = 30$ m s^{-1}, $a = -10$ m s^{-2}, $t = 5.0$ s, $v = ?$
$v = u + at$
$= 30 + (-10 \times 5.0) = -20$ m s^{-1}
The ball is travelling downwards at 20 m s^{-1}.

d The ball moves with an acceleration of 10 m s^{-2} down throughout its entire flight. Thus at its highest point, where its velocity is zero, its acceleration is still 10 m s^{-2} down.

e Since the acceleration of the ball is a constant −10 m s^{-2}, its acceleration–time graph will be as shown below in graph (a).



f The velocity–time graph above in graph (b) shows an initial velocity of 30 m s^{-1} reducing to zero after 3 s, then speeding up to −30 m s^{-1} after 6 s. The gradient of this graph is constant and is equal to −10, i.e. the acceleration of the ball.

Physics File

The acceleration of a falling object near the Earth's surface is 9.8 m s^{-2}. This quantity, g, can be used when describing large accelerations. For example, an acceleration of 19.6 m s^{-2} is $2g$. An astronaut will experience an acceleration of about $4g$ (39.2 m s^{-2}) at take off. The forces involved give a crushing sensation similar to if the astronaut had three identical astronauts lying on top of him or her! Space missions are designed so that the acceleration does not exceed $6g$. Sustained accelerations greater than this can lead to the astronauts losing consciousness.

Physics File

The acceleration due to gravity on Earth varies according to the location. The strength of gravity is different on the surface of different bodies in the solar system depending on their mass and size.

Table 8.7 The acceleration due to gravity at various locations around the solar system

Location	*Acceleration due to gravity (m s^{-2})*
Perth	9.80
South Pole	9.83
Equator	9.78
Moon	1.6
Mars	3.6
Jupiter	24.6
Pluto	0.67

8.4 SUMMARY Equations of motion

- Equations of motion can be used to analyse problems involving constant acceleration. These equations are:

$$v = u + at$$
$$s = ut + \tfrac{1}{2}at^2$$
$$v^2 = u^2 + 2as$$

- If air resistance is not significant, bodies falling freely near the Earth will move with the same constant acceleration.
- The acceleration due to gravity is represented by g and is equal to $9.8\ m\ s^{-2}$ in the direction of the centre of the Earth.
- The equations for uniform acceleration can be used to solve vertical motion problems. It is often necessary to specify a positive and negative direction.

8.4 QUESTIONS

1 A car starts from rest and accelerates uniformly for 8.0 s. It reaches a final speed of 16 m s^{-1}.
- **a** What is the acceleration of the car?
- **b** What is the average velocity of the car?
- **c** Calculate the distance travelled by the car.

2 A new model BMW can start from rest and travel 400 m in 16 s.
- **a** What is its average acceleration during this time?
- **b** Calculate the final speed of the car.
- **c** How fast is this final speed in km h^{-1}?

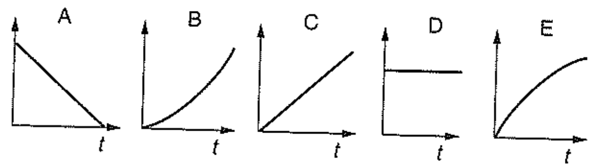
3 A car is travelling along a straight road at 75 km h^{-1}. In an attempt to avoid an accident, the motorist has to brake to a sudden stop.
- **a** What is the car's initial speed in m s^{-1}?
- **b** If the reaction time of the motorist is 0.25 s, what distance does the car travel while the driver is reacting to apply the brakes?
- **c** Once the brakes are applied, the car has an acceleration of -6.0 m s^{-2}. How far does the car travel whilst pulling up?
- **d** What total distance does the car travel from when the driver first notices the danger to when the car comes to a stop?

4 A billiard ball rolls from rest down a smooth ramp that is 8.0 m long. The acceleration of the ball is constant at 2.0 m s^{-2}.
- **a** What is the speed of the ball when it is halfway down the ramp?
- **b** What is the final speed of the ball?
- **c** How long does the ball take to roll the first 4.0 m?
- **d** How long does the ball take to travel the final 4.0 m?

5 A cyclist is travelling at a constant speed of 12 m s^{-1} when he passes a stationary bus. The bus starts moving just as the cyclist passes, and accelerates uniformly at 1.5 m s^{-2}.
- **a** When does the bus reach the same speed as the cyclist?
- **b** How long does the bus take to catch the cyclist?
- **c** What distance has the cyclist travelled before the bus catches up?

For questions 6–10, the acceleration due to gravity is 9.8 m s^{-2} down and air resistance is considered to be negligible.

6 A student drops a golf ball from a height of 5.0 m and uses a multiflash photograph to analyse its motion. The student designates down as the positive direction.



- **a** Which of the graphs A–E best represents the velocity of the ball?
- **b** Which of the graphs A–E best represents the acceleration of the ball?
- **c** How long does the ball take to reach the ground?
- **d** Calculate the speed of the ball as it hits the ground.

7 A book is knocked off a bench and falls vertically to the floor. If the book takes 1.0 s to fall to the floor, calculate:
- **a** its speed as it lands
- **b** the height from which it fell
- **c** the distance it falls during the first 0.5 s
- **d** the distance it falls during the final 0.5 s.

8 While celebrating her eighteenth birthday, a girl pops the cork off a bottle of champagne. The cork travels vertically into the air. Being a keen physics student, the girl notices that the cork takes 4.0 s to return to its starting position.
- **a** How long does the cork take to reach its maximum height?
- **b** What was the maximum height reached by the cork?
- **c** How fast was the cork travelling initially?
- **d** What was the speed of the cork as it returned to its starting point?
- **e** Describe the acceleration of the cork at each of these times after its launch:
  - **i** 1.0 s
  - **ii** 2.0 s
  - **iii** 3.0 s.

9 At the start of a football match, the umpire bounces the ball so that it travels vertically and reaches a height of 15.0 m.
- **a** How long does the ball take to reach this maximum height?
- **b** One of the ruckmen is able to leap and reach to a height of 4.0 m with his hand. How long after the bounce should this ruckman endeavour to make contact with the ball?

10 A hot-air balloon is 80 m above the ground and travelling vertically downwards at 8.0 m s^{-1} when one of the passengers accidently drops a coin over the side. How long after the coin reaches the ground does the balloon touch down?

Chapter review

For the following questions, the acceleration due to gravity is 9.8 m s^{-2} down and air resistance is considered to be negligible.

The following information relates to questions 1–3. During a game of mini-golf, a girl putts a ball so that it hits an obstacle and travels straight up into the air, reaching its highest point after 1.5 s.

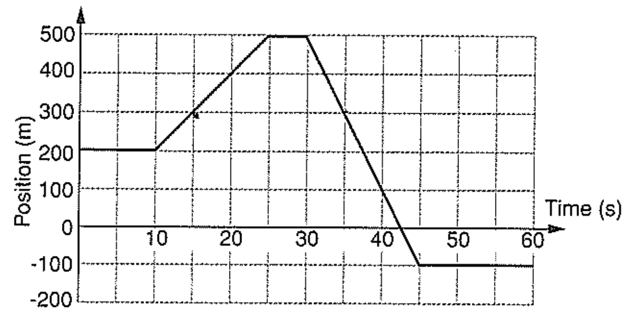
1 Which one of the following statements best describes the acceleration of the ball while it is in the air?
- **A** The acceleration of the ball decreases as it travels upwards, becoming zero as it reaches its highest point.
- **B** The acceleration is constant as the ball travels upwards, then reverses direction as the ball falls down again.
- **C** The acceleration of the ball is greatest when the ball is at the highest point.
- **D** The acceleration of the ball is constant throughout its motion upwards and downwards.

2 What was the initial velocity of the ball as it launched into the air?

3 Calculate the maximum height reached by the ball.

4 Which one of the following is given by the area under a velocity–time graph:
- **A** the distance travelled during the time interval?
- **B** the acceleration of the object during the time interval?
- **C** the displacement of the object during the time interval?
- **D** the average velocity during the time interval?

The following information relates to questions 5–8.



The graph shows the position of a motorbike along a straight stretch of road as a function of time. The motorcyclist starts 200 m north of an intersection.

5 During what time interval is this motorcyclist:
- **a** travelling in a northerly direction?
- **b** travelling in a southerly direction?
- **c** stationary?

6 When does the motorcyclist pass back through the intersection?

7 Calculate the instantaneous velocity of the motorcyclist at each of the following times:
- **a** 15 s
- **b** 35 s.

8 For the 60 s motion, calculate the:
- **a** average velocity of the motorcyclist
- **b** average speed of the motorcyclist.

The following information relates to questions 9 and 10. A skier is travelling along a horizontal ski-run at a speed of 10 m s^{-1}. After falling over, the skier takes 10 m to come to rest.

9 Which one of the following best describes the average acceleration of the skier?
- **A** -1 m s^{-2}
- **B** -10 m s^{-2}
- **C** -5 m s^{-2}
- **D** zero.

10 Calculate the time that the skier takes to come to a stop.

The following information relates to questions 11 and 12. An athlete in training for a marathon runs 15 km north along a straight road before realising that she has dropped her drink bottle. She turns around and runs back 5 km to find her bottle, then resumes running in the original direction. After running for 2.0 h, the athlete reaches 20 km from her starting position and stops.

11 Calculate the average speed of the athlete in km h^{-1}.

12 Calculate her average velocity in:
- **a** km h^{-1}
- **b** m s^{-1}.

13 A jet-ski starts from rest and accelerates uniformly. If it travels 2.0 m in its first second of motion, calculate:
- **a** its acceleration
- **b** its speed at the end of the first second
- **c** the distance that the jet-ski travels in its second second of motion.

b The additional energy causes the nucleus to break apart.

7.2 Nuclear fission weapons

1 B **2** It doesn't have a high enough concentration of the fissile isotope, uranium-235. **3** B
4 a 3.2×10^{-11} J **b** 3.2×10^{13} J **c** 8000 tonnes
5 Firstly, a neutron causes fission to occur in a uranium-235 nucleus, thus releasing 2 or 3 more neutrons. These then go on and induce fission in more uranium-235 nuclei, each resulting in the release of 2 or 3 neutrons and so on. The chain reaction grows very rapidly and energy is released in each fission reaction.
6 As a result of its shape, a very high proportion of neutrons are able to escape from the material, and so the chain reaction dies out.
7 a It is carried as two or more subcritical masses.
b The subcritical masses are forced together to form a combined supercritical mass.
8 0.044 kg

7.3 Nuclear reactors

1 B **2** D
3 a The fission process in the reactor core produces heat. This heat energy is conducted into the coolant which is flowing through the core. The energy is used to produce steam which drives a turbine to generate electricity.
b The difference is that the heat energy that makes the steam is produced by burning coal instead of a nuclear fission reaction.
c They both use steam to turn a turbine to generate electricity.
4 The nucleus is too heavy. When a neutron collides with a lead nucleus, the neutron will keep almost all of its energy, and so not slow down sufficiently to be captured by a fissile nucleus.
5 a The chain reaction will be self sustaining, i.e. critical, and a steady release of energy will result. **b** The chain reaction will die out because it is subcritical. This will lead to a decrease in the amount of energy produced. **c** The chain reaction will grow, causing an increasing amount of energy to be produced. This may be dangerous and could result in an explosion.
6 a Fast neutrons are most unlikely to be captured by the nuclei.
b Slow neutrons are likely to be absorbed by the nuclei and cause fission.
7 a It results in the uranium-238 transmuting into plutonium-239.
b Plutonium is highly radioactive and has a half-life of about 24 000 years.
8 a plutonium-239 **b** They rely on fast, high energy neutrons to induce fission in plutonium nuclei.
c They produce, or breed, more of their own fuel, plutonium-239, when neutrons are absorbed by uranium-238 nuclei.
d Fast breeder reactors do not have moderators.
9 Since only one neutron is required to sustain the chain reaction, the remaining neutrons are able to breed more plutonium.
10 Over a period of months, the fissile nuclei in the fuel rods become depleted, the number of fissions decreases, and so fewer neutrons are flying around in the core. In order to maintain the chain reaction, the control rods must be gradually withdrawn.
11 tritium **12** proton

7.4 Nuclear waste and weapons testing—an Australian perspective

1 Plutonium because it has the longer half-life. Most of the cobalt-60 would have decayed over the past 40 years.
2 a To bury the radioactive material that was lying on the surface.
b The low penetrating ability of the alpha emissions is the reason this method was used.
3 The radioactive dust could be inhaled.
4 The fuel rods are still generating a lot of heat, and the water removes this heat energy. The level of radioactivity decreases over the several years that the rods are in the ponds.
5 a 10^5 years **b** The fission fragments, having relatively short half-lives, have decayed.
6 SYNROC is more stable in the presence of water.
7 Containment: storage in vessels
Dispersal: releasing in oceans or atmosphere
8 Alpha is a more highly ionising form of radiation and so is considered to be more harmful.
9 Neptunium is formed when a uranium nucleus absorbs a neutron, then undergoes a beta decay. A similar process occurs for the other elements.

CHAPTER 7 REVIEW

1 C **2 a** uranium-238 **b** uranium-235
c The concentration of the fissile uranium-235 is too low.
3 2 **4** 2.7×10^3 tonnes **5** B
6 They are mostly absorbed by uranium-238 nuclei, absorbed by the moderator, or have escaped from the reactor core.
7 The uranium deposits would have spontaneously exploded millions of years ago.
8 a sliced **b** two hemispherical pieces **c** a two kilogram lump
d The material is carried as small subcritical pieces, then combined at the time of detonation.
9 a The kinetic energy of the fission fragments. **b** The heat energy is removed from the reactor core by a coolant. This then is used to create steam which is used to turn a turbine and generate electricity.
10 a ${}^{1}_{0}n + {}^{238}_{92}U \rightarrow {}^{239}_{92}U \rightarrow {}^{239}_{93}Np + {}^{0}_{-1}\beta \rightarrow {}^{239}_{94}Pu + {}^{0}_{-1}\beta$
b It has a relatively short half-life (24 400 years) and so has completely decayed since the formation of the Earth.
11 a synthetic rock **b** It presents a possible solution to the problem of the permanent disposal of high level radioactive waste.
12 a The oceans are so vast that any radioactivity leaks would be greatly diluted. The radioisotopes also have relatively short half-lives. **b** The radioactivity could leak and cause damage to fish and other marine life.
13 a The control rods absorb neutrons and control the rate of the fission process. **b** The coolant, after being heated by the fuel rods, is used to produce steam. This is in turn used to drive a turbine around and generate electricity.
c It can reach higher temperatures when under pressure.
14 Possible accidents at launch
15 a Able to split in two when hit by a neutron
b Able to absorb a neutron and become a fissile isotope
16 a slow **b** Iron is not fissile. **c** The decrease in the nuclear mass during fission. **d** They also cause fission and so produce a chain reaction.
17 The reactors at Lucas Heights create high level radioactive waste which we export to France.
18 a 4.99×10^{-28} kg **b** 4.45×10^{-11} J **c** 280 MeV **19** D
20 a 50 **b** It would require too much (2000 kg) uranium.

STUDY REVIEW (NUCLEAR TECHNOLOGY)

1 5.25×10^{-28} kg **2** 4.73×10^{-11} J **3** 0.13% **4** 27 g
5 2.41×10^{15} J **6** 0.50 Gy **7** 250 Gy

8 The testes are the most radiosensitive, then the breasts and lastly the hands.
9 The testes **10** ${}^{238}_{92}U + {}^{1}_{0}n \rightarrow {}^{239}_{92}U$
11 ${}^{239}_{92}U \rightarrow {}^{239}_{93}Np + {}^{0}_{-1}\beta + \gamma$, and finally ${}^{239}_{93}Np \rightarrow {}^{239}_{94}Pu + {}^{0}_{-1}\beta + \gamma$
12 60 s **13** 4.7 g **14** ${}^{26}_{11}Na \rightarrow {}^{26}_{12}Mg + {}^{0}_{-1}\beta$ **15** B
16 The smaller piece has more surface area per volume, loses a higher proportion of fission neutrons, resulting in the chain reaction dying out. In the larger mass, a smaller proportion of neutrons is lost and so it is capable of spontaneously exploding.
17 ${}^{9}_{4}Be + {}^{4}_{2}\alpha \rightarrow {}^{12}_{6}C + {}^{1}_{0}n$
18 ${}^{235}U$ has a shorter half-life and so is decaying at a slightly faster rate than ${}^{238}U$. Therefore the proportion of uranium-235 will be decreasing.
19 Leukaemia, tumours, radiation sickness, probable death within months.
20 Yes, genetic problems could arise in future generations.
21 To extract heat from the reactor core. This energy is used to produce steam which is used to drive turbines and generate electricity.
22 42% **23** B
24 The bismuth-215 sample will have twice the activity of bismuth-211.
25 Gamma rays have the ability to penetrate the skull and pass through the tumour region. The half-life of 5.3 years means that the source would retain its activity for a number of years and would not need replacing very often.
26 Gamma rays have enough energy to ionise atoms in the body cells. These ions may damage the structure of the DNA, leading to genetic problems. Infrared radiation does not have enough energy to do this.
27 Multiple beam therapy enables a large dose of radiation to be delivered to the tumour site without irradiating the healthy body cells with an equally large dose.
28 Yes, the statement is correct. Exposure to ionising radiation is known to be one cause of cancer, and ionising radiation is also one of the most effective treatments for cancer.
29 3 **30** 1.4×10^7 m s^{-1}
31 The fission neutrons are moving too fast to induce further fission in uranium-235 nuclei, and so a moderator is used to slow them down.
32 The moderating nuclei must be relatively light so that the incident neutrons lose some of their energy upon colliding.
33 Their fuel, plutonium-239, is highly fissile when struck by fast moving neutrons.
34 In the core of nuclear reactors when uranium-238 nuclei absorb neutrons and decay to form plutonium-239.
35 Electrons that are emitted from the nucleus of an unstable atom.
36 7 protons, 9 neutrons, 16 nucleons
37 ${}^{16}_{7}N \rightarrow {}^{16}_{8}O + {}^{0}_{-1}\beta$ **38** No, its half-life is too short.
39 $\alpha, \beta, \beta, \alpha, \alpha, \alpha$ **40** 25 **41** 375 J **42** None of them!
43 5.98×10^{25} MeV
44 ${}^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + {}^{0}_{1}e$ ${}^{2}_{1}H + {}^{1}_{1}H \rightarrow {}^{3}_{2}He$ ${}^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + 2{}^{1}_{1}p$
45 240 MW

Chapter 8 Aspects of motion

8.1 Describing motion in a straight line

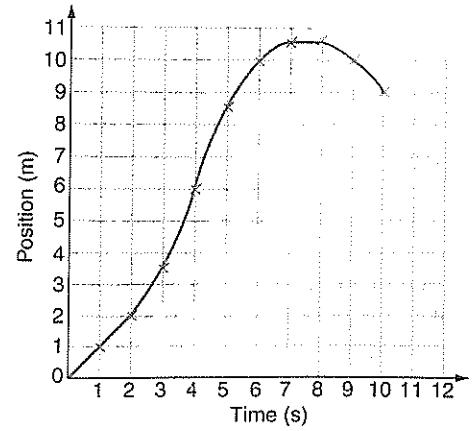
1 a +40 cm, 40 cm **b** −10 cm, 10 cm **c** +20 cm, 20 cm
d +20 cm, 80 cm
2 a 80 km **b** 20 km north
3 a 10 m down **b** 60 m up **c** 70 m **d** 50 m up
4 displacement **5 a** 25 m east **b** 20 m west
6 a D **b** D **c** C **d** A **7 a** 10 m south **b** zero
8 a 39 steps **b** 1 step west of the clothes line
c 1 step west of the clothes line

8.2 Speed, velocity and acceleration

1 a ~2 m s^{-1} **b** ~1 mm s^{-1} **c** ~10 m s^{-1} **d** ~5 m s^{-1}
2 a 15 km h^{-1} **b** 4.2 m s^{-1}
c No, she would probably be travelling faster or slower than this average speed. It depends on the traffic and the terrain.
3 a 22.2 m s^{-1} **b** 6.7 km h^{-1} s^{-1} **c** 1.85 m s^{-2} **d** 20 m
4 a 5 m s^{-1} west **b** 4 m s^{-1} west
5 a −10 m s^{-1} **b** 40 m s^{-1} west **c** 800 m s^{-2} west
6 a 12 km h^{-1} s^{-1} south **b** −3.3 m s^{-1}
7 a 1500 m **b** 1.7 m s^{-1} **c** 0 **d** 0 **8** D **9** B **10** C
11, 12 Answers to these questions will vary according to estimations used in calculations.

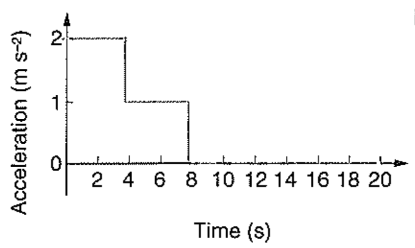
8.3 Graphing motion: position, velocity and acceleration

1 a +4 m **b** A, C **c** B **d** D
2 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.
3 a +8 m **b** +8 m **c** +4 m **d** −2 m **4** 8 s
5 a +4 m s^{-1} **b** 0 **c** −2 m s^{-1} **d** −2 m s^{-1} **e** −2 m s^{-1}
6 a 18 m **b** −2 m
7 a The cyclist travels with a constant velocity in a positive direction for the first 30 s, travelling 150 m during this time. Then the cyclist speeds up for 10 s, travelling a further 150 m. Finally the cyclist maintains this increased speed for the final 10 s, covering another 200 m in this time. **b** +5 m s^{-1} **c** +20 m s^{-1} **d** ~13 m s^{-1}
e +15 m s^{-1} **8 a** B **b** A **c** C **d** D
9 a Running north at 1 m s^{-1} **b** Increasing speed from 1 m s^{-1} to 3 m s^{-1} while running north **c** Running north but slowing to a stop
d Stationary **e** Accelerating from rest to 1 m s^{-1} while running south **f** Running south at 1 m s^{-1}
10 a 2 m north **b** 10.5 m north **c** 9 m north
11



12 a 80 s **b** ~1.3 m s^{-2} **c** ~0.5 m s^{-2} **d** ~4900 m
13 a +2 m s^{-2} **b** 4 s **c** 10 s **d** 80 m **e** +7 m s^{-1}

14 a



b +12 m s^{-1}

8.4 Equations of motion

1 a +2.0 m s^{-2} **b** +8.0 m s^{-1} **c** 64 m
2 a +3.1 m s^{-2} **b** 50 m s^{-1} **c** 180 km h^{-1}
3 a 21 m s^{-1} **b** 5.2 m **c** 37 m **d** 42 m
4 a 4.0 m s^{-1} **b** 5.7 m s^{-1} **c** 2.0 s **d** 0.83 s
5 a 8.0 s **b** 16 s **c** 192 m **6 a** C **b** D **c** 1.0 s **d** 9.9 m s^{-1}
7 a 9.8 m s^{-1} **b** 4.9 m **c** 1.2 m **d** 3.7 m
8 a 2.0 s **b** 19.6 m **c** 19.6 m s^{-1} **d** 19.6 m s^{-1}
e i 9.8 m s^{-2} down **ii** 9.8 m s^{-2} down **iii** 9.8 m s^{-2} down
9 a 1.7 s **b** 3.2 s **10** 6.7 s

CHAPTER 8 REVIEW

1 D **2** 14.7 m s^{-1} up **3** 11.0 m **4** C
5 a from 10 s to 25 s **b** from 30 s to 45 s
c from 0 s to 10 s, 25 s to 30 s, and 45 s to 60 s
6 a After 42.5 s **7 a** 20 m s^{-1} north **b** 40 m s^{-1} south
8 a 5 m s^{-1} south **b** 15 m s^{-1} **9** C **10** 2.0 s **11** 15 km h^{-1}
12 a 10 km h^{-1} north **b** 2.8 m s^{-1} north
13 a 4.0 m s^{-2} **b** 4.0 m s^{-1} **c** 6.0 m
14 a 0.80 m s^{-1} **b** 0.50 m s^{-1} **c** 0.67 m s^{-1}
15 a 0.75 m s^{-1} **b** −5.0 m s^{-2} **16 a** 3.50 s **b** 2.89 s
17 1.00 s **18** ~10 m s^{-1} north **19** A
20 a 0 **b** ~ 2.0 m s^{-2} north **c** 7.0 m s^{-2} south
21 Answer will depend on estimations used in calculations.

Chapter 9 Forces in two dimensions

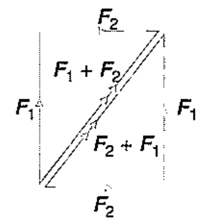
9.1 Force as a vector

1 a A scalar is a quantity which is completely defined by its magnitude, whereas a magnitude and a direction are essential for a vector quantity to be fully defined.
b Scalar: refractive index, mass, distance travelled, average speed, time. Vector: displacement, velocity, acceleration, force
c Average speed is a scalar quantity—defined as the rate of change of distance (a scalar). Average velocity is a vector quantity—defined as the rate of change of displacement (a vector). For the same motion, these quantities can be different, e.g. running around an oval and returning to the same point. The average speed will be a certain value, and the average velocity will be zero, i.e. $v_{av} = 0$.
2 a 10 N **b** 100 N **c** 50–100 N **d** 1 N
3 1000 N, 10 000 N **4** B, C, D
5 a 60°T **b** 320°T **c** 240°T **d** 135°T **e** 22.5°T
6 a 75 N east **b** 180 N west **c** 15 N west
7 a 70 N right **b** 50 N up **c** 80 N down

9.2 Vector techniques

1 a $F_1 + F_2 = 35$ N north 45° east **b** $2F_1 = 50$ N north
c $2F_1 + F_2 = 56$ N north 27° east **d** $2F_1 + 2F_2 = 71$ N north 45° east

2



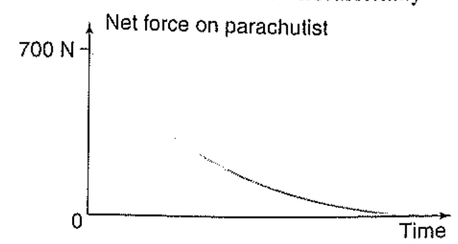
3 a B **b** C **c** A, D, F **d** E, G **e** E, G
4 a 0 N **b** 10 N south 60° west
c The chair will move in the direction provided by the of the sum of the forces provided by Hugh and Elisa, i.e. N60°E
5 a 5 N 143°T **b** 100 N 323°T **c** 7.1 N north 15° east
d 2.5 N 73°T
6 610 N in a direction that bisects the two ropes
7 a 50 N south, 87 N east **b** 60 N north
c 282 N south, 103 N east **d** 1.5×10^5 N up, 2.6×10^5 N horizontal
8 150 N upwards, 260 N horizontal
9 100 N acting down the incline **10** 85 N

9.3 Newton's first law of motion

1 Aristotle felt that the natural state for any object was at rest in its natural place. This meant that any moving body would come to rest of its own accord. Galileo introduced the idea that friction was a force that could be added to other forces that act on a moving body, but it was Newton who explained that the moving object should continue to travel with constant velocity unless a net force is acting.
2 No force acts on the person. In accordance with Newton's first law of motion, the bus slows, and the standing passenger will continue to move with constant velocity unless acted on by a force—usually the passenger will lose his or her footing and fall forward.
3 Hard leather soles provide little or no grip on the ice—there is no friction. As a consequence, no force can be applied to begin walking, and the net force on the person will be zero. To be propelled with ice skates, the blade of the skate has to be dug into the surface of the ice, allowing the skater a fixed point from which to 'push off'.
4 20 N in a forward direction, so that the net force will be zero
5 To exactly balance the other forces, lift = 50 kN up, and drag = 12 kN west
6 a 25 N **b** 25 N horizontally **c** 29 N at 30° to the horizontal
7 When the car or aircraft slows suddenly, a passenger will continue to travel with the same velocity as before, until being acted on by an unbalanced force. The purpose of the seat belt is to supply that force, but across the body where the effects of the force are reduced.
8 A Gravitation **B** Electric force
C Friction between the tyres and the road **D** Tension in the wire

9.4 Newton's second law of motion

1 244 N **2** 1110 N opposing the motion
3 The 1.5 kg shot-put is the larger of the two masses, and so for the same applied force, its acceleration will be lower. This means a lower speed on leaving the athlete's arm, and so it cannot be thrown as far as the lighter 1.0 kg ball.
4 a 160 N **b** 141°T
c 213 m s^{-2} 141°T (but this is for a very short time)
5 2600 N in the direction of travel
6 On Earth's surface, the gravitational field strength is almost the same at every point, so the weight of a stationary object is proportional to its mass ($W \propto m$, g constant). Scales make use of this fact and are calibrated in kilograms. Scales would be inappropriate for use on the moon, reading 12 kg. Scales measure weight, not mass.
7 $m = 1500$ g, $W = 5.4$ N **8** 10 m s^{-2} horizontally
9



As the parachutist leaves the aircraft, his or her weight will be the net force acting, accelerating at 9.8 m s^{-2} but as the speed increases, the drag force (air resistance) opposing the motion also increases until it equals the weight. At this point in time, the net force will be zero and the parachutist will travel with a constant speed.

9.5 Newton's third law of motion

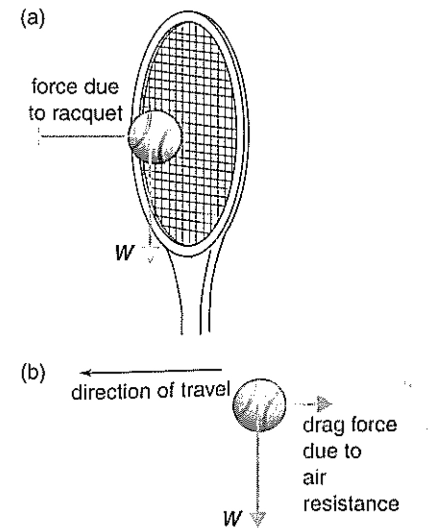
1

Situation	*Action force*	*Reaction force*
A	Force from the bat on to the ball	Ball exerts a force on the bat in the opposite direction
B	Weight of pine cone, i.e. gravitation pulling it to the Earth	Earth pulled toward the pine cone with the same force
C	Air under pressure is forced (escapes) backwards	Balloon is forced forwards

2 a 140 N in the opposite direction to the leaping fisherman
b 3.5 m s^{-2} in the opposite direction to the fisherman
c Fisherman: 1.0 m s^{-1}. Boat: 1.75 m s^{-1}
3 a If no other forces act, there will be an action/reaction force pair in which the action force is the force on the tool kit, and the reaction force will act on the astronaut in the opposite direction. If the kit is thrown directly away from the ship, hopefully the reaction force will propel him back to the craft.
b 20 N act on each mass, but in opposite directions
c 0.2 m s^{-1} **d** 500 s or 8 min 20 s
4 12.5 m s^{-2} south
5 The force of gravitation on the speaker will be 49 N downwards and the normal force exerted by the bookshelf on the speaker will be 49 N upwards. The reaction force to the weight of the speaker will be a force on the Earth of 49 N acting towards the speaker.
6 a Weight vertically down, normal force up and perpendicular to the incline, friction up the incline **b** $W = 637$ N downwards, $N = 409$ N up and perpendicular to the track **c** $\Sigma F = 488$ N along the incline **d** 7.5 m s^{-2} along the track **7** 280 N
8 As the lift accelerates, the normal force that you experience from the floor increases—this is your apparent weight. The normal force has to balance your weight and provide extra force to accelerate you upwards. $N = \Sigma F - W$
The same situation occurs when the lift comes to rest while 'going down' as the net force must still be upwards.
9 a 784 N down **b** 960 N down **c** 784 N down
d 608 N down **e** 608 N down
10 a 196 N down on the side of the student
b 2.45 m s^{-2} down to the side of the student **c** 370 N

CHAPTER 9 REVIEW

1 a A person tripping—because their foot stops momentarily, and the rest of the body continues with constant velocity.
b The constant velocity of a satellite in deep space far from the influence of any gravitational fields.
c A racing car will leave the race track at a bend and continue in a straight line if it hits an oil patch owing to a lack of friction.
2 47.5 N **3** 6.7 m s^{-1}
4 a Kicking the tyre of a car hurts because you apply a force to the tyre (action) and the tyre will apply a reaction force to your foot (reaction).
b Hot gases are forced out of a jet engine (action) and the gases push the engine forward (reaction).
c The weight of any object can be considered an action force—the Earth pulls on the body. The reaction force acts on the Earth—the object pulls on the Earth.
5 a 5.0 m s^{-1}
b i 540 N down **ii** 650 N down **iii** 540 N down **iv** 430 N down
6 a 833 N down **b** 136 N down **c** 306 N down
d 833 N down (note the difference between weight and apparent weight) **e** 0 N (zero normal force) **f** 1260 N down
7 A block is struck with a sharp blow so that it is overcomes the grip of the blocks within which it is in contact, and so it is ejected from the pile. The other blocks experience no horizontal net force, and so stay in the vertical stack.
8 a 113 N horizontally, 41 N down **b** 113 N to the south
c $N = 196 + 41 = 237$ N upwards
d When the trolley is pulled, the vertical component of the applied force is upwards rather than downwards, and so a smaller (upward) normal force is needed—helping the wheels to rotate more freely.
9 7.0 m s^{-1} **10** B
11 a 1.5 m s^{-2} in the direction of the force **b** 75 N
12 a 1:1 **b** 1:4 **c** 1:4
13 To maintain a tension of less than 100 N in the rope, the bucket must accelerate at greater than 1.47 m s^{-2} downwards. If the acceleration falls below this, the rope will snap.
14 4.2 kg **15** 70.6 km h^{-1} **16** 30°
17 2.05 m s^{-2} down the incline
18



19 3.27 m s^{-2}, 65.3 N