2. Kinematics

2.1 Equations of motion

Paper 2

Question Paper

1 **(a)** Define velocity.

.....

..... [1]

(b) A student throws a ball over a vertical wall of height *h*, as shown in Fig. 2.1.

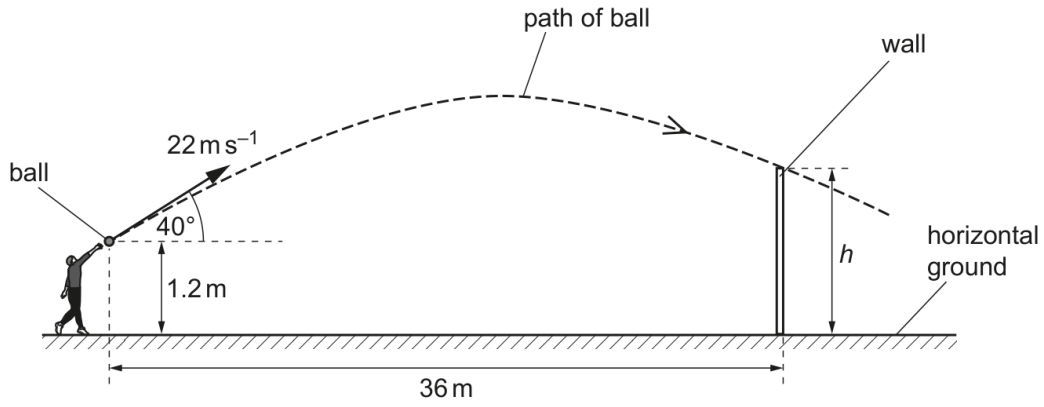


Fig. 2.1 (not to scale)

The ball leaves the hand of the student at a height of 1.2 m above the horizontal ground.
The ball has an initial velocity of 22 m s^{-1} at an angle of 40° to the horizontal.
The wall is a horizontal distance of 36 m from where the student releases the ball.

Air resistance is negligible.

(i) Determine the time taken for the ball to reach the wall.

time taken = ... s [2]

(iii) The ball just goes over the wall.

Calculate the height *h* of the wall.

h = ... m [3]

2 A skydiver jumps from an aircraft at time $t = 0$ and falls vertically downwards. The variation with t of her velocity v is shown in Fig. 2.1.

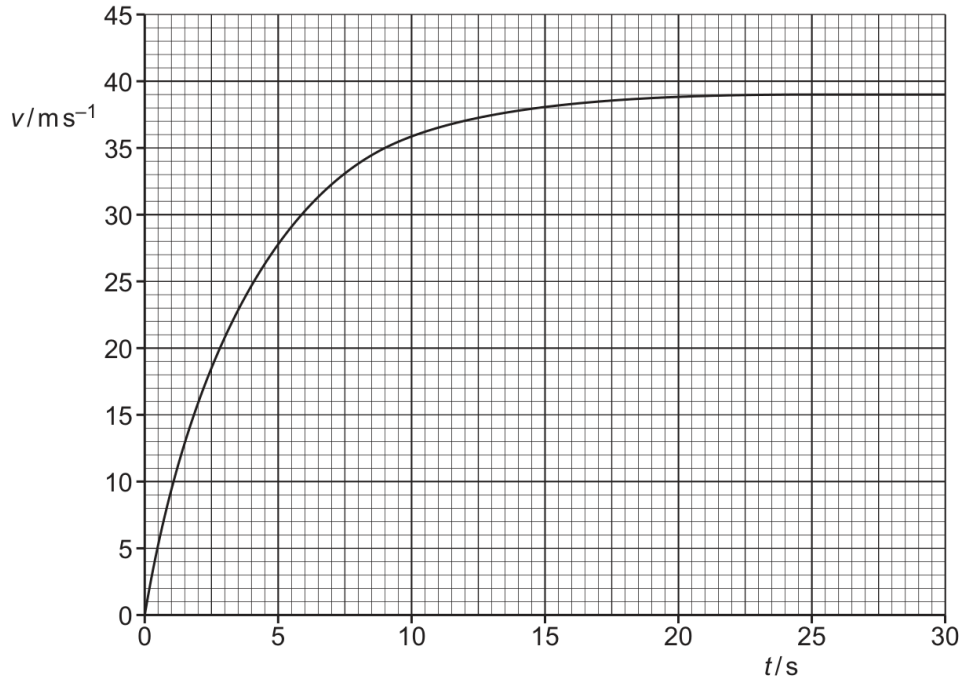


Fig. 2.1

(a) (ii) By drawing a suitable line on Fig. 2.1, determine the acceleration of the skydiver at time $t = 9.0\,s$.

acceleration = ...$m\,s^{-2}$ [2]

3 **(b)** A car of mass 1800 kg is moving in a straight line. Fig. 2.1 shows the variation with time t of the momentum p of the car.

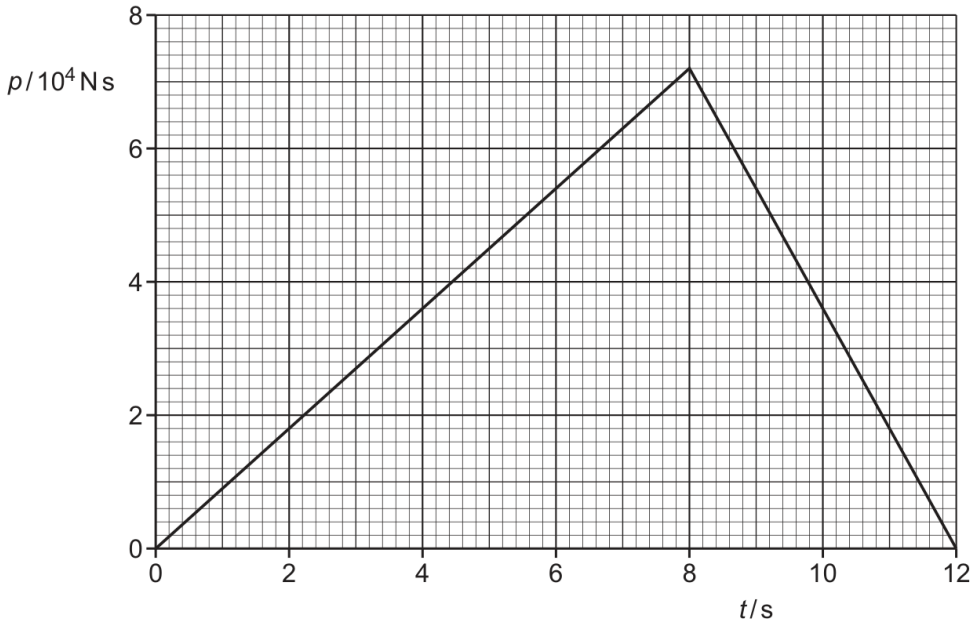


Fig. 2.1

(iv) Determine the distance travelled by the car between times $t = 0$ and $t = 12.0$ s.

distance = ... m [2]

4 **(c)** Later, the child in **(b)** travels down a slope at a constant angle to the horizontal, as shown in Fig. 2.1.

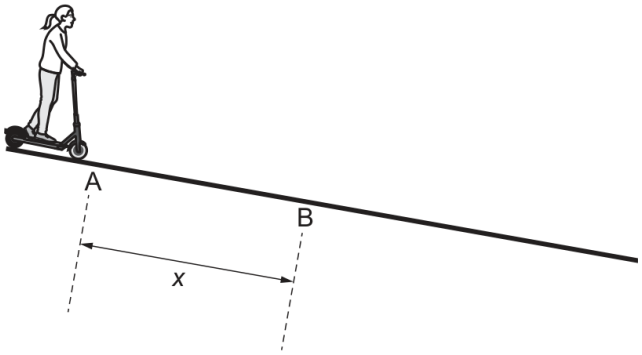


Fig. 2.1 (not to scale)

At point A her speed is $0.60\,m\,s^{-1}$. She has a constant acceleration of $0.85\,m\,s^{-2}$ parallel to the slope. After a time of 3.7 s, she reaches point B.

Calculate the distance x travelled by the child along the slope from A to B.

x = ... m [2]

5 A rigid uniform beam of weight *W* is connected to a fixed support by a hinge, as shown in Fig. 2.1.

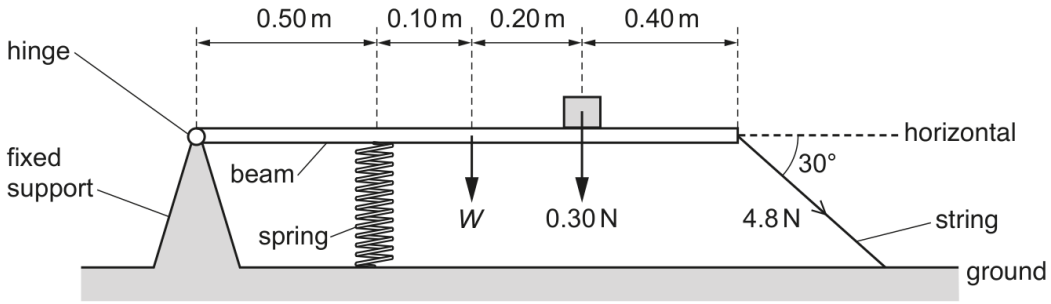


Fig. 2.1 (not to scale)

A compressed spring exerts a total force of 8.2 N vertically upwards on the horizontal beam. A block of weight 0.30 N rests on the beam. The right-hand end of the beam is connected to the ground by a string at an angle of 30° to the horizontal. The tension in the string is 4.8 N. The distances along the beam are shown in Fig. 2.1.

The beam is in equilibrium. Assume that the hinge is frictionless.

(c) The string is cut so that the spring extends upwards. This causes the beam to rotate and launch the block into the air. The block reaches its maximum height and then falls back to the ground.

Fig. 2.2 shows part of the path of the block in the air shortly before it hits the horizontal ground.

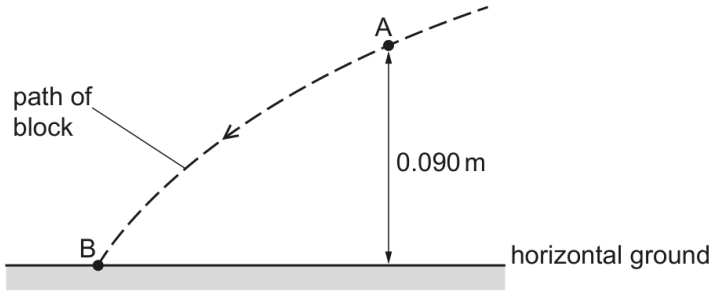


Fig. 2.2 (not to scale)

The block is at a height of 0.090 m above the ground when it passes through point A. The block has a kinetic energy of 0.044 J when it hits the ground at point B.
Air resistance is negligible.

(iii) By reference to the force on the block, explain why the horizontal component of the velocity of the block remains constant as it moves from A to B.

.....

..... [1]

(iv) The block passes through point A at time t_A and arrives at point B at time t_B.

On Fig. 2.3, sketch a graph to show the variation of the magnitude of the vertical component v_Y of the velocity of the block with time t from $t = t_A$ to $t = t_B$.
Numerical values of v_Y are not required.

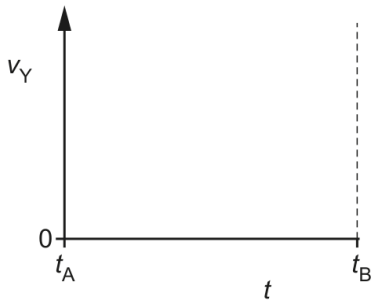


Fig. 2.3

[1]

6 **(c)** The beam in **(b)** rotates when the string is cut and the small block of weight 2.4 N is projected through the air. Fig. 2.2 shows the last part of the path of the block before it hits the ground at point Y.

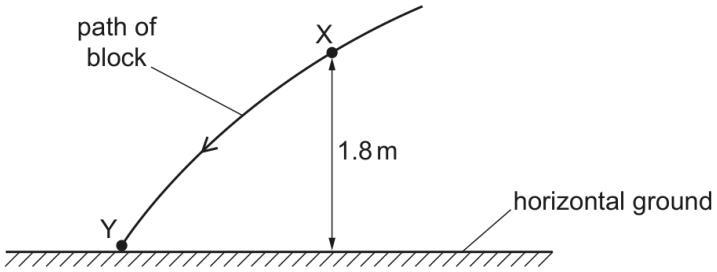


Fig. 2.2 (not to scale)

At point X on the path, the block has a speed of 3.4 m s^{-1} and is at a height of 1.8 m above the horizontal ground. Air resistance is negligible.

(iii) State the variation, if any, in the direction of the acceleration of the block as it moves from X to Y.

..... [1]

(iv) The block passes point X at time t_X and arrives at point Y at time t_Y.

On Fig. 2.3, sketch a graph to show the variation of the magnitude of the horizontal component of the velocity of the block with time from t_X to t_Y.
Numerical values are not required.

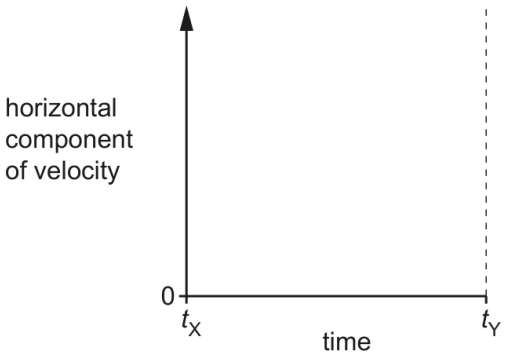


Fig. 2.3

[1]

7 A trolley A moves along a horizontal surface at a constant velocity towards another trolley B which is moving at a lower constant speed in the same direction. Fig. 3.1 shows the trolleys at time $t = 0$.



Fig. 3.1

Table 3.1 shows data for the trolleys.

Table 3.1

trolley	mass / kg	initial speed / m s^{-1}
A	0.25	0.48
B	0.75	0.12

The two trolleys collide elastically and then separate. Resistive forces are negligible.

Fig. 3.2 shows the variation with time t of the velocity v for trolley B.

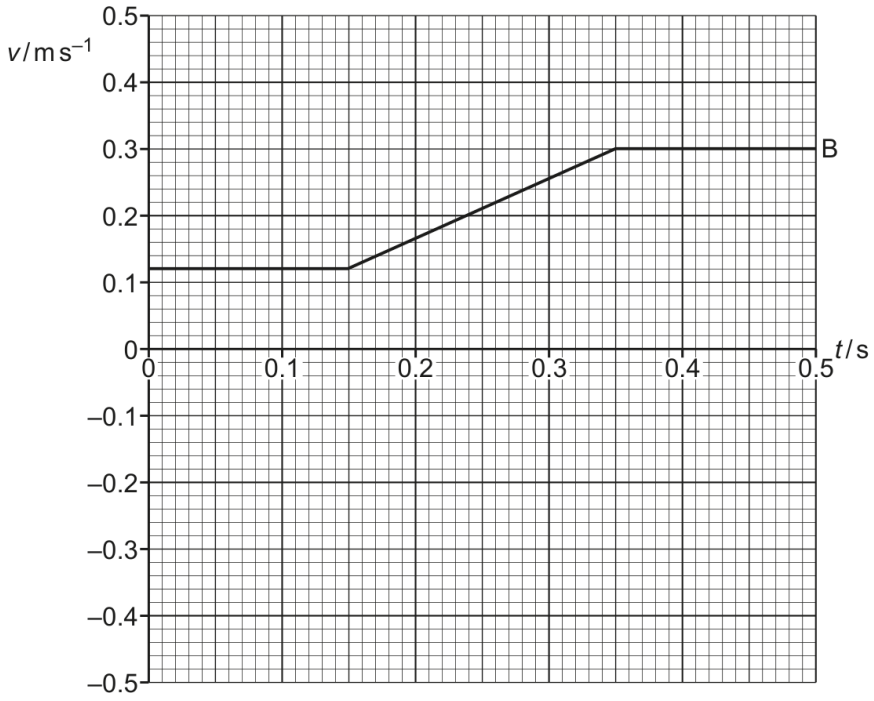


Fig. 3.2

(a) State what is represented by the area under a velocity–time graph.

..... [1]

(b) Use Table 3.1 and Fig. 3.2 to determine:

(i) the acceleration of trolley B during the collision

acceleration of B = ... $m\,s^{-2}$ [2]

8 **(b)** Under certain conditions, the distance s moved in a straight line by an object in time t is given by

$$s = \tfrac{1}{2}at^2$$

where a is the acceleration of the object.

State **two** conditions under which the above expression applies to the motion of the object.

1 .....

2 .....

[2]

(c) The variation with time t of the velocity v of a car that is moving in a straight line is shown in Fig. 1.1.

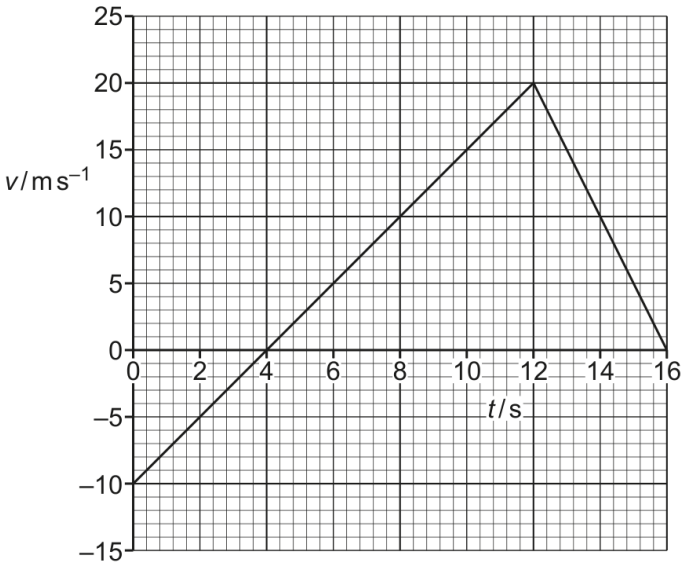


Fig. 1.1

(i) Compare, qualitatively, the acceleration of the car at time t = 8.0 s and at time t = 14.0 s in terms of:

- magnitude

.....

.....

- direction.

.....

.....

[2]

(ii) Determine the magnitude of the acceleration of the car at time $t = 4.0\,s$.

acceleration = ... $m\,s^{-2}$ [2]

(iii) The car is at point X at time $t = 0$.

Determine the magnitude of the displacement of the car from X at time $t = 12.0\,s$.

displacement = ... m [2]

9 **(a)** Define velocity.

.....

..... [1]

(b) A rock of mass 7.5 kg is projected vertically upwards from the surface of a planet. The rock leaves the surface of the planet with a speed of 4.0 m s^{-1} at time t = 0. The variation with time t of the velocity v of the rock is shown in Fig. 1.1.

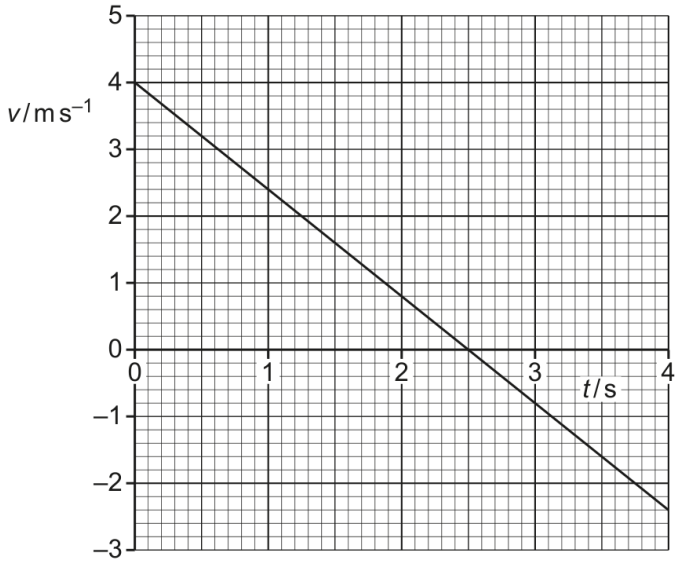


Fig. 1.1

Assume that the planet does not have an atmosphere and that the viscous force acting on the rock is always zero.

(i) Determine the height of the rock above the surface of the planet at time t = 4.0 s.

height = ... m [3]

10 A man standing on a wall throws a small ball vertically upwards with a velocity of $5.6\,m\,s^{-1}$. The ball leaves his hand when it is at a height of 3.1 m above the ground, as shown in Fig. 3.1.

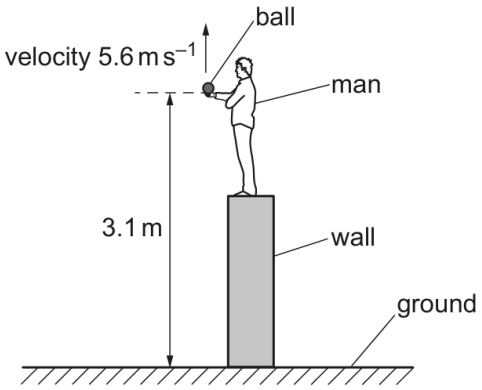


Fig. 3.1 (not to scale)

Assume that air resistance is negligible.

(a) Show that the ball reaches a maximum height above the ground of 4.7 m.

[2]

(b) The man does not catch the ball as it falls.

Calculate the time taken for the ball to fall from its maximum height to the ground.

time taken = ... s [2]

(c) The ball leaves the man's hand at time $t = 0$ and hits the ground at time $t = T$.

On Fig. 3.2, sketch a graph to show the variation of the velocity v of the ball with time t from $t = 0$ to $t = T$. Numerical values of v and t are not required. Assume that v is positive in the upward direction.

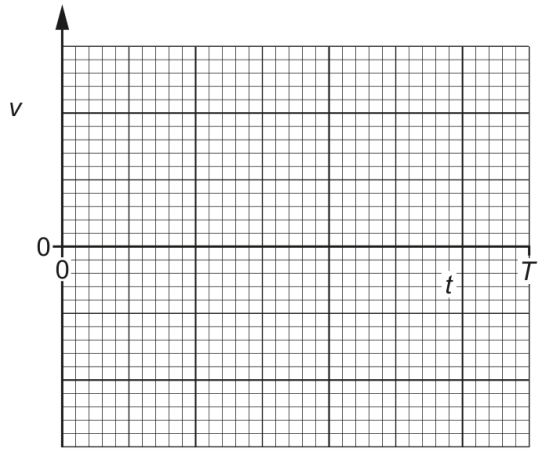


Fig. 3.2

[3]

(d) State what is represented by the gradient of the graph in **(c)**.

..... [1]

(e) The man now throws a second ball with the same velocity and from the same height as the first ball. The mass of the second ball is greater than that of the first ball. Assume that air resistance is still negligible.

For the first and second balls, compare:

(ii) the speeds with which they hit the ground.

..... [1]

11 A steel ball is projected horizontally from the top of a table, as shown in Fig. 2.1.

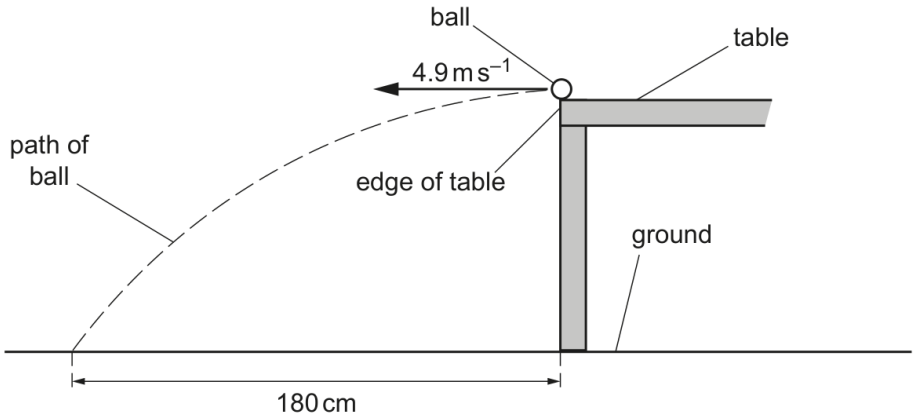


Fig. 2.1 (not to scale)

The ball is projected horizontally at a speed of 4.9 m s^{-1}. The ball lands on the ground a horizontal distance of 180 cm from the edge of the table.

Assume that air resistance is negligible.

(a) (i) Calculate the time taken for the ball to reach the ground.

time = ... s [1]

(ii) Calculate the vertical component of the velocity of the ball as it hits the ground.

velocity = ... m s^{-1} [2]

12 A spherical balloon is filled with a fixed mass of gas. A small block is connected by a string to the balloon, as shown in Fig. 2.1.

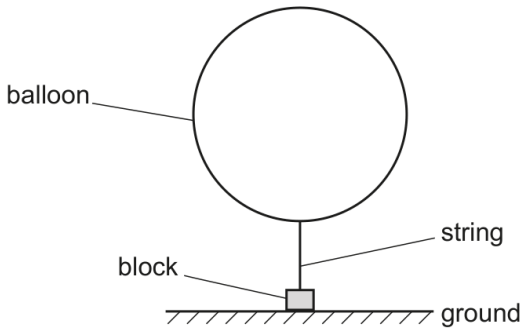


Fig. 2.1 (not to scale)

The block is held on the ground by an external force so that the string is vertical. The density of the air surrounding the balloon is $1.2\,\text{kg}\,\text{m}^{-3}$. The upthrust acting on the balloon is 0.071 N. The upthrust acting on the string and block is negligible.

(c) The balloon continues to lift the block. The string breaks as the block is moving vertically upwards with a speed of $1.4\,\text{m}\,\text{s}^{-1}$. After the string breaks, the detached block briefly continues moving upwards before falling vertically downwards to the ground. The block hits the ground with a speed of $3.6\,\text{m}\,\text{s}^{-1}$.

Assume that the air resistance on the block is negligible.

(i) By considering the motion of the block after the string breaks, calculate the height of the block above the ground when the string breaks.

height = ... m [2]

(ii) The string breaks at time $t = 0$ and the block hits the ground at time $t = T$.

On Fig. 2.2, sketch a graph to show the variation of the velocity v of the block with time t from $t = 0$ to $t = T$.

Numerical values of t are not required. Assume that v is positive in the upward direction.

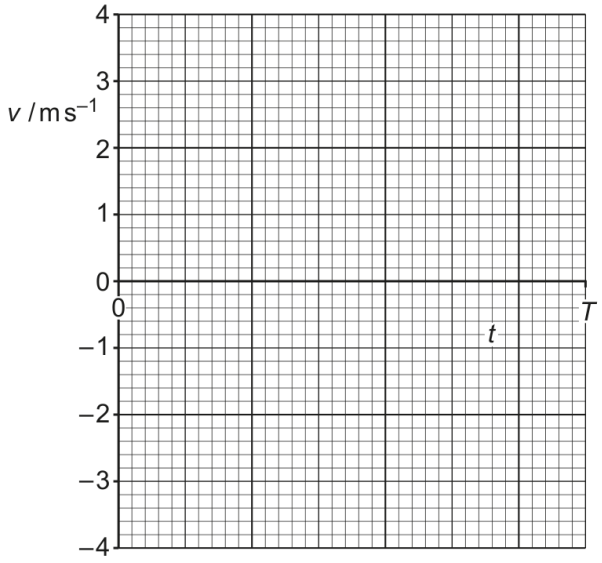


Fig. 2.2

[2]

13 A ball is thrown vertically downwards to the ground, as illustrated in Fig. 2.1.

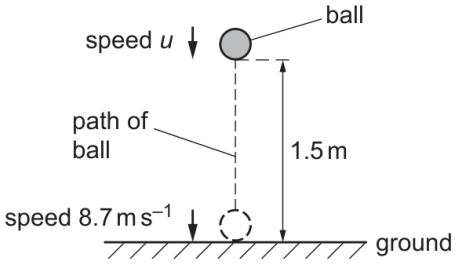


Fig. 2.1

The ball is thrown with speed u from a height of 1.5 m. The ball then hits the ground with speed 8.7 m s^{-1}. Assume that air resistance is negligible.

(a) Calculate speed u.

u = ... m s^{-1} [2]

(d) The ball was thrown downwards at time $t = 0$ and hits the ground at time $t = T$.

On Fig. 2.2, sketch a graph to show the variation of the speed of the ball with time t from $t = 0$ to $t = T$. Numerical values are not required.

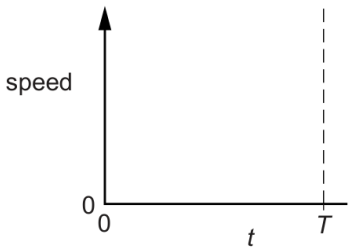


Fig. 2.2

[1]

14 A child of weight 330 N is at point X at the top of a slide. The slide is at the edge of a swimming pool, as shown in Fig. 3.1.

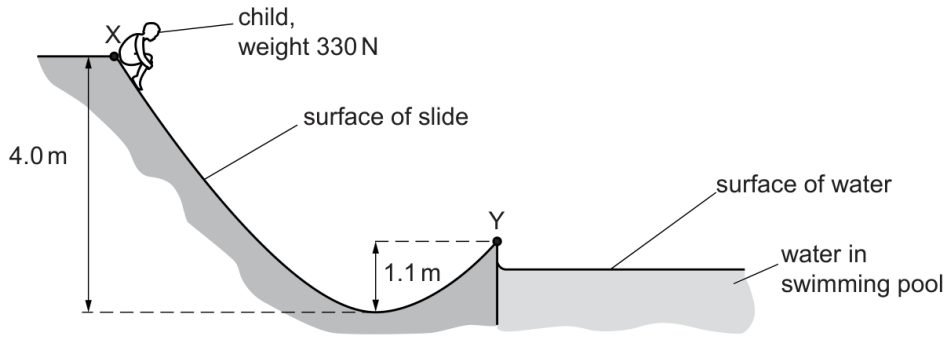


Fig. 3.1 (not to scale)

The child moves from rest to the lowest point of the slide that is a vertical distance of 4.0 m below X. The child continues moving towards point Y which is at the end of the slide and a vertical distance of 1.1 m above the lowest point. The kinetic energy of the child at Y is 540 J.

(c) The child leaves the slide at point Y with a velocity that is at an angle of 41° to the horizontal. The path of the child through the air is shown in Fig. 3.2.

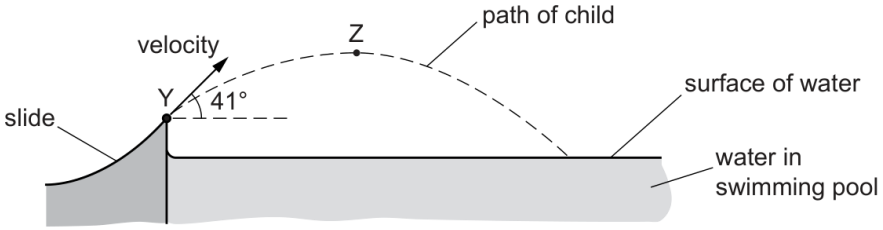


Fig. 3.2 (not to scale)

Point Z is the highest point on the path of the child through the air.
Assume that air resistance is negligible.

Calculate the speed of the child at:

(ii) point Z.

speed = ... $m\,s^{-1}$ [2]

15 A charged oil drop is in a vacuum between two horizontal metal plates. A uniform electric field is produced between the plates by applying a potential difference of 1340 V across them, as shown in Fig. 2.1.

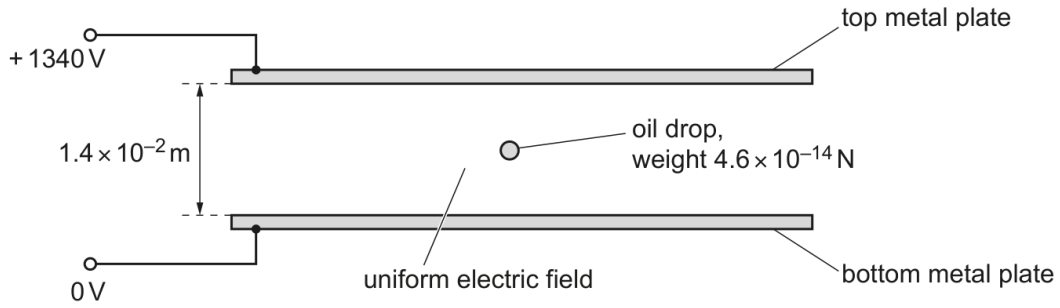


Fig. 2.1

The separation of the plates is 1.4×10^{-2} m.

The oil drop of weight 4.6×10^{-14} N remains stationary at a point mid-way between the plates.

(b) The electric potentials of the plates are instantaneously reversed so that the top plate is at a potential of 0 V and the bottom plate is at a potential of +1340 V. This change causes the oil drop to start moving downwards.

(iv) Assume that the radius of the oil drop is negligible.

Use the information in **(b)(iii)** to calculate the time taken for the oil drop to move to the bottom metal plate from its initial position mid-way between the plates.

time = ... s [2]

(c) The oil drop in **(b)** starts to move at time $t = 0$. The distance of the oil drop from the bottom plate is x.

On Fig. 2.2, sketch the variation with time t of distance x for the movement of the drop from its initial position until it hits the surface of the bottom plate. Numerical values of t are not required.

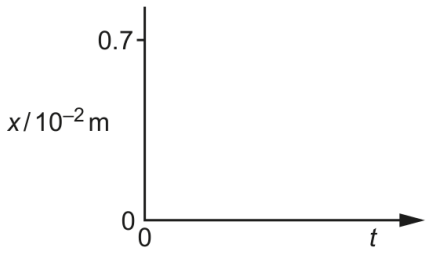


Fig. 2.2

[2]

16 A child sits on the ground next to a remote-controlled toy car. At time $t = 0$, the car begins to move in a straight line directly away from the child. The variation with time t of the velocity of the car along this line is shown in Fig. 4.1.

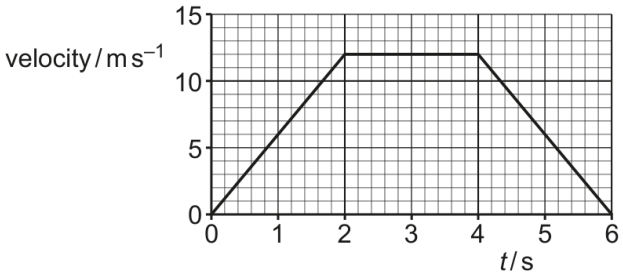


Fig. 4.1

The car's horn continually emits sound of frequency 925 Hz between time $t = 0$ and time $t = 6.0$ s. The speed of the sound in the air is 338 m s^{-1}.

(c) Determine the time taken for the sound emitted at time $t = 4.0$ s to travel to the child.

time taken = ... s [2]

17 (b) A delivery company suggests using a remote-controlled aircraft to drop a parcel into the garden of a customer. When the aircraft is vertically above point P on the ground, it releases the parcel with a velocity that is horizontal and of magnitude $5.4\,m\,s^{-1}$. The path of the parcel is shown in Fig. 2.1.

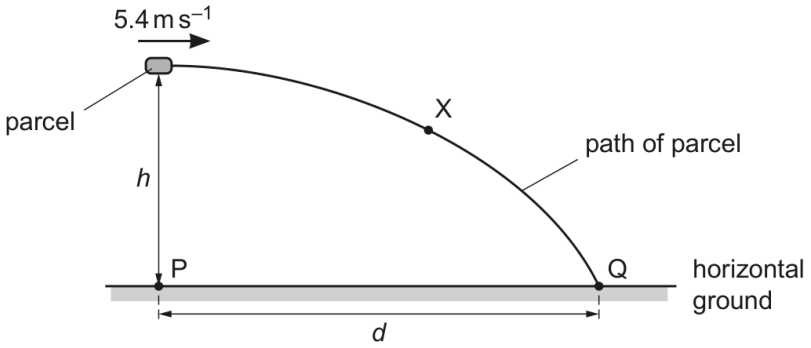


Fig. 2.1 (not to scale)

The parcel takes a time of 0.81 s after its release to reach point Q on the horizontal ground. Assume air resistance is negligible.

(i) On Fig. 2.1, draw an arrow from point X to show the direction of the acceleration of the parcel when it is at that point. [1]

(ii) Determine the height *h* of the parcel above the ground when it is released.

h = ... m [2]

(iii) Calculate the horizontal distance *d* between points P and Q.

d = ... m [1]

18 (a) Define *velocity*.

.....

..... [1]

19 (a) Fig. 2.1 shows the velocity–time graph for an object moving in a straight line.

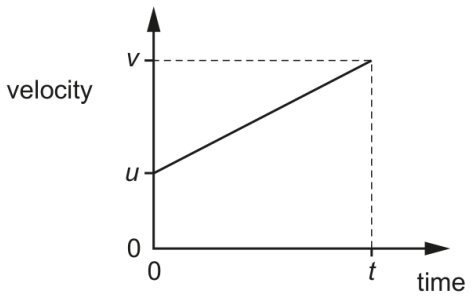


Fig. 2.1

(i) Determine an expression, in terms of *u*, *v* and *t*, for the area under the graph.

area = ... [1]

(ii) State the name of the quantity represented by the area under the graph.

..... [1]

(b) A ball is kicked with a velocity of $15\,m\,s^{-1}$ at an angle of 60° to horizontal ground. The ball then strikes a vertical wall at the instant when the path of the ball becomes horizontal, as shown in Fig. 2.2.

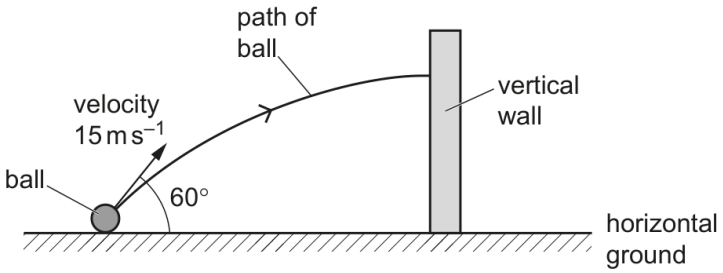


Fig. 2.2 (not to scale)

Assume that air resistance is negligible.

(i) By considering the vertical motion of the ball, calculate the time it takes to reach the wall.

time = ... s [3]

(ii) Explain why the horizontal component of the velocity of the ball remains constant as it moves to the wall.

.....

..... [1]

20 A small block is lifted vertically upwards by a toy aircraft, as illustrated in Fig. 2.1.

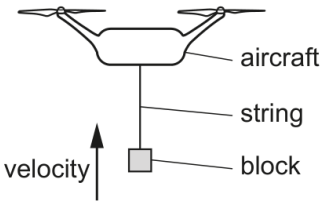


Fig. 2.1

As the block is moving upwards, the string breaks at time $t = 0$. The block initially continues moving upwards and then falls and hits the ground at time $t = 0.90$ s. The variation with time t of the velocity v of the block is shown in Fig. 2.2.

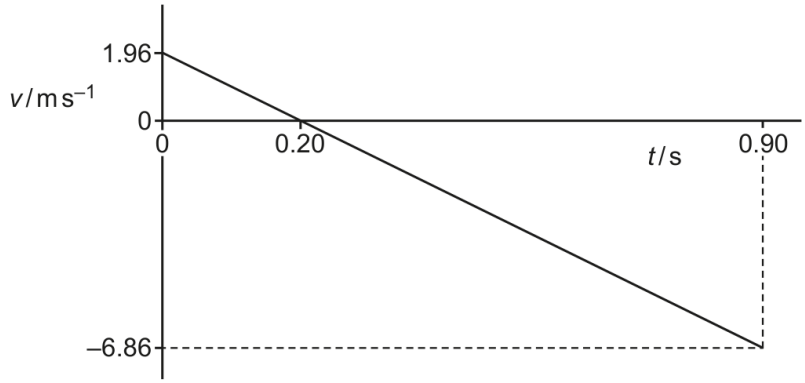


Fig. 2.2

Air resistance is negligible.

(a) State the feature of the graph in Fig. 2.2 that shows the block has a constant acceleration.

..... [1]

(b) Use Fig. 2.2 to determine the height of the block above the ground when the string breaks at time $t = 0$.

height = ... m [3]

(d) On Fig. 2.3, sketch a line to show the variation of the distance moved by the block with time t from $t = 0$ to $t = 0.20$ s. Numerical values of distance are not required.

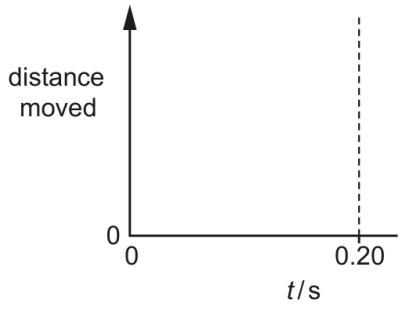


Fig. 2.3

[2]

(e) A block of greater mass is now released from the same height with the same upward velocity. Air resistance is still negligible.

State and explain the effect, if any, of the increased mass on the speed with which the block hits the ground.

.....

..... [1]

21 (b) A toy train moves along a straight section of track. Fig. 1.1 shows the variation with time t of the distance d moved by the train.

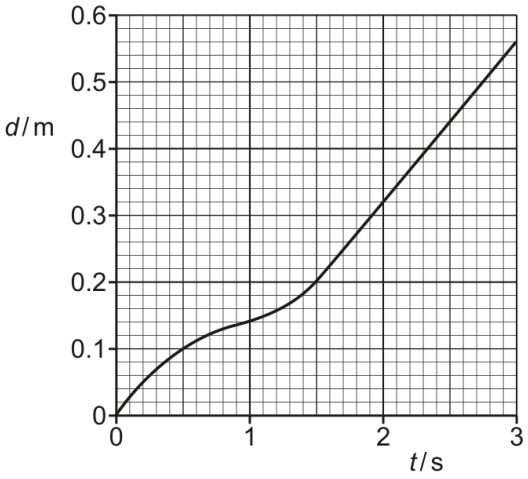


Fig. 1.1

(i) Describe qualitatively the motion of the train between time $t = 0$ and time $t = 1.0\,s$.

.....

..... [1]

(ii) Determine the speed of the train at time $t = 2.0\,s$.

speed = ... $m\,s^{-1}$ [2]

22 **(b)** The string is now used to move the cylinder in **(a)** vertically upwards through the water. The variation with time t of the velocity v of the cylinder is shown in Fig. 2.2.

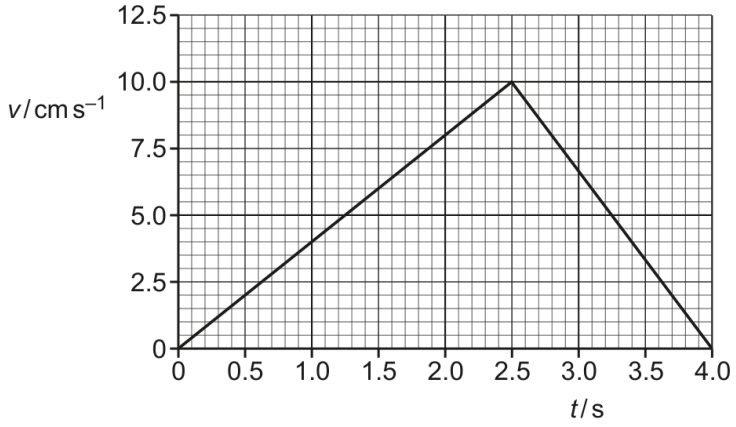


Fig. 2.2

(i) Use Fig. 2.2 to determine the acceleration of the cylinder at time $t = 2.0\,s$.

acceleration = ... $m\,s^{-2}$ [2]

(ii) The top face of the cylinder is at a depth of 0.32 m below the surface of the water at time $t = 0$.

Use Fig. 2.2 to determine the depth of the top face below the surface of the water at time $t = 4.0\,s$.

depth = ... m [2]

23 (a) Define *velocity*.

.....

.....[1]

24 (b) A car of mass 850 kg tows a trailer in a straight line along a horizontal road, as shown in Fig. 2.1.

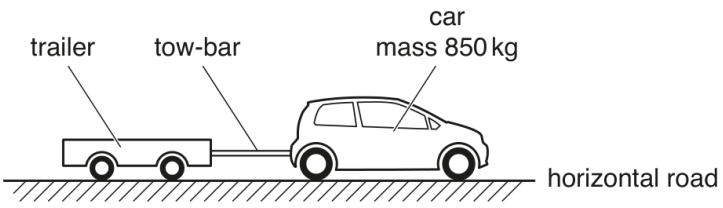


Fig. 2.1

The car and the trailer are connected by a horizontal tow-bar.

The variation with time t of the velocity v of the car for a part of its journey is shown in Fig. 2.2.

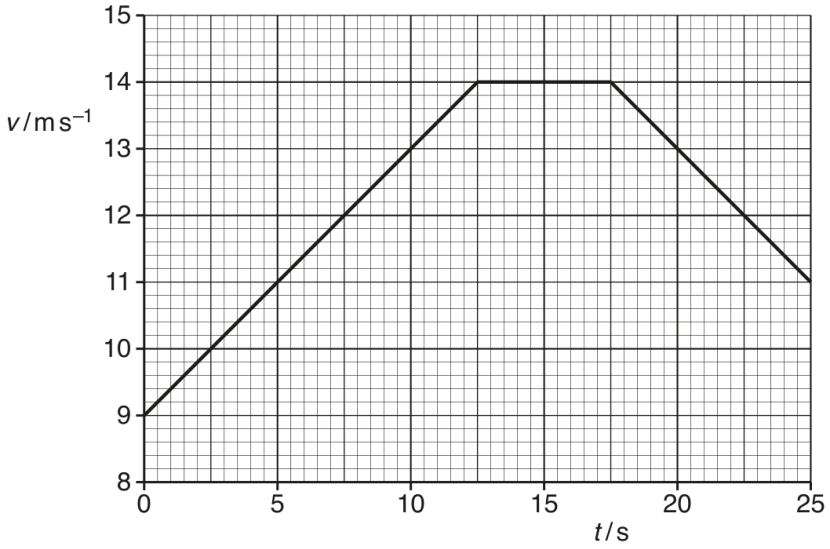


Fig. 2.2

(i) Calculate the distance travelled by the car from time $t = 0$ to $t = 10\,\text{s}$.

distance = ... m [2]

25 (c) The sign in **(b)** is held together by nuts and bolts. One of the nuts falls vertically from rest through a distance of 4.8 m to the pavement below. The nut lands on the pavement with a speed of $9.2\,\text{m s}^{-1}$.

Determine, for the nut falling from the sign to the pavement, the ratio

$$\frac{\text{change in gravitational potential energy}}{\text{final kinetic energy}}.$$

ratio = ... [4]

26 A small charged glass bead of weight 5.4×10^{-5} N is initially at rest at point A in a vacuum. The bead then falls through a uniform horizontal electric field as it moves in a straight line to point B, as illustrated in Fig. 2.1.

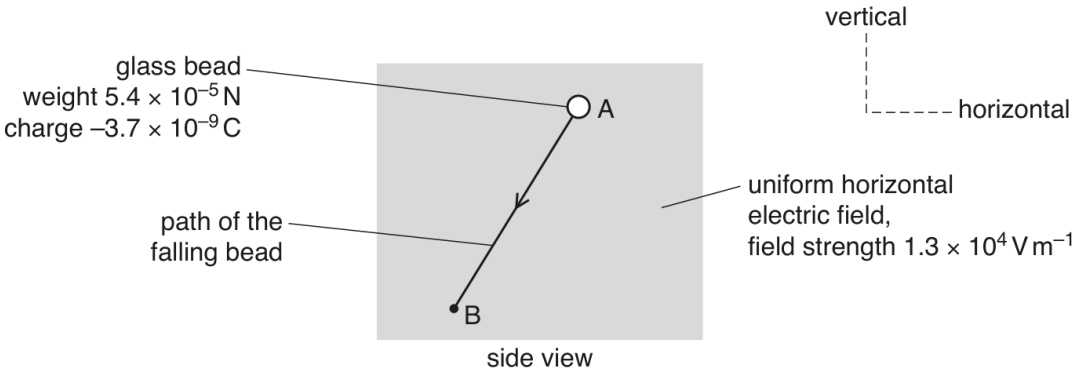


Fig. 2.1 (not to scale)

The electric field strength is 1.3×10^{4} V m^{-1}. The charge on the bead is -3.7×10^{-9} C.

(e) (ii) The path AB has length 0.58 m.

Use your answer in **(i)** to determine the speed of the bead at point B.

speed = ... m s^{-1} [2]

27 **(a)** Define *acceleration*.

..... [1]

(b) A steel ball of diameter 0.080 m is released from rest and falls vertically in air, as illustrated in Fig. 2.1.

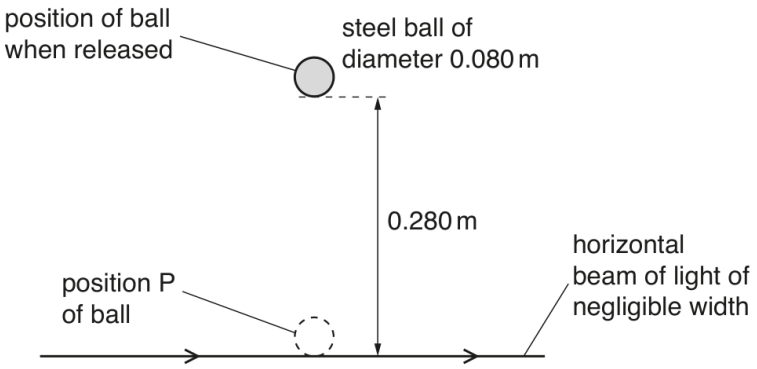


Fig. 2.1 (not to scale)

A horizontal beam of light of negligible width is a vertical distance of 0.280 m below the bottom of the ball when it is released. The ball falls through and breaks the beam of light.

(ii) Calculate the time taken for the ball to fall from rest to position P where the bottom of the ball touches the beam of light.

time taken = ... s [2]

(iii) Determine the time interval during which the beam of light is broken by the ball.

time interval = ... s [2]

28 (b) A block of weight 15 N hangs by a wire from a remotely controlled aircraft, as shown in Fig. 2.1.

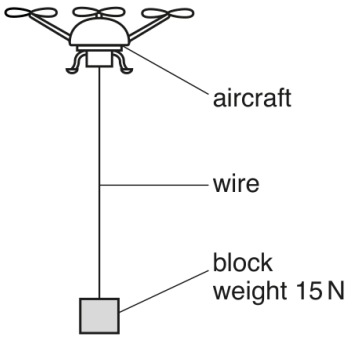


Fig. 2.1

The aircraft is used to move the block only in a vertical direction. The force on the block due to air resistance is negligible.

The variation with time t of the vertical velocity v of the block is shown in Fig. 2.2.
The velocity is taken to be positive in the upward direction.

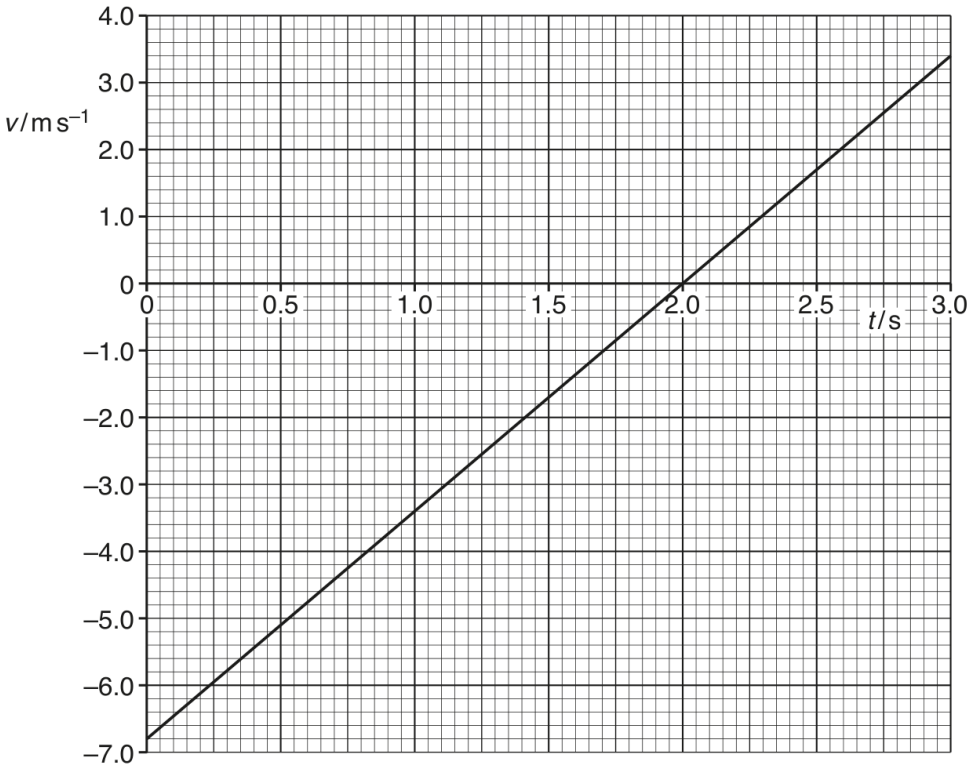


Fig. 2.2

(i) Determine, for the block,

1. the displacement from time $t = 0$ to $t = 3.0\,s$,

magnitude of displacement = ... m

direction of displacement .....
[3]

2. the change in gravitational potential energy from time $t = 0$ to $t = 3.0\,s$.

change in gravitational potential energy = ... J [2]

(ii) Calculate the magnitude of the acceleration of the block at time $t = 2.0\,s$.

acceleration = ... $m\,s^{-2}$ [2]

29 A child on a sledge slides down a steep hill and then travels in a straight line up an ice-covered slope, as illustrated in Fig. 3.1.

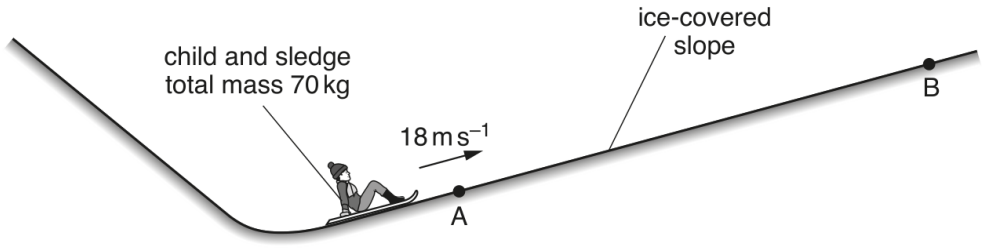


Fig. 3.1 (not to scale)

The sledge passes point A with speed 18 m s^{-1} at time $t = 0$ and then comes to rest at point B. The child applies a brake to the sledge at point B. The brake does not keep the sledge stationary and it immediately slides back down the slope towards A.

The variation with time t of the velocity v of the sledge from $t = 0$ to $t = 24$ s is shown in Fig. 3.2.

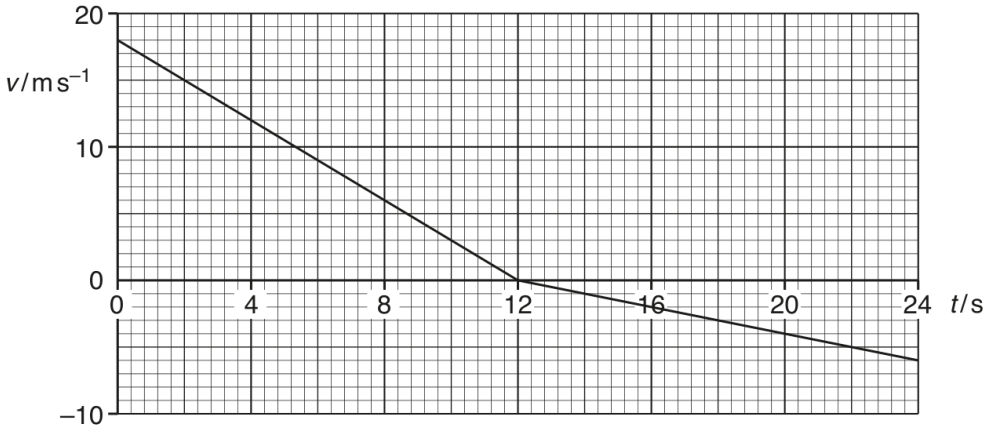


Fig. 3.2

(a) State the time taken for the sledge to travel from A to B.

time = ... s [1]

(b) Determine the displacement of the sledge up the slope from point A at time $t = 24$ s.

displacement = ...m [3]

(c) Show that the acceleration of the sledge as it moves from B back towards A is $0.50\,m\,s^{-2}$.

[2]

30 (a) Define

(i) *displacement*,

.....

..... [1]

(ii) *acceleration*.

.....

..... [1]

(b) A remote-controlled toy car moves up a ramp and travels across a gap to land on another ramp, as illustrated in Fig. 1.1.

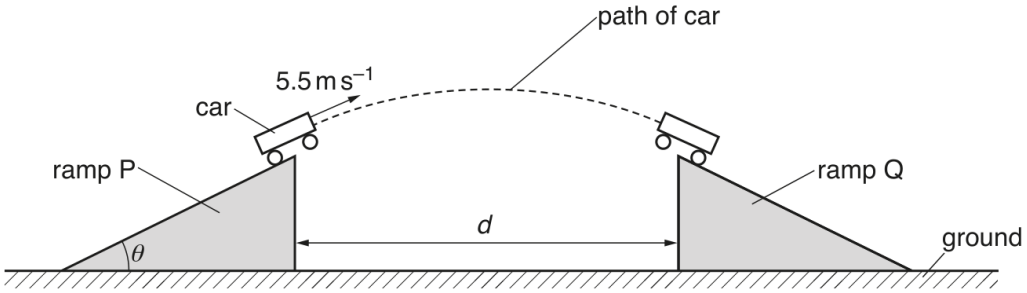


Fig. 1.1

The car leaves ramp P with a velocity of $5.5\,m\,s^{-1}$ at an angle θ to the horizontal. The horizontal component of the car's velocity as it leaves the ramp is $4.6\,m\,s^{-1}$. The car lands at the top of ramp Q. The tops of both ramps are at the same height and are distance *d* apart. Air resistance is negligible.

(ii) Determine the time taken for the car to travel between the ramps.

time taken = ... s [2]

(iii) Calculate the horizontal distance *d* between the tops of the ramps.

d = ... m [1]

(c) Ramp Q is removed. The car again leaves ramp P as in **(b)** and now lands directly on the ground. The car leaves ramp P at time $t = 0$ and lands on the ground at time $t = T$.

On Fig. 1.2, sketch the variation with time t of the vertical component v_y of the car's velocity from $t = 0$ to $t = T$. Numerical values of v_y and t are not required.

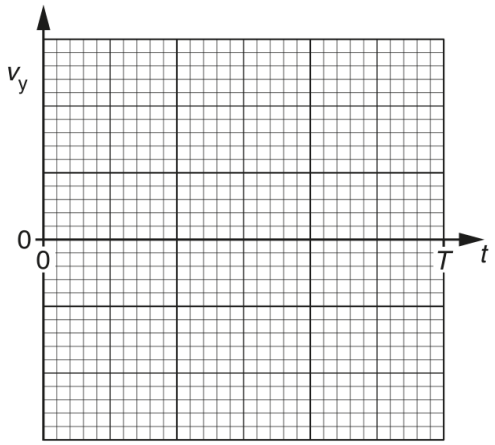


Fig. 1.2

[2]

31 A golfer strikes a ball so that it leaves horizontal ground with a velocity of $6.0\,m\,s^{-1}$ at an angle θ to the horizontal, as illustrated in Fig. 1.1.

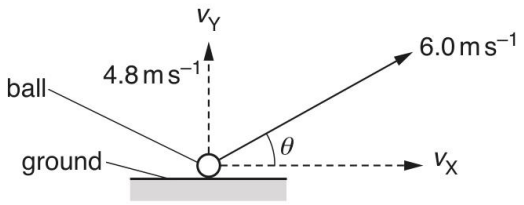


Fig. 1.1 (not to scale)

The magnitude of the initial vertical component v_Y of the velocity is $4.8\,m\,s^{-1}$.
Assume that air resistance is negligible.

(b) The ball leaves the ground at time $t = 0$ and reaches its maximum height at $t = 0.49\,s$.

On Fig. 1.2, sketch separate lines to show the variation with time t, until the ball returns to the ground, of

(i) the vertical component v_Y of the velocity (label this line Y), [2]

(ii) the horizontal component v_X of the velocity (label this line X). [2]

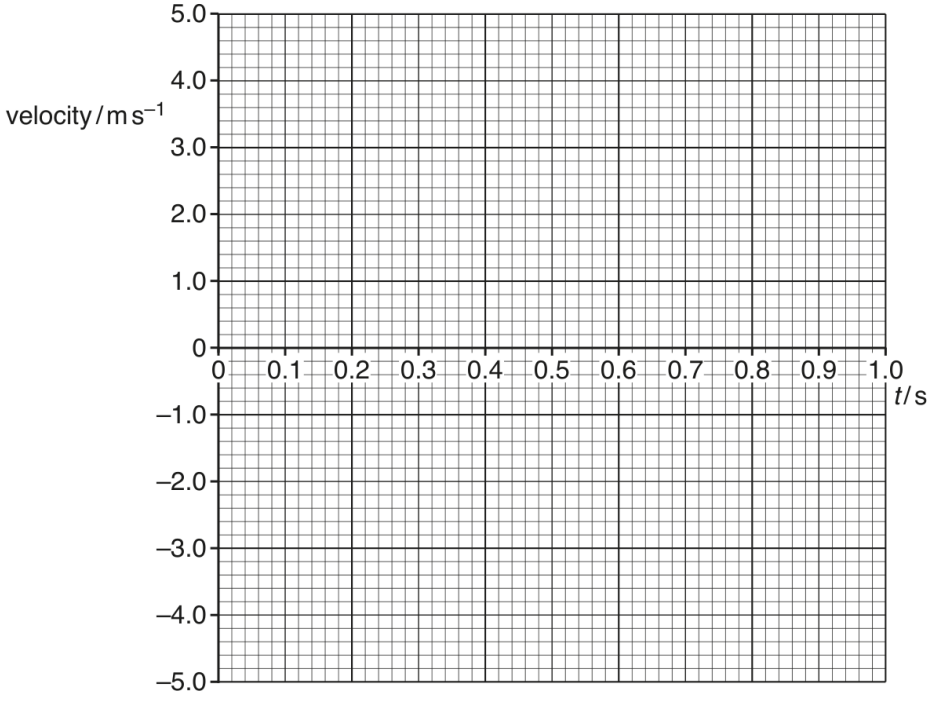


Fig. 1.2

(c) Calculate the maximum height reached by the ball.

maximum height = ... m [2]