3. Dynamics

3.1 Momentum and Newton's laws of motion

Paper 2

Question Paper

1 **(c)** An object of mass 4.2 kg is travelling in a straight line at a speed of 6.0 m s^{-1}. The object is brought to rest in a distance of 0.050 m by a constant force.

Calculate the magnitude of this force.

force = ... N [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.

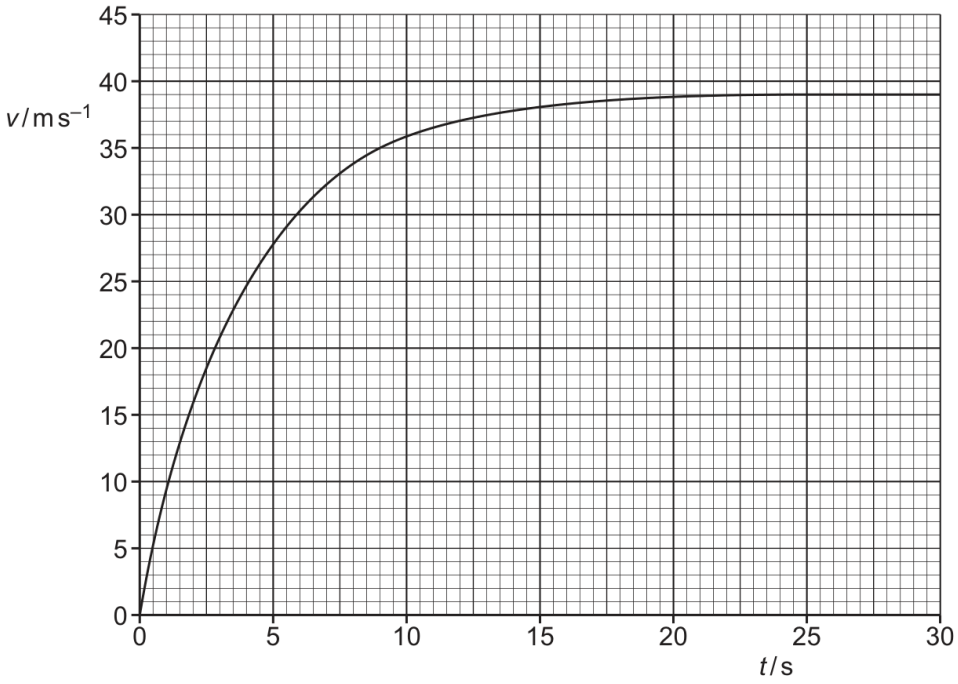


Fig. 2.1

(b) The mass of the skydiver and her equipment is 68 kg. The upthrust on the skydiver is negligible.

After reaching terminal velocity, the skydiver opens her parachute at time t_1. A total drag force of 1800 N acts on the skydiver.

Determine the magnitude and direction of the acceleration of the skydiver at time t_1.

acceleration = ...m s^{-2}

direction = ...

[3]

(c) The parachute is fully open at time t_2. At a later time t_3 the skydiver reaches a constant velocity of $5.7\,m\,s^{-1}$.

(ii) Calculate the change in momentum of the skydiver between time t_1 and time t_3.

change in momentum = ... N s [2]

3 **(a)** Define linear momentum.

.....

..... [1]

(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.

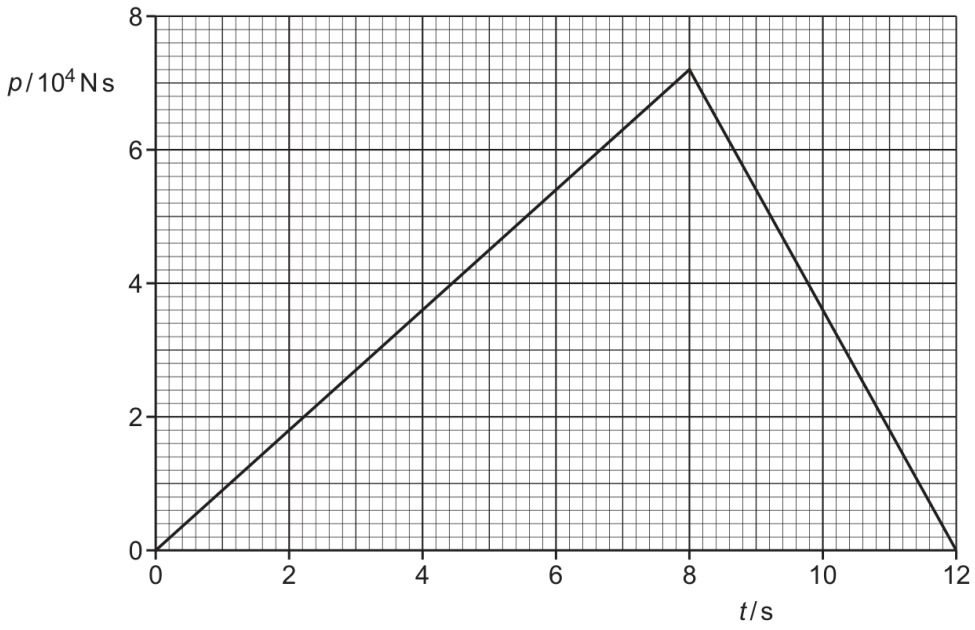


Fig. 2.1

(i) Calculate the maximum speed reached by the car.

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

(iii) Show that the acceleration of the car at time $t = 4.0$ s is $5.0 m s^{-2}$.

[2]

(c) On Fig. 2.2, sketch the variation with time t of the acceleration a of the car in **(b)** from $t = 0$ to $t = 12.0\,s$.

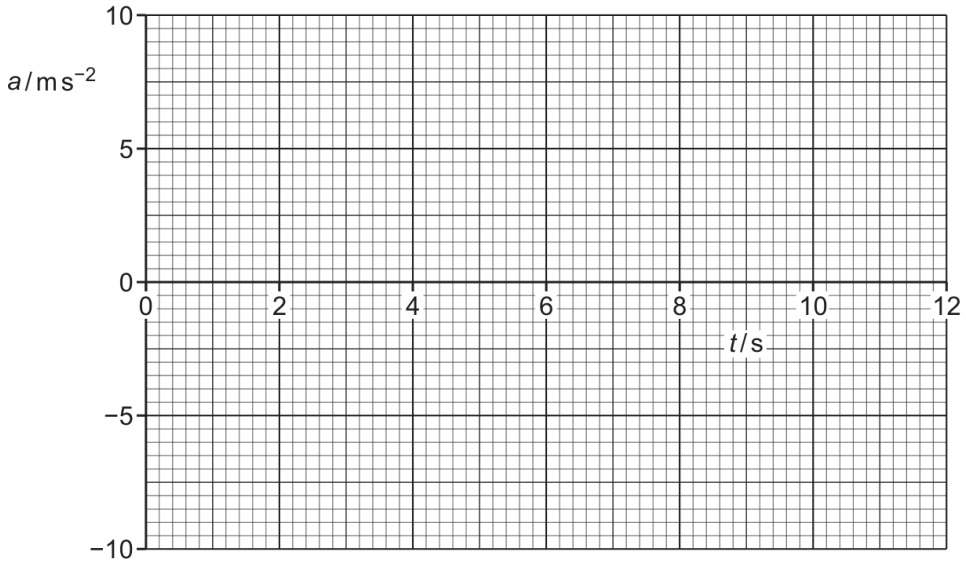


Fig. 2.2

[3]

4 **(a)** Define momentum.

.....

..... [1]

(b) A child stands on a scooter on horizontal ground. The combined mass of the child and the scooter is 16 kg.
The child starts from rest and pushes once on the ground with her foot which causes her to accelerate. The push lasts for a time of 1.1 s. The speed of the child and the scooter after the push is 0.60 m s^{-1}.

Determine the average resultant force acting horizontally on the child and the scooter during the push.

average force = ... N [2]

5 A block is pulled in a straight line along a rough horizontal surface by a varying force *X*, as shown in Fig. 3.1.

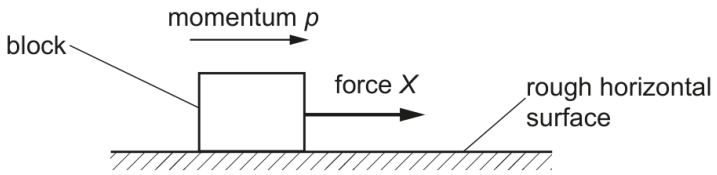


Fig. 3.1

Air resistance is negligible. Assume that the frictional force exerted on the block by the surface is constant and has magnitude 2.0 N.

The variation with time *t* of the momentum *p* of the block is shown in Fig. 3.2.

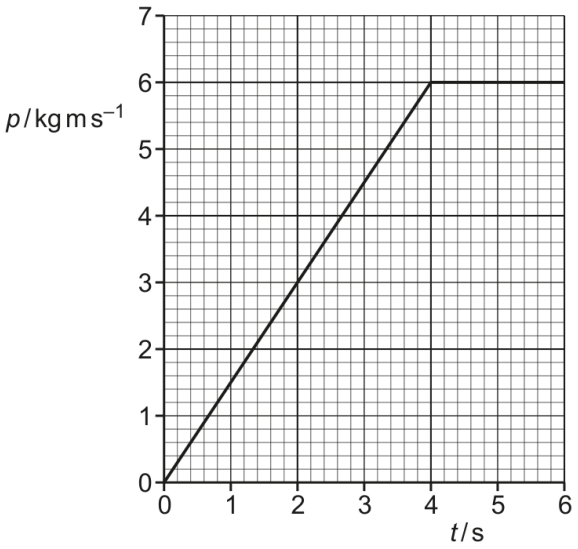


Fig. 3.2

(a) State Newton's second law of motion.

.....

..... [1]

(b) Use Fig. 3.2 to determine, for the block at time *t* = 2.0 s, the magnitude of:

(i) the resultant force on the block

resultant force = ... N [1]

(ii) the force *X*.

X = ... N [1]

(c) On Fig. 3.3, sketch a graph to show the variation of force *X* with time *t* from *t* = 0 to *t* = 6.0 s.

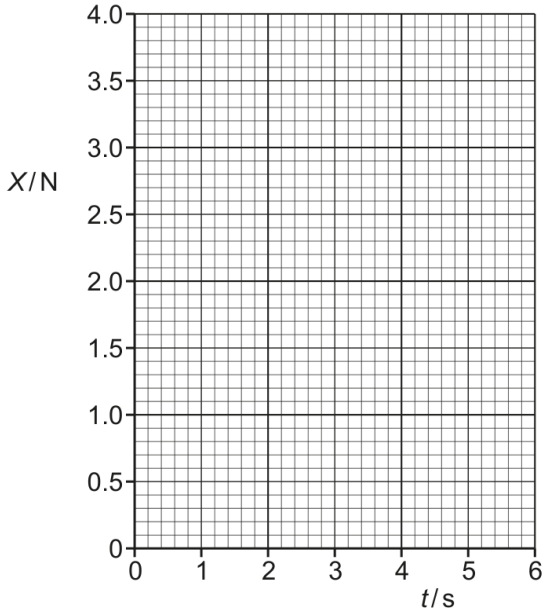


Fig. 3.3

[3]

6 A block is pulled by a force X in a straight line along a rough horizontal surface, as shown in Fig. 3.1.

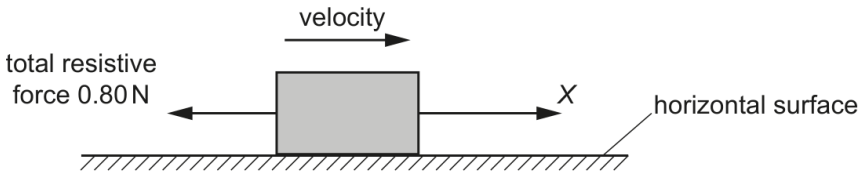


Fig. 3.1

Assume that the total resistive force opposing the motion of the block is 0.80 N at all speeds of the block.

The variation with time t of the magnitude of the force X is shown in Fig. 3.2.

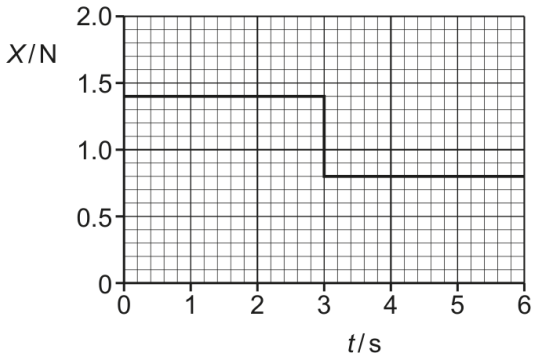


Fig. 3.2

(a) (i) Define force.

.....

..... [1]

(ii) Determine the change in momentum of the block from time $t = 0$ to time $t = 3.0$ s.

change in momentum = ... kg m s^{-1} [2]

(b) **(i)** Describe and explain the motion of the block between time $t = 3.0\,s$ and time $t = 6.0\,s$.

.....

.....

.....

..... [2]

(c) The block is at rest at time $t = 0$.

On Fig. 3.3, sketch a graph to show the variation of the momentum of the block with time t from $t = 0$ to $t = 6.0\,s$.
Numerical values of momentum are not required.

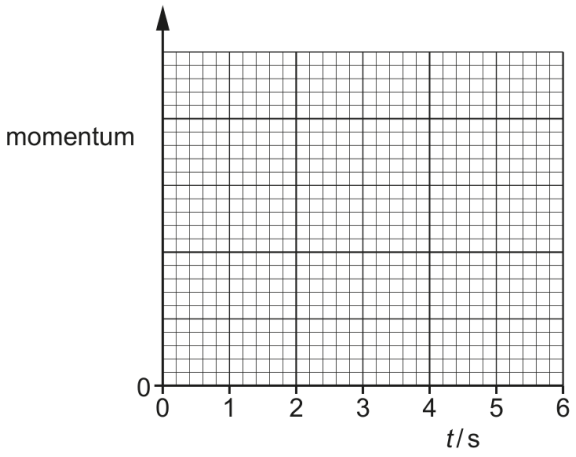


Fig. 3.3

[2]

7 A hot-air balloon floats just above the ground. The balloon is stationary and is held in place by a vertical rope, as shown in Fig. 2.1.

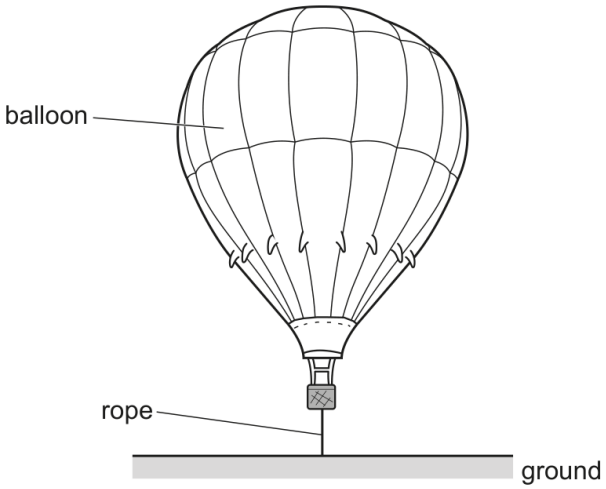


Fig. 2.1

The balloon has a weight W of 3.39×10^4 N. The tension T in the rope is 4.00×10^2 N.
Upthrust U acts on the balloon.
The density of the surrounding air is $1.23\,\text{kg}\,\text{m}^{-3}$.

(a) (iii) The balloon is released from the rope.

Calculate the initial acceleration of the balloon.

acceleration = ... $\text{m}\,\text{s}^{-2}$ [3]

8 A high-altitude balloon is stationary in still air. A solid sphere is suspended from the balloon by a string, as shown in Fig. 2.1.

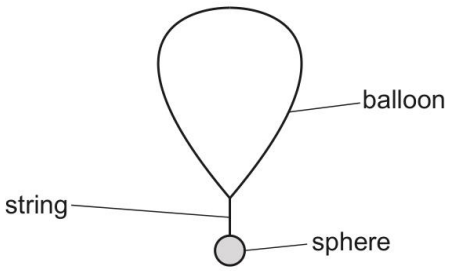


Fig. 2.1 (not to scale)

The volume of the balloon is 7.5 m^3. The total weight of the balloon, string and sphere is 65 N. The upthrust acting on the string and sphere is negligible.

(b) The string breaks, releasing the sphere.

(i) State the magnitude of the acceleration of the sphere immediately after the string breaks.

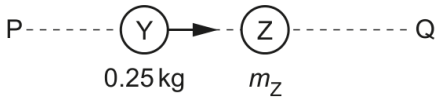
acceleration = ... $m\,s^{-2}$ [1]

(c) The sphere has a mass of 4.0 kg.

Calculate the total resistive force acting on the sphere at the instant when its acceleration is 1.9 $m\,s^{-2}$.

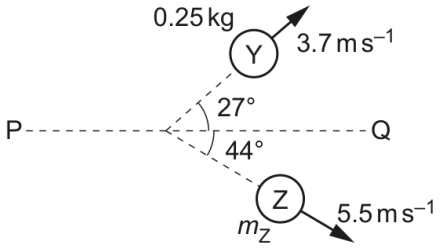
resistive force = ... N [2]

9 **(a)** A ball Y moves along a horizontal frictionless surface and collides with a ball Z, as illustrated in the views from above in Fig. 4.1 and Fig. 4.2.



BEFORE COLLISION

Fig. 4.1 (not to scale)



AFTER COLLISION

Fig. 4.2 (not to scale)

Ball Y has a mass of 0.25 kg and initially moves along a line PQ.
Ball Z has a mass m_Z and is initially stationary.

After the collision, ball Y has a final velocity of 3.7 m s^{-1} at an angle of 27° to line PQ and ball Z has a final velocity of 5.5 m s^{-1} at an angle of 44° to line PQ.

(iii) During the collision, the average force exerted on Y by Z is F_Y and the average force exerted on Z by Y is F_Z.

Compare the magnitudes and directions of F_Y and F_Z. Numerical values are not required.

magnitudes: .....

directions: .....

[2]

10 (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.

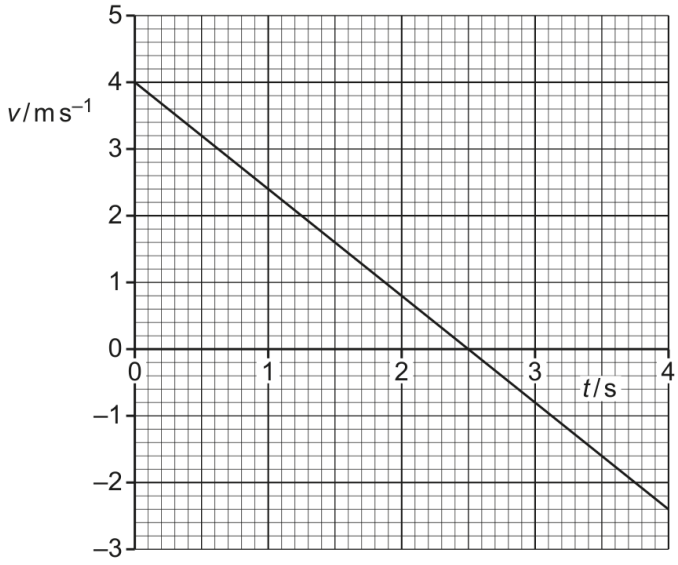


Fig. 1.1

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

(ii) Determine the change in the momentum of the rock from time t = 0 to time t = 4.0 s.

change in momentum = ... N s [2]

(iii) Determine the weight W of the rock on this planet.

W = ... N [2]

11 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.

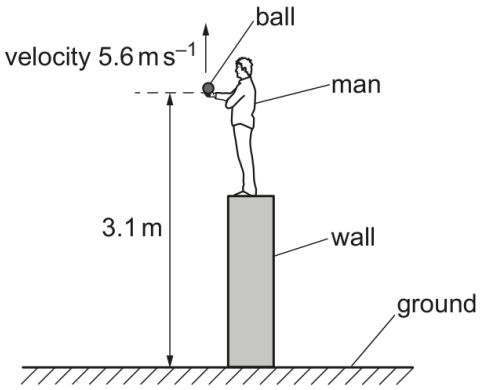


Fig. 3.1 (not to scale)

Assume that air resistance is negligible.

(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:

(i) the magnitudes of their accelerations

..... [1]

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.

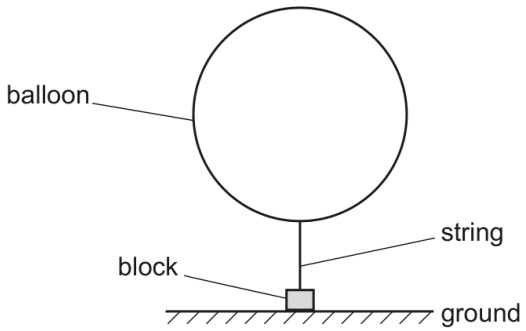


Fig. 2.1 (not to scale)

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.

(b) The total weight of the balloon, string and block is 0.053 N.

The external force holding the block on the ground is removed so that the released block is lifted vertically upwards by the balloon.

Calculate the acceleration of the block immediately after it is released.

acceleration = ... $\text{m}\,\text{s}^{-2}$ [3]

13 A horizontal spring is fixed at one end. A block is pushed against the other end of the spring so that the spring is compressed, as shown in Fig. 4.1.

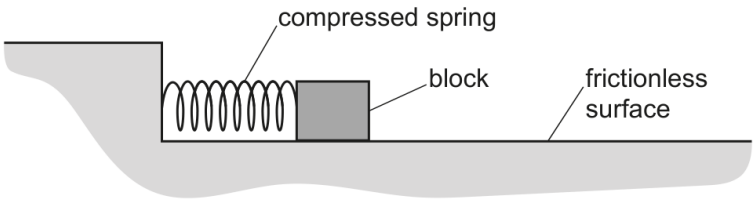


Fig. 4.1

The block is released and accelerates along a horizontal frictionless surface as the spring returns to its original length. The block leaves the end of the spring with a speed of $2.3\,m\,s^{-1}$, as shown in Fig. 4.2.

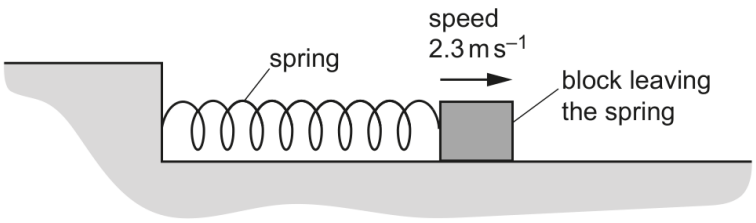


Fig. 4.2

The block has a mass of 250 g and the spring has a spring constant of $420\,N\,m^{-1}$.

Assume that the spring always obeys Hooke's law and that all the elastic potential energy of the spring is transferred to the kinetic energy of the block.

(c) After leaving the spring, the block moves along the surface until it hits a barrier at a speed of $2.3\,m\,s^{-1}$. The block then rebounds at a speed of $1.5\,m\,s^{-1}$ and moves back along its original path. The block is in contact with the barrier for a time of 0.086 s.

Calculate:

(i) the change in momentum of the block during the collision

change in momentum = ... N s [2]

(ii) the average resultant force exerted on the block during the collision.

average resultant force = ... N [1]

14 A person uses a trolley to move suitcases at an airport. The total mass of the trolley and suitcases is 72 kg.

(a) The person pushes the trolley and suitcases along a horizontal surface with a constant speed of 1.4 m s^{-1} and then releases the trolley. The released trolley moves in a straight line and comes to rest. Assume that a constant total resistive force of 18 N opposes the motion of the trolley and suitcases.

(ii) Calculate the time taken for the trolley to come to rest after it is released.

time = ... s [3]

(b) At another place in the airport, the trolley and suitcases are on a slope, as shown in Fig. 2.1.

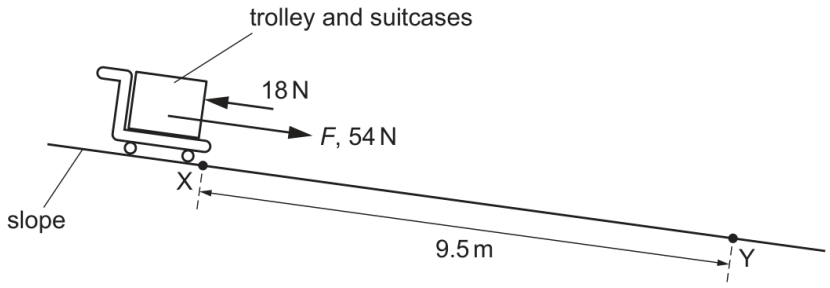


Fig. 2.1 (not to scale)

The person releases the trolley from rest at point X. The trolley moves down the slope in a straight line towards point Y. The distance along the slope between points X and Y is 9.5 m.

The component *F* of the weight of the trolley and suitcases that acts along the slope is 54 N. Assume that a constant total resistive force of 18 N opposes the motion of the trolley and suitcases.

(i) Calculate the speed of the trolley at point Y.

speed = ... m s^{-1} [3]

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

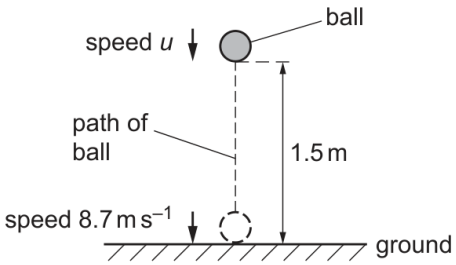


Fig. 2.1

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.

(b) State how Newton's third law applies to the collision between the ball and the ground.

.....

.....

.....

..... [2]

(c) The ball is in contact with the ground for a time of 0.091 s. The ball rebounds vertically and leaves the ground with speed 5.4 m s^{-1}. The mass of the ball is 0.059 kg.

(i) Calculate the magnitude of the change in momentum of the ball during the collision.

change in momentum = ... N s [2]

(ii) Determine the magnitude of the average resultant force that acts on the ball during the collision.

average resultant force = ... N [1]

(iii) Use your answer in **(c)(ii)** to calculate the magnitude of the average force exerted by the ground on the ball during the collision.

average force = ... N [2]

16 (a) Define *momentum*.

.....

..... [1]

(b) Two balls X and Y, of equal diameter but different masses 0.24 kg and 0.12 kg respectively, slide towards each other on a frictionless horizontal surface, as shown in Fig. 2.1.

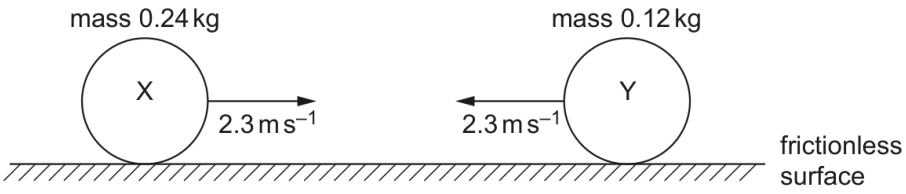


Fig. 2.1

Both balls have initial speed 2.3 m s^{-1} before they collide with each other. Fig. 2.2 shows the variation with time t of the force F_Y exerted on ball Y by ball X during the collision.

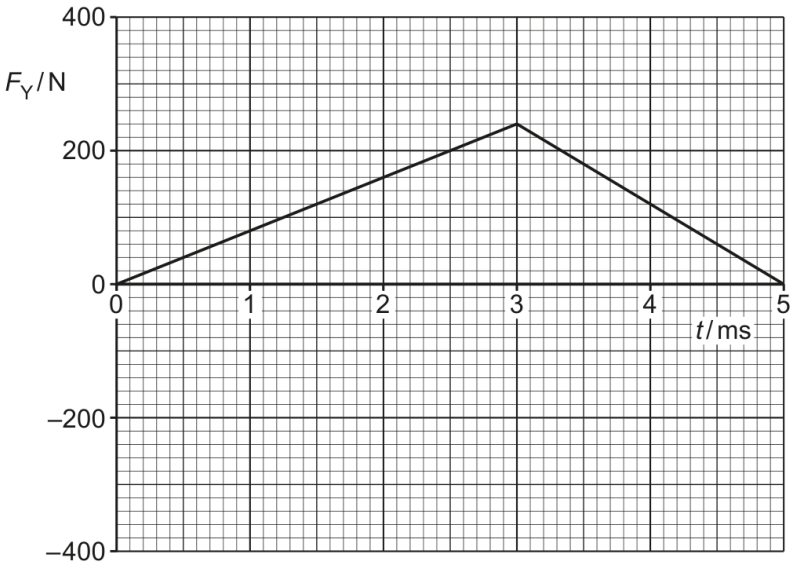


Fig. 2.2

(ii) The area enclosed by the lines and the time axis in Fig. 2.2 represents the change in momentum of ball Y during the collision.

Determine the magnitude of the change in momentum of ball Y.

change in momentum = ... N s [2]

(iii) Calculate the magnitude of the velocity of ball Y after the collision.

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

(c) On Fig. 2.3, sketch the variation with time t of the force F_X exerted on ball X by ball Y during the collision in **(b)**.

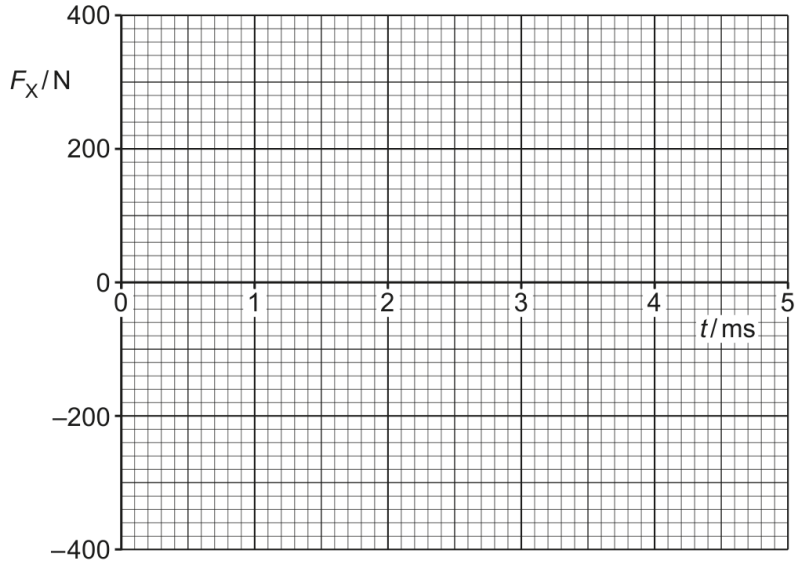


Fig. 2.3

[3]

17 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.

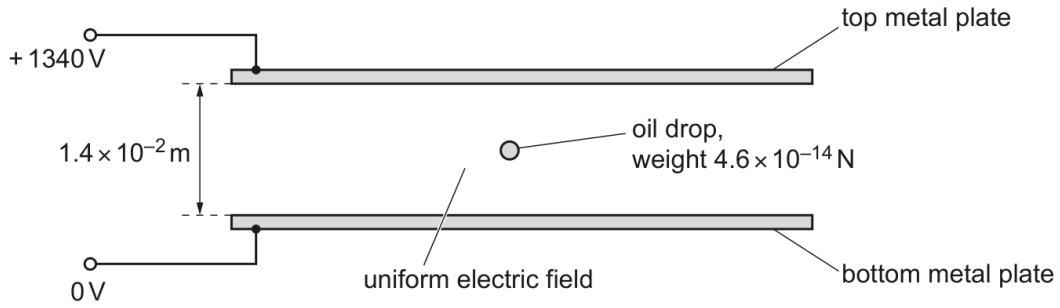


Fig. 2.1

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.

(iii) Show that the magnitude of the acceleration of the oil drop is 20 m s^{-2}.

[2]

18 **(a)** State Newton's second law of motion.

.....

..... [1]

19 **(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.

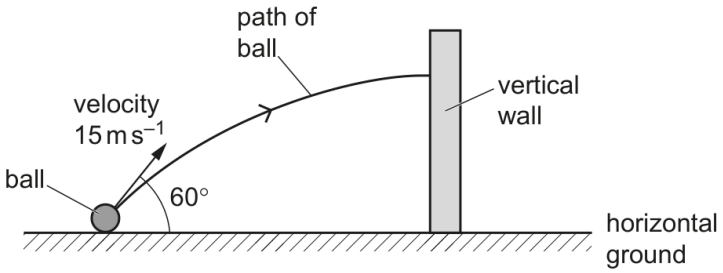


Fig. 2.2 (not to scale)

Assume that air resistance is negligible.

(iii) Show that the ball strikes the wall with a horizontal velocity of $7.5\,m\,s^{-1}$.

(c) The mass of the ball in **(b)** is 0.40 kg. It is in contact with the wall for a time of 0.12 s and rebounds horizontally with a speed of $4.3\,m\,s^{-1}$.

(i) Use the information from **(b)(iii)** to calculate the change in momentum of the ball due to the collision.

change in momentum = ... $kg\,m\,s^{-1}$ [2]

(ii) Calculate the magnitude of the average force exerted on the ball by the wall.

average force = ... N [1]

20 **(a)** Define *force*.

.....

..... [1]

(b) A ball falls vertically downwards towards a horizontal floor and then rebounds along its original path, as illustrated in Fig. 3.1.

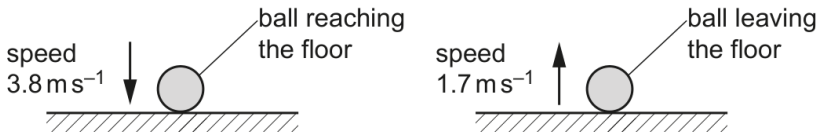


Fig. 3.1

The ball reaches the floor with speed $3.8\,m\,s^{-1}$. The ball is then in contact with the floor for a time of 0.081 s before leaving it with speed $1.7\,m\,s^{-1}$. The mass of the ball is 0.062 kg.

(ii) Determine the magnitude of the change in momentum of the ball during the collision.

change in momentum = ... N s [2]

(iii) Show that the magnitude of the average resultant force acting on the ball during the collision is 4.2 N.

[1]

(iv) Use the information in **(iii)** to calculate the magnitude of:

1. the average force of the floor on the ball during the collision

average force = ... N

2. the average force of the ball on the floor during the collision.

average force = ... N
[2]

21 (b) A child's toy uses the spring in **(a)** to launch a ball of mass 0.020 kg vertically into the air. The ball is initially held against one end of the spring which has a compression of 0.045 m. The spring is then released to launch the ball. The kinetic energy of the ball as it leaves the toy is 0.72 J.

(ii) Determine the initial momentum of the ball as it leaves the toy.

momentum = ... N s [3]

22 A block X slides along a horizontal frictionless surface towards a stationary block Y, as illustrated in Fig. 2.1.

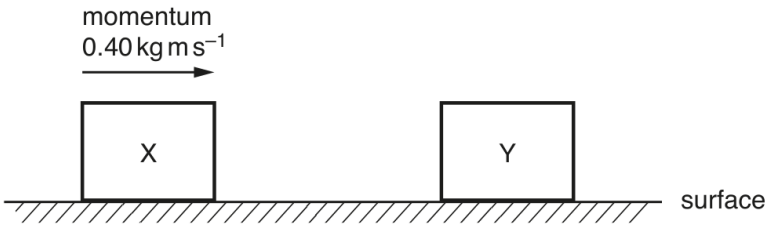


Fig. 2.1

There are no resistive forces acting on block X as it moves towards block Y. At time $t = 0$, block X has momentum 0.40 kg m s^{-1}. A short time later, the blocks collide and then separate.

The variation with time t of the momentum of block Y is shown in Fig. 2.2.

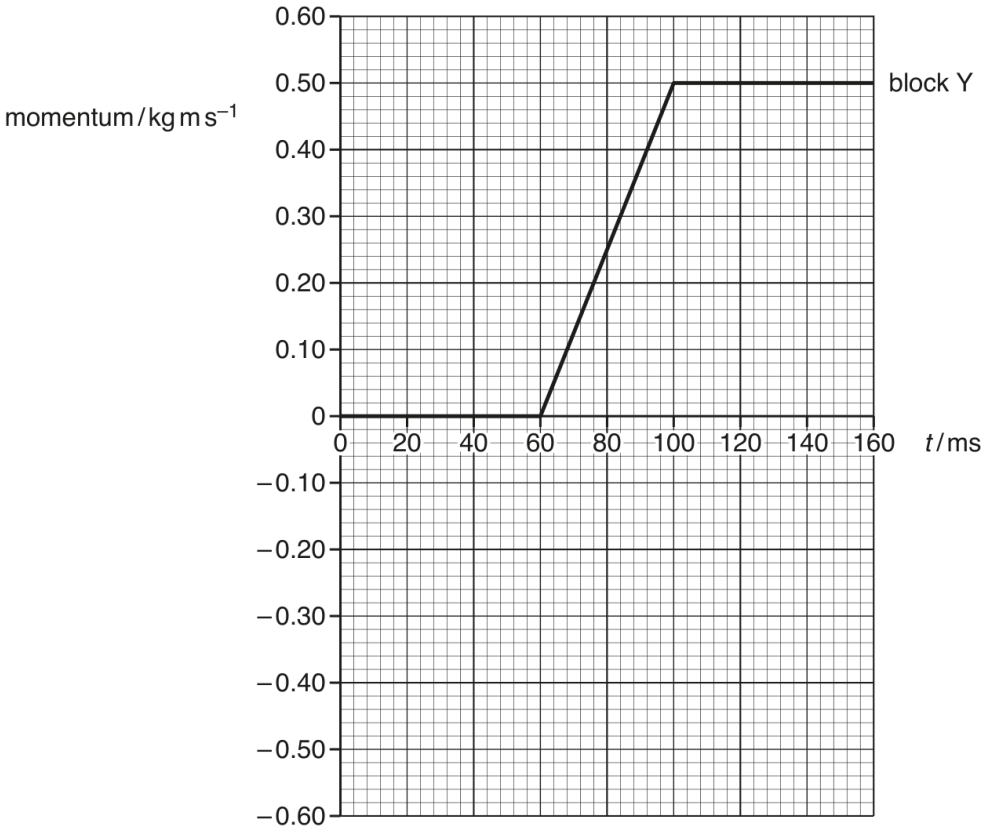


Fig. 2.2

(a) Define *linear momentum*.

.....[1]

(b) Use Fig. 2.2 to:

(i) determine the time interval over which the blocks are in contact with each other

time interval = ... ms [1]

(ii) describe, without calculation, the magnitude of the acceleration of block Y from:

1. time $t = 80$ ms to $t = 100$ ms

.....

2. time $t = 100$ ms to $t = 120$ ms.

.....
[2]

(c) Use Fig. 2.2 to determine the magnitude of the force exerted by block X on block Y.

force = ... N [2]

23 **(a)** State Newton's second law of motion.

.....

.....[1]

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

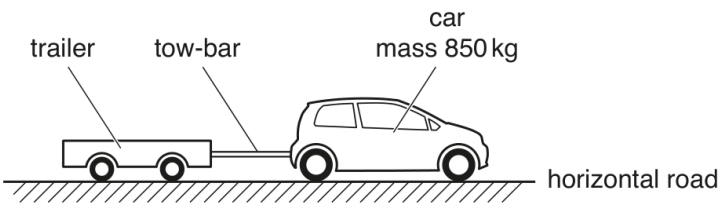


Fig. 2.1

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.

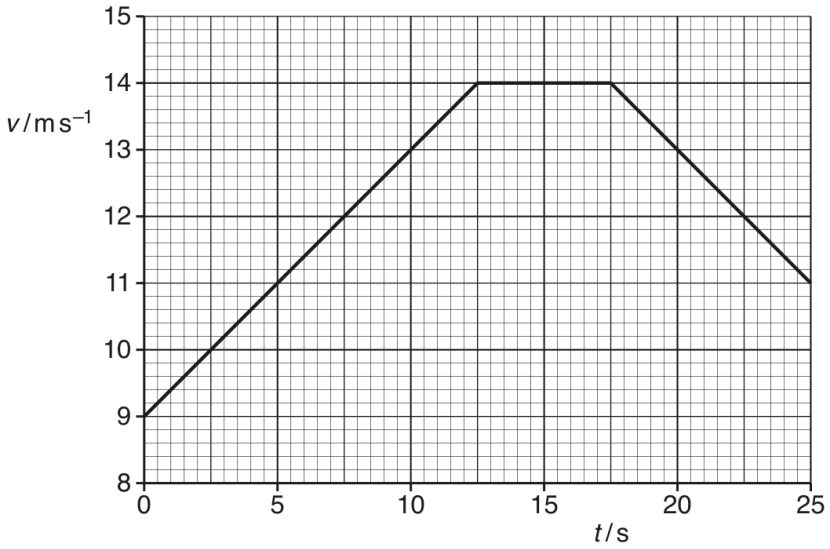


Fig. 2.2

(ii) At time $t = 10\,s$, the resistive force acting on the car due to air resistance and friction is 510 N. The tension in the tow-bar is 440 N.

For the car at time $t = 10\,s$:

1. use Fig. 2.2 to calculate the acceleration

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

2. use your answer to calculate the resultant force acting on the car

resultant force = ... N [1]

3. show that a horizontal force of 1300 N is exerted on the car by its engine

[1]

4. determine the useful output power of the engine.

output power = ... W [2]

24 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.

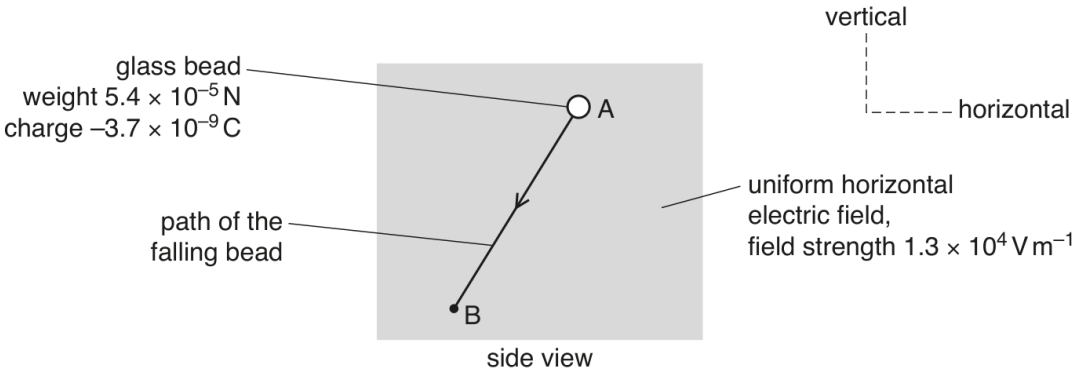


Fig. 2.1 (not to scale)

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

(e) (i) Calculate the magnitude of the acceleration of the bead along the path AB.

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

25 A small remote-controlled model aircraft has two propellers, each of diameter 16 cm. Fig. 3.1 is a side view of the aircraft when hovering.

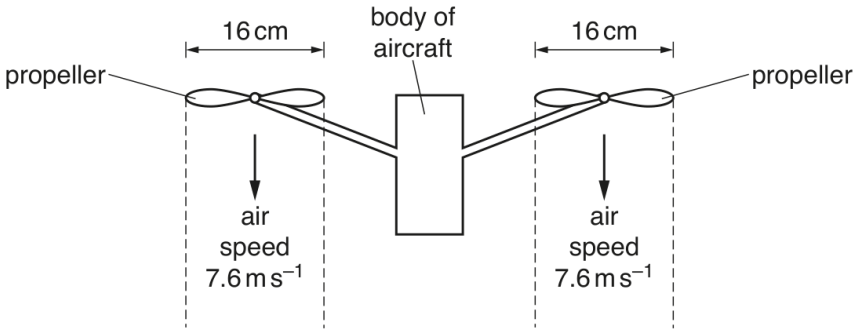


Fig. 3.1

Air is propelled vertically downwards by each propeller so that the aircraft hovers at a fixed position. The density of the air is 1.2 kg m^{-3}. Assume that the air from each propeller moves with a constant speed of 7.6 m s^{-1} in a uniform cylinder of diameter 16 cm. Also assume that the air above each propeller is stationary.

(b) Calculate:

(i) the increase in momentum of the mass of air in **(a)**

increase in momentum = ... Ns [1]

(ii) the downward force exerted on this mass of air by the propeller.

force = ... N [1]

(c) State:

(i) the upward force acting on **one** propeller

force = ... N [1]

(ii) the name of the law that explains the relationship between the force in **(b)(ii)** and the force in **(c)(i)**.

..... [1]

(d) Determine the mass of the aircraft.

mass = ... kg [1]

26 **(a)** State Newton's third law of motion.

.....

.....

..... [2]

(c) The variation with time t of the momentum of block X in **(b)** is shown in Fig. 3.3.

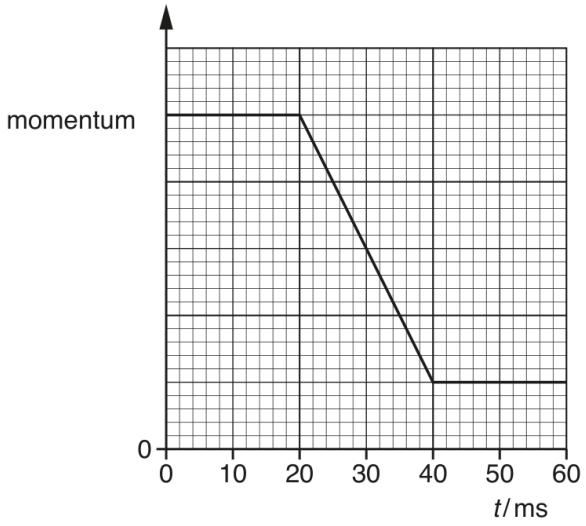


Fig. 3.3

Block X makes contact with block Y at time $t = 20$ ms.

(i) Describe, qualitatively, the magnitude and direction of the resultant force, if any, acting on block X in the time interval:

1. $t = 0$ to $t = 20$ ms

.....

2. $t = 20$ ms to $t = 40$ ms.

.....

.....

[3]

27 **(a)** State Newton's first law of motion.

.....

.....[1]

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

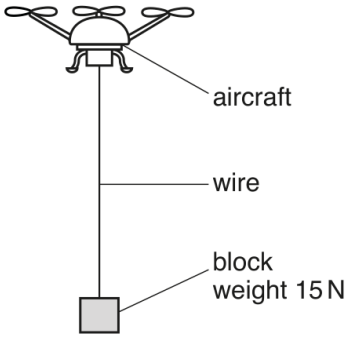


Fig. 2.1

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.

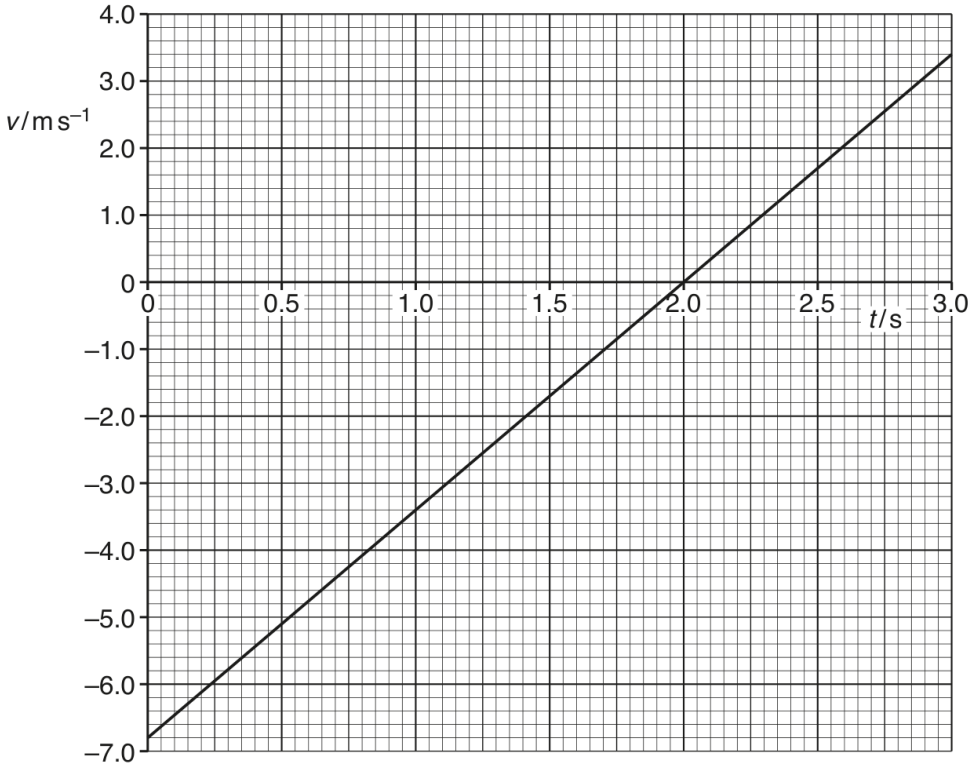


Fig. 2.2

(iii) Use your answer in **(b)(ii)** to show that the tension T in the wire at time $t = 2.0\,s$ is 20 N.

[2]

(v) At some time after $t = 3.0\,s$ the tension in the wire has a constant value of 15 N.

State and explain whether it is possible to deduce that the block is moving vertically after $t = 3.0\,s$.

.....

.....

.....

.....[2]

28 **(a)** State what is meant by the *mass* of a body.

.....

.....[1]

(b) Two blocks travel directly towards each other along a horizontal, frictionless surface. The blocks collide, as illustrated in Fig. 3.1.

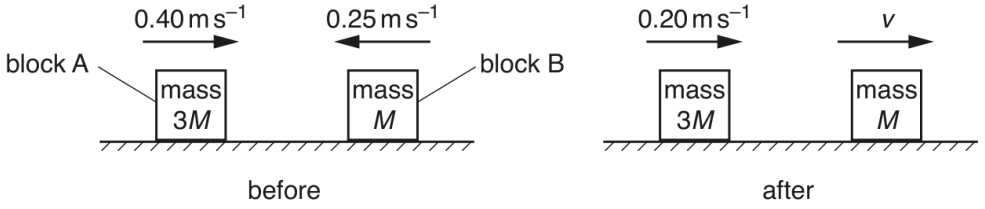


Fig. 3.1

Block A has mass $3M$ and block B has mass M.
Before the collision, block A moves to the right with speed $0.40\,m\,s^{-1}$ and block B moves to the left with speed $0.25\,m\,s^{-1}$.
After the collision, block A moves to the right with speed $0.20\,m\,s^{-1}$ and block B moves to the right with speed v.

(i) Use Newton's third law to explain why, during the collision, the change in momentum of block A is equal and opposite to the change in momentum of block B.

.....

.....

.....

.....[2]

29 **(a)** Define *force*.

.....[1]

30 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.

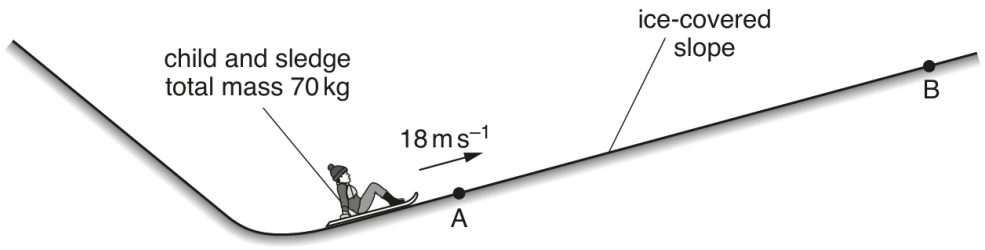


Fig. 3.1 (not to scale)

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.

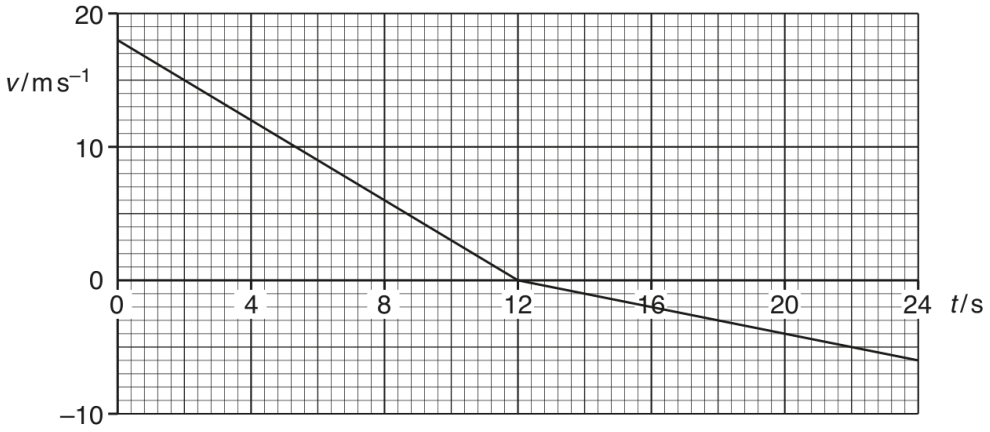


Fig. 3.2

(d) The child and sledge have a total mass of 70 kg. The component of the total weight of the child and sledge that acts down the slope is 80 N.

Determine

(i) the frictional force on the sledge as it moves from B towards A,

frictional force = ... N [2]

(ii) the angle θ of the slope to the horizontal.

$\theta =$ ..... ° [2]

31 A wooden block moves along a horizontal frictionless surface, as shown in Fig. 2.1.

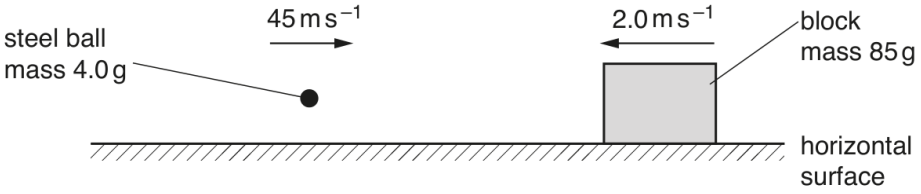


Fig. 2.1

The block has mass 85 g and moves to the left with a velocity of 2.0 m s^{-1}. A steel ball of mass 4.0 g is fired to the right. The steel ball, moving horizontally with a speed of 45 m s^{-1}, collides with the block and remains embedded in it. After the collision the block and steel ball both have speed *v*.

(c) Use Newton's third law to explain the relationship between the rate of change of momentum of the ball and the rate of change of momentum of the block during the collision.

.....

.....

.....

..... [2]

32 **(b)** The propulsion system of a toy car consists of a propeller attached to an electric motor, as illustrated in Fig. 3.1.

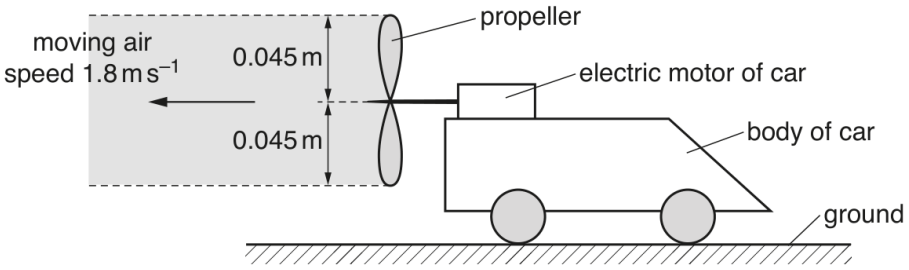


Fig. 3.1

The car is on horizontal ground and is initially held at rest by its brakes. When the motor is switched on, it rotates the propeller so that air is propelled horizontally to the left. The density of the air is 1.3 kg m^{-3}.

Assume that the air moves with a speed of 1.8 m s^{-1} in a uniform cylinder of radius 0.045 m. Also assume that the air to the right of the propeller is stationary.

(ii) Calculate

1. the increase in the momentum of the mass of air in **(b)(i)**,

increase in momentum = ... Ns

2. the force exerted on this mass of air by the propeller.

force = ... N
[3]

(iii) Explain how Newton's third law applies to the movement of the air by the propeller.

.....

.....

.....[2]

(iv) The total mass of the car is 0.20 kg. The brakes of the car are released and the car begins to move with an initial acceleration of 0.075 m s^{-2}.

Determine the initial frictional force acting on the car.

frictional force = ... N [2]