Kinematics and Momentum

For Examiner's Use

1 A bullet of mass 2.0 g is fired horizontally into a block of wood of mass 600 g. The block is suspended from strings so that it is free to move in a vertical plane.
The bullet buries itself in the block. The block and bullet rise together through a vertical distance of 8.6 cm, as shown in Fig. 3.1.

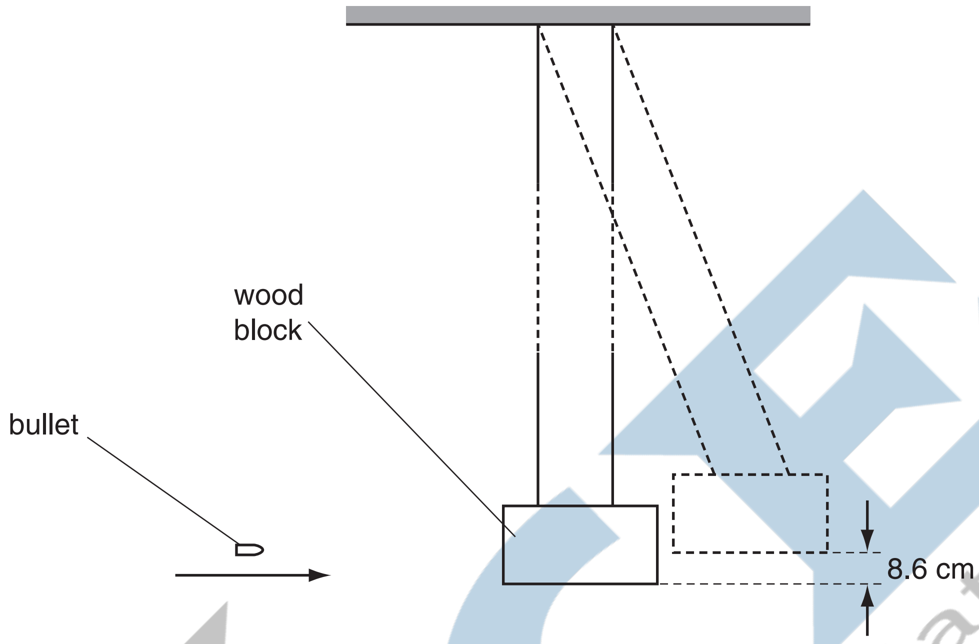

Fig. 3.1

(a) **(i)** Calculate the change in gravitational potential energy of the block and bullet.

change = ... J [2]

(ii) Show that the initial speed of the block and the bullet, after they began to move off together, was 1.3 m s^{-1}.

[1]

For Examiner's Use

(b) Using the information in **(a)(ii)** and the principle of conservation of momentum, determine the speed of the bullet before the impact with the block.

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

(c) **(i)** Calculate the kinetic energy of the bullet just before impact.

kinetic energy = ... J [2]

(ii) State and explain what can be deduced from your answers to **(c)(i)** and **(a)(i)** about the type of collision between the bullet and the block.

....

....

....[2]

2 An experiment is conducted on the surface of the planet Mars.
A sphere of mass 0.78 kg is projected almost vertically upwards from the surface of the planet. The variation with time t of the vertical velocity v in the upward direction is shown in Fig. 2.1.

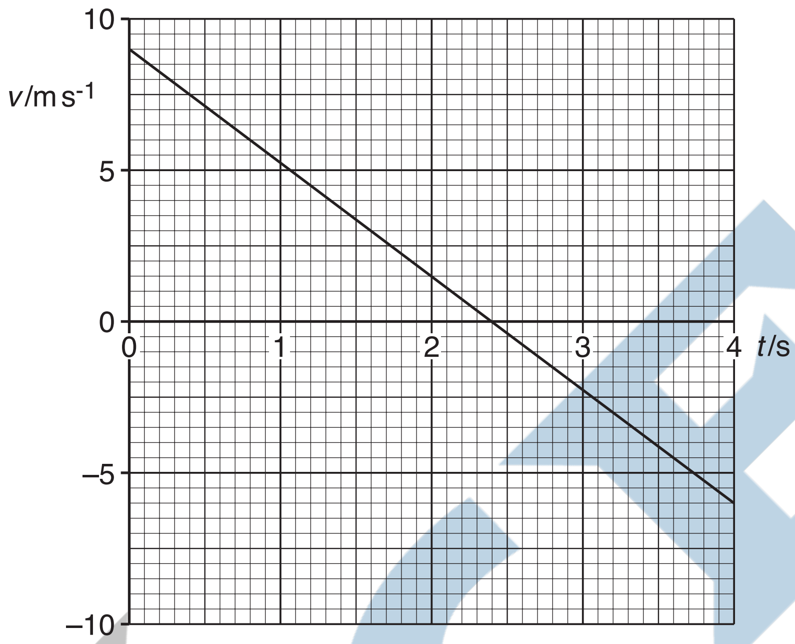

Fig. 2.1

The sphere lands on a small hill at time t = 4.0 s.

(a) State the time t at which the sphere reaches its maximum height above the planet's surface.

t = ... s [1]

(b) Determine the vertical height above the point of projection at which the sphere finally comes to rest on the hill.

height = ... m [3]

(c) Calculate, for the first 3.5 s of the motion of the sphere,

(i) the change in momentum of the sphere,

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

(ii) the force acting on the sphere.

force = ... N [2]

(d) Using your answer in **(c)(ii)**,

(i) state the weight of the sphere,

weight = ... N [1]

(ii) determine the acceleration of free fall on the surface of Mars.

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

3 **(a)** A stone of mass 56 g is thrown horizontally from the top of a cliff with a speed of $18\,\text{m}\,\text{s}^{-1}$, as illustrated in Fig. 4.1.

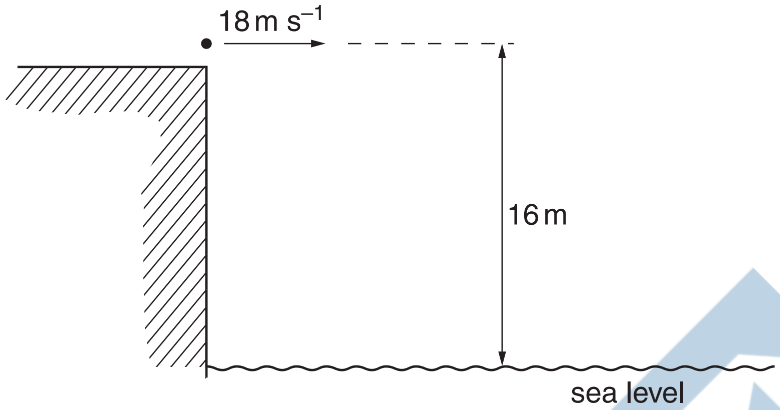

Fig. 4.1

The initial height of the stone above the level of the sea is 16 m. Air resistance may be neglected.

(i) Calculate the change in gravitational potential energy of the stone as a result of falling through 16 m.

change = ... J [2]

(ii) Calculate the total kinetic energy of the stone as it reaches the sea.

kinetic energy = ... J [3]

(b) Use your answer in **(a)(ii)** to show that the speed of the stone as it hits the water is approximately 25 m s^{-1}.

[1]

(c) State the horizontal velocity of the stone as it hits the water.

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

(d) **(i)** On the grid of Fig. 4.2, draw a vector diagram to represent the horizontal velocity and the resultant velocity of the stone as it hits the water. [1]

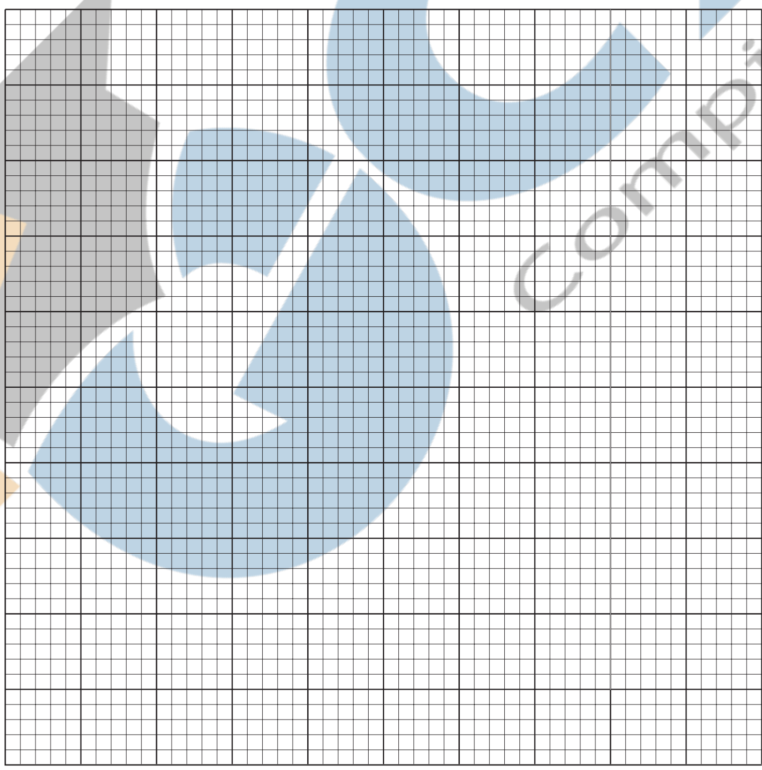

Fig. 4.2

(ii) Use your vector diagram to determine the angle with the horizontal at which the stone hits the water.

angle = ... ° [2]

4 A ball B of mass 1.2 kg travelling at constant velocity collides head-on with a stationary ball S of mass 3.6 kg, as shown in Fig. 2.1.

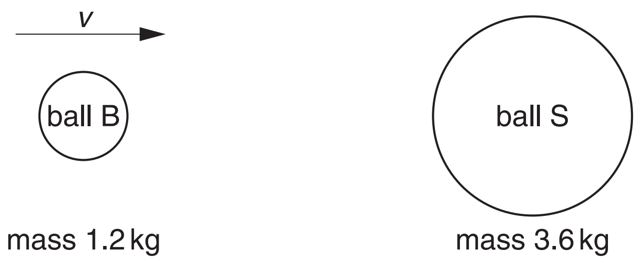

Fig. 2.1

Frictional forces are negligible.

The variation with time *t* of the velocity *v* of ball B before, during and after colliding with ball S is shown in Fig. 2.2.

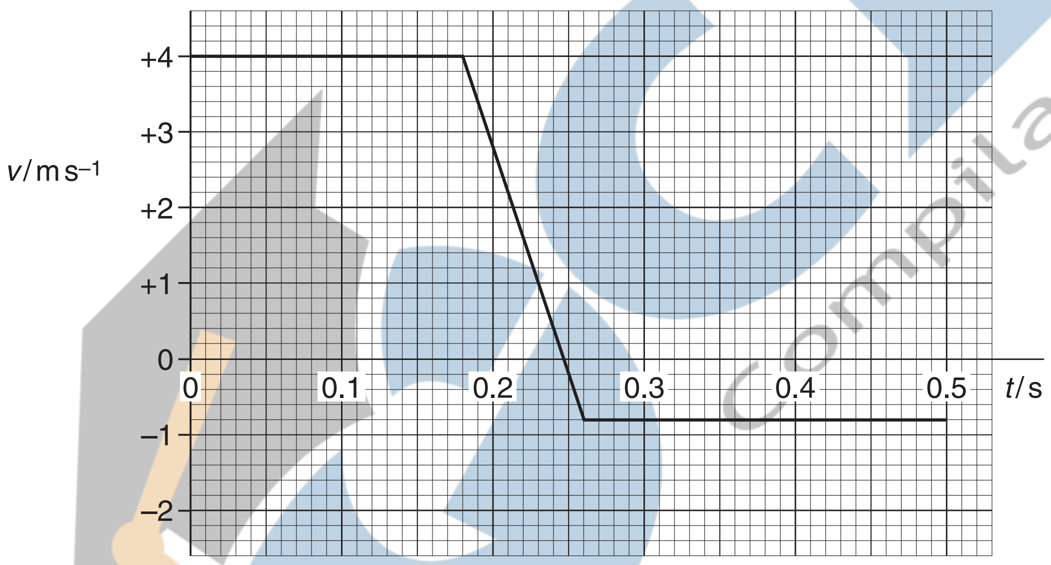

Fig. 2.2

(a) State the significance of positive and negative values for *v* in Fig. 2.2.

....

.... [1]

For Examiner's Use

(b) Use Fig. 2.2 to determine, for ball B during the collision with ball S,

(i) the change in momentum of ball B,

change in momentum = ... N s [3]

(ii) the magnitude of the force acting on ball B.

force = ... N [3]

(c) Calculate the speed of ball S after the collision.

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

(d) Using your answer in **(c)** and information from Fig. 2.2, deduce quantitatively whether the collision is elastic or inelastic.

....

.... [2]

5 A ball falls from rest onto a flat horizontal surface. Fig. 3.1 shows the variation with time *t* of the velocity *v* of the ball as it approaches and rebounds from the surface.

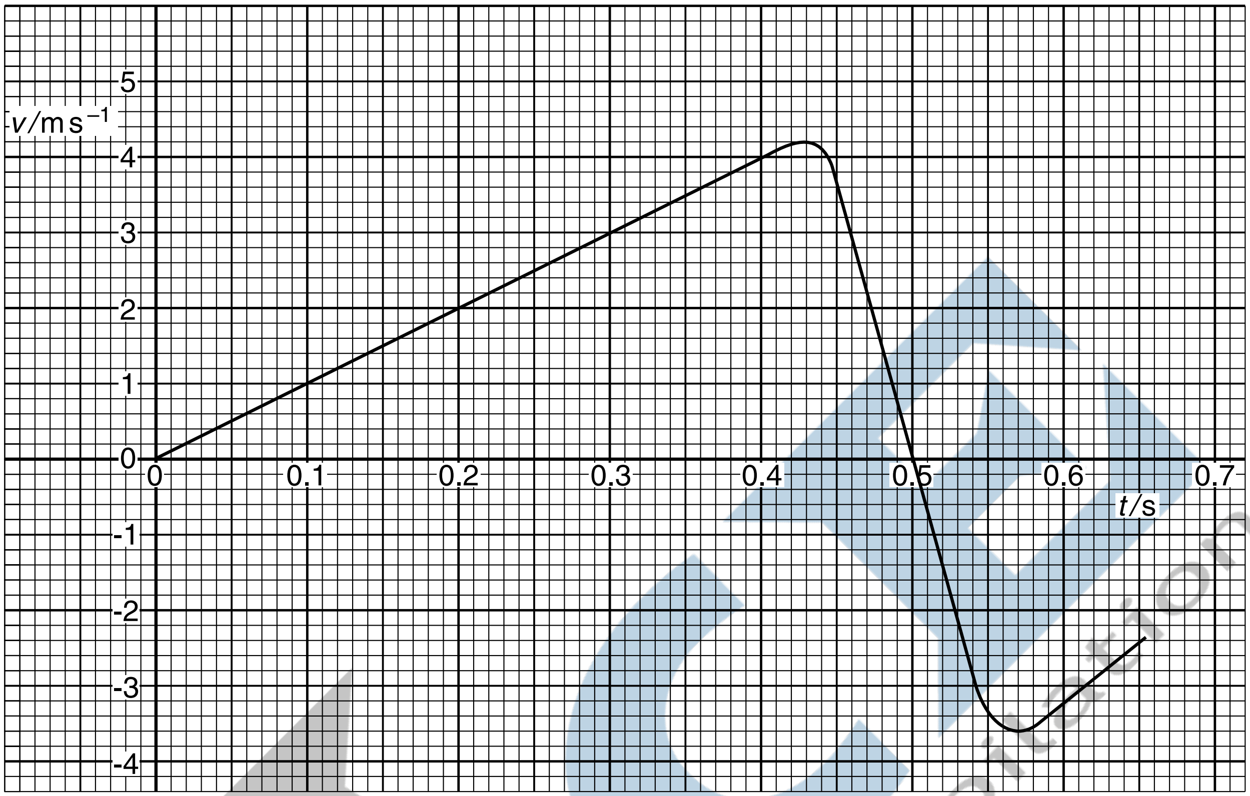

Fig. 3.1

Use data from Fig. 3.1 to determine

(a) the distance travelled by the ball during the first 0.40 s,

distance = ... m [2]

For Examiner's Use

(b) the change in momentum of the ball, of mass 45 g, during contact of the ball with the surface,

change = ... N s [4]

(c) the average force acting on the ball during contact with the surface.

force = ... N [2]

For Examiner's Use

6 A girl stands at the top of a cliff and throws a ball vertically upwards with a speed of $12\,\mathrm{m\,s^{-1}}$, as illustrated in Fig. 3.1.

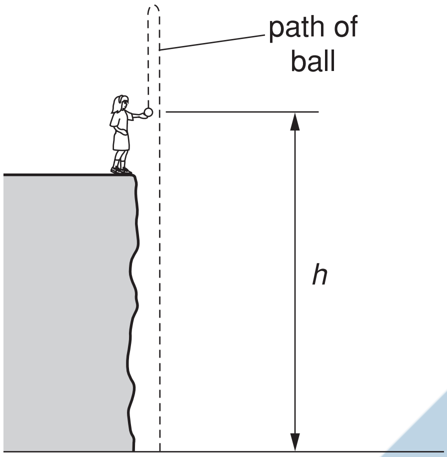

Fig. 3.1

At the time that the girl throws the ball, her hand is a height h above the horizontal ground at the base of the cliff.
The variation with time t of the speed v of the ball is shown in Fig. 3.2.

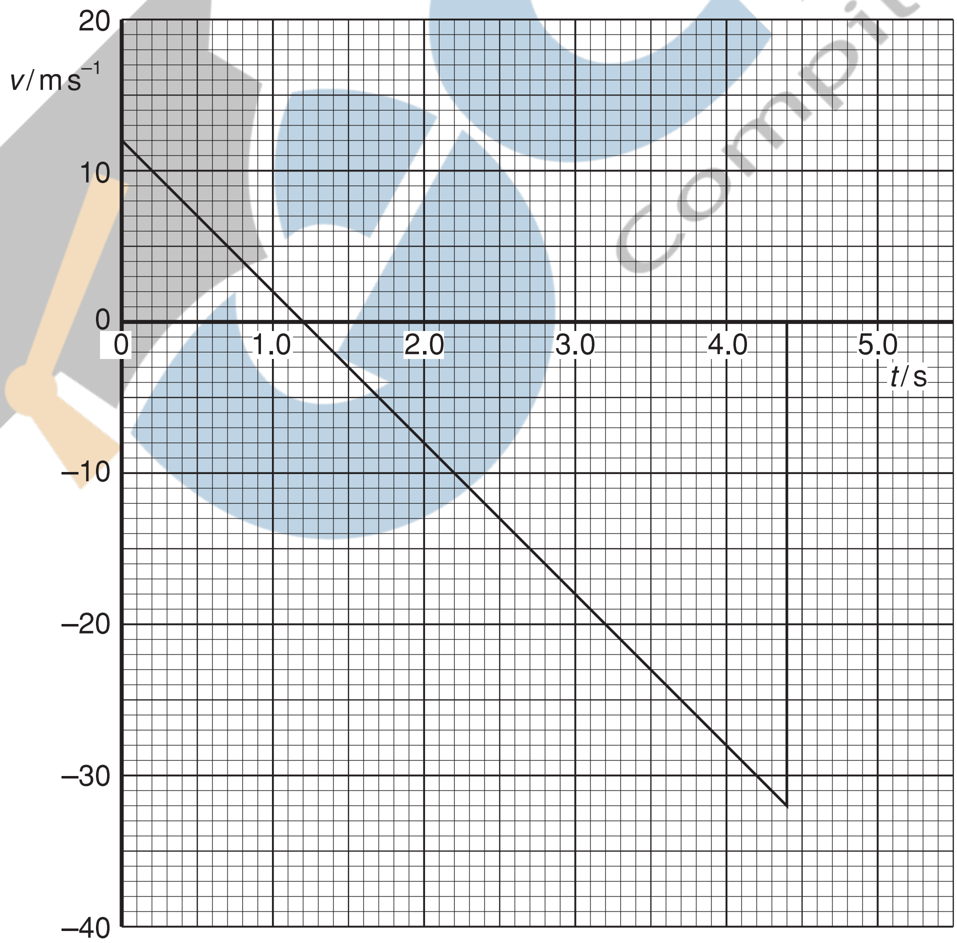

Fig. 3.2

For Examiner's Use

Speeds in the upward direction are shown as being positive. Speeds in the downward direction are negative.

(a) State the feature of Fig. 3.2 that shows that the acceleration is constant.

.... [1]

(b) Use Fig. 3.2 to determine the time at which the ball

(i) reaches maximum height,

time = ... s

(ii) hits the ground at the base of the cliff.

time = ... s
[2]

(c) Determine the maximum height above the base of the cliff to which the ball rises.

height = ... m [3]

(d) The ball has mass 250 g. Calculate the magnitude of the change in momentum of the ball between the time that it leaves the girl's hand to time $t = 4.0$ s.

change = ... N s [3]

For Examiner's Use

(e) **(i)** State the principle of conservation of momentum.

....

....

.... [2]

(ii) Comment on your answer to **(d)** by reference to this principle.

....

....

....

.... [3]

7 A trolley of mass 930 g is held on a horizontal surface by means of two springs, as shown in Fig. 4.1.

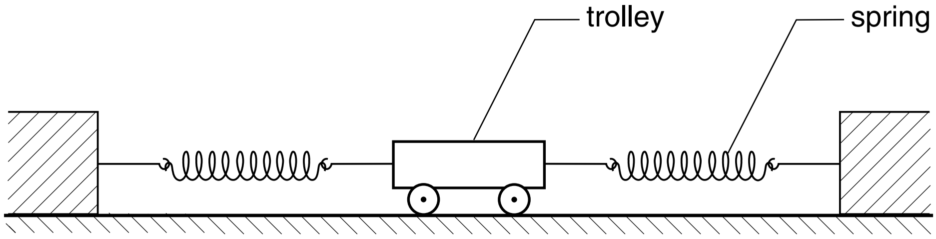

Fig. 4.1

The variation with time t of the speed v of the trolley for the first 0.60 s of its motion is shown in Fig. 4.2.

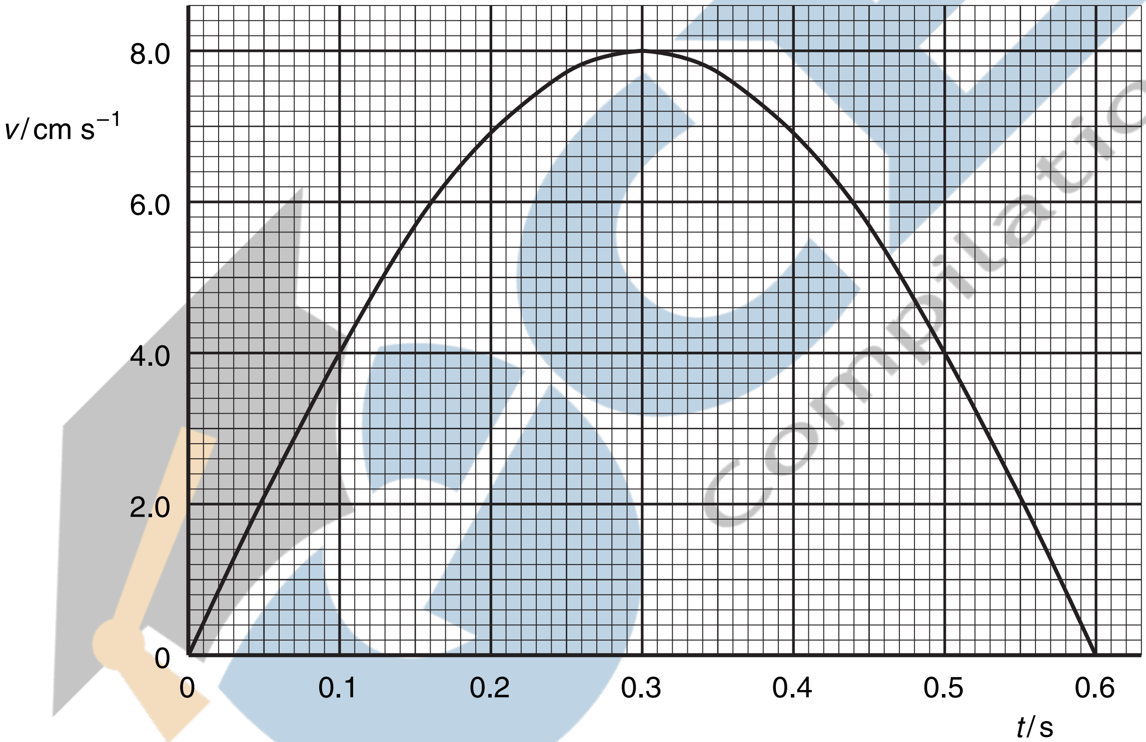

Fig. 4.2

(a) Use Fig. 4.2 to determine

(i) the initial acceleration of the trolley,

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

For Examiner's Use

(ii) the distance moved during the first 0.60 s of its motion.

distance = ... m [3]

(b) **(i)** Use your answer to **(a)(i)** to determine the resultant force acting on the trolley at time $t = 0$.

force = ... N [2]

(ii) Describe qualitatively the variation with time of the resultant force acting on the trolley during the first 0.60 s of its motion.

....

....

....

.... [3]

For Examiner's Use

8 A stone on a string is made to travel along a horizontal circular path, as shown in Fig. 3.1.

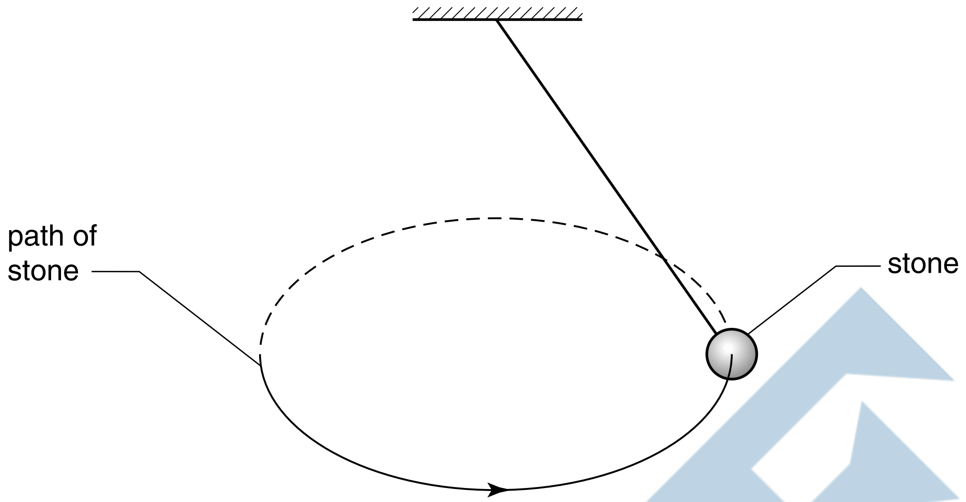

Fig. 3.1

The stone has a constant speed.

(a) Define *acceleration*.

....

.... [1]

(b) Use your definition to explain whether the stone is accelerating.

....

....

.... [2]

(c) The stone has a weight of 5.0 N. When the string makes an angle of 35° to the vertical, the tension in the string is 6.1 N, as illustrated in Fig. 3.2.

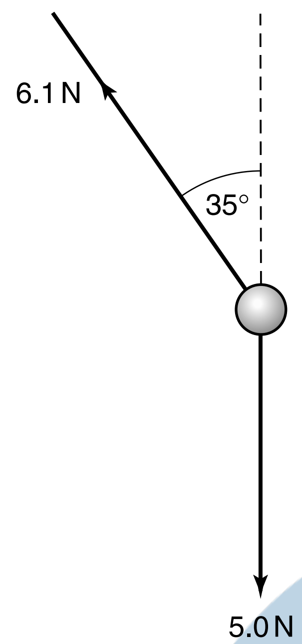

Fig. 3.2

Determine the resultant force acting on the stone in the position shown.

magnitude of force = ... N

direction of force.. [4]

9 A student investigates the speed of a trolley as it rolls down a slope, as illustrated in Fig. 2.1.

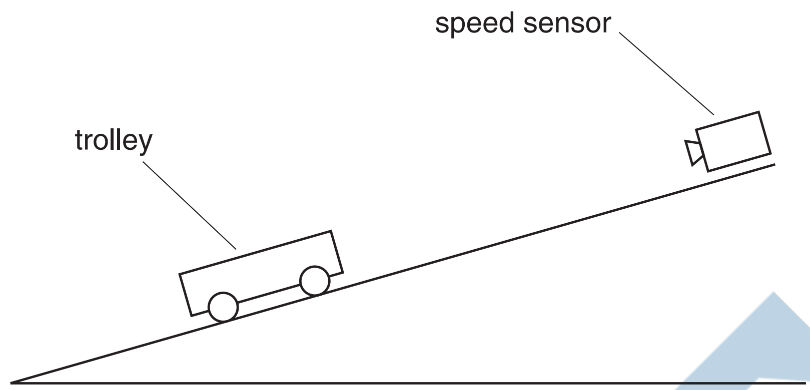

Fig. 2.1

The speed v of the trolley is measured using a speed sensor for different values of the time t that the trolley has moved from rest down the slope.

Fig. 2.2 shows the variation with t of v.

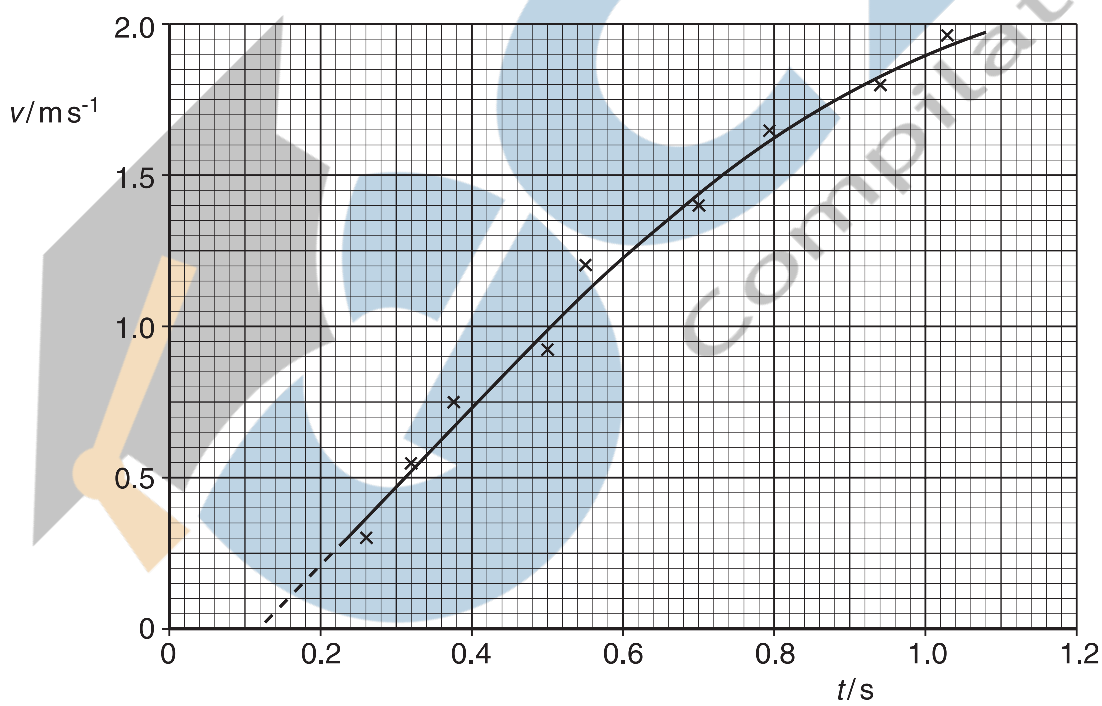

Fig. 2.2

(a) Use Fig. 2.2 to determine the acceleration of the trolley at the point on the graph where $t = 0.80$ s.

acceleration = ... m s^{-2} [4]

(b) **(i)** State whether the acceleration is increasing or decreasing for values of t greater than 0.6 s. Justify your answer by reference to Fig. 2.2.

....

....

.... [2]

(ii) Suggest an explanation for this change in acceleration.

....

.... [1]

(c) Name the feature of Fig. 2.2 that indicates the presence of

(i) random error,

....

.... [1]

(ii) systematic error.

....

.... [1]

10 Francium-208 is radioactive and emits α-particles with a kinetic energy of 1.07×10^{-12} J to form nuclei of astatine, as illustrated in Fig. 3.1.

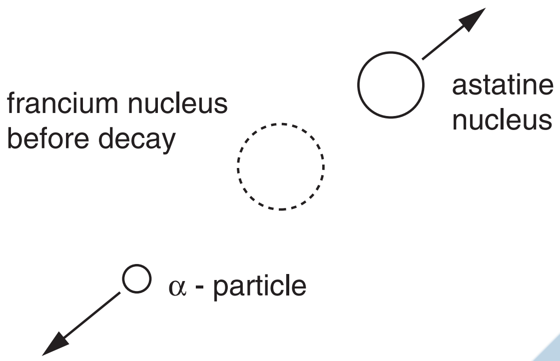

Fig. 3.1

(a) State the nature of an α-particle.

....

.... [1]

(b) Show that the initial speed of an α-particle after the decay of a francium nucleus is approximately $1.8 \times 10^{7}\,\mathrm{m\,s^{-1}}$.

[2]

(c) **(i)** State the principle of conservation of linear momentum.

....

....

.... [2]

(ii) The Francium-208 nucleus is stationary before the decay. Estimate the speed of the astatine nucleus immediately after the decay.

For Examiner's Use

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

(d) Close examination of the decay of the francium nucleus indicates that the astatine nucleus and the α-particle are not ejected exactly in opposite directions.

Suggest an explanation for this observation.

....

....

.... [2]

11 A girl G is riding a bicycle at a constant velocity of 3.5 m s^{-1}. At time $t = 0$, she passes a boy B sitting on a bicycle that is stationary, as illustrated in Fig. 2.1.

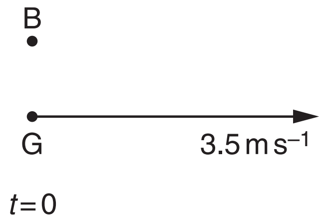

Fig. 2.1

At time $t = 0$, the boy sets off to catch up with the girl. He accelerates uniformly from time $t = 0$ until he reaches a speed of 5.6 m s^{-1} in a time of 5.0 s. He then continues at a constant speed of 5.6 m s^{-1}. At time $t = T$, the boy catches up with the girl.
T is measured in seconds.

(a) State, in terms of T, the distance moved by the girl before the boy catches up with her.

distance = ... m [1]

(b) For the boy, determine

(i) the distance moved during his acceleration,

distance = ... m [2]

(ii) the distance moved during the time that he is moving at constant speed.
Give your answer in terms of T.

distance = ... m [1]

(c) Use your answers in **(a)** and **(b)** to determine the time T taken for the boy to catch up with the girl.

T = ... s [2]

(d) The boy and the bicycle have a combined mass of 67 kg.

(i) Calculate the force required to cause the acceleration of the boy.

force = ... N [3]

(ii) At a speed of 4.5 m s^{-1}, the total resistive force acting on the boy and bicycle is 23 N.
Determine the output power of the boy's legs at this speed.

power = ... W [2]

12 A car is travelling along a straight road at speed v. A hazard suddenly appears in front of the car. In the time interval between the hazard appearing and the brakes on the car coming into operation, the car moves forward a distance of 29.3 m. With the brakes applied, the front wheels of the car leave skid marks on the road that are 12.8 m long, as illustrated in Fig. 2.1.

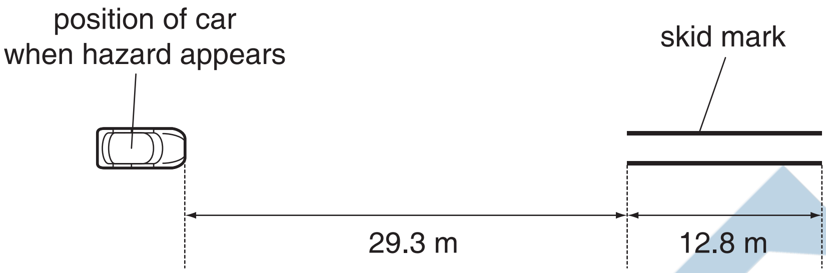

Fig. 2.1

It is estimated that, during the skid, the magnitude of the deceleration of the car is $0.85\,g$, where g is the acceleration of free fall.

(a) Determine

(i) the speed v of the car before the brakes are applied,

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

(ii) the time interval between the hazard appearing and the brakes being applied.

time = ... s [2]

(b) The legal speed limit on the road is 60 km per hour.
Use both of your answers in **(a)** to comment on the standard of the driving of the car.

....

....

....

.... [3]

13 A sky-diver jumps from a high-altitude balloon.

(a) Explain briefly why the acceleration of the sky-diver

(i) decreases with time,

....

....

.... [2]

(ii) is $9.8\,\mathrm{m\,s^{-2}}$ at the start of the jump.

....

.... [1]

(b) The variation with time t of the vertical speed v of the sky-diver is shown in Fig. 2.1.

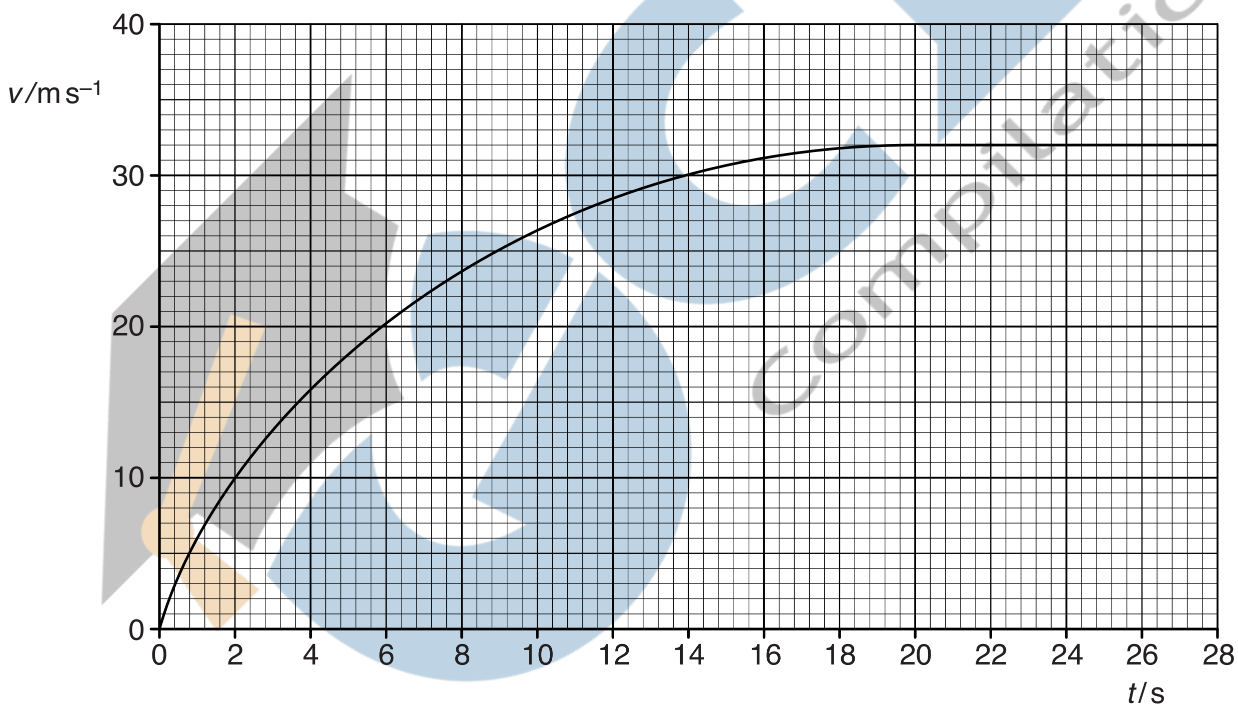

Fig. 2.1

Use Fig. 2.1 to determine the magnitude of the acceleration of the sky-diver at time $t = 6.0\,\text{s}$.

acceleration = ... m s^{-2} [3]

(c) The sky-diver and his equipment have a total mass of 90 kg.

(i) Calculate, for the sky-diver and his equipment,

1. the total weight,

weight = ... N [1]

2. the accelerating force at time $t = 6.0\,\text{s}$.

force = ... N [1]

(ii) Use your answers in **(i)** to determine the total resistive force acting on the sky-diver at time $t = 6.0\,\text{s}$.

force = ... N [1]

14 A stationary nucleus of mass 220u undergoes radioactive decay to produce a nucleus D of mass 216u and an α-particle of mass 4u, as illustrated in Fig. 3.1.

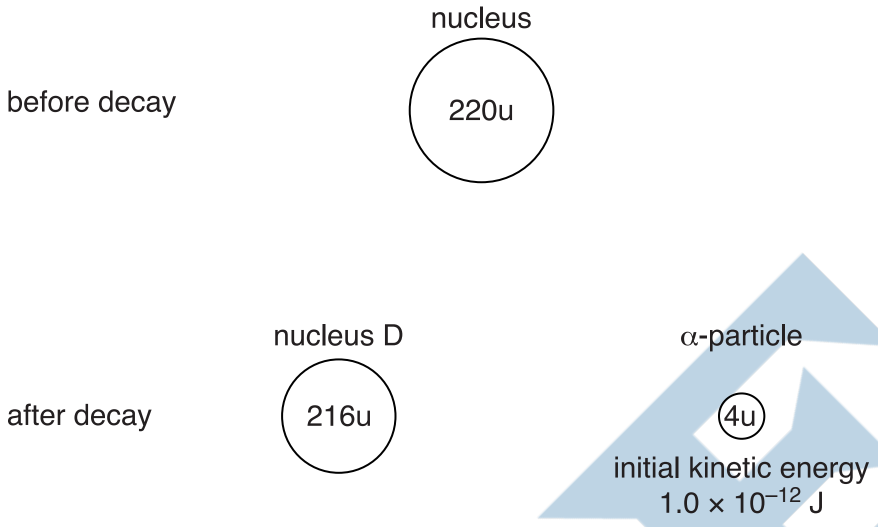

Fig. 3.1

The initial kinetic energy of the α-particle is 1.0×10^{-12} J.

(a) **(i)** State the law of conservation of linear momentum.

....

....

.... [2]

(ii) Explain why the initial velocities of the nucleus D and the α-particle must be in opposite directions.

....

....

.... [2]

(b) **(i)** Show that the initial speed of the α-particle is $1.7 \times 10^{7}\,\mathrm{m\,s^{-1}}$.

[2]

(ii) Calculate the initial speed of nucleus D.

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

(c) The range in air of the emitted α-particle is 4.5 cm.
Calculate the average deceleration of the α-particle as it is stopped by the air.

deceleration = ... $m s^{-2}$ [2]

15 A small ball is thrown horizontally with a speed of $4.0\,m\,s^{-1}$. It falls through a vertical height of 1.96 m before bouncing off a horizontal plate, as illustrated in Fig. 3.1.

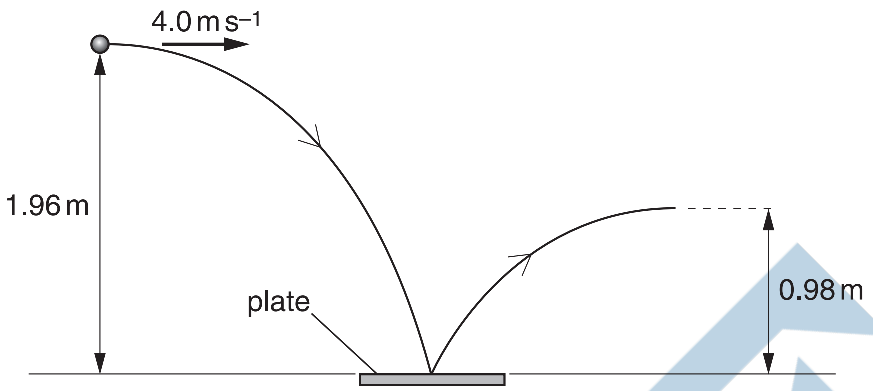

Fig. 3.1

Air resistance is negligible.

(a) For the ball, as it hits the horizontal plate,

(i) state the magnitude of the horizontal component of its velocity,

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

(ii) show that the vertical component of the velocity is $6.2\,m\,s^{-1}$.

[1]

For Examiner's Use

(b) The components of the velocity in **(a)** are both vectors.

Complete Fig. 3.2 to draw a vector diagram, to scale, to determine the velocity of the ball as it hits the horizontal plate.

Fig. 3.2

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

at .... ° to the vertical [3]

(c) After bouncing on the plate, the ball rises to a vertical height of 0.98 m.

(i) Calculate the vertical component of the velocity of the ball as it leaves the plate.

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

For Examiner's Use

(ii) The ball of mass 34 g is in contact with the plate for a time of 0.12 s.

Use your answer in **(c)(i)** and the data in **(a)(ii)** to calculate, for the ball as it bounces on the plate,

1. the change in momentum,

change = ... $kg\,m\,s^{-1}$ [3]

2. the magnitude of the average force exerted by the plate on the ball due to this momentum change.

force = ... N [2]

16 A steel ball of mass 73 g is held 1.6 m above a horizontal steel plate, as illustrated in Fig. 4.1.

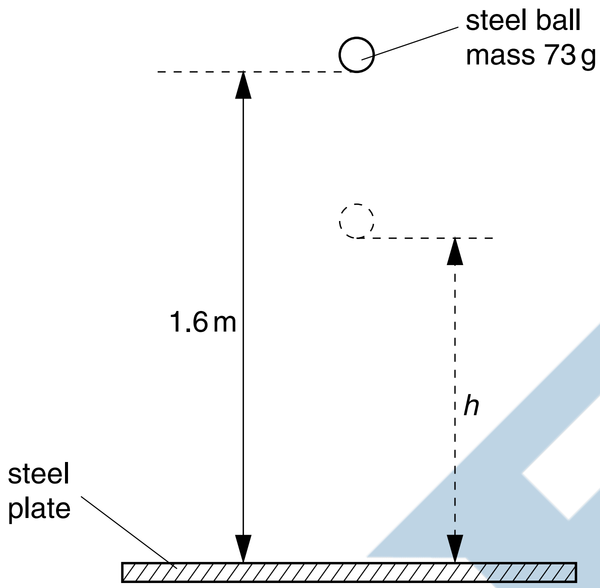

Fig. 4.1

The ball is dropped from rest and it bounces on the plate, reaching a height *h*.

(a) Calculate the speed of the ball as it reaches the plate.

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

(b) As the ball loses contact with the plate after bouncing, the kinetic energy of the ball is 90% of that just before bouncing. Calculate

(i) the height *h* to which the ball bounces,

h = ... m

(ii) the speed of the ball as it leaves the plate after bouncing.

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

[4]

(c) Using your answers to **(a)** and **(b)**, determine the change in momentum of the ball during the bounce.

change = ... N s [3]

(d) With reference to the law of conservation of momentum, comment on your answer to **(c)**.

....

....

....[3]

17 A ball has mass *m*. It is dropped onto a horizontal plate as shown in Fig. 4.1.

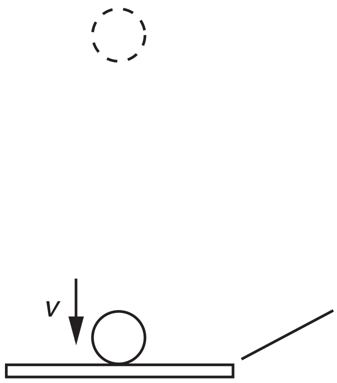

Fig. 4.1

Just as the ball makes contact with the plate, it has velocity *v*, momentum *p* and kinetic energy E_k.

(a) **(i)** Write down an expression for momentum *p* in terms of *m* and *v*.

....

(ii) Hence show that the kinetic energy is given by the expression

$$E_k = \frac{p^2}{2m}.$$

[3]

For Examiner's Use

(b) Just before impact with the plate, the ball of mass 35 g has speed 4.5 m s^{-1}. It bounces from the plate so that its speed immediately after losing contact with the plate is 3.5 m s^{-1}. The ball is in contact with the plate for 0.14 s.

Calculate, for the time that the ball is in contact with the plate,

(i) the average force, in addition to the weight of the ball, that the plate exerts on the ball,

magnitude of force = ... N

direction of force = ...
[4]

(ii) the loss in kinetic energy of the ball.

loss = ... J [2]

(c) State and explain whether linear momentum is conserved during the bounce.

....

....

....

.... [3]

For Examiner's Use

2 **(a)** Complete Fig. 2.1 to show whether each of the quantities listed is a vector or a scalar.

	vector / scalar
distance moved	....
speed	....
acceleration	....

Fig. 2.1

[3]

(b) A ball falls vertically in air from rest. The variation with time *t* of the distance *d* moved by the ball is shown in Fig. 2.2.

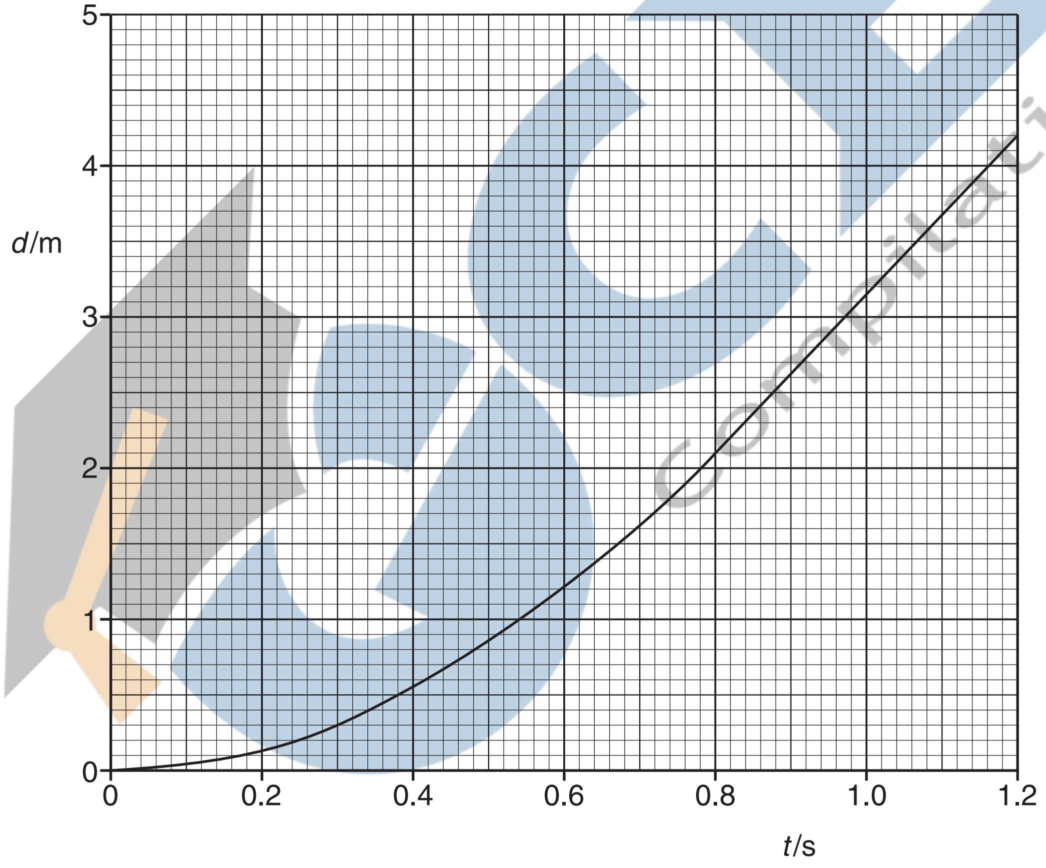

Fig. 2.2

For Examiner's Use

(i) By reference to Fig. 2.2, explain how it can be deduced that

1. the ball is initially at rest,

....

....

.... [2]

2. air resistance is not negligible.

....

.... [1]

(ii) Use Fig. 2.2 to determine the speed of the ball at a time of 0.40 s after it has been released.

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

(iii) On Fig. 2.2, sketch a graph to show the variation with time *t* of the distance *d* moved by the ball for negligible air resistance. You are not expected to carry out any further calculations. [3]

2 **(a)** The distance *s* moved by an object in time *t* may be given by the expression

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

where *a* is the acceleration of the object.

State two conditions for this expression to apply to the motion of the object.

1. ....

....

2. ....

.... [2]

(b) A student takes a photograph of a steel ball of radius 5.0 cm as it falls from rest. The image of the ball is blurred, as illustrated in Fig. 2.1.
The image is blurred because the ball is moving while the photograph is being taken.

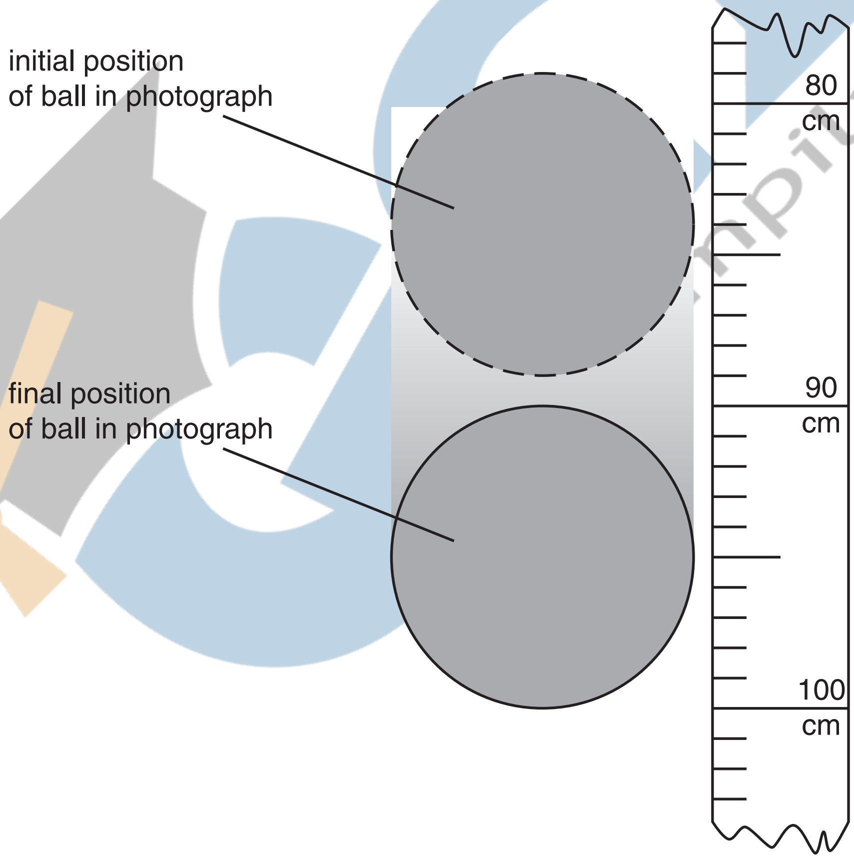

Fig. 2.1

The scale shows the distance fallen from rest by the ball. At time $t = 0$, the top of the ball is level with the zero mark on the scale. Air resistance is negligible.

Calculate, to an appropriate number of significant figures,

(i) the time the ball falls before the photograph is taken,

time = ... s [3]

(ii) the time interval during which the photograph is taken.

time interval = ... s [3]

(c) The student in **(b)** takes a second photograph starting at the same position on the scale. The ball has the same radius but is less dense, so that air resistance is not negligible.

State and explain the changes that will occur in the photograph.

....

....

....

....[2]

2 A ball is thrown horizontally from the top of a building, as shown in Fig. 2.1.

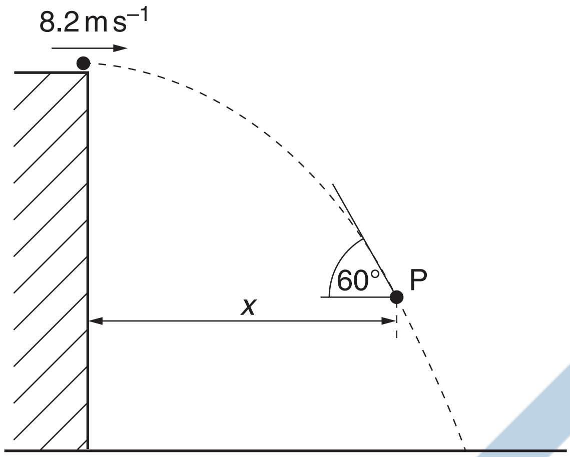

Fig. 2.1

The ball is thrown with a horizontal speed of $8.2\,\text{m}\,\text{s}^{-1}$. The side of the building is vertical. At point P on the path of the ball, the ball is distance x from the building and is moving at an angle of 60° to the horizontal. Air resistance is negligible.

(a) For the ball at point P,

(i) show that the vertical component of its velocity is $14.2\,\text{m}\,\text{s}^{-1}$,

[2]

(ii) determine the vertical distance through which the ball has fallen,

distance = ... m [2]

(iii) determine the horizontal distance x.

x = ... m [2]

(b) The path of the ball in **(a)**, with an initial horizontal speed of $8.2\,\text{m}\,\text{s}^{-1}$, is shown again in Fig. 2.2.

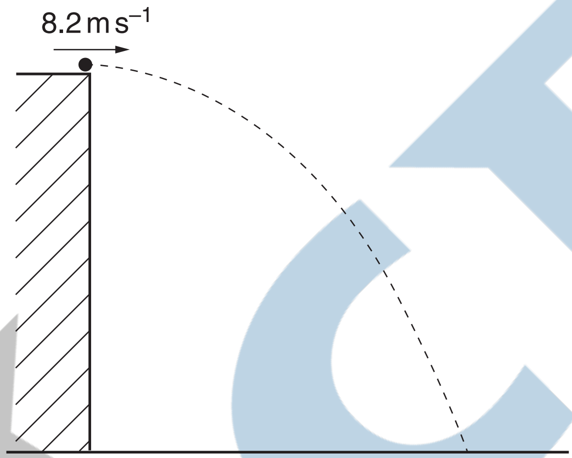

Fig. 2.2

On Fig. 2.2, sketch the new path of the ball for the ball having an initial horizontal speed

(i) greater than $8.2\,\text{m}\,\text{s}^{-1}$ and with negligible air resistance (label this path G), [2]

(ii) equal to $8.2\,\text{m}\,\text{s}^{-1}$ but with air resistance (label this path A). [2]

2 A ball is thrown from a point P, which is at ground level, as illustrated in Fig. 2.1.

For Examiner's Use

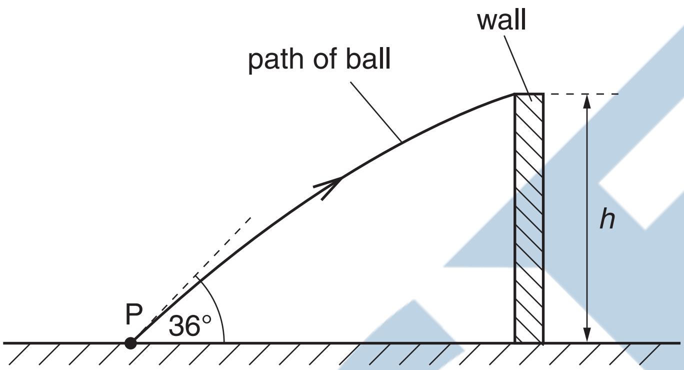

Fig. 2.1

The initial velocity of the ball is 12.4 m s^{-1} at an angle of 36° to the horizontal.
The ball just passes over a wall of height h. The ball reaches the wall 0.17 s after it has been thrown.

(a) Assuming air resistance to be negligible, calculate

(i) the horizontal distance of point P from the wall,

distance = ... m [2]

(ii) the height *h* of the wall.

h = ...m [3]

(b) A second ball is thrown from point P with the same velocity as the ball in **(a)**. For this ball, air resistance is not negligible.
This ball hits the wall and rebounds.

On Fig. 2.1, sketch the path of this ball between point P and the point where it first hits the ground. [2]

4 A student takes measurements to determine a value for the acceleration of free fall. Some of the apparatus used is illustrated in Fig. 4.1.

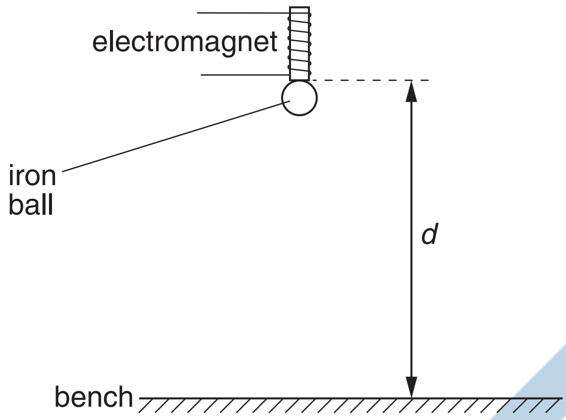

Fig. 4.1

The student measures the vertical distance d between the base of the electromagnet and the bench. The time t for an iron ball to fall from the electromagnet to the bench is also measured.
Corresponding values of t^2 and d are shown in Fig. 4.2.

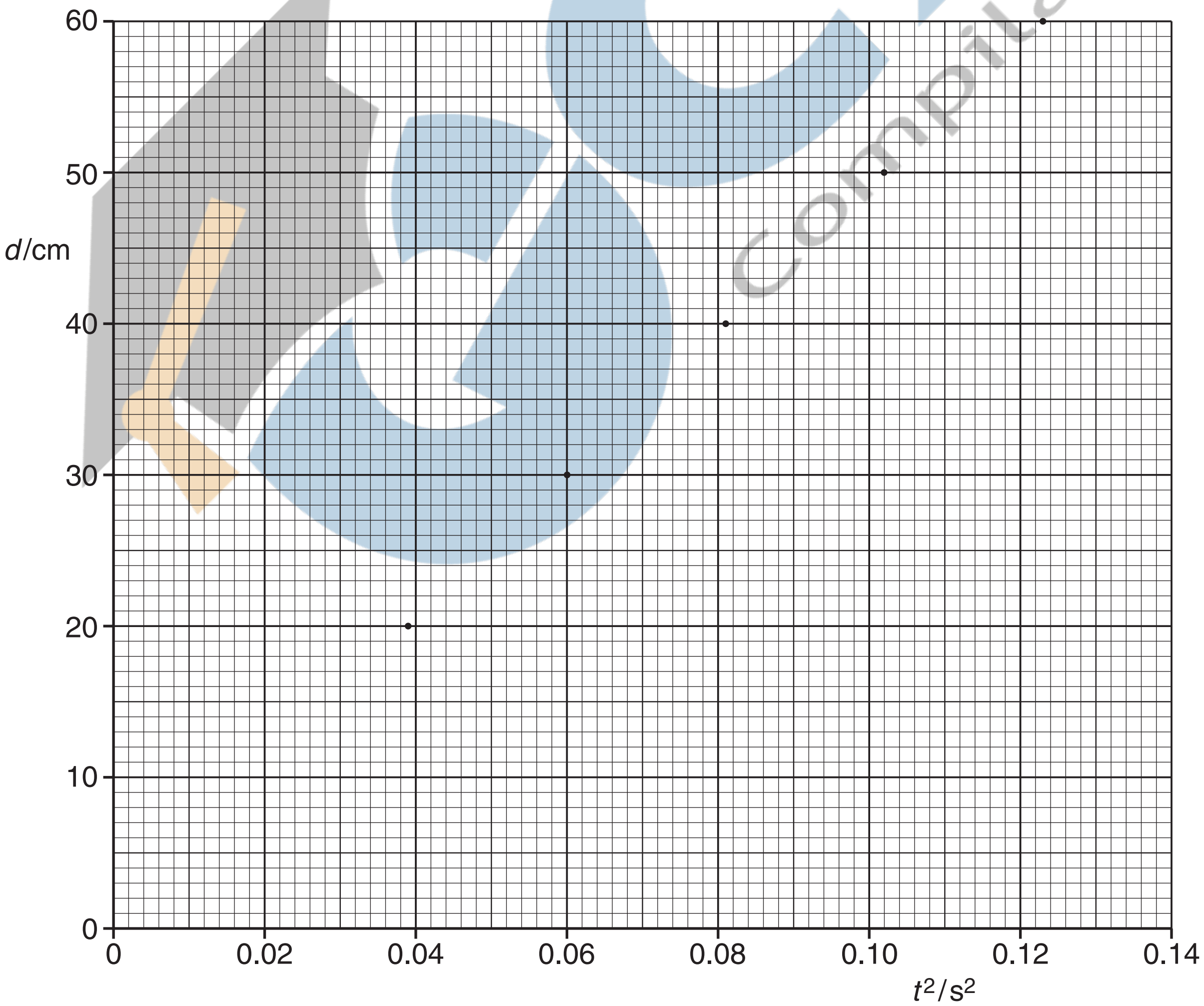

Fig. 4.2

For Examiner's Use

(a) On Fig. 4.2, draw the line of best fit for the points. [1]

(b) State and explain why there is a non-zero intercept on the graph of Fig. 4.2.

....

....

.... [2]

(c) Determine the student's value for

(i) the diameter of the ball,

diameter = ... cm [1]

(ii) the acceleration of free fall.

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

Answer **all** the questions in the spaces provided.

1 **(a)** Distinguish between *scalar* quantities and *vector* quantities.

....

....

.... [2]

(b) In the following list, underline **all** the scalar quantities.

acceleration   force   kinetic energy   mass   power   weight   [1]

(c) A stone is thrown with a horizontal velocity of $20\,\mathrm{m\,s^{-1}}$ from the top of a cliff 15 m high. The path of the stone is shown in Fig. 1.1.

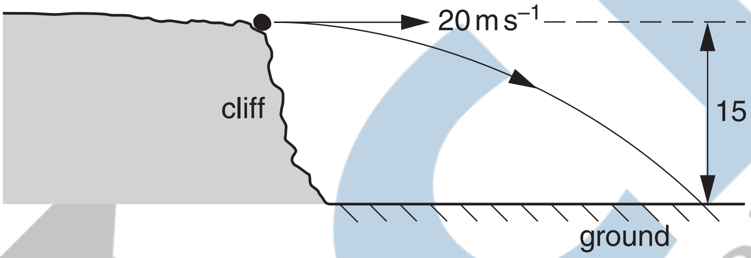

Fig. 1.1

Air resistance is negligible.

For this stone,

(i) calculate the time to fall 15 m,

time = ... s [2]

(ii) calculate the magnitude of the resultant velocity after falling 15 m,

resultant velocity = ... $\mathrm{m\,s^{-1}}$ [3]

(iii) describe the difference between the displacement of the stone and the distance that it travels.

For Examiner's Use

....

....

.... [2]

3 A helicopter has a cable hanging from it towards the sea below, as shown in Fig. 3.1.

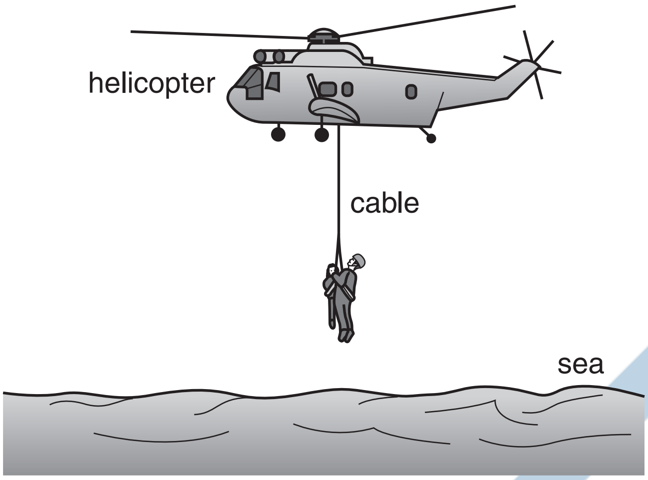

Fig. 3.1

A man of mass 80 kg rescues a child of mass 50.5 kg. The two are attached to the cable and are lifted from the sea to the helicopter. The lifting process consists of an initial uniform acceleration followed by a period of constant velocity and then completed by a final uniform deceleration.

(a) Calculate the combined weight of the man and child.

weight = ... N [1]

(b) Calculate the tension in the cable during

(i) the initial acceleration of $0.570\,\mathrm{m\,s^{-2}}$,

tension = ... N [2]

(ii) the period of constant velocity of $2.00\,\mathrm{m\,s^{-1}}$.

tension = ... N [1]

(c) During the final deceleration the tension in the cable is 1240 N. Calculate this deceleration.

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

(d) (i) Calculate the time over which the man and child are

1. moving with uniform acceleration,

time = ... s [1]

2. moving with uniform deceleration.

time = ... s [1]

(ii) The time over which the man and child are moving with constant velocity is 20 s. On Fig. 3.2, sketch a graph to show the variation with time of the velocity of the man and child for the complete lifting process.

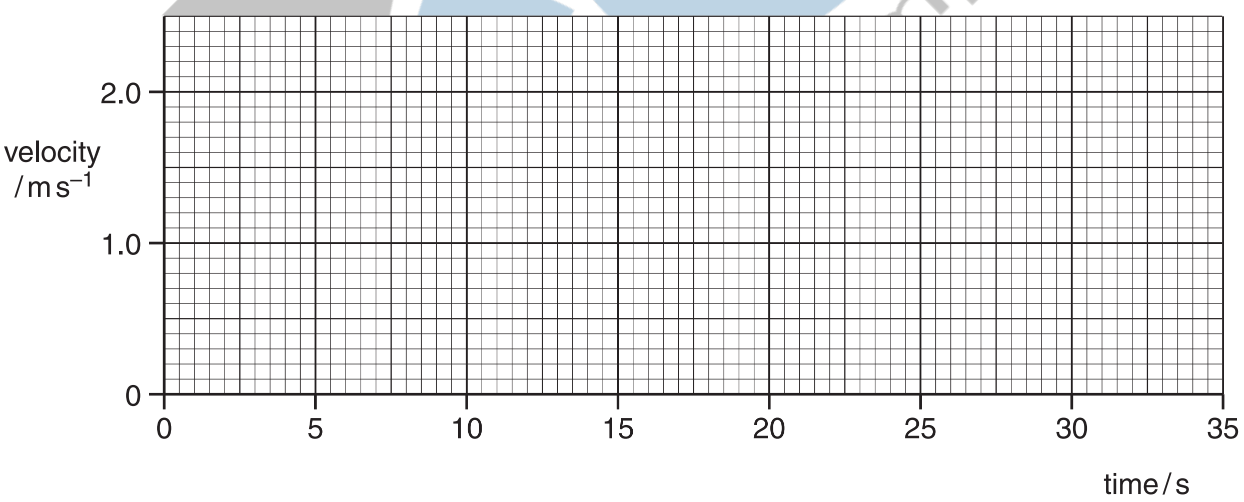

Fig. 3.2

[2]

For Examiner's Use