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International Examinations Papers

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Momentum: 6

TOPIC- Linear momentum, Collisions in two dimensions (elastic and inelastic), momentum conservation

01 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.

For Examiner's Use

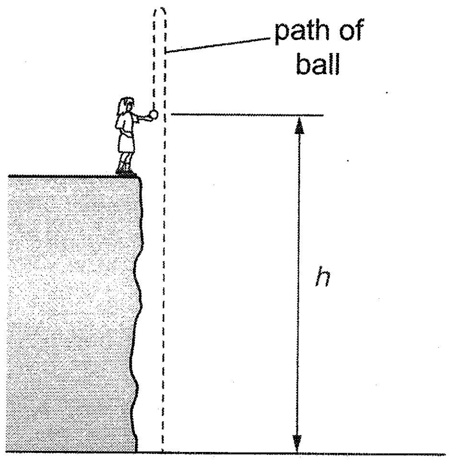

Fig. 3.1

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.

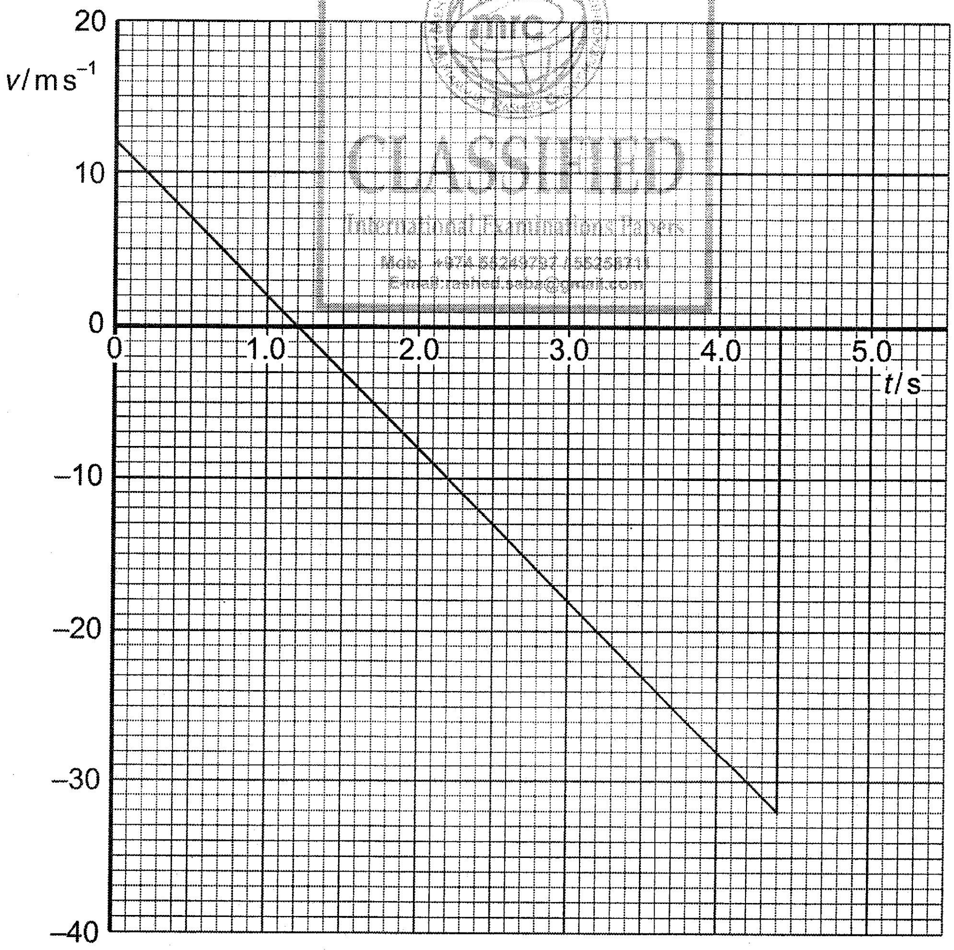

Fig. 3.2

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

For Examiner's Use

(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]

For Examiner's Use

2 **(a)** State Newton's second law.

....

.... [1]

(b) A ball of mass 65 g hits a wall with a velocity of 5.2 m s^{-1} perpendicular to the wall. The ball rebounds perpendicularly from the wall with a speed of 3.7 m s^{-1}. The contact time of the ball with the wall is 7.5 ms.

Calculate, for the ball hitting the wall,

(i) the change in momentum,

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

(ii) the magnitude of the average force.

force = ... N [1]

(c) **(i)** For the collision in **(b)** between the ball and the wall, state how the following apply:

1. Newton's third law,

....

....

....

.... [2]

2. the law of conservation of momentum.

....

.... [1]

(ii) State, with a reason, whether the collision is elastic or inelastic.

....

.... [1]

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

For Examiner's Use

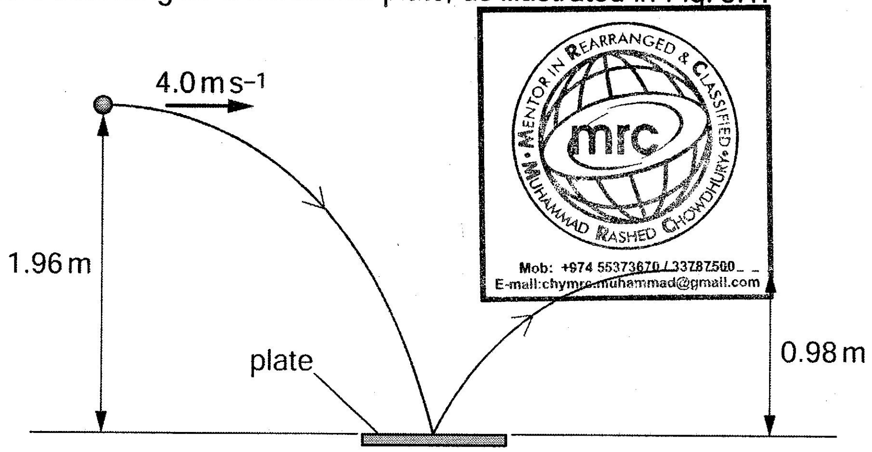

Fig. 3.1

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

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

[1]

(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]

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

For Examiner's Use

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]

4 **(a)** State the principle of conservation of momentum.

....

....

....[2]

(b) A ball X and a ball Y are travelling along the same straight line in the same direction, as shown in Fig. 4.1.

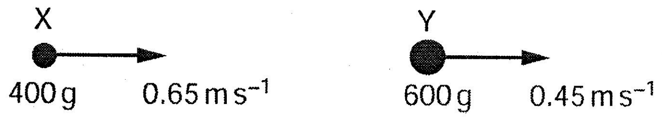

Fig. 4.1

Ball X has mass 400 g and horizontal velocity 0.65 m s^{-1}.
Ball Y has mass 600 g and horizontal velocity 0.45 m s^{-1}.

Ball X catches up and collides with ball Y. After the collision, X has horizontal velocity 0.41 m s^{-1} and Y has horizontal velocity v, as shown in Fig. 4.2.

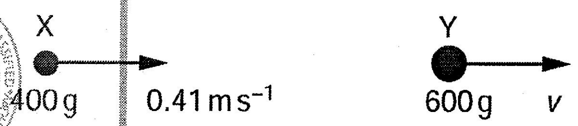

Fig. 4.2

Calculate

(i) the total initial momentum of the two balls,

momentum = ... N s [3]

(ii) the velocity v,

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

(iii) the total initial kinetic energy of the two balls.

kinetic energy = ... J [3]

(c) Explain how you would check whether the collision is elastic.

....

....[1]

(d) Use Newton's third law to explain why, during the collision, the change in momentum of X is equal and opposite to the change in momentum of Y.

....

....

....

....[2]

05 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.

For Examiner's Use

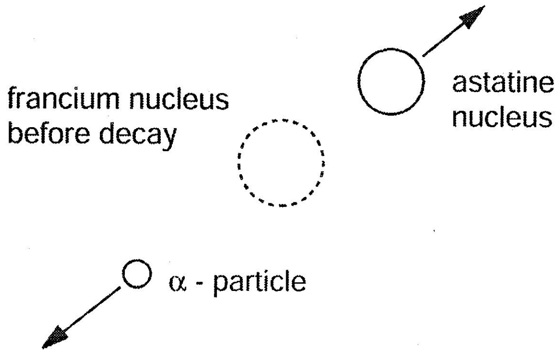

Fig. 3.1

(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 $1.8 \times 10^{7}\ \text{m s}^{-1}$.

[2]

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

....

....

.... [2]

For Examiner's Use

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

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]

For Examiner's Use

06 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.

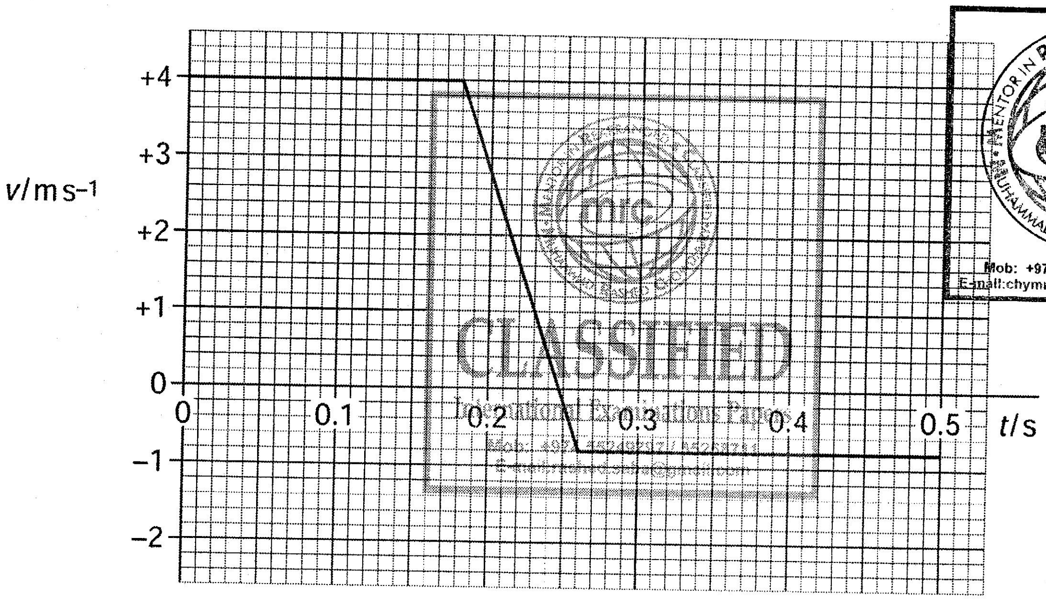

Fig. 2.2

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

....

.... [1]

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

For Examiner's Use

(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]

07

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

....

....[1]

(b) A constant resultant force *F* acts on an object A. The variation with time *t* of the velocity *v* for the motion of A is shown in Fig. 2.1.

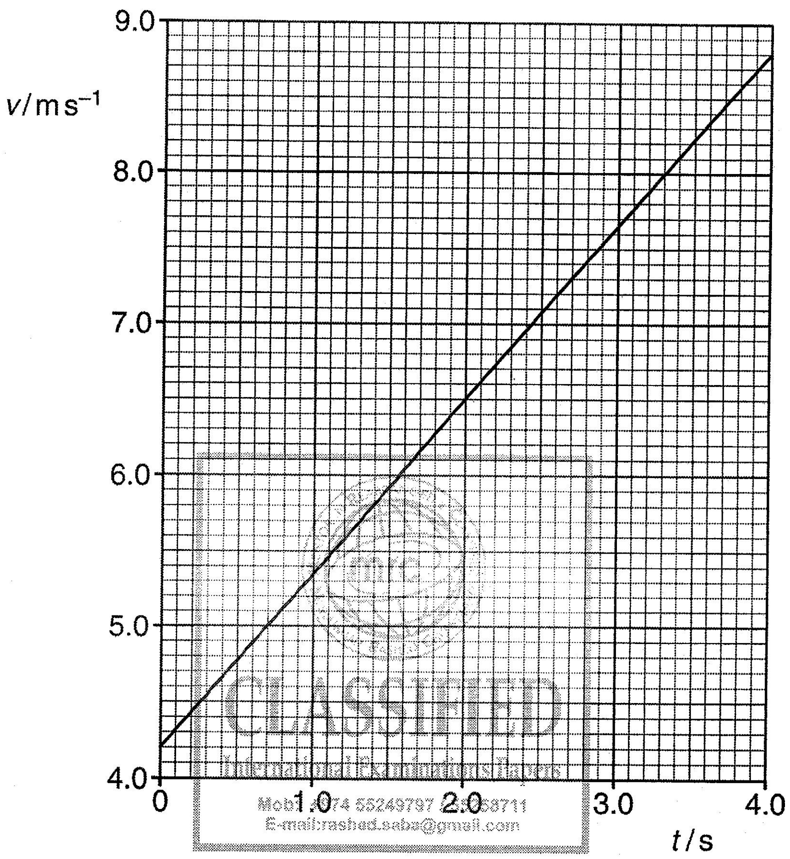

Fig. 2.1

The mass of A is 840 g.

Calculate, for the time $t = 0$ to $t = 4.0$ s,

(i) the change in momentum of A,

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

(ii) the force *F*.

F = ... N [1]

(c) The force F is removed at $t = 4.0\,s$. Object A continues at constant velocity before colliding with an object B, as illustrated in Fig. 2.2.

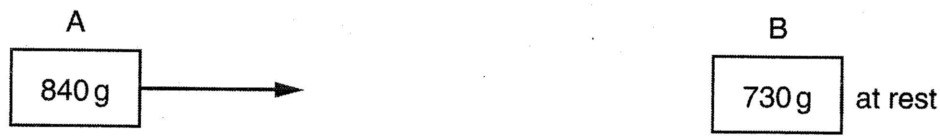

Fig. 2.2

Object B is initially at rest. The mass of B is 730 g.
The objects A and B join together and have a velocity of $4.7\,m\,s^{-1}$.

(i) By calculation, show that the changes in momentum of A and of B during the collision are equal and opposite.

[2]

(ii) Explain how the answers obtained in **(i)** support Newton's third law.

....

....

....

....[2]

(iii) By reference to the speeds of A and B, explain whether the collision is elastic.

....

....[1]

[Total: 9]

08 **(a)** **(i)** Define *force*.

For Examiner's Use

....

.... [1]

(ii) State Newton's third law of motion.

....

....

....

.... [3]

(b) Two spheres approach one another along a line joining their centres, as illustrated in Fig. 3.1.

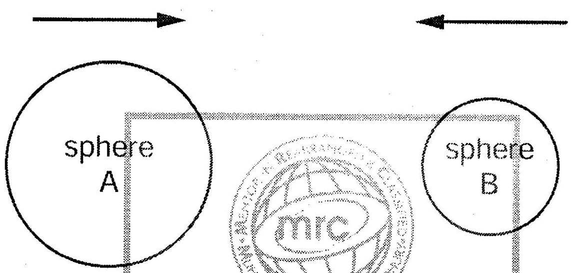

Fig. 3.1

When they collide, the average force acting on sphere A is F_A and the average force acting on sphere B is F_B.

The forces act for time t_A on sphere A and time t_B on sphere B.

(i) State the relationship between

1. F_A and F_B,

.... [1]

2. t_A and t_B.

.... [1]

(ii) Use your answers in **(i)** to show that the change in momentum of sphere A is equal in magnitude and opposite in direction to the change in momentum of sphere B.

....

.... [1]

(c) For the spheres in **(b)**, the variation with time of the momentum of sphere A before, during and after the collision with sphere B is shown in Fig. 3.2.

For Examiner's Use

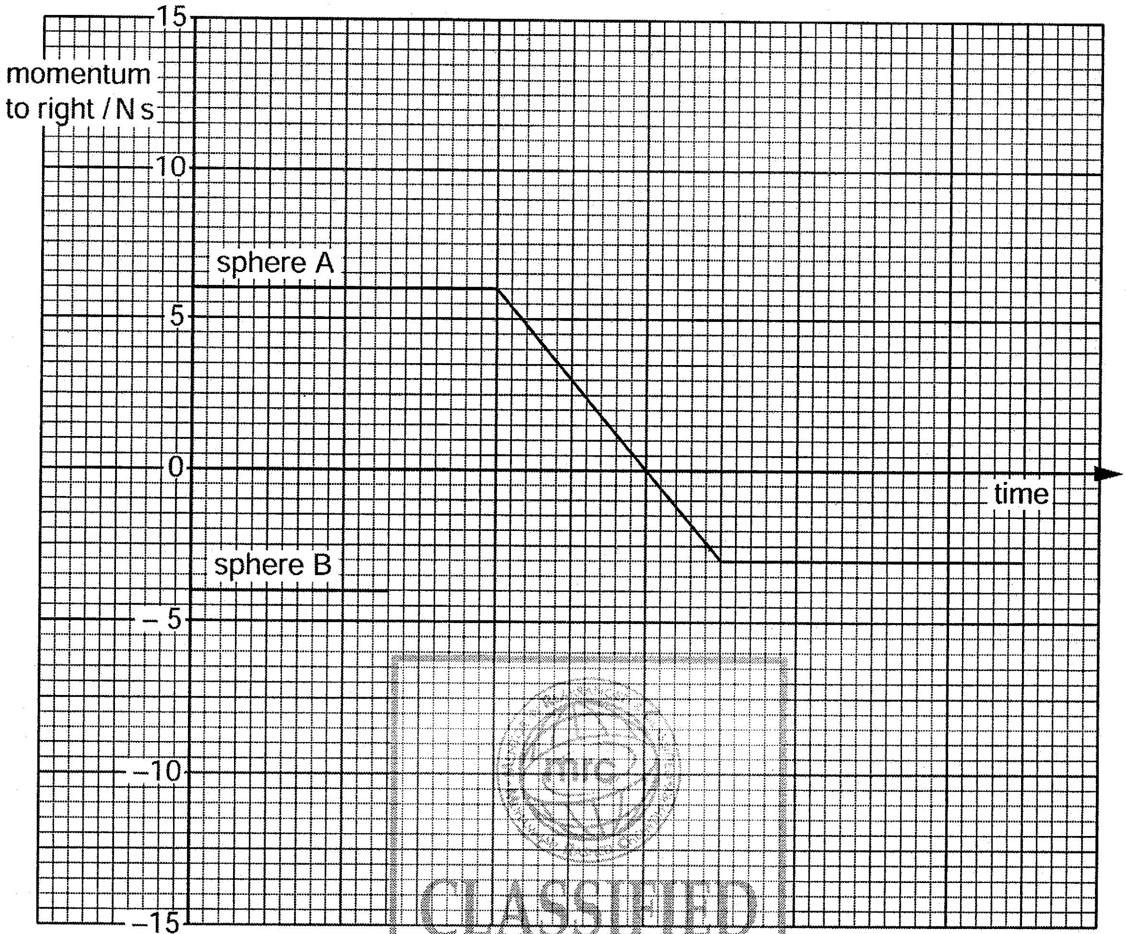

Fig. 3.2

The momentum of sphere B before the collision is also shown on Fig. 3.2.

Complete Fig. 3.2 to show the variation with time of the momentum of sphere B during and after the collision with sphere A. [3]

09 **(a)** **(i)** State the principle of conservation of momentum.

For Examiner's Use

....

....

.... [2]

(ii) State the difference between an elastic and an inelastic collision.

.... [1]

(b) An object A of mass 4.2 kg and horizontal velocity $3.6\,m\,s^{-1}$ moves towards object B as shown in Fig. 3.1.

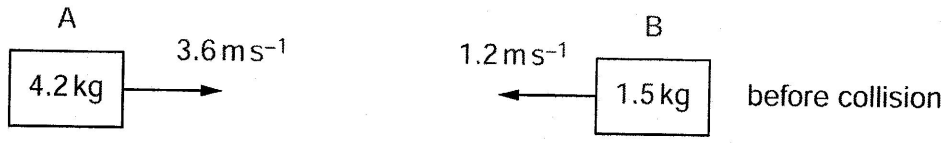

Fig. 3.1

Object B of mass 1.5 kg is moving with a horizontal velocity of $1.2\,m\,s^{-1}$ towards object A.

The objects collide and then both move to the right, as shown in Fig. 3.2.

Fig. 3.2

Object A has velocity v and object B has velocity $3.0\,m\,s^{-1}$.

(i) Calculate the velocity v of object A after the collision.

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

(ii) Determine whether the collision is elastic or inelastic.

[3]

10 (a) State the law of conservation of momentum.

....

....

.... [2]

(b) Two particles A and B collide elastically, as illustrated in Fig. 5.1.

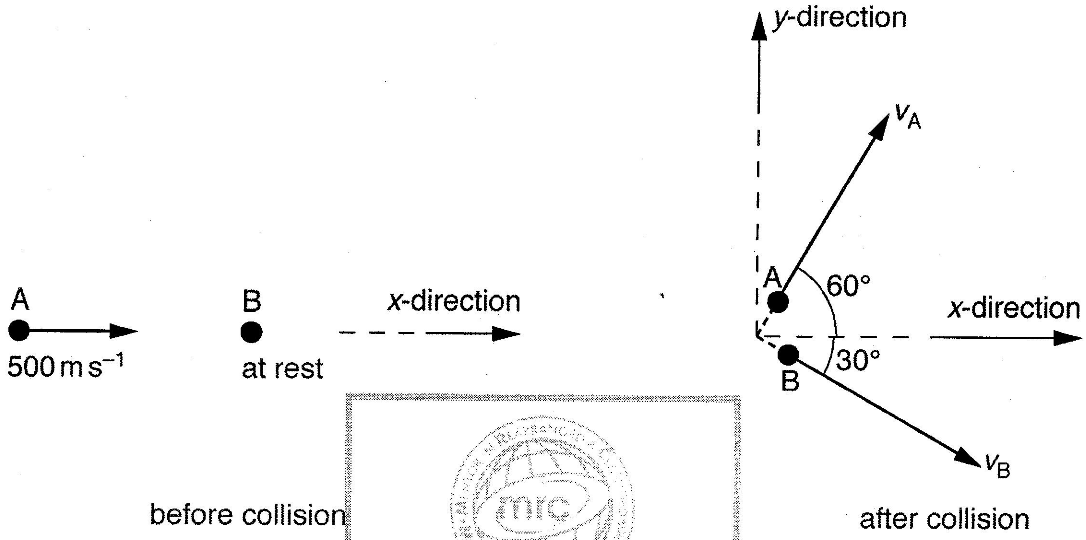

Fig. 5.1

The initial velocity of A is 500 m s^{-1} in the *x*-direction and B is at rest.

The velocity of A after the collision is v_A at 60° to the *x*-direction. The velocity of B after the collision is v_B at 30° to the *x*-direction.

The mass *m* of each particle is 1.67×10^{-27} kg.

(i) Explain what is meant by the particles colliding *elastically*.

.... [1]

(ii) Calculate the total initial momentum of A and B.

momentum = ... N s [1]

(iii) State an expression in terms of m, v_A and v_B for the total momentum of A and B after the collision

1. in the x-direction,

....

2. in the y-direction.

....
[2]

(iv) Calculate the magnitudes of the velocities v_A and v_B after the collision.

v_A = ... m s^{-1}

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

[Total: 9]

1 (a) A gas molecule has a mass of 6.64×10^{-27} kg and a speed of $1250\,\text{m s}^{-1}$. The molecule collides normally with a flat surface and rebounds with the same speed, as shown in Fig. 4.1.

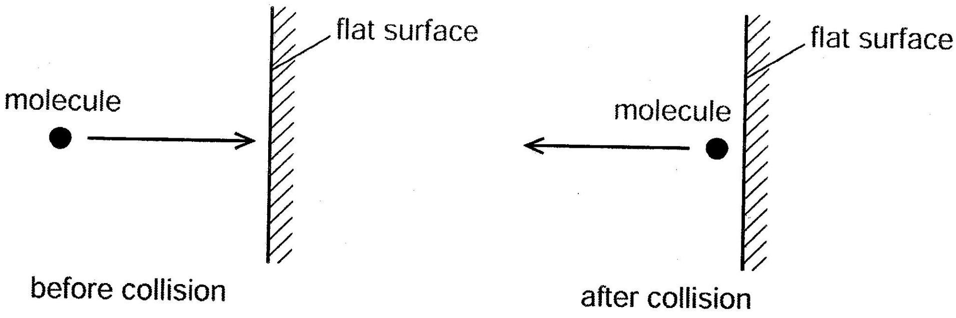

Fig. 4.1

Calculate the change in momentum of the molecule.

change in momentum = ... Ns [2]

(b) (i) Use the kinetic model to explain the pressure exerted by gases.

....

....

....

....

....

.... [3]

(ii) Explain the effect of an increase in density, at constant temperature, on the pressure of a gas.

....

.... [1]

12 Two balls X and Y are supported by long strings, as shown in Fig. 3.1.

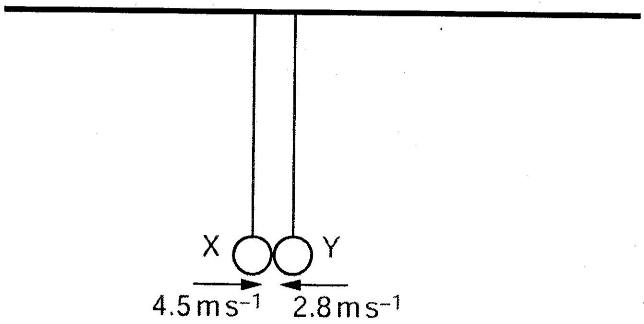

Fig. 3.1

The balls are each pulled back and pushed towards each other. When the balls collide at the position shown in Fig. 3.1, the strings are vertical. The balls rebound in opposite directions.

Fig. 3.2 shows data for X and Y during this collision.

ball	mass	velocity just before collision / m s^{-1}	velocity just after collision / m s^{-1}
X	50 g	+4.5	−1.8
Y	*M*	−2.8	+1.4

Fig. 3.2

The positive direction is horizontal and to the right.

(a) Use the conservation of linear momentum to determine the mass *M* of Y.

M = ... g [3]

(b) State and explain whether the collision is elastic.

....

....

.... [1]

(c) Use Newton's second and third laws to explain why the magnitude of the change in momentum of each ball is the same.

....

....

....

....

.... [3]

3 A ball is thrown vertically down towards the ground with an initial velocity of $4.23\,m\,s^{-1}$. The ball falls for a time of 1.51 s before hitting the ground. Air resistance is negligible.

For Examiner's Use

(a) **(i)** Show that the downwards velocity of the ball when it hits the ground is $19.0\,m\,s^{-1}$.

[2]

(ii) Calculate, to three significant figures, the distance the ball falls to the ground.

distance = ... m [2]

(b) The ball makes contact with the ground for 12.5 ms and rebounds with an upwards velocity of $18.6\,m\,s^{-1}$. The mass of the ball is 46.5 g.

(i) Calculate the average force acting on the ball on impact with the ground.

magnitude of force = ... N

direction of force ....

[4]

(ii) Use conservation of energy to determine the maximum height the ball reaches after it hits the ground.

height = ... m [2]

(c) State and explain whether the collision the ball makes with the ground is elastic or inelastic.

....

....

.... [1]

For Examiner's Use

14 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.

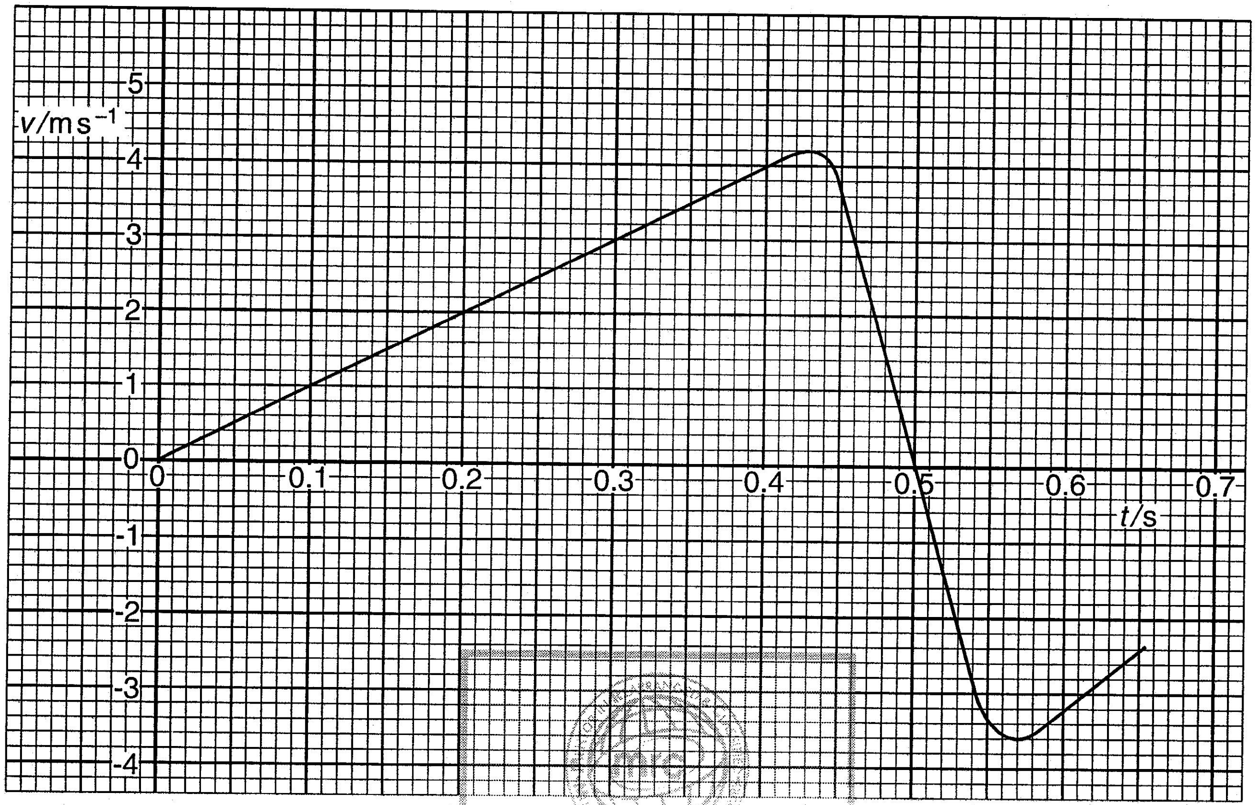

Fig. 3.1

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]

4 **(a)** Explain what is meant by the concept of *work*.

....

....

....[2]

(b) Using your answer to **(a)**, derive an expression for the increase in gravitational potential energy ΔE_p when an object of mass m is raised vertically through a distance Δh near the Earth's surface.

The acceleration of free fall near the Earth's surface is g. [2]

5 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.

For Examiner's Use

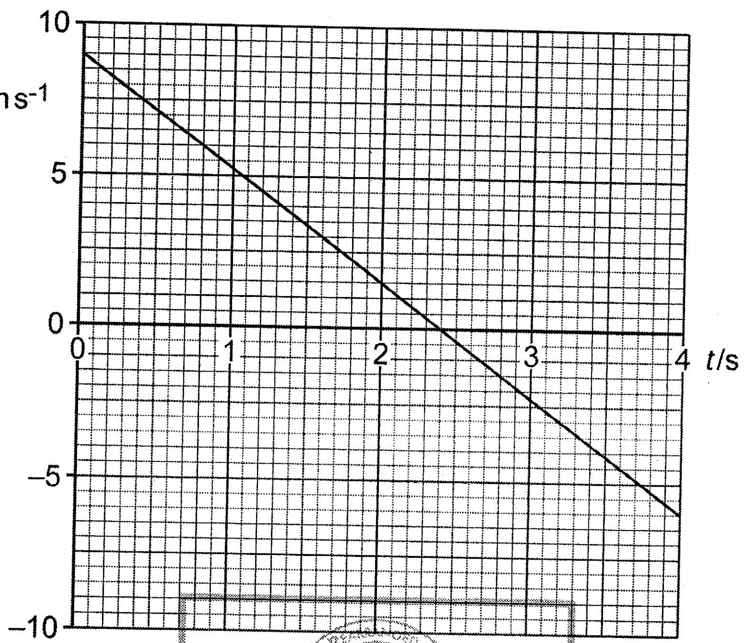

Fig. 2.1

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]

For Examiner's Use

(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]

16 **(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]

3 A ball of mass 150 g is at rest on a horizontal floor, as shown in Fig. 3.1.

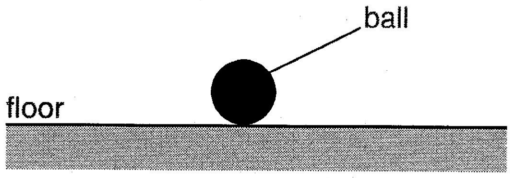

Fig. 3.1

(a) (i) Calculate the magnitude of the normal contact force from the floor acting on the ball.

force = ... N [1]

(ii) Explain your working in **(i)**.

....

....

....[1]

(b) The ball is now lifted above the floor and dropped so that it falls vertically, as illustrated in Fig. 3.2.

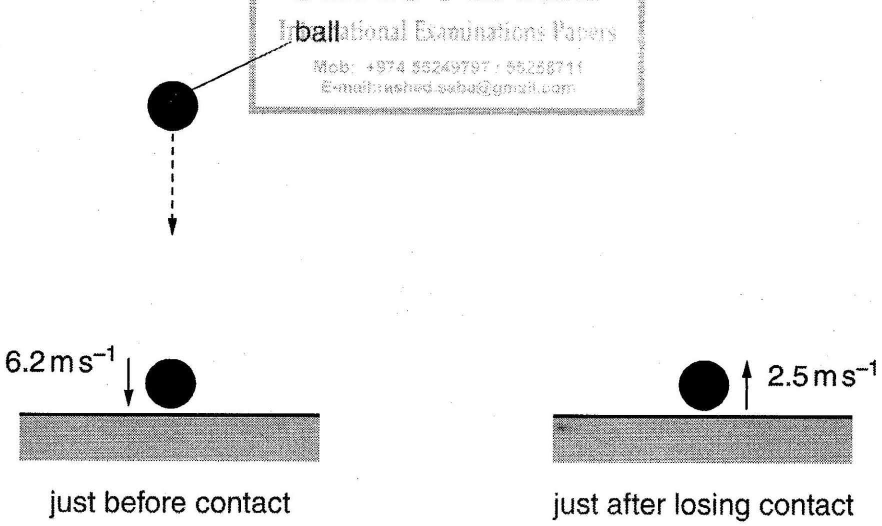

Fig. 3.2

Just before contact with the floor, the ball has velocity $6.2\,m\,s^{-1}$ downwards. The ball bounces from the floor and its velocity just after losing contact with the floor is $2.5\,m\,s^{-1}$ upwards. The ball is in contact with the floor for 0.12 s.

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

....

....[1]

(ii) Calculate the average resultant force on the ball when it is in contact with the floor.

magnitude of force = ... N

direction of force ....
[3]

(iii) State and explain whether linear momentum is conserved during the collision of the ball with the floor.

....

....

....

....[2]

[Total: 8]