5. Work, Energy and Power

5.2 Gravitational potential energy and kinetic energy

Paper 2

Question Paper

1 A pinball machine uses a spring to launch a small metal ball of mass 4.5×10^{-2} kg up a ramp. The spring is compressed by 8.0×10^{-2} m and held in equilibrium, as shown in Fig. 4.1.

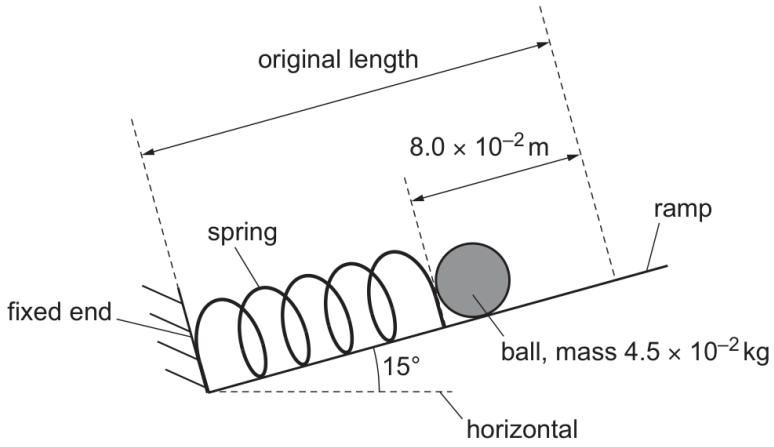


Fig. 4.1 (not to scale)

The ramp is at an angle of 15° to the horizontal.

(b) The spring is released and expands quickly back to its original length.

(i) Calculate the increase in gravitational potential energy of the ball when the spring returns to its original length.

increase in gravitational potential energy = ... J [3]

(ii) The ball leaves the spring when the spring reaches its original length. Assume that all the elastic potential energy of the spring is transferred to the ball.

Calculate the speed of the ball as it leaves the spring.

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

2 **(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.

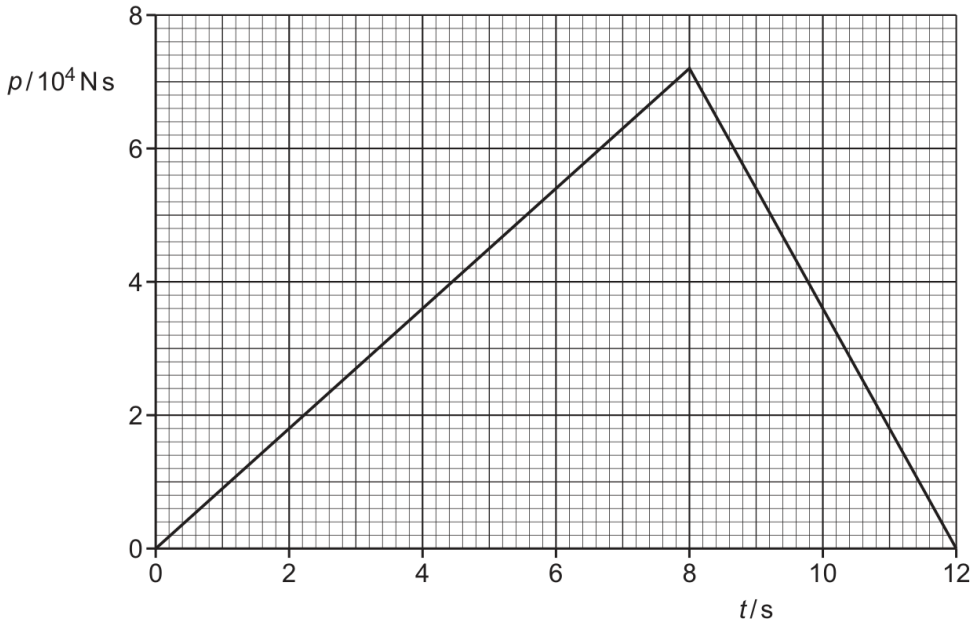


Fig. 2.1

(ii) Calculate the maximum kinetic energy of the car.

maximum kinetic energy = ... J [2]

3 **(b)** A block of mass m is raised vertically at constant speed. The vertical height gained by the block is Δh, as shown in Fig. 3.1.

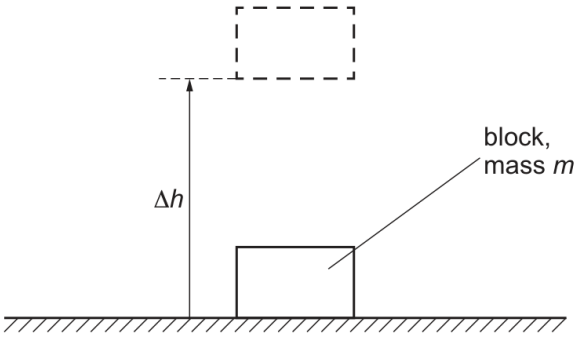


Fig. 3.1

Derive an expression, in terms of m and Δh, for the change in gravitational potential energy ΔE_P of the block. State the meaning of any other symbols you use.

[2]

4 **(d)** At point B, the child in **(c)** applies the brake with a constant force to maintain a constant velocity. Point C is 18 m from point B, as shown in Fig. 2.2.

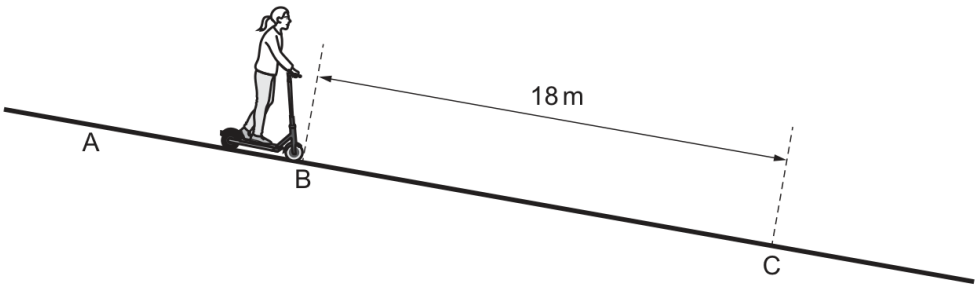


Fig. 2.2 (not to scale)

The work done by the braking force between B and C is 250 J.

(ii) On Fig. 2.3, sketch the variation of the kinetic energy of the child and scooter with distance travelled from point A to point C.
Numerical values for kinetic energy are not required.

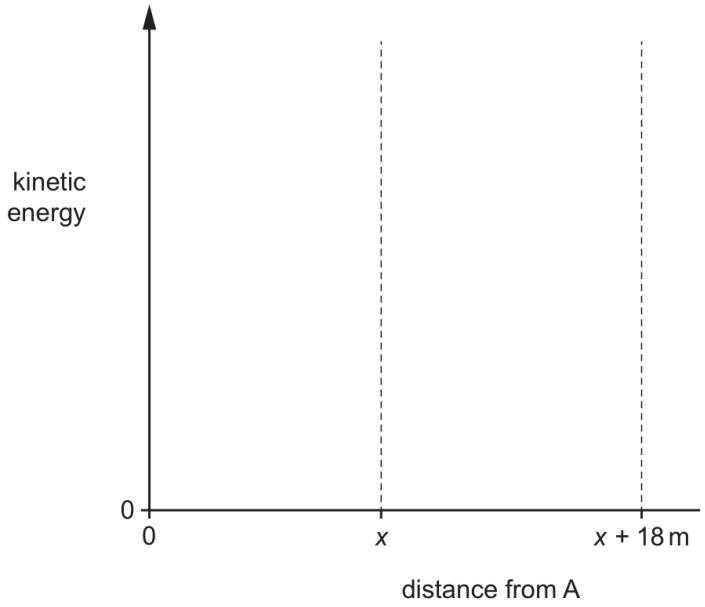


Fig. 2.3

[3]

5 **(c)** Before the α-decay, P is travelling at a constant velocity. After the decay, Q has a velocity of $1.3 \times 10^5\,m\,s^{-1}$ at an angle of 68° to the original path of P.
The α-particle has a velocity of $150 \times 10^5\,m\,s^{-1}$ at an angle of θ to the original path of P, as shown in Fig. 6.2.

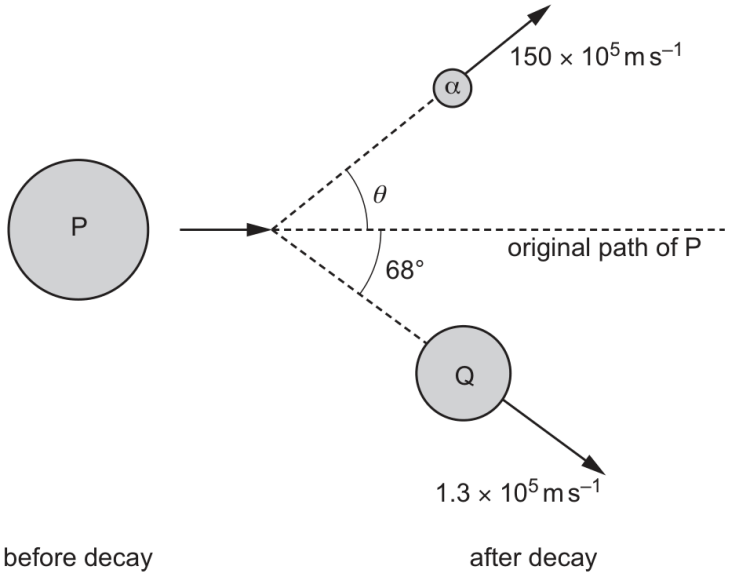


Fig. 6.2 (not to scale)

(ii) Calculate the kinetic energy of the α-particle.

kinetic energy = ... J [2]

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

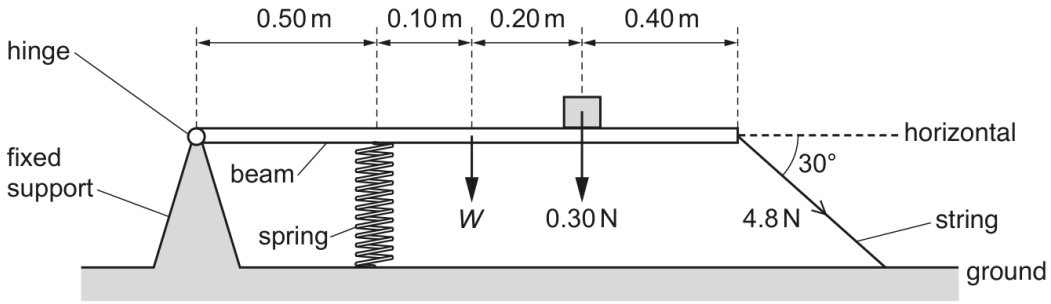


Fig. 2.1 (not to scale)

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.

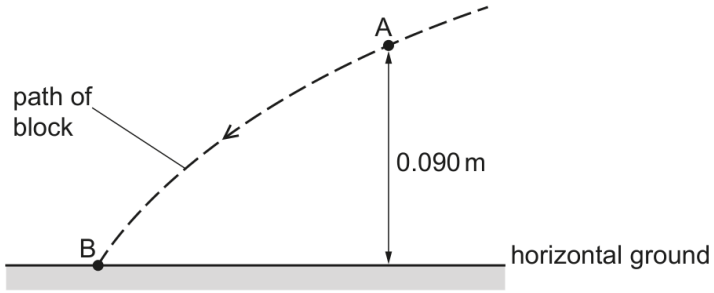


Fig. 2.2 (not to scale)

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.

(i) Calculate the decrease in the gravitational potential energy of the block for its movement from A to B.

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

(ii) Use your answer in **(c)(i)** and conservation of energy to determine the speed of the block at point A.

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

7 **(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.

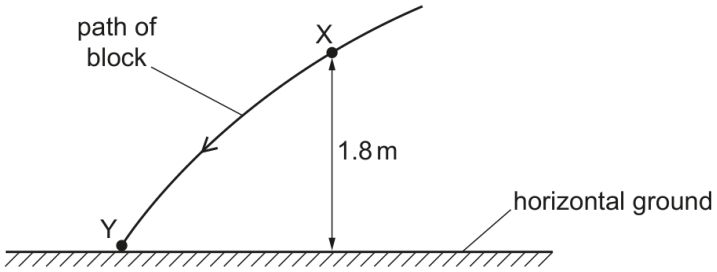


Fig. 2.2 (not to scale)

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.

(i) Calculate the decrease in the gravitational potential energy of the block for its movement from X to Y.

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

(ii) Use your answer to **(c)(i)** and conservation of energy to determine the kinetic energy of the block at Y.

kinetic energy = ... J [3]

8 A vertical rod is fixed to the horizontal surface of a table, as shown in Fig. 3.1.

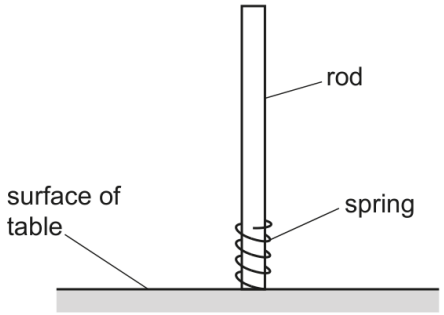


Fig. 3.1 (not to scale)

A spring of mass 7.5 g is able to slide along the full length of the rod.

The spring is first pushed against the surface of the table so that it has an initial compression of 2.1 cm. The spring is then suddenly released so that it leaves the surface of the table with a kinetic energy of 0.048 J and then moves up the rod.

Assume that the spring obeys Hooke's law and that the initial elastic potential energy of the compressed spring is equal to the kinetic energy of the spring as it leaves the surface of the table. Air resistance is negligible.

(b) Calculate the speed of the spring as it leaves the surface of the table.

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

(c) The spring rises to its maximum height up the rod from the surface of the table. This causes the gravitational potential energy of the spring to increase by 0.039 J.

(i) Calculate, for this movement of the spring, the increase in height of the spring after leaving the surface of the table.

increase in height = ... m [2]

9 A sphere is attached by a metal wire to the horizontal surface at the bottom of a river, as shown in Fig. 2.1.

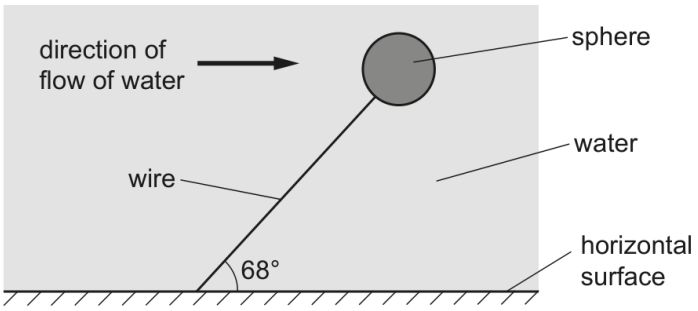


Fig. 2.1 (not to scale)

The sphere is fully submerged and in equilibrium, with the wire at an angle of 68° to the horizontal surface. The weight of the sphere is 32 N. The upthrust acting on the sphere is 280 N. The density of the water is 1.0×10^3 kg m^{-3}.

Assume that the force on the sphere due to the water flow is in a horizontal direction.

(c) The centre of the sphere is initially at a height of 6.2 m above the horizontal surface. The speed of the water then increases, causing the sphere to move to a different position. This movement of the sphere causes its gravitational potential energy to decrease by 77 J.

Calculate the final height of the centre of the sphere above the horizontal surface.

height = ... m [3]

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

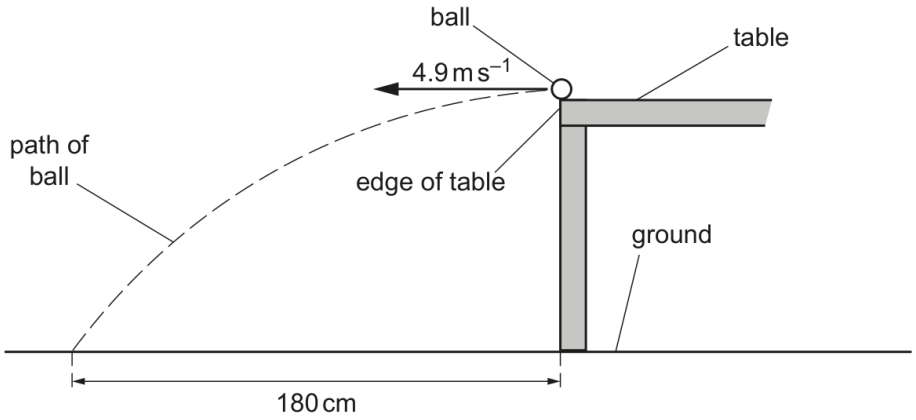


Fig. 2.1 (not to scale)

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.

(b) The ball is projected by means of a compressed spring which is attached to a fixed block as shown in Fig. 2.2.

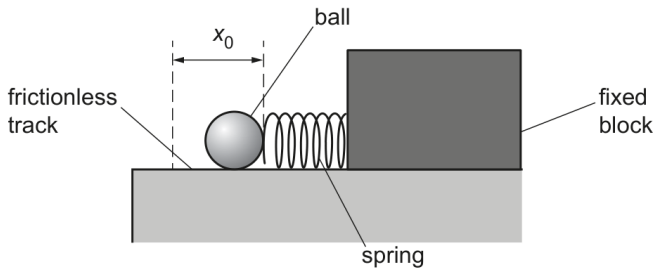


Fig. 2.2

The ball is placed on a frictionless track in front of the spring. The ball is then pulled back so that the spring has compression x_0.

When the spring is released, the ball is projected horizontally as shown in Fig. 2.3.

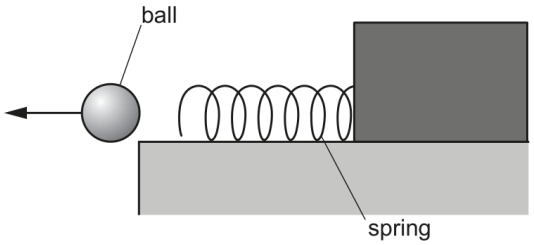


Fig. 2.3

The variation with compression x of the applied force F for the spring is shown in Fig. 2.4.

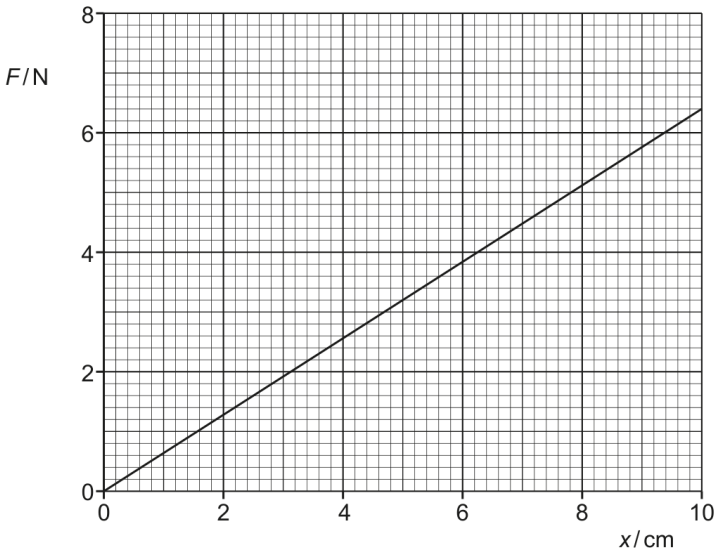


Fig. 2.4

The ball is a uniform sphere of steel of diameter 0.016 m and mass 0.017 kg.

(ii) All of the elastic potential energy in the spring is converted into kinetic energy of the ball. The speed of the ball as it leaves the spring is $4.9\,m\,s^{-1}$.

Show that the maximum elastic potential energy of the spring is 0.20 J.

[2]

(c) The steel ball is replaced by a polystyrene ball of the same diameter but of much lower mass. The spring is given compression x_0 and is then released.

Air resistance on this ball is **not** negligible after it leaves the spring.

Explain:

(i) why this ball leaves the spring with a greater speed than that of the steel ball

.....

.....

..... [1]

11 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.

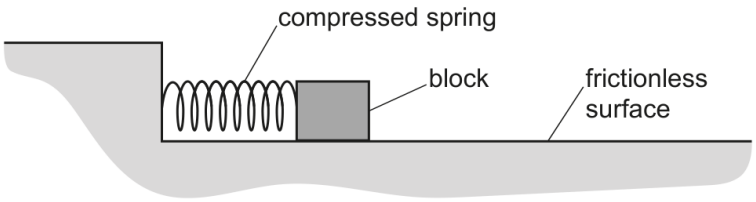


Fig. 4.1

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.

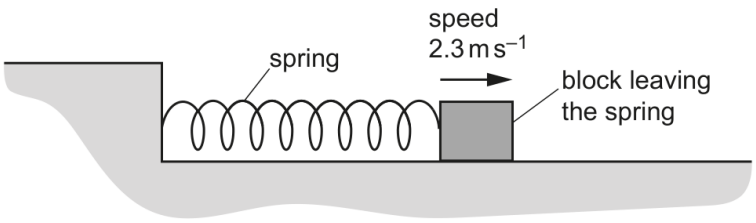


Fig. 4.2

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.

(a) Calculate the kinetic energy of the block as it leaves the spring.

kinetic energy = ... J [2]

12 A pendulum consists of a solid sphere suspended by a string from a fixed point P, as shown in Fig. 3.1.

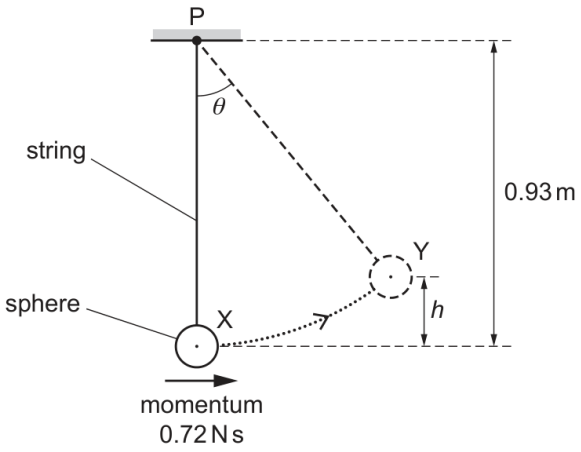


Fig. 3.1 (not to scale)

The sphere swings from side to side. At one instant the sphere is at its lowest position X, where it has kinetic energy 0.86 J and momentum 0.72 N s in a horizontal direction. A short time later the sphere is at position Y, where it is momentarily stationary at a maximum vertical height *h* above position X.

The string has a fixed length and negligible weight. Air resistance is also negligible.

(b) Show that the mass of the sphere is 0.30 kg.

[3]

(c) Calculate height *h*.

h = ... m [2]

13 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.

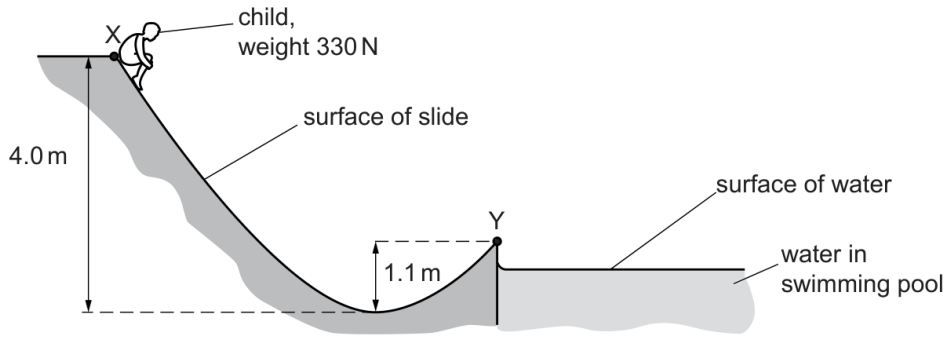


Fig. 3.1 (not to scale)

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.

(a) Calculate the difference in the gravitational potential energy of the child at points X and Y.

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

(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.

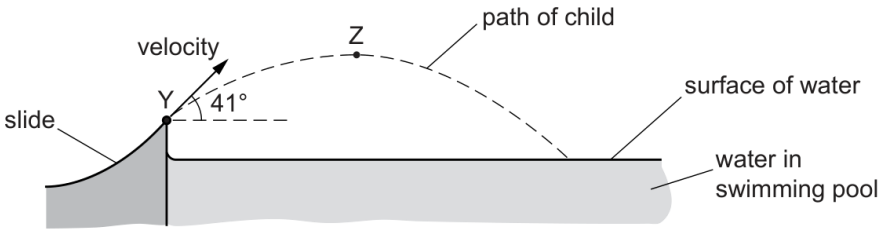


Fig. 3.2 (not to scale)

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:

(i) point Y

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

14 (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.

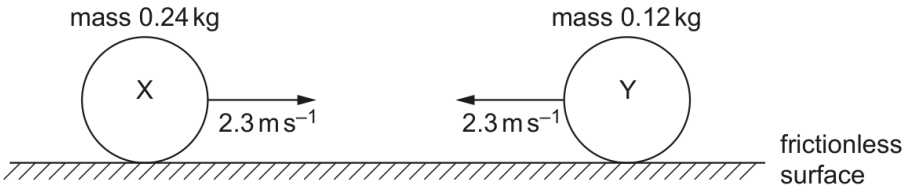


Fig. 2.1

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.

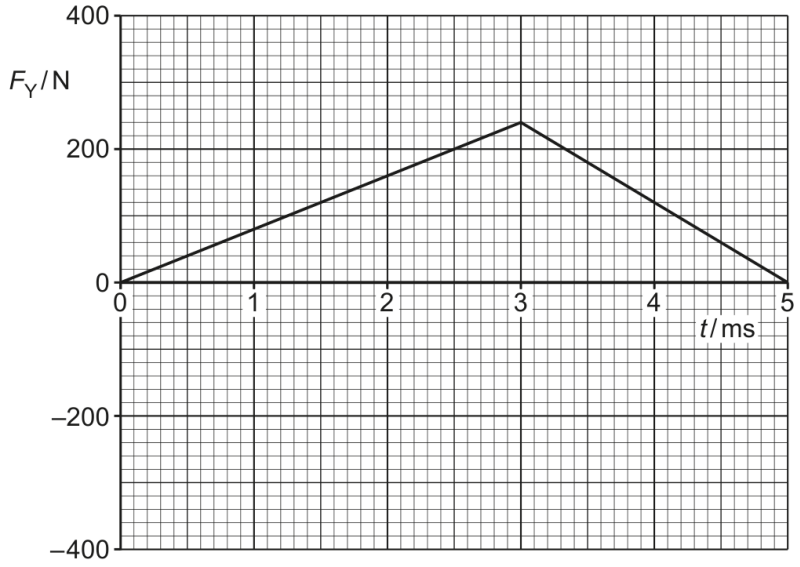


Fig. 2.2

(i) Calculate the kinetic energy of ball X before the collision.

kinetic energy = ... J [3]

15 (b) A car of mass 1700 kg moves in a straight line along a slope that is at an angle θ to the horizontal, as shown in Fig. 3.1.

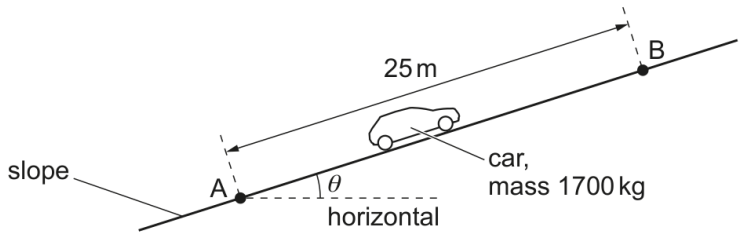


Fig. 3.1 (not to scale)

The car moves at constant velocity for a distance of 25 m from point A to point B.
Air resistance and friction provide a total resistive force of 440 N that opposes the motion of the car.

For the movement of the car from A to B:

(i) state the change in the kinetic energy

change in kinetic energy = ... J [1]

(c) The movement of the car in **(b)** from A to B causes its gravitational potential energy to increase by 4.8×10^4 J.

Calculate:

(i) the increase in vertical height h of the car for its movement from A to B

h = ... m [2]

16 A stationary nucleus P of mass 243 u decays by emitting an α-particle of mass 4 u to form a different nucleus Q, as illustrated in Fig. 7.1.

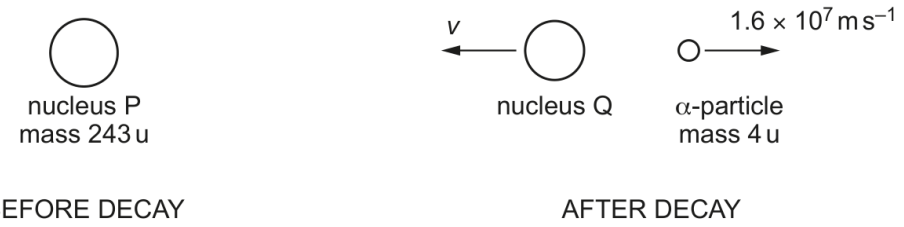


Fig. 7.1

The initial speed of the α-particle is $1.6 \times 10^7\,\text{m s}^{-1}$.

(c) Calculate the initial kinetic energy, in MeV, of the α-particle.

kinetic energy = ... MeV [3]

17 (c) The string is disconnected from the sphere in **(b)**. The sphere then swings from its initial rest position A, as illustrated in Fig. 3.2.

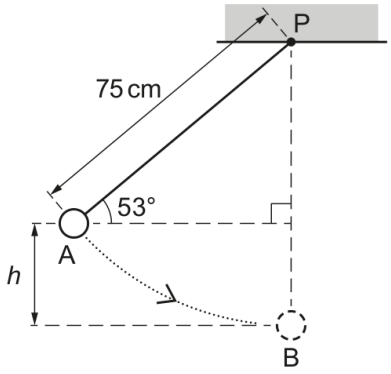


Fig. 3.2 (not to scale)

The sphere reaches maximum speed when it is at the bottom of the swing at position B. The distance between P and the centre of the sphere is 75 cm.
Air resistance is negligible and energy losses at P are negligible.

(i) Show that the vertical distance *h* between A and B is 15 cm.

[1]

(ii) Calculate the change in gravitational potential energy of the sphere as it moves from A to B.

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

(iii) Use your answer in **(c)(ii)** to determine the speed of the sphere at B.
Show your working.

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

18 (b) A ball of mass 0.42 kg is dropped from the top of a building. The ball falls from rest through a vertical distance of 78 m to the ground. Air resistance is significant so that the ball reaches constant (terminal) velocity before hitting the ground. The ball hits the ground with a speed of 23 $m\,s^{-1}$.

(i) Calculate, for the ball falling from the top of the building to the ground:

1. the decrease in gravitational potential energy

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

2. the increase in kinetic energy.

increase in kinetic energy = ... J [2]

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

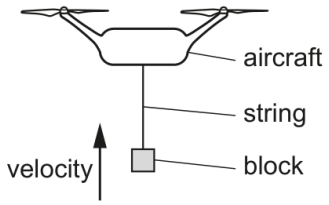


Fig. 2.1

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.

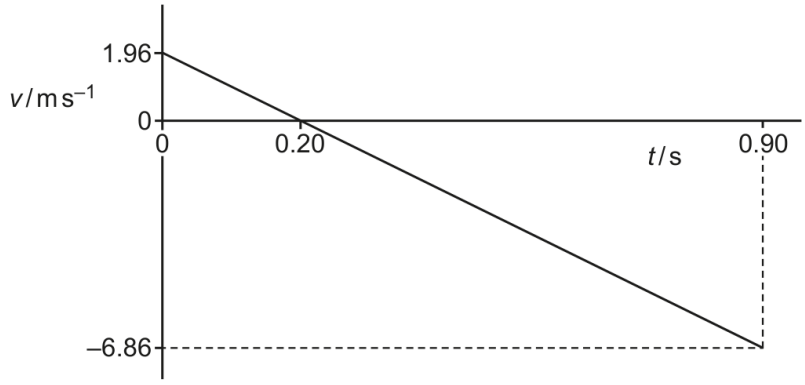


Fig. 2.2

Air resistance is negligible.

(c) The block has a weight of 0.86 N.

Calculate the difference in gravitational potential energy of the block between time $t = 0$ and time $t = 0.90$ s.

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

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

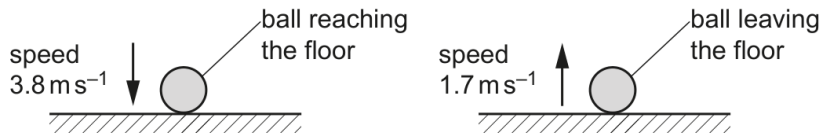


Fig. 3.1

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.

(i) Calculate the loss of kinetic energy of the ball during the collision.

loss of kinetic energy = ... J [2]

21 (c) The ball in **(b)** leaves the toy at point A and moves vertically upwards through the air. Point B is the position of the ball when it is at maximum height *h* above point A, as illustrated in Fig. 3.2.

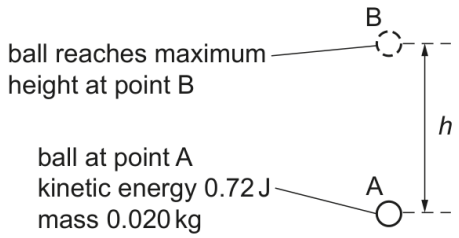


Fig. 3.2 (not to scale)

The gravitational potential energy of the ball increases by 0.60 J as it moves from A to B.

(i) Calculate *h*.

h = ... m [2]

22 The variation with extension x of the force F acting on a spring is shown in Fig. 3.1.

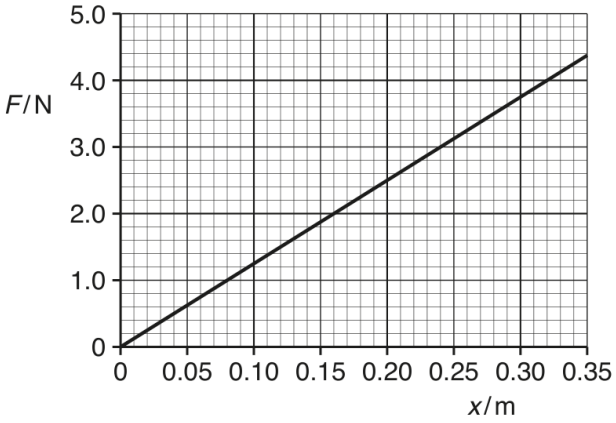


Fig. 3.1

The spring of unstretched length 0.40 m has one end attached to a fixed point, as shown in Fig. 3.2.

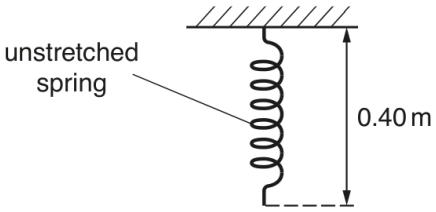


Fig. 3.2

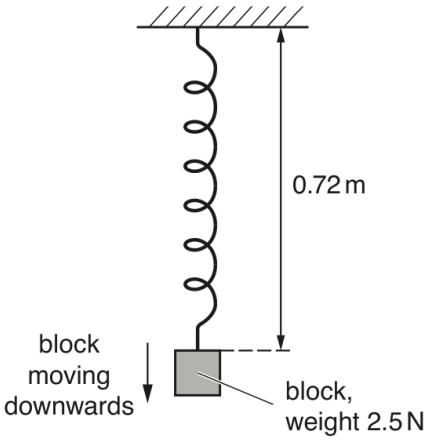


Fig. 3.3

A block of weight 2.5 N is then attached to the spring. The block is then released and begins to move downwards. At one instant, as the block is continuing to move downwards, the spring has a length of 0.72 m, as shown in Fig. 3.3.

Assume that the air resistance and the mass of the spring are both negligible.

(a) For the change in length of the spring from 0.40 m to 0.72 m:

(i) use Fig. 3.1 to show that the increase in elastic potential energy of the spring is 0.64 J

[2]

(ii) calculate the decrease in gravitational potential energy of the block of weight 2.5 N.

decrease in potential energy = ... J [2]

(b) Use the information in **(a)(i)** and your answer in **(a)(ii)** to determine, for the instant when the length of the spring is 0.72 m:

(ii) the speed of the block.

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

23 The variation with extension x of the force F applied to a spring is shown in Fig. 4.1.

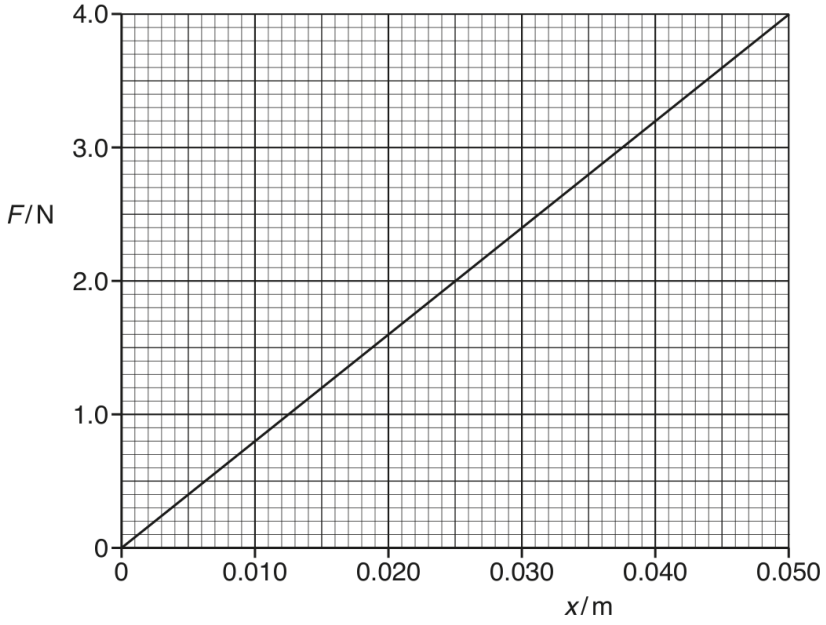


Fig. 4.1

The spring has an unstretched length of 0.080 m and is suspended vertically from a fixed point, as shown in Fig. 4.2.

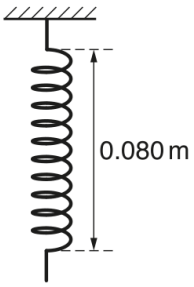


Fig. 4.2

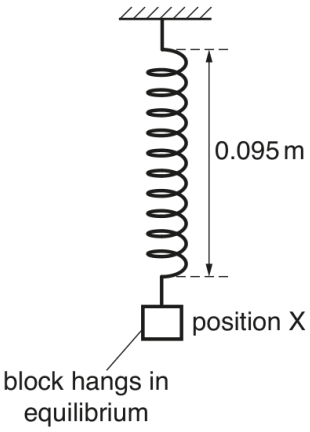


Fig. 4.3

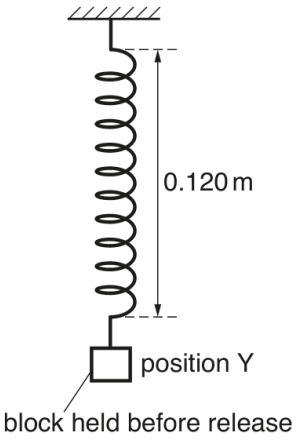


Fig. 4.4

A block is attached to the lower end of the spring. The block hangs in equilibrium at position X when the length of the spring is 0.095 m, as shown in Fig. 4.3.

The block is then pulled vertically downwards and held at position Y so that the length of the spring is 0.120 m, as shown in Fig. 4.4. The block is then released and moves vertically upwards from position Y back towards position X.

(b) Use Fig. 4.1 to show that the decrease in elastic potential energy of the spring is 0.055 J when the block moves from position Y to position X.

[2]

(c) The block has a mass of 0.122 kg. Calculate the increase in gravitational potential energy of the block for its movement from position Y to position X.

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

(d) Use the decrease in elastic potential energy stated in **(b)** and your answer in **(c)** to determine, for the block, as it moves through position X:

(i) its kinetic energy

kinetic energy = ... J [1]

(ii) its speed.

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

24 A β^- particle from a radioactive source is travelling in a vacuum with kinetic energy 460 eV. The particle enters a uniform electric field at a right-angle and follows the path shown in Fig. 7.1.

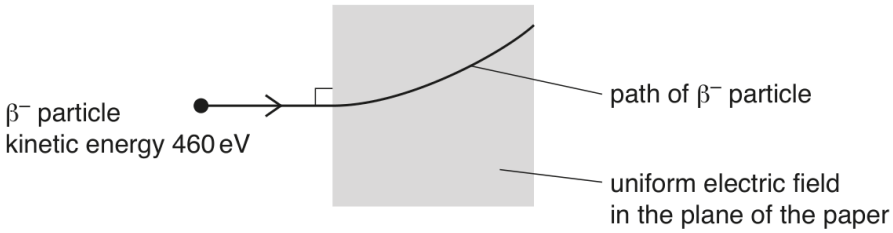


Fig. 7.1

(b) Calculate the speed of the β^- particle before it enters the electric field.

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

25 (b) A stationary firework explodes into three different fragments that move in a horizontal plane, as illustrated in Fig. 2.1.

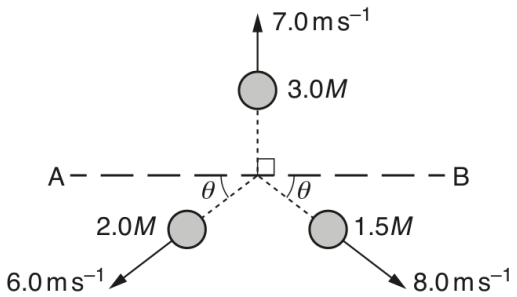


Fig. 2.1

The fragment of mass $3.0M$ has a velocity of $7.0\,\text{m s}^{-1}$ perpendicular to line AB.
The fragment of mass $2.0M$ has a velocity of $6.0\,\text{m s}^{-1}$ at angle θ to line AB.
The fragment of mass $1.5M$ has a velocity of $8.0\,\text{m s}^{-1}$ at angle θ to line AB.

(ii) Calculate the ratio

$$\frac{\text{kinetic energy of fragment of mass } 2.0M}{\text{kinetic energy of fragment of mass } 1.5M}.$$

ratio = ...[2]

26 **(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.

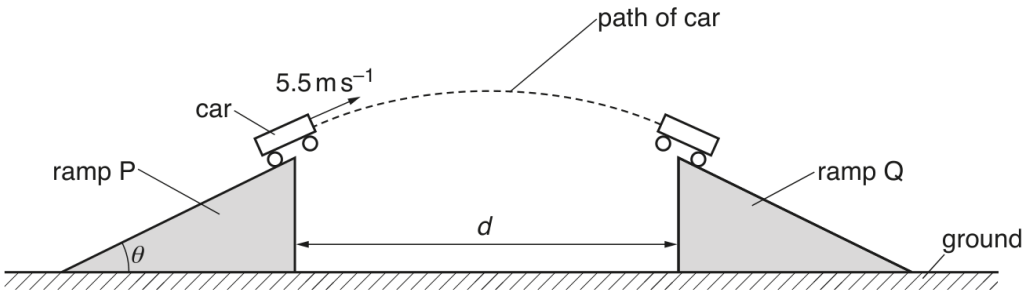


Fig. 1.1

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.

(iv) Calculate the ratio

$$\frac{\text{kinetic energy of the car at its maximum height}}{\text{kinetic energy of the car as it leaves ramp P}}.$$

ratio = ... [3]

27 (a) (ii) State what is meant by *gravitational potential energy*.

.....

..... [1]

28 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.

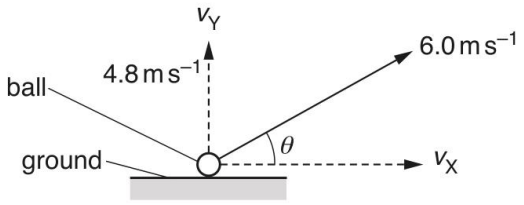


Fig. 1.1 (not to scale)

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

(d) For the movement of the ball from the ground to its maximum height, determine the ratio

$$\frac{\text{kinetic energy at maximum height}}{\text{change in gravitational potential energy}}.$$

ratio = ...[4]