5. Work, Energy and Power

5.1 Energy conservation

Paper 2

Question Paper

1 **(b)** A square solar panel with sides of length 1300 mm is shown in Fig. 1.1.

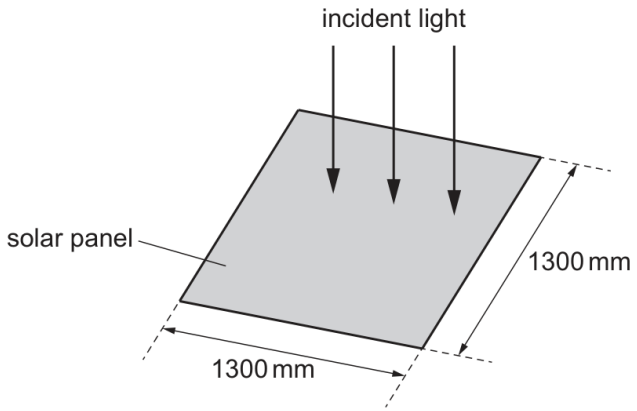


Fig. 1.1 (not to scale)

Light is incident normally on the solar panel.

(iii) The useful power output of the solar panel is 160 W.

Calculate the percentage efficiency of the solar panel.

efficiency = ... % [1]

(iv) Another square solar panel is placed so that light of the same intensity is incident normally on it. The new panel has shorter sides than the original panel. The new panel has the same power output as the original panel.

State and explain whether the efficiency of the new panel is greater than, less than or the same as the efficiency of the original panel.

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.....

.....

..... [3]

2 **(a)** State what is meant by the work done by a force.

.....

..... [1]

(c) An electric motor has an input power of 900 W. The motor takes 1.0 minute to lift a load of weight 240 N at constant speed through a vertical height of 150 m. Resistive forces are negligible.

(i) Show that the work done by the motor on the load in 1.0 minute is 36 kJ.

[1]

(ii) Determine the useful output power of the motor.

power = ... W [2]

(iii) Use your answer in **(c)(ii)** to determine the efficiency of the motor.

efficiency = ... [2]

3 **(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.

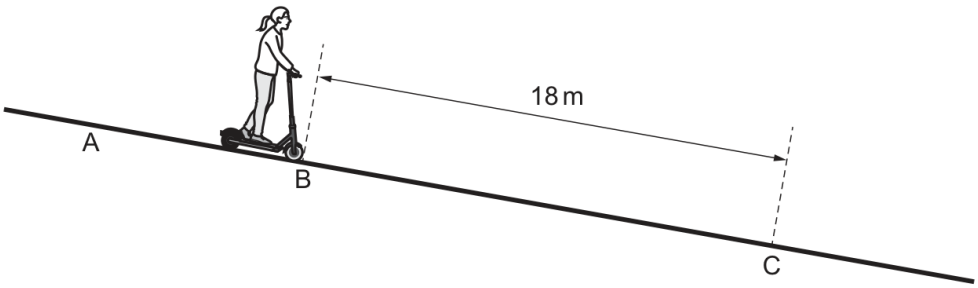


Fig. 2.2 (not to scale)

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

(i) Determine the magnitude of the braking force.

force = ... N [2]

4 **(b)** A power supply, three resistors and a component X are connected in the circuit shown in Fig. 5.1.

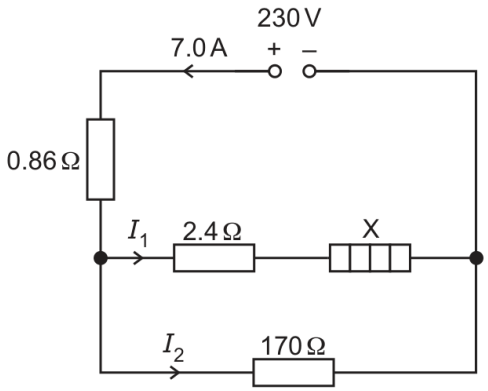


Fig. 5.1

The power supply has an electromotive force (e.m.f.) of 230 V and negligible internal resistance. The current in the power supply is 7.0 A.

(vi) The purpose of the circuit is to provide power to component X.

Determine the percentage efficiency of the circuit.

efficiency = ...% [2]

5 **(a)** **(i)** Define power.

.....

..... [1]

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

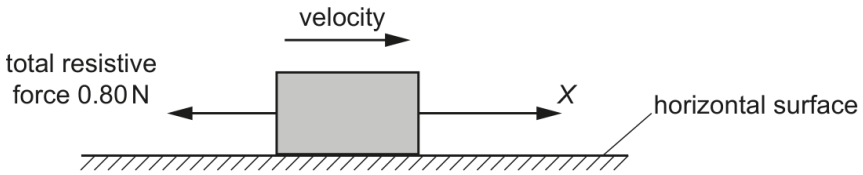


Fig. 3.1

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.

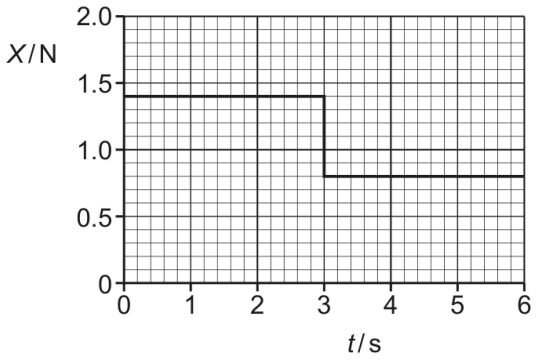


Fig. 3.2

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

.....

.....

.....

..... [2]

(ii) Force *X* produces a total power of 2.0 W when moving the block between time $t = 3.0$ s and time $t = 6.0$ s.

Calculate the distance moved by the block during this time interval.

distance = ... m [3]

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

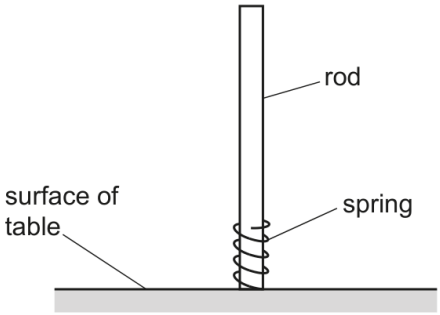


Fig. 3.1 (not to scale)

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.

(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.

(ii) Calculate the average frictional force exerted by the rod on the spring as it rises.

average frictional force = ... N [2]

8 **(a)** **(i)** Define power.

.....

..... [1]

(ii) A force F takes time t to move an object through a displacement x at constant velocity v in the direction of the force. The work done by the force is W.

Use the definition of power to show that the power P transferred by the force is given by

$$P = Fv.$$

[2]

(b) A block is pulled up a slope by a wire attached to a motor, as shown in Fig. 3.1.

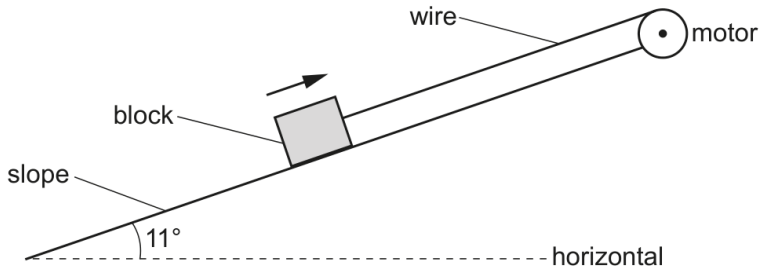


Fig. 3.1 (not to scale)

The useful power output of the motor is 56 W. The block has a weight of 430 N and travels with constant velocity along the slope at an angle of 11° to the horizontal.

Assume that there are no resistive forces opposing the motion of the block.

(ii) Calculate the speed of the block.

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

(iii) The rate of increase of gravitational potential energy of the block is equal to the useful power output of the motor. One of the reasons for this is that there is no work done against resistive forces.

By considering the motion of the block, state another reason for this.

.....

..... [1]

(iv) The motor has an efficiency of 80%.

Calculate the time taken for an input energy of 1.2 kJ to be supplied to the motor.

time taken = ... s [2]

9 **(a)** **(i)** Define power.

.....

..... [1]

(ii) Mechanical power P can be calculated using the formula $P = Fv$.

Use the concept of work and the definition of power to show how this formula is derived.

[2]

(b) The engine of a lorry provides 130 kW of power to the lorry's wheels when it is travelling at a constant speed of 25 m s^{-1} along a straight horizontal road.

Show that the resistive force opposing the forward motion of the lorry is 5200 N.

[1]

(c) The lorry in **(b)** travels up a straight section of road that is inclined at an angle θ to the horizontal, as shown in Fig. 3.1.

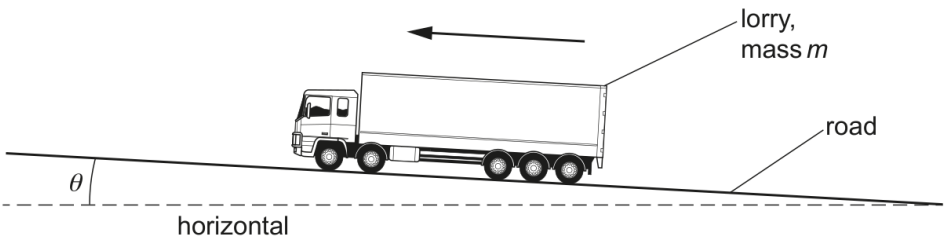


Fig. 3.1 (not to scale)

The lorry has mass m and the acceleration of free fall is g.

(ii) The total resistive force remains unchanged at 5200 N and the engine now provides greater power to maintain the speed of 25 m s^{-1}. The total mass m of the lorry is 36 000 kg. The angle θ is 1.4°.

Determine the power, in kW, now provided by the engine.

power = ... kW [3]

10 (a) State what is meant by work done.

.....

..... [1]

11 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.

(i) Calculate the power required to overcome the total resistive force on the trolley and suitcases when they move with a constant speed of $1.4\,m\,s^{-1}$.

power = ... W [2]

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

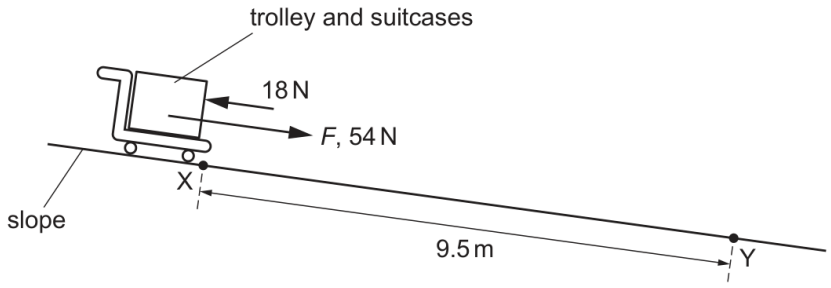


Fig. 2.1 (not to scale)

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.

(ii) Calculate the work done by *F* for the movement of the trolley from X to Y.

work done = ... J [1]

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

On Fig. 2.2, sketch a graph to show the variation with time t of the work done by F for the movement of the trolley from X to Y.
Numerical values of the work done and t are not required.

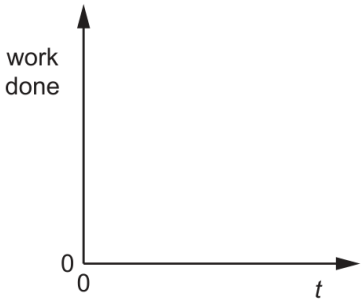


Fig. 2.2

[2]

12 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.

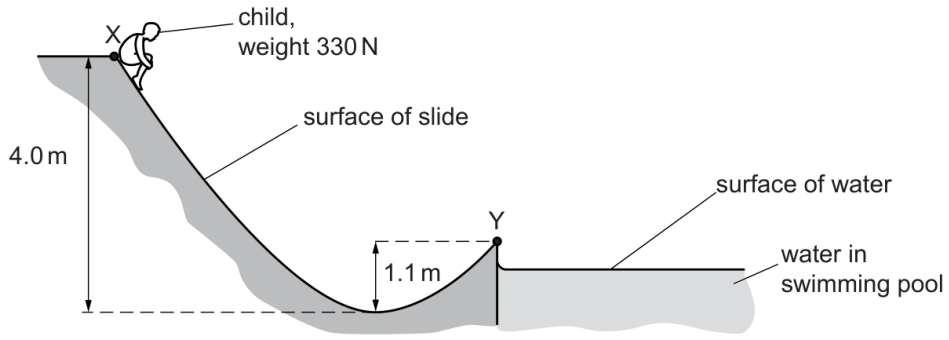


Fig. 3.1 (not to scale)

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.

(b) An average frictional force of 52 N acts on the child when moving from X to Y.

By considering changes of energy, determine the distance moved by the child from X to Y.

distance moved = ... m [2]

13 **(a)** Define *power*.

.....

..... [1]

(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.

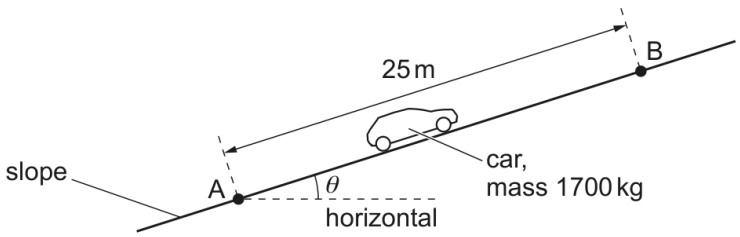


Fig. 3.1 (not to scale)

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:

(ii) calculate the work done against the total resistive force.

work done = ... J [1]

(d) The engine of the car in **(b)** produces an output power of 1.7×10^4 W to move the car along the slope.

Calculate the time taken for the car to move from A to B.

time = ... s [2]

14 A cell of electromotive force (e.m.f.) 0.48 V is connected to a metal wire X, as shown in Fig. 6.1.

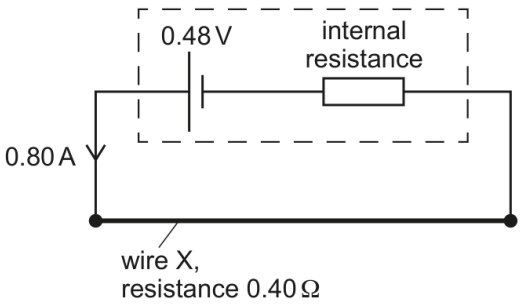


Fig. 6.1

The cell has internal resistance. The current in the cell is 0.80 A.

Wire X has length 3.0 m, cross-sectional area 1.3×10^{-7} m^2 and resistance 0.40 Ω.

(b) Calculate the percentage efficiency with which the cell supplies power to wire X.

efficiency = ... % [3]

15 (c) Another parcel is accidentally released from rest by a different aircraft when it is hovering at a great height above the ground. Air resistance is now significant.

(iii) Describe the energy conversion that occurs when the parcel is falling through the air at constant (terminal) speed.

.....

..... [1]

16 (c) The value of k, in SI base units, for the car in **(b)** is 0.24. The cross-sectional area A of the car is $5.1\,m^2$.

The car is travelling with a constant speed along a straight road and the output power of the engine is 4.8×10^4 W. Assume that the output power of the engine is equal to the rate at which the drag force F_D is doing work against the car.

Determine the speed of the car.

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

17 **(a)** Explain what is meant by *work done*.

.....

..... [1]

(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 $m\,s^{-1}$.

(ii) Use your answers in **(b)(i)** to determine the average resistive force acting on the ball as it falls from the top of the building to the ground.

average resistive force = ... N [2]

18 **(a)** A spring is fixed at one end and is compressed by applying a force to the other end. The variation of the force F acting on the spring with its compression x is shown in Fig. 3.1.

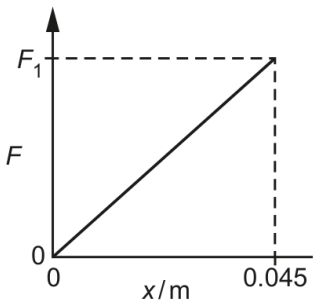


Fig. 3.1

A compression of 0.045 m is produced when a force F_1 acts on the spring. The spring has a spring constant of 800 N m^{-1}.

(ii) Use Fig. 3.1 to show that, for a compression of 0.045 m, the elastic potential energy of the spring is 0.81 J.

(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.

(i) The toy converts the elastic potential energy of the spring into the kinetic energy of the ball. Use the information in **(a)(ii)** to calculate the percentage efficiency of this conversion.

efficiency = ... % [1]

(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.

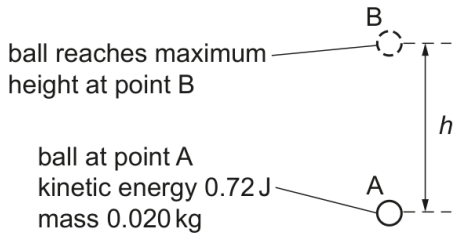


Fig. 3.2 (not to scale)

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

(ii) Determine the average force due to air resistance acting on the ball for its movement from A to B.

average force = ... N [2]

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

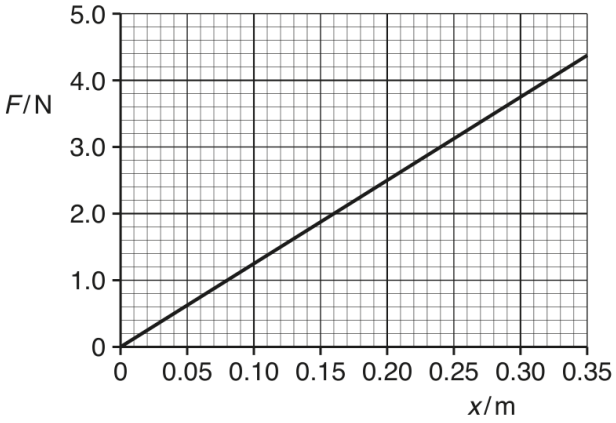


Fig. 3.1

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

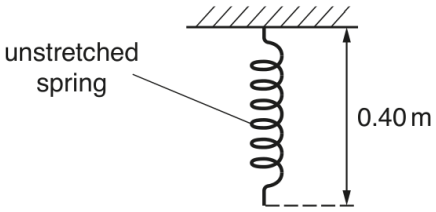


Fig. 3.2

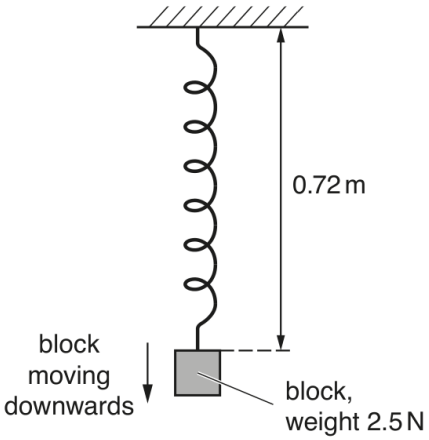


Fig. 3.3

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

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

(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:

(i) the kinetic energy of the block

kinetic energy = ... J [1]

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

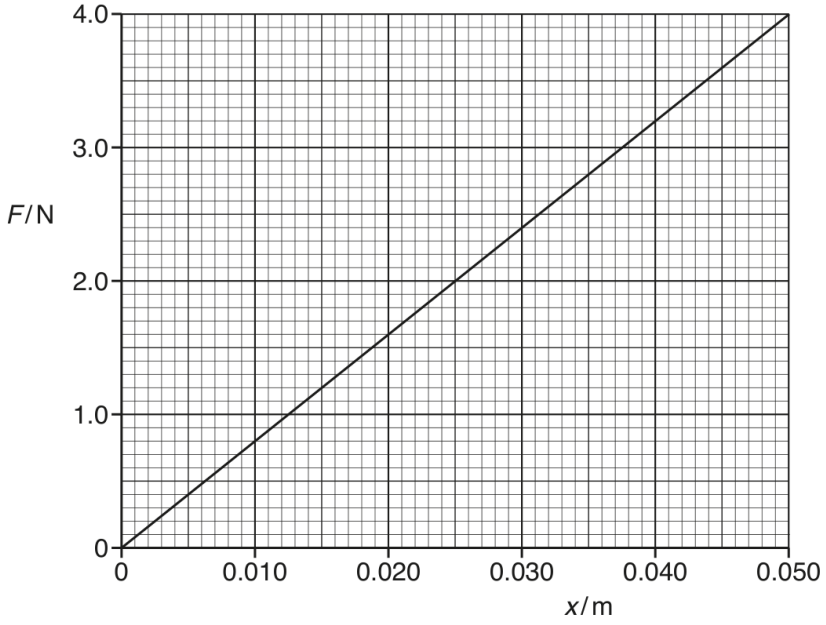


Fig. 4.1

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

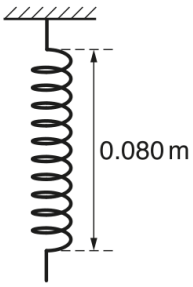


Fig. 4.2

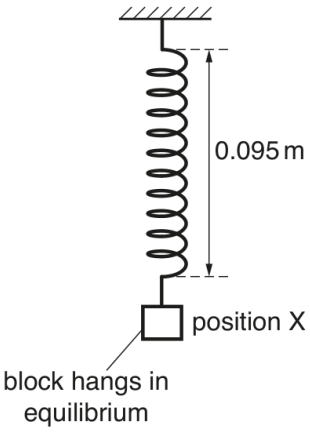


Fig. 4.3

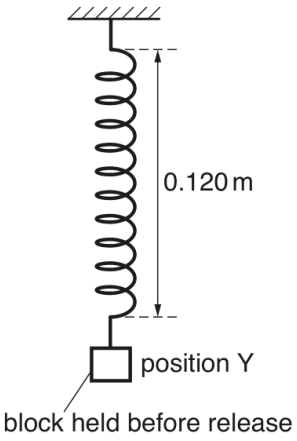


Fig. 4.4

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.

(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.

(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]

21 A nucleus of plutonium-238 ($^{238}_{94}$Pu) decays by emitting an α-particle to produce a new nucleus X and 5.6 MeV of energy. The decay is represented by

$$^{238}_{94}\text{Pu} \rightarrow \text{X} + \alpha + 5.6\,\text{MeV}.$$

(b) Calculate the number of plutonium-238 nuclei that must decay in a time of 1.0 s to produce a power of 0.15 W.

number = ... [2]

22 A solid cylinder is lifted out of oil by a wire attached to a motor. Fig. 5.1 shows two different positions X and Y of the cylinder during the lifting process.

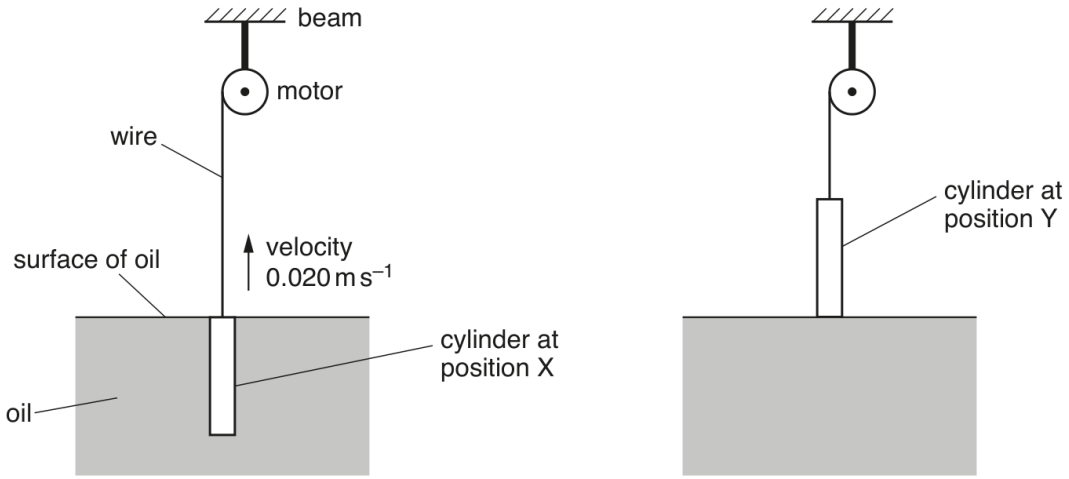


Fig. 5.1

The motor is fixed to an overhead beam.
The cylinder has cross-sectional area 0.018 m^2, length 1.2 m and weight 560 N.
The density of the oil is 940 kg m^{-3}.

Throughout the lifting process, the cylinder moves vertically upwards with a constant velocity of 0.020 m s^{-1}. The viscous force of the oil acting on the cylinder is negligible.

(c) Calculate, for the moving cylinder at position X,

(ii) the power output of the motor.

power = ... W [2]

(d) The cylinder is raised with constant velocity from position X to position Y.

(i) State and explain the variation, if any, of the power output of the motor as the cylinder is raised. Numerical values are not required.

.....

.....

.....

.....

.....[3]

(ii) The rate of energy output of the motor is less than the rate of increase of gravitational potential energy of the cylinder. Without calculation, explain this difference.

.....

.....[1]

23 (a) (i) Define *power*.

.....

..... [1]

(b) An aircraft of mass 1200 kg climbs upwards with a constant velocity of 45 m s^{-1}, as shown in Fig. 3.1.

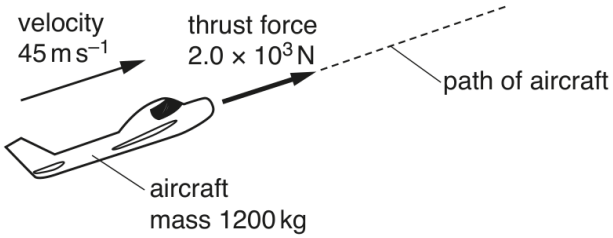


Fig. 3.1 (not to scale)

The aircraft's engine produces a thrust force of 2.0 × 10^3 N to move the aircraft through the air. The rate of increase in height of the aircraft is 3.3 m s^{-1}.

(i) Calculate the power produced by the thrust force.

power = ... W [2]

(ii) Determine, for a time interval of 3.0 minutes,

1. the work done by the thrust force to move the aircraft,

work done = ... J [2]

2. the increase in gravitational potential energy of the aircraft,

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

3. the work done against air resistance.

work done = ... J [1]

(iii) Use your answer in **(b)(ii) part 3** to calculate the force due to air resistance acting on the aircraft.

force = ... N [1]

24 **(b)** A battery of electromotive force (e.m.f.) 7.0 V and negligible internal resistance is connected in series with three components, as shown in Fig. 6.1.

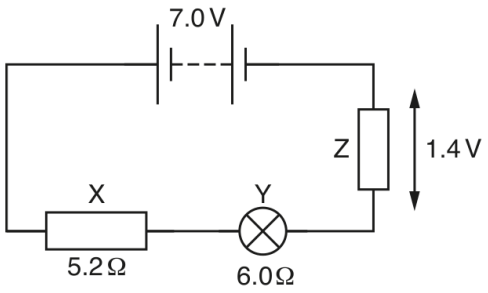


Fig. 6.1

Resistor X has a resistance of 5.2 Ω. The resistance of the filament wire of lamp Y is 6.0 Ω. The potential difference across resistor Z is 1.4 V.

(iii) Calculate the percentage efficiency with which the battery supplies power to the lamp.

efficiency = ... % [3]