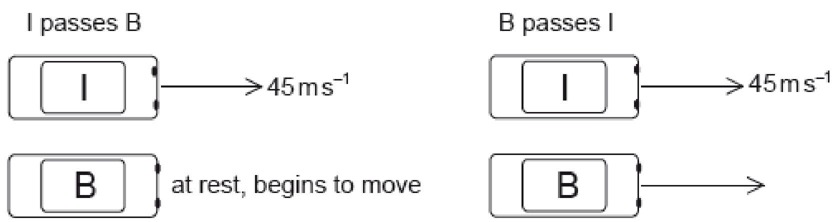
SL Paper 2

This question is in **two** parts. **Part 1** is about kinematics and Newton's laws of motion.

Part 2 is about electrical circuits.

Part 1 Kinematics and Newton's laws of motion

Cars I and B are on a straight race track. I is moving at a constant speed of $45\ \mathrm{m\,s^{-1}}$ and B is initially at rest. As I passes B, B starts to move with an acceleration of $3.2\ \mathrm{m\,s^{-2}}$.



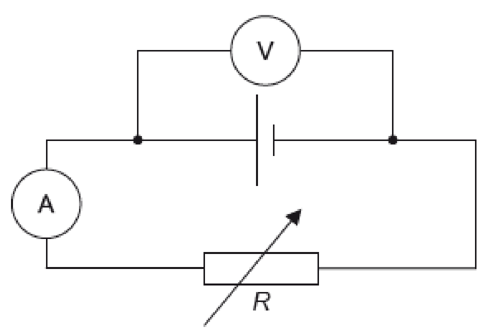
At a later time B passes I. You may assume that both cars are point particles.

A third car O with mass 930 kg joins the race. O collides with I from behind, moving along the same straight line as I. Before the collision the speed of I is $45\ \mathrm{m\,s^{-1}}$ and its mass is 850 kg. After the collision, I and O stick together and move in a straight line with an initial combined speed of $52\ \mathrm{m\,s^{-1}}$.

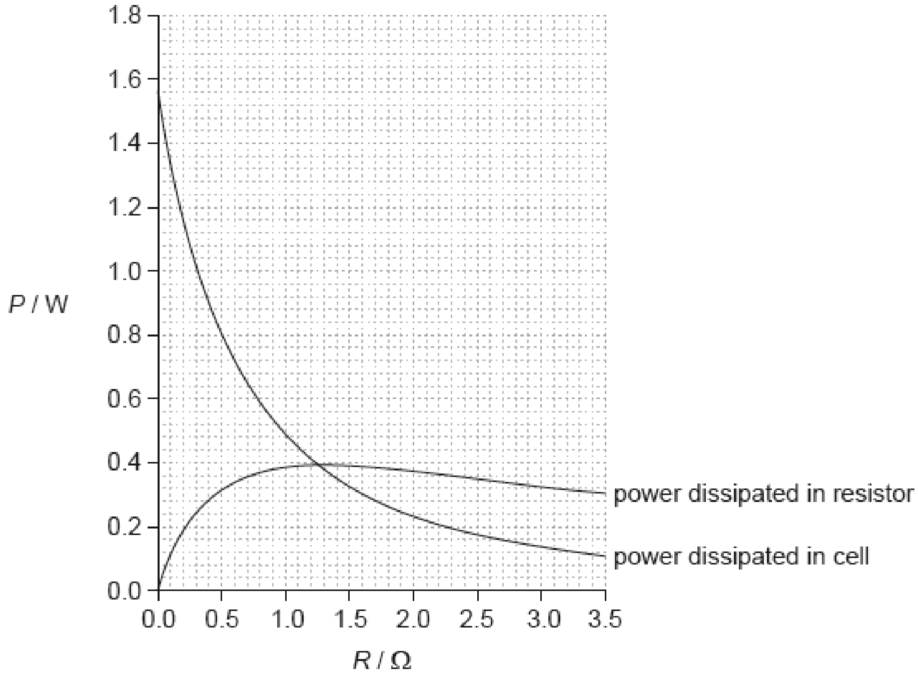
This question is in **two** parts. **Part 1** is about kinematics and Newton's laws of motion.

Part 2 Electrical circuits

The circuit shown is used to investigate how the power developed by a cell varies when the load resistance R changes.



The variable resistor is adjusted and a series of current and voltage readings are taken. The graph shows the variation with R of the power dissipated in the cell and the power dissipated in the variable resistor.



The cell has an internal resistance.

a.i. Show that the time taken for B to pass I is approximately 28 s. [4]

a.ii. Calculate the distance travelled by B in this time. [2]

b. B slows down while I remains at a constant speed. The driver in each car wears a seat belt. Using Newton's laws of motion, explain the difference in the tension in the seat belts of the two cars. [3]

c.i. Calculate the speed of O immediately before the collision. [2]

c.ii. The duration of the collision is 0.45 s. Determine the average force acting on O. [2]

d. An ammeter and a voltmeter are used to investigate the characteristics of a variable resistor of resistance R. State how the resistance of the ammeter and of the voltmeter compare to R so that the readings of the instruments are reliable. [2]

e. Show that the current in the circuit is approximately 0.70 A when $R = 0.80\ \Omega$. [3]

f.i. Outline what is meant by the internal resistance of a cell. [2]

f.ii. Determine the internal resistance of the cell. [3]

g. Calculate the electromotive force (emf) of the cell. [2]

In 1997 a high-speed car of mass $1.1 \times 10^4\ \mathrm{kg}$ achieved the world land speed record. The car accelerated uniformly in two stages as shown in the table. The car started from rest.

	Time / s	Speed attained at end of stage / m s^{-1}
Stage 1	0.0 – 4.0	44
Stage 2	4.0 – 12	280

Use the data to calculate the

a. average acceleration of the car in stage 1. [1]

b. average net force required to accelerate the car in stage 2. [3]

c. total distance travelled by the car in 12 s. [2]

Part 2 Momentum

b. State the law of conservation of momentum. [2]

c. Far from any massive object, a space rocket is moving with constant velocity. The engines of the space rocket are turned on and it accelerates by burning fuel and ejecting gases. Discuss how the law of conservation of momentum relates to this situation. [3]

d. Jane and Joe are two ice skaters initially at rest on a horizontal skating rink. They are facing each other and Jane is holding a ball. Jane throws the ball to Joe who catches it. The speed at which the ball leaves Jane, measured relative to the ground, is 8.0 m s^{-1}. [4]

The following data are available.

Mass of Jane = 52 kg

Mass of Joe = 74 kg

Mass of ball = 1.3 kg

Use the data to calculate the

(i) speed *v* of Jane relative to the ground immediately after she throws the ball.

(ii) speed *V* of Joe relative to the ground immediately after he catches the ball.

This question is in **two** parts. **Part 1** is about the motion of a car. **Part 2** is about electricity.

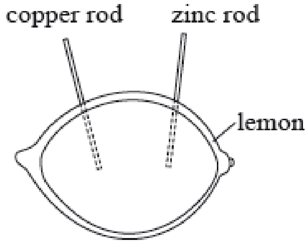
Part 1 Motion of a car

A car is travelling along the straight horizontal road at its maximum speed of $56\ \mathrm{m\,s^{-1}}$. The power output required at the wheels is 0.13 MW.

A driver moves the car in a horizontal circular path of radius 200 m. Each of the four tyres will not grip the road if the frictional force between a tyre and the road becomes less than 1500 N.

Part 2 Electricity

A lemon can be used to make an electric cell by pushing a copper rod and a zinc rod into the lemon.



A student constructs a lemon cell and connects it in an electrical circuit with a variable resistor. The student measures the potential difference *V* across the lemon and the current *I* in the lemon.

a. A car accelerates uniformly along a straight horizontal road from an initial speed of $12\ \mathrm{m\,s^{-1}}$ to a final speed of $28\ \mathrm{m\,s^{-1}}$ in a distance of 250 m. The mass of the car is 1200 kg. Determine the rate at which the engine is supplying kinetic energy to the car as it accelerates. [4]

b. A car is travelling along a straight horizontal road at its maximum speed of $56\ \mathrm{m\,s^{-1}}$. The power output required at the wheels is 0.13 MW. [5]

(i) Calculate the total resistive force acting on the car when it is travelling at a constant speed of $56\ \mathrm{m\,s^{-1}}$.

(ii) The mass of the car is 1200 kg. The resistive force F is related to the speed v by $F \propto v^2$. Using your answer to (b)(i), determine the maximum theoretical acceleration of the car at a speed of $28\ \mathrm{m\,s^{-1}}$.

c. (i) Calculate the maximum speed of the car at which it can continue to move in the circular path. Assume that the radius of the path is the same for each tyre. [6]

(ii) While the car is travelling around the circle, the people in the car have the sensation that they are being thrown outwards. Outline how Newton's first law of motion accounts for this sensation.

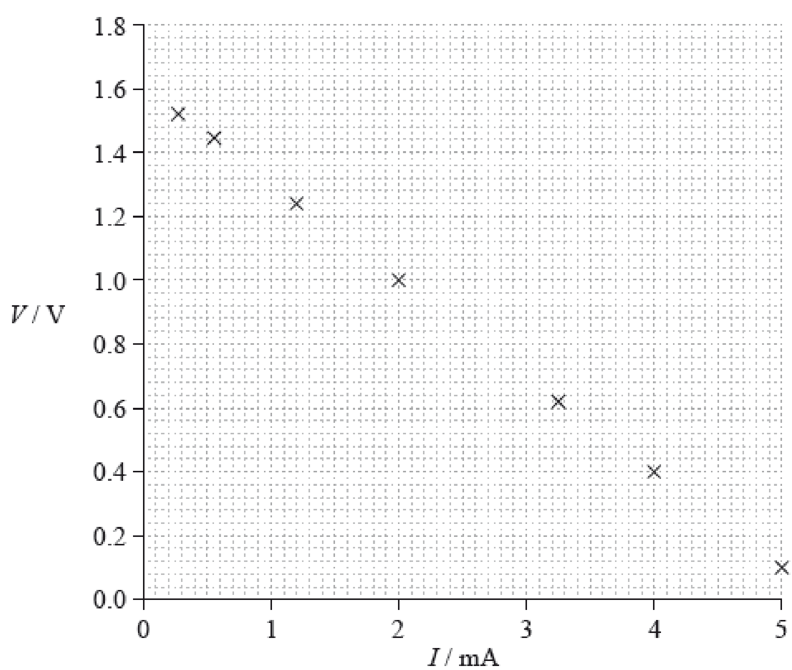
d. (i) Draw a circuit diagram of the experimental arrangement that will enable the student to collect the data for the graph. [10]

(ii) Show that the potential difference V across the lemon is given by

$$V = E - Ir$$

where E is the emf of the lemon cell and r is the internal resistance of the lemon cell.

(iii) The graph shows how V varies with I.

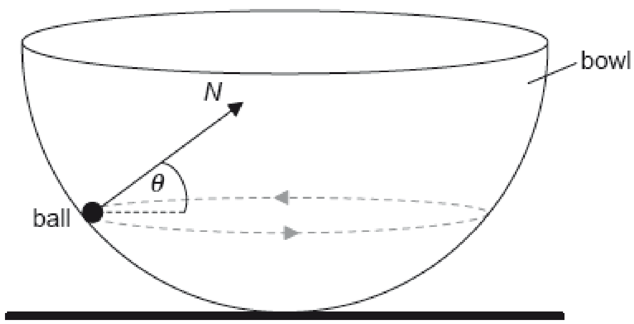


Using the graph, estimate the emf of the lemon cell.

(iv) Determine the internal resistance of the lemon cell.

(v) The lemon cell is used to supply energy to a digital clock that requires a current of $6.0\ \mu\mathrm{A}$. The clock runs for 16 hours. Calculate the charge that flows through the clock in this time.

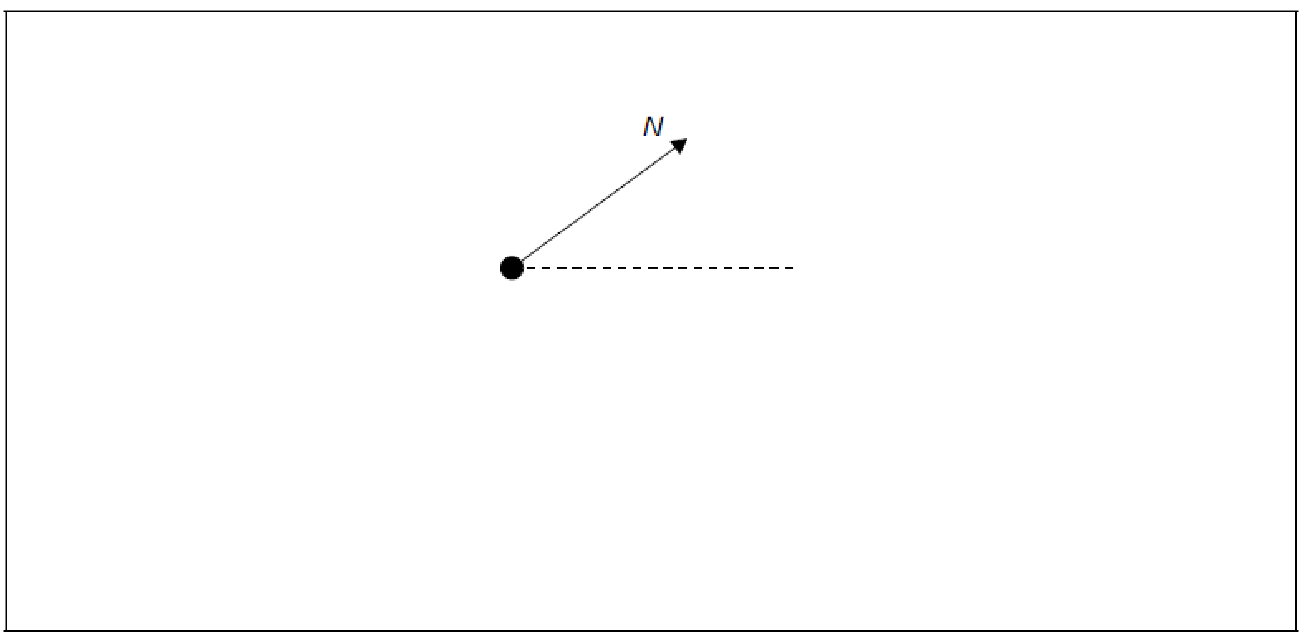
A small ball of mass *m* is moving in a horizontal circle on the inside surface of a frictionless hemispherical bowl.



The normal reaction force *N* makes an angle *θ* to the horizontal.

a.i. State the direction of the resultant force on the ball. [1]

a.ii. On the diagram, construct an arrow of the correct length to represent the weight of the ball. [2]



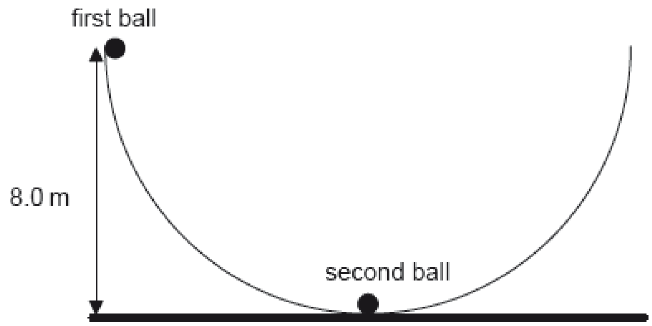
a.iii Show that the magnitude of the net force *F* on the ball is given by the following equation. [3]

$$F = \frac{mg}{\tan\theta}$$

b. The radius of the bowl is 8.0 m and *θ* = 22°. Determine the speed of the ball. [4]

c. Outline whether this ball can move on a horizontal circular path of radius equal to the radius of the bowl. [2]

d. A second identical ball is placed at the bottom of the bowl and the first ball is displaced so that its height from the horizontal is equal to 8.0 m. [3]



The first ball is released and eventually strikes the second ball. The two balls remain in contact. Determine, in m, the maximum height reached by the two balls.

This question is about the use of energy resources.

Electrical energy is obtained from tidal energy at La Rance in France.

Water flows into a river basin from the sea for six hours and then flows from the basin back to the sea for another six hours. The water flows through turbines and generates energy during both flows.

The following data are available.

Area of river basin $= 22\ \mathrm{km}^2$

Change in water level of basin over six hours $= 6.0\ \mathrm{m}$

Density of water $= 1000\ \mathrm{kg\,m^{-3}}$

Nuclear reactors are used to generate energy. In a particular nuclear reactor, neutrons collide elastically with carbon-12 nuclei $\left({}^{12}_{6}\mathrm{C}\right)$ that act as the moderator of the reactor. A neutron with an initial speed of $9.8 \times 10^6\ \mathrm{m\,s^{-1}}$ collides head-on with a stationary carbon-12 nucleus. Immediately after the collision the carbon-12 nucleus has a speed of $1.5 \times 10^6\ \mathrm{m\,s^{-1}}$.

a. State the difference between renewable and non-renewable energy sources. [1]

b. (i) The basin empties over a six hour period. Show that about $6000\ \mathrm{m}^3$ of water flows through the turbines every second. [10]

(ii) Show that the average power that the water can supply over the six hour period is about 0.2 GW.

(iii) La Rance tidal power station has an energy output of $5.4 \times 10^8\ \mathrm{kW\,h}$ per year. Calculate the overall efficiency of the power station. Assume that the water can supply 0.2 GW at all times.

Energy resources such as La Rance tidal power station could replace the use of

fossil fuels. This may result in an increase in the average albedo of Earth.

(iv) State **two** reasons why the albedo of Earth must be given as an average value.

d. (i) State the principle of conservation of momentum. [10]

(ii) Show that the speed of the neutron immediately after the collision is about $8.0 \times 10^6\ \mathrm{m\,s^{-1}}$.

(iii) Show that the fractional change in energy of the neutron as a result of the collision

is about 0.3.

(iv) Estimate the minimum number of collisions required for the neutron to reduce its initial energy by a factor of 10^6.

(v) Outline why the reduction in energy is necessary for this type of reactor to function.

This question is in **two** parts. **Part 1** is about the production of energy in nuclear fission. **Part 2** is about collisions.

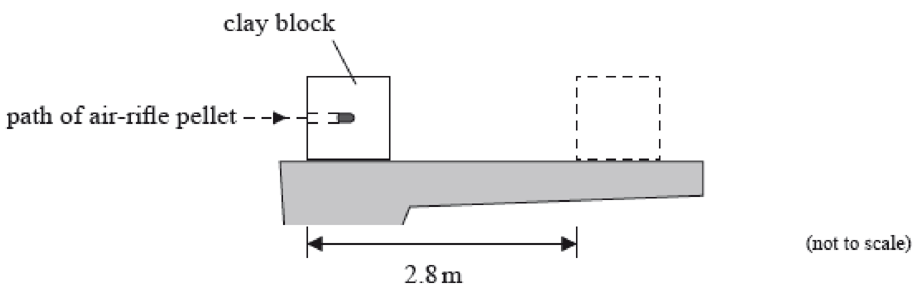
Part 1 Production of energy in nuclear fission

A possible fission reaction is

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{92}_{36}Kr + ^{141}_{56}Ba + x^{1}_{0}n.$$

Part 2 Collisions

In an experiment, an air-rifle pellet is fired into a block of modelling clay that rests on a table.



The air-rifle pellet remains inside the clay block after the impact.

As a result of the collision, the clay block slides along the table in a straight line and comes to rest. Further data relating to the experiment are given below.

$$\begin{array}{ll} \text{Mass of air - rifle pellet} & = 2.0 \text{ g} \\ \text{Mass of clay block} & = 56 \text{ g} \\ \text{Velocity of impact of air - rifle pellet} & = 140 \text{ m s}^{-1} \\ \text{Stopping distance of clay block} & = 2.8 \text{ m} \end{array}$$

Part 1.a. (i) State the value of x. [6]

(ii) Show that the energy released when one uranium nucleus undergoes fission in the reaction in (a) is about 2.8×10^{-11} J.

$$\begin{array}{ll} \text{Mass of neutron} & = 1.00867 \text{ u} \\ \text{Mass of U - 235 nucleus} & = 234.99333 \text{ u} \\ \text{Mass of Kr - 92 nucleus} & = 91.90645 \text{ u} \\ \text{Mass of Ba - 141 nucleus} & = 140.88354 \text{ u} \end{array}$$

(iii) State how the energy of the neutrons produced in the reaction in (a) is likely to compare with the energy of the neutron that initiated the reaction.

Part 1.b. Outline the role of the moderator. [2]

Part 1.c. A nuclear power plant that uses U-235 as fuel has a useful power output of 16 MW and an efficiency of 40%. Assuming that each fission of U-235 gives rise to 2.8×10^{-11} J of energy, determine the mass of U-235 fuel used per day. [4]

Part 2.a. State the principle of conservation of momentum. [2]

Part 2.b. (i) Show that the initial speed of the clay block after the air-rifle pellet strikes it is 4.8 m s^{-1}. [6]

(ii) Calculate the average frictional force that the surface of the table exerts on the clay block whilst the clay block is moving.

Part 2 c. Discuss the energy transformations that occur in the clay block and the air-rifle pellet from the moment the air-rifle pellet strikes the block until the clay block comes to rest. [3]

Part 2 d. The clay block is dropped from rest from the edge of the table and falls vertically to the ground. The table is 0.85 m above the ground. Calculate the speed with which the clay block strikes the ground. [2]

This question is in **two** parts. **Part 1** is about Newton's laws and momentum. **Part 2** is about the greenhouse effect.

Part 1 Newton's laws and momentum

Part 2 The greenhouse effect

a. State the condition for the momentum of a system to be conserved. [1]

b. A person standing on a frozen pond throws a ball. Air resistance and friction can be considered to be negligible. [5]

(i) Outline how Newton's third law and the conservation of momentum apply as the ball is thrown.

(ii) Explain, with reference to Newton's second law, why the horizontal momentum of the ball remains constant whilst the ball is in flight.

c. The maximum useful power output of a locomotive engine is 0.75 M W. The maximum speed of the locomotive as it travels along a straight horizontal track is 44 m s^{-1}. Calculate the frictional force acting on the locomotive at this speed. [2]

d. The locomotive engine in (c) gives a truck X a sharp push such that X moves along a horizontal track and collides with a stationary truck Y. As a result of the collision the two trucks stick together and move off with speed *v*. The following data are available. [4]

Mass of truck X=3.7×10^3 kg
Mass of truck Y=6.3×10^3 kg
Speed of X just before collision=4.0 m s^{-1}

(i) Calculate *v*.

(ii) Determine the kinetic energy lost as a result of the collision.

e. The trucks X and Y come to rest after travelling a distance of 40 m along the horizontal track. Determine the average frictional force acting on X and Y. [3]

f. Nuclear fuels, unlike fossil fuels, produce no greenhouse gases. [5]

(i) Identify **two** greenhouse gases.

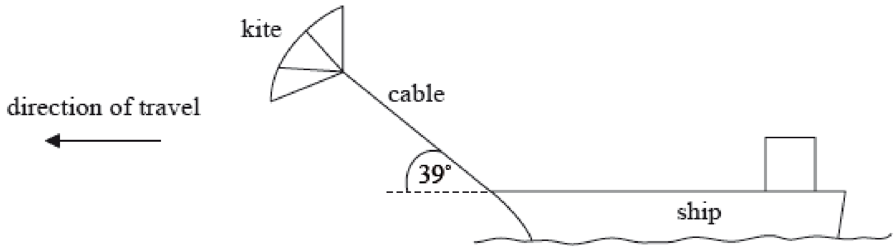
(ii) Discuss, with reference to the mechanism of infrared absorption, why the temperature of the Earth's surface would be lower if there were no greenhouse gases present in the atmosphere.

g. Outline how an increase in the amount of greenhouse gases in the atmosphere of Earth could lead to an increase in the rate at which glaciers melt and thereby a reduction of the albedo of the Earth's surface. [3]

This question is in **two** parts. **Part 1** is about the motion of a ship. **Part 2** is about melting ice.

Part 1 Motion of a ship

Some cargo ships use kites working together with the ship's engines to move the vessel.



The tension in the cable that connects the kite to the ship is 250 kN. The kite is pulling the ship at an angle of 39° to the horizontal. The ship travels at a steady speed of $8.5\ \mathrm{m\,s^{-1}}$ when the ship's engines operate with a power output of 2.7 MW.

The ship's engines are switched off and the ship comes to rest from a speed of $7\ \mathrm{m\,s^{-1}}$ in a time of 650 s.

Part 2 Melting ice

A container of negligible mass, isolated from its surroundings, contains 0.150 kg of ice at a temperature of –18.7 °C. An electric heater supplies energy at a rate of 125 W.

a. Outline the meaning of work. [2]

b.i. Calculate the work done on the ship by the kite when the ship travels a distance of 1.0 km. [2]

b.ii. Show that, when the ship is travelling at a speed of $8.5\ \mathrm{m\,s^{-1}}$, the kite provides about 40% of the total power required by the ship. [4]

c. The kite is taken down and no longer produces a force on the ship. The resistive force F that opposes the motion of the ship is related to the speed v of the ship by [3]

$$F = kv^2$$

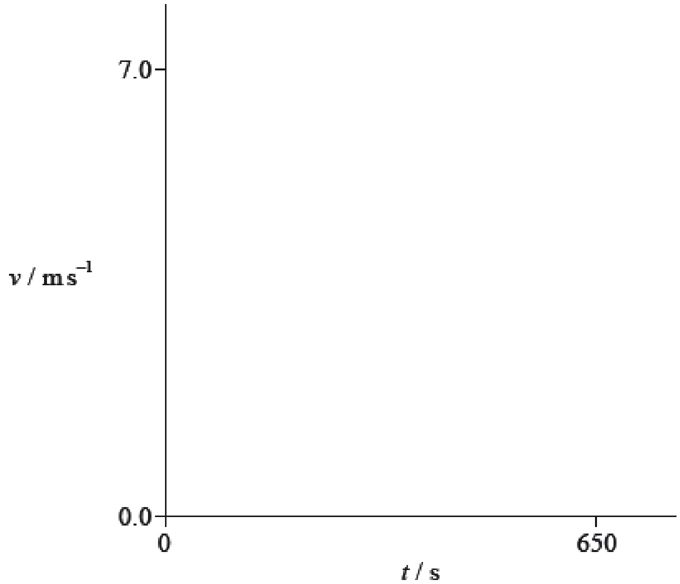
where k is a constant.

Show that, if the power output of the engines remains at 2.7 MW, the speed of the ship will decrease to about $7\ \mathrm{m\,s^{-1}}$. Assume that k is independent of whether the kite is in use or not.

d.i. Estimate the distance that the ship takes to stop. Assume that the acceleration is uniform. [2]

d.ii. It is unlikely that the acceleration of the ship will be uniform given that the resistive force acting on the ship depends on the speed of the ship. [2]

Using the axes, sketch a graph to show how the speed v varies with time t after the ship's engines are switched off.



e. Describe, with reference to molecular behaviour, the process of melting ice. [2]

f.i. After a time interval of 45.0 s all of the ice has reached a temperature of 0 °C without any melting. Calculate the specific heat capacity of ice. [2]

f.ii. The following data are available. [3]

Specific heat capacity of water $= 4200\ \mathrm{J\,kg^{-1}K^{-1}}$

Specific latent heat of fusion of ice $= 3.30 \times 10^5\ \mathrm{J\,kg^{-1}}$

Determine the final temperature of the water when the heater supplies energy for a further 600 s.

g. The whole of the experiment in (f)(i) and (f)(ii) is repeated with a container of negligible mass that is not isolated from the surroundings. The temperature of the surroundings is 18 °C. Comment on the final temperature of the water in (f)(ii). [3]

Part 2 Electric motor

An electric motor is used to raise a load.

a. Whilst being raised, the load accelerates uniformly upwards. The weight of the cable is negligible compared to the weight of the load. [6]

(i) Draw a labelled free-body force diagram of the forces acting on the accelerating load. The dot below represents the load.

(ii) The load has a mass of 350 kg and it takes 6.5 s to raise it from rest through a height of 8.0 m.

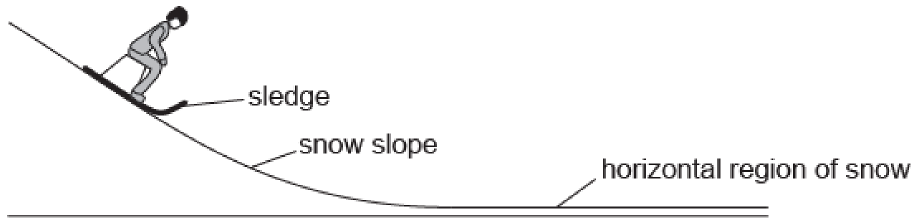
Determine the tension in the cable as the load is being raised.

b. The electric motor can be adjusted such that, after an initial acceleration, the load moves at constant speed. The motor is connected to a 450 V supply and with the load moving at constant speed, it takes the motor 15 s to raise the load through 7.0 m. [4]

(i) Calculate the power delivered to the load by the motor.

(ii) The current in the motor is 30 A. Estimate the efficiency of the motor.

A girl on a sledge is moving down a snow slope at a uniform speed.



The sledge, without the girl on it, now travels up a snow slope that makes an angle of 6.5° to the horizontal. At the start of the slope, the speed of the sledge is 4.2 m s^{-1}. The coefficient of dynamic friction of the sledge on the snow is 0.11.

a. Draw the free-body diagram for the sledge at the position shown on the snow slope. [2]

b. After leaving the snow slope, the girl on the sledge moves over a horizontal region of snow. Explain, with reference to the physical origin of the forces, why the vertical forces on the girl must be in equilibrium as she moves over the horizontal region. [3]

c. When the sledge is moving on the horizontal region of the snow, the girl jumps off the sledge. The girl has no horizontal velocity after the jump. The velocity of the sledge immediately after the girl jumps off is 4.2 m s^{-1}. The mass of the girl is 55 kg and the mass of the sledge is 5.5 kg. Calculate the speed of the sledge immediately before the girl jumps from it. [2]

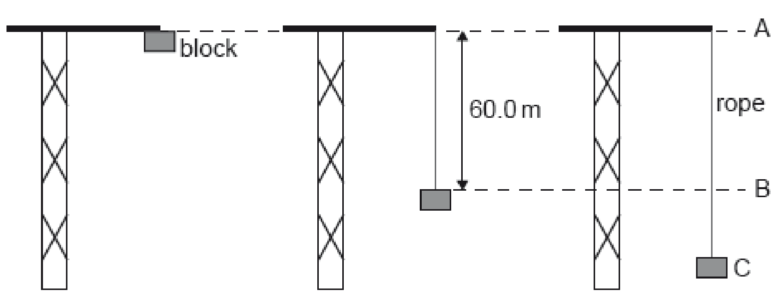
d. The girl chooses to jump so that she lands on loosely-packed snow rather than frozen ice. Outline why she chooses to land on the snow. [3]

e.i. Show that the acceleration of the sledge is about –2 m s^{-2}. [3]

e.ii. Calculate the distance along the slope at which the sledge stops moving. Assume that the coefficient of dynamic friction is constant. [2]

f. The coefficient of static friction between the sledge and the snow is 0.14. Outline, with a calculation, the subsequent motion of the sledge. [2]

An elastic climbing rope is tested by fixing one end of the rope to the top of a crane. The other end of the rope is connected to a block which is initially at position A. The block is released from rest. The mass of the rope is negligible.



The unextended length of the rope is 60.0 m. From position A to position B, the block falls freely.

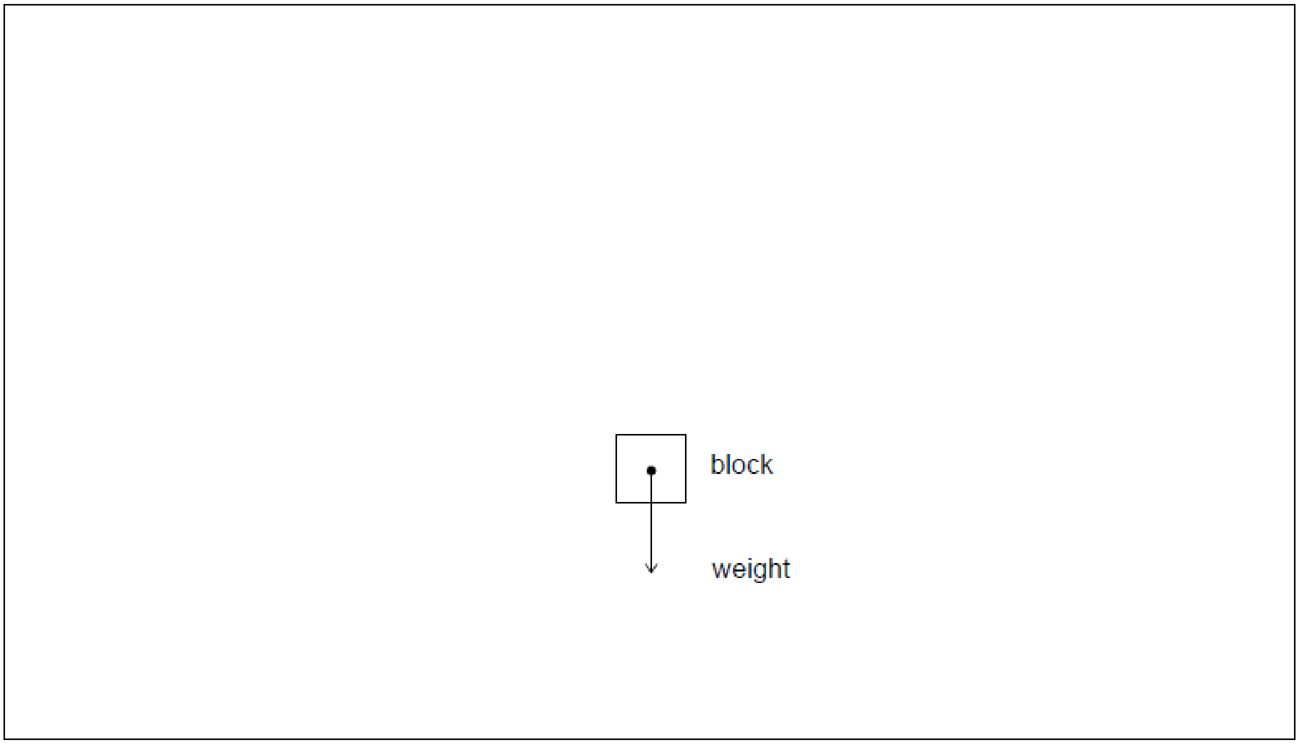
At position C the speed of the block reaches zero. The time taken for the block to fall between B and C is 0.759 s. The mass of the block is 80.0 kg.

For the rope and block, describe the energy changes that take place

a. At position B the rope starts to extend. Calculate the speed of the block at position B. [2]

b.i. Determine the magnitude of the average resultant force acting on the block between B and C. [2]

b.ii. Sketch on the diagram the average resultant force acting on the block between B and C. The arrow on the diagram represents the weight of the block. [2]



b.iii. Calculate the magnitude of the average force exerted by the rope on the block between B and C. [2]

c.i. between A and B. [1]

c.ii. between B and C. [1]

d. The length reached by the rope at C is 77.4 m. Suggest how energy considerations could be used to determine the elastic constant of the rope. [2]

This question is in **two** parts. **Part 1** is about kinematics and mechanics. **Part 2** is about electric potential difference and electric circuits.

Part 1 Kinematics and mechanics

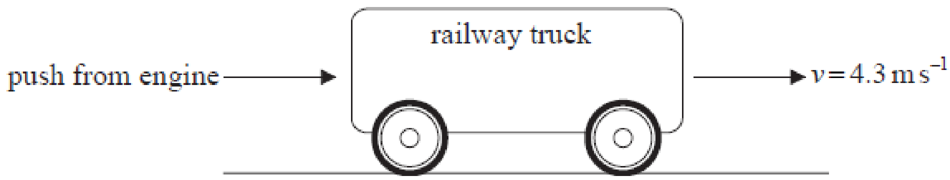
a. Define *linear momentum*. [1]

b. State, in terms of momentum, Newton's second law of motion. [1]

c. Show, using your answer to (b), how the impulse of a force F is related to the change in momentum Δp that it produces. [1]

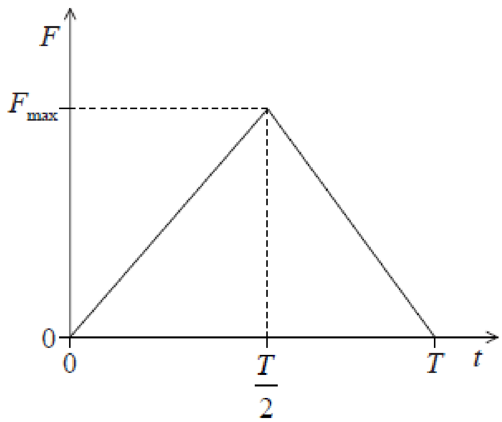
c. Show, using your answer to (b), how the impulse of a force F is related to the change in momentum Δp that it produces. [1]

d. A railway truck on a level, straight track is initially at rest. The truck is given a quick, horizontal push by an engine so that it now rolls along the track. [12]



The engine is in contact with the truck for a time $T = 0.54$ s and the initial speed of the truck after the push is $4.3\ ms^{-1}$. The mass of the truck is 2.2×10^3 kg.

Due to the push, a force of magnitude F is exerted by the engine on the truck. The sketch shows how F varies with contact time t.



(i) Determine the magnitude of the maximum force F_{max} exerted by the engine on the truck.

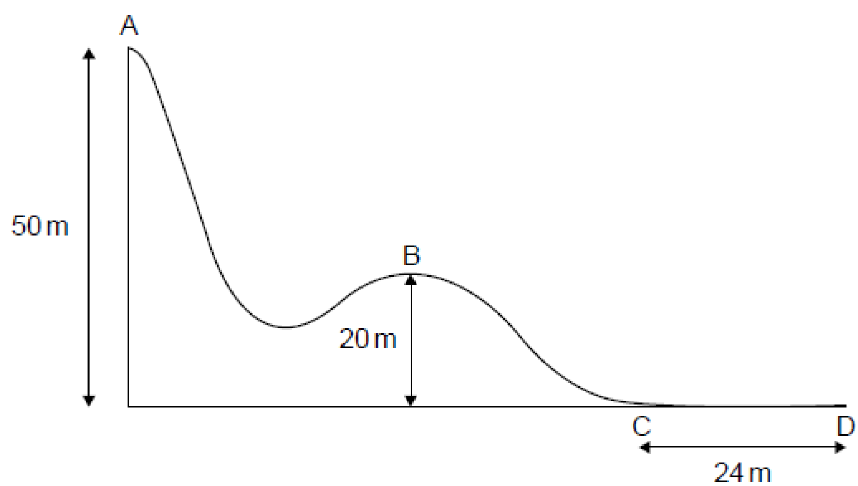
(ii) After contact with the engine ($t = 0.54$ s) the truck moves a distance 15 m along the track. After travelling this distance the speed of the truck is $2.8\ ms^{-1}$. Assuming a uniform acceleration, calculate the time it takes the truck to travel 15 m.

(iii) Calculate the average rate at which the kinetic energy of the truck is dissipated as it moves along the track.

(iv) When the speed of the truck is $2.8 ms^{-1}$ it collides with a stationary truck of mass 3.0×10^3kg. The two trucks move off together with a speed V. Show that the speed V=$1.2 ms^{-1}$.

(v) Outline the energy transformations that take place during the collision of the two trucks.

The diagram below shows part of a downhill ski course which starts at point A, 50 m above level ground. Point B is 20 m above level ground.



A skier of mass 65 kg starts from rest at point A and during the ski course some of the gravitational potential energy transferred to kinetic energy.

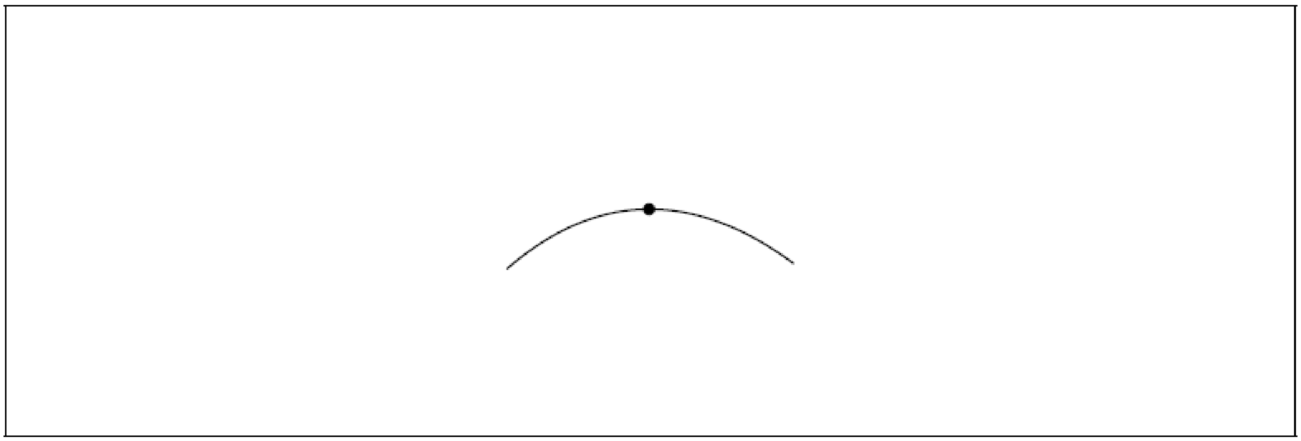
At the side of the course flexible safety nets are used. Another skier of mass 76 kg falls normally into the safety net with speed 9.6 m s^{-1}.

a.i. From A to B, 24 % of the gravitational potential energy transferred to kinetic energy. Show that the velocity at B is 12 m s^{-1}. [2]

a.ii. Some of the gravitational potential energy transferred into internal energy of the skis, slightly increasing their temperature. Distinguish between internal energy and temperature. [2]

b.i. The dot on the following diagram represents the skier as she passes point B. [2]

Draw and label the vertical forces acting on the skier.



b.ii. The hill at point B has a circular shape with a radius of 20 m. Determine whether the skier will lose contact with the ground at point B. [3]

c. The skier reaches point C with a speed of 8.2 m s^{-1}. She stops after a distance of 24 m at point D. [3]

Determine the coefficient of dynamic friction between the base of the skis and the snow. Assume that the frictional force is constant and that air resistance can be neglected.

d.i. Calculate the impulse required from the net to stop the skier and state an appropriate unit for your answer. [2]

d.ii. Explain, with reference to change in momentum, why a flexible safety net is less likely to harm the skier than a rigid barrier. [2]

This question is in **two** parts. **Part 1** is about momentum change. **Part 2** is about an oscillating water column (OWC) energy converter.

Part 1 Momentum change

a. State the law of conservation of linear momentum. [2]

b. Gravel falls vertically onto a moving horizontal conveyor belt. [7]

(i) The gravel falls at a constant rate of 13 kg s^{-1} through a height of 1.9 m. Show that the vertical speed of the gravel as it lands on the conveyor belt is about 6 m s^{-1}.

(ii) The gravel lands on the conveyor belt without rebounding. Calculate the rate of change of the vertical momentum of the gravel.

(iii) Gravel first reaches the belt at t = 0.0 s and continues to fall. Determine the total vertical force that the gravel exerts on the conveyor belt at t = 5.0 s.

c. The conveyor belt moves with a constant horizontal speed of 1.5 m s^{-1}. As the gravel lands on the belt, it has no horizontal speed. [4]

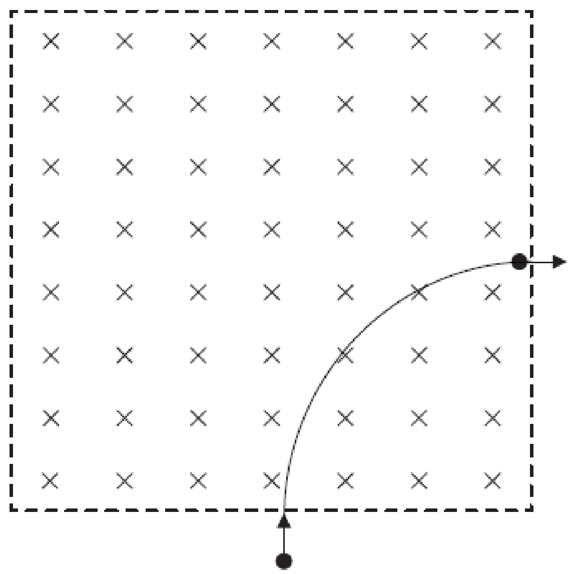
(i) Calculate the rate of change of the kinetic energy of the gravel due to its change in horizontal speed.

(ii) Determine the power required to move the conveyor belt at constant speed.

(iii) Outline why the answers to (c)(i) and (ii) are different.

This question is about motion in a magnetic field.

An electron, that has been accelerated from rest by a potential difference of 250 V, enters a region of magnetic field of strength 0.12 T that is directed into the plane of the page.

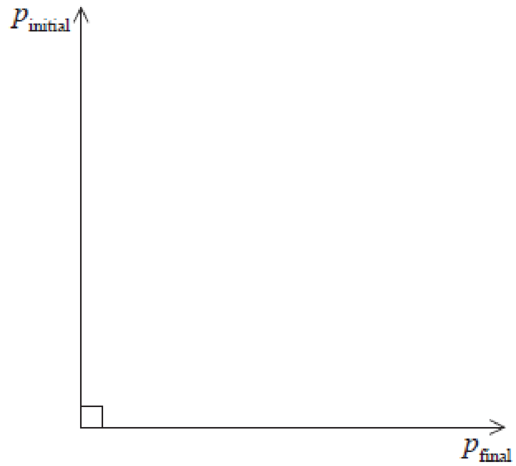


a. The electron's path while in the region of magnetic field is a quarter circle. Show that the [4]

(i) speed of the electron after acceleration is $9.4\times10^{6}ms^{-1}$.

(ii) radius of the path is 4.5×10^{-4}m.

b. The diagram below shows the momentum of the electron as it enters and leaves the region of magnetic field. The magnitude of the initial momentum and of the final momentum is 8.6×10^{-24}Ns. [3]



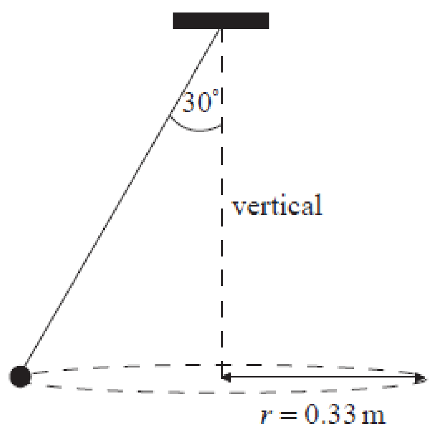
(i) On the diagram above, draw an arrow to indicate the vector representing the change in the momentum of the electron.

(ii) Show that the magnitude of the change in the momentum of the electron is 1.2×10^{-23}Ns.

(iii) The time the electron spends in the region of magnetic field is 7.5×10^{-11}s. Estimate the magnitude of the average force on the electron.

This question is about circular motion.

A ball of mass 0.25 kg is attached to a string and is made to rotate with constant speed *v* along a horizontal circle of radius *r* = 0.33m. The string is attached to the ceiling and makes an angle of 30 ° with the vertical.



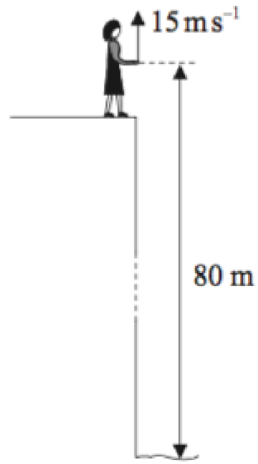
a. (i) On the diagram above, draw and label arrows to represent the forces on the ball in the position shown. [4]

(ii) State and explain whether the ball is in equilibrium.

b. Determine the speed of rotation of the ball. [3]

This question is about kinematics.

Lucy stands on the edge of a vertical cliff and throws a stone vertically upwards.

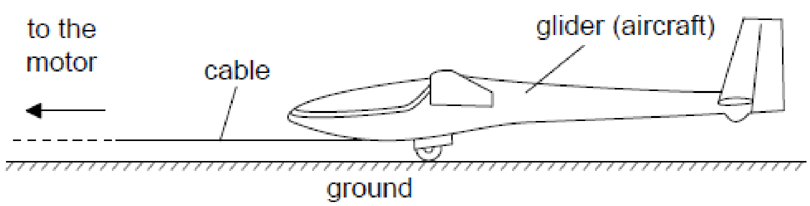


The stone leaves her hand with a speed of 15ms^{-1} at the instant her hand is 80m above the surface of the sea. Air resistance is negligible and the acceleration of free fall is 10ms^{-2}.

a. Calculate the maximum height reached by the stone as measured from the point where it is thrown. [2]

b. Determine the time for the stone to reach the surface of the sea after leaving Lucy's hand. [3]

A glider is an aircraft with no engine. To be launched, a glider is uniformly accelerated from rest by a cable pulled by a motor that exerts a horizontal force on the glider throughout the launch.



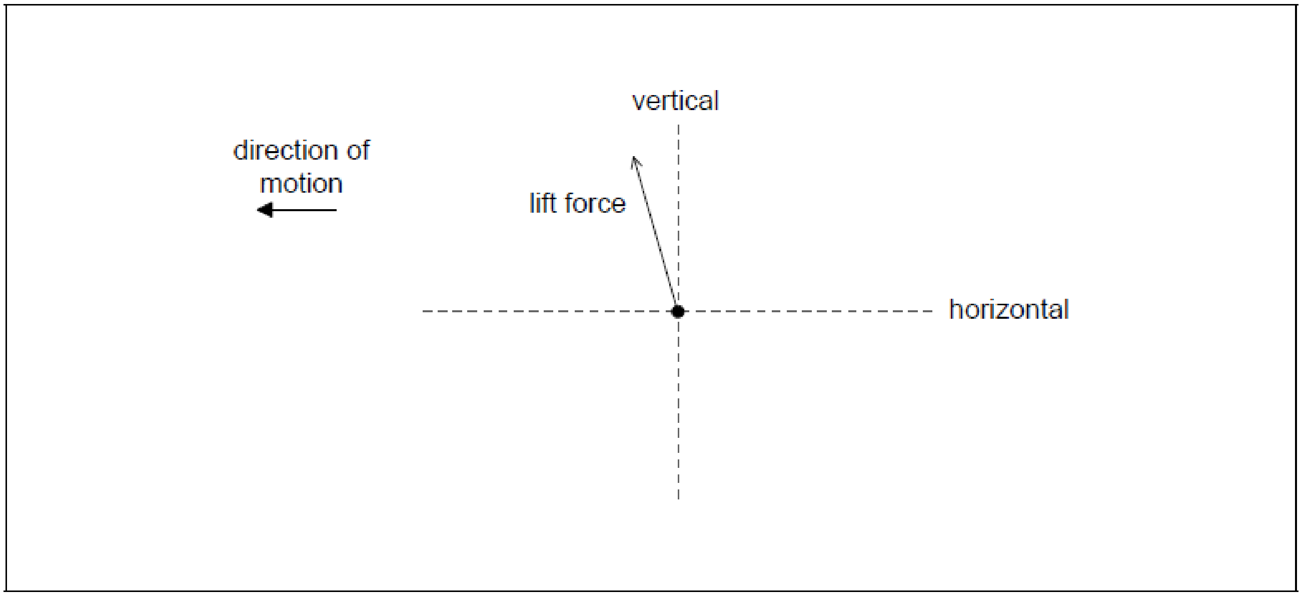
a. The glider reaches its launch speed of 27.0 m s^{-1} after accelerating for 11.0 s. Assume that the glider moves horizontally until it leaves the ground. Calculate the total distance travelled by the glider before it leaves the ground. [2]

b. The glider and pilot have a total mass of 492 kg. During the acceleration the glider is subject to an average resistive force of 160 N. Determine the average tension in the cable as the glider accelerates. [3]

c. The cable is pulled by an electric motor. The motor has an overall efficiency of 23 %. Determine the average power input to the motor. [3]

d. The cable is wound onto a cylinder of diameter 1.2 m. Calculate the angular velocity of the cylinder at the instant when the glider has a speed of 27 m s^{-1}. Include an appropriate unit for your answer. [2]

e. After takeoff the cable is released and the unpowered glider moves horizontally at constant speed. The wings of the glider provide a lift force. The diagram shows the lift force acting on the glider and the direction of motion of the glider. [2]



Draw the forces acting on the glider to complete the free-body diagram. The dotted lines show the horizontal and vertical directions.

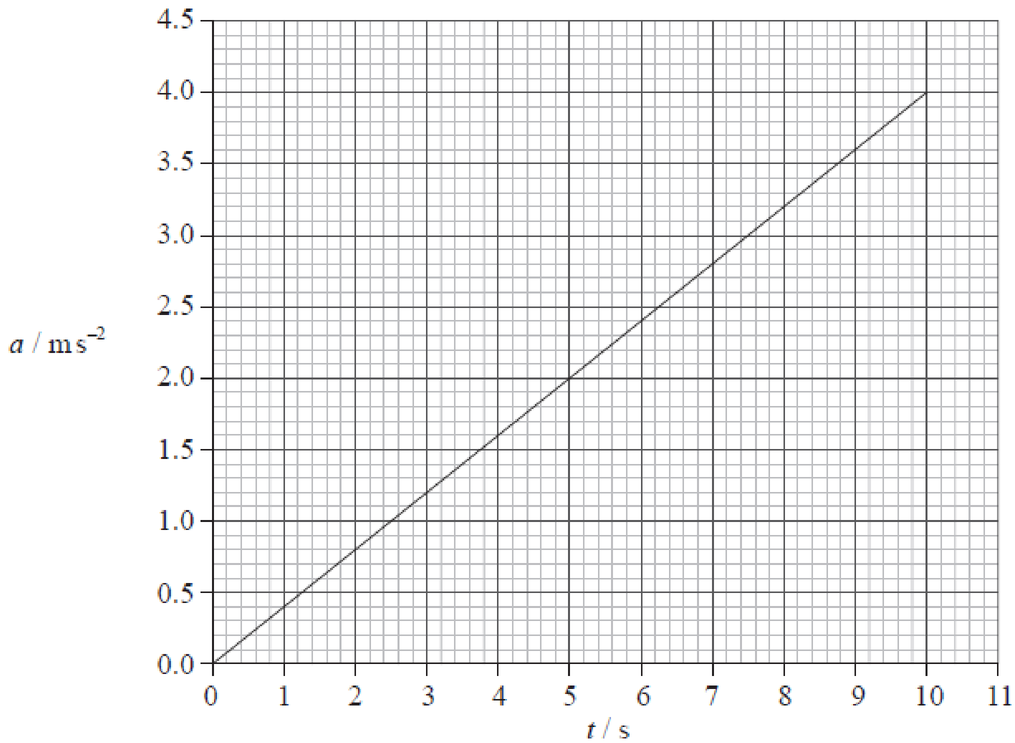
f. Explain, using appropriate laws of motion, how the forces acting on the glider maintain it in level flight. [2]

g. At a particular instant in the flight the glider is losing 1.00 m of vertical height for every 6.00 m that it goes forward horizontally. At this instant, the horizontal speed of the glider is 12.5 m s^{-1}. Calculate the **velocity** of the glider. Give your answer to an appropriate number of significant figures. [3]

This question is about kinematics.

a. State the difference between average speed and instantaneous speed. [2]

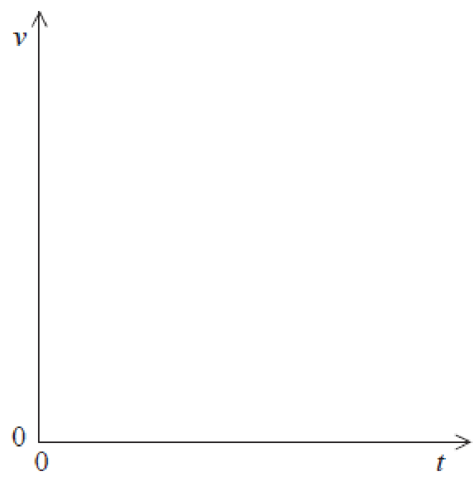
b. The graph shows how the acceleration *a* of a particle varies with time *t*. [3]



At time $t = 0$ the instantaneous speed of the particle is zero.

(i) Calculate the instantaneous speed of the particle at $t = 7.5$ s.

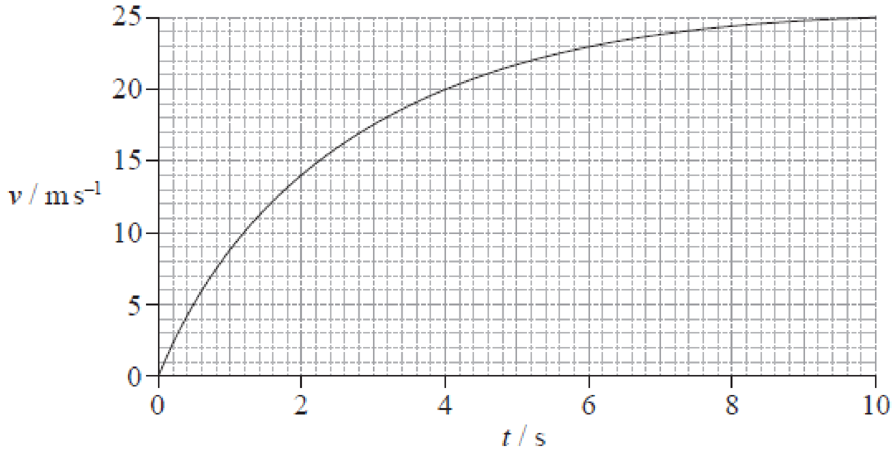
(ii) Using the axes below, sketch a graph to show how the instantaneous speed v of the particle varies with t.



This question is in **two** parts. **Part 1** is about mechanics and thermal physics. **Part 2** is about nuclear physics.

Part 1 Mechanics and thermal physics

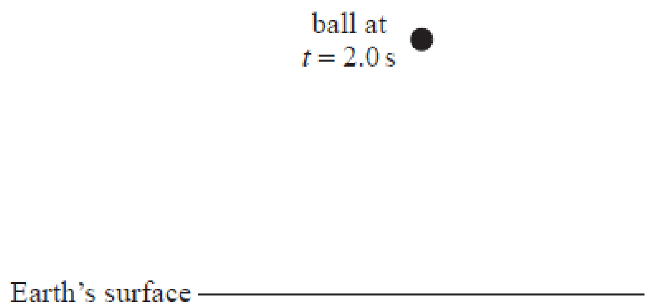
The graph shows the variation with time t of the speed v of a ball of mass 0.50 kg, that has been released from rest above the Earth's surface.



The force of air resistance is **not** negligible. Assume that the acceleration of free fall is g = 9.81ms^{-2}.

a. State, without any calculations, how the graph could be used to determine the distance fallen. [1]

b. (i) In the space below, draw and label arrows to represent the forces on the ball at 2.0 s. [7]



(ii) Use the graph opposite to show that the acceleration of the ball at 2.0 s is approximately 4 ms^{-2}.

(iii) Calculate the magnitude of the force of air resistance on the ball at 2.0 s.

(iv) State and explain whether the air resistance on the ball at t = 5.0 s is smaller than, equal to **or** greater than the air resistance at t = 2.0 s.

c. After 10 s the ball has fallen 190 m. [6]

(i) Show that the sum of the potential and kinetic energies of the ball has decreased by 780 J.

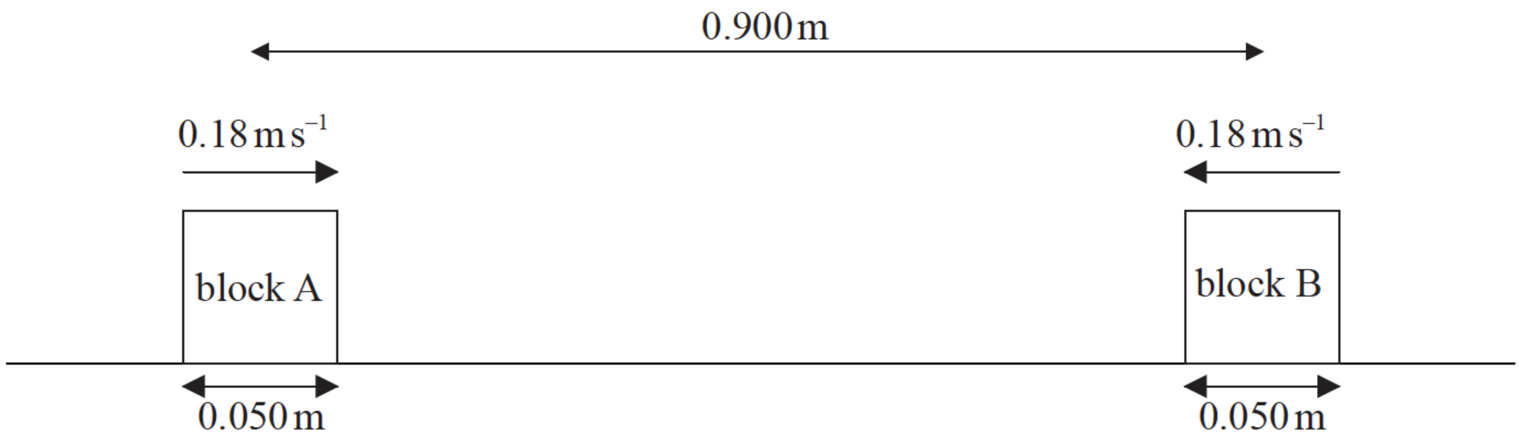
(ii) The specific heat capacity of the ball is 480 J kg^{-1} K^{-1}. Estimate the increase in the temperature of the ball.

(iii) State an assumption made in the estimate in (c)(ii).

This question is in **two** parts. **Part 1** is about a collision. **Part 2** is about electric current and resistance.

Part 1 A collision

Two identical blocks of mass 0.17kg and length 0.050m are travelling towards each other along a straight line through their centres as shown below. Assume that the surface is frictionless.



The initial distance between the centres of the blocks is 0.900m and both blocks are moving at a speed of $0.18ms^{-1}$ relative to the surface.

a. Determine the time taken for the blocks to come into contact with each other. [3]

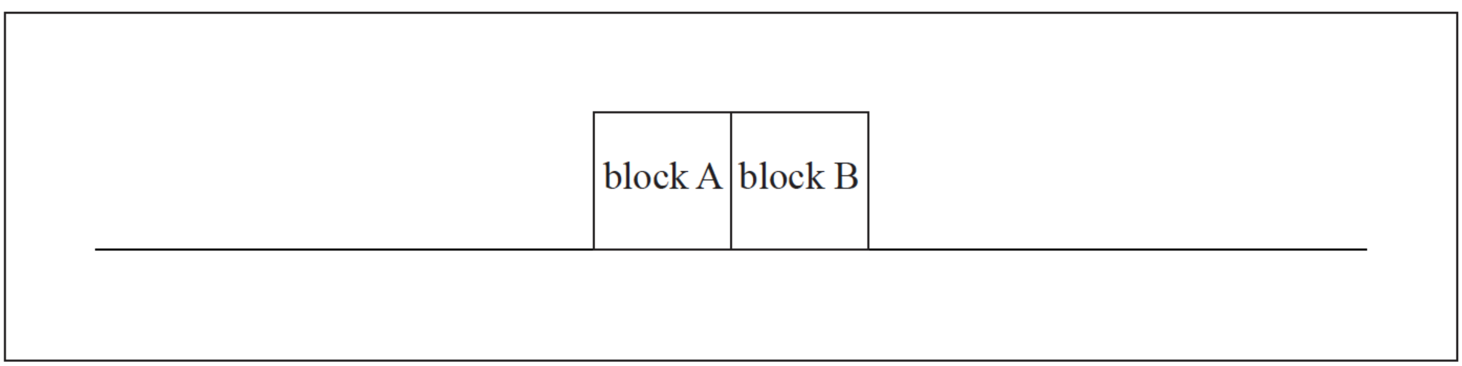
b. As a result of the collision, the blocks reverse their direction of motion and travel at the same speed as each other. During the collision, 20% of the kinetic energy of the blocks is given off as thermal energy to the surroundings. [5]

(i) State and explain whether the collision is elastic or inelastic.

(ii) Show that the final speed of the blocks relative to the surface is $0.16\ m\ s^{-1}$.

c. (i) State Newton's third law of motion. [7]

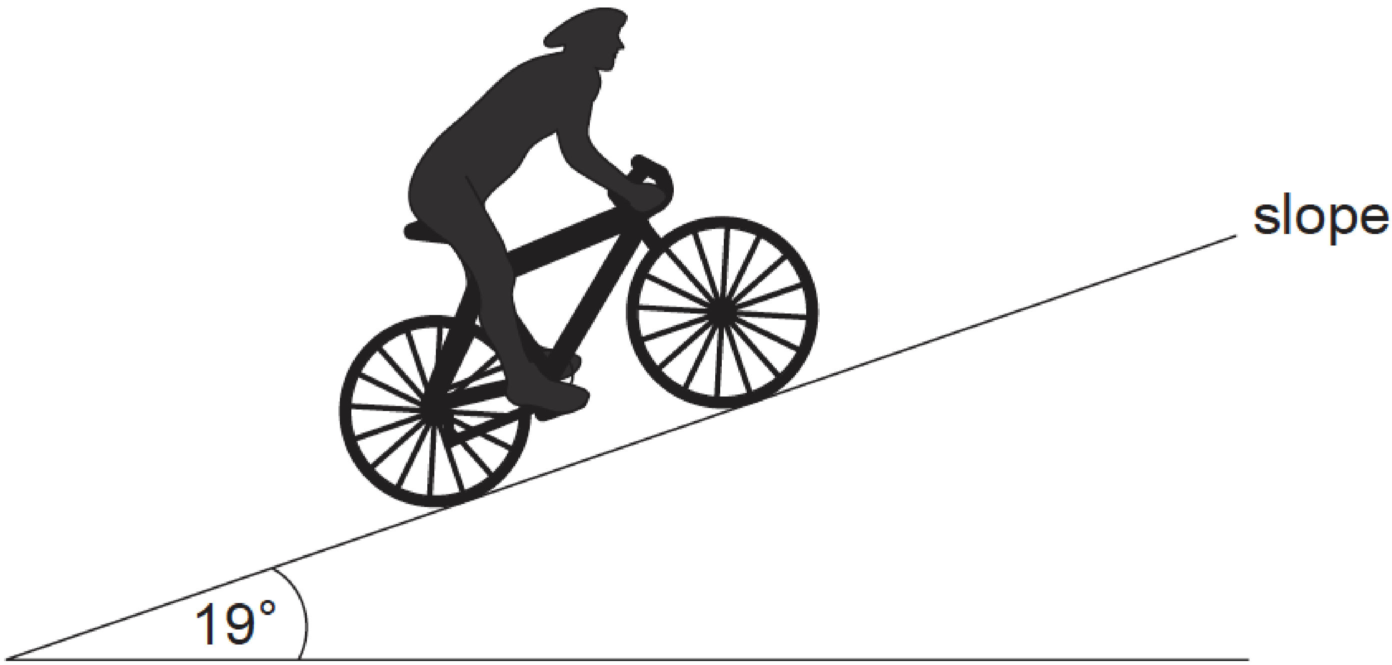
(ii) During the collision of the blocks, the magnitude of the force that block A exerts on block B is F_{AB} and the magnitude of the force that block B exerts on block A is F_{BA}. On the diagram below, draw labelled arrows to represent the magnitude and direction of the forces F_{AB} and F_{BA}.



(iii) The duration of the collision between the blocks is 0.070 s. Determine the average force one block exerted on the other.

This question is about the motion of a bicycle.

A cyclist is moving up a slope that is at an angle of 19° to the horizontal. The mass of the cyclist and the bicycle is 85 kg.



a. Calculate the [3]

(i) component of the weight of the cyclist and bicycle parallel to the slope.

(ii) normal reaction force on the bicycle from the slope.

b. At the bottom of the slope the cyclist has a speed of $5.5 ms^{-1}$. The cyclist stops pedalling and applies the brakes which provide an additional decelerating force of 250 N. Determine the distance taken for the cyclist to stop. Assume air resistance is negligible and that there are no other frictional forces. [4]

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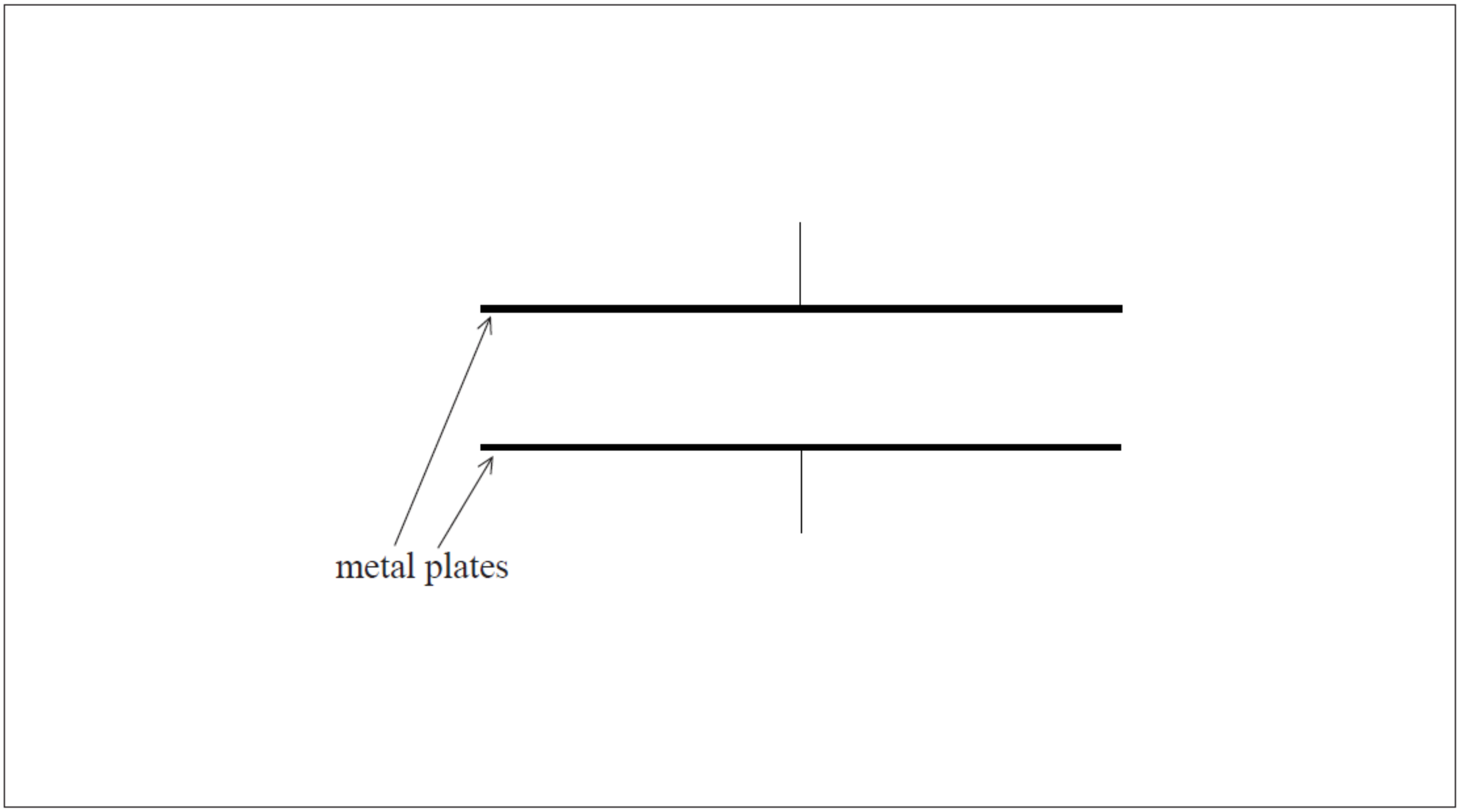
a. Define *electric field strength*. [2]

b. The diagram shows a pair of horizontal metal plates. Electrons can be deflected vertically using an electric field between the plates. [5]

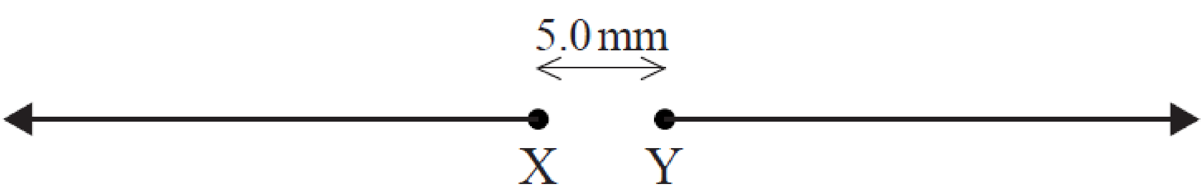


(i) Label, on the diagram, the polarity of the metal plates which would cause an electron positioned between the plates to accelerate upwards.

(ii) Draw the shape and direction of the electric field between the plates on the diagram.

(iii) Calculate the force on an electron between the plates when the electric field strength has a value of 2.5×10^3 NC^{-1}.

c. The diagram shows two isolated electrons, X and Y, initially at rest in a vacuum. The initial separation of the electrons is 5.0 mm. The electrons subsequently move apart in the directions shown. [8]

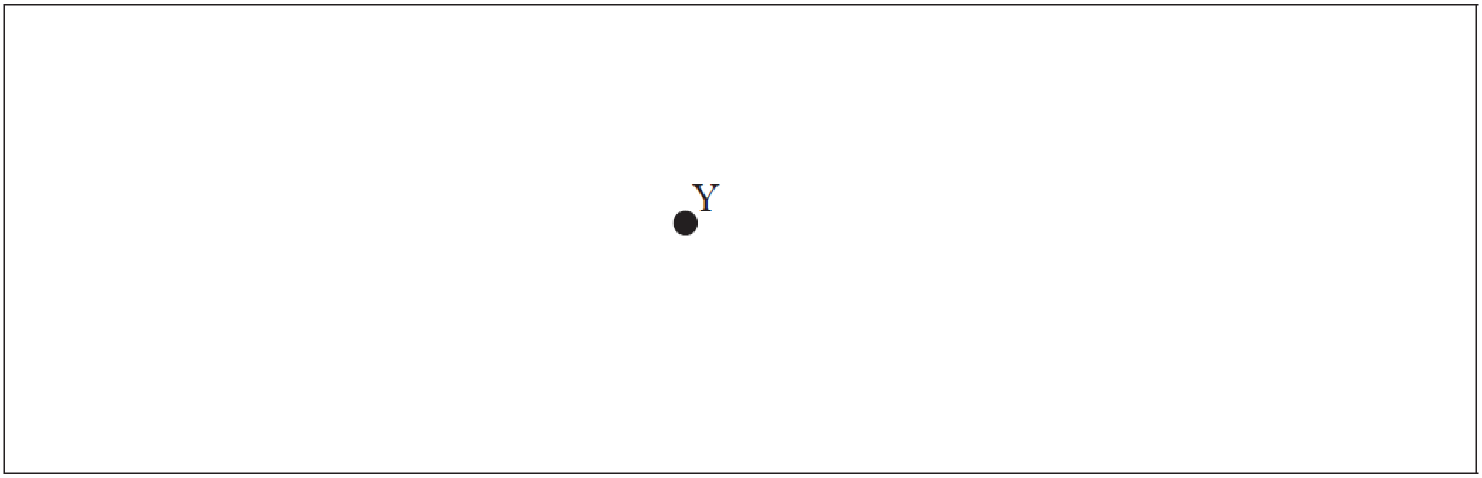


(i) Show that the initial electric force acting on each electron due to the other electron is approximately 9×10^{-24}N.

(ii) Calculate the initial acceleration of one electron due to the force in (c)(i).

(iii) Discuss the motion of one electron after it begins to move.

(iv) The diagram shows Y as seen from X, at one instant. Y is moving into the plane of the paper. For this instant, draw on the diagram the shape and direction of the magnetic field produced by Y.



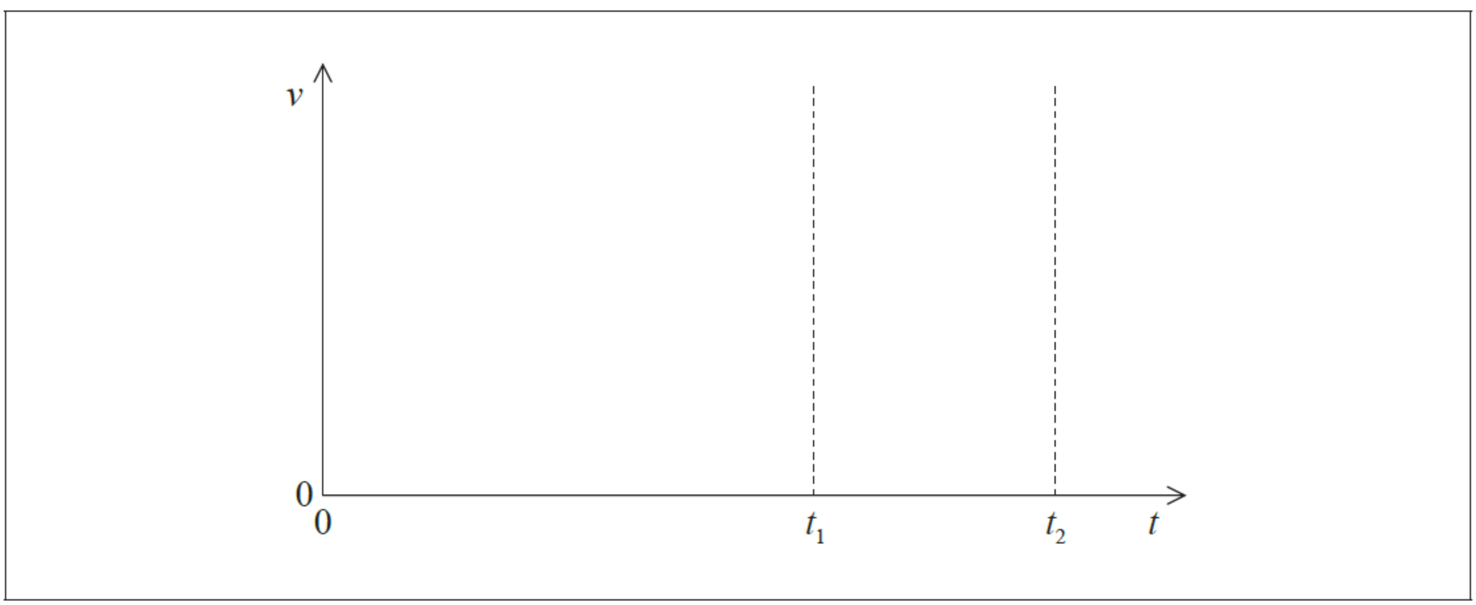
This question is about kinematics.

a. Fiona drops a stone from rest vertically down a water well. She hears the splash of the stone striking the water 1.6 s after the stone leaves her hand. Estimate the [3]

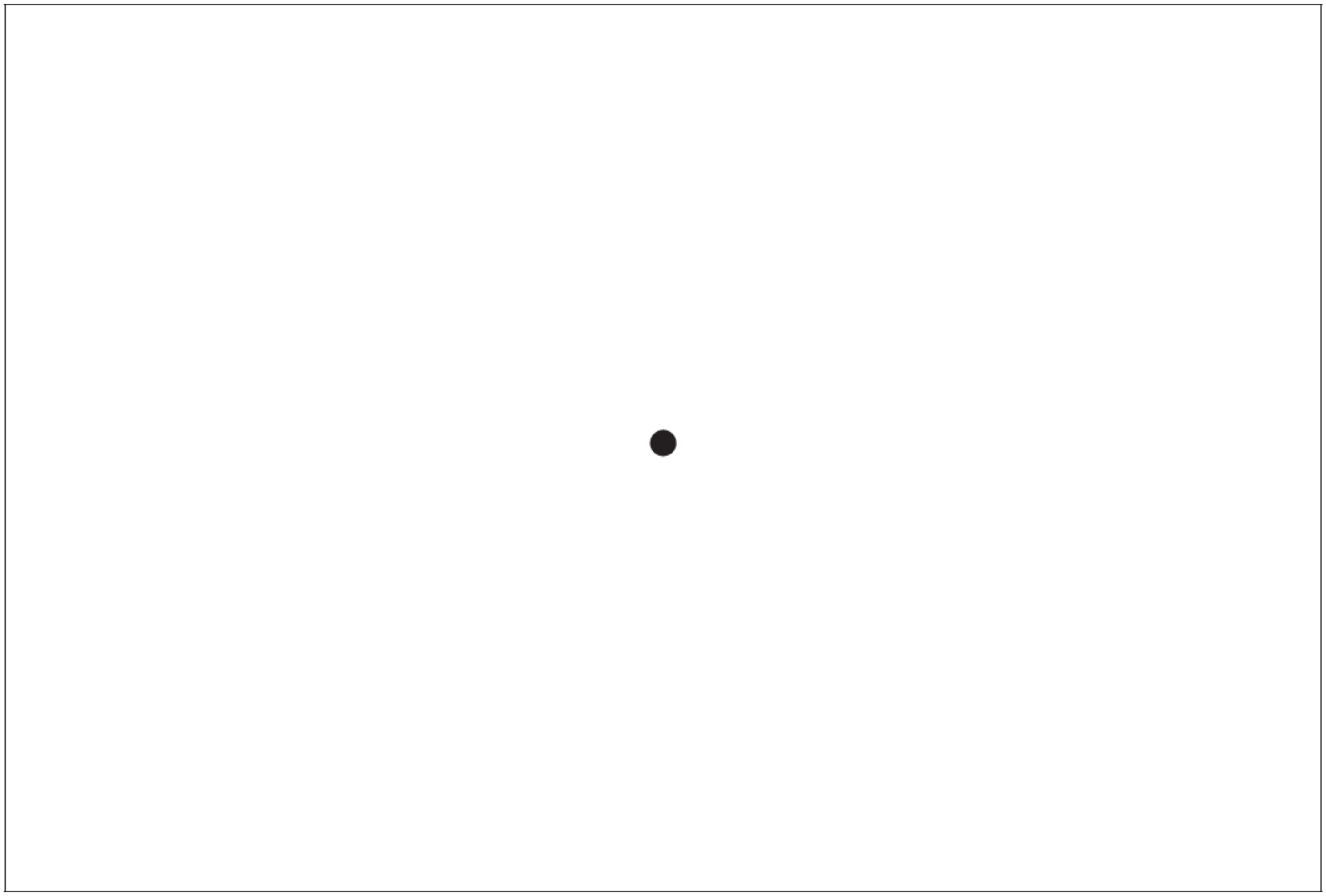
(i) distance between Fiona's hand and the water surface.

(ii) speed with which the stone hits the water.

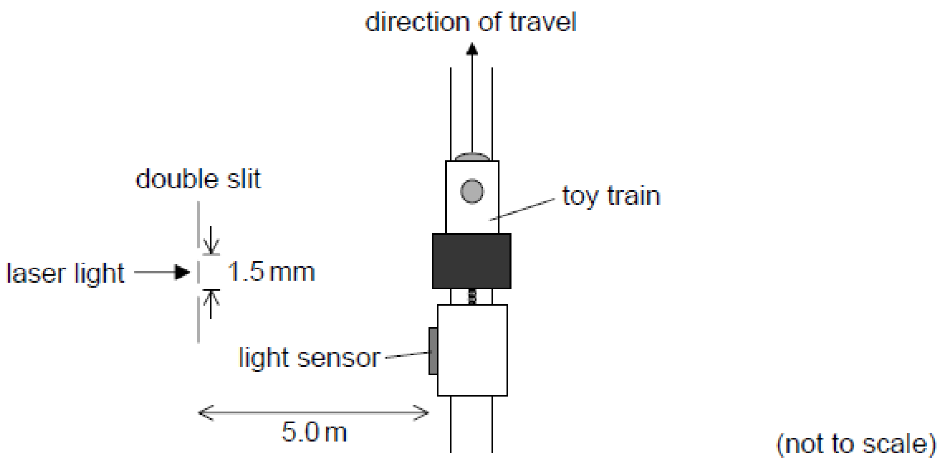
b. After the stone in (a) hits the water surface it rapidly reaches a terminal speed as it falls through the water. The stone leaves Fiona's hand at time $t = 0$. It hits the water surface at t_1 and it comes to rest at the bottom of the water at t_2. Using the axes below, sketch a graph to show how the speed v of the stone varies from time $t = 0$ to just before $t = t_2$. (There is no need to add any values to the axes.) [3]



c. Draw and label a free-body diagram representing the forces acting on the stone as it falls through the water at its terminal speed. [2]

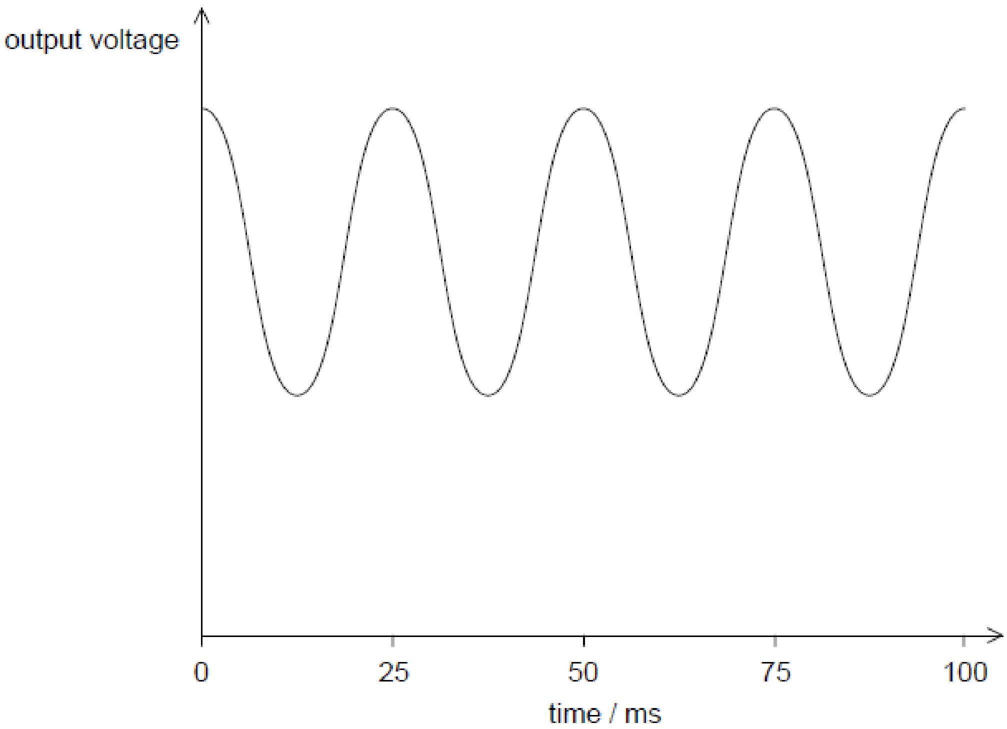


A student investigates how light can be used to measure the speed of a toy train.



Light from a laser is incident on a double slit. The light from the slits is detected by a light sensor attached to the train.

The graph shows the variation with time of the output voltage from the light sensor as the train moves parallel to the slits. The output voltage is proportional to the intensity of light incident on the sensor.

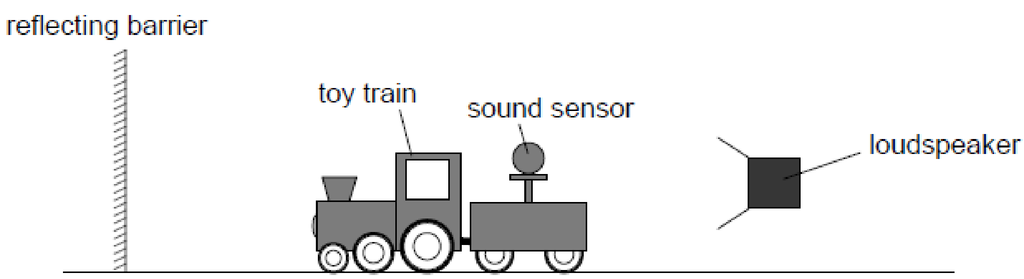


a. Explain, with reference to the light passing through the slits, why a series of voltage peaks occurs. [3]

b.i. The slits are separated by 1.5 mm and the laser light has a wavelength of 6.3 x 10^{-7} m. The slits are 5.0 m from the train track. Calculate the separation between two adjacent positions of the train when the output voltage is at a maximum. [1]

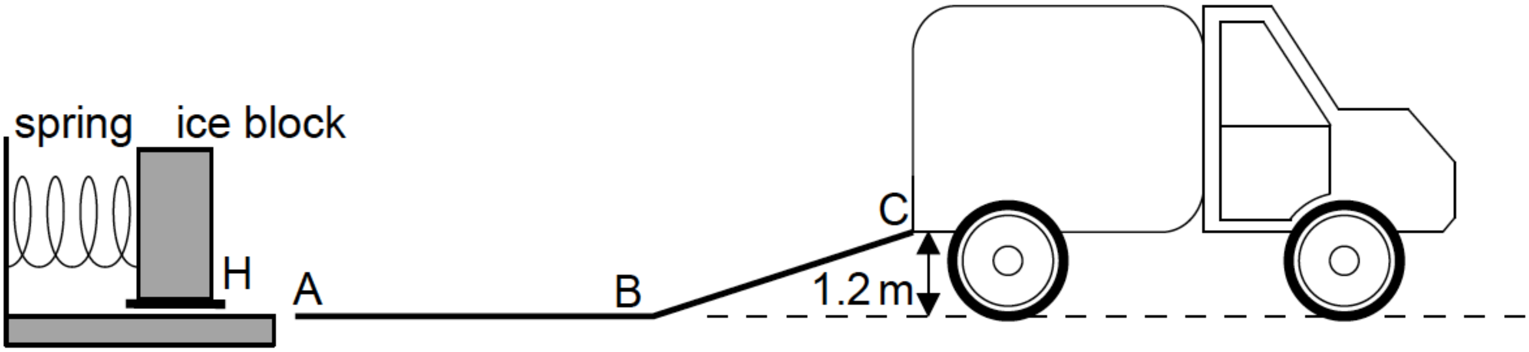
b.ii. Estimate the speed of the train. [2]

c. In another experiment the student replaces the light sensor with a sound sensor. The train travels away from a loudspeaker that is emitting sound waves of constant amplitude and frequency towards a reflecting barrier. [2]



The sound sensor gives a graph of the variation of output voltage with time along the track that is similar in shape to the graph shown in the resource. Explain how this effect arises.

A company designs a spring system for loading ice blocks onto a truck. The ice block is placed in a holder H in front of the spring and an electric motor compresses the spring by pushing H to the left. When the spring is released the ice block is accelerated towards a ramp ABC. When the spring is fully decompressed, the ice block loses contact with the spring at A. The mass of the ice block is 55 kg.



Assume that the surface of the ramp is frictionless and that the masses of the spring and the holder are negligible compared to the mass of the ice block.

a. (i) The block arrives at C with a speed of $0.90 ms^{-1}$. Show that the elastic energy stored in the spring is 670J. [4]

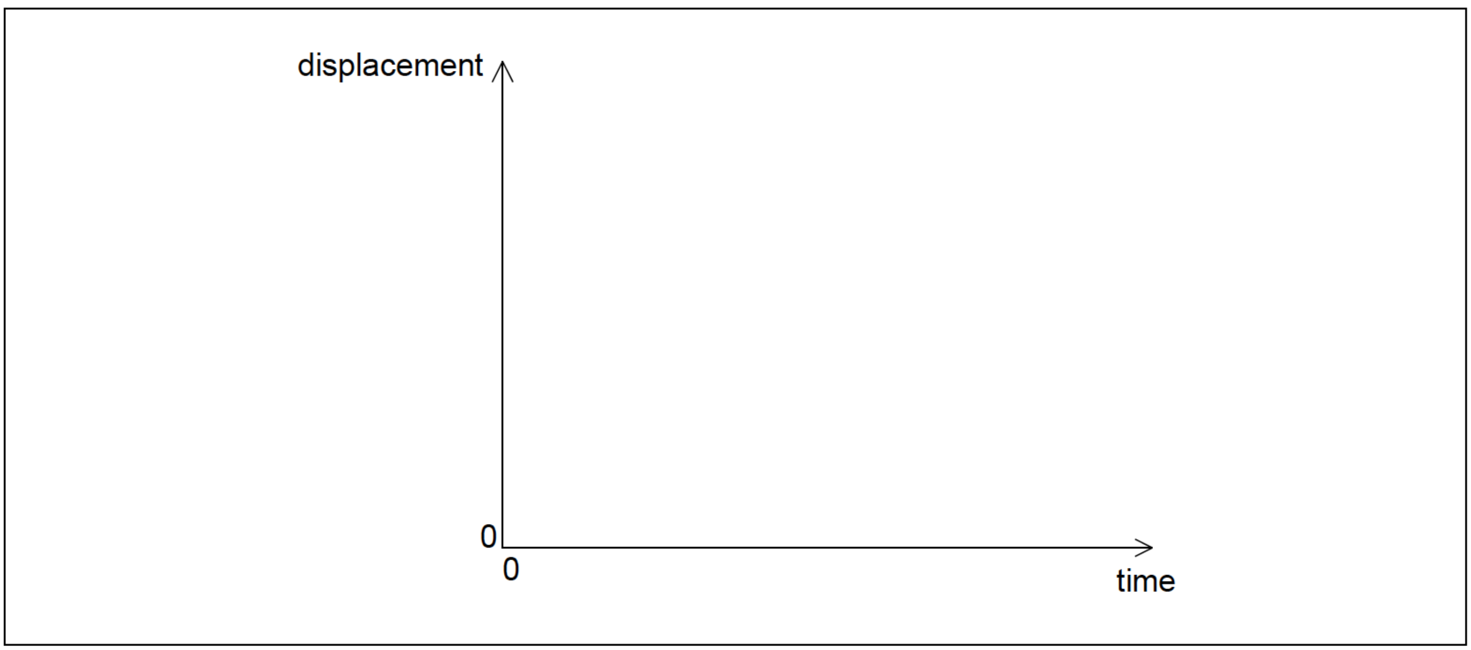
(ii) Calculate the speed of the block at A.

b. Describe the motion of the block [3]

(i) from A to B with reference to Newton's first law.

(ii) from B to C with reference to Newton's second law.

c. On the axes, sketch a graph to show how the displacement of the block varies with time from A to C. (You do not have to put numbers on the axes.) [2]



d. The spring decompression takes 0.42s. Determine the average force that the spring exerts on the block. [2]

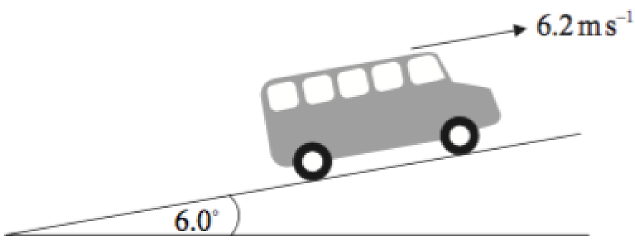
e. The electric motor is connected to a source of potential difference 120V and draws a current of 6.8A. The motor takes 1.5s to compress the spring. [2]

Estimate the efficiency of the motor.

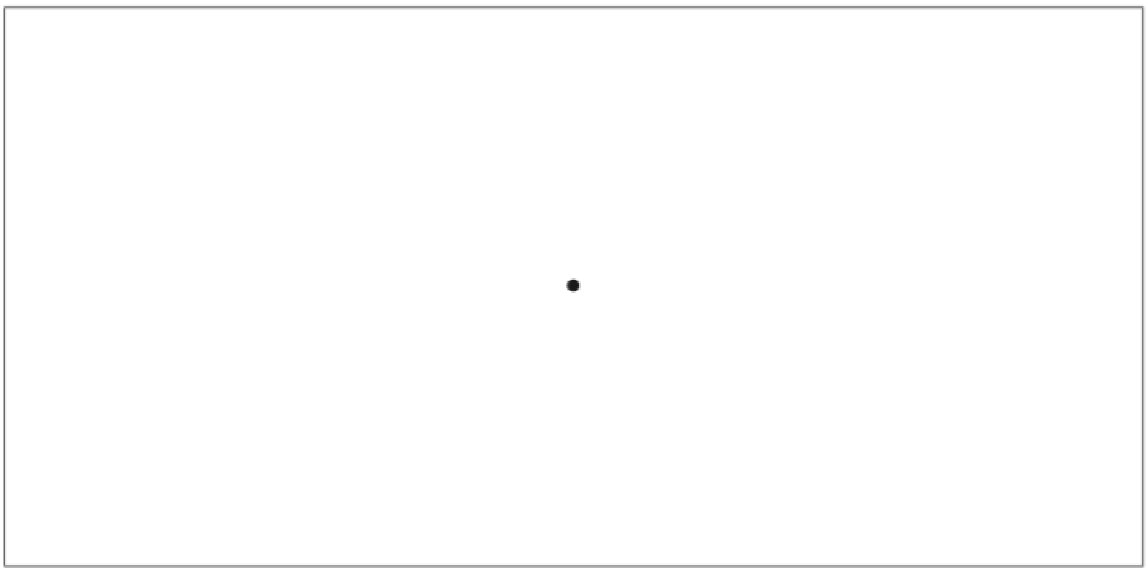
This question is in **two** parts. **Part 1** is about power and efficiency. **Part 2** is about electrical resistance.

Part 1 Power and efficiency

A bus is travelling at a constant speed of 6.2 m s^{-1} along a section of road that is inclined at an angle of 6.0° to the horizontal.



a. (i) The bus is represented by the black dot shown below. Draw a labelled sketch to represent the forces acting on the bus. [5]



(ii) State the value of the rate of change of momentum of the bus.

b. The total output power of the engine of the bus is 70kW and the efficiency of the engine is 35%. Calculate the input power to the engine. [2]

c. The mass of the bus is 8.5×10^3 kg. Determine the rate of increase of gravitational potential energy of the bus. [3]

d. Using your answer to (c) and the data in (b), estimate the magnitude of the resistive forces acting on the bus. [3]

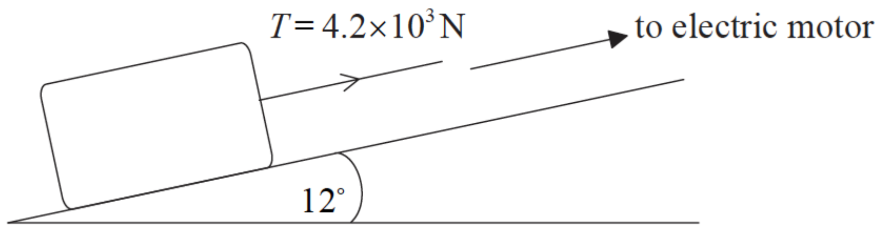
e. The engine of the bus suddenly stops working. [4]

(i) Determine the magnitude of the net force opposing the motion of the bus at the instant at which the engine stops.

(ii) Discuss, with reference to the air resistance, the change in the net force as the bus slows down.

This question is about forces.

A stone block is pulled at constant speed up an incline by a cable attached to an electric motor.



The incline makes an angle of 12 ° with the horizontal. The weight of the block is 1.5×10^4N and the tension *T* in the cable is 4.2×10^3N.

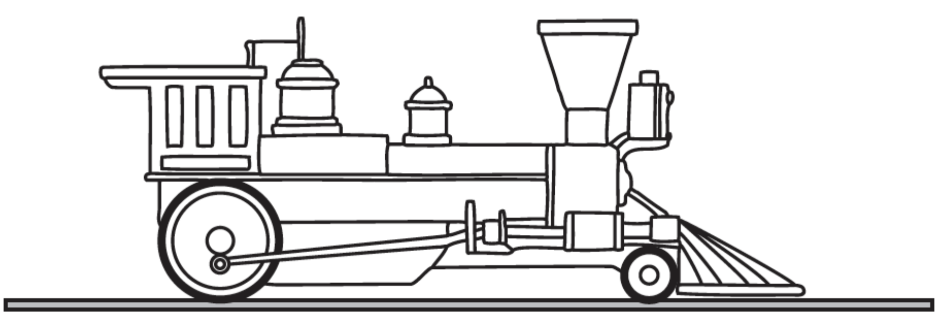
a. On the diagram draw and label arrows that represent the forces acting on the block. [2]

b. Calculate the magnitude of the friction force acting on the block. [3]

This question is in two parts. **Part 1** is about forces. **Part 2** is about internal energy.

Part 1 Forces

A railway engine is travelling along a horizontal track at a constant velocity.



a. On the diagram above, draw labelled arrows to represent the vertical forces that act on the railway engine. [3]

b. Explain, with reference to Newton’s laws of motion, why the velocity of the railway engine is constant. [2]

c. The constant horizontal velocity of the railway engine is 16 ms^{-1}. A total horizontal resistive force of 76 kN acts on the railway engine. [2]

Calculate the useful power output of the railway engine.

d. The power driving the railway engine is switched off. The railway engine stops, from its speed of 16 ms^{-1}, without braking in a distance of 1.1 km. A student hypothesizes that the horizontal resistive force is constant. [2]

Based on this hypothesis, calculate the mass of the railway engine.

e. Another hypothesis is that the horizontal force in (c) consists of two components. One component is a constant frictional force of 19 kN. The other component is a resistive force F that varies with speed v where F is proportional t o v^3. [5]

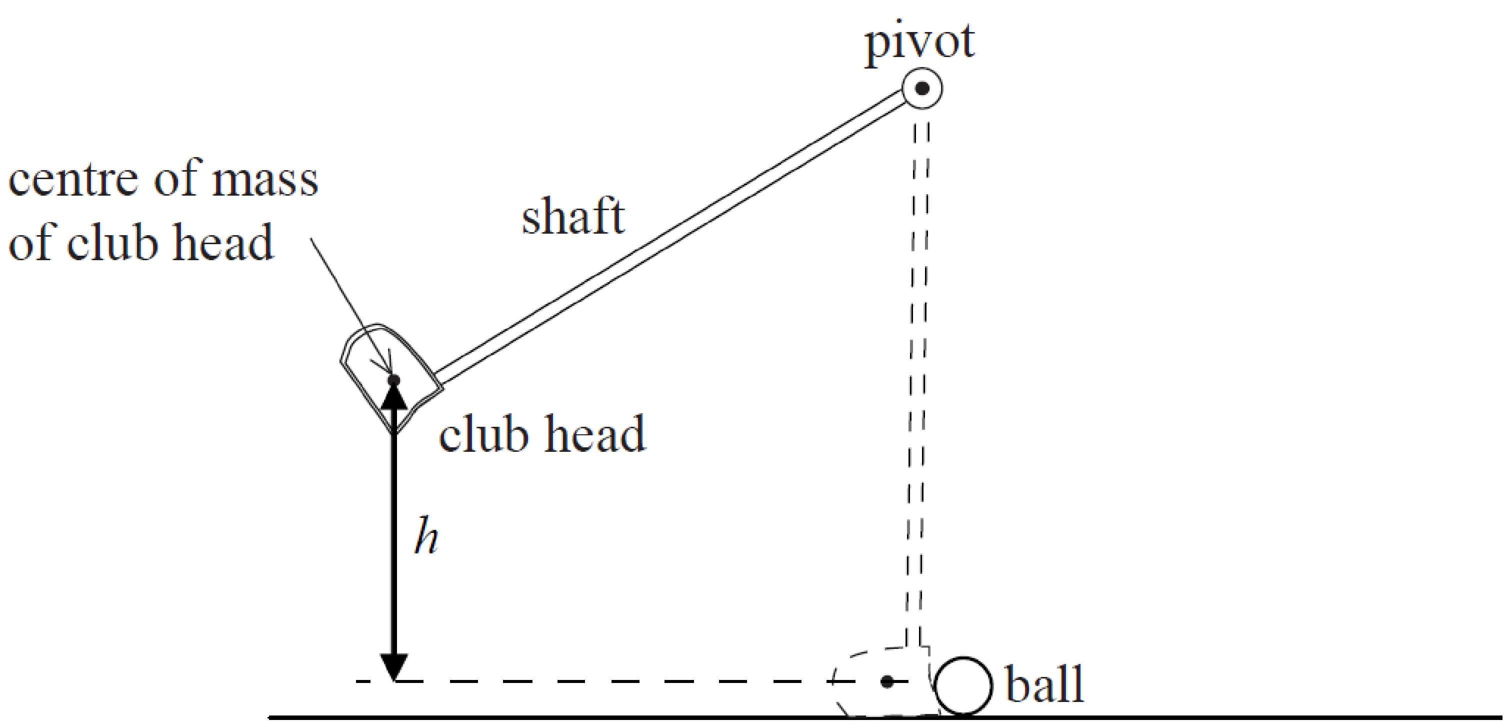
(i) State the value of the magnitude of F when the railway engine is travelling at 16 ms^{-1}.

(ii) Determine the **total** horizontal resistive force when the railway engine is travelling at 8.0 ms^{-1}.

f. On its journey, the railway engine now travels around a curved track at constant speed. Explain whether or not the railway engine is accelerating. [3]

Impulse and momentum

The diagram shows an arrangement used to test golf club heads.

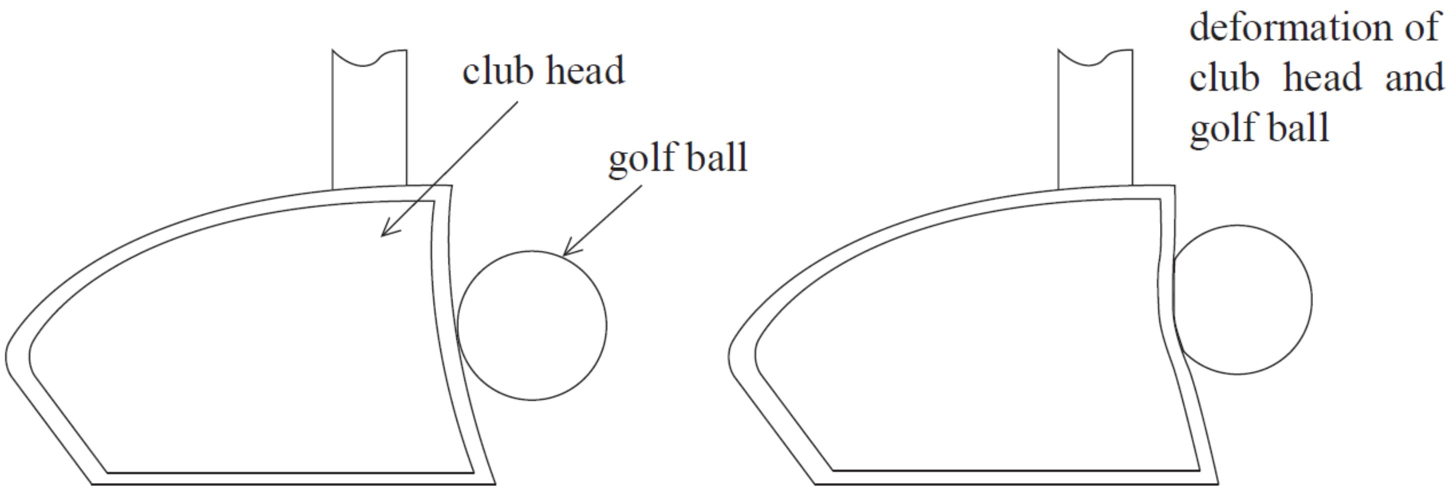


The shaft of a club is pivoted and the centre of mass of the club head is raised by a height h before being released. On reaching the vertical position the club head strikes the ball.

a. (i) Describe the energy changes that take place in the club head from the instant the club is released until the club head and the ball separate. [4]

(ii) Calculate the maximum speed of the club head achievable when h = 0.85 m.

b. The diagram shows the deformation of a golf ball and club head as they collide during a test. [2]



Explain how increasing the deformation of the club head may be expected to increase the speed at which the ball leaves the club.

c. In a different experimental arrangement, the club head is in contact with the ball for a time of 220 μs. The club head has mass 0.17 kg and the ball has mass 0.045 kg. At the moment of contact the ball is at rest and the club head is moving with a speed of 38 ms^{-1}. The ball moves off with an initial speed of 63 ms^{-1}. [5]

(i) Calculate the average force acting on the ball while the club head is in contact with the ball.

(ii) State the average force acting on the club head while it is in contact with the ball.

(iii) Calculate the speed of the club head at the instant that it loses contact with the ball.

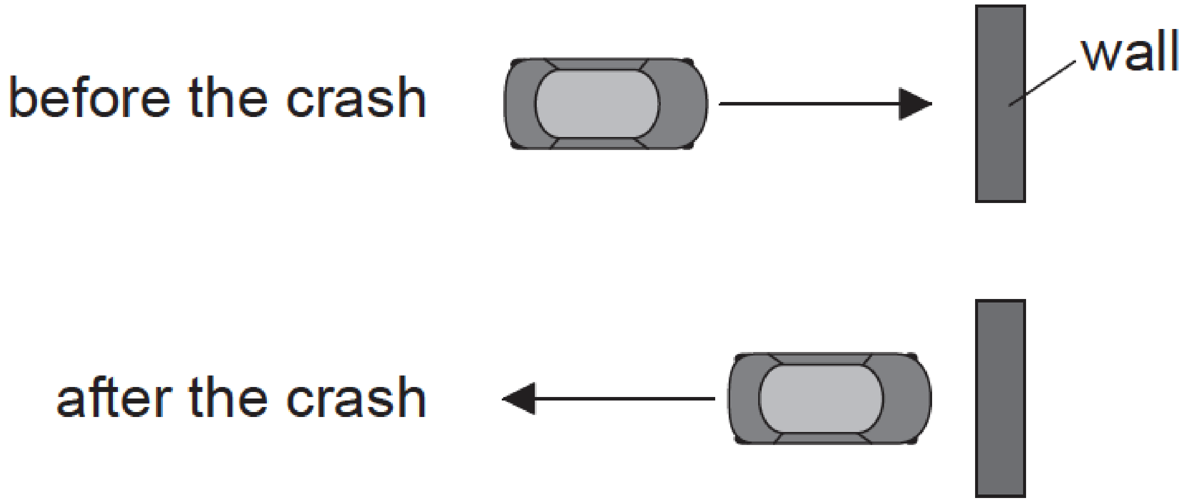
This question is in two parts. **Part 1** is about momentum. **Part 2** is about electric point charges.

Part 1 Momentum

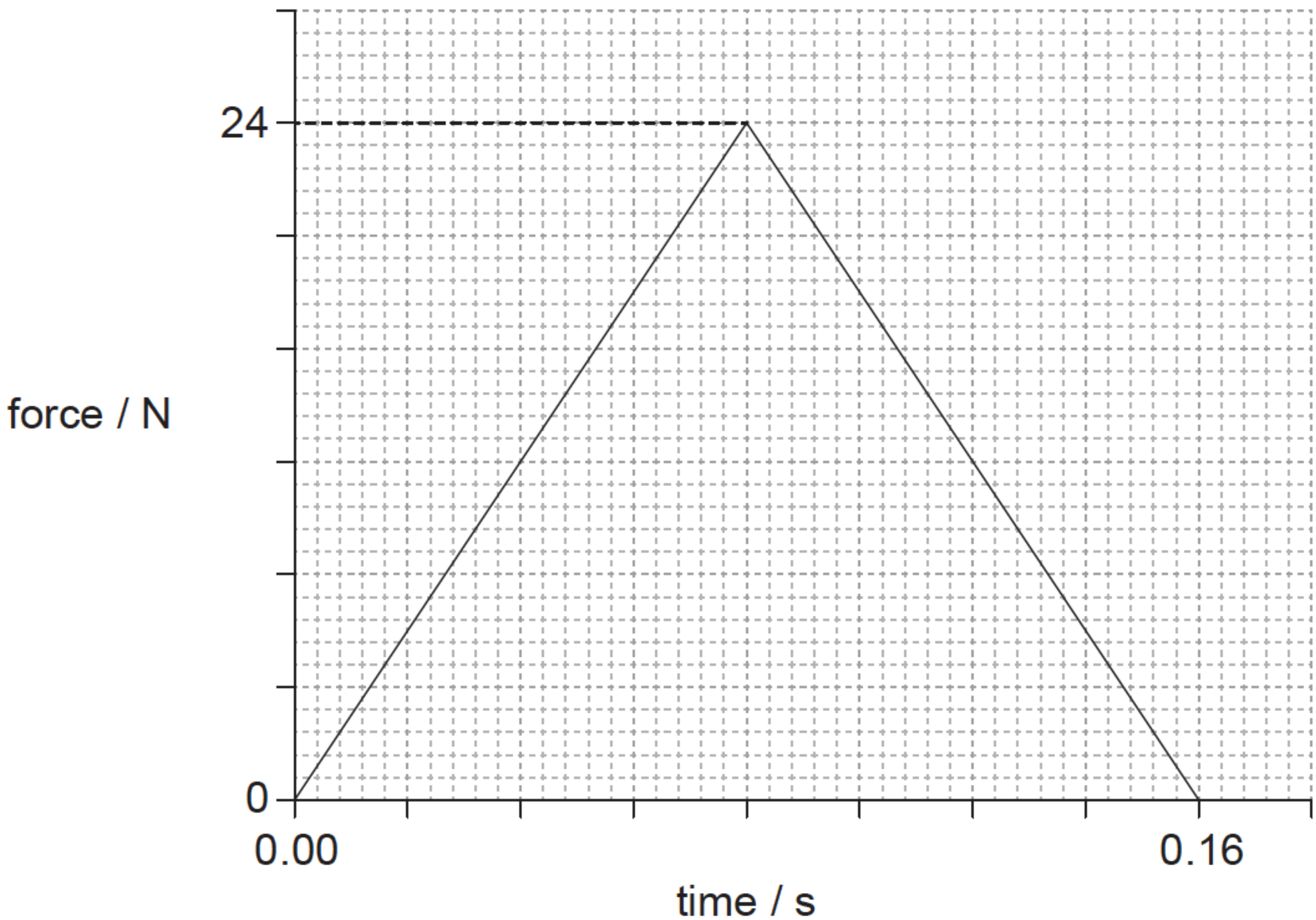
Part 2 Electric point charges

a. State the law of conservation of linear momentum. [2]

b. A toy car crashes into a wall and rebounds at right angles to the wall, as shown in the plan view. [9]



The graph shows the variation with time of the force acting on the car due to the wall during the collision.

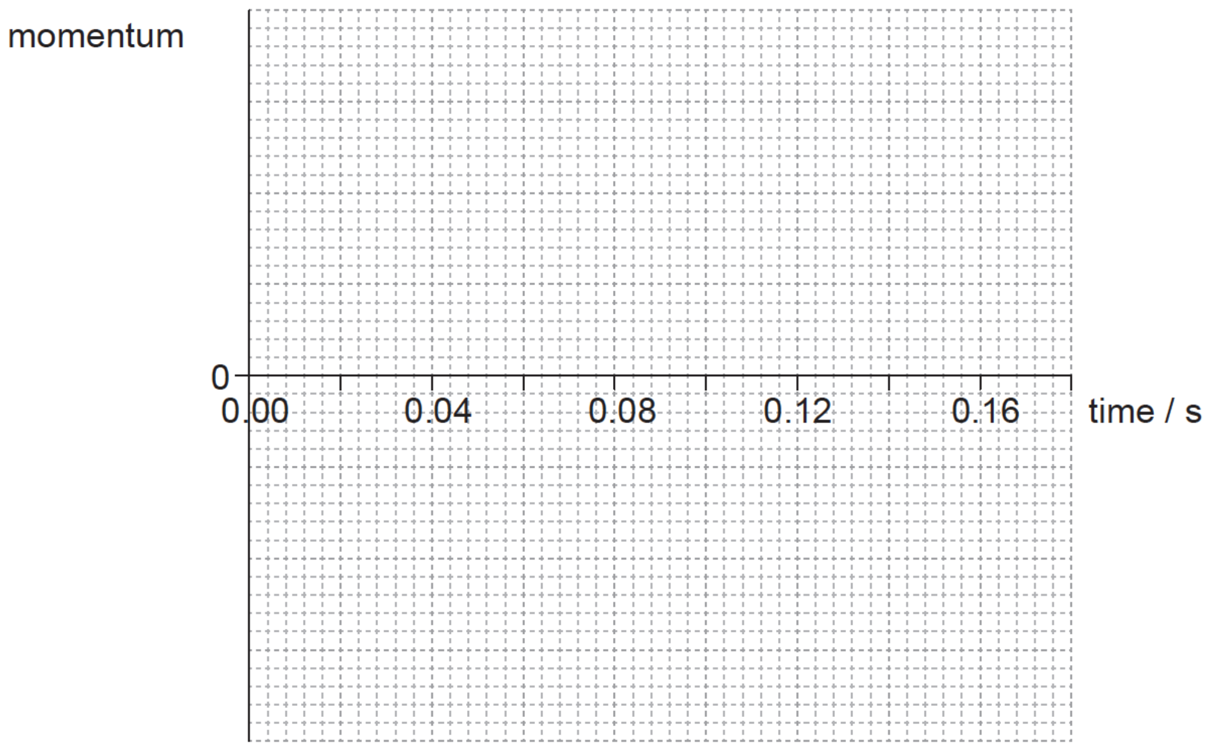


The kinetic energy of the car is unchanged after the collision. The mass of the car is 0.80 kg.

(i) Determine the initial momentum of the car.

(ii) Estimate the average acceleration of the car before it rebounds.

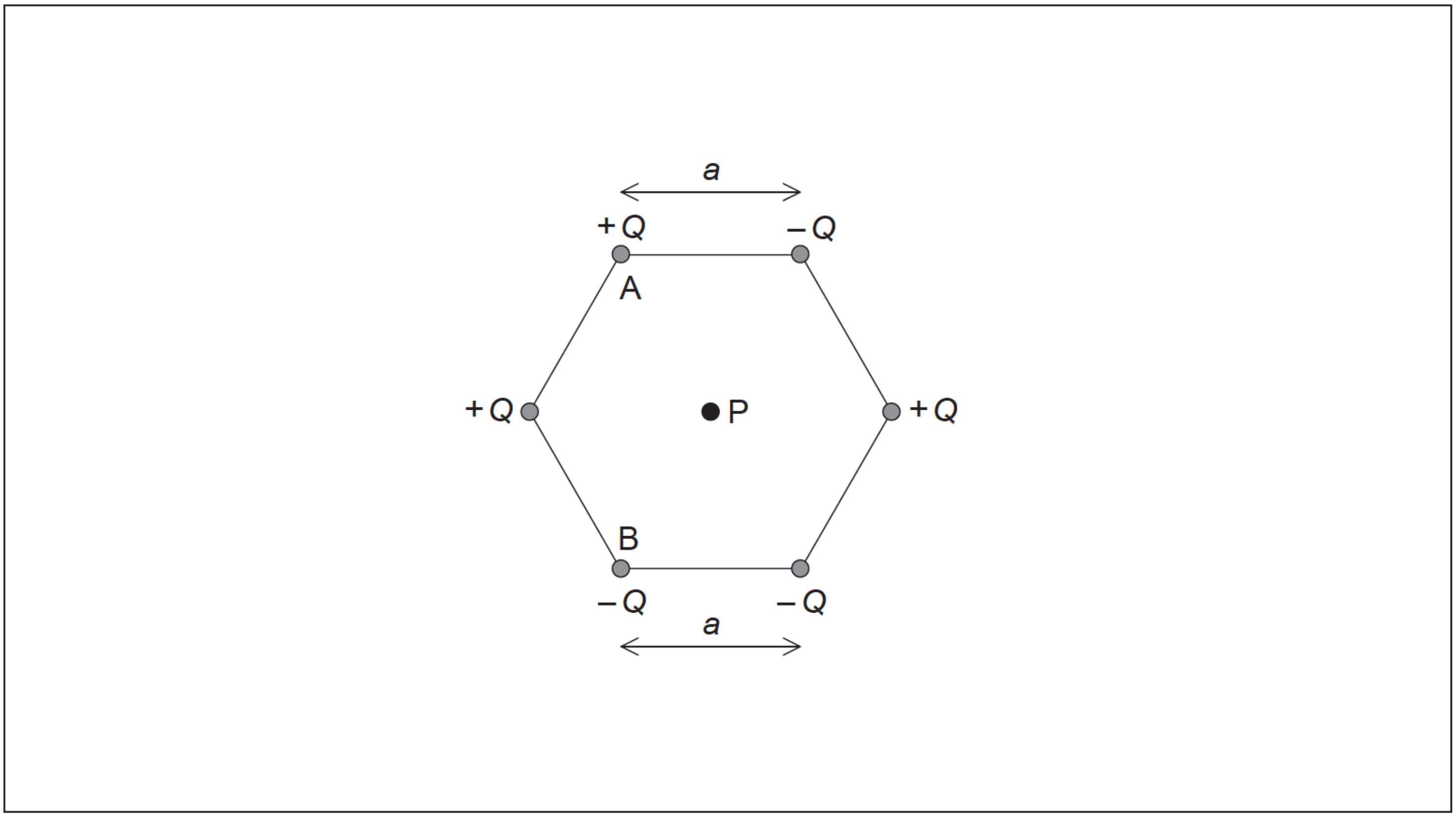
(iii) On the axes, draw a graph to show how the momentum of the car varies during the impact. You are not required to give values on the y-axis.



c. Two identical toy cars, A and B are dropped from the same height onto a solid floor without rebounding. Car A is unprotected whilst car B is in a box with protective packaging around the toy. Explain why car B is less likely to be damaged when dropped. [4]

d. Define *electric field strength* at a point in an electric field. [2]

e. Six point charges of equal magnitude *Q* are held at the corners of a hexagon with the signs of the charges as shown. Each side of the hexagon has a length *a*. [8]



P is at the centre of the hexagon.

(i) Show, using Coulomb's law, that the magnitude of the electric field strength at point P due to **one** of the point charges is

$$\frac{kQ}{a^2}$$

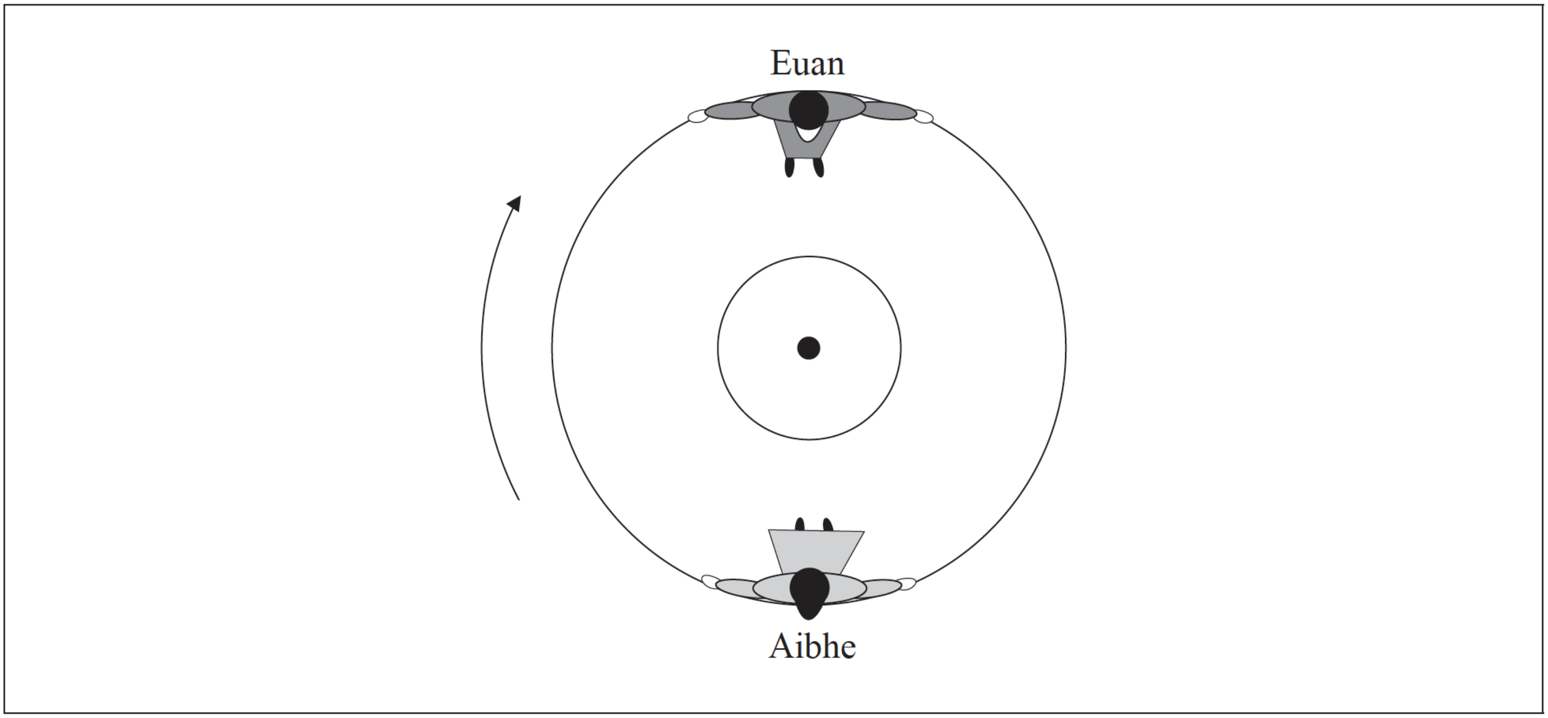
(ii) On the diagram, draw arrows to represent the direction of the field at P due to point charge A (label this direction A) and point charge B (label this direction B).

(iii) The magnitude of Q is 3.2 μC and length a is 0.15 m. Determine the magnitude and the direction of the electric field strength at point P due to all six charges.

This question is in **two** parts. **Part 1** is about two children on a merry-go-round. **Part 2** is about electric circuits.

Part 1 Two children on a merry-go-round

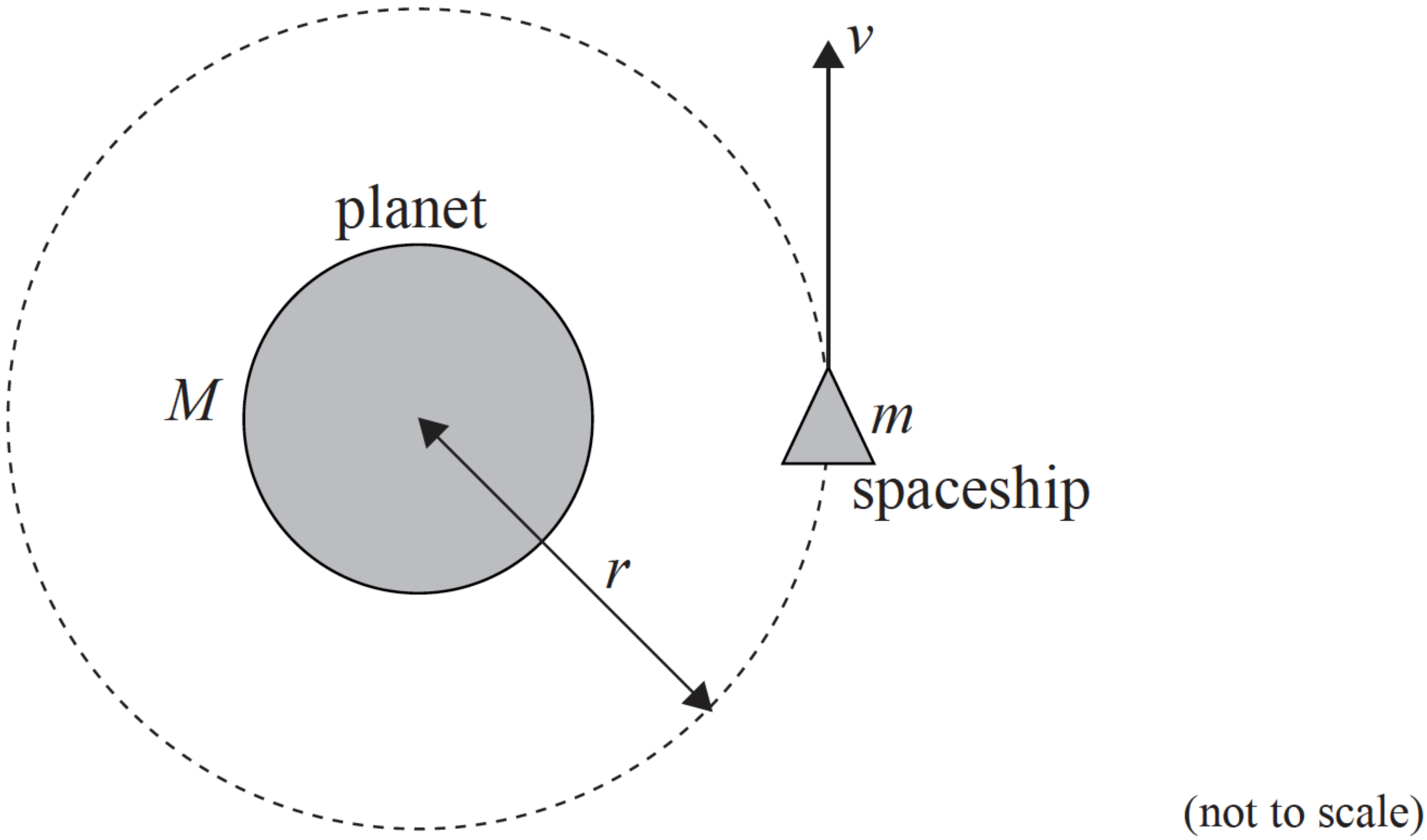
Aibhe and Euan are sitting on opposite sides of a merry-go-round, which is rotating at constant speed around a fixed centre. The diagram below shows the view from above.



Aibhe is moving at speed 1.0ms^{-1} relative to the ground.

Part 2 Orbital motion

A spaceship of mass *m* is moving at speed *v* in a circular orbit of radius *r* around a planet of mass *M*.



a. Determine the magnitude of the velocity of Aibhe relative to [2]

(i) Euan.

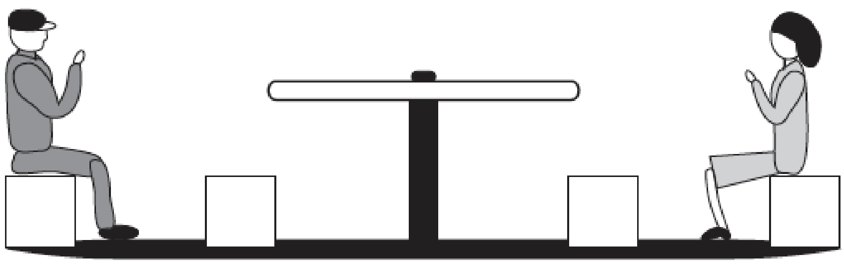
(ii) the centre of the merry-go-round.

b. (i) Outline why Aibhe is accelerating even though she is moving at constant speed. [6]

(ii) Draw an arrow on the diagram on page 22 to show the direction in which Aibhe is accelerating.

(iii) Identify the force that is causing Aibhe to move in a circle.

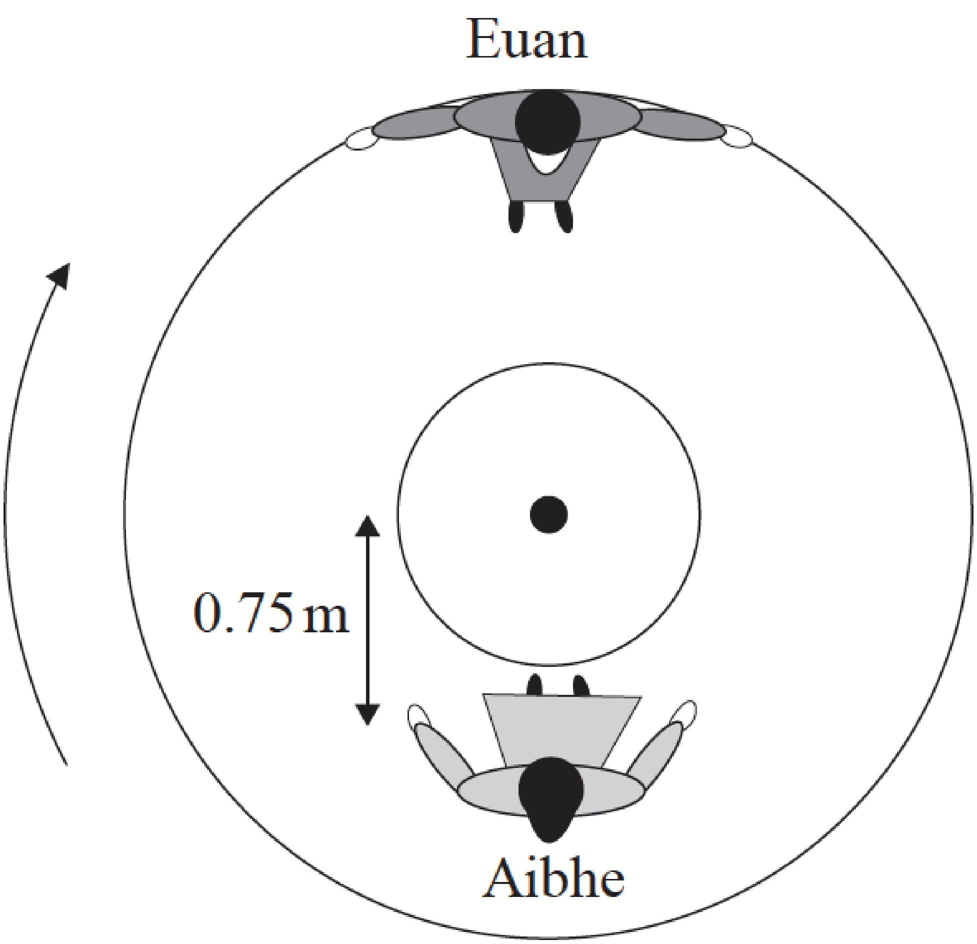
(iv) The diagram below shows a side view of Aibhe and Euan on the merry-go-round.



Explain why Aibhe feels as if her upper body is being “thrown outwards”, away from the centre of the merry-go-round.

c. Euan is rotating on a merry-go-round and drags his foot along the ground to act as a brake. The merry-go-round comes to a stop after 4.0 rotations. The radius of the merry-go-round is 1.5 m. The average frictional force between his foot and the ground is 45 N. Calculate the work done. [2]

d. Aibhe moves so that she is sitting at a distance of 0.75 m from the centre of the merry-go-round, as shown below. [5]



Euan pushes the merry-go-round so that he is again moving at 1.0 ms^{-1} relative to the ground.

(i) Determine Aibhe’s speed relative to the ground.

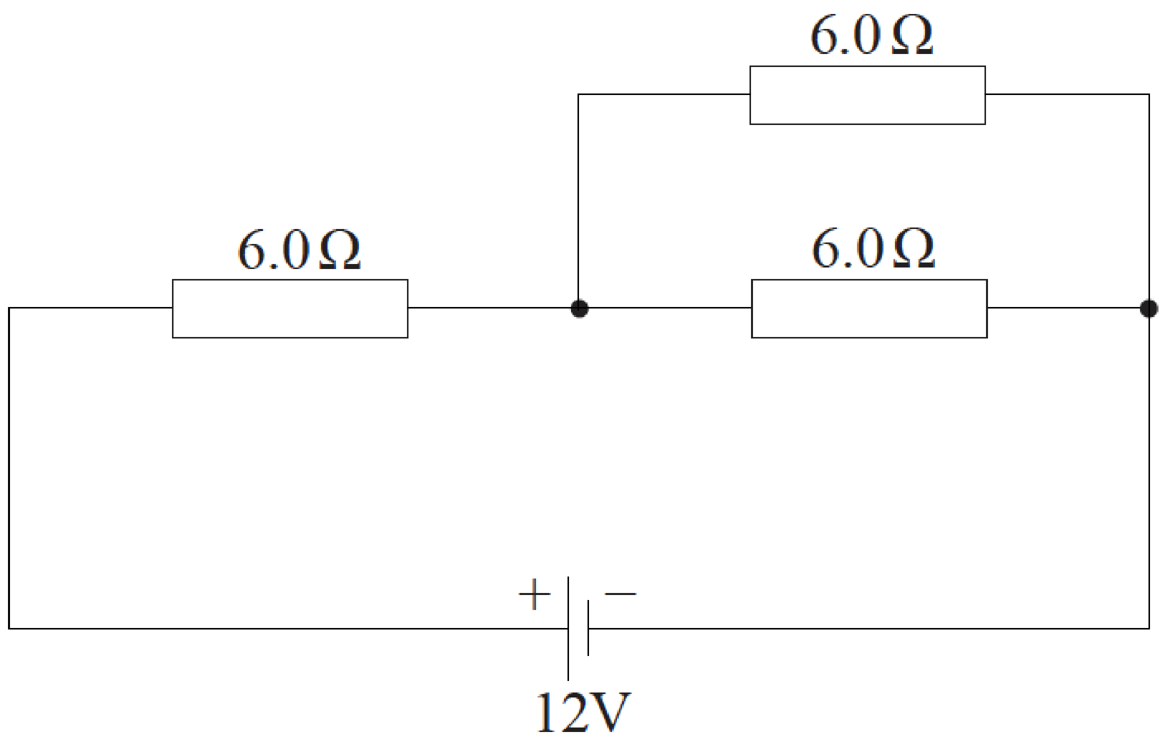
(ii) Calculate the magnitude of Aibhe's acceleration.

e. Define the *electric resistance* of a wire. [1]

f. Using the following data, calculate the length of constantan wire required to make a resistor with a resistance of 6.0Ω. [3]

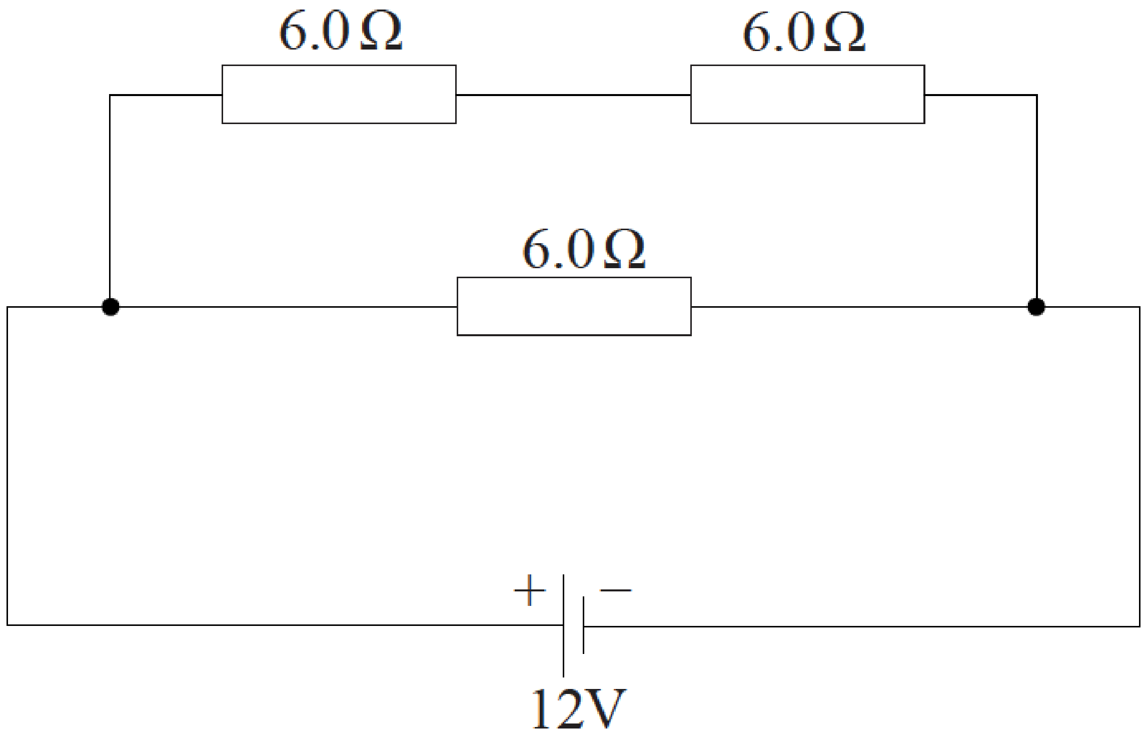
Resistivity of constantan = $5.0\times10^{-7}\Omega m$
Average radius of wire = $2.5\times10^{-5}m$

g. Three resistors, each of resistance 6.0Ω, are arranged in the circuit shown below. The cell has an emf of 12V and negligible internal resistance. [3]



Determine the total power supplied by the cell.

h. The same resistors and cell are now re-arranged into a different circuit, as shown below. [3]

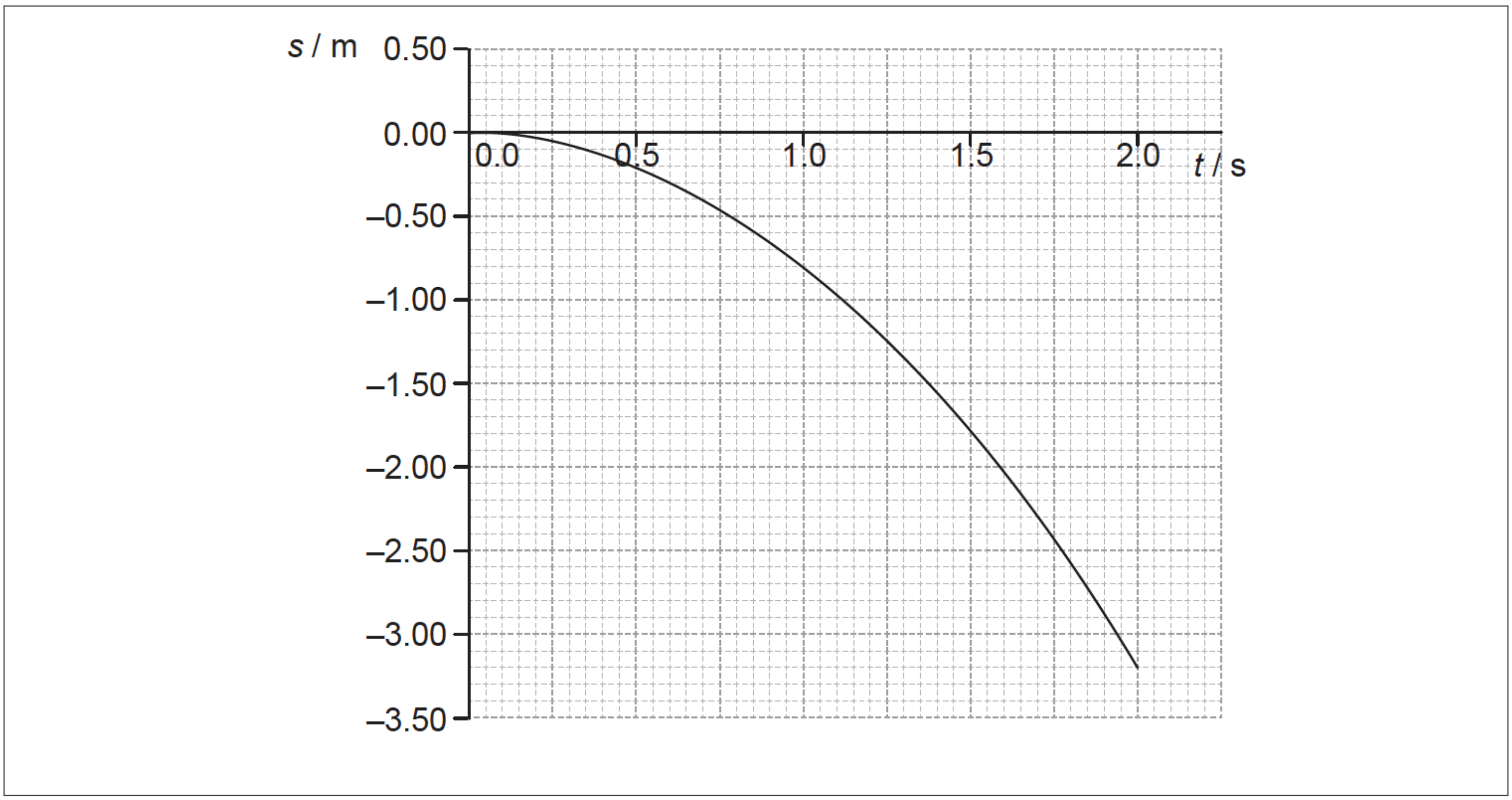


Explain why the total power supplied by the cell is greater than for the circuit in (g).

This question is in **two** parts. **Part 1** is about kinematics and gravitation. **Part 2** is about radioactivity.

Part 1 Kinematics and gravitation

A ball is released near the surface of the Moon at time t=0. The point of release is on a straight line between the centre of Earth and the centre of the Moon. The graph below shows the variation with time t of the displacement s of the ball from the point of release.



Part 2 Radioactivity

Two isotopes of calcium are calcium-40 $\left({}^{40}_{20}\mathrm{Ca}\right)$ and calcium-47 $\left({}^{47}_{20}\mathrm{Ca}\right)$. Calcium-40 is stable and calcium-47 is radioactive with a half-life of 4.5 days.

a. State the significance of the negative values of *s*. [1]

b. Use the graph to [6]

(i) estimate the velocity of the ball at $t = 0.80$ s.

(ii) calculate a value for the acceleration of free fall close to the surface of the Moon.

c. The following data are available. [4]

Mass of the ball = 0.20 kg

Mean radius of the Moon = 1.74×10^6 m

Mean orbital radius of the Moon about the centre of Earth = 3.84×10^8 m

Mass of Earth = 5.97×10^{24} kg

Show that Earth has no significant effect on the acceleration of the ball.

d. Calculate the speed of an identical ball when it falls 3.0 m from rest close to the surface of Earth. Ignore air resistance. [1]

e. Sketch, on the graph, the variation with time *t* of the displacement *s* from the point of release of the ball when the ball is dropped close to the surface of Earth. (For this sketch take the direction towards the Earth as being negative.) [3]

f. Explain, in terms of the number of nucleons and the forces between them, why calcium-40 is stable and calcium-47 is radioactive. [3]

g. Calculate the percentage of a sample of calcium-47 that decays in 27 days. [3]

h. The nuclear equation for the decay of calcium-47 into scandium-47 $\left({}^{47}_{21}\mathrm{Sc}\right)$ is given by [4]

$$ {}^{47}_{20}\mathrm{Ca} \rightarrow {}^{47}_{21}\mathrm{Sc} + {}^{0}_{-1}\mathrm{e} + \mathrm{X} $$

(i) Identify X.

(ii) The following data are available.

Mass of calcium-47 nucleus = 46.95455 u
Mass of scandium-47 nucleus = 46.95241 u

Using the data, determine the maximum kinetic energy, in MeV, of the products in the decay of calcium-47.

(iii) State why the kinetic energy will be less than your value in (h)(ii).