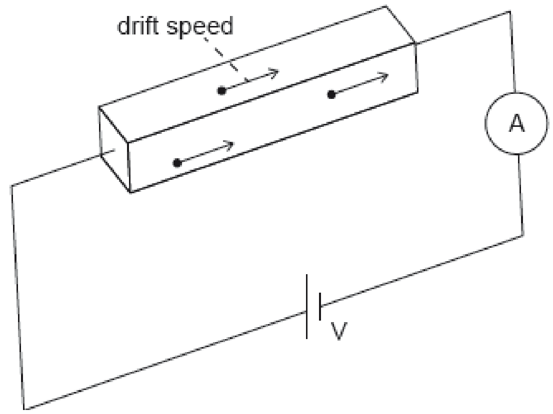
SL Paper 2

An ohmic conductor is connected to an ideal ammeter and to a power supply of output voltage V.



The following data are available for the conductor:

density of free electrons = 8.5×10^{22} cm^{-3}

resistivity $\rho = 1.7 \times 10^{-8}$ Ωm

dimensions $w \times h \times l = 0.020$ cm × 0.020 cm × 10 cm.

The ammeter reading is 2.0 A.

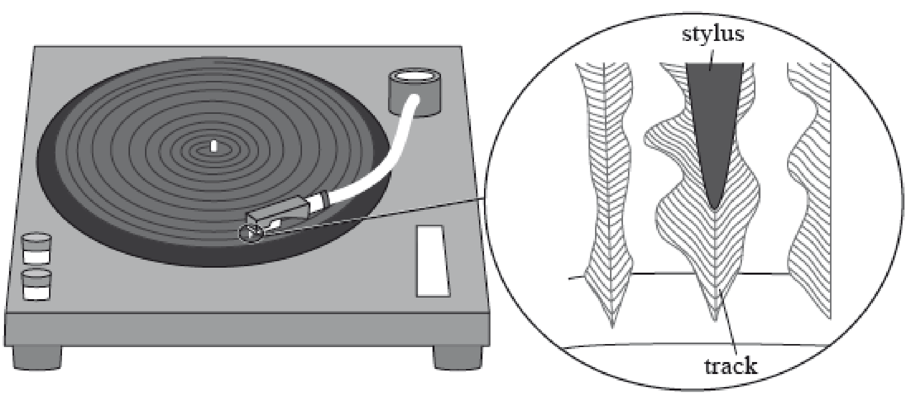
a. Calculate the resistance of the conductor. [2]

b. Calculate the drift speed v of the electrons in the conductor in cm s^{-1}. State your answer to an appropriate number of significant figures. [3]

This question is in **two** parts. **Part 1** is about simple harmonic motion (SHM) and sound. **Part 2** is about electric and magnetic fields.

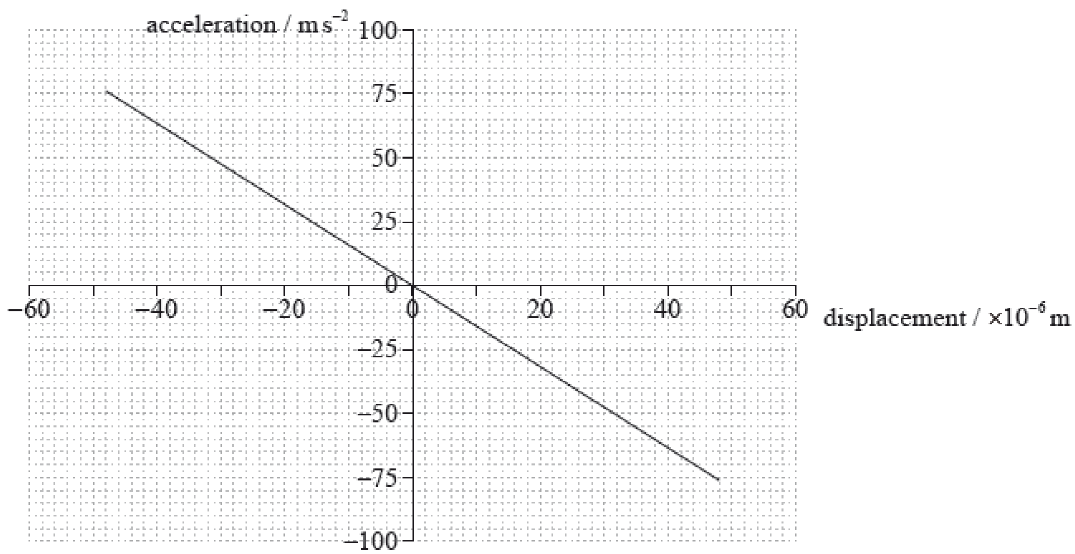
Part 1 Simple harmonic motion (SHM) and sound

The diagram shows a section of continuous track of a long-playing (LP) record. The stylus (needle) is placed in the track of the record.



As the LP record rotates, the stylus moves because of changes in the width and position of the track. These movements are converted into sound waves by an electrical system and a loudspeaker.

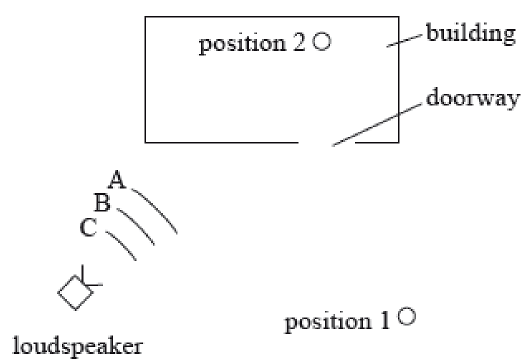
A recording of a single-frequency musical note is played. The graph shows the variation in horizontal acceleration of the stylus with horizontal displacement.



Sound is emitted from a loudspeaker which is outside a building. The loudspeaker emits a sound wave that has the same frequency as the recorded

note.

A person standing at position 1 outside the building and a person standing at position 2 inside the building both hear the sound emitted by the loudspeaker.



A, B and C are wavefronts emitted by the loudspeaker.

Part 2 Electric and magnetic fields

Electrical leads used in physics laboratories consist of a central conductor surrounded by an insulator.

a. Explain why the graph shows that the stylus undergoes simple harmonic motion. [4]

b. (i) Using the graph on page 14, show that the frequency of the note being played is about 200 Hz. [5]

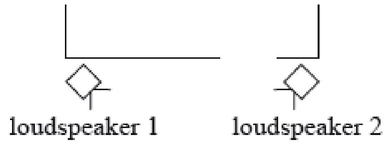
(ii) On the graph on page 14, identify, with the letter P, the position of the stylus at which the kinetic energy is at a maximum.

c. (i) Draw rays to show how the person at **position 1** is able to hear the sound emitted by the loudspeaker. [4]

(ii) The speed of sound in the air is $330\ \mathrm{m\,s^{-1}}$. Calculate the wavelength of the note.

(iii) The walls of the room are designed to absorb sound. Explain how the person at **position 2** is able to hear the sound emitted by the loudspeaker.

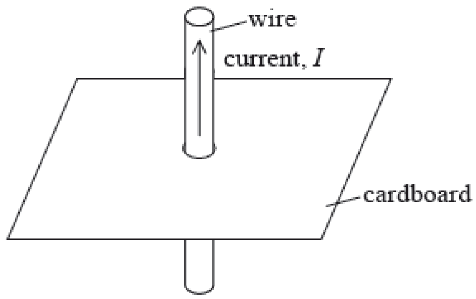
d. The arrangement in (c) is changed and another loudspeaker is added. Both loudspeakers emit the same recorded note in phase with each other. [3]



Outline why there are positions between the loudspeakers where the sound can only be heard faintly.

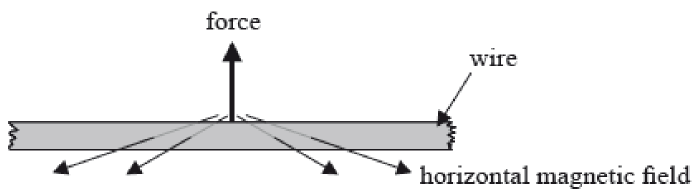
e. Distinguish between an insulator and a conductor. [2]

f. The diagram shows a current *I* in a vertical wire that passes through a hole in a horizontal piece of cardboard. [3]



On the cardboard, draw the magnetic field pattern due to the current.

g. (i) The diagram shows a length of copper wire that is horizontal in the magnetic field of the Earth. [4]

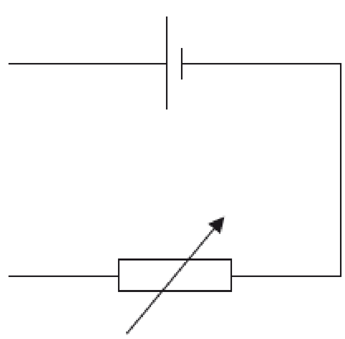


The wire carries an electric current and the force on the wire is as shown. Identify, with an arrow, the direction of electron flow in the wire.

(ii) The horizontal component of the magnetic field of the Earth at the position of the wire is $40\ \mu\mathrm{T}$. The mass per unit length of the wire is $1.41 \times 10^{-4}\ \mathrm{kg\,m^{-2}}$. The net force on the wire is zero. Determine the current in the wire.

This question is about the internal resistance of a cell.

A circuit is used to determine the internal resistance and emf of a cell. It consists of the cell, a variable resistor, an ideal ammeter and an ideal voltmeter. The diagram shows part of the circuit with the ammeter and voltmeter missing.



The variable resistor is set to $1.5\ \Omega$. When the cell converts 7.2 mJ of energy, 5.8 mC of charge moves completely around the circuit. The potential difference across the variable resistor is 0.55 V.

a. Define *electromotive force (emf)*. [1]

b.i. Draw on the diagram the positions of the ammeter and voltmeter. [1]

b.ii. Show that the emf of the cell is 1.25 V. [1]

b.iii. Determine the internal resistance of the cell. [2]

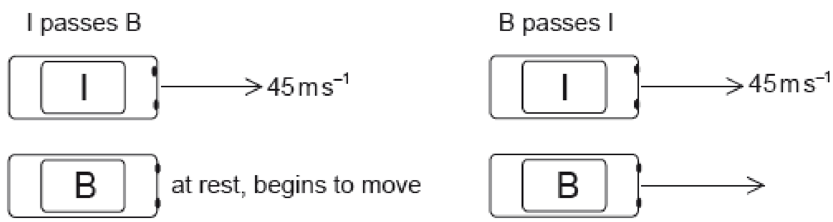
b.iv. Calculate the energy dissipated per second in the variable resistor. [2]

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 $3.2\ \mathrm{m\,s^{-2}}$.



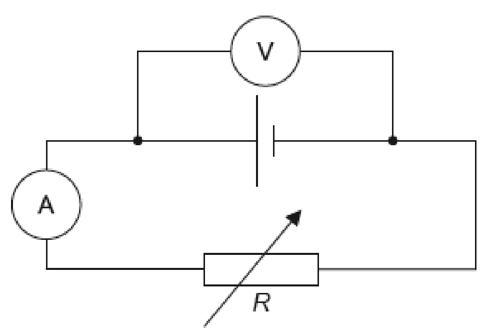
At a later time B passes I. You may assume that both cars are point particles.

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 $52\ \mathrm{m\,s^{-1}}$.

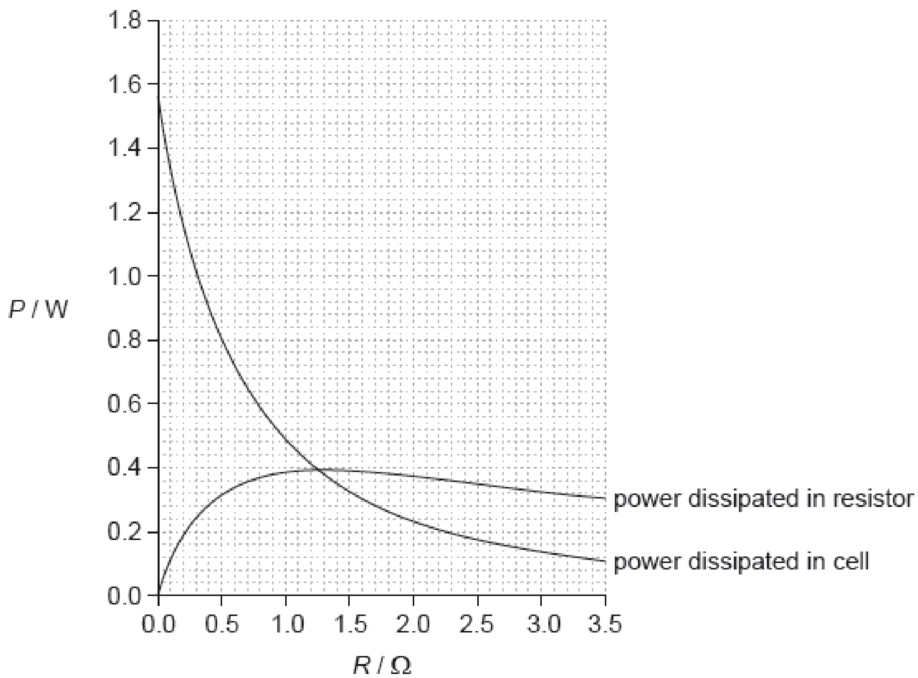
This question is in **two** parts. **Part 1** is about kinematics and Newton's laws of motion.

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]

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

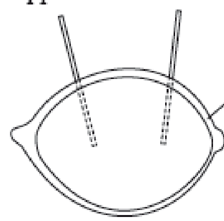
Part 1 Motion of a car

A car is travelling along the straight horizontal road at its maximum speed of 56 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 m s^{-1} to a final speed of 28 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 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 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 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.

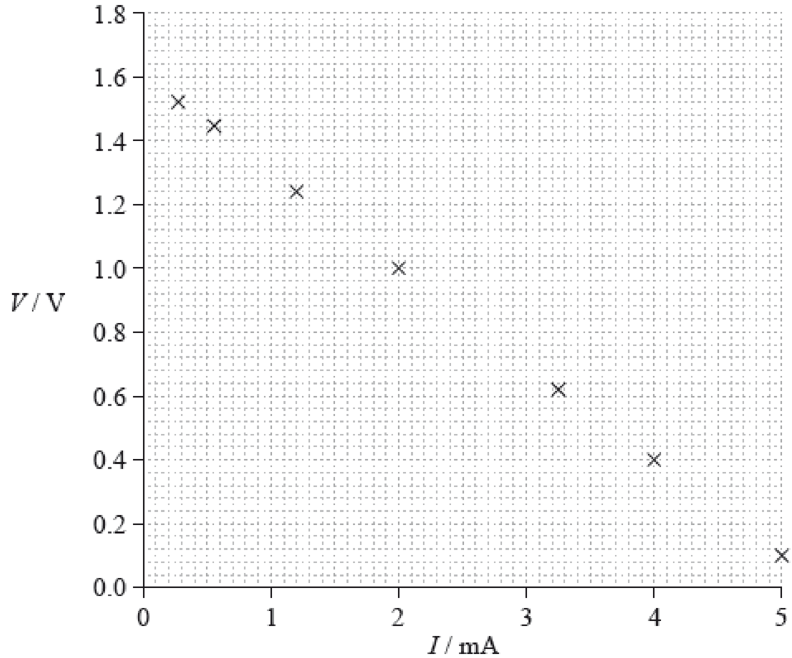
d. (i) Draw a circuit diagram of the experimental arrangement that will enable the student to collect the data for the graph. [10]

(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 $6.0\ \mu A$. The clock runs for 16 hours. Calculate the charge that flows through the clock in this time.

A heater in an electric shower has a power of 8.5 kW when connected to a 240 V electrical supply. It is connected to the electrical supply by a copper cable.

The following data are available:

Length of cable = 10 m
Cross-sectional area of cable = 6.0 mm^2
Resistivity of copper = $1.7 \times 10^{-8}\ \Omega$ m

a.i. Calculate the current in the copper cable. [1]

a.ii. Calculate the resistance of the cable. [2]

b. Explain, in terms of electrons, what happens to the resistance of the cable as the temperature of the cable increases. [3]

c. The heater changes the temperature of the water by 35 K. The specific heat capacity of water is 4200 J kg^{-1} K^{-1}. [4]

Determine the rate at which water flows through the shower. State an appropriate unit for your answer.

This question is in **two** parts. **Part 1** is about a lightning discharge. **Part 2** is about fuel for heating.

Part 1 Lightning discharge

The magnitude of the electric field strength E between two infinite charged parallel plates is given by the expression

$$E = \frac{\sigma}{\varepsilon_0}$$

where σ is the charge per unit area on one of the plates.

A thundercloud carries a charge of magnitude 35 C spread over its base. The area of the base is $1.2 \times 10^7\ \mathrm{m}^2$.

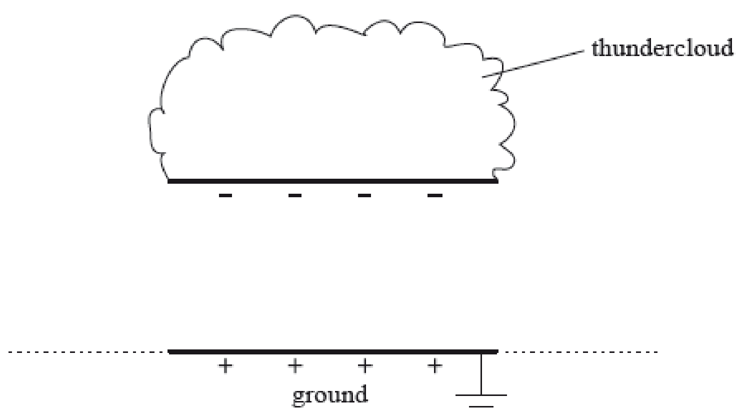
Part 2 Fuel for heating

A room heater burns liquid fuel and the following data are available.

Density of liquid fuel	$= 8.0 \times 10^2\ \mathrm{kg\,m^{-3}}$
Energy produced by 1 m^3 of liquid fuel	$= 2.7 \times 10^{10}\ \mathrm{J}$
Rate at which fuel is consumed	$= 0.13\ \mathrm{g\,s^{-1}}$
Latent heat of vaporization of the fuel	$= 290\ \mathrm{kJ\,kg^{-1}}$

Part 1.a. Define *electric field strength*. [2]

Part 1.b. A thundercloud can be modelled as a negatively charged plate that is parallel to the ground. [3]



The magnitude of the charge on the plate increases due to processes in the atmosphere. Eventually a current discharges from the thundercloud to the ground.

On the diagram, draw the electric field pattern between the thundercloud base and the ground.

Part 1.c. (i) Determine the magnitude of the electric field between the base of the thundercloud and the ground. [12]

(ii) State **two** assumptions made in (c)(i).

1.

2.

(iii) When the thundercloud discharges, the average discharge current is 1.8 kA. Estimate the discharge time.

(iv) The potential difference between the thundercloud and the ground before discharge is $2.5 \times 10^8\ \mathrm{V}$. Determine the energy released in the discharge.

Part 2.a. Define the *energy density* of a fuel. [1]

Part 2.b. (i) Use the data to calculate the power output of the room heater, ignoring the power required to convert the liquid fuel into a gas. [5]

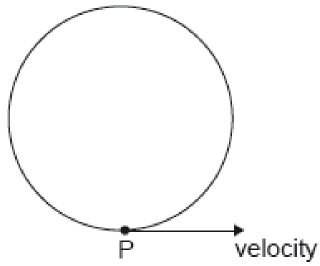
(ii) Show why, in your calculation in (b)(i), the power required to convert the liquid fuel into a gas at its boiling point can be ignored.

Part 2.c. State, in terms of molecular structure and their motion, **two** differences between a liquid and a gas. [2]

1.

2.

An electron moves in circular motion in a uniform magnetic field.



The velocity of the electron at point P is 6.8×10^5 m s^{-1} in the direction shown.

The magnitude of the magnetic field is 8.5 T.

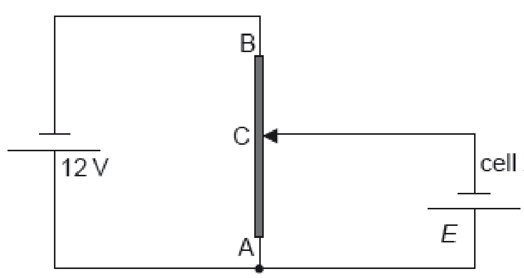
a. State the direction of the magnetic field. [1]

b. Calculate, in N, the magnitude of the magnetic force acting on the electron. [1]

c.i. Explain why the electron moves at constant speed. [1]

c.ii. Explain why the electron moves on a circular path. [2]

The diagram shows a potential divider circuit used to measure the emf E of a cell X. Both cells have negligible internal resistance.



AB is a wire of uniform cross-section and length 1.0 m. The resistance of wire AB is 80 Ω. When the length of AC is 0.35 m the current in cell X is zero.

a. State what is meant by the emf of a cell. [2]

b.i. Show that the resistance of the wire AC is 28 Ω. [2]

b.ii. Determine E. [2]

Part 2 Electric potential difference and electric circuits

a. Ionized hydrogen atoms are accelerated from rest in the vacuum between two vertical parallel conducting plates. The potential difference between the plates is *V*. As a result of the acceleration each ion gains an energy of 1.9×10^{-18}J. [2]

Calculate the value of *V*.

b. The plates in (a) are replaced by a cell that has an emf of 12.0 V and internal resistance 5.00 Ω. A resistor of resistance *R* is connected in series with the cell. The energy transferred by the cell to an electron as it moves through the resistor is 1.44×10^{-18} J. [8]

(i) Define *resistance* of a resistor.

(ii) Describe what is meant by internal resistance.

(iii) Show that the value of *R* is 15.0 Ω.

(iv) Calculate the total power supplied by the cell.

This question is in **two** parts. **Part 1** is about energy resources. **Part 2** is about electric fields.

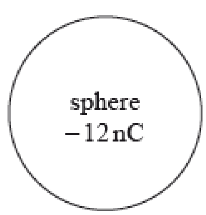
Part 1 Energy resources

A photovoltaic panel is made up of a collection (array) of photovoltaic cells. The panel has a total area of $1.3\ \mathrm{m}^2$ and is mounted on the roof of a house. The maximum intensity of solar radiation at the location of the panel is $750\ \mathrm{W\,m}^{-2}$. The panel produces a power output of 210 W when the solar radiation is at its maximum intensity.

The owner of the house chooses between photovoltaic panels and solar heating panels to provide 4.2 kW of power to heat water. The solar heating panels have an efficiency of 70%. The maximum intensity of solar radiation at the location remains at $750\ \mathrm{W\,m}^{-2}$.

Part 2 Electric fields

An isolated metal sphere is placed in a vacuum. The sphere has a negative charge of magnitude 12 nC.



Outside the sphere, the electric field strength is equivalent to that of a point negative charge of magnitude 12 nC placed at the centre of the sphere. The radius r of the sphere is 25 mm.

An electron is initially at rest on the surface of the sphere.

a. The Sun is a renewable energy source whereas a fossil fuel is a non-renewable energy source. Outline the difference between renewable and non-renewable energy sources. [2]

b. With reference to the energy transformations and the operation of the devices, distinguish between a photovoltaic cell and a solar heating panel. [2]

c.i. Determine the efficiency of the photovoltaic panel. [2]

c.ii. State **two** reasons why the intensity of solar radiation at the location of the panel is not constant. [2]

1.

2.

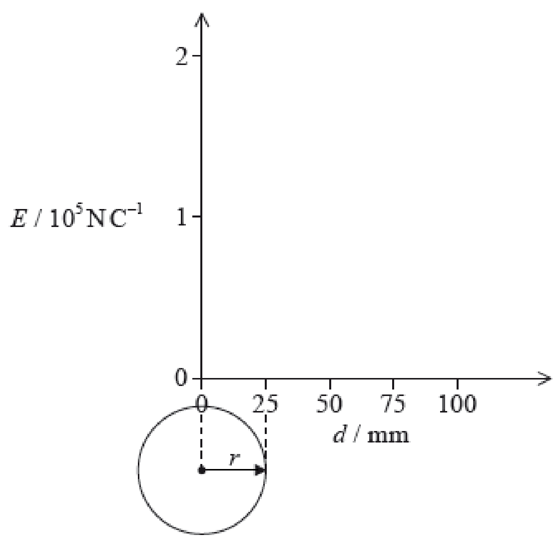
d.i. Calculate the minimum area of solar heating panel required to provide this power. [2]

d.ii. Comment on whether it is better to use a solar heating panel rather than an array of photovoltaic panels for the house. Do not consider the installation cost of the panels in your answer. [2]

f. Using the diagram, draw the electric field pattern due to the charged sphere. [2]

g.i. Show that the magnitude of the electric field strength at the surface of the sphere is about $2 \times 10^5\ \mathrm{N\,C^{-1}}$. [2]

g.ii. On the axes, draw a graph to show the variation of the electric field strength E with distance d from the centre of the sphere. [2]



h.i. Calculate the initial acceleration of the electron. [2]

h.ii. Discuss the subsequent motion of the electron. [2]

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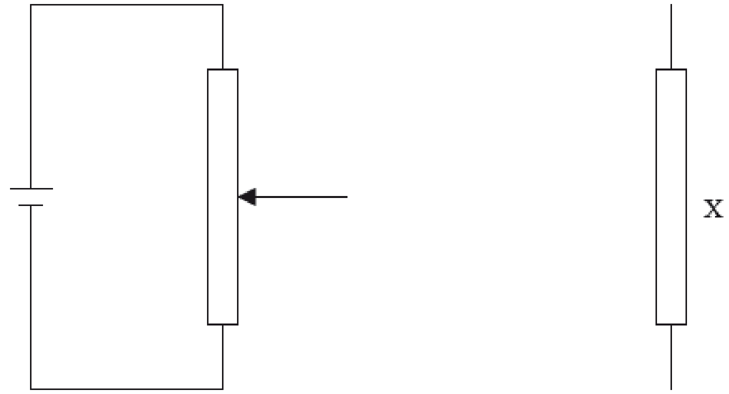
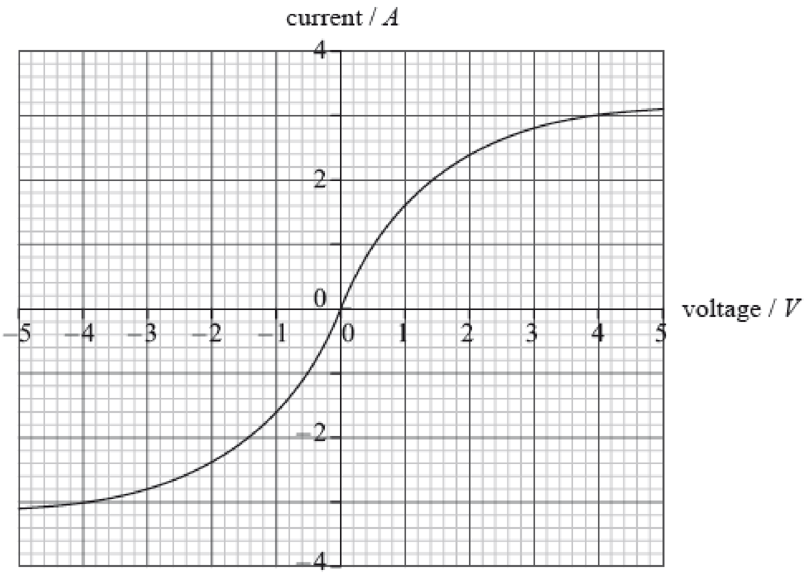
a. Draw the complete diagram of the circuit that uses a potential divider, ammeter, voltmeter and cell to measure the current-voltage characteristics for component X. [3]



b. The graph shows the current-voltage characteristics for the component X. [2]



Component X is now connected across the terminals of a cell of emf 2.0 V and negligible internal resistance. Use the graph to show that the resistance of X is $0.83\ \Omega$.

Part 2 Gravitational fields and electric fields

a. The magnitude of gravitational field strength *g* is defined from the equation shown below. [4]

$$g = \frac{F_g}{m}$$

The magnitude of electric field strength *E* is defined from the equation shown below.

$$E = \frac{F_E}{q}$$

For each of these defining equations, state the meaning of the symbols

(i) F_g.

(ii) F_E.

(iii) m.

(iv) q.

b. In a simple model of the hydrogen atom, the electron is regarded as being in a circular orbit about the proton. The magnitude of the electric field strength at the electron due to the proton is E_p. The magnitude of the gravitational field strength at the electron due to the proton is g_p. [5]

(i) Draw the electric field pattern of the proton alone.

(ii) Determine the order of magnitude of the ratio shown below.

$$\frac{E_p}{g_p}$$

This question is in two parts. **Part 1** is about electric charge and electric circuits. **Part 2** is about momentum.

Part 1 Electric charge and electric circuits

a. State Coulomb's law. [2]

b. In a simple model of the hydrogen atom, the electron can be regarded as being in a circular orbit about the proton. The radius of the orbit is 2.0×10^{-10} m. [7]

(i) Determine the magnitude of the electric force between the proton and the electron.

(ii) Calculate the magnitude of the electric field strength E and state the direction of the electric field due to the proton at a distance of 2.0×10^{-10} m from the proton.

(iii) The magnitude of the gravitational field due to the proton at a distance of 2.0×10^{-10} m from the proton is H.
Show that the ratio $\frac{H}{E}$ is of the order 10^{-28}C kg^{-1}.

(iv) The orbital electron is transferred from its orbit to a point where the potential is zero. The gain in potential energy of the electron is 5.4×10^{-19}J. Calculate the value of the potential difference through which the electron is moved.

c. An electric cell is a device that is used to transfer energy to electrons in a circuit. A particular circuit consists of a cell of emf ε and internal resistance r connected in series with a resistor of resistance 5.0 Ω. [6]

(i) Define *emf of a cell.*

(ii) The energy supplied by the cell to one electron in transferring it around the circuit is 5.1×10^{-19}J. Show that the emf of the cell is 3.2V.

(iii) Each electron in the circuit transfers an energy of 4.0×10^{-19} J to the 5.0 Ω resistor. Determine the value of the internal resistance r.

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.

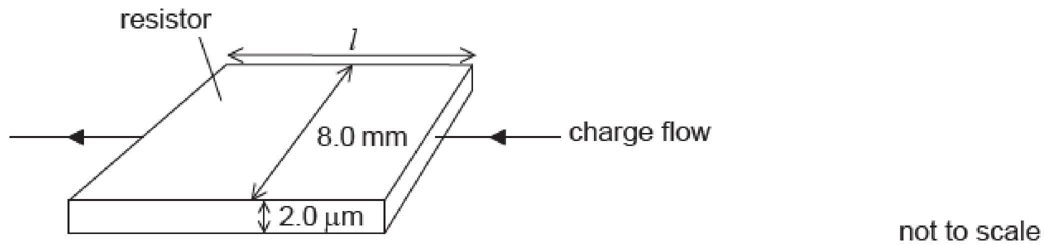
b. The electric motor can be adjusted such that, after an initial acceleration, the load moves at constant speed. The motor is connected to a 450 V supply and with the load moving at constant speed, it takes the motor 15 s to raise the load through 7.0 m. [4]

(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.

Electrical resistors can be made by forming a thin film of carbon on a layer of an insulating material.

A carbon film resistor is made from a film of width 8.0 mm and of thickness 2.0 μm. The diagram shows the direction of charge flow through the resistor.

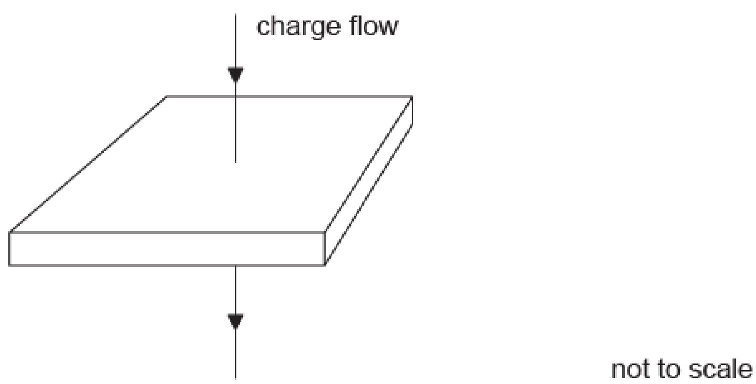


a.i. The resistance of the carbon film is 82 Ω. The resistivity of carbon is 4.1 x 10^{-5} Ω m. Calculate the length *l* of the film. [1]

a.ii. The film must dissipate a power less than 1500 W from each square metre of its surface to avoid damage. Calculate the maximum allowable current for the resistor. [2]

a.iii State why knowledge of quantities such as resistivity is useful to scientists. [1]

b. The current direction is now changed so that charge flows vertically through the film. [2]

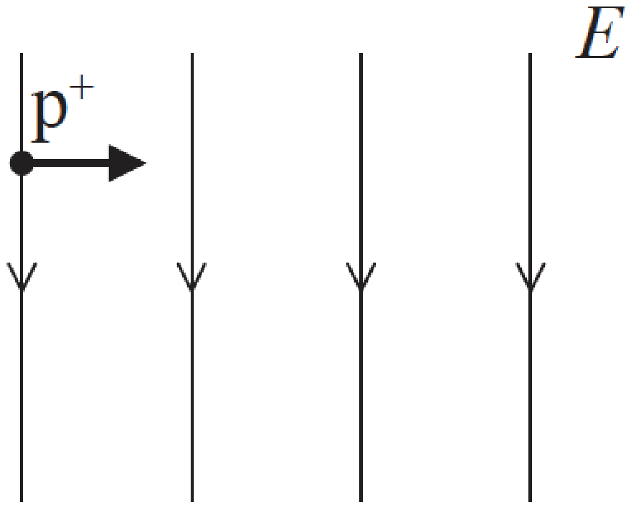


Deduce, without calculation, the change in the resistance.

c. Draw a circuit diagram to show how you could measure the resistance of the carbon-film resistor using a potential divider arrangement to limit the potential difference across the resistor. [2]

This question is about electric and magnetic fields.

A proton travelling to the right with horizontal speed $1.6\times10^{4}ms^{-1}$ enters a uniform electric field of strength *E*. The electric field has magnitude $2.0\times10^{3}NC^{-1}$ and is directed downwards.



a. Calculate the magnitude of the electric force acting on the proton when it is in the electric field. [2]

b. A uniform magnetic field is applied in the same region as the electric field. A second proton enters the field region with the same velocity as the proton in (a). This second proton continues to move horizontally. [5]

(i) Determine the magnitude and direction of the magnetic field.

(ii) An alpha particle enters the field region at the same point as the second proton, moving with the same velocity. Explain whether or not the alpha particle will move in a straight line.

This question is about the properties of tungsten.

a. Tungsten is a conductor used as the filament of an electric lamp. The filament of the lamp is surrounded by glass which is an insulator. [2]

Outline, in terms of their atomic structure, the difference between the electrical properties of tungsten and of glass.

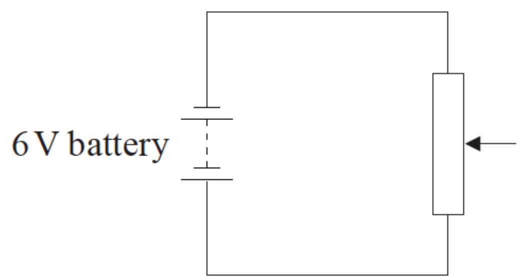
b. A tungsten filament lamp is marked 6.0 V, 15 W. [3]

(i) Show that the resistance of the lamp at its working voltage is 2.4 Ω.

(ii) The length of the filament is 0.35 m and the resistivity of tungsten is 5.6×10^{-7} Ω m at its working voltage.

Calculate the cross-sectional area of the tungsten filament.

c. The diagram shows part of a potential divider circuit used to measure the current-potential difference (*I*–*V*) characteristic of the bulb. [2]



Draw the complete circuit showing the correct position of the bulb, ammeter and voltmeter.

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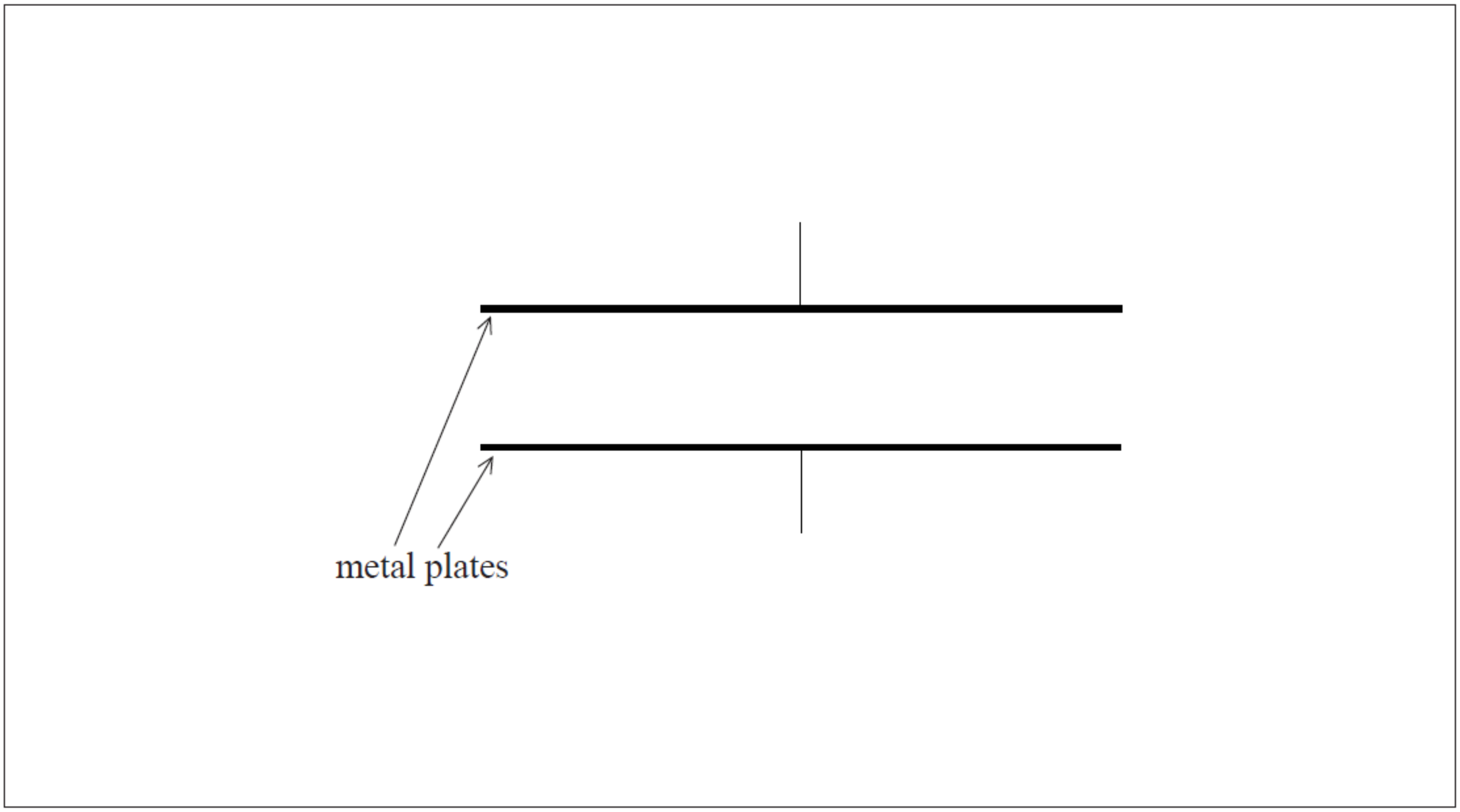
a. Define *electric field strength*. [2]

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

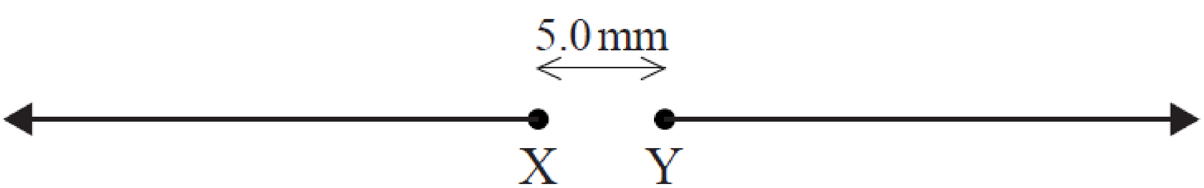


(i) Label, on the diagram, the polarity of the metal plates which would cause an electron positioned between the plates to accelerate upwards.

(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]

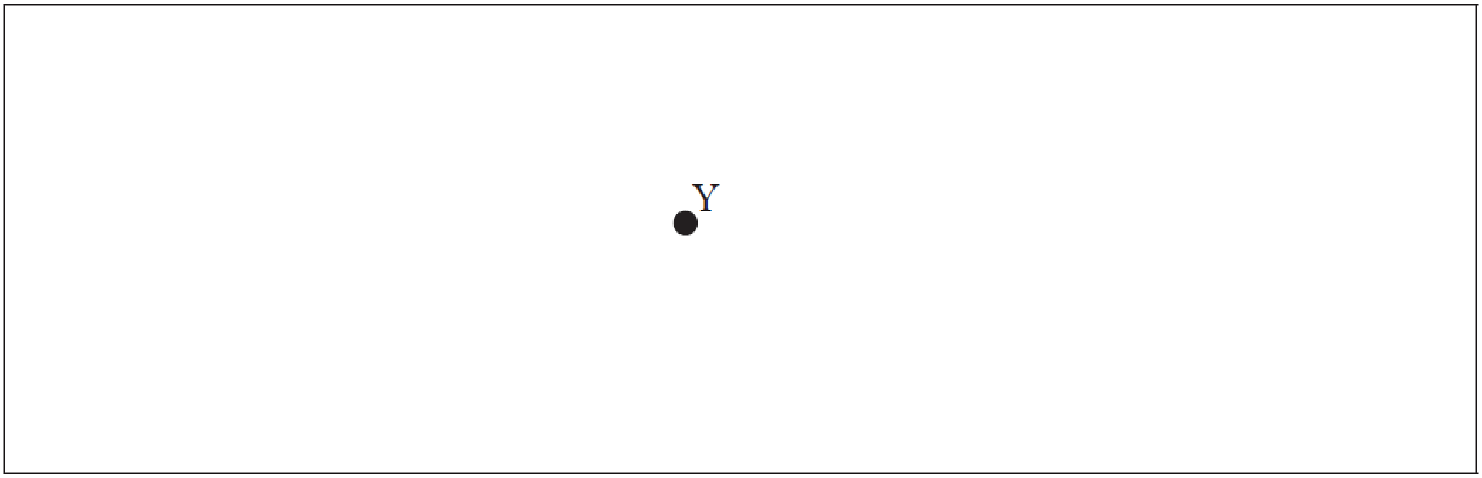


(i) Show that the initial electric force acting on each electron due to the other electron is approximately 9×10^{-24}N.

(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.



Part 2 Electrical resistance

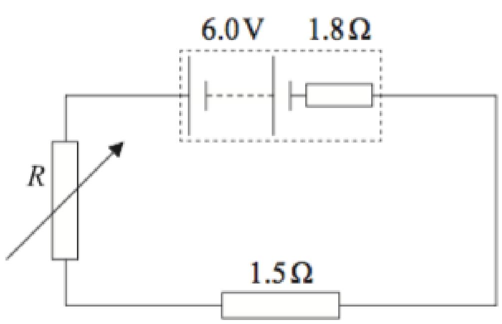
a. A resistor of resistance 1.5Ω is made from copper wire of radius 0.18mm. The resistivity of copper is 1.7×10^{-8}Ωm. Determine the length of copper wire used to make the resistor. [2]

b. The manufacturer of the resistor in (a) guarantees that the resistance is within 10% of 1.5Ω, provided that the power dissipation in the resistor does not exceed 1.0W. [6]

(i) Suggest why the resistance of the resistor might be greater than 1.65Ω if the power dissipation in the resistor is greater than 1.0W.

(ii) Show that, for a power dissipation of 1.0W, the current in a resistor of resistance 1.5Ω is 0.82A.

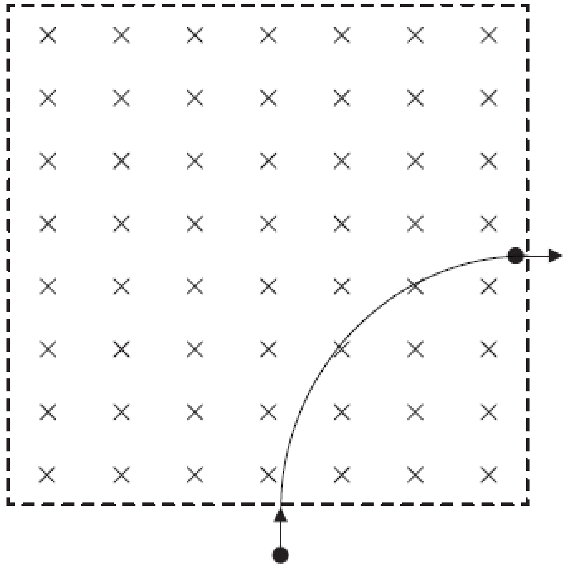
(iii) The 1.5Ω resistor is connected in series with a variable resistor and battery of emf 6.0V and internal resistance 1.8Ω.



Estimate the resistance *R* of the variable resistor that will limit the current to 0.82A.

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.

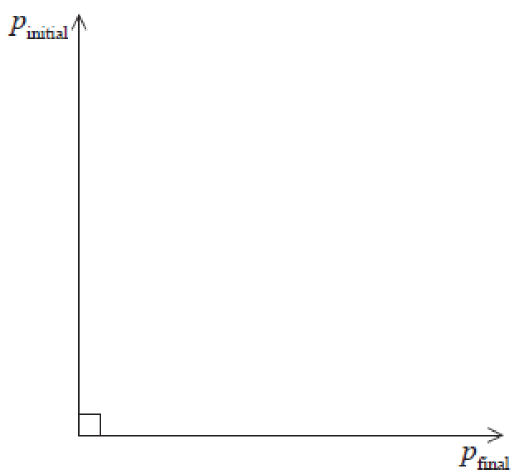


a. The electron's path while in the region of magnetic field is a quarter circle. Show that the [4]

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

(ii) radius of the path is $4.5\times10^{-4}m$.

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 $8.6\times10^{-24}Ns$. [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 $1.2\times10^{-23}Ns$.

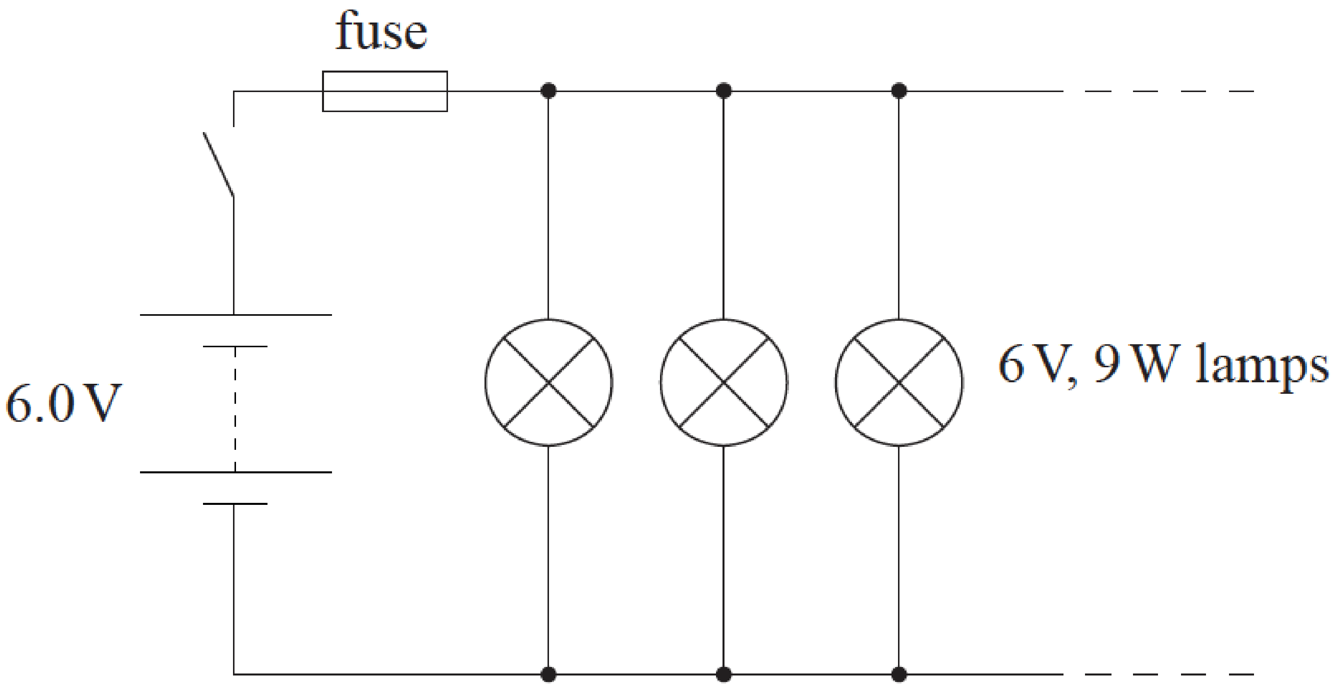
(iii) The time the electron spends in the region of magnetic field is $7.5\times10^{-11}s$. Estimate the magnitude of the average force on the electron.

This question is in **two** parts. **Part 1** is about a lighting system. **Part 2** is about a satellite.

Part 1 Lighting system

a. State Ohm's law. [1]

b. A lighting system is designed so that additional lamps can be added in parallel. [8]



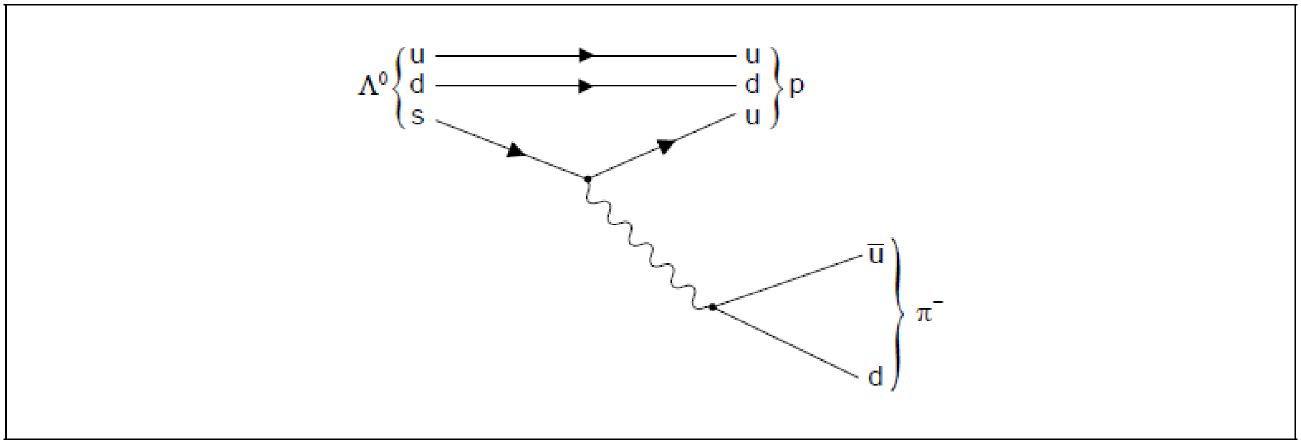
The diagram shows three 6V, 9W lamps connected in parallel to a supply of emf 6.0V and negligible internal resistance. A fuse in the circuit melts if the current in the circuit exceeds 13A.

(i) Determine the maximum number of lamps that can be connected in parallel in the circuit without melting the fuse.

(ii) Calculate the resistance of a lamp when operating at its normal brightness.

(iii) By mistake, a lamp rated at 12V, 9W is connected in parallel with three lamps rated at 6V, 9W. Estimate the resistance of the circuit stating any assumption that you make.

A possible decay of a lambda particle (Λ^0) is shown by the Feynman diagram.



a. State the quark structures of a meson and a baryon. [2]

Meson: ....

....

Baryon: ....

....

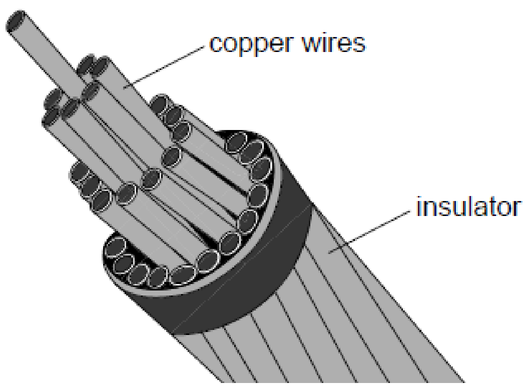
b.i. Explain which interaction is responsible for this decay. [2]

b.ii. Draw arrow heads on the lines representing $\bar{u}$ and d in the π^{-}. [1]

b.iii. Identify the exchange particle in this decay. [1]

c. Outline **one** benefit of international cooperation in the construction or use of high-energy particle accelerators. [1]

A cable consisting of many copper wires is used to transfer electrical energy from a generator to an electrical load. The copper wires are protected by an insulator.



The cable consists of 32 copper wires each of length 35 km. Each wire has a resistance of 64 Ω. The resistivity of copper is 1.7 x 10^{-8} Ω m.

a. The copper wires and insulator are both exposed to an electric field. Discuss, with reference to charge carriers, why there is a significant electric current only in the copper wires. [3]

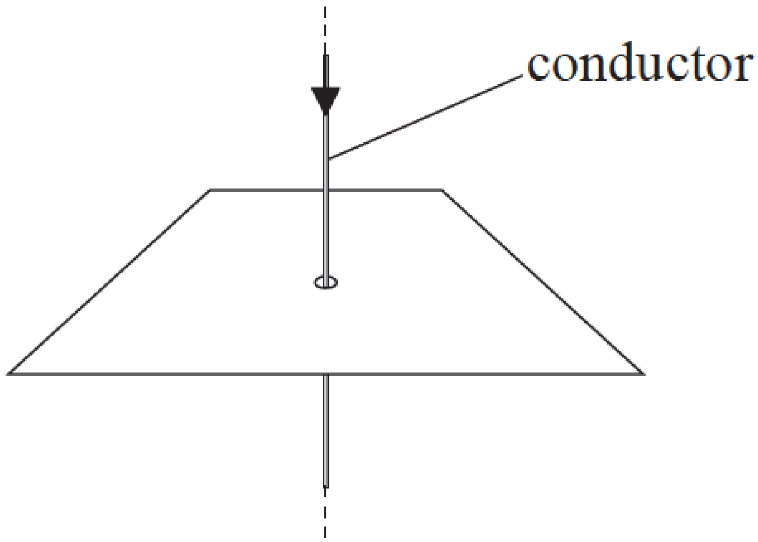
b.i. Calculate the radius of each **wire**. [2]

b.ii. There is a current of 730 A in the cable. Show that the power loss in 1 m of the cable is about 30 W. [2]

b.iii. When the current is switched on in the cable the initial rate of rise of temperature of the cable is 35 mK s^{-1}. The specific heat capacity of copper is 390 J kg^{-1} K^{-1}. Determine the mass of a length of one metre of the cable. [2]

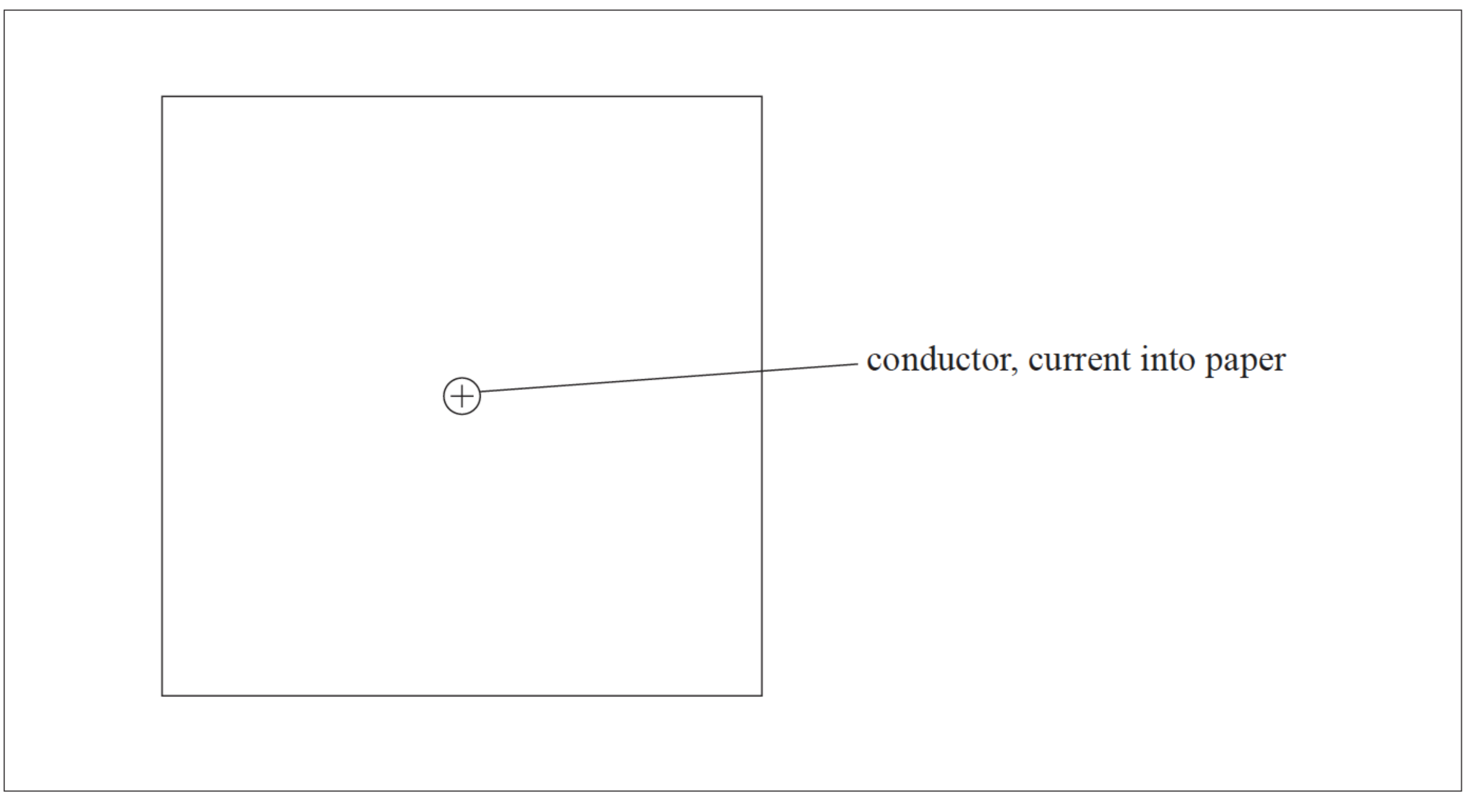
This question is about magnetic fields.

A long straight vertical conductor carries an electric current. The conductor passes through a hole in a horizontal piece of paper.



a. State how a magnetic field arises. [1]

b. On the diagram below, sketch the magnetic field pattern around the long straight current-carrying conductor. The direction of the current is into the plane of the paper. [2]



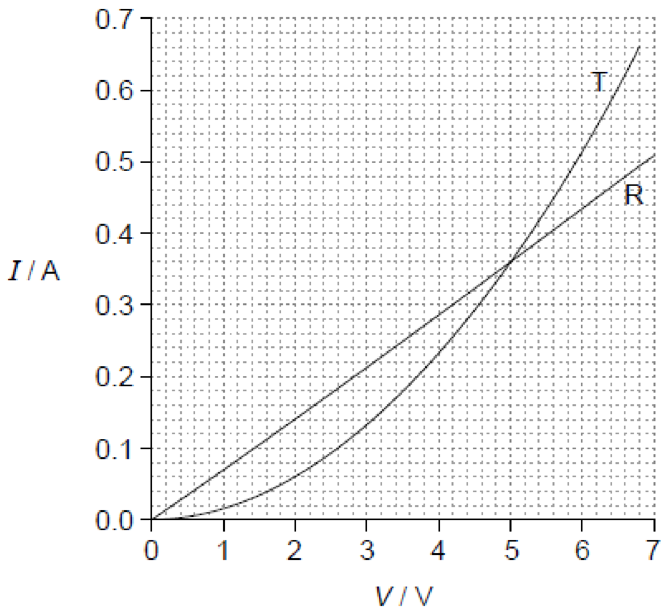
c. The long straight conductor is formed into a coil consisting of two separate turns, X and Y. The coil hangs with its axis vertical. [5]

Assume that the turns of the coil each behave as a long straight conductor.

(i) Explain why, when there is a current in the coil, the separation of X and Y decreases.

(ii) The current in the coil is 15 A and the circumference of one turn is 0.48m. In order to restore X and Y to their original separation, a mass of 2.8×10^{-4} kg is suspended from turn Y. Estimate the magnetic field strength at X due to Y.

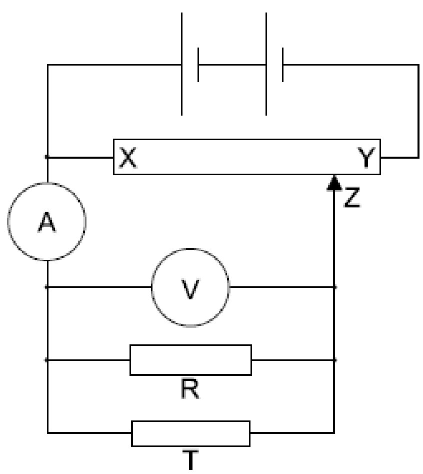
The graph shows how current *I* varies with potential difference *V* for a resistor R and a non-ohmic component T.



a. (i) State how the resistance of T varies with the current going through T. [3]

(ii) Deduce, without a numerical calculation, whether R **or** T has the greater resistance at *I*=0.40 A.

b. Components R and T are placed in a circuit. Both meters are ideal. [3]

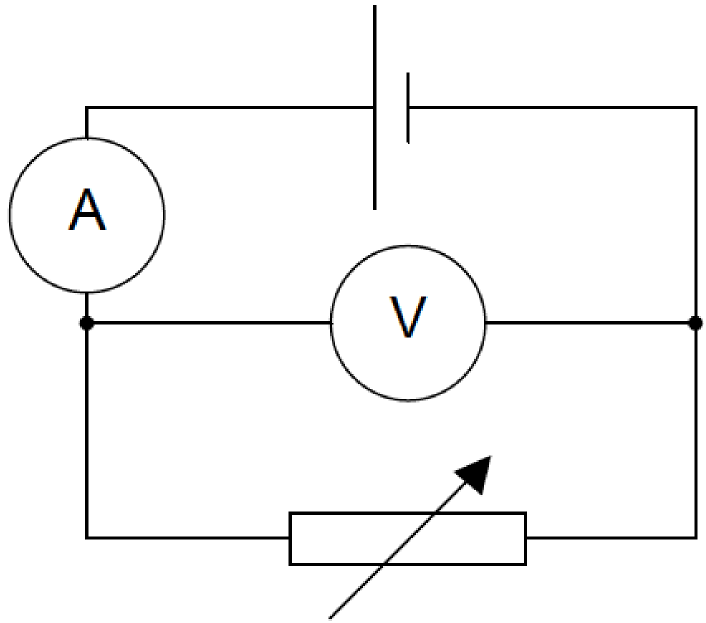


Slider Z of the potentiometer is moved from Y to X.

(i) State what happens to the magnitude of the current in the ammeter.

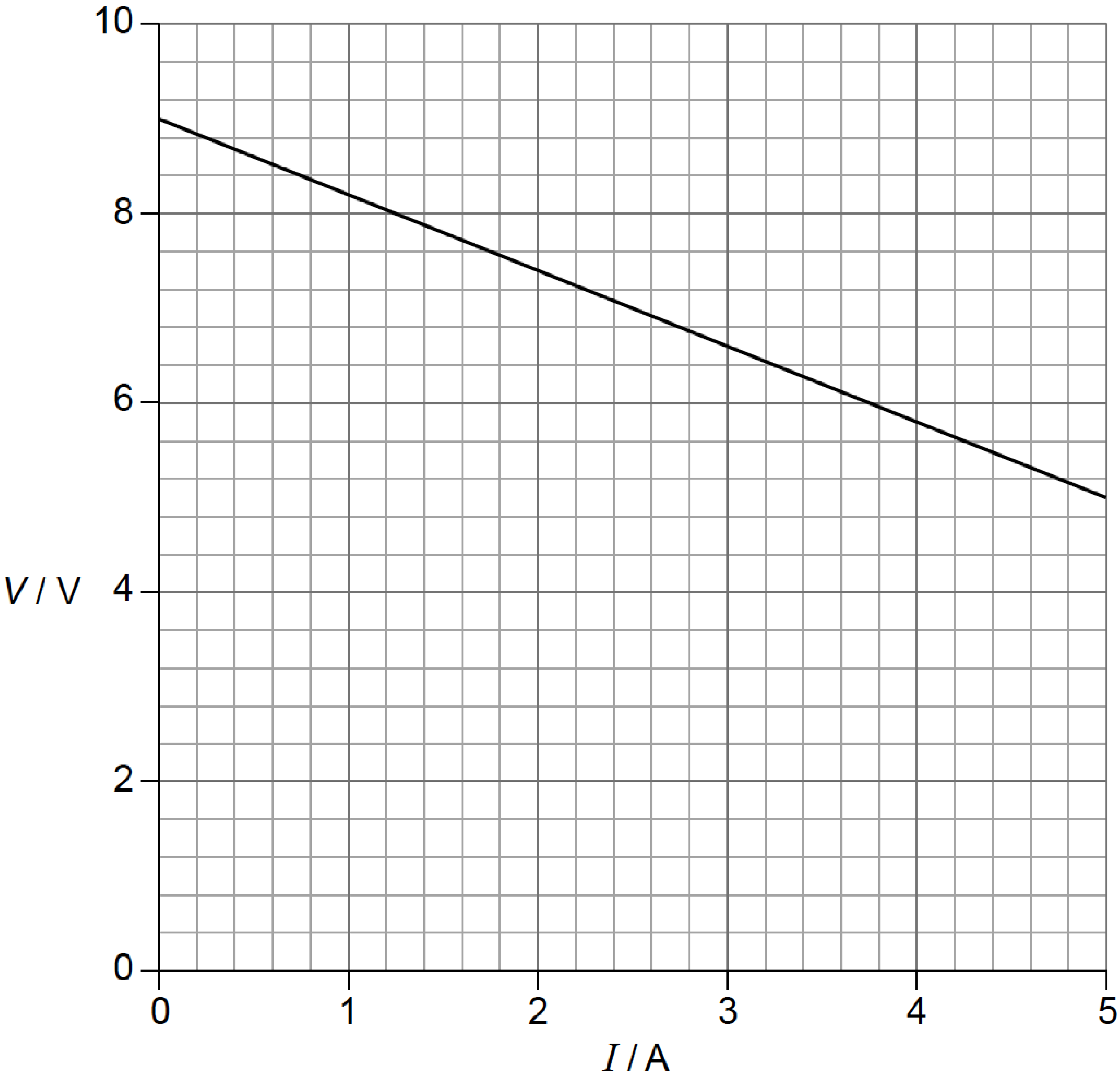
(ii) Estimate, with an explanation, the voltmeter reading when the ammeter reads 0.20 A.

In an experiment a student constructs the circuit shown in the diagram. The ammeter and the voltmeter are assumed to be ideal.



a. State what is meant by an ideal voltmeter. [1]

b. The student adjusts the variable resistor and takes readings from the ammeter and voltmeter. The graph shows the variation of the voltmeter reading *V* with the ammeter reading *I*. [3]



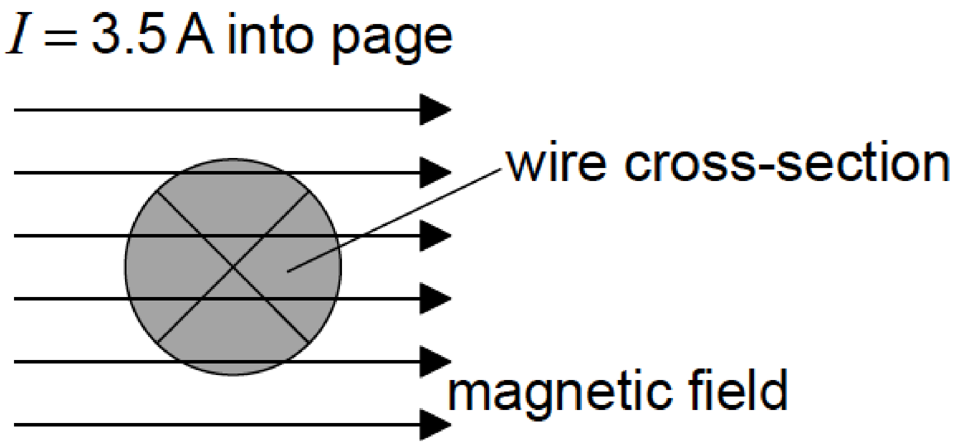
Use the graph to determine

(i) the electromotive force (emf) of the cell.

(ii) the internal resistance of the cell.

c. A connecting wire in the circuit has a radius of 1.2mm and the current in it is 3.5A. The number of electrons per unit volume of the wire is $2.4\times10^{28}m^{-3}$. Show that the drift speed of the electrons in the wire is $2.0\times10^{-4}ms^{-1}$. [1]

d. The diagram shows a cross-sectional view of the connecting wire in (c). [2]



The wire which carries a current of 3.5A into the page, is placed in a region of uniform magnetic field of flux density 0.25T. The field is directed at right angles to the wire.

Determine the magnitude **and** direction of the magnetic force on one of the charge carriers in the wire.

This question is in **two** parts. **Part 1** is about electric circuits. **Part 2** is about the energy balance of the Earth.

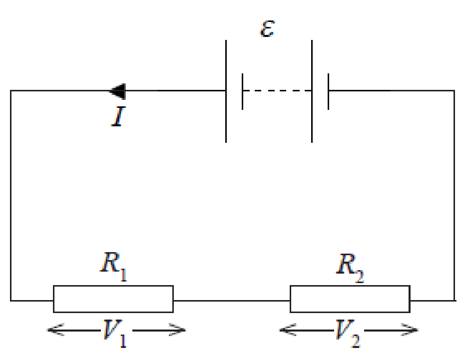
Part 1 Electric circuits

a. Define [2]

(i) *electromotive force* (emf) of a battery.

(ii) *electrical resistance* of a conductor.

b. A battery of emf ε and negligible internal resistance is connected in series to two resistors. The current in the circuit is *I*. [3]

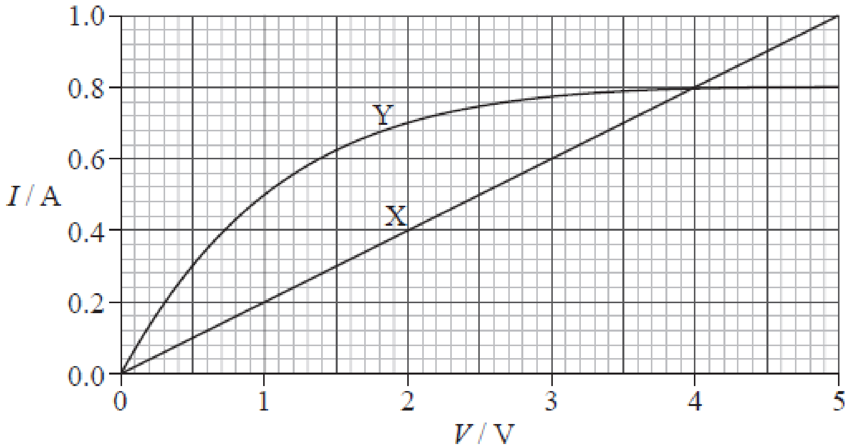


(i) State an equation giving the total power delivered by the battery.

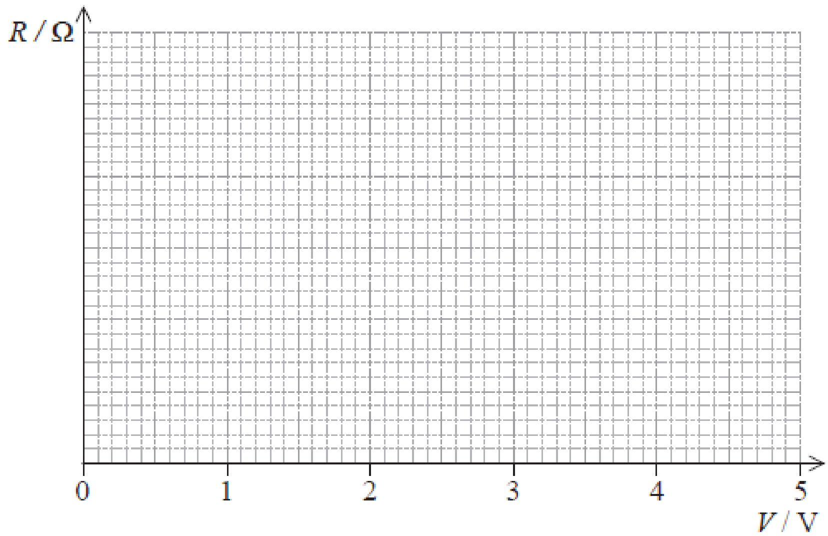
(ii) The potential difference across resistor R_1 is V_1 and that across resistor R_2 is V_2. Using the law of the conservation of energy, deduce the equation below.

$$\varepsilon = V_1 + V_2$$

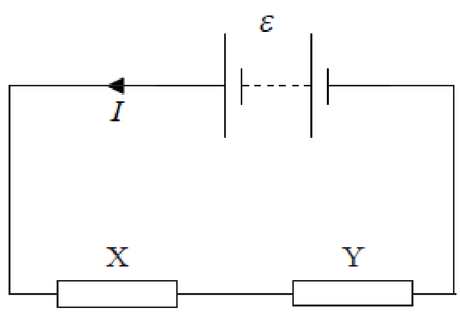
c. The graph shows the *I*-*V* characteristics of two conductors, X and Y. [3]



On the axes below, sketch graphs to show the variation with potential difference *V* of the resistance of conductor X (label this graph X) and conductor Y (label this graph Y). You do not need to put any numbers on the vertical axis.



d. The conductors in (c) are connected in series to a battery of emf *ε* and negligible internal resistance. [4]



The power dissipated in each of the two resistors is the same.

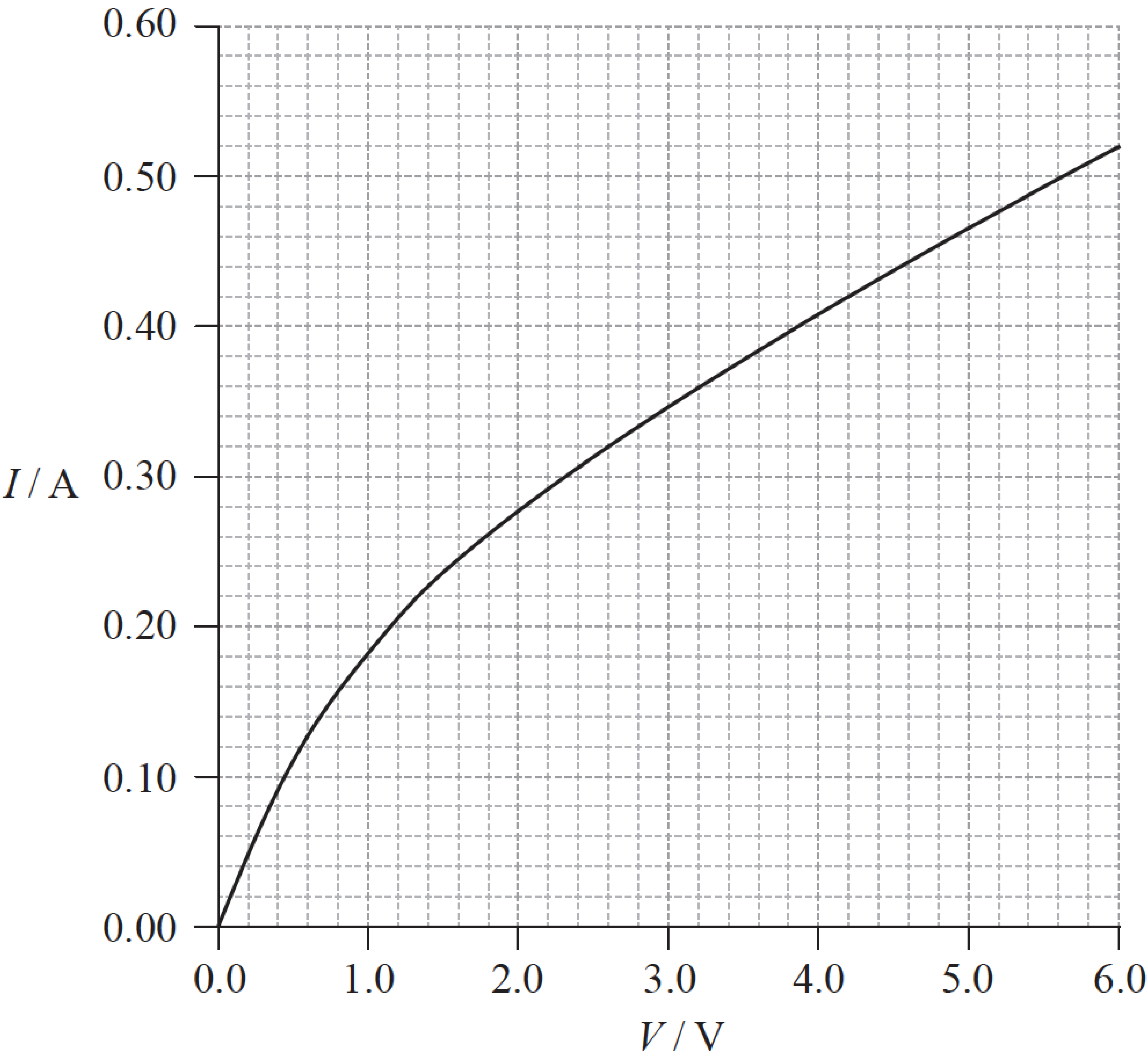
Using the graph given in (c),

(i) determine the emf of the battery.

(ii) calculate the total power dissipated in the circuit.

Part 2 Electric current and resistance

The graph below shows how the current *I* in a tungsten filament lamp varies with potential difference *V* across the lamp.



a. (i) Define the electrical *resistance* of a component. [3]

(ii) Explain whether or not the filament obeys Ohm's law.

b. (i) Calculate the resistance of the filament lamp when the potential difference across it is 2.8 V. [5]

(ii) The length of the filament in a lamp is 0.40 m. The resistivity of tungsten when the potential difference across it is 2.8 V is $5.8\times10^{-7}\Omega$ m. Calculate the radius of the filament.

c. Two identical filament lamps are connected in series with a cell of emf 6.0 V and negligible internal resistance. Using the graph on page 26, calculate the total power dissipated in the circuit. [2]

This question is in **two** parts. **Part 1** is about electric fields and radioactive decay. **Part 2** is about change of phase.

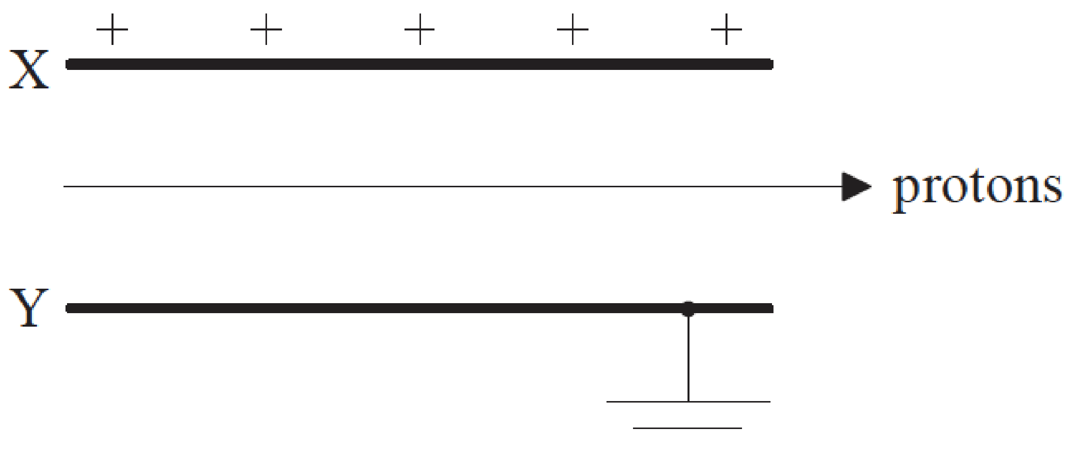
Part 1 Electric fields and radioactive decay

Part 2 Change of phase

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

b. A simple model of the proton is that of a sphere of radius 1.0×10^{-15}m with charge concentrated at the centre of the sphere. Estimate the magnitude of the field strength at the surface of the proton. [2]

c. Protons travelling with a speed of 3.9×10^{6}ms^{-1} enter the region between two charged parallel plates X and Y. Plate X is positively charged and plate Y is connected to earth. [4]



A uniform magnetic field also exists in the region between the plates. The direction of the field is such that the protons pass between the plates without deflection.

(i) State the direction of the magnetic field.

(ii) The magnitude of the magnetic field strength is 2.3×10^{-4}T. Determine the magnitude of the electric field strength between the plates, stating an appropriate unit for your answer.

d. Protons can be produced by the bombardment of nitrogen-14 nuclei with alpha particles. The nuclear reaction equation for this process is given below. [1]

$$^{14}_{7}\mathrm{N} + {}^{4}_{2}\mathrm{He} \rightarrow \mathrm{X} + {}^{1}_{1}\mathrm{H}$$

Identify the proton number and nucleon number for the nucleus X.

e. The following data are available for the reaction in (d). [3]

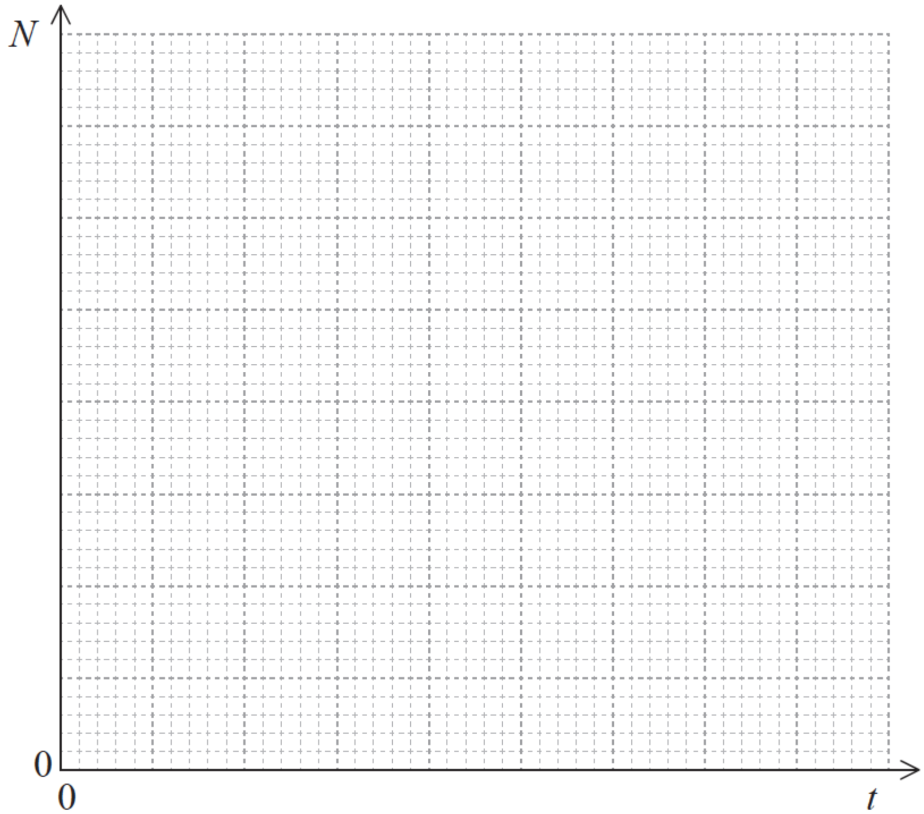
Rest mass of nitrogen-14 nucleus =14.0031 u
Rest mass of alpha particle =4.0026 u
Rest mass of X nucleus =16.9991 u
Rest mass of proton =1.0073 u

Show that the minimum kinetic energy that the alpha particle must have in order for the reaction to take place is about 0.7 Me V.

f. A nucleus of another isotope of the element X in (d) decays with a half-life $T_{\frac{1}{2}}$ to a nucleus of an isotope of fluorine-19 (F-19). [5]

(i) Define the terms *isotope* and *half-life*.

(ii) Using the axes below, sketch a graph to show how the number of atoms *N* in a sample of X varies with time *t*, from *t*=0 to $t = 3T_{\frac{1}{2}}$. There are N_0 atoms in the sample at *t*=0.



g. Water at constant pressure boils at constant temperature. Outline, in terms of the energy of the molecules, the reason for this. [2]

h. In an experiment to measure the specific latent heat of vaporization of water, steam at 100°C was passed into water in an insulated container. [4]

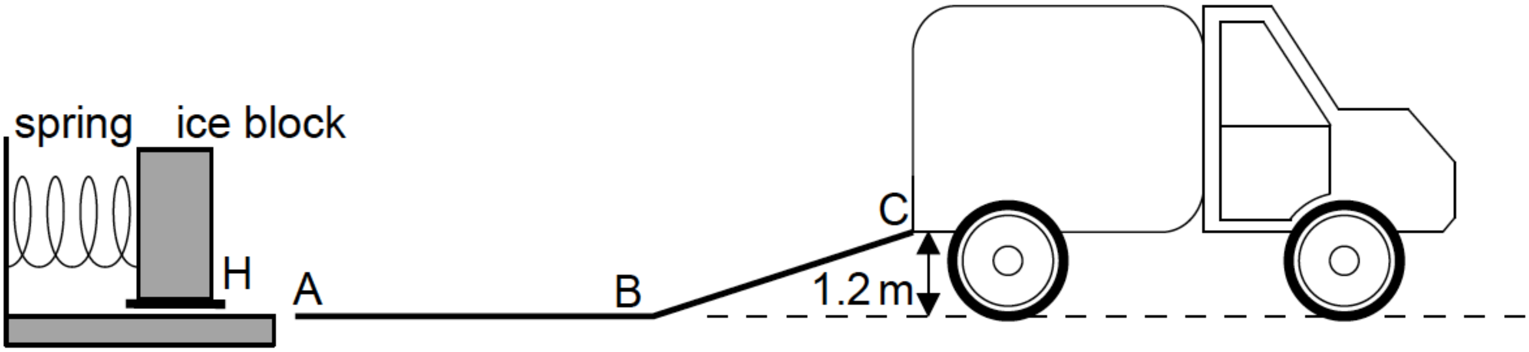
The following data are available.

Initial mass of water in container = 0.300kg
Final mass of water in container = 0.312kg
Initial temperature of water in container = 15.2°C
Final temperature of water in container = 34.6°C
Specific heat capacity of water = $4.18\times10^3 Jkg^{-1}K^{-1}$

Show that the data give a value of about $1.8\times10^6 Jkg^{-1}$ for the specific latent heat of vaporization *L* of water.

i. Explain why, other than measurement or calculation error, the accepted value of *L* is greater than that given in (h). [2]

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 0.90ms^{-1}. Show that the elastic energy stored in the spring is 670J. [4]

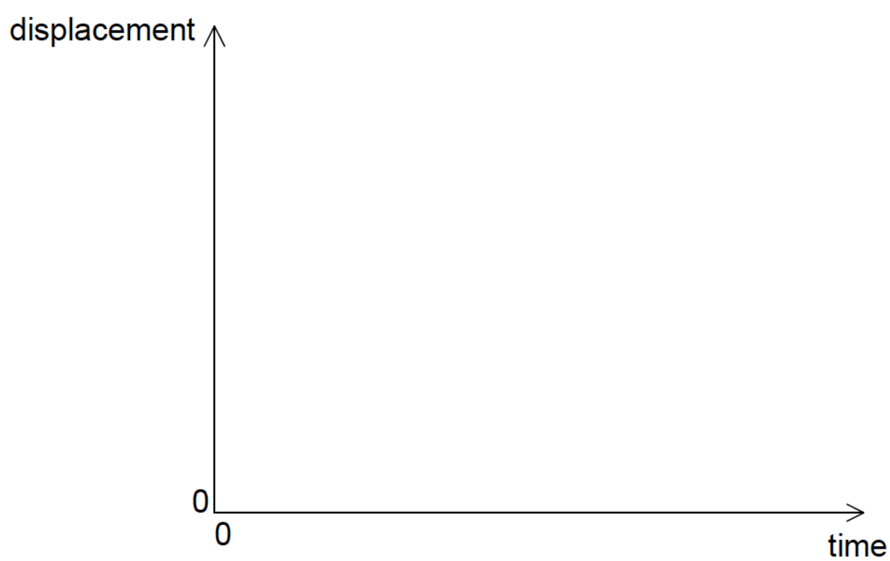
(ii) Calculate the speed of the block at A.

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]

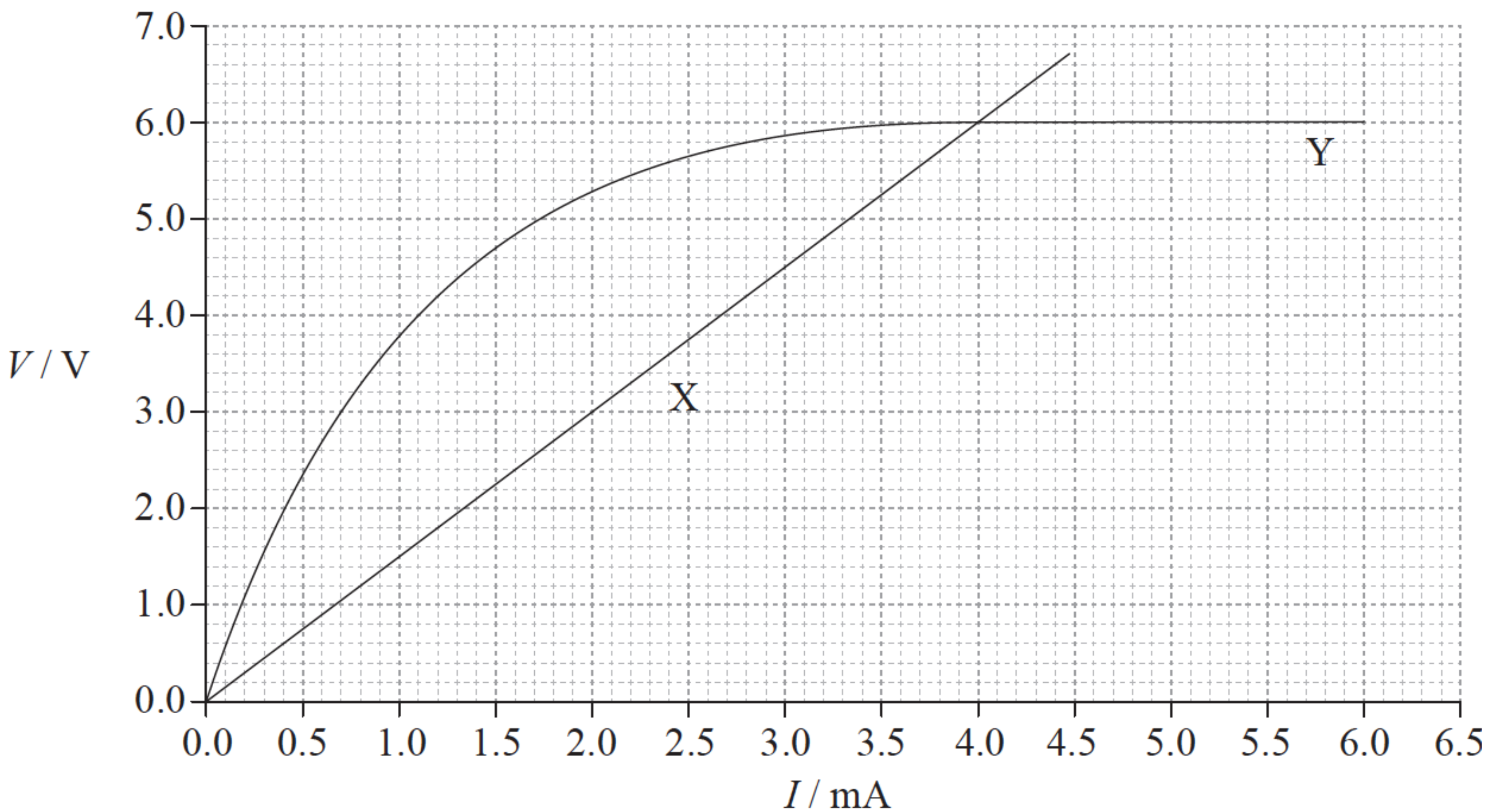
Estimate the efficiency of the motor.

This question is in **two** parts. **Part 1** is about simple harmonic motion (SHM) and waves. **Part 2** is about voltage–current (V–I) characteristics.

Part 1 Simple harmonic motion (SHM) and waves

Part 2 Voltage–current (V–I) characteristics

The graph shows the voltage–current (V–I) characteristics, at constant temperature, of two electrical components X and Y.



a. A particle P moves with simple harmonic motion. State, with reference to the motion of P, what is meant by simple harmonic motion. [2]

b. Use the graph opposite to determine for the motion of P the [7]

(i) period.

(ii) amplitude.

(iii) displacement of P from equilibrium at t=0.2s.

c. The particle P in (b) is a particle in medium M_1 through which a transverse wave is travelling. [5]

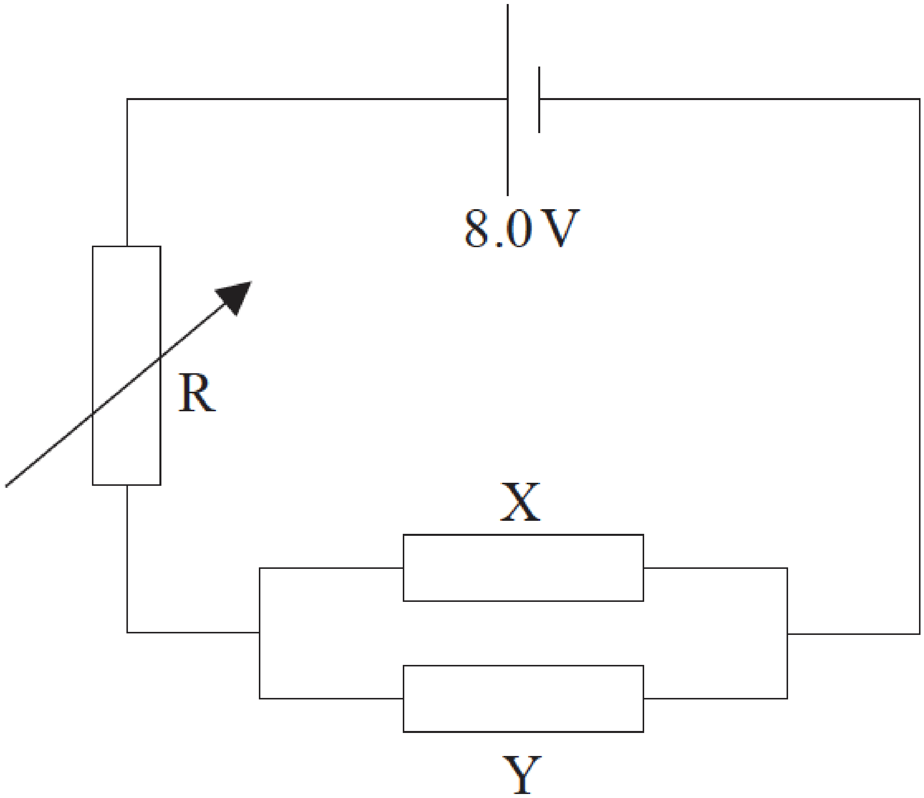
(i) Describe, in terms of energy propagation, what is meant by a transverse wave.

(ii) The speed of the wave through the medium is 0.40ms^{-1}. Calculate, using your answer to (b)(i), the wavelength of the wave.

(iii) The wave travels into another medium M_2. The refractive index of M_2 relative to M_1 is 1.8. Calculate the wavelength of the wave in M_2.

d. Outline, with reference to the graph and to Ohm's law, whether or not each component is ohmic. [3]

e. Components X and Y are connected in parallel. The parallel combination is then connected in series with a variable resistor R and a cell of emf 8.0V and negligible internal resistance. [8]



The resistance of R is adjusted until the currents in X and Y are equal.

(i) Using the graph, calculate the resistance of the parallel combination of X and Y.

(ii) Using your answer to (e)(i), determine the resistance of R.

(iii) Determine the power delivered by the cell to the circuit.

This question is about alternative energy supplies.

A small island community requires a peak power of 850 kW. Two systems are available for supplying the energy: using wind power or photovoltaic cells.

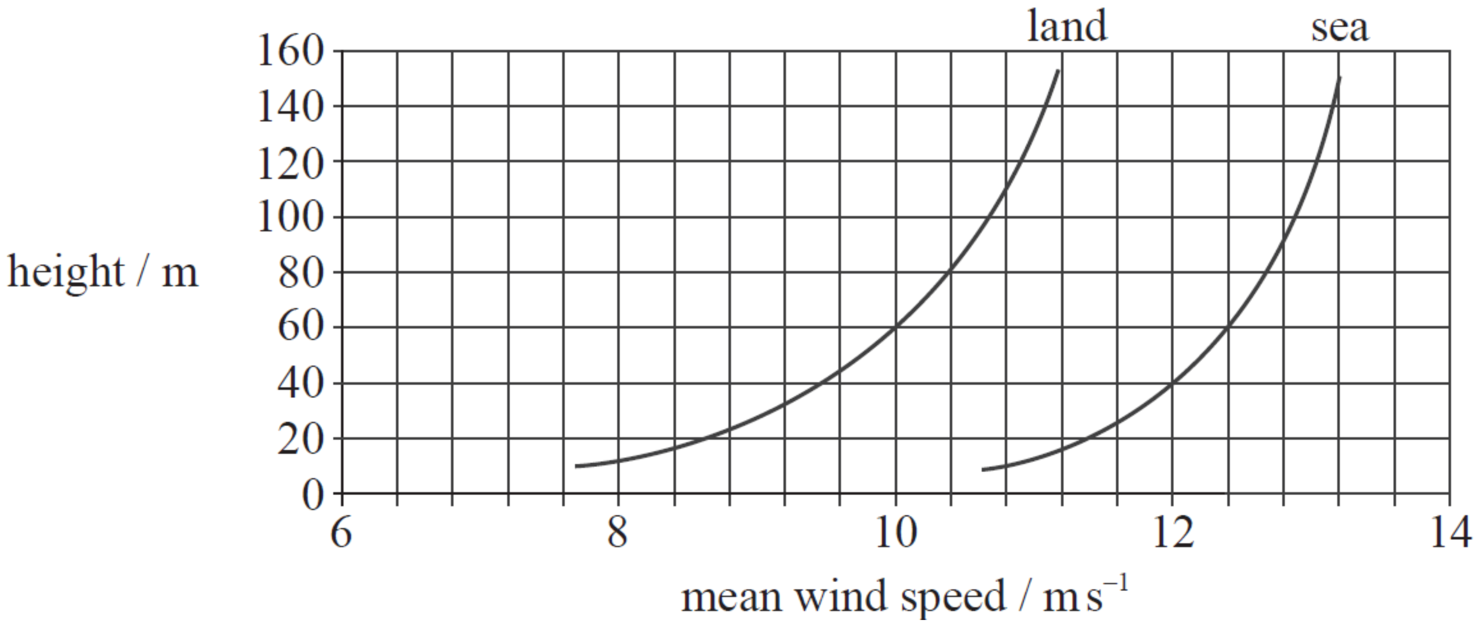
a. (i) Outline, with reference to the energy conversions in the machine, the main features of a conventional horizontal-axis wind generator. [7]

(ii) The mean wind speed on the island is 8.0 ms^{-1}. Show that the maximum power available from a wind generator of blade length 45 m is approximately 2 MW.

Density of air = 1.2 kg m^{-3}

(iii) The efficiency of the generator is 24%. Deduce the number of these generators that would be required to provide the islanders with enough power to meet their energy requirements.

b. The graph below shows how the wind speed varies with height above the land and above the sea. [3]



(i) Suggest why, for any given height, the mean wind speed above the sea is greater than the mean wind speed above the land.

(ii) There is a choice of mounting the wind generators either 60m above the land or 60m above the sea.

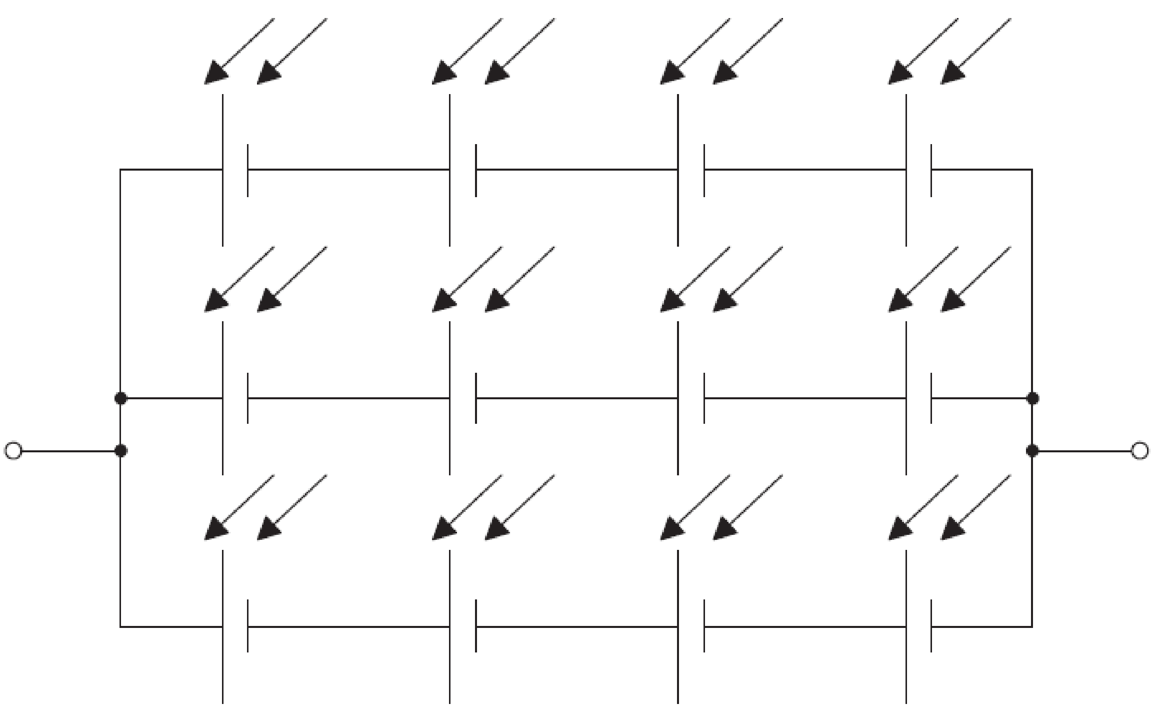
Calculate the ratio

$$\frac{\text{poweravailablefromaland} - \text{basedgenerator}}{\text{poweravailablefromasea} - \text{basedgenerator}}$$

at a height of 60m.

c. Distinguish between photovoltaic cells and solar heating panels. [2]

d. The diagram shows 12 photovoltaic cells connected in series and in parallel to form a module to provide electrical power. [8]

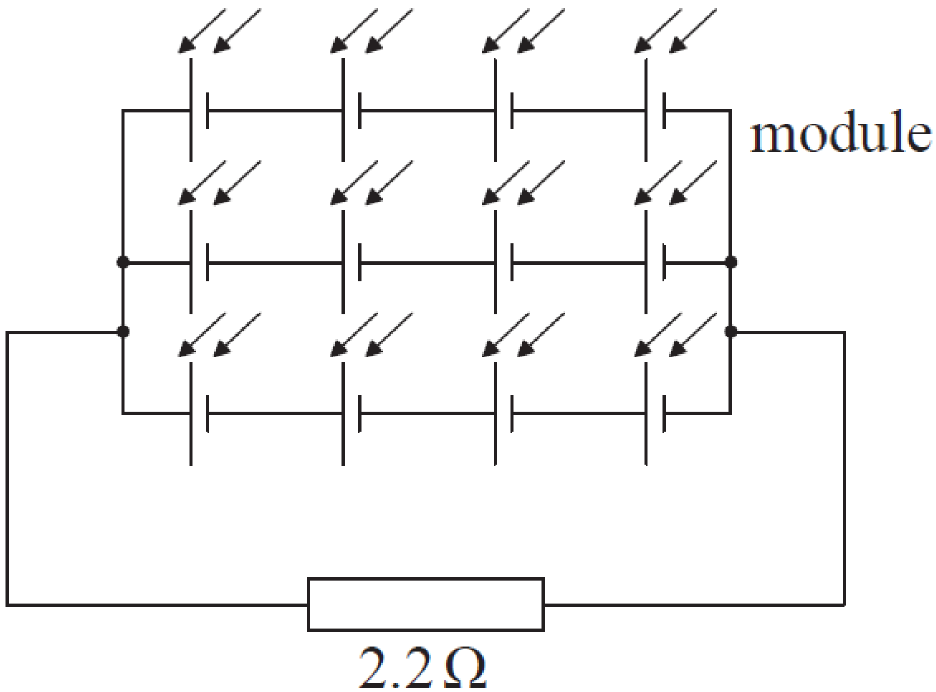


Each cell in the module has an emf of 0.75V and an internal resistance of 1.8Ω.

(i) Calculate the emf of the module.

(ii) Determine the internal resistance of the module.

(iii) The diagram below shows the module connected to a load resistor of resistance 2.2Ω.



Calculate the power dissipated in the load resistor.

(iv) Discuss the benefits of having cells combined in series and parallel within the module.

e. The intensity of the Sun's radiation at the position of the Earth's orbit (the solar constant) is approximately $1.4\times10^3 Wm^{-2}$. [5]

(i) Explain why the average solar power per square metre arriving at the Earth is 3.5×10^2 W.

(ii) State why the solar constant is an approximate value.

(iii) Photovoltaic cells are approximately 20% efficient. Estimate the minimum area needed to supply an average power of 850kW over a 24 hour period.

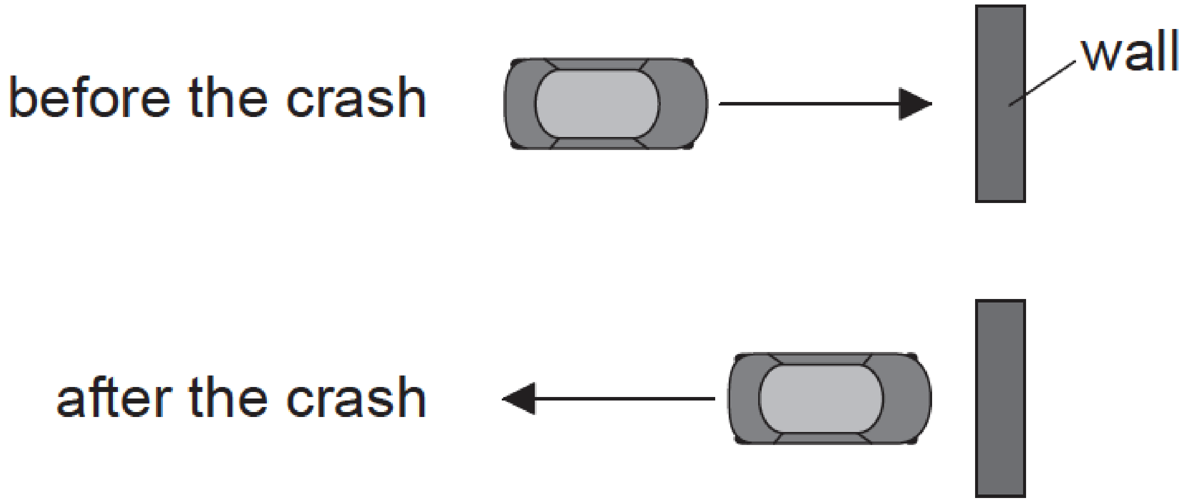
This question is in two parts. **Part 1** is about momentum. **Part 2** is about electric point charges.

Part 1 Momentum

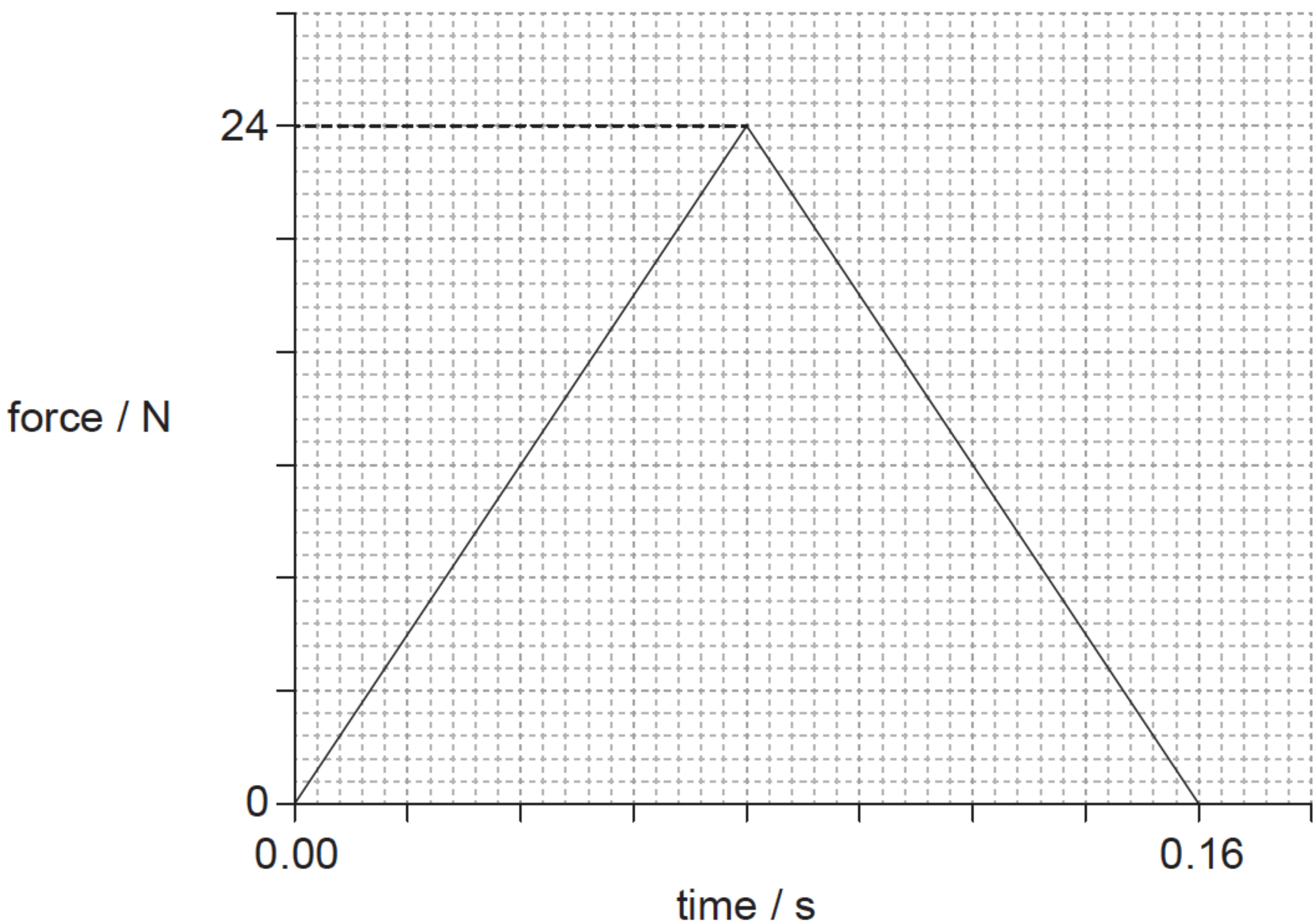
Part 2 Electric point charges

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.

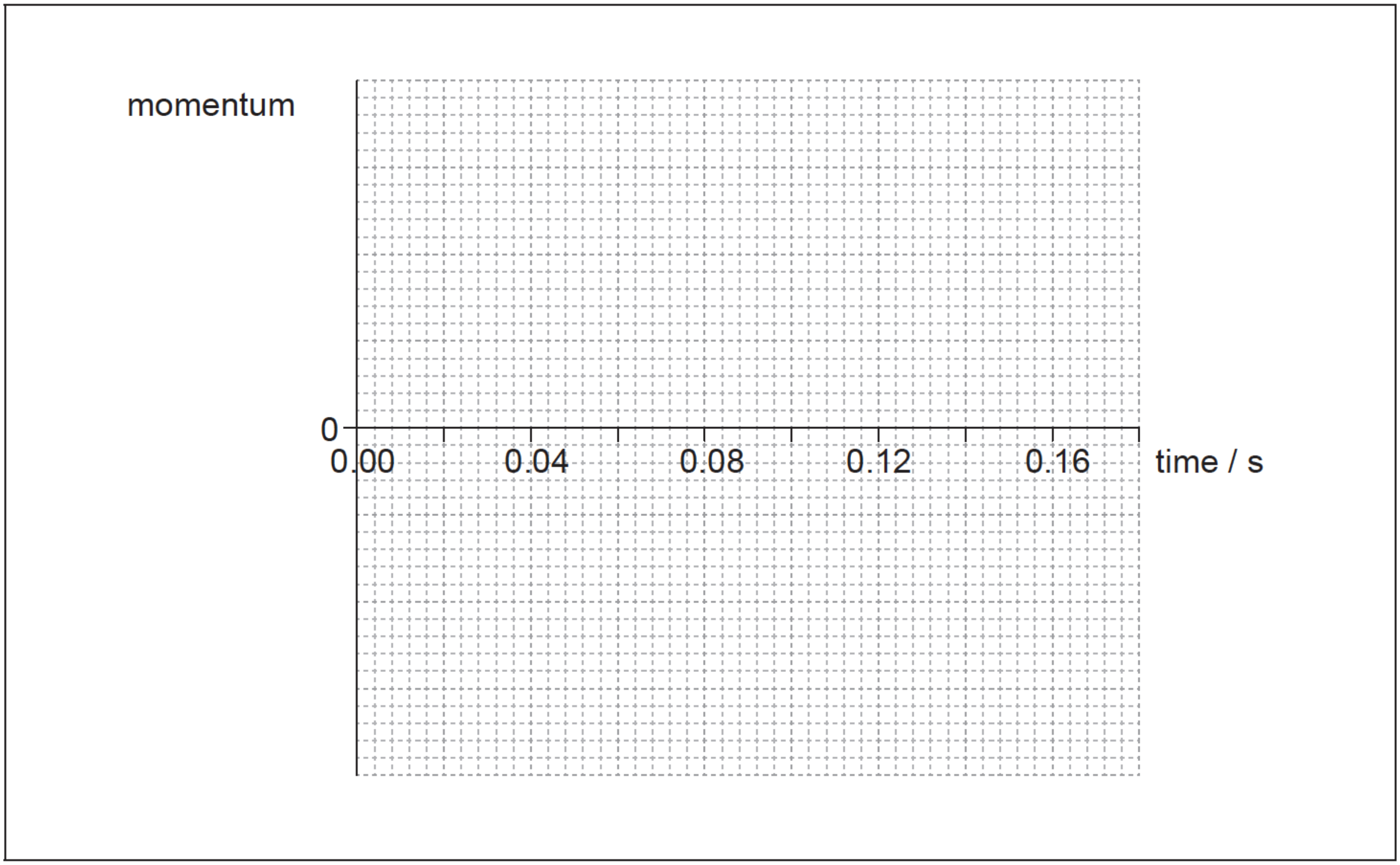


The kinetic energy of the car is unchanged after the collision. The mass of the car is 0.80 kg.

(i) Determine the initial momentum of the car.

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

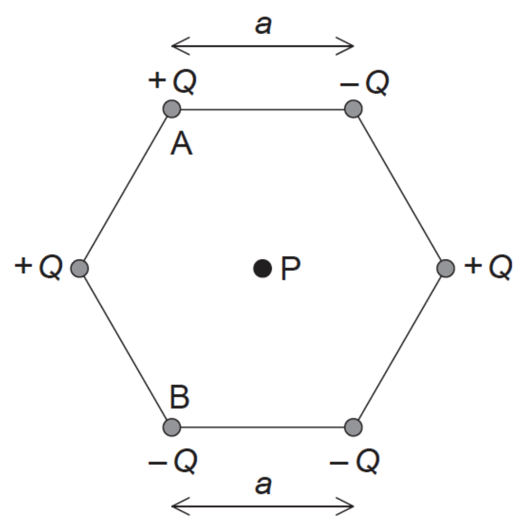
(iii) On the axes, draw a graph to show how the momentum of the car varies during the impact. You are not required to give values on the y-axis.



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

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

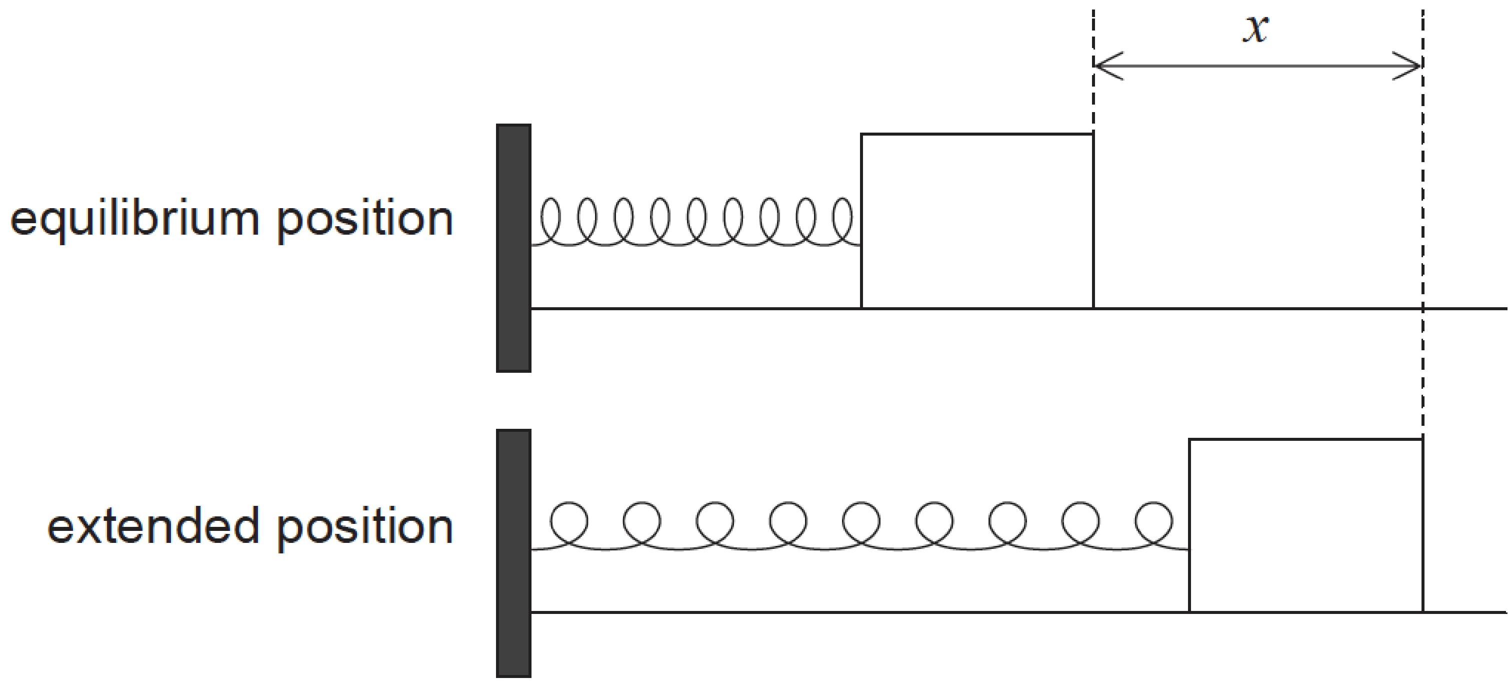
(ii) On the diagram, draw arrows to represent the direction of the field at P due to point charge A (label this direction A) and point charge B (label this direction B).

(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 simple harmonic motion (SHM). **Part 2** is about current electricity.

Part 1 Simple harmonic motion (SHM)

An object is placed on a frictionless surface. The object is attached by a spring fixed at one end and oscillates at the end of the spring with simple harmonic motion (SHM).

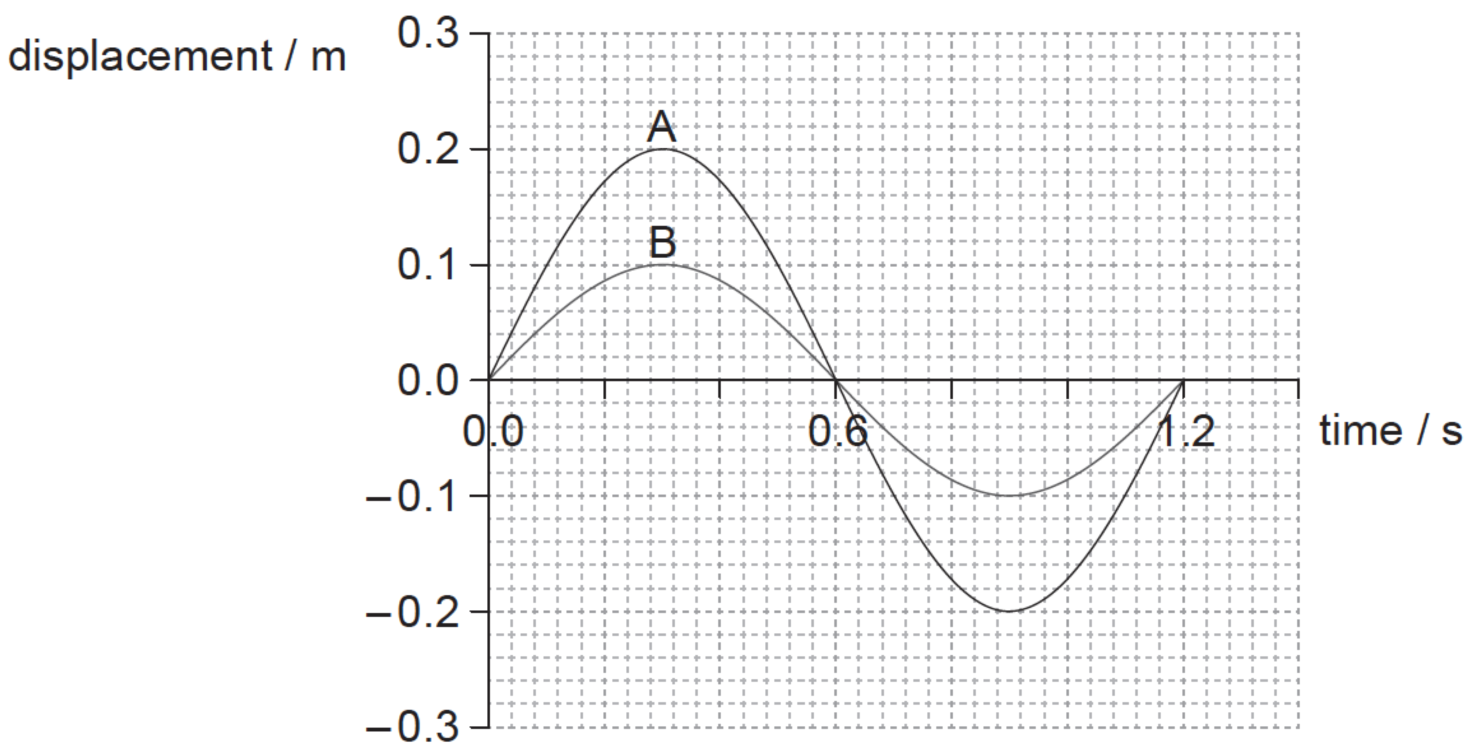


The tension F in the spring is given by $F = k\,x$ where x is the extension of the spring and k is a constant.

Part 2 Current electricity

a. Show that $\omega^2 = \frac{k}{m}$. [2]

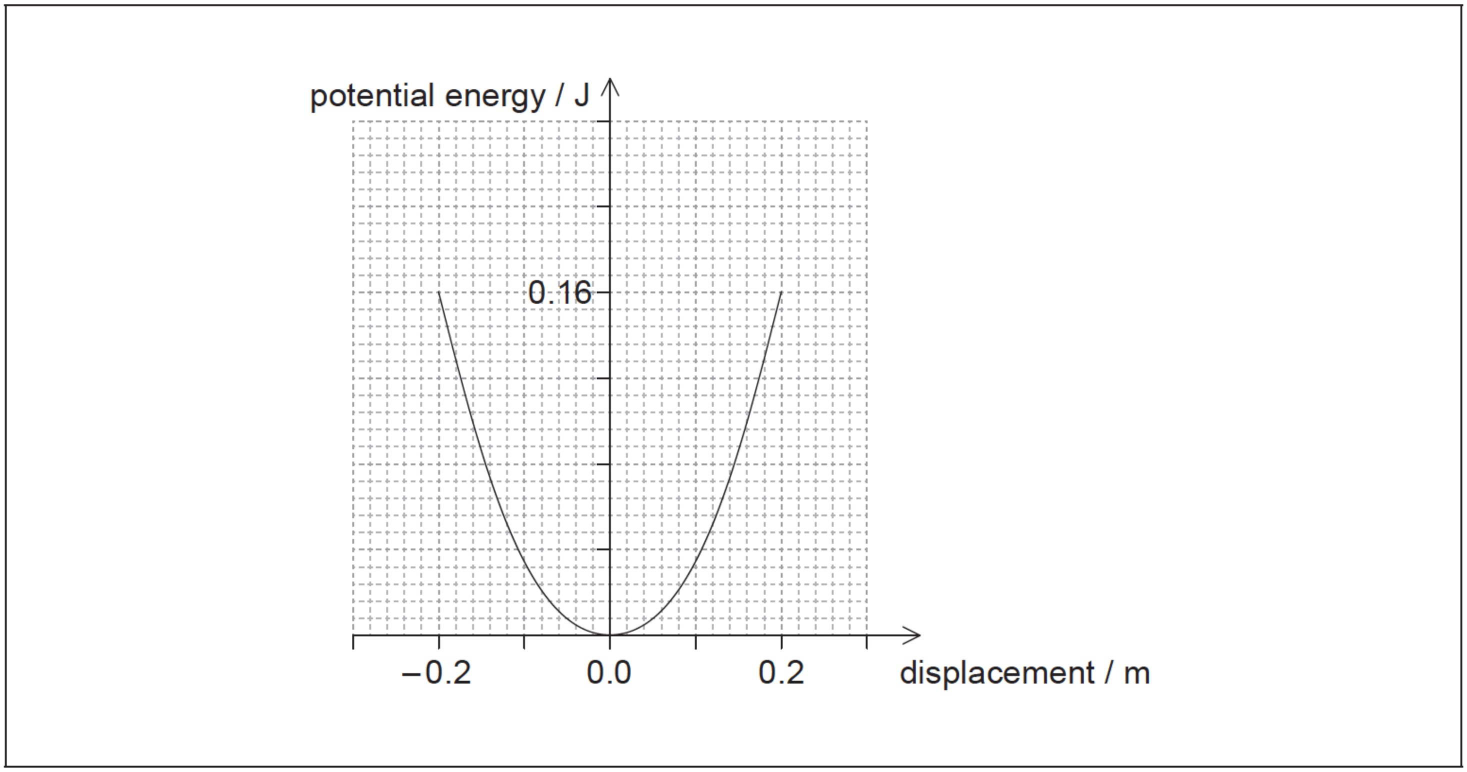
b. One cycle of the variation of displacement with time is shown for two separate mass–spring systems, A and B. [3]



(i) Calculate the frequency of the oscillation of A.

(ii) The springs used in A and B are identical. Show that the mass in A is equal to the mass in B.

c. The graph shows the variation of the potential energy of A with displacement. [5]



On the axes,

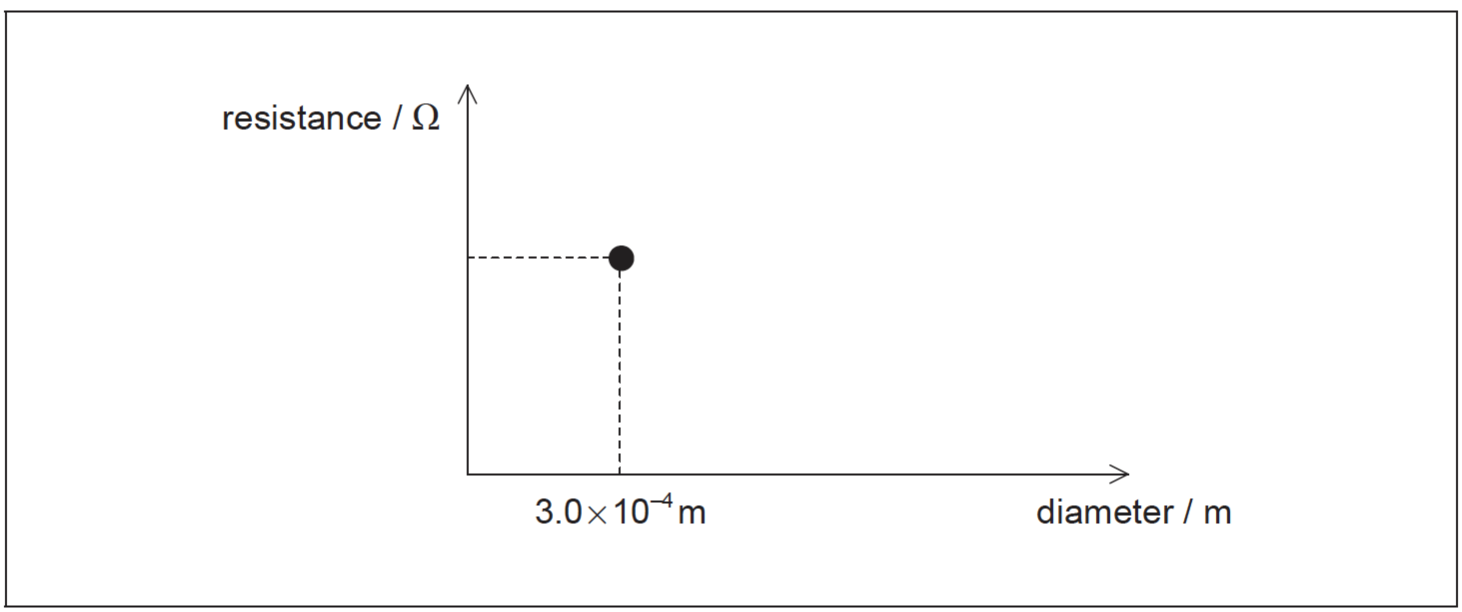
(i) draw a graph to show the variation of kinetic energy with displacement for the mass in A. Label this A.

(ii) sketch a graph to show the variation of kinetic energy with displacement for the mass in B. Label this B.

d. A 24 Ω resistor is made from a conducting wire. [4]

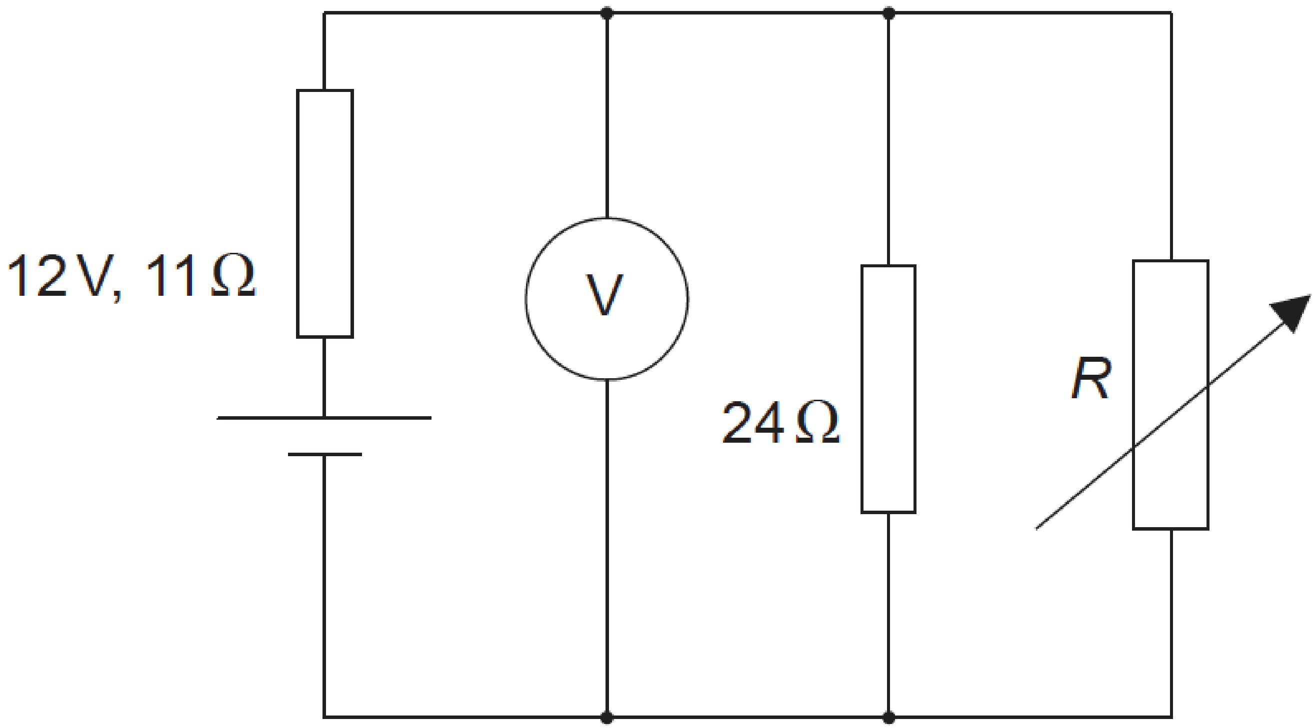
(i) The diameter of the wire is 0.30 mm and the wire has a resistivity of $1.7 \times 10^{-8}\,\Omega\text{m}$. Calculate the length of the wire.

(ii) On the axes, draw a graph to show how the resistance of the wire in (d)(i) varies with the diameter of the wire when the length is constant. The data point for the diameter of 0.30 mm has already been plotted for you.



e. The 24 Ω resistor is covered in an insulating material. Explain the reasons for the differences between the electrical properties of the insulating material and the electrical properties of the wire. [3]

f. An electric circuit consists of a supply connected to a 24Ω resistor in parallel with a variable resistor of resistance *R*. The supply has an emf of 12V and an internal resistance of 11Ω. [8]



Power supplies deliver maximum power to an external circuit when the resistance of the external circuit equals the internal resistance of the power supply.

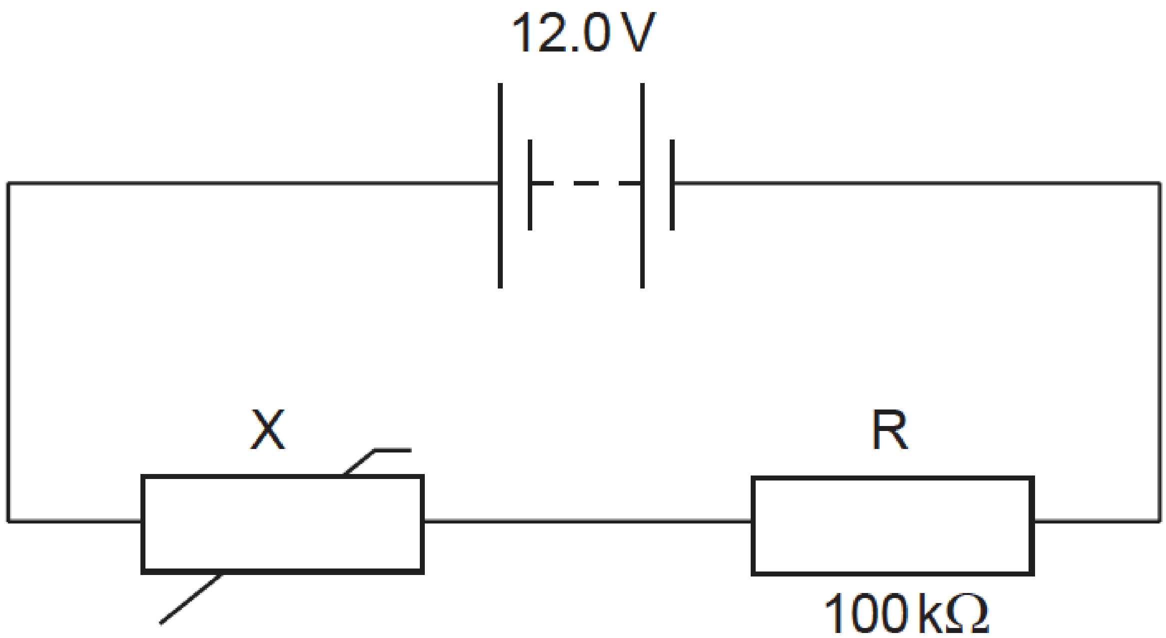
(i) Determine the value of *R* for this circuit at which maximum power is delivered to the external circuit.

(ii) Calculate the reading on the voltmeter for the value of *R* you determined in (f)(i).

(iii) Calculate the total power dissipated in the circuit when the maximum power is being delivered to the external circuit.

This question is in two parts. Part 1 is about a thermistor circuit. Part 2 is about vibrations and waves.

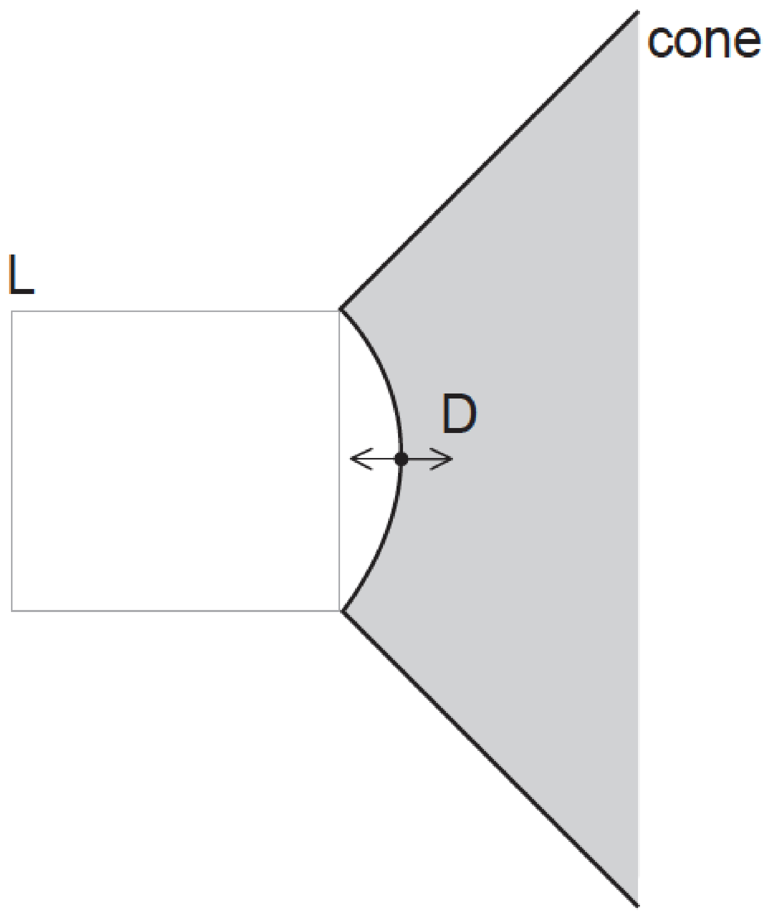
Part 1 Thermistor circuit
The circuit shows a negative temperature coefficient (NTC) thermistor X and a 100 kΩ fixed resistor R connected across a battery.



The battery has an electromotive force (emf) of 12.0 V and negligible internal resistance.

Part 2 Vibrations and waves

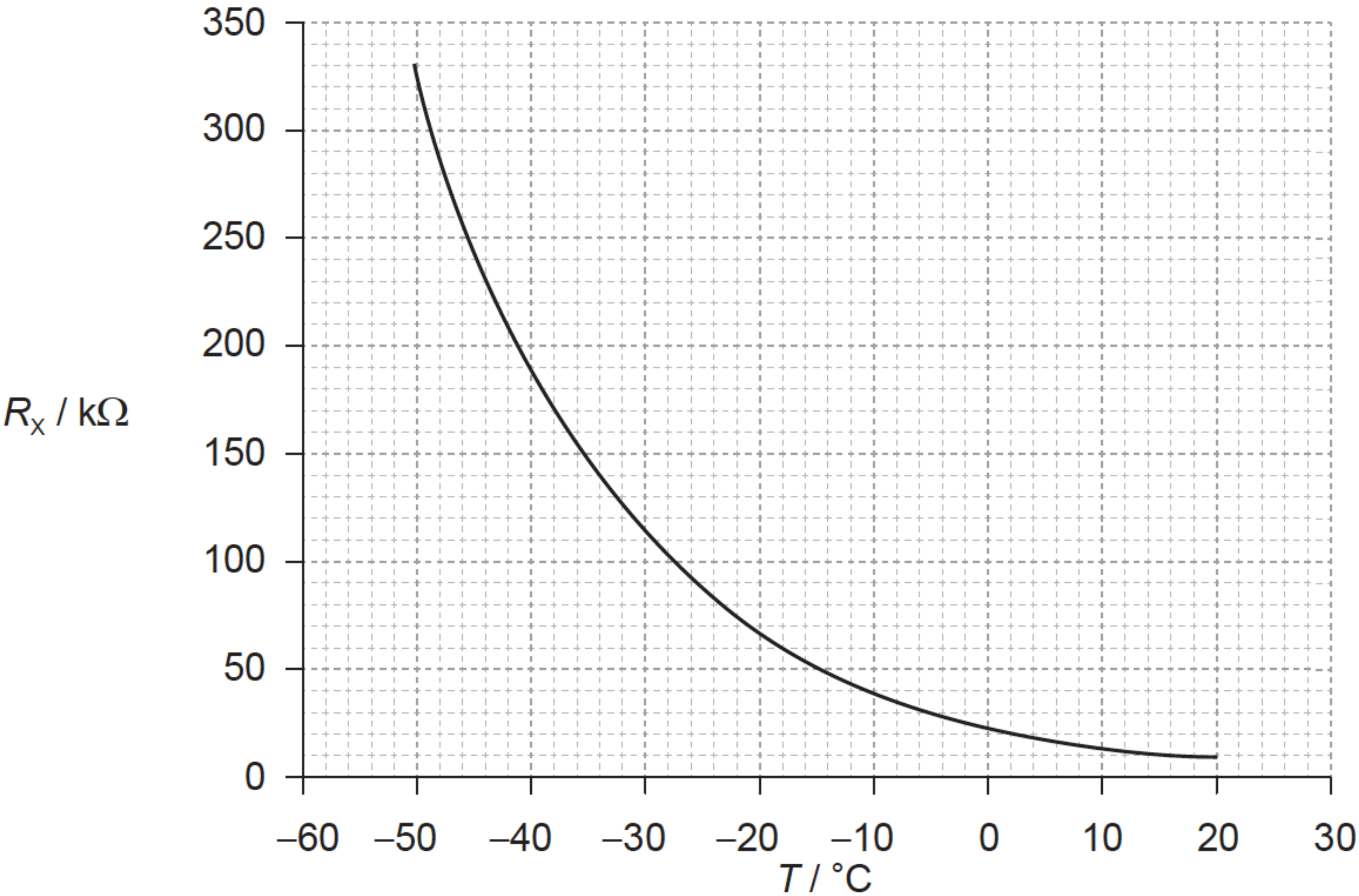
The cone and dust cap D of a loudspeaker L vibrates with a frequency of 1.25 kHz with simple harmonic motion (SHM).



a. (i) Define *electromotive force (emf)*. [2]

(ii) State how the emf of the battery can be measured.

b. The graph below shows the variation with temperature T of the resistance R_X of the thermistor. [7]



(i) Determine the temperature of X when the potential difference across R is 4.5V.

(ii) State the range of temperatures for which the change in the resistance of the thermistor is most sensitive to changes in temperature.

(iii) State and explain the effect of a decrease in temperature on the ratio

$$\frac{\text{voltageacrossX}}{\text{voltageacrossR}}$$

.

c. Define *simple harmonic motion (SHM)*. [2]

d. D has mass 6.5×10^{-3} kg and vibrates with amplitude 0.85 mm. [4]

(i) Calculate the maximum acceleration of D.

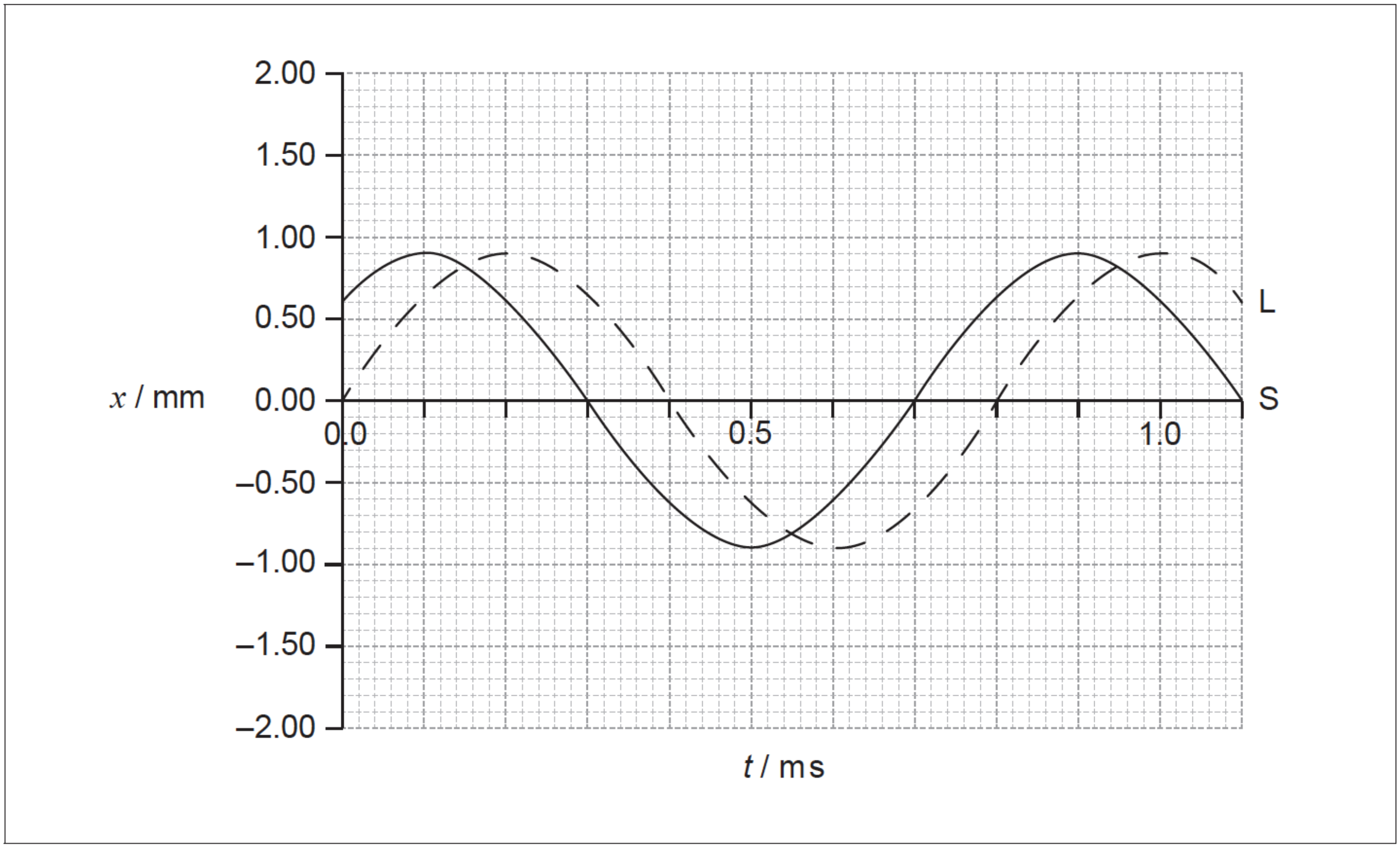
(ii) Determine the total energy of D.

e. The sound waves from the loudspeaker travel in air with speed 330 ms^{-1}. [2]

(i) Calculate the wavelength of the sound waves.

(ii) Describe the characteristics of sound waves in air.

f. A second loudspeaker S emits the same frequency as L but vibrates out of phase with L. The graph below shows the variation with time *t* of the displacement *x* of the waves emitted by S and L. [6]



(i) Deduce the relationship between the phase of L and the phase of S.

(ii) On the graph, sketch the variation with *t* of *x* for the wave formed by the superposition of the two waves.