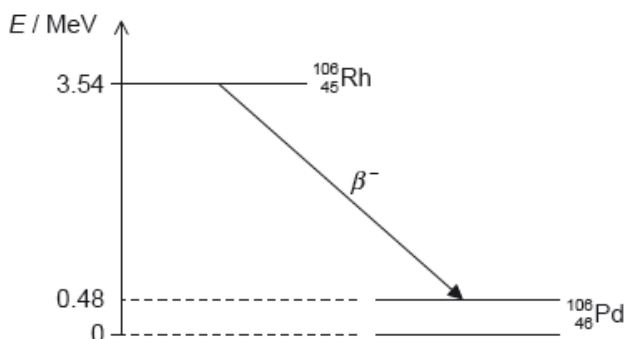


## HL Paper 2

Rhodium-106 ( $^{106}_{45}\text{Rh}$ ) decays into palladium-106 ( $^{106}_{46}\text{Pd}$ ) by beta minus ( $\beta^-$ ) decay. The diagram shows some of the nuclear energy levels of rhodium-106 and palladium-106. The arrow represents the  $\beta^-$  decay.



b. Bohr modified the Rutherford model by introducing the condition  $mvr = n \frac{h}{2\pi}$ . Outline the reason for this modification. [3]

c.i. Show that the speed  $v$  of an electron in the hydrogen atom is related to the radius  $r$  of the orbit by the expression [1]

$$v = \sqrt{\frac{ke^2}{m_e r}}$$

where  $k$  is the Coulomb constant.

c.ii. Using the answer in (b) and (c)(i), deduce that the radius  $r$  of the electron's orbit in the ground state of hydrogen is given by the following expression. [2]

$$r = \frac{h^2}{4\pi^2 k m_e e^2}$$

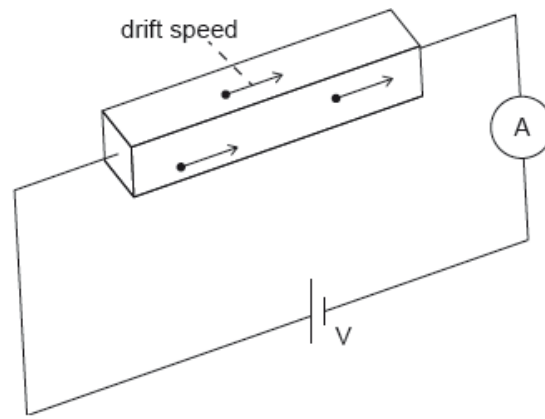
c.iii. Calculate the electron's orbital radius in (c)(ii). [1]

d.i. Explain what may be deduced about the energy of the electron in the  $\beta^-$  decay. [3]

d.ii. Suggest why the  $\beta^-$  decay is followed by the emission of a gamma ray photon. [1]

d.iii. Calculate the wavelength of the gamma ray photon in (d)(ii). [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:

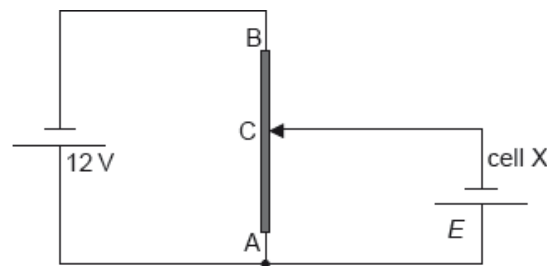
- density of free electrons =  $8.5 \times 10^{22} \text{ cm}^{-3}$
- resistivity  $\rho = 1.7 \times 10^{-8} \Omega\text{m}$
- dimensions  $w \times h \times l = 0.020 \text{ cm} \times 0.020 \text{ cm} \times 10 \text{ cm}$ .

The ammeter reading is 2.0 A.

The electric field  $E$  inside the sample can be approximated as the uniform electric field between two parallel plates.

- b. Calculate the drift speed  $v$  of the electrons in the conductor in  $\text{cm s}^{-1}$ . [2]
- c.i. Determine the electric field strength  $E$ . [2]
- c.ii. Show that  $\frac{v}{E} = \frac{1}{ne\rho}$ . [3]

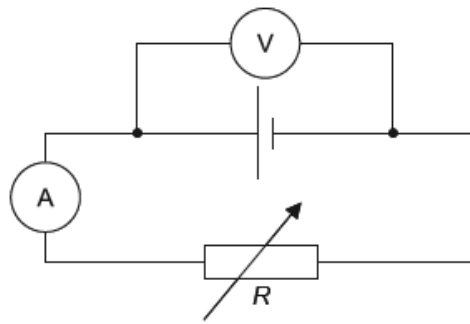
The diagram shows a potential divider circuit used to measure the emf  $E$  of a cell X. Both cells have negligible internal resistance.



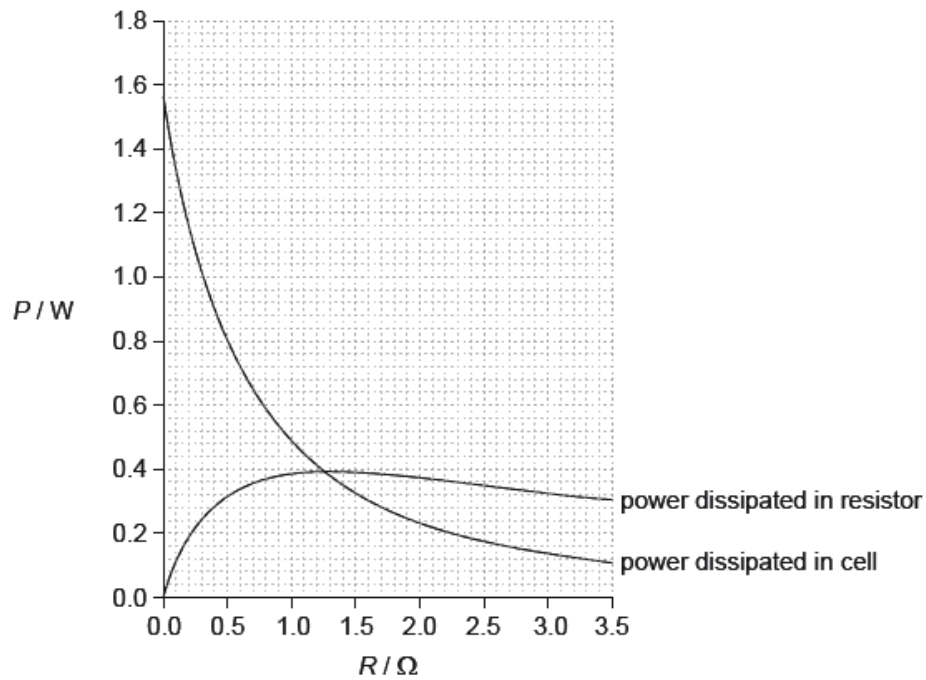
Cell X is replaced by a second cell of identical emf  $E$  but with internal resistance  $2.0 \Omega$ . Comment on the length of AC for which the current in the second cell is zero.

This question is in **two** parts. **Part 1** is about electrical circuits. **Part 2** is about magnetic fields.

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



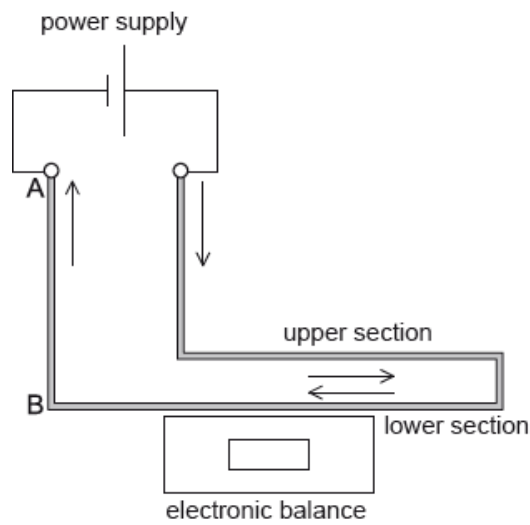
The variable resistor is adjusted and a series of current and voltage readings are taken. The graph shows the variation with  $R$  of the power dissipated in the cell and the power dissipated in the variable resistor.



This question is in **two** parts. **Part 1** is about electrical circuits. **Part 2** is about magnetic fields.

**Part 2** Magnetic fields

The diagram shows an arrangement for measuring the force between two parallel sections of the same rigid wire carrying a current as viewed from the front.



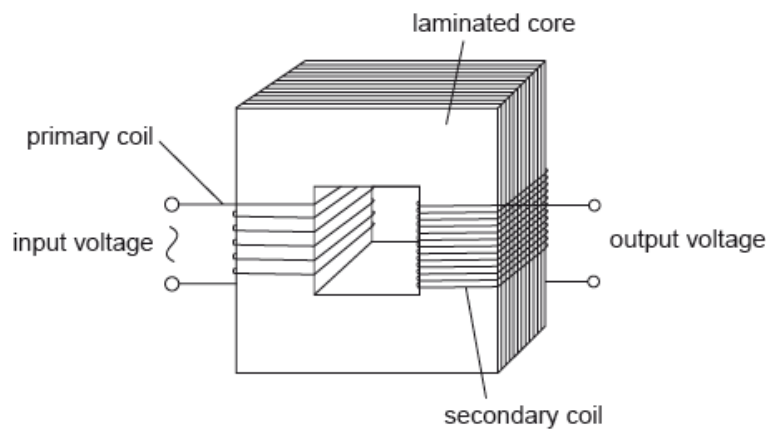
The supports for the upper section of the wire and the power supply are not shown.

When the current in the wire is 0.20 A, the magnetic field strength at the upper section of wire due to the lower section of wire is  $1.3 \times 10^{-4}$  T.

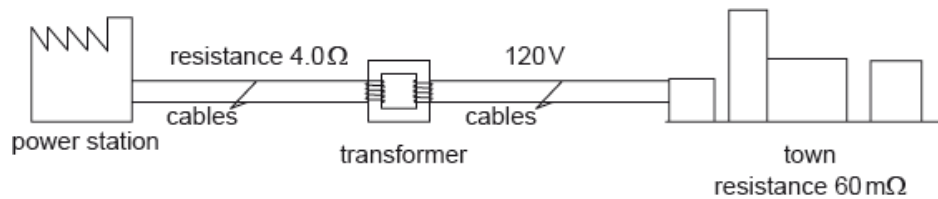
- d. The cell may be damaged if it dissipates a power greater than 1.2 W. Outline why damage in the cell may occur if the terminals of the cell are short-circuited. [2]
- e. The part of the wire from A to B is viewed from above. The direction of the current is out of the plane of the paper. [2]  
Using the diagram, draw the magnetic field pattern due to just the current in wire AB.
- f. Deduce what happens to the reading on the electronic balance when the current is switched on. [3]
- g.i. Calculate the magnetic force acting per unit length on the upper section of wire. [1]
- g.ii. Each cubic metre of the wire contains approximately  $8.5 \times 10^{28}$  free electrons. The diameter of the wire is 2.5 mm and the length of wire within the magnetic field is 0.15 m. Using the force per unit length calculated in (g)(i), deduce the speed of the electrons in the wire when the current is 0.20 A. [4]
- h. The upper section of wire is adjusted to make an angle of  $30^\circ$  with the lower section of wire. Outline how the reading of the balance will change, if at all. [3]

## Part 2 Power transmissions

The diagram shows the main features of an ideal transformer whose primary coil is connected to a source of alternating current (ac) voltage.



A different transformer is used to transmit power to a small town.



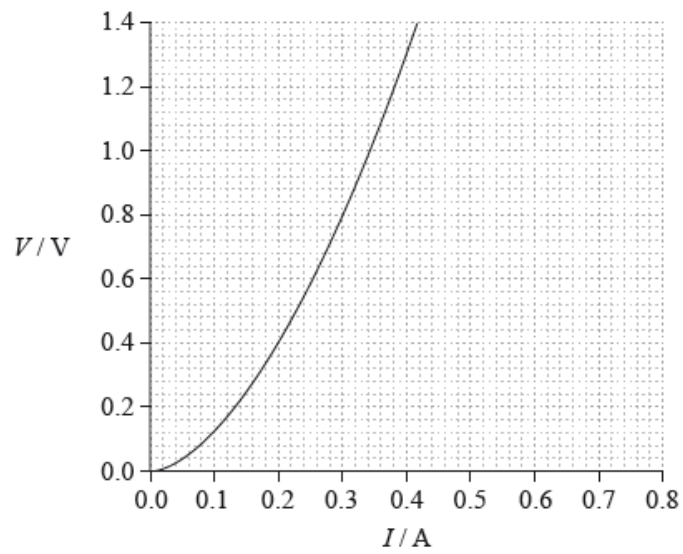
The transmission cables from the power station to the transformer have a total resistance of  $4.0 \Omega$ . The transformer is 90% efficient and steps down the voltage to 120 V. At the time of maximum power demand the effective resistance of the town and of the cables from the transformer to the town is  $60 \text{ m}\Omega$ .

- d. Outline, with reference to electromagnetic induction, how a voltage is induced across the secondary coil. [3]
- e. The primary coil has 25 turns and is connected to an alternating supply with an input voltage of root mean squared (rms) value 12 V. The secondary coil has 80 turns and is not connected to an external circuit. Determine the peak voltage induced across the secondary coil. [2]
- f.i. Calculate the current in the cables connected to the town [1]
- f.ii. Calculate the power supplied to the transformer. [2]
- f.iii. Determine the input voltage to the transformer if the power loss in the cables from the power station is 2.0 kW. [2]
- g. Outline why laminating the core improves the efficiency of a transformer. [2]

This question is in **two** parts. **Part 1** is about internal resistance of a cell. **Part 2** is about expansion of a gas.

**Part 1** Internal resistance of a cell

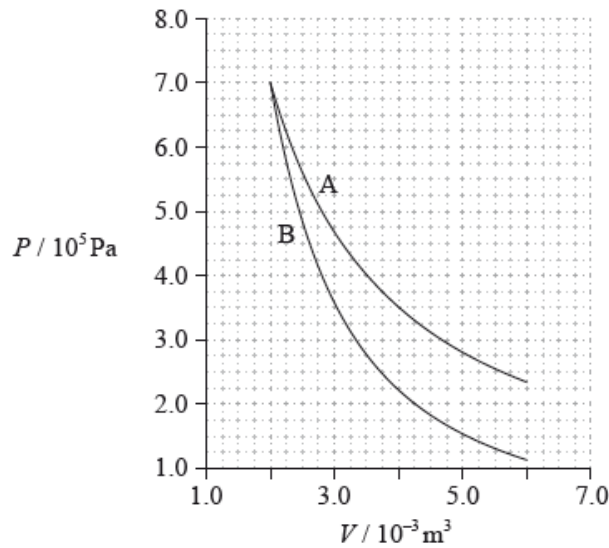
The graph shows the voltage–current ( $V-I$ ) characteristics of a non-ohmic conductor.



The variable resistor in the circuit in (c) is replaced by this non-ohmic conductor.

**Part 2** Expansion of a gas

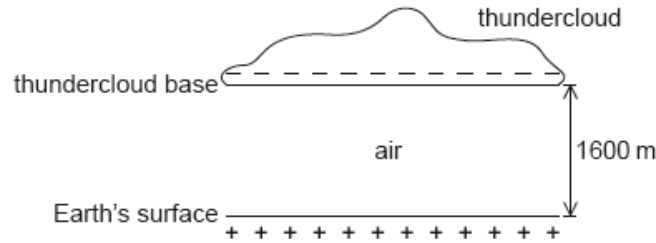
- b. Outline, with reference to charge carriers, what is meant by the internal resistance of a cell. [3]
- d.i. On the graph, sketch the variation of  $V$  with  $I$  for the cell. [2]
- d.ii. Using the graph, determine the current in the circuit. [3]
- e. The graph shows how the pressure  $P$  of a fixed mass of gas varies with volume  $V$ . The lines show the state of the gas sample during adiabatic expansion and during isothermal expansion. [2]



State and explain whether line A or line B represents an adiabatic expansion.

- f. Determine the work done during the change represented by line A. [4]
- g. Outline, with reference to the first law of thermodynamics, the direction of change in temperature during the adiabatic expansion. [4]

A negatively charged thundercloud above the Earth's surface may be modelled by a parallel plate capacitor.



The lower plate of the capacitor is the Earth's surface and the upper plate is the base of the thundercloud.

The following data are available.

Area of thundercloud base	$= 1.2 \times 10^8 \text{ m}^2$
Charge on thundercloud base	$= -25 \text{ C}$
Distance of thundercloud base from Earth's surface	$= 1600 \text{ m}$
Permittivity of air	$= 8.8 \times 10^{-12} \text{ F m}^{-1}$

Lightning takes place when the capacitor discharges through the air between the thundercloud and the Earth's surface. The time constant of the system is 32 ms. A lightning strike lasts for 18 ms.

- a. Show that the capacitance of this arrangement is  $C = 6.6 \times 10^{-7} \text{ F}$ . [1]
- b.i. Calculate in V, the potential difference between the thundercloud and the Earth's surface. [2]
- b.ii. Calculate in J, the energy stored in the system. [2]
- c.i. Show that about  $-11 \text{ C}$  of charge is delivered to the Earth's surface. [3]
- c.ii. Calculate, in A, the average current during the discharge. [1]
- d. State **one** assumption that needs to be made so that the Earth-thundercloud system may be modelled by a parallel plate capacitor. [1]

This question is in **two** parts. **Part 1** is about fields, electric potential difference and electric circuits. **Part 2** is about thermodynamic cycles.

**Part 1** Fields, electric potential difference and electric circuits

- 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 [3]  
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  $g_p$ .

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 cells. **Part 2** is about atoms.

### Part 1 Electric cells

Cells used to power small electrical devices contain both conductors and insulators.

Cells also have the property of internal resistance.

### Part 2 Atoms

Photoelectric emission occurs when ultraviolet radiation is incident on the surface of mercury but not when visible light is incident on the metal.

Photoelectric emission occurs when visible light of all wavelengths is incident on caesium.

- a. (i) Distinguish between an insulator and a conductor. [4]  
(ii) Outline what is meant by the internal resistance of a cell.
- c. State what is meant by the photoelectric effect. [1]
- d. (i) Suggest why the work function for caesium is smaller than that of mercury. [4]  
(ii) Ultraviolet radiation of wavelength 210 nm is incident on the surface of mercury. The work function for mercury is 4.5 eV. Determine the maximum kinetic energy of the photoelectrons emitted.
- f. An exact determination of the location of the electron in a hydrogen atom is not possible. Outline how this statement is consistent with the [3]  
Schrödinger model of the hydrogen atom.

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:

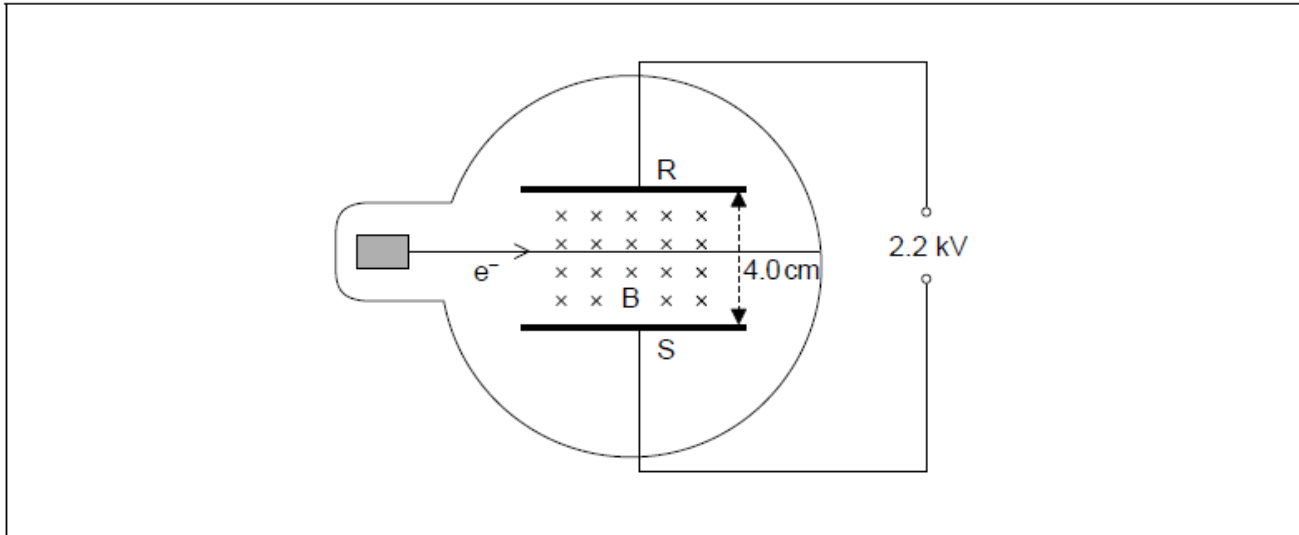
@TOPhysicsTutor

facebook.com/TheOnlinePhysicsTutor

Length of cable = 10 m  
 Cross-sectional area of cable = 6.0 mm<sup>2</sup>  
 Resistivity of copper = 1.7 × 10<sup>-8</sup> Ω m

Calculate the power dissipated in the cable.

A beam of electrons e<sup>-</sup> enters a uniform electric field between parallel conducting plates RS. RS are connected to a direct current (dc) power supply. A uniform magnetic field B is directed into the plane of the page and is perpendicular to the direction of motion of the electrons.



The magnetic field is adjusted until the electron beam is **undeflected** as shown.

a. Identify, on the diagram, the direction of the electric field between the plates. [1]

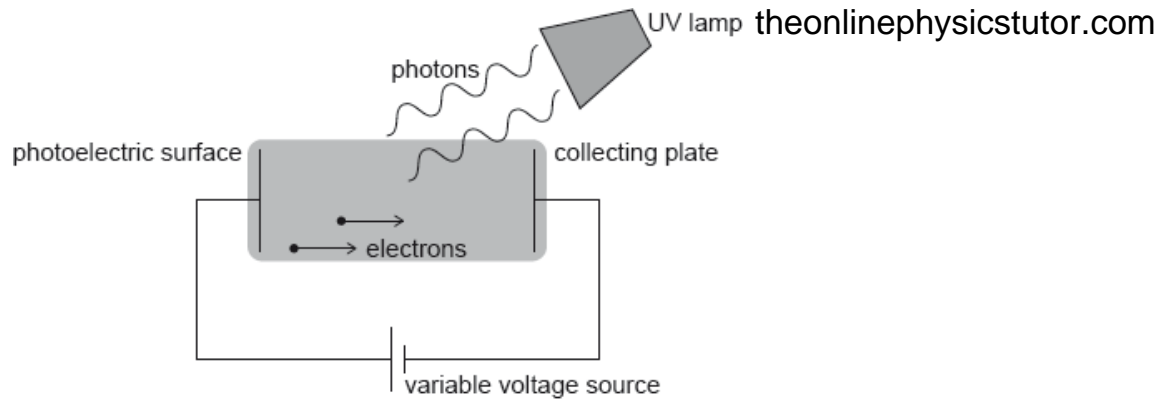
b. The following data are available. [2]

Separation of the plates RS	= 4.0 cm
Potential difference between the plates	= 2.2 kV
Velocity of the electrons	= 5.0 × 10 <sup>5</sup> m s <sup>-1</sup>

Determine the strength of the magnetic field B.

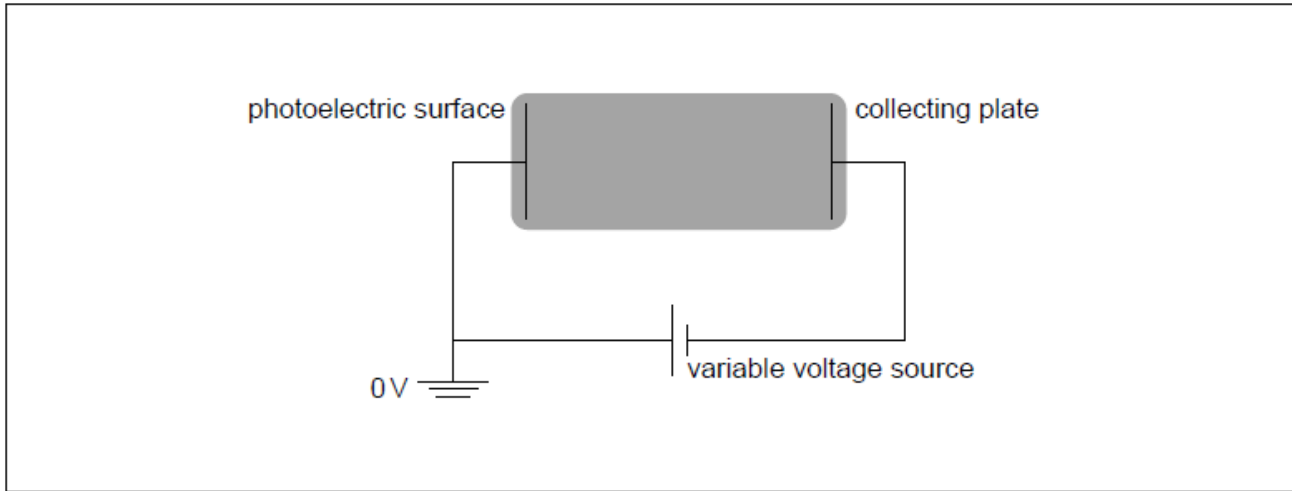
c. The velocity of the electrons is now increased. Explain the effect that this will have on the path of the electron beam. [2]

Hydrogen atoms in an ultraviolet (UV) lamp make transitions from the first excited state to the ground state. Photons are emitted and are incident on a photoelectric surface as shown.



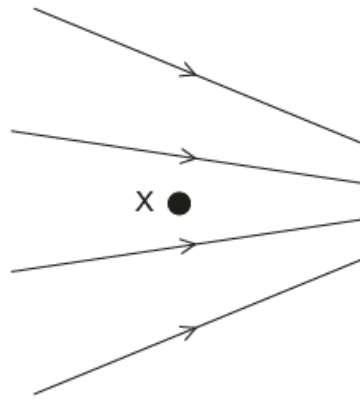
The photons cause the emission of electrons from the photoelectric surface. The work function of the photoelectric surface is 5.1 eV.

The electric potential of the photoelectric surface is 0 V. The variable voltage is adjusted so that the collecting plate is at  $-1.2$  V.



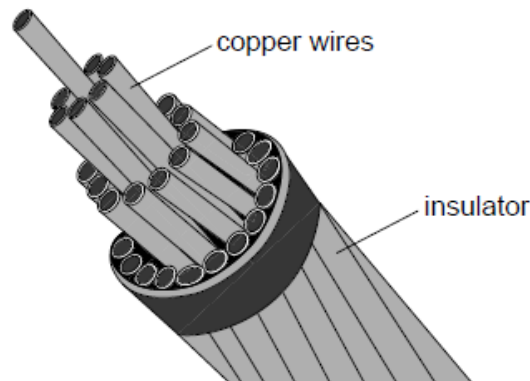
- a. Show that the energy of photons from the UV lamp is about 10 eV. [2]
- b.i. Calculate, in J, the maximum kinetic energy of the emitted electrons. [2]
- b.ii. Suggest, with reference to conservation of energy, how the variable voltage source can be used to stop all emitted electrons from reaching the collecting plate. [2]
- b.iii. The variable voltage can be adjusted so that no electrons reach the collecting plate. Write down the minimum value of the voltage for which no electrons reach the collecting plate. [1]
- c.i. On the diagram, draw and label the equipotential lines at  $-0.4$  V and  $-0.8$  V. [2]
- c.ii. An electron is emitted from the photoelectric surface with kinetic energy 2.1 eV. Calculate the speed of the electron at the collecting plate. [2]

A non-uniform electric field, with field lines as shown, exists in a region where there is no gravitational field. X is a point in the electric field. The field lines and X lie in the plane of the paper.



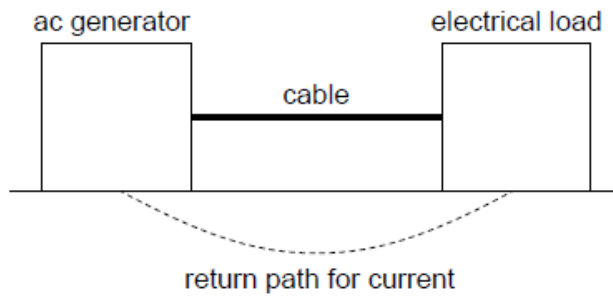
- a. Outline what is meant by electric field strength. [2]
- b. An electron is placed at X and released from rest. Draw, on the diagram, the direction of the force acting on the electron due to the field. [1]
- c. The electron is replaced by a proton which is also released from rest at X. Compare, without calculation, the motion of the electron with the motion of the proton after release. You may assume that no frictional forces act on the electron or the proton. [4]

A cable consisting of many copper wires is used to transfer electrical energy from an alternating current (ac) generator to an electrical load. The copper wires are protected by an insulator.

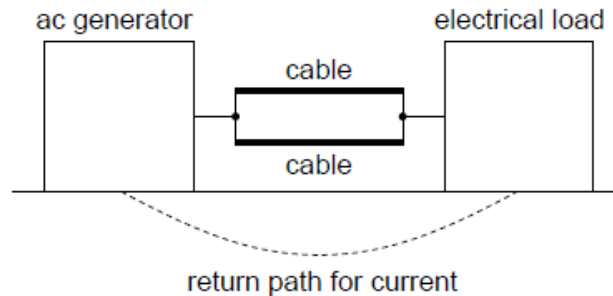


The cable consists of 32 copper wires each of length 35 km. Each wire has a resistance of  $64 \Omega$ . The cable is connected to the ac generator which has an output power of 110 MW when the peak potential difference is 150 kV. The resistivity of copper is  $1.7 \times 10^{-8} \Omega \text{ m}$ .

output power = 110 MW



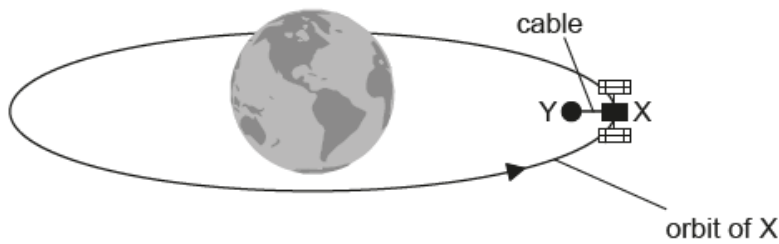
To ensure that the power supply cannot be interrupted, two identical cables are connected in parallel.



The energy output of the ac generator is at a much lower voltage than the 150 kV used for transmission. A step-up transformer is used between the generator and the cables.

- b.i. Calculate the radius of each **wire**. [2]
- b.ii. Calculate the peak current in the **cable**. [1]
- b.iii. Determine the power dissipated in the cable per unit length. [3]
- c. Calculate the root mean square (rms) current in each cable. [1]
- d. The two cables in part (c) are suspended a constant distance apart. Explain how the magnetic forces acting between the cables vary during the course of one cycle of the alternating current (ac). [2]
- e.i. Suggest the advantage of using a step-up transformer in this way. [2]
- e.ii. The use of alternating current (ac) in a transformer gives rise to energy losses. State how eddy current loss is minimized in the transformer. [1]

There is a proposal to power a space satellite X as it orbits the Earth. In this model, X is connected by an electronically-conducting cable to another smaller satellite Y.



not to scale

Satellite Y orbits closer to the centre of Earth than satellite X. Outline why

The cable acts as a spring. Satellite Y has a mass  $m$  of  $3.5 \times 10^2$  kg. Under certain circumstances, satellite Y will perform simple harmonic motion (SHM) with a period  $T$  of 5.2 s.

a. Satellite X orbits 6600 km from the centre of the Earth. [2]

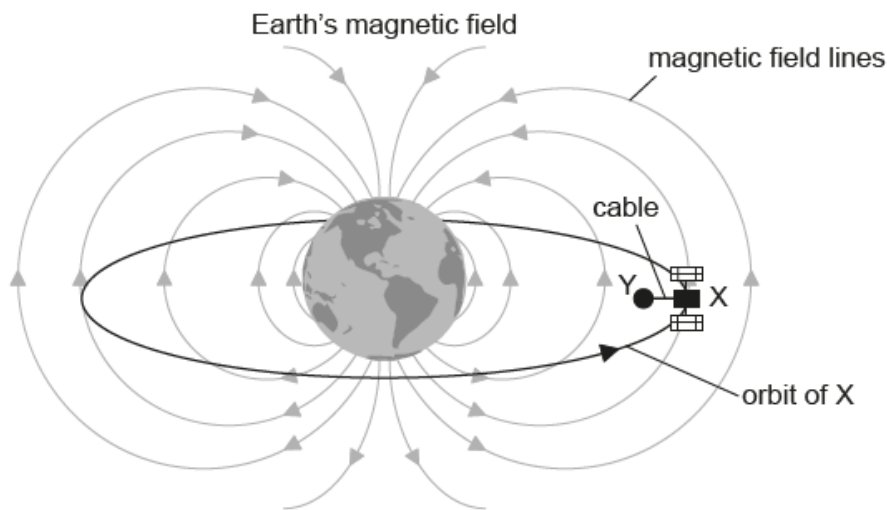
Mass of the Earth =  $6.0 \times 10^{24}$  kg

Show that the orbital speed of satellite X is about  $8 \text{ km s}^{-1}$ .

b.i. the orbital times for X and Y are different. [1]

b.ii. satellite Y requires a propulsion system. [2]

c. The cable between the satellites cuts the magnetic field lines of the Earth at right angles. [3]



not to scale

Explain why satellite X becomes positively charged.

d. Satellite X must release ions into the space between the satellites. Explain why the current in the cable will become zero unless there is a method for transferring charge from X to Y. [3]

e. The magnetic field strength of the Earth is  $31 \mu\text{T}$  at the orbital radius of the satellites. The cable is 15 km in length. Calculate the emf induced in the cable. [2]

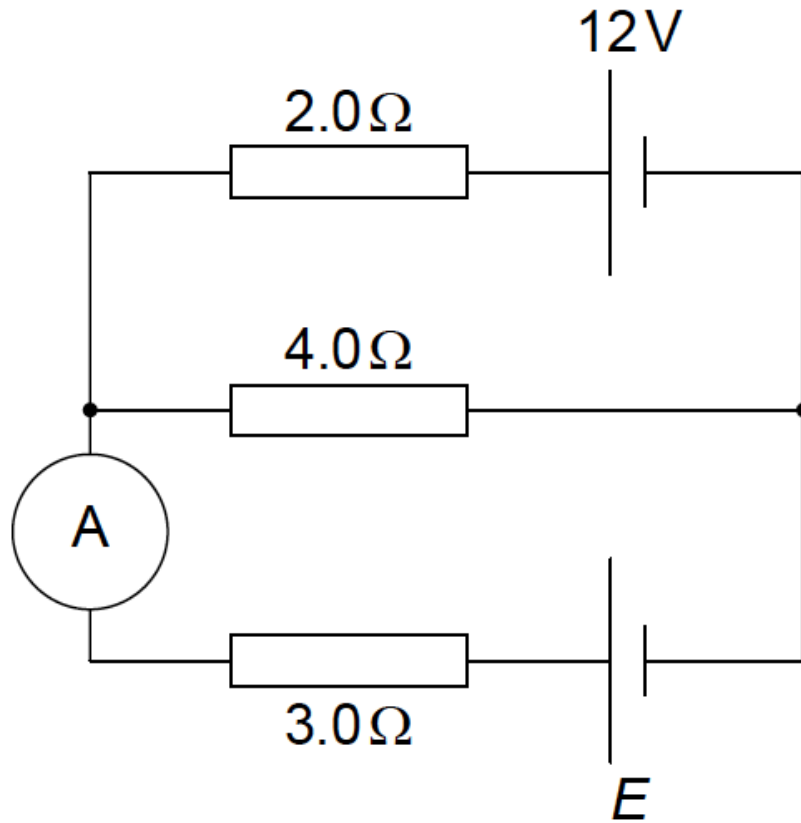
f.i. Estimate the value of  $k$  in the following expression. [3]

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Give an appropriate unit for your answer. Ignore the mass of the cable and any oscillation of satellite X.

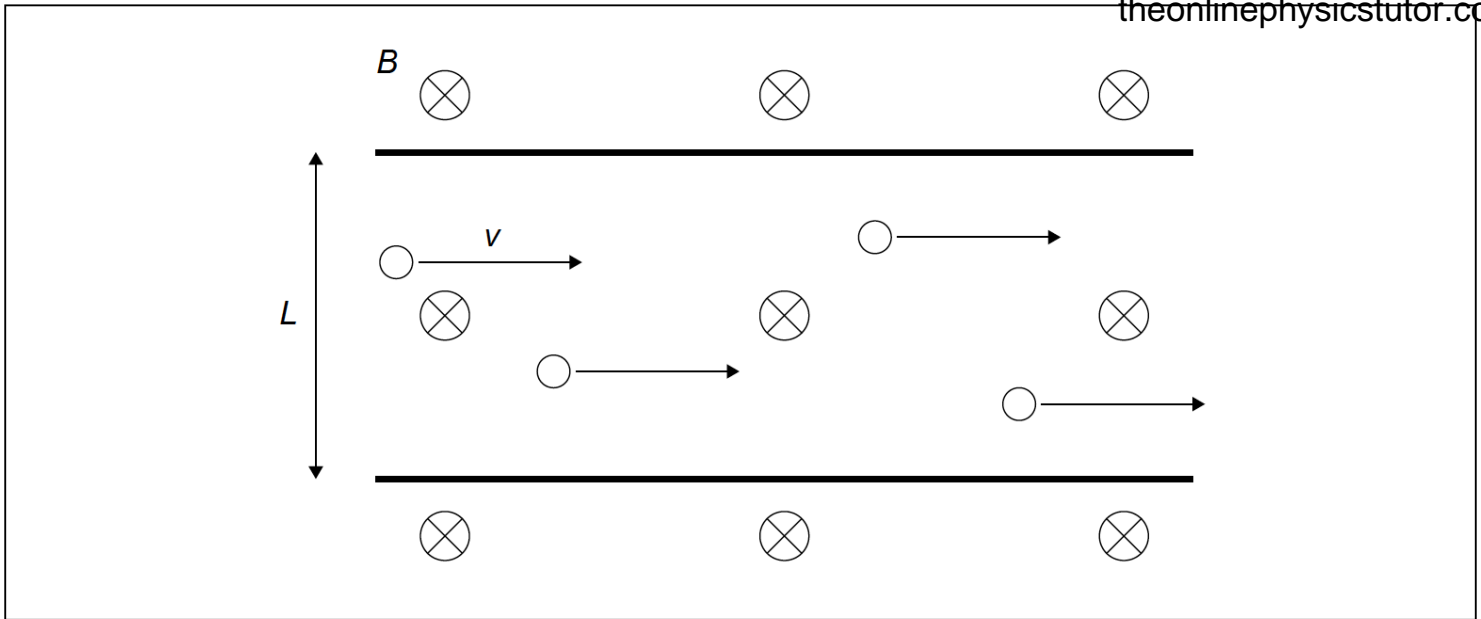
f.ii. Describe the energy changes in the satellite Y-cable system during one cycle of the oscillation.

a. Two cells of negligible internal resistance are connected in a circuit. [2]



The top cell has electromotive force (emf) 12V. The emf of the lower cell is unknown. The ideal ammeter reads zero current. Calculate the emf  $E$  of the lower cell.

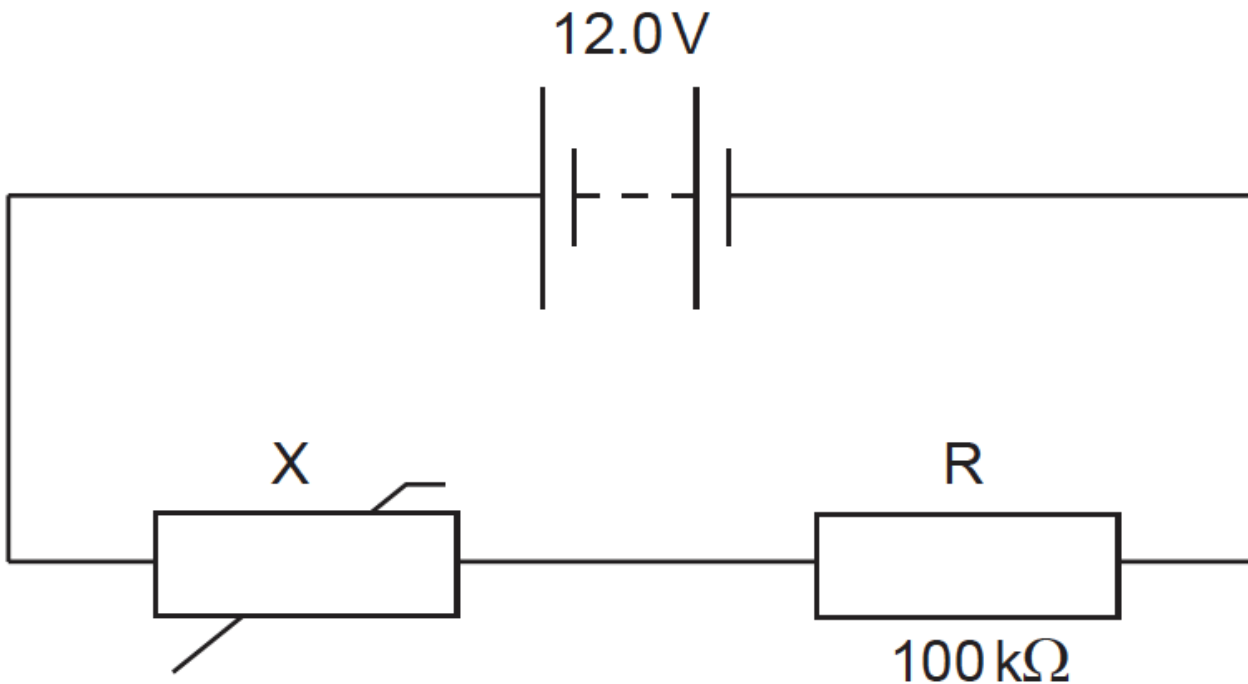
b. The diagram shows charge carriers moving with speed  $v$  in a metallic conductor of width  $L$ . The conductor is exposed to a uniform magnetic field  $B$  that is directed into the page. [3]



- (i) Show that the potential difference  $V$  that is established across the conductor is given by  $V = vBL$ .
- (ii) On the diagram, label the part of the conductor where negative charge accumulates.

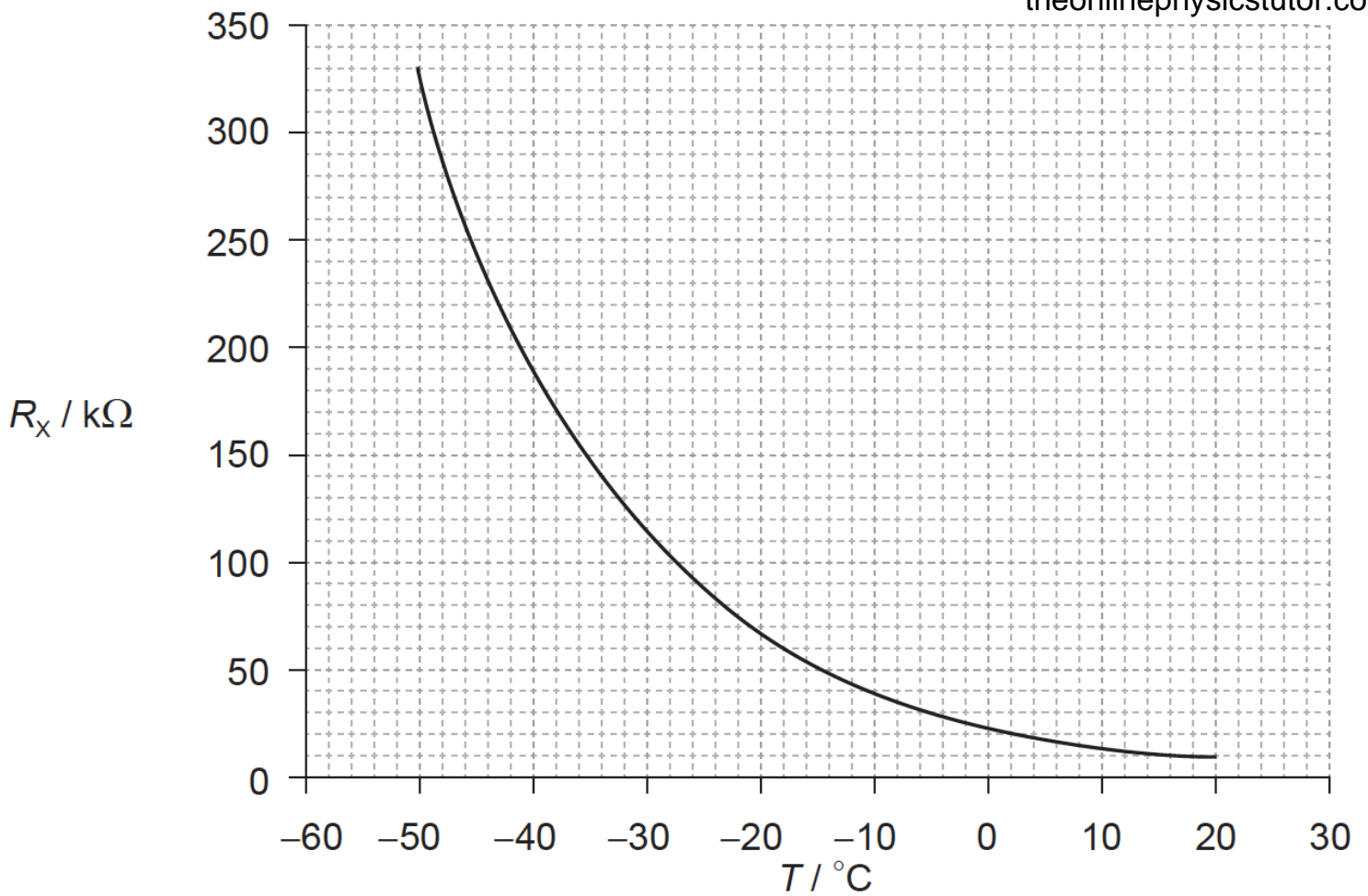
This question is about a thermistor circuit.

The circuit shows a negative temperature coefficient (NTC) thermistor  $X$  and a  $100\text{ k}\Omega$  fixed resistor  $R$  connected across a battery.



The battery has an electromotive force (emf) of  $12.0\text{ V}$  and negligible internal resistance.

- a. Define *electromotive force (emf)*. [1]
- b. The graph below shows the variation with temperature  $T$  of the resistance  $R_x$  of the thermistor. [7]

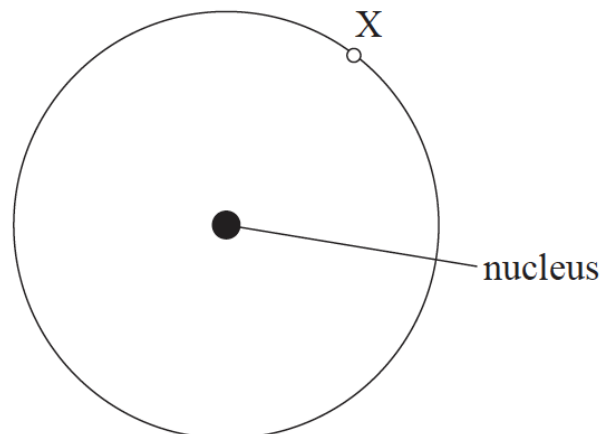


- (i) Determine the temperature of X when the potential difference across R is 4.5 V.
- (ii) State the range of temperatures for which the change in the resistance of the thermistor is most sensitive to changes in temperature.
- (iii) State and explain the effect of a decrease in temperature on the ratio  $\frac{\text{voltage across X}}{\text{voltage across R}}$ .

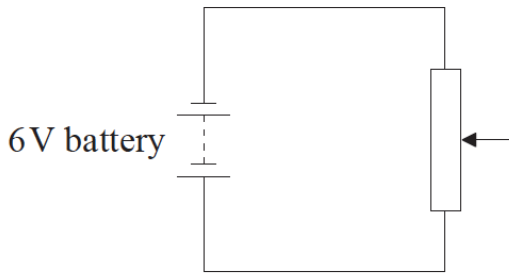
This question is in **two** parts. **Part 1** is about the properties of tungsten. **Part 2** is about the properties of a gas.

**Part 1** Properties of tungsten

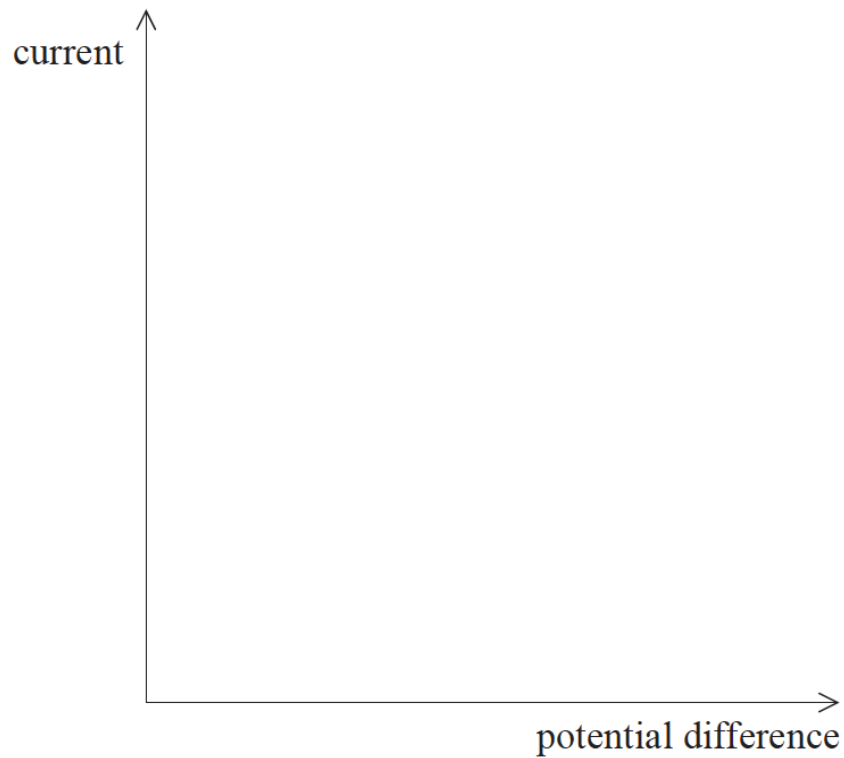
An isolated nucleus of an atom of the metal tungsten contains 74 protons.



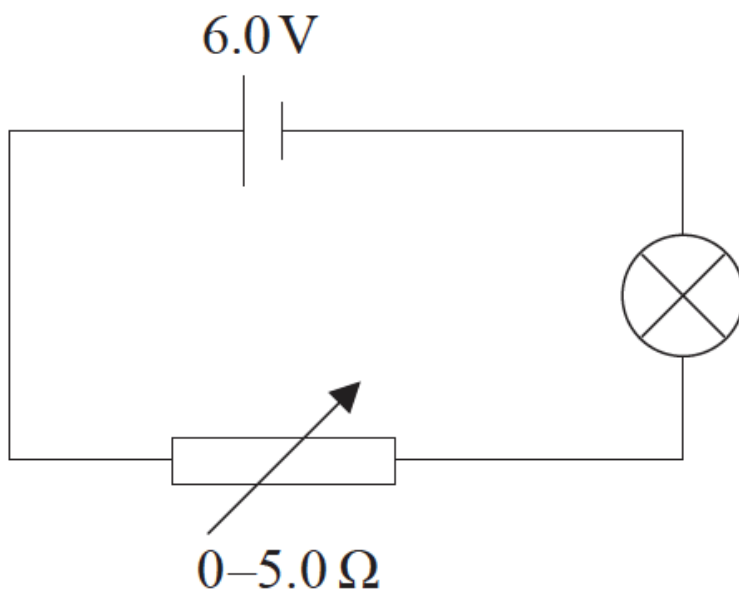
- a. (i) On the diagram above, draw an arrow to show the direction of the electric field at point X. [3]
- (ii) Assuming the nucleus acts as a point charge, determine the magnitude of the electric field strength at point X.
- d. (d) The diagram shows part of a potential divider circuit used to measure the current-potential difference ( $I$ - $V$ ) characteristic of the bulb. [4]



- (i) Draw the complete circuit showing the correct position of the bulb, ammeter and voltmeter.
- (ii) On the axes provided, sketch a graph to show how the current in the bulb varies with the potential difference.



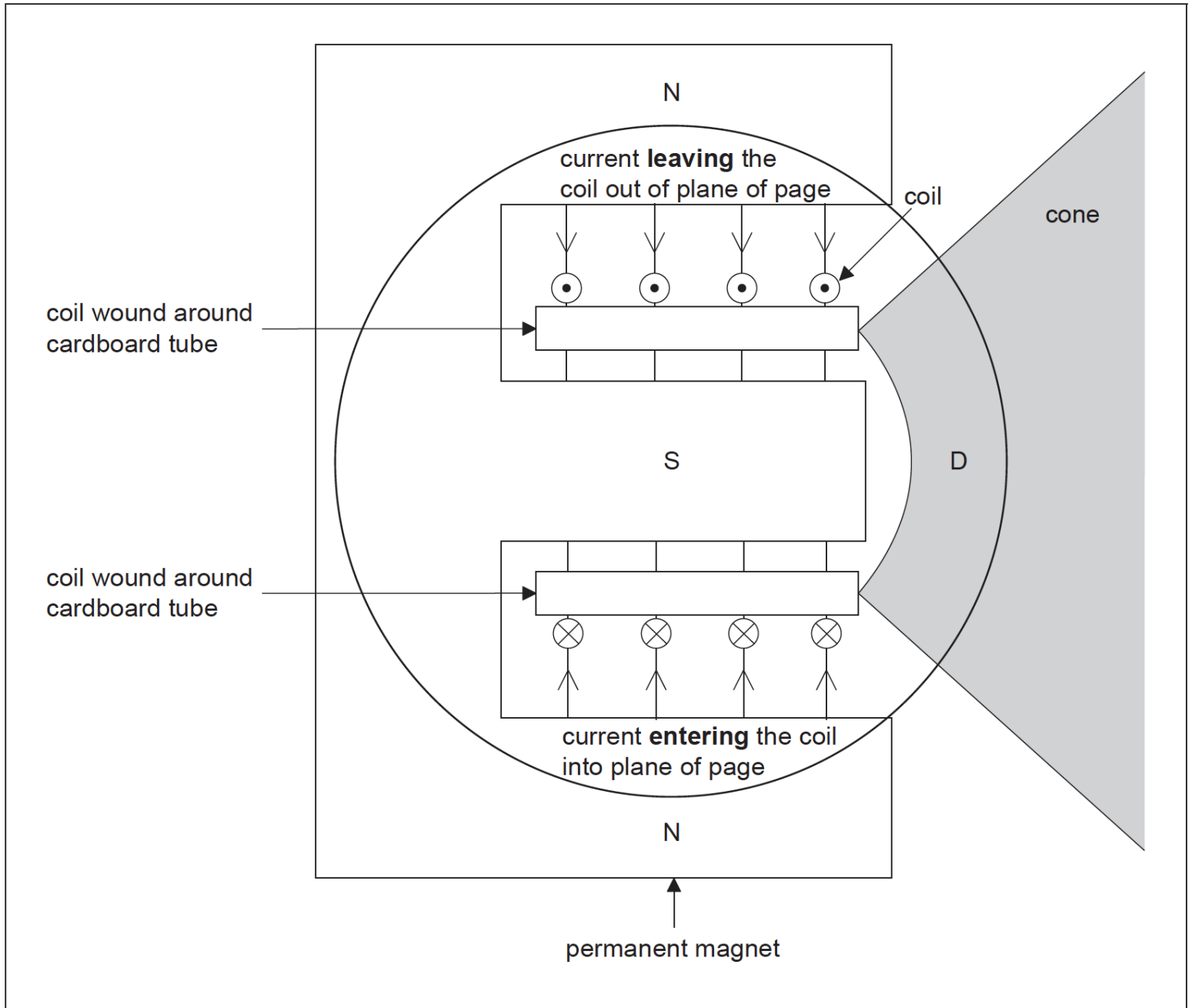
- e. A student sets up a different circuit to measure the  $I$ - $V$  graph. The cell has an emf of  $6.0\text{ V}$  and negligible internal resistance. The variable resistor has a minimum resistance of zero and a maximum resistance of  $5.0\ \Omega$ . [3]



Explain, with a calculation, why this circuit will not allow for a full range of potential difference from  $0\text{ V}$  to  $6\text{ V}$  across the bulb. Assume that the resistance of the lamp remains constant at a value of  $2.4\ \Omega$ .

**Part 1** Electrical and magnetic characteristics of a loudspeaker

The diagram shows the main features of a loudspeaker L. A current-carrying coil is positioned within the magnetic field provided by a permanent magnet. The diagram also shows the directions of the magnetic field and of the current in the coil at a particular instant. The dust cap D prevents dust from blocking the gap between the cardboard tube and the south pole of the magnet.



The coil consists of 150 turns, each of average diameter 2.5 cm. The magnetic field of the permanent magnet has strength 0.40 mT. The peak current in the coil is 0.45 mA.

- a. Identify, **on the diagram**, the direction of the force on the coil with the current directions shown. [2]
- b. Calculate the maximum magnetic force acting on the coil. [3]
- d. Explain, with reference to electromagnetic induction, the effect of the motion of the coil on the current. [3]

This question is in two parts. **Part 1** is about current electricity. **Part 2** is about atoms.

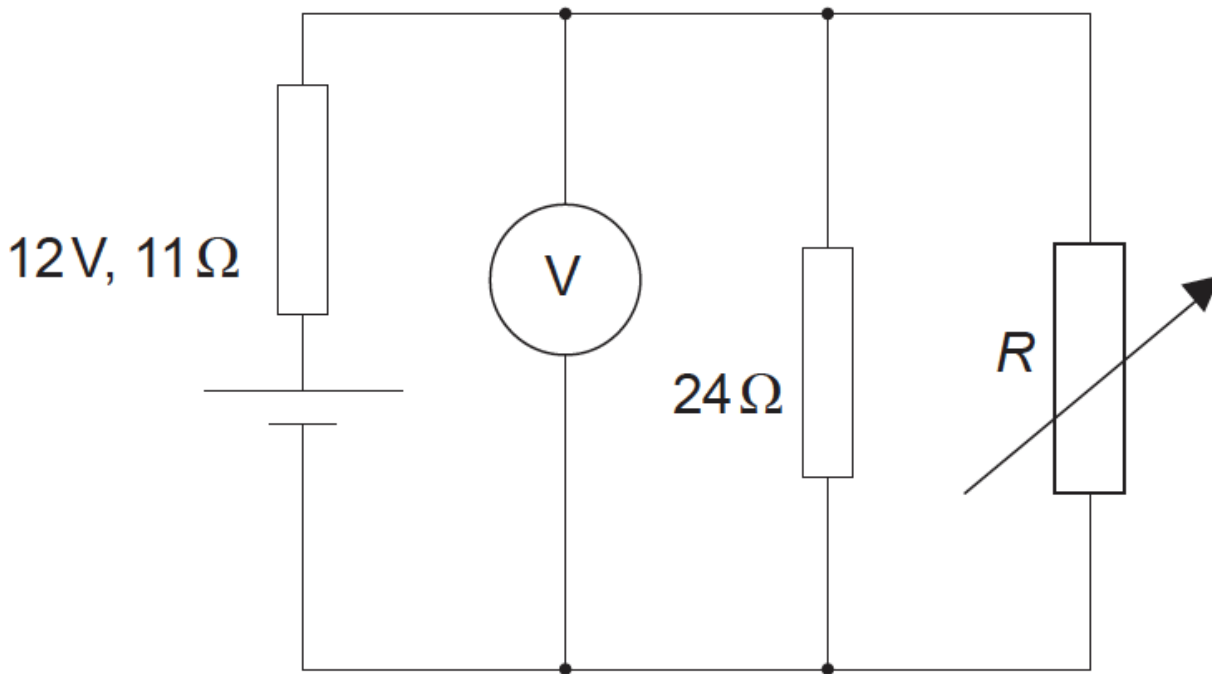
**Part 1** Current electricity

**Part 2** Atoms

a. A  $24\Omega$  resistor is made from a conducting wire. [8]

- (i) The diameter of the wire is  $0.30\text{ mm}$  and the wire has a resistivity of  $1.7 \times 10^{-8}\ \Omega\text{ m}$ . Calculate the length of the wire.
- (ii) A potential difference of  $12\text{V}$  is applied between the ends of the wire. Calculate the acceleration of a free electron in the wire.
- (iii) Suggest why the average speed of the free electron does not keep increasing even though it is being accelerated.

b. An electric circuit consists of a supply connected to a  $24\Omega$  resistor in parallel with a variable resistor of resistance  $R$ . The supply has an emf of  $12\text{V}$  and an internal resistance of  $11\Omega$ . [7]



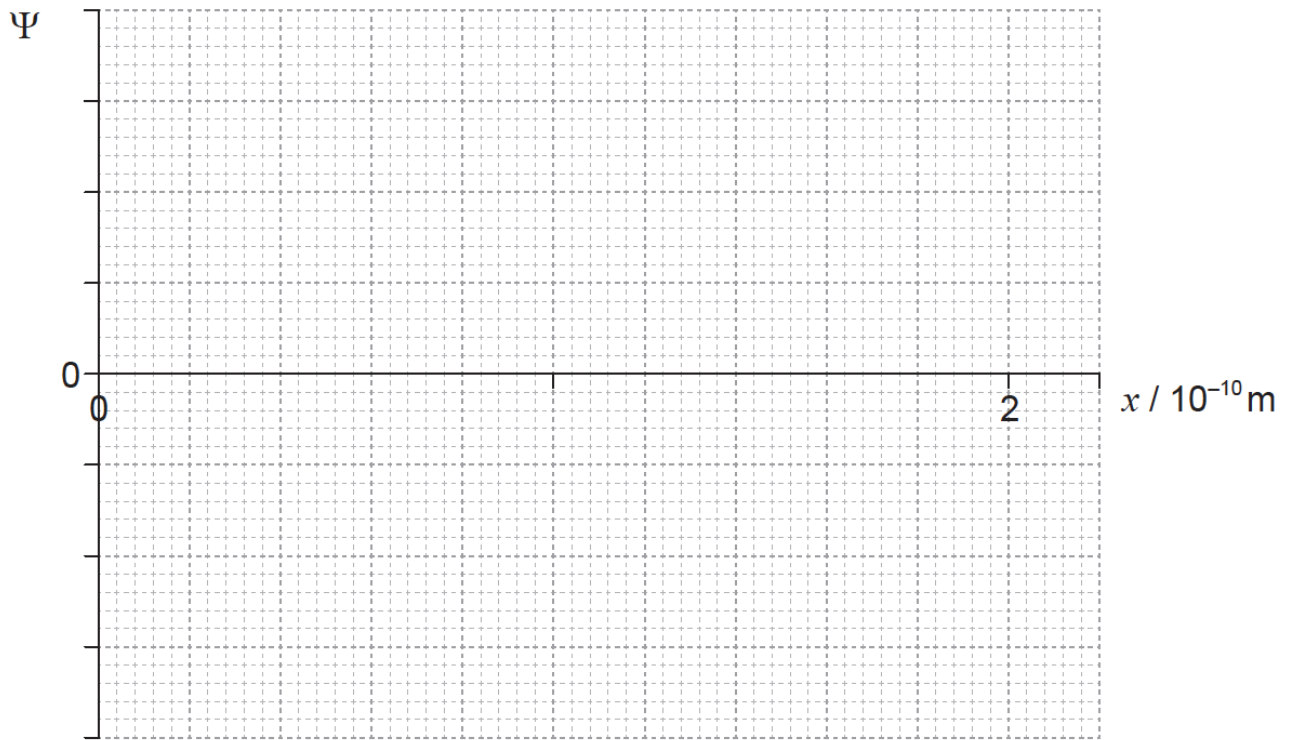
Power supplies deliver maximum power to an external circuit when the resistance of the external circuit equals the internal resistance of the power supply.

- (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 (b)(i).
- (iii) Calculate the power dissipated in the  $24\Omega$  resistor when the maximum power is being delivered to the external circuit.

c. State what is meant by the wavefunction of an electron. [1]

d. An electron is confined in a length of  $2.0 \times 10^{-10}\text{ m}$ . [9]

- (i) Determine the uncertainty in the momentum of the electron.
- (ii) The electron has a momentum of  $2.0 \times 10^{-23}\text{Ns}$ . Determine the de Broglie wavelength of the electron.
- (iii) On the axes, sketch the variation of the wavefunction  $\Psi$  of the electron in (d)(ii) with distance  $x$ . You may assume that  $\Psi = 0$  when  $x = 0$ .



(iv) Identify the feature of your graph in (d)(iii) that gives the probability of finding the electron at a particular position and at a particular time.