

Answer **all** the questions.

Section A

- 1 (a) Fig. 1.1 shows three possible paths of alpha particles as they pass a gold nucleus.

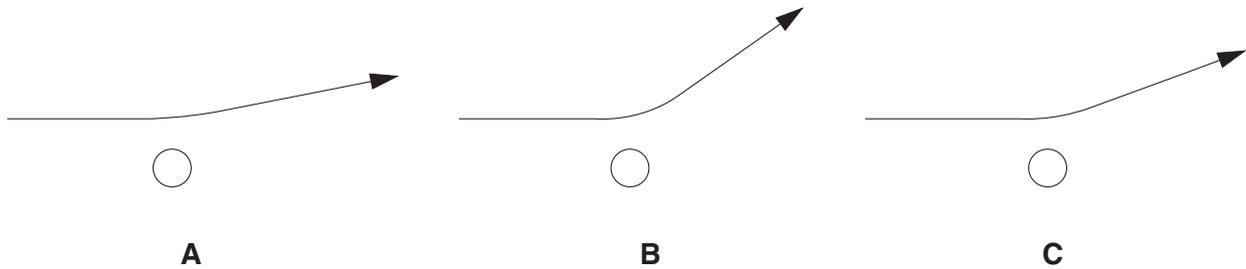


Fig. 1.1

Which path would be followed by the alpha particle with the lowest initial kinetic energy?

path [1]

- (b) Calculate the force on an alpha particle (charge $3.2 \times 10^{-19} \text{ C}$) at a distance of $1.0 \times 10^{-13} \text{ m}$ from the centre of a gold nucleus (charge $1.3 \times 10^{-17} \text{ C}$).

$$k = \frac{1}{4\pi\epsilon_0} = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

force = N [2]

- 2 Fig. 2.1 shows some equipotential lines around an electricity transmission cable at + 200 kV.

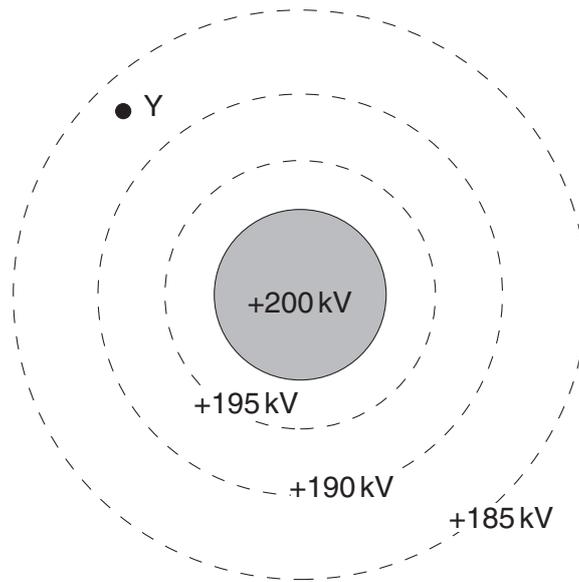


Fig. 2.1

- (a) State the feature of the diagram which shows that the electric field strength is strongest near the transmission cable.

[1]

- (b) Draw an arrow through point **Y** to show the direction of the electric field at that point.

[1]

- (c) The 195 kV equipotential is 5 mm from the surface of the 200 kV transmission cable. Use this information to choose the best estimate of the electric field strength at the surface of the cable from the four values below.

40 V m^{-1} $1 \times 10^3 \text{ V m}^{-1}$ $1 \times 10^6 \text{ V m}^{-1}$ $4 \times 10^7 \text{ V m}^{-1}$

the best estimate is V m^{-1} [1]

3 Fig. 3.1 shows a model dynamo.

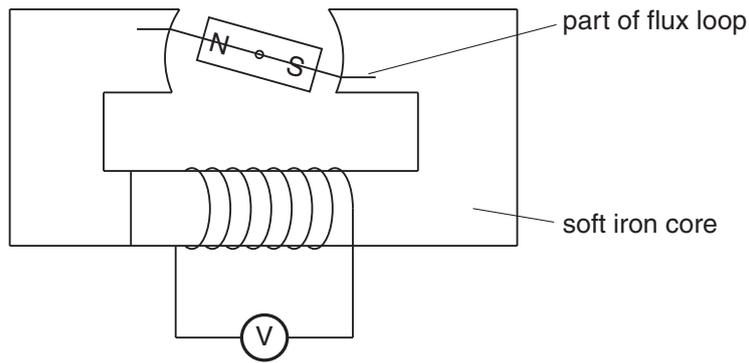


Fig. 3.1

(a) Complete the flux loop in Fig. 3.1. [1]

(b) When the magnet is rotated at 20Hz the maximum emf induced across the coil is 10V. State the maximum emf induced across the coil when the magnet is rotated at 10Hz.

emf induced across coil = V [1]

4 A wire of length 0.3m carries a current of 2A. It is placed in a magnetic field which is uniform over the length of wire as shown in Fig. 4.1.

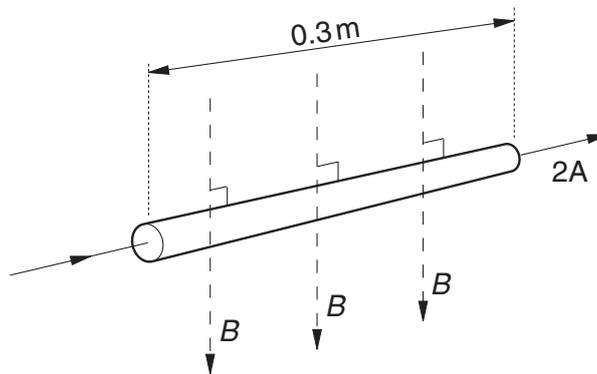


Fig. 4.1

The force on the length of wire is 0.05N. Calculate the magnetic flux density B .

magnetic flux density = T [2]

- 5 Fig. 5.1 shows a sketch graph of average binding energy per nucleon plotted against nucleon number.

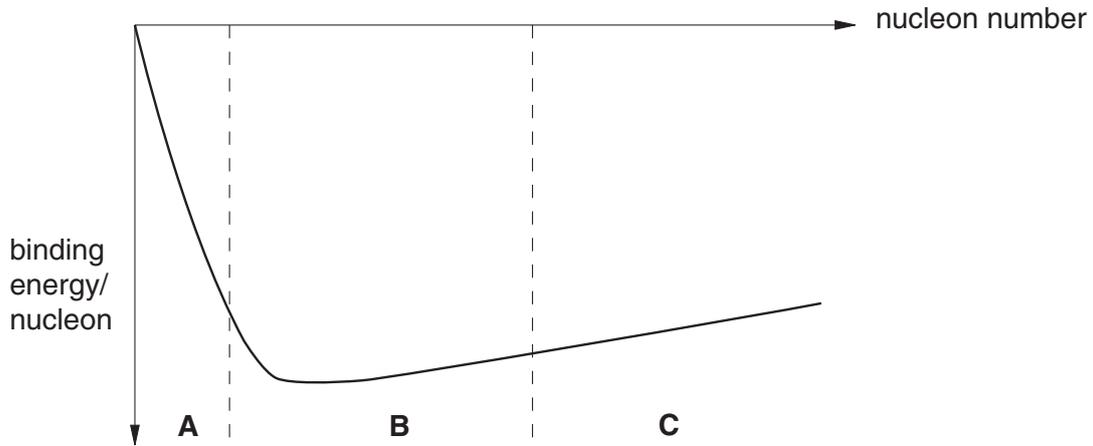


Fig. 5.1

The graph is divided into three regions **A**, **B** and **C**.

Complete the sentence below.

Nuclei in region may release energy by fission. [1]

- 6 Radium was discovered by Pierre and Marie Curie. Radium decays into radon gas as shown.



- (a) Complete the decay equation and identify particle **X**.

particle **X** is [2]

- (b) Marie Curie liked to keep a small glass bottle containing radium on her bedside table because it emitted a blue glow. This was a very risky habit because the radon gas produced is also radioactive and would be hazardous if it leaked from the bottle. However, the release of the 'X' particles from the decay of radium would not be harmful. State why this is the case.

[1]

- 7 CAT scans are used in medical diagnosis. Many individual X-ray images are combined in a single scan. This means that the patient is exposed to more radiation than in a conventional X-ray.

One type of scan delivers an exposure of about 6 mSv.

- (a) The risk of developing cancer from radiation is about 5% per sievert.

Calculate the risk of developing cancer from a 6 mSv CAT scan.

risk = % [2]

- (b) The energy from the scan is absorbed in 15 kg of body tissue. The quality factor of X-ray radiation is 1.

Calculate the energy absorbed in the body from the scan.

energy absorbed = J [2]

- 8 Nucleons are composed of up-quarks and down-quarks. The up-quark has charge $+2/3 e$. The charge on the down-quark is $-1/3 e$.

State the combination of quarks that make up a neutron.

combination of quarks = [1]

[Section A Total: 19]

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Section B

- 9 This question is about muons. These particles are formed as cosmic rays enter the upper atmosphere.

A negatively-charged muon decays in the following manner.



- (a) Explain how the decay equation above shows that this muon is a negatively-charged lepton.

[2]

- (b) In an experiment, the numbers of electrons produced in muon decays are counted in two detectors, one high in the atmosphere, the other at ground level 9.0 km below.

The muons travel through the atmosphere at a speed of $0.98c$.

Show that a muon travelling at $0.98c$ would take about $30\mu\text{s}$ to travel from one detector to the other $9.0 \times 10^3\text{m}$ below.

$$c = 3.0 \times 10^8 \text{ms}^{-1}$$

[1]

- (c) The half-life of a muon at rest is $1.5 \times 10^{-6}\text{s}$.

Show that about 0.0001% of the muons formed high in the atmosphere would remain after travelling $9.0 \times 10^3\text{m}$. Ignore relativistic factors.

[3]

- (d) When this experiment is performed the fraction of muons reaching the lower detector is 6.5%. This is much greater than the value in (c) suggests.
- (i) Estimate the number of half-lives that have passed if the fraction of muons remaining is 6.5%.

number of half-lives = [1]

- (ii) Use the values in (d)(i) and (b) to show that the half life of the high speed muons is about $7.5 \mu\text{s}$.

[2]

- (e) The theory of special relativity predicts that the half-life of a high speed particle will be longer than that of a stationary particle. This is shown in the equation

$$\text{half-life of particle moving at speed } v = \frac{\text{half-life of particle at rest}}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Explain whether the results of the muon experiment support the theory of special relativity.

[3]

[Total: 12]

Turn over

10 This question is about transformers.

Fig. 10.1 shows a transformer consisting of two coils wound on a laminated iron core. This consists of thin sheets of iron separated by layers of insulating material.

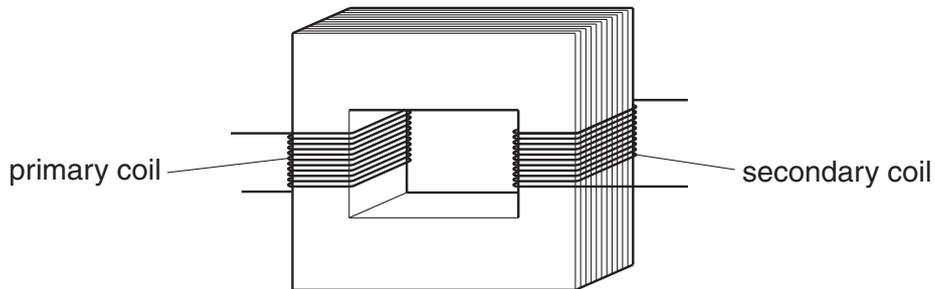


Fig. 10.1

The graph in Fig. 10.2 shows how the current in the primary coil and the induced emf in the secondary coil vary with time. There is no current in the secondary coil.

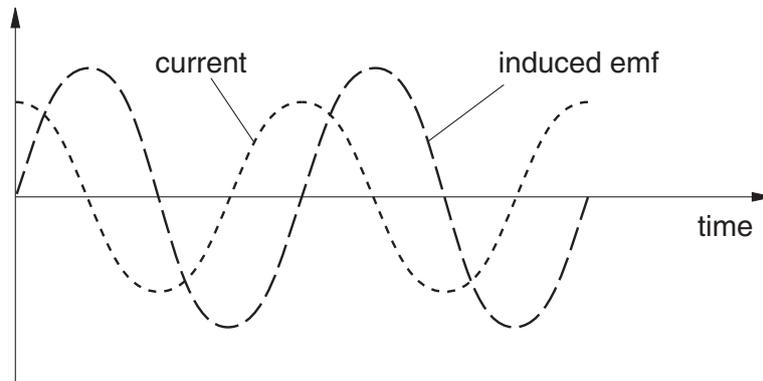


Fig. 10.2

- (a) (i) On Fig. 10.2 sketch a graph to show how the flux in the secondary coil varies with time. [2]
- (ii) Use the relationship between induced emf and rate of change of flux to explain why the induced emf in the secondary coil is zero when the current in the primary coil is a maximum.

[2]

(b) Here are some data about the transformer:

cross-sectional area of core = $6.0 \times 10^{-4} \text{ m}^2$

maximum flux density in core = $7.0 \times 10^{-2} \text{ T}$

frequency f of the circuit in the primary coil = 50 Hz

number of turns on secondary coil = 300

(i) Show that the maximum rate of change of flux is about 0.01 Wb s^{-1} .

$$\text{maximum rate of change of flux} = 2\pi f \times \text{maximum flux}$$

[2]

(ii) Calculate the maximum emf across the secondary coil.

maximum emf = V [2]

(c) The laminated core is replaced with a solid core of the same material. Nothing else is changed. It is observed that the maximum emf across the secondary coil is now lower than that calculated in (b) (ii). Explain why this is the case.

[3]

[Total: 11]

- 11 This question is about a machine used to accelerate electrons.

Fig. 11.1 shows that the machine has three main components. The electrons are first accelerated to an energy of 100 MeV in a linear accelerator. They are then further accelerated to 3 GeV in the booster synchrotron. The 3 GeV electrons then follow an approximately circular path in the storage ring. Electrons are continually added to the storage ring. When enough electrons are stored they are deflected out of the storage ring into the experimental area.

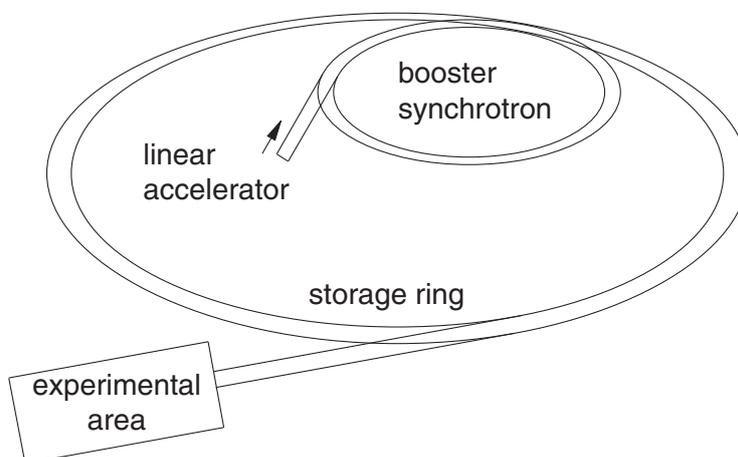


Fig. 11.1

- (a) Show that the 100 MeV electrons have about 200 times their rest energy when they leave the linear accelerator.

$$m_e = 9.1 \times 10^{-31} \text{ kg}$$

$$e = 1.6 \times 10^{-19} \text{ C}$$

$$c = 3.0 \times 10^8 \text{ m s}^{-1}$$

[3]

- (b) The electrons leave the linear accelerator at near-light speeds. The momentum p of a particle travelling at a speed approaching that of light is given by the approximation

$$p \approx E/c$$

where E is the energy of the particle and c is the velocity of light.

Estimate the ratio

$$\frac{\text{momentum of a 3 GeV electron}}{\text{momentum of a 100 MeV electron}}$$

ratio = [1]

- (c) Fig. 11.2 shows two electrons, e_1 and e_2 moving through a magnetic field acting into the paper. The arrows labelled v indicate the velocities of the electrons.

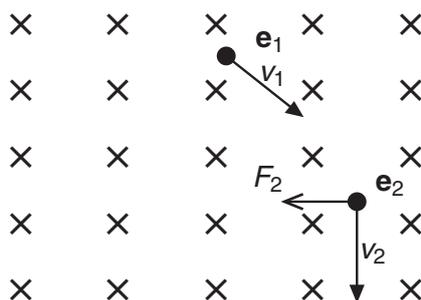


Fig. 11.2

Draw a second arrow on e_1 to show the direction of the force on e_1 due to the magnetic field. The force F_2 on e_2 is already shown. [1]

- (d) (i) The magnetic field in the ring is at right angles to the path of the electrons. Show that, for electrons moving at non-relativistic speed, the magnetic field strength B required for electrons to move around a circle of radius r is given by

$$B = \frac{mv}{er}$$

where m = mass of electron
 v = velocity of electron
 e = charge on electron.

[1]

- (ii) For electrons moving at near-light speeds the magnetic field required is given by

$$B = \frac{E}{cer}$$

where E = electron energy
 c = speed of light.

The storage ring has a radius of 89m. Calculate the value of B required for 3GeV electrons to follow this path.

$$B = \dots\dots\dots \text{T} [2]$$

[Total: 8]

Turn over

12 This question is about modelling electron waves in long chain molecules.

A carotene molecule $C_{40}H_{56}$ is about 2 nm in length. Electrons form standing waves along the whole length of the molecule.

Fig. 12.1 (a) shows the standing wave for the lowest energy level ($n = 1$) wave. Fig. 12.1 (b) shows a representation of the carotene molecule.

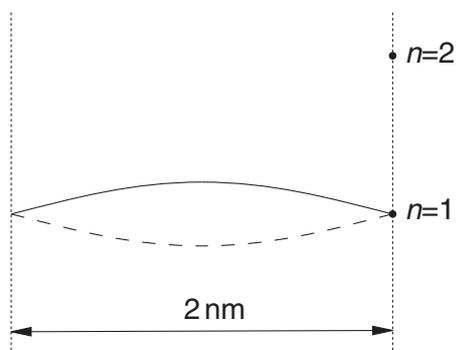


Fig. 12.1 (a)

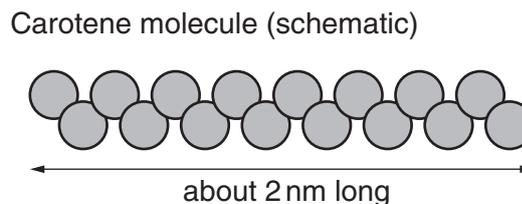


Fig. 12.1 (b)

(a) (i) State the wavelength of the electron at the $n = 1$ energy level.

wavelength = m [1]

(ii) On Fig. 12.1 (a) draw the wave representing an electron at the next energy level, $n = 2$. [1]

(b) The wavelength λ of the electron wave is given by

$$\lambda = \frac{h}{mv}$$

where h is the Planck constant
 m is the mass of electron
 v is the velocity of electron.

Show that the kinetic energy E_k of a non-relativistic electron with wavelength λ is given by

$$E_k = \frac{h^2}{2m\lambda^2}$$

[2]

- (c) Explain, without calculation, why the kinetic energy of the electron at the $n = 2$ state is four times that of an electron at the $n = 1$ state.

[2]

- (d) (i) Show that the energy required when an electron is promoted from the $n = 1$ to the $n = 2$ state, is about 5×10^{-20} J.

$$h = 6.6 \times 10^{-34} \text{ Js}$$
$$m_e = 9.1 \times 10^{-31} \text{ kg}$$

[2]

- (ii) Using relevant calculations, explain whether or not carotene molecules can absorb visible light by promoting electrons from the $n = 1$ level.

[3]

[Total: 11]

[Section B Total: 42]

Section C

The questions in this section are based on the Advance Notice Article.

13 This question is about electric charge.

Although a good model for electrical current was not developed until the twentieth century, charge itself has been known about for much longer (lines 6–21 in the article).

(a) Here are four products of quantities:

- A current x potential difference
- B energy x potential difference
- C current x time
- D current x capacitance

Which product gives electric charge? Put a ring around the correct letter:

A B C D

[1]

(b) When a small area of a large glass ball is rubbed with a silk cloth, it gains a positive charge of $+5.0 \times 10^{-6}$ C, as shown in Fig. 13.1.

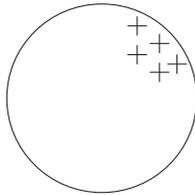


Fig. 13.1

(i) In terms of electron movement, state how this happens.

[1]

- (ii) Calculate the number of electrons moved.

$$e = -1.6 \times 10^{-19} \text{ C}$$

number = [2]

- (iii) State the charge gained by the silk cloth.

charge = C [1]

- (iv) Explain why the **whole** of the ball does not become positively charged.

[1]

[Total: 6]

14 This question is about the motion of free electrons in a vacuum.

In the gun of a cathode ray tube, electrons are accelerated through a potential difference of $4.0 \times 10^3 \text{V}$. A student works out the speed reached by the electrons, by using the equation:

$$eV = \frac{1}{2}m_e v^2$$

(a) Explain how this equation follows from the principle of the conservation of energy.

[1]

(b) (i) Calculate the final speed of the electrons.

$$m_e = 9.1 \times 10^{-31} \text{ kg}$$

$$e = -1.6 \times 10^{-19} \text{ C}$$

speed =m s⁻¹ [2]

(ii) Calculate the time taken for the electrons to reach the speed calculated in (b) (i).

distance from cathode to anode = 0.1 m

time =s [2]

(iii) State one important assumption made in this calculation.

[1]

[Total: 6]

15 The article describes how Paul Drude used the idea of electron flow to describe electrical current in wires made from metals such as copper (line 34 onwards).

(a) Show that the number of free electrons per cubic metre of copper is of the order of 10^{29} m^{-3} .

density of copper, at 300K = 8900 kg m^{-3}
 molar mass of copper = $0.064 \text{ kg mol}^{-1}$
 Avogadro's number, $N_A = 6.0 \times 10^{23} \text{ mol}^{-1}$

[2]

(b) (i) Fig. 15.1 shows a 3.0 m length of copper wire.

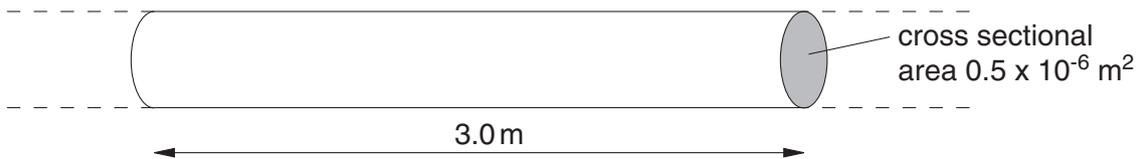


Fig. 15.1

Show that the conductance of the copper wire is about 10 S at 300 K.

conductivity of copper at 300 K, $\sigma = 5.9 \times 10^7 \text{ S m}^{-1}$

[2]

(ii) Calculate the current, I , through this wire with a p.d. across it of 1.5 V.

$I = \dots\dots\dots$ A [1]

[Total: 5]

16 This question uses the idea that free electrons in a metal wire can be considered as an ideal gas.

- (a) Using Equation 2 (line 59), explain why nitrogen molecules at 300K have a greater mean speed than more massive oxygen molecules at the same temperature.

[2]

- (b) Write down the factor by which the speed of a molecule will change if the temperature doubles.

factor = [1]

- (c) Calculate the average thermal speed of an electron, at 300K.

$$k = 1.4 \times 10^{-23} \text{ JK}^{-1}$$

$$m_e = 9.1 \times 10^{-31} \text{ kg}$$

speed =m s⁻¹ [2]

- (d) Electrons are moving in the copper wire at great speed. Explain why this does not result in a current in the wire when there is no p.d. across it.

[2]

[Total: 7]

17 This question considers the electrical implications of the Drude model (see Box 1 in the article).

(a) Show that the units for current density are the same as those of the product σE .

[3]

(b) Explain how Equation 6 is an alternative statement of Ohm's law.



You should make each step of your argument clear.

[3]

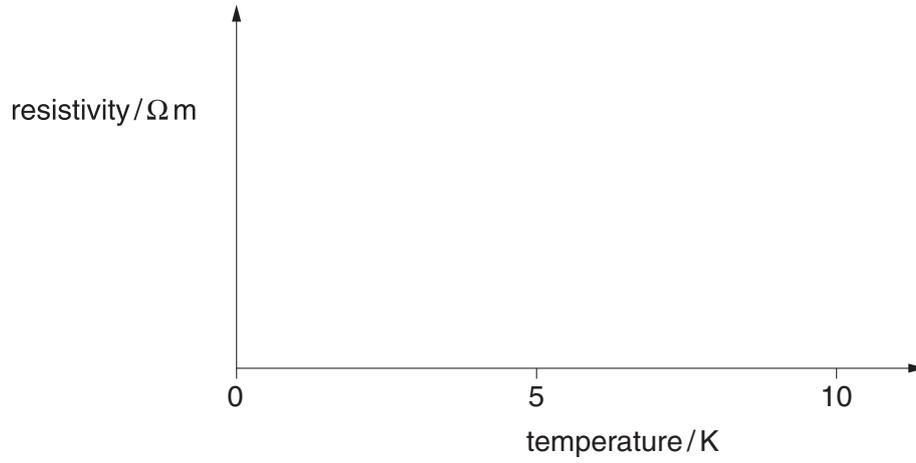
(c) Confirm that the relaxation time, τ , for electrons in copper is around 10^{-14} s.

$$m_e = 9.1 \times 10^{-31} \text{ kg}$$

$$e = 1.6 \times 10^{-19} \text{ C}$$

[3]

- (d) Sketch a graph of the variation of **resistivity** with temperature at low temperatures (lines 82–89), as suggested by Drude's model.



[2]

[Total: 11]

18 This question is about the use of models in physics.

- (a) Suggest why early models of electrical current tended to focus on electricity being a sort of fluid.

[1]

- (b) Describe one observation from the experimental evidence which led to the development of Rutherford's nuclear atom from Thomson's 'plum pudding' model.



In your answer you should make it clear how this observation changed the Thomson model.

[2]

- (c) State one reason why Drude's model was successful.

[1]

[Total: 4]

[Section C Total: 39]

END OF QUESTION PAPER

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