THIS IS A NEW SPECIFICATION

OCR
RECOGNISING ACHIEVEMENT

ADVANCED GCE
PHYSICS B (ADVANCING PHYSICS)
G495
Field and Particle Pictures

Candidates answer on the Question Paper

OCR Supplied Materials:
- Data, Formulae and Relationships Booklet
- Insert (inserted)

Other Materials Required:
- Electronic calculator
- Ruler (cm/mm)

Friday 18 June 2010
Morning

Duration: 2 hours

Candidate Forename		Candidate Surname	

Centre Number						Candidate Number				

INSTRUCTIONS TO CANDIDATES

- Write your name clearly in capital letters, your Centre Number and Candidate Number in the boxes above.
- Use black ink. Pencil may be used for graphs and diagrams only.
- Read each question carefully and make sure that you know what you have to do before starting your answer.
- Answer **all** the questions.
- Do **not** write in the bar codes.
- Write your answer to each question in the space provided. Additional paper may be used if necessary but you must clearly show your Candidate Number, Centre Number and question number(s).

INFORMATION FOR CANDIDATES

- The number of marks is given in brackets **[ ]** at the end of each question or part question.
- The total number of marks for this paper is **100**.
- You may use an electronic calculator.
- ✎ Where you see this icon you will be awarded marks for the quality of written communication in your answer.
  This means for example, you should
  - ensure that text is legible and that spelling, punctuation and grammar are accurate so that the meaning is clear;
  - organise information clearly and coherently, using specialist vocabulary when appropriate.
- You are advised to show all the steps in any calculations.
- This document consists of **24** pages. Any blank pages are indicated.
- The questions in Section C are based on the material in the Insert.

DC (NH/SW) 15569/12

Answer **all** the questions.

Section A

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

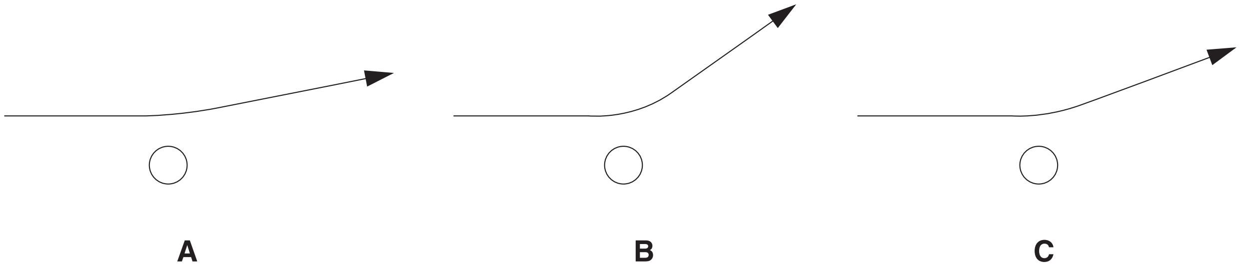

Fig. 1.1

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 3.2×10^{-19} C) at a distance of 1.0×10^{-13} m from the centre of a gold nucleus (charge 1.3×10^{-17} C).

$$k = \frac{1}{4\pi\varepsilon_0} = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

force = ...N **[2]**

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

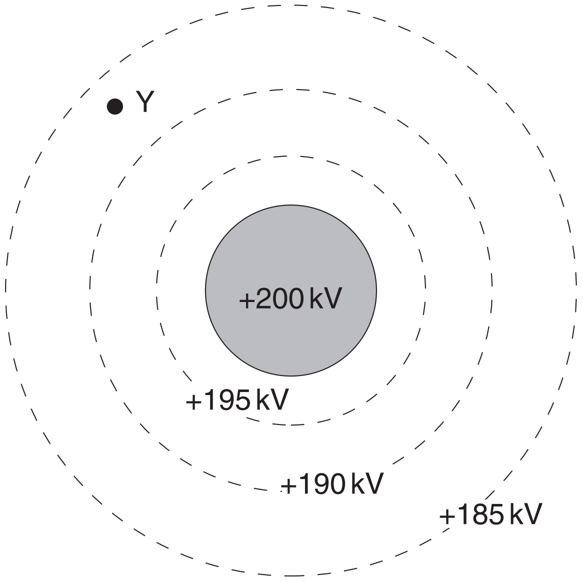

Fig. 2.1

(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 × 10^3 V m^{-1} 1 × 10^6 V m^{-1} 4 × 10^7 V m^{-1}

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

3 Fig. 3.1 shows a model dynamo.

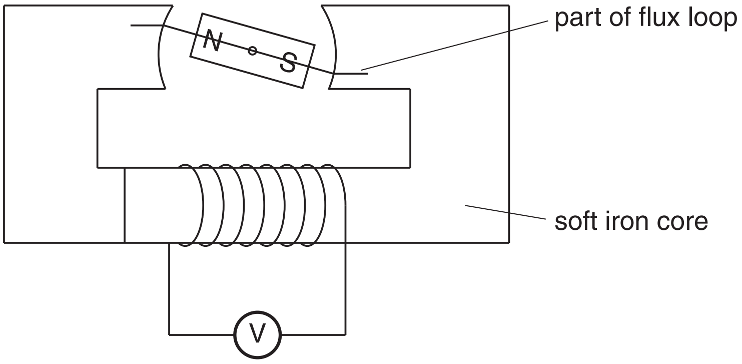

Fig. 3.1

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

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

emf induced across coil = ... V **[1]**

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

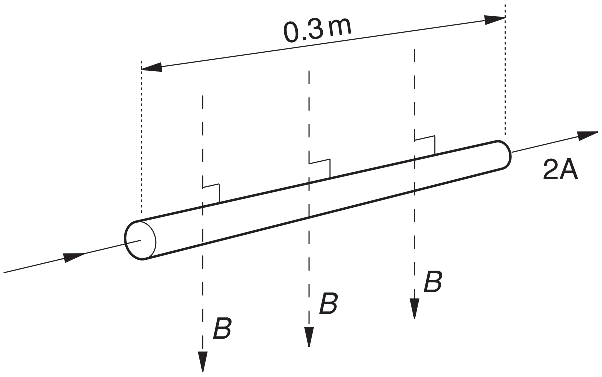

Fig. 4.1

The force on the length of wire is 0.05 N. 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.

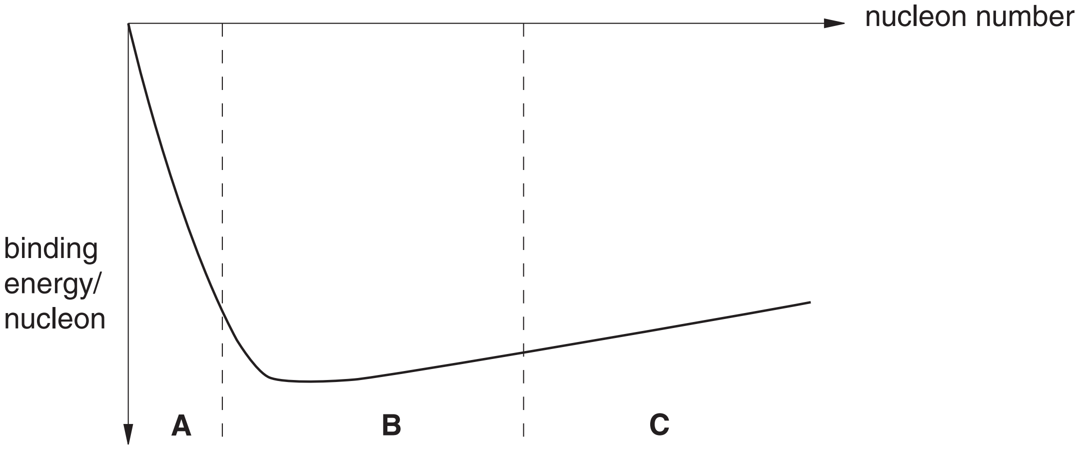

Fig. 5.1

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.

$$^{226}_{88}\text{Ra} \longrightarrow {}^{222}_{86}\text{Rn} + {}^{\dots\dots\dots}_{\dots\dots\dots}\text{X}$$

(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.

muon ⟶ electron + neutrino + antineutrino

(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 0.98 c.

Show that a muon travelling at 0.98 c would take about 30 μs to travel from one detector to the other 9.0×10^3 m below.

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

[1]

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

Show that about 0.0001% of the muons formed high in the atmosphere would remain after travelling 9.0×10^3 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 μs.

[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

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

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

[3]

[Total: 12]

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.

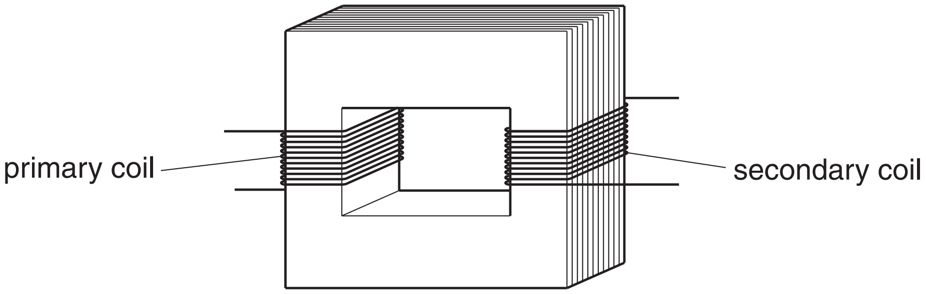


Fig. 10.1

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.

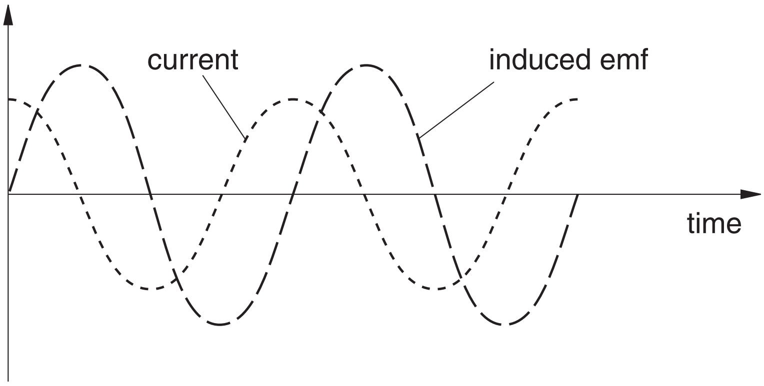


Fig. 10.2

(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}.

maximum rate of change of flux = $2\pi f \times$ 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.

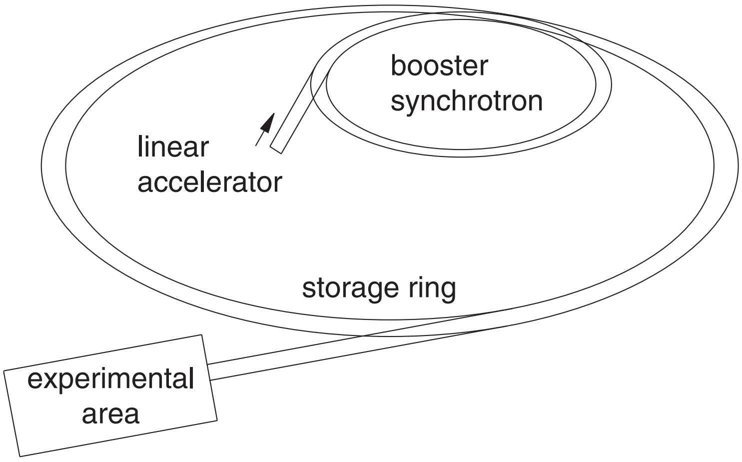


Fig. 11.1

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

$m_e = 9.1 \times 10^{-31}$ kg
$e = 1.6 \times 10^{-19}$ C
$c = 3.0 \times 10^{8}$ 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.

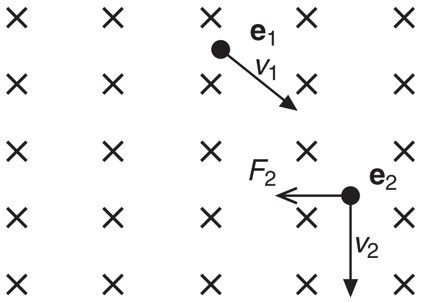


Fig. 11.2

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 89 m. Calculate the value of *B* required for 3 GeV electrons to follow this path.

B = ... T **[2]**

[Total: 8]

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.

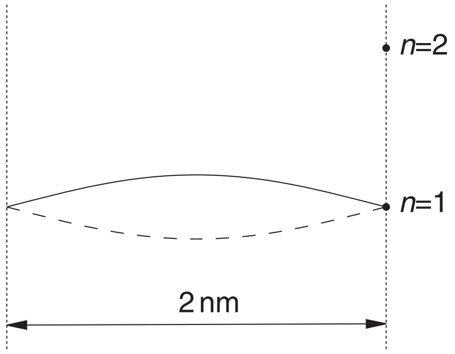


Fig. 12.1 (a)

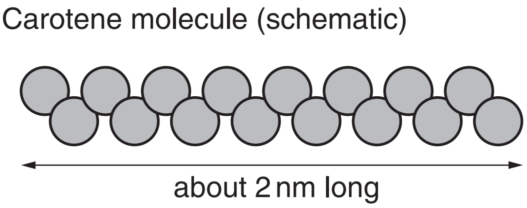


Fig. 12.1 (b)

(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.

$h = 6.6 \times 10^{-34}$ J s
$m_e = 9.1 \times 10^{-31}$ 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.

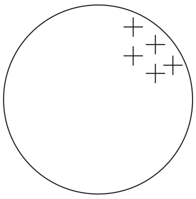


Fig. 13.1

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

[1]

(ii) Calculate the number of electrons moved.

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

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 4.0×10^3 V. A student works out the speed reached by the electrons, by using the equation:

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

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

[1]

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

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

$e = -1.6 \times 10^{-19}$ 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 $10^{29}\,\mathrm{m}^{-3}$.

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

[2]

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

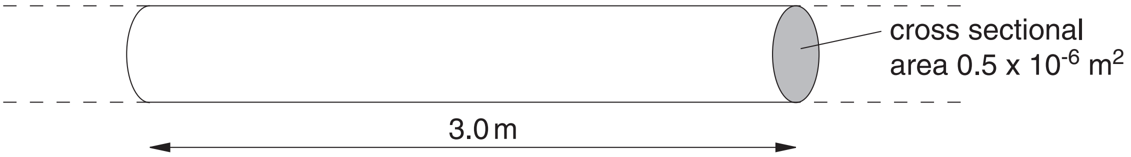


Fig. 15.1

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

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

[2]

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

I = ... 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 300 K 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 300 K.

$k = 1.4 \times 10^{-23}\,\mathrm{J\,K^{-1}}$

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

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.

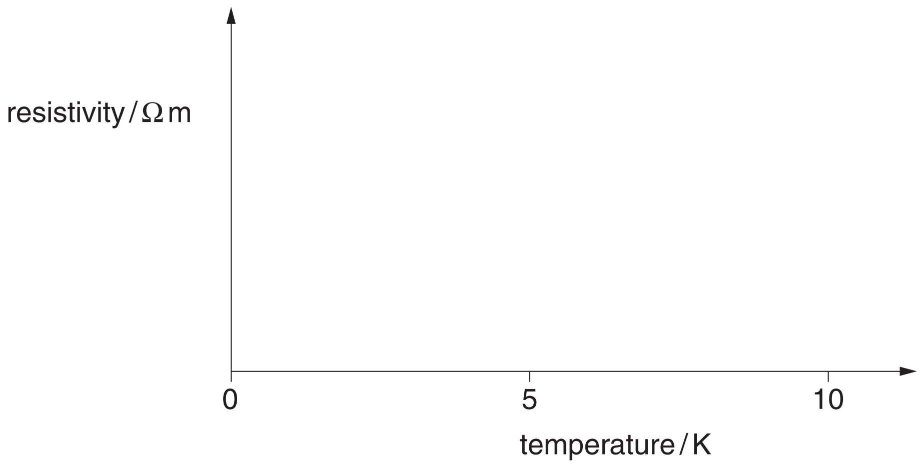
[3]

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

$m_e = 9.1 \times 10^{-31}$ kg
$e = 1.6 \times 10^{-19}$ 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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OCR
RECOGNISING ACHIEVEMENT

ADVANCED GCE

PHYSICS B (ADVANCING PHYSICS) G495

Unit G495: Field and Particle Pictures

INSERT

Friday 18 June 2010
Morning

Duration: 2 hours

OCE/15570

INSTRUCTIONS TO CANDIDATES

- This insert contains the article required to answer the questions in Section C.

INFORMATION FOR CANDIDATES

- This document consists of **8** pages. Any blank pages are indicated.

INSTRUCTION TO EXAMS OFFICER / INVIGILATOR

- Do not send this Insert for marking; it should be retained in the centre or destroyed.

Turn over

Developing a Model for Electrical Current

Electrical current can be understood as the flow of charged particles. This model has proven to be very robust and successful for well over a century now, but it took many years to develop. We owe the success of the model to the contributions of various physicists from across the world whose independent work in different areas of science was brought together into one theory of electrical conduction.

Amberisation and Charge

It was known in ancient Greece that rubbed amber attracted small objects, like hair and dust. The phenomenon was given a name by the Englishman Francis Gilbert in 1600, who called it *amberisation*, and then *electrification* from *electron*, the Greek word for amber. Further investigations by the French scientist Charles Du Fay led to the idea that there were two types of electrification which, towards the middle of the 18th century, the American Benjamin Franklin called 'positive' and 'negative'. Franklin also asserted that a glass rod rubbed with a silk cloth becomes as positive as the cloth becomes negative.

This idea of the rod losing as much charge as the cloth gains was experimentally proven in London by Michael Faraday in 1837. Meanwhile, a theory had emerged that in matter there existed two fluids where a positively charged body had an excess of positive fluid, whilst a negatively charged body had an excess of negative fluid. Franklin himself, though, believed in the existence of an electrical particle, even though this was at odds with the fluid theory. Faraday's experiments on electrolysis provided evidence for an atomic hypothesis for electricity. The idea of charges as separate entities became established but physicists were still reluctant to believe in a model of charge flow in solid conductors.

The Electron

In 1871, in Germany, Wilhelm Weber explained several electrical phenomena, including thermoelectricity, by assuming that there were two types of *electrical atom*, one of which was more mobile than the other. Furthermore, the Irish physicist G Johnstone Stoney, in a lecture given in 1874, described a clear picture of a particle theory of electricity and even went on to obtain a value of the elementary electrical charge. It was he, indeed, in 1891, who first used the word *electron* as a name for the basic unit of electricity, but the notion of electrical current in solids as a flow of charged particles had still not evolved.

This changed, however, in 1897 when J J Thomson demonstrated that cathode rays are streams of tiny, electrical particles – the electrons of Stoney's theory. This inevitably led to new theories on the nature of matter itself, including Thomson's own 'Plum Pudding Model' and, later, Rutherford's nuclear atom. However, it also opened the door for new models of electrical conduction.

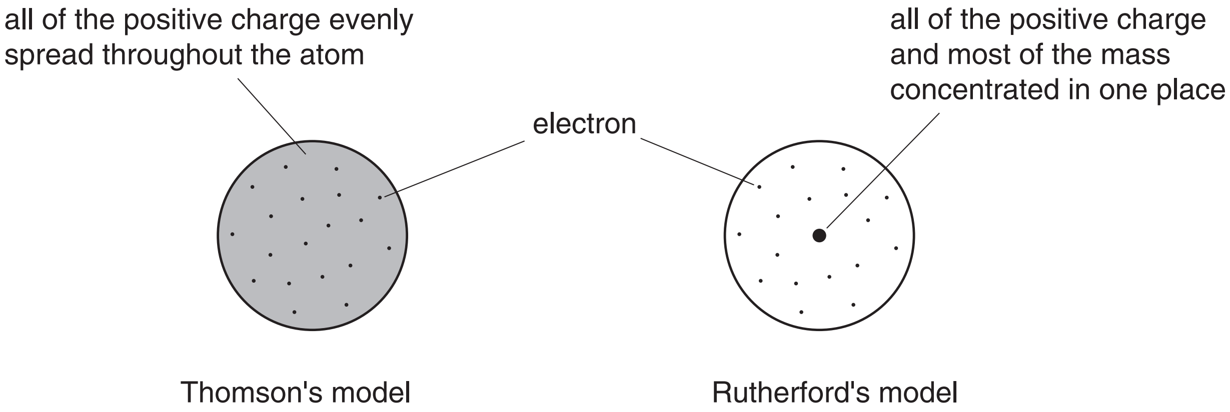

Fig. 1 Early models of the atom

Drude's Theory and basic conduction

Sure enough, in 1900, a theory for electrical conduction in metals was proposed by the German Paul Drude. He based the theory on the idea that the metal consisted of a sea of mobile electrons in a lattice of positive ions. It was the movement of these electrons which constituted the electric current in the metal and the large numbers of mobile electrons in metals explained why metals were such good conductors. Consider copper, for example: knowing the density of copper and the mass of a copper atom and allowing for one free electron per atom, it can be shown that the number of free electrons per cubic metre (the number density, N) is of the order of 10^{29} m^{-3}.

Fig. 2 The German physicist Paul Drude

Electrons and the Ideal Gas law

The success of Drude's model was to be found in the explanations it offered of well-known properties of metals, electrical and otherwise. A useful quantity to consider in this context is the current density, j, which is the current per unit cross-sectional area. For electrons moving with a speed, u, through the lattice, it can be shown that

$$j = N e u \qquad \textbf{Equation 1}$$

where N is the number density of the electrons and e the charge on an electron. Copper has a conductivity of about 6×10^7 S m^{-1}. So, for instance, a copper wire 1.0 metre long, with a circular cross-section of 0.5 mm^2 and a p.d. of 1.5 V across it, would have in it a current density of nearly $10^8\,\text{A}\,\text{m}^{-2}$, i.e. a current of almost 50 A. Even this huge current implies a drift velocity of only a few $\text{mm}\,\text{s}^{-1}$. This is at odds with what might be expected, suggesting that the underlying picture behind the model is far from complete.

Inspired by the kinetic theory for ideal gases, developed by Lord Kelvin and others, Drude assumed that electrons are free to move around the whole volume of the metal, like molecules of a gas in a container. In the absence of any electric field and at non-zero temperatures, the electrons would move around in random directions, colliding from time to time with defects in the lattice.

In this way, it is possible to estimate the average 'thermal' speed , v, using

$$\tfrac{1}{2} mv^2 = 3/2\, kT \qquad \textbf{Equation 2}$$

in which m is the mass of the electron, k is the Boltzmann constant and T is the absolute temperature.

For the electrons in a copper wire at room temperature, this suggests an average thermal (random) speed of around $10^5\,\text{m}\,\text{s}^{-1}$. This is much larger than the speed of, say, a nitrogen molecule in air at the same temperature, but, more significantly, considerably larger than the drift velocity calculated earlier.

Turn over

To appreciate the reason for the enormous difference between the drift and thermal speeds of the electron, a closer look at the motion of the electron through the lattice is required.

Drude Relaxation

Placing a potential difference across a metal wire produces an electric field within it. Being charged, the electrons experience a force and accelerate in a direction parallel to the field. However, they do not accelerate indefinitely, for, as already noted, from time to time they are scattered by defects in the lattice. Drude's theory considered the momentum gained by an electron accelerating for a time τ (the *relaxation time*) before being scattered; the theory confirmed Ohm's Law, among other things, which made it very convincing (see Box 1).

Box 1

An electron in an electric field E experiences a force eE and accelerates in a direction parallel to the field. Accelerating for a time τ (the relaxation time) before being scattered, the electron gains momentum p given by:

$$p = eE\tau$$ **Equation 3**

and so a drift velocity of

$$u = \frac{eE\tau}{m}$$ **Equation 4**

Combining Equation 4 with Equation 1 (line 47 in the main text), gives

$$j = \frac{Ne^2E\tau}{m}$$ **Equation 5**

or

$$j = \sigma E$$ **Equation 6**

where σ is the electrical conductivity, and is given by

$$\sigma = \frac{Ne^2\tau}{m}$$ **Equation 7**

Equation 6 is, in fact, an alternative statement of Ohm's Law.

Further implications of the Drude Model

Substituting data quoted earlier in the passage into Equation 7, Box 1, τ is shown to be about 10^{-14} s. The drift speed of the electron, u, typically $10^{-3}\,\mathrm{m\,s^{-1}}$, is superimposed on its much higher, random thermal speed, $10^{5}\,\mathrm{m\,s^{-1}}$. This is a similar notion to that of considering the speed of an air particle in a steady breeze, for which the wind speed is much less than the particle's thermal speed. It also becomes apparent that in time τ an electron can travel a considerable distance on the atomic scale before being scattered.

Equation 7, Box 1, shows that the conductivity is proportional to N and τ. In a given metal, N will be constant, but τ can vary. For temperatures greater than about 5 K, the conductivity (and therefore τ) decreases as the absolute temperature increases. This is because the electrons are scattered by concentrations of positive charge produced by lattice vibrations and the lower the temperature, the less the lattice vibrates so the less likely it is that a scattering concentration will occur. Below 5 K scattering by static defects, such as impurity atoms and grain boundaries, starts to dominate. This scattering, and therefore the conductivity, is independent of temperature, though it does depend on the sample.

The Drude Model and the Absorption of Light

One interesting effect related to the Drude relaxation time is the reflection or absorption of light. If electromagnetic radiation of frequency f is shone on a metal surface, what happens to it (whether it is reflected or absorbed) depends upon how the value of f compares with that of $1/\tau$. If f is much less than $1/\tau$, then an electron, being oscillated by the electric field of the electromagnetic wave, can make many energy-losing collisions in one cycle of the wave and so the radiation is absorbed. If f is much greater than $1/\tau$, then many cycles of radiation occur before energy is lost. So, the metal will be transparent to high frequency radiation, which for a value of τ of 10^{-14} s equates to ultraviolet and x-rays, but opaque to lower frequencies such as visible light, infrared and radio waves.

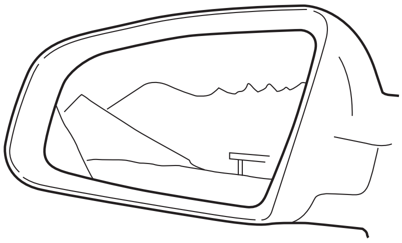

Fig. 3

Drude's relaxation time can be used to account for the opacity and reflectivity of metals.

Superconductivity

In 1911, not long after Drude developed his model, the Dutch physicist Kamerlingh Onnes investigated how the electrical resistivity of the metal mercury was affected by temperature. When it was cooled to 4.2 K, using liquid helium, he found that the resistivity disappeared altogether. This implied an infinite value of τ: electrons passing through the lattice without experiencing any scattering at all. Onnes had discovered what is known today as superconductivity and in order to explain this, physicists needed to radically refine the Drude model and looked to a new branch of physics emerging at the time: quantum theory.

And that's another story.

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