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Centre number

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Candidate number

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Surname

StemUp Model Solution

Forename(s)

Candidate signature

I declare this is my own work.

A-level PHYSICS

Paper 3

Section B Turning points in physics

Thursday 15 June 2023

Morning

Time allowed: The total time for both sections of this paper is 2 hours. You are advised to spend approximately 50 minutes on this section.

Materials

For this paper you must have:

- a pencil and a ruler
- a scientific calculator
- a Data and Formulae Booklet
- a protractor.

Instructions

- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- Do all rough work in this book. Cross through any work you do not want to be marked.
- Show all your working.

Information

- The marks for questions are shown in brackets.
- The maximum mark for this paper is 35.
- You are expected to use a scientific calculator where appropriate.
- A Data and Formulae Booklet is provided as a loose insert.

For Examiner's Use

Question	Mark
1	
2	
3	
4	
TOTAL	



J U N 2 3 7 4 0 8 3 B D 0 1

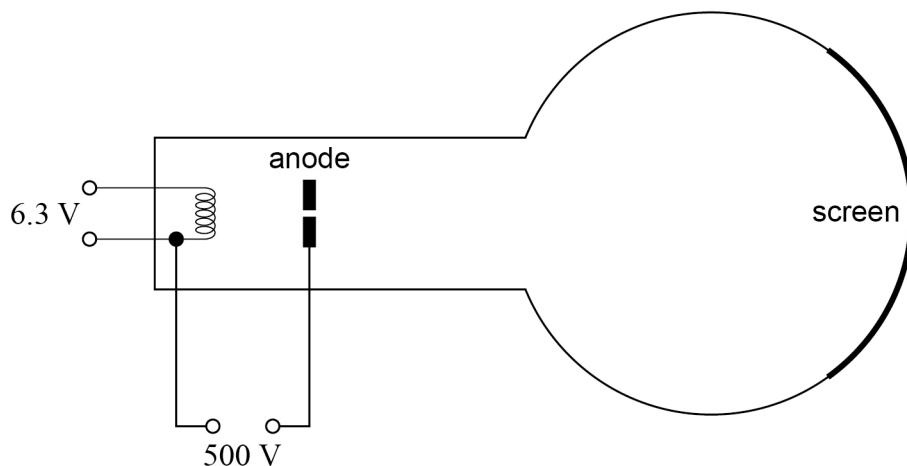
Section B

Answer **all** questions in this section.

0 1

In **Figure 1**, a beam of electrons travels through the aperture in the anode and hits the screen.

Figure 1



0 1 . 1

Explain how the electrons that form the beam are emitted.

[1 mark]

The filament (cathode) is heated by an electric current, which gives some of the electrons in the metal enough energy to leave the metal surface (thermionic emission).

0 1 . 2

Show that the maximum speed of the electrons in the beam is about $1.3 \times 10^7 \text{ m s}^{-1}$.

[1 mark]

Kinetic energy gained = work done by the p.d.: $\frac{1}{2}mv^2 = eV$

$$v = \sqrt{(2eV / m)} = \sqrt{(2 \times 1.60 \times 10^{-19} \times 500 / (9.11 \times 10^{-31}))}$$

$$v = \sqrt{(1.76 \times 10^{14})}$$

$$v = 1.33 \times 10^7 \text{ m s}^{-1} \quad (\approx 1.3 \times 10^7 \text{ m s}^{-1})$$



0 1 3

A student suggests that the apparatus can be used to demonstrate the wave properties of electrons in the beam, provided that the aperture in the anode has a suitable diameter.

Discuss whether the student is correct.
Support your answer with a calculation.

[3 marks]

$$\text{de Broglie wavelength: } \lambda = h / mv = h / \sqrt{2meV}$$

$$\lambda = 6.63 \times 10^{-34} / (9.11 \times 10^{-31} \times 1.33 \times 10^7)$$

$$\lambda = 5.5 \times 10^{-11} \text{ m}$$

For diffraction (a wave property) to be demonstrated, the diameter of the aperture (gap) must be of the same order of magnitude as the de Broglie wavelength of the electrons, about $5.5 \times 10^{-11} \text{ m}$.

This diameter is smaller than an atom (about 10^{-10} m), so a hole this small cannot be made in the anode.

So the student is incorrect: this apparatus cannot demonstrate the wave properties of electrons at this speed (a thin crystal, such as graphite, would be needed instead).

Question 1 continues on the next page

Turn over ►



0 1 . 4

In 1897, J J Thomson determined a value for the specific charge of an unknown particle.

The unknown particle is now known to be the electron.

Describe **one** method to determine the specific charge of the electron.

Your answer should include:

- a description of the apparatus used and the measurements made
- a description of how the specific charge can be determined using these measurements
- an explanation of the conclusion made by Thomson from the value that he determined.

[6 marks]

Apparatus: a fine beam tube. This is a glass bulb containing a gas (e.g. hydrogen) at low pressure, with an electron gun inside: a heated filament emits electrons, which are accelerated through a p.d. V between the filament (cathode) and the anode. Electrons collide with gas atoms, which emit light, so the path of the beam is visible.

A pair of Helmholtz coils on either side of the tube produce a uniform magnetic field perpendicular to the beam. The magnetic force on the electrons is always perpendicular to their velocity, so the beam moves in



a circle.

Measurements: the accelerating voltage V (voltmeter); the magnetic flux density B (calibrated Hall probe, or calculated from the coil current); the diameter of the circular path, measured with a scale inside the tube, avoiding parallax, so the radius $r = \text{diameter} / 2$.

Determination of e/m : the kinetic energy gained equals the work done by the accelerating p.d., so $\frac{1}{2}mv^2 = eV$, giving $v^2 = 2eV / m$.

The magnetic force provides the centripetal force: $Bev = mv^2 / r$, so $r = mv / Be$ and $v = Ber / m$.

Substituting: $(Ber / m)^2 = 2eV / m$, so $e / m = 2V / (r^2 B^2)$.

Repeat for several values of V and B and find the mean value of e/m (or plot r^2 against V : gradient $= 2m / (eB^2)$).

Conclusion: Thomson found $e/m \approx 1.76 \times 10^{11} \text{ C kg}^{-1}$, which is about 1800 times larger than the specific charge of the hydrogen ion, the largest specific charge known at the time. The value was the same whatever metal or gas was used.

So these particles must have either a very large charge or a very small mass. Assuming the charge is the same size as that of a hydrogen ion, the mass is about $1/1800$ of the mass of a hydrogen ion, much smaller than any atom, so the particles (electrons) are a constituent of all atoms.



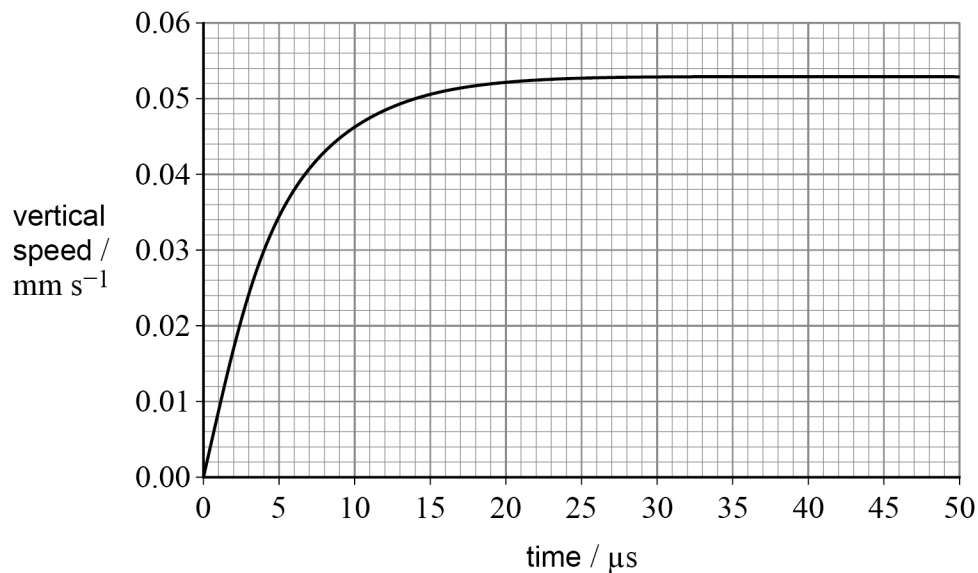
0 2

In an experiment to determine the electronic charge, a charged oil drop falls from rest between two uncharged plates.

The oil drop has a weight of 1.2×10^{-14} N and a radius of 6.8×10^{-7} m. Ignore the buoyancy force of the air on the oil drop.

Figure 2 shows the variation of the vertical speed of the oil drop with time.

Figure 2

**0 2****. 1**

Calculate the viscosity of the air between the plates.

[3 marks]

Terminal speed (from graph): $v = 0.053 \text{ mm s}^{-1} = 5.3 \times 10^{-5} \text{ m s}^{-1}$

At terminal speed: weight = viscous drag, $mg = 6\pi\eta rv$

$$\eta = mg / (6\pi rv) = 1.2 \times 10^{-14} / (6\pi \times 6.8 \times 10^{-7} \times 5.3 \times 10^{-5})$$

$$\eta = 1.77 \times 10^{-5} \text{ N s m}^{-2}$$

viscosity = 1.8×10^{-5} N s m⁻²



0 2 . 2

During the experiment, an electric field is produced between the plates and is adjusted until the oil drop is stationary.
The electric field strength is 18.8 kV m^{-1} .

Discuss whether the outcome of the experiment is consistent with the accepted value for electronic charge.

[3 marks]

Stationary drop: electric force = weight, $EQ = mg$

$$Q = mg / E = 1.2 \times 10^{-14} / (18.8 \times 10^3)$$

$$Q = 6.4 \times 10^{-19} \text{ C}$$

$$Q / e = 6.38 \times 10^{-19} / 1.60 \times 10^{-19} = 3.99 \approx 4$$

Q is (almost exactly) a whole-number multiple of e ($Q = 4e$), so the outcome is consistent with the accepted value for the electronic charge.

6

Turn over for the next question

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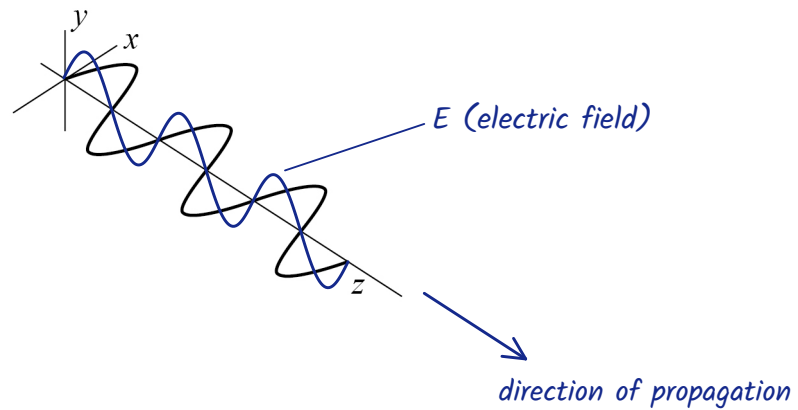


0 3

An electromagnetic wave is propagating through space.

Figure 3 shows the variation of the magnetic flux density of the wave with distance. The magnetic field is in the xz plane. The y -axis is at right-angles to the xz plane.

Figure 3



0 3 . 1

Draw and label on **Figure 3**:

- the corresponding electric field
- the direction of propagation of the wave.

[1 mark]

0 3 . 2

Which scientist proposed the electromagnetic wave model of light?

Tick (✓) **one** box.

[1 mark]

Hertz

☐

Huygens

☐

Maxwell

☒

Young

☐


0 3 . 3

Another theory of the nature of light was proposed by Isaac Newton.

Describe how Newton's theory was used to explain the refraction of light as it moves from air into glass.

[3 marks]

Newton's corpuscular theory: light is made of tiny particles called corpuscles.

At the boundary the corpuscles feel a short-range force of attraction towards the glass, perpendicular to the surface.

This increases the component of velocity perpendicular to the surface; the component parallel to the surface is unchanged.

So the corpuscles bend towards the normal (angle of refraction < angle of incidence) and light travels faster in glass.

Question 3 continues on the next page

Turn over ►



0 3 . 4

Describe a demonstration using visible light that can be performed in a school laboratory to show that Newton's theory is not correct.

[3 marks]

Shine a laser (monochromatic, coherent visible light) through a double slit (two narrow slits less than 1 mm apart) onto a white screen about 2 m away, in a darkened room.

A series of equally spaced bright and dark fringes (maxima and minima) is seen on the screen, with a bright fringe at the centre.

This pattern is due to diffraction and interference (superposition), which are wave phenomena. Newton's corpuscular theory predicts just two bright lines (images of the slits), with no dark fringes and no bright fringe in the centre, so Newton's theory is not correct.

8



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0 4

Einstein developed his theory of special relativity from two postulates. One postulate states that physical laws have the same form in all inertial frames.

0 4 . 1

State the other postulate and explain how it is consistent with the equation:

$$c = \sqrt{\frac{1}{\mu_0 \epsilon_0}}$$

[2 marks]

The speed of light in free space is invariant: the same in all inertial frames, independent of the speed of the source or observer.

μ_0 and ϵ_0 are constants that do not depend on the frame of reference, so $c = 1/\sqrt{\mu_0 \epsilon_0}$ is the same in every frame.

A proton leaves a particle accelerator at point **X** and moves at a constant speed towards a target at point **Y**.

The speed of the proton is $2.5 \times 10^8 \text{ m s}^{-1}$ in the frame of reference of the target.

The distance **XY** in the frame of reference of the proton is 38 m.

0 4 . 2

Calculate the distance **XY** in the frame of reference of the target.

[2 marks]

XY is at rest in the target's frame, so 38 m is the contracted length l :

$$l = l_0 \sqrt{1 - v^2/c^2}$$

$$l_0 = l / \sqrt{1 - v^2/c^2} = 38 / \sqrt{1 - (2.5 \times 10^8)^2 / (3.0 \times 10^8)^2}$$

$$l_0 = 38 / 0.553 = 68.7 \text{ m}$$

distance **XY** in the frame of reference of the target = 69 m



0 4 . 3

Show that the kinetic energy E_k of the proton is about 1.2×10^{-10} J.

[3 marks]

$$1 / \sqrt{1 - v^2/c^2} = 1 / \sqrt{1 - (2.5 \times 10^8 / 3.00 \times 10^8)^2} = 1.809$$

$$E_k = \text{total energy} - \text{rest energy} = m_0 c^2 / \sqrt{1 - v^2/c^2} - m_0 c^2$$

$$E_k = (1.809 - 1) \times 1.673 \times 10^{-27} \times (3.00 \times 10^8)^2$$

$$E_k = 0.809 \times 1.506 \times 10^{-10}$$

$$E_k = 1.22 \times 10^{-10} \text{ J } (\approx 1.2 \times 10^{-10} \text{ J})$$

0 4 . 4

Sketch on **Figure 4** the variation of E_k with speed v for a proton.

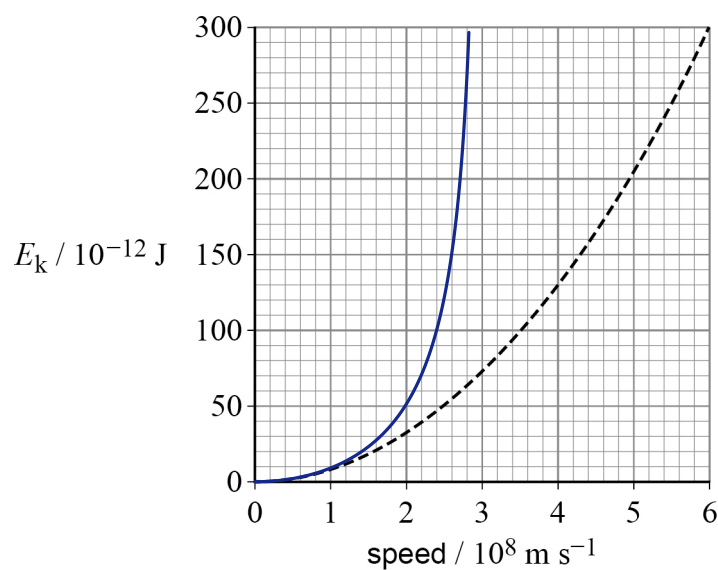
To help you, the dashed line represents

$$E_k = \frac{1}{2} m_0 v^2$$

where m_0 is equal to the mass of a proton at rest.

[3 marks]

Figure 4



END OF QUESTIONS



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