

A-level PHYSICS (7408/3BD)

Paper 3 – Section B (Turning points in Physics)

Specimen 2014

Morning

Time allowed: 2 hours

Materials

For this paper you must have:

- a pencil
- a ruler
- a calculator
- a data and formulae booklet
- a question paper / answer book for Section A.

Instructions

- Answer **all** questions.
- Show **all** your working.
- The total time for both sections of this paper is 2 hours.

Information

- The maximum mark for this section is 35.

Please write clearly, in block capitals, to allow character computer recognition.

Centre number

Candidate number

Surname

Forename(s)

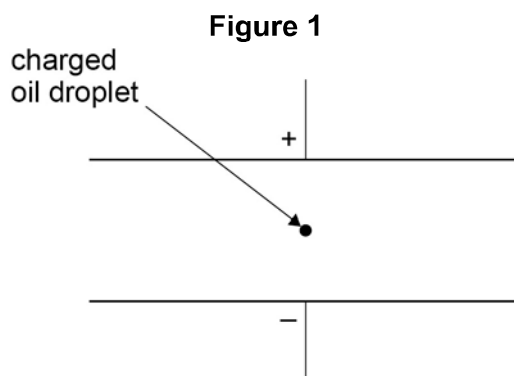
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Section B

Answer **all** questions in this section.

0 1

In an experiment to measure the charge of the electron, a spherical charged oil droplet of unknown mass is observed between two horizontal parallel metal plates, as shown in **Figure 1**.



0 1

. 1

The droplet falls vertically at its terminal speed when the potential difference (pd) between the plates is zero.

A droplet of radius r falls at its terminal velocity, v .

Derive an expression for r in terms of v , η , ρ and g , where η is the viscosity of air and ρ is the density of the oil droplet.

[2 marks]

At terminal speed the viscous force on the droplet = its weight:

$$6\pi\eta rv = \frac{4\pi r^3 \rho g}{3}$$

$$\text{Rearranging: } r^2 = \frac{9\eta v}{2\rho g}, \text{ so } r = \left(\frac{9\eta v}{2\rho g}\right)^{1/2}$$

0 1

. 2

Explain how the mass of the oil droplet can be calculated from its radius and other relevant data.

[1 mark]

Use r (calculated as above) in $m = \frac{4\pi r^3 \rho}{3}$, as the volume of a sphere $\times$ density, to find the mass m (ρ is known).

0 1 . 3

A potential difference (pd) is applied across the plates and is adjusted until the droplet is held stationary. The two horizontal parallel metal plates are 15.0 mm apart. The mass of the droplet is 3.4×10^{-15} kg.

The droplet is held stationary when the pd across the plates is 1560 V.

Calculate the charge of the oil droplet.

[2 marks]

$$\text{Electric force} = \text{weight: } QV / d = mg$$

$$Q = mgd / V$$

$$Q = (3.4 \times 10^{-15} \times 9.81 \times 15.0 \times 10^{-3}) / 1560$$

$$Q = 3.2 \times 10^{-19} \text{ C}$$

$$\text{charge} = \underline{3.2 \times 10^{-19}} \text{ C}$$

0 1 . 4

A student carries out Millikan's oil drop experiment and obtains the following results for the charges on the oil drops that were investigated.

$$-9.6 \times 10^{-19} \text{ C}$$

$$-12.8 \times 10^{-19} \text{ C}$$

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

Discuss the extent to which the student's results support Millikan's conclusion and how the student's conclusion should be different.

[3 marks]

Millikan: charge is quantised; electron charge is $1.6 \times 10^{-19} \text{ C}$.

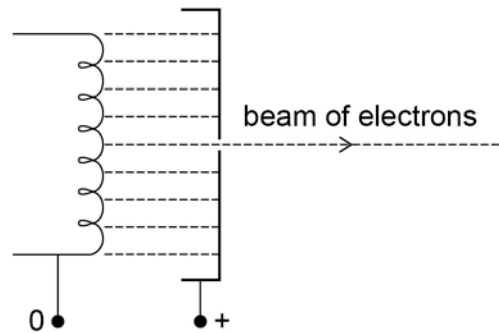
*Each charge is a whole number $\times 1.6 \times 10^{-19} \text{ C}$ (6, 8 and 4),
which agrees with Millikan.*

*But all are also multiples of $3.2 \times 10^{-19} \text{ C}$, so the student's results
suggest $-3.2 \times 10^{-19} \text{ C}$ as the smallest quantum of charge.*

0 2

Figure 2 shows a narrow beam of electrons produced by attracting the electrons emitted from a filament wire, to a positively charged metal plate which has a small hole in it.

Figure 2



0 2

. 1

Explain why an electric current through the filament wire causes the wire to emit electrons.

[2 marks]

The current heats the filament wire (resistive heating).

Electrons in the filament gain sufficient kinetic energy to leave the filament surface (thermionic emission).

0 2

. 2

Explain why the filament wire and the metal plates must be in an evacuated tube.

[1 mark]

Otherwise the electrons would collide with gas atoms / molecules and be absorbed or scattered, so no beam would form.

- 0 2 . 3** The potential difference between the filament wire and the metal plate is 4800 V.

Calculate the de Broglie wavelength of the electrons in the beam.

[4 marks]

$$\frac{1}{2}mv^2 = eV, \text{ so } v = (2eV / m)^{1/2}$$

$$v = (2 \times 1.60 \times 10^{-19} \times 4800 / 9.11 \times 10^{-31})^{1/2} = 4.1 \times 10^7 \text{ m s}^{-1}$$

$$\lambda = h / mv = 6.63 \times 10^{-34} / (9.11 \times 10^{-31} \times 4.1 \times 10^7)$$

$$\lambda = 1.8 \times 10^{-11} \text{ m}$$

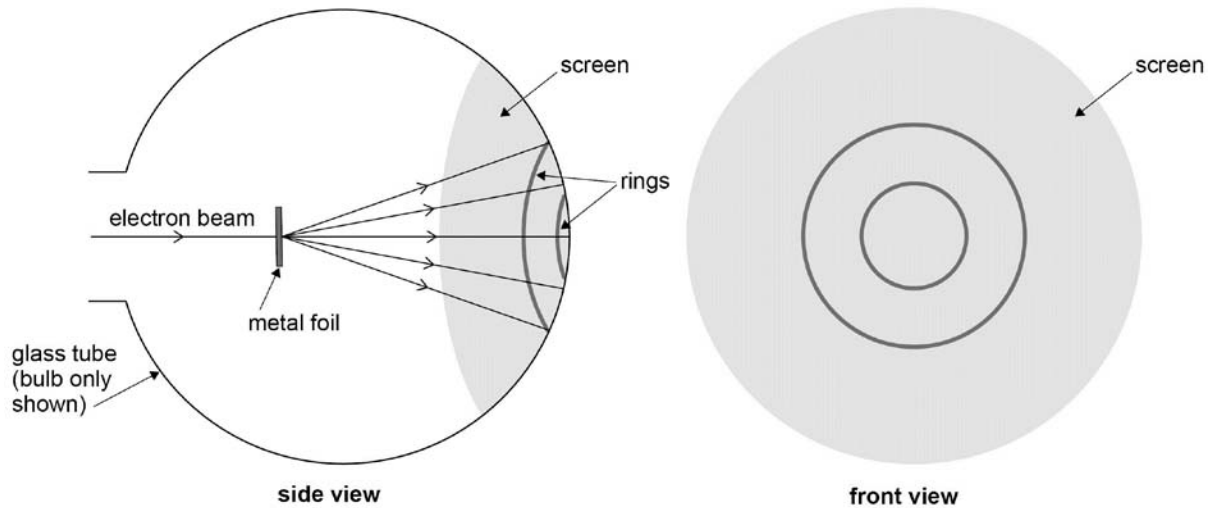
wavelength = 1.8 × 10⁻¹¹ m

Question 2 continues on the next page

Turn over ►

The beam is directed at a thin metal foil between the metal plate and a fluorescent screen at the end of the tube, as shown in **Figure 3**. The electrons that pass through the metal foil cause a pattern of concentric rings on the screen.

Figure 3



0 2 . 4

The potential difference between the filament and the metal plate is increased. State and explain the effect this has on the diameter of the rings. **[3 marks]**

The diameter of the rings decreases.

Increasing the pd increases the speed (kinetic energy and momentum) of the electrons.

Since $\lambda = h / mv$, this decreases their de Broglie wavelength, so the electrons are diffracted less by the foil and the rings become smaller.

0 3

Maxwell's theory suggested the existence of electromagnetic waves that travel at a speed of $\sqrt{\frac{1}{\epsilon_0 \mu_0}}$.

Hertz later discovered radio waves and performed experiments to investigate their properties.

Figure 4 shows a radio wave transmitter and a detector. The wave is transmitted by a dipole aerial. The detector consists of a metal loop connected to a meter.

Figure 4



0 3

. 1

Explain how the detection of the wave by the loop demonstrates the magnetic nature of the radio waves.

[2 marks]

The induced emf in the loop must be caused by a changing magnetic flux through the loop. This must be caused by the wave passing through the loop, so the wave is magnetic in nature.

0 3

. 2

Explain how the electric nature of the waves emitted by the dipole could be demonstrated.

[1 mark]

Use a second dipole (aerial) aligned parallel to the transmitting dipole; it detects an electric field which changes (oscillates), shown by a meter connected to it.

0 3 . 3 Hertz used an arrangement like that shown in **Figure 4** to determine the speed of radio waves.

Describe how the speed was determined. Go on to discuss how the experiments of Hertz confirmed Maxwell's prediction and the experimental evidence that suggests that light is also an electromagnetic wave.

[6 marks]

Speed: a metal sheet reflector is placed beyond the detector, in line with the transmitter. Reflected waves interfere with incident waves, so stationary waves are set up between transmitter and reflector.

The loop is moved along the line between them: the meter reading is a minimum at nodes and a maximum at antinodes. The distance between nodes is measured; adjacent nodes are $\lambda/2$ apart, giving the wavelength. The frequency f is known from the signal generator; speed $c = f\lambda$.

Maxwell's prediction: Maxwell's theory of electromagnetic waves gives $c = 1 / \sqrt{(\mu_0 \epsilon_0)}$. Substituting μ_0 and ϵ_0 from the data booklet gives $c = 3.0 \times 10^8 \text{ m s}^{-1}$. Hertz found the speed of radio waves was the same as the speed of electromagnetic waves predicted by Maxwell, confirming Maxwell's theory.

Light: Fizeau shone light through a gap in a rotating toothed wheel to a distant mirror and back. The wheel speed was increased until the returning light was blocked by the next tooth; $c = 2d / \text{time for the wheel to turn from a gap to a tooth}$. His value (about $3 \times 10^8 \text{ m s}^{-1}$) agreed with the value predicted by Maxwell, suggesting light waves are also electromagnetic waves.

0 4

One of the two postulates of Einstein's theory of special relativity is that the speed of light in free space is invariant.

0 4

. 1

Explain what is meant by this postulate.

[1 mark]

The speed of light in free space is the same for all observers: it is independent of the motion of the source and of the motion of the observer.

0 4

. 2

State the other postulate.

[1 mark]

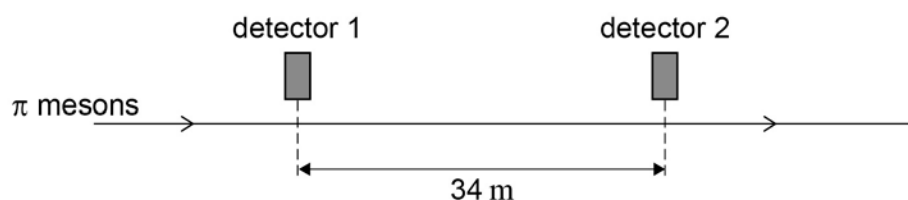
The laws of physics have the same form in all inertial frames of reference.

0 4

. 3

Two detectors are measured to be 34 m apart by an observer in a stationary frame of reference. A beam of π mesons travel in a straight line at a speed of $0.95c$ past the two detectors, as shown in **Figure 5**.

Figure 5



Calculate the time taken, in the frame of reference of the observer, for a π meson to travel between the two detectors.

[1 mark]

$$\text{time} = \text{distance} / \text{speed} = 34 / (0.95 \times 3.0 \times 10^8)$$

$$\text{time} = 1.2 \times 10^{-7} \text{ s}$$

$$\text{time} = \underline{1.2 \times 10^{-7} \text{ s}}$$

Turn over ►

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π mesons are unstable and decay with a half-life of 18 ns.

It is found in experiments that approximately 75% of the π mesons that pass the first detector decay before reaching the second detector.

Show how this provides evidence to support the theory of special relativity. In your answer compare the percentage expected by the laboratory observer with and without application of the theory of special relativity.

[5 marks]

Half-life in the lab (detectors') frame, using time dilation:

$$t = t_0 / (1 - v^2/c^2)^{1/2} = 18 / (1 - 0.95^2)^{1/2}$$

$$t = 58 \text{ ns}$$

$$\text{Time between detectors} = 1.2 \times 10^{-7} \text{ s} = 120 \text{ ns}$$

With relativity: $120 / 58 \approx 2$ half-lives (approximately) in the detectors' frame of reference.

After 2 half-lives $1/4 = 25\%$ remain, so 75% of the π mesons passing the first detector do not reach the second detector.

Without relativity: $120 / 18 \approx 6.7$, so about 6 half-lives would have passed in the lab frame.

In 6 half-lives only $1/64$ would be left, so about 98% (well over 90%) should have decayed.

Conclusion: using special relativity (time dilation) gives 75%, in agreement with experiment, whereas failing to use relativity predicts far too many decaying. This supports the theory.

END OF QUESTIONS