AQA

SPECIMEN MATERIAL

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)

Candidate signature ____________________

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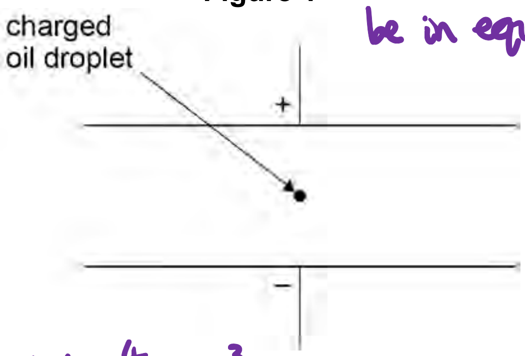
Section B

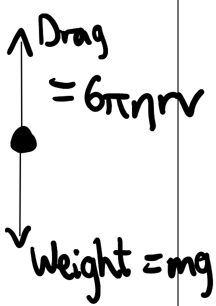
Answer **all** questions in this section.

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.**

Terminal velocity, so must be in equilibrium

Figure 1





$V = \frac{4}{3}\pi r^3$

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.

mass = density × volume

$m = \rho V$

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]

$6\pi\eta r v = mg = \frac{4}{3}\pi r^3 \rho g$ ✓ $\Rightarrow 6\eta v = \frac{4}{3} r^2 \rho g$

$r^2 = \frac{6\eta v}{\frac{4}{3}\rho g} = \frac{9\eta v}{2\rho g} \Rightarrow r = \left(\frac{9\eta v}{2\rho g}\right)^{1/2}$ ✓

0 1 . 2 Explain how the mass of the oil droplet can be calculated from its radius and other relevant data.

[1 mark]

$r = \left(\frac{9\eta v}{2\rho g}\right)^{1/2}$, $V = \frac{4}{3}\pi r^3$, $m = \rho V = \frac{4}{3}\pi r^3 \rho$

Find radius from $r = \left(\frac{9\eta v}{2\rho g}\right)^{1/2}$, substitute into $m = \frac{4}{3}\pi r^3 \rho$ ✓

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]

$$E = \frac{F}{Q} = \frac{V}{d} \Rightarrow F = \frac{QV}{d} = mg$$ ✓

$$Q = \frac{mgd}{V} = \frac{3.4\times10^{-15} \times 9.81 \times 1.5\times10^{-2}}{1560}$$

3.207×10^{-19} C

charge = 3.2×10^{-19} ✓ 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.

-9.6×10^{-19} C $= 6e$ -12.8×10^{-19} C $= 8e$ -6.4×10^{-19} C $= 4e$

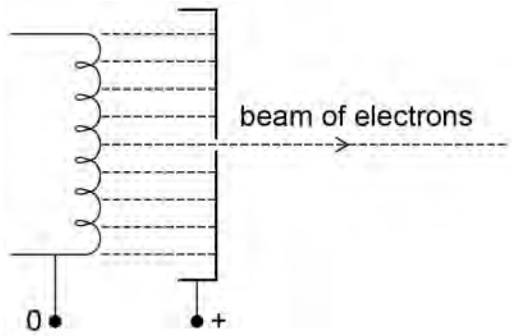
Discuss the extent to which the student's results support Millikan's conclusion and how the student's conclusion should be different.

[3 marks]

- Millikan's conclusion was that the charge on an electron is -1.6×10^{-19} C ✓
- The student's results are all integer multiples of -1.6×10^{-19} C ✓
- Student's results suggest that electron charge is -3.2×10^{-19} C (as the smallest quantum) ✓

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]

• Current passing through the wire causes it to heat up ✓

• Electrons gain enough kinetic energy to leave the filament ✓

0 2 . 2 Explain why the filament wire and the metal plates must be in an evacuated tube.

[1 mark]

• The electrons would collide with gas molecules ✓

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]

$\lambda = \frac{h}{mv}$ — Planck constant (h), speed of electron (v), mass of electron (m)

$eV = \frac{1}{2}mv^2$ — charge on electron (e), mass of electron (m), speed of electron (v)

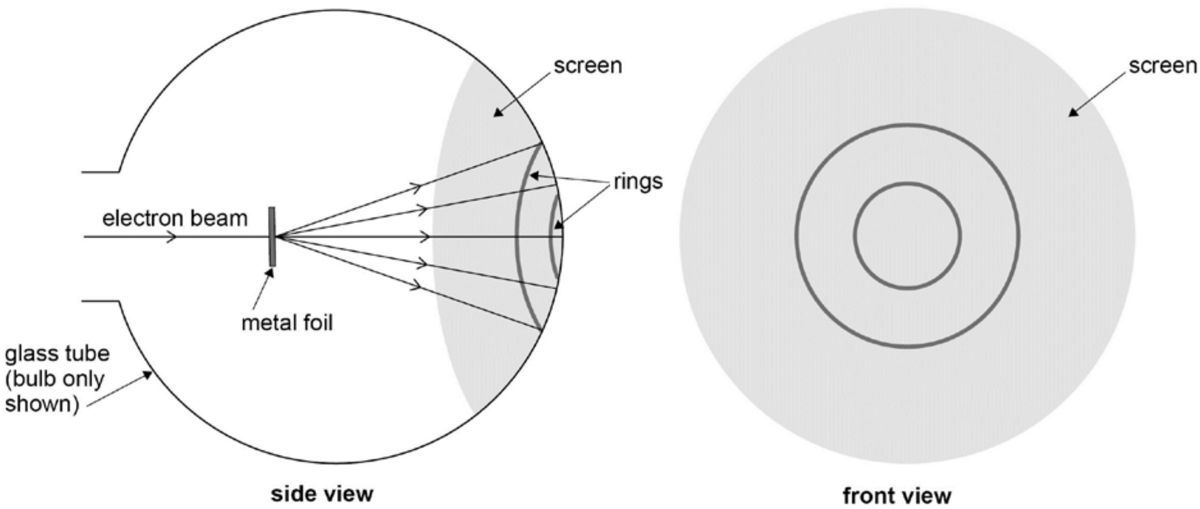
$\Rightarrow v = \sqrt{\frac{2eV}{m}}$

$\Rightarrow \lambda = \frac{h}{m\sqrt{\frac{2eV}{m}}} = \frac{6.63\times10^{-34}}{9.11\times10^{-31}\sqrt{\frac{2\times1.6\times10^{-19}\times4800}{9.11\times10^{-31}}}} = 1.772\times10^{-11}\,m$

wavelength = 1.8×10^{-11} m

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]

- Increasing the potential difference causes the speed of the electrons to be higher ✓ ①
- If the electrons have a higher speed, they will have a lower de Broglie wavelength ✓ ②
- The electrons diffract less, so rings get smaller ✓ ③

① $eV = \frac{1}{2}mv^2$ ② $\lambda = \frac{h}{mv}$ ③ $n\lambda = d\sin\theta$

0 3 Maxwell's theory suggested the existence of electromagnetic waves that travel at a speed of $\sqrt{\dfrac{1}{\varepsilon_0\mu_0}}$.

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]

• We need a changing magnetic flux in the loop to generate an e.m.f. ✓

• The wave is causing this to happen, so it must have a magnetic nature ✓

0 3 . 2 Explain how the electric nature of the waves emitted by the dipole could be demonstrated.

[1 mark]

Place another dipole near the transmitter, aligned with it. The dipole can detect an electric field. If the electric field changes, the wave must have an electric field. ✓

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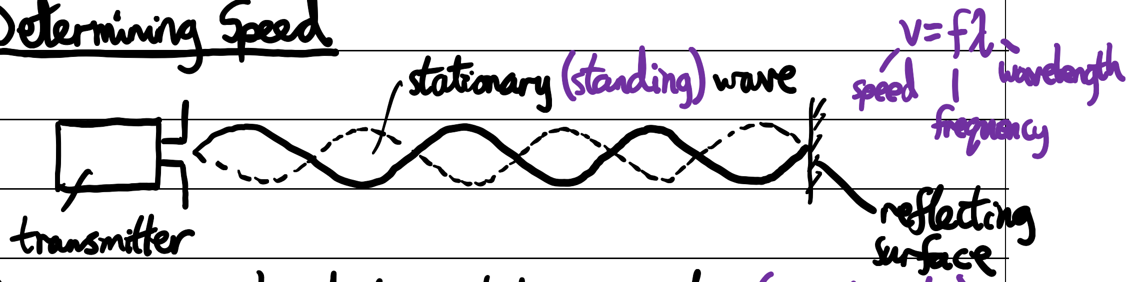
0 3 . 3 Hertz used an arrangement like that shown in **Figure 4** to determine the speed of radio waves.

[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]

Determining Speed

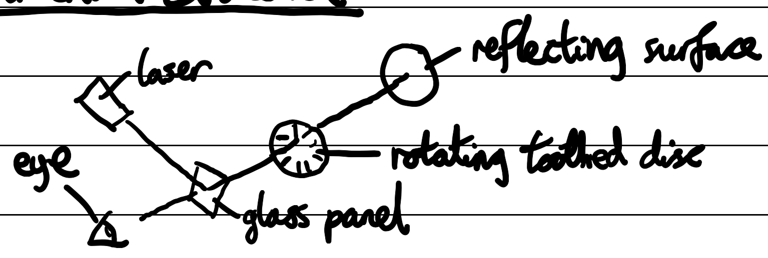


By measuring the distance between nodes (or antinodes) to find the wavelength, we can make substitutions into v=fλ with a known frequency to find the wave speed

Supporting Maxwell's Prediction

- Maxwell's result came from a prediction around electromagnetic waves
- $v = \sqrt{\frac{1}{\varepsilon_0\mu_0}} = \sqrt{\frac{1}{8.85\times10^{-12}\times1.26\times10^{-6}}} = 2.99\times10^{8}\,ms^{-1}$
- Measured speed is the same as Maxwell's predicted speed

Experimental Evidence



- Speed of the disc is increased until the light is no longer seen. At this point, light is blocked by a tooth where a gap initially was.
- Measured speed from Fizeau's experiment is similar to Maxwell's predicted speed, which suggests that light is also an electromagnetic wave.

QWC ✓

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 independent of the motion of the source and the observer. ✓

0 4 . 2 State the other postulate.

[1 mark]

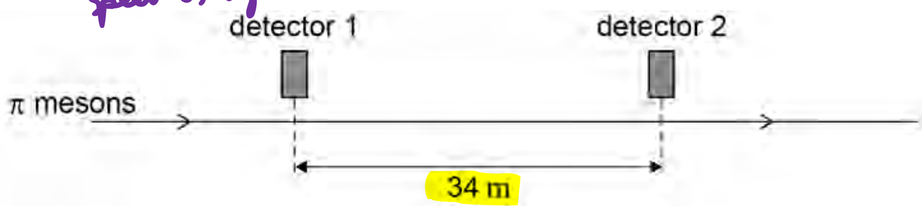
Laws of physics are the same in any inertial frame ✓

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**.

0.95 times the speed of light

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

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]

$\text{speed} = \frac{\text{distance}}{\text{time}}$ $\quad \text{time} = \frac{\text{distance}}{\text{speed}}$

$t = \frac{34}{0.95 \times 3.0 \times 10^8} = 1.193 \times 10^{-7} \text{ s} \simeq 1.2 \times 10^{-7} \text{ s}$

time = 1.2×10^{-7} s ✓

0 4 . 4 π mesons are unstable and decay with a half-life of 18 ns. so 25% left
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]

dropped to 25%

The number of mesons has halved twice, so two half-lives have passed in the observer's frame

$$t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{18}{\sqrt{1-0.95^2}} = 57.65\text{ns}$$

$$\simeq 58\text{ns}$$

$\Rightarrow$ Approximately half of 120ns

$\frac{120}{18} = 6.7$, so more than 6 half-lives have passed if there is no special relativity

$$\left(\frac{1}{2}\right)^{6.7} = 9.6\times10^{-3} \simeq 10\%$$

So 90% of the muons should have decayed without special relativity.