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Centre number

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Candidate number

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A-level PHYSICS

Paper 3

Section B Turning points in physics

Thursday 14 June 2018

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.

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.
- Do **all** rough work in this book. Cross through any work you do not want to be marked.
- Show **all** your working.

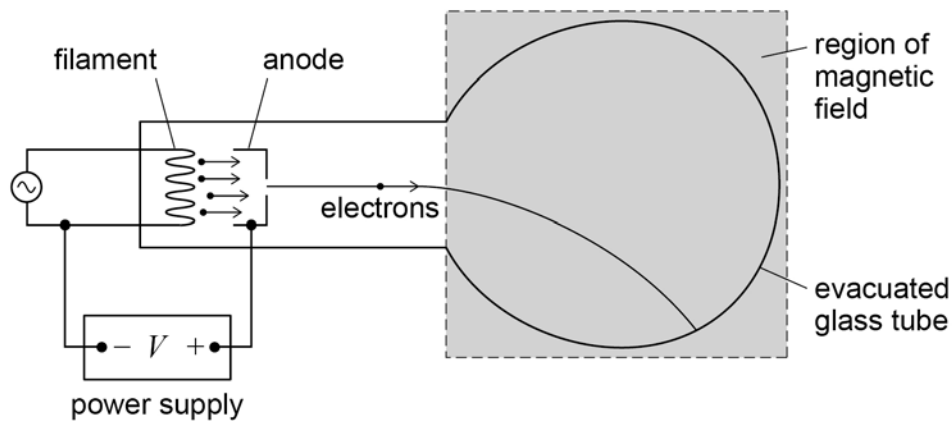
Information

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

Section BAnswer **all** questions in this section.**0 1****Figure 1** shows apparatus which can be used to determine the specific charge of an electron.**Figure 1**

Electrons are emitted from the filament and accelerated by a potential difference between the filament and anode to produce a beam. The beam is deflected into a circular path by applying a magnetic field perpendicular to the plane of the diagram.

0 1 . 1

Describe the process that releases the electrons emitted at the filament.

[3 marks]

A current passes through the filament, so the metal filament is heated by the current (its temperature rises).

The free (conduction) electrons in the metal gain enough kinetic energy to overcome the work function and leave the metal surface.

This process is called thermionic emission.



0 1 . 2

Table 1 shows the data collected when determining the specific charge of the electron by the method shown in **Figure 1**.

Table 1

potential difference V that accelerates the electrons	320 V
radius r of circular path of the electrons in the magnetic field	4.0 cm
flux density B of the applied magnetic field	1.5 mT

Show that the specific charge of the electron is given by the expression $\frac{2V}{B^2 r^2}$

[2 marks]

Accelerated through p.d. V : $\frac{1}{2}mv^2 = eV$, so $v^2 = 2eV / m$

In the field, magnetic force = centripetal force: $Bev = mv^2 / r$

so $v = Ber / m$, giving $v^2 = B^2 e^2 r^2 / m^2$

Equate: $B^2 e^2 r^2 / m^2 = 2eV / m$

so $e / m = 2V / (B^2 r^2)$

0 1 . 3

Using data from **Table 1**, calculate a value for the specific charge of the electron. Give your answer to an appropriate number of significant figures.

[2 marks]

$$e / m = 2V / (B^2 r^2) = (2 \times 320) / ((1.5 \times 10^{-3})^2 \times (0.040)^2)$$

$$= 640 / (2.25 \times 10^{-6} \times 1.6 \times 10^{-3}) = 1.78 \times 10^{11}$$

$$= 1.8 \times 10^{11} \text{ C kg}^{-1} \text{ (2 s.f., as the data are to 2 s.f.)}$$

specific charge of the electron = 1.8×10^{11} C kg⁻¹

Question 1 continues on the next page

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0 1 . 4

At the time when Thomson measured the specific charge of the particles in cathode rays, the largest specific charge known was that of the hydrogen ion.

State how Thomson's result for the specific charge of each particle within a cathode ray compared with that for the hydrogen ion and explain what he concluded about the nature of the particles.

[2 marks]

Thomson's specific charge for the cathode ray particles was much larger

(about 1800 times larger) than the specific charge of the hydrogen ion.

He concluded that cathode rays are made of particles (electrons) with a

very small mass, much smaller than the mass of a hydrogen ion, and a

(negative) charge, i.e. they are subatomic particles.



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0 2

Figure 2 shows a modern version of the apparatus used by Hertz to investigate the properties of electromagnetic waves. Electromagnetic waves are continuously emitted from a dipole transmitter. The electromagnetic waves are detected by a dipole receiver.

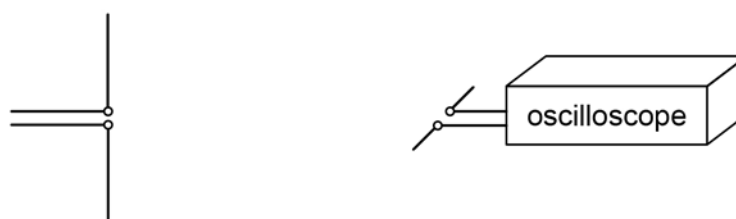
An oscilloscope is used to display the amplitude of the detected signal at the dipole receiver.

Figure 2



Figure 3 shows the same apparatus when the dipole receiver has been rotated through an angle of 90°

Figure 3



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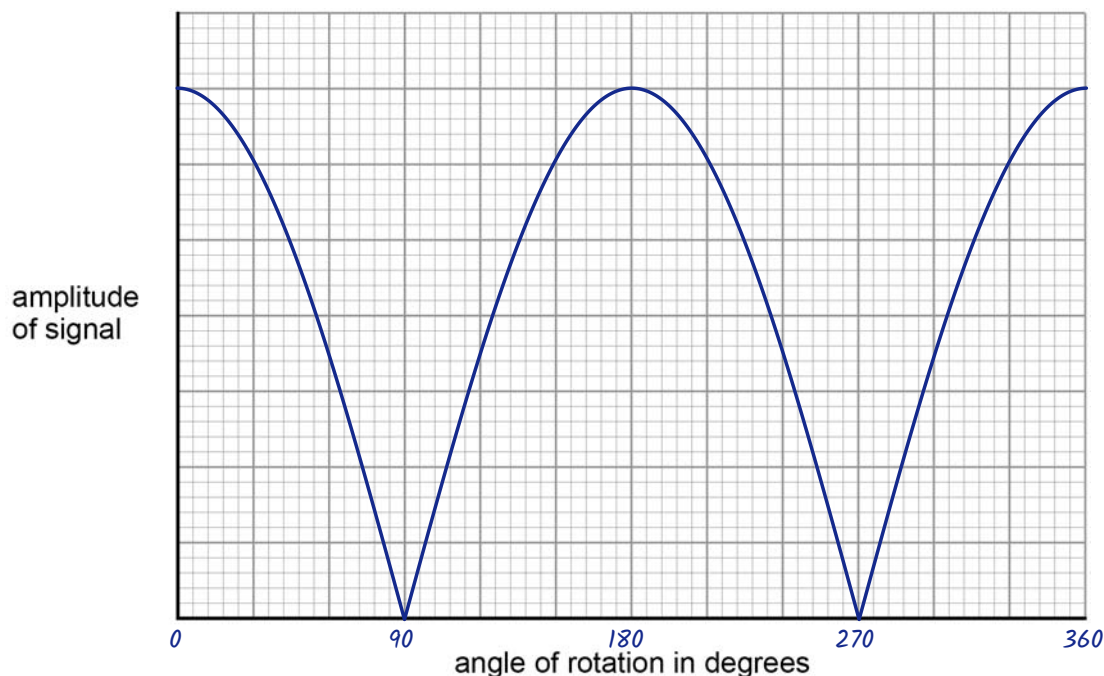


0 2 . 1

Sketch a graph on **Figure 4** to show how the amplitude detected by the dipole receiver varies with angle of rotation as the receiver is turned through 360° . Start your graph from the position shown in **Figure 2**.

[3 marks]

Figure 4



0 2 . 2

Maxwell derived the equation $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$ for the speed c of electromagnetic waves,

where μ_0 is the permeability of free space and ϵ_0 is the permittivity of free space.

Explain, using a suitable calculation, why this equation led to the conclusion that light is an electromagnetic wave.

[2 marks]

$$c = 1 / \sqrt{(\mu_0 \epsilon_0)} = 1 / \sqrt{(4\pi \times 10^{-7} \times 8.85 \times 10^{-12})}$$

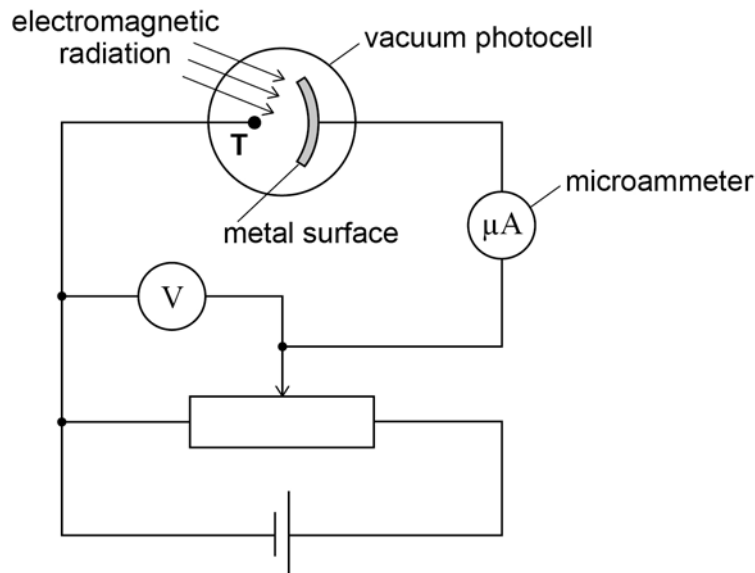
$$= 1 / \sqrt{(1.112 \times 10^{-17})} = 3.0 \times 10^8 \text{ m s}^{-1} \quad (2.998 \times 10^8)$$

This calculated value agrees with the measured (experimentally determined) speed of light, e.g. Fizeau's result, so light was concluded to be an electromagnetic wave.



0 3

Figure 5 shows a vacuum photocell in which a metal surface is illuminated by electromagnetic radiation of a single wavelength. Electrons emitted from the metal surface are collected by terminal T in the photocell. This results in a photocurrent, I , which is measured by the microammeter.

Figure 5

The potential divider is adjusted until the photocurrent is zero.

The potential difference shown on the voltmeter is 0.50 V

The work function of the metal surface is 6.2 eV

0 3 . 1

Calculate the wavelength, in nm, of the electromagnetic radiation incident on the metal surface.

[3 marks]

$$\text{Photon energy} = \phi + E_{k \max} = 6.2 + 0.50 = 6.7 \text{ eV}$$

$$E = 6.7 \times 1.6 \times 10^{-19} = 1.07 \times 10^{-18} \text{ J}$$

$$\lambda = hc / E = (6.63 \times 10^{-34} \times 3.00 \times 10^8) / 1.07 \times 10^{-18}$$

$$= 1.86 \times 10^{-7} \text{ m} = 186 \text{ nm}$$

wavelength = 186 nm



0 3 . 2

The intensity of the electromagnetic radiation is increased. No adjustment is made to the potential divider.

The classical wave model and the photon model make different predictions about the effect on the photocurrent.

Explain the effect on the photocurrent that each model predicts and how experimental observations confirm the photon model.

[3 marks]

Wave model: more energy is transferred to each electron (over time), so electrons can gain enough KE to reach T; it predicts an increase in the photocurrent.

Photon model: photon energy depends on frequency, not intensity, so each photon's energy and the maximum KE of the electrons do not change.

So the electrons are still unable to reach T; it predicts no change, the photocurrent stays at zero. This is observed, confirming the photon model.

0 3 . 3

The potential divider in **Figure 5** is returned to its original position so that a photocurrent is detected by the microammeter. The potential divider is then adjusted to increase the potential difference shown on the voltmeter.

Explain why the photocurrent decreases when this adjustment to the potential divider is made.

[2 marks]

The emitted electrons have a range of kinetic energies, and increasing the p.d. means electrons need more energy to cross the gap, so fewer electrons have sufficient kinetic energy to reach T.

So fewer electrons per second reach terminal T, and the current decreases.

Question 3 continues on the next page

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0 3 . 4

The apparatus shown in **Figure 5** is used to investigate three different metal surfaces **A**, **B** and **C**.

Table 2 shows, for each of the three surfaces, a voltmeter reading V and the corresponding photocurrent I . The same source of electromagnetic radiation is used throughout the investigation.

Table 2

	V/V	$I/\mu A$
Metal surface A	1.5	56
Metal surface B	2.5	56
Metal surface C	2.5	78

Which conclusion about the relationship between the work functions of **A**, **B** and **C** is correct?

Tick (✓) the correct box.

[1 mark]

A > B > C
☒
A < B < C
☐
B > A > C
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B < A < C
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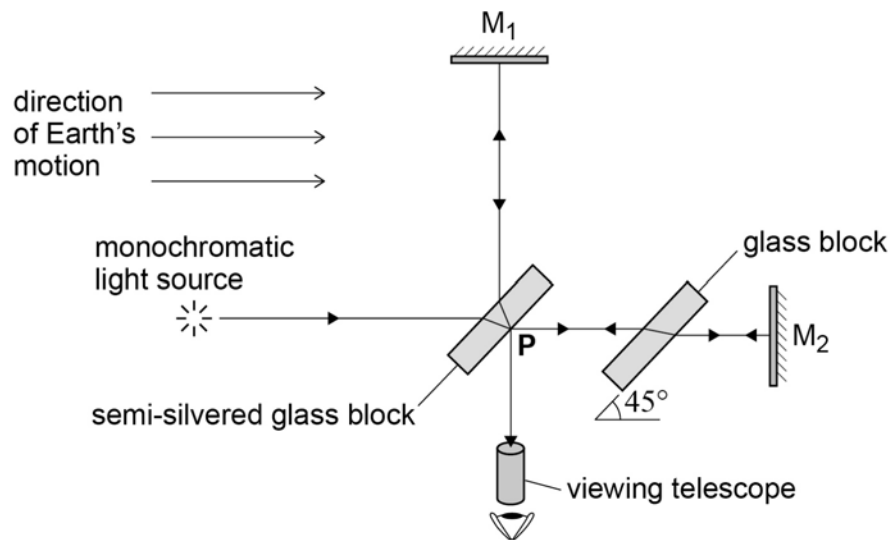


0 4

Figure 6 shows a diagram of the Michelson-Morley interferometer that was used to try to detect the absolute motion of the Earth through the ether (æther).

Light from the monochromatic source passes through the semi-silvered glass block and takes two different paths to the viewing telescope. The two paths, PM_1 and PM_2 , are the same length. Interference fringes are observed through the viewing telescope.

Figure 6



It was predicted that when the interferometer was rotated through 90° the fringe pattern would shift by 0.4 of the fringe spacing.

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0 4 . 1

Explain how the experiment provided a means of testing the idea that the Earth had an absolute motion relative to the ether.

Your answer should include:

- an explanation of why a shift of the fringe pattern was predicted
- a comparison of the results of the experiment to the prediction
- the conclusion about the Earth's absolute motion through the ether.

[6 marks]

PM₂ lies along the direction of the Earth's motion through the ether, while PM₁ is perpendicular to it. If the speed of light depends on the Earth's velocity through the ether, light would travel at different speeds relative to the apparatus in the two directions.

So, although the paths are the same length, the time taken for light to travel from P to M₂ and back to P would be greater than the time taken from P to M₁ and back to P. This time difference gives a phase difference between the two beams, which produces the fringe pattern seen in the telescope.

Rotating the apparatus through 90° swaps the roles of the two arms, so the time difference would reverse. This changes the phase difference between the waves at each point, so the fringe pattern was predicted to shift (by 0.4 of a fringe spacing).

Results: the apparatus was capable of detecting a shift of about 0.05 of a fringe spacing, much smaller than the 0.4 predicted. However, no shift was detected when the apparatus was rotated, either then or in later repeats at different times of year.

Conclusion: the experiment showed that the Earth has no detectable absolute motion through the ether, so absolute motion cannot be detected. The ether does not exist and light travels without needing a material medium; the speed of light is the same in all directions. (An

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*alternative explanation proposed was that the Earth drags the ether
with it.)*



0 4 . 2

The Michelson-Morley experiment provides evidence for one of the postulates of Einstein's theory of special relativity.

State this postulate.

[1 mark]

The speed of light in free space (a vacuum) is invariant: it has the same value for all observers in all inertial frames of reference.

0 4 . 3

State the other postulate of Einstein's theory of special relativity.

[1 mark]

Physical laws have the same form in all inertial frames of reference (frames moving at constant velocity relative to each other).

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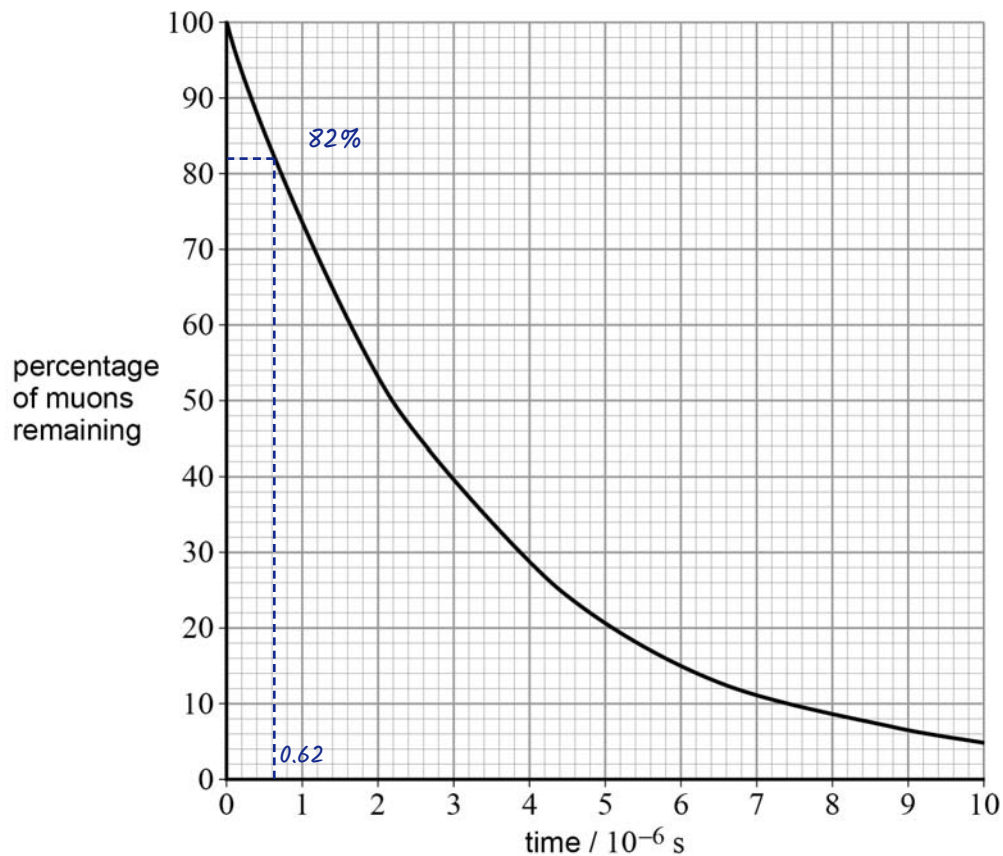


0 4 . 4 One consequence of the special theory of relativity is length contraction.

Experimental evidence for length contraction is provided by the decay of muons produced in the atmosphere by cosmic rays.

Figure 7 shows how the percentage of the number of muons remaining in a sample changes with time as measured by an observer in a frame of reference that is stationary relative to the muons.

Figure 7



In a particular experiment, muons moving with a velocity $0.990c$ travel a distance of 1310 m through the atmosphere to a detector.

Determine the percentage of muons that reach the detector.

[4 marks]

Time in Earth frame: $t = d / v = 1310 / (0.990 \times 3.00 \times 10^8) = 4.41 \times 10^{-6} \text{ s}$

Proper time (muon frame): $t_0 = t \sqrt{1 - v^2/c^2}$

$t_0 = 4.41 \times 10^{-6} \times \sqrt{1 - 0.990^2} = 4.41 \times 10^{-6} \times 0.141$

$t_0 = 6.22 \times 10^{-7} \text{ s} = 0.622 \times 10^{-6} \text{ s}$

(or: $L = 1310 \times 0.141 = 185 \text{ m}$, $t = 185 / (0.990 \times 3.00 \times 10^8) = 6.23 \times 10^{-7} \text{ s}$)

From Figure 7 at $t = 0.62 \times 10^{-6} \text{ s}$, percentage remaining = 82%

percentage = 82 %

12

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