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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

Tuesday 17 June 2025

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	



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Section B

Answer **all** questions in this section.

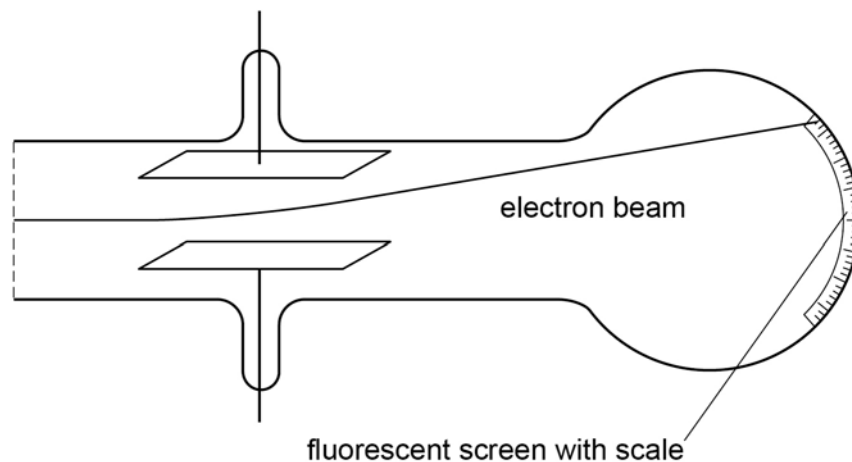
0 1

This question is about Thomson's determination of the electron's specific charge.

You should **not** use the values of the electron charge, mass or specific charge from the data and formulae booklet in this question.

Figure 1 shows part of the apparatus that Thomson used to measure the specific charge of the electron.

Figure 1

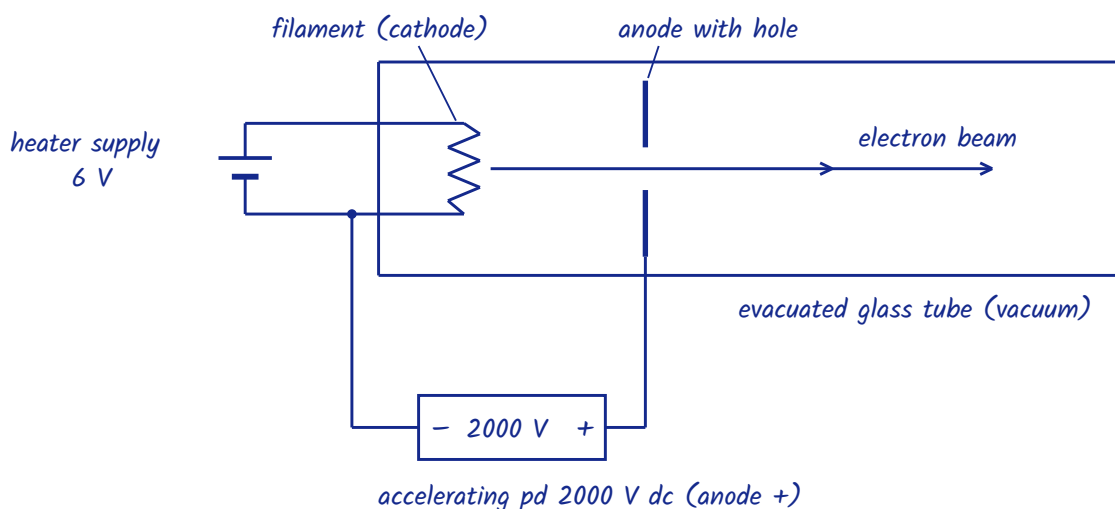


0 1. 1

A modern version of Thomson's apparatus uses thermionic emission in the production of the electron beam.

Suggest how the electron beam is produced in this modern version.
You should include a labelled diagram and suitable values for the power supplies used.

[3 marks]



The filament (cathode) is in an evacuated glass tube (vacuum). A low voltage heater supply of about 6 V is connected across the filament so a current passes through it and heats it.

Electrons gain enough energy to escape from the hot metal surface: this is thermionic emission.

A dc accelerating pd of about 2000 V is connected between the filament (negative) and an anode with a hole in it (positive). The electrons are accelerated towards the anode and some pass through the hole to form a narrow beam.

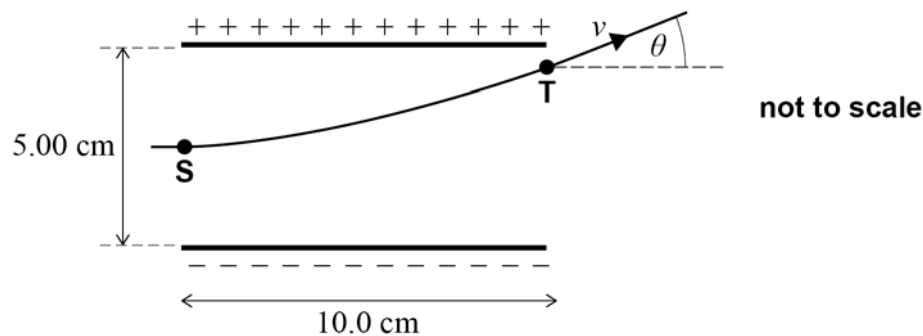
Question 1 continues on the next page

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A potential difference (pd) of 750 V is applied between the horizontal parallel plates. **Figure 2** shows the plates and the path of the electrons.

Figure 2



The electrons enter the electric field between the plates at **S** and leave it at **T** with speed v . Beyond **T** the electrons travel in a straight line at an angle θ . θ is read from a scale on a fluorescent screen.

The plates are of length 10.0 cm and are separated by a distance of 5.00 cm.

0 1 . 2

A uniform magnetic field of flux density 0.640 mT is now applied between the plates. This returns the electron beam to its undeflected position.

Show that the horizontal component of the velocity of the electrons is approximately $2.3 \times 10^7 \text{ m s}^{-1}$.

[2 marks]

Beam undeflected: electric force = magnetic force

$$eV / d = Bev, \quad \text{so} \quad v = V / (dB)$$

$$v = 750 / (0.0500 \times 0.640 \times 10^{-3})$$

$$v = 2.34 \times 10^7 \text{ m s}^{-1} \quad (\approx 2.3 \times 10^7 \text{ m s}^{-1})$$

The magnetic field is switched off and θ is measured to be 25° .

0 1 . 3

Show that the vertical component of the velocity of the electrons at **T** is approximately $1.1 \times 10^7 \text{ m s}^{-1}$.

[1 mark]

$$v_v = v_h \tan \theta = 2.34 \times 10^7 \times \tan 25^\circ$$

$$v_v = 1.09 \times 10^7 \text{ m s}^{-1} \quad (\approx 1.1 \times 10^7 \text{ m s}^{-1})$$



0 1 . 4

Show that the vertical acceleration of the electrons between the plates is approximately $2.5 \times 10^{15} \text{ m s}^{-2}$.

[2 marks]

$$\text{Time between plates: } t = L / v_h = 0.100 / (2.34 \times 10^7)$$

$$t = 4.27 \times 10^{-9} \text{ s}$$

$$\text{Vertically from rest: } v_v = at, \text{ so } a = v_v / t$$

$$a = 1.09 \times 10^7 / 4.27 \times 10^{-9} = 2.56 \times 10^{15} \text{ m s}^{-2}$$

0 1 . 5

Determine a value for the specific charge of the electron.

[3 marks]

$$\text{Force on electron: } ma = eE = eV / d$$

$$\text{so } e / m = ad / V$$

$$e / m = (2.56 \times 10^{15} \times 0.0500) / 750$$

$$e / m = 1.71 \times 10^{11} \text{ C kg}^{-1}$$

$$\text{specific charge} = \underline{1.7 \times 10^{11}} \text{ C kg}^{-1}$$

0 1 . 6

Explain the significance of the result of Thomson's determination.

[2 marks]

The specific charge of the electron was much larger than that of the hydrogen ion (proton), which had the largest specific charge known before: about 2000 times larger.

So the electron has a much smaller mass than the hydrogen ion, so it is a sub-atomic particle.

Question 1 continues on the next page

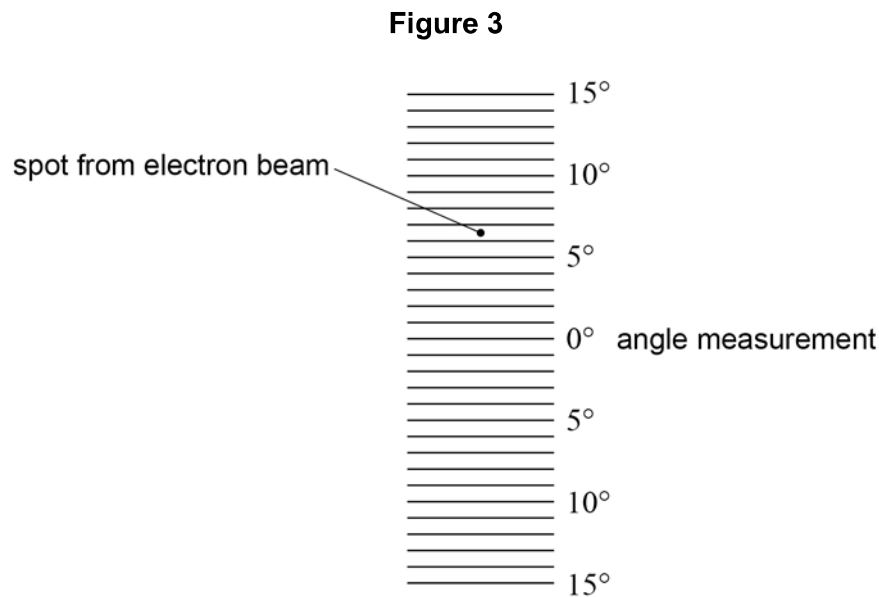
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0 1 7

Some students are given a version of the apparatus to repeat Thomson's experiment.

Figure 3 shows a section of the measuring scale on the fluorescent screen and the spot from the electron beam.



The students consider two methods for minimising the percentage uncertainty in the measurement of the angle.

Method 1:

- choose a magnetic flux density B
- then set the magnetic flux density to B with no pd
- then adjust only the pd until the beam is horizontal
- then switch off the magnetic field and measure the angle θ .

Method 2:

- choose an angle θ
- then set the pd so that the spot from the electron beam is at θ with no magnetic field
- then adjust only the magnetic field until the beam is horizontal.

Discuss both of these methods with reference to the percentage uncertainty in θ that they will produce.

In your answer, suggest which method will minimise the percentage uncertainty. No calculations are required.

[3 marks]

Method 2 will minimise the percentage uncertainty. In method 1 the angle is whatever it turns out to be when the field is switched off, so the spot is unlikely to be on a scale line and its position must be



estimated between lines.

In method 2 the pd can be adjusted so that the centre of the spot is exactly on a scale line, and a large angle (e.g. 15°) can be chosen, so the percentage uncertainty in θ is smaller.

The magnetic field (or coil current) is read from a meter, which has a smaller percentage uncertainty than reading the angle.

16

Turn over for the next question

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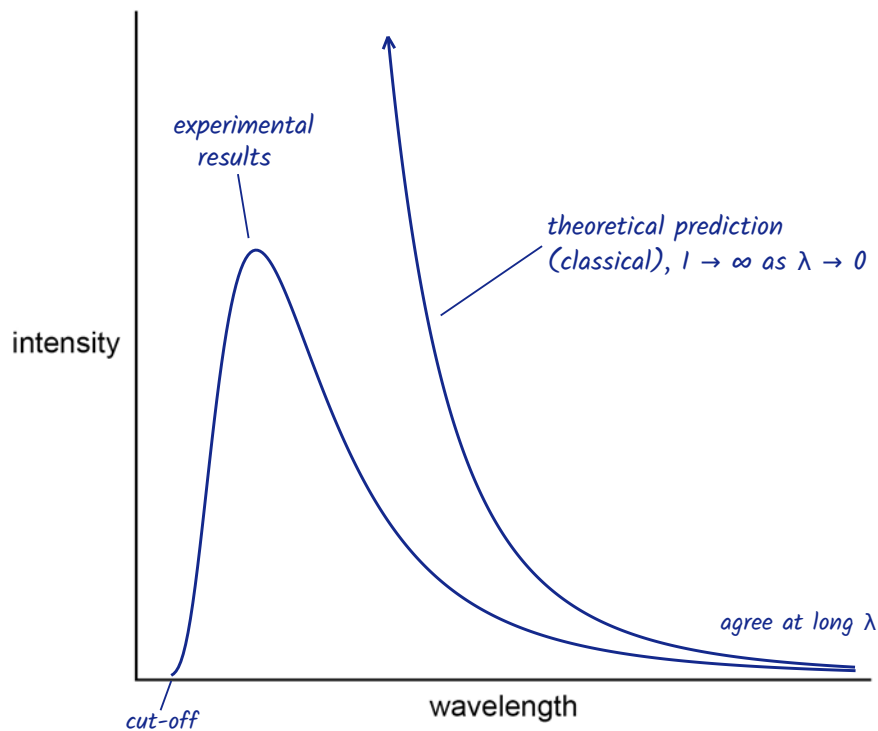


0 2

In the early 1900s a contradiction between experimental results and theoretical predictions was termed the ultraviolet catastrophe.

0 2 . 1

Compare these experimental results and theoretical predictions. You may sketch and label a graph or graphs on **Figure 4** as part of your answer.

[3 marks]**Figure 4**

At long wavelengths the experimental results agree with the theoretical prediction.

Experimentally the intensity rises to a peak at a certain wavelength and then falls to a cut-off at a low (non-zero) wavelength, but the theory predicts no peak and no cut-off.

The classical theory predicts that the intensity tends to infinity as the wavelength tends to zero (in the ultraviolet), which is not matched by the experimental results.



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A proposal was made that allowed a resolution of the contradiction.

Outline this proposal.

[1 mark]

*Planck proposed that electromagnetic radiation is emitted in quanta
(discrete packets of energy), and the energy of each quantum is
proportional to its frequency, $E = hf$.*

4

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0 3

The work of Fizeau, Foucault, Hertz and Maxwell contributed to our understanding of the nature of light.

Fizeau measured the speed of light in air.

Foucault confirmed that light travels faster in air than in water.

Hertz measured the speed of radio waves in air.

Maxwell developed a theory that was used to obtain the speed of light.

Discuss how the work of these four scientists contributed to our understanding of the nature of light.

In your answer you should refer to:

- the two pre-1800 models for the nature of light
- the predictions that these models made about the speed of light
- Maxwell's theory
- the significance of the measurements made by Fizeau, Foucault and Hertz.

Do **not** include any experimental details in your answer.

[6 marks]

Before 1800 there were two models of light: Newton's corpuscular (particle) theory, in which light is a stream of tiny particles, and Huygens' wave theory, in which light is a wave.

To explain refraction, Newton's corpuscular model predicted that light travels faster in a denser medium such as water or glass than in air (the corpuscles are attracted towards the denser medium). Huygens' wave model predicted that light travels slower in water or glass than in air.

Foucault showed that light travels faster in air than in water. This matched the prediction of the wave model, so it suggested that Huygens' wave theory was correct and that Newton's corpuscular theory was wrong.

Maxwell's theory predicted the existence of electromagnetic waves, consisting of oscillating electric and magnetic fields, perpendicular to each other and to the direction of energy transfer and in phase. His equations related the electric and magnetic fields and gave the speed of electromagnetic waves in free space as $c = 1 / \sqrt{(\mu_0 \epsilon_0)}$, where μ_0 (the



permeability of free space) relates to magnetic flux density and ϵ_0 (the permittivity of free space) relates to electric field strength. This gave a value of about $3 \times 10^8 \text{ m s}^{-1}$.

Fizeau's measured speed of light in air matched this predicted speed of electromagnetic waves, which suggested that light is an electromagnetic wave.

Hertz produced and detected radio waves and his measured speed of radio waves was equal to the speed predicted for electromagnetic waves, so this confirmed Maxwell's theory of electromagnetic waves.

Together these results showed that light is a transverse electromagnetic wave, rather than a stream of corpuscles.

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0 4

In a science-fiction novel, spaceship **A** transports cargo from planet **O** to planet **P**.

A travels at a constant speed of $0.50c$ in the reference frame of an observer on **P**.

0 4 . 1

The observer on **P** measures the distance from **O** to **P** as 1.4×10^{14} m.
Some of the cargo is food and must experience a journey time of no more than 10 days.

Determine whether **A** is able to deliver the cargo within this time.

[4 marks]

$$\text{Planet frame: } t = s / v = 1.4 \times 10^{14} / (0.50 \times 3.00 \times 10^8)$$

$$t = 9.33 \times 10^5 \text{ s (10.8 days)}$$

$$\text{Proper time } t_0 \text{ in A's frame: } t = t_0 / \sqrt{1 - v^2/c^2}$$

$$t_0 = 9.33 \times 10^5 \times \sqrt{1 - 0.50^2} = 9.33 \times 10^5 \times 0.866$$

$$t_0 = 8.1 \times 10^5 \text{ s (9.4 days)}$$

$$\text{Maximum: 10 days} = 10 \times 24 \times 3600 = 8.64 \times 10^5 \text{ s}$$

$8.1 \times 10^5 \text{ s} < 8.64 \times 10^5 \text{ s}$ (9.4 days < 10 days), so yes, A can deliver the food in time.

0 4 . 2

The observer on **P** measures the length of a cargo at rest on **P** to be 210 m.
There is a cargo hold along the full length of **A**.
The observer on **P** measures the length of **A** to be 200 m in the direction of travel while the spaceship is moving at $0.50c$.

Determine whether the cargo will fit into the cargo hold of **A**.

[4 marks]

$$\text{Ship's length is measured by P, who sees it moving: } l = 200 \text{ m}$$

$$l = l_0 \sqrt{1 - v^2/c^2}, \text{ so } l_0 = l / \sqrt{1 - 0.50^2}$$

$$l_0 = 200 / \sqrt{0.75} = 200 / 0.866$$

$$\text{Proper length of hold, } l_0 = 231 \text{ m}$$

$$(\text{or cargo in A's frame: } l = 210 \times 0.866 = 182 \text{ m} < 200 \text{ m})$$

$231 \text{ m} > 210 \text{ m}$, so yes, the cargo will fit into the cargo hold of A.



0 4 . 3

Spaceships **A** and **B** are travelling towards each other along the same straight line. The speed of **B** is $0.30c$ with respect to **P**.

Figure 5 shows the situation.

Figure 5



B sends a radio signal to **A**.

What is the speed of the radio signal measured by **A**?

Tick (✓) **one** box.

[1 mark]

$0.20c$

☐

$0.40c$

☐

$0.80c$

☐

c

☒

$1.8c$

☐

9

END OF QUESTIONS



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