A-Level Physics

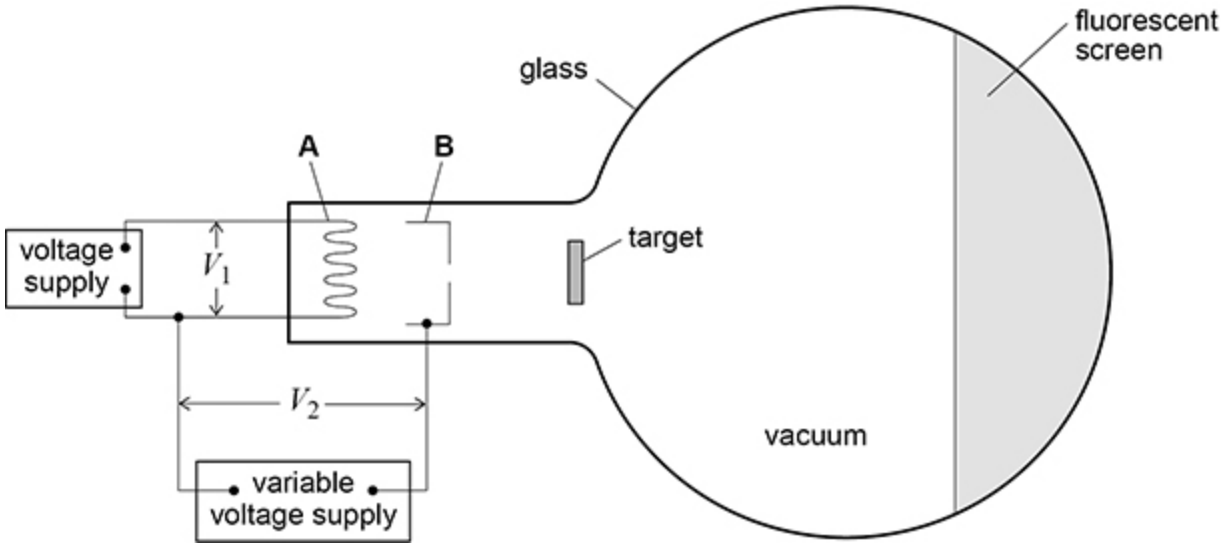
Thermionic Emissions of Electrons

Question Paper

Time available: 70 minutes
Marks available: 49 marks

1. **Figure 1** shows the apparatus used in an experiment to investigate electron diffraction and the de Broglie hypothesis.

Figure 1



(a) Explain how high-speed electrons are produced in the apparatus in **Figure 1**.

In your answer you should:

- name parts **A** and **B**
- discuss the purposes of potential differences V_1 and V_2.

(4)

(b) In the experiment, electrons are incident on a target made of a crystalline material. The electron wavelengths need to be about 50% the size of an atom to produce a diffraction pattern on the screen.

Suggest a suitable value for V_2.
Support your answer with a calculation.

V_2 = _____ V

(4)

(c) **Figure 2** shows a typical diffraction pattern produced on the screen by the electrons.

Figure 2

Explain how measurements made with the apparatus in **Figure 1** can be used to support the de Broglie hypothesis.

(4)

(d) STM and TEM are abbreviations for two types of electron microscope.

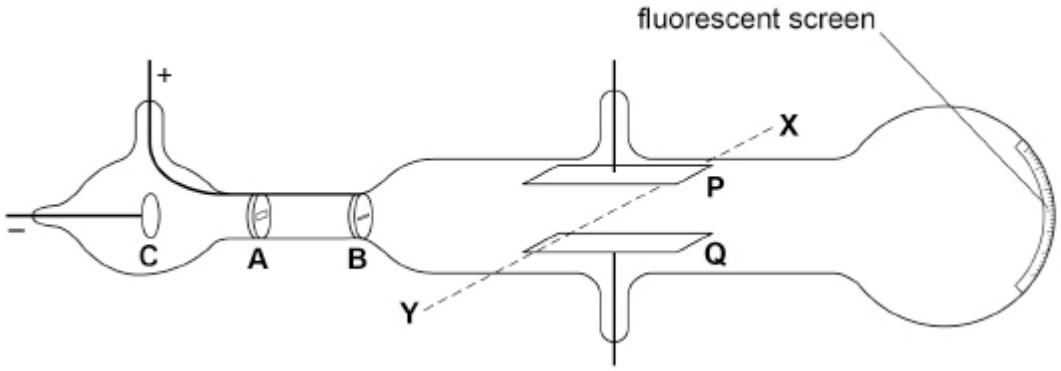
Which row links the type of microscope to a relevant property of moving electrons? Tick (✓) **one** box.

STM	TEM	
Moving electrons can cross a potential barrier.	Moving electrons can be deflected by a magnetic field.	☐
Moving electrons can be deflected by a magnetic field.	Moving electrons can be deflected by a magnetic field.	☐
Moving electrons can be deflected by a magnetic field.	Moving electrons can cross a potential barrier.	☐
Moving electrons can cross a potential barrier.	Moving electrons can cross a potential barrier.	☐

(1)

(Total 13 marks)

2. The figure shows a diagram of a discharge tube used by JJ Thomson to investigate cathode rays.



The direction **XY** is horizontal and at right angles to the axis of the tube.

(a) When correct connections are made to a high-voltage power supply, a cathode ray is produced. The cathode ray hits the centre of the fluorescent screen.

Describe how a cathode ray is produced in the discharge tube in the figure above.

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(2)

(b) **P** and **Q** are metal plates that can be attached to a second power supply.

In an experiment, a potential difference (pd) is applied across **P** and **Q** so that **P** is positively charged and **Q** is negatively charged. This deflects the cathode ray.

Then a magnetic field is applied between the plates so that the cathode ray follows its original path to the centre of the screen.

What is the direction of the magnetic field?
Tick (✓) **one** box.

from **P** to **Q** ☐

from **Q** to **P** ☐

from **X** to **Y** ☐

from **Y** to **X** ☐

(1)

(c) Changes are made to the apparatus so that the particles in the cathode ray travel with a greater speed as they pass between plates **P** and **Q**.

Explain how the cathode ray is restored to its original path by adjusting:

- only the electric field strength between **P** and **Q**
- only the magnetic flux density.

electric field strength only _____

_____

_____

_____

_____

magnetic flux density only _____

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(3)

(d) Using the apparatus in the figure above, Thomson determined the specific charge of the particles in the cathode rays. Thomson compared this result with the specific charge of the hydrogen ion.

Discuss the significance of Thomson's results for the particles in cathode rays, when compared with the specific charge of the hydrogen ion.

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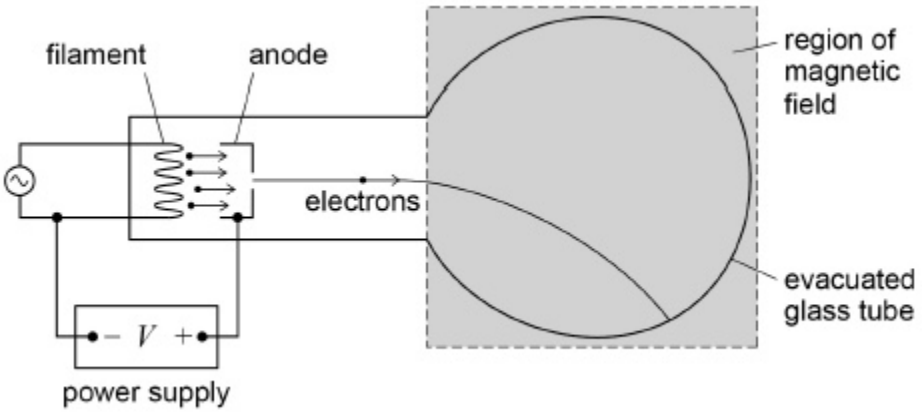
(2)

(Total 8 marks)

3. The diagram shows apparatus which can be used to determine the specific charge of an electron.



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.

(a) Describe the process that releases the electrons emitted at the filament.

(3)

(b) The table shows the data collected when determining the specific charge of the electron by the method shown in the diagram.

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 $\frac{2V}{B^2r^2}$

(2)

(c) Using data from the table, calculate a value for the specific charge of the electron.
Give your answer to an appropriate number of significant figures.

specific charge of the electron = _____ C kg^{-1}

(2)

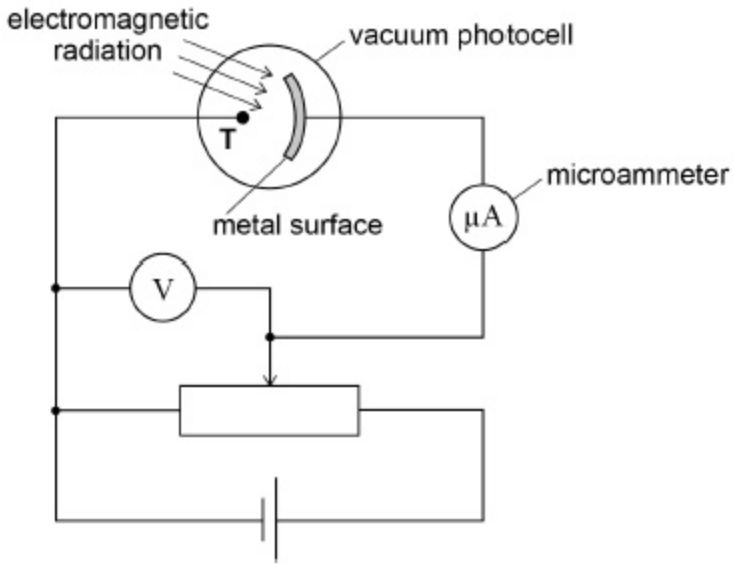
(d) At the time when Thomson measured the specific charge of the particles in cathode rays, the largest specific charge known was that of the hydrogen ion.

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)

(Total 9 marks)

4. The diagram 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.



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

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

wavelength = _____ nm

(3)

(b) 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.

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(3)

(c) The potential divider in the diagram 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.

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(2)

(d) The apparatus shown in the diagram above is used to investigate three different metal surfaces **A**, **B** and **C**.
The table 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.

	V/V	I/μA
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.

A > B > C. ☐

A < B < C. ☐

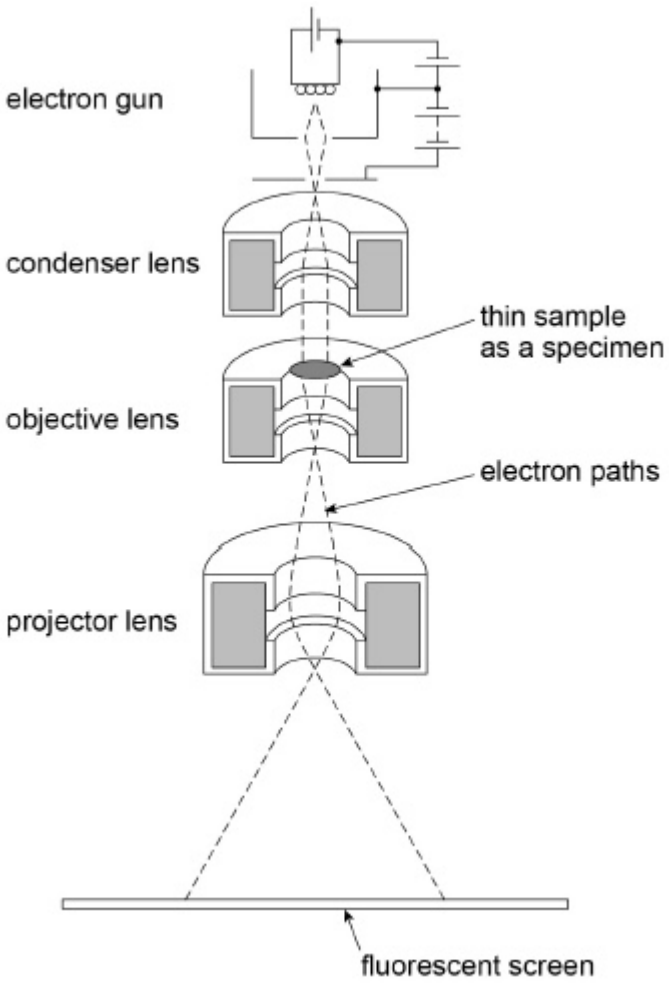
B > A > C. ☐

B < A < C. ☐

(1)

(Total 9 marks)

5. The diagram shows the main parts of a transmission electron microscope (TEM).



(a) What is the process by which electrons are produced in an electron gun?
Tick (✓) the correct box.

Beta particle emission ☐

Electron diffraction ☐

Photoelectric effect ☐

Thermionic emission ☐

(1)

(b) The electrons in a particular TEM have a kinetic energy of 4.1×10^{-16} J.
Relativistic effects are negligible for this electron energy.

Suggest, with a calculation, whether the images of individual atoms can, in principle, be resolved in this TEM.

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_____

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_____

(3)

(c) A typical TEM can accelerate electrons to very high speeds and form high resolution images.

Explain:

- the process of image formation, and
- the factors that affect the quality of, and the level of detail in, the image.

(6)

(Total 10 marks)