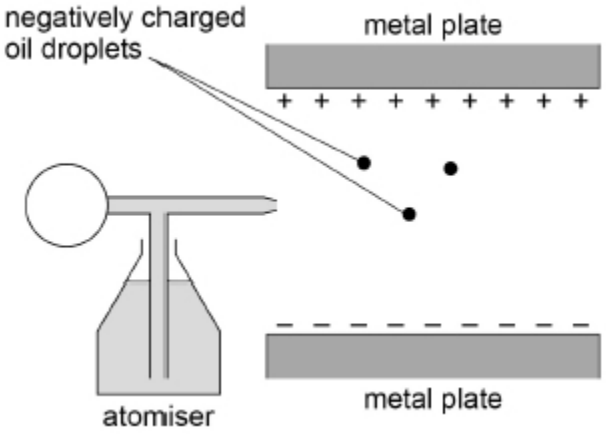
A-Level Physics

Specific Charge of an Electron

Question Paper

Time available: 62 minutes
Marks available: 49 marks

1. The diagram shows an experiment to measure the charge of the electron.



not to scale

Negatively charged oil droplets are sprayed from the atomiser into the gap between the two horizontal metal plates. A potential difference is applied between the metal plates.

One of the droplets remains stationary.

(a) Identify the forces acting on the stationary droplet.
In your answer you should state the relationship between the forces.

The upthrust on the droplet due to the air it displaces is negligible.

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(2)

(b) The potential difference between the plates is changed to zero and the droplet falls at a terminal velocity of 1.0×10^{-4} m s^{-1}.

The density of the oil is 880 kg m^{-3}
The viscosity of air is 1.8×10^{-5} N s m^{-2}

Show that the radius of the droplet is about 1×10^{-6} m.

Assume that the droplet is spherical.

(3)

(c) The potential difference between the plates is restored to its initial value and the droplet becomes stationary.

The charge on the droplet is -4.8×10^{-19} C.

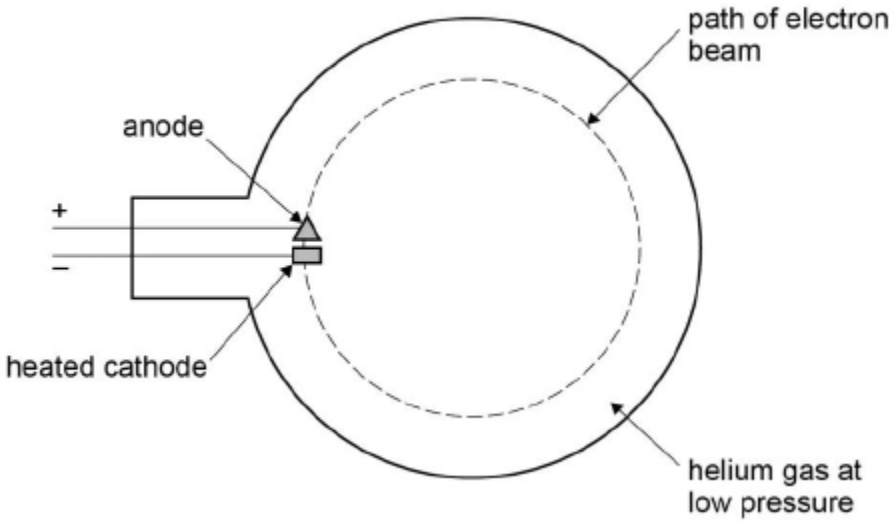
A student suggests that, if the droplet splits into two spheres of equal size, both spheres would remain stationary.

Deduce whether this suggestion is correct.

(3)

(Total 8 marks)

2. The diagram below shows part of an apparatus used to determine the specific charge of an electron.



Electrons are emitted by the cathode by thermionic emission. They are accelerated by the potential difference between the cathode and anode. The tube contains helium gas at a low pressure and the gas emits light to show the path of the electron beam.

The beam is bent into a circular path by applying a magnetic field perpendicular to the plane of the diagram.

(a) Explain how light is emitted as the electrons travel through the helium gas.

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(3)

(b) In one experiment the potential difference between the cathode and anode is 2.5 kV.

Show that the speed of the electrons is about 3.0×10^7 m s^{-1}.

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(2)

(c) When the flux density of the magnetic field is 3.1 mT the diameter of the path of the beam is 0.114 m.

Calculate the value for the specific charge of an electron from the data in this experiment.

specific charge _____ C kg^{-1}

(3)

(d) In practice the path of the electron beam is not a perfect circle.

Discuss how the presence of the gas affects the path of the electrons.

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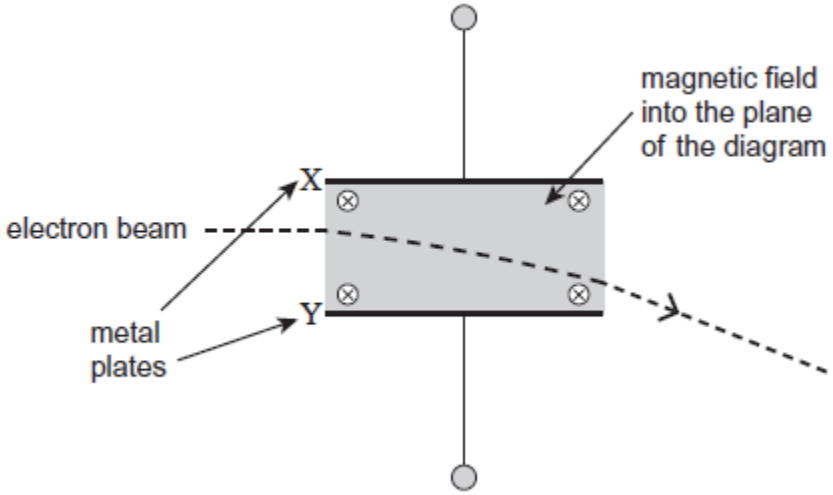
(3)

(Total 11 marks)

3. The diagram below shows part of an evacuated tube that is used to determine the specific charge (e / m) for an electron. An electron beam is directed between the two parallel metal plates, X and Y. In the region between the plates, a magnetic field is applied perpendicularly into the plane of the diagram. An electric field can be applied in this region by applying a potential difference (pd) between the plates.



(a) The diagram shows the path of the electron beam when the magnetic field is applied and the pd between X and Y is zero.

(i) Explain why the path followed by the electron beam in the magnetic field is a circular arc.

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(2)

(ii) Show that the speed v of the electrons is given by $v = \frac{Ber}{m}$

where r is the radius of the path of an electron in the magnetic field and B is the flux density of the magnetic field.

(1)

(iii) A pd V is now applied between X and Y without changing the flux density of the magnetic field. V is adjusted until the electron beam is not deflected as it travels in the region between the plates.

Determine an expression for the speed v of the electrons in terms of V, B and the separation d of the metal plates.

(1)

(b) Use the equation given in part (ii) and your answer to part (iii) to show that the specific charge for the electron = $\frac{V}{B^2 r d}$

(1)

(c) If the charge on an electron is known then its mass can be determined from the specific charge. Describe how Millikan's experiment with charged oil droplets enables the electronic charge to be determined.

Include in your answer:

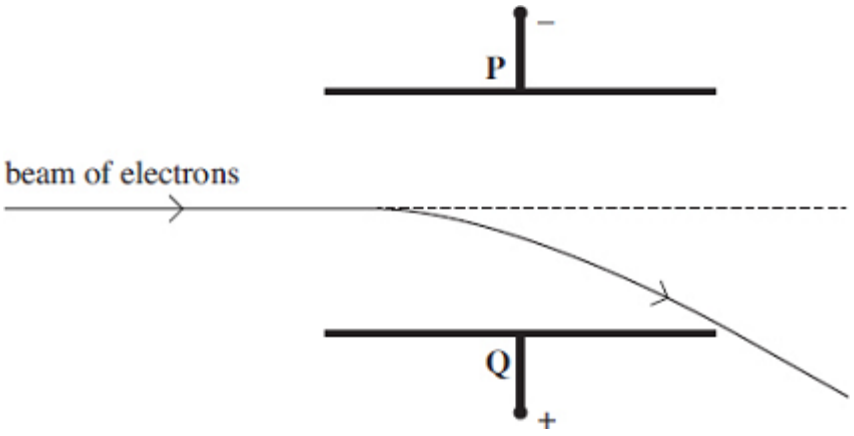
- the procedures used to determine the radius of a droplet and the charge on a droplet
- how the measurements made are used
- how the electronic charge can be deduced.

The quality of your written communication will be assessed in your answer.

(6)

(Total 11 marks)

4. A narrow beam of electrons is directed into the region between two parallel plates, **P** and **Q**. When a constant potential difference is applied between the two plates, the beam curves downwards towards plate **Q** as shown in the figure below.



(a) Explain why the beam curves downwards at an increasing angle to its initial direction.

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(3)

(b) A uniform magnetic field is then applied at right angles to both the beam and the electric field between the plates **P** and **Q**. As a result, the downward deflection of the beam is increased.

(i) The arrangement is to be used to determine the speed of the electrons in the beam. Describe what adjustments to the flux density *B* of the magnetic field should be made to reduce the deflection of the beam to zero.

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(1)

(ii) Explain why the electrons pass undeflected through the fields when their speed v is given by

$$v = \frac{V}{Bd}$$

where V is the potential difference between plates **P** and **Q** and d is the perpendicular distance between the plates.

(2)

(c) The beam of electrons was produced by thermionic emission from a heated filament. When the potential difference between the anode and the filament was 4200 V, the speed of the electrons in the beam was 3.9×10^7 ms^{-1}.

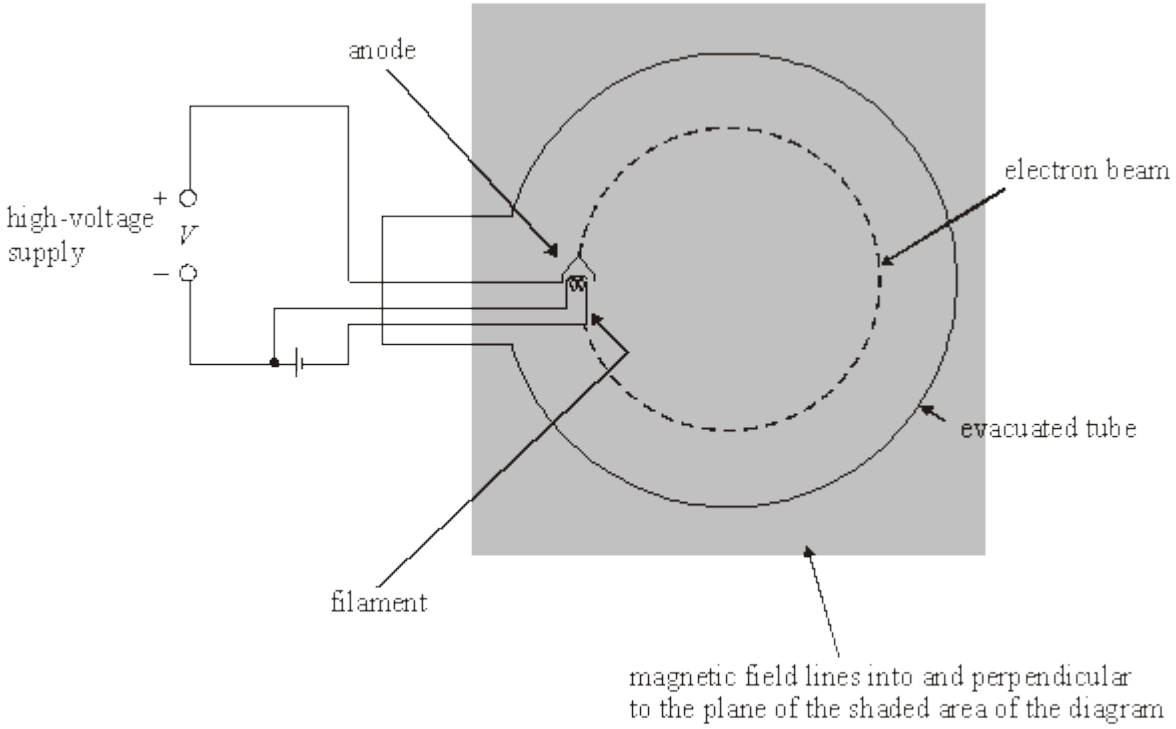
Use this information to determine the specific charge of the electron.

answer = _____ $C\ kg^{-1}$

(3)

(Total 9 marks)

5. The figure below shows an electron gun in an evacuated tube. Electrons emitted by *thermionic emission* from the metal filament are attracted to the metal anode which is at a fixed potential, *V*, relative to the filament. Some of the electrons pass though a small hole in the anode to form a beam which is directed into a uniform magnetic field.



(a) (i) Explain what is meant by thermionic emission.

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(ii) Show that the speed, v, of the electrons in the beam is given by

$$v = \left(\frac{2eV}{m}\right)^{\frac{1}{2}}$$

where *m* is the mass of the electron and *e* is the charge of the electron.

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(3)

(b) The beam of electrons travels through the field in a circular path at constant speed.

(i) Explain why the electrons travel at constant speed in the magnetic field.

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(ii) Show that the radius, *r*, of the circular path of the beam in the field is given by

$$r = \left(\frac{2mV}{B^2 e}\right)^{\frac{1}{2}}$$

where *B* is the magnetic flux density and *V* is the pd between the anode and the filament.

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(iii) The arrangement described above was used to measure the specific charge of the electron, *e/m*. Use the following data to calculate *e/m*.

B = 3.1 mT
r = 25 mm
V = 530 V

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(7)

(Total 10 marks)