1 (a) J J Thomson devised the first experiments to determine the specific charge for cathode rays produced in discharge tubes. He found that the value did not depend on the gas in the tube. He also discovered that particles emitted by a heated filament and particles emitted in the photoelectric effect had the same specific charge.

State **two** conclusions that were drawn from Thomson's experiments.

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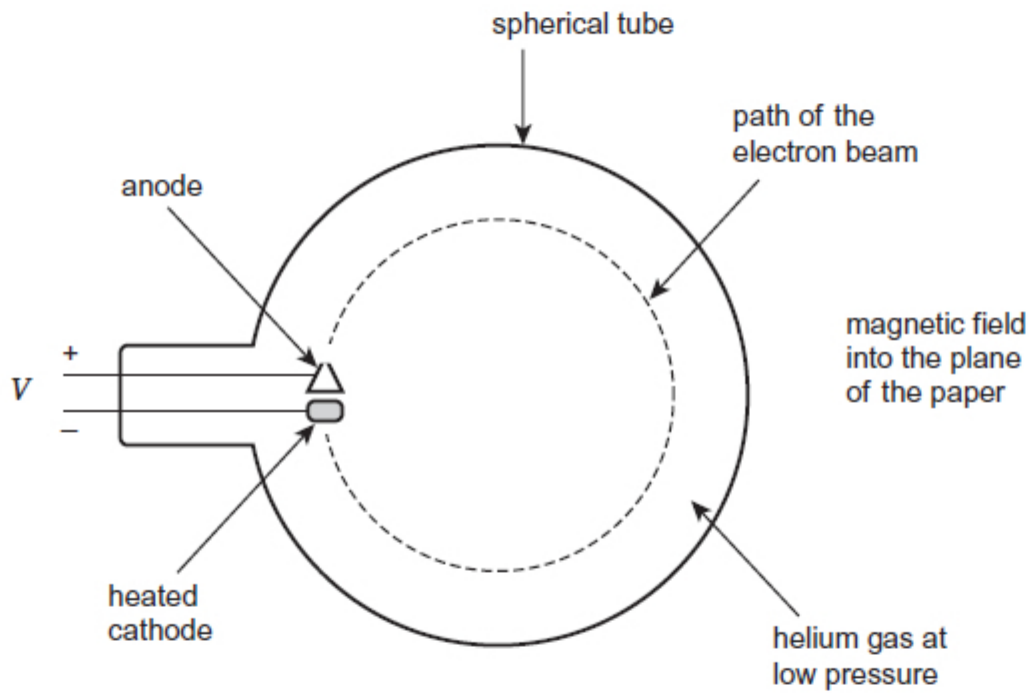
(2)

(b) The diagram shows a spherical tube, filled with low-pressure helium gas, that is used in an experiment to determine the specific charge of an electron.



Electrons are accelerated by a potential difference (pd) V applied between the cathode and anode. A magnetic field of known flux density B, directed into the plane of the diagram, causes the electrons to move in a circular path.

(i) Explain the process that causes the low-pressure helium gas to emit light so that the path of the electron beam can be seen.

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(3)

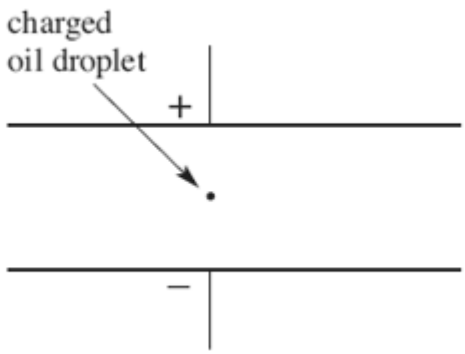
(ii) In one experiment using the apparatus in the diagram, the accelerating pd is 1.6 kV and the flux density of the magnetic field is 2.2 mT. The path of the electron beam has a radius of 0.059 m.

Determine a value for the specific charge of an electron using these data. State an appropriate unit for your answer.

specific charge = ... unit = ...

(4)
(Total 9 marks)

2 In an experiment to measure the charge of the electron, a charged oil droplet of unknown mass was observed between two horizontal parallel metal plates, as shown in the figure below.



(a) The droplet was observed falling vertically at its terminal speed when the pd between the plates was zero.

(i) By considering the forces acting on the droplet as it falls at its terminal velocity, *v*, show that the radius, *r*, of the droplet is given by

$$r = \left(\frac{9\eta v}{2\rho g}\right)^{\frac{1}{2}}$$

where η is the viscosity of air and ρ is the density of the oil droplet.

(2)

(ii) Explain how the mass of the oil droplet can be determined from its radius, *r*.

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(1)

(b) (i) The two horizontal parallel metal plates were 5.0 mm apart. The mass of the droplet was 6.8×10^{-15} kg. The droplet was held stationary when the plate pd was 690 V.

Calculate the charge of the oil droplet, expressing your answer to an appropriate number of significant figures.

answer.. C

(3)

(ii) Millikan made the first accurate measurements of the charge carried by charged oil droplets. Outline what Millikan concluded from these measurements.

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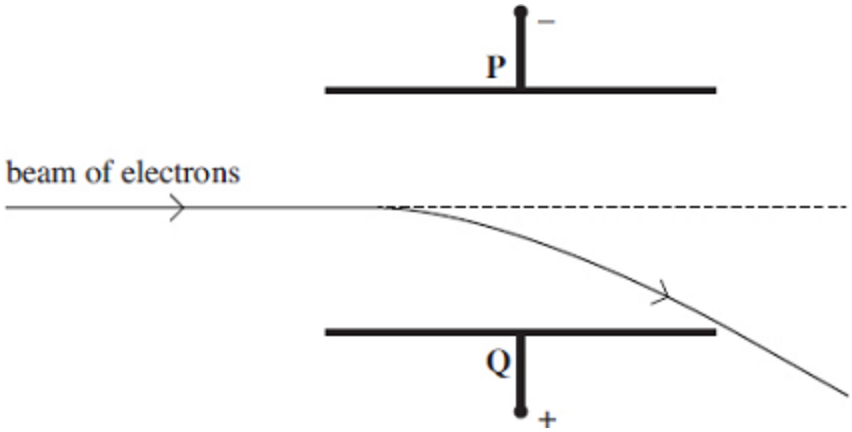
(2)
(Total 8 marks)

3 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.

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(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.

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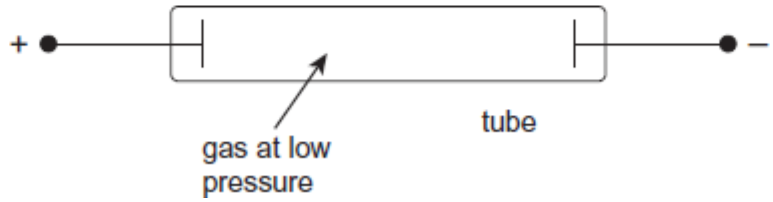
answer = ... C kg^{-1}

(3)
(Total 9 marks)

4 The following figure shows a discharge tube containing a gas at low pressure. When a sufficiently high potential difference is applied between the two electrodes in the tube the gas becomes conducting and emits light.



(a) (i) Describe how the charged particles responsible for conduction in the gas are produced.

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(2)

(ii) Explain why the gas emits light and why it must be at low pressure.

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(3)

(b) The charged particles moving towards the negative electrode were initially referred to as positive rays. Explain why their **specific charge** depends on the choice of gas in the tube.

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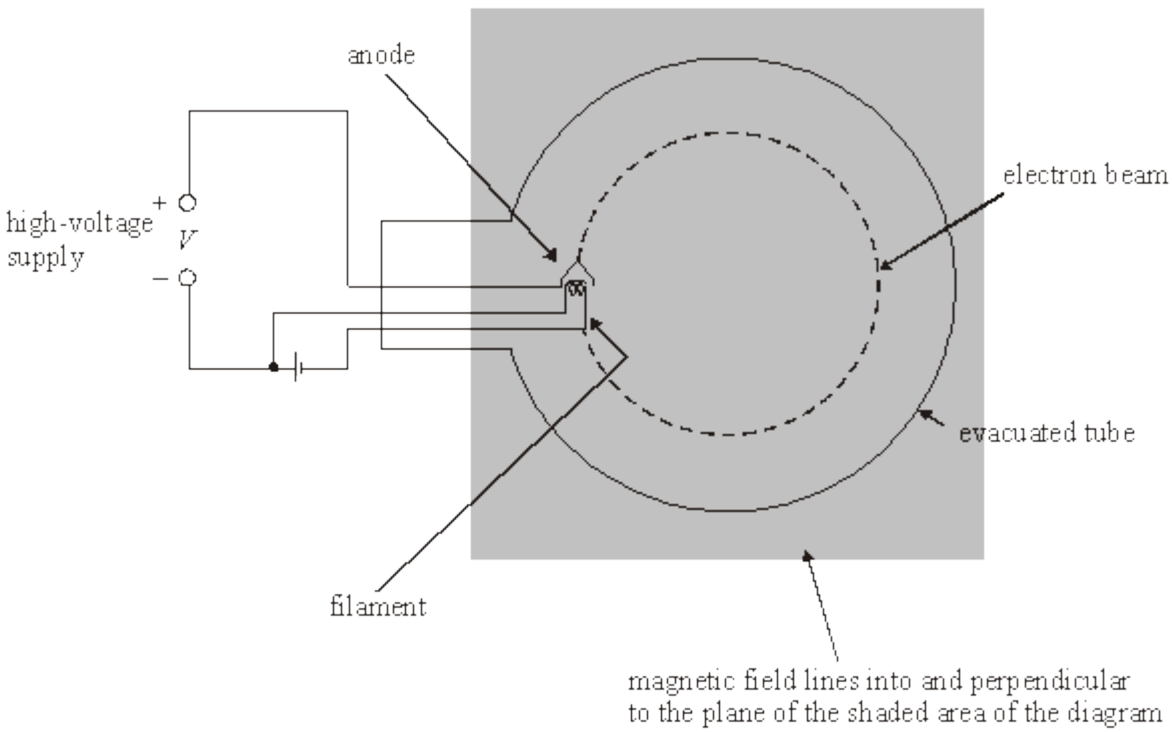
(2)
(Total 7 marks)

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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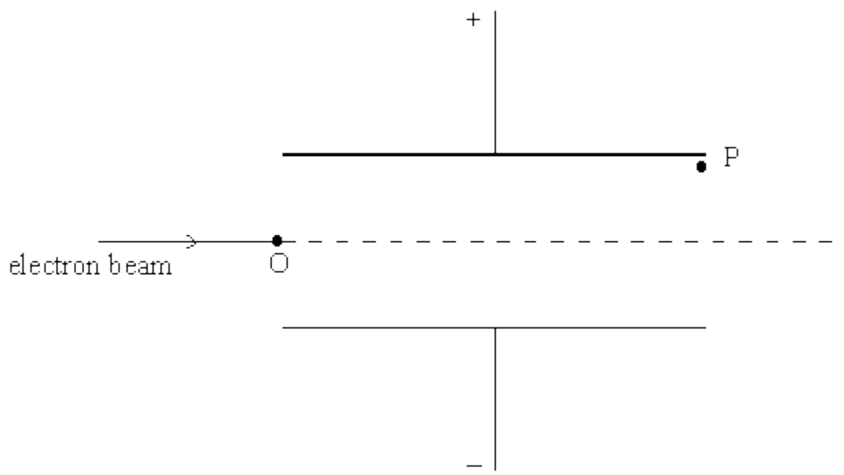
(7)
(Total 10 marks)

6 The diagram shows a narrow beam of electrons directed at right angles into a uniform electric field between two oppositely-charged parallel metal plates at a fixed potential difference.



(a) The electrons enter the field at O and leave it at P. Sketch the path of the beam from O to P and beyond P.

(2)

(b) A uniform magnetic field is applied to the beam perpendicular to the electric field and to the direction of the beam. The magnetic field reduces the deflection of the beam from its initial direction.

(i) Explain why the magnetic field has this effect on the beam.

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(ii) The magnetic flux density is adjusted until the beam passes through the two fields without deflection. Show that the speed v of the electrons when this occurs is given by

$$v = \frac{E}{B}$$

where E is the electric field strength and B is the magnetic flux density.

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(5)

(c) In an experiment to measure the specific charge of the electron, electrons were accelerated from rest through a potential difference of 2900 V to a speed of 3.2×10^{7} m s^{-1}. Use this information to calculate the specific charge of the electron.

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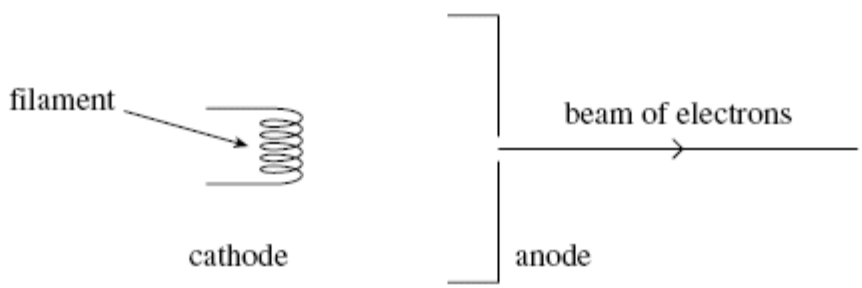
(3)
(Total 10 marks)

7 A narrow beam of electrons is produced in a vacuum tube using an electron gun, part of which is shown in **Figure 1**.

Figure 1



(a) (i) State and explain the effect on the beam of electrons of increasing the filament current.

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(2)

(ii) State and explain the effect on the beam of electrons of increasing the anode potential.

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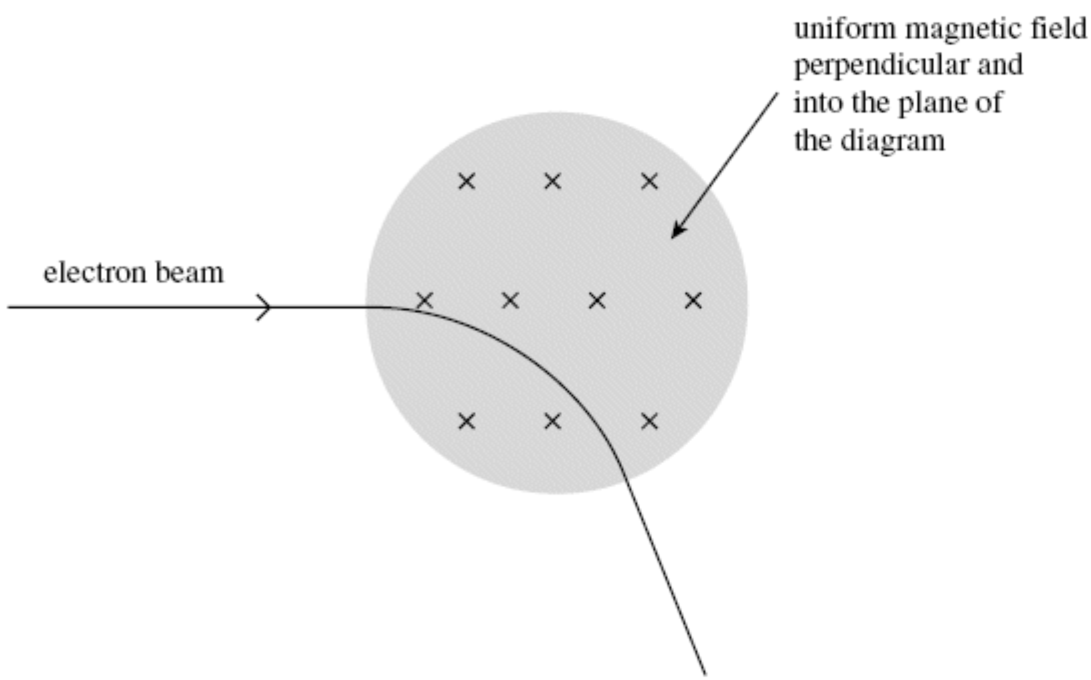
(2)

(b) The beam of electrons is directed at right angles into a uniform magnetic field as shown in **Figure 2**.

Figure 2



(i) Explain why the electrons move in a circular path at a constant speed in the magnetic field.

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(3)

(ii) When the speed of the electrons in the beam is 7.4×10^6 m s^{-1} and the magnetic flux density is 0.60 m T, the radius of curvature of the beam is 68 mm.

Use these data to calculate the specific charge of the electron, stating an appropriate unit. Give your answer to an appropriate number of significant figures.

answer = ...

(4)

(iii) Discuss the historical relevance of the value of the specific charge of the electron compared with the specific charge of the H^+ ion.

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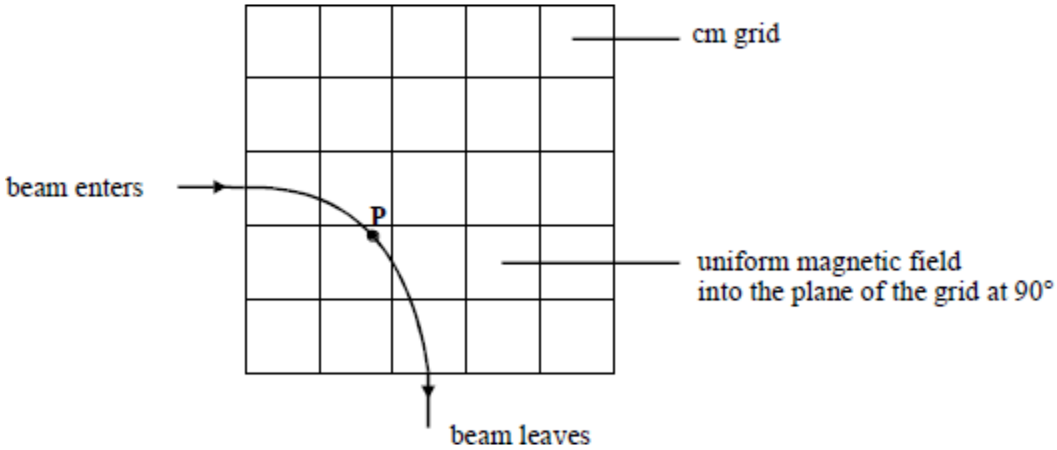
(2)
(Total 13 marks)

8 (a) An electron beam enters a uniform magnetic field and leaves at right angles, as shown in the diagram which is drawn to full-scale.



(i) Draw an arrow at P to show the direction of the force on an electron in the beam.

(ii) Explain why the kinetic energy of the electrons in the beam is constant.

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(3)

(b) (i) Measure the radius of curvature of the electron beam in the diagram

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(ii) The electron beam was produced by means of an electron gun in which each electron was accelerated through a potential difference of 3.2 kV. The magnetic flux density was 7.6 mT. Use these data and your measured value of the radius of curvature of the electron beam to determine the specific charge of the electron, e/m.

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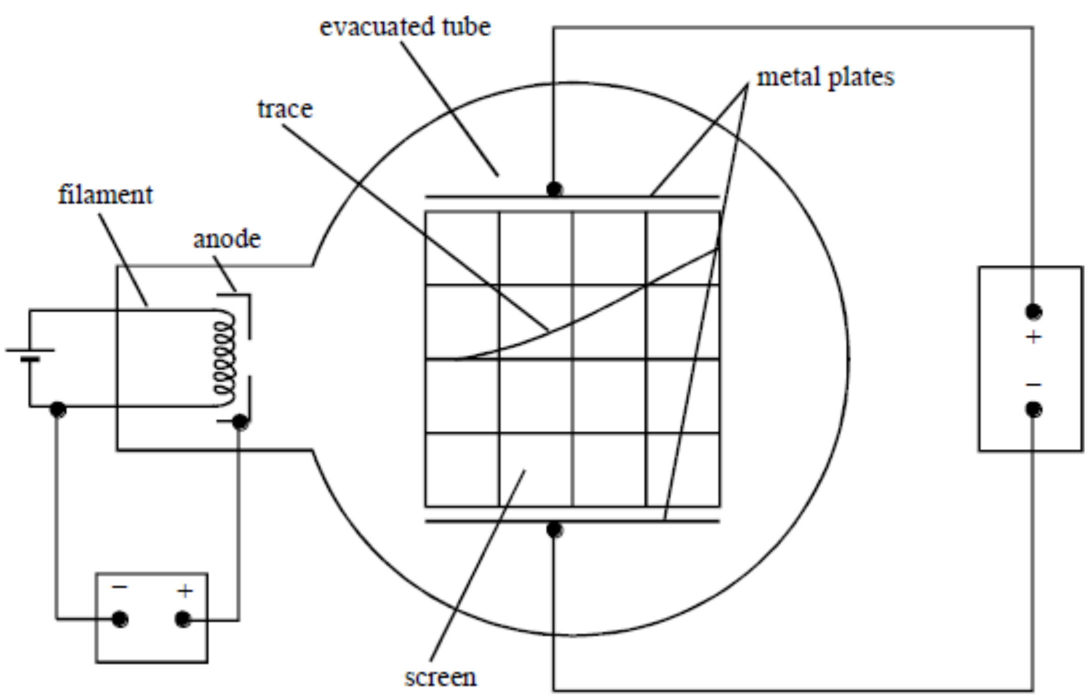
(6)
(Total 9 marks)

9 A narrow beam of electrons is directed into a uniform electric field created by two oppositely-charged parallel metal plates at right angles to the field lines. A fluorescent screen is used to make the beam give a visible trace.



(a) (i) Explain why the beam curves towards the positive plate.

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(ii) How does the trace show that, on entry to the electric field, all the electrons have the same speed?

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(3)

(b) The beam is produced as a result of accelerating electrons between the filament and a metal anode.

(i) Explain why the wire filament must be hot.

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(ii) Write down an equation relating the speed of the electrons, υ, to the potential difference, V_A, between the anode and the filament.

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(2)

(c) The deflection of the beam due to the electric field can be cancelled by applying a suitable uniform magnetic field *in* the same region as the electric field.

(i) What direction should the magnetic field be in to do this?

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(ii) Write down an equation relating the speed of the electrons υ to the plate voltage V_p, the plate separation d, and the magnetic flux density B necessary to make the beam pass undeflected between the plates.

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(iii) The following measurements were made when the beam was undeflected.

V_A = 3700 V V_p = 4500 V d = 50 mm B = 2.5 mT

Use the two equations you have written down and the given data to calculate the specific charge, e/m, of the electron.

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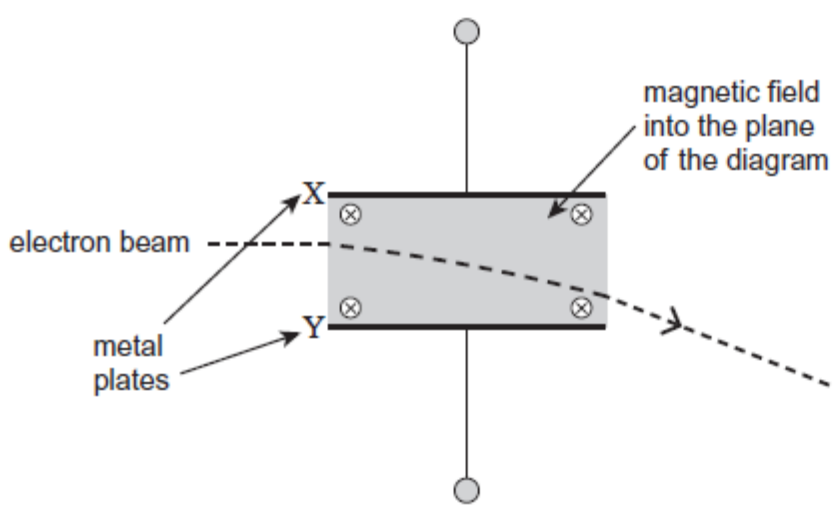
(5)
(Total 10 marks)

10 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)

11 **Figure 1** shows an electron gun that produces electrons with a kinetic energy of 6.0×10^{-16} J.

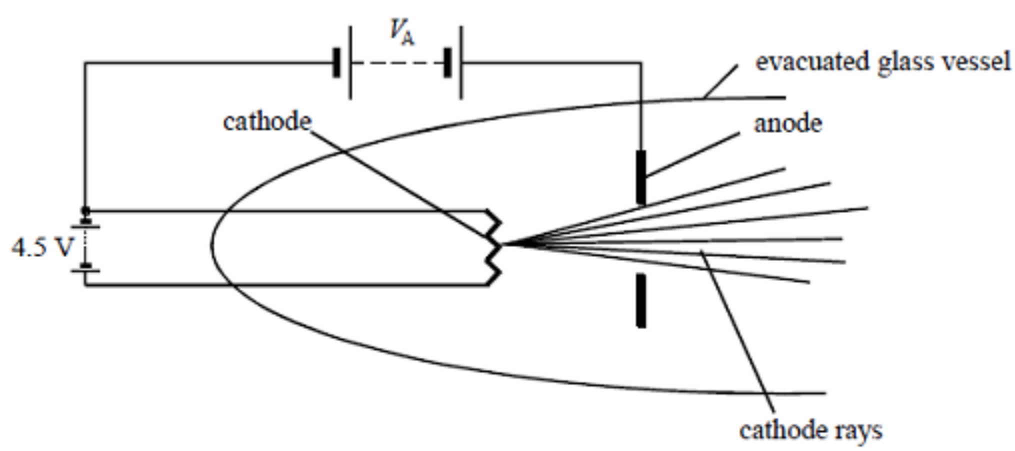

Figure 1

(a) (i) Calculate the cathode-anode potential, V_A.

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(ii) What part does the 4.5 V power supply play in producing electrons?

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(4)

(b) After leaving an electron gun, a narrow beam of electrons of speed 3.6×10^7 m s^{-1} enters a uniform electric field at right angles to the field. The electric field is due to two oppositely charged parallel plates of length 60 mm, separated by a distance of 25 mm as shown in **Figure 2**. The potential difference between the plates is adjusted to 1250 V so that the beam just emerges from the field at P without touching the positive plate.

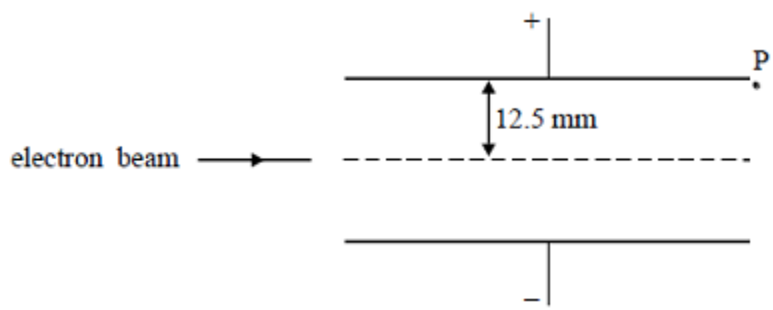

Figure 2

(i) On **Figure 2**, sketch the path of the beam in the field and beyond.

(ii) Calculate the time for which each electron is between the plates.

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(iii) Use the data above to calculate the specific charge of the electron, e/m.

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(8)
(Total 12 marks)