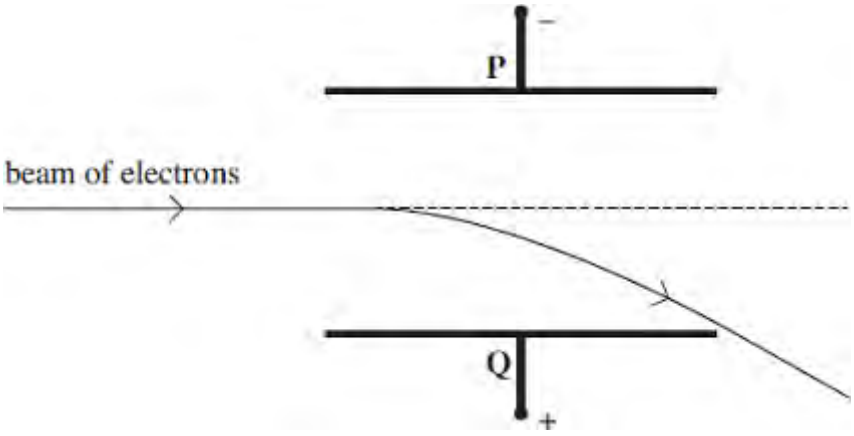
Q1. A narrow beam of electrons is directed into the region between two parallel plates, **P** and **Q**. When a constant potential difference is applied between the two plates, the beam curves downwards towards plate **Q** as shown in the figure below.



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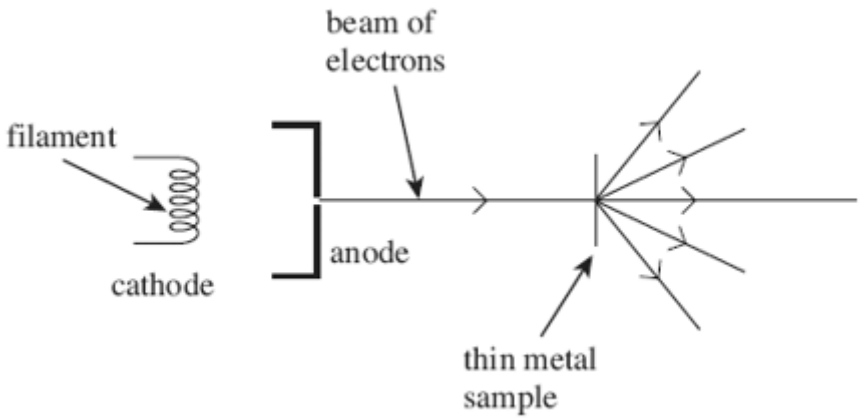
answer = ... C kg^{-1}

(3)

(Total 9 marks)

Q2. In the figure below, a beam of monoenergetic electrons is produced by thermionic emission from a wire filament in an evacuated tube. The beam is directed at a thin metal sample at normal incidence and it emerges from the sample in certain directions only, including its initial direction.



(a) (i) Name the physical process occurring at the thin metal sample in the figure above which shows the electrons behaving as waves.

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(1)

(ii) Explain why the electrons need to be monoenergetic in order for them to emerge in certain directions only.

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(2)

(b) A transmission electron microscope (TEM) operating at an anode potential of 25kV is used to observe an image of a thin sample.

(i) Calculate the momentum of the electrons emerging from the anode, stating an appropriate unit.

answer = ...

(4)

(ii) Describe and explain how the resolution of the image would change if the anode potential were increased.

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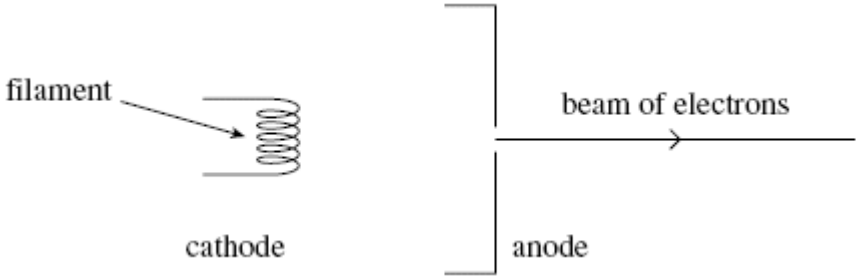
(3)
(Total 10 marks)

Q3. 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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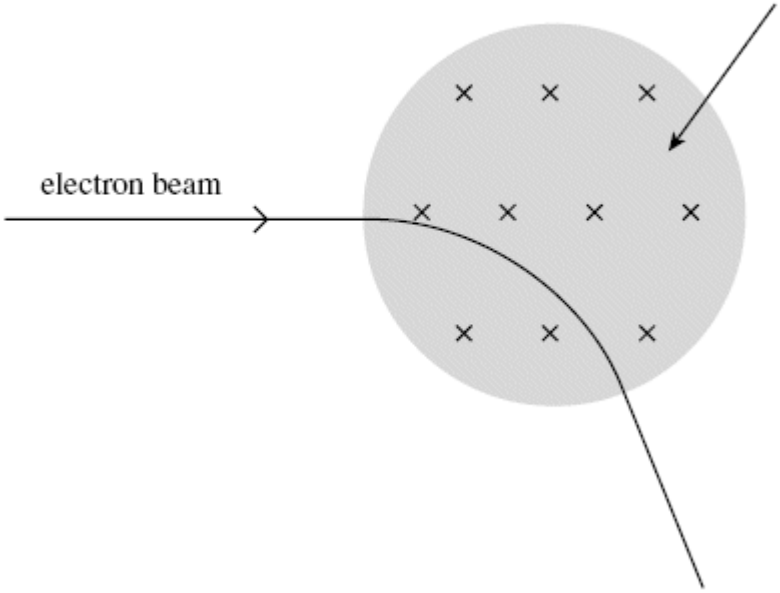
(2)

(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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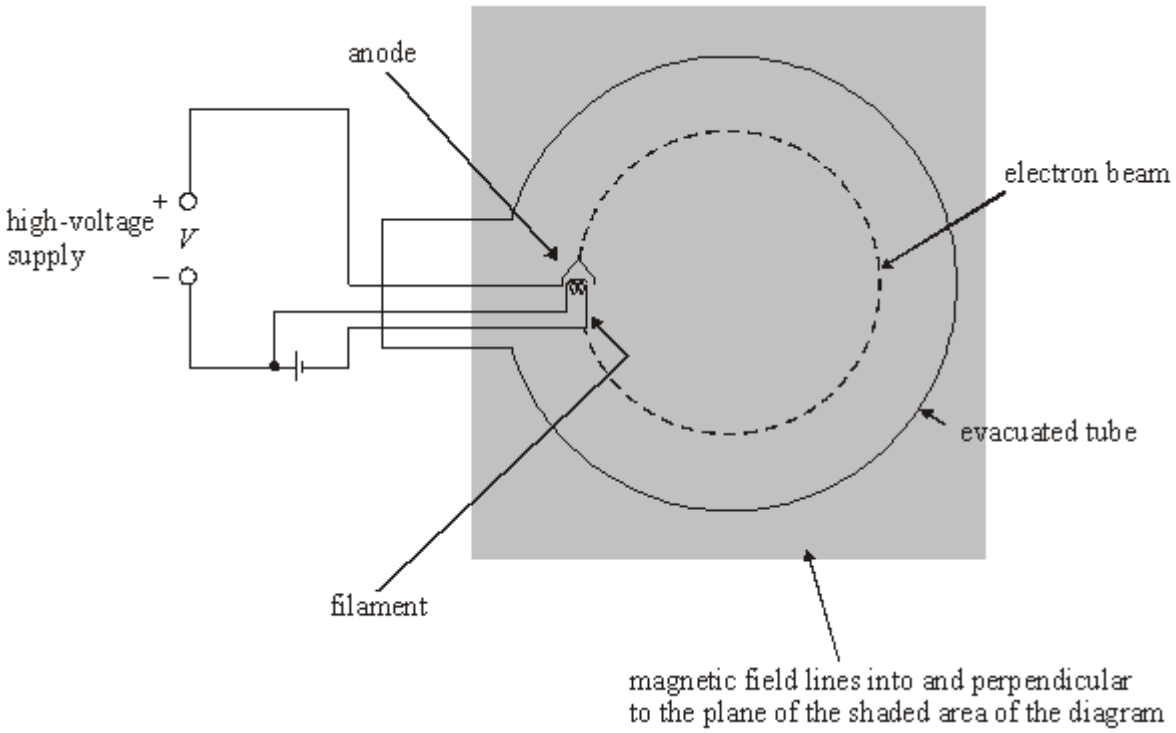
(2)
(Total 13 marks)

Q4. 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)

Q5. Electrons are emitted by the process of *thermionic emission* from a metal wire in an *evacuated* container. The electrons are attracted to a metal anode which has a small hole at its centre. The anode is at a fixed *positive potential* relative to the wire. A beam of electrons emerges through the hole at constant velocity.

(a) Explain

(i) what is meant by thermionic emission,

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(ii) why it is essential that the container is evacuated,

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(iii) why the anode must be at a positive potential.

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(4)

(b) An electron is accelerated from rest through a potential difference of 2500 V between the wire and the anode.

Calculate

(i) the kinetic energy of the electron at the anode,

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(ii) the speed of the electron at the anode. Ignore relativistic effects.

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(4)
(Total 8 marks)