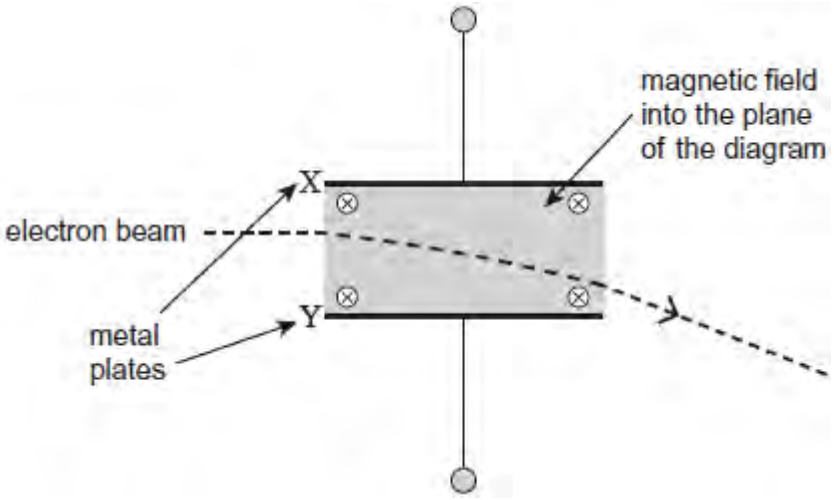
**Q1.** The diagram below shows part of an evacuated tube that is used to determine the specific charge ($e / m$) for an electron. An electron beam is directed between the two parallel metal plates, $\mathrm{X}$ and $\mathrm{Y}$. In the region between the plates, a magnetic field is applied perpendicularly 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 $\mathrm{X}$ and $\mathrm{Y}$ 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 $\mathrm{X}$ and $\mathrm{Y}$ 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:

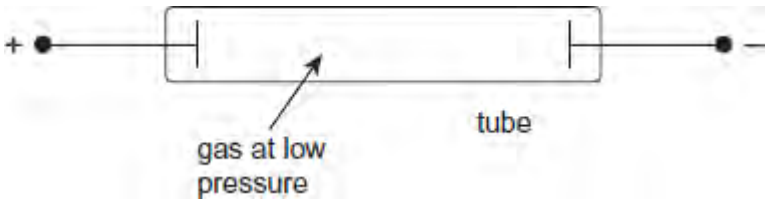
- the procedures used to determine the radius of a droplet and the charge on a

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)**

**Q2.** 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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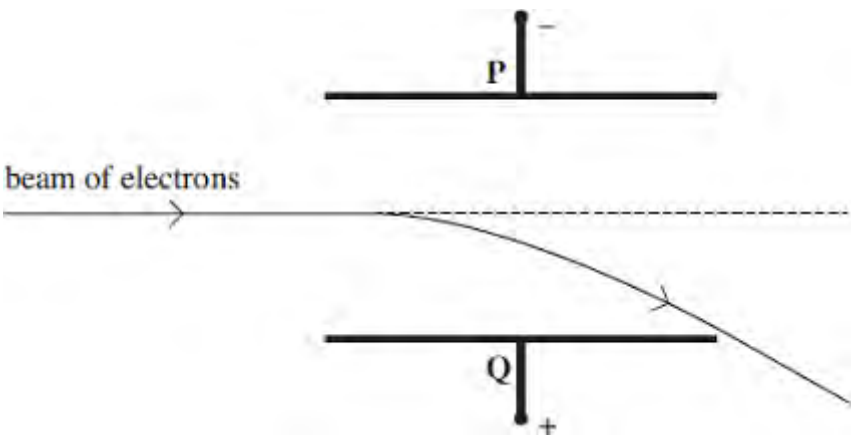
**(2)**
**(Total 7 marks)**

**Q3.** 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 $3.9 \times 10^7$ $ms^{-1}$.

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

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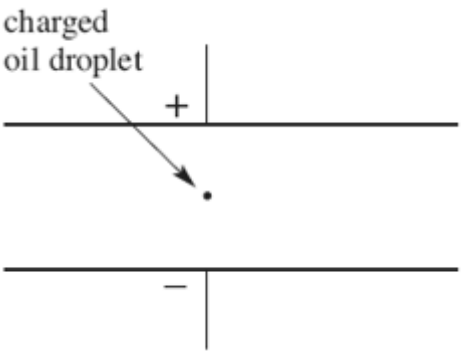
answer = ..... C kg$^{-1}$

**(3)**

**(Total 9 marks)**

**Q4.** 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 $\eta$ is the viscosity of air and $\rho$ 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 $6.8 \times 10^{-15}$ 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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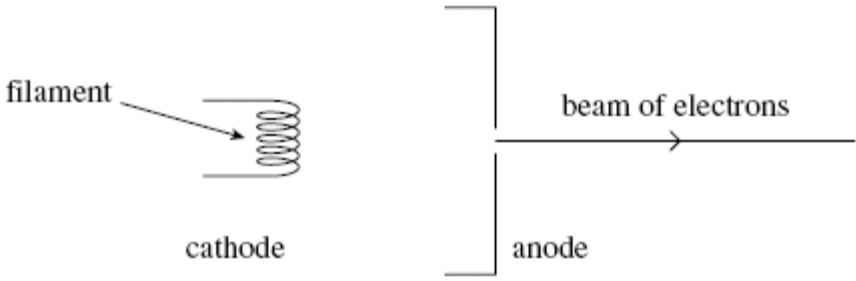
**(2)**
**(Total 8 marks)**

**Q5.** 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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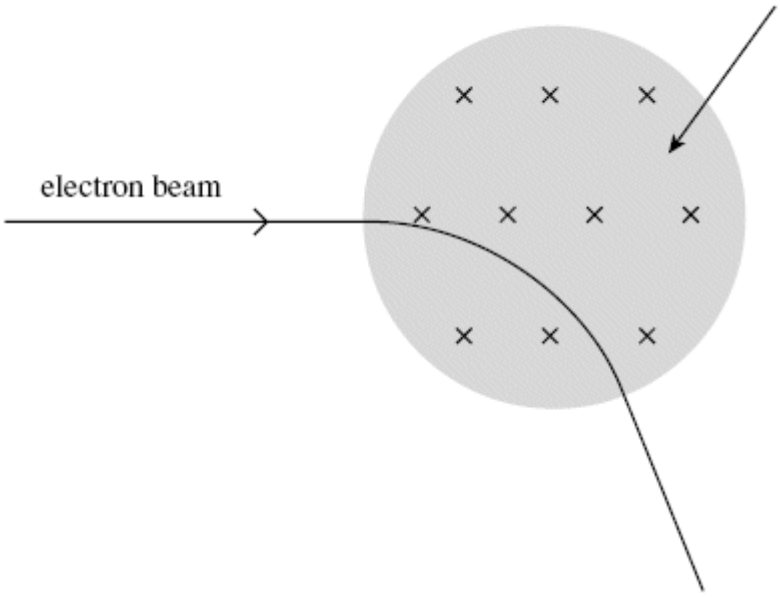
**(2)**

(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 $7.4 \times 10^{6}$ 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)**