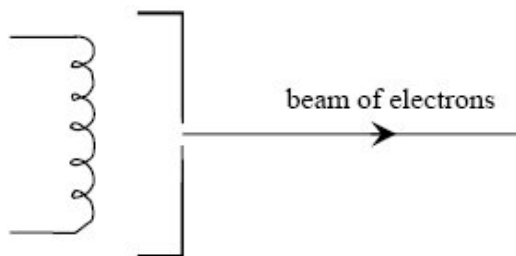


- Q1.** (a) The diagram below shows a narrow beam of electrons produced by attracting electrons emitted from a filament wire to a metal plate which has a small hole in it.



- (i) Why does electric current through the filament wire cause the wire to emit electrons?

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- (ii) Why must the filament wire and the metal plate be in an evacuated tube?

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(3)

- (b) The voltage between the filament wire and the metal plate is 3900 V. For each electron emerging through the hole in the plate, calculate

- (i) the kinetic energy, in J,

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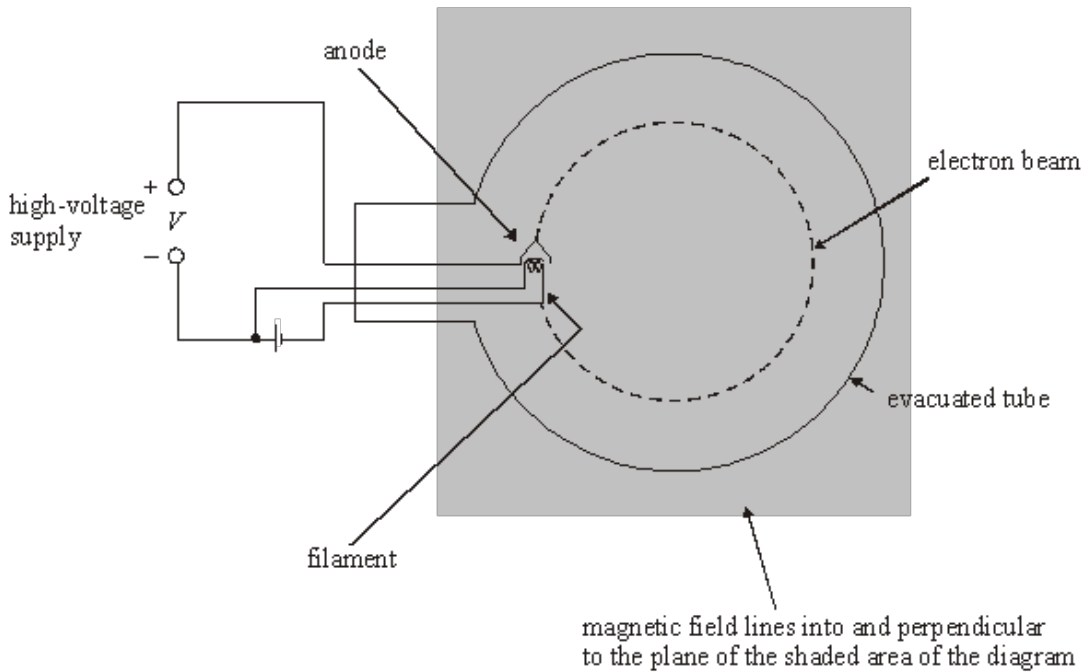
- (ii) the speed.

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(4)

(Total 7 marks)

**Q2.** 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 through 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.

.....  
 .....

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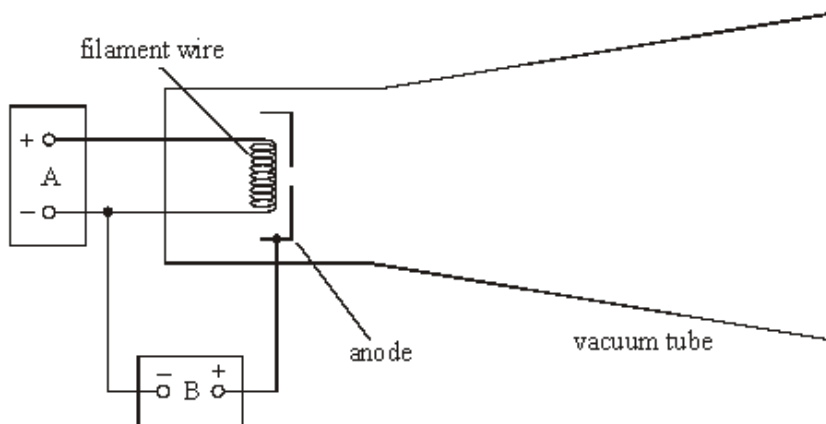
- (iii) The arrangement described above was used to measure the specific charge of the electron,  $e/m$ . Use the following data to calculate  $e/m$ .

$B = 3.1 \text{ mT}$   
 $r = 25 \text{ mm}$   
 $V = 530 \text{ V}$

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(7)  
(Total 10 marks)

**Q3.** A narrow beam of electrons is produced in a vacuum tube using the arrangement shown in **Figure 1**.



**Figure 1**

(a) Describe the function of each voltage supply unit and state a typical voltage for each unit.

(i) unit A

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 .....

(ii) unit B

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 .....

**(3)**

(b) State and explain the effect on the beam of

(i) reducing the voltage of A,

.....  
 .....

(ii) increasing the voltage of B.

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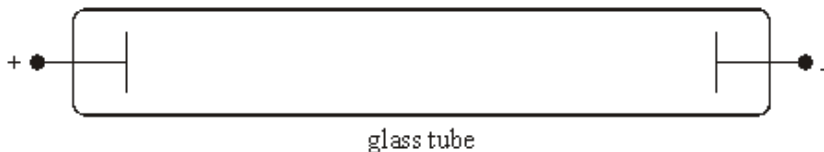
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(4)  
(Total 7 marks)

**Q4.** A potential difference was applied between two electrodes in a glass tube containing air, as shown in the diagram below. The pressure of the air in the tube was gradually reduced until a glow of light was observed between the electrodes.



(i) Explain why light was emitted.

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(ii) State why the glow was not observed until the pressure of the air in the tube was low enough.

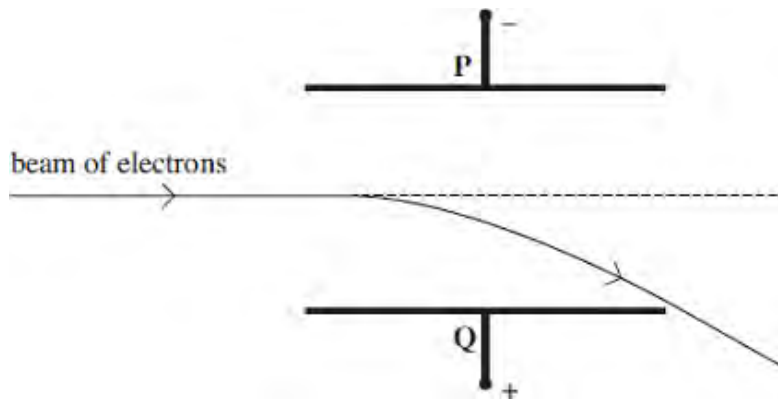
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(Total 4 marks)

- Q5.** 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

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

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

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

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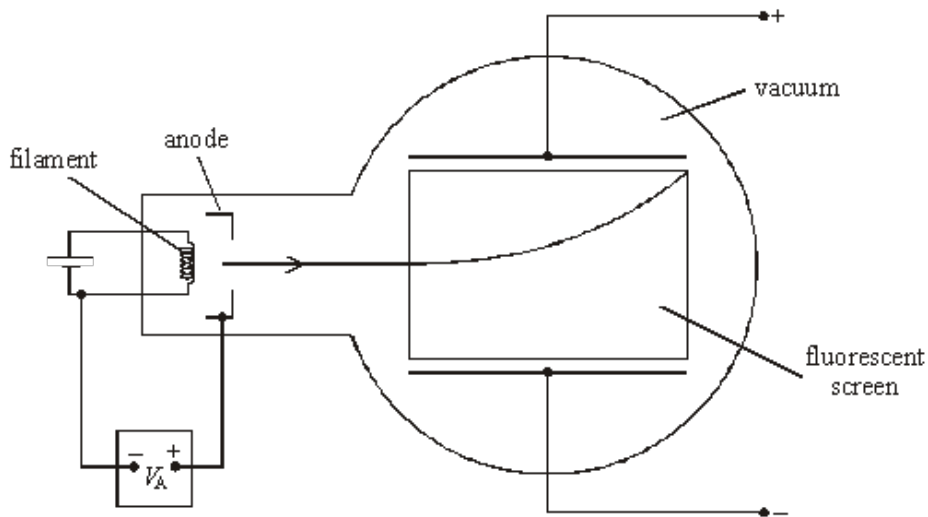
.....

answer = ..... C kg<sup>-1</sup>

(3)

(Total 9 marks)

**Q6.** A narrow beam of electrons is directed into a uniform electric field created by two oppositely charged parallel horizontal plates, as shown in the figure below. The initial direction of the beam is perpendicular to the direction of the electric field. The beam makes a visible trace on a vertical fluorescent screen.



(a) Explain why the beam curves upwards at an increasing angle to the horizontal.

You may be awarded marks for the quality of written communication in your answer.

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(4)

(b) When a uniform magnetic field of a certain flux density is applied perpendicular to the screen, the beam passes between the plates undeflected.

(i) Show that the beam is undeflected when the magnetic flux density  $B = \frac{E}{v}$ ,

where  $E$  is the electric field strength between the plates and  $v$  is the speed of the electrons.

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(ii) Hence show that the specific charge,  $e/m$ , of the electron can be calculated using

$$\frac{e}{m} = \frac{E^2}{2B^2V_A}$$

where  $V_A$  is the anode voltage and  $B$  is the magnetic flux density

needed for zero deflection.

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(iii) Determine the specific charge of the electron using the following data:

- anode voltage = 4500 V
- potential difference between the plates = 3800 V
- plate separation = 50 mm
- magnetic flux density = 1.9 mT

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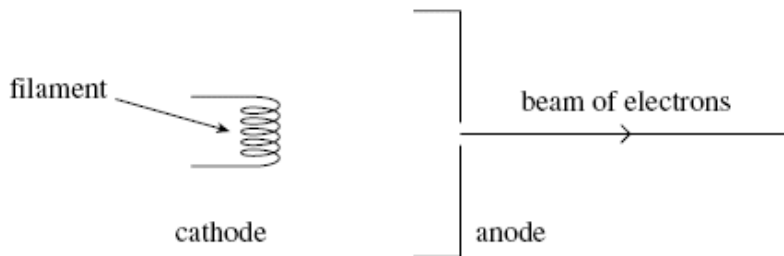
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(7)  
(Total 11 marks)

**Q7.** 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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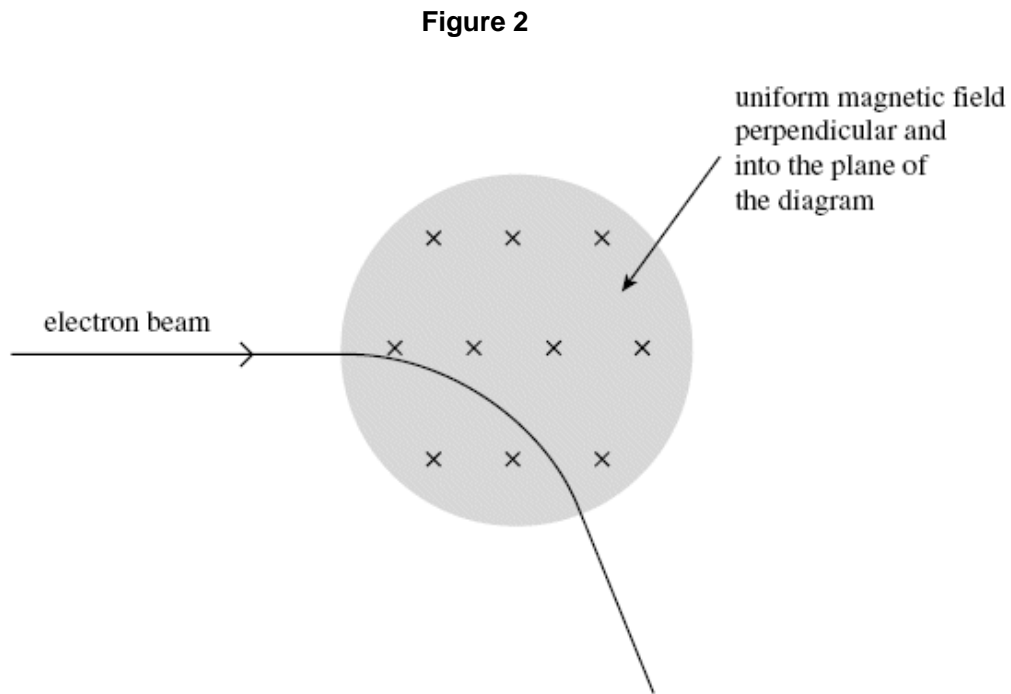
(2)

(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**.



- (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  $7.4 \times 10^6 \text{ m s}^{-1}$  and the magnetic flux density is  $0.60 \text{ m T}$ , the radius of curvature of the beam is  $68 \text{ mm}$ .

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)

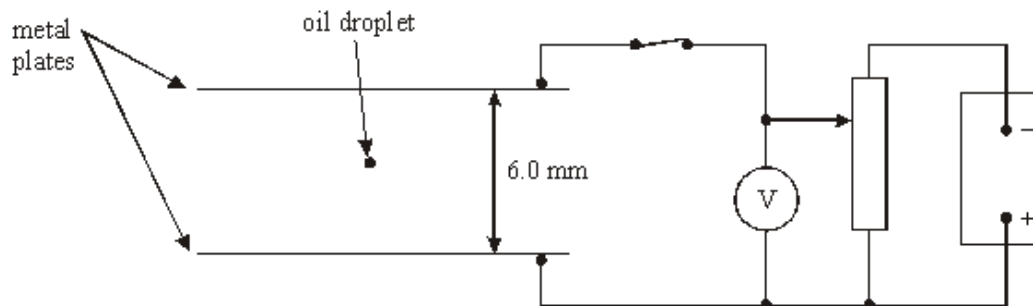
- (iii) Discuss the historical relevance of the value of the specific charge of the electron compared with the specific charge of the  $\text{H}^+$  ion.

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(2)

(Total 13 marks)

**Q8.** In an experiment to measure the charge on a charged oil droplet, a droplet was observed between two horizontal metal plates, as shown in the diagram below, spaced 6.0 mm apart.



(a) The oil droplet was held stationary when a negative potential of 320 V was applied to the top plate, keeping the lower plate at zero potential.

(i) State the sign of the charge on the droplet.

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(ii) With reference to the forces acting on the droplet explain why it was stationary.

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(2)

(b) The potential difference between the plates was then switched off and the droplet fell at constant speed through a vertical distance of 1.20 mm in 13.8 s.

(i) Calculate its speed of descent.

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 .....

- (ii) By considering the forces on the spherical droplet of radius  $r$  as it falls at constant speed  $v$ , show that

$$v = \frac{2\rho gr^2}{9\eta}$$

where  $\eta$  is the viscosity of the air between the plates and  $\rho$  is the density of the oil. Ignore buoyancy effects.

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- (iii) Calculate the radius of the droplet and hence show that its mass is  $2.6 \times 10^{-15}$  kg.

viscosity of the air =  $1.8 \times 10^{-5}$  N s m<sup>-2</sup>

density of the oil = 960 kg m<sup>-3</sup>

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(iv) Calculate the charge carried by this droplet.

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(10)  
(Total 12 marks)

**Q9.** In an experiment to measure the charge of an oil droplet, a positively charged oil droplet was held stationary by means of a uniform electric field of strength  $4.9 \times 10^5 \text{ V m}^{-1}$ .

(a) (i) What was the direction of the electric field?

.....

(ii) Show that the specific charge of the oil droplet was  $2.0 \times 10^{-5} \text{ C kg}^{-1}$ .

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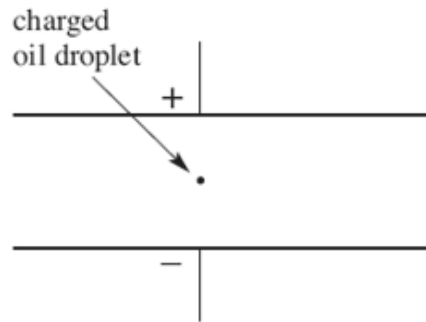
(3)

(b) When the electric field was switched off the oil droplet fell and quickly reached constant speed.  
Explain why the oil droplet reached constant speed.

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(3)  
(Total 6 marks)

**Q10.** 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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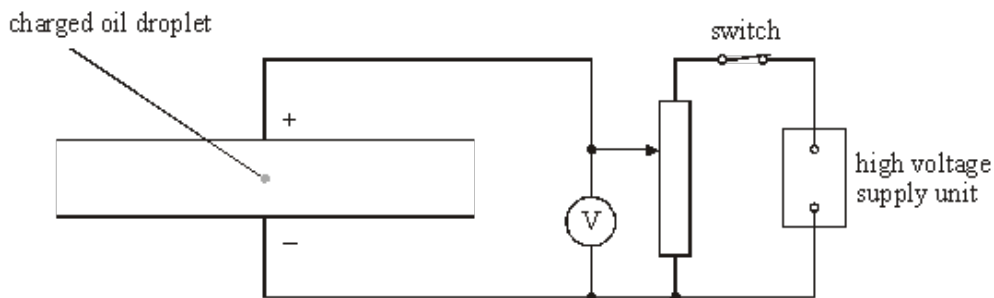
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(2)  
(Total 8 marks)

**Q11.** A charged oil droplet was observed falling between two oppositely charged parallel plates, as shown in **Figure 1**.



**Figure 1**

- (a) Explain why the droplet stopped moving and remained stationary when the potential difference between the plates was adjusted to a certain value,  $V_c$ .

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(3)

- (b) (i) The spacing between the plates is 6.0 mm. A charged oil droplet of mass  $6.2 \times 10^{-14}$  kg is stopped when  $V_c = 5700$  V. Calculate the charge on this droplet.

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- (ii) Describe and explain what would have happened to this droplet if the potential difference had been greater than 5700 V.

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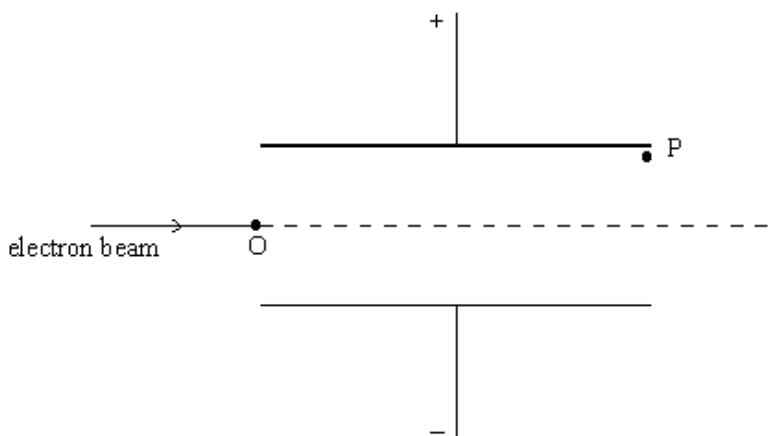
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(5)  
(Total 8 marks)

**Q12.** 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)

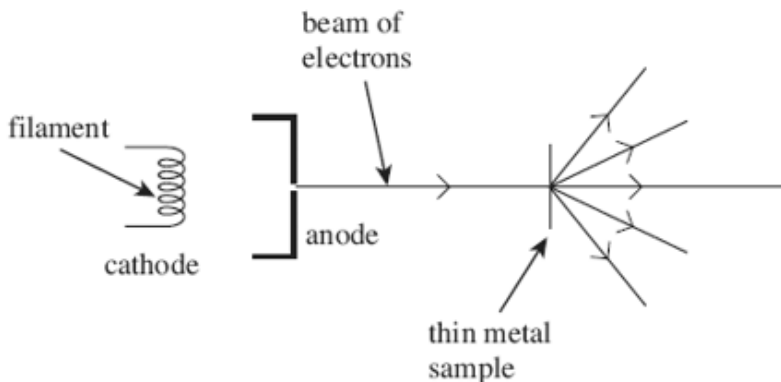
(c) In an experiment to measure the specific charge of the electron, electrons were accelerated from rest through a potential difference of 2900 V to a speed of  $3.2 \times 10^7 \text{ m s}^{-1}$ . Use this information to calculate the specific charge of the electron.

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(3)

(Total 10 marks)

**Q13.** 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.

.....  
.....

(1)

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

.....  
.....  
.....  
.....

(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)

**M1.** (a) (i) current heats the wire **(1)**

electrons (in filament) gain sufficient k.e. (to leave the filament) **(1)**

(ii) electrons would collide (or be absorbed or scattered) by gas atoms (or molecules) **(1)**

3

(b) (i) k.e. ( $= eV$ )  $= 1.6 \times 10^{-19} \times 3900$  **(1)**  $= 6.2 \times 10^{-16}$  (J) **(1)**

(ii) (rearrange  $\frac{1}{2} m v^2 = eV$  to give)

$$v (= (2eV/m)^{1/2}) = \left( \frac{2 \times 1.6 \times 10^{-19} \times 3900}{9.1 \times 10^{-31}} \right)^{1/2} \text{ (1)} = 3.7 \times 10^7 \text{ m s}^{-1}$$

4

**[7]**

**M2.** (a) (i) emission of (conduction) electrons from a heated metal (surface) or filament/cathode **(1)**  
work done on electron  $= eV$  **(1)**

(ii) gain of kinetic energy (or  $\frac{1}{2} m v^2$ )  $= eV$ ; rearrange to give required equation **(1)**

3

- (b) (i) work done = force  $\times$  distance moved in direction of force **(1)**  
 force (due to magnetic field) is at right angles to the direction of motion/velocity  
 [or no movement in the direction of the magnetic force  
 $\therefore$  no work done] **(1)**  
 electrons do not collide with atoms **(1)**

any two **(1)(1)**

[alternative for 1<sup>st</sup> and 2<sup>nd</sup> marks  
 (magnetic) force has no component along direction of motion **(1)**  
 no acceleration along direction of motion **(1)**  
 or acceleration perpendicular to velocity]

$$r = \frac{mv}{Be} \left( \text{or } Bev = \frac{mv^2}{r} \right) \text{ (1)}$$

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

$$\therefore r^2 \left( = \frac{m^2 v^2}{B^2 e^2} \right) = \frac{m^2}{B^2 e^2} \times \frac{2eV}{m} = \frac{2mV}{B^2 e} \text{ (1)}$$

(iii) (rearranging the equation gives)  $\frac{e}{m} = \frac{2V}{B^2 r^2} \text{ (1)}$

$$\frac{e}{m} = \frac{2 \times 530}{(3.1 \times 10^{-3})^2 \times (25 \times 10^{-3})^2} = 1.7(6) \times 10^{11} \text{ Ckg}^{-1} \text{ (1)}$$

7

[10]

- M3.** (a) (i) unit A: supplies current/power/energy to the filament or heats the filament **(1)**  
 0 – 50 V **(1)**
- (ii) unit B: to make the anode positive w.r.t. the filament, so that electrons are attracted/accelerated to the anode **(1)**  
 > 250 V **(1)**

max 3

- (b) (i) beam current or intensity is reduced **(1)**  
 (because) fewer electrons are emitted (per sec) from the filament **(1)**  
 [or no beam as no electrons emitted if voltage of A  
 reduced enough **(1)**  
 (only)]
- (ii) electrons travel faster [or more kinetic energy] **(1)**  
 (because the force of) attraction to the anode is greater **(1)**

4

[7]

- M4.** (i) electrons [or ions] present **(1)**  
 electron /ion accelerated by electric field  
 [or electrons and ions collide] **(1)**  
 excitation/ionisation of gas atoms/ions/molecules/particles occur **(1)**  
 photons emitted on return to lower energy or ground state **(1)**
- (ii) electrons/ions do not gain enough kinetic energy  
 (to produce ionisation) **(1)**  
 because too many atoms/ions/molecules/particles present **(1)**

max 4  
QWC 1

[4]

- M5.** (a) force due to electric field acts (vertically) downwards on electrons ✓  
vertical (component) of velocity of each electron increases ✓  
 horizontal (component of) velocity unchanged (so angle to initial direction  
 increases) ✓
- (b) (i) magnetic flux density should be reversed and adjusted in strength  
 (gradually until the beam is undeflected) ✓
- (ii) magnetic (field) force =  $Bev$   
 and electric (field) force =  $eV/d$  ✓  
 (Accept Q or q as symbol for e (charge of electron)  
 $Bev = eV/d$  (for no deflection) gives  $v = V/Bd$  ✓

3

1

2



- (c) (gain of) kinetic energy of electron = work done by anode pd or  $\frac{1}{2} m v^2 = e V_{(A)}$  ✓

$$\frac{e}{m} \left( = \frac{v^2}{2V_{(A)}} \right) = \frac{(3.9 \times 10^7)^2}{2 \times 4200} \checkmark$$

$$= 1.8 \times 10^{11} \text{ C kg}^{-1}.$$

3

[9]

- M6.** (a) each electron experiences an electrostatic force (vertically) upwards **(1)**  
 this force does not change as the electron moves across the field **(1)**  
 each electron (therefore) has a (constant) acceleration vertically upward **(1)**  
 velocity of each electron has a constant horizontal component of velocity **(1)**  
 [or has an increasing vertical component of velocity]  
 so the direction of motion/velocity becomes closer and closer to a  
 vertical line (as electron moves across the field) **(1)**  
 [or angle to the vertical becomes less]

Max 4  
QWC 1

- (b) (i) (for beam to be undeflected)  
 force due to electric field,  $eE$  (or  $qE$ ) **(1)**

$$\text{equals force due to magnetic field, } Bev \text{ (1) (gives } v = \frac{E}{B} \text{)}$$

- (ii) (k.e. at anode) =  $\frac{1}{2}mv^2 = eV_A$  **(1)**

$$\text{gives } \frac{e}{m} = \frac{v^2}{2V_A} \text{ (1) (i.e. } = \frac{E^2}{2B^2V_A} \text{)}$$

- (iii)  $E \left( \frac{V}{d} \right) = \frac{3800}{50 \times 10^{-3}}$  **(1)** ( $7.6 \times 10^4 \text{ (V m}^{-1}\text{)}$ )

$$\frac{e}{m} = \left( \frac{E^2}{2B^2V_A} \right) = \frac{(7.6 \times 10^4)^2}{2 \times (1.9 \times 10^{-3})^2 \times 4500} \text{ (1)}$$

$$= 1.8 \times 10^{11} \text{ C kg}^{-1} \text{ (1)}$$

7

[11]

- M7.** (a) (i) The number of electrons (per second) in the beam will increase **(1)**  
because the filament will become hotter and will emit more  
electrons (per 2 second) **(1)** 2
- (ii) the speed (or kinetic energy) of the electrons will increase **(1)**  
because the electrons (from the filament) are attracted towards  
the anode with a greater acceleration (or force) **(1)**  
(or gain more kinetic energy in crossing a greater pd) 2
- (b) (i) (magnetic) force on each electron in the beam is perpendicular  
to velocity **(1)**  
no work is done on each electron by (magnetic) force so ke  
(or speed) is constant **(1)**  
magnitude of (magnetic) force is constant because speed  
is constant **(1)**  
(magnetic) force is always perpendicular to velocity so  
is centripetal **(1)** max 3
- (ii) rearranging  $r = \frac{mv}{Be}$  gives  $\frac{e}{m} = \frac{v}{Br}$  **(1)**  
$$\frac{e}{m} = \frac{7.4 \times 10^6}{6.0 \times 10^{-4} \times 68 \times 10^{-3}} = 1.81 \times 10^{11} \text{ (1) C kg}^{-1} \text{ (1)}$$
for correct answer to 2 sf **(1)** 4
- (iii) specific charge for the electron  $\approx 2000 \times$  specific charge of  $\text{H}^+$  **(1)**  
(accept = and accept any value between 1800 and 2000)  
which was the largest known specific charge before the specific  
charge of the electron was determined/measured **(1)**  
(or which could be due to a much greater charge or a much smaller  
mass of the electron) 2

[13]

- M8.** (a) (i) positive **(1)**  
(ii) electric force directed **upwards** = weight **(1)**  
[or  $\frac{QV}{d} = mg$ ]

2

(b) (i)  $v = \frac{1.20 \times 10^{-3}}{13.8} = 8.7 \times 10^{-5} \text{ m s}^{-1}$  (1)

(ii) weight [or  $mg$ ] =  $\frac{4}{3} \pi r^3 \rho g$  (1)  
 (since speed constant) viscous force =  $6 \pi \eta r v$  (1)  
 $\therefore \frac{4}{3} \pi r^3 \rho g = 6 \pi \eta r v$  to give desired equation (1)

(iii) rearrange equation to give  $r = \left( \frac{9 \eta v}{2 \rho g} \right)^{1/2}$  (1)

$$\left\{ = \left( \frac{9 \times 1.8 \times 8.7 \times 10^{-5}}{2 \times 960 \times 9.8} \right)^{1/2} \right\} = 8.7 \times 10^{-7} \text{ m (1) } (8.65 \times 10^{-7} \text{ m})$$

(allow C.E. for value of  $v$  from (i), but not 3rd mark)

$$m (= \frac{4}{3} \pi r^3 \rho) = \frac{4}{3} \pi (8.65 \times 10^{-7})^3 \times 960 \text{ (1) } (= 2.6 \times 10^{-15} \text{ kg})$$

(iv)  $\frac{QV}{d} = mg$  (1)

$$Q = \frac{2.6 \times 10^{-15} \times 9.8 \times 6.0 \times 10^{-3}}{320} \text{ (1)}$$

$$= 4.8 \times 10^{-19} \text{ C (1) } (4.78 \times 10^{-19} \text{ C})$$

10

[12]

**M9.** (a) (i) (vertically) upwards (1)

(ii)  $mg = qE, \therefore \frac{q}{m} = \frac{g}{E}$  (1)

$$\frac{9.8}{4.9 \times 10^5} \text{ (1) } (= 2.0 \times 10^{-5} \text{ C kg}^{-1})$$

3

- (b) initial downwards acceleration due to weight (or gravity) (1)  
 viscous force/drag/friction (or resistance) due to air  
 increases with increase in speed (1)  
 speed increases until drag become equal to (and opposite to) weight  
 (no resultant force) hence no acceleration (1)

max 3

[6]

**M10.** (a) (i) **either**

(at terminal speed ( $v$ )) the viscous force on the droplet = its weight (or  $mg$  or the force of gravity on it)

**or**

viscous force =  $6\pi\eta rv$  (where  $r$  is the radius of the droplet and  $\eta$  is its viscosity) and weight (=  $mg$ ) =  $4\pi r^3\rho g/3$  ✓

$$4\pi r^3\rho g/3 = 6\pi\eta rv \quad \checkmark$$

(which gives  $r = (9\eta v/2\rho g)^{1/2}$ )

2

(ii)  $r$  (can be calculated as above then) used in the formula  $m = 4\pi r^3\rho/3$  to find the droplet mass,  $m$  [owtte] ✓

**alternatively;** (from  $6\pi\eta rv = mg$ ) (as all values are known use)  $m = 6\pi\eta rv/g$  ✓

1

(b) (i) electric force (or  $QV/d$ ) = the droplet weight (or  $mg$ ) ✓

$$Q = \frac{mgd}{v} = \frac{6.8 \times 10^{-15} \times 9.8(1) \times 5.0 \times 10^{-3}}{690} = 4.8 \times 10^{-19} \text{ C} \quad \checkmark$$

2 sf answer ✓

3

(ii) **any two from**

the charge on each droplet is a whole number  $\times 1.6 \times 10^{-19} \text{ C}$  (or  $\times$  charge of the electron) ✓

the least amount of charge (or the quantum of charge) is the charge of the electron ✓

the quantum of charge is  $1.6 \times 10^{-19} \text{ C}$  [owtte] ✓

max 2

[8]

**M11.** (a) force due to electric field is vertically upwards and proportional (or related to) plate pd **(1)**

at  $V = V_c$ , force due to field is equal and opposite to the weight of the droplet **(1)**

no resultant force (or forces balance) at  $V_c$  (droplet remains stationary) **(1)**

3

- (b) (i) electric force (or  $qV/d$ ) = weight (or  $mg$ ) **(1)**

$$q\left(\frac{mgd}{V}\right) = \frac{6.2 \times 10^{-14} \times 9.8 \times 6.0 \times 10^{-3}}{5700} \quad \mathbf{(1)}$$

$$= 6.4 \times 10^{-19} \text{C} \quad \mathbf{(1)}$$

- (ii) for  $pd > 5700$  (V), droplet moves upwards **(1)**  
 due to increased electric force **(1)**  
 droplet reaches terminal velocity **(1)**

max 5

**[8]**

- M12.** (a) path curves upwards from O to P  
 path is tangential to curve at P and straight beyond P

2

- (b) (i) magnetic field exerts a force on a moving charge/electron **(1)**  
 magnetic force has a downwards component (at all points)  
 [or magnetic force < electric force] **(1)**

- (ii) magnetic force =  $Bev$  **(1)**

$$\text{electric force} \left( \frac{eV_p}{d} \right) = eE \quad \mathbf{(1)}$$

$$Bev = eE \text{ (gives } v = \frac{E}{B} \text{)} \quad \mathbf{(1)}$$

5

- (c) work done (or  $eV$ ) = gain of kinetic energy (or  $\frac{1}{2}mv^2$ ) **(1)**

$$\frac{e}{m} = \frac{v^2}{2} \quad \mathbf{(1)}$$

$$= \frac{(3.2 \times 10^7)^2}{2 \times 2900} = 1.8 \times 10^{11} \text{ C kg}^{-1} \quad \mathbf{(1)}$$

3

**[10]**

**M13.** (a) (i) diffraction ✓✓

1

(ii) the electrons in the beam must have the same wavelength ✓✓

otherwise electrons of different wavelengths (or speeds/velocities/energies/momenta) would diffract by different amounts (for the same order) [owtte] ✓✓

2

(b) (i) ( $eV = \frac{1}{2} m v^2$  gives) **either**  $v = \sqrt{\frac{2eV}{m}}$

or  $1.6 \times 10^{-19} \times 25000 = \frac{1}{2} \times 9.1 \times 10^{-31} \times v^2$  ✓✓

$$v = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 25000}{9.1 \times 10^{-31}}} = 9.4 \times 10^7 \text{ m s}^{-1} \checkmark \checkmark$$

$p$  or  $mv$  ( $= 9.1 \times 10^{-31} \times 9.4 \times 10^7$ )  $= 8.5 \times 10^{-23}$  ✓✓

kg m s<sup>-1</sup> (or N s) ✓✓

**alternatives for first two marks**

$p$  or  $mv = \sqrt{2meV}$  ✓✓ =

$$\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 25000} \checkmark \checkmark$$

4

(ii) **any two of the first three mark points**

increase of pd increases the speed (or velocity/energy/momentum) of the electrons ✓✓

(so) the electron wavelength would be smaller ✓✓

(and) the electrons would diffract less (when they pass through the lenses) ✓✓

**and**

the image would show greater resolution (or be more detailed) ✓✓

max 3

[10]

