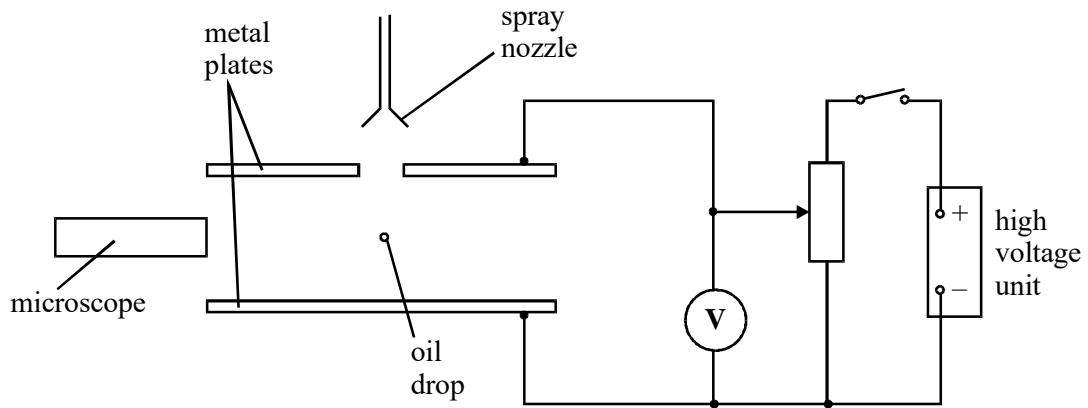


1. Millikan determined the charge on individual oil droplets using an arrangement as represented in the diagram. The plate voltage necessary to hold a charged droplet stationary was measured. The time the droplet took to fall a known distance with the plate voltage off was then measured.



- (a) (i) Explain why a charged oil droplet reaches a constant speed when the plate voltage is switched off.

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- (ii) By considering the forces on such a droplet, show that the radius, r , of the droplet is related to the speed, v by

$$r^2 = \frac{9\eta v}{2\rho g},$$

where η is the viscosity of air and ρ is the density of the oil. Ignore the effects of buoyancy.

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(6)

- (b) In an experiment to measure the charge on an oil droplet, a charged droplet was held stationary by a voltage of 225 V between two plates at a separation of 5.0 mm. When the plate voltage was switched off, the droplet descended a vertical distance of 1.20mm in a time of 15.5s.
Ignore the effect of buoyancy of the air.

density of oil = 950 kg m⁻³

viscosity of air = 1.8 × 10⁻⁵ N s m⁻²

(i) Show that the mass of this droplet was 2.2×10^{-15} kg.

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(ii) Calculate the charge carried by this droplet.

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(6)

(c) Millikan measured the charge on each of many oil droplets. Explain what he concluded from his measurements.

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(2)

(Total 14 marks)

2.

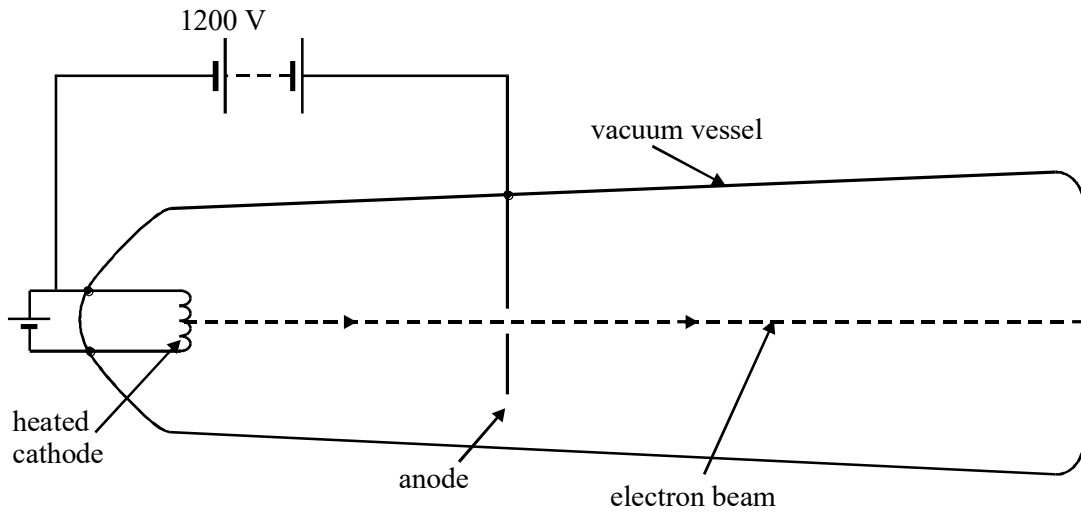


figure 1

- (a) A side view of a simple electron gun is shown in figure 1. Show that the speed with which electrons emerge from the anode of this gun will be about $2 \times 10^7 \text{ m s}^{-1}$ when the potential difference between the cathode and the anode is 1200 V.

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(3)

- (b) Electrons emerging horizontally from the electron gun in part (a) then enter a uniform magnetic field which is directed upwards in the plane of the diagram (figure 1). Calculate the magnitude of the force on an electron in this magnetic field of flux density 0.080 T.

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(2)

- (c) Draw the path of an electron passing through the field described in part (b) on each of the two diagrams shown in figure 2. No further calculations are expected.

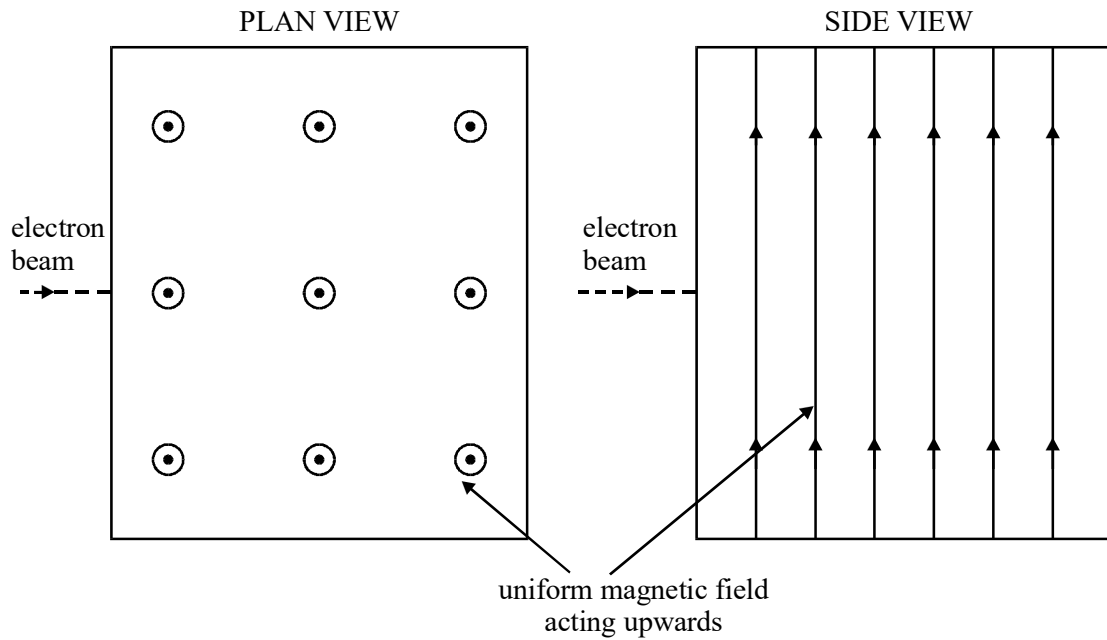


figure 2

(3)

- (d) (i) State whether the speed of an electron changes while it is in the magnetic field. Explain your answer.

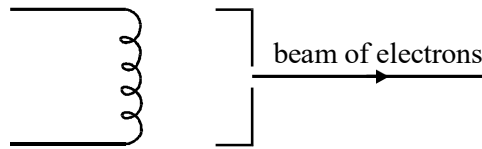
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- (ii) State, with a reason, whether the force on the electron alters while it is in the magnetic field.

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(2)
 (Total 10 marks)

3. (a) The diagram 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 an 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 plate is 3600 V. For each electron emerging through the hole in the plate, calculate

- (i) the kinetic energy, in J,

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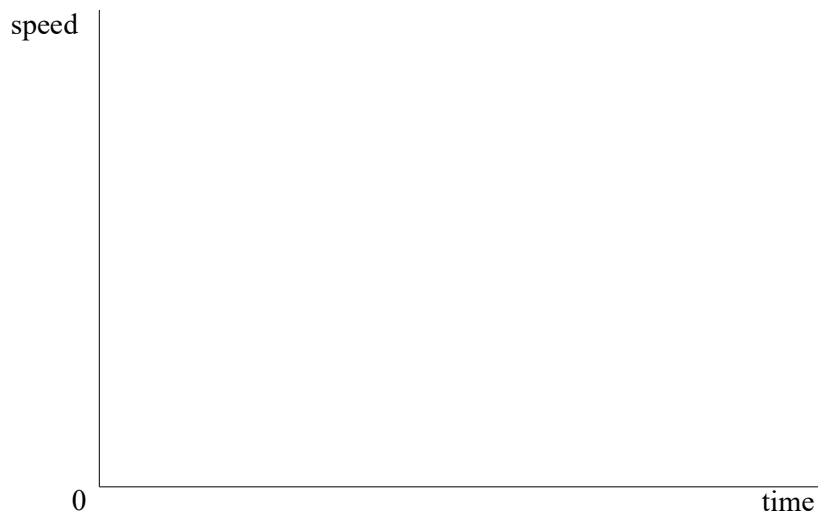
(ii) the speed.

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(4)
(Total 7 marks)

4. In an experiment to measure the charge carried by an oil droplet, Millikan determined the mass of the oil droplet by timing the fall of the droplet through a measured vertical distance in the absence of an electric field.

(a) (i) Sketch a graph, on the axes, to show how the speed of an oil droplet increases from zero after the electric field holding it stationary has been switched off.



(ii) Explain why the initial acceleration of the droplet is equal to g , the acceleration due to gravity. Assume the effect of buoyancy is negligible.

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(iii) Explain why the droplet reaches terminal speed.

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(6)

(b) A charged droplet was held stationary by a suitable electric field. When the field was switched off, the droplet took 12.8 s to fall through a vertical distance of 1.00 mm from its rest position.

(i) Calculate the terminal speed of the droplet, assuming that it took negligible time to reach terminal speed.

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(ii) The acceleration of the droplet decreased after the electric field was switched off, in accordance with the equation

$$a = g e^{-kt}$$

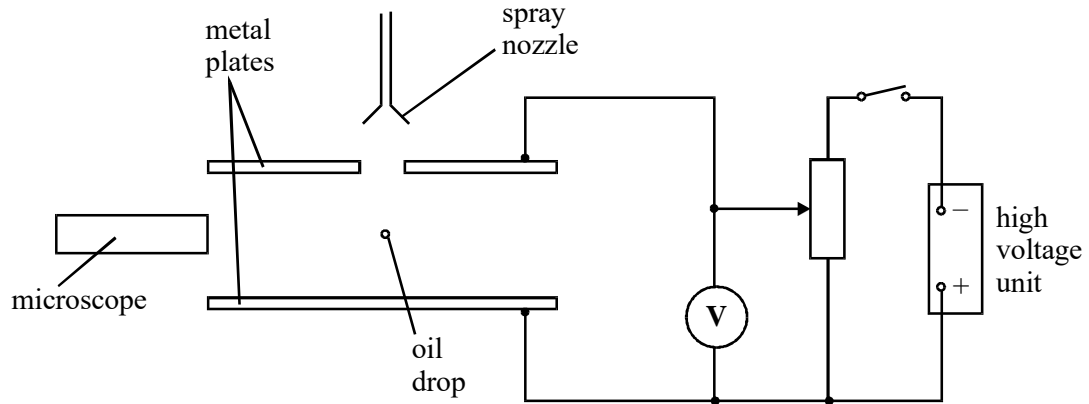
where $k = g/v_0$ and v_0 is the terminal speed of the droplet.
Justify the assumption in (i) by means of a suitable calculation.

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(4)

(Total 10 marks)

5. A charged oil droplet of mass 46×10^{-16} kg is observed between two horizontal metal plates spaced 40 mm apart.



- (a) The droplet is held stationary with the top plate at a potential of -565 V relative to the lower plate.

(i) What is the sign of the charge carried by the droplet?

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(ii) Calculate the magnitude of the charge on the droplet. Ignore buoyancy effects

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(iii) Comment on the significance of this result

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- (b) State and explain the direction in which the droplet would move if the top plate were made more negative relative to the lower plate.

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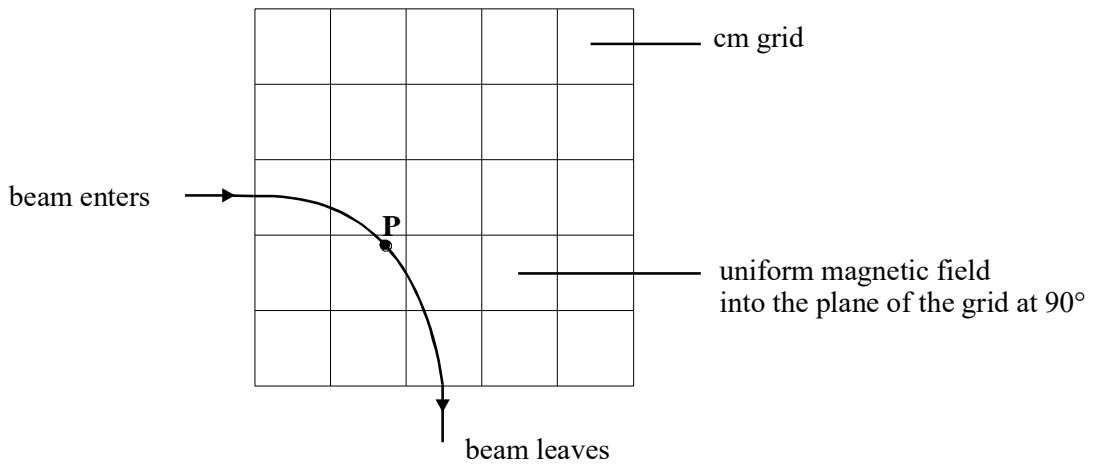
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(2)
(Total 7 marks)

6. (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)

7. Figure 1 shows an electron gun that produces electrons with a kinetic energy of $6.0 \times 10^{-16} \text{ J}$.

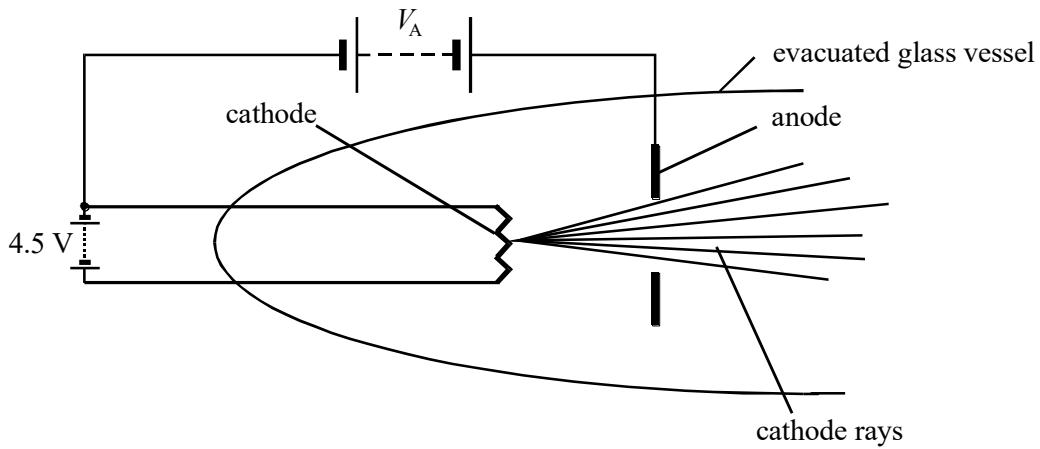


figure 1

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

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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 $3.6 \times 10^7 \text{ m s}^{-1}$ 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.

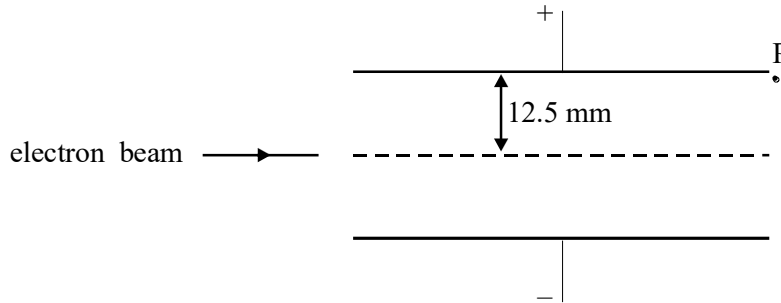


figure 2

- (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)

8. In an experiment to determine the charge on a charged oil droplet, the droplet was held stationary in a vertical electric field of strength 57 k V m^{-1} . After the electric field was switched off, the droplet fell at a steady speed, taking 18.3 s to fall through a vertical distance of 2.0 mm .

viscosity of air = $1.8 \times 10^{-5} \text{ N s m}^{-2}$,
 density of the oil = 970 kg m^{-3} .

- (a) Calculate the speed of the droplet when it was falling.

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(1)

- (b) Show that the droplet's radius was $9.7 \times 10^{-7} \text{ m}$.

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(3)

(c) Calculate the charge of the droplet.

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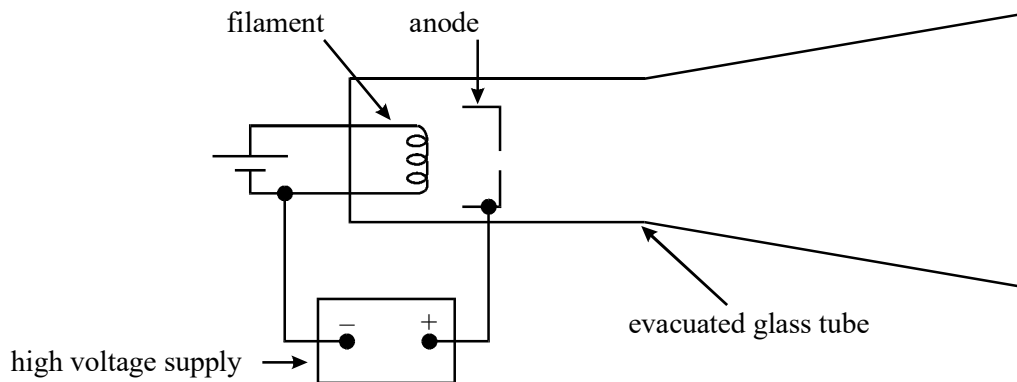
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(3)
(Total 7 marks)

9. (a) A beam of monoenergetic electrons is produced by *thermionic emission* from a metal filament, using an arrangement represented in the diagram.



(i) Describe the process of thermionic emission.

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- (ii) Explain why thermionic emission is negligible when the filament current is too low.

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(4)

- (b) The anode is at a positive potential of 4200 V with respect to the filament.

- (i) Calculate the kinetic energy, in J, of an electron in the beam in part (a) as it passes through the anode.

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- (ii) Calculate the speed of the electrons in this beam as they pass through the anode. Ignore relativistic effects.

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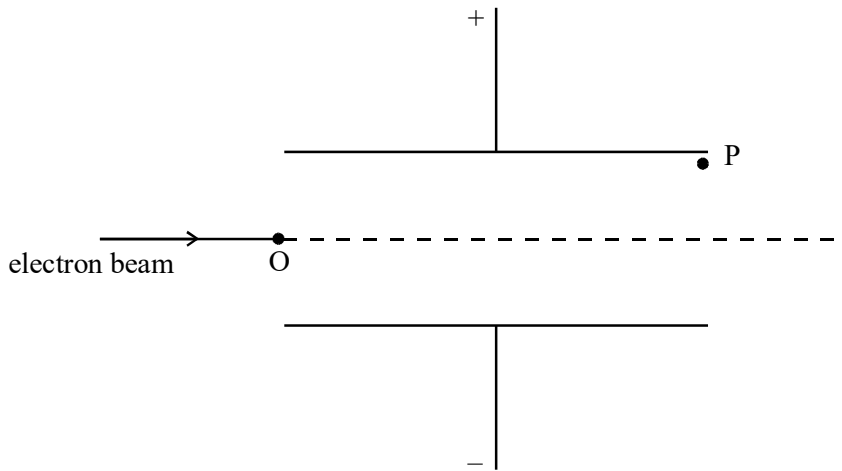
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(4)
(Total 8 marks)

10. 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)

11. 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?

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(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.

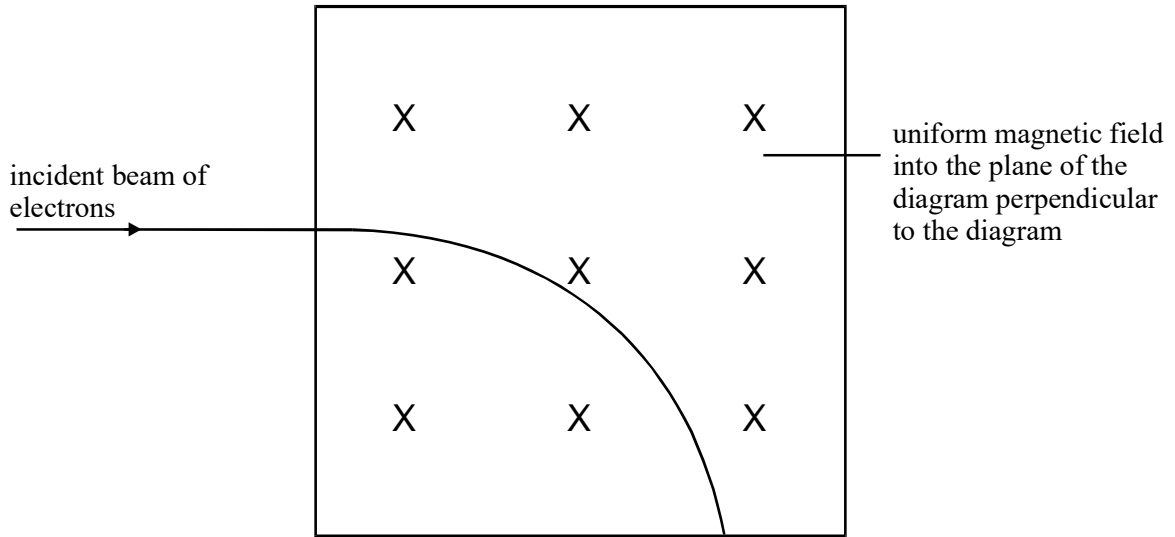
Explain why the oil droplet reached constant speed.

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(3)

(Total 6 marks)

12. A narrow beam of electrons at a speed of $3.2 \times 10^7 \text{ m s}^{-1}$ travels along a circular path in a uniform magnetic field of flux density, B , as shown in the diagram.



- (a) Explain why the path of the beam in the field is circular.

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

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- (b) (i) Show that the speed, v , of the electrons in the field is given by

$$v = \frac{Ber}{m},$$

where r is the radius of the circular path of the beam in the field.

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- (ii) When the flux density was 7.3 mT, the radius of the circular path of the beam in the field was 25 mm. Use the data to calculate the specific charge of the electron.

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(5)
(Total 8 marks)

13. 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,

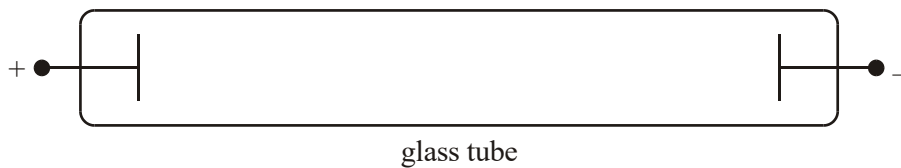
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- (ii) the speed of the electron at the anode. Ignore relativistic effects.

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(4)
(Total 8 marks)

14. 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.

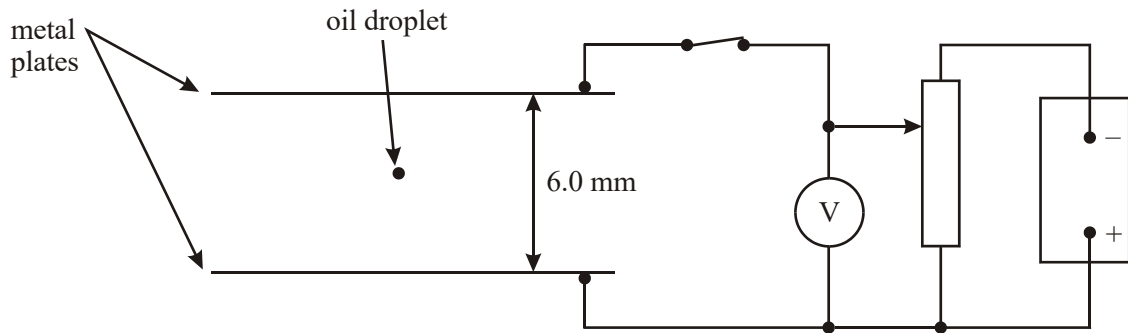
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- (ii) State why the glow was not observed until the pressure of the air in the tube was low enough.

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(Total 4 marks)

15. 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

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

where η is the viscosity of the air between the plates and ρ 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 2.6×10^{-15} kg.

viscosity of the air = 1.8×10^{-5} N s m⁻²
 density of the oil = 960 kg m⁻³

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(iv) Calculate the charge carried by this droplet.

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(10)
(Total 12 marks)

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

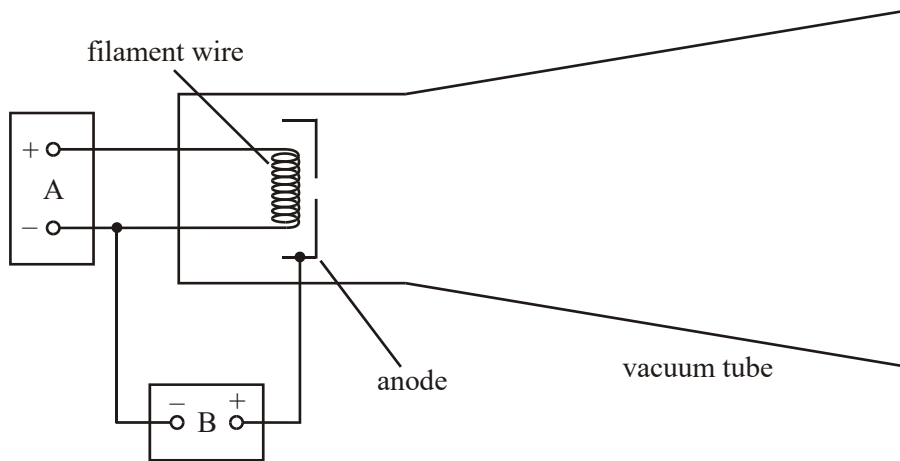


Figure 1

(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,

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(ii) increasing the voltage of B.

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(4)

(Total 7 marks)

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

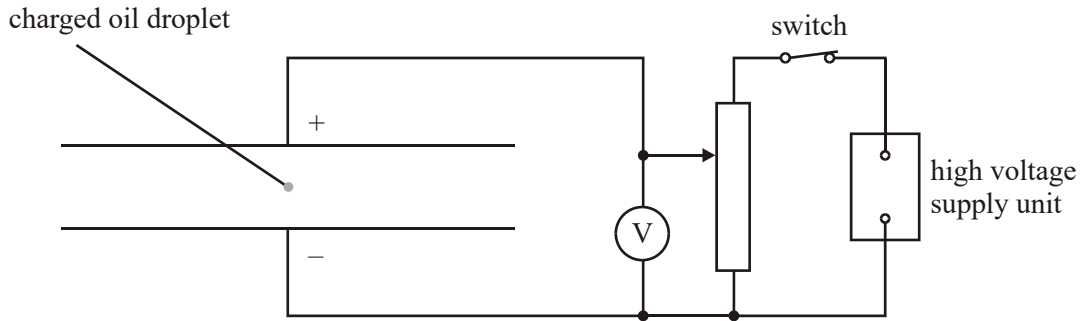


Figure 1

- (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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- (b) (i) The spacing between the plates is 6.0 mm. A charged oil droplet of mass 6.2×10^{-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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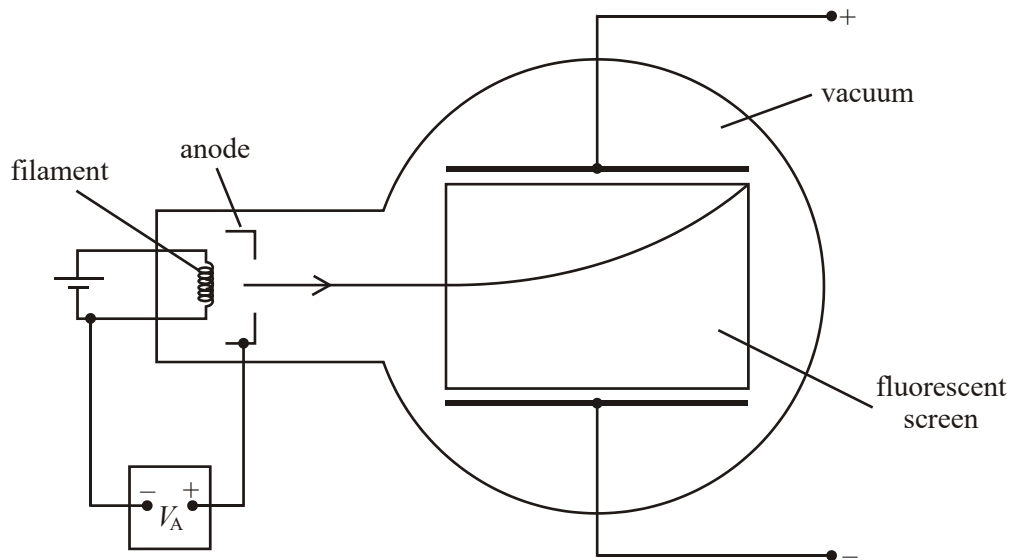
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(5)
(Total 8 marks)

18. 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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(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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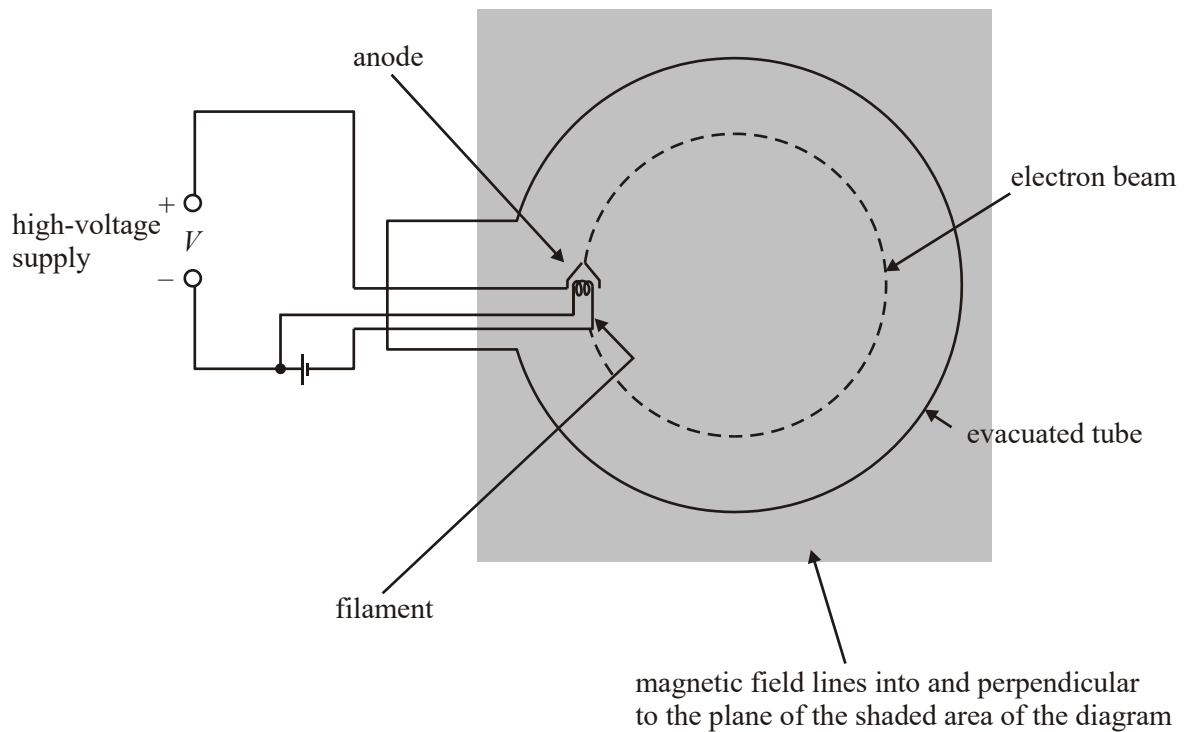
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(7)
(Total 11 marks)

19. 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.

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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 .

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

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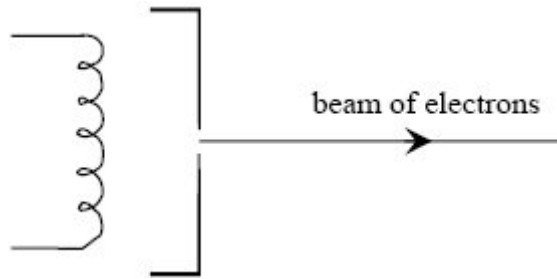
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(7)
(Total 10 marks)

20. (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)