Question 17 (20 marks)

JJ Thomson discovered electrons in 1897. He used evacuated cathode ray tubes to determine the ratio of electric charge to mass of these rays, which we now know were electrons.

Modern-day physics students plan an experiment to measure the ratio of the charge, e, to the mass, m, of electrons. This can be written as e/m. The apparatus they use is shown schematically in Figure 19.

An electron gun ejects a beam of electrons horizontally from the left side of the apparatus through the evacuated glass tube. A fluorescent screen displays the path the electrons take.

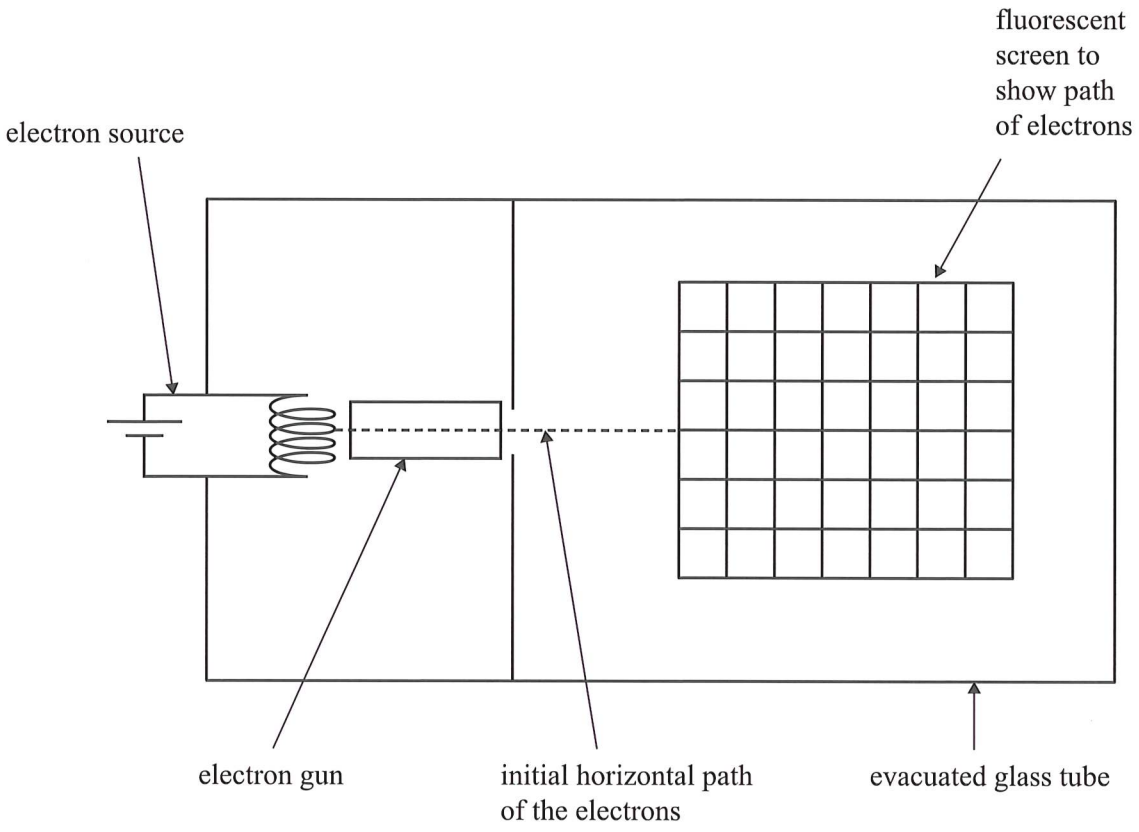


Figure 19

The electron gun can be modelled as shown in Figure 20. Electrons are produced at the electron source and accelerated between plate A and plate B.

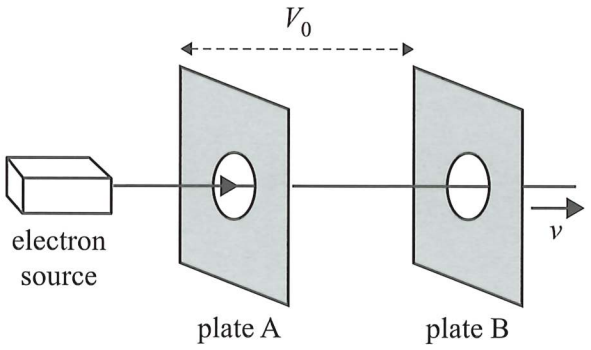


Figure 20

Electrons reach plate A with negligible speed and are accelerated by the potential difference between the plates, V_0, emerging from plate B with speed, v.

a. Write an equation that gives the speed, v, in terms of potential difference, V_0, the electron mass, m, and the electron charge, e. Assume that v is much less than the speed of light, c. 1 mark

$eV = \frac{mv^2}{2}$ $\quad v = \sqrt{\frac{2eV_0}{m}}$

b. A uniform magnetic field, B, directed into the page, is applied to the region of the fluorescent screen and the electrons follow a circular arc of radius, r, as shown in Figure 21.

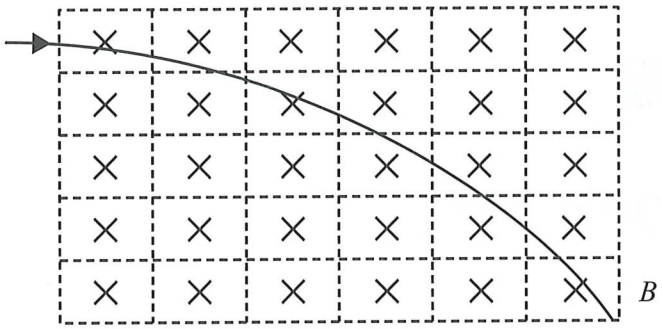


Figure 21

Explain why the path followed by the electrons is a circular arc. 2 marks

Magnetic force is constant in magnitude and always at the right angle to velocity.

c. Write an equation that represents the relationship between the electron mass, m, the electron charge, e, the electron speed, v, the magnetic field, B, and the radius, r, of the circular arc. 1 mark

$\frac{mv^2}{r} = qvB$ $\quad r = \frac{mv}{qB}$

The equations in **part a.** and **part c.** can be combined to show that

$$V_0 = \frac{eB^2}{2m} r^2$$

(Do not attempt to derive this equation.)

The physics students planning the experiment keep the uniform magnetic field constant at 2.0 mT. They vary the voltage, V_0, and measure the resulting radius, r, of the circular path of the electrons.

d. Identify the independent variable, the dependent variable and one controlled variable. 2 marks

independent variable:	voltage V_0
dependent variable:	r
controlled variable:	magnetic field

e. The table below shows the values of V_0 and r measured by the students. Complete the missing values of r^2 in the table. 2 marks

V_0 (volts)	r (m)	r^2 (m^2)
500	0.036	0.0013
1000	0.052	0.0027
1500	0.059	0.0035
2000	0.072	0.0052

$$r^2 = \frac{2mV_0}{eB^2}$$

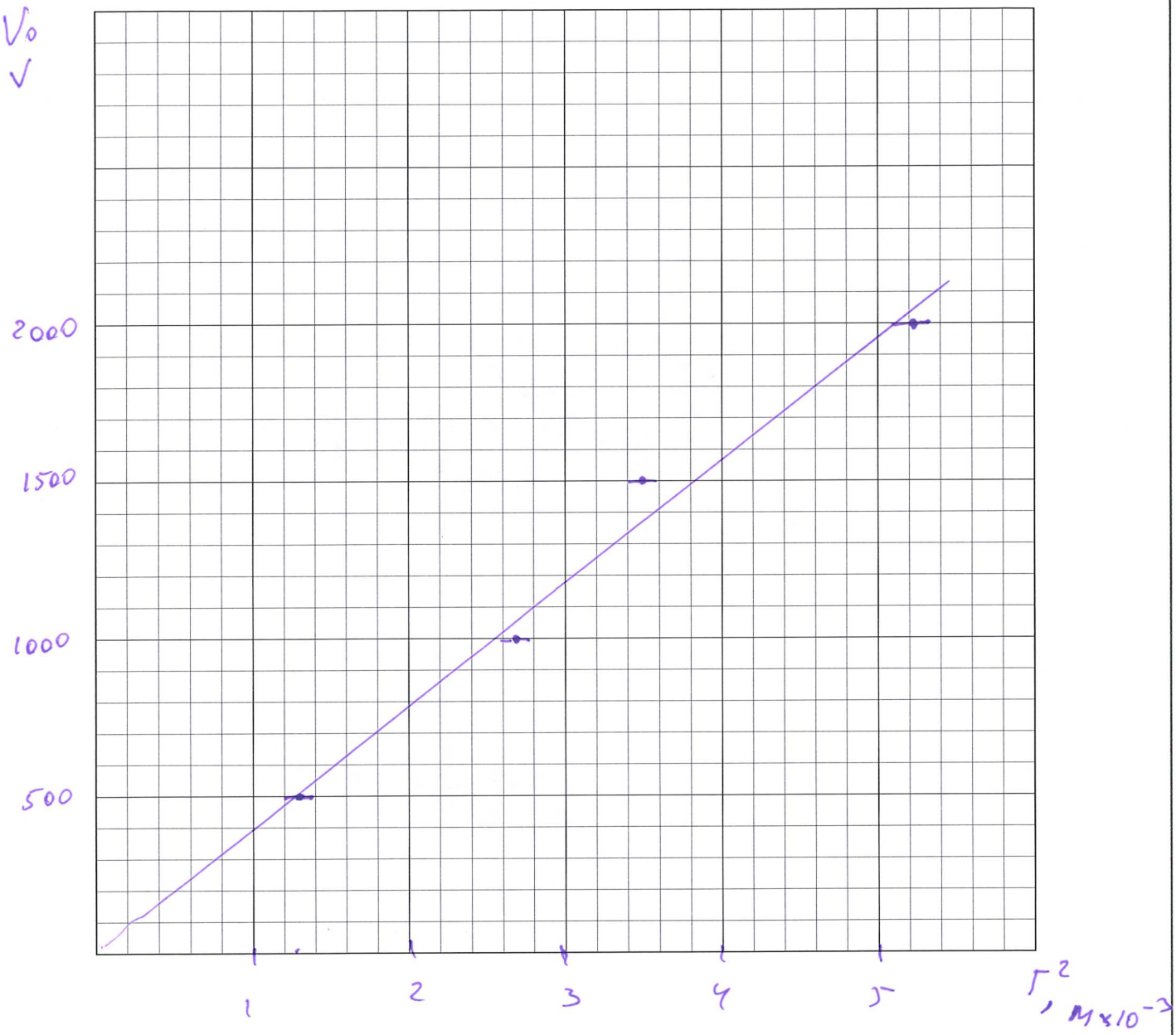
$$\frac{eB^2}{2m} = 3.5 \times 10^5$$

DO NOT WRITE IN THIS AREA

f. On the grid below:

- Plot the values of V_0 on the y-axis and the corresponding value of r^2 on the x-axis. Include a point for $V_0 = 0$.
- Label the axes correctly.
- Add an uncertainty of +/– 0.0002 to the r^2 values.
- Draw a straight line of best fit through the plotted points.

7 marks



g. Using the graph produced in **part f.**, calculate the gradient of the line of best fit. Show your working. 2 marks

$\frac{500}{0.0013} = 3.8 \times 10^5$

V m^{-2}

h. Use the value of the gradient found in **part g.** to find a value for e/m. Show your working. 3 marks

$\frac{eB^2}{2m} = 3.8 \times 10^5$

$\frac{e}{m} = \frac{2 \times 3.8 \times 10^5}{0.002^2} = 1.9 \times 10^{11}$

C kg^{-1}

$\frac{1.6 \times 10^{-19}}{9.1 \times 10^{-31}} = 1.8 \times 10^{11}$

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END OF QUESTION AND ANSWER BOOK