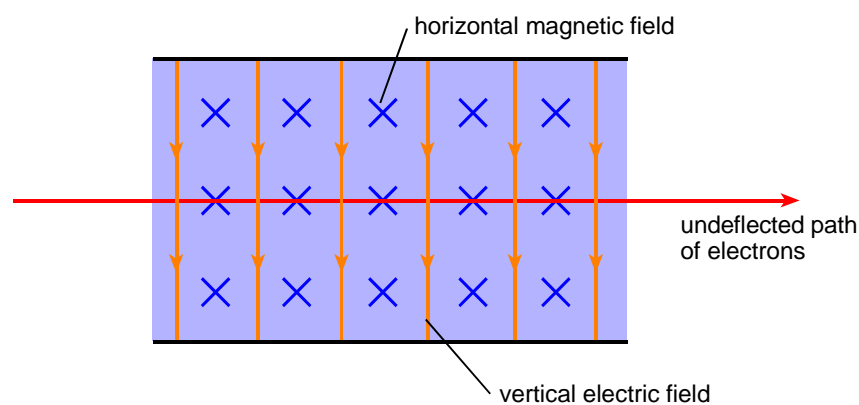


5. Use your answer to question 4 to calculate the radius of the orbit in the magnetic field.

In an electron tube, electrons were passed through a region containing a vertical electric field E and a horizontal magnetic field B . When the forces on the electron were balanced the electrons passed through the tube undeflected.



6. Show that the electrons of charge e pass undeflected when they have a velocity $v = E/B$.

The separation of the deflector plates was 24 mm and no deflection was observed when the voltage across the plates was 3.2 kV and the magnetic field was 8.2×10^{-3} T.

7. Calculate the velocity of the electrons.

The voltage used to accelerate the electrons to this velocity was 750 V.

8. Use your answer to question 7 to calculate the ratio e/m for electrons where m is the mass of an electron.

A proton joined to a neutron is known as a deuteron or deuterium ion and is used in nuclear scattering experiments. A deuteron has a mass of 3.3×10^{-27} kg and a charge of $+1.6 \times 10^{-19}$ C.

9. Calculate the voltage required to accelerate a deuteron from rest in a vacuum to a velocity of 9×10^6 m s⁻¹ (3% of the speed of light).

In an early form of particle accelerator, deuterons were made to move in a circular path within a toroidal tube of diameter 1 m. A toroidal tube is like a hollow ring.

10. Calculate the magnetic field required to constrain a deuteron within the tube at the velocity of 9×10^6 m s⁻¹.

Hints

4. The charge and mass of the electron are given in the 'Instructions and information'.
6. The electric and magnetic forces are equal in magnitude.
7. You will need to change the units before calculating the electric field strength.
8. You will need to consider the equation for the electron gun used to accelerate the electrons.
9. You are used to calculating the speed of electrons when accelerated. The mass of a deuteron is not the same as the mass of an electron.
10. The question gives the diameter of the orbit and not the radius.

Practical advice

In questions 7 and 8 there are several stages in the calculation so excessive rounding in the earlier parts of the question would lead to errors in the final answer. All answers have been rounded to two significant figures, but three significant figures have been used for numerical values that have been carried through to the next stage of the calculation.

Answers and worked solutions

1.

$$\begin{aligned}V &= Ed \\ &= 10^6 \text{ V m}^{-1} \times 200 \text{ m} \\ &= 2 \times 10^8 \text{ V.}\end{aligned}$$

2.

$$\begin{aligned}Q &= \epsilon_0 AE \\ &= (8.9 \times 10^{-12} \text{ F m}^{-1}) \times (1000 \text{ m})^2 \times 10^6 \text{ V m}^{-1} \\ &= 8.9 \text{ C.}\end{aligned}$$

3.

$$\begin{aligned}\frac{1}{2} QV &= \frac{1}{2} \times 8.9 \text{ C} \times (2 \times 10^8 \text{ V}) \\ &= 8.9 \times 10^8 \text{ J.}\end{aligned}$$

4.

$$eV = \frac{1}{2} mv^2$$

so

$$\begin{aligned}v &= \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2 \times (1.6 \times 10^{-19} \text{ C}) \times 200 \text{ V}}{9.1 \times 10^{-31} \text{ kg}}} \\ &= 8.39 \times 10^6 \text{ m s}^{-1} \\ &\approx 8.4 \times 10^6 \text{ m s}^{-1}.\end{aligned}$$

5.

$$Bev = mv^2 / r$$

so

$$\begin{aligned}r &= \frac{mv}{Be} = \frac{(9.1 \times 10^{-31} \text{ kg}) \times (8.39 \times 10^6 \text{ m s}^{-1})}{0.001 \text{ T} \times (1.6 \times 10^{-19} \text{ C})} \\ &= 0.048 \text{ m.}\end{aligned}$$

6.

$$eE = Bev$$

so

$$v = E/B.$$

7.

$$\begin{aligned}
 E &= \frac{V}{d} = \frac{3200 \text{ V}}{0.024 \text{ m}} \\
 &= 1.33 \times 10^5 \text{ V m}^{-1}. \\
 v &= \frac{E}{B} = \frac{1.33 \times 10^5 \text{ V m}^{-1}}{8.2 \times 10^{-3} \text{ T}} \\
 &= 1.63 \times 10^7 \text{ m s}^{-1} \\
 &\approx 1.6 \times 10^7 \text{ m s}^{-1}.
 \end{aligned}$$

8.

$$eV = \frac{1}{2}mv^2$$

so

$$\begin{aligned}
 \frac{e}{m} &= \frac{v^2}{2V} = \frac{(1.63 \times 10^7 \text{ m s}^{-1})^2}{2 \times 750 \text{ V}} \\
 &= 1.8 \times 10^{11} \text{ C kg}^{-1}.
 \end{aligned}$$

9.

$$qV = \frac{1}{2}mv^2$$

so

$$\begin{aligned}
 V &= \frac{\frac{1}{2}mv^2}{q} = \frac{(3.3 \times 10^{-27} \text{ kg}) \times (9 \times 10^6 \text{ m s}^{-1})^2}{2 \times (1.6 \times 10^{-19} \text{ C})} \\
 &= 8.4 \times 10^5 \text{ V}.
 \end{aligned}$$

10.

$$Bqv = mv^2 / r$$

so

$$\begin{aligned}
 B &= \frac{mv}{qr} = \frac{(3.3 \times 10^{-27} \text{ kg}) \times (9 \times 10^6 \text{ m s}^{-1})}{(1.6 \times 10^{-19} \text{ C}) \times 0.5 \text{ m}} \\
 &= 0.37 \text{ T}.
 \end{aligned}$$

External reference

This activity is taken from Advancing Physics chapter 16, 160S