Grade 12 (Science)
October 4, 2020

Solution to Homework 1

Short Answer Questions

1. An electron and a proton move with the same speed in a uniform magnetic field of equal magnitude. Compare the radii of their circular path.

   $\Longrightarrow$ The radius of circular path of charged particle having charge(q) and mass(m) moving in a uniform magnetic field of flux density(B) is given by,

   $$r = \frac{mv}{Bq}$$

   Here, the speed(v), magnetic flux density(B) and charge(q) of both electron and proton is same. So,

   $$r \propto m$$

   So, since the mass of proton is greater than the mass of electron, the radius of circular path of proton is greater than the radius of circular path of electron i.e. $r_p > r_e$

2. Beams of electrons and protons having same initial kinetic energy enter normally into an electric field, which beam will be more curved, justify.

   $\Longrightarrow$ The vertical deflection of a charged particle having charge(q) and mass(m) projected normally into the electric field(E) with velocity(u) is given by,

   $$y = \frac{1}{2}at^2 = \frac{1}{2}\frac{F}{m}\left(\frac{x}{u}\right)^2 = \frac{qEx^2}{2mu^2} = \frac{qEx^2}{4 \times \frac{1}{2}mu^2} = \frac{qEx^2}{4E_k}$$

   Therefore, for identical condition, $y \propto \frac{1}{E_k}$
   So, since the initial kinetic energy of both beam of electrons and protons is equal, both beam will be curved equally.

Numerical Problems

1. An electron moving with a speed of $10^7 m/s$ is passed into a magnetic field of intensity 0.1 T normally. What is the radius of the path of the electron inside the field? If the strength of the magnetic field is doubled, what is the radius of the new path? (e/m = 1.8×10^{11}C/kg)
   Here,
   Speed of electron (v) = 10^7m/s
   Magnetic flux density (B) = 0.1 T
   Specific charge of electron $\left(\frac{e}{m}\right) = 1.8 \times 10^{11} Ckg^{-1}$
   radius of the path (r) = ?
   radius of the new path (r') = ?

We have,

$$r = \frac{mv}{Be}$$
$$r = \frac{v}{B\frac{e}{m}}$$
$$\therefore r = \frac{10^7}{0.1 \times 1.8 \times 10^{11}} = 5.6 \times 10^{-4} m$$

Again, when the strength of the magnetic field is doubled,

$$r \propto \frac{1}{B}$$
$$\frac{r}{r'} = \frac{B'}{B}$$
$$\frac{r}{r'} = \frac{2B}{B}$$
$$r' = \frac{1}{2} r$$
$$\therefore r' = \frac{1}{2} \times 5.6 \times 10^{-4} = \underline{2.78 \times 10^{-4} m}$$

2. An electron having energy 500 eV enters at right angle to a uniform magnetic field of $10^4 T$. If its specific charge (e/m) is $1.75 \times 10^{11} Ckg^{-1}$, calculate the radius of its circular path.
   Here,
   Energy of electron $= \frac{1}{2} mv^2 = 500\, eV = 500 \times 1.6 \times 10^{-19}$ J $= 8 \times 10^{-17}$ J

$$v = \sqrt{\frac{2 \times 8 \times 10^{-17}}{9.1 \times 10^{-31}}} = 1.32 \times 10^7\ m/s$$

   Magnetic flux density (B) = 10^{-4} T
   Specific charge $\left(\frac{e}{m}\right) = 1.75 \times 10^{11}\ Ckg^{-1}$
   Radius of orbit (r) = ?
   We have,

$$r = \frac{mv}{Be}$$
$$r = \frac{v}{B\frac{e}{m}} = \frac{1.32 \times 10^7}{10^{-4} \times 1.75 \times 10^{11}} = \underline{0.75\ m}$$

3. Two plane metal plates 4 cm long are held horizontally 3 cm apart in a vacuum, one being vertically above the other. The upper plate is at a potential of 300 V and the

lower is earthed. Electrons having a velocity of 10^7 m/s are injected horizontally mid-way between the plates and in a direction parallel to the 4 cm edge. Calculate the vertical deflection of the electron beam as it emerges from the plates. [Given: e/m for electron = $1.8 \times 10^{11}\ Ckg^{-1}$]

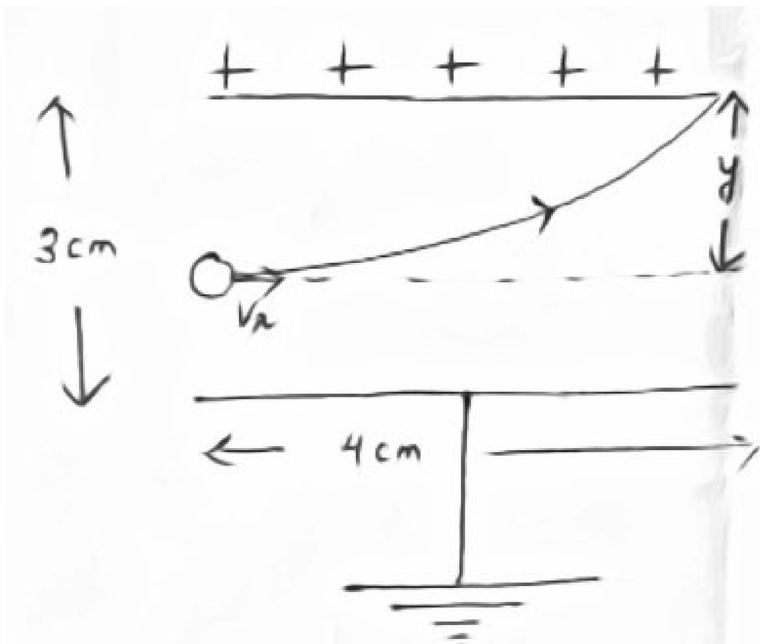

Figure 1: Cellular membrane. [3]

Given,
Distance of separation of plates (d) = 3 cm = 0.03 m
Length of plate (D) = 4 cm = 0.04 m
Potential difference (V) = 300 V
Velocity of electron along X-axis (v_x) = 10^7 m/s
$\frac{e}{m} = 1.8 \times 10^{11}\ Ckg^{-1}$
Vertical deflection of electron (y) = ?
The vertical deflection of electron is given by,

$$y = \frac{1}{2}at^2 \tag{1}$$

We have,

$$a = \frac{F}{m} = \frac{eE}{m} = \frac{e}{m} \times \frac{V}{d} = 1.8 \times 10^{11} \times \frac{300}{0.03} = 1.8 \times 10^{15}\ m/s^2$$

Also, the time take for the vertical deflection of electron is same as the time take by the electron to travel the length of the plate. So,

$$v_x = \frac{D}{t}$$

$$t = \frac{D}{v_x} = \frac{0.04}{10^7} = 4 \times 10^{-9}\ s$$

Substituting the value of 'a' and 't' into (1) we have,

$$y = \frac{1}{2} \times 1.8 \times 10^{15} \times (4 \times 10^{-9})^2$$

$$\therefore \underline{y = 1.44 \times 10^{-2}\ m}$$

4. In Millikan apparatus, the horizontal plates are 1.5 cm apart. With the electric field switched off, an oil drop is observed to fall with the steady velocity 2.5×10^{-2} cm/s. When the electric field is switched on, the upper plate being positive, the drop just remains stationary when the p.d. between plates is 1500 V. (a) Calculate the radius of the drop (b) How many electronic charges does it carry? (Given: density of oil = 900 kgm^{-3} and viscosity of air = 1.8×10^{-5} Nsm^{-2}, Neglect air density)
Given,
Distance of separation of plates (d) = 1.5 cm = 1.5×10^{-2} m
Terminal velocity (v) = 2.5×10^{-2} cm/s = 2.5×10^{-4} cm/s
Potential difference (V) = 1500 V
Density of oil (ρ) = 900 kgm^{-3}
Density of air (σ) = 0
Viscosity of air = 1.8×10^{-5} Nsm^{-2}
When the electric field is switched off, we have,

$$r = \sqrt{\frac{9\eta v}{2(\rho - \sigma)g}}$$

$$r = \sqrt{\frac{9 \times 1.8 \times 10^{-5} \times 2.5 \times 10^{-4}}{2(900 - 0) \times 9.8}}$$

$$\therefore \underline{r = 1.5 \times 10^{-6}\ m}$$

When the electric field is switched on, we have,

$$E = \frac{V}{d} = \frac{1500}{1.5 \times 10^{-2}} = 1 \times 10^5 V/m$$

Again, we have,

$$qE = mg = \frac{4}{3}\pi r^3 \rho g$$

$$\begin{aligned} q &= \frac{\frac{4}{3}\pi r^3 \rho g}{E} \\ &= \frac{4 \times \pi \times (1.5 \times 10^{-6})^3 \times 900 \times 9.8}{3 \times 10^5} \\ &= 12.723 \times 10^{-19} C \end{aligned}$$

Since, $q = ne$

$$\begin{aligned} n &= \frac{q}{e} \\ &= \frac{12.723 \times 10^{-19}}{1.6 \times 10^{-19}} \\ \therefore n &= 7.95 \approx 8 \end{aligned}$$

Hence, the required number of electrons is 8.