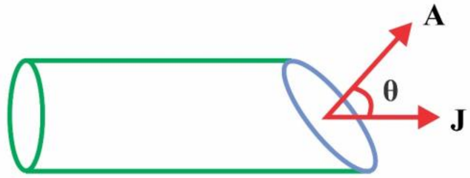

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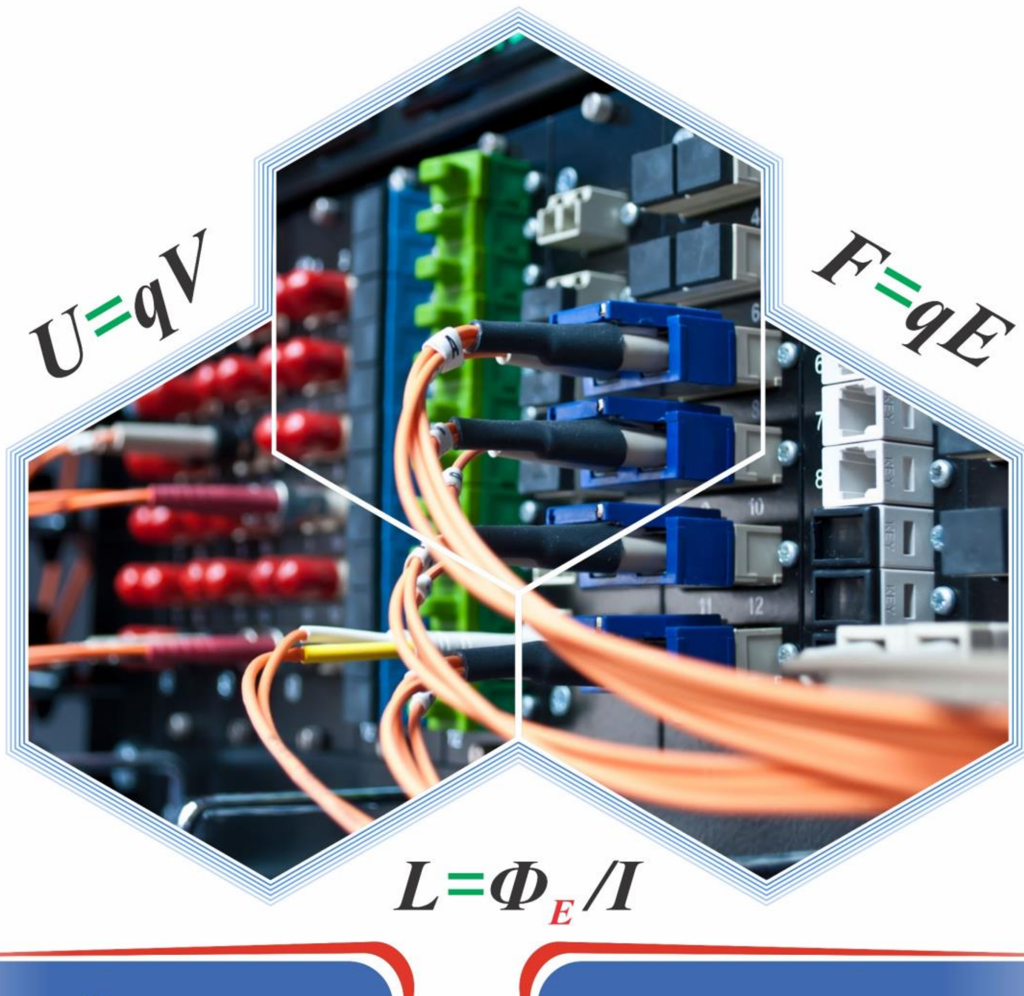
TEACH YOURSELF

ELECTRICITY & MAGNETISM-I

For BS Physics Programme

$U=qV$

$F=qE$



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TEACH YOURSELF

ELECTRICITY & MAGNETISM - I

1st Edition

For **BS Physics/Chemistry/Mathematics** students

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Contents

Chapter 1

Electric Field

SOLVED PROBLEMS

Problem: 1.1- The average distance r between the electron and the proton in the hydrogen atom is 5.3×10^{-11} m. **(a)** what is the magnitude of the average electrostatic force that acts between these two particles? **(b)** What is the magnitude of the average gravitational force that acts between these particles?

Solution

(a)- We have, for the electrostatic force,

$$F_e = \frac{1}{4\pi\varepsilon_\circ}\frac{e^2}{r^2}$$

$$F_e = \frac{(8.99 \times 10^9)(1.60 \times 10^{-19})^2}{(5.3 \times 10^{-11})^2}$$

$$F_e = 8.2 \times 10^{-8} \ N$$

Although this force may seem small (it is about equal to the weight of a speck of dust), it produces an enormous acceleration of the electron within the atom, about 10^{23} m/s^2.

(b)- For the gravitational force, we have

$$F_g = G\frac{m_1 m_2}{r^2}$$

$$F_g = \frac{(6.67 \times 10^{-11})(9.11 \times 10^{-31})(1.67 \times 10^{-27})}{(5.3 \times 10^{-11})^2}$$

$$F_g = 3.6 \times 10^{-47}\ N$$

Problem: 1.2- A proton is placed in uniform electric field E. What must be the magnitude and direction of electric field. If electrostatic force is balanced by weight?

Solution

$$m = 1.67 \times 10^{-27}\ kg$$

$$q = 1.6 \times 10^{-19}\ C$$

$$E = ?$$

Since, the electrical force is balanced by the weight. So,

$$F_e = F_g$$

$$qE = mg$$

$$E = \frac{mg}{q}$$

$$E = \frac{1.67 \times 10^{-27} \times 9.8}{1.6 \times 10^{-19}}$$

$$E = 1 \times 10^{-7}\ N/C$$

The electric field $\vec{E}$ is directed against gravity force.

Problem: 1.3- What is the magnitude of point charge, chosen so that electric field 75 cm away has value 2.30 N/C?

Solution

$$E = 2.30\ N/C$$

$$r = 75\ cm$$

$$r = 75 \times 10^{-2}\ m$$

$$k = 9 \times 10^9\ Nm^2/C^2$$

$$q = ?$$

Since, we know that

$$E = k\frac{q}{r^2}$$
$$q = \frac{Er^2}{k}$$
$$q = \frac{2.30 \times (75 \times 10^{-2})^2}{9 \times 10^9}$$
$$q = 1.4 \times 10^{-10}\ C$$

Problem: 1.4- An electric dipole consists of charges of magnitude 1.48 nC, separated by 6.23 μm. It is in electric field of 1100 N/C. Calculate the magnitude of dipole moment and what is the difference in potential energy corresponding to dipole orientation parallel and anti-parallel to field?

Solution

$$d = 6.23\ \mu m$$
$$d = 6.23 \times 10^{-6}\ m$$

$$q = 1.48\ nC$$
$$q = 1.48 \times 10^{-9}\ C$$
$$E = 1100\ N/C$$
$$P = ?$$
$$U = ?$$

Since, we know that

$$P = qd$$
$$P = 1.48 \times 10^{-9} \times 6.23 \times 10^{-6}$$
$$P = 9.2 \times 10^{-15}\ Cm$$

For parallel condition of dipole and field,

$$U = -PE\cos\theta$$

$$U = -9.2 \times 10^{-15} \times 1100 \cos(0^\circ)$$
$$U = -9.2 \times 10^{-15} \times 1100(1)$$
$$U = -1.012 \times 10^{-11}\ J$$

For anti-parallel condition of dipole and field

$$U = -PE\cos\theta$$
$$U = -9.2 \times 10^{-15} \times 1100 \cos(180^\circ)$$
$$U = -9.2 \times 10^{-15} \times 1100(-1)$$
$$U = 1.012 \times 10^{-11}\ J$$

Problem: 1.5- An electron remains stationary in electric field directed downward in the earth gravitational field. If electric field is due to charge on two parallel conducting plates oppositely charged and separated by 2.3 cm. What is the surface charge density assumed uniform on plates.

Solution

$$m = 9.1 \times 10^{-31}\ kg$$
$$q = 1.6 \times 10^{-19}\ C$$
$$\varepsilon_\circ = 8.85 \times 10^{-12}\ C^2/Nm^2$$
$$g = 9.8\ ms^{-2}$$
$$\sigma = ?$$

To keep electron in stationary its weight mg must be balanced by force qE. The force is directed upward.

$$F_e = F_g$$
$$qE = mg$$
$$E = \frac{mg}{q}$$

The electric field between two oppositely charged plates is

$$E = \frac{\sigma}{\varepsilon_\circ}$$

On comparing, we get

$$\frac{\sigma}{\varepsilon_\circ} = \frac{mg}{q}$$
$$\sigma = \frac{mg}{q}\varepsilon_\circ$$
$$\sigma = \frac{9.1 \times 10^{-31} \times 9.8}{1.6 \times 10^{-19}} \times 8.85 \times 10^{-12}$$
$$\sigma = 4.9 \times 10^{-22}\ C/m^2$$

Chapter 2

Electric Potential

SOLVED PROBLEMS

Problem: 2.1- (a) If earth had a net surface charge density of 1 electron per m^2 $(-1.6 \times 10^{-19} m^{-2})$, what would be Earth's potential (set V=0 at infinity). (b) What would be E due to earth just outside its surface?

Solution

(a)

$$V = \frac{1}{4\pi\varepsilon_\circ}\frac{Q}{R_e}$$
$$V = \frac{1}{4\pi\varepsilon_\circ}\frac{4\pi R_e^2 \sigma e}{R_e}$$
$$V = \frac{R_e \sigma e}{\varepsilon_\circ}$$
$$V = \frac{6.4 \times 10^6 \times (-1.6 \times 10^{-19})}{8.85 \times 10^{-12}}$$
$$V = -0.12\ V$$

(b)

$$E = \frac{\sigma}{\varepsilon_\circ}$$
$$E = \frac{-1.6 \times 10^{-19}}{8.85 \times 10^{-12}}$$
$$E = -1.8 \times 10^{-8}\ NC^{-1}$$

Problem: 2.2- Calculate the radial potential gradient in V/m at the surface of the gold nucleus of radius $7.0 \times 10^{-15}\ m$ and 79 protons.

Solution

$$\begin{aligned} r &= 7.0 \times 10^{-15}\ m \\ k &= 9 \times 10^{9}\ Nm^2/C^2 \\ n &= 79 \\ e &= 1.6 \times 10^{-19}\ C \\ q &= ne\ =\ 79 \times 1.6 \times 10^{-19}\ C \\ \frac{dV}{dr} &= ? \end{aligned}$$

Since, we know that

$$\begin{aligned} V &= k\frac{q}{r} \\ \frac{dV}{dr} &= k\frac{d}{dr}\left(\frac{q}{r}\right) \qquad \because \text{Taking derivative on both sides} \end{aligned}$$

$$\begin{aligned} \frac{dV}{dr} &= kq\frac{d}{dr}\left(\frac{1}{r}\right) \\ \frac{dV}{dr} &= kq\frac{d}{dr}(r^{-1}) \\ \frac{dV}{dr} &= -kq(r^{-2}) \\ \frac{dV}{dr} &= -\frac{kq}{r^2} \\ \frac{dV}{dr} &= -\frac{9 \times 10^{9} \times 79 \times 1.6 \times 10^{-19}}{(7.0 \times 10^{-15})^2} \\ \frac{dV}{dr} &= -2.3 \times 10^{21}\ V/m \end{aligned}$$

Problem: 2.3- Two large parallel metal plates are 1.48 cm apart and carry equal but opposite charges on their facing surface. The negative plate is grounded and its potential is taken to be zero. If the potential halfway between the plates is 5.12 V, what is the electric field in this region.

Solution

$$S = 1.48\ cm$$
$$S = 1.48 \times 10^{-2}\ m$$
$$dV = 5.12\ V$$
$$E = ?$$

Since,

$$dr = \frac{S}{2}$$
$$dr = \frac{1.48 \times 10^{-2}}{2}$$
$$dr = 7.4 \times 10^{-3}\ m$$

Also, the electric field is the negative gradient of potential with distance is given as

$$E = \frac{dV}{dr} = \frac{5.12}{7.4 \times 10^{-3}}$$
$$E = 692\ V/m$$

Problem: 2.4-

Two parallel plate conducting surfaces of spacing $d = 1\ cm$ have a potential difference ΔV of 10.3 kV. An electron is projected from one plate directly towards second. What is the initial velocity of electron if it comes to rest just at the surface second plate? Ignore the relativistic effect.

Solution

$$d = 1\ cm = 1 \times 10^{-2}\ m$$

$$\begin{aligned}
\Delta V &= 10.3\ kV \\
\Delta V &= 10.3 \times 10^3\ V \\
q &= 1.6 \times 10^{-19}\ C \\
m &= 9.1 \times 10^{-31}\ kg \\
V_f &= 0 \\
V_i &= ?
\end{aligned}$$

From work energy relation, we get

$$\begin{aligned}
Fd &= \frac{mV_f^2}{2} - \frac{mV_i^2}{2} \\
qEd &= \frac{mV_f^2}{2} - \frac{mV_i^2}{2} && \because E = \frac{F}{q} \\
qEd &= \frac{m(0)^2}{2} - \frac{mV_i^2}{2} \\
qEd &= -\frac{mV_i^2}{2} \\
-q\Delta V &= -\frac{mV_i^2}{2} && \because E = -\frac{\Delta V}{d} \\
q\Delta V &= \frac{mV_i^2}{2}
\end{aligned}$$

$$\begin{aligned}
2q\Delta V &= mV_i^2 \\
\text{or} \quad V_i^2 &= \frac{2q\Delta V}{m} \\
V_i^2 &= \frac{2 \times 1.6 \times 10^{-19} \times 10.3 \times 10^3}{9.1 \times 10^{-31}} \\
V_i &= 6 \times 10^7\ ms^{-1}
\end{aligned}$$

Problem: 2.5- An alpha particle in a nuclear accelerator moves from one terminal of a potential of $V_a = 6.5 \times 10^6\ V$ to another at a potential of $V_b = 0\ V$. What is the corresponding change in potential energy of the system. Also calculate the change in kinetic energy of the particle.

Solution

$$\begin{aligned} n &= 2 \\ e &= 1.6 \times 10^{-19}\ C \\ q &= ne\ =\ 2 \times 1.6 \times 10^{-19}\ C \\ V_a &= 6.5 \times 10^6\ V \\ V_b &= 0\ V \\ \Delta U &= ? \\ \Delta K.E &= ? \end{aligned}$$

Since,
$$\begin{aligned} \Delta U &= q(V_b - V_a) \\ \Delta U &= 2 \times 1.6 \times 10^{-19}(0 - 6.5 \times 10^6) \\ \Delta U &= -\ 2.1 \times 10^{12}\ J \end{aligned}$$

Also, we know that

$$\begin{aligned} \Delta K.E &= -\ \Delta U \\ \Delta K.E &= -\ (-2.1 \times 10^{12})\ =\ +2.1 \times 10^{12}\ J \end{aligned}$$

Chapter 3

Capacitance

SOLVED PROBLEMS

Problem: 3.1- A storage capacitor on a random access memory (RAM) chip has a capacitance of $55 \times 10^{-15}\ F$. If it is charged to $5.3\ V$, how many excess electrons are there on its negative plates?

Solution

$$C = 55 \times 10^{-15}\ F$$
$$V = 5.3\ V$$
$$e = 1.6 \times 10^{-19}\ C$$
$$N = ?$$

$$\text{As} \quad q = CV$$
$$q = 55 \times 10^{-15} \times 5.3$$

And,

$$N = \frac{\text{Total charge}}{\text{Charge of electron}}$$
$$N = \frac{q}{e}$$

$$N = \frac{55 \times 5.3 \times 10^{-15}}{1.6 \times 10^{-19}}$$
$$N = 1.8 \times 10^{6} \text{ electrons}$$

Problem: 3.2- The space between the conductors of a long coaxial cable, used to transmit T.V signals has an inner radius $a = 0.15 \times 10^{-3}\ m$ and outer radius $b = 2.1 \times 10^{-3}\ m$. What is capacitance per unit length of this cable?

Solution

$$a = 0.15 \times 10^{-3}\ m$$
$$b = 2.1 \times 10^{-3}\ m$$
$$\varepsilon_\circ = 8.85 \times 10^{-12}\ C^2/Nm = \frac{F}{m}$$
$$L = 1\ m$$
$$C = ?$$

Since,

$$C = \frac{2\pi\epsilon_\circ L}{\log\left(\frac{b}{a}\right)}$$
$$C = \frac{2 \times 3.14 \times 8.85 \times 10^{-12} \times 1}{\log(2.1 \times 10^{-3}/0.15 \times 10^{-3})}$$
$$C = \frac{55.56}{\log(14)} = 21 \times 10^{-12}\ F$$

Problem: 3.3- An isolated conducting sphere whose radius is R is 0.0685 m carries a charge q is 1.25×10^{-9}C (a) How much energy is stored in electric field of this charged conductor. (b) What is energy density at the surface of the sphere?

Solution

(a) Capacity of charged sphere

$$R = 0.0685\ m$$
$$q = 1.25 \times 10^{-9}\ C$$

$$\varepsilon_\circ = 8.85 \times 10^{-12}\ C^2/Nm^2$$
$$U = ?$$
$$\text{Energy density} = ?$$

Since,

$$C = 4\pi\varepsilon_\circ R$$
$$C = 4 \times 3.14 \times 8.85 \times 10^{-12} \times 0.0685$$
$$C = 12.56 \times 0.606 \times 10^{-12}$$
$$C = 7.615 \times 10^{-12}\ F$$

We have to know that the energy is defined as

$$U = \frac{1}{2}\frac{q^2}{C}$$
$$U = \frac{1}{2} \times \frac{(1.25 \times 10^{-9})^2}{7.615 \times 10^{-12}}$$
$$U = \frac{1}{2} \times \frac{1.56 \times 10^{-18}}{7.615 \times 10^{-12}}$$
$$U = \frac{1.56}{15.23} \times 10^{-6}$$
$$U = 1.03 \times 10^{-7}\ J$$

(b)

Electric field at surface of sphere is

$$E = \frac{1}{4\pi\varepsilon_\circ}\frac{q}{R^2}$$
$$E = 9 \times 10^9 \frac{1.25 \times 10^{-9}}{(0.0685)^2}$$
$$E = 9 \times 10^9 \times \frac{1.256 \times 10^{-9}}{0.0047}$$
$$E = \frac{11.25 \times 10^4}{0.47}$$
$$E = 0.24 \times 10^4$$
$$E = 14 \times 10^2 = 2400 N/C$$

Energy density at surface of sphere

$$U = \frac{1}{2}\varepsilon_{\circ}E^2$$
$$U = \frac{1}{2} \times 8.85 \times 10^{-12} \times 2400 \times 2400$$
$$U = 2548.8 \times 10^{-8}\ J/m^3$$

Problem: 3.4- The plates of a parallel-plate capacitor are separated by a distance $d = 1.0\ mm$. What must be the plate area if the capacitance is to be 1.0 F?

Solution

$$d = 1\ mm$$
$$d = 1 \times 10^{-3}\ m$$
$$C = 1\ F$$
$$\varepsilon_{\circ} = 8.85 \times 10^{-12}\ C^2/Nm^2$$
$$A = ?$$

$$\text{Since} \quad C = \frac{A\varepsilon_{\circ}}{d}$$
$$\text{or} \quad A = \frac{Cd}{\varepsilon_{\circ}}$$

$$A = \frac{(1.0)(1.0 \times 10^{-3})}{8.85 \times 10^{-12}}$$
$$A = 1.1 \times 10^{8}\ m^2$$

This is the area of a square more than 10 Km one edge. The Farad is indeed a large unit.

Problem: 3.5- Two parallel plates of area 110 cm^2 are each given equal but opposite charges of 890 nC. The electric field within the dielectric material filling the space between the plates is 1.4 MV/m. Calculate the dielectric constant of the material and also determine the magnitude of the charge induced on each dielectric surface.

Solution

$$A = 110\ cm^2$$
$$A = 110 \times 10^{-4}\ m^2$$
$$Q = 890\ nC$$
$$Q = 890 \times 10^{-9}\ C$$
$$E = 1.4\ MV/m$$
$$E = 1.4 \times 10^{6}\ V/m$$
$$\varepsilon_\circ = 8.85 \times 10^{-12}\ C^2/Nm^2$$
$$\kappa_e = ?$$

Since, we have to know that

$$E = \frac{Q}{A\varepsilon_\circ \kappa_e}$$
$$\kappa_e = \frac{Q}{A\varepsilon_\circ E}$$
$$\kappa_e = \frac{890 \times 10^{-9}}{110 \times 10^{-4} \times 8.85 \times 10^{-12} \times 1.4 \times 10^{6}}$$
$$\kappa_e = 6.5$$

Since,

$$E_\circ = \frac{Q}{A\varepsilon_\circ}$$
$$E_\circ = \frac{890 \times 10^{-9}}{110 \times 10^{-4} \times 8.85 \times 10^{-12}}$$
$$E_\circ = 9.1 \times 10^{6}\ V/m$$

Also, to calculate the magnitude of charge induced on each dielectric surface is calculate as

$$\frac{q'}{A\varepsilon_\circ} = E_\circ - E$$

$$q' = A\varepsilon_\circ(E_\circ - E)$$

$$q' = 110 \times 10^{-4} \times 8.85 \times 10^{-12}(9.1 - 1.4) \times 10^{6}$$

$$q' = 7.4 \times 10^{-7}\ C$$

Chapter 4

DC Circuits

SOLVED PROBLEMS

Problem: 4.1- A resistor of 6.2 $M\Omega$ and a capacitor 2.45 μF are connected in series with battery of 12 V of negligible internal resistance. What is capacitive time constant. What time after the battery is connected does the potential difference across the capacitor equal 5.6 V.

Solution

$$R = 6.2\ M\Omega$$
$$R = 6.2 \times 10^{6}\ \Omega$$
$$C = 2.45\ \mu F$$
$$C = 2.45 \times 10^{-6}\ F$$
$$\varepsilon = 12\ V$$
$$V_c = ?$$
$$\tau_c = ?$$
$$t = ?$$

As,

$$\tau_c = RC$$

$$\tau_c = 6.2 \times 10^6 \times 2.45 \times 10^{-6}$$
$$\tau_c = 15\ s$$

And,

$$V_c = \epsilon(1 - e^{-t/RC})$$
$$5.6 = 12(1 - e^{-t/15})$$
$$t = 9.5\ s$$

Problem: 4.2- A 5.12 A current is set up in external circuit by a 6 V battery for 5.75 min. By how much is the chemical energy of the battery reduced.

Solution

$$I = 5.12\ A$$
$$dt = 5.75\ min$$
$$dt = 5.75 \times 60\ s$$
$$\varepsilon = 6\ V$$
$$dW = ?$$

Since,

$$dW = \varepsilon I dt$$
$$dW = 6 \times 5.12 \times 5.75 \times 60$$
$$dW = 10598\ J$$

Problem: 4.3- A fluid with a resistivity 9.4 Ωm seeps into the space between plates of a 110 pF parallel plate capacitor. When space is completely filled what is resistance between plates?

Solution

$$\begin{aligned}\rho &= 9.4\ \Omega m\\ \varepsilon_\circ &= 8.85\times10^{-12}\ C^2/Nm^2\\ C &= 110\ pF\end{aligned}$$

$$\begin{aligned}C &= 110\times10^{-12}\ F\\ R &= ?\end{aligned}$$

Since,

$$R = \frac{\rho L}{A}$$

And,

$$C = \frac{\varepsilon_\circ A}{L}$$

$$\text{or} \quad A = \frac{CL}{\varepsilon_\circ}$$

Now,, we get

$$\begin{aligned}R &= \frac{\rho L}{\frac{CL}{\varepsilon_\circ}}\\ R &= \frac{\rho\varepsilon_\circ}{C}\\ R &= \frac{9.4\times8.85\times10^{-12}}{110\times10^{-12}}\\ R &= 0.75\ \Omega\end{aligned}$$

Problem: 4.4- A block in shape of a rectangular solid has a cross sectional area of 3.5 cm^2, length 15.8 cm and resistance 935 Ω. The material of block 5.33×10^{22} electrons/m^3. A potential difference of 35.8 V is maintained between its ends. Find current in block, current density, drift velocity and electric field.

Solution

$$\begin{aligned} A &= 3.5\ cm^2 \\ A &= 3.5\ \times 10^{-4}\ m^2 \\ L &= 15.8\ cm \\ L &= 15.8 \times 10^{-2}\ m \\ R &= 935\ \Omega \end{aligned}$$

$$\begin{aligned} n &= 5.33 \times 10^{22}\ \text{electrons}/m^3 \\ V &= 35.8\ V \\ e &= 1.6 \times 10^{-19}\ C \\ I &= ? \\ J &= ? \\ V_d &= ? \\ E &= ? \end{aligned}$$

Since, we know that the current block is given by Ohm's law

$$\begin{aligned} V &= IR \\ \Rightarrow\ I &= \frac{V}{R} \\ I &= \frac{35.8}{935} \\ I &= 0.038\ A \end{aligned}$$

Current density is defined as;

$$J = \frac{I}{A}$$
$$J = \frac{0.038}{3.5 \times 10^{-4}}$$
$$J = 109.3\ A/m^2$$

Drift speed is calculated as;

$$V_d = \frac{J}{ne}$$
$$V_d = \frac{109.3}{5.33 \times 10^{22} \times 1.6 \times 10^{-19}}$$
$$V_d = 1.2 \times 10^{-2}\ ms^{-1}$$

Also, electric field is given as;

$$E = \frac{V}{L}$$
$$E = \frac{35.8}{15.8 \times 10^{-2}}$$
$$E = 226.5\ V/m$$

Problem: 4.5- When 115 V is applied across a 9.66 m length of material and current density is $1.42 \times 10^4\ A/m^2$. Calculate the conductivity of wire material.

Solution

$$V = 115\ V$$
$$d = 9.66\ m$$
$$J = 1.42 \times 10^4\ A/m^2$$
$$\sigma = ?$$

Since, we have to know that

$$\sigma = \frac{J}{E}$$

$$\sigma = \frac{J}{V/d}$$

$$\sigma = \frac{Jd}{V}$$

$$\sigma = \frac{1.42 \times 10^4 \times 9.66}{115}$$

$$\sigma = 1190\ (\Omega m)^{-1}$$

Chapter 5

Magnetic Field

SOLVED PROBLEMS

Problem: 5.1- A strip of copper 150 μm thick is placed in a magnetic field 0.65 T perpendicular to the plane of strip, and a current 23 A is set up in the strip. What Hall potential difference would appear across the width of strip of there were one charge carries per atom?

Solution

Given data: For copper strip

$$n = 8.49 \times 10^{28} \text{ electrons}/ms$$
$$B = 0.65\ T$$
$$t = 150\ \mu m$$
$$t = 150 \times 10^{-6}\ m$$
$$I = 23\ A$$
$$e = 1.6 \times 10^{-19}\ C$$
$$V = ?$$

As, we know that

$$V = \frac{IB}{nte}$$

$$V = \frac{23 \times 0.65}{8.49 \times 10^{28} \times 150 \times 10^{-6} \times 1.6 \times 10^{-19}}$$
$$V = 7.3 \times 10^{-6}\ V$$

Problem: 5.2- What is magnetic dipole moment of the coil which is 2.1 cm high and 1.2 cm wide with 250 turns and assuming that it carries current of 85 μA. The magnetic dipole moment of the coil is lined up with external magnetic field of 0.85 T. How much work would be done by external agent to rotate the coil through and angle of 180°.

Solution

$$A = 2.1 \times 1.2\ cm^2$$
$$A = 2.1 \times 1.2 \times 10^{-4}\ m^2$$
$$A = 2.52 \times 10^{-4}\ m^2$$
$$N = 250$$
$$I = 85\ \mu A$$
$$I = 85 \times 10^{-6}\ A$$
$$B = 0.85\ T$$
$$\mu = ? \quad \text{and} \quad W = ?$$

Since, we have to know that

$$\mu = NIA$$
$$\mu = 250 \times 85 \times 10^{-6} \times 2.52 \times 10^{-4}$$
$$\mu = 5.36 \times 10^{-6}\ J/T$$

Also,

$$W = \mu B(\cos\theta - \cos\theta_\circ)$$
$$W = \mu B(\cos 180^\circ - \cos 0^\circ)$$
$$W = \mu B((-1) - (1))$$

$$W = \mu B(-2)$$
$$W = -2\mu B$$
$$W = -2 \times 5.36 \times 10^{-6} \times 0.85$$
$$W = -9.1 \times 10^{-6}\ J$$
$$W = -9.1\ \mu J$$

Problem: 5.3- A 1.15 kg copper rod rests on two horizontal rails 95 m apart and carries a current of 53.2 A from one rail to other. The coefficient of static friction is 0.58. Find the smallest magnetic field that would cause the bar to slide.

Solution

Given data:

$$m = 1.15\ kg$$
$$L = 95\ m$$
$$\mu_s = 0.58$$
$$I = 53.2\ A$$
$$B = ?$$

Since,

$$F_m = F$$
$$ILB = \mu_s mg$$
$$B = \frac{\mu_s mg}{IL}$$
$$B = \frac{0.58 \times 1.15 \times 9.8}{53.2 \times 95}$$
$$B = 1.3 \times 10^{-3}\ T$$

Problem: 5.4- A circular coil of 160 turns has a radius of 1.93 cm. Calculate the current that results in a magnetic moment of 2.3 Am^2. Find the maximum torque on the coil that can be experienced in field of 34.6 mT.

Solution

Given data:

$$N = 160$$
$$r = 1.93\ cm = 1.93 \times 10^{-2}\ m$$
$$\mu = 2.3\ Am^2$$
$$B = 34.6\ mT$$
$$I = ?$$
$$\tau = ?$$

Since, we know that

$$\mu = NIA$$
$$\mu = NI\pi r^2$$
$$\text{or} \quad I = \frac{\mu}{N\pi r^2}$$
$$I = \frac{2.3}{160 \times 3.14 \times (1.93 \times 10^{-2})^2}$$
$$I = 12.4\ A$$

Since, the torque is maximum when angle is 90°. So,

$$\tau = \mu B \sin\theta$$
$$\tau = NIAB \sin\theta$$
$$\tau = 160 \times 12.4 \times 3.14(1.93 \times 10^{-2})^2 \times 34.6 \sin 90^\circ$$
$$\tau = 80\ Nm$$

Problem: 5.5- A circular wire loop having radius 8 cm carries a current of $0.2A$. A unit vector parallel to the dipole moment μ of the loop is given by $\left(0.6\hat{i} - 0.8\hat{j}\right)$. If the loop is located in $\vec{B} = \left(0.25\ \hat{i} + 0.3\hat{k}\right)\ T$. Find the torque on the loop and also find the magnetic potential energy of the loop.

Solution

$$\begin{aligned}
\vec{B} &= \left(0.25\ \hat{i} + 0.3\hat{k}\right)\ T \\
\hat{\mu} &= \left(0.6\hat{i} - 0.8\hat{j}\right) \\
I &= 0.2\ A \\
r &= 8\ cm\ =\ 8 \times 10^{-2}\ m \\
N &= 1 \\
\vec{\tau} &= ? \\
U_m &= ?
\end{aligned}$$

Since, we have to know that

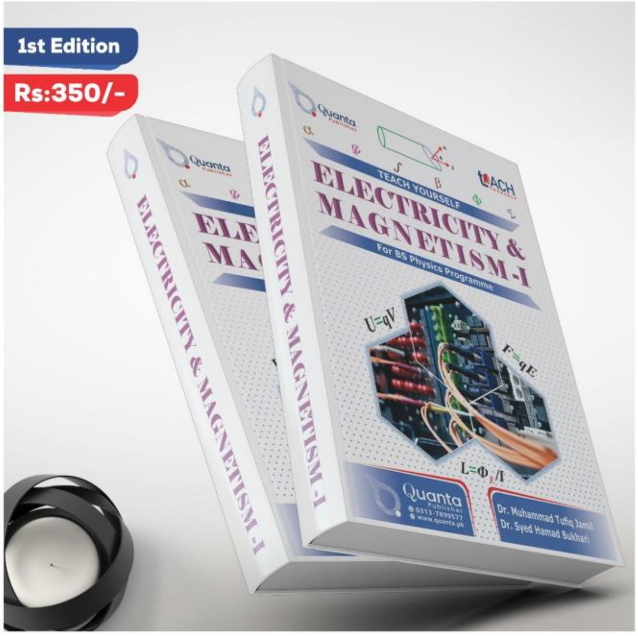
$$\begin{aligned}
\vec{\mu} &= \mu\hat{\mu} \\
\vec{\mu} &= NIA\hat{\mu} && \because \mu = NIA \\
\vec{\mu} &= NI\pi r^2\hat{\mu} && \because A = \pi r^2 \\
\vec{\mu} &= 1 \times 0.2 \times 3.14 \times (8 \times 10^{-2})^2 \left(0.6\hat{i} - 0.8\hat{j}\right) \\
\vec{\mu} &= 4.01 \times 10^{-3} \left(0.6\hat{i} - 0.8\hat{j}\right)\ J/T \\
\vec{\mu} &= \left(2.41 \times 10^{-3}\hat{i} - 3.20 \times 10^{-3}\hat{j}\right)\ J/T
\end{aligned}$$

Now, the torque acting on the loop is

$$\begin{aligned}
\vec{\tau} &= \vec{\mu} \times \vec{B} \\
\vec{\tau} &= \left(2.41 \times 10^{-3}\hat{i} - 3.20 \times 10^{-3}\hat{j}\right) \times \left(0.25\ \hat{i} + 0.3\hat{k}\right) \\
\vec{\tau} &= 9.60 \times 10^{-3}\hat{i} - 7.23 \times 10^{-3}\hat{j} - 80.0 \times 10^{-3}\hat{k}
\end{aligned}$$

Also, we know that

$$U_m = -\vec{\mu} \cdot \vec{B}$$
$$U_m = -\left(2.41 \times 10^{-3}\hat{i} - 3.20 \times 10^{-3}\hat{j}\right) \cdot \left(0.25\ \hat{i} + 0.3\hat{k}\right)$$
$$U_m = -\left(-2.41 \times 10^{-3} \times 0.25\right)$$
$$U_m = 2.41 \times 10^{-3} \times 0.25$$
$$U_m = 6.025 \times 10^{-4}\ Nm$$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