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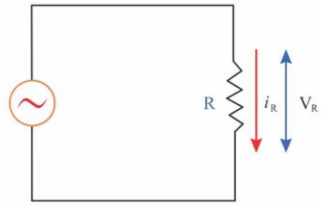

TEACH YOURSELF

$\alpha \quad \Psi \quad \int \quad \beta \quad \Phi \quad \Sigma$

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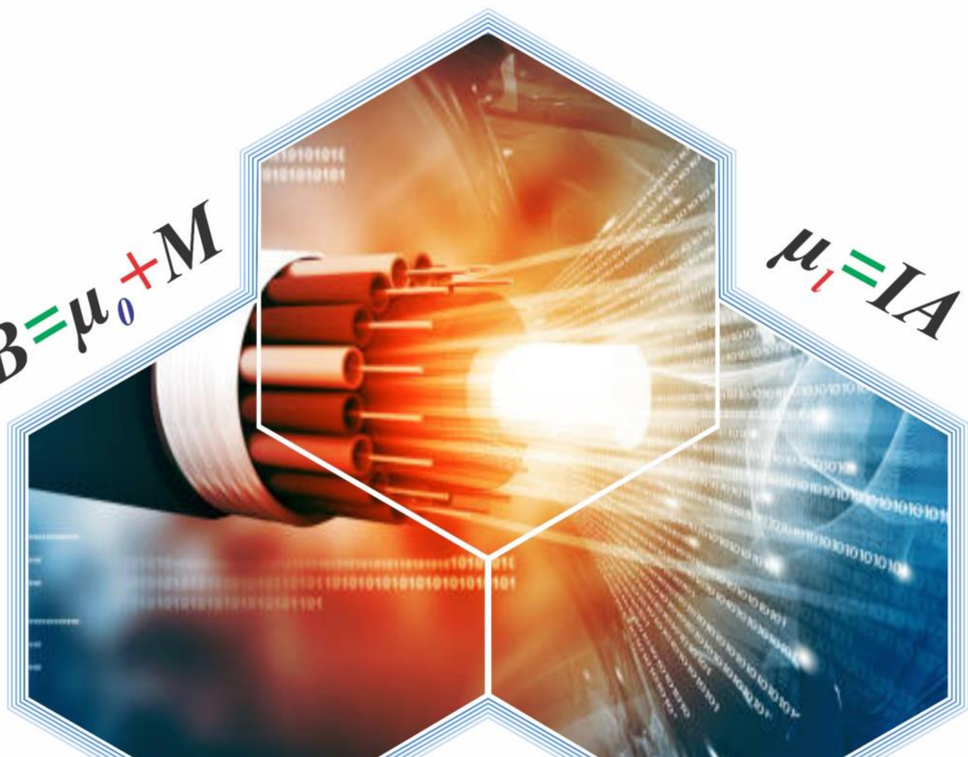
ELECTRICITY & MAGNETISM - II

For BS Physics Programme

$B=\mu_0+M$

$\mu_l=IA$



$\varepsilon=-N\Delta\Phi/\Delta t$

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Dr. M. Tufiq Jamil
Dr. Syed Hamad Bukhari

TEACH YOURSELF

ELECTRICITY & MAGNETISM - II

1st Edition

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

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Dr. Muhammad Tufiq Jamil
Department of Physics
Govt. Postgraduate College, Muzaffargarh

&

Dr. Syed Hamad Bukhari
Department of Physics
G.C. University Faisalabad, Sub-Campus, Layyah

•

Assisted by
Ameed-ul-Hassan Alvi
Department of Physics
G.C. University Faisalabad, Sub-Campus, Layyah

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Contents

Chapter 1

INDUCTION

SOLVED PROBLEMS

Problem: 1.1- A solenoid has inductance 53 mH and a resistance of 0.37 Ω, so $\frac{L}{R} = 0.143\ H/\Omega$. If it is connected to a battery, how long will it take for the current to reach one half of its final equilibrium value.

Solution

$$\begin{aligned} L &= 53\ mH = 53 \times 10^{-3}\ H \\ R &= 0.37\ \Omega \\ t &= ? \end{aligned}$$

Since, the current in RL series circuit at any time is

$$I = \frac{\varepsilon}{R}\left(1 - e^{-Rt/L}\right)$$

The equilibrium current is

$$I_\circ = \frac{\varepsilon}{R}$$

Given condition is

$$\begin{aligned} I &= \frac{I_\circ}{2} \\ \frac{\varepsilon}{R}\left(1 - e^{-Rt/L}\right) &= \frac{\varepsilon}{2R} \end{aligned}$$

$$e^{-Rt/L} = \frac{1}{2}$$
$$t = 0.10\ s$$

Problem: 1.2- In a 100 MeV betatron, the orbit radius is 84 cm. The magnetic field in the region enclosed by the orbit rises periodically from zero to maximum average value of $B = 0.80\ T$ in an interval of 4.2 ms. Calculate the average emf in weber per second.

Solution

$$N = 1$$
$$K.E = 100\ MeV$$

$$r = 84\ cm = 84 \times 10^{-2}\ m$$
$$dB = 0.80\ T$$
$$dt = 4.2\ ms = 4.2 \times 10^{-3}\ s$$
$$\varepsilon = ?$$

Now, according to Faraday's law of electromagnetic induction, we have the magnitude of induced emf is.

$$\varepsilon = N\frac{d\phi_B}{dt}$$
$$\varepsilon = N\frac{AdB}{dt}$$
$$\varepsilon = N\frac{\pi r^2 dB}{dt}$$
$$\varepsilon = 1 \times \frac{3.14 \times (84 \times 10^{-2})^2 \times 0.80}{4.2 \times 10^{-3}}$$
$$\varepsilon = 422\ Wb/s$$

Problem: 1.3- A conductor of length 0.5 m is sliding along a loop of 0.7 Ω resistance with velocity 0.2 m/s. The loop is placed in magnetic field of 1.5 T. Find the motional emf if the conductor moves perpendicular to field, current through the loop, electric power and mechanical power.

Solution

$$L = 0.5\ m$$
$$v = 0.2\ m/s$$
$$B = 1.5\ T$$
$$R = 0.7\ \Omega$$
$$\varepsilon = ?$$
$$I = ?$$
$$P_m = ?$$
$$P_e = ?$$

Since, we know that the motional emf is

$$\varepsilon = vBL$$
$$\varepsilon = 0.2 \times 1.5 \times 0.5$$
$$\varepsilon = 0.15\ V$$

The value of current is determined as

$$\varepsilon = IR$$
$$I = \frac{\varepsilon}{R}$$
$$I = \frac{0.15}{0.7} = 0.21$$

The mechanical power is calculated as

$$
\begin{aligned}
P_m &= F_m v \\
P_m &= (ILB)v \\
P_m &= 0.21 \times 0.5 \times 1.5 \times 0.2 \\
P_m &= 0.032\ W
\end{aligned}
$$

Now, the electrical power is defined as

$$
\begin{aligned}
P_e &= I\varepsilon \\
P_e &= 0.21 \times 0.15 \\
P_e &= 0.032\ W
\end{aligned}
$$

Problem: 1.4- A toroid having 5.2 cm square cross-section. Its mean radius is 15.3 cm and has 536 turns of wire, carries a current of 810 mA. Calculate the magnetic flux through the cross-section.

Solution

$$
\begin{aligned}
A &= 5.2 \times 10^{-2} \times 5.2 \times 10^{-2}\ m^2 \\
r &= 15.3\ cm = 15.3 \times 10^{-2}\ m \\
N &= 536 \\
I &= 810\ mA = 810 \times 10^{-3}\ A \\
\mu_\circ &= 4\pi \times 10^{-7}\ WB/m \\
\phi_m &= ?
\end{aligned}
$$

Since, the magnetic flux is defined as

$$
\begin{aligned}
\phi_m &= BA \\
\phi_m &= \frac{\mu_\circ NIA}{2\pi r} \\
\phi_m &= \frac{4\pi \times 10^{-7} \times 536 \times 810 \times 10^{-3} \times 5.2 \times 10^{-2} \times 5.2 \times 10^{-2}}{2 \times 3.14 \times 15.3 \times 10^{-2}} \\
\phi_m &= 1.5 \times 10^{-6}\ Wb
\end{aligned}
$$

Problem: 1.5- A solenoid is wound with single layer of insulated copper wire having diameter 2.52 mm. It is 4.10 cm in diameter and 2 m long. What is the inductance per meter of solenoid by assuming that adjacent wires touch together and insulation thickness is negligible?

Solution

$$\begin{aligned}
\text{Diameter of wire} &= 2.52\ mm\ =\ 2.52\times10^{-3}\ m\\
\text{Diameter of solenoid} &= 4.10\ cm\ =\ 4.10\times10^{-2}\ m\\
\text{Radius of solenoid} &= 2.05\ cm\ =\ 2.05\times10^{-2}\ m\\
\text{Length of solenoid} &= 2\ m\\
\frac{L}{l} &= ?
\end{aligned}$$

Now,

$$\begin{aligned}
2.52\times10^{-3}\ m\ \text{diameter of wire makes turns} &= 1\\
1\ m\ \text{length of wire makes turns} &= \frac{1}{2.52\times10^{-3}}\\
2\ m\ \text{length of wire makes turns} &= \frac{2}{2.52\times10^{-3}}
\end{aligned}$$

Since, $N\ =\ 794$

$$\begin{aligned}
n &= \frac{N}{l}\\
n &= \frac{794}{2}\ =\ 397
\end{aligned}$$

Now,

$$\begin{aligned}
L &= \mu_\circ n^2 A\ell\\
\frac{L}{\ell} &= \mu_\circ n^2 A\\
\frac{L}{\ell} &= \mu_\circ n^2 \pi r^2
\end{aligned}$$

$$\frac{L}{\ell} = 4\pi \times 10^{-7} \times (397)^2 \times 3.14 \times (2.05 \times 10^{-3})^2$$
$$\frac{L}{\ell} = 2.61 \times 10^{-4}\ H/m$$

Chapter 2

Alternating Current Circuits

SOLVED PROBLEMS

Problem: 2.1- Let $C = 15 \times 10^{-6}\ F$, $R = 160\ \Omega$, $L = 230 \times 10^{-3}\ H$ and $f = 60\ Hz$. Find impedance Z for circuit, the current amplitude I and the phase constant ϕ when applied e.m.f $E_m = 35V$.

Solution

$$\begin{aligned} X_L &= 2\pi f L \\ X_L &= 2 \times 3.14 \times 60 \times 230 \times 10^{-3} \\ X_L &= 86.7\ \Omega \end{aligned}$$

Also we know that

$$\begin{aligned} X_C &= \frac{1}{2\pi f C} \\ X_C &= \frac{1}{2 \times 3.14 \times 60 \times 15 \times 10^{-6}} \\ X_C &= 177\ \Omega \end{aligned}$$

Also, the impedance is given as

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$Z = \sqrt{(160)^2 + (86.7 - 177)^2}$$
$$Z = 184\ \Omega$$

And,

$$I = \frac{E_m}{Z}$$
$$I = \frac{36}{184} = 0.196\ A$$

The phase constant is given as

$$\tan\phi = \frac{X_L - X_C}{R}$$
$$\tan\phi = \frac{86.7 - 177}{160}$$

$$\tan\phi = -0.564$$
$$\phi = -29.4^\circ$$

$X_C > X_L$, so ϕ is negative.

Problem: 2.2- A $45\times10^{-3}\ H$ inductor has a reactance of 1300 Ω. What is its operating frequency. What is capacitance of capacitor with the same reactance at that frequency. If the frequency is doubled, then what is reactance of inductor and capacitor.

Solution

$$L = 45 \times 10^{-3} H$$
$$X_L = 1300\omega$$
$$f = ?$$
$$C = ?$$

Reactance of inductor is given as

$$X_L, = \omega L = 2\pi f L$$

$$
\begin{aligned}
f &= \frac{X_L}{2\pi L} \\
f &= \frac{1300}{2 \times 3.14 \times 45 \times 10^{-3}} \\
f &= 4.6 \times 10^3 \ Hz
\end{aligned}
$$

And the reactance of capacitor is given as

$$
\begin{aligned}
X_C &= \frac{1}{\omega C} \\
X_C &= \frac{1}{2\pi f C} \\
C &= \frac{1}{2\pi f X_C} \\
C &= \frac{1}{2 \times 3.14 \times 4.6 \times 10^3 \times 1300} \\
C &= 2600 \ \Omega
\end{aligned}
$$

When frequency is doubled, then the reactance of inductor and capacitor is

$$
\begin{aligned}
X_L^{'} &= 2\pi(2f)L \\
X_L^{'} &= 2(2\pi f L) \\
X_L^{'} &= 2X_L \\
X_L^{'} &= 2 \times 1300 \\
X_L^{'} &= 2600 \ \Omega
\end{aligned}
$$

Also,

$$
\begin{aligned}
X_C^{'} &= \frac{1}{2\pi(2f)C} \\
X_C^{'} &= \frac{1}{2}\frac{1}{2\pi f C} \ = \frac{1}{2}X_C \\
X_C^{'} &= \frac{1300}{2} \\
X_C^{'} &= 650 \ \Omega
\end{aligned}
$$

Problem: 2.3- Can the amplitude of voltage across an inductor be greater than the amplitude of the generator e.m.f in RLC circuit. Consider an RLC circuit with $E_m = 10\ V,\ R = 10\ \Omega,\ L = 1\ H$ and $C = 10^{-6}\ F$. Find amplitude of voltage across the inductor at resonance.

Solution

Voltage across inductor is given as

$$\begin{aligned} V_L &= IX_L \\ V_L &= I\omega L \\ V_L &= \frac{IL}{\sqrt{LC}} \qquad \because \omega = \frac{1}{LC} \\ V_L &= I\sqrt{\frac{L}{C}} \\ V_L &= I\sqrt{\frac{1}{10^{-6}}} \\ V_L &= 1000\ I \end{aligned}$$

At resonance,

$$\begin{aligned} I &= \frac{E_m}{Z} \\ I &= \frac{E_m}{\sqrt{(X_L - X_C)^2 + R^2}} \\ I &= \frac{E_m}{\sqrt{(X_L - X_L)^2 + R^2}} \qquad \because X_L = X_C \\ I &= \frac{E_m}{\sqrt{R^2}} \\ I &= \frac{E_m}{R} = \frac{10}{10} \\ I &= 1\ A \end{aligned}$$

So,

$$\begin{aligned} V_L &= 1000 \times 1 \\ V_L &= 1000\ V \end{aligned}$$

It is much greater than amplitude of generator voltage of 10 V.

Problem: 2.4- What is resonance frequency of a circuit containing $R = 160\ \Omega,\ C = 15\ \mu F,\ L = 230\ mH$ and $\varepsilon_\circ = 36\ V$.

Solution

$$\begin{aligned} R &= 160\ \Omega \\ C &= 15\ \mu F\ =\ 15 \times 10^{-6}\ F \\ L &= 230\ mH\ =\ 230 \times 10^{-3}\ H \\ f_r &= ? \end{aligned}$$

Since, we know that the resonance frequency is

$$\begin{aligned} f_r &= \frac{1}{2\pi\sqrt{LC}} \\ f_r &= \frac{1}{2 \times 3.14\sqrt{230 \times 10^{-3} \times 15 \times 10^{-6}}} \\ f_r &= 86\ Hz \end{aligned}$$

Problem: 2.5- The resonance frequency of RLC series circuit is 86 Hz. If $C = 15\ \mu F$, find the inductance.

Solution

$$\begin{aligned} f_r &= 86\ Hz \\ C &= 15\ \mu F\ =\ 15 \times 10^{-6}\ F \\ L &= ? \end{aligned}$$

Since, we know that the resonance frequency is

$$\begin{aligned} f_r &= \frac{1}{2\pi\sqrt{LC}} \\ 86 &= \frac{1}{2 \times 3.14\sqrt{L \times 15 \times 10^{-6}}} \\ L &= 229 \times 10^{-3}\ H \end{aligned}$$

Chapter 3

Maxwell's Equations and Electromagnetic Waves

SOLVED PROBLEMS

Problem: 3.1- An observer is 1.8 m from a light source whose power output is 250 W. Calculate the rms values of electric field and magnetic field at the position of observer. Assume that source radiates uniformly in all directions.

Solution

Given data:

$$\begin{aligned} r &= 1.8\ m \\ P &= 250\ W \\ \mu_\circ &= 4\pi \times 10^{-7}\ Wb/Am \\ c &= 3 \times 10^{8}\ ms^{-1} \\ E_m &= ? \\ B_m &= ? \end{aligned}$$

As,

$$I = \frac{P}{4\pi r^2}$$

and,

$$I = \frac{E_{r.m.s}^2}{\mu_\circ c}$$

On comparing, we get

$$\begin{aligned}
\frac{E_{r.m.s}^2}{\mu_\circ c} &= \frac{P}{4\pi r^2} \\
E_{r.m.s}^2 &= \frac{P\mu_\circ c}{4\pi r^2} \\
E_{r.m.s} &= \sqrt{\frac{P\mu_\circ c}{4\pi r^2}} \\
E_{r.m.s} &= \sqrt{\frac{250 \times 4\pi \times 10^{-7} \times 3 \times 10^8}{4 \times 3.14 \times (1.8)^2}} \\
E_{r.m.s} &= 48\ V/m
\end{aligned}$$

Now, the root mean square value of magnetic field is

$$\begin{aligned}
\frac{E_{r.m.s}}{B_{r.m.s}} &= c \\
\text{or} \quad \frac{B_{r.m.s}}{E_{r.m.s}} &= \frac{1}{c} \\
B_{r.m.s} &= \frac{E_{r.m.s}}{c} \\
B_{r.m.s} &= \frac{48}{3 \times 10^8} \\
B_{r.m.s} &= 1.6 \times 10^{-7}\ T
\end{aligned}$$

Problem: 3.2- Currently operating neodymium glass laser can provide 100 TW of power in 1.0 ns pulses at a wavelength of 0.26 μm. How much energy is contained in a single pulse?

Solution

$$P = 100\ TW$$
$$P = 100 \times 10^{12}\ W$$
$$t = 1.0\ ns$$
$$t = 1.0 \times 10^{-9}\ s$$
$$U = ?$$

Since,

$$P = \frac{U}{t}$$
$$U = P \times t$$
$$U = 100 \times 10^{12} \times 1.0 \times 10^{-9}$$
$$U = 1 \times 10^{5}\ J$$
$$U = 0.1 \times 10^{6}\ J$$
$$U = 0.1\ MJ$$

Problem: 3.3- What must be the magnitude of a uniform electric field if it is so to have the same energy density as possessed by 0.5 T magnetic field?

Solution

Given data:

$$B = 0.5\ T$$
$$\mu_\circ = 4\pi \times 10^{-7}\ Wb/Am$$
$$\varepsilon_\circ = 8.85 \times 10^{-12}\ C^2/Nm^2$$
$$E = ?$$

Since, the given condition

$$
\begin{aligned}
U_e &= U_m \\
\frac{1}{2}\varepsilon_\circ E^2 &= \frac{1}{2\mu_\circ}B^2 \\
\varepsilon_\circ E^2 &= \frac{1}{\mu_\circ}B^2 \\
E^2 &= \frac{B^2}{\mu_\circ\varepsilon_\circ} \\
E &= \sqrt{\frac{B^2}{\mu_\circ\varepsilon_\circ}}
\end{aligned}
$$

$$
\begin{aligned}
E &= \frac{B}{\sqrt{\mu_\circ\varepsilon_\circ}} \\
E &= \frac{0.50}{\sqrt{4\pi \times 10^{-7} \times 8.85 \times 10^{-12}}} \\
E &= 1.5 \times 10^8\ N/C
\end{aligned}
$$

Problem: 3.4- The intensity of direct solar radiation that was unabsorbed by the atmosphere on a particular summer day is 130 W/m^2. How close would you have to stand to a 1.0 kW electric heater to feel the same intensity? Assume that heater radiates uniformly in all directions.

Solution

$$
\begin{aligned}
I &= 130\ W/m^2 \\
P &= 1.0\ kW \\
P &= 1.0 \times 10^3\ W \\
r &= ?
\end{aligned}
$$

Since, we know that

$$I = \frac{P}{4\pi r^2}$$
$$r^2 = \frac{P}{4\pi I}$$
$$r = \sqrt{\frac{P}{4\pi I}}$$
$$r = \sqrt{\frac{1.0 \times 10^3}{4 \times 3.14 \times 130}}$$
$$r = 0.78\ m$$

Problem: 3.5- The maximum electric field at a distance of 11.2 m from a point light source is 1.96 V/m. Calculate the maximum value of magnetic field, intensity and power output of the source.

Solution

$$E_m = 1.96\ V/m$$
$$r = 11.2\ m$$
$$c = 3 \times 10^8\ ms^{-1}$$
$$\mu_\circ = 4\pi \times 10^{-7}\ Wb/Am$$

$$B_m = ?$$
$$I = ?$$
$$P = ?$$

Since, we have to know that

$$\frac{E_m}{B_m} = c$$
$$\frac{B_m}{E_m} = \frac{1}{c}$$
$$B_m = \frac{E_m}{c}$$
$$B_m = \frac{1.96}{3 \times 10^8}$$
$$B_m = 6.5 \times 10^{-9}\ T$$

Also,

$$I = \frac{E_m B_m}{2\mu_\circ}$$
$$I = \frac{1.96 \times 6.5 \times 10^{-9}}{2 \times 4\pi \times 10^{-7}}$$
$$I = 5.10 \times 10^{-3}\ W/m^2$$

And, the power is calculated as

$$
\begin{aligned}
I &= \frac{P}{4\pi r^2} \\
\text{or} \quad P &= 4\pi r^2 I \\
P &= 4 \times 3.14 \times (11.2)^2 \times 5.10 \times 10^{-3} \\
P &= 8.03\ W
\end{aligned}
$$


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