HIGHER SECONDARY
SECOND YEAR

இயற்பியல்

PHYSICS

NUMERICAL PROBLEMS

2022 – 2023

PREPARED BY

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“thoehs; KOtJk; xt;ntU kzpj;JspAk; NeHikaha;, cz;ikaha; ciof;fpd;wtHfspd; fuq;fNs J}a;ikahd fuq;fs;.”

UNIT - I (ELECTROSTATICS)

1. Calculate the number of electrons in one coulomb of negative charge.

Solution:

According to the quantization of charge **q = ne**

Here q = 1C. So the number of electrons in 1 coulomb of charge is

$$n = \frac{q}{e} = \frac{1\text{ C}}{1.6 \times 10^{-19}} = 6.25 \times 10^{18} \text{ electrons}$$

No.	Log
10^{19}	19.0000
1.6	0.2041
(−)	18.7959
Antilog	6.25×10^{18}

2. A sample of HCl gas is placed in a uniform electric field of magnitude 3×10^4 N C^{-1}. The dipole moment of each HCl molecule is 3.4×10^{-30} Cm. Calculate the maximum torque experienced by each HCl molecule.

Solution:

The maximum torque experienced by the dipole is when it is aligned perpendicular to the applied field.

$\tau_{max} = pE \sin 90^0$; $= 3.4 \times 10^{-30} \times 3 \times 10^4$ N m

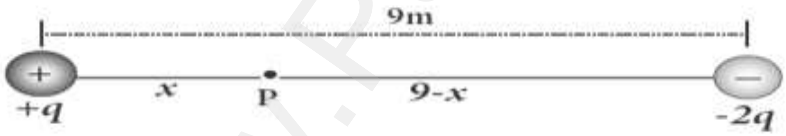
$\tau_{max} = 10.2 \times 10^{-26}$ Nm.

3. Consider a point charge +q placed at the origin and another point charge -2q placed at a distance of 9 m from the charge +q. Determine the point between the two charges at which electric potential is zero.

Solution:

According to the superposition principle, the total electric potential at a point is equal to the sum of the potentials due to each charge at that point.

Consider the point at which the total potential zero is located at a distance x from the charge +q as shown in the figure.



The total electric potential at P is zero. $V_{tot} = \frac{1}{4\pi\epsilon_0}\left(\frac{q}{x} - \frac{2q}{(9-x)}\right) = 0$

Which gives, $\frac{q}{x} = \frac{2}{(9-x)}$ (or) $\frac{1}{x} = \frac{2}{(9-x)}$ Hence, x = 3m

4. Calculate the electric flux through the rectangle of sides 5 cm and 10 cm kept in the region of a uniform electric field 100 NC^{-1}. The angle θ is 60^0. Suppose θ becomes zero, what is the electric flux?

Solution:

The electric flux $\Phi_E = \vec{E}.\vec{A}$ = EA cosθ = 100 x 5 x 10x10^{-4} x cos60^0

$\Rightarrow \Phi_E = 0.25$ Nm^{2}C^{-1}

For $\theta = 0^0$, $\Phi_E = \vec{E}.\vec{A}$ = EA cosθ = 100 x 5 x 10x10^{-4}

= 0.5Nm^{2}C^{-1}

5. A parallel plate capacitor has square plates of side 5 cm and separated by a distance of 1 mm. (a) Calculate the capacitance of this capacitor. (b) If a 10 V battery is connected to the capacitor, what is the charge stored in any one of the plates? (The value of $\varepsilon_o = 8.85 \times 10^{-12}$ Nm² C⁻²)

Solution:

(a) The capacitance of the capacitor is $C = \frac{\epsilon_0 A}{d}; \frac{8.854 \times 10^{-12} \times 25 \times 10^{-4}}{1 \times 10^{-3}}$

$= 221.2 \times 10^{-13}$ F;

$C = 22.12 \times 10^{-12}$ F; $= 22.12\ pF$

(b) The charge stored in any one of the plates is Q = CV, Then

$Q = 22.12 \times 10^{-12} \times 10 = 221.2 \times 10^{-12}$C

$Q = 221.2\ pC$

6. A parallel plate capacitor filled with mica having $\varepsilon_r = 5$ is connected to a 10 V battery. The area of the parallel plate is 6 m² and separation distance is 6 mm. (a) Find the capacitance and stored charge.

(b) After the capacitor is fully charged, the battery is disconnected and the dielectric is removed carefully. Calculate the new values of capacitance, stored energy and charge.

Solution:

The capacitance of the capacitor in the presence of dielectric is

$$C = \frac{\epsilon_r \epsilon_0 A}{d} = \frac{5 \times 8.854 \times 10^{-12} \times 6}{6 \times 10^{-3}}; = 44.25 \times 10^{-9} \text{ F} = 44.25 \text{ nF}$$

The stored charge is $Q = CV = 44.25 \times 10^{-9} \times 10$

$= 442.5 \times 10^{-9}$; **C = 442.5nC**

The stored energy is $U = \frac{1}{2} CV^2; = \frac{1}{2} \times 44.25\ C \times 10^{-9} \times 100$

$= 2.21 \times 10^{-6}$ J $= 2.21\ \mu J$

(b) After the removal of the dielectric, since the battery is already disconnected the total charge will not change. But the potential difference between the plates increases. As a result, the capacitance is decreased.

New capacitance is $C_0 = \frac{C}{\epsilon_r} = \frac{44.25 \times 10^{-9}}{5}$; 8.85×10^{-9} F = 8.85nF

The stored charge remains same and 442.5 nC.

Hence newly stored energy is $U_0 = \frac{Q^2}{2C_0}; = \frac{Q^2 \epsilon_r}{2C} = \epsilon_r U$

$= 5 \times 2.21\ \mu J = 11.05\ \mu J$

The increased energy is $\Delta U = 11.05\ \mu J - 2.21\ \mu J = 8.84\ \mu J$

When the dielectric is removed, it experiences an inward pulling force due to the plates. To remove the dielectric, an external agency has to do work on the dielectric which is stored as additional energy. This is the source for the extra energy 8.84 μJ.

7. Dielectric strength of air is 3 × 10⁶ V m⁻¹. Suppose the radius of a hollow sphere in the Van de Graff generator is R = 0.5 m, calculate the maximum potential difference created by this Van de Graaff generator.

Solution:

The electric field on the surface of the sphere (by Gauss law) is given by

$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R^2}$

The potential on the surface of the hollow metallic sphere is given by

$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R} = ER$

With $V_{max} = E_{max} R$

Here $E_{max} = 3 \times 10^6 \frac{V}{m}$. So, the maximum potential difference created is given by $V_{max} = 3 \times 10^6 \times 0.5$

$= 1.5 \times 10^6$ V (or) 1.5 million volt

8. A water molecule has an electric dipole moment of 6.3×10^{-30} Cm. A sample contains 10^{22} water molecules, with all the dipole moments aligned parallel to the external electric field of magnitude 3×10^5 N C⁻¹. How much work is required to rotate all the water molecules from θ = 0° to 90°?

Solution:

$\theta_i = 0^0; \theta_f = 90^0$; E = $3\text{x}10^5$ NC⁻¹; p = $6.3\text{x}10^{-30}$ Cm; n= 10^{22}

When the water molecules are aligned in the direction of the electric field, it has minimum potential energy.

The work done to rotate the dipole from θ = 0° to 90° is equal to the potential energy difference between these two configurations

$W = U(\theta_f) - U(\theta_i)$

$W = -pE\cos\theta_f + pE\cos\theta_i$; $= pE\cos(\theta_i - \theta_f)$; $= pE\cos(0^0 - 90^0)$

$= pE\cos(1 - 0)$; W= pE ; $= 6.3\text{x}10^{-30} \text{ x } 3\text{x}10^5$; **= $18.9 \text{ x}10^{-25}$J**

Hence for 1022 water molecules, the total work done is

$W_{tot} = 10^{22} \text{ x } 18.9 \text{ x } 10^{-25}$; **$W_{tot} = 18.9 \text{ x } 10^{-3}$J**

EXERCISE PROBLEM

9. When two objects are rubbed with each other, approximately a charge of 50 nC can be produced in each object. Calculate the number of electrons that must be transferred to produce this charge.

Solution:

Charge produced in each object q = 50 nc (or) q = $50 \text{ x } 10^{-9}$ C

Charge of electron (e) = $1.6 \text{ x } 10^{-19}$ C

Number of electron transferred, $n = \frac{q}{e} = \frac{50 \text{ x } 10^{-9}}{1.6 \text{ x } 10^{-19}}$

$= 31.25 \text{ x } 10^{-9} \text{ x } 10^{19}$

N = $31.25 \text{ x } 10^{10}$ electrons.

No.	Log
50	1.6990
1.6	0.2041
(−)	1.4949
Antilog	$3.125 \text{ x } 10^1$

10. The total number of electrons in the human body is typically in the order of 10^{28}. Suppose, due to some reason, you and your friend lost 1% of this number of electrons. Calculate the electrostatic force between you and your friend separated at a distance of 1m. Compare this with your weight. Assume mass of each person is 60 kg and use point charge approximation.

Solution:

Number of electrons in the human body = 10^{28}

Number of electrons in me and my friend after lost of 1 % = 10^{28} x 1%

= $10^{28} \times \frac{1}{100}$ n = 10^{26} electrons.

Separate distance d = 1m,

Charge of each person q = $10^{26} \times 1.6 \times 10^{-19}$;

q = 1.6×10^{7} C

Electrostatic force, F = $\frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}$;

$\frac{9 \times 10^9 \times 1.6 \times 10^7 \times 1.6 \times 10^7}{1}$

F = 2.304×10^{24} N

No.	Log
23.04	1.3625
588	2.7694
(−)	2.5931
Antilog	3.918×10^{-2}

Mass of the person, M = 60 kg,

Acceleration due to gravity, g = 9.8 ms^{-2} ; Wight (W) = mg

= 60 x 9.8 W = 588 N

Comparison: Electrostatic force is equal to 3.92×10^{21} times of weight of the person.

11. A spark plug in a bike or a car is used to ignite the air-fuel mixture in the engine. It consists of two electrodes separated by a gap of around 0.6 mm gap. To create the spark, an electric field of magnitude 3×10^6 Vm^{-1} is required. (a) What potential difference must be applied to produce the spark? (b) If the gap is increased, does the potential difference increase, decrease or remains the same? (c) find the potential difference if the gap is 1 mm.

Solution:

Separation gap between two electrodes, d = 0.6 mm (or) d = 0.6×10^{-3}m

Magnitude of electric field E = 3×10^6 Vm^{-1}; Electric field E = $\frac{V}{d}$

a) Applied potential difference, V = E . d

= $3 \times 10^6 \times 0.6 \times 10^{-13}$; = 1.8×10^3 ; V = 1800V

b) From equation, V = E. d (If the gap (distance) between the electrodes increases, the potential difference also increases.

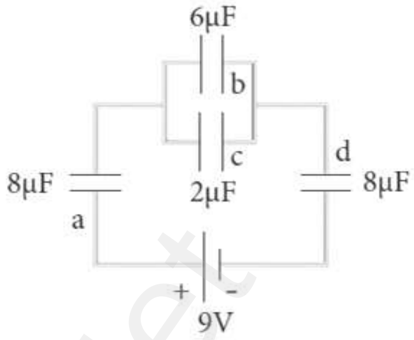
c) Gap between the electrodes, d = 1mm = 1×10^{-3} m

Potential difference, V = E . d

= $3 \times 10^6 \times 1 \times 10^{-3}$; 3×10^3 ; V = 3000 V

12. For the given capacitor configuration (a) Find the charges on each capacitor (b) potential difference across them (c) energy stored in each capacitor

Solution:



Capacitor b and c in parallel combination

$C_P = C_b + C_c = (6 + 2)\ \mu F = 8\mu F$

Capacitor, a, Cp and d are in series combination, so the resultant capacitance.

$$\frac{1}{C_s} = \frac{1}{C_a} + \frac{1}{C_{cp}} + \frac{1}{C_d}\ ; = \frac{1}{8} + \frac{1}{8} + \frac{1}{8} = \frac{3}{8}$$

a) Charge on capacitor a, $Q_a = C_s V = \frac{8}{3} \times 9$; $Q_a = 24\ \mu C$

Charge on capacitor d, $Q_d = C_s V = \frac{8}{3} \times 9$; $Q_d = 24\ \mu C$

Capacitor b and c in parallel

Charge on capacitor b, $Q_b = C_s V = \frac{6}{3} \times 9$; $Q_b = 18\ \mu C$

Charge on capacitor c, $Q_c = C_s V = \frac{2}{3} \times 9$; $Q_c = 6\ \mu C$

b) Potential difference across each capacitor, $V = \frac{q}{C}$

Capacitor C_a, $V_a = \frac{q_a}{C_a} = \frac{24 \times 10^{-6}}{8 \times 10^{-6}}$; $V_a = 3V$

Capacitor C_b, $V_b = \frac{q_b}{C_b} = \frac{18 \times 10^{-6}}{6 \times 10^{-6}}$; $V_b = 3V$

Capacitor C_c, $V_c = \frac{q_c}{C_c} = \frac{6 \times 10^{-6}}{2 \times 10^{-6}}$; $V_c = 3V$

Capacitor C_d, $V_d = \frac{q_d}{C_d} = \frac{24 \times 10^{-6}}{8 \times 10^{-6}}$; $V_d = 3V$

c) Energy stores in a capacitor, $U = \frac{1}{2} CV^2$

Energy in capacitor C_a, $U_a = \frac{1}{2} C_a V_a^2 = \frac{1}{2} \times 8 \times 10^{-6} \times (3)^2$; $U_a = 36\mu J$

Energy in capacitor C_b, $U_b = \frac{1}{2} C_b V_b^2 = \frac{1}{2} \times 6 \times 10^{-6} \times (3)^2$; $U_b = 27\mu J$

Energy in capacitor C_c, $U_c = \frac{1}{2} C_c V_c^2 = \frac{1}{2} \times 2 \times 10^{-6} \times (3)^2$; $U_b = 9\mu J$

Energy in capacitor C_d, $U_d = \frac{1}{2} C_d V_d^2 = \frac{1}{2} \times 8 \times 10^{-6} \times (3)^2$; $U_b = 36\mu J$

UNIT - II (CURRENT ELECTRICITY)

13. Compute the current in the wire if a charge of 120 C is flowing through a copper wire in 1 minute.

Solution:

The current (rate of flow of charge) in the wire is $I = \frac{Q}{t} = \frac{120}{60}$ = 2A

14. If an electric field of magnitude 570 N C^{-1}, is applied in the copper wire, find the acceleration experienced by the electron.

Solution:

E = 570 N C^{-1}, e = 1.6 × 10^{-19} C, m = 9.11 × 10^{-31} kg and a = ?

F = ma = eE ; a = $\frac{\mathrm{e\,E}}{\mathrm{m}}$; = $\frac{570 \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31}}$; = $\frac{912 \times 10^{-19} \times 10^{31}}{9.11}$

= 1.001 x 10^{14} ms^{-2}

15. A copper wire of cross-sectional area 0.5 mm^2 carries a current of 0.2 A. If the free electron density of copper is 8.4 x 10^{28} m^{-3} then compute the drift velocity of free electrons.

Solution:

The relation between drift velocity of electrons and current in a wire of cross- sectional area A is $V_d = \frac{I}{neA}$; $= \frac{0.2}{8.4 \times 10^{28} \times 1.6 \times 10^{-19} \times 0.5 \times 10^{-6}}$ ‘

$= \frac{2 \times 10^{-3}}{6.72}$ V_d = 0.03 x 10^{-3} ms^{-1}

16. Determine the number of electrons flowing per second through a conductor, when a current of 32 A flows through it.

Solution:

I = 32 A , t = 1 s Charge of an electron, e = 1.6 × 10^{-19} C The number of electrons flowing per second, n =?

$I = \frac{q}{t} = \frac{ne}{t}$; n = $\frac{It}{e}$; n = $\frac{32 \times 1}{1.6 \times 10^{-19}\,C}$

n= 20 × 10^{19} = 2 × 10^{20} electrons

17. The resistance of a wire is 20 Ω. What will be new resistance, if it is stretched uniformly 8 times its original length?

Solution:

R_1 = 20 Ω, R_2= ? ; Let the original length (l_1) be l

The new length, $l_2 = 8l_1$ (i.e.) , $l_2 = 8\,l$

The original resistance, $R_1 = \rho \frac{l_1}{A_2}$

The new resistance $R_2 = \rho \frac{l_2}{A_2} = \frac{\rho\,(8l)}{A_2}$

Though the wire is stretched, its volume is unchanged.

Initial volume = Final volume

$$A_1 l_1 = A_2 l_2 \;;\; A_1 l = A_2\, 8l \;;\; \frac{A_1}{A_2} = \frac{8\,l}{l} = 8$$

By dividing equation R_2 by equation R_1, we get $\frac{R_2}{R_1} = \frac{\rho\,(8l)}{A_2} \text{x} \frac{A_1}{\rho l}$

$\frac{R_2}{R_1} = \frac{A_1}{A_2} \text{x}\, 8$

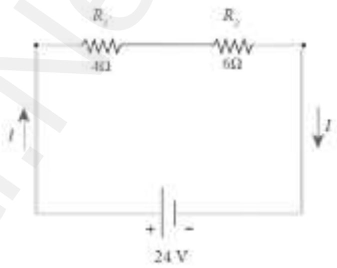
Substituting the value of $\frac{A_1}{A_2}$, we get $\frac{R_2}{R_1} = 8 \text{ x } 8 = 64$

$R_2 = 64 \times 20 = 1280\ \Omega$

Hence, stretching the length of the wire has increased its resistance.

18. Calculate the equivalent resistance for the circuit which is connected to 24 V batteries and also find the potential difference across 4 Ω and 6 Ω resistors in the circuit.

Solution:



Since the resistors are connected in series, the effective resistance in the circuit = 4 Ω + 6 Ω = 10 Ω

The Current I in the circuit $= \frac{V}{R_{eq}} = \frac{24}{10} = 2.4\text{A}$

Voltage across 4Ω resistor

$V_1 = IR_1 = 2.4\text{A} \times 4\ \Omega = 9.6$ V

Voltage across 6 Ω resistors

$V_2 = IR_1 = 2.4\text{A} \times 6\ \Omega = 14.4$ V

19. Calculate the equivalent resistance in the following circuit and also find the current I, I_1 and I_2 in the given circuit.

Solution:

Since the resistances are connected in parallel, therefore, the equivalent resistance in the circuit is

$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{4} + \frac{1}{6}$; $\frac{1}{R_P} = \frac{5}{12}\Omega$ (or) $R_P = \frac{12}{5}\Omega$

The resistors are connected in parallel; the potential (voltage) across each resistor is the same.

$I_1 = \frac{V}{R_1} = \frac{24\,V}{4\,\Omega} = 6\text{A}$; $I_2 = \frac{V}{R_2} = \frac{24\,V}{6\,\Omega} = 4\text{A}$

The current I is the total of the currents in the two branches. Then,

$I = I_1 + I_2 = 6\text{ A} + 4\text{ A} = 10\text{ A}$

20. When two resistances connected in series and parallel their equivalent resistances are 15 Ω and $\frac{56}{15}$ Ω respectively. Find the individual resistances.

Solution:

$R_s = R_1 + R_2 = 15\ \Omega$ .... (1)

$R_P = \frac{R_1 R_2}{R_1 + R_2} = \frac{\mathbf{56}}{\mathbf{15}}\Omega$ .... (2)

From equation (1) substituting for $R_1 + R_2$ in equation (2)

$\frac{R_1 R_2}{15} = \frac{\mathbf{56}}{\mathbf{15}}\Omega$; $\therefore R_1R_2 = 56$

$R_2 = \frac{\mathbf{56}}{\mathbf{15}}\Omega$ ....(3)

Substituting for R_2 in equation (1) from equation (3)

$R_1 + \frac{56}{R_1} = 15$; Then , $\frac{R_1^2+56}{R_1} = 15$; $R_1^2 + 56 = 15\ R_1$

$R_1^2 - 15\ R_1 + 56 = 0$

The above equation can be solved using factorization.

$R_1^2 - 8\ R_1 - 7\ R_1 + 56 = 0$; $R_1\ (R_1 - 8) - 7\ (R_1 - 8) = 0$

$(R_1 - 8)\ (R_1 - 7) = 0$; If ($R_1 = 8\ \Omega$)

Using in equation (1)

$8 + R_2 = 15$; $R_2 = 15 - 8 = 7\ \Omega$,

$R_2 = 7\ \Omega$ i.e , (when $R_1 = 8\ \Omega$; $R_2 = 7\ \Omega$) ; If ($R_1 = 7\ \Omega$)

Substituting in equation (1) $7 + R_2 = 15$

$R_2 = 8\ \Omega$, i.e , (when $R_1 = 8\ \Omega$; $R_2 = 7\ \Omega$)

21. If the resistance of coil is 3 Ω at 20ºC and α = 0.004/ºC then determine its resistance at 100ºC.

Solution:

$R_O = 3\ \Omega$, $T = 100^0C$, $T_O = 20^0C$

$\alpha = 0.004/^0C$, $R_T = ?$

$R_T = R_O(1 + \alpha(T - T_O))$

$R_{100} = 3(1 + 0.004 \times 80)$; $R_{100} = 3(1 + 0.32)$

$R_{100} = 3(1.32)$; $R_{100} = 3.96\ \Omega$

22. Resistance of a material at 10ºC and 40ºC are 45 Ω and 85 Ω respectively. Find its temperature co-efficient of resistance.

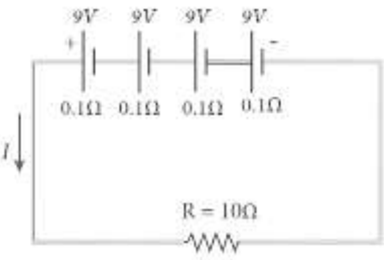
Solution:

$T_O = 10^0C$, $T = 40^0C$, $R_O = 45\ \Omega$, $R = 85\ \Omega$

$$\alpha = \frac{1}{R_0}\frac{\Delta R}{\Delta T} \ ; \alpha = \frac{1}{45}\left(\frac{85-45}{40-10}\right) ; = \frac{1}{45}\left(\frac{40}{30}\right)$$

$$\alpha = 00296\ /^0C$$

23. From the given circuit,
Find
i) Equivalent emf of the combination
ii) Equivalent internal resistance
iii) Total current
iv) Potential difference across external resistance
v) Potential difference across each cell



Solution:

i) Equivalent emf of the combination $\xi_{eq} = n\xi = 4\ 9 = 36$ V

ii) Equivalent internal resistance $r_{eq} = nr = 4 \times 0.1 = 0.4\ \Omega$

iii) Total current $I = \frac{n\xi}{R+nr}$; $= \frac{4 \times 9}{10+(4 \times 0.1)}$; $= \frac{4 \times 9}{10+0.4}$; $= \frac{36}{10.4}$

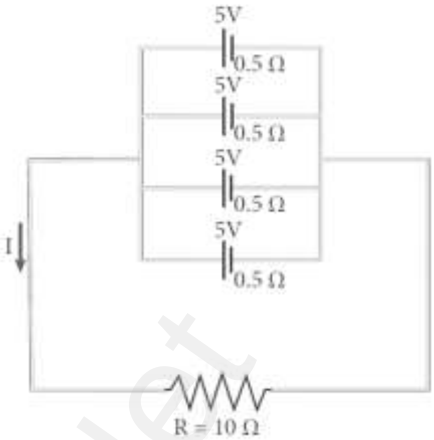
I = 3.46 A

iv) Potential difference across external resistance

V = IR = 3.46 × 10 = 34.6 V. The remaining 1.4 V is dropped across the internal resistance of cells.

v) Potential difference across each cell $\frac{V}{n} = \frac{34.6}{4} = 8.65$ V

24. **From the given circuit**
Find
i) Equivalent emf
ii) Equivalent internal resistance
iii) Total current (I)
iv) Potential difference across each cell
v) Current from each cell



Solution:

i) Equivalent emf ξ_{eq} = 5 V

ii) Equivalent internal resistance, $R_{eq} = \frac{r}{n}$

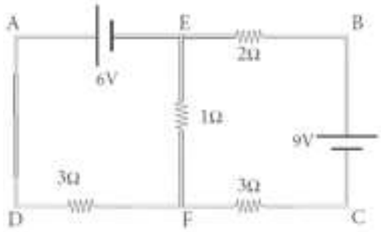
$= \frac{0.5}{4} = 0.125\Omega$

iii) Total Current, $I = \frac{\xi}{R+\frac{r}{n}}$; $I = \frac{5}{10+0.125} = \frac{5}{10.125}$ $I \approx 0.5$A

iv) Potential difference across each cell V = IR = 0.5 × 10 = 5 V

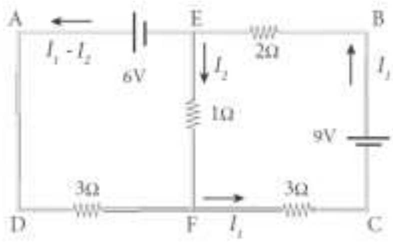
v) Current from each cell, $I' = \frac{I}{n}$; $I' = \frac{0.5}{4} = 0.125$ A

25. **Calculate the current that flows in the 1 Ω resistor in the following circuit.**



Solution:

We can denote the current that flows from 9V battery as I_1 and it splits into I_2 and $I_1 - I_2$ in the junction according Kirchhoff's current rule (KCR). It is shown below.



Now consider the loop EFCBE and apply KVR, we get

$1I_2 + 3I_1 + 2I_1 = 9$

$5I_1 + I_2 = 9$ ....(1)

Applying KVR to the loop EADFE, we get

$3(I_1 - I_2) - 1I_2 = 6$

$3I_1 - 4I_2 = 6$ ....(2)

Solving equation (1) and (2), we get

$I_1 = 1.83$ A and I2 = – 0.13 A

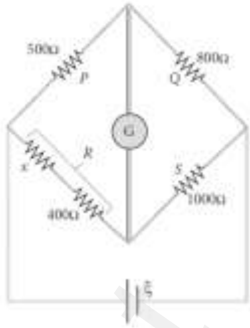
It implies that the current in the 1 ohm resistor flows from F to E.

26. **In a Wheatstone's Bridge P = 100 Ω, Q = 1000 Ω and R = 40 Ω. If the galvanometer shows zero deflection, determine the value of S.**

Solution:

$\frac{P}{Q} = \frac{R}{S}$; $S = \frac{Q}{P} \times R$; $S = \frac{1000}{100} \times 40$; S = 400 Ω

27. What is the value of x when the Wheatstone's network is balanced?
P = 500 Ω, Q = 800 Ω, R = x + 400,
S = 1000 Ω



Solution:

$\frac{P}{Q} = \frac{R}{S}$; $\frac{500}{800} = \frac{x+400}{1000}$; $\frac{x+400}{1000} = \frac{500}{800}$

$x + 400 = \frac{500}{800} \times 1000$; $x + 400 = \frac{5}{8} \times 1000$

$x + 400 = 0.625 \times 1000$

$x + 400 = 625$; $x = 625 - 400$

$x = 225\ \Omega$

28. In a meter bridge, the value of resistance in the resistance box is 10 Ω. The balancing length is l_1 = 55 cm. Find the value of unknown resistance.

Solution:

Q = 10 Ω $\frac{P}{Q} = \frac{l_1}{100 - l_1} = \frac{l_1}{l_2}$; P = Q x $\frac{l_1}{100 - l_1}$ P = $\frac{10 \times 55}{100-55}$

P = $\frac{550}{45}$; P= 12.2 Ω

29. Find the heat energy produced in a resistance of 10 Ω when 5 A current flow through it for 5 minutes.

Solution:

R = 10 Ω, I = 5 A, t = 5 minutes = 5 × 60 s

H = I^2 R t

= 5^2 × 10 × 5 × 60 ; = 25 × 10 × 300

= 25 × 3000 ; = 75000 J (or) 75 kJ

30. A battery has an emf of 12 V and connected to a resistor of 3 Ω. The current in the circuit is 3.93 A. Calculate (a) terminal voltage and the internal resistance of the battery (b) power delivered by the battery and power delivered to the resistor

Solution:

I = 3.93 A ; ϵ = 12 V ; R = 3 Ω

(a) The terminal voltage of the battery is equal to voltage drop across the resistor V = IR= 3.93 x 3 = 11.79V

Internal resistance of the battery, r = $\left[\frac{\epsilon - V}{V}\right]$ R ; = $\left[\frac{12 - 11.79}{11.79}\right]$ x 3

= $\frac{0.21 \times 3}{11.79}$; = $\frac{0.63}{11.79}$; = 5.341 x 10^{-2}Ω ; **r= 0.05341 Ω**

(b) The power delivered by the battery P = $\epsilon I = 12 \times 3.93 = 47.16$W

The power delivered to the resistor P= VI = 11.79 x 3.93 = 46.33 W

The remaining power P = 47.16 − 46.33 = 0.83W is delivered to the internal resistance and cannot be used to do useful work. (It is equal to $I^2 r$).

EXERCISE PROBLEM

31. A copper wire of 10^{-6} m² area of cross section, carries a current of 2 A. If the number of electrons per cubic meter is 8×10^{28}, calculate the current density and average drift velocity.

Solution:

Cross – sections area of copper wire, $A = 10^{-6}$ m² , I = 2A

Number of electron, $n = 8 \times 10^{28}$

Current density, $J = \frac{I}{A} = \frac{2}{10^{-6}}$; $J = 2 \times 10^{6}$ Am^{-2}

Average drift velocity, $V_d = \frac{I}{neA}$

e is the charge of electron = 1.6×10^{-19} C

$$V_d = \frac{2}{8 \times 10^{28} \times 1.6 \times 10^{-19} \times 10^{-6}} = \frac{1}{64 \times 10^{3}}$$

No.	Log
1	0.0000
6.490	0.8062
(−)	$\bar{1}.1938$
Antilog	1.562×10^{-1}

$V_d = 0.15625 \times 10^{-3}$; $V_d = 15.625 \times 10^{-3}$ ms^{-1}

32. The resistance of a nichrome wire at 0°C is 10Ω. If its temperature coefficient of resistance is 0.004/°C, find its resistance at boiling point of water. Comment on the result.

Solution:

Resistance of nichrome wire at 0°C, R_0 = 10 Ω

Temperature coefficient of resistance α = 0.004/°C

Resistance at boiling point of water, R_T = ?

Temperature of boiling point of water, T = 100° C ?

$R_T = R_0 (1 + \alpha T)$; = 10[1+(0.004 x 100°]

R_T = 10(1+0.4) = 10 x 1.4 ; R_T = 14 Ω

As the temperature increases the resistance of the wire also increases.

33. An electronics hobbyist is building a radio which requires 150 Ω in her circuit, but she has only 220 Ω, 79 Ω and 92 Ω resistors available. How can she connect the available resistors to get desired value of resistance?

Solution:

Required effective resistance = 150 Ω

Resistors of resistance, R_1 = 220 Ω, R_2 = 79 Ω , R_3 = 92 Ω

Parallel combination of R_1 and R_2

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{220} + \frac{1}{79} ; \frac{79+220}{220 \times 79} \quad R_p = 58\ \Omega$$

No.	Log
17380	4.2400
299	2.4757
(−)	1.7643
Antilog	5.811×10^{1}

Parallel combination of R_P and R_3

$R_S = R_P + R_3$; = 58 + 92 Rs = 150 Ω

34. A potentiometer wire has a length of 4 m and resistance of 20 Ω. It is connected in series with resistance of 2980 Ω and a cell of emf 4 V. Calculate the potential along the wire.

Solution:

Resistance of the wire, r = 20 Ω

Length of the potential wire, l= 4m

Resistance connected series with potentiometer wire, R - 2980 Ω

Emf of the cell, ξ = 4V

Effective resistance, R = r + R = 20 + 2980 = 3000 Ω

Current flowing through the wire, $I = \frac{\xi}{R_S} = \frac{4}{3000}$

I = 1.33 x 10^{-3} A

35. Two cells each of 5V are connected in series across a 8 Ω resistor and three parallel resistors of 4 Ω, 6 Ω and 12 Ω. Draw a circuit diagram for the above arrangement. Calculate i) the current drawn from the cell (ii) current through each resistor.

Solution:

V_1 = 5V ; V_2 = 5V

R_1 = 8 Ω , R_2 = 4 Ω, R_3 = 6 Ω, R_4 = 12 Ω

Three resistors R_2, R_3 and R_4 are connected parallel combination

$$\frac{1}{R_P} = \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}; = \frac{1}{4} + \frac{1}{6} + \frac{1}{12};$$

$$= \frac{3}{12} + \frac{2}{12} + \frac{1}{12}; = \frac{6}{12}; \quad R_P = 2\,\Omega$$

Resistors R_1, and R_P are connected in series combination

$R_S = R_1 + R_P$; = 8 + 2 =10

Total voltage connected series to the circuit V = $V_1 + V_2$

= 5 + 5 = 10 ; V = 10 V

i) Current through the circuit, $I = \frac{V}{R_S} = \frac{10}{10}$; I =1A

Potential drop across the parallel combination, V′ = IR_P = 1 x 2; V′ =2 V

ii) Current in 4 Ω resistor, $I = \frac{V'}{R_2} = \frac{2}{4}$ = 0.5 A

Current in 6 Ω resistor, $I = \frac{V'}{R_3} = \frac{2}{6}$ = 0.33 A

Current in 12 Ω resistor, $I = \frac{V'}{R_4} = \frac{2}{12}$ = 0.17 A

36. In a potentiometer arrangement, a cell of emf 1.25 V gives a balance point at 35 cm length of the wire. If the cell is replaced by another cell and the balance point shifts to 63 cm, what is the emf of the second cell?

Solution:

Emf of the cell$_1$, ξ_1 = 1.25V

Balancing length of the cell, l_1 = 35 cm = 35 x 10^{-2} m

Balancing length after interchanged, l_2 = 63 cm = 63 x 10^{-2} m

Emf of the cell$_2$, ξ_2 ?

The ratio of emf's $\frac{\xi_1}{\xi_2} = \frac{l_1}{l_2}$

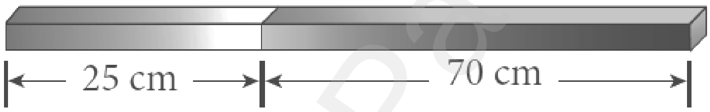
The ratio of emf's $\xi_2 = \xi_1 \left(\frac{l_1}{l_2}\right)$

$= 1.25 \text{ x } \left(\frac{63 \text{ x } 10^{-2}}{35 \text{ x } 10^{-2}}\right)$

= 12.5 x 1.8

$\xi_2 = 2.25$V

37. The rod given in the figure is made up of two different materials



Both have square cross sections of 3 mm side. The resistivity of the first material is 4×10^{-3} Ωm and that of second material has resistivity of 5×10^{-3} Ωm. What is the resistance of rod between its ends?

Solution:

A = 3mm x 3mm = 9mm^2 = 9x10^{-6} m^2; l_1 = 25 cm = 25x10^{-2}m,

l_2 = 70 cm = 70x10^{-2}m ; ρ_1 = 4x10^{-3} ; ρ_2 = 5x10^{-3} ;

Resistance of first material R$_1$ = $\frac{\rho_1 l_1}{A}$; $= \frac{4 \text{ x } 10^{-3} \text{ x } 25 \text{ x } 10^{-2}}{9 \text{ x } 10^{-6}}$; $\frac{1000}{9}\Omega$

Resistance of second material R$_2$ = $\frac{\rho_2 l_2}{A}$; $= \frac{5 \text{ x } 10^{-3} \text{ x } 70 \text{ x } 10^{-2}}{9 \text{ x } 10^{-6}}$; $\frac{3500}{9}\Omega$

The two materials are in series, their effective resistance

R$_{tot}$ = R$_1$ + R$_2$; $= \frac{1000}{9} + \frac{3500}{9}$; $\frac{4500}{9}$; **R$_{tot}$ = 500 Ω**

UNIT - III (MAGNETISM AND MAGNETIC EFFECTS OF ELECTRIC CURRENT)

38. The horizontal component and vertical component of Earth's magnetic field at a place are 0.15 G and 0.26 G respectively. Calculate the angle of dip and resultant magnetic field. (G-gauss, cgs unit for magnetic field 1G = 10^{-4} T)

Solution:

B_H = 0.15 G and B_V = 0.26 G

Angle of dip I is tan I = $\frac{B_V}{B_H}$; = $\frac{0.26}{0.15}$; = $\frac{26}{15}$ = 1.733; I = $\tan^{-1}$(1.733) = 60^0

Resultant magnetic field. B = $\sqrt{B_H^2 + B_V^2}$; = $\sqrt{0.15^2 + 0.26^2}$

= $\sqrt{0.0225 + 0.0676}$; = $\sqrt{0.0901}$; **B = 0.3G**

39. The repulsive force between two magnetic poles in air is 9 x 10^{-3} N. If the two poles are equal in strength and are separated by a distance of 10 cm, calculate the pole strength of each pole.

Solution:

The force between two poles are given by $\vec{F} = k\frac{q_{mA}q_{mB}}{r^2}\hat{r}$

The magnitude of the force is F = $k\frac{q_{mA}q_{mB}}{r^2}$

Given : F = 9 x 10^{-3}N, r = 10 cm = 10 x 10^{-2} m

Therefore, 9 x 10^{-3} = 10^{-7} x $\frac{q_m^2}{(10 \text{ x } 10^{-2})^2}$ $\Longrightarrow$ 30 NT^{-1}

40. A coil of a tangent galvanometer of diameter 0.24 m has 100 turns. If the horizontal component of Earth's magnetic field is 25 × 10^{-6} T then, calculate the current which gives a deflection of 60^0.

Solution:

The diameter of the coil is 0.24 m.
Therefore, radius of the coil is 0.12 m.
Number of turns is 100 turns.
Earth's magnetic field is 25 x 10^{-6} T
Deflection is $\theta = 60^0 \Longrightarrow \tan 60^0 = \sqrt{3}$ = 1.732

$I = \frac{2RB_H}{\mu_0 N}\tan\theta$; $= \frac{2 \text{ x } 0.12 \text{ x } 25 \text{ x } 10^{-6}}{4 \text{ x } 10^{-7}\text{x}3.14 \text{ x}100}$ x 1.732

= 0.82 x 10^{-1} A (or) $I =$ 0082 A.

No.	Log
6 1.732	0.7782 0.2385
(+) 12.56	1.0167 1.0990
(−)	$\bar{1}$.9177
Antilog	8.274 x 10^{-1}

41. Compute the magnitude of the magnetic field of a long, straight wire carrying a current of 1 A at distance of 1m from it. Compare it with Earth's magnetic field.

Solution:

Given that 1 = 1 A and radius r = 1 m

$$B_{\text{straight wire}} = \frac{\mu_0 I}{2\pi r} = \frac{4\pi \text{ x } 10^{-7}\text{x } 1}{2\pi \text{ x } 1} = 2 \text{ x } 10^{-7} \text{ T}$$

But the Earth's magnetic field is $B_{\text{Earth}} \sim 10^{-5}$T

So, $B_{\text{straight wire}}$ is one hundred times smallerB_{Earth}

42. Compute the intensity of magnetisation of the bar magnet whose mass, magnetic moment and density are 200 g, 2 A m$_2$ and 8 g cm^{-3}, respectively.

Solution:

Density of the magnet is, Density = $\frac{\text{Mass}}{\text{Volume}}$ ⟹Volume = $\frac{\text{Mass}}{\text{Density}}$

Volume = $\frac{200 \text{ x } 10^{-3} \text{ kg}}{(8 \text{ x } 10^{-3}) \text{ x } 10^{6} \text{ m}^{-3}}$ = 25 x 10^{-6} m^3

Magnitude of magnetic moment p_m = 2 Am^2

Intensity of magnetization, $\text{I} = \frac{\text{Magnetic moment}}{\text{Volume}}$; $= \frac{2}{25 \text{ x } 10^{-6}}$

M = 0.8 x $10^5 Am^{-1}$

43. Two materials X and Y are magnetized, whose intensity of magnetization are 500 Am^{-1} and 2000 Am^{-1}, respectively. If the magnetizing field is 1000 Am^{-1}, then which one among these materials can be easily magnetized? (March 2020)

Solution:

The susceptibility of material X is $\chi_m X = \frac{|\vec{M}|}{|\vec{H}|} = \frac{500}{1000}$ = 0.5

The susceptibility of material Y is $\chi_m Y = \frac{|\vec{M}|}{|\vec{H}|} = \frac{2000}{1000}$ = 2

Since, susceptibility of material Y is greater than that of material X, material Y can be easily magnetized than X.

44. An electron moving perpendicular to a uniform magnetic field 0.500 T undergoes circular motion of radius 2.80 mm. What is the speed of electron?

Solution:

Charge of an electron q = -1.60 × 10^{-19} C ⟹ $|q|$ = 1.60 × 10^{-19} C

Magnitude of magnetic field B = 0.500 T

Mass of the electron, m = 9.11 × 10^{-31} kg

Radius of the orbit, r = 2.50 mm = 2.50 × 10^{-3}m

Velocity of the electron, $v = |q|\frac{rB}{m}$

$$v = 1.60 \text{ x } 10^{-19} \text{ x } \frac{2.50 \text{ x } 10^{-3} \text{x } 0.500}{9.11 \text{ x } 10^{-31}} ;$$

v = 2.195 x 10^8 ms^{-1}

45. Suppose a cyclotron is operated to accelerate protons with a magnetic field of strength 1 T. Calculate the frequency in which the electric field between two Dees could be reversed.

Solution:

Magnetic field B = 1 T

Mass of the proton, m_p = 1.67 x 10^{-27} kg

Charge of the proton, q = 1.6 x 10^{-19} C

$$f = \frac{qB}{2\pi m_p} = \frac{1.6 \text{ x } 10-19 \text{ x } 1}{2 \text{ x } 3.14 \text{ x } 1.67 \text{ x } 10^{-27}}$$

= 15.3 x 10^6 Hz; $f = 15.3$ MHz

46. The resistance of a moving coil galvanometer is made twice its original value in order to increase current sensitivity by 50%. Will the voltage sensitivity change? If so, by how much?

Solution:

Yes, voltage sensitivity will change. ; Voltage sensitivity is $V_s = \frac{I_s}{R}$

When the resistance is doubled, then new resistance is R' = 2R

Increase in current sensitivity is $I_s' = \left(1 + \frac{50}{100}\right) I_s = \frac{3}{2} I_s$

The new voltage sensitivity is $V_s' = \frac{\frac{3}{2} I_s}{2R} = \frac{3}{4} V_s$

Hence the voltage sensitivity decreases. The percentage decrease in voltage sensitivity is $\frac{V_s - V_s'}{V_s}$ x 100% = 25%

EXERCISE PROBLEM

47. A circular coil with cross-sectional area 0.1 cm² is kept in a uniform magnetic field of strength 0.2 T. If the current passing in the coil is 3 A and plane of the loop is perpendicular to the direction of magnetic field. Calculate
(a) Total torque on the coil (b) Total force on the coil
(c) Average force on each electron in the coil due to the magnetic field of the free electron density for the material of the wire is 10^{28} m^{-3}.

Solution:

Cross sectional area of coil, A = 0.1 cm² ; A = 0.1×10^{-4}m²
Uniform magnetic field of strength, B = 0.2T
Current passing in the coil, I = 3A
Angle between the magnetic field and normal to the coil, $\theta = 0^0$
a) Total torque on the coil,
τ = ABI sin θ = 0.1 x 10-4 x 0.2 x 3 sin 0^0 sin 0^0 = 0
$\tau = 0$
b) Total force on the coil F= BIl sin θ = 0.2 x 3 x l x sin 0^0
F = 0
c) Average force: F = qV_dB [∴ q = e]

Drift velocity, $V_d = \frac{I}{neA}$; $F = e\left(\frac{I}{neA}\right)B$ [∴ n = 10^{28} m^{-3}]

$= \frac{IB}{nA} = \frac{3 \times 0.2}{10^{28} \times 0.1 \times 10^{-4}}$ = 6×10^{-24} ; $F_{av} = 0.6 \times 10^{-23}$ N

48. Calculate the magnetic field at the center of a square loop which carries a current of 1.5 A, length of each loop is 50 cm.

Solution:

Current through the square loop, I = 1.5A
Length of each loop, l = 50 cm = 50×10^{-2}m
According to Biot – Savart Law,
Magnetic field due to a current carrying straight wire

$$B = \frac{\mu_0 I}{4\pi a}(\sin\alpha + \sin\beta)$$

$$= \frac{4\pi \times 10^{-7} \times 1.5}{4\pi \times \left(\frac{1}{2}\right)}(\sin 45^0 + \sin 45^0)$$

$$= \frac{2 \times 1.5 \times 10^{-7}}{l}[2\sin 45^0] = \frac{2 \times 1.5 \times 10^{-7}}{50 \times 10^{-2}}[2\sin 45^0]$$

$= \frac{1.5 \times 10^{-5}}{25}[2\sin 45^0]$; = $0.06 \times 10^{-5} \times 2 \times \frac{1}{\sqrt{2}}$; $= 6\sqrt{2} \times 10^{-7}$ T

B = $4 \times 6\sqrt{2} \times 10^{-7}$; = $24 \times 1.414 \times 10^{-7}$; = 33.936×10^{-7}
= 3.3936×10^{-6} T
B = 3.4×10^{-6}T

UNIT - IV (ELECTROMAGNETIC INDUCTION AND ALTERNATING CURRENT)

49. A circular antenna of area 3m² is installed at a place in Madurai. The plane of the area of antenna is inclined at 47⁰ with the direction of Earth's magnetic field. If the magnitude of Earth's field at that place is 40773.9 nT find the magnetic flux linked with the antenna.

Solution:

$B = 40773.9$ nT; $\theta = 90^0 - 47^0 = 43^0$; $A = 3m^2$

We know that $\phi_B = BA \cos\theta$

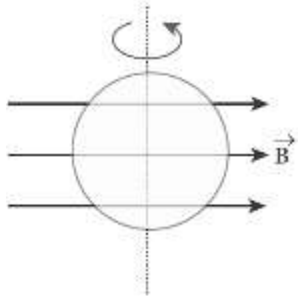
$= 40{,}773.9 \times 10^{-9} \times 3 \times \cos 43^0$

$= 40.7739 \times 10^{-6} \times 3 \times 0.7314$

$\phi_B = 89.47 \times 10^{-6}$ μWb

50. A circular loop of area 5 x 10⁻²m² rotates in a uniform magnetic field of 0.2 T. If the loop rotates about its diameter which is perpendicular to the magnetic field as shown in figure. Find the magnetic flux linked with the loop when its plane is (i) normal to the field (ii) inclined 60⁰ to the field and (iii) parallel to the field.

Solution:



$A = 5 \times 10^{-2}\ m^2$; $B = 0.2$ T

(i) $\theta = 0^0$;

$\phi_B = BA \cos\theta$

$= 0.2 \times 5 \times 10^{-2} \times \cos 0^0$; $\phi_B = 1 \times 10^{-2}$ Wb.

(ii) $\theta = 90^0 - 60^0 = 30^0$;

$\phi_B = BA \cos\theta$;

$= 0.2 \times 5 \times 10^{-2} \times \cos 30^0$; $\phi_B = 1 \times 10^{-2} \times \frac{\sqrt{3}}{2} = 8.66 \times 10^{-3}$Wb.

(iii) $\theta = 90^0$; $\phi_B = BA \cos 90^0 = 0$

51. A cylindrical bar magnet is kept along the axis of a circular solenoid. If the magnet is rotated about its axis, find out whether an electric current is induced in the coil.

Solution:

The magnetic field of a cylindrical magnet is symmetrical about its axis. As the magnet is rotated along the axis of the solenoid, there is no induced current in the solenoid because the flux linked with the solenoid does not change due to the rotation of the magnet.

52. A closed coil of 40 turns and of area 200 cm², is rotated in a magnetic field of flux density 2 Wb m⁻². It rotates from a position where its plane makes an angle of 30⁰ with the field to a position perpendicular to the field in a time 0.2 sec. Find the magnitude of the emf induced in the coil due to its rotation.

Solution:

N = 40 turns; B = 2 Wb m^{-2} ; A = 200 cm^2 = 200 x 10^{-4} m^2;

Initial flux, ϕ_i = BA cos θ ; = 2 x 200 x 10^{-4} x cos 60^0

Since θ = 90^0 – 30^0 = 60^0 ; ϕ_i = 2 x 10^{-2} Wb

Final flux, ϕ_f = BA cos θ ; = 2 x 200 x 10^{-4} x cos 0^0

Since θ = 0^0 ; ϕ_f = 4 x 10^{-2} Wb

Magnitude of the induced emf is $\epsilon = N\frac{d_{\phi B}}{dt}$

$$= \frac{40 \text{ x } (4 \text{ x } 10^{-2} - 2 \text{ x } 10^{-2})}{0.2} = 4V$$

53. A straight conducting wire is dropped horizontally from a certain height with its length along east – west direction. Will an emf be induced in it? Justify your answer.

Solution:

Yes! An emf will be induced in the wire because it moves perpendicular to the horizontal component of Earth's magnetic field.

54. A conducting rod of length 0.5 m falls freely from the top of a building of height 7.2 m at a place in Chennai where the horizontal component of Earth's magnetic field is 40378.7nT. If the length of the rod is perpendicular to Earth's horizontal magnetic field, find the emf induced across the conductor when the rod is about to touch the ground. [Take g = 10 m s⁻²]

Solution:

l = 0.5 m; h = 7.2 m; u = 0 m s^{-1}; g = 10 ms^{-2}; B_H = 40378.7nT

The final velocity of the rod is $v^2 = u^2 + 2gh$; 0 + (2 x 10 x 7.2)

$v^2 = 144$; v = 12 ms^{-1}

Induced emf when the rod is about to touch the ground, $\epsilon = B_H l v$

= 40378.7 x 10^{-9} x 0.5 x 12 ; = 242.27 x 10^{-6} V

ϵ = 242.27μF

55. A solenoid of 500 turns is wound on an iron core of relative permeability 800. The length and radius of the solenoid are 40 cm and 3 cm respectively. Calculate the average emf induced in the solenoid if the current in it changes from 0 to 3 A in 0.4 second.

Solution:

N = 500 turns; $\mu_r = 800$; l = 40 cm = 0.4 m; r = 3 cm = 0.03 m;

di = 3 – 0 = 3 A; dt = 0.4 s

Self-inductance, L=$\mu n^2 A\, l$

$\left(\therefore\ \mu = \mu_0\mu_r; A = \pi r^2; n = \frac{N}{l}\right) = \frac{\mu_0 \mu_r N^2 \pi r^2}{l}$;

$= \frac{4 \text{ x } 3.14 \text{ x } 10^{-7} \text{x } 800 \text{ x } 500^2 \text{x } 3.14 \text{ x } (3 \text{ x}10^{-2})^2}{0.4}$

No.	Log
3.14	0.4969
3.14	0.4969
1800	3.2553
(−)	4.2491
Antilog	1.775 x 10^4

L = 1.77 H

Magnitude of induced emf, $\epsilon = L\frac{di}{dt}$; $\frac{1.77 \text{ x } 3}{0.4}$; $\epsilon = 13.275$V

56. The self-inductance of an air-core solenoid is 4.8 mH. If its core is replaced by iron core, then its self-inductance becomes 1.8 H. Find out the relative permeability of iron.

Solution:

L_{air} = 4.8 x 10^{-3} H ; L_{iron} = 1.8 H ; L_{air} = $\mu_0 n^2 A\, l$ = 4.8 x 10^{-3} H

L_{iron} = $\mu n^2 A\, l$; $\mu_0\mu_r n^2 A\, l$ = 1.8 H

$\therefore\ \mu_r = \frac{L_{iron}}{L_{air}} = \frac{1.8}{4.8 \text{ x } 10^{-3}} = 375$

57. The current flowing in the first coil changes from 2 A to 10 A in 0.4 sec. Find the mutual inductance between two coils if an emf of 60 mV is induced in the second coil. Also determine the induced emf in the second coil if the current in the first coil is changed from 4 A to 16 A in 0.03 sec. Consider only the magnitude of induced emf.

Solution:

Case (i): di_1 = 10 – 2 = 8 A; dt = 0.4 s; ϵ_2 = 60 x 10^{-3} V

Case (ii): di_1= 16 – 4 = 12 A; dt = 0.03 s

(i) Mutual inductance of the second coil with respect to the first coil

$M_{21} = \frac{\epsilon_2}{\frac{di_1}{dt}} = \frac{60 \text{ x } 10^{-3} \text{x } 0.4}{8}$; M_{21} = 3 x 10^{-3} H

(ii) Induced emf in the second coil due to the rate of change of current

in the first coil is $\epsilon_2 = M_{21}\frac{di}{dt}$; $= \frac{3 \text{ x } 10^{-3} \text{x } 12}{0.03}$; ϵ_2 = 1.2 V

58. A circular metal of area 0.03 m² rotates in a uniform magnetic field of 0.4 T. The axis of rotation passes through the centre and perpendicular to its plane and is also parallel to the field. If the disc completes 20 revolutions in one second and the resistance of the disc is 4 Ω, calculate the induced emf between the axis and the rim and induced current flowing in the disc.

Solution:

$A = 0.03\ m^2$; $B = 0.4$ T; $f = 20$ rps; $R = 4\ \Omega$

Area covered in 1 sec = Area of the disc × frequency

$= 0.03 \times 20$; $= 0.6\ m^2$

Induced emf, ε = Rate of change of flux

$$\varepsilon = \frac{d\phi_B}{dt} = \frac{d(BA)}{dt}\ ;\ \varepsilon = \frac{0.4 \times 0.6}{1}\ ;\ \varepsilon = 0.24\ V$$

Induced current, $= \frac{\epsilon}{R} = \frac{0.24}{4}$; $i = 0.06$ A

59. A rectangular coil of area 70 cm² having 600 turns rotates about an axis perpendicular to a magnetic field of 0.4 Wb m⁻². If the coil completes 500 revolutions in a minute, calculate the instantaneous emf when the plane of the coil is (i) perpendicular to the field (ii) parallel to the field and (iii) inclined at 60⁰ with the field.

Solution:

$A = 70 \times 10^{-4} m^2$; $N = 600$ turns, $B = 0.4\ Wbm^{-2}$; $f = 500$ rpm

The instantaneous emf is $\epsilon = \epsilon_m \sin\omega t$ since $\epsilon_m = N\phi_m\omega$

$= N (BA) (2\pi f)$

$\epsilon = NBA \times 2\pi f \times \sin\omega t$

i) When $\omega t = 0^0$, $\epsilon = \epsilon_m \sin 0^0 = 0$

ii) When $\omega t = 90^0$, $\epsilon = \epsilon_m \sin 90^0 = NBA \times 2\pi f \times 1$

$= 600 \times 0.4 \times 70 \times 10^{-4} \times 2 \times \frac{22}{7} \times \left(\frac{500}{60}\right)$

$\epsilon = 88$ V

iii) When $\omega t = 90^0 - 60^0 = 30^0$, $\epsilon = \epsilon_m \sin 30^0 = 88 \times \frac{1}{2}$

$\epsilon = 44$ V

60. An ideal transformer has 460 and 40,000 turns in the primary and secondary coils respectively. Find the voltage developed per turn of the secondary if the transformer is connected to a 230 V AC mains. The secondary is given to a load of resistance 10⁴ Ω. Calculate the power delivered to the load. (March 2020)

Solution:

$N_P = 460$ turns; $N_S = 40{,}000$ turns; $V_P = 230$ V; $R_S = 10^4\ \Omega$

(i) Secondary voltage, $V_S = \frac{V_P N_S}{N_P} = \frac{230 \times 40000}{460}$; $V_S = 20000$V

Secondary voltage per turn, $\frac{V_S}{N_S} = \frac{20000}{40000}$; $= 0.5$ V

(ii) Power delivered $= V_S I_S = \frac{V_S^2}{R_S} = \frac{20000 \times 20000}{10^4}$; $= 40$ kW

61. An inverter is common electrical device which we use in our homes. When there is no power in our house, inverter gives AC power to run a few electronic appliances like fan or light. An inverter has inbuilt step-up transformer which converts 12 V AC to 240 V AC. The primary coil has 100 turns and the inverter delivers 50 mA to the external circuit. Find the number of turns in the secondary and the primary current.

Solution:

V_p = 12 V; V_s = 240 V, I_s = 50mA; N_p = 100 turns

$\frac{V_S}{V_P} = \frac{N_S}{N_P} = \frac{I_P}{I_S}$ = K ; Transformation ratio, K = $\frac{240}{12}$ = 20

The number of turns in the secondary N_S = N_P x K = 100 x 20 = 2000

Primary current, I_P = K x I_S = 20 x 50 mA = 1A

62. The equation for an alternating current is given by i = 77 sin 314t. Find the peak value, frequency, time period and instantaneous value at t = 2 ms.

Solution:

i = 77 sin 314t; t = 2 ms = 2×10^{-3} s

The general equation of an alternating current is $i = I_m\, sin\omega t$.

On comparison,

(i) Peak value, I_m = 77 A

(ii) Frequency, $f = \frac{\omega}{2\pi} = \frac{314}{2 \times 3.14}$; = 50Hz

(iii) Time period, T = $\frac{1}{f} = \frac{1}{50}$ = 0.02 s

(iv) At t = 2 m s, Instantaneous value,

i = 77 sin (314 x 2×10^{-3}) i = 45.24 A

No.	Log
77 0.5878	1.8865 1.7692
(−)	1.6557
Antilog	4.526 x 10^{1}

63. A 400 mH coil of negligible resistance is connected to an AC circuit in which an effective current of 6 mA is flowing. Find out the voltage across the coil if the frequency is 1000 Hz.

Solution:

L = 400 x 10^{-3} H; I_{eff} = 6 x 10^{-3}A ; f = 1000 Hz

Inductive reactance, X_L = Lω = L x 2πf

= 2 x 3.14 x 1000 x 0.4 ; =2512 Ω

Voltage across L, V = IX_L = 6 x 10^{-3} x 2512

V = 15.072V$_{(RMS)}$

64. A capacitor of capacitance $\frac{10^2}{\pi}$μF is connected across a 220 V, 50 Hz A.C. mains. Calculate the capacitive reactance, RMS value of current and write down the equations of voltage and current.

Solution:

C = $\frac{10^2}{\pi}$ x 10^{-6}F, V_{RMS} = 220V; f = 50 Hz

i) Capacitive reactance, $X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$; $= \frac{1}{2 \times \pi \times 50 \times \frac{10^{-4}}{\pi}}$; =100Ω

ii) RMS value of current, $I_{RMS} = \frac{V_{RMS}}{X_C}$; $= \frac{220}{100}$; = 2.2A

iii) $V_m = 220 \times \sqrt{2} = 311$ V ; $I_m = 2.2 \times \sqrt{2} = 3.1$ A

Therefore, $v = 311 \sin 314t$; $i = 3.1 \sin\left(314\,t + \frac{\pi}{2}\right)$

65. Find the impedance of a series RLC circuit if the inductive reactance, capacitive reactance and resistance are 184 Ω, 144 Ω and 30 Ω respectively. Also calculate the phase angle between voltage and current.

Solution:

$X_L = 184\ \Omega$; $X_C = 144\ \Omega$; $R = 30\ \Omega$

(i) The impedance is Impedance, $Z = \sqrt{R^{2}+(X_L-X_C)^2}$

$= \sqrt{30^{2}+(184-144)^2}$; $= \sqrt{900+1600}$

Impedance, Z = 50 Ω

(ii) Phase angle is $\tan\phi = \frac{X_L - X_C}{R}$; $\frac{184-144}{30}$; = 1.33 ; $\phi = 53.1^0$

Since the phase angle is positive, voltage leads current by 53.1^0 for this inductive circuit.

66. The current in an inductive circuit is given by 0.3 sin ($200t - 40^0$) A. Write the equation for the voltage across it if the inductance is 40 mH.

Solution:

$L = 40 \times 10^{-3}$ H; i = 0.1 sin ($200t - 40^0$)

$X_L = \omega L = 200 \times 40 \times 10^{-3} = 8\ \Omega$

$V_m = I_m X_L = 0.3 \times 8 = 2.4$ V

In an inductive circuit, the voltage leads the current by 90^0. Therefore,

$v = v_m \sin(\omega t + 90^0)$; $v = 2.4 \sin(200t - 40^0 + 90^0)$

$v = 2.4 \sin(200t + 50^0)$

EXERCISE PROBLEM

67. A square coil of side 30 cm with 500 turns is kept in a uniform magnetic field of 0.4 T. The plane of the coil is inclined at an angle of 30^o to the field. Calculate the magnetic flux through the coil.

Square coil of side (a) = 30 cm = 30×10^{-2}m

Area of square coil (A) = $a^2 = (30 \times 10^{-2})^2 = 9 \times 10^{-2}$ m²

Number of turns (N) = 500; Magnetic field (B) = 0.4 T

Angular between the field and coil (θ) = 90 – 30 = 60^0

Magnetic flux (ϕ) = NBA cosθ = $500 \times 0.4 \times 9 \times 10^{-2} \times \cos 60^0$

$= 18 \times \frac{1}{2}$; ϕ = 9 Wb

68. A straight metal wire crosses a magnetic field of flux 4 mWb in a time 0.4 s. Find the magnitude of the emf induced in the wire.

Solution:

Magnetic flux (ϕ) =4 mWb = 4×10^{-3} Wb ; time (t) = 0.4 Sec.

The magnitude of induced emf (e) = $\frac{d\phi}{dt} = \frac{4 \times 10^{-3}}{0.4} = 10^{-2}$

e = 10 mV

69. An induced current of 2.5 mA flows through a single conductor of resistance 100 Ω. Find out the rate at which the magnetic flux is cut by the conductor.

Solution:

Induced Current, I = 2.5 mA , Resistance of conductor, R = 100 Ω

∴ The rate of change of flux, $\frac{d\phi_B}{dt} = e$

$\frac{d\phi_B}{dt} = e = IR = 2.5 \times 10^{-3} \times 100$

$= 250 \times 10^{-3}$ $\frac{d\phi_B}{dt} = 250\ mWbs^{-1}$

70. A fan of metal blades of length 0.4 m rotates normal to a magnetic field of 4 x 10^{-3} T. If the induced emf between the centre and edge of the blade is 0.02 V, determine the rate of rotation of the blade.

Solution:

Length of the metal blade, l = 0.4m

Magnetic field, B = 4 x 10^{-3} T; Induced emf, e = 0.02V

Rotational area of the blade, A = πr^2 = 3.14 x $(0.4)^2$ = 0.5024 m^2

Induced emf in rotational of the coil, e = NBA ω sinθ

$\omega = \frac{e}{NBA \sin\theta}$ [N = 1, θ = 90^0, sin 90^0 = 1]

$\omega = \frac{0.02}{1 \times 4 \times 10^{-3} \times 0.5024 \times \sin 90^0} = \frac{0.02}{2.0096 \times 10^{-3}}$

= 9.95222 x 10^{-3} x 10^3

= 9.95 revolutions / second

Rate of rotational of the blade, ω = 9.95 revolutions / second

71. A bicycle wheel with metal spokes of 1 m long rotates in Earth's magnetic field. The plane of the wheel is perpendicular to the horizontal component of Earth's field of 4 x 10^{-5} T. If the emf induced across the spokes is 31.4 mV, calculate the rate of revolution of the wheel.

Solution:

Length of the metal spokes, l = 1m

Rotational area of the spokes, A = πr^2 = 3.14 x $(1)^2$ = 3.14 m^2

Horizontal area of the Earth's field, B = 4 x 10^{-5} T

Induced emf , e = 3.14 mV

The rate of revolution of wheel, $\omega = \frac{e}{NBA \sin\theta}$ [N = 1, θ = 90^0, sin 90^0 = 1]

$\omega = \frac{31.4 \times 10^{-3}}{1 \times 4 \times 10^{-5} \times 3.14 \times \sin 90^0} = \frac{31.4 \times 10^{-3}}{12.56 \times 10^{-5}}$

= 2.5 x 10^2 ; ω = 250 revolutions / second

72. Determine the self-inductance of 4000 turn air-core solenoid of length 2m and diameter 0.04 m.

Solution:

Length of the air core solenoid, l = 2m; Diameter, d = 0.04 m;

Radius, r = $\frac{d}{2}$ = 0.02 m

Area of the air core solenoid, A = πr^2 = 3.14 x $(0.02)^2$ = 1.256 x 10^{-3} m^2

Number of turns, N = 4000 turns

Self-inductance, L = $\mu_{0}n^2Al$; = $\mu_0 \frac{N^2}{l^2} Al$ [$n = \frac{N}{l}$, μ_0 = 4π x 10^{-7} Hm^{-1}]

$= \mu_0 \frac{N^2A}{l} = \frac{4\pi \times 10^{-7} \times (4000)^2 \times 1.256 \times 10^{-3}}{2}$

$= \frac{252405760 \times 10^{-10}}{2}$; = 126202880 x 10^{-10}

= 12.62 x 10^{-3}; **L = 12.62 mH**

73. A coil of 200 turns carries a current of 4 A. If the magnetic flux through the coil is 6 x 10^{-5} Wb, find the magnetic energy stored in the medium surrounding the coil.

Solution:

Number of turns of the coil, N = 200, Current, I = 4 A

Magnetic flux through the coil, ϕ = 6 x 10^{-5} Wb

Energy stored in the coil, U = $\frac{1}{2}LI^2$; Self-inductance of the coil, L = $\frac{N\phi}{I}$

U = $\frac{1}{2}\frac{N\phi}{I} \times I^2$ = $\frac{1}{2} N\phi I$; = $\frac{1}{2}$ x 200 x 6 x 10^{-5} x 4

U = 2400 x 10^{-5}; **U = 0.024 J (or) Joules**

74. A coil of 200 turns carries a current of 0.4 A. If the magnetic flux of 4 mWb is linked with the coil, find the inductance of the coil.

Solution:

Number of turns of the coil, N = 200, Current, I = 0.4 A

Magnetic flux linked with coil, ϕ = 4mWb = 4 x 10^{-3} Wb

Inductance of the coil, L = $\frac{N\phi}{I}$; = $\frac{200 \times 4 \times 10^{-3}}{0.4}$; = $\frac{800 \times 10^{-3}}{0.4}$; L = 2 H

75. A 200 turn coil of radius 2 cm is placed co-axially within a long solenoid of 3 cm radius. If the turn density of the solenoid is 90 turns per cm, then calculate mutual inductance of the coil.

Solution: Number of turns of the solenoid, N_2 = 200;

Radius of the solenoid, r = 2 cm = 2 x 10^{-2} m

Area of the solenoid, A=πr^2 =3.14x$(2 \times 10^{-2})^2$ =1.256x10^{-3} m^2

Turn density of long solenoid per cm, N_1 = 90 x 10^2

Mutual inductance of the coil, M = $\frac{\mu_0 N_1 N_2 A}{l}$

$= \frac{4\pi \times 10^{-7} \times 90 \times 10^2 \times 200 \times 1.256 \times 10^{-3}}{1}$

= 283956.48 x 10^{-8} ⟹ M = 2.84 mH

No.	Log
3.14	0.4969
3.14	0.4969
288	2.4594
(+)	3.4532
Antilog	2.839 x 10^3

76. A step-down transformer connected to main supply of 220 V is made to operate 11V,88 W lamp. Calculate (i) Transformation ratio and (ii) Current in the primary.

Solution:

Voltage in primary coil, V_p = 220 V; Voltage in secondary coil, V_s =11 V

Output power = 88 W

i) To find transformation ratio, k = $\frac{V_s}{V_p} = \frac{11}{220} = \frac{1}{20}$

ii) Current in primary, $I_p = \frac{V_s}{V_p} I_s$ So, I_s = ?

Output power = $V_s I_s$ $\Longrightarrow$ 88 = 11 x I_s

$I_s = \frac{88}{11}$ = 8A Therefore, $I_p = \frac{V_s}{V_p} I_s$; = $\frac{11}{220}$ x 8 = 0.4A

77. Calculate the instantaneous value at 60⁰, average value and RMS value of an alternating current whose peak value is 20 A.

Solution:

Peak value of current, I_m = 20 A ; Angle, θ = 60^0

i) Instantaneous value of current, $i = I_m \, sin\omega t; \; = I_m \, sin\theta$

= 20 sin 60^0 = 20 x $\frac{\sqrt{3}}{2}$ = 10 $\sqrt{3}$ = 10 x 1.732

i = **17.32 A**

ii) Average value of current, $I_{av} = \frac{2I_m}{\pi} = \frac{2 \times 20}{3.14}$; **I_{av} =12.74 A**

iii) RMS value of current, $I_{RMS} = 0.707 I_m$ or $\frac{I_m}{\sqrt{2}}$ = 0.707 x 20

I_{RMS} = 14.14 A

UNIT - V (ELECTROMAGNETIC WAVES)

78. Consider a parallel plate capacitor which is maintained at potential of 200 V. If the separation distance between the plates of the capacitor and area of the plates are 1 mm and 20 cm². Calculate the displacement current for the time in μs.

Solution:

Potential difference between the plates of the capacitor, V = 200 V
The distance between the plates, d = 1 mm = 1×10^{-3} m
Area of the plates of the capacitor, A = 20 cm² = 20×10^{-4} m²
Time is given in micro-second, $\mu_s = 10^{-6}$ s

Displacement current, $I_d = \epsilon_0 \frac{d\phi_B}{dt} \Longrightarrow I_d = \epsilon_0 \frac{EA}{t}$

But electric field, $E = \frac{V}{d}$; Therefore, $I = \frac{V}{d} I_d$; $= \epsilon_0 \frac{VA}{td}$;

$= 8.85 \times 10^{-12} \times \frac{200 \times 20 \times 10^{-4}}{10^{-6} \times 1 \times 10^{-3}}$; $= 35400 \times 10^{-7} = 3.5$ mA

79. The relative magnetic permeability of the medium is 2.5 and the relative electrical permittivity of the medium is 2.25. Compute the refractive index of the medium.

Solution:

Dielectric constant (relative permeability of the medium) is $\varepsilon_r = 2.25$
Magnetic permeability is $\mu_r = 2.5$
Refractive index of the medium, $n = \sqrt{\epsilon_r \mu_r}$; $= \sqrt{2.25 \times 2.5}$;
$= \sqrt{5.625}$; n =2.37

No.	Log
$\sqrt{5.625}$	0.7501 x ½ 0.3751
Antilog	2.372×10^0

80. Compute the speed of the electromagnetic wave in a medium if the amplitude of electric and magnetic fields are 3×10^4 N C^{-1} and 2×10^{-4} T, respectively.

Solution:

The amplitude of the electric field, $E_o = 3 \times 10^4$ N C^{-1}
The amplitude of the magnetic field, $B_o = 2 \times 10^{-4}$ T.
Therefore, speed of the electromagnetic wave in a medium is

$$v = \frac{3 \times 10^4}{2 \times 10^{-4}} = 1.5 \times 10^8 \text{ ms}^{-1}$$

81. A magnetron in a microwave oven emits electromagnetic waves (em waves) with frequency f = 2450 MHz. What magnetic field strength is required for electrons to move in circular paths with this frequency?

Solution:

Frequency of the electromagnetic waves given is f = 2450 MHz
The corresponding angular frequency is
$\omega = 2\pi f = 2 \times 3.14 \times 2450 \times 10^6$
$= 15{,}386 \times 10^6$ Hz
$= 1.54 \times 10^{10}$ s^{-1}

The magnetic field B = $\frac{m_e \omega}{|q|}$

Mass of the electron, me = 9.22 x 10^{-31} kg

Charge of the electron q = - 1.60 x 10^{-19} C $\Rightarrow |q|$ = 1.60 x 10^{-19} C

B = $\frac{(9.22 \times 10^{-31})(1.54 \times 10^{10})}{(1.60 \times 10^{-19})}$; = 8.87425 x 10^{-2} T ; B = 0.0887 T

This magnetic field can be easily produced with a permanent magnet. So, electromagnetic waves of frequency 2450 MHz can be used for heating and cooking food because they are strongly absorbed by water molecules.

82. A transmitter consists of LC circuit with an inductance of 1 μH and a capacitance of 1 μF. What is the wavelength of the electromagnetic waves it emits?

Solution:

Inductance of LC circuit, L = 1 μH = 1 x 10^{-6} H

Capacitance of LC circuit, C = 1 μF = 1 x 10^{-6} F

Wavelength of the electromagnetic wave $\lambda = \frac{C}{f}$

Velocity of light C = 3 x 10^8 ms^{-1}

Frequency of electromagnetic wave, f = $\frac{1}{2\pi\sqrt{LC}}$

= $\frac{1}{2 \times 3.14\sqrt{1 \times 10^{-6} \times 10^{-6}}}$; = $\frac{1}{6.28 \times 10^{-6}}$ $\Rightarrow$ f = 15.92 x 10^4 Hz

Wave length $\lambda = \frac{C}{f} = \frac{3 \times 10^8}{15.92 \times 10^4}$; 0.1884 x 10^4

λ = 18.84 x 10^2 m

EXERCISE PROBLEM

83. A pulse of light of duration 10^{-6} s is absorbed completely by a small object initially at rest. If the power of the pulse is 60 x 10^{-3} W, calculate the final momentum of the object.

Solution:

Duration of the absorption of light pulse, t = 10^{-6} s

Power of the pulse P = 60 x 10^{-3} W

Final momentum of the object, P = $\frac{U}{C}$

Velocity of light, C = 3 x 10^8

Energy U = power x time

Momentum, P = $\frac{60 \times 10^{-3} \times 10^{-6}}{3 \times 10^8}$; P = 20 x 10^{-17} kg ms^{-1}

84. If the relative permeability and relative permittivity of the medium is 1.0 and 2.25, respectively. Find the speed of the electromagnetic wave in this medium.

Solution:

Relative permeability of the medium, $\mu_r = 1$

Relative permittivity of the medium, $\epsilon_r = 2.25$ $\left(\epsilon_r = \frac{\epsilon}{\epsilon_0} \;\&\; \mu_r = \frac{\mu}{\mu_0}\right)$

Speed of electromagnetic wave, $v = \frac{1}{\sqrt{\mu\epsilon}}$

$= \frac{1}{\sqrt{\mu_r\mu_0\epsilon_r\epsilon_0}} = \frac{C}{\sqrt{\mu_r\epsilon_r}}$ $\left[\text{Where, } C = \frac{1}{\sqrt{\mu_0\epsilon_0}}\right]$

$= \frac{3 \times 10^8}{\sqrt{1 \times 2.25}}$; $= \frac{3 \times 10^8}{1.5}$ $v = 2 \times 10^8 \text{ ms}^{-1}$

UNIT – VI (RAY OPTICS)

85. An object is placed at a distance of 20.0 cm from a concave mirror of focal length 15.0 cm.
(a) What distance from the mirror a screen should be placed to get a sharp image? (b) What is the nature of the image?

Solution:

Given, f = –15 cm, u = –20 cm

(a) Mirror equation, $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$; Rewriting to find v, $\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$

Substituting for f and u, $\frac{1}{v} = \frac{1}{-15} - \frac{1}{-20}$; $\frac{1}{v} = \frac{(-200)-(-15)}{300}$

$= \frac{-5}{300} = \frac{-1}{60}$; $v = -60.0$ cm

As the image is formed at 60.0 cm to the left of the concave mirror, the screen is to be placed at distance 60.0 cm to the left of the concave mirror.

(b) Magnification, m = $\frac{h'}{h} = -\frac{v}{u}$; m = $\frac{h'}{h} = -\frac{(-60)}{(-20)}$; $= -3$

As the sign of magnification is negative, the image is inverted.

As the magnitude of magnification is 3, the image is enlarged three times. As the image is formed to the left of the concave mirror, the image is real.

86. One type of transparent glass has refractive index 1.5. What is the speed of light through this glass?

Solution:

n = $\frac{c}{v}$; $v = \frac{c}{n}$; $v = \frac{3 \times 10^8}{1.5}$; = $2 \times 10^8 \text{ ms}^{-1}$

Light travels with a speed of $2 \times 10^8 \text{ ms}^{-1}$ through this glass.

87. Pure water has refractive index 1.33. What is the speed of light through it.

Solution:

$n = \frac{c}{v}$; $v = \frac{c}{n}$; $v = \frac{3 \times 10^8}{1.33}$; $= 2.25 \times 10^8\ ms^{-1}$

Light travels with a speed of $2.25 \times 10^8\ ms^{-1}$ through pure water.

88. Light travels from air in to glass slab of thickness 50 cm and refractive index 1.5.
(i) What is the speed of light in glass?
(ii) What is the time taken by the light to travel through the glass slab?
(iii) What is the optical path of the glass slab?

Solution:

Given, thickness of glass slab, d = 50 cm = 0.5 m, refractive index, n = 1.5

refractive index, $n = \frac{c}{v}$

Speed of light in glass is, $v = \frac{c}{n}$; $= \frac{3 \times 10^8}{1.5}$; $= 2 \times 10^8\ ms^{-1}$.

Time taken by light to travel through glass slab is,

$t = \frac{d}{v}$; $= \frac{0.5}{2 \times 10^8} = 2.5 \times 10^{-9}$ s

Optical path, $d' = nd = 1.5 \times 0.5$; $= 0.75$m ; =75 cm

Light would have travelled 25 cm more (75 cm – 50 cm) in vacuum by the same time had there not been a glass slab.

89. Light travelling through transparent oil enters in to glass of refractive index 1.5. If the refractive index of glass with respect to the oil is 1.25, what is the refractive index of the oil?

Solution:

Given, $n_{go} = 1.25$ and $n_g = 1.5$;

Refractive index of glass with respect to oil, $n_{go} = \frac{n_g}{n_o}$

Rewriting for refractive index of oil, $n_o = \frac{n_g}{n_{go}} = \frac{1.5}{1.25} = 1.2$

The refractive index of oil is, $n_o = 1.2$

90. What is the radius of the illumination when seen above from inside a swimming pool from a depth of 10 m on a sunny day? What is the total angle of view? [Given, refractive index of water is $\frac{4}{3}$]

Solution:

Given, $n = \frac{4}{3}$, d = 10 m, Radius of illumination, $R = \frac{d}{\sqrt{n^2-1}}$

$R = \frac{10}{\sqrt{\left(\frac{4}{3}\right)^2 - 1}}$; $= \frac{10 \times 3}{\sqrt{16-9}}$; $R = \frac{30}{\sqrt{7}}$; R = 11.32m

To find the angle of the view of the cone, $i_c = \sin^{-1}\left(\frac{1}{n}\right)$

$i_c = \sin^{-1}\left(\frac{1}{\frac{4}{3}}\right)$; $= \sin^{-1}\left(\frac{3}{4}\right)$; = 48.6^0

The total angle of view is, $2i = 2 \times 48.6^0 = 97.2^0$

91. The thickness of a glass slab is 0.25 m. it has a refractive index of 1.5. A ray of light is incident on the surface of the slab at an angle of 60^0. Find the lateral displacement of the light when it emerges from the other side of the mirror.

Solution:

Given, thickness of the lab, t = 0.25 m,

Refractive index, n = 1.5, angle of incidence,

$i = 60^0$.Using Snell's law, $1 \times \sin i = n \sin r$;

$\sin r = \frac{\sin i}{n} = \frac{\sin 60}{1.5} = 0.58$

$R = \sin^{-1} 0.58 = 35.25^0$

Lateral displacement is, $L = t\left(\frac{\sin(i-r)}{\cos(r)}\right)$;

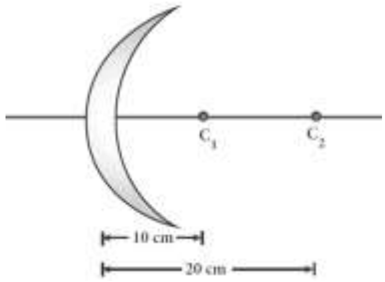
$L = (0.25) \times \left(\frac{\sin(60-35.25)}{\cos(35.25)}\right)$; = 0.1282 m

The lateral displacement is, L = 12.82 cm

No.	Log
0.25 0.4187	1.3979 1.6219
(+) 0.8166	1.0198 1.9120
(−)	1.1078
Antilog	1.282×10^{-1}

92. Determine the focal length of the lens made up of a material of refractive index 1.52 as shown in the diagram. (Points C_1 and C_2 are the centers of curvature of the first and second surface.)

Solution:



This lens is called convexo-concave lens

Given, n = 1.52, R_1= 10 cm and R_2= 20 cm

Lens makers formula, $\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

Substituting the values,

$\frac{1}{f} = (1.52-1)\left(\frac{1}{10} - \frac{1}{20}\right)$

$\frac{1}{f} = (0.52)\left(\frac{2-1}{20}\right)$; $= (0.52)\left(\frac{1}{20}\right) = \frac{0.52}{20}$;

$f = \frac{20}{0.52} = 38.46$ cm

As the focal length is positive, the lens is a converging lens.

No.	Log
20 0.52	1.3010 1.7160
(−)	1.5850
Antilog	3.846×10^{1}

93. If the focal length is 150 cm for a glass lens, what is the power of the lens?

Solution:

Given, focal length, f = 150 cm (or) f = 1.5 m

Equation for power of lens is, $P = \frac{1}{f}$

Substituting the values, $P = \frac{1}{1.5} = 0.67$ diopter

As the power is positive, it is a converging lens.

94. What is the focal length of the combination if a lens of focal length –70 cm is brought in contact with a lens of focal length 150 cm? What is the power of the combination?

Solution:

Given, focal length of first lens, f_1 = –70 cm,
focal length of second lens, f_2 = 150 cm.

Equation for focal length of lenses in contact, $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$

Substituting the values, $\frac{1}{F} = \frac{1}{-70} + \frac{1}{150}$; $= -\frac{1}{70} + \frac{1}{150}$

$\frac{1}{F} = \frac{-150+70}{70 \times 150}$; $= \frac{-80}{70 \times 150}$;

$= -\frac{80}{10500}$; F = $-\frac{1050}{8}$; $= -131.25$ cm

No.	Log
1	0.0000
1.3125	0.1183
(–)	$\bar{1}$.8857
Antilog	7.616×10^{-1}

As the focal length is negative, the combination of two lenses is a diverging system of lenses.

The power of combination is, P = $\frac{1}{F} = \frac{1}{-1.3125\ m} = -0.76$ diopter

95. A monochromatic light is incident on an equilateral prism at an angle 30⁰ and emerges at an angle of 75⁰. What is the angle of deviation produced by the prism?

Solution:

Given, as the prism is equilateral,
A=60^0; i_1 =30^0; i_2 =75^0
Equation for angle of deviation, d = $i_1 + i_2$ – A
Substituting the values, d = $30^0 + 75^0 - 60^0 = 45^0$
The angle of deviation produced is, d = 45^0

96. The angle of minimum deviation for a prism is 37^0. If the angle of prism is 60^0, find the refractive index of the material of the prism.

Solution:

Given, A= 60^0; D=37^0; Equation for refractive index is, n = $\frac{\sin\left(\frac{A+D}{2}\right)}{\sin\left(\frac{A}{2}\right)}$

Substituting the values, n = $\frac{\sin\left(\frac{60^0+37^0}{2}\right)}{\sin\left(\frac{60^0}{2}\right)}$; $= \frac{\sin(48.5^0)}{\sin(30^0)}$; $= \frac{0.75}{0.5}$; = 1.5;

The refractive index of the material of the prism is, n = 1.5

97. Find the dispersive power of flint glass if the refractive indices of flint glass for red, green and violet light are 1.613, 1.620 and 1.632 respectively.

Solution:

Given, n_V =1.632; n_R =1.613; n_G =1.620

Equation for dispersive power is, $\omega = \frac{(n_V - n_R)}{(n_G - 1)}$

Substituting the values, $\omega = \frac{1.632 - 1.613}{1.620 - 1}$; $= \frac{0.019}{0.620}$; = 0.0306

The dispersive power of flint glass is, $\omega = 0.0306$

EXERCISE PROBLEM

98. An object is placed at a certain distance from a convex lens of focal length 20 cm. Find the distance of the object if the image obtained is magnified 4 times.

Solution:

f = -20 cm ; $v = -4u$

According to lens formula, $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$; $\frac{1}{(-20)} = \frac{1}{(-4u)} + \frac{1}{u}$

$\frac{1}{(-20)} = \frac{1}{u}\left[-\frac{1}{4} + 1\right]$; $= \frac{1}{u}\left[\frac{3}{4}\right]$; $u = \frac{3 \times 20}{4}$; $= -15$ cm.

99. An object of 4 cm height is placed at 6 cm in front of a concave mirror of radius of curvature 24 cm. Find the position, height, magnification and nature of the image.

Solution:

H = 4cm, R = -24cn, u = -6cm

i) Position of the image

From the relation between focal length(f) and radius of curvature(R)

R = 2f or f = $\frac{R}{2}$; $= \frac{-24}{2}$; -12cm

From Mirror Equation $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$; $\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$; $= \frac{1}{(-12)} - \frac{1}{(-6)}$; $= -\frac{1}{(12)} + \frac{1}{(6)}$

$= \frac{-1+2}{(12)}$; $= \frac{1}{12}$ V = 12cm

ii) Magnification m $= -\frac{v}{u}$; $= -\frac{12}{(-6)}$; m = 2

Height of the image : Magnification m $= -\frac{h'}{h}$; Height of the image

h' = mh = 2 x 4 = 8cm

Thus the image is virtual, twice the height of object formed on right side of mirror.

100. Refractive index of material of the prism is 1.541. Find the critical angle.

Solution:

n = 1.541

Let i_c be the critical angle, then

$\sin i_c = \frac{1}{n} = \frac{1}{1.541}$ = 0.6489

$I_c = \sin^{-1}(0.6489)$ $I_c = 42^0\ 27'$

No.	Log
1 1.541	0.0000 0.1878
(−)	$\bar{1}$.8122
Antilog	6.489×10^{-1}

UNIT – VII (WAVE OPTICS)

101. Two light sources with amplitudes 5 units and 3 units respectively interfere with each other. Calculate the ratio of maximum and minimum intensities.

Solution:

Amplitudes, $a_1 = 5$, $a_2 = 3$

Resultant amplitude, $A = \sqrt{a_1^2 + a_2^2 + 2a_1a_2\cos\phi}$

Resultant amplitude is, maximum when,

$\phi = 0$, $\cos 0 = 1$, $A_{max} = \sqrt{a_1^2 + a_2^2 + 2a_1a_2}$

$A_{max} = \sqrt{(a_1 + a_2)^2}$; $= \sqrt{(5+3)^2}$; $= \sqrt{(8)^2}$; = 8 units

Resultant amplitude is, minimum when,

$\phi = \pi$, $\cos \pi = -1$, $A_{min} = \sqrt{a_1^2 + a_2^2 - 2a_1a_2}$

$A_{min} = \sqrt{(a_1 - a_2)^2}$; $= \sqrt{(5-3)^2}$; $= \sqrt{(2)^2}$; = 2 units

$I \propto A^2$; $\frac{I_{max}}{I_{min}} = \frac{(A_{max})^2}{(A_{min})^2}$; Substituting $\frac{I_{max}}{I_{min}} = \frac{(8)^2}{(2)^2}$;

$= \frac{64}{4}$; 16 $I_{max} : I_{min} = 16 : 1$

102. The wavelength of a light is 450 nm. How much phase it will differ for a path of 3 mm?

Solution:

The wavelength is, $\lambda = 450$ nm $= 450 \times 10^{-9}$ m

Path difference is, $\delta = 3$ mm $= 3 \times 10^{-3}$ m

Relation between phase difference and path difference is, $\phi = \frac{2\pi}{\lambda} \times \delta$

Substituting, $\phi = \frac{2\pi}{450 \times 10^{-9}} \times 3 \times 10^{-3}$; $= \frac{\pi}{75} \times 10^6$;

$\phi = \frac{\pi}{75} \times 10^6$ rad $= 4.19 \times 10^4$ rad.

103. A monochromatic light of wavelength 5000 Å passes through a single slit producing diffraction pattern for the central maximum as shown in the figure. Determine the width of the slit.

Solution:

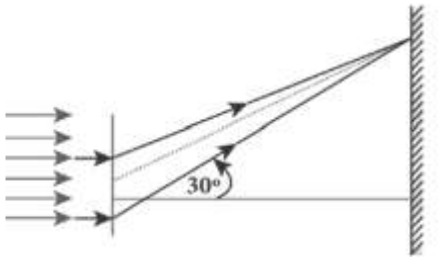
$\lambda = 5000$ Å $= 5000 \times 10^{-10}$m ;

$\sin 30^0 = 0.5$, $n = 1$, $a = ?$

Equation for diffraction minimum is,

$a \sin\theta = n\lambda$

The central maximum is spread up to the first minimum. Hence, n = 1



Rewriting, $a = \frac{\lambda}{\sin\theta}$; substituting, $a = \frac{5000 \times 10^{-10}}{0.5}$

$a = 1 \times 10^{-6}$ m $= 0.001 \times 10^{-3}$ m $= 0.001$ mm

104. Calculate the distance for which ray optics is good approximation for an aperture of 5 mm and wavelength 500 nm.

Solution:

a = 5 mm = 5×10^{-3}m, λ = 500nm = 500×10^{-9}m ; z = ?

Equation for Fresnel's distance, z = $\frac{a^2}{2\lambda}$

Substituting, z = $\frac{(5 \times 10^{-3})^2}{2 \times 500 \times 10^{-9}}$; = $\frac{25 \times 10^{-6}}{1 \times 10^{-6}}$; z = 25 m

105. A diffraction grating consisting of 4000 slits per centimeter is illuminated with a monochromatic light that produces the second order diffraction at an angle of 30⁰. What is the wavelength of the light used?

Solution:

Number of lines per cm = 4000; m = 2; θ = 30^0 ; λ = ?

Number of lines per unit length, N = $\frac{4000}{1 \times 10^{-2}}$; =4×10^5

Equation for diffraction maximum in grating is, sin θ = Nm λ

Rewriting,, $\lambda = \frac{\sin\theta}{Nm}$; Substituting, $\lambda = \frac{\sin 30^0}{4 \times 10^5 \times 2} = \frac{0.5}{4 \times 10^5 \times 2}$;

$= \frac{1}{2 \times 10^5 \times 2}$; $= \frac{1}{16 \times 10^5}$

$\lambda = 6250 \times 10^{-10}$ m = 6250 Å

106. A monochromatic light of wavelength of 500 nm strikes a grating and produces fourth order bright line at an angle of 30⁰. Find the number of slits per centimeter.

Solution:

λ = 500 nm = 500×10^{-9} m; m = 4; θ = 30^0 ,

Number of lines per cm = ?

Equation for diffraction maximum in grating is, sin θ = Nm λ

Rewriting, $\lambda = \frac{\sin\theta}{Nm}$; Substituting, N = $\frac{0.5}{2 \times 4 \times 500 \times 10^{-9}}$

= 2.5×10^5 lines per meter

Number of lines centimeter

=$2.5 \times 10^5 \times 10^{-2}$ = 2500 lines per centimeter

107. The optical telescope in the Vainu Bappu observatory at Kavalur has an objective lens of diameter 2.3 m. What is its angular resolution if the wavelength of light used is 589 nm?

Solution:

a = 2.3 m; λ = 589 nm = 589×10^{-9} m; θ = ?

The equation for angular resolution is, $\theta = \frac{1.22\,\lambda}{a}$

Substituting, $= \frac{1.22 \times 589 \times 10^{-9}}{2.3}$; = 321.4×10^{-9}

$\theta = 3.214 \times 10^{-7}$ rad $\approx 0.0011'$

Note: The angular resolution of human eye is approximately,

3×10^{-4} rad $\approx 1.03'$

108. Find the polarizing angles for (i) glass of refractive index 1.5 and (ii) Water of refractive index 1.33.

Solution:

Brewster's law, tani_P = n

For glass, tani_P = 1.5; i_P = tan^{-1} 1.5; i_P = 56.3^0

For water, tani_P = 1.33; i_P = tan^{-1} 1.33; i_P = 53.1^0

109. A microscope has an objective and eyepiece of focal lengths 5 cm and 50 cm respectively with tube length 30 cm. Find the magnification of the microscope in the (i) near point and (ii) normal focusing.

Solution:

f_0 = 5cm = 5 x 10^{-2} m ; f_e = 50 cm = 50 x 10^{-2} m

L = 30 cm = 30 x 10^{-2}m ; D = 25 cm = 25 x 10^{-2} m

(i) The total magnification m in near point focusing is ,

$$m = m_o m_e = \left(\frac{L}{f_0}\right)\left(1+\frac{D}{f_e}\right)$$

Substituting, $m_o m_e = \left(\frac{30 \text{ x } 10^{-2}}{5 \text{ x } 10^{-2}}\right)\left(1+\frac{25 \text{ x } 10^{-2}}{50 \text{ x } 10^{-2}}\right)$;

= (6) (1.5) = 9

(ii) The total magnification m in normal focusing is,

$$m = m_o m_e = \left(\frac{L}{f_0}\right)\left(\frac{D}{f_e}\right)$$

Substituting, $m_o m_e = \left(\frac{30 \text{ x } 10^{-2}}{5 \text{ x } 10^{-2}}\right)\left(\frac{25 \text{ x } 10^{-2}}{50 \text{ x } 10^{-2}}\right)$;

= (6) (0.5) = 3

110. A small telescope has an objective lens of focal length 125 cm and an eyepiece of focal length 2 cm. What is the magnification of the telescope? What is the separation between the objective and the eyepiece? Two stars separated by 1′ will appear at what separation when viewed through the telescope?

Solution:

f_o = 125 cm; f_e = 2 cm; m = ?; L = ?; θ_i = ?

Equation for magnification of telescope, $m = \frac{f_0}{f_e}$

Substituting, $m = \frac{125}{2}$ = 62.5

Equation for approximate length of telescope, L = f_o+ f_e

Substituting, L = 125 + 2 = 127 cm = 1.27 m

Equation for angular magnification, $m = \frac{\theta_i}{\theta_0}$

Rewriting, θ_i = m x θ_0 ;

Substituting, $\theta_i = 62.5 \text{ x } 1' = 62.5' = \frac{62.5}{60}$; = 1.04^0

111. Calculate the power of the lens of the spectacles necessary to rectify the defect of nearsightedness for a person who could see clearly only up to a distance of 1.8 m.

Solution:

The maximum distance the person could see is, x = 1.8 m.

The lens should have a focal length of, f = –x m = –1.8 m.

It is a concave or diverging lens. The power of the lens is,

$$P = -\frac{1}{1.8\,m} = -\ 0.56 \text{ diopter}$$

112. A person has farsightedness with the minimum distance he could see clearly is 75 cm. Calculate the power of the lens of the spectacles necessary to rectify the defect.

Solution:

The minimum distance the person could see clearly is, y = 75 cm.

The lens should have a focal length of, $f = \frac{\text{y x 25 cm}}{\text{y}-25\text{ cm}}$;

$f = \frac{\text{75 cm x 25 cm}}{75\text{ cm}-25\text{ cm}}$; f = 37.5 cm

It is a convex or converging lens. The power of the lens is,

$$P = \frac{1}{0.375\,m} = 2.67 \text{ diopter}$$

113. A compound microscope has a magnification of 30. The focal length of eye piece is 5 cm. Assuming the final image to be at least distance of distinct vision, find the magnification produced by the objective.

Solution:

Magnification of compound microscope, M = 30

Focal length, f = 5 cm, Least distance of distinct vision, D = 25 cm

Now, $M = M_0 \text{ x } M_e$; $= M_0 \text{ x } \left[1 + \frac{D}{f_e}\right]$; $30 = M_0 \text{ x } \left[1 + \frac{25}{5}\right]$

$M_0 = \frac{30}{6}$; $M_0 = 5$

114. Two polaroids are kept with their transmission axes inclined at 30°. Unpolarised light of intensity I falls on the first polaroid. Find out the intensity of light emerging from the second polaroid.

Solution

As the intensity of the unpolarised light falling on the first polaroid is I, the intensity of polarized light emerging from it will $I_0 = \frac{1}{2}$

Let I' be the intensity of light emerging from the second polaroid

$I' = I_0 cos^2\theta$; $= \frac{1}{2} cos^2 30^0$; $= \frac{1}{2}\left(\frac{\sqrt{3}}{2}\right)^2$; $= \frac{1}{2} \text{x} \frac{3}{4}$ $I' = \frac{3}{8} I$

EXERCISE PROBLEM

115. In Young's double slit experiment, 62 fringes are seen in visible region for sodium light of wavelength 5893 Å. If violet light of wavelength 4359 Å is used in place of sodium light, then what is the number of fringes seen?

Solution:

$\lambda_1 = 5893$ Å; $\lambda_2 = 4359$ Å , $n_1 = 62$, $n_2 = ?$

From young's double slit experiment.

$$\frac{n_1\lambda_1 D}{d} = \frac{n_2\lambda_2 D}{d}$$

The above condition is total extent of fringes is constant for both wavelengths. $\frac{62 \text{ x } 5893 \text{ x } 10^{-10} \text{ x D}}{\text{d}}$

$$= \frac{n_2 \text{x } 5893 \text{ x } 10^{-10} \text{ x D}}{\text{d}}$$

$n_2 = \frac{62 \text{ x } 5893}{4359}$; = $\frac{365366}{4359}$; = 83.8

$n_2 \approx 84$

No.	Log
62 5893	1.7924 3.7703
(+) 4359	5.5627 3.6394
(−)	1.9233
Antilog	8.3181x 10¹

116. A compound microscope has a magnifying power of 100 when the image is formed at infinity. The objective has a focal length of 0.5 cm. and the tube length is 6.5 cm. What is the focal length of the eyepiece?

Solution:

Magnifying Power, m = 100, Focal length of the objective, f_0 = 0.5 cm

Tube length, l = 6.5 cm

Since the image is formed at infinity, the real image produced by the objective lens should lie on the focus of the eyepiece.

$v_0 + f_e$ = 6.5 cm ....(1)

The magnifying power for normal adjustment is given by

$$M = \left(\frac{v_0}{u_0}\right) \text{x} \frac{D}{fe} \; ; \; = -\left[1 - \frac{v_0}{f_0}\right]\frac{D}{f_e}$$

$$100 = -\left[1 - \frac{v_0}{0.5}\right]\frac{25}{f_e} \; ; \; 2v_0 - 4f_e = 1 \text{ ....(2)}$$

On solving equations (1) and (2), we get v_0 = 4.5 cm and f_e = 2 cm

Thus, the focal length of the eyepiece is 2 cm.

117. The ratio of maximum and minimum intensities in an interference pattern is 36 : 1. What is the ratio of the amplitudes of the two interfering waves?

Solution:

$I_{max} = I_{max}$ = 36 : 1

$$\frac{I_{max}}{I_{min}} = \frac{(a_1+a_2)^2}{(a_1-a_2)^2} \text{ or } \frac{a_1+a_2}{a_1-a_2} = \sqrt{\frac{I_{max}}{I_{min}}} = \sqrt{\frac{36}{1}} = 6$$

$a_1 + a_2 = 6(a_1 - a_2)$; $a_1 + a_2 = 6a_1 - 6a_2$

$a_2 + 6a_2 = 6a_1 - a_1$; $7a_2 = 5a_1$

$\frac{a_1}{a_2} = \frac{7}{5}$; $a_1 : a_2 = 7 : 5$

118. Light of wavelength 600 nm that falls on a pair of slits producing interference pattern on a screen in which the bright fringes are separated by 7.2 mm. What must be the wavelength of another light which produces bright fringes separated by 8.1 mm with the same apparatus?

Solution:

λ_1 = 600 nm = 600 x 10^{-9}m ; β_1 = 7.2 mm = 7.2 x 10^{-3}m ;

β_2 = 8.1 mm = 8.1 x 10^{-3}m;

Equation of fringe width $\beta = \frac{\lambda D}{d}$; $\frac{\beta_1}{\beta_2} = \frac{\lambda_1}{\lambda_2}$ or $\lambda_2 = \lambda_1 \frac{\beta_2}{\beta_1}$

$\lambda_2 = 600 \text{ x } 10^{-9} \text{ x } \frac{8.1 \text{ x } 10^{-3}}{7.2 \text{ x } 10^{-3}} = \frac{4860}{7.2} \text{x} 10^{-9}$; 675 x 10^{-9}m; $\boldsymbol{\lambda_2}$ = **675nm**

119. Light of wavelength of 5000 Å produces diffraction pattern of the single slit of width 2.5 μm. What is the maximum order of diffraction possible?

Solution:

a = 2.5 μm = 2.5 x 10^{-6}m , λ = 5000Å = 5000 x 10^{-10}m

Equation for diffraction minimum $a \sin\theta = n\lambda$

For maximum order $\theta = 90^0$ or $\sin\theta = 1$

n = $\frac{a \sin\theta}{\lambda} = \frac{2.5 \text{ x } 10^{-6} \text{ x } 1}{5000 \text{ x } 10^{-10}}$; = 0.5 x 10^1 = 5

120. The reflected light is found to be plane polarised when an unpolarized light falls on a denser medium at 60° with the normal. Find the angle of refraction and critical angle of incidence for total internal reflection in the denser to rarer medium reflection.

Solution:

The angle of incidence at which the reflected ray gets completely plane polarized is called angle of polarization (i_p). Hence $i_p = 60^0$

At polarizing angle, the angle of refraction, $\mathbf{r}$=90°− i_p=90^0−60^0=$\mathbf{30^0}$

From Brewster's law, n=tan i_p=tan 60^0= $\sqrt{3}$

Let i_c be the critical angle, then sini_c = $\frac{1}{n} = \frac{1}{\sqrt{3}}$ = 0.5774

I_c = $\sin^{-1}$ (0.5774) ; = 35.26^0 ; **I_c = $\mathbf{35^0 16'}$**

UNIT – VIII (DUAL NATURE OF RADIATION AND MATTER)

121. A radiation of wavelength 300 nm is incident on a silver surface. Will photoelectrons be observed?

Solution:

Energy of the incident photon is E = $h\nu = \frac{hc}{\lambda}$ (in Joules)

E = $\frac{hc}{\lambda e}$ (in eV)

Substituting the known values, we get

$= \frac{6.634 \text{ x } 10^{-34} \text{ x } 3 \text{ x } 10^{8}}{300 \text{ x } 10^{-9} \text{ x } 1.6 \text{ x } 10^{-19}}$; $= \frac{19.902 \text{ x } 10^{-26}}{480 \text{ x } 10^{-28}}$; 0.04146 x 10^2

E = 4.14 eV

The work function of silver = 4.7 eV. Since the energy of the incident photon is less than the work function of silver, photoelectrons are not observed in this case.

122. The work function of potassium is 2.2 eV. UV light of wavelength 3000 Å and intensity 2 Wm^{-2} is incident on the potassium surface.
i) Determine the maximum kinetic energy of the photo electrons
ii) If 40% of incident photons produce photo electrons, how many electrons are emitted per second if the area of the potassium surface is 2 cm^2 ?

Solution:

i) The energy of the photon is E= $\frac{hc}{\lambda}$; $= \frac{6.6 \text{ x } 10^{-34} \text{ x } 3 \text{ x } 10^{8}}{3000 \text{ x } 10^{-10}}$

E = 6.626 x 10^{-19} J = 4.14 eV

Maximum KE of the photoelectrons is

$K_{max} = h\nu - \phi_0$ = 4.14 – 2.30 = 1.84 eV

ii) The number of photons reaching the surface per second is

$n_P = \frac{P}{E}$ x A ; $= \frac{2}{6.626 \text{ x } 10^{-19}}$ x 2 x 10^{-4}

The rate of emission of photoelectrons is

=(0.40) n_P = 0. 4 × 6. 04 ×10^{14}

= 2.415 x10^{14} photoelectrons / sec

123. Calculate the cut-off wavelength and cutoff frequency of x-rays from an X –ray tube of accelerating potential 20,000 V.

Solution:

The cut-off wavelength of the characteristic x-rays is $\lambda_0 = \frac{12400}{V}$ Å

$= \frac{12400}{20000}$ Å ; = 0.62 Å

The corresponding frequency is $\nu_0 = \frac{c}{\lambda_0}$; $= \frac{3 \text{ x } 10^{8}}{0.62 \text{ x } 10^{-10}}$

= 4.84 x 10^{18} Hz

124. Find the de Broglie wavelength associated with an alpha particle which is accelerated through a potential difference of 400 V. Given that the mass of the proton is 1.67×10^{-27} kg.

Solution:

An alpha particle contains 2 protons and 2 neutrons. Therefore, the mass M of the alpha particle is 4 times that of a proton (mp) (or a neutron) and its charge q is twice that of a proton (+e). The de Broglie wavelength associated with it is $\lambda = \frac{h}{\sqrt{2\,MqV}} = \frac{h}{\sqrt{2 \times (4m_p) \times (2e) \times V}}$

$$= \frac{6.634 \times 10^{-34}}{\sqrt{2 \times 4 \times 1.67 \times 10^{-27} \times 2 \times 1.6 \times 10^{-19} \times 400}}$$

$$= \frac{6.634 \times 10^{-34}}{4 \times 20 \times 10^{-23}\sqrt{1.67 \times 1.6}}\ ; = 0.00507\ \text{Å}$$

125. Calculate the momentum and the de Broglie wavelength in the following cases: i) an electron with kinetic energy 2 eV. ii) a bullet of 50 g fired from rifle with a speed of 200 m/s iii) a 4000 kg car moving along the highways at 50 m/s. Hence show that the wave nature of matter is important at the atomic level but is not really relevant at macroscopic level.

Solution:

i) Momentum of the electron is

$p = \sqrt{2mK} = \sqrt{2 \times 9.1 \times 10^{-31} \times 2 \times 1.6 \times 10^{-19}}\ ; \sqrt{58.24 \times 10^{-50}}$

$p = 7.63 \times 10^{-25}$ kg ms^{-1}

Its de Broglie wavelength is $= \frac{h}{p} = \frac{6.634 \times 10^{-34}}{7.63 \times 10^{-25}}$; $= 0.868 \times 10^{-9}$ m

$\lambda = 8.68$ Å

ii) Momentum of the bullet is $p = mv = 0.050 \times 200 = 10$ kgms^{-1}

Its de Broglie wavelength is $\lambda = \frac{h}{p} = \frac{6.634 \times 10^{-34}}{10}$; $= 6.626 \times 10^{-33}$ m

iii) Momentum of the car is $p = mv = 4000 \times 50 = 2 \times 10^5$ kgms^{-1}

Its de Broglie wavelength is $= \frac{h}{p} = \frac{6.634 \times 10^{-34}}{2 \times 10^5}$; $= 3.313 \times 10^{-39}$ m

From these calculations, we notice that electron has significant value of de Broglie wavelength ($\approx 10^{-9}$m which can be measured from diffraction studies) but bullet and car have negligibly small de Broglie wavelengths associated with them ($\approx 10^{-33}$m and 10^{-39}m respectively, which are not measurable by any experiment). This implies that the wave nature of matter is important at the atomic level but it is not really relevant at the macroscopic level.

No.	Log
$\sqrt{58.24}$	1.7652 x ½ 0.8826
Antilog	7.631×10^0

No.	Log
6.626 7.631	0.8213 0.8826
(−)	1.9387
Antilog	8.684×10^{-1}

EXERCISE PROBLEM

126. How many photons per second emanate from a 50 mW laser of 640 nm?

Solution:

P = 50 mW , λ = 640 nm , h = 6.6 x 10^{-34} Js,

c = 3 x10^{8} ms^{-1}

Number of photons emanate per second

$n_P = \frac{P}{E} = \frac{P\lambda}{hc}$; $= \frac{50 \text{ x } 10^{3} \text{x } 640 \text{ x } 10^{-9}}{6.6 \text{ x } 10^{-34} \text{ x } 3 \text{ x } 10^{8}}$; $= \frac{32000 \text{ x } 10^{-6}}{19.8 \text{ x } 10^{-26}}$;

= 1616.16 x 10^{20} n_P =1.6 x 10^{17} s^{-1}

No.	Log
32000 19.878	4.5051 1.2984
(−)	3.2067
Antilog	1.610 x 10^{3}

127. Calculate the energies of the photons associated with the following radiation: (i) Violet light of 413 nm (ii) X-rays of 0.1 nm (iii) radio waves of 10 m.

Solution:

h = 6.6 x 10^{-34} Js, c = 3 x10^{8} ms^{-1}

Energy of photon, E = $h\upsilon$; E = $\frac{hc}{\lambda}$

i) Violet light, λ = 413 nm ; E = $\frac{6.6 \text{ x } 10^{-34} \text{x } 3 \text{ x } 10^{8}}{413 \text{ x } 10^{-9}}$ = 0.04794 x 10^{-17}

= 4.794 x 10^{-19} J ; = $\frac{4.794 \text{ x } 10^{-19}}{1.6 \text{ x } 10^{-19}}$ eV

E = 3 eV

ii) X –Ray, λ = 0.1 nm ; E = $\frac{6.6 \text{ x } 10^{-34} \text{x } 3 \text{ x } 10^{8}}{0.1 \text{ x } 10^{-9}}$ = 198 x 10^{-17}

= $\frac{198 \text{ x } 10^{-17}}{1.6 \text{ x } 10^{-19}}$; 123.75 x 10^{2}

E = 12375 eV

iii) Radio waves, λ = 10 m ; E = $\frac{6.6 \text{ x } 10^{-34} \text{x } 3 \text{ x } 10^{8}}{10}$ = 1.98 x 10^{-26}J

= $\frac{1.98 \text{ x } 10^{-26}}{1.6 \text{ x } 10^{-19}}$; 1.2375 x 10^{-7}

E = 1.24 x 10^{-7} eV

128. A 150 W lamp emits light of mean wavelength of 5500 Å . If the efficiency is 12%, find out the number of photons emitted by the lamp in one second.

Solution:

P = 150 W , λ = 5500 Å , h = 6.6 x 10^{-34} Js, c = 3 x10^{8} ms^{-1}

Number of photons emanated per second n = $\frac{P\lambda}{hc}$

If the efficiency is 12% , $\eta = \frac{12}{100}$ = 0.12

n = $\frac{P\eta\lambda}{hc}$

= $\frac{150 \text{ x } 0.12 \text{ x } 5500 \text{ x } 10^{-10}}{6.6 \text{ x } 10^{-34} \text{ x } 3 \text{ x } 10^{8}}$; = $\frac{99000 \text{ x } 10^{-10}}{19.8 \text{ x } 10^{-26}}$;

= 5000 x 10^{16} ; n =5 x 10^{19}

No.	Log
825 19.878	2.9165 1.2984
(−)	1.6181
Antilog	4.150 x 10^{1}

129. How many photons of frequency 10^{14} Hz will make up 19.86 J of energy?

Solution:

Total energy emitted per second = Power x time

19.86 = Power x 1 s ; ∴ Power = 19.86 W

Number of photons, n = $\frac{P}{E} = \frac{P}{h\nu}$; = $\frac{19.86}{6.6 \times 10^{-34} \times 10^{14}}$

= 3.009×10^{20} n = 3×10^{20};

$n_p = 3 \times 10^{20}$

No.	Log
19.86 6.626	1.2980 0.8213
(−)	0.4767
Antilog	2.997×10^0

130. What should be the velocity of the electron so that its momentum equals that of 4000 Å wavelength photon.

Solution:

$\lambda = \frac{h}{P} = \frac{h}{mv}$; $v = \frac{h}{m\lambda}$; = $\frac{6.6 \times 10^{-34}}{9.11 \times 10^{-31} \times 4000 \times 10^{10}}$

$\frac{6.6 \times 10^{-34}}{36.44 \times 10^{-38}}$; = 0.1821×10^4;

$v = 1821 \text{ ms}^{-1}$

No.	Log
6.626 36.4	0.8213 1.5611
(−)	1.2602
Antilog	1.821×10^{-1}

131. Calculate the de Broglie wavelength of a proton whose kinetic energy is equal to 81.9×10^{-15} J. (Given: mass of proton is 1836 times that of electron).

Solution:

Mp = 1.67×10^{-27} kg, KE = 81.9×10^{-15} J

de Broglie wavelength of a proton, $\lambda = \frac{h}{\sqrt{2mK}}$

= $\frac{6.6 \times 10^{-34}}{\sqrt{2 \times 1.67 \times 10^{-27} \times 81.9 \times 10^{-15}}}$;

= $\frac{6.6 \times 10^{-34}}{1.6539 \times 10^{-20}}$; = 3.99×10^{-14}

$\lambda = 4 \times 10^{-14}$ m

132. An electron is accelerated through a potential difference of 81V. What is the de Broglie wavelength associated with it? To which part of electromagnetic spectrum does this wavelength correspond?

Solution:

de – Broglie wavelength of an electron beam accelerated through a potential difference of V volts is $\lambda = \frac{h}{\sqrt{2mV}}$; = $\frac{1.23}{\sqrt{V}}$ nm

V = 81 V, So $\lambda = \frac{1.23}{\sqrt{81}} \times 10^{-9}$ m = 0.1366×10^{-9} m

$\lambda = 1.36$ Å

X –Ray is the part of electromagnetic spectrum does this wavelength corresponds. X – Ray has the wavelengths ranging from about 10^{-8} to 10^{-12} m

133. When a light of frequency $9X10^{14}$ Hz is incident on a metal surface, photoelectrons are emitted with a maximum speed of $8X10^5$ ms^{-1}. Determine the threshold frequency of the surface.

Solution:

$V = 9x10^{14}Hz$; $V_{max} = 8x\ 10^5\ ms^{-1}$

By Einstein's Photo electric equation, $hv = hv_0 + \frac{1}{2}mv_{max}^2$ or

$hv_0 = hv - \frac{1}{2}mv_{max}^2$;

$= [6.626 \text{ x } 10^{-34} \text{ x } 9 \text{ x } 10^{-14}] - \left[\frac{1}{2} \text{x } 9.1 \text{ x } 10^{-31} \text{x} 64 \text{ x } 10^{10}\right]$

$= [59.634 \text{ x } 10^{-20}] - [291.2 \text{ x } 10^{-21}]$;

$= [59.634 - 29.12] \text{ x } 10^{-20}$

$\boldsymbol{hv_0} =$ **30.514 x 10^{-20}**

$v_0 = \frac{30.514 \text{ x } 10^{-20}}{h} = \frac{30.514 \text{ x } 10^{-20}}{6.626 \text{ x } 10^{-34}} = \frac{30.514 \text{ x } 10^{14}}{6.626}$;

No.	Log
6.626 30.514	0.8213 1.4844
(−)	0.6631
Antilog	4.603 x 10^0

$v_0 = 4.603 \text{ x } 10^{14}$Hz

134. At the given point of time, the earth receives energy from sun at 4 cal cm^{-2} min^{-1}. Determine the number of photons received on the surface of the Earth per cm2 per minute.

(Given: Mean wavelength of sun light = 5500 Å)

Solution:

P = 4 cal cm^{-2} min^{-1} = 4 x 4.2 = 16.8 J cm^{-2} min^{-1};

λ = 5500 Å = 5500 x 10^{-10}m

The number of photons received on the surface of the Earth per cm^2 per minute , $n_p = \frac{P}{E} = \frac{P}{hv} = \frac{P}{\left(\frac{hc}{\lambda}\right)} = \frac{P\lambda}{hc}$;

No.	Log
924 19.878	2.9657 1.2984
(−)	1.6673
Antilog	4.648 x 10^1

$= \frac{1.68 \text{ x } 5500 \text{ x } 10^{-10}}{6.626 \text{ x } 10^{-34} \text{ x } 3 \text{ x } 10^8}$;

$= \frac{924 \text{ x } 10^{-18}}{19.878}$; = 4.648 x 10^1 x 10^{18} ; n_p = **4.648 x 10^{19}**

UNIT – IX (ATOMIC AND NUCLEAR PHYSICS)

135. The radius of the 5th orbit of hydrogen atom is 13.25 Å. Calculate the wavelength of the electron in the 5th orbit.

Solution:

$2\pi r = n\lambda$; 2 x3.14 x 13.25 $\AA$ = 5 x λ ; $\therefore\ \lambda = 16.64$ Å

136. Find the (i) angular momentum (ii) velocity of the electron in the 5th orbit of hydrogen atom.

Solution:

(i) Angular momentum is given by $= n\hbar = \frac{nh}{2\pi}$; $= \frac{5 \text{ x } 6.6 \text{ x} 10^{-34}}{2 \text{ x } 3.14}$

= 5.25 x 10^{-34} kgm^2s^{-1}

(ii) Velocity is given by velocity, $= \frac{l}{mr}$; $= \frac{(5.25 \text{ x } 10^{-34}\ \cancel{\text{kg}}\text{m}^{\cancel{2}}\text{s}^{-1})}{(9.1 \text{ x } 10^{-31}\ \cancel{\text{kg}})\ (13.25 \text{ x } 10^{-10}\ \cancel{\text{m}})}$

$v = 4.4 \text{ x } 10^5\ ms^{-1}$

137. Calculate the average atomic mass of chlorine if no distinction is made between its different isotopes?

Solution:

The element chlorine is a mixture of 75.77% of ${}^{35}_{17}Cl$ and 24.23% of ${}^{37}_{17}Cl$. So the average atomic mass will be

$$\frac{75.77}{100} \text{ x } 34.96885u + \frac{24.23}{100} \text{ x } 36.96593u \text{ ; } = 35.453 \text{ u}$$

In fact, the chemist uses the average atomic mass or simply called chemical atomic weight (35.453u for chlorine) of an element. So it must be remembered that the atomic mass which is mentioned in the periodic table is basically averaged atomic mass.

138. Calculate the radius of ${}^{197}_{79}Au$ nucleus.

Solution:

According to the equation ($R = R_0A^{\frac{1}{3}}$), R = 1.2 x 10^{-15} x $(197)^{\frac{1}{3}}$

= 6.97 x 10^{-15}m (or) R = 6.97 F

139. Compute the binding energy of ${}^{4}_{2}He$ nucleus using the following data: Atomic mass of Helium atom, M_A (He) = 4.00260 u and that of hydrogen atom, m_H = 1.00785.

Solution:

Binding energy BE $[Zm_H + Nm_n - M_A]\ c^2$

For helium nucleus, Z = 2, N = A–Z = 4–2 = 2

Mass defect Δm = [(2 x 1.00785u) + (2 x 1.008665u) – 4.00260u]

Δm = 0.03038 u ; B.E = 0.03038 u x c^2

B.E = 0.03038 × 931MeV = 28MeV ; $[\therefore 1uc^2 = 931\ MeV]$

140. Calculate the number of nuclei of carbon-14 un-decayed after 22,920 years if the initial number of carbon-14 atoms is 10,000. The half-life of carbon-14 is 5730 years.

Solution:

To get the time interval in terms of half-life, n = $\frac{t}{T_{1/2}} = \frac{22920\text{ yr}}{5730\text{ yr}}$ = 4

The number of nuclei remaining un-decayed after 22,920 years,

N = $\left(\frac{1}{2}\right)^n$ N_o = = $\left(\frac{1}{2}\right)^4$ x 10000 ; N = 625

141. Compute the binding energy per nucleon of ^4_2He

Solution:

Z=2 ; A = 4

Mass defect of helium nucleus, Δm = 0.03043u

Binding energy of helium nucleus,

BE = Δm x 931 MeV = 0.03043 x 931 = 28MeV

Hence Binding energy per nucleon, $\overline{\text{BE}} = \frac{\text{BE}}{\text{A}} = \frac{28}{7}$; $\overline{\textbf{BE}}$ =7MeV

EXERCISE PROBLEM

142. Calculate the mass defect and the binding energy per nucleon of the $^{108}_{47}Ag$ nucleus. [Atomic mass of Ag = 107.905949]

Solution:

Mass of proton, m_p = 1.007825 amu, Mass of neutron, m_n = 1.008865 amu

Mass defect, Δm = $\text{Zm}_\text{p} + \text{Zm}_\text{N} - \text{M}_\text{N}$;

= 47 x 1.007825 + 61 x 1.008665 – 107.905949

= 108.89634 – 107.905949; Δm = 0.990391u

Binding energy per nucleon of the $^{108}_{47}Ag$ nucleus

$\overline{\text{B.E}} = \frac{\Delta\text{m x 931}}{\text{A}}$; = $\frac{0.990391 \text{ x } 931}{108}$; = $\frac{922.054021}{108}$;

= 8.539 $\overline{\text{B.E}} = 8.5\ \frac{\text{MeV}}{\text{A}}$

No.	Log
922.1 108	2.9648 2.0334
(−)	0.9314
Antilog	8.539 x 10^0

143. Half lives of two radioactive elements A and B are 20 minutes and 40 minutes respectively. Initially, the samples have equal number of nuclei. Calculate the ratio of decayed numbers of A and B nuclei after 80 minutes.

Solution:

80 minutes = 4 half-lives of A = 2 half live of B

Let the initial number of nuclei in each sample be N.

N_A after 80 minutes = $\frac{\text{N}}{2^4}$

Number of A nuclides decayed = $\frac{15}{16}$ N

N_B after 80 minutes = $\frac{\text{N}}{2^4}$

Number of B nuclides decayed = $\frac{3}{4}$ N

Required ratio = $\frac{15}{16}$ x $\frac{4}{3}$ = $\frac{5}{4}$; N_A :N_B = 5 : 4

144. Calculate the time required for 60% of a sample of radon undergo decay. (Given $T_{½}$ of radon =3.8 days.)

Solution:

Here consider R_n – 222 with a half-life of 3.823 days.

From decay equation, Current amount = Initial amount x $(2)^{-n}$

$N = N_0\,(2)^{-n}$; $\frac{N}{N_0} = (2)^{-\frac{t}{T_{1/2}}}$

$\log\left(\frac{N}{N_0}\right) = \log(2) \times \left(-\frac{t}{T_{1/2}}\right)$; $\frac{\log\left(\frac{N}{N_0}\right)}{\log(2)} = \left(-\frac{t}{T_{1/2}}\right)$

$t = \frac{\log(0.4)}{\log(2)} \times (-3.823)$; time t = 5.05 days.

145. Assuming that energy released by the fission of a single $_{92}U^{235}$ nucleus is 200MeV, calculate the number of fissions per second required to produce 1 Watt power.

Solution:

The fission of a single $_{92}U^{235}$ nucleus releases 200 Mev of energy

Energy released in the fission is given by the formula $E = \frac{Pt}{n} \Rightarrow \frac{n}{t} = \frac{P}{E}$

$E = 200$ Mev $= 200 \times 10^6 \times 1.6 \times 10^{-19}$

$E = 320 \times 10^{-13}$; $E = 3.2 \times 10^{-11}$ J

$\frac{n}{t} = \frac{P}{E} = \frac{1}{3.2 \times 10^{-11}}$; $= 0.3125 \times 10^{11} = 3.125 \times 10^{10}$

$\frac{n}{t} = 3.125 \times 10^{10}$

146. Show that the mass of radium ($_{88}Ra^{226}$) with an activity of 1 curie is almost a gram. (Given $T_{½}$ =1600 years.)

Solution:

The activity of the sample at any time t

$R = \lambda N$; Here, $\lambda = \frac{0.6931}{T_{1/2}}$; $R = 1Ci = 3.7 \times 10^{10}$ dis s^{-1}

$T_{1/2}$ = 1600 year = $1600 \times 3.16 \times 10^7$ dis

∴ The amount of radium, $N = \frac{R}{\lambda} = \frac{RT_{1/2}}{0.6931}$

$= \frac{3.7 \times 10^{10} \times 1600 \times 3.16 \times 10^7}{0.6931}$; $= \frac{18707.2 \times 10^{17}}{0.6931}$

$= 26990.62 \times 10^{17}$; $N = 2.7 \times 10^{21}$ atoms

As 226g of radiation contains 6.023×10^{23} atoms so the amount of required strength.

$= \frac{226 \times 2.7 \times 10^{21}}{6.023 \times 10^{23}}$; $= 101.311 \times 10^{-2}$; $= 1.013g \approx 1g$

147. Characol pieces of tree is found from an archeological site. The carbon-14 content of this characol is only 17.5% that of equivalent sample of carbon from a living tree. What is the age of tree?

Solution:

R_0 = 100% , R = 17.5%, $\lambda = \frac{0.6931}{T_{1/2}}$, $T_{1/2}$ = 5730 years

According to radioactive law R = $R_0\, e^{-\lambda t}$; $e^{\lambda t} = \frac{R_0}{R}$

Taking log on both sides t = $\frac{1}{\lambda}$ ln $\left(\frac{R_0}{R}\right)$

Half-life of carbon, $T_{1/2}$ = 5730 years

T = $\frac{T_{1/2}}{0.6931}$ ln $\left(\frac{1}{0.175}\right)$; $\frac{5730 \text{ years}}{0.6931}$ x 1.74297

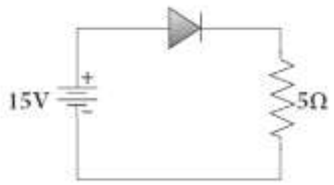
= 14409.49 years; t = 1.44 x 10^4 years

No.	Log
5730 2.303 0.757	3.7582 0.3623 1.8791
(+) 0.6931	3.9996 1.8408
(−)	4.1588
Antilog	1.441 x 10^4

UNIT – X (ELECTRONICS AND COMMUNICATION)

148. An ideal diode and a 5 Ω resistor are connected in series with a 15 V power supply as shown in figure below. Calculate the current that flows through the diode.

Solution:



The diode is forward biased and it is an ideal one. Hence, it acts like a closed switch with no barrier voltage. Therefore, current that flows through the diode can be calculated using Ohm's law. V = IR ; I = $\frac{V}{R}$; = 5 ; = 3A

149. Consider an ideal junction diode. Find the value of current flowing through

Solution:

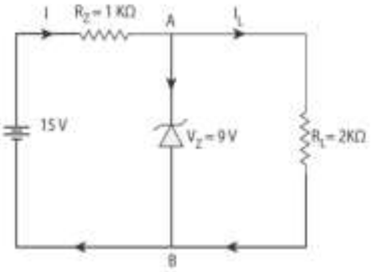
The barrier potential of the diode is neglected as it is an ideal diode.

The value of current flowing through AB can be obtained by using Ohm's law,

$I = \frac{V}{R}$; = $\frac{3-(-7)}{1 \text{ x } 10^3}$; = $\frac{10}{10^3}$; 10^{-2} A = 10 mA

150. Find the current through the Zener diode when the load resistance is 1 KΩ. Use diode approximation.

Solution:



Voltage across AB is V_Z = 9V

Voltage drop across R = 15 - 9 = 6V

Therefore, current through the resistor R,

$I = \frac{6}{1 \text{ x } 10^3}$ = 6 mA

Voltage across the load resistor = V_{AB} = 9V

Current through load resistor, $I_L = \frac{V_{AB}}{R_L} = \frac{9}{2 \text{ x } 10^3}$; = 4.5 mA

The current through the Zener diode,

$I_z = I - I_L$ = 6 mA – 4.5 mA = 1.5 mA

151. Determine the wavelength of light emitted from LED which is made up of GaAsP semiconductor whose forbidden energy gap is 1.875 eV. Mention the colour of the light emitted (Take h = 6.6 × 10^{-34} Js).

Solution:

$E_g = \frac{hc}{\lambda}$; Therefore, $\lambda = \frac{hc}{E_g}$; $= \frac{6.6 \text{ x } 10^{-34} \text{ x } 3 \text{ x } 10^{8}}{1.875 \text{ x } 1.6 \text{ x } 10^{-19}}$

= 660 nm

The wavelength 660 nm corresponds to red colour light.

152. In a transistor connected in the common base configuration, a α =0.95 , $I_E = 1$ mA . Calculate the values of I_C and I_B.

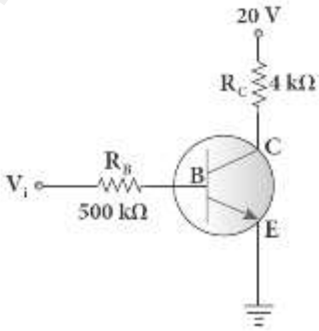
Solution:

$\alpha = \frac{I_C}{I_B}$; $I_C = \alpha I_E$ = 0.95 x 1 = 0.95 mA

$I_E = I_B + I_C \ \therefore I_B = I_C - I_E$; = 1 – 0.95 = 0.05 mA

153. In the circuit shown in the figure, the input voltage V_i is 20 V, V_{BE} = 0 V and V_{CE} = 0 V. What are the values of I_B, I_C, β? (March 2020)

Solution:



$I_B = \frac{V_i}{R_B} = \frac{20 \text{ V}}{500 \text{ k}\Omega}$; = 40μA

$[\because V_{BE} = 0V]$

$I_C = \frac{V_{CC}}{R_C} = \frac{20 \text{ V}}{4 \text{ k}\Omega}$; = 5mA

$[\because V_{CE} = 0V]$

$\beta = \frac{I_C}{I_B} = \frac{5 \, mA}{40 \mu A}$; β = 125

154. Calculate the range of the variable capacitor that is to be used in a tuned-collector oscillator which has a fixed inductance of 150 μH. The frequency band is from 500 kHz to 1500 kHz.

Solution:

Resonant frequency, $f_0 = \frac{1}{2\pi\sqrt{LC}}$; On simplifying we get $C = \frac{1}{4\pi^2 f_0^2 L}$

When frequency is equal to 500 kHz

$C = \frac{1}{4 \text{ x } 3.14^2 \text{ x } (500 \text{ x } 10^3)^2 \text{ x } 150 \text{ x } 10^{-6}}$; = 676 pF

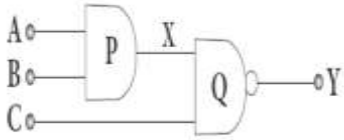
When frequency is equal to 1500 kHz

$C = \frac{1}{4 \text{ x } 3.14^2 \text{ x } (1500 \text{ x } 10^3)^2 \text{ x } 150 \text{ x } 10^{-6}}$; = 75 pF

Therefore, the capacitor range is 75 – 676 pF

155. What is the output Y in the following circuit, when all the three inputs A, B, and C are first 0 and then 1?

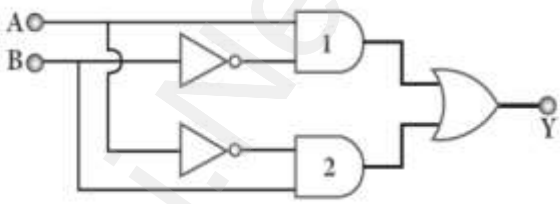
Solution:



A	B	C	X = A.B	Y = $\overline{X.C}$
0	0	0	0	1
1	1	1	1	0

156. In the combination of the following gates, write the Boolean equation for output Y in terms of inputs A and B.

Solution:



The output at the 1st AND gate: $A\,\overline{B}$

The output at the 2nd AND gate: $\overline{A}\,B$

The output at the OR gate: Y = $A.\,\overline{B} + \overline{A}.\,B$

157. Simplify the Boolean identity AC + ABC = AC

Solution:

Step 1: AC (1 + B) = AC.1 [OR law – 2]

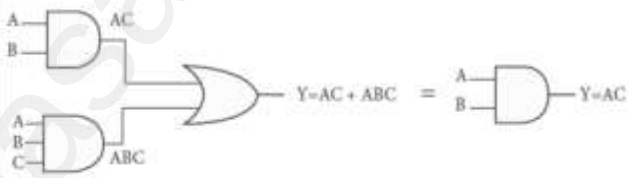
Step 2: AC. 1 = AC [AND law – 2]

Therefore, AC + ABC = AC

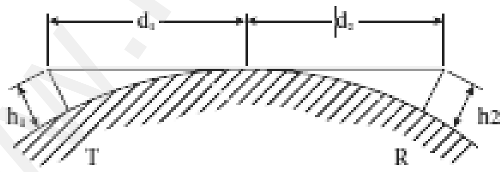
Circuit Description

Y=AC + ABC Y=AC

Thus the given statement is proved.



158. A transmitting antenna has a height of 40 m and the height of the receiving antenna is 30 m. What is the maximum distance between them for line-of-sight communication? The radius of the earth is 6.4×10⁶ m.



Solution:

The total distance *d* between the transmitting and receiving antennas will be the sum of the individual distances of coverage.

d = $d_1 + d_2$; = $\sqrt{2\,Rh_1} + \sqrt{2Rh_2} = \sqrt{2R}\left(\sqrt{h_1} + \sqrt{h_2}\right)$

= $\sqrt{2 \text{ x } 6.4 \text{ x } 10^6}\left(\sqrt{40} + \sqrt{30}\right)$; = $\sqrt{2 \text{ x } 6.4 \text{ x } 10^6} \text{ x } \sqrt{10}\left(\sqrt{4} + \sqrt{3}\right)$

= $\sqrt{2 \text{ x } 6.4 \text{ x } 10^7}\left(\sqrt{4} + \sqrt{3}\right)$; = $\sqrt{2 \text{ x } 64 \text{ x } 10^6}\left(\sqrt{4} + \sqrt{3}\right)$

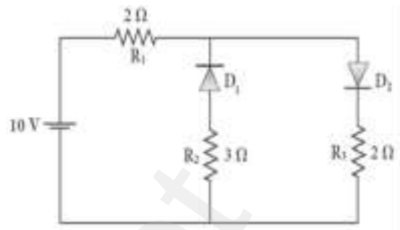
d = 1.414 x 8 x 10^3 (2 + 1.732)

d = 42.21 x 10^3 m; **d = 42.21km**

EXERCISE PROBLEM

159. The given circuit has two ideal diodes connected as shown in figure below. Calculate the current flowing through the resistance R_1

Solution:



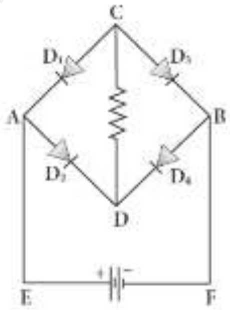
Diode D_1 is reverse biased so, it will block the current and Diode D_2 is forward biased, so it will pass the current.

Current in the circuit is $I = \frac{V}{R}$; $= \frac{10}{2+2} = \frac{10}{4}$;

$I = 2.5A$

160. Four silicon diodes and a 10 Ω resistor are connected as shown in figure below. Each diode has a resistance of 1Ω. Find the current flows through the 18Ω resistor.

Solution:



Diode D_2 and D_4 are forward biased while diodes D_1 and D_3 are reverse biased . Only current flowing through the closed loop is EADCBFE. Consider the applied voltage is 4V. For silicon diode, Barrier voltage is 0.7 V.

Net circuit voltages = 4 – (0.7 + 0.7) = 4 – 1.4

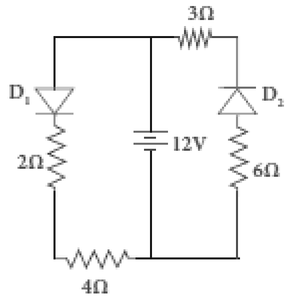
V = 2.6 V

Total circuit resistance = 1 + 18 + 1 R = 20 Ω

$\therefore$ Circuit Current $I = \frac{V}{R} = \frac{2.6}{20}$; = 0.13 A

161. Determine the current flowing through 3Ω and 4Ω resistors of the circuit given below. Assume that diodes D_1 and D_2 are ideal diodes.

Solution:



Here diode D_1 is forward biased (closed switch) and D_2 is reverse biased (open switch)

So D_1 conducts while D_2 do not conduct the current.

For ideal diode, there is no barrier voltage (i.e.) VB = 0

Let 'I' be the current through D_1, then by Ohm's Kirchoff's voltage law,

2I + 4I = 12 (or) 6I = 12 or I = 2A

Since D_2 will not conduct, no current flows through diode D_2

Thus current flowing through 3Ω and 4Ω resistors of the circuit are **0 and 2 A** Respectively.