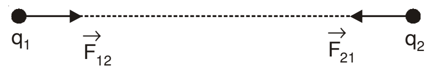
CBSE Sample Question Paper for 2024

General Instructions:

1. *There are 33 questions in all. All questions are compulsory.*
2. *This question paper has five sections: Section A, Section B, Section C, Section D and Section E. All the sections are compulsory.*
3. *Section A contains sixteen questions, twelve MCQ of 1 mark each and four assertion-reasoning based of 1 mark each, Section B contains seven questions of two marks each, Section C contains five questions of three marks each, Section D contains two case study based questions of 4 marks each. and Section E contains three long questions of five marks each.*
4. *There is no overall choice. However, an internal choice has been provided in one question in Section B, one question in C, one question in each CBQ in section D and all three questions in section E. You have to attempt only one of the choices in such questions.*
5. *Use of calculators is not allowed.*

SECTION A

Q. 1. According to Coulomb's law, which is the correct relation for the following figure?



(*a*) $q_1 q_2 > 0$ (*b*) $q_1 q_2 < 0$

(*c*) $q_1 q_2 = 0$ (*d*) $1 > \frac{q_1}{q_2} > 0$

Ans. (*b*) As force is attractive; charges are unlike $q_1 q_2 < 0$.

Q. 2. The temperature (*T*) dependence of resistivity of material *A* and material *B* is represented by Fig. (*i*) and Fig. (*ii*) respectively.
Identify material *A* and material *B*.

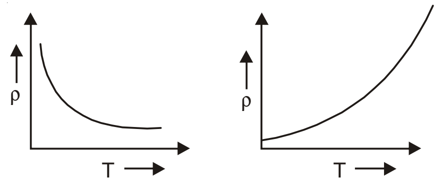


Fig. (*i*) **Fig. (*ii*)**

(*a*) Material *A* is copper and material *B* is germanium
(*b*) Material *A* is germanium and material *B* is copper
(*c*) Material *A* is nichrome and material *B* is germanium
(*d*) Material *A* is copper and material *B* is nichrome

Ans. (*b*) Resistivity of semiconductor (Ge) decreases and that of a metallic conductor (Copper) increases with rise in temperature.

Q. 3. Two concentric and coplanar circular loops *P* and *Q* have their radii in the ratio 2 : 3. Loop *Q* carries a current 9 A in the anticlockwise direction. For the magnetic field to be zero at the common centre, loop *P* must carry

(*a*) 3 A in clockwise direction
(*b*) 9 A in clockwise direction
(*c*) 6 A in anticlockwise direction
(*d*) 6 A in the clockwise direction.

Ans. (*d*) $|B_P| = |B_Q|$ or $\frac{I_1}{R_1} = \frac{I_2}{R_2}$

$\Rightarrow I_1 = I_2 \times \frac{R_1}{R_2} = 9 \times \frac{2}{3} = 6$ A

The current should be clockwise to make the net field zero.

Q. 4. A long straight wire of circular cross-section of radius '*a*' carries a steady current *I*. The current is uniformly distributed across its cross-section. The ratio of the magnitudes of magnetic field at a point distant *a*/2 above the surface of wire to that at a point distant *a*/2 below its surface is:

(*a*) 4 : 1 (*b*) 1 : 1
(*c*) 4 : 3 (*d*) 3 : 4

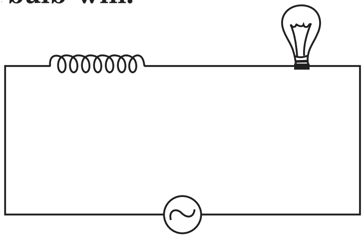
Ans. (*c*) $B_1 = \frac{\mu_0 I}{2\pi r}$ (for $r > a$)

$B_2 = \frac{\mu_0 I r'}{2\pi a^2}$ (for $r' < a$)

$\therefore \frac{B_1}{B_2} = \frac{1}{r} \times \frac{a^2}{r'} = \frac{1}{\frac{3}{2}a} \times \frac{a^2}{a/2}$

$= \frac{2}{3a} \times 2a = 4 : 3$

Q. 5. An iron cored coil is connected in series with an electric bulb with an *AC* source as shown in figure. When iron piece is taken out of the coil, the brightness of the bulb will:



(*a*) decrease
(*b*) increase
(*c*) remain unaffected
(*d*) fluctuate

Ans. (*b*) On removing the rod, X_L decreases; current increases. The bulb glows brighter.

Q. 6. A rectangular, a square, a circular and an elliptical loop, all in the $(X-Y)$ plane, are moving out of a uniform magnetic field with a constant velocity $\vec{v} = v\hat{i}$. The magnetic field is directed along the negative *z*-axis direction. The induced emf, during the passage of these loops, out of the field region, will not remain constant for:

(*a*) any of the four loops
(*b*) the circular and elliptical loops
(*c*) the rectangular, circular and elliptical loops
(*d*) only the elliptical loops

Ans. (*b*) The emf will change if the rate of change of magnetic flux changes. So the loops should be circular or elliptical.

Q. 7. In a Young's double slit experiment, the path difference at a certain point on the screen between two interfering waves is $\frac{1}{8}$th of the wavelength. The ratio of intensity at this point to that at the centre of a bright fringe is close to:

(*a*) 0.80 (*b*) 0.74
(*c*) 0.94 (*d*) 0.85

Ans. (*d*) We have, $I_{max} = 4I$

For $\Delta p = \frac{\lambda}{8}$; $\Delta\phi = \frac{360}{8} = 45°$

$I_{net} = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos\phi$

$= 2I + 2I \cos 45 = (2+\sqrt{2})I$

$\frac{I_{net}}{I_{max}} = \frac{2+\sqrt{2}}{4} = \frac{3.414}{4} = 0.85$

Q. 8. The work function for a metal surface is 4.14 eV. The threshold wavelength for this metal surface is nearly.

(*a*) 4125 Å (*b*) 2062.5 Å
(*c*) 3000 Å (*d*) 6000 Å

Ans. (*c*) $\lambda_{min} = \frac{12500}{W_0} = \frac{12500}{4.14}$ Å $\simeq$ 3000 Å

Q. 9. The radius of the innermost electron orbit of a hydrogen atom is 5.3×10^{-11} m. The radius of the $n = 3$ orbit is:

(*a*) 1.01×10^{-10} m (*b*) 1.59×10^{-10} m
(*c*) 2.12×10^{-10} m (*d*) 4.77×10^{-10} m

Ans. (*d*) $r_n \propto n^2$

$\therefore r_3 = 9r_1 = 9 \times 0.53$ Å

$= 9 \times 5.3 \times 10^{-11}$ m

Q. 10. Which of the following statements about nuclear forces is not true?

(*a*) The nuclear force between two nucleons falls rapidly to zero as their distance is more than a few femtometres.

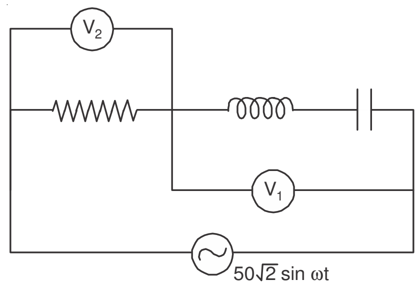
(*b*) The nuclear force is much weaker than the Coulomb force.

(*c*) The force is attractive for distances larger than 0.8 fm and repulsive if they are separated by distances less than 0.8 fm.

(*d*) The nuclear force between neutron-neutron, proton-neutron and proton-proton is approximately the same.

Ans. (*b*) The nuclear force is known to be very strong than coulombic force.

Q. 11. In the figure given below, the reading of the voltmeter V_1 is 40 V. The reading of voltmeter V_2 is:



(*a*) 30 V (*b*) 58 V

(*c*) 29 V (*d*) 15 V

Ans. (*a*) **Hint:** For the source

$$E_0 = 50\sqrt{2}\ \text{V}$$

$$\therefore \quad E_{eff} = 50\ \text{V}$$

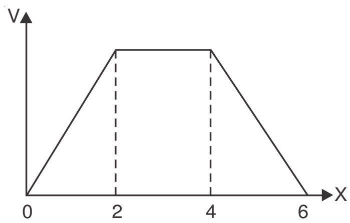
$$\text{Now} \quad V^2 = V_R^2 + (V_L - V_C)^2$$

(Effective values)

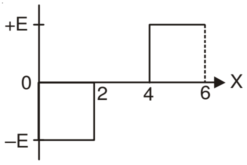
$$(50)^2 = V_R^2 + (40)^2$$

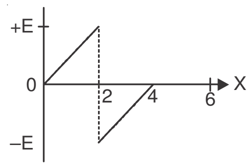
$$\Rightarrow \quad V_R = 30\ \text{V}$$

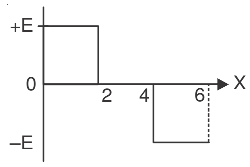
Q. 12. The electric potential *V* as a function of distance *X* is plotted in the figure below.

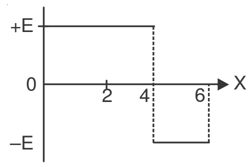


The graph of the magnitude of electric field intensity *E* as a function of *X* is:

(*a*)


(*b*)


(*c*)


(*d*)


Ans. (*a*) As $$E = -\frac{dV}{dr}$$

$\therefore$ From $x = 0$ to 2 units; E is –ve and constant.

From $x = 2$ to 4 units, $E = 0$

From $x = 4$ to 6 units, E is +ve and constant.

INSTRUCTIONS FOR Q.13–Q.16

Two statements are given – one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

(*a*) Both *A* and *R* are true and *R* is the correct explanation of *A*.

(*b*) Both *A* and *R* are true but *R* is NOT the correct explanation of *A*.

(*c*) A is true but *R* is false.

(*d*) *A* is false but *R* is true.

Q. 13. Assertion (A) : The electric point at every point on equatorial line of an electric dipole is zero.

Reason (R) : The two charges have equal but opposite potential at every pint on the equatorial line as the points are equidistant from the two charges of the dipole.

Q. 14. Assertion (A): The electrical conductivity of a semiconductor increases on doping.

Reason (R): Doping always increases the number of holes in the semiconductor.

Ans. (*c*) **Hint:** Doping with *p*-type impurity does not result in an increase in the number of holes.

Q. 15. Assertion (A): In an interference pattern observed in Young's double slit experiment, if the separation (d) between coherent sources as well as the distance (D) of the screen from the coherent sources both are reduced to 1/3rd, then new fringe width remains the same.

Reason (R): Fringe width is proportional to (d/D).

Ans. (c) **Hint:** We have, $\beta = \frac{\lambda D}{d}$.

So $\beta \propto \frac{D}{d}$ and not $\frac{d}{D}$.

Q. 16. Assertion (A): The photoelectrons produced by a monochromatic light beam incident on a metal surface have a spread in their kinetic energies.

Reason (R): The energy of electrons emitted from inside the metal surface, is lost in collision with the other atoms in the metal.

Ans. (a) **Hint:** Some energy of the electrons emitted from the interior is lost in collision with the metals of the atom. So (R) is correct explanation for (A).

SECTION B

Q. 17. What is the nuclear radius of ^{125}Fe, if that of ^{27}Al is 3.6 fermi?

Ans. For a nucleus of mass number A; we have nuclear radius $R = R_0 A^{1/3}$.

$$\therefore \quad \frac{R_{Fe}}{R_{Al}} = \left(\frac{A_{Fe}}{A_{Al}}\right)^{1/3} = \left(\frac{125}{27}\right)^{1/3} = \frac{5}{3}$$

$$\therefore \quad R_{Fe} = \frac{5}{3} \times R_{Al}$$

$$= \frac{5}{3} \times 3.6 \text{ fermi} = 6.0 \text{ fermi}$$

OR

The short wavelength limit for the Lyman series of the hydrogen spectrum is 913.4 Å. Calculate the short wavelength limit for the Balmer series of the hydrogen spectrum.

Ans. Rydberg formula for wave number in hydrogen spectrum is

$$\frac{1}{\lambda} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

$\therefore$ For minimum wavelength of Lyman series is

$$\frac{1}{913.4} = R\left(\frac{1}{1^2} - \frac{1}{\infty^2}\right) = R \quad ...(1)$$

$$\frac{1}{(\lambda_b)_{min}} = R\left(\frac{1}{2^2} - \frac{1}{\infty^2}\right) = \frac{R}{4} \quad ...(2)$$

(1) ÷ (2) gives $\frac{(\lambda_B)_{min}}{913.4} = 4$

$$\lambda_B = 4 \times 913.4 = 3653.6 \text{ Å}.$$

Q. 18. A biconvex lens made of a transparent material of refractive index 1.25 is immersed in water (refractive index 1.33). Will the lens behave as a converging or a diverging lens? Justify your answer.

Ans. We have, $\mu_{lens} = 1.25$ (Biconvex)

$$\mu_{med} = 1.33$$

$$= \left[\frac{5}{4} \times \frac{3}{4} - 1\right] [+\text{ve}]$$

$$= \left[\frac{15}{16} - 1\right] [+\text{ve}]$$

$$= -\left(\frac{1}{16}\right) [+\text{ve}] < 0$$

By lens maker formula

$$\frac{1}{f} = \left(\frac{\mu_{lens}}{\mu_{med}} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

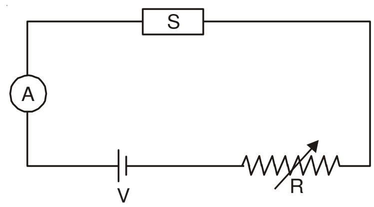
$$= \left(\frac{1.25}{1.33} - 1\right) = (+\text{ve})$$

As R_1 is positive and R_2 is negative.

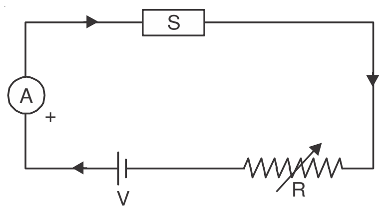
$\Rightarrow \frac{1}{f}$ is negative.

Hence the lens behaves as a diverging lens.

Q. 19. The figure shows a piece of pure semi-conductor S in series with a variable resistor R and a source of constant voltage V. Should the value of R be increased or decreased to keep the reading of the ammeter constant, when semiconductor S is heated? Justify your answer.



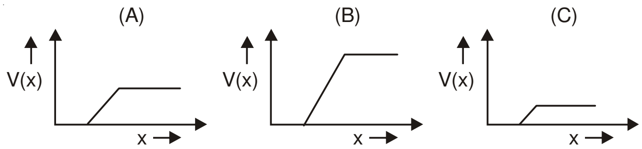
Ans. On heating a semiconductor, the resistance decreases. This will lower the resistance in the circuit increasing the current.



In order to keep the current constant the value of R (the variable resistance) has to be increased.

OR

The graph of potential barrier versus width of depletion region for an unbiased diode is shown in graph *A*. In comparison to *A*, graphs *B* and *C* are obtained after biasing the diode in different ways. Identify the type of biasing in *B* and *C* and justify your answer.



Ans. The *pn*-junction in *B* is **Reverse biased** because the reverse biasing increases the potential barrier.

The *pn*-junction in *C* is **Forward biased** as the forward biasing lowers the potential barrier.

Q. 20. A narrow slit is illuminated by a parallel beam of monochromatic light of wavelength λ equal to 6000 Å and the angular width of the central maxima in the resulting diffraction pattern is measured. When the slit is next illuminated by light of wavelength 'λ′', the angular width decreases by 30%. Calculate the value of the wavelength 'λ′'.

Ans. Suppose θ is the angular width for wavelength 6000 Å and θ′ for the wavelength λ.

We have,

$$\text{Angular width, } \theta = \frac{2\lambda}{d} = \frac{2(6000)}{d} \text{ units}$$

$$\text{and} \quad \theta' = \frac{2\lambda'}{d} \text{ units} = 70\% \text{ of } \theta$$

$$= 0.7\,\theta$$

$$\therefore \quad \frac{\theta'}{\theta} = \frac{2\lambda'}{d} \times \frac{d}{12000} = 0.7$$

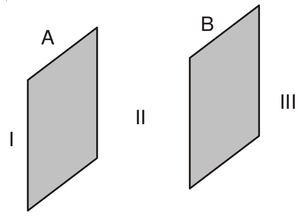
$$\Rightarrow \quad \lambda' = \frac{0.7 \times 12000}{2} = 4200 \text{ Å}$$

Q. 21. Two large, thin metal plates are parallel and close to each other. On their inner faces, the plates have surface charge densities of opposite signs and of magnitude 17.7×10^{-22} C/m². What is electric field intensity *E*

(*a*) in the outer region of the first plate, and

(*b*) between the plates?

Ans. We have,



Surface charge density of A

$$= +17.7 \times 10^{-22} \text{ C/m}^2$$

Surface charge density of B

$$= -17.7 \times 10^{-22} \text{ C/m}^2$$

(*a*) Electric field intensity outside the plates

= Zero

(*b*) Electric field intensity between the plates

$$= E = \frac{\sigma}{\varepsilon_0}$$

$$= \frac{17.7 \times 10^{-22} \text{ C/m}^2}{8.85 \times 10^{-12} \text{ N}^{-1} \text{ C}^2 \text{ N}^{-2}}$$

$$= 2 \times 10^{-10} \text{ N/C}$$

Q. 22(*a*) $\vec{E}$ and $\vec{B}$ denote the instantaneous values of intensity of electric field and magnetic field respectively associated with an electromagnetic field.

(*i*) What is the angle between $\vec{E}$ and $\vec{B}$?

(ii) How are $|\vec{E}|$ and $|\vec{B}|$ related?

(*b*) Electromagnetic waves with wavelength:

(*i*) λ_1 is suitable for radar systems used in aircraft navigation.

(*ii*) λ_2 is used to kill germs in water purifiers.

(*iii*) λ_3 is used to improve visibility in runways during fog and mist conditions.

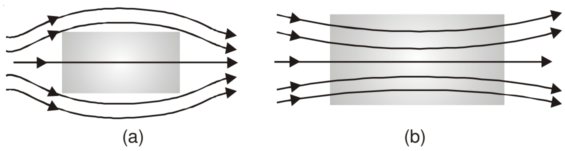
Identify and name the part of the electromagnetic spectrum to which these radiations belong. Also arrange these

wavelengths in ascending order of their magnitude.

Ans. (*a*) λ_1 (Microwaves)
λ_2 Ultraviolet
λ_3 Infrared
Wavelengths in ascending order are
λ_2 (Minimum) < λ_3 < λ_1 (Maximum).

Q. 23(*a*) Write the expression for the magnetic dipole moment of a current loop. Give its SI unit.

(*b*) A uniform magnetic field gets modified as shown in figure when two specimens *A* and *B* are in turn placed in it.



(*i*) Identify the specimens *A* and *B*.

(*ii*) How is the magnetic susceptibility of specimen *A* different from that of specimen *B*?

Ans. (*b*) (*i*) *A* is Diamagnetic.
B is Paramagnetic.

(*ii*) Magnetic susceptibility of *A* is **small and negative** whereas that of *B* is **small and positive.**

SECTION C

Q. 24. Two long straight parallel conductors carrying currents I_1 and I_2 are separated by a distance *d*. If the currents are flowing in the same direction, show how the magnetic field produced by one exerts an attractive force on the other. Obtain the expression for this force and hence define 1 ampere.

Ans. Let X_1Y_1 and X_2Y_2 be two long straight conductors carrying currents I_1 and I_2 separated by a distance '*d*'. The conductors exert a force on each other due to their magnetic fields.

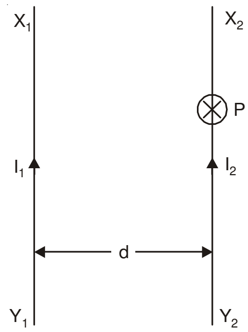
Magnetic field at *P* (on X_2Y_2) due to current through $X_1Y_1 = B = \frac{\mu_0 I_1}{2\pi d}$.

By Ampere's right hand rule, the magnetic field at *P* is directed into the paper represented by $\otimes$. X_2Y_2 is placed in the magnetic field *B*.

$\therefore$ Force on a length '*l*' of $X_2Y_2 = F = BI_2l$

or $$F = \frac{\mu_0 I_1 I_2}{2\pi d}$$

or Force per unit length $= \frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi d}$



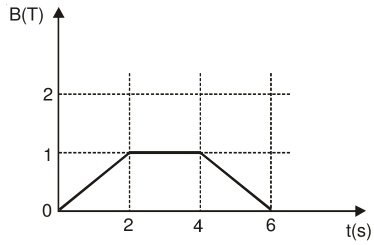
By Fleming's left hand rule, force on X_2Y_2 is towards left and hence attractive.

ampere: If $I_1 = I_2 = 1$ A and $d = 1$ m, we get

$$\frac{F}{l} = \frac{\mu_0}{2\pi} = 2 \times 10^{-7} \text{ N/m}$$

Hence one ampere is the current which when flowing through two infinitely long straight parallel conductors with negligible cross-section held 1 m apart in vacuum exerts a force of 2×10^{-7} Nm^{-1} of the conductor.

Q. 25. The magnetic field through a circular loop of wire, 12 cm in radius and 8.5 Ω resistance, changes with time as shown in the figure. The magnetic field is perpendicular to the plane of the loop. Calculate the current induced in the loop and plot a graph showing induced current as a function of time.



Ans. Given, radius, r = 12 cm = 0.12 m
Resistance, R = 8.5 Ω
Area of the coil = $A = \pi r^2 = (0.045)$ m^2

As the magnetic field is changing with time; the magnetic flux flinked with the circular loop also changes resulting in induced emf and hence the current. The current can be calculated as under:

(*i*) $t = 0$ s to $t = 2$ s

$B_i = 0$ T; $B_f = 1$ T

$$e = -\frac{d\phi_B}{dt} = -\frac{\phi_{final} - \phi_{initial}}{t}$$

$$= -\frac{B_f A \cos 0 - B_i A \cos 0}{t}$$

$$= -\frac{(1\ \text{tesla})(0.045\ \text{m}^2)(1)}{2\ \text{s}}$$

$$= -2.25 \times 10^{-2}\ \text{V} = -0.0225\ \text{V}$$

$$I = \frac{e}{R} = -\frac{0.0225}{8.5} = -2.6\ \text{mA}$$

(*ii*) Between $t = 2$ s to $t = 4$ s, magnetic field B and hence magnetic flux remains constant

$\therefore$ $e_{induced} = 0$

$\Rightarrow$ $I = 0$

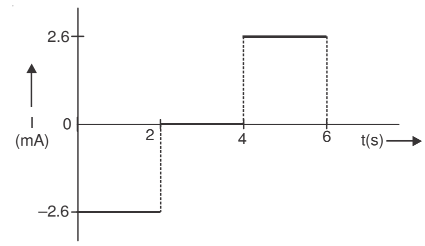
(*iii*) Between $t = 4$ s to $t = 6$ s

$$e = -\frac{d\phi_B}{dt} = -\frac{\phi_{final} - \phi_{in}}{f}$$

$$= -\frac{0 - 0.045}{2} = 0.0225\ \text{V}$$

$$I = \frac{e}{R} = \frac{0.0225\ \text{V}}{8.5}\ \text{A} = +2.6\ \text{mA}$$

The current variation with time can be represented as shown in the graph.

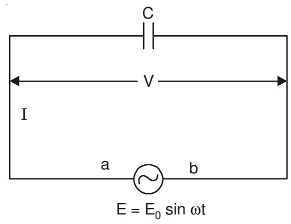


Q. 26. An a.c. source generating a voltage $\varepsilon = \varepsilon_0 \sin \omega t$ is connected to a capacitor of capacitance C. Find the expression for the current I flowing through it. Plot a graph of ε and I versus ωt to show that the current is ahead of the voltage by $\pi/2$.

Ans. The circuit diagram of a capacitor with capacitance C connected to an *ac* source of emf

$$E = E_0 \sin \omega t \quad ...(1)$$

is as shown.



At any instant, we have potential difference

$$V = E = \frac{Q}{C} = E_0 \sin \omega t$$

$\therefore$ $Q = CE_0 \sin \omega t$

Differentiating w.r.t. time '*t*'

$$\text{Current } I = \frac{dQ}{dt} = \frac{d}{dt}(CE_0 \sin \omega t)$$

$$= CE_0 \frac{d}{dt}(\sin \omega t)$$

$$= \omega CE_0 \cos \omega t$$

$$= I_0 \cos \omega t$$

$$= I_0 \sin \left(\omega t + \frac{\pi}{2}\right) \quad ...(2)$$

Comparing (1) and (2), we see that the current leads the emf in phase by $\frac{\pi}{2}$ in a pure capacitance *ac* circuit.

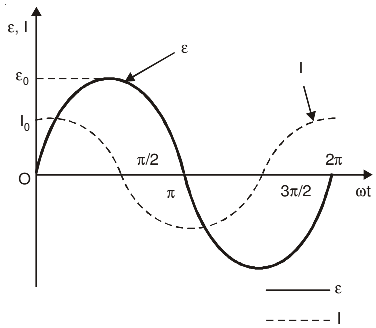
In equation (2),

$I_0 = \omega CE_0$ is the peak current

$$\frac{E_0}{I_0} = \frac{1}{\omega C} = X_C$$

= Capacitance reactance

The variation of I and ε version ωt in as shown.

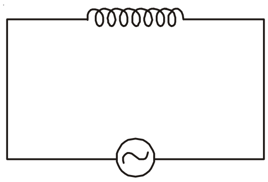


I leads ε in phase by $\frac{\pi}{2}$ in pure capacitive AC circuit.

OR

An a.c. voltage $V = V_0 \sin \omega t$ is applied across a pure inductor of inductance L. Find an expression for the current i, flowing in the circuit and show mathematically that the current flowing through it lags behind the applied voltage by a phase angle of $\frac{\pi}{2}$. Also draw graphs of V and i versus ωt for the circuit.

Ans.



$$V = V_0 \sin \omega t$$

Consider a pure inductor L ($R = 0$) connected to an a.c. voltage source.

$$V = V_0 \sin \omega t \qquad ...(1)$$

As the voltage and hence the current vary, a back emf is set up in the coil.

Self-induced back emf = $-L\frac{dI}{dt}$

$$\text{Net emf} = V - L\frac{dI}{dt}$$

We have, $V - L\frac{dI}{dt} = IR$ (Ohm's law)

$= 0$ [For pure inductor]

$$\therefore \quad L\frac{dI}{dt} = V = V_0 \sin \omega t$$

$$dI = \frac{V_0}{L}\sin \omega t \, dt$$

Integrating

$$I = \frac{V_0}{L}\sin \omega t \, dt$$

$$= \frac{V_0}{L}\frac{-\cos \omega t}{\omega}$$

$$= \frac{V_0}{\omega L}\sin\left(\omega t - \frac{\pi}{2}\right)$$

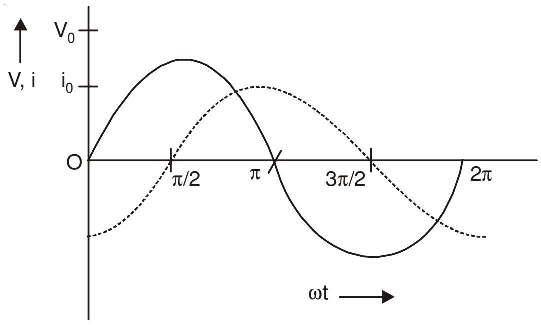
or $$I = I_0 \sin\left(\omega t - \frac{\pi}{2}\right) \qquad ...(2)$$

Which is the derived expression for current.

We have, $I_0 = \frac{V_0}{\omega L}$ or $\frac{V_0}{I_0} = \omega L = X_L$

(called inductive reactance)

Comparing (1) and (2), we see that the current in a pure inductive AC circuit lags behind the emf in phase by $\frac{\pi}{2}$.



V, I verses ωt graph for pure inductive *ac* circuit.

Q. 27. Radiation of frequency 10^{15} Hz is incident on three photosensitive surfaces A, B and C.

Following observations are recorded:

Surface A: No photoemission occurs.

Surface B: Photoemission occurs but the photoelectrons have zero kinetic energy.

Surface C: Photo emission occurs and photoelectrons have some kinetic energy.

Using Einstein's photo electric equation, explain the three observations.

Ans. Frequency of incident radiation = 10^{15} Hz

Energy of photon = $h\nu$

$= 6.67 \times 10^{-34} \times 10^{15}$ J

$= \frac{6.67 \times 10^{-19}}{1.9 \times 10^{-19}}$ eV $\simeq 3.5$ eV

Einstein's photoelectric effect equation gives the kinetic energy of the photoelectrons as

$$K = h\nu - W$$

and the maximum K.E. as

$$K_{max} = h\nu - W_0$$

Where W is the work done to eject the photoelectrons from the metal and W_0 is the work function (the minimum energy required to eject photoelectrons) of the metal.

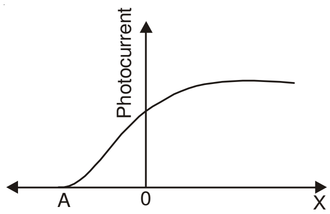
As no photoemission occurs from the surface of metal A; the work function of metal A exceeds 3.5 eV.

As photoelectrons emitted from B have zero kinetic energy; the work function of the metal B is 3.5 eV and the threshold frequency is 10^{15} Hz.

For C, using the equation we can conclude that the work function of the metal C is less than 3.5 eV.

OR

The graph shows the variation of photocurrent for a photosensitive metal:



(*a*) What does *X* and *A* on the horizontal axis represent?

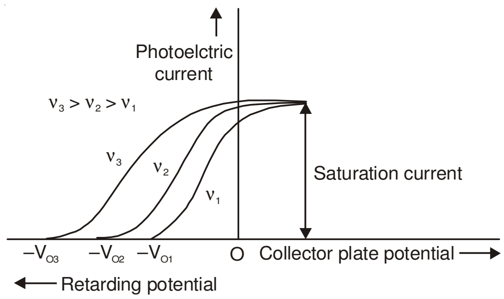
(*b*) Draw this graph for three different values of frequencies of incident radiation ν_1, ν_2 and ν_3 ($\nu_3 > \nu_2 > \nu_1$) for the same intensity.

(*c*) Draw this graph for three different values of intensities of incident radiation I_1, I_2 and I_3 ($I_3 > I_2 > I_1$) having the same frequency.

Ans. (*a*) *X* represents the applied potential and the point *A* represents the cut-off or the stopping potential.

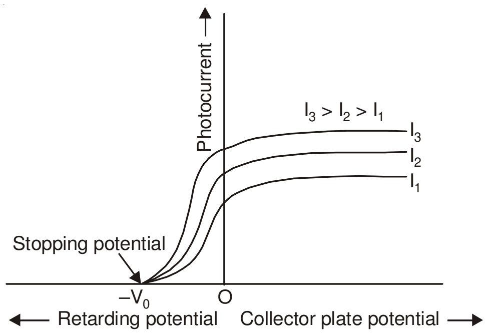
(*b*) The required graph is as under:

Numerically $V_{03} > V_{02} > V_{01}$



Variation of photoelectric current with collector plate potential for different frequencies of incident radiation

(*c*) The required graph for different intensities and the same frequency is as shown.



Variation of photocurrent with collector plate potential for different intensity of incident radiation

Q. 28. The ground state energy of hydrogen atom is –13.6 eV. The photon emitted during the transition of electron from *n* = 3 to *n* = 1 state, is incident on a photosensitive material of unknown work function. The photoelectrons are emitted from the material with the maximum kinetic energy of 9 eV. Calculate the threshold wave-length of the material used.

Ans. The electron energy in the *n*th state in a hydrogen atom is given by

$$E_n = -\frac{13.6}{n^2} \text{ eV}$$

∴ We have, $E_1 = -13.6$ eV

and $E_3 = -\frac{13.6}{9} = -1.51$ eV

$\simeq -1.5$ eV

∴ Energy of the photon corresponding to the transition $n = 3$ to $n = 1$ is

$$E = E_3 - E_1 = 12.1 \text{ eV } (= h\nu)$$

Given $K_{max} = h\nu - W_0$

or $W_0 = h\nu - K_{max}$

$= 12.1 - 9 = 3.1$ eV

If λ_0 is the threshold wavelength, we have

$$h\nu_0 = \frac{hc}{\lambda_0}$$

$$= 3.1 \text{ eV} = 3.1 \times 1.6 \times 10^{-19} \text{ J}$$

or $$\lambda_0 = \frac{hc}{3.1 \times 1.6 \times 10^{-19}}$$

$$= \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{3.1 \times 1.6 \times 10^{-19}} \text{ m}$$

$$= 4 \times 10^{-7} \text{ m}$$

SECTION D

Q. 29. CASE STUDY

Read the following paragraph and answer the questions:

A number of optical devices and instruments such as periscope, binoculars, microscopes and telescopes utilising the reflecting and refracting properties of mirrors, lenses and prisms have been designed and developed. Most of them are in common use. Our knowledge about the formation of images by the mirrors and lenses is the basic requirement for understanding the working of these devices.

(*i*) **Why the image formed at infinity is often considered most suitable for viewing? Explain.**

(*ii*) **In modern microscopes multi-component lenses are used for both the objective and the eyepiece. Why?**

(*iii*) **Write two points of difference between a compound microscope and an astronomical telescope.**

OR

Write two distinct advantages of a reflecting type telescope over a refracting type telescope.

Ans. (*i*) When the image is formed at infinity, it can be observed by the eye with minimum strain on the ciliary muscles of the eye. So the eye remains relaxed.

(*ii*) The multicomponent lenses in microscopes, *i.e.*, a combination of lenses used as objective and eye-piece help to minimise defects in lenses besides producing larger magnifying power.

(*iii*)

Compound Microscope	Telescope
1. It is used to see minute objects clearly.	It is used to see distant objects clearly.
2. The focal length of the objective is smaller as compared to that of the eye-piece.	The focal length of the objective is very large as compared to that of the eye-piece.

OR

(*a*) A reflecting type telescope produces much brighter image than the image formed by a refracting telescope.

(*b*) It is easier to design a reflecting type telescope with objective of large aparture than a refracting type telescope and hence achieve larger resolving power.

Q. 30. CASE STUDY

Read the following paragraph and answer the questions:

Light Emitting Diode

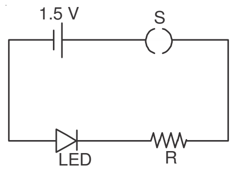
LED is a heavily doped *pn*-junction which under forward bias emits spontaneous radiation. When it is forward biased, due to recombination of holes and electrons at the junction, energy is released in the form of photons. In the case of Si and Ge diode, the energy released in recombination lies in the infrared region. LEDs that can emit red, yellow, orange, green and blue light are commercially available. The semiconductor used for fabrication of visible LEDs must at least have a band gap of 1.8 eV. The compound semiconductor Gallium Arsenide – Phosphide is used for making LEDs of different colours.

LEDs of different kinds:

(*i*) **Why are LEDs made of compound semiconductor and not of elemental semiconductors?**

(*ii*) **What should be the order of bandgap of an LED, if it is required to emit light in the visible range?**

(*iii*) **A student connects the blue coloured LED as shown in the figure. The LED did not glow when switch *S* is closed. Explain, why?**



OR

Draw *V-I* characteristic of a *p-n* junction diode in (*i*) forward bias and (*ii*) reverse bias.

Sol. (*i*) For elemental semiconductors, the band gap is small and the photons emitted are in infrared region which cannot emit visible light. The compound semi-conductors have a band gap of about 1.8 eV and hence the light emitted lies in visible region.

(*ii*) The desired band gap should be between 1.8 eV to 3 eV so as to get light is visible region. Different values of band gap provide light of different colours.

(*iii*) The LED in the circuit is reverse biased and is hence non-conducting. So no current is allowed to pass. Hence the LED does not glow.

OR

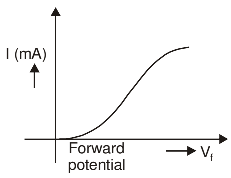


Fig. (*a*) V-I characteristic curve of a forward biased *pn*-junction diode

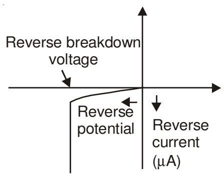


Fig. (*b*) V-I curve reverse biased diode

SECTION E

Q. 31. (*a*) Draw equipotential surfaces for (*i*) an electric dipole and (*ii*) two identical positive charges placed near each other.

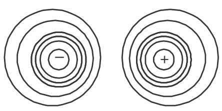
(*b*) In a parallel plate capacitor with air between the plates, each plate has an area of 6 × 10^{-3} m^2 and the separation between the plates is 3 mm.

(*i*) Calculate the capacitance of the capacitor.

(*ii*) If the capacitor is connected to 100 V supply, what would be the the charge on each plate?

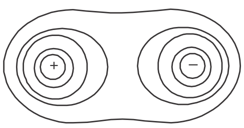
(*iii*) How would charge on the plate be affected if a 3 mm thick mica sheet of *k* = 6 is inserted between the plates while the voltage supply remains connected?

Ans. (*a*)



(a)

Fig. Equipotential surfaces for an electric dipole



(b)

Fig. Equipotential surfaces for two identical positive charges

(*b*) **Given:** $A = 6 \times 10^{-3}\ m^2$;

$d = 3\ mm = 3 \times 10^{-3}\ m$

$\varepsilon_0 = 8.85 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$

(*i*) Capacitance

$$C = \frac{\varepsilon_0 A}{d} = \frac{(8.85 \times 10^{-12})(6 \times 10^{-3})}{3 \times 10^{-3}}$$

$= 17.7 \times 10^{-12}$ F

(*ii*) **Given:** $V = 100$ Volts

∴ Charge $Q = CV$

$= (17.7 \times 10^{-12})\ (100)$ C

$= 17.7 \times 10^{-10}$ C

(*iii*) With a mica plate of thickness *t* (= *d*)* filling the region between the plates, capacitance

$C' = KC = 6 \times (17.7 \times 10^{-12})$ F

$= 106.2 \times 10^{-12}$ F

Charge $Q' = C'V$

$= 106.2 \times 10^{-10}$ C

$= 1.062 \times 10^{-8}$ C

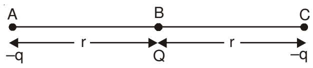
OR

(*a*) Three charges –*q*, *Q* and –*q* are placed at equal distances on a straight line. If the potential energy of the system of these charges is zero, then what is the ratio *Q* : *q*?

(*b*) (*i*) Obtain the expression for the electric field intensity due to a uniformly charged spherical shell of radius *R* at a point distant *r* from the centre of the shell outside it.

(*ii*) Draw a graph showing the variation of electric field intensity *E* with *r*, for *r* > *R* and *r* < *R*.

Sol. (*a*)



Let the charges be places at points *A*, *B* and *C* as shown above.

Potential energy of a pair of charges

$$= \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{d}$$

According to the problem, the total potential energy of the system of the three charges is zero.

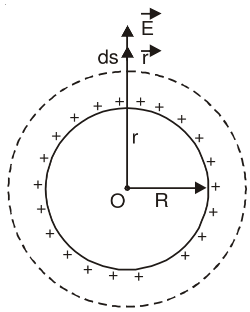
∴ $W_{AB} + W_{BC} + W_{AC} = 0$

or $$\frac{1}{4\pi\varepsilon_0}\left[\frac{-qQ}{r} - \frac{Qq}{r} + \frac{q^2}{2r}\right] = 0$$

or $+\frac{2qQ}{r} = \frac{q^2}{2r}$

$\Rightarrow \frac{Q}{q} = \frac{1}{4}$

(*b*) (*i*) Consider a point *P* at a distance *r* from centre '*O*' of a spherical shell of radius *R*. Let *q* be the charge on the shell.



Take a spherical gaussian surface *S* with centre *O* and radius *r*. For an area *ds* of *S*, we have

$\vec{E}\cdot\vec{ds} = Eds \cos 0° = Eds$

$\phi_E = \oint \vec{E}\cdot\vec{ds}$

$= \oint_s Eds = E\cdot 4\pi r^2$ ...(1)

By Gauss theorem,

$\phi_E = \oint \vec{E}\cdot\vec{ds} = \frac{1}{\varepsilon_0}$ (charge inside *S*) ...(2)

From (1) and (2)

$E \cdot 4\pi r^2 = \frac{1}{\varepsilon_0}$ (charge inside *S*)

(*ii*) (*a*) Outside the shell, $r > R$

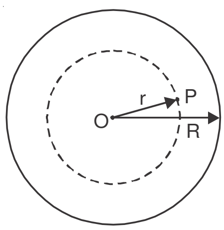
Equation (1) $\Rightarrow E \cdot 4\pi r^2 = \frac{1}{\varepsilon_0} q$

$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$.

It is same as the electric field due to a point charge at the centre of the shell.

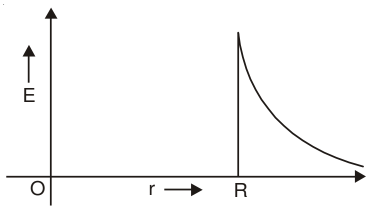
(*b*) Inside $\Rightarrow r < R$

$E \cdot 4\pi r^2 = 0$ [$\because q = 0$]



$E = 0$

Electric field inside a charged shell is zero.



Q. 32. (*a*) Explain the term drift velocity of electrons in a conductor. Hence obtain the expression for the current through a conductor in terms of drift velocity.

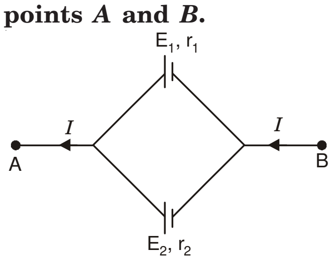
(*b*) Two cells of emfs E_1 and E_2 and internal resistances r_1 and r_2 respectively are connected in parallel as shown in the figure.

Deduce the expression for the:

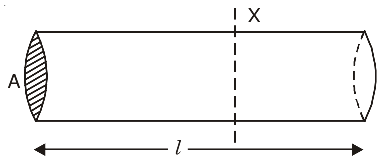
(*i*) equivalent emf of the combination

(*ii*) equivalent internal resistance of the combination

(*iii*) potential difference between the points *A* and *B*.

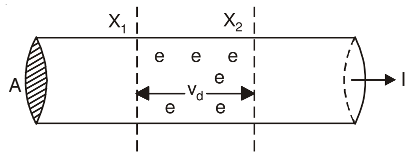


Sol. (*a*) **Drift Velocity:** Metallic conductors have free electrons in them. These free electrons are in constant random thermal motion. In absence of any external source of potential difference (or electric field); the net number of electrons crossing any section *X* of the conductor is zero.



On application of an external electric field (due to potential difference), the free electrons begin to drift in a direction opposite to the applied field. The velocity acquired by the free electrons in a conductor under the action of the external field is called Drift velocity. This drift velocity causes the flow of electric current.

Relation between drift velocity and current:



Let A be the area of cross-section of a conductor and n the number of free electrons per unit volume. Suppose a current I is flowing through the conductor. Take two sections X_1 and X_2 of the conductor, a distance v_d apart (numerically equal to the drift velocity). In one second all free electrons between X_1 and X_2 drift past X_1 causing current.

$\therefore$ Current, I = Charge per sec

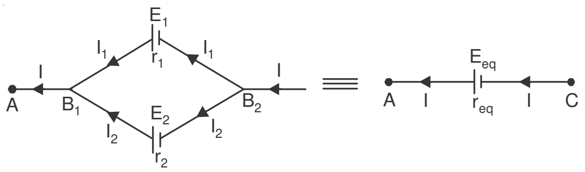
= (No. of free electrons between X_1 and X_2) e

= (n) (Volume between X_1X_2) e

= $n\,(Av_d)\,e$

Hence, $I = ne\,Av_d$

(*b*)



From the figure

$$I = I_1 + I_2 \qquad ...(1)$$

Consider the first cell. The potential difference across it is

$$V = V_{B1} - V_{B2} = E_1 - I_1r_1$$

$$\Rightarrow \quad I_1 = \frac{E_1 - V}{r_1} \qquad ...(2)$$

Now consider the second cell. The potential difference across it is

$$V = V_{B1} - V_{B2} = E_2 - I_2r_2$$

$$\Rightarrow \quad I_2 = \frac{E_2 - V}{r_2} \qquad ...(3)$$

From equations (1), (2) and (3), we have

$$I = \frac{E_1r_2 + E_2r_1}{r_1r_2} - V\left[\frac{r_1 + r_2}{r_1r_2}\right] \qquad ...(4)$$

$$Ir_1r_2 = (E_1\,r_2 + E_2\,r_1) - V(r_1 + r_2)$$

Hence the potential difference is given by

$$V = \frac{E_1r_2 + E_2r_1}{r_1 + r_2} - I\frac{r_1r_2}{r_1 + r_2} \qquad ...(5)$$

Let us replace it with an equivalent cell of EMF E_{eq} and internal resistance r_{eq} so that

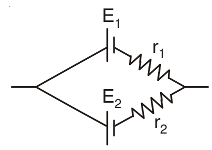
$$V = E_{eq} - Ir_{eq} \qquad ...(6)$$

Comparing (5) and (6), we have

$$E_{eq} = \frac{E_1r_2 + E_2r_1}{r_1 + r_2} \qquad ...(7)$$

and
$$r_{eq} = \frac{r_1r_2}{r_1 + r_2} \qquad ...(8)$$

$$\left.\begin{aligned} \frac{1}{r_{eq}} &= \frac{1}{r_1} + \frac{1}{r_2} \\ \frac{E_{eq}}{r_{eq}} &= \frac{E_1}{r_1} + \frac{E_2}{r_2} \end{aligned}\right\}$$



OR

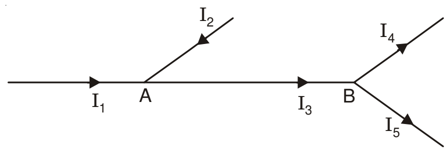
(*a*) State the two Kirchhoff's rules used in the analysis of electric circuits and explain them.

(*b*) Derive the equation of the balanced state in a Wheatstone bridge using Kirchhoff's laws.

Sol. (*a*) **Kirchhoff's laws:** The laws are useful in complicated electrical circuits where Ohm's law fails to give results. The two laws are:

(*i*) **Junction rule or current rule:** It states that the algebraic sum of the currents meeting at any junction of an electrical circuit is zero.

The law is based on principle of conservation of electric charge.



In the given diagram; at A: $I_1 + I_2 - I_3 = 0$ and at B: $I_3 - I_4 - I_5 = 0$.

Sign convention: The current entering a junction is taken as positive and that leaving the junction is taken as negative.

(*ii*) **Loop rule or voltage rule:** It states that the algebraic sum of the potential drops across various parts and e.m.f.'s encountered in a closed current loop is always zero.

$$\Sigma\,(E + IR) = 0$$

The law is based on the principle of conservation of energy.

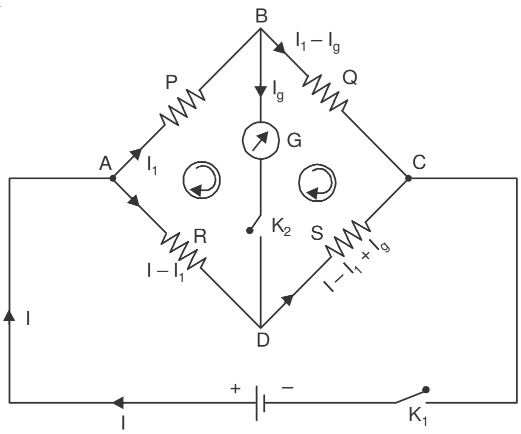
Sign Conventions:

Wheatstone Bridge

1. The product *IR* is taken positive if we move against current and negative if we move along the direction of current.
2. The e.m.f. of a cell is taken as positive if we travel from negative to positive terminal of battery. It is taken as negative if we travel from positive to negative terminal of the battery in the loop.

Wheatstone Bridge: It is a combination of four resistances *P, Q, R* and *S* connected as shown and used to measure any one in terms of the other three.

Balance condition in terms of the resistances of four arms of wheatstone bridge: Consider the circuit shown in the diagram. With keys K_1 and K_2 closed, the current distribution is as marked. Let *G* be the galvanometer resistance. Using loop rule in *ABDA*.



Wheatstone Bridge Circuit

$$I_1 P + I_g G - (I - I_1) R = 0 \quad ...(1)$$

In loop *BCDB*, we get

$$(I_1 - I_g) Q - (I - I_1 + I_g) S - I_g G = 0 \quad ...(2)$$

Adjust values of *P, Q, R* and *S* so that no current flows through the galvanometer, *i.e.,* $\boldsymbol{I_g = 0}$.

The bridge is said to be balanced in this case.

Equations (1) and (2) become

$$I_1 P = (I - I_1) R \quad ...(3)$$

$$I_1 Q = (I - I_1) S \quad ...(4)$$

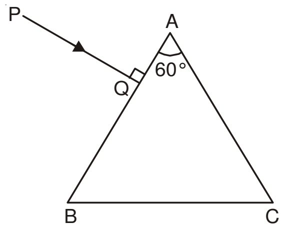
Equations (3) ÷ (4) gives

$$\frac{P}{Q} = \frac{R}{S}$$

which is the condition for balance in the bridge.

Q. 33. **(*a*) Draw the graph showing intensity distribution of fringes with phase angle due to diffraction through a single slit. What is the width of the central maximum in comparison to that of a secondary maximum?**

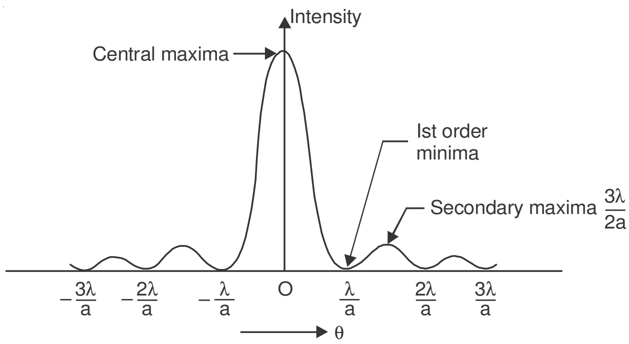
(*b*) A ray *PQ* is incident normally on the face *AB* of a triangular prism of refracting angle 60° as shown in figure. The prism is made of a transparent material of refractive index $\frac{2}{\sqrt{3}}$. Trace the path of the ray as it passes through the prism. Calculate the angle of emergence and the angle of deviation.



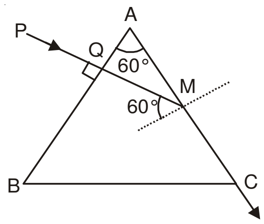
Ans. (*a*) Width of the central maxima $= \frac{2\lambda D}{d}$

Width of a secondary maxima $= \frac{\lambda D}{d}$

∴ Width of the central maxima is *twice* that of a secondary maxima.



(*b*) For ray *PQ* on face *AB*



$$\angle i = 0°$$

$$\therefore \quad \angle r = 0°$$

$\therefore$ $QM \perp AB$ as the ray of light passes out undeviated.

In right triangle AQM

$$\angle AMQ = 30°$$

$\therefore$ In face AC

$$\angle i = 60°$$

Also $\mu = \dfrac{1}{\sin C} = \dfrac{2}{\sqrt{3}} \Rightarrow \sin C = \dfrac{\sqrt{3}}{2}$

$\therefore$ QM is incident at $\angle C$ on the face AC. Hence, after refraction; the light grazes along the face AC at M. The path of light is shown in the figure.

We get, $\angle e = 90°$

For a prism,

$$\angle i + \angle e = \angle A + \angle \delta$$

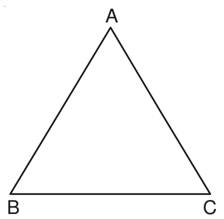
Deviation $\delta = i + e - A$

$= 0 + 90 - 60 = \mathbf{30°}$

OR

(*a*) Write two points of difference between an interference pattern and a diffraction pattern.

(*b*) (*i*) A ray of light incident on face *AB* of an equilateral glass prism, shows minimum deviation of 30°. Calculate the speed of light through the prism.



(*ii*) Find the angle of incidence at face *AB* so that the emergent ray grazes along the face *AC*.

Ans. (*a*) Due to diffraction, the light waves encroach into the region of geometrical shadow of the obstacle.

Interference	Diffraction
1. All fringes are of the same size $\beta = \dfrac{\lambda D}{d}$.	All secondary fringes are of the same width but the central fringe which is maximum is of double the width $= \dfrac{2\lambda D}{d}$.
2. All fringes are of the same intensity.	Intersity decreases as the order of maximum increases.

(*b*) (*i*) We have, $\angle A = 60°$

$$\delta_m = 30°$$

Refractive index $\mu = \dfrac{\sin \dfrac{A+\delta_m}{2}}{\sin \dfrac{A}{2}}$

$$= \frac{\sin \frac{60+30}{2}}{\sin \frac{60}{2}} = \frac{\sin 45°}{\sin 30°}$$

$$= \frac{1}{\sqrt{2}} \times \frac{2}{1} = \sqrt{2}$$

Also $\mu = \dfrac{\text{Speed of light in vacuum}}{\text{Speed of light in medium}}$

or $\sqrt{2} = \dfrac{3 \times 10^8 \text{ m/s}}{v}$

$\therefore$ $v = \dfrac{3 \times 10^8}{\sqrt{2}} = \dfrac{3 \times \sqrt{2}}{2} \times 10^8$ m/s

$= 3 \times 0.707 \times 10^8$ m/s

$= 2.121 \times 10^8$ m/s

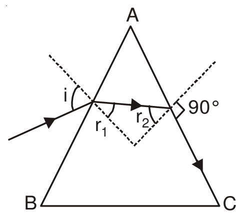
(*ii*) At face *AC*, let the angle of incidence be r_2.

For grazing emergence

$$e = 90°$$

$\Rightarrow$ $\mu = \dfrac{1}{\sin r_2}$

$\Rightarrow$ $r_2 = \sin^{-1} \dfrac{1}{\sqrt{2}} = 45°$



Let the angle of refraction at AB be r_1

We have $r_1 + r_2 = A$

$\therefore$ $r_1 = A - r_2$

$= 60° - 45° = 15°$

$\therefore$ $\angle i$ on face AB is given by

$$\mu = \frac{\sin i}{\sin r_1}$$

$\Rightarrow$ $\sqrt{2} = \dfrac{\sin i}{\sin 15}$

$\therefore$ $\sin i = \sqrt{2} \sin 15°$

Calculations give $i = 21.5°$

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