Answers to RSPL/1

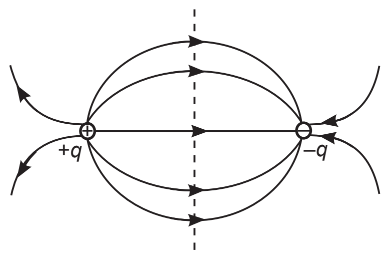
SECTION – A

1. For medium B angle of refraction will be smaller.

2. Electrical reactance depends on frequency of A.C. whereas electrical resistance is independent of frequency.

3. (*a*) 2 A (*b*) Y to X

4. The electric field lines are as shown



5. (*i*) Receiver (*ii*) Transmitter

SECTION – B

6. (*a*) An increase in value of resistance '*R*' reduces the current in the potentiometer wire. So the potential gradient $k\left(= I \cdot \frac{\text{Resistance}}{\text{Length}}\right)$ decreases. This causes an increase in the balancing length. The balance point will hence shift towards right.

(*b*) In the potentiometer experiments; the emf '*E*' of the cell is balanced by a part of the cell '*P*'. As *E* exceeds the emf of '*P*'; no balance point will be obtained.

7. Modulation index: For a modulated wave; the modulation index (μ) is defined as the ratio of the amplitude of the message signal to the amplitude of the carrier wave.

We have,
$$\mu = \frac{A_{max} - A_{min}}{A_{max} + A_{min}} = \frac{A_m}{A_c}$$

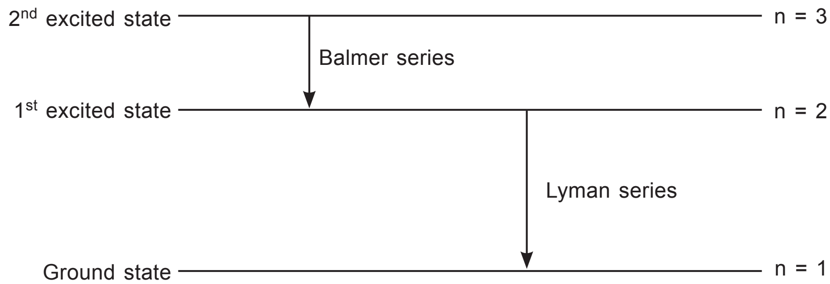
Given $A_{max} = A_c + A_m = 10$ V, $A_{min} = A_c - A_m = 2$ V

$\therefore$ $A_c = 6$ V and $A_m = 4$ V

$\therefore$
$$\mu = \frac{A_m}{A_c} = \frac{4}{6} = \frac{2}{3}$$

If $A_{min} = 0$; then $A_c = A_m$ and $\mu = 1$.

8. (*a*) The transitions are represented in the diagram below:



The transition from second excited state to the first excited state (n = 3 to n = 2) belongs to Balmer series. The transition from the first excited state to the ground state (n = 1 to n = 0) belongs to Lyman series.

(*b*) We have,
$$\frac{1}{\lambda} = R\left[\frac{1}{n_2^2} - \frac{1}{n_1^2}\right]$$

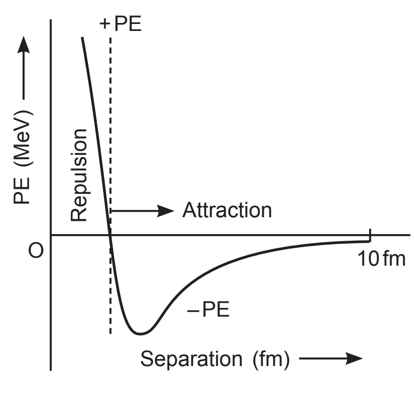
$\therefore$
$$\frac{\lambda_{\text{Balmar}}}{\lambda_{\text{Lyman}}} = \frac{R\left[\frac{1}{2^2} - \frac{1}{3^2}\right]}{R\left[\frac{1}{1^2} - \frac{1}{2^2}\right]} = \frac{\frac{1}{4} - \frac{1}{9}}{1 - \frac{1}{4}}$$

$$= \frac{\frac{5}{36}}{\frac{3}{4}} = \frac{5}{36} \times \frac{4}{3} = 5 : 27$$

9. (*a*) A nucleus is a very stable system. When the nucleons form a nucleus, a small mass called mass defect is converted into energy. The surplus energy is given up due to the mutual attraction between the nucleons.

The mass defect [Δ_m = Total mass of the neutrons and protons — Mass of resulting nucleus] is the cause of smaller mass of the nucleus than the total mass of the nucleons which constitute it.

(*b*) The variation of potential energy versus separation between a pair of nucleons is as shown.



10. Given f_{air} = 20 cm

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

∴ In air
$$\frac{1}{f} = \left(\frac{3/2}{1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$
$$= \frac{1}{2}\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ...(i)$$

In water
$$\frac{1}{f'} = \left(\frac{3/2}{4/3} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$
$$= \frac{1}{8}\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ...(ii)$$

dividing (*i*) by (*ii*), gives
$$\frac{f'}{f} = 4 \quad \Rightarrow \quad f' = 4f = 4 \times 20 \text{ cm} = 80 \text{ cm.}$$

For the lens to be converging, the refractive index of the surrounding medium should be less than 1.5.

OR

The rays being normal to the face AB pass undeviated and will be incident on the face AC at on angle of 45°.

For total internal reflection to occur; the minimum value of refractive index is
$$\mu = \frac{1}{\sin C}$$
$$= \frac{1}{\sin 45°} = \frac{1}{1/\sqrt{2}} = \sqrt{2} = 1.414$$

As μ_G and μ_B exceed 1.414; so the green and blue rays suffer total internal reflection on the face AC.

The red ray emerges out of AC as μ_R (= 1.39) < 1.414.

SECTION – C

11. (*a*) γ-rays have the shortest wavelength.

(*b*) Heat waves (electromagnetic radiations) from sun impart momentum and kinetic energy to air molecules setting air into motion. Hence, the e.m. waves carry both KE and momentum.

(*c*) For an E.M wave, we have
$$\vec{E} \perp \vec{B} \perp \vec{v}$$

∴ $\vec{E}$ oscillates along Y-direction and $\vec{B}$ along Z-direction or $\vec{E}$ oscillates along Z-direction and $\vec{B}$ along Y-direction

12. (*a*) We have,

$$\text{Current} = \frac{\text{Charge}}{\text{Time}}$$

$$\therefore \quad I = \frac{e}{T} = \frac{e}{2\pi r/v} = \frac{ev}{2\pi r}$$

$$= \frac{1.6 \times 10^{-19} \times 2 \times 10^{5}}{2 \times 3.14 \times 0.51 \times 10^{-10}} \simeq 10^{-4}\ \text{A} = 0.1\ \text{mA}$$

(*b*)

$$B = \frac{\mu_0 I}{2r}$$

$$= \frac{4\pi \times 10^{-7} \times 10^{-4}}{2 \times 0.51 \times 10^{-10}} \simeq 1.2\ \text{T}$$

(*c*)

$$\mu_{mag} = I.A. = \left(\frac{ev}{2\pi r}\right)(\pi r^2) = \frac{1}{2}\ \text{evr}$$

$$= \frac{1}{2} \times 1.6 \times 10^{-19} \times 2 \times 10^{5} \times 0.51 \times 10^{-10}$$

$$\simeq 8.2 \times 10^{-25}\ \text{Am}^2$$

OR

We have $n = 200$; r = 10 cm = 0.1 m; $B = 0.5$ T; $I = 3$ A

(*a*) Given $\vec{B} \perp$ plane of the coil

$$\therefore \quad \theta = 0$$

If $\vec{m}$ denotes magnetic dipole moment of the coil, we have

$$\vec{\tau} = n(\vec{m} \times \vec{B}) = n(m\,B \sin 0°) = 0$$

(*b*) As the given magnetic field is uniform

$$\therefore \quad \vec{F}_{net} = \text{Zero}$$

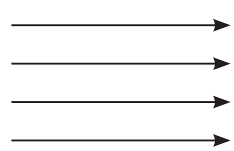
(*c*) Force on each electron, $|\vec{f}\,| = |e(\vec{v}_d \times \vec{B})|$

$$= ev_d B \sin\theta = ev_d B$$

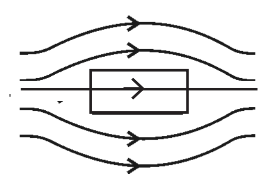
or

$$f = e\left(\frac{I}{neA}\right)B = \frac{IB}{nA} = \frac{3 \times 0.5}{10^{29} \times 10^{-5}} = 1.5 \times 10^{-24}\ \text{N}$$

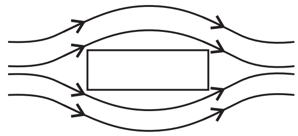
13. (*a*) Uniform magnetic field in plane of paper



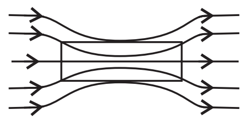
(*b*) Copper is diamagnetic. So the field lines are repelled.



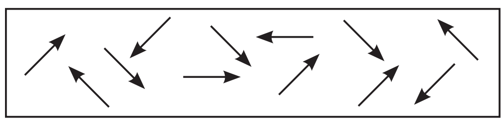
(*c*) Mercury cooled to 4.2 K becomes solid, superconductor and is perfectly diamagnetic. The magnetic field lines are completely expelled.



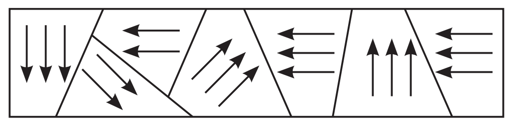
(*d*) Aluminium is paramagnetic. The field lines tend to pass through aluminium.



In a paramagnetic substance, every molecule is independent of the other. In a ferromagnetic substance, the molecules form domains. In a domain, all the tiny molecular magnets are aligned so as to have magnetic dipole moment in same direction.



Paramagnetic



Ferromagnetic

14. (*a*) The three segment of the transistor are

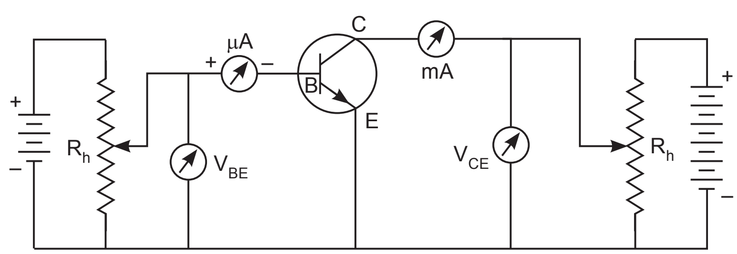
(*i*) Emitter (*ii*) Base (*iii*) Collector

The emitter acts as a source of the charge carriers in a transistor; electrons in *n*-*p*-*n* and holes in *p*-*n*-*p*. It has a moderate size and is a heavily doped semiconductor.

The base helps to control the number of charge carriers flowing from the emitter to the collector. It is thin; lightly doped and stops only a small a small fraction (< 5%) of the charge carriers from the emitter towards the collector.

The collector is moderately doped. It is the thickest with widest area of cross-section and is capable of efficiently collecting the charge carriers from the emitter.

(*b*) The circuit diagram for *n*-*p*-*n* transistor

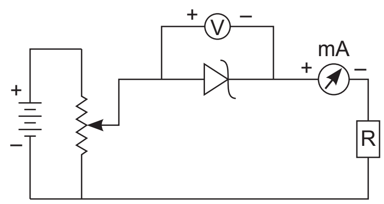


A simple circuit of a CE transistor amplifier

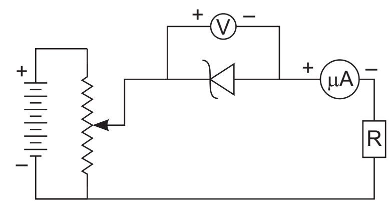
For study of input characteristics, V_{CE} is kept constant whereas for study of output characteristics, I_b is kept constant.

15. (*a*) It is a zener diode.

(*b*) The circuits used for study of the forward and the reverse characteristics are as under:

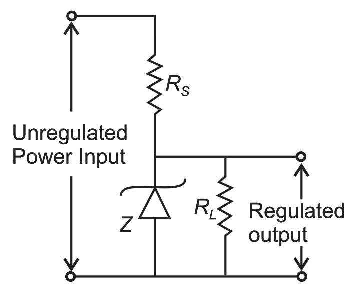


(*i*) For forward characteristics



(*ii*) For reverse characteristics

(*c*) Use of Zener diode as voltage regulator



A zener diode is specially designed to operate in reverse breakdown region.

The zener diode used as shown in the diagram, is given unregulated voltage as input. It provides a constant voltage (zener voltage) as the output regulated supply.

16. Initially, $C_1 = 10\ \mu F$, $V_1 = 20\ V$, $C_2 = 20\ \mu F$, $V_2 = 10\ V$

Total charge, $$Q = C_1V_1 + C_2V_2$$

$$= [(10 \times 10^{-6}\ (20) + (20 \times 10^{-6})\ (10)]\ C = 400\ \mu C$$

Total energy, $$U_i = \frac{1}{2}C_1V_1^2 + \frac{1}{2}C_2V_2^2$$

$$= \left[\frac{1}{2}(10)\,(20)^2 + \frac{1}{2}(20)\,(10)^2\right]\ \mu J$$

$$= [2000 + 1000]\ \mu J = 3 \times 10^{-3}\ J$$

After the capacitors have been inter-connected,

Common potential, $$V = \frac{C_1V_1 + C_2V_2}{C_1 + C_2} = \frac{10 \times 20 + 20 \times 10}{10 + 20} = \frac{400}{30} = \frac{40}{3}\ \text{volt}$$

$$\text{Total charge} = CV = (C_1 + C_2)\ V = 30 \times \frac{40}{3}\ \mu C = 400\ \mu C$$

$$\text{Total Final energy} = \frac{1}{2}\ (C_1 + C_2)\ V^2$$

$$= \frac{1}{2} \times 30 \times \frac{40}{3} \times \frac{40}{3}\ \mu J = \frac{8000}{3}\ \mu J = \frac{8}{3} \times 10^{-3}\ J$$

The charge remains unchanged **(principle of conservation of charge)** and some of the energy is lost as heat energy.

17. The instantaneous rate of decay (number of radioactive nuclei decaying per sec) of a radioactive substance, i.e. $\frac{dN}{dt}$ is called the activity of the substance.

$$A = -\frac{dN}{dt}$$

The negative sign indicates that the number of radioactive nuclei decreases with time.

By decay law, $$\frac{dN}{dt} = -\lambda N \quad ...(i)$$

Also decay constant $$\lambda = \frac{0.693}{T_{1/2}} \quad ...(ii)$$

and $$N = N_0 e^{-\lambda t}$$

$\therefore$ $$\frac{dN}{dt} = A = \lambda N_0 e^{-\lambda t}$$

$\therefore$ $$\frac{dA}{dt} = \frac{d^2N}{dt^2} = \lambda N_0(e^{-\lambda t})(-\lambda) = -N_0 e^{-\lambda t} . \lambda^2$$

$$= -N_0 e^{-\lambda t}\left(\frac{0.693}{T_{1/2}}\right)^2 = \frac{-N(0.693)^2}{(T_{1/2})^2}$$

$\Rightarrow$ $$\left|\frac{dA}{dt}\right| \propto \frac{1}{(T_{1/2})^2}$$

18. (*a*) **Need of coherent sources:** Two sources of light are said to be coherent if they emit monochromatic light of same wavelength either in same phase or with a time independent path difference.

The coherent sources are essential to get a permanent observable interference pattern. If the phase difference changes with time, the intensity at a point varies with time. So at a point, the intensity changes rapidly and hence the pattern can not be observed due to persistence of vision.

(*b*) Let I be the intensity due to each source

For $\Delta p = \lambda$; $\phi = 2\pi$

$\therefore$ $$I_{net} = I_1 + I_2 + 2I_1I_2 \cos\phi$$

As $I_1 = I_2 = I$; we get $$I_{net} = 2I + 2I\cos\phi = 2I(1 + \cos\phi) = 4I\cos^2\frac{\phi}{2}$$

$$= 4I\cos^2\pi = 4I(-1)^2 = 4I = K \text{ (Given)}$$

For $\Delta p = \frac{\lambda}{3}$; $\phi = \frac{2\pi}{\lambda} . \Delta p = \frac{2\pi}{\lambda} . \frac{\lambda}{3} = \frac{2\pi}{3}$

$\therefore$ Net intensity at this point $$I' = 4I\cos^2\frac{\phi}{2}$$

$$= 4I\cos^2\frac{1}{2}\left(\frac{2\pi}{3}\right) = 4I\cos^2\frac{\pi}{3}$$

$$= 4I\left(\frac{1}{2}\right)^2 = I' = \frac{K}{4}$$

19. (*a*) (*i*) According to the wave theory, increase in intensity of light results in increase in energy. However, experimental study of photoelectric effect shows that the energy of the photoelectrons emitted is independent of the intensity of incident light. The wave theory fails to explain this feature.

(*ii*) According to wave theory, the electron in a metal should gradually absorb energy from incident light. The electron should be ejected when it accumulates sufficient energy.

In photoelectric effect experiments, the emission of photoelectrons is found to be an instantaneous process above threshold frequencies. The wave theory fails to explain this observation.

(*b*) Features of photon picture of light:

(*i*) Light consists of photons which behave as packets of energy $h\nu$.

(*ii*) The photon energy depends on frequency. An increase in intensity of light from a source implies increase in number of photons and does not affect photon energy.

(*iii*) The photons undergo elastic collision with electrons in an atom.

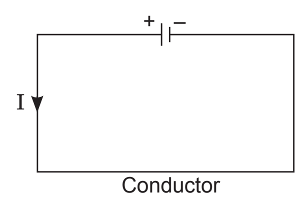
(*iv*) During photon-electron interaction, the energy of photon is either completely absorbed or completely rejected. No electron can absorb two photons.

20. (*i*) **Drift speed:** It is the speed acquired by the free electrons in a conductor when subjected to an electric potential difference across its ends.

(*ii*) **Relaxation time:** The free electrons in a conductor are in constant random motion and collide with each other during this motion. The average time elapsed between two successive collisions is called relaxation time.

For a conductor of length '*L*' and area of cross-section '*A*' connected to a current source,

we have $$I = \frac{E}{R} = \frac{E}{\rho\frac{L}{A}} = \frac{EA}{\rho L} \quad ...(i)$$



Also, $$I = neAv_d$$

$\therefore$ $$neAv_d = \frac{EA}{\rho L}$$

$\Rightarrow$ $$v_d = \frac{E}{(\rho ne)L}$$

$\therefore$ $$v_d \propto \frac{1}{L}$$

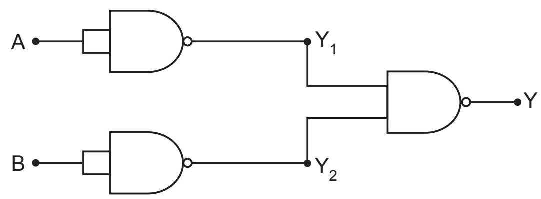
As the drift speed is reduced to one-third; the new conductor must have a length L' (= $3L$); three times that of the original conductor.

21. (*a*)

Gate 1	NOT gate
Gate 2	NOT gate
Gate 3	NAND gate

(*b*) The NOT gate (1) inverts the input applied to it.

The input and output combinations are as in the table below:



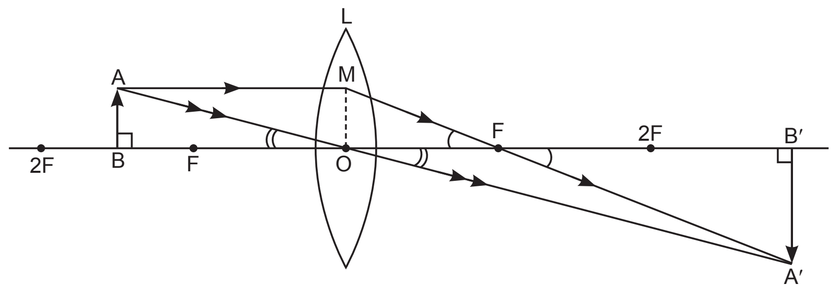
A	B	Y_1	Y_2	Y
0	0	1	1	0
1	0	0	1	1
0	1	1	0	1
1	1	0	0	1

$\Rightarrow$

A	B	Y
0	0	0
1	0	1
0	1	1
1	1	1

(*c*) The overall gate is OR gate.

22. The required ray diagram is as under:



The convex lens L produces a real and magnified image A_1B_1 of an object AB placed in front of the lens. Join O to M.

We have, $\Delta A_1B_1O \sim \Delta ABO$ (AA similarity)

$$\therefore \quad \frac{A_1B_1}{AB} = \frac{OB_1}{OB}$$

$$\text{or} \quad \frac{I}{O} = \frac{+v}{-u} \quad ...(i)$$

Also $\Delta A_1B_1F \sim \Delta MOF$ (AA)

$$\therefore \quad \frac{A_1B_1}{MO} = \frac{B_1F}{OF}$$

$$\text{or} \quad \frac{A_1B_1}{AB} = \frac{OB_1 - OF}{OF} = \frac{+v-(+f)}{+f} = \frac{v-f}{f} \quad ...(ii)$$

From (*i*) and (*ii*)

$$\frac{v-f}{f} = \frac{v}{-u}$$

$$\text{or} \quad -uv + uf = vf$$

Dividing by $u.v.f$, we get

$$-\frac{1}{f} + \frac{1}{v} = \frac{1}{u}$$

Hence, $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$, which is the required lens equation

SECTION – D

23. (*a*) Values displayed by Asha

(*i*) Well-read

(*ii*) Concern for her relatives

(*iii*) Analytical ability and desire to apply the acquired knowledge.

The family and the doctor are of helping and caring nature.

(*b*) The test is costly because of the fact that it is difficult to develop and maintain strong magnetic fields of the order of 1 tesla.

(*c*) Given $B = 0.1$ T; $q = 1.6 \times 10^{-19}$ C; $v = 10^4$ m/s

(*i*) For maximum force; $\vec{v} \perp \vec{B}$

$$\vec{F} = q(\vec{v} \times \vec{B})$$

$$\therefore \quad F_{max} = qvB \sin 90° = qvB$$

$$= 1.6 \times 10^{-19} \times 10^4 \times 10^{-1} = 1.6 \times 10^{-16} \text{ N}$$

(*ii*) For minimum force; $\theta = 0°$ or $\theta = 180°$

$$\therefore \quad F_{min} = qvB \sin \theta = \text{Zero}$$

SECTION – E

24. (*a*) **Wavefront:** It is the locus of all points in a medium vibrating in same phase and are simultaneously disturbed.

Examples: (*i*) Spherical wavefront: Produced by a point source in space.

(*ii*) Cylinderical wavefront: Produced by a linear source like a tubelight.

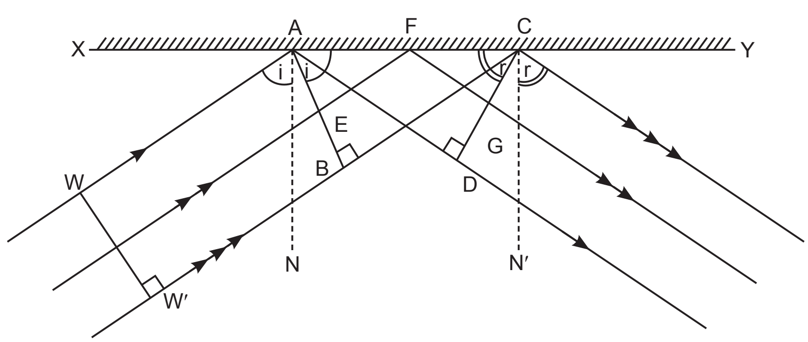
(*iii*) Plane wavefront: Spherical or cylindrical wave front at large distance from the source.

(*b*) **Laws of reflection:**

(*i*) The angle of incidence ($\angle i$) is always equal to the angle of reflection ($\angle r$).

(*ii*) The incident ray, the reflected ray and the normal all lie in the same plane.

Laws of reflection using Huygen's theory: Consider a plane wavefront WW′ progressing towards a plane reflecting surface *XY*.



As the wavefront progresses, point A (on XY) is disturbed first followed by successive points to C.

Let 'c' denote the speed of light. The time in which the incident light travels from B to C, the reflected light moves from A to D or along EFG.

$$\therefore \quad t_{EFG} = t_{EF} + t_{FG}$$

$$= \frac{EF}{c} + \frac{FG}{c}$$

$$= \frac{AF \sin i + FC \sin r}{c} = \frac{AF \sin i + (AC - AF) \sin r}{c}$$

$$t_{EFG} = \frac{AC \sin r + AF (\sin i - \sin r)}{c} \qquad \text{...}(i)$$

The values of AF are different as F is any arbitrary point between A and C.

For CD to be reflected wavefront; the light from different points of the incident wavefront AB should take the same time to reach corresponding points on CD. (the reflected wavefront).

Hence t_{EFG} should be independent of F.

$$\therefore \quad AF(\sin i - \sin r) = 0$$

$$\Rightarrow \quad \sin i = \sin r$$

$$\text{or} \quad \angle i = \angle r$$

Which is the first law of reflection.

Second Law: The incident wave front, the reflecting surface and the reflected wavefront are all perpendicular to the plane of the paper.

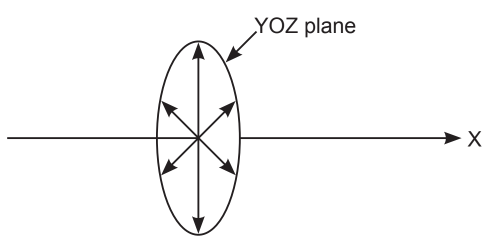
So, the incident ray (perpendicular to incident wavefront); the reflected ray (perpendicular to reflected wavefront) and the normal (perpendicular to the reflecting surface), all lie in the plane of the paper i.e. the same plane.

OR

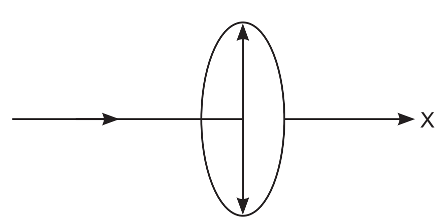
(a) Polarisation of light is the phenomenon by which the vibration of the electric field in the wave are confined to a single plane.

In ordinary light; the vibrations are possible in any direction in the plane perpendicular to the direction of propagation of light. If light propagates along X-direction; the vibration may be in any direction in YOZ plane ($\perp X$-direction).

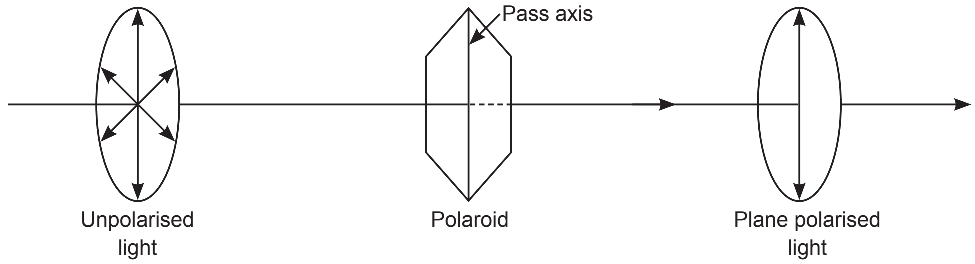
This is represented in the diagram as follows:



(i) Unpolarised light

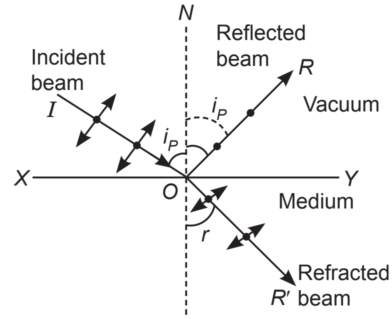


(ii) Plane polarised light



For unpolarised light incident on a polaroid; the crystal allows only such vibration to pass which are parallel to its pass axis. As a result; the transmitted light becomes plane polarised as shown above.

(*b*) Consider unpolarised light *IO* incident on a refracting surface *XY* with medium of refractive index μ as shown.



The light gets partly reflected and partly refracted. For a particular angle of incidence, called polarising angle i_p; the reflected light *OR* is found to be plane polarised.

In this condition refracted ray $OR' \perp$ reflected ray

OR $$i_p + r = 90° \qquad ...(i)$$

Also $$\mu = \frac{\sin i}{\sin r} = \frac{\sin i_p}{\sin(90° - i_p)} = \frac{\sin i_p}{\cos i_p} = \tan i_p$$

$\mu = \tan i_p$, which is Brewster's law

25. (*a*) **Electric flux:** The electric flux linked with a surface is the surface integral of electric field linked with the surface.

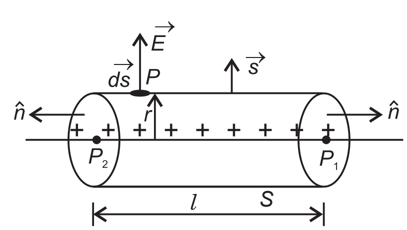
$$\text{Mathematically } \phi_E = \int_S \vec{E} \cdot \vec{dS} \text{ if } \vec{E} \text{ is non-uniform}$$
$$= \vec{E} \cdot \vec{S} \text{ if } \vec{E} \text{ is uniform}$$

It measures the total number of electric field lines linked with the surface.

$$\phi_E = E.\ \text{Area}$$
$$= \frac{F}{q}.\ \text{Area} = \frac{MLT^{-2}.L^2}{A.T} = ML^3T^{-3}A^{-1}$$

(*b*) Gauss law in electrostatics states that the total number of electric field lines linked with a closed surface is $\frac{1}{\varepsilon_0}$ times the total charge enclosed in the surface.

Expression for the field: Consider an infinitely long line of charge with linear charge density +'λ' Cm^{-1}. Let *P* be a point at a distance '*r*' from the line where the electric field intensity is to be calculated. Take a cylindrical Gaussian surface '*S*' of length '*l*' and radius '*r*' with the given line of charge as the axis.



We have, electric flux linked with the surface as

$$\phi_E = \int_S \vec{E} \cdot \vec{ds} = \int_{\text{Curved surface}} \vec{E} \cdot \vec{ds} + \int_{\text{Circular ends}} \vec{E} \cdot \vec{ds}$$

$$= \underset{\text{curved surface}}{\int} Eds\cos 0° + \underset{\text{Circular ends}}{\int} Eds\cos 90° = E\underset{\text{Curved surface}}{\int} ds + 0$$

$$= E\,.\,2\pi rl \qquad ...(i)$$

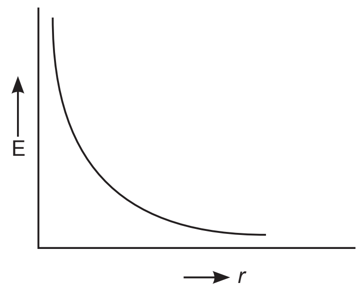
By Gauss theorem, $\phi_E = \frac{1}{\varepsilon_0}$ (Charge inside S)

$$= \frac{1}{\varepsilon_0}(\lambda l) \qquad ...(ii)$$

From (*i*) and (*ii*) $E.\,2\pi rl = \frac{\lambda l}{\varepsilon_0}$

$\Rightarrow$ $E = \frac{\lambda}{2\pi\varepsilon_0 r} \Rightarrow E \propto \lambda$ and $E \propto \frac{1}{r}$

The variation of E with 'r' can be graphically represented as under:



(*c*) (*i*) $\phi_E = \frac{1}{\varepsilon_0}$ (Charge in the sphere of radius 8 cm)

$$= \frac{1}{\varepsilon_0}(10^{-6}) = \frac{10^{-6}}{\varepsilon_0}\ \text{NC}^{-1}\,\text{m}^2$$

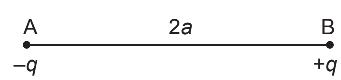
(*ii*) $\phi_E = \frac{1}{\varepsilon_0}$ (Charge in the sphere of radius 16 cm)

$$= \frac{1}{\varepsilon_0}[+10^{-6} - 10^{-6}] = \text{Zero}$$

OR

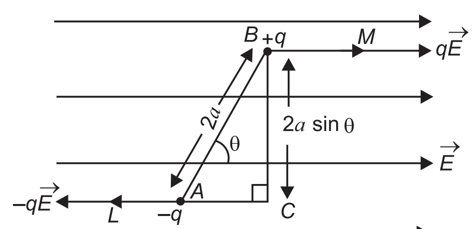
(*a*) The electric dipole moment ($\vec{p}$) of an electric dipole is defined as the product of either of the charges and the distance between the charges.

Mathematically, $\vec{p} = q\,.\,\overrightarrow{2a}$



It is a vector and its SI unit is Cm.

(*b*) Consider an electric dipole ($\pm q$, $2a$) placed in a uniform electric field of intensity $\vec{E}$ as shown. The charges experience force due to the electric field.



Force on charge $(-q)$ at A due to the field = $\vec{F_1}$

$$= (-q)\vec{E}$$

$$= qE \text{ along } \overrightarrow{AL}$$

Force on charge $(+q)$ at B due to the field = $\vec{F_2} = (+q)\vec{E}$

$$= qE \text{ along } \overrightarrow{BM}$$

Net force on the dipole = $+q\vec{E} - q\vec{E}$ = zero

The forces being equal, opposite and parallel form a couple.

Moment of the couple (= Torque) = Either force × Perpendicular distance between the forces

$$= (qE) . BC$$

$$= qE(AB \sin \theta)$$

$$= qE(2a \sin \theta)$$

$$= (q . 2a)E \sin \theta$$

$$= pE \sin \theta$$

or $\vec{\tau} = \vec{p} \times \vec{E}$

(*c*) (*i*) For maximum torque

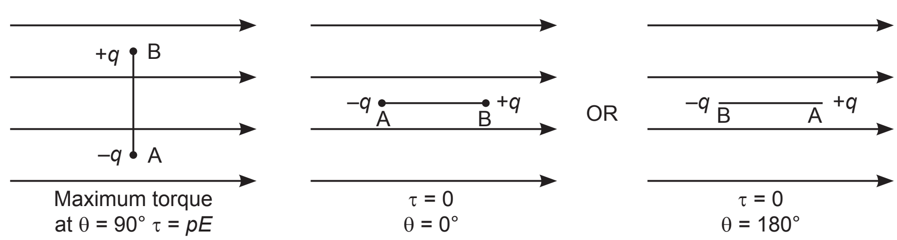
$$\theta = 90°$$

and $\tau_{max} = pE$

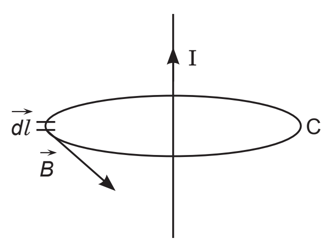
(*ii*) For zero torque $\theta = 0°$

or $\theta = 180°$

The orientation for the maximum and zero torque are as shown



26. (*a*) **Ampere's Circuital Law:** The law states that the line integral of magnetic field along any closed loop '*C*' is μ_0 times the current passing through the loops.



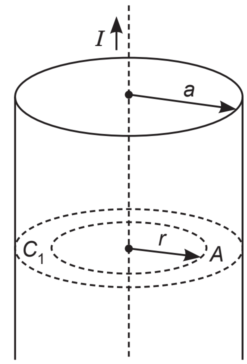
For the loop '*C*' shown, $\oint \vec{B} . \vec{dl} = \mu_0 I$

(*b*) The conductor carrying current '*I*' is as shown in the diagram. Let '*a*' be the radius of the conductor.

Current per unit area of the conductor = $\frac{I}{\pi a^2}$

Take a circular Amperean loop with centre at '*O*' and radius *r*

(*i*) $r < a$: We consider C_1 as Amperean loop.



Area enclosed in $C_1 = \pi r^2$

Current through $C_1 = \frac{I}{\pi a^2} \cdot \pi r^2 = I\frac{r^2}{a^2}$

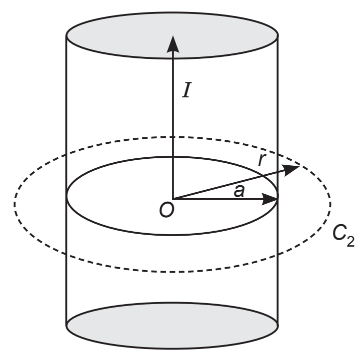
Using ampere's circuital law $\oint_{C_2} \vec{B} \cdot \vec{dl} = \mu_0$ (Current threading C_1)

or $\quad B.2\pi r = \mu_0\left[I\frac{r^2}{a^2}\right]$

$\Rightarrow \quad B = \frac{\mu_0 I}{2\pi a^2} \cdot r$

$\therefore \quad B \propto r$ for $r \leq a$

(*ii*) For $r > a$: C_2 is the loop.



Applying Ampere's circuital law to the loop, we get

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 \text{ (Current through the loop)}$$

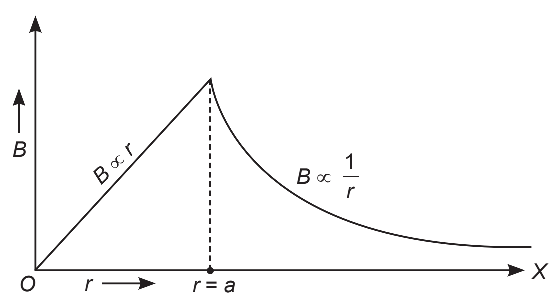
or $\quad B\, 2\pi r = \mu_0 I$

$\Rightarrow \quad B = \frac{\mu_0 I}{2\pi r}$

$\therefore \quad B \propto \frac{1}{r}$ for $r > a$

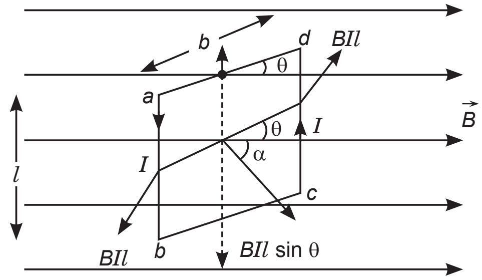
The magnetic field acts along tangent to the loop at every point.

The variation is as shown in the graph below.

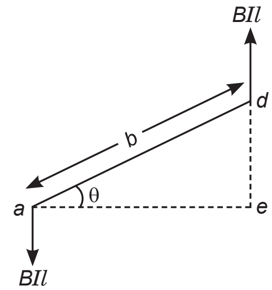


OR

Consider the rectangular *abcd* placed in uniform magnetic field of intensity $\vec{B}$ as shown. The field exerts force on each of the four arms of the loop.



(A)



(B)

We have $\vec{F} = I(\vec{l} \times \vec{B})$

$\therefore$ Force on $ab = BIl$ {out of the paper $\vec{l} \perp \vec{B}$}

Force on $bc = BIl \sin\theta$ vertically downwards

Force on $cd = BIl$ (directed into the paper)

Force on $da = BIl \sin\theta$ vertically upwards

The forces on '*bc*' and '*da*' cancel out being equal, opposite and along same line of action.

The forces on '*ab*' and '*cd*' from a couple (Figure B)

Net force on the loop = Zero

Moment of the couple = τ = Either force × Perpendicular distance between the forces

or $\tau = (BIl)(ae)$

$= BIl \,.\, b \cos\theta$ $[\theta = 90° - \alpha]$

$= BI(lb) \sin\alpha$

$= BIA \sin\alpha$

Where α is the angle between $\vec{B}$ and normal to the plane of the coil.

$\therefore$ $\tau = (IA)B \sin\alpha$

But $IA = m$ = Magnetic dipole moment of the current loop

$\therefore$ $\tau = mB \sin\alpha$

or $\vec{\tau} = (\vec{m} \times \vec{B})$

The direction of the torque $\vec{\tau}$ is given by right hand rule applied to $\vec{m} \times \vec{B}$

For stable equilibrium $\tau = 0$, i.e. $\alpha = 0$

The plane of the coil should be normal to the magnetic field.