Series : OSR/1

Code No. 55/1/3

Roll No. | X | X | X | X | X | X | X |

Candidates must write the Code on the title page of the answer-book.

- Please check that this question paper contains 15 printed pages.
- Code number given on the right hand side of the question paper should be written on the title page of the answer-book by the candidate.
- Please check that this question paper contains 26 questions.
- **Please write down the Serial Number of the questions before attempting it.**
- 15 minutes time has been allotted to read this question paper. The question paper will be distributed at 10.15 a.m. From 10.15 a.m. to 10.30 a.m., the student will read the question paper only and will not write any answer on the answer script during this period.

PHYSICS (Theory)

[Time allowed : 3 hours] ***[Maximum marks : 70]***

General Instructions:

(i) *All questions are compulsory.*

(ii) *There are 26 questions in total. All questions are complusory.*

(iii) *This question paper has five sections: Section A, Section B, Section C, Section D and Section E.*

(iv) *Section A contains (question Nos. 1 to 5) are very short answer type questions and carry one mark each.*

(v) *Section B contains (question Nos. 6 to 10) carry two marks each. Section C contains (question Nos. 11 to 22) carry three marks each and Section D contains value based question (question no. 23) carry four marks each. Section E contains (questin no. 24 to 26) carry five marks each.*

(vi) *There is no overall choice. However, an internal choice has been provided in one question of two marks, one question of three marks and all three questions of five marks each weightage. You have to attempt only one of the choices in such questions.*

(vii) *Use of calculators is not permitted. However, you may use log tables if necessary.*

(viii) *You may use the following values of physical constants wherever necessary :*

$c = 3 \times 10^{8}$ m/s

$h = 6.63 \times 10^{-34}$ Js

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

$\mu = 4\pi \times 10^{-7}$ T mA^{-1}

$$\frac{1}{4\pi\varepsilon_0} = 9 \times 10^{9} \text{ Nm}^2 \text{ C}^{-2}$$

SECTION – A

1. A concave lens of refractive index 1.5 is immersed in a medium of refractive index 1.65. What is the nature of the lens?

Sol. Since $\mu_{lens} < \mu_{surrounding}$

$\therefore$ It behaves like converging lens.

2. How are side bands produced?

Sol. Side bands are produced by the method of amplitude modulation.

It produces two new frequencies ($f_c + f_m$) and ($f_c - f_m$) around original frequency (f_c), which are called side band frequencies.

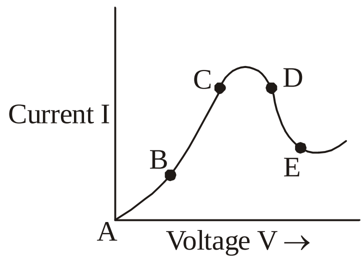
Upper side band frequency = USB = $f_c + f_m$

and Lower side band frequency = LSB = $f_c - f_m$.

3. Graph showing the variation of current versus voltage for a material GaAs is shown in the figure. Identify the region of

(a) negative resistance.

(b) where Ohm's law is obeyed.



Sol. (a) DE [$\because$ Slope is negative.]

(b) BC [$\because V \propto I$]

4. Define capacitor reactance. Write its S.I. units.

Sol. The resistance offered by the capacitor to the flow of a.c. through it is called capacitive reactance. It is denoted by X_C.

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

Its S.I. unit is ohm.

5. What is the electric flux through a cube of side 1 cm which encloses an electric dipole?

Sol. Net flux enclosed = 0

Because net charge enclosed by cube = 0.

SECTION – B

6. Distinguish between intrinsic and extrinsic semiconductors.

Sol.

Intrinsic semi-conductors	Extrinsic semi-conductors
1. These are pure semi-conducting tetravalent crystals.	1. These are semi-conducting tetravalent crystals doped with impurity atoms of group III or V.
2. Their electrical conductivity is low.	2. Their electrical conductivity is high.

7. Use the mirror equation to show that an object placed between f and 2f of a concave mirror produces a real image beyond 2f.

Sol. From mirror formula, $\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$

Now, for a concave mirror, f < 0 and for an object on left, u < 0.

$\therefore \quad 2f < u < f$ or $\frac{1}{2f} > \frac{1}{u} > \frac{1}{f}$

or $-\frac{1}{2f} < -\frac{1}{u} < -\frac{1}{f}$ or $\frac{1}{f} - \frac{1}{2f} < \frac{1}{f} - \frac{1}{u} < \frac{1}{f} - \frac{1}{f}$

or $\frac{1}{2f} < \frac{1}{v} < 0$

it implies v is negative. So that image is formed on left.

Also 2f > v

or $|2f| < |v|$ [$\because$ 2f and v are negative]

i.e. the real image is formed beyond 2f.

OR

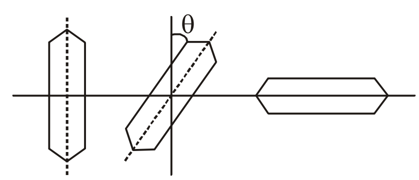
7. Find an expression for intensity of transmitted light when a polaroid sheet is rotated between two crossed polaroids. In which position of the polaroid sheet will the transmitted intensity be maximum?

Sol. By Malus law, the intensity of light emerging from the middle polaroid C, will be

$I_1 = I_0 \cos^2\theta$; where I_0 = intensity of light falling on middle polaroid.

Thus, intensity I_1 falls on the polaroid at the end (polaroid B) whose polarisation axis makes an angle of (90° – θ) with the polarisation axis of the angle of middle polaroid.

Therefore, the intensity of light emerging from the polaroid B will be



$I_2 = I_1 \cos^2(90 - \theta) = (I_0 \cos^2\theta)\cos^2(90 - \theta)$

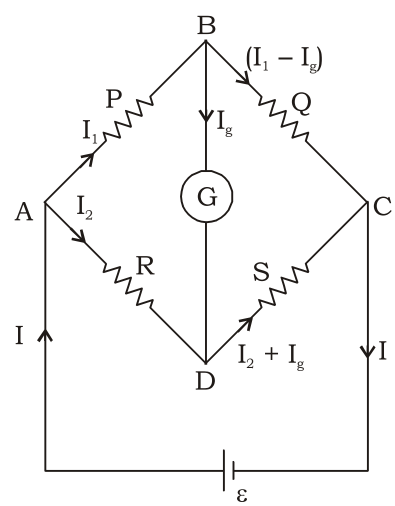
$= I_0 \cos^2\theta \sin^2\theta = \frac{1}{4} I_0 (2\sin\theta\cos\theta)^2$

$I_2 = \frac{I_0}{4}\sin^2 2\theta$

Transmitted intensity I_2 will be maximum when sin 2θ = 1 or 2θ = 90° or θ = 45°.

8. Use Kirchhoff's rule to obtain conditions for the balance condition in a Wheatstone bridge.

Sol.



Applyng Kirchoff's second law to the loop ABDA, we get

$I_1P + I_gG - I_2R = 0$

where G is the resistance of the galvanometer. Again, applying Kirchoff's second law to the loop BCDB, we get

$(I_1 - I_g)Q - (I_2 + I_g)S - G\,I_g = 0$

In the balanced condition of the bridge I_g = 0. The above equations become

$I_1P - I_2R = 0$ or $I_1P = I_2R$ ... (1)

and $I_1Q - I_2S = 0$ or $I_1Q = I_2S$ ... (2)

On dividing equation (1) by (2), we get

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

This proves the conditon for the balanced wheatstone bridge.

9. A proton and an α-particle have the same de-Broglie wavelength. Determine the ratio of (i) their accelerating potentials (b) their speeds.

Sol. De-Broglie wavelength is given by

$$\lambda=\frac{h}{p}=\frac{h}{mv}=\frac{h}{\sqrt{2mqV}}$$, where, V = accelerating potential; v = speed of particle

As, Charge on proton = q_p

Charge on α-particle = $q_\alpha = 2q_p$

and mass of proton = m_p

mass of α-particle = $m_\alpha = 4m_p$

(i) Given $\lambda_\alpha = \lambda_p$

$$\Rightarrow \frac{h}{\sqrt{2m_\alpha q_\alpha V_\alpha}}=\frac{h}{\sqrt{2m_p q_p V_p}}$$

$$\Rightarrow m_\alpha q_\alpha V_\alpha = m_p q_p V_p$$

$$\Rightarrow \frac{V_p}{V_\alpha}=\frac{m_\alpha q_\alpha}{m_p q_p}=\left(\frac{4m_p}{m_p}\right)\left(\frac{2q_p}{q_p}\right)$$

$$=\frac{8}{1}$$

(ii) As, $\lambda_\alpha = \lambda_p$

$$\Rightarrow \frac{h}{m_\alpha v_\alpha}=\frac{h}{m_p v_p}$$

$$\Rightarrow \frac{v_p}{v_\alpha}=\frac{m_\alpha}{m_p}=\frac{4m_p}{m_p}$$

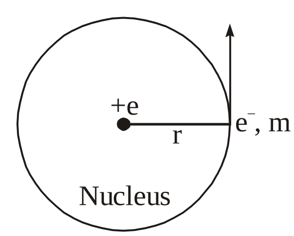
$$=\frac{4}{1}$$

10. Show that the radius of the orbit in hydrogen atom varies as n^2, where n is the principal quantum number of atom.

Sol. According to Bohr's theory, a hydrogen atom consists of a nucleus with a positive charge e and a single electron of charge –e, which revolves around it in circular orbit of radius r.

The electrostatic force of attraction between the nucleus and the electron is

$$F=\frac{ke^2}{r^2}$$



To keep electron in its orbit, the centripetal force on the electron must be equal to the electrostatic attraction. Therefore,

$$\frac{mv^2}{r}=\frac{ke^2}{r^2}$$

$$mv^2=\frac{ke^2}{r}$$

$$\Rightarrow \quad r=\frac{ke^2}{mv^2} \quad \ldots(i)$$

Where, m = mass of electron

v = speed in an orbit of radius r.

Bohr's quantisation condition for angular momentum is

$$L = mvr = \frac{nh}{2\pi}$$

$\Rightarrow \quad v = \frac{nh}{2\pi mr}$ ...(ii)

On substituting (ii) in (i), we get

$$r = \frac{ke^2}{m\left(\frac{nh}{2\pi mr}\right)^2}$$

$$r = \frac{ke^2}{\frac{mn^2h^2}{4\pi^2m^2r^2}}$$

$\Rightarrow \quad r = \frac{ke^2}{mn^2h^2}\left(4\pi^2m^2r^2\right)$

$\Rightarrow \quad r = \frac{n^2h^2}{4\pi^2mke^2}$

$\Rightarrow \quad r \propto n^2$

where, n = principal quantum number.

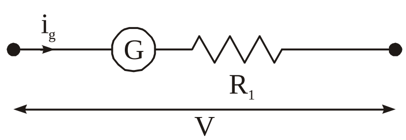
SECTION – C

11. State the principle of working of a galvanometer.

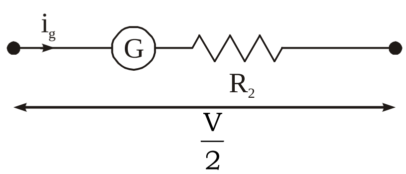
A galvanometer of resistance G is converted into a voltmeter to measure upto V volts by connecting a resistance R_1 in series with the coil. If a resistance R_2 is connected in series with it, then it can measure upto V/2 volts. Find the resistance, in terms of R_1 and R_2, required to be connected to convert it into a voltmeter that can read upto 2V. Also find the resistance G of the galvanometer in terms of R_1 and R_2.

Sol. Principle:

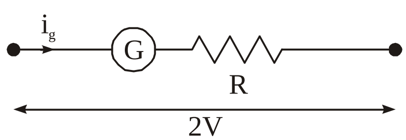
Moving coil galvanometer is based on the fact that when a current carrying loop or coil is placed in the uniform magnetic field, it experiences a torque.



$V = i_g (G + R_1)$ ...(i)



$\frac{V}{2} = i_g(G + R_2)$ ...(ii)



$2V = i_g (G + R)$ ...(iii)

From (i) and (ii)

$$2i_g(G + R_2) = i_g(G + R_1)$$

$\Rightarrow \quad 2G + 2R_2 = G + R_1$

$\therefore \quad G = R_1 - 2R_2$ ...(iv)

From (i) and (iii)

$$2i_g(G + R_1) = i_g(G + R)$$

$2G + 2R_1 = G + R$

$G = R - 2R_1$ ...(v)

From (iv) and (v)

$R_1 - 2R_2 = R - 2R_1$

$R = 3R_1 - 2R_2$ ...(vi)

Using (vi) in (v)

$G = R - 2R_1$

$G = 3R_1 - 2R_2 - 2R_1$

$G = R_1 - 2R_2$

12. With what considerations in view, a photodiode is fabricated? State its working with the help of a suitable diagram.

Eventhough the current in the forward bias is known to be more than in the reverse bias, yet the photodiode works in reverse bias. What is the reason?

Sol. A photodiode is used to observe the change in current with change in the light intensity under reverse bias condition.

In fabrication of photodiode, material chosen should have band gap ~1.5 eV or lower so that solar conversion efficiency is better. This is the reason to choose Si or GaAs material.

Working: It is a p – n junction fabricated with a transparent window to allow light photons to fall on it. These photons generate electron hole pairs upon absorption. If the juction is reverse biased using an electrical circuit, these electron hole pair move in opposite directions so as to produce current in the circuit. This current is very small and is detected by the microammeter placed in the circuit.

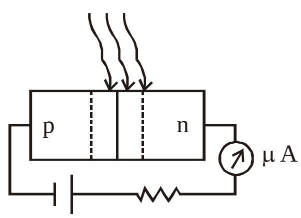
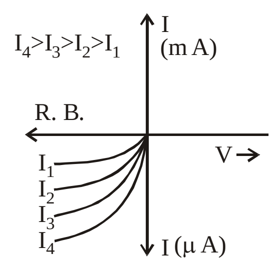


Fig. 13: (a) Photodiode (R.B.),



(b) I-V character of photodiode for different illumination intensities

A photodiode is preferably operated in reverse bias condition. Consider an *n*-type semiconductor. Its majority carrier (electron) density is much larger than the minority hole density *i.e.,* $n >> p$. When illuminated with light, both types of carries increase euqally in number

$n' = n + \Delta n \, ; \, p' = p + \Delta p$

Now $n >> p$ and $\Delta n = \Delta p$

$\therefore \quad \frac{\Delta n}{n} << \frac{\Delta p}{p}$

That is, the fractional increase in majority carries is much less than the fractional increase in minority carriers. Consequently, the fractional change due to the photo-effects on the minority carrier dominated reverse bias current is more easily measurable than the fractional change in the majority carrier dominated forward bias current. Hence, photodiodes are preferable used in the reverse bias condition for measuring light intensity.

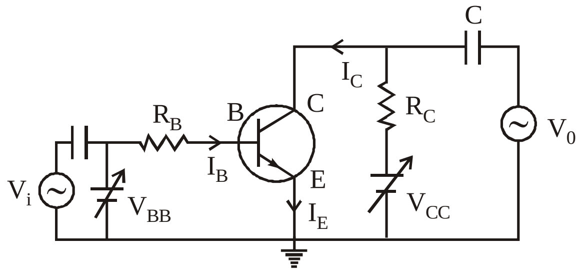
13. Draw a circuit diagram of a transistor amplifer in CE configuration.

Define the terms:

(a) Input resistance and (b) Current amplification factor.

How are these determined using typical input and output characteristics?

Sol.



Transistor amplifer in CE configuration

(a) Input resistance = $\dfrac{\text{Change in base-emitter voltage}}{\text{Base current}}$

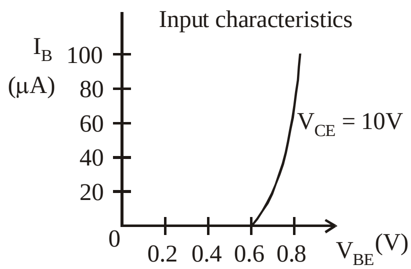
$\Rightarrow r_i = \dfrac{\Delta V_{BE}}{\Delta I_B} \rightarrow$ dynamic resistance

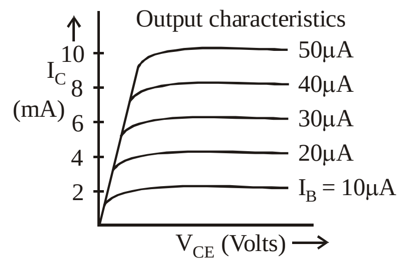
From the input characteristics we can calculate the change in V_{BE} (ΔV_{BE}) and change in I_B (ΔI_B).

(b) Current amplification factor (β)

$$\beta_{ac} = \left(\frac{\Delta I_C}{\Delta I_B}\right)_{V_{CE}} ; \beta_{dc} = \frac{I_C}{I_B} \Rightarrow \beta_{ac} \simeq \beta_{dc}$$

From the output characteristics we can calculate the change in I_C (ΔI_C) and change in I_B (ΔI_B).





14. Answer the following questions:

(a) In a double slit experiment using light of wavelength 600 nm, the angular width of the fringe formed on a distant screen is 0.1°. Find the spacing between the two slits.

(b) Light of wavelength 5000 Å propagating in air gets partly reflected from the surface of water. How will the wavelengths and frequencies of the reflected and refracted light be affected?

Sol. (a) λ = 600 nm = 600 × 10^{-9} m

θ = 0.1°

$$\theta = \frac{\lambda}{d}$$

$$d = \frac{\lambda}{\theta}$$

$$= \frac{600 \times 10^{-9} m}{\frac{\pi}{180} \times 0.1}$$

$$= \frac{600 \times 10^{-9} \times 180 \times 10}{3.14}$$

= 34394.90 × 10^{-8}

= 0.343 × 10^{-3} m

= 0.343 × 10^{-3}m

(b) $\lambda = 5000\text{Å}$

$$\nu = \frac{C}{\lambda}$$

$$= \frac{3\times10^8}{5000\times10^{-10}} = \frac{3\times10^8}{5\times10^{-7}}$$

$$= \frac{3}{5}\times10^{15}$$

$$= \frac{30}{5}\times10^{14}$$

$= 6 \times 10^{14}$ Hz.

Frequency of reflected and refracted light is 6×10^{14}Hz

Velocity of light in water

$$\mu = \frac{\text{speed of light in air}}{\text{speed of light in water}}$$

$$\frac{4}{3} = \frac{3\times10^8}{\upsilon}$$

$$\upsilon = \frac{3\times10^8\times3}{4}$$

$$= \frac{9}{4}\times10^8 = 2.25\times10^8\,\text{m/s}$$

$$\lambda' = \frac{2.25\times10^8}{6\times10^{14}} = 0.375\times10^{-6}\,\text{m}$$

$= 0.375 \times 10^{-6}$ m

Wavelength of the refracted light is 0.375×10^{-6}m

15. An inductor L of inductance X_L is connected in series with a bulb B and an ac source. How would brightness of the bulb change when (a) number of turn in the inductor is reduced, (b) an iron rod is inserted in the inductor and (c) a capacitor of reactance $X_C = X_L$ is inserted in series in the circuit. Justify your answer in each case.

Sol. (i) $L = \mu_0 \dfrac{N^2}{l} A$

If N is reduced L will decrease

As $X_L = \omega L$

X_L will decrease. $\therefore$ Current is increased and brightness is increased.

(ii) When iron rod inserted in the inductor L will increase

X_L will also increase

current will decrease

so brightness will decrease

(iii) A capacitor of reactance $X_C = X_L$ in series in the circuit, due to it circuit attains resonance condition.

Total impedance will decrease, current will increase and brightness will increase.

16. Name the parts of the electromagnetic spectrum which is

(a) suitable for radar systems used in aircraft navitation.

(b) used to treat muscular strain.

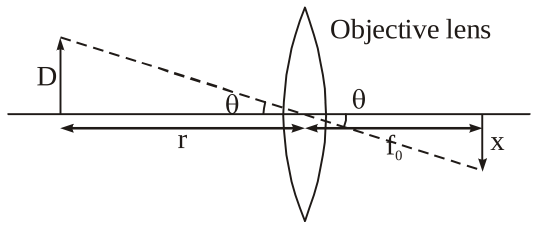
(c) used as a diagnostic tool in medicine.

Write in brief, how these waves can be produced.

Sol. (a) Microwave
These waves can be produced by klystron valve or magnetron valve.
(b) Infrared
These waves are produced by vibrations of atoms and molecules.
(c) γ-rays
These waves are produced by the radioactive decay of the nucleus.

17. (a) A giant refracting telescope has an objective lens of focal length 15 m. If an eye piece of focal length 1.0 cm is used, what is the angular magnification of the telescope?
(b) If this telescope is used to view the moon, what is the diameter of the image the moon formed by the objective lens? The diameter of the moon is 3.48×10^6 m and the radius of lunar orbit is 3.8×10^8 m.

Sol. (a) $|m| = \frac{f_0}{f_e} = \frac{15}{1 \times 10^{-2}} = 1500$



(b) D = diameter of moon
r = radius of lunar orbit
f_0 = focal length of objective
x = diameter of image of moon

$$\tan\theta = \frac{x}{15} = \frac{3.48 \times 10^6}{3.8 \times 10^8}$$

$$x = \frac{3.48 \times 10^6 \times 15}{3.8 \times 10^8} = 13.73 \times 10^{-2} \text{ m}$$

x = 13.73 cm

18. Write Einstein's photoelectric equation and mention which important features in photoelectric effect can be explained with the help of this equation.
The maximum kinetic energy of the photoelectrons gets doubled when the wavelength of light incident on the surface changes from λ_1 to λ_2. Derive the expressions for the threshold wavelength λ_0 and work function for the metal surface.

Sol. Einstein's photoelectric equation

$h\nu = \phi_0 + K_{max}$

$h\nu$ = Energy of the photon
ϕ_0 = Work function of the metal
K_{max} = Maximum kinetic energy of the emitted photoectron

$$K_{max} = \frac{1}{2}mv_{max}^2 = h\nu - \phi_0$$

or $K_{max} = h\nu - h\nu_0$
whee, ν_0 = threshold frequency of metal surface.
Explanation of features of photoelectric effect.

(a) Einstein said that one photoelectron is ejected from a metal surface if one photon of suitable light radiation falls on it. If the intensity of the light is increased, the number of incident photon increases, which results in an increase in the number of photo-electrons ejected. This implies photo current is proportional to intensity and radiation.
(b) If $\nu < \nu_0$, than maximum K.E. is negative, which is impossible. Hence photoelectric emission does not take place for the incident radiation below threshold frequency.
(c) If $\nu > \nu_0$, maximum K.E. increases. This means, maximum K.E. of photoelectrons depends only the frequency of incident light.

Einstein equation corresponding to wavelength λ_1.

$$K_{max} = \frac{hc}{\lambda_1} - \phi_0 \qquad \ldots(i)$$

Einstein equation corresponding to wavelength λ_2.

$$2K_{max} = \frac{hc}{\lambda_2} - \phi_0$$

$$\Rightarrow \quad K_{max} = \frac{hc}{2\lambda_2} - \frac{\phi_0}{2} \qquad \ldots(ii)$$

From (i) and (ii), we get

$$\frac{hc}{\lambda_1} - \phi_0 = \frac{hc}{2\lambda_2} - \frac{\phi_0}{2}$$

$$\frac{hc}{\lambda_1} - \frac{hc}{2\lambda_2} = \phi_0 - \frac{\phi_0}{2}$$

$$hc\left(\frac{1}{\lambda_1} - \frac{1}{2\lambda_2}\right) = \frac{\phi_0}{2}$$

$$\Rightarrow \quad \phi_0 = 2hc\left(\frac{1}{\lambda_1} - \frac{1}{2\lambda_2}\right)$$

$$\Rightarrow \quad \boxed{\phi_0 = hc\left(\frac{2}{\lambda_1} - \frac{1}{\lambda_2}\right)}$$

$$\Rightarrow \quad \frac{hc}{\lambda_0} = hc\left(\frac{2}{\lambda_1} - \frac{1}{\lambda_2}\right)$$

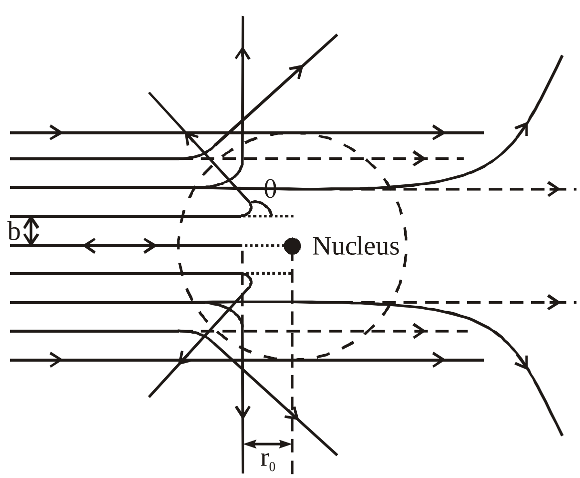
$$\Rightarrow \quad \frac{1}{\lambda_0} = \left(\frac{2\lambda_2 - \lambda_1}{\lambda_1\lambda_2}\right)$$

$$\Rightarrow \quad \boxed{\lambda_0 = \frac{\lambda_1\lambda_2}{2\lambda_2 - \lambda_1}}$$

19. In the study of Geiger-Marsden experiment on scattering of α-particles by a thin foil of gold, draw the trajectory of α-particles in the coulomb field of target nucleus. Explain briefly how one gets the information on the size of the nucleus from this study.

From the relation $R = R_0 A^{1/3}$, where R_0 is constant and A is the mass number of the nucleus, show that nuclear matter density is independent of A.

Sol.



- Suppose, an α-particle with initial K.E. = $\frac{1}{2}mv^2$ is directed towards the center of the nuclues of an atom.
- On account of Coulomb's repulsive force between nucleus and α-particle, at the distance of closest approach (r_0) the particle stops and it cannot go closer to the nucleus and its K.E. gets converted in P.E., i.e.,

$$\frac{1}{2}mv^2 = \frac{Ze(2e)}{4\pi\varepsilon_0 r_0}$$

$$\boxed{r_0 = \frac{Ze(2e)}{4\pi\varepsilon_0\left(\frac{1}{2}mv^2\right)}}$$

Radius of the nucleus must be approximately equal to the 'r_0'.

- Nuclear density

Volume of nucleus = $\frac{4}{3}\pi R^3$

$$= \frac{4}{3}\pi(R_0 A^{1/3})^3$$

$$= \frac{4}{3}\pi R_0^3 A$$

Density of nuclear matter = $\frac{\text{mass of nucleus}}{\text{Volume of nucleus}}$

$$= \frac{mA}{\frac{4}{3}\pi R_0^3 A} = \frac{3m}{4\pi R_0^3}$$

m = average mass of nucleus

∴ m and R_0 are constant

∴ $$\boxed{\rho = \frac{3m}{4\pi R_0^3}}$$

⇒ Density of nuclear matter is same for all elements.

OR

19. Distinguish between nuclear fission and fusion. Show how in both these processes energy is released.

Calculate the energy release in MeV in the deuterium-tritium fusion reaction:

$${}^2_1H + {}^3_1H \longrightarrow {}^4_2He + n$$

Using the data:

$m({}^2_1H)$ = 2.014102 u

$m({}^3_1H)$ = 3.016049 u

$m({}^4_2He)$ = 4.002603 u

m_n = 1.008665 u

1u = 931.5 MeV/c^2

Sol.

Nuclear Fission	**Nuclear Fusion**
It is the phenomenon of breaking of heavy nucleus to form two or more lighter nuclei.	It is the phenomenon of fusing two or more lighter nuclei to form a single heavy nucleus.
Ex. $^{1}_{0}n + ^{235}_{92}\text{U} \longrightarrow ^{140}_{54}\text{Xe} + ^{94}_{38}\text{Sr} + 2^{1}_{0}n + 200.4\text{MeV}$	Ex. $^{1}_{1}\text{H} + ^{1}_{1}\text{H} \longrightarrow ^{2}_{1}\text{H} + e^{+} + \nu + 0.42\text{MeV}$

In both the processes, a certain mass (Δm) disappears, which appears in the form of energy as per Einstein equation : $E = (\Delta m)c^2$.

$\Rightarrow$ Given equation is

$$^{2}_{1}\text{H} + ^{3}_{1}\text{H} \longrightarrow ^{4}_{2}\text{He} + n$$

Total mass of the reactant

$$m_r = m(^{2}_{1}\text{H}) + m(^{3}_{1}\text{H})$$

$= (2.014102 + 3.016049)\text{u}$

$= 5.030151\text{u}$

Total mass of the product

$$m_p = m(^{4}_{2}\text{He}) + m_n$$

$= (4.002603 + 1.008665)\text{u}$

$= 5.011268\ \mu$

$\Delta m = m_r - m_p$

$= (5.030151 - 5.011268)\text{u}$

$\Delta m = 0.018883\text{u}$

Energy Released

$E = \Delta mc^2$

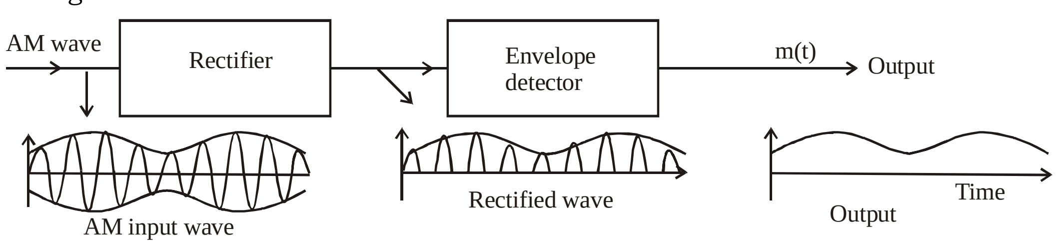
$= \Delta mc^2$

$= 0.018883 \times 931.5$ MeV

$= 17.589514$ MeV

20. Draw a block diagram of a detector for AM signal and show, using necessary processes and the waveforms, how the original message signal is detected from the input AM waves.

Sol. Block diagram of a deterctor



Detection is the process of recovering the modutating signal from the modulated carrier wave.

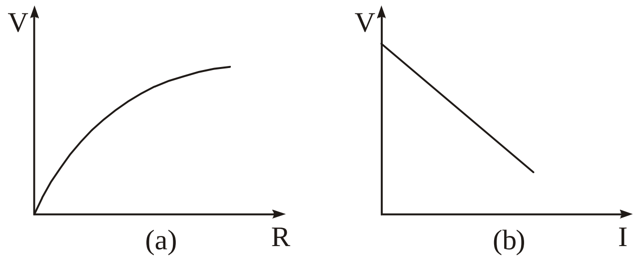
The modulated signal of the form given in (a) is passed through a rectifier to produce the output as shown in (b). This envelop of signal (b) is the message signal.

To obtain modulating signal $m(t)$ the signal in passed through an envelop detector.

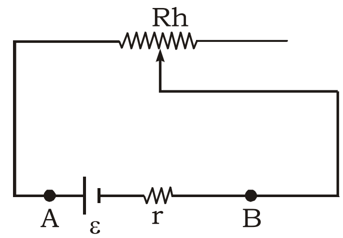
21. A cell of emf 'ε' and internal resistance 'r' is connected across a variable load resistor R. Draw the plots of the terminal voltage V versus (i) R and (ii) the current I.

It is found that when R = 4Ω, the current is 1A and when R is increased to 9Ω, the current reduces to 0.5A. Find the values of the emf ε and internal resistance r.

Sol.



Current in circuit is



$$I = \frac{\varepsilon}{(R+r)}$$

$(V_A - V_B)$ = V = Terminal voltage = IR

$$V = \frac{\varepsilon R}{(R+r)} = \varepsilon - Ir$$

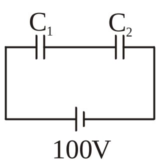
$$\boxed{I = \frac{\varepsilon}{(R+r)}} \quad I = \frac{\varepsilon}{4+r} \Rightarrow r + 4 = \varepsilon \quad \text{... (1)}$$

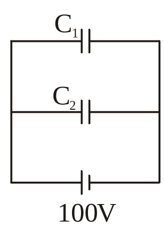
$$0.5 = \frac{\varepsilon}{9+r} \Rightarrow 0.5r + 4.5 = \varepsilon \quad \text{... (2)}$$

⇒ ***r* = 1Ω; ε = 5 volt**

22. Two capacitors of unknown capacitances C_1 and C_2 are connected first in series and then in parallel across a battery of 100 V. If the energy stored in the two combinations is 0.045 J and 0.25 J respectively, determine the value of C_1 and C_2. Also calculate the charge on each capacitor in parallel combination.

Sol.





$$\frac{1}{2}\left(\frac{C_1C_2}{C_1+C_2}\right)V^2 = 0.045$$

$$\frac{C_1C_2}{C_1+C_2} = 0.9 \times 10^{-5} F$$

$$\frac{C_1C_2}{C_1+C_2} = 9\mu F$$

⇒ $C_1C_2 = 450$

$$C_2 = \frac{450}{C_1}$$

$$C_1 + \frac{450}{C_1} = 50$$

$C_1^2 - 50\,C_1 + 450 = 0$

$$C_1 = \frac{50 \pm \sqrt{2500 - 1800}}{2}$$

$$\frac{1}{2}(C_1 + C_2)V^2 = 0.25$$

$C_1 + C_2 = 0.5 \times 10^{-4}$F

$C_1 + C_2 = 50\mu$F

$= 25 \pm \sqrt{175} = 11.8$

C_1 = 11.8 μF, C_2 = 38.2 μF

SECTION – D

23. A group of students while coming from the school noticed a box marked "Danger H.T. 2200 V" at a substation in the main street. They did not understand the utility of a such a high voltage, while they argued, the supply was only 220 V. They asked their teacher this question the next day. The teacher thought it to be an important question and therefore explained to the whole class.

Answer the following questions:

(a) What device is used to bring the high voltage down to low voltage of a.c. current and what is the principle of its working?

(b) Is it possible to use this device for bringing down the high dc voltage to the low voltage? Explain.

(c) Write the values displayed by the students and the teacher.

Sol. (a) A step down transformer is used to bring high voltage to low voltage. It's working is based on mutual indirection.

(b) No, because its working is based on electromagnetic induction, which is associated with varying magnetic flux, but in case of dc source, current will be constant, flux will be constant. This means we can not get output from transformer.

(c) Values displayed by students.

→ Scientific aptitude, Student has investigative skills.

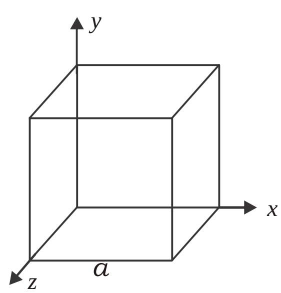
Values displaced by teacher

→ Patient, Motivating, ability to make use of subject knowledge of explain practical application.

SECTION – E

24. (a) An electric dipole of dipole moment $\vec{p}$ consists of point charges $+q$ and $-q$ separated by a distance 2a apart. Deduce the expression for the electric field $\vec{E}$ due to the dipole at a distance x from the centre of the dipole on its axial line in terms of the dipole moment $\vec{p}$. Hence show that in the limit $x >> a, \vec{E} \to 2\vec{p}/\left(4\pi \epsilon_0 x^3\right)$.

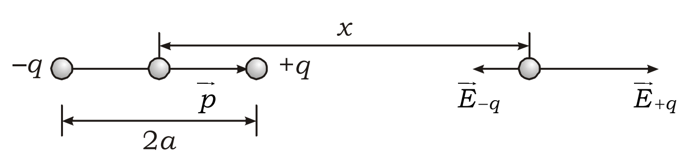
(b) Given the electric field in the region $\vec{E} = 2x\hat{i}$, find the net electric flux through the cube and the charge enclosed by it.



Sol. (a) Electric Field at a point on the axial line

$$\left|\vec{E}_{+q}\right| = \frac{kq}{(x-a)^2}$$

$$\left|\vec{E}_{-q}\right| = \frac{kq}{(x+a)^2}$$



$\vec{E} = \vec{E}_{+q} + \vec{E}_{-q} = \frac{kq}{(x-a)^2} - \frac{kq}{(x+a)^2}$ $\Rightarrow$ $|\vec{E}| = \frac{kq4ax}{(x^2-a^2)^2}$

$\vec{E} = \frac{2k\vec{p}x}{(x^2-a^2)^2}$ (Parallel to $\vec{p}$)

If $x >> a$ $E = \frac{2p}{4\pi\varepsilon_0 x^3}$ In vector form $\vec{E} = \frac{2\vec{p}}{4\pi\varepsilon_0 x^3}$

(b) Since, the electric field is parallel to the faces parallel to xy and xz planes, the electric flux through them is zero.

Electric flux through the left face

$\phi_L = (E_L)(a^2) \cos 180°$

$= (0)(a^2) \cos 180° = 0$

Electric flux through the right face

$\phi_R = (E_R)(a^2) \cos 0°$

$= (2a)(a^2) \times 1$

$= 2a^3$

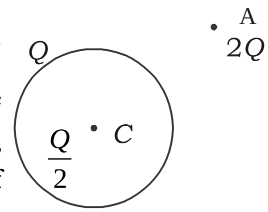
Total flux $(\phi) = 2a^3 = \frac{q_{enclosed}}{\varepsilon_0}$

$\therefore$ $q_{enclosed} = 2a^3 \varepsilon_0$

OR

24. (a) Explain, using suitable diagrams, the difference in the behaviour of a (i) conductor and (ii) dielectric in the presence of external electric field. Define the terms polariazation of a dielectric and write its relation with susceptibility.

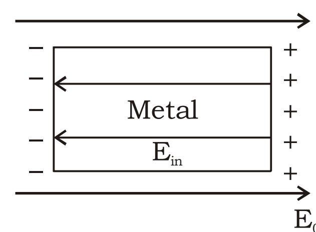
(b) A thin metallic spherical shell of radius R carries a charge Q on its surface. A point charge $\frac{Q}{2}$ is placed at its centre C and another charge +2Q is placed outside the shell at a distance x from the centre as shown in the figure. Find (i) the force on the charge at the centre of shell and at the point A, (ii) the electric flux through the shell.



Sol. (a) (i) Conductor

$E_0 \rightarrow$ external field

$E_{in} \rightarrow$ internal field created by the redistribution of electrons inside the metal



When a conductor like a metal is subjected to external electric field, the electrons experience a force in the opposite direction collecting on the left hand side.

A positive charge is therefore induced on the right hand side. This creates on opposite electric field (E_{in}) that balances out (E_0)

$\therefore$ The net electric field inside the conductor becomes zero.

(b) Dielectric: refer to NCERT : figure 2.22 and page no 72

Polariazation of a dielectric (P) is defined as the dipole moment per unit volume of the polarized dielectric.

$P = \chi_e \in_0 E$

Where χ_e = susceptibility

E = Electric field

(b) (i) Since, the electric field inside a spherical shell is zero, the force on the charge placed at the centre of the shell is zero. For the charge at A, the shell will behave as if the entire charge 'Q' is placed at the centre of the shell. Therefore, the total charge is $Q + \frac{Q}{2} = \frac{3Q}{2}$.

Since, its distance from 2Q is 'x', the electric field at A is

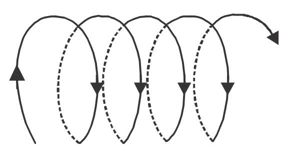
$$E = \frac{K\left(\frac{3Q}{2}\right)}{x^2}$$

So, electric force F = (2Q) × E = $\frac{1}{4\pi\varepsilon_0} \times \frac{3Q^2}{x^2}$

(ii) Since, the total charge enclosed by the shell is $q_{en} = \frac{Q}{2}$, the total flux according to Gauss's law is $\phi = \frac{Q/2}{\varepsilon_0} = \frac{Q}{2\varepsilon_0}$

25. (a) State Ampere's circuital law. Use this law to obtain the expression for the magnetic field inside an air cored toroid of average radius 'r' having 'n' turns per unit length and carrying a steady current I.

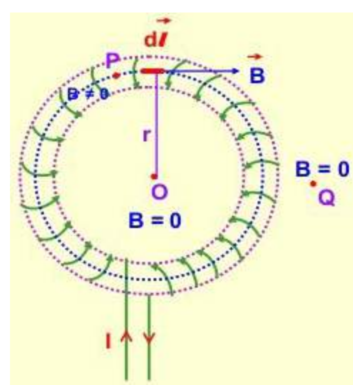
(b) An observer to the left of a solenoid of N turns each of cross section area 'A' observes that a steady current I in it flows in the clockwise direction. Depict the magnetic field lines due to the solenoid specifying its polarity and show that its acts as a bar magnet of magnetic moment m = NIA.



Sol. (a) The line integral of magnetic field $\vec{B}$ around any closed path in vacuum is μ_0 times the total current through the closed path, i.e.

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 I$$

Consider a circle of radius r.



Now, $\oint \vec{B}.\vec{dl} = \oint Bdl \cos\theta$

Angle θ between $\vec{B}$ and $\vec{dl}$ is 0. Hence,

$$\oint \vec{B}.\vec{dl} = \oint Bdl\cos\theta = \oint Bdl = B\oint dl$$

= B × circumference of the circle of radius r

or $\oint \vec{B}.\vec{dl} = B \times 2\pi r$ ...(i)

According to Ampere's circuital law,

$\oint \vec{B}.\vec{dl}$ = μ_0 × net current enclosed by the circle of radius r

= μ_0 × tota number of turns × I

= μ_0 (n × 2πr) I ...(ii)

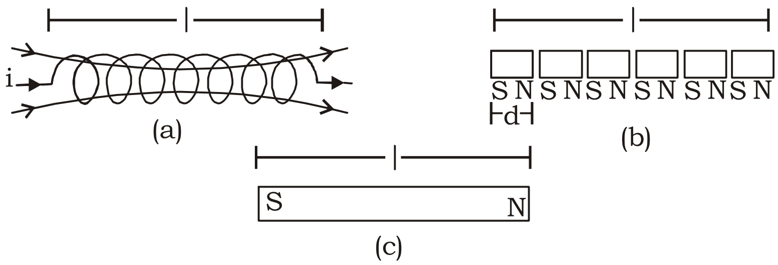
Comparing equation (i) and (ii), we get

$B \times 2\pi r = \mu_0 (n \times 2\pi r) I$

or $B = \mu_0 nI$

Which is the magnetic field due to a toroid carrying current.

(b) ***Solenoid as a magnetic dipole***



Each turn of the solenoid has been replaced by a dipole. The magnetic moment of each turn is I × A. Since there are N turns the total magnetic moment of the solenoid is m = NIA. As shown in figure (b), intermediate poles neutralize each other and we are left with the poles at the ends. Hence, the solenoid behaves like a bar magnet with south pole on the left and north pole on the right.

OR

25. (a) Define mutual inductance and write its S.I. units.

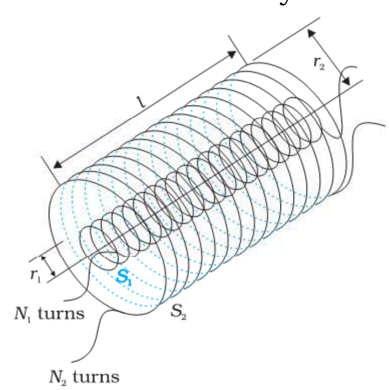
(b) Derive an expression for the mutual inductance of two long co-axial solendoids of same length wound one over the other.

(c) In an experiment, two coils C_1 and C_2 are placed close to each other. Find out the expression for the emf induced in the coil C_1 due to a change in the current through the coil C_2.

Sol. (a) Coefficient of mutual induction (M) or mutual inductance of two coils is equal to the e.m.f. induced in one coil when rate of change of current through the other coil is unity.

The SI unit of M is henry.

(b) ***Mutual inductance of two long co-axial solenoids***



- B_1 and B_2 – Magnetic fields created by each solenoid.
- I_1 and I_2 – Current through each solenoid.
- ϕ_1 and ϕ_2 – Flux associated with each solenoid.
- N_1 and N_2 – Number of turns in each coil.
- l – Length of each solenoid.

Pass current through S_2, and record flux associated with S_1

$\phi_1 = N_1 B_2 A_1$

$\phi_1 = (n_1 l)(\mu_0 n_2 I_2)(\pi r_1^2)$

$\phi_1 = M_{12} I_2$

$M_{12} = \mu_0 n_1 n_2 \pi r_1^2 l = \mu_0 n_1 n_2 A l$

Similarly pass current through S_1 and record the flux associated with S_2

$\phi_2 = N_2 B_1 A_1$

$\phi_2 = (n_2 l)(\mu_0 n_1 I_1)(\pi r_1^2)$

$\phi_2 = M_{21} I_1$

$M_{21} = \mu_0 n_1 n_2 \pi r_1^2 l = \mu_0 n_1 n_2 A l$

$M_{21} = M_{12} = \mu_0 n_1 n_2 A l$

(c) I = current in coil 2

ϕ = total amount of magnetic flux linked with all the turns of the neighbouring coil 1.

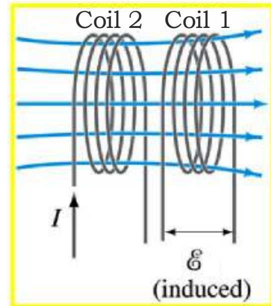
It is found that

$\phi \propto I$ or $\phi = MI$

where M is a constant of proportionality and is called coefficient of mutual induction or mutual inductance of the two coils.

The e.m.f. induced in the neighbouring coil (1) is given by

$$\varepsilon = \frac{-d\phi}{dt} = \frac{-d}{dt}(MI) = -M\frac{dI}{dt}$$



26. (a) Using Huygen's construction of secondary wavelets explain how a diffraction pattern is obtained on a screen due to a narrow slit on which a monochromatic beam of light is incident normally.

(b) Show that the angular width of the first diffraction fringe is half that of the central fringe.

(c) Explain why the maxima at $\theta = \left(n + \frac{1}{2}\right)\frac{\lambda}{a}$ become weaker and weaker with increasing n.

Sol. (a) **Diffraction of light at a Single slit**

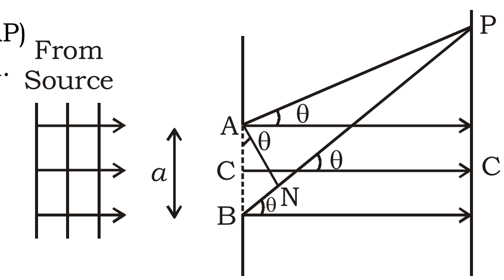
A single narrow slit is illuminated by a monochromatic source of light. The diffraction pattern is obtained on the screen placed infront of the slits.

There is a central bright region called as central maximum. All the waves reaching this region are in phase hence the intensity is maximum.

On both side of central maximum, there are alternate dark and bright regions, the intensity becoming weaker away from the centre.

The intensity at any point P on the screen depends on the path difference between the waves arsing from different parts of the wavefront at the slit.

According to the figure, the path difference (BP – AP) between the two edges of the slit can be calculated.



Path difference, BP – AP = NQ = $a\sin\theta \approx a\theta$

At the central point C on the screen, the angle θ is zero; therefore all path difference are zero and hence all the parts of slit contribute in phase. Due to this, the intensity at C is maximum.

If this path difference is λ, (the wavelength of light used), then P will be point of minimum intensity. This is because the whole wvaefront can be considered to be divided into two equal halves CA and CB and if the path difference between the secondary waves from A and B is λ, then the path difference between the secondary waves from A and C reaching P will be $\lambda/2$, and path difference between the secondary waves from B and C reaching P will again be $\lambda/2$. Also, for every point in the upper half AC, there is a corresponing point in the lower half CB for which the path difference between the secondary waves, reaching P is $\lambda/2$. Thus, destructive interference takes place at P and therefore, P is a point of first secondary minimum.

(b) Central bright lies between $\theta = \frac{+\lambda}{a}$ and $\theta = \frac{-\lambda}{a}$

$\therefore$ Angular width of central bright = $2\theta = \frac{2\lambda}{a}$ ...(1)

first diffraction fringe lies between $\theta = \frac{\lambda}{a}$ and $\theta = \frac{2\lambda}{a}$

∴ Angular width of first difraction fringe is $\frac{2\lambda}{a} - \frac{\lambda}{a} = \frac{\lambda}{a}$ ...(2)

Hence proved from (1) and (2).

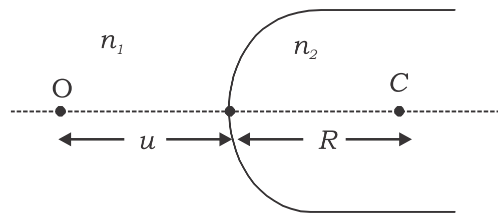
(c) For the first maxima of diffraction pattern 2/3rd of the slit is responsible for destructive interference. Hence first maxima is weaker than the central maxima.

∴ maxima gets weaker with increasing n.

OR

26. (a) A point object 'O' is kept in a medium of refractive index n_1 in front of a convex spherical surface of radius of curvature R which separates the second medium of refractive index n_2 from the first one, as shown in the figure.

Draw the ray diagram showing the image formation and deduce the relationship between the object distance and the image distance in terms of n_1, n_2 and R.

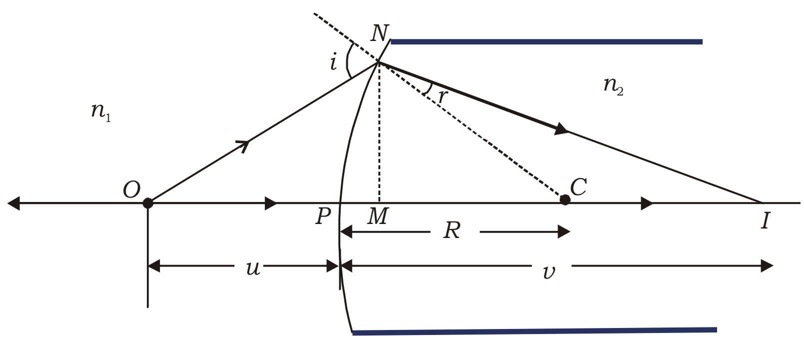


(b) When the image formed above acts as a virtual object for a concave spherical surface separating the medium n_2 from n_1(n_2 > n_1), draw this ray diagram and write the similar (similar to (a)) relation. Hence obtain the expression for the lens maker's formula.

Sol. (a) Refraction at spherical surface

Figure shows the geometry of formation of image I of an object O on the principal axis of a spherical surface with centre of curvature C, and radius of curvature R.

The rays are incident from a medium of refractive index n_1, to another of refractive index n_2.



In particular NM will be taken to be nearly equal to the length of the perpenedicular from the point N on the principal axis.

For small angles, We have

$$\tan\angle NOM = \frac{MN}{OM} \simeq \angle NOM \qquad \tan\angle NCM = \frac{MN}{MC} \simeq \angle NCM$$

$$\tan\angle NIM = \frac{MN}{MI} \simeq \angle NIM$$

Now, for ΔNOC, i is the exterior angle. Therefore, $i = \angle NOM + \angle NCM$

$$i = \frac{MN}{OM} + \frac{MN}{MC} \qquad ...(i)$$

Similarly, from ΔNCI

$r = \angle NMC - \angle NIM$

i.e., $r = \frac{MN}{MC} - \frac{MN}{MI}$ ...(*ii*)

Now, by Snell's law $n_1 \sin i = n_2 \sin r$

Or for small angles $n_1 i = n_2 r$

Substituting *i* and *r* from Equations, (*i*) and (*ii*), we get :

$$n_1\left(\frac{MN}{OM} + \frac{MN}{MC}\right) = n_2\left(\frac{MN}{MC} - \frac{MN}{MI}\right)$$

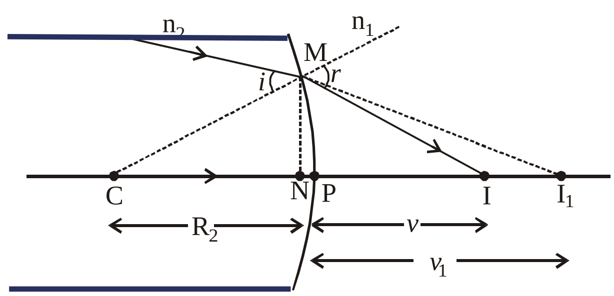
$$\Rightarrow \quad \frac{n_1}{OM} + \frac{n_2}{MI} = \frac{n_2 - n_1}{MC} \qquad ...(iii)$$

Here, OM, MI and MC represent magnitudes of distances. Applying the Cartesian sign convention.

$OM = -u$, $MI = +v$, $MC = +R$

Substituting these in equation (*iii*), we get : $\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$

(b) $n_2 > n_1$



$$\frac{n_1}{v} - \frac{n_2}{v_1} = \frac{n_1 - n_2}{R_2} \qquad ... (i)$$

from equation in part (a)

$$\frac{n_2}{v_1} - \frac{n_1}{u} = \frac{n_2 - n_1}{R_1} \qquad ... (ii)$$

Adding (i) and (ii)

$$\frac{n_1}{v} - \frac{n_1}{u} = (n_2 - n_1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{v} - \frac{1}{u} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$u = \infty$, $v = f$

$$\Rightarrow \quad \boxed{\frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)}$$

The questions in other sets are same but jumbled. If you have any doubt call me at mob. **9990088009**