SOLUTIONS

1. The rms value of the output voltage at the load resistance, $V_{rms} = \frac{V_0}{\sqrt{2}}$.

2. Given $f = \frac{-3R}{4}$,

From lens-maker's formula,

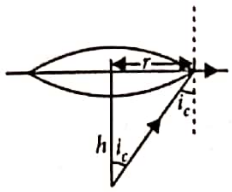
$$\frac{1}{f} = (\mu - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \Rightarrow \frac{1}{\frac{-3R}{4}} = (\mu - 1)\left[\frac{1}{-R} - \frac{1}{R}\right]$$

$$\frac{4}{3R} = \frac{2(\mu - 1)}{R} \Rightarrow \mu = \frac{5}{3}$$

It will behave as a converging lens if $(\mu - 1) < 0$ or $\mu < 1$.

OR

Radius,



$$r = h \tan i_c = h\frac{\sin i_c}{\cos i_c}$$

$$r = h\frac{1/\mu}{\sqrt{1 - \frac{1}{\mu^2}}} = \frac{h}{\sqrt{\mu^2 - 1}}$$

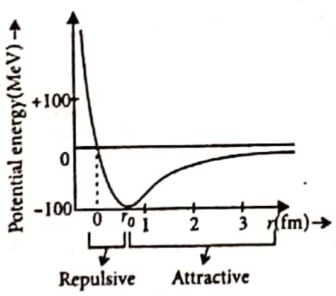
3. Here, $n_i = 10^6 \text{ m}^{-3}$,

$n_h = 5 \times 10^{22} \text{ m}^{-3}$

As $n_e n_h = n_i^2$

$$\therefore \; n_e = \frac{n_i^2}{n_h} = \frac{(10^{16} \text{m}^{-3})^2}{5 \times 10^{22} \text{ m}^{-3}} = 2 \times 10^9 \text{ m}^{-3}$$

4. Plot of potential energy of a pair of nucleons as a function of their separation is given in the figure.



Conclusions: (i) The nuclear force is much stronger than the coulomb force acting between charges or the gravitational forces between masses.

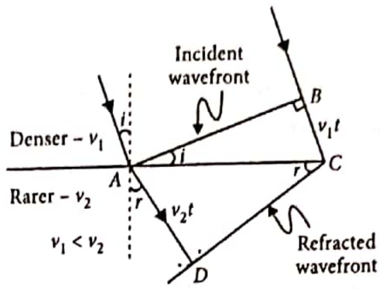
(ii) The nuclear force between two nucleons falls rapidly to zero as their distance is more than a few fermies.

(iii) For a separation greater than r_0, the force is attractive and for separation less than r_0, the force is strongly repulsive.

5. Refractive index (μ) : Refractive index of a medium is defined as the ratio of the speed of light in vacuum to the speed of light in that medium. *i.e.*,

$$\mu = \frac{c}{v} = \frac{\text{speed of light in vacuum}}{\text{speed of light in medium}}$$

Given figure shows the refraction of a plane wavefront at a rarer medium *i.e.*, $v_2 > v_1$



Let the angles of incidence and refraction be i and r respectively.

From right ΔABC, we have,

$$\sin \angle BAC = \sin i = \frac{BC}{AC}$$

From right ΔADC, we have,

$$\sin \angle DCA = \sin r = \frac{AD}{AC}$$

$$\therefore \; \frac{\sin i}{\sin r} = \frac{BC}{AD} = \frac{v_1 t}{v_2 t}$$

or $\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = {}^1\mu_2$ (a constant)

This verifies Snell's law of refraction. The constant ${}^1\mu_2$ is called the refractive index of the second medium with respect to first medium.

6. The refractive index of the material of a prism is

$$\mu = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin\frac{A}{2}}$$

where δ_m is the angle of minimum deviation.

Here, $\mu = \sqrt{2}$, $A = \delta_m$

$$\therefore \; \sqrt{2} = \frac{\sin\left(\frac{A + A}{2}\right)}{\sin\frac{A}{2}} = \frac{\sin A}{\sin\frac{A}{2}}$$

$$= \frac{2\sin\frac{A}{2}\cos\frac{A}{2}}{\sin\frac{A}{2}} = 2\cos\frac{A}{2}$$

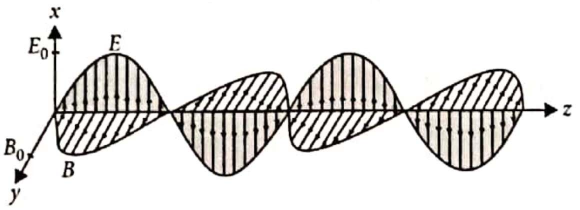
or $\cos\frac{A}{2} = \frac{1}{\sqrt{2}}$ or $\cos\frac{A}{2} = \cos 45^\circ$

or $A = 90^\circ$

7. (a) An oscillating or accelerated charge is supposed to be source of an electromagnetic wave. An oscillating charge produces an oscillating electric field in space which further produces an oscillating magnetic field which in turn is a source of electric field. These oscillating electric and magnetic field hence, keep on regenerating each other and an electromagnetic wave is produced.

(b) Electromagnetic waves or photons transport energy and momentum. When an electromagnetic wave interacts with a small particle, it can exchange energy and momentum with the particle. The force exerted on the particle is equal to the momentum transferred per unit time. Optical tweezers use this force to provide a non-invasive technique for manipulating microscopic-sized particles with light.

(i) The *e.m.* wave propagates along *z*-axis.



For an *e.m.* wave propagating in *Z*-direction, electric field is directed along *X*-axis and magnetic field is directed along *Y*-axis.

$\hat{k} = \hat{i} \times \hat{j}$

8. (i) Since, $E_n = \frac{-13.6}{n^2}$ eV

Energy of the photon emitted during a transition of the electron from the first excited state to its ground state is,

$\Delta E = E_2 - E_1$

$$= \frac{-13.6}{2^2} - \left(\frac{-13.6}{1^2}\right) = \frac{-13.6}{4} + \frac{13.6}{1} = -3.40 + 13.6$$

= 10.2 eV

This transition lies in the region of Lyman series.

(ii) (a) The energy levels of H-atom are given by

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

For first excited state $n = 2$

$$E_2 = -\frac{13.6}{(2)^2} \text{ eV} = -3.4 \text{ eV}$$

Kinetic energy of electron in ($n = 2$) state is

$K_2 = -E_2 = +3.4$ eV

(b) Radius in the first excited state

$r_1 = (2)^2\,(0.53)$ Å

$r_1 = 2.12$ Å

OR

Bohr's quantization condition : The electron revolves around the nucleus only in those orbits for which the angular momentum is an integral multiple of $h/2\pi$.

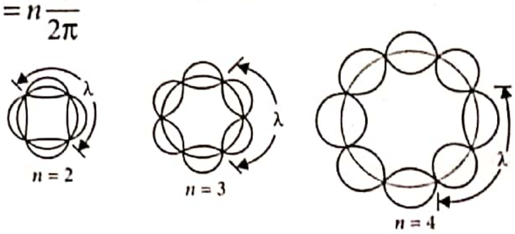
i.e., $L = mvr = n\frac{h}{2\pi}$; $n = 1, 2, 3, \ldots$

de-Broglie hypothesis may be used to derive Bohr's formula by considering the electron to be a wave spread over the entire orbit, rather than as a particle which at any instant is located at a point in its orbit. The stable orbits in an atom are those which are standing waves. Formation of standing waves require that the circumference of the orbit is equal in length to an integral multiple of the wavelength. Thus, if *r* is the radius of the orbit

$$2\pi r = n\lambda = \frac{nh}{p} \qquad \left(\because \lambda = \frac{h}{p}\right)$$

which gives the angular momentum quantization.

$$L = pr = n\frac{h}{2\pi}$$



9. Depletion layer : The small region in the vicinity of the junction which is depleted of free charge carriers and has only immobile ions is called the depletion layer.

Barrier potential : Due to accumulation of negative charges in the *p*-region and positive charges in the *n*-region sets up a potential difference across the junction sets up. This acts as a barrier and is called potential barrier V_B which opposes the further diffusion of electrons and holes across the junction.

(i) When there is an increase in doping concentration, the applied potential difference causes an electric field which acts opposite to the potential barrier. This results in reducing the potential barrier and hence the width of depletion layer decreases.

(ii) As reverse voltage supports the potential barrier and effective barrier potential increases. It makes the width of the depletion layer larger.

10. Given : wavelength in air, $\lambda_a = 589$ nm $= 5.89 \times 10^{-7}$ m

Refractive index of water, $\mu_w = 1.33$

$\because$ speed of light in vacuum, $c = 3 \times 10^8$ m/s

$\therefore$ frequency, $\upsilon = \frac{c}{\lambda_a}$

$$= \frac{3\times10^8 \text{ m/s}}{5.89\times10^{-7} \text{ m}} = 5.093\times10^{14} \text{ Hz}$$

($\because$ speed in air $\approx c$)

Now, speed of light in water, $v = \frac{c}{\mu_w}$

$$= \frac{3\times10^8 \text{ m/s}}{1.33} \approx 2.2605\times10^8 \text{ m/s}$$

$\therefore$ Wavelength in water, $\lambda_w = \frac{v}{\upsilon}$

$$= \frac{\frac{c}{\mu_w}}{\frac{c}{\lambda_a}} = \frac{\lambda_a}{\mu_w} = \frac{5.89\times10^{-7} \text{ m}}{1.33} \approx 4.43 \times 10^{-7} \text{ m}$$

Thus, for the refracted light

Wavelength, $\lambda_w \approx 4.43 \times 10^{-7}$ m

Frequency, $\upsilon = 5.09 \times 10^{14}$ Hz and

Speed, $v \approx 2 \times 10^8$ m/s

11. Path difference $= \frac{\lambda}{4}$; phase difference, $\delta = 90°$

$$I_1 = I_0\cos^2\frac{90}{2} = I_0 \times \frac{1}{2} \Rightarrow I_0 = 2I_1$$

Path difference $= \frac{\lambda}{3}$; phase difference, $\delta = 120°$

$$I = I_0 \cos^2 60° = 2I_1 \times \frac{1}{4} = \frac{I_1}{2}$$

OR

Here, $a = 2$ mm $= 2 \times 10^{-3}$ m

$\lambda = 500$ nm $= 500 \times 10^{-9}$ m $= 5 \times 10^{-7}$ m, $D = 1$ m

The distance between the first minima on either side on a screen is

$$= \frac{2\lambda D}{a} = \frac{2\times5\times10^{-7}\times1}{2\times10^{-3}}$$

$$= 5 \times 10^{-4} \text{ m} = 0.5 \times 10^{-3} \text{ m} = 0.5 \text{ mm}$$

12. (i) **(b)** : Let R be the radius of the metallic sphere and r be its distance from the source S. The power received at the sphere is

$$P' = \frac{P\times\pi R^2}{4\pi r^2} = \frac{PR^2}{4r^2}$$

(ii) **(a)**: Number of photons striking the metal sphere per second is

$$n' = \frac{P'}{E} = \frac{6{\cdot}4\times10^{-9}}{6{\cdot}0\times1{\cdot}6\times10^{-19}} = 6{\cdot}7\times10^9 \text{ s}^{-1}$$

(iii) **(b)**:Number of photoelectrons emitted from metal sphere, $\frac{n'}{10^5} = \frac{6{\cdot}7\times10^{-9}}{10^5} = 6{\cdot}7\times10^4$

(iv) **(b)**: Kinetic energy of the fastest photoelectrons is

$$K_{max.} = 6{\cdot}0 - 3{\cdot}0 = 3{\cdot}0 \text{ eV}$$

$\therefore$ Stopping potential, $V_s = \frac{K_{max}}{e} = \frac{3{\cdot}0\text{eV}}{e} = 3.0$ V

(v) **(b)**: When $r = 2r$, then power received by the sphere

$$P'' = \frac{P\pi R^2}{4\pi(2r)^2} = \frac{1}{4}\left(\frac{PR^2}{4r^2}\right)$$

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