1. An electron revolving in an orbit of H-atom, has both kinetic energy and electrostatic potential energy. Kinetic energy of the electron revolving in a circular orbit of radius r is $E_K = \frac{1}{2}mv^2$

Since, $\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$

$\therefore\ E_K = \frac{1}{2}\times\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$ or $E_K = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{2r}$ ... (i)

Electrostatic potential energy of electron of charge $-e$ revolving around the nucleus of charge $+e$ in an orbit of radius r is

$E_P = \frac{1}{4\pi\varepsilon_0}\frac{+e\times -e}{r}$ or $E_P = \frac{-1}{4\pi\varepsilon_0}\frac{e^2}{r}$ ... (ii)

So, total energy of electron in orbit of radius r is

$E = E_K + E_P$ or $E = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{2r} - \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$

or $E = \frac{-1}{4\pi\varepsilon_0}\frac{e^2}{2r}$

The –ve sign of the energy of electron indicates that the electron and nucleus together form a bound system *i.e.*, electron is bound to the nucleus.

2. A light emitting diode is simply a forward biased p-n junction which emits spontaneous light radiation. At the junction, energy is released in the form of photons due to the recombination of the excess minority charge carrier with the majority charge carrier.

Advantages :

(i) Low operational voltage and less power.

(ii) Fast action and no warm up time required.

OR

Since the diode is reversed biased, only drift current exists in circuit which is 20 μA.

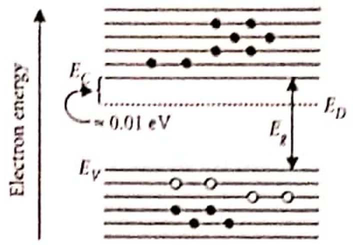
Potential drop across 15 Ω resistor, = 15 Ω × 20 μA

= 300 μV = 0.0003 V

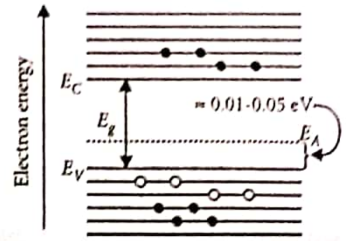
Potential difference across the diode = 4 – 0.0003

= 3.99 ≅ 4 V

3. (a) The required energy band diagrams are given below:

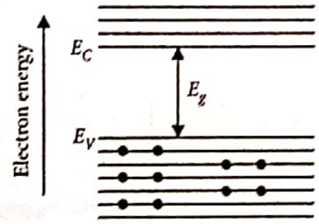


(a)
Energy band diagram of n-type semiconductor at $T > 0$ K



(b)
Energy band diagram of p-type semiconductor at $T > 0$ K

(b)



Energy band diagram of semiconductor at $T = 0$ K

At absolute zero temperature (0 K) conduction band of semiconductor is completely empty, *i.e.*, σ = 0. Hence the semiconductor behaves as an insulator. At room temperature, some valence electrons acquire enough thermal energy and jump to the conduction band where they are free to conduct electricity. Thus the semiconductor acquires a small conductivity at room temperature.

4. Total average energy density of electromagnetic wave is $\frac{1}{2}\varepsilon_0 E_{rms}^2 + \frac{1}{2}\varepsilon_0 E_{rms}^2 = \varepsilon_0 E_{rms}^2$

$= 8.85\times10^{-12}\times(720)^2 = 4.58\times10^{-6}\ \text{J m}^{-3}$

5. As 1 g of H-atom = N_A

$\therefore$ 1000 g of H-atom = $1000N_A$

So, 4 kg of H-atom = $4000N_A$

$\therefore$ Number of fusion = $\frac{4000N_A}{4} = 1000N_A$

Energy released per fusion process

$= 1000N_A \times 26$ MeV

Now, 235 g of Uranium = N_A

23.5 kg of Uranium = $100N_A$

So, energy released for fission process

$= 100N_A \times 200$ MeV

$$\therefore \frac{E_{fusion}}{E_{fission}} = \frac{1000N_A \times 26 \text{ MeV}}{100N_A \times 200 \text{ MeV}} = \frac{13}{10}$$

6. (b) : Given; $n_e = 5 \times 10^{18}$ m^{-3}, $n_h = 5 \times 10^{19}$ m^{-3}, $\mu_e = 2$ m^2 V^{-1} s^{-1}, $\mu_h = 0.01$ m^2 V^{-1} s^{-1} then conductivity,

$\sigma = e(n_e\mu_e + n_h\mu_h)$

Putting values, we get

$\sigma = 1.6 \times 10^{-19}(5 \times 10^{18} \times 2 + 5 \times 10^{19} \times 0.01)$

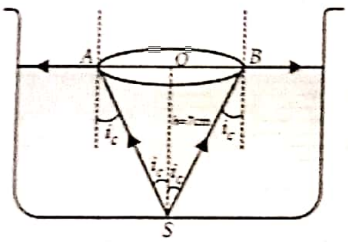
$= 1.6 \times 10^{-19}(10^{19} + 0.05 \times 10^{19}) = 1.68\ (\Omega\text{-m})^{-1}$

7. The angle of incidence in denser medium for which the angle of refraction in rarer medium is 90° is called the critical angle (i_c) for the pair of media.

The light rays emerge through a circle of radius r.

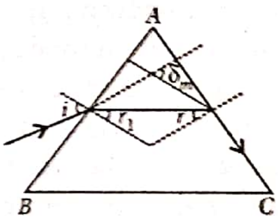
Area of water surface $= \dfrac{\pi h^2}{\mu^2 - 1}$

$$= \frac{22}{7} \times \frac{(7)^2}{(1.33)^2 - 1} = 200.28 \text{ cm}^2$$



8. (a) The refractive index of the material of prism

$$\mu = \frac{\sin\left[\frac{A+\delta_m}{2}\right]}{\sin\frac{A}{2}},$$



Given : $A = 60°$, $\delta_m = 30°$

$$\therefore\ \mu = \frac{\sin 45°}{\sin 30°} = \frac{1}{\sqrt{2}}.2 \Rightarrow \mu = \sqrt{2}$$

$$\because\ \mu = \frac{c}{v} \Rightarrow v = \frac{c}{\mu} = \frac{3\times10^8}{1.414} = 2.12 \times 10^8 \text{ m s}^{-1}$$

(b) $\sin i_C = \dfrac{1}{\mu} = \dfrac{1}{\sqrt{2}}$

$i_C = r = 45°$

$\because A = r_1 + r$

$\Rightarrow r_1 = 15°$

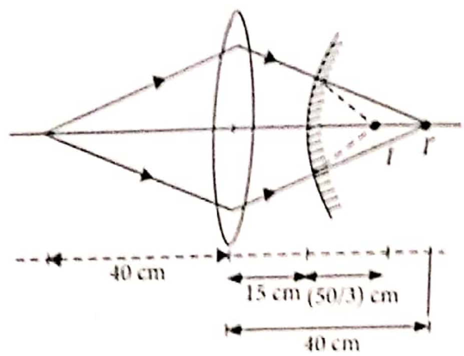
$$\frac{\sin i}{\sin r_1} = \sqrt{2}$$

$$\therefore\ \sin i = \sqrt{2}\sin 15° = \frac{(\sqrt{3}-1)}{2\sqrt{2}} \times \sqrt{2}$$

$$\sin i = \frac{\sqrt{3}-1}{2}$$

$$i = \sin^{-1}\left(\frac{\sqrt{3}-1}{2}\right)$$

OR



For the lens

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

$u = -40$ cm, $f = +20$ cm. This gives $v = +40$ cm

This image acts as a (virtual) object for the convex mirror.

$\therefore\ u = (+40 - 15)$ cm = 25 cm

Also $f = +\dfrac{20}{2}$ cm $= +10$ cm

From $\dfrac{1}{f} = \dfrac{1}{v} + \dfrac{1}{u}$

We get $v = \dfrac{50}{3}$ cm $= 16.67$ cm

The final image is, therefore formed at a distance of 16.67 cm $\left(= \dfrac{50}{3} \text{ cm}\right)$ to the right of the convex mirror.

(at a distance of 31.67 cm $\left(= \dfrac{95}{3} \text{ cm}\right)$ to the right of the convex lens.

9. According to Einstein's photoelectric equation,

$$K_{max} = \frac{hc}{\lambda} - \frac{hc}{\lambda_0} = hc\left[\frac{1}{\lambda} - \frac{1}{\lambda_0}\right]$$

$$= 6.62\times10^{-34}\times3\times10^8\left[\frac{1}{20\times10^{-8}} - \frac{1}{36\times10^{-8}}\right]$$

$$= \frac{6.62\times10^{-34}\times3\times10^8\times4}{180\times10^{-8}\times1.6\times10^{-19}} \text{ eV} = 2.76 \text{ eV}$$

10. The frequencies of the emitted photon in the Paschen series are given by

$$\upsilon = Rc\left(\frac{1}{3^2} - \frac{1}{n^2}\right), \text{ where } n = 4, 5, 6, ...$$

The highest frequency corresponds to $n = \infty$

$$\therefore \upsilon_{highest} = \frac{Rc}{9} = \frac{1.097\times10^7\ \text{m}^{-1}\times3\times10^8\ \text{m/s}}{9}$$

$$= 0.37 \times 10^{15}\ \text{s}^{-1} = 3.7 \times 10^{14}\ \text{Hz}$$

11. (a) Reflection and refraction arise through interaction of incident light with atomic constituents of matter which vibrate with the same frequency as that of the incident light. Hence frequency remains unchanged.

(b) Energy carried by a wave depends on the frequency of the wave, not on the speed of wave propagation.

(c) For a given frequency, intensity of light in the photon picture is determined by

$$I = \frac{\text{Energy of photons}}{\text{area} \times \text{time}} = \frac{n\times h\upsilon}{A\times t}$$

where n is the number of photons incident normally on crossing area A in time t.

OR

(a) Coherent sources are necessary to produce a sustained interference pattern otherwise the phase difference changes very rapidly with time and hence no interference will be observed.

(b) Intensity at a point, $I = 4I_0\cos^2\left(\frac{\phi}{2}\right)$

$$\text{Phase difference} = \frac{2\pi}{\lambda}\times \text{ Path difference}$$

At path difference λ,

$$\text{Phase difference, } \phi = \frac{2\pi}{\lambda}\times\lambda = 2\pi$$

$$\therefore \text{ Intensity, } K = 4I_0\cos^2\left(\frac{2\pi}{2}\right)$$

[$\because$ Given $I = K$, at path difference λ]

$$K = 4I_0 \quad \text{...(i)}$$

If path difference is $\frac{\lambda}{3}$, then phase difference will be

$$\phi' = \frac{2\pi}{\lambda}\times\frac{\lambda}{3} = \frac{2\pi}{3}$$

$$\therefore \text{ Intensity, } I' = 4I_0\cos^2\left(\frac{2\pi}{6}\right) = \frac{K}{4} \quad \text{(Using (i))}$$

12. (i) **(c)** : Here, $d = 0.1$ mm, $\lambda = 6000$ Å, $D = 0.5$ m

For third dark band, $d\sin\theta = 3\lambda$; $\sin\theta = \frac{3\lambda}{d} = \frac{y}{D}$

$$y = \frac{3D\lambda}{d} = \frac{3\times0.5\times6\times10^{-7}}{0.1\times10^{-3}} = 9\times10^{-3}\ \text{m} = 9\ \text{mm}$$

(ii) **(b)** : Given $d = 0.2$ mm $= 0.2 \times 10^{-3}$ m, $D = 2$ m

$\lambda = 5000$ Å $= 5 \times 10^{-7}$ m

The distance between the first minimum on other side of the central maximum

$$x = \frac{2\lambda D}{d} = \frac{2\times5\times10^{-7}\times2}{0.2\times10^{-3}} \Rightarrow x = 10^{-2}\ \text{m}$$

(iii) **(a)** : Here, $\lambda = 600$ nm $= 6 \times 10^{-7}$ m

$a = 0.2$ mm $= 2 \times 10^{-4}$ m, $\theta = ?$

Angular width of central maxima,

$$\theta = \frac{2\lambda}{a} = \frac{2\times6\times10^{-7}}{2\times10^{-4}} = 6\times10^{-3}\ \text{rad}$$

(iv) **(d)** : When red light is replaced by blue light ($\lambda_B < \lambda_R$) the diffraction pattern bands becomes narrow and crowded together.

(v) **(b)** : To observe diffraction, the size of the obstacle should be of the order of wavelength.

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