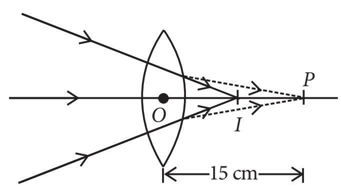
SOLUTIONS

1. (a) (i) There is very little resistance to limit the current in LED. Therefore, a resistor must be used in series with the LED to avoid any damage to it.
(ii) The reverse breakdown voltages of LEDs are very low, typically around 5 V. So care should be taken while fabricating a *p*-*n*-junction diode so that the *p* side should only attached to the positive of battery and vice versa as LED easily get damaged by a small reverse voltage.
(b) The semiconductor used for fabrication of visible LEDs must have at least a band gap of 1.8 eV because spectral range of visible light is about 0.4 mm to 0.7 mm, i.e., about 3 eV to 1.8 eV.

2. $f = 10$ cm, $u = 15$ cm, $v = ?$

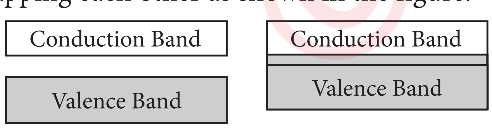


Using lens formula,

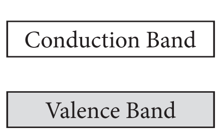
$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f} \text{ or, } \frac{1}{v}=\frac{1}{u}+\frac{1}{f}=\frac{1}{15}+\frac{1}{10}=\frac{5}{30}$$

$v = 6$ cm

3. Metals : For metals, the valence band is completely filled and the conduction band can have two possibilities-either it is partially filled with an extremely small energy gap between the valence and conduction bands or it is empty, with the two bands overlapping each other as shown in the figure.



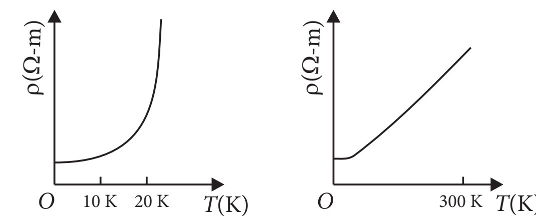
On applying even an small electric field, metals can conduct electricity.
Insulators : For insulators, the energy gap between the conduction and valence bands is very large. Also, the conduction band is practically empty, as shown in the figure.



When an electric field is applied across such a solid, the electrons find it difficult to acquire such a large amount of energy to reach the conduction band. Thus, the conduction band continues to be empty. That is why no current flows through insulators.

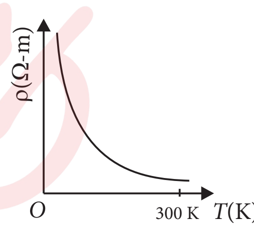
OR

(i) The resistivity of a conductor increases non-linearly with increase in temperature.



(For low temperature) (For high temperature)

(ii) The resistivity of a semiconductor decreases with increase in temperature.



4. (a) Given, $\lambda = 600$ nm $= 6 \times 10^{-7}$ m

$$E=\frac{hc}{\lambda}=\frac{6.6\times10^{-34}\times3\times10^{8}}{5\times10^{-7}\times1.6\times10^{-19}}\text{ eV} = 2.47 \text{ eV}$$

As, energy gaps of diodes D_1 and D_3 are greater than the given energy of the incident radiation. Hence diodes D_1 and D_3 will not be able to detect light of wavelength 600 nm.
(b) In reverse bias condition of photodiode, the change in saturation reverse current is directly proportional to the change in the incident light flux or light intensity, which can be measured accurately. It is not so when photodiode is forward biased.

5. (a) (i) ${}^{208}_{84}\text{Po} \rightarrow {}^{204}_{82}\text{Pb} + {}^{4}_{2}\text{He}$

$208 = 204 + A$
$A = 208 - 204 = 4$
$84 = 82 + Z$; $Z = 84 - 82 = 2$

(ii) ${}^{32}_{15}\text{P} \rightarrow {}^{32}_{16}\text{S} + {}_{-1}e^{0} + \bar{\nu}$

$32 + 32 + A$
$A = 32 - 32 = 0$; $A = 0$
$15 = 16 + Z$;
$Z = 15 - 16 = -1$

(b) In both processes the conversion of neutron to proton and proton to neutron take place inside the nucleus.

$${}^{A}_{Z}X \rightarrow \beta^- + {}^{A}_{Z+1}Y + \bar{\nu}\ (\beta^- \text{ decay})$$

$${}^{A}_{Z}X \rightarrow \beta^+ + {}^{A}_{Z-1}Y + \nu\ (\beta^+ \text{ decay})$$

(c) Neutrinos are chargeless (neutral) and almost massless particles that hardly interact with matter.

6. In a nuclear reaction, the sum of the masses of the target nucleus (${}^{2}_{1}H$) and the bombarding particle (${}^{2}_{1}H$) may be greater than the product nucleus (${}^{3}_{2}He$) and the outgoing neutron ${}_{0}^{1}n$. So from the law of conservation of mass-energy some energy (3.27 MeV) is evolved due to mass defect in the nuclear reaction. This energy is called Q-value of the nuclear reaction.

7. Here, ${}^{a}\mu_g = 1.5$

Let f_{air} be the focal length of the lens in air,
Then,

$$\frac{1}{f_{air}} = ({}^{a}\mu_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

or $$\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \frac{1}{f_{air}({}^{a}\mu_g - 1)} = \frac{1}{f_{air}(1.5-1)}$$

or $$\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \frac{2}{f_{air}} \qquad \text{... (i)}$$

(i) When lens is dipped in medium A

Here, ${}^{a}\mu_A = 1.65$

Let f_A be the focal length of the lens, when dipped in medium A. Then,

$$\frac{1}{f_A} = ({}^{A}\mu_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \left(\frac{{}^{a}\mu_g}{{}^{a}\mu_A} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Using the equation (i), we have

$$\frac{1}{f_A} = \left(\frac{1.5}{1.65} - 1\right) \times \frac{2}{f_{air}} = -\frac{1}{5.5 f_{air}}$$

or $f_A = -5.5 f_{air}$

As the sign of f_A is opposite to that of f_{air} the lens will behave as a diverging lens.

(ii) When lens is dipped in medium B

Here, ${}^{a}\mu_B = 1.33$

Let f_B be the focal length of the lens, when dipped in medium B. Then,

$$\frac{1}{f_B} = ({}^{B}\mu_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \left(\frac{{}^{a}\mu_g}{{}^{a}\mu_B} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Using the equation (i), we have

$$\frac{1}{f_B} = \left(\frac{1.5}{1.33} - 1\right) \times \frac{2}{f_{air}} = \frac{0.34}{1.33 f_{air}}$$

or $f_B = 3.91 f_{air}$

As the sign of f_B is same as that of f_{air}, the lens will behave as a converging lens.

OR

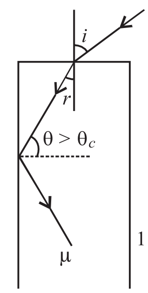
Here, $d = 1$ mm $= 1 \times 10^{-3}$ m

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

Fringe spacing,

$$\beta = \frac{\lambda D}{d} = \frac{5 \times 10^{-7} \times 1}{1 \times 10^{-3}} = 5 \times 10^{-4} \text{ m} = 0.5 \text{ mm}$$

8. The ray will total internally reflect at the vertical surface if $\theta > \theta_c$.



Now, $r = (90° - \theta)$ and

Snell's law is $\sin i = \mu \sin r$

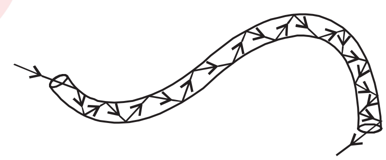
$$\frac{\sin i}{\mu} = \sin(90° - \theta)$$

$$\Rightarrow \cos\theta = \frac{\sin i}{\mu}$$

or $$\sin\theta = \sqrt{1 - \cos^2\theta} = \sqrt{1 - \frac{\sin^2 i}{\mu^2}}$$

If $\theta > \theta_C$, then $\sin\theta > \sin\theta_C$ (As $\sin\theta$ is an increasing function for $0 < \theta < 90°$)

$$\sqrt{1 - \frac{\sin^2 i}{\mu^2}} > \frac{1}{\mu}$$



$$1 - \frac{\sin^2 i}{\mu^2} > \frac{1}{\mu^2}$$

$\mu^2 - \sin^2 i > 1$ or $(\mu^2 - 1) > \sin^2 i$

If total internal reflection has to be larger for all value, the above inequality must be satisfied for all $(\sin^2 i)_{max} = 1$

$\Rightarrow \mu^2 - 1 > 1$ or $\mu > \sqrt{2}$

This total internal reflection phenomenon is used in fibre optics to bend light in a curved path.

9. The position of n^{th} order bright fringe from the central bright fringe is

$$x_n = \frac{n\lambda D}{d}$$

where, λ = wavelength of light used

D = Distance of screen from the slits

d = Distance between the slits

For wavelength λ(= 480 nm), the position of 3^{rd} order bright fringe from the central bright fringe is

$$x_3 = \frac{3\lambda D}{d}$$

For wavelength λ' (= 600 nm), the position of 3^{rd} order bright fringe from the central bright fringe is

$$x_3' = \frac{3\lambda' D}{d}$$

$\therefore$ The separation between the third order bright fringes of the two interferene patterns is $x_3' - x_3 = \dfrac{3(\lambda' - \lambda)D}{d}$

Here, $\lambda = 480$ nm $= 480 \times 10^{-9}$ m

$\lambda' = 600$ nm $= 600 \times 10^{-9}$ m

$D = 1.0$ m

$d = 5.0$ mm $= 5.0 \times 10^{-3}$ mm

$$\therefore\ x_3' - x_3 = \frac{3(600-480)\times 10^{-9}\times 1.0}{5.0\times 10^{-3}}$$

$= 0.07 \times 10^{-3}$ m $= 0.07$ mm

OR

The n^{th} bright fringe of the λ pattern and the n'^{th} bright fringe of the λ' pattern are situated at $yn = n\cdot\dfrac{D\lambda}{d}$ and $yn' = n'\dfrac{D\lambda'}{d}$.

As this coincide, $yn = yn'$

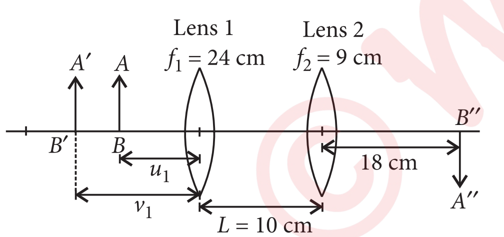
$$\Rightarrow \frac{nD\lambda}{d} = \frac{n'D\lambda'}{d}$$

$$\Rightarrow \frac{n}{n'} = \frac{\lambda'}{\lambda} = \frac{900}{750} = \frac{6}{5}$$

hence the first position where overlapping occur is

$$y_5{}' = y_6 = \frac{nD\lambda}{d} = \frac{6(2\text{m})(750\times 10^{-9}\text{m})}{(2\times 10^{-3}\text{m})} = 4.5 \text{ mm.}$$

10.



First image is formed by lens 1.

Here, $u_1 = -6$ cm, $f_1 = 24$ cm, $v_1 = ?$

Using lens formula,

$$\frac{1}{v_1} - \frac{1}{u_1} = \frac{1}{f_1} \Rightarrow \frac{1}{v_1} = \frac{1}{f_1} + \frac{1}{u_1}$$

$$\Rightarrow \frac{1}{v_1} = \frac{1}{24} - \frac{1}{6} = \frac{-3}{24} = -\frac{1}{8}$$

$\therefore\ v_1 = -8$ cm (*i.e.*, image is virtual formed on same side of lens 1)

Image formed by lens 1 acts as an object for lens 2.

Therefore final image is formed by lens 2.

Here, $u_2 = -|v_1 + L| = -(8 + 10) = -18$ cm

$f_2 = 9$ cm, $v_2 = ?$

Using lens formula,

$$\frac{1}{v_2} = \frac{1}{f_2} + \frac{1}{u_2} \Rightarrow \frac{1}{v_2} = \frac{1}{9} - \frac{1}{18} = \frac{1}{18}$$

$\Rightarrow\ v_2 = 18$ cm

11. (a) Descending order of wavelengths for given electromagnetic waves is:

Microwaves $(10^{-3} - 10^{-1})$ m

Infra-red rays $(7.5 \times 10^{-7} - 10^{-3})$ m

Ultra-violet radiation $(10^{-9} - 4 \times 10^{-7})$ m

Gamma rays $(< 10^{-12})$ m

(b) Microwaves :

Frequency range $\rightarrow 3 \times 10^8$ Hz -3×10^{11} Hz.

These are suitable for the radar system, used in aircraft navigation.

Gamma rays :

Frequency range $\rightarrow > 3 \times 10^{21}$ Hz.

These wave are used for the treatment of cancer cells.

12. (i) **(d) :** de-Broglie wavelength

$$\lambda = \frac{h}{p}\ i.e., \lambda \propto \frac{1}{p}$$

So the graph between (d) represent the variation of particle momentum and the asociated de-Broglie wavelength.

(ii) **(c) :** $K_{max} = h\upsilon - \phi_0$,

When $\upsilon = \upsilon_0$, $K_{max} = 0$

$\therefore\ 0 = h\upsilon_0 - \phi_0$ or $\phi_0 = h\upsilon_0$

If $\upsilon < \upsilon_0$, then K_{max} is negative, *i.e.*, no photoelectric emission takes place. Thus, graph (c) is possible.

(iii) **(a) :** Photoelectric current (i) is proportional to the intensity of the emission light. Thus, graph (a) is possible.

(iv) **(c) :** From Einstein's photoelectric equation,

$$K_{max} = eV_0 = \frac{hc}{\lambda} - \phi \quad \text{or} \quad V_0 = \frac{hc}{e}\cdot\frac{1}{\lambda} - \frac{\phi}{e}$$

Graph of V_0 versus $\dfrac{1}{\lambda}$ is a straight line

Slope of straight line, $\tan\theta = \dfrac{hc}{e}$

At $V_0 = 0$, we have

$$\phi_1 : \phi_2 : \phi_3 = \frac{hc}{\lambda_{01}} : \frac{hc}{\lambda_{02}} : \frac{hc}{\lambda_{03}}$$

$0.001\ hc : 0.002\ hc : 0.004\ hc$

Therefore, the ratio is 1 : 2 : 4

(v) **(b) :** $K_{max} = h\upsilon - \phi_0 = \dfrac{hc}{\lambda} - \phi_0$

$$= \frac{(6\cdot 6\times 10^{-34})\times(3\times 10^{8})}{(300\times 10^{-9})\times(1\cdot 6\times 10^{-19})} - 3\cdot 3$$

$= 4.125 \times 3.3 = 0.825$ eV

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Self Evaluation Sheet

*Once you complete **SQP-3**, check your answers with the given solutions and fill your marks in the marks obtained column according to the marking scheme. Performance Analysis Table given at the bottom will help you to check your readiness.*

Q.No.	Chapter	Marks Per Question	Marks Obtained
1	Semiconductor Electronics : Materials, Devices and Simple Circuits	2	
2	Ray Optics and Optical Instruments	2	
3	Semiconductor Electronics : Materials, Devices and Simple Circuits / Semiconductor Electronics : Materials, Devices and Simple Circuits	2	
4	Semiconductor Electronics : Materials, Devices and Simple Circuits	3	
5	Nuclei	3	
6	Nuclei	3	
7	Ray Optics and Optical Instruments / Ray Optics and Optical Instruments	3	
8	Ray Optics and Optical Instruments	3	
9	Wave Optics / Wave Optics	3	
10	Ray Optics and Optical Instruments	3	
11	Electromagnetic Waves	3	
12	Dual Nature of Radiation and Matter	1×5	
	Total Marks	**35**	....
		Percentage	..............%

Performance Analysis Table

If your marks is

> 90%	TREMENDOUS!	➢ *You are done! Keep on revising to maintain the position.*
81-90%	EXCELLENT!	➢ *You have to take only one more step to reach the top of the ladder. Practise more.*
71-80%	VERY GOOD!	➢ *A little bit of more effort is required to reach the 'Excellent' bench mark.*
61-70%	GOOD!	➢ *Revise thoroughly and strengthen your concepts.*
51-60%	FAIR PERFORMANCE!	➢ *Need to work hard to get through this stage.*
40-50%	AVERAGE!	➢ *Try hard to boost your average score.*