Solutions

1\. Refractive index of glass with respect to air, ${}_a\mu_g = \frac{3}{2}$

Refractive index of water with respect to air, ${}_a\mu_w = \frac{4}{3}$

Refractive index of glass with respect to water,

$${}_w\mu_g = \frac{{}_a\mu_g}{{}_a\mu_w} = \frac{\left(\frac{3}{2}\right)}{\left(\frac{4}{3}\right)} = \frac{9}{8}$$ [1]

Or

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

Substituting the given values, we get

$$\frac{1}{30} = (\mu - 1)\left(\frac{1}{10}\right)$$

The refractive index of the material of the lens,

$$\mu = \frac{4}{3} = 1.33$$ [1]

2\. We have, $\lambda = \frac{h}{\sqrt{2mK}}$

where, K = kinetic energy

and m = mass of particle

$\Rightarrow \quad \lambda_e = \frac{h}{\sqrt{2m_e K_e}}$

$\lambda_p = \frac{h}{\sqrt{2m_p K_p}}$

Given, $K_e = K_p = K$

$\Rightarrow \quad \frac{\lambda_p}{\lambda_e} = \sqrt{\frac{m_e}{m_p}}$; as $m_e < m_p$

$\Rightarrow \quad \lambda_p < \lambda_e$ [1]

3\. Because the protons are positively charged and repel each other. This repulsive force is more, so that an excess of neutrons are required to reduce this repulsion. [1]

4\. As the force per unit length, $\frac{F}{l} = \frac{\mu_0}{4\pi} \cdot \frac{2I_1 I_2}{d}$

When $d = 1\text{m}, l = 1\text{m}, I_1 = I_2 = 2\text{A}$

then $F = \frac{10^{-7} \times 2 \times 2 \times 2}{1} = 8 \times 10^{-7}\ \text{Nm}^{-1}$ [1]

Or

Since $I_s = \frac{E_s}{R_s} = \frac{22}{220} = 0.1\text{A}$

$\because \quad \frac{I_p}{I_s} = \frac{E_s}{E_p}$

$I_p = \frac{E_s}{E_p} \times I_s = \frac{22 \times 0.1}{220} = 10^{-2}\ \text{A}$ [1]

5\. As the two charges are identical, the electric field created by them will be equal in magnitude and opposite in direction at some location. Thus, at the mid-way point along the line joining these two charges (of the same type and magnitude), the electric field would be zero. [1]

Or

If any arbitrary surface encloses a dipole, then the net charge is zero because the total charge on the dipole is zero (dipole consists of two equal and opposite charges). According to Gauss's law,

total flux $= 1/\varepsilon_0 \times$ charge enclosed

$= 1/\varepsilon_0 \times (0) = 0 \Rightarrow \phi = 0$ [1]

6\. At low temperature, all states in valence band of semiconductor are filled while all states in conduction band are empty. [1/2]

Any applied electric field cannot give enough energy to the valence electrons, so that they can cross the gap and enter the conduction band. Hence, at low temperatures, semiconductors behave like insulators. [1/2]

Or

This is because the negative charge due to excess electrons is balanced by an equal positive charge on the positive ion of the pentavalent impurity atom. [1]

7\. A moderator slows down fast moving neutrons released in a nuclear reactor. As lighter elements have mass more equivalent to a neutron, so they act as better moderators than heavier elements. [1]

8\. Electric field lines start at positive charge and end at negative charge. Therefore, they do not form closed loops. [1]

9\. de-Brogile wavelength, $\lambda = \frac{h}{mv}$

Planck's constant h is very small. [1/2]

For macroscopic objects, mass is very large. Therefore de-Brogile wavelength associated is very small as compared to their size. So, these objects do not show wave properties. [1/2]

10\. Conductors have only one type of charge carriers, i.e. electrons. But semiconductors have two types of charge carriers and they are electrons and holes. [1]

11\. (c) When a positive charge initially at rest is placed in a uniform electric field, then it moves along the electric lines of force.

But if a point charge is released from rest in a direction making an angle with the field, then it follows a parabolic path.

Therefore, A is true but R is false. [1]

12\. (c) Surface density of parallel plate capacitor without a dielectric slab is given as

$$\sigma = \frac{q}{A} = \frac{CV}{A} \quad \text{...(i)}$$

Surface density on a parallel plate capacitor in the presence of dielectric slab is,

$$\sigma' = \frac{q'}{A} = \frac{CV'}{A} = \frac{(KC)V}{A} \quad (\text{as } C' = KC, V' = V)$$

So from Eq. (i), the above equation can be written as

$$\sigma' = \frac{Kq}{A} = K\sigma$$

The electric field on introduction of dielectric between plates of a capacitor becomes,

$$E' = \frac{K\sigma}{\varepsilon_0} = KE \quad \left[\because E = \frac{\sigma}{\varepsilon_0}\right]$$

Thus, the electric field and surface density both become K times on introducing the dielectric inside the plates.

Therefore, A is true but R is false. [1]

13\. (a) According to the Einstein's picture of photoelectric effect, intensity of the radiation is proportional to the number of energy quanta per unit area per unit time. Thus, greater the number of the energy quanta available, greater is the number of electrons the absorbing the energy quanta and therefore greater is the number of electrons coming out of the metal.

Hence, for $v > v_0$ photoelectric current is proportional to intensity.

Therefore, A and R are true and R is the correct explanation of A. [1]

14\. (b) Consider the case of an n-type semiconductor. Obviously, the majority carrier density n is considerably larger than the minority hole density p (i.e. $n >> p$). On illumination, let the excess electrons and holes generated be Δn and Δp, respectively, $n' = n + \Delta n$, $p' = p + \Delta p$

Here, n' and p' are the electron and hole concentrations at any particular illumination and n and p are carriers concentration when there is no illumination. Remember $\Delta n = \Delta p$ and $n >> p$. Hence, the fractional change in the majority carriers (i.e., $\Delta n / n$) would be much less than that in the minority carriers (i.e., $\Delta p / p$). In general, we can state that the fractional change due to the photo-effects on the minority carrier dominated reverse bias current, which is more easily measurable than the fractional change in the forward bias current.

Hence, photodiodes are preferably used in the reverse bias condition for measuring light intensity.

Therefore, A and R are true but R is not the correct explanation of A. [1]

15\. (i) (d) Refraction does not change the frequency of light. [1]

(ii) (d) From Snell's law of refraction,

$${}^a\mu_g = \frac{\sin i}{\sin r} = \text{constant} \quad \text{...(i)}$$

Since, angle of incidence increase, the angle of refraction has to increase. So, that the ratio $\left(\frac{\sin i}{\sin r}\right)$ is a constant according to Eq. (i). [1]

(iii) (a) When an object lying in a denser medium is observed from rarer medium, then real depth of object is more than that observed depth. [1]

(iv) (c) As, $\mu = \frac{\sin i}{\sin r}$ ...(i)

or $\mu \propto \frac{1}{\sin r}$

$\Rightarrow \mu$ is maximum for R, since r is minimum and hence, $\sin r$ is minimum.

Also, $\mu = \frac{c}{v}$ ...(ii)

Therefore, if μ is maximum, v is minimum, i.e. velocity of light is minimum in medium R and order of velocity will be $v_P > v_Q > v_R$ [1]

(v) (a) We see that, ray of light bends towards the normal as we go from medium A to medium B. And we know that, when ray goes from rarer to denser medium, it bends towards normal.

So, that means refractive index of B is greater than A. Thus, refractive index of B relative than A = Refractive index of B/Refractive index of A.
Since, Refractive index of B > Refractive of A.
Therefore, refractive index of B relative than $A > 1$. [1]

16\. (i) (c) Current will be larger, when the magnet is pushed faster towards the coil, also current is large when magnet is pulled faster away but now it is in opposite direction. [1]

(ii) (d) $\phi = t^3 + 3t - 7$

$\therefore$ Induced emf, $e = -\frac{d\phi}{dt} = -(3t^2 + 3) = -3t^2 - 3$

At $t = 0, e = -3\ \text{V}$

Therefore, shape of graph will be a parabola not through origin. $(\because e \propto t^2)$ [1]

(iii) (b) If a wire loop is rotated in a magnetic field, the frequency of change in the direction of the induced emf is twice per revolution. [1]

(iv) (b) Given, $\phi = (5t^3 - 100t + 300)$, $t = 2\ \text{s}$

Induced electromotive force,

$$e = -\frac{d\phi}{dt} = -\frac{d}{dt}(5t^3 - 100t + 300)$$

$$e = -5 \times 3t^2 + 100 = -5 \times 3(2)^2 + 100$$

$$= -5 \times 12 + 100 = -60 + 100 = 40\ \text{V}$$ [1]

(v) (c) From Faraday's law of electromagnetic induction,

$$e = -\frac{d\phi}{dt} = -BAN \qquad (\because dt = 1s)$$

Given, $B = 0.1\,T$, $N = 20$, $A = \pi r^2 = \pi(0.1)^2$

$$\therefore \quad e = 0.1 \times 20 \times \pi(0.1)^2 = 20\pi\text{ mV}$$ [1]

17. (i) Number of $^{235}_{92}U$ atoms fissioned,

$$n = \frac{\text{Total energy released}}{\text{Energy released per fission}}$$

$$= \frac{7.6 \times 10^{13}}{200 \times 1.6 \times 10^{-13}} = 2.375 \times 10^{24}$$ [1]

(ii) Mass of uranium used,

$$= \frac{\text{Mass number}}{\text{Avogadro's number}} \times n$$

$$= \frac{235 \times 2.375 \times 10^{24}}{6.023 \times 10^{23}} = 926.66\,g$$ [1]

Or

(i) As, energy of hydrogen atom is -13.6 eV, the negative sign signifies that the electron is bound to the proton (i.e. nucleus of hydrogen atom) or the force acting on the electron is attractive in nature. [1]

(ii) Energy in ground state ($n = 1$),

$$E_1 = -13.6\text{ eV}$$

Energy in 1st excited state ($n = 2$)

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

Energy required to take an electron in hydrogen atom from ground state to the first excited state.

$$\Delta E = E_2 - E_1$$

$$= (-3.4\text{ eV}) - (-13.6\text{ eV})$$

$$= +10.2\text{ eV}$$ [1]

18. (i) The compass needle may rest in any direction because the horizontal component of earth's magnetic field is zero at the north pole. [1]

(ii) The axis of the dip needle will become vertical because the angle of dip is 90° at the north pole. [1]

19. For an ideal capacitor C after it is charged, the current in C and R_3 stops and remains only in R_1 and R_2. Hence, there is no potential difference across R_3 and the potential difference across C is same as between A and B or that is between the ends of R_2. [1]

The current in R_1 and R_2 is

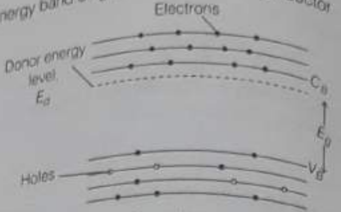
$$I = \frac{E}{R_1 + R_2}$$ [1/2]

$\therefore$ The potential difference across R_2 is

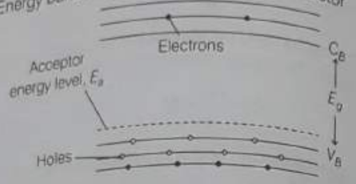
$$V = IR_2 = \frac{ER_2}{R_1 + R_2}$$

Thus, this is the voltage upto which the capacitor is charged. [1/2]

20. Energy band diagram for n-type semiconductor



Energy band diagram for p-type semiconductor [1]



21. From junction rule, we know, $I_1 = I_2 + I_3$ [1]

From loop rule, for loop $CDFEC$,

$$10I_1 + 20I_2 - 10 = 0$$

$$\Rightarrow \quad I_1 + 2I_2 = 1$$

$$\Rightarrow \quad I_1 + 2(I_1 - I_3) = 1 \quad \ldots(i)$$

$$\Rightarrow \quad 3I_1 - 2I_3 = 1 \quad \ldots(ii)$$ [1]

From loop $ABFEA$,

$$20I_2 + 20 - 20I_3 = 0$$

$$\Rightarrow \quad I_2 - I_3 = -1$$

$$\Rightarrow \quad (I_1 - I_3) - I_3 = -1$$

$$\Rightarrow \quad I_1 - 2I_3 = -1 \quad \ldots(iii)$$

From Eqs. (ii) and (iii), we get

$$I_1 = 1A$$ [1]

Or

Initially, at the balanced condition,

$$\frac{X}{Y} = \frac{60r}{(100-60)r} \Rightarrow \frac{X}{Y} = \frac{3}{2} \quad \ldots(i)$$

(where, r = resistance per cm length of wire)

When resistance 15 Ω is connected in series with Y, then

$$\frac{X}{Y+15} = \frac{50r}{(100-50)r} = 1$$

$$\Rightarrow \quad X = Y + 15$$

Substituting this value in Eq. (i), we get

$$\frac{Y+15}{Y} = \frac{3}{2}$$

$$\Rightarrow \quad 2Y + 30 = 3Y$$

$$\Rightarrow \quad Y = 30\,\Omega$$

So, $X = Y + 15 = 30 + 15 = 45\,\Omega$ [1]

When a resistance 30 Ω is connected in parallel with Y, new value of resistance between B and C become

$$Y' = \frac{30 \times 30}{30 + 30} = 15\,\Omega$$

Let the null point be obtained at a distance l cm, then

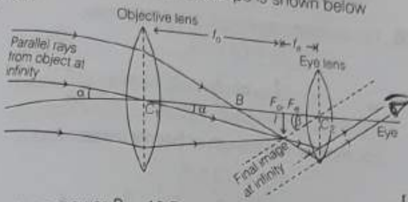
$$\frac{X}{Y'} = \frac{lr}{(100-l)r} \Rightarrow \frac{45}{15} = \frac{l}{100-l}$$

$$\Rightarrow \quad 3 = \frac{l}{100-l} \text{ or } 300 - 3l = l$$

$$\Rightarrow \quad 4l = 300$$

$$l = 75\text{ cm from end } A$$ [1]

22. Figure of astronomical telescope is shown below



Given, power $P_1 = 10$ D and $P_2 = 1$ D [1]

…(i)

To get larger magnification, f_o must be large and f_e must be small as $|m| = \frac{f_o}{f_e}$

As, $$P = \frac{1}{f}$$

Lens of power 10 D is suitable for eyepiece and that of power 1 D is suitable for objective. [1]

Or

Given, angle of incidence, $i_1 = 60°$

Thickness of glass slab, $t = 0.1$ m

Refractive index, $\mu = 1.5$

Since, $$\frac{\sin i_1}{\sin r_1} = \mu$$

$$\therefore \quad \sin r_1 = \frac{\sin i_1}{\mu} = \frac{\sin 60°}{1.5} = 0.5773$$

$$\left(\because \sin 60° = \frac{\sqrt{3}}{2}, \sqrt{3} = 1.732\right)$$

$$r_1 = \sin^{-1}(0.5773) = 35.3°$$ [1]

$$\because \quad \text{Lateral shift} = \frac{t\sin(i_1 - r_1)}{\cos r_1}$$

$$= \frac{0.1\sin(60° - 35.3°)}{\cos 35.3°} = \frac{0.1\sin 24.7°}{\cos 35.3°}$$

$$= \frac{0.1 \times 0.418}{0.816} = 0.0513\text{ m}$$ [1]

23. Consider a long air-cored solenoid having n number of turns per unit length. When an electric current I flows through it, then the magnetic field produced in it is given by

$$B = \mu_0 nI$$

where, μ_0 is the permeability of free space.

If A is the area of cross-section of the solenoid, then magnetic field linked with each turn of the solenoid,

$$\phi' = B \cdot A = \mu_0 nIA$$ [1/2]

Total number of turns in the solenoid, $N = nl$

Here, n = number of turns per unit length.

$\therefore$ Total magnetic flux linked with the solenoid,

$$\phi = \phi' \times N = \mu_0 nI\,A \times nl$$ [1/2]

$$\phi = \mu_0 n^2 IAl \quad \ldots(i)$$

But total magnetic flux linked with a solenoid is given by

$$\phi = LI \quad \ldots(ii)$$ [1/2]

From Eqs. (i) and (ii), we get

$$L = \mu_0 n^2 Al$$

or $$L = \mu_0 \frac{N^2}{l^2} Al$$

or $$L = \frac{\mu_0 N^2 A}{l}$$

This is the required expression. [1/2]

24. (i) Since, we know that, the energy of an electromagnetic wave, $E \propto \nu$ (frequency)

$$\because \nu_{\text{visible light}} < \nu_{\text{ultraviolet rays}} < \nu_{\text{X-rays}}$$

Thus, $E_{\text{visible light}} < E_{\text{ultraviolet rays}} < E_{\text{X-rays}}$ [1]

(ii) All electromagnetic waves travel with the same speed c equal to 3×10^8 m/s (in vacuum), but they have different frequency.

Speed of EM waves in any medium is however expressed as,

$$v = \frac{c}{\sqrt{\mu_r \varepsilon_r}}$$

where, μ_r = permeability of a medium

and ε_r = permittivity of a medium. [1]

25. (i) The special purpose diode used for detecting optical signals is called photodiode. It converts light incident on it into electrical current and is able to detect them. [1]

(ii) It is operated on reverse bias. This is because the small reverse bias current due to minority carriers is more sensitive to variation in intensities of light than large forward bias current due to majority carriers.

So variations in intensities will be more easily noticable, if we used it in reverse bias. [1]

26. (i) This wavelength 0.135 nm falls in the region of X-ray of electromagnetic spectrum. [1/2]

(ii) From de-Broglie matter wave equation,

$$\lambda = h/mv$$

$$\Rightarrow \quad m = h/\lambda v$$

Here, $\lambda = 0.135 \times 10^{-9}$ m, $v = 5 \times 10^6$ m/s

$$\therefore \quad m = \frac{6.63 \times 10^{-34}}{0.135 \times 10^{-9} \times 5 \times 10^6}$$

$$= 9.82 \times 10^{-31}\text{ kg}$$ [1]

Kinetic energy of electron,

$$K = \frac{1}{2}mv^2 = \frac{1}{2}\times(9.82\times10^{-31})(5\times10^{6})^2$$
$$= 4.91\times10^{-31}\times25\times10^{12}$$
$$= 122.75\times10^{-19}\,J$$
$$= \frac{122.75\times10^{-19}}{1.6\times10^{-19}}\,eV$$
$$= 76.719\,eV$$ [1½]

27. (i) Since the electron enters the chamber normal to the field, the path of the electron is a circle of radius r given by

$$r = \frac{mv}{qB}$$

Here, $B = 8.0\,G = 8\times10^{-4}\,T$,

$$v = 4.0\times10^{6}\,ms^{-1}$$
$$e = 1.6\times10^{-19}\,C$$
$$m = 9.1\times10^{-31}\,kg$$
$$\Rightarrow \quad r = \frac{9.1\times10^{-31}\times4\times10^{6}}{1.6\times10^{-19}\times8\times10^{-4}}$$
$$= 2.8\times10^{-2}\,m = 2.8\,cm$$

Now, accordance to Fleming's Left's hand rule, the electron revolves in clockwise direction. [2]

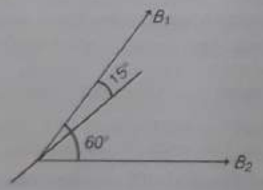
(ii) The frequency of revolution of the electron in its circular orbit is

$$f = \frac{eB}{2\pi m} = \frac{1.6\times10^{-19}\times8.0\times10^{-4}}{2\times3.14\times9.1\times10^{-31}}$$
$$= 0.22\times10^{8}\,Hz$$
$$= 22\,MHz$$ [1]

Or

Let one of the magnetic fields be B_1 and other be B_2. Angle between B_1 and B_2 is 60°.

Given, $B_1 = 1.2\times10^{-2}\,T$



Dipole is in equilibrium at an angle 15° from B_1 or $60° - 15° = 45°$ from B_2.

Torque on dipole due to magnetic field B_1,

$$\tau_1 = M\times B_1 \sin 15° \quad \ldots(i)$$ [1]

where, M is the magnetic moment.

Torque on dipole due to magnetic field B_2,

$$\tau_2 = M\times B_2 \sin 45° \quad \ldots(ii)$$

As, dipole is in the equilibrium, then $\tau_1 = \tau_2$ [1]

From Eqs. (i) and (ii), we get

$$M\times B_1 \sin 15° = M\times B_2 \sin 45°$$
$$\frac{1.2\times10^{-2}\times\sin 15°}{\sin 45°} = B_2$$
$$B_2 = \frac{1.2\times10^{-2}\times0.2588}{0.7071}$$
$$= 4.4\times10^{-3}\,T$$

Thus, the magnitude of the other field is $4.4\times10^{-3}\,T$. [1]

28. For shortest wavelength of Lyman series,

$$n_1 = 1, n_2 = \infty$$
$$\Rightarrow \quad \frac{1}{\lambda_L} = R\left[\frac{1}{1^2} - \frac{1}{\infty^2}\right] = R;\ \lambda_L = \frac{1}{R}$$ [1]

For shortest wavelength of Balmer series,

$$n_1 = 2, n_2 = \infty$$
$$\frac{1}{\lambda_B} = R\left[\frac{1}{2^2} - \frac{1}{\infty^2}\right] = \frac{R}{4};\ \lambda_B = \frac{4}{R}$$ [1]

For shortest wavelength of Paschen series,

$$n_1 = 3, n_2 = \infty$$
$$\frac{1}{\lambda_P} = R\left[\frac{1}{3^2} - \frac{1}{\infty^2}\right] = \frac{R}{9};\ \lambda_P = \frac{9}{R}$$

Hence, $\lambda_L : \lambda_B : \lambda_P = 1 : 4 : 9$ [1]

29. Fringe width in Young's double slit experiment, $\beta = \frac{D\lambda}{d}$

When apparatus is immersed in liquid, only wavelength of light (λ) changes.

Wavelength of light in liquid, $\lambda' = \frac{\lambda}{n}$, where n = refractive index of liquid.

Initial fringe width, $\beta = \frac{D\lambda}{d}$ ...(i)

Fringe width in liquid, $\beta' = \frac{D\lambda'}{d}$ ...(ii) [1]

On dividing Eq. (ii) by Eq. (i), we get

$$\frac{\beta'}{\beta} = \frac{\lambda'}{\lambda}$$

or $$\frac{\beta'}{\beta} = \frac{\frac{\lambda}{n}}{\lambda} = \frac{1}{n} \text{ or } \beta' = \frac{\beta}{n}$$

The new fringe width, $\beta' = \frac{2.0}{1.33}\,mm = 1.5\,mm$ [1]

Location of maxima on the screen is given by

$y_n = \frac{D}{d}(n\lambda)$, where D is the distance between screen and slits and d is distance between the slits.

When apparatus is immersed in the liquid, wavelength of light decreases. Thus, maxima gets closer to centre of the screen. [1]

Or

For the convex lens, $f = +10\,cm$, $u = -30\,cm$

From lens formula, $\frac{1}{v} = \frac{1}{f} + \frac{1}{u} = \frac{1}{10} - \frac{1}{30} = \frac{1}{15}$

or $$v = +15\,cm$$

This image is at 10 cm from the concave lens which is placed at 5 cm from the convex lens. It will act as a virtual object.

For concave lens, $u = +10\,cm$, $f = -10\,cm$ [1]

$$\therefore \quad \frac{1}{v} = \frac{1}{f} + \frac{1}{u} = \frac{1}{-10} + \frac{1}{10} = 0$$

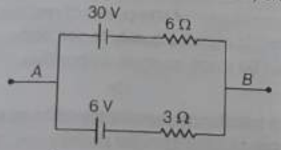
or $$v = \infty$$

Hence, the final image is formed at infinity. [1]

Net focal length of the system when they are kept in contact is given by

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{+10} + \left(\frac{1}{-10}\right)$$
$$= \frac{1}{10} - \frac{1}{10} = 0$$
$$\Rightarrow \quad f = \infty$$ [1]

30. As, one terminal of cells is connect to A and another to B, hence these cells can be replaced by single cells as (ignoring the internal resistance of cells) shown below



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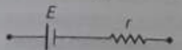


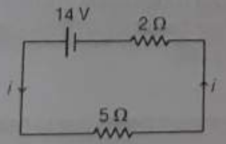
where, E = emf or potential of cells in parallel combination.

$$\Rightarrow \quad E = \frac{\frac{E_1}{r_1} + \frac{E_2}{r_2}}{\frac{1}{r_1} + \frac{1}{r_2}} = \frac{\frac{30}{6} + \frac{6}{3}}{\frac{1}{6} + \frac{1}{3}} = \frac{5+2}{\frac{1}{2}} = 14\,V$$ [1½]

and r = the equivalent resistance in parallel combination

$$\Rightarrow \quad r = \frac{r_1 r_2}{r_1 + r_2} = \frac{3\times6}{3+6} = 2\Omega$$ [1/2]

Thus the circuit becomes



$\therefore$ Current in circuit, $i = \frac{14}{5+2} = 2A$

and potential difference acrosts A and B,

$$V_A - V_B = 14 - 2i = 14 - 4 = 10\,V$$ [1]

31. (i) Smaller value of angle of refraction $\left(\frac{\theta}{2}\right)$ as compared to angle of incidence (θ) indicates bending of light towards the normal in second medium.

Hence, medium 2 is optically denser. [1]

(ii) By Snell's law, ${}^1\mu_2 = \frac{\sin i}{\sin r} = \frac{\sin\theta}{\sin(\theta/2)}$

$$= \frac{2\sin(\theta/2)\cos(\theta/2)}{\sin(\theta/2)} = 2\cos(\theta/2)$$ [1]

Also, $${}_1\mu_2 = \frac{c_1}{c_2}$$

$$\therefore \quad \frac{c_1}{c_2} = 2\cos(\theta/2)$$

or $$\theta = 2\cos^{-1}\left(\frac{c_1}{2c_2}\right)$$ [1]

(iii) As, ${}^a\mu_g = \frac{1}{\sin i_c} = \frac{1}{\sin 45°} = \sqrt{2} = 1.414$

Refractive index of glass with respect to water will be

$${}^w\mu_g = \frac{{}^a\mu_g}{{}^a\mu_w} = \frac{1.414}{1.33}$$ [1]

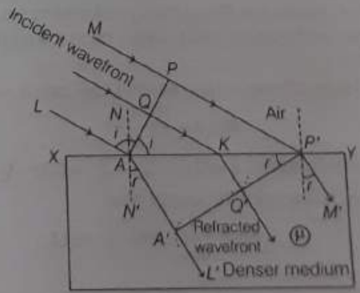
When glass slab is immersed in water, then critical angle i_c' is given by

$$\sin i_c' = \frac{1}{{}^w\mu_g} = \frac{1}{\frac{1.414}{1.33}}$$
$$= \frac{1.33}{1.414} = 0.9432$$
$$\therefore \quad i_c' = 70°\,36'$$ [1]

Or

(i) **Huygens' Principle** Each point on the primary wavefront acts as a source of secondary wavelets, sending out disturbance in all directions in a similar manner as the original source of light does. The new position of the wavefront at any instant (called secondary wavefront) is the envelope of the secondary wavelets at that instant. [1]

Refraction on the Basis of Wave Theory



Consider any point Q on the incident wavefront PA. Suppose, when disturbance from point P on incident wavefront PA reaches point P' on the refracted wavefront, the disturbance from point Q reaches Q' on the refracted wavefront $P'A'$. Since $P'A'$ represents the refracted wavefront, the time taken by light to travel from a point on incident wavefront to the corresponding point on refracted wavefront should always be the same. Now, time taken by light to go from Q to Q' will be

$$t = \frac{QK}{c} + \frac{KQ'}{v} \quad \text{...(i)}$$

Here, c = speed of light in air

and v = speed of light in denser medium.

In right angled ΔAQK, $\angle QAK = i$ ...(ii)

$\therefore \quad QK = AK \sin i$

In right angled $\Delta P'Q'K$,

$\angle Q'P'K = r$ and $KQ' = KP' \sin r$ ...(iii)

[2]

Substituting values of Eqs. (ii) and (iii) in Eq. (i), we get

$$t = \frac{AK \sin i}{c} + \frac{KP' \sin r}{v}$$

or $$t = \frac{AK \sin i}{c} + \frac{(AP' - AK)\sin r}{v} \quad [\because KP' = AP' - AK]$$

or $$t = \frac{AP'}{v}\sin r + AK\left(\frac{\sin i}{c} - \frac{\sin r}{v}\right) \quad \text{...(iv)}$$

The rays from different points on the incident wavefront will take the same time to reach the corresponding points on the refracted wavefront, i.e. t is given by Eq. (iv) is independent of AK. It will happen, so if $\frac{\sin i}{c} - \frac{\sin r}{v} = 0$

$$\Rightarrow \quad \frac{\sin i}{\sin r} = \frac{c}{v}$$

$$\Rightarrow \quad \mu = \frac{\sin i}{\sin r}$$

This is the Snell's law for refraction of light. [1]

(ii) The frequency of reflected and refracted light remains same as the frequency of incident light because frequency only depends on the source of light. [1]

32. (i) **Condition for resonance to occur in series *L-C-R* as circuit**

For resonance, the current produced in the circuit and emf applied must always be in the same phase. [1]

Phase difference (ϕ) in series L-C-R circuit is given by

$$\tan\phi = \frac{X_C - X_L}{R}$$

For resonance, $\phi = 0 \Rightarrow X_C - X_L = 0$ or $X_C = X_L$

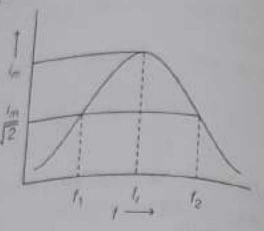
If ω_r is resonant frequency, then

$$X_C = \frac{1}{\omega_r C} \text{ and } X_L = \omega_r L$$

$$\therefore \quad \frac{1}{\omega_r C} = \omega_r L \Rightarrow \omega_r = \frac{1}{\sqrt{LC}}$$

Linear resonant frequency, $f_r = \frac{\omega_r}{2\pi} = \frac{1}{2\pi\sqrt{LC}}$ [1]

(ii) The graph of variation of peak current i_m with frequency is shown below



Half power frequencies are the frequencies on either side of resonant frequency for which current reduces half of its maximum value. In the above figure, f_1 and f_2 are half power frequencies.

Quality Factor (Q) The quality factor is defined as the ratio of resonant frequency to the width of half power frequencies.

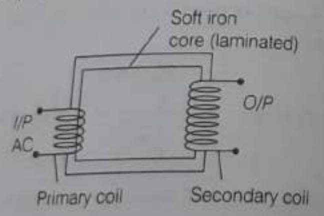
$$\text{i.e. } Q = \frac{\omega_r}{\omega_2 - \omega_1} = \frac{f_r}{f_2 - f_1} = \frac{\omega_r L}{R} = \frac{1}{\omega_r CR}$$

[2]

It is an indicator of sharpness of resonance. It has no unit. To improve quality factor, ohmic resistance should be made as small as positive. [1]

Or

(i) If in a transformer, secondary coil has a greater number of turns than the primary coil, the voltage is stepped up. This type of arrangement is called a step-up transformer as shown below



[1]

Working When alternating current source is connected to the ends of primary coil, the current changes continuously in the primary coil, due to which the magnetic flux linked with the secondary coil changes continuously. Therefore, the alternating emf of same frequency is developed across the secondary coil. [2]

(ii) **Losses**

(i) Eddy current losses due to heating of iron core.

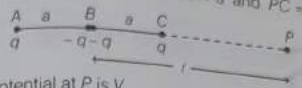
(ii) Flux leakage losses between primary and secondary coil. [1]

(iii) If a transformer is 100% efficient, Input power = Output power

i.e. $\quad V_p I_p = V_s I_s \Rightarrow \frac{V_s}{V_p} = \frac{I_p}{I_s}$

So, any increase in voltage is accompanied by a corresponding decrease in current such that the product VI remains constant. So, there is no violation. [1]

33. Given, $AC = 2a$, $BP = r$, $AP = r + a$ and $PC = r - a$



Let potential at P is V.

V = Potential at P due to A + Potential at P due to B + Potential at P due to C [1]

$$V = \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{AP} - \frac{2q}{BP} + \frac{q}{CP}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\cdot q\left[\frac{1}{r+a} - \frac{2}{r} + \frac{1}{r-a}\right]$$

$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{r(r-a) - 2(r+a)(r-a) + r(r+a)}{r(r+a)(r-a)}\right] \quad [1]$$

$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{r^2 - ra - 2r^2 + 2a^2 + r^2 + ra}{r(r^2 - a^2)}\right]$$

$$= \frac{q\cdot 2a^2}{4\pi\varepsilon_0 r(r^2 - a^2)} = \frac{q\cdot 2a^2}{4\pi\varepsilon_0\cdot r\cdot r^2\left(1 - \frac{a^2}{r^2}\right)}$$

According to the question, if $\frac{r}{a} >> 1$ or $a << r$

$$\therefore \quad V \approx \frac{q\cdot 2a^2}{4\pi\varepsilon_0\cdot r^3} \Rightarrow V \propto \frac{1}{r^2}$$

As we know that electric potential at a point on axial line due to an electric dipole,

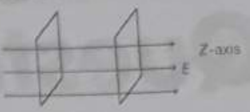
$$V \propto \frac{1}{r^2}$$

In case of electric monopole, $V \propto \frac{1}{r}$ [2]

Then, we conclude that for larger r, the electric potential due to a quadruple is inversely proportional to the cube of the distance r, while due to an electric dipole it is inversely proportional to the square of r and is inversely proportional to the distance r for a monopole. [1]

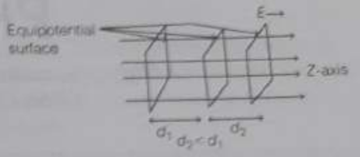
Or

(i) (a) As, the electric field is constant in the z-direction, the equipotential surfaces are normal to the field, i.e. in xy-plane. The equipotential surfaces are equidistant from each other.



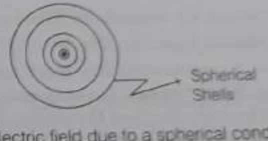
[1]

(b) As, the electric field increases in the direction of Z-axis, the equipotential surface is normal to Z-axis, i.e. in xy-plane and they become closer and closer as the field increases.



[1]

(c) As, a single positive charge is placed at origin, the equipotential surfaces are concentric spheres with origin as centre.



[1]

(ii) (a) Electric field due to a spherical conductor is given by

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$$

I. At a point 18 cm from the centre of conductor, electric field.

$$\Rightarrow \quad E = 9\times 10^9 \times \frac{16\times 10^{-7}}{(18\times 10^{-2})^2}$$

$$= 4.4\times 10^4 \text{ NC}^{-1}$$

II. Electric field inside the conductor is zero. [1½]

(b) Electric potential at the surface

= Electric potential inside

$$= \frac{kQ}{R} = \frac{9\times 10^9 \times 1.6\times 10^{-7}}{(12\times 10^{-2})}$$

$$= 12\times 10^4 \text{ V}$$

So, both for (i) and (ii), the electric potential is 12×10^4 V. [1/2]