Date: 04/03/2024

Question Paper Code

55/5/2

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Time: 3 hrs.

Class-XII

Max. Marks: 70

PHYSICS (Theory)

(CBSE 2024)

SECTION-A

1. An ammeter and a voltmeter are connected in series to a battery. Their readings are noted as '*A*' and '*V*' respectively. If a resistor is connected in parallel with the voltmeter, then

   (A) *A* will increase, *V* will decrease.
   (B) *A* will decrease, *V* will increase.
   (C) Both *A* and *V* will decrease.
   (D) Both *A* and *V* will increase.

Answer (A)

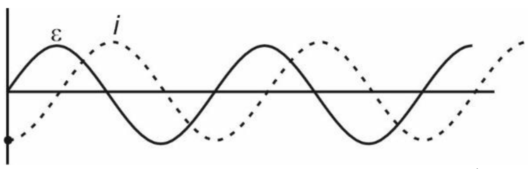
Sol. When the resistor is connected in parallel with the voltmeter then the equivalent resistance of the circuit decreases hence the current flowing through circuit increases. As a result of increase in the current through circuit the ammeter reading increases while the reading of voltmeter decreases as potential difference across it decreases.

2. An ac voltage is applied across an ideal inductor. The current in it

   (A) Leads the voltage by $\left(\frac{1}{4}\right)$ cycle.
   (B) Lags the voltage by $\left(\frac{1}{4}\right)$ cycle.
   (C) Leads the voltage by $\left(\frac{1}{2}\right)$ cycle.
   (D) Lags the voltage by $\left(\frac{1}{2}\right)$ cycle.

Answer (B)

Sol. Let the A.C voltage applied across inductor be $\varepsilon = \varepsilon_0 \sin(\omega t)$



$\Rightarrow$ Current through inductor, $i = i_0 \sin\left(\omega t - \frac{\pi}{2}\right)$

i.e., current lags by a phase difference of $\frac{\pi}{2}$

hence it lags the voltage by $\frac{1}{4}$ cycle

3. An iron needle is kept near a strong bar magnet. It will experience

   (A) A force of attraction and no torque.
   (B) A force of attraction and a torque.
   (C) A torque and no force.
   (D) Neither a force nor a torque.

Answer (B)

Sol. The iron needle experiences a non-uniform field due to a bar magnet. There is induced magnetic moment in the nail hence it experiences an attractive force.

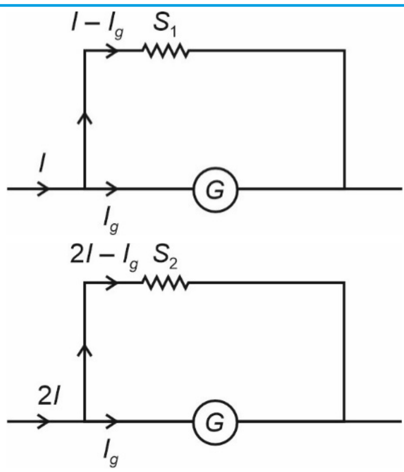
Due to presence of magnetic moment, it will experience a net torque also.

4. A galvanometer shows full scale deflection for a current I_g. If a shunt of resistance S_1 is connected to the galvanometer, it gets converted into an ammeter of range $(0 - I)$. When resistance of the shunt is made S_2, its range becomes $(0 - 2I)$. Then $\left(\frac{S_1}{S_2}\right)$ is

   (A) $\frac{I + I_g}{I - I_g}$
   (B) $\frac{I - I_g}{I + I_g}$
   (C) $\frac{2I - I_g}{I - I_g}$
   (D) $\frac{I - I_g}{2I - I_g}$

Answer (C)

Sol.



$\Rightarrow \dfrac{S_1}{G} = \dfrac{I_g}{I - I_g}$ ... (1)

$\Rightarrow \dfrac{S_2}{G} = \dfrac{I_g}{2I - I_g}$ ...(2)

From equations (1) and (2)

$\dfrac{S_1}{S_2} = \dfrac{2I - I_g}{I - I_g}$

5. A coil of area of cross-section 0.5 m^2 is placed in a magnetic field acting normally to its plane. The field varies as $B = 0.5t^2 + 2t$, where B is in tesla and t in seconds. The emf induced in the coil at $t = 1$ s is

(A) 0.5 V (B) 1.0 V

(C) 1.5 V (D) 3.0 V

Answer (C)

Sol. $\phi = BA\cos 0° \Rightarrow \phi = B \times A = (0.5t^2 + 2t)(0.5)$

$\phi = 0.25t^2 + t, \quad \varepsilon = \dfrac{-d\phi}{dt} \Rightarrow \varepsilon = -[0.5t + 1]$

$\Rightarrow \varepsilon_{\text{at } t=1} = -(0.5 \times 1 + 1) = -1.5$ V

6. A pure Si crystal having 5×10^{28} atoms m^{-3} is dopped with 1 ppm concentration of antimony. If the concentration of holes in the doped crystal is found to be 4.5×10^9 m^{-3}, the concentration (in m^{-3}) of intrinsic charge carriers in Si crystal is about

(A) 1.2×10^{15} (B) 1.5×10^{16}

(C) 3.0×10^{15} (D) 2.0×10^{16}

Answer (B)

Sol. Number of atoms in pure Si crystal = 5×10^{28} atoms m^{-3}.

$\Rightarrow$ Number of electrons, $n_e = \dfrac{5 \times 10^{28}}{10^6} \Rightarrow n_e = 5 \times 10^{22}\ m^{-3}$

$\Rightarrow$ Hole concentration = $4.5 \times 10^9\ m^{-3}$

We know that,

$(n_i)^2 = n_e \times n_h = 5 \times 10^{22} \times 4.5 \times 10^9$

$(n_i)^2 = 22.5 \times 10^{31} = 225 \times 10^{30}$

$n_i = 15 \times 10^{15} = 1.5 \times 10^{16}$

7. The potential energy between two nucleons inside a nucleus is minimum at a distance of about

(A) 0.8 fm (B) 1.6 fm

(C) 2.0 fm (D) 2.8 fm

Answer (A)

Sol. The potential energy is minimum at a distance r_0 of about 0.8 fm.

8. In a Young's double-slit experiment in air, the fringe width is found to be 0.44 mm. If the entire setup is immersed in water $\left(n = \frac{4}{3}\right)$, the fringe width will be

(A) 0.88 mm (B) 0.59 mm

(C) 0.33 mm (D) 0.44 mm

Answer (C)

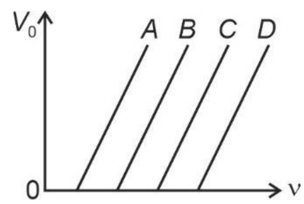
Sol. $\beta = \frac{\lambda D}{d}$

When the whole setup is immersed in water then

$$\lambda' = \frac{\lambda}{\mu} = \frac{\lambda}{\frac{4}{3}} = \frac{3\lambda}{4}$$

$$\Rightarrow \quad \beta' = \frac{\lambda' D}{d} = \frac{3}{4}\frac{\lambda D}{d} = \frac{3}{4}\times\beta = \frac{3}{4}\times 0.44 = 0.33 \text{ mm}$$

9. The variation of the stopping potential (V_0) with the frequency (ν) of the incident radiation for four metals A, B, C and D is shown in the figure. For the same frequency of incident radiation producing photo-electrons in all metals, the kinetic energy of photo-electrons will be maximum for metal

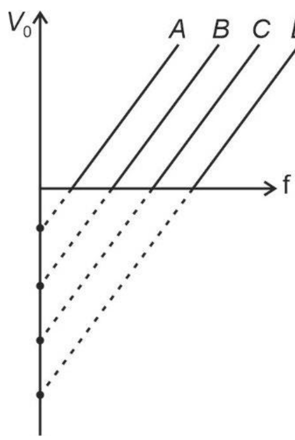


(A) A (B) B

(C) C (D) D

Answer (A)

Sol.



As per the variation shown above, for the same frequency of incident radiation the work function for metal A is minimum hence the kinetic energy of photo electrons will be maximum for metal A.

10. The energy of an electron in the ground state of hydrogen atom is –13.6 eV. The kinetic and potential energy of the electron in the first excited state will be

(A) –13.6 eV, 27.2 eV (B) –6.8 eV, 13.6 eV

(C) 3.4 eV, –6.8 eV (D) 6.8 eV, –3.4 eV

Answer (C)

Sol. $(T.E)_{\text{ground state}} = -13.6$ eV

$(T.E)_{\text{first excited state}} = \frac{-13.6}{4} = -3.4$ eV

$(P.E)_{\text{first excited state}} = -3.4 \times 2 = -6.8$ eV

$(K.E)_{\text{first excited state}} = -(-3.4 \text{ eV}) = 3.4$ eV

11. The electromagnetic waves used to purify water are

(A) Infrared rays
(B) Ultraviolet rays
(C) X-rays
(D) Gamma rays

Answer (B)

Sol. Ultraviolet rays are used to kill germs in water purifiers.

12. The focal lengths of the objective and the eyepiece of a compound microscope are 1 cm and 2 cm respectively. If the tube length of the microscope is 10 cm, the magnification obtained by the microscope for most suitable viewing by relaxed eye is :

(A) 250
(B) 200
(C) 150
(D) 125

Answer (D)

Sol. When the image is formed at infinity,

$$m = \frac{L}{f_o}\left[\frac{D}{f_e}\right]$$

$$\Rightarrow \quad m = \frac{10}{1} \times \frac{25}{2} = 125$$

For Questions **13** to **16**, two statements are given – one labelled Assertion (A) and other labelled Reason (R). Select the correct answer to these questions from the options as given below.

(A) If both Assertion (A) and Reason (R) are true and Reason (R) is correct explanation of Assertion (A).

(B) If both Assertion (A) and Reason (R) are true and Reason (R) is not the correct explanation of Assertion (A).

(C) If Assertion (A) is true but Reason (R) is false.

(D) If both Assertion (A) and Reason (R) are false.

13. **Assertion (A) :** An alpha particle is moving towards a gold nucleus. The impact parameter is maximum for the scattering angle of 180°.

Reason (R) : The impact parameter in an alpha particle scattering experiment does not depend upon the atomic number of the target nucleus.

Answer (D)

Sol. When $\theta = 180°$, then the impact parameter would be zero.

$$b = \frac{ze^2 \cot\left(\frac{\theta}{2}\right)}{4\pi\varepsilon_0 E}$$

$\Rightarrow$ Impact parameter is directly proportional to atomic number of target nucleus.

Hence both assertion and reason are incorrect.

14. **Assertion (A) :** In a Young's double-slit experiment, interference pattern is not observed when two coherent sources are infinitely close to each other.

Reason (R) : The fringe width is proportional to the separation between the two sources.

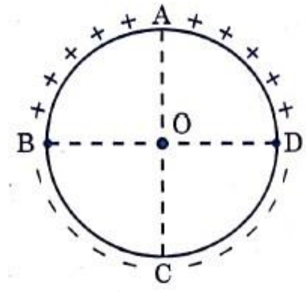
Answer (C)

Sol. $\beta = \frac{\lambda D}{d}$ as $d \to 0$, $\beta \to \infty \Rightarrow$ since the fringe width is tending to infinity hence when two sources are placed infinitely close then interference pattern would not be observed. Hence assertion is correct.

$\beta = \frac{\lambda D}{d} \Rightarrow \beta \propto \frac{1}{d} \Rightarrow$ Reason incorrect.

15. **Assertion (A) :** Equal amount of positive and negative charges are distributed uniformly on two halves of a thin circular ring as shown in figure. The resultant electric field at the centre *O* of the ring is along *OC*.

Reason (R) : It is so because the net potential at *O* is not zero.



Answer (C)

Sol. The net field at point *O* is along *OC* due to vector sum of all the fields.

Hence assertion is correct.

The potential at centre of ring will be zero.

Hence reason is incorrect.

16. **Assertion (A) :** The energy of a charged particle moving in a magnetic field does not change.

Reason (R) : It is because the work done by the magnetic force on the charge moving in a magnetic field is zero.

Answer (A)

Sol. Yes, the energy of the moving charged particle in a magnetic field does not change as no work is done by the magnetic force on the charged particle. Hence both assertion and reason are correct and reason is correct explanation.

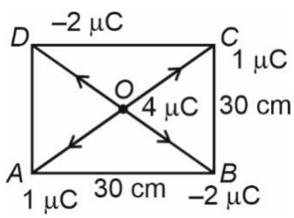
SECTION-B

17. (a) Four-point charges of 1 μC, –2 μC, 1 μC and –2 μC are placed at the corners *A*, *B*, *C* and *D* respectively, of a square of side 30 cm. Find the net force acting on a charge of 4 μC placed at the centre of the square.

OR

(b) Three-point charges, 1 pC each, are kept at the vertices of an equilateral triangle of side 10 cm. Find the net electric field at the centroid of triangle.

Sol. (a)



$$\vec{F}_{OA} = \frac{K \times 1 \times 4 \times 10^{-12}}{\left(\frac{0.3\sqrt{2}}{2}\right)^2}$$

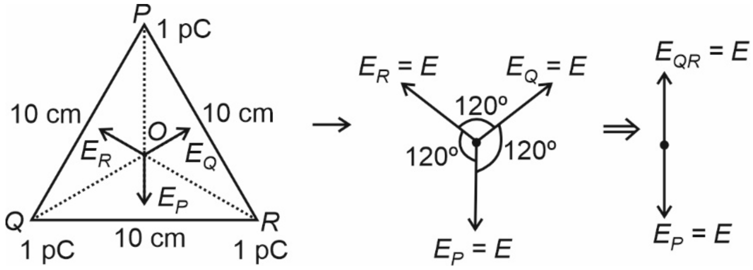
$$F_{OC} = -F_{OA}$$

$$\vec{F}_{OB} = \frac{K \times 4 \times 2 \times 10^{-12}}{\left(\frac{0.3\sqrt{2}}{2}\right)^2}$$

$$F_{OB} = -F_{OD}$$

$\therefore$ Net force on 4 μC due to charges at corners is zero.

(b)

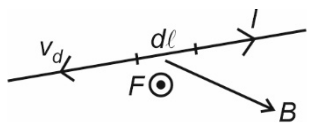


$\therefore$ Net electric field at the centroid of equilateral triangle will be zero.

$E_{net} = 0$

18. Derive an expression for magnetic force F acting on a straight conductor of length L carrying current I in an external magnetic field B. Is it valid when the conductor is in zig-zag form? Justify.

Sol. Consider a conducting wire, carrying a current I, is placed in a magnetic field B. Consider a small element dl of the wire. The free electrons drift with a speed v_d opposite to the direction of the current. The relation between the current I and the drift speed v_d is



$I = jA = nev_dA$ ...(i)

Here A is the area of cross-section of the wire and n is the number of free electrons per unit volume. Each electron experiences an average magnetic force

$f_m = -e\vec{v}_d \times B$

The number of free electrons in the small element considered is $nAd\ell$. Thus, the magnetic force on the wire of length dl is

$d\vec{F} = (nAd\ell)(-e\vec{v}_d \times \vec{B})$

If we denote the length $d\ell$ along the direction of the current by $d\ell$, the above equation becomes

$dF = nAev_d d\ell \times B$

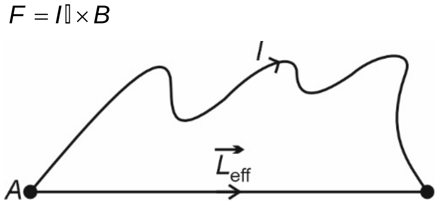
Using (i)

$dF = Id\ell \times B$

The quantity $Id\ell$ is called a current element.

If a straight wire of length ℓ carrying a current I is placed in a uniform magnetic field B, the force on it is

$F = I\ell \times B$



Yes, it is valid for zig-zag wire as,

$F_m = I(L_{eff} \times B)$

For zig-zag wire effective length of wire is considered between initial and final point (L_{eff} shortest distance between initial and final point).

19. The radius of curvature of a convex mirror is 30 cm. It forms an image of an object which is half the size of the object. Find the separation between the object and the image.

Sol.

$R = 2f$

$30 = 2f$

$f = 15$ cm

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

$$\frac{v}{15} = 1 + \frac{v}{u}$$

Given $\frac{h_i}{h_0} = \frac{1}{2}$

$$\frac{-v}{u} = \frac{1}{2}$$

$$v = \frac{15}{2}\text{ cm}$$

$u = -v \times 2$

$u = -15$ cm

So, separation

$$d = 15 + \frac{15}{2}$$

$$= \frac{3}{2} \times 15$$

$$= \frac{45}{2}\text{ cm}$$

20. Calculate the energy released/absorbed (in MeV) in the nuclear reaction:

$${}_1^1H + {}_1^3H \longrightarrow {}_1^2H + {}_1^2H$$

Given: $m\left({}_1^1H\right) = 1.007825$ u

$m\left({}_1^2H\right) = 2.014102$ u

$m\left({}_1^3H\right) = 3.016049$ u

Sol. ${}_1^1H + {}_1^3H \longrightarrow {}_1^2H + {}_1^2H$

Mass of products = 2(2.014102) u

= 4.028204 u

Mass of reactants = (3.016049 + 1.007825) u

= 4.023874 u

Mass of products > Mass of reactants

So, energy is absorbed.

$\Delta m = 0.00433$

$E_{abs} = 0.00433 \times 931$ MeV.

= 4.03123 MeV

21. A proton of energy 1.6 MeV approaches a gold nucleus (Z = 79). Find the distance of its closest approach.

Sol. $r = \frac{1}{4\pi\varepsilon_0}\frac{ze^2}{\text{K.E.}}$

K.E. = $1.6 \times 10^{6} \times 1.6 \times 10^{-19}$

= 2.56×10^{-13} J

$$r = \frac{9 \times 10^{9} \times 79 \times (1.6 \times 10^{-19})^2}{2.56 \times 10^{-13}}$$

$$= \frac{9 \times 10^{9} \times 79 \times 1.6 \times 1.6 \times 10^{-38}}{2.56 \times 10^{-13}}$$

= $9 \times 79 \times 10^{-16} = 711 \times 10^{-16}$ m

$R \approx 71.1$ fm

SECTION-C

22. A photosensitive surface of work function 2.1 eV is irradiated by radiation of wavelength 150 nm. Calculate (i) the threshold wavelength, (ii) energy (in eV) of an incident photon, and (iii) maximum kinetic energy of emitted photoelectron.

Sol. Given,

(i) Threshold wavelength :

$\phi_0 = 2.1\,\text{eV}$

$$E = \frac{12400}{\lambda} \Rightarrow \lambda = \frac{12400}{2.1} = 5904.7\ \text{Å}$$

(ii) Energy of an incident photon

λ = 150 nm = 1500 Å

Energy of photon

$$E = \frac{12400}{\lambda(\text{Å})}\text{eV}$$

$$E = \frac{12400}{1500}\text{eV} = 8.26\ \text{eV}$$

(iii) Einstein's photoelectric equation: $E = \phi_0 + KE_{max}$

$KE_{max} = E - \phi_0$

$= 8.26 - 2.1$

$KE_{max} = 6.16$ eV

23. (a) (i) State Lenz's Law. In a closed circuit, the induced current opposes the change in magnetic flux that produced it as per the law of conservation of energy. Justify.

(ii) A metal rod of length 2 m is rotated with a frequency 60 rev/s about an axis passing through its centre and perpendicular to its length. A uniform magnetic field of 2T perpendicular to its plane of rotation is switched-on in the region. Calculate the e.m.f. induced between the centre and the end of the rod.

OR

(b) (i) State and explain Ampere's circuital law.

(ii) Two long straight parallel wires separated by 20 cm, carry 5 A and 10 A current respectively, in the same direction. Find the magnitude and direction of the net magnetic field at a point midway between them.

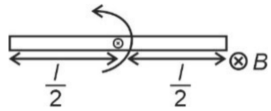
Sol. (a) (i) Lenz's law states that the direction of the electric current induced in a conductor by a changing magnetic field is such that the magnetic field created by the induced current opposes change in the initial magnetic field.

In a closed circuit, there will be extra effort to work against opposing force. This extra effort is transformed into electrical energy which satisfy the conservation of energy.

(ii) Given l = 2 m, $\omega = 60 \times 2\pi$ rad/s = 120π rad/s

B = 2 T

Emf between the centre and the end of the rod is given by



$$\varepsilon = \frac{B\omega r^2}{2}$$

$$\varepsilon = \frac{2 \times 120\pi \times (1)^2}{2} = 120\pi\,\text{volt}$$

OR

(b) (i) Ampere's circuital law–Ampere's law states that the path integral or line integral over a closed loop in any magnetic field B produced by a current distribution is given by

$$\int B \cdot dl = \mu_0 I$$

where I refers to the current enclosed by the loop.

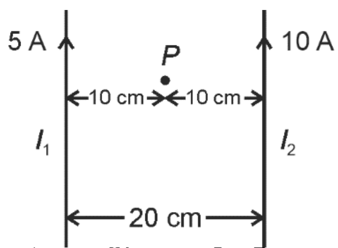
If B is directed along the tangent to every point on the perimeter L of a closed curve and is constant in magnitude along perimeter then

$BL = \mu_0 I_e$

where I_e is the net current enclosed by the closed circuit.

(ii) Net magnetic field at point P

$$B_{net} = B_{\text{due to } I_1} + B_{\text{due to } I_2}$$



$$\vec{B}_1 = \frac{\mu_0}{4\pi}\frac{2I_1}{r} = \frac{\mu_0}{4\pi}\frac{2\times 5}{10^{-1}} \text{ (perpendicularly downward)}$$

$$\vec{B}_2 = \frac{\mu_0}{4\pi}\frac{2I_2}{r} = \frac{\mu_0}{4\pi}\frac{2\times 10}{10^{-1}} \text{ (perpendicularly upward)}$$

$$\text{Hence, } B_{\text{net}} = \frac{\mu_0}{4\pi}\frac{2}{10^{-1}}(10-5) \text{ (perpendicularly upward)}$$

$$= \frac{\mu_0}{4\pi} \times \frac{2\times 5}{10^{-1}}$$

$$= 10^{-7} \times \frac{10}{10^{-1}}$$

$= 10^{-5}$ T

24. (i) Define 'temperature coefficient of resistance' of a metal.

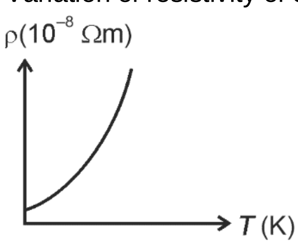
(ii) Show the variation of resistivity of copper with rise in temperature.

(iii) The resistance of a wire is 10 Ω at 27 °C. Find its resistance at –73 °C. The temperature coefficient of resistance of the material of the wire is 1.70×10^{-4} °C^{-1}.

Sol. (i) Temperature coefficient of resistance is defined as resistance change factor per degree celsius of temperature change.

$$\alpha = \frac{\Delta R}{R_0 \Delta T}$$

(ii) Variation of resistivity of copper with temperature



(iii) Given,

$R_1 = 10\ \Omega$ at $T_1 = 27°C$

$\alpha = 1.7 \times 10^{-4}\ °C^{-1}$

$R_2 = ?$ at $T_2 = -73°C$

$R_2 = R_1(1 + \alpha\Delta T)$

$R_2 = 10[1 + 1.7 \times 10^{-4}(-73 - 27)]$

$R_2 = 10[1 - 1.7 \times 10^{-4} \times 100]$

$R_2 = 10[1 - .017]$

$= 10 \times 0.983 = 9.83\ \Omega$

25. Name the part of the electromagnetic spectrum which are

(i) stopped by face mask worn by welders.

(ii) used in detectors in Earth satellites.

(iii) used in 'short-wave band' in communication.

Also write the order of wavelengths, in each case.

Sol. (i) UV rays produced by welding arcs are stopped by face mask worn by welders. 1 nm < λ_{UV} < 400 nm

(ii) Infrared detectors are used in Earth satellites. 700 nm < λ_{IR} < 1 mm

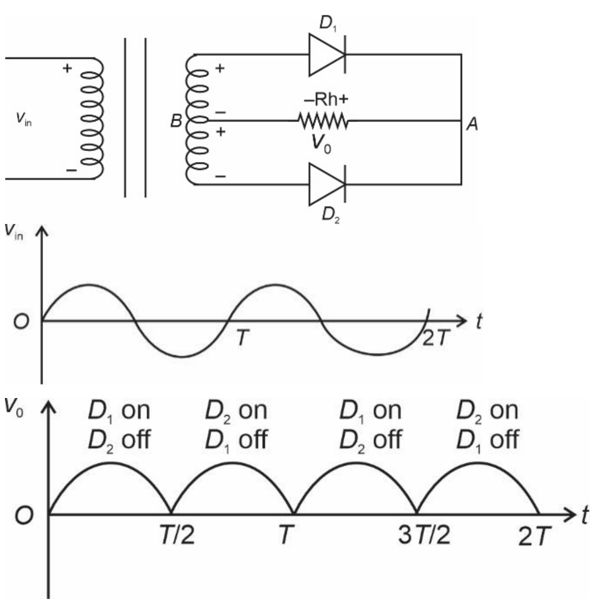
(iii) Radio waves are used in short wave band communication. λ_R > 0.1 m

26. (a) Explain the characteristics of a *p-n* junction diode that makes it suitable for its use as a rectifier.

(b) With the help of a circuit diagram, explain the working of a full wave rectifier.

Sol. (a) An ideal *p-n* junction diode is conducting or act as short circuit. When forward bias is applied and it becomes open at reverse bias. It acts as switch. So this allow current to pass in one direction and block in opposite direction

(b) Full wave rectifier : It convert A.C. current to D.C. current



During positive cycle diode D_1 is on and D_2 is off. The current will flow through load resistance (R_L) from *A* to *B.* For negative cycle diode D_2 is on and D_1 is off but direction of current through load resistance (R_L) is still from *A* to *B*. The output is always in same direction irrespective direction of input.

27. Explain the following, giving reasons:
   (a) A doped semiconductor is electrically neutral.
   (b) In a p-n junction under equilibrium, there is no net current.
   (c) In a diode, the reverse current is practically not dependent on the applied voltage.

Sol. (a) In a doped semiconductor the total positive charge is equal to total negative charge so its is electrically neutral
   (b) Under equilibrium condition the diffusion current is equal to the drift current in magnitude and they are in opposite direction. So net current is zero
   (c) Under reverse bias, drift current is very small because it is due to the flow of minority charge carrier. Increasing voltage does increase the minority carrier density so current remains constant with respect to applied voltage.

28. An electron moving with a velocity $\vec{v} = (1.0\times10^7\ \text{m/s})\,\hat{i} + (0.5\times10^7\ \text{m/s})\,\hat{j}$ enters a region of uniform magnetic field $B = (0.5\ \text{mT})\,\hat{j}$. Find the radius of the circular path described by it. While rotating; does the electron trace a linear path too? If so, calculate the linear distance covered by it during the period of one revolution.

Sol. Given, $\vec{v} = (1.0\times10^7\ \hat{i}) + (0.5\times10^7\ \hat{j})$

$B = (0.5\times10^{-3}\ \hat{j})$ tesla

$m_e = 9.1 \times 10^{-31}$ kg

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

Radius of path, $R = \dfrac{mv_\perp}{qB}$

Where $v_\perp$ is component of velocity perpendicular to magnetic field.

$$R = \frac{9.1\times10^{-31}\ \times1\times10^{7}}{1.6\times10^{-19}\ \times0.5\times10^{-3}} = \frac{9.1\times10^{-31+7+22}}{0.8}$$

$R = 11.375 \times 10^{-2}$ m = 11.375 cm

Since the electron has perpendicular and parallel components of velocity, it will move on helical path, hence it will trace a linear path too virtually. The linear distance covered by it during one period of revolution is equal to pitch (P)

$$P = v_{\parallel} \times T \qquad \left\{T = \frac{2\pi m}{qB}\right\}$$

$$P = \frac{0.5\times10^{7}\ \times2\pi\times9.1\times10^{-31}}{1.6\times10^{-19}\ \times0.5\times10^{-3}} = \frac{18.2\pi\ \times10^{-24}}{1.6\times10^{-22}}$$

$= 11.375\pi \times 10^{-2}$ m or 11.375π cm

29. A prism is an optical medium bounded by three refracting plane surfaces. A ray of light suffers successive refractions on passing through its two surfaces and deviates by a certain angle from its original path. The refractive index of the material of the prism is given by $\mu = \sin\left(\dfrac{A+\delta m}{2}\right)/\sin\dfrac{A}{2}$. If the angle of incidence on the second surface is greater than an angle called critical angle, the ray will not be refracted from the second surface and is totally internally reflected.
   (i) The critical angle for glass is θ_1 and that for water is θ_2. The critical angle for glass-water surface would be (given ${}_a\mu_g = 1.5$, ${}_a\mu_w = 1.33$)
   (A) less than θ_2 (B) between θ_1 and θ_2
   (C) greater than θ_2 (D) less than θ_1

(ii) When a ray of light of wavelength λ and frequency ν is refracted into a denser medium

(A) λ and ν both increase. (B) λ increases but ν is unchanged.

(C) λ decreases but ν is unchanged. (D) λ and ν both decrease.

(iii) (a) The critical angle for a ray of light passing from glass to water is minimum for

(A) red colour (B) blue colour

(C) yellow colour (D) violet colour

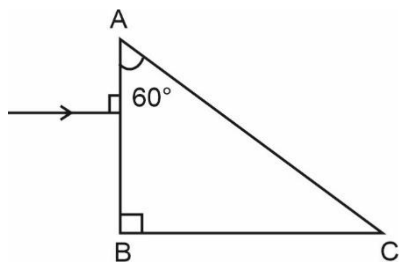
OR

(iv) (b) Three beams of red, yellow and violet colours are passed through a prism, one by one under the same condition. When the prism is in the position of minimum deviation, the angles of refraction from the second surface are r_R, r_Y and r_V respectively. Then

(A) $r_V < r_Y < r_R$ (B) $r_Y < r_R < r_V$

(C) $r_R < r_Y < r_V$ (D) $r_R = r_Y = r_V$

(iv) A ray of light is incident normally on a prism ABC of refractive index $\sqrt{2}$, as shown in figure. After it strikes face AC, it will



(A) go straight undeviated (B) just graze along the face AC

(C) refract and go out of the prism (D) undergo total internal reflection

Sol. (i) **Answer (C)**

$$\sin\theta_1 = \frac{1}{\mu_g} = \frac{2}{3} \Rightarrow \theta_1 = \sin^{-1}\left(\frac{2}{3}\right)$$

$$\sin\theta_2 = \frac{1}{\mu_w} = \frac{3}{4} \Rightarrow \theta_2 = \sin^{-1}\left(\frac{3}{4}\right)$$

$$\sin\theta_3 = \frac{\mu_w}{\mu_g} = \frac{4\times 2}{3\times 3} = \frac{8}{9} \Rightarrow \theta_3 = \sin^{-1}\left(\frac{8}{9}\right)$$

$\theta_3 > \theta_2 > \theta_1$

(ii) **Answer (C)**

ν = frequency remain unchanged for light ray in different medium.

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

(iii) (a) **Answer (D)**

$$\sin\theta_C = \frac{\mu_w}{\mu_g} = \frac{1}{\mu}$$

Refractive index of glass water is maximum for violet colour. So, critical angle is minimum for violet colour.

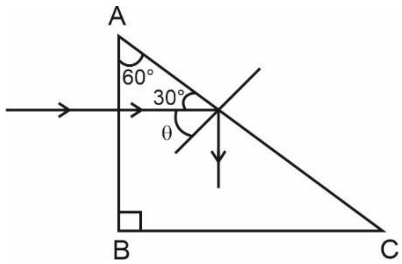
OR

(iv) (b) **Answer (C)**

For second surface, angle of emergence is angle of refraction.

So $r_V > r_Y > r_R$

(iv) **Answer (D)**



$\theta = 60°$

$\sin\theta_C = \frac{1}{\mu} = \frac{1}{\sqrt{2}} \Rightarrow \theta_C = 45°$

$\theta > \theta_C$, so the ray will undergo total internal reflection at AC.

30. Dielectrics play an important role in design of capacitors. The molecules of a dielectric may be polar or non-polar. When a dielectric slab is placed in an external electric field, opposite charges appear on the two surfaces of the slab perpendicular to electric field. Due to this an electric field is established inside the dielectric.

The capacitance of a capacitor is determined by the dielectric constant of the material that fills the space between the plates. Consequently, the energy storage capacity of a capacitor is also affected. Like resistors, capacitors can also be arranged in series and/or parallel.

(i) Which of the following is a polar molecule?

(A) O_2 (B) H_2

(C) N_2 (D) HCl

(ii) Which of the following statements about dielectrics is correct?

(A) A polar dielectric has a net dipole moment in absence of an external electric field which gets modified due to the induced dipoles.

(B) The net dipole moments of induced dipoles is along the direction of the applied electric field.

(C) Dielectrics contain free charges.

(D) The electric field produced due to induced surface charges inside a dielectric is along the external electric field.

(iii) When a dielectric slab is inserted between the plates of an isolated charged capacitor, the energy stored in it:

(A) Increases and the electric field inside it also increases.

(B) Decreases and the electric field also decreases.

(C) Decreases and the electric field increases.

(D) Increases and the electric field decreases.

(iv) (a) An air-filled capacitor with plate area A and plate separation d has capacitance C_0. A slab of dielectric constant K, area A and thickness $\left(\frac{d}{5}\right)$ is inserted between the plates. The capacitance of the capacitor will become

(A) $\left[\frac{4K}{5K+1}\right]C_0$ (B) $\left[\frac{K+5}{4}\right]C_0$

(C) $\left[\frac{5K}{4K+1}\right]C_0$ (D) $\left[\frac{K+4}{5K}\right]C_0$

OR

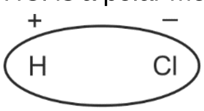
(iv) (b) Two capacitors of capacitances 2 C_0 and 6 C_0 are first connected in series and then in parallel across the same battery. The ratio of energies stored in series combination to that in parallel is

(A) $\frac{1}{4}$ (B) $\frac{1}{6}$

(C) $\frac{2}{15}$ (D) $\frac{3}{16}$

Sol. (i) Answer (D)

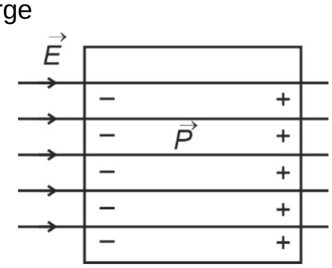
HCl is a polar molecule



because its one end is positive, other end is negative.

(ii) Answer (B)

The net dipole moment of induced dipoles is along the direction of the applied electric field because dipole moment is along –ve to +ve charge



(iii) Answer (B)

For isolated charge capacitor Q is constant

$C' = KC$

$V' = \frac{Q}{C'} = \frac{Q}{KC} = \frac{V}{K}$

$E' = \frac{E}{K}$

The electric field decreases

$U' = \frac{1}{2}\frac{Q^2}{C'} = \frac{1}{2}\frac{Q^2}{KC} = \frac{U}{K}$

The energy also decreases

(iv) (a) Answer (C)

$$C' = \frac{\varepsilon_0 A}{d - t + \frac{t}{K}} \text{ and } C_0 = \frac{\varepsilon_0 A}{d}$$

$$= \frac{\varepsilon_0 A}{d - \frac{d}{5} + \frac{d}{5K}}$$

$$= \frac{\varepsilon_0 A}{\frac{4d}{5} + \frac{d}{5K}} = \frac{\varepsilon_0 A}{\frac{d}{5}\left(4 + \frac{1}{K}\right)}$$

$$= \frac{\varepsilon_0 A\, 5K}{d(4K+1)} = \frac{(5K)C_0}{4K+1}$$

(iv) (b) Answer (D)

$C_2 = 2C_0 + 6C_0 = 8C_0$

$$C_1 = \frac{2C_0(6C_0)}{2C_0 + 6C_0} = \frac{12C_0^2}{8C_0} = \frac{3}{2}C_0$$

$$\frac{U_1}{U_2} = \frac{\left(\frac{1}{2}\right)\left(\frac{3}{2}C_0\right)V^2}{\left(\frac{1}{2}\right)(8C_0)V^2}$$

$$\frac{U_1}{U_2} = \frac{3}{16}$$

SECTION-D

31. (a) (i) A plane light wave propagating from a rarer into a denser medium, is incident at an angle i on the surface separating two media. Using Huygen's principle, draw the refracted wave and hence verify Snell's law of refraction.

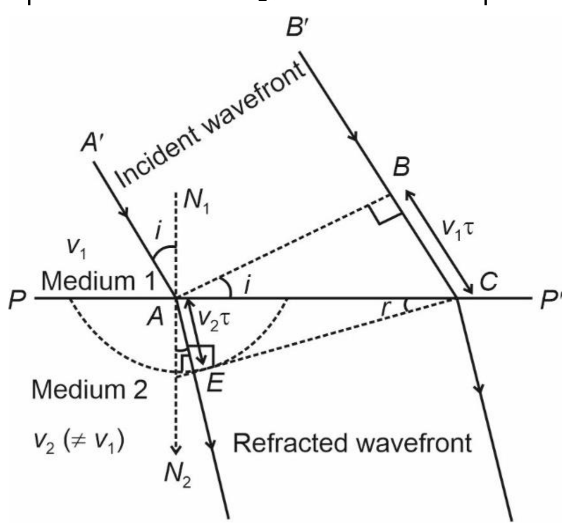
(ii) In a Young's double slit experiment, the slits are separated by 0.30 mm and the screen is kept 1.5 m away. The wavelength of light used is 600 nm. Calculate the distance between the central bright fringe and the 4th dark fringe.

OR

(b) (i) Discuss briefly diffraction of light from a single slit and draw the shape of the diffraction pattern.

(ii) An object is placed between the pole and the focus of a concave mirror. Using mirror formula, prove mathematically that it produces a virtual and an enlarged image.

Sol. (a) (i) In order to determine the shape of the refracted wavefront, we draw a sphere of radius $v_2\tau$ from the point A in the second medium. Let CE represent a tangent plane drawn from the point 'C' on to the sphere. Then $AE = v_2\tau$ and CE would represent the refracted plane wavefront.



At 'A' draw a normal N_1AN_2. In the ΔABC, AB is perpendicular to AA' and AC is the perpendicular to AN_1. We know that the angles between two lines and their perpendiculars are same.

So, the angle between AB and AC

= angle between AA' and $AN_1 = i$

In triangle AEC,

$\angle A + \angle E + \angle C = 180°$

$(90° - r) + 90° + \angle C = 180°$, So $\angle C = r$

If we now consider the triangles ABC and AEC, we obtain

$$\sin i = \frac{BC}{AC} = \frac{v_1\tau}{AC} \quad \text{and} \quad \sin r = \frac{AE}{AC} = \frac{v_2\tau}{AC}$$

Here i and r are the angles of incidence and refraction respectively.

Thus we obtain $\frac{\sin i}{\sin r} = \frac{v_1}{v_2}$

If c represents the speed of light in vacuum, then

$\mu_1 = \frac{c}{v_1}$ and $\mu_2 = \frac{c}{v_2}$ are known as the refractive indices of medium 1 and medium 2 respectively.

$\therefore \frac{\mu_2}{\mu_1} = \frac{v_1}{v_2}$; Hence $\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1}$

$\mu_1 \sin i = \mu_2 \sin r$

This is the Snell's law for refraction

(ii) Position of dark fringe $X_D = \frac{(2n-1)\lambda D}{2d}$

For fourth dark $n = 4$

$$X_D = \frac{(2\times 4-1)\lambda D}{2d}$$

$$= \left(\frac{7\lambda D}{2d}\right)$$

$D = 1.5$ m, $d = 0.30$ mm, $\lambda = 600$ nm

On putting these value in above equation

$$X_D = \frac{7\times 6\times 10^{-7}\times 1.5}{2\times 3\times 10^{-4}}$$

$= 10.5 \times 10^{-3}$ m

$= 10.5$ mm

OR

(b) (i) The bending of light from the corner of small obstacles or apertures is called diffraction of light.

Diffraction due to a Single Slit:

When a parallel beam of light is incident normally on a single slit, the beam is diffracted from the slit and the diffraction pattern consists of a very intense central maximum and secondary maxima and minima on either side alternately.

If a is width of slit and θ the angle of diffraction, then for maxima

$a\sin\theta = \left(n + \frac{1}{2}\right)\lambda \qquad n = 1, 2, 3$

The position of n^{th} minima is given by

$a\sin\theta = n\lambda$,

Where $n = \pm1, \pm2, \pm3, \ldots$ for various minima on either side of principal maxima.

Width of Central Maximum:

The width of central maximum is the separation between the first minima on either side.

The condition of minima is

$a\sin\theta = \pm n\lambda (n = 1, 2, 3, \ldots..)$.

The angular position of the first minimum (n = 1) on either side of central maximum is given by

$a\sin\theta = \pm\lambda$

$$\Rightarrow \theta = \pm \sin^{-1}\left(\frac{\lambda}{a}\right)$$

$\therefore$ Half-width of central maximum, $\theta = \sin^{-1}\left(\frac{\lambda}{a}\right)$

$\therefore$ Total width of central maximum, $\beta = 2\theta = 2\sin^{-1}\left(\frac{\lambda}{a}\right)$

Linear width : If D is the distance of the screen from slit and y is the distance of n^{th} minima from the centre of the principal maxima, then

$$\sin\theta \approx \tan\theta \approx \theta = \frac{y}{D}$$

Now,

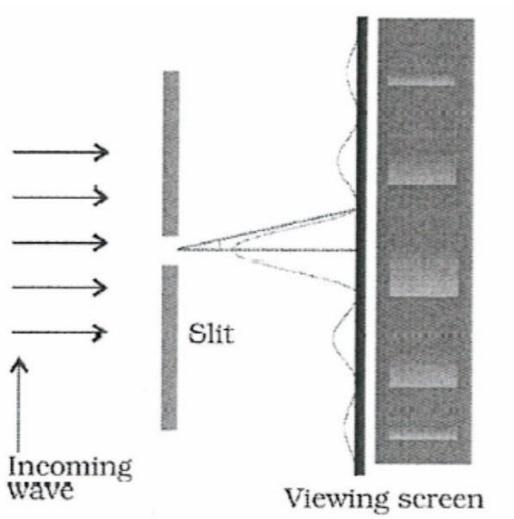
$$\lambda = a\sin\theta \approx a\theta$$

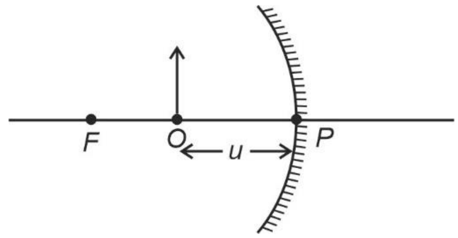
$$\theta = \frac{\lambda n}{a} = \frac{y_n}{D}$$

$$\Rightarrow y_n = \frac{n\lambda D}{a}$$

Linear half-width of central maximum, $y = \frac{\lambda D}{a}$

Total linear width of central maximum, $\beta = 2y = \frac{2\lambda D}{a}$



(ii) 

Using mirror equation

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

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

$$\therefore\ v = \frac{uf}{f-u}$$

$\because |f| > |u|$

$\therefore$ v will always be positive *i.e.,* virtual and erect

Also, magnification, $M = \dfrac{f}{u-f}$

$\because u < f$ $\therefore$ Numerator will always be greater than denominator

Hence, $M > 1$

$\therefore$ Enlarged image will be formed.

32. (a) (i) Draw equipotential surfaces for an electric dipole.

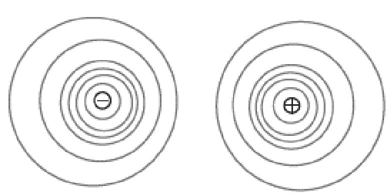
(ii) Two-point charges q_1 and q_2 are located at r_1 and r_2 respectively in an external electric field E . Obtain an expression for the potential energy of the system.

(iii) The dipole moment of a molecule is 10^{-30} Cm. It is placed in an electric field E of 10^5 V/m such that its axis is along the electric field. The direction of E is suddenly changed by 60° at an instant. Find the change in the potential energy of the dipole, at that instant.

OR

(b) (i) A thin spherical shell of radius R has a uniform surface charge density σ. Using Gauss's law, deduce an expression for electric field (i) outside and (ii) inside the shell.

(ii) Two long straight thin wires AB and CD have linear charge densities 10 μC/m, and –20 μC/m, respectively. They are kept parallel to each other at a distance 1 m. Find magnitude and direction of the net electric field at a point midway between them.

Sol. (a) (i) 

(ii) Potential energy of a charge q at r in an external field = $qV(r)$

Work done on q_1 to bringing it from infinity to r_1 against the electric field (E) = $q_1V(r_1)$

Work done on q_2 to bringing it from infinity to r_2 against the electric field (E) = $q_2V(r_2)$

Work done on q_2 against the electric field of q_1 is $\dfrac{q_1q_2}{4\pi\varepsilon_0 r_{12}}$ (where r_{12} is distance between the charges)

Potential energy of the system = the total work done in assembling the configuration

$$= q_1V(r_1) + q_2V(r_2) + \frac{q_1q_2}{4\pi\varepsilon_0 r_{12}}$$

(iii) We know that potential energy of a dipole in electric field is given by

$U = -P.E$

$U = -PE\cos\theta$

$U_i = -PE\cos\theta$

$= -PE$

$U_f = -PE\cos 60°$

$= -\frac{PE}{2}$

$\Delta U = U_f - U_i$

$= \frac{-PE}{2} + PE$

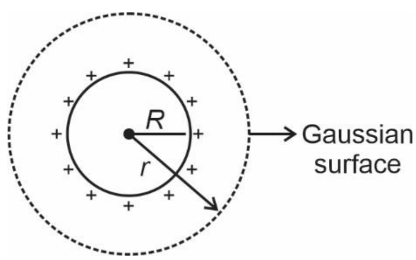
$= \frac{PE}{2}$

$= \frac{10^{-30} \times 10^{5}}{2}$

$= 5 \times 10^{-26}$ J

OR

(b) (i) Consider a thin spherical shell of radius R [Surface charge density $\Rightarrow \sigma$]



Charge on sphere

Here $q = \sigma A$

$q = \sigma 4\pi R^2$

For : $r > R$

Using Gauss's law

$\int \vec{E} \cdot \vec{ds} = \frac{q_{in}}{\varepsilon_0}$

$E\int ds \cos 0° = \sigma A$

$E(4\pi r^2) = \sigma(4\pi R^2)$

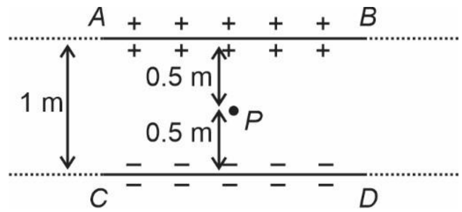
$\boxed{E = \frac{\sigma R^2}{r^2}}$

For : $r < R$

$\int \vec{E} \cdot \vec{ds} = \frac{q_{in}}{\varepsilon_0}$

But $q_{in} = 0$ [shell]

$\boxed{\therefore E = 0}$

(ii) 

Net electric field at P, $E = E_{CD} + E_{AB}$

$$= \frac{k\lambda_1}{2r} + \frac{k\lambda_2}{2r}$$

$$E = \frac{9\times10^9}{2\left(\frac{1}{2}\right)}[10+20]\times10^{-6}$$

$E = 9 \times 30 \times 10^3$

$E = 270 \times 10^3$

$\boxed{E = 2.7\times10^5 \text{ N/C}}$

33. (a) (i) You are given three circuit elements X, Y and Z. They are connected one by one across a given ac source. It is found that V and I are in phase for element X. V leads I by $\left(\frac{\pi}{4}\right)$ for element Y while I leads V by $\left(\frac{\pi}{4}\right)$ for element Z. Identify elements X, Y and Z.

(ii) Establish the expression for impedance of circuit when elements, X, Y and Z are connected in series to an ac source. Show the variation of current in the circuit with the frequency of the applied ac source.

(iii) In a series LCR circuit, obtain the conditions under which (i) impedance is minimum and (ii) wattless current flows in the circuit.

OR

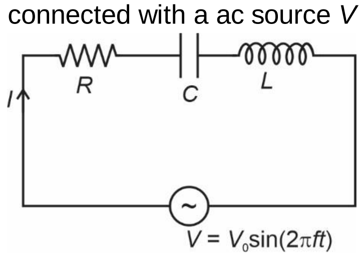
(b) (i) Describe the construction and working of a transformer and hence obtain the relation for $\left(\frac{V_s}{V_p}\right)$ in terms of number of turns of primary and secondary.

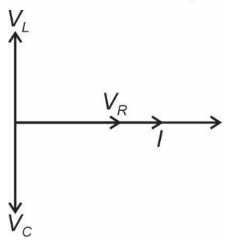
(ii) Discuss four main causes of energy loss in a real transformer.

Sol. (a) (i)
- If an ac source applied across resistor, then current will be in phase of voltage.
- If an ac source applied across the capacitor, then current will lead with voltage.
- If an ac source applied across the inductor, then current will lag with voltage.

So X is resistor, Y is inductor and Z is capacitor.

(ii) Consider a resistor of resistance R, capacitor of capacitance C and an inductor of inductance L is connected with a ac source $V = V_0\sin(2\pi ft)$ in series given below





From Phasor diagram

$$V = \sqrt{V_R^2 + (V_L - V_C)^2}$$

$$V = \sqrt{(IR)^2 + I^2(X_L - X_C)^2}$$

$V = IZ$

$$IZ = \sqrt{(IR)^2 + I^2(X_L - X_C)^2}$$

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$X_L = 2\pi fL$

$$X_C = \frac{1}{2\pi fL}$$

$$Z = \sqrt{R^2 + \left(2\pi fL - \frac{1}{2\pi fC}\right)^2}$$

(iii) (a) We know that impedance

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

For impedance $Z = Z_{min}$

$X_L = X_C$

$$2\pi fL = \frac{1}{2\pi fC}$$

$$f = \frac{1}{2\pi}\frac{1}{\sqrt{LC}}$$

Hence, for minimum impedance

$X_L = X_C$ or $Z = R$

(b) Wattless current $I_1 = I\sin\phi$

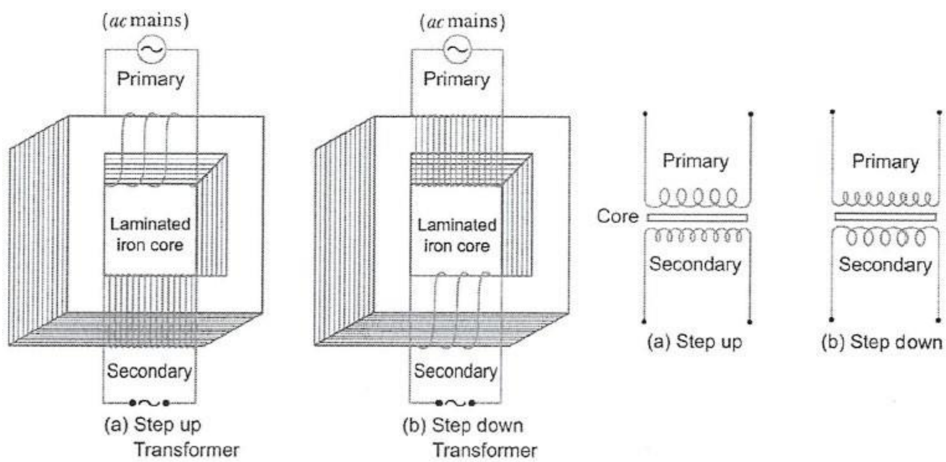
And $\cos\phi = \dfrac{R}{Z}$

For Wattless current

$\cos\phi = 0$, it means $R = 0$.

OR

(b) (i) **Construction:** It consists of laminated core of soft iron, on which two coils of insulated copper wire are separately, wound. These coils are kept insulated from each other and from the iron-core, but are coupled through mutual induction. The number of turns in these coils are different. Out of these coils one coil is called primary coil and other is called the secondary coil. The terminals of primary coils are connected to ac mains and the terminals of the secondary coil are connected to external circuit in which alternating current of desired voltage is required. Transformers are of two types:



(a) **Step up Transformer:** It transforms the alternating low voltage to alternating high voltage and in this the number of turns in secondary coil is more than that in primary coil (*i.e.*, $N_S > N_P$).

(b) **Step down Transformer:** It transforms the alternating high voltage to alternating low voltage and in this the number of turns in secondary coil is less than that in primary coil (*i.e.*, $N_S < N_P$).

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.

Let N_P be the number of turns in primary coil, N_S the number of turns in secondary coil and ϕ the magnetic flux linked with each turn. We assume that there is no leakage of flux so that the flux linked with each turn of primary coil and secondary coil is the same. According to Faraday's laws the emf induced in the primary coil.

$$\varepsilon_P = -N_P \frac{\Delta\phi}{\Delta t} \quad \ldots\text{(i)}$$

and emf induced in the secondary coil.

$$\varepsilon_S = -N_S \frac{\Delta\phi}{\Delta t} \quad \ldots\text{(ii)}$$

From (i) and (ii)

$$\frac{\varepsilon_S}{\varepsilon_P} = \frac{N_S}{N_P} \quad \ldots\text{(iii)}$$

For step up transformer $\varepsilon_S > \varepsilon_P$ as $N_S > N_P$

For step down transformer $\varepsilon_S < \varepsilon_P$ as $N_S < N_P$

(ii) Energy Losses and Efficiency of a Transformer

(a) **Copper Losses:** When current flows in primary and secondary coils, heat is produced. The power loss due to Joule's heating in coils will be i^2R, where R is resistance and i is the current.

(b) **Iron Losses (Eddy currents):** The varying magnetic flux produces eddy currents in iron-core, which leads to dissipation of energy in the core of transformer. This is minimised by using a laminated iron core or by cutting slots in the plate.

(c) **Flux Leakage:** In actual transformer, the coupling of primary and secondary coils is never perfect, *i.e.*, the whole of magnetic flux generated in primary coil is never linked up with the secondary coil. This causes loss of energy.

(d) **Hysteresis Loss**: The alternating current flowing through the coils magnetises and demagnetises the iron core repeatedly. The complete cycle of magnetisation and demagnetisation is termed as hysteresis. During each cycle some energy is dissipated. However, this loss of energy is minimised by choosing silicon-iron core having a thin hysteresis loop.

❑ ❑ ❑