Solved Question Paper
2016
Class – XII
Subject – Physics
All India: Set – III

Time allowed: 3 hours **Maximum Marks: 70**

General Instructions:

(a) All questions are compulsory.

(b) There are 26 questions in all. Question number 1 to 5 carry one mark each, question number 6 to 10 carry two marks each, question number 11 to 22 carry three marks each, question number 23 carry four marks and question number 24 to 26 carry 5 marks each.

(c) There is no overall choice. However, internal choices have been provided in some questions.

(d) You may use the following values of physical constants wherever necessary:

$$c = 3 \times 10^{8}\text{m/s}$$
$$h = 6.63 \times 10^{-34}\text{Js}$$
$$e = 1.6 \times 10^{-19}\text{C}$$
$$\mu_0 = 4\pi \times 10^{-7}\ \text{T m A}^{-1}$$
$$\varepsilon_0 = 8.854 \times 10^{-12}\ \text{C}^2\text{N}^{-1}\text{m}^{-2}$$
$$\frac{1}{4\pi\varepsilon_0} = 9 \times 10^{9}\ \text{N m}^2\text{C}^{-2}$$
$$m_e = 9.1 \times 10^{-31}\ \text{kg}$$
$$\text{Mass of neutron} = 1.675 \times 10^{-27}\ \text{kg}$$
$$\text{Mass of proton} = 1.673 \times 10^{-27}\ \text{kg}$$
$$\text{Avogadro's number} = 6.023 \times 10^{23}\ \text{per gram mole}$$
$$\text{Boltzmann constant} = 1.38 \times 10^{-23}\ \text{JK}^{-1}$$

Question1: Why does sun appear red at sunrise and sunset?

Sol:

At the time of sun rise and sun set, light from the sun has to pass maximum distance through the earth's atmosphere. As, wavelength of red colour is maximum in comparison of other colours of visible spectrum and amount of scattering is inversely proportional wavelength of light, therefore red colour is scattered least and enter our eyes.

Question2: Name the essential components of a communication system.

Sol:

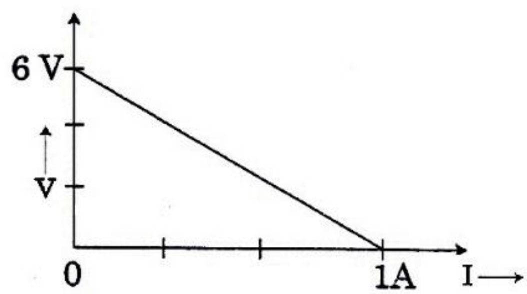
Essential components of a communication system are:
Information source, transmitter, communication channel, receiver,

Question3: In what way is the behavior of a diamagnetic material different from that of a paramagnetic, when kept in an external magnetic field?

Sol:

When diamagnetic substances are placed in external magnetic field, are feebly magnetized opposite to the direction of magnetic field.
When paramagnetic substances are placed in external magnetic field, are feebly magnetized in the direction of magnetic field.

Question4: The plot of the variation of Potential difference across a combination of three identical cells in series, versus current is shown below. What is the emf and internal resistance of each cell?



Sol:

Let E and r be the emf and internal resistance of the combination of cell and E' and r' be the emf and internal resistance of each cell.

If V is the terminal potential difference then,

$V = E - I\,r$ …(i) [where I is the current]

When, $I = 0$ then $E = V$,

From the graph, when $I = 0$, $E = 6$ V.

As, there are three cells so,

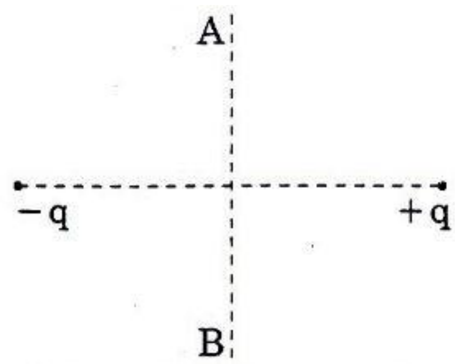
$E = 3\,E' \Rightarrow E' = 2$ V.

When, $V = 0$ then, $E = I r \Rightarrow r = E/I \Rightarrow r = 6/1 = 6\ \Omega$.

It is given that cells are connected in series, therefore the combined resistance of the cells is given by: $r' = r/3 \Rightarrow r' = 6/3 = 2\ \Omega$.

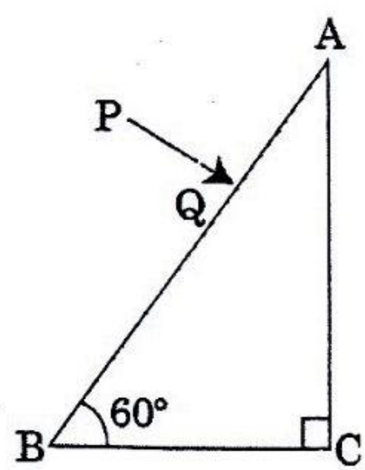
Therefore, emf of each cell is 2 V and internal resistance of each cell is 2 Ω.

Question5: A charge 'q' is moved from a point A above a dipole of dipole moment 'p' to a point B below the dipole in equatorial plane without acceleration. Find the work done in the process.



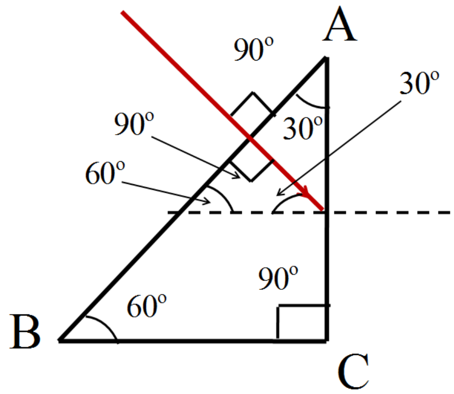
Sol:
Net potential (ΔV) at any point on equatorial plane of a dipole is zero.
As, AB lies in the equatorial plane of the dipole, therefore the work done in moving charge (q) from A to B without acceleration is q(ΔV) = 0.

Question6: A ray PQ incident normally on the refracting face BA is refracted in the prism BAC made of material of refractive index 1.5. Complete the path of ray through the prism. From which face will the ray emerge? Justify your answer.



Sol:

Here, ray PQ is falling normally on face BA of the prism. Therefore, the ray will not deviate while passing from face BA of the prism as shown in the figure given below.



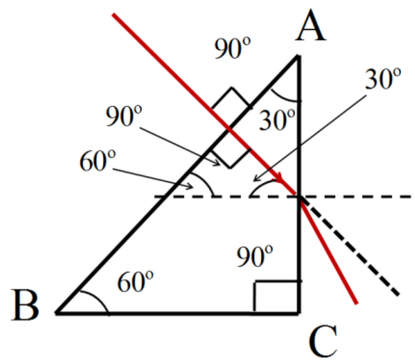
After passing through face AB ray falls on face AC making an angle 30^o with the normal. In this case, there is a possibility that the ray may suffer total internal reflection.

So, let i_c be the critical angle, then

$$\sin i_c = \frac{1}{\mu} \Rightarrow \sin i_c = \frac{1}{1.5} \Rightarrow \sin i_c = \frac{10}{15} \Rightarrow \sin i_c = 0.66 \quad ...(i)$$

Now, angle of incidence (i) of ray is 30^0 and $\sin i = \sin 30^o = 0.5 \Rightarrow \sin i = 0.5$ …(ii)

Now, $\sin i < \sin i_c \Rightarrow i < i_c$, therefore total internal reflection will not occur and will pass from face AC of the prism. The final figure is shown below.



Question7: Calculate the de-Broglie wavelength of the electron orbiting in the $n = 2$ state of hydrogen atom.

Sol:

For a electron present in n^{th} orbit of a hydrogen atom, $mvr_n = \frac{nh}{2\pi} \quad ...(i)$

So, 2^{nd} orbit of hydrogen, $mvr_2 = \frac{2h}{2\pi} \Rightarrow mvr_2 = \frac{h}{\pi} \Rightarrow mv = \frac{h}{\pi r_2} \quad ...(ii)$

From ....(i) and ....(ii), we have $\lambda = \pi r_2$

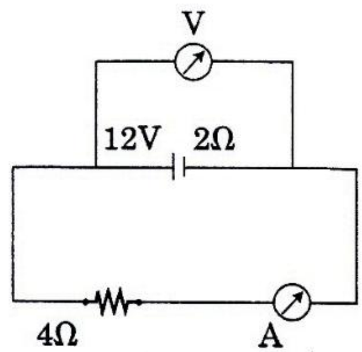
Now, radius of nth orbit of hydrogen atom is given by, $r_n = n^2 \times 5.29 \times 10^{-11}$ m.

$\therefore r_2 = (2)^2 \times 5.29 \times 10^{-11}\text{m} = 2.1 \times 10^{-10}$ m.

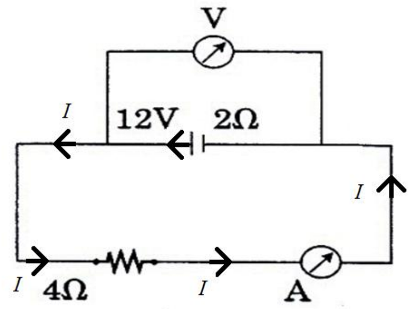
Therefore, $\lambda = \pi r_2 = \frac{22}{7} \times 2.1 \times 10^{-10}\text{m} = 6.6 \times 10^{-10}\text{m}$.

Question8: Define modulation index. Why is it kept low? What is the role of a bandpass filter?
Sol:
Modulation Index indicates the depth of modulation. The modulation index (μ) of an amplitude modulated wave is defined as the ratio of the amplitude of modulating signal (A_m) to the amplitude of carrier wave (A_c) i.e., $\mu = A_m/A_c$.
In order to avoid distortion modulation index is always kept low (less than 1).
A band pass filter rejects low and high frequencies and allows a band of frequencies to pass through.

Question9: A battery of emf 12V and internal resistance 2 Ω is connected to a 4 Ω resistor as shown in the figure.
(*a*) Show that a voltmeter when placed across the cell and across the resistor, in turn, gives the same reading.
(*b*) To record the voltage and the current in the circuit, why is voltmeter placed in parallel and ammeter in series in the circuit?



Sol:
(*a*) If V is the potential difference of the cell and E is the total emf of the cell, r is the internal resistance of the cell and I is the current drawn from cell then, $V = E - Ir$.
Here, $E = 12$ V, $r = 2\ \Omega$, $\therefore V = 12 - 2I$ … (*i*)
When voltmeter is connected across the cell then, $V = 12$
On ideal voltmeter does not draw any current from the circuit,



Applying Kirchhoff's law, we have

$12 - 4I - 2I = 0 \Rightarrow I = 2$ A ...(*ii*)

When voltmeter is connected across the cell then the reading in voltmeter will be

$V_1 = 12 - 2\ (2) \Rightarrow V_1 = 8$ V.

Now when voltmeter will be connected across the resistor then,

$V_2 = IR = 2 \times 4 = 8$ V.

Clearly both the positions will give same reading.

(*b*) A voltmeter has very high resistance, due to which it is placed parallel to the load so that it does not affect the current flowing through the circuit.

Ammeter has very little resistance due to which it is connected in series to the circuit so that all the current flows through it and it can measures the value of current accurately.

Question10: Define ionization energy.

How would the ionization energy change when electron in hydrogen atom is replaced by a particle of mass 200 times that of the electron but having the same charge?

Sol:

Ionization energy is the minimum amount of energy required to remove an electron from the outermost orbit of a neutral atom in its ground state.

(Ionization energy of hydrogen atom) $\propto$ (mass of electron), and mass of electron is constant.

But here, electron in hydrogen atom is replaced by a particle having mass 200 times of electron.

Therefore, ionization energy will be increase 200 times.

OR

Question10: Calculate the shortest wavelength of the spectral lines emitted in Balmer series.

[Given Rydberd constant, R = 10^7 m^{-1}].

Sol:

The wavelength (λ) of different spectral lines of Balmer series is given by: $\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{n^2}\right]$

For shortest wavelength of Balmer, $n_2 = \infty$.

$$\therefore \frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{\infty^2}\right] = \frac{R}{4} \Rightarrow \lambda = \frac{4}{R} \Rightarrow \lambda = 4 \times 10^{-7}\,\text{m}$$

Question11: For a CE-transistor amplifier, the audio signal voltage across the collector resistance of 2 kΩ is 2 V. Suppose the current amplification factor of the transistor is 100, find the input signal voltage and base current, if the base resistance is 1 kΩ.

Sol:

Here,

Output voltage, V_o = 2V, output resistance, R_o = 2 kΩ, base resistance, R_i = 1 kΩ, current amplification factor, β = 100.

Input signal voltage = $\frac{V_o}{V_i} = \frac{R_o}{R_i} \times \beta \Rightarrow \frac{2}{V_i} = \frac{2}{1} \times 100 \Rightarrow V_i = 10 \text{ mV}$

Now, collector current, $I_C = \frac{V_o}{R_o} = \frac{2}{2} = 1 \text{ mA}$

Base current, $I_B = \frac{I_C}{\beta} = \frac{1 \text{ mA}}{100} = 10 \ \mu\text{A}.$

Question12: (i) State law of Malus.

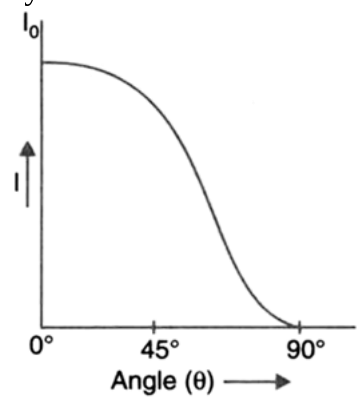
(ii) Draw a graph showing the variation of intensity (I) of polarised light transmitted by an analyser with angle (θ) between polariser and analyser.

(iii) What is the value of refractive index of a medium of polarising angle 60^0?

Sol:

(i) According to the Law of Malus, when a beam of completely plane polarised light is incident on an anlyser, the resultant intensity of light (I) transmitted from the analyser varies directly as the square of cosine of the angle (θ) between the plane of analyser and polariser i.e. $I \propto \cos^2\theta$.

(ii) Graph showing the variation of intensity (I) of polarised light transmitted by an analyser with angle (θ) between polariser and analyser.



(iii) Here, polarising angle = i_p

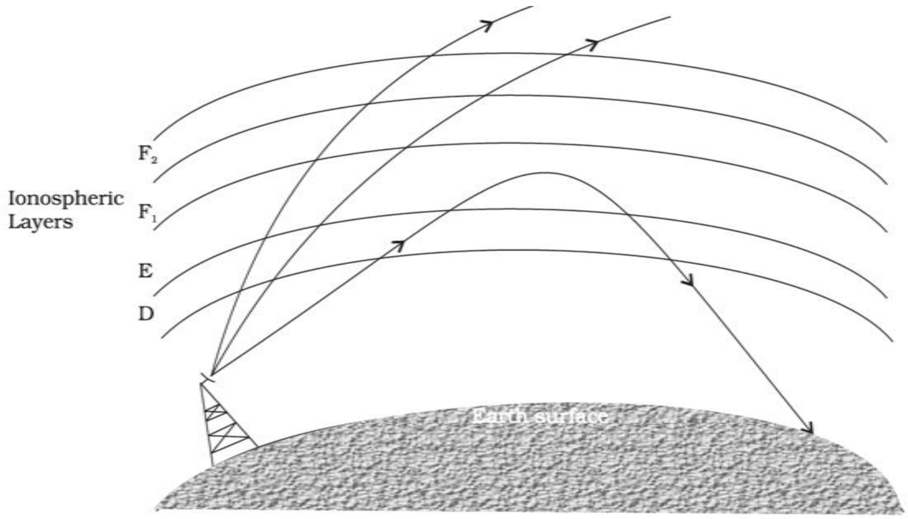
Refractive index of the medium = $\mu = \tan i_p = \tan 60^o = 1.73$.

Question13: (i) Which mode of propagation is used by shortwave broadcast services having frequency range from a few MHz upto 30 MHz? Explain diagrammatically how long distance communication can be achieved by this mode.

(ii) Why is there an upper limit to frequency of waves used in this mode?

Sol:

(i) Sky wave propagation is used to by short wave broadcast service having frequency range from a few MHz upto 30 MHz.



The ionosphere is so called because of the presence of a large number of ions or charged particles. It extends from a height of ~ 65 Km to about 400 Km above the earth's surface. Ionisation occurs due to the absorption of the ultraviolet and other high-energy radiation coming from the sun by air molecules. The ionosphere is further subdivided into D, E, F_1 and F_2 layers. The electromagnetic waves of different frequencies sent to the atmosphere are reflected back from different layers of ionosphere.

In a single reflection from the ionosphere, the radio-waves covers a distance of about 4000 km and in this way globe communication is possible with the help of sky wave propagation.

(ii) For every layer of ionosphere, there is certain maximum frequency of electromagnetic wave (called critical frequency), above which the wave is not reflected back and gets refracted through that layer. Due to this reason there is an upper limit to frequency of waves used in this mode.

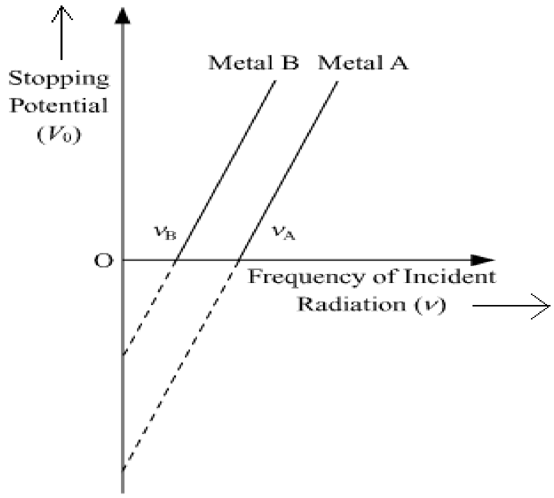
Question14: Sketch the graphs showing variation of stopping potential with frequency of incident radiations for two photosensitive materials A and B having threshold frequencies $\nu_A > \nu_B$.

(i) In which case is the stopping potential more and why?

(ii) Does the slope of the graph depend on the nature of the material used? Explain.

Sol:

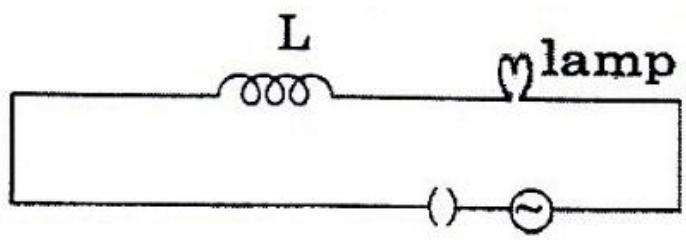
The required graph is shown below



(i) The stopping potential is inversely proportional to the threshold frequency. Therefore, the stopping potential is higher for metal B.

(ii) The slope of the graph does not depend on the nature of the material used because the slope of the graph is given by $\frac{h}{e}$ where, h is Planck's constant and e is the charge on the electron, which does not depend on the nature of the metal.

Question15: (i) When an AC source is connected to an ideal inductor show that the average power supplied by the source over a complete cycle is zero.
(ii) A lamp is connected in series with an inductor and an AC source. What happens to the brightness of the lamp when the key is plugged in and an iron rod is inserted inside the inductor? Explain.



Sol:
(i) The average power supplied by an AC source is given by, $P = V\,I\cos\phi$, where $\cos\phi$ is called power factor.

For pure inductive circuit, the phase difference between current and voltage is $\pi/2$.

$\therefore \cos\phi = \cos\frac{\pi}{2} = 0 \Rightarrow$ Average power dissipated is zero.

(ii) The bulb will start to glow dimmer. This is because on introducing soft iron core in the solenoid, its inductance (L) increases, the inductive reactance $(X_L = \omega L)$ increases and hence the current through the bulb decreases.

Question16: (i) Explain with the help of a diagram the formation of depletion region and barrier potential in a p-n junction.

(ii) Draw the circuit diagram of a half wave rectifier and explain its working.

Sol:

(i)

When a p-type semiconductor is joined with n-type semiconductor then there will be a wafer contains p-region and n-region and a metallurgical junction between p-, and n- region.

Two important processes occur during the formation of a p-n junction: *diffusion* and *drift*.

In an n-type semiconductor, the concentration of electrons (number of electrons per unit volume) is more compared to the concentration of holes.

Similarly, in a p-type semiconductor, the concentration of holes is more than the concentration of electrons.

During the formation of p-n junction, and due to the concentration gradient across p-, and n-sides, holes diffuse from p-side to n-side (p → n) and electrons diffuse from n-side to p-side (n→p).

This motion of charge carries gives rise to diffusion current across the junction.

When an electron diffuses from n → p, it leaves behind an ionized donor on n-side. This ionised donor (positive charge) is immobile as it is bonded to the surrounding atoms. As the electrons continue to diffuse from n → p, a layer of positive charge (or positive space-charge region) on n-side of the junction is developed.

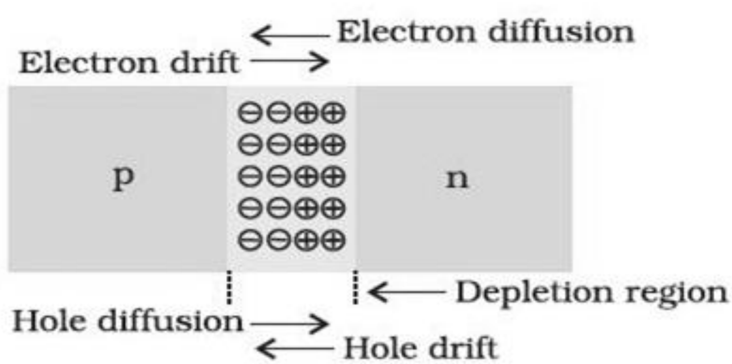
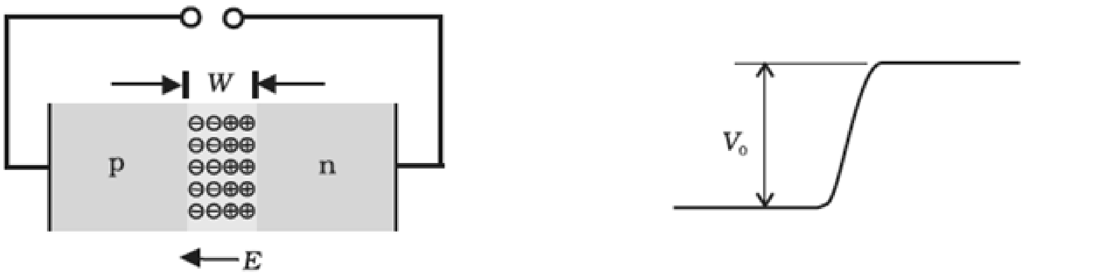


Figure: 1

Similarly, when a hole diffuses from p → n due to the concentration gradient, it leaves behind an ionised acceptor (negative charge) which is immobile. As the holes continue to diffuse, a layer of negative charge (or negative space-charge region) on the p-side of the junction is developed.

This space-charge region on either side of the junction together is known as *depletion region* as the electrons and holes taking part in the initial movement across the junction *depleted* the region of its free charges.

Due to the positive space-charge region on n-side of the junction and negative space charge region on p-side of the junction, an electric field directed from positive charge towards negative charge develops. Due to this field, an electron on p-side of the junction moves to n-side and a hole on n-side of the junction moves to p-side. The motion of charge carriers due to the electric field is called drift. Thus, a drift current, which is opposite in direction to the diffusion current starts.

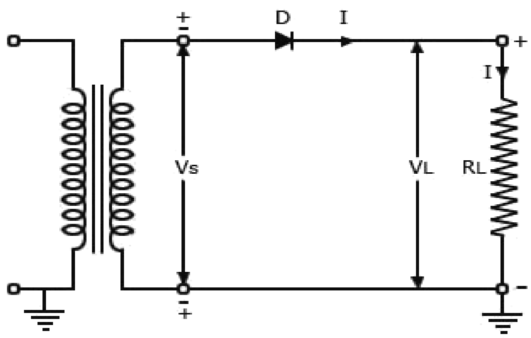


(a) Diode under equilibrium (V = 0) (b) Barrier potential under no bias

Figure: 2

Initially, diffusion current is large and drift current is small. As the diffusion process continues, the space-charge regions on either side of the junction extend, thus increasing the electric field strength and hence drift current. This process continues until the diffusion current equals the drift current. Thus a p-n junction is formed. In a p-n junction under equilibrium there is *no net* current. The loss of electrons from the n-region and the gain of electron by the p-region causes a difference of potential across the junction of the two regions. The polarity of this potential is such as to oppose further flow of carriers so that a condition of equilibrium exists. Figure 2, shows the p-n junction at equilibrium and the potential across the junction. The n-material has lost electrons, and p material has acquired electrons. The n material is thus positive relative to the p material. Since this potential tends to prevent the movement of electron from the n region into the p region, it is often called a *barrier potential*.

(ii) The circuit diagram for half wave rectifier is as shown below

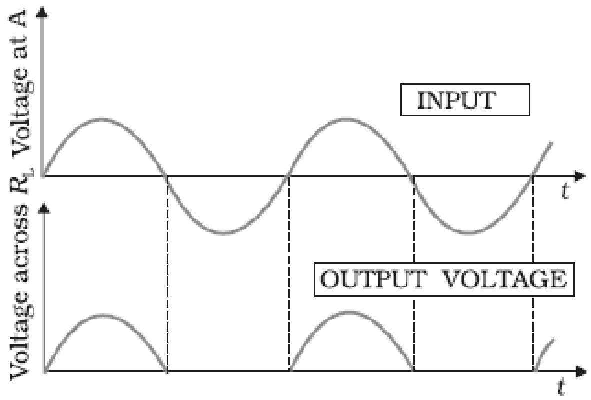


Half-Wave Rectifier

Working:

During the positive half cycle of the input a.c. The *p-n* junction is forward biased i.e. the forward current flows from *p* to *n*, the diode offers a low resistance path to the current. Thus we get output across-load i.e. a.c. input will be obtained as d.c. output

During the negative half cycle of the input a.c. The *p*-*n* junction is reversed biased i.e. the reverse current flows from *n* to p, the diode offers a high resistance path to the current. Thus we get no output across the load.
This principle is explained in the diagram given below.

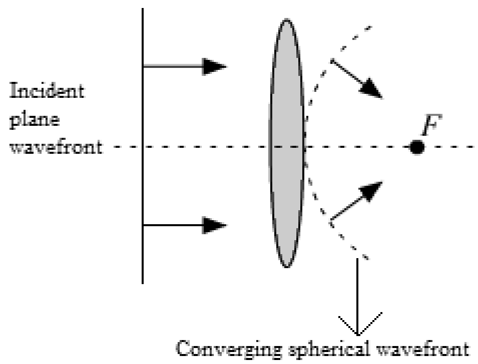


Question17: (i) Identify the part of the electromagnetic spectrum which is:
(*a*) suitable for radar system used in aircraft navigation,
(*b*) produced by bombarding a metal target by high speed electrons.
(ii) Why does a galvanometer show a momentary deflection at the time of charging or discharging a capacitor? Write the necessary expression to explain this observation.
Sol:
(i) (*a*) Microwaves, (*b*) X-rays
(ii) When a uncharged capacitor is charged, the transfer of electrons takes place until the capacitor is fully charged so for a certain amount of time there is conduction current in the capacitor. When a galvanometer is connected to the capacitor then it shows a momentary deflection. Similar phenomenon happens when a capacitor is discharged.

Question18: Define the term wave front. State Huygens's principle.
Consider a plane wave front incident on a thin convex lens. Draw a proper diagram to show how the incident wave front traverses through the lens and after refraction focuses on the focal point of the lens, giving the shape of the emergent wave front.
Sol:
A wavefront is defined as the continuous locus of all the particles of a medium, which are vibrating in the same phase.

Huygens proposed a geometrical construction to explain the propagation of a wavefront in the medium and determined the position of the wavefront after any interval of time. This is known as 'Huygens principle' and stated as follows:

(i) Every particle of the medium situated on the wavefront acts as a new wave source from which fresh waves originate. These waves are called 'secondary wavelets'.
(ii) The secondary wavelets travel in the medium in all directions with the speed of light in the medium.
(iii) The envelope of the secondary wavelets in the forward direction at any instant gives the new wavefront at that instant.



OR

Question18: Explain the following, giving reasons:
(i) When monochromatic light is incident on a surface separating two media, the reflected and refracted light both have the same frequency as the incident frequency.
(ii) When light travels from a rarer to a denser medium, the speed decreases.
Does this decrease in speed imply a reduction in the energy carried by the wave?
(iii) In the wave picture of light, intensity of light is determined by the square of the amplitude of the wave. What determines the intensity in the photon picture of light?

Sol:
(i) When light enters from one medium to another medium then, only its frequency remains constants whereas its velocity and wavelength changes.
Due to this reason, the reflected light and refracted light both has same frequency and as the incident frequency.
(ii) No, because energy carried by light wave does not depends on speed of the light wave.
(iii) The intensity in the photon picture of light is determined by the number of photons per unit area per unit time.

Question19: (a) Write the basic nuclear process involved in the emission of β^+ in a symbolic form, by a radioactive nucleus.
(b) In the reactions given below:

$(i)\ {}^{11}_{6}\mathrm{C} \rightarrow {}^{z}_{y}\mathrm{B} + x + v$

$(ii)\ {}^{12}_{6}\mathrm{C} + {}^{12}_{6}\mathrm{C} \rightarrow {}^{20}_{a}\mathrm{Ne} + {}^{c}_{b}\mathrm{He}$

Find the values of *x*, *y*, and *z* and a, b and c.

Sol:

(a) Beta-plus decay, a proton converts into neutron within the nucleus according to the following equation: $p \rightarrow n + e^{+} + \gamma$.

(b) (*i*) ${}^{11}_{6}\mathrm{C} \rightarrow {}^{z}_{y}\mathrm{B} + x + \nu$

$\Rightarrow {}^{11}_{6}\mathrm{C} \rightarrow {}^{11}_{5}\mathrm{B} + {}^{0}_{1}\beta + \nu$.

Therefore, y and z are 5 and 11 respectively. *x* is a positron.

(*ii*) ${}^{12}_{6}\mathrm{C} + {}^{12}_{6}\mathrm{C} \rightarrow {}^{20}_{a}\mathrm{Ne} + {}^{c}_{b}\mathrm{He}$

${}^{12}_{6}\mathrm{C} + {}^{12}_{6}\mathrm{C} \rightarrow {}^{20}_{10}\mathrm{Ne} + {}^{4}_{2}\mathrm{He}$.

Therefore, a, b and c are 10, 2 and 4 respectively.

Question20: Use Biot-Savart law to derive the expression for the magnetic field on the axis of a current carrying circular loop of radius R.

Draw the magnetic field lines due to a circular wire carrying current *I*.

Sol:

Expression for the Magnetic Field at the centre of circular loop:

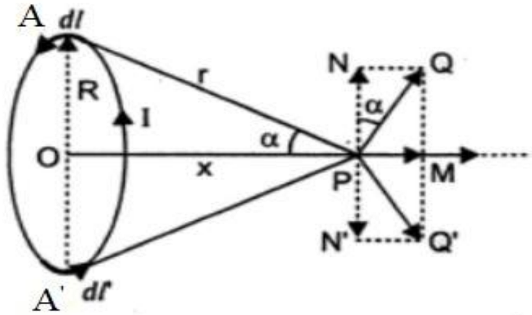
Consider a circular coil of radius R with centre O carrying a current *I*, with its plane perpendicular to the plane of the paper.

Let P be a point of observation on the axis of this circular loop at a distance *x* from its centre O.

Consider a small element of length δl of the coil at point A.

The magnitude of magnetic induction $\overrightarrow{\Delta B}$ at point P due to this element is given by,

$$\delta B = \frac{\mu_o}{4\pi}\frac{I\delta l \sin\alpha}{r^2} \quad ...(i)$$



The direction of $\overrightarrow{\delta B}$ is perpendicular to the plane containing $\vec{\delta l}$ and $\vec{r}$, which is given by right hand screw rule.

The angle between $I\vec{\delta l}$ and $\vec{r}$ is 90°. The magnitude of the magnetic induction is given by,

$$\delta B = \frac{\mu_o}{4\pi}\frac{I\delta l \sin 90^o}{r^2} = \frac{\mu_o I \delta l}{4\pi r^2} \quad ...(ii)$$

In figure $\overrightarrow{\delta B}$ has been represented by $\overrightarrow{PQ}$.

The vector $\overrightarrow{\delta B}$ can be resolved into two components, namely PM and PN along and perpendicular to the axis respectively.

Now consider another small current element 'of length $\overrightarrow{\delta I}$' at A', the magnetic induction $\overrightarrow{\delta B}$ due to this element is represented by $\overrightarrow{PQ'}$ whose magnitude is $\frac{\mu_o I \delta l'}{4\pi r^2}$ and which can be resolved into two components: PM and PN' along and perpendicular to the axis respectively. Hence, if we consider the magnetic induction produced by the whole circular coil, then by symmetry the components of magnetic induction perpendicular to the axis will be cancelled out, while those parallel to the axis will be added up.

So, the resultant magnetic induction $\vec{B}$ at axial point P is along the axis and can be calculated as follows:

The component of $\overrightarrow{\delta B}$ along the axis, $\delta B_x = \frac{\mu_o I \delta l}{4\pi r^2}\sin\alpha$

From the figure, $\sin\alpha = \frac{R}{r}$ *and* $r = (R^2 + x^2)^{1/2}$.

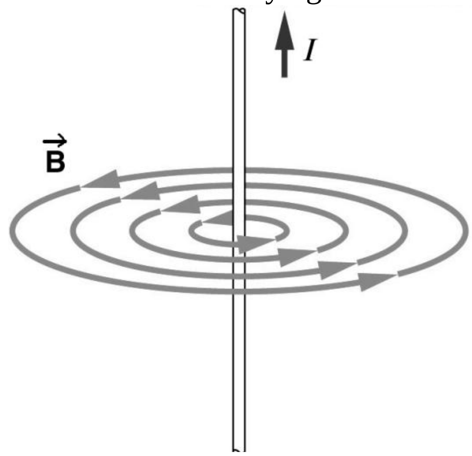
$$\Rightarrow \delta B_x = \frac{\mu_o I \delta l}{4\pi r^2}\frac{R}{r} = \frac{\mu_o IR}{4\pi r^3}\delta l = \frac{\mu_o IR}{4\pi (R^2+x^2)^{3/2}}\delta l$$

Therefore the magnitude of resultant magnetic induction axial point P due the whole circular coil is given by: $B = \oint \frac{\mu_o IR}{4\pi (R^2+x^2)^{3/2}} dl = \frac{\mu_o IR}{4\pi (R^2+x^2)^{3/2}} \oint dl$

Now, $\oint dl = \text{length of the loop} = 2\pi R$

Therefore, $\mathrm{B} = \frac{\mu_o IR}{4\pi (R^2+x^2)^{3/2}}(2\pi R) \Rightarrow \mathrm{B} = \frac{\mu_o IR^2}{2(R^2+x^2)^{3/2}}$.

The magnetic field lines due to a circular wire carrying current is shown below:



Question21: (i) Derive an expression for drift velocity of free electrons.
(ii) How does drift velocity of electrons in a metallic conductor vary with increase in temperature? Explain.

Sol:

(i) Suppose, a metallic conductor having n number of free conduction electrons. At room temperature, these free electrons are in continuous random motion.

If $u_1, u_2, \ldots u_n$ are there thermal velocities then, $\frac{u_1 + u_2 \ldots + u_n}{n} = 0 \ldots (i)$

When an electric field $(\vec{E})$ is applied then, each electron (having charge e, and mass m) will experience a force $-e\vec{E}$.

The acceleration of each electron will be, $\vec{a} = \frac{-e\vec{E}}{m}$.

At any instant of time, the velocity of electron having thermal velocity $(\vec{u_1})$ will be $(\vec{u_1} + \vec{a}t_1)$ where t_1 is the time that elapsed since its last collision with ion/atom of the conductor.

Similarly, the velocities of other electrons are $(\vec{u_2} + \vec{a}t_2)$, $(\vec{u_3} + \vec{a}t_3)$, … and $(\vec{u_n} + \vec{a}t_n)$.

$$\text{Drift velocity } (v_d) = \text{average velocity of all } n \text{ electrons} = \frac{(\vec{u_1} + \vec{a}t_1) + (\vec{u_2} + \vec{a}t_2) + \ldots (\vec{u_n} + \vec{a}t_n)}{n}$$

$$\Rightarrow v_d = \frac{(\vec{u_1} + \vec{u_2} + \vec{u_3} \ldots \vec{u_n})}{n} + \vec{a}\frac{(t_1 + t_2 + \ldots t_n)}{n}$$

$$\Rightarrow v_d = 0 + \vec{a}\,\tau \qquad [\textit{from equation} \ldots (i)]$$

$$\text{where, } \tau = \frac{(t_1 + t_2 + \ldots t_n)}{n} = \text{relaxation time}$$

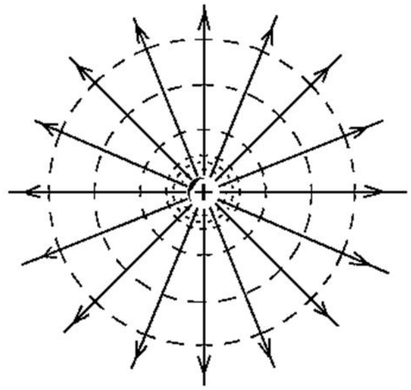
$$\Rightarrow \vec{v_d} = \frac{-e\vec{E}\tau}{m}.$$

(ii) The drift velocity of electron decreases with rise in temperature because with rise in temperature, the rate of collision of electrons with the ions of lattice increase, due to which relaxation time decrease

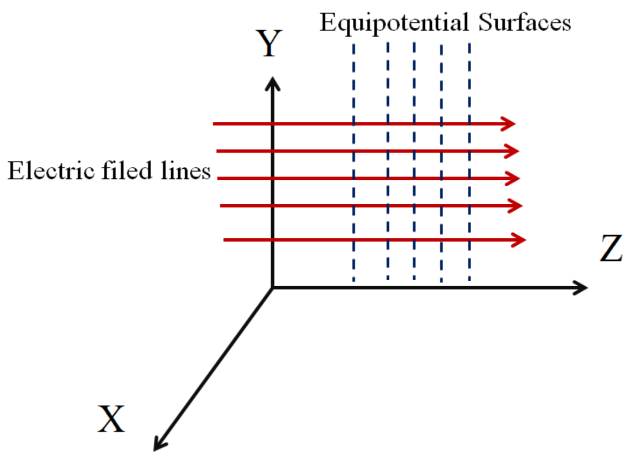
Question22: Define an equipotential surface. Draw equipotential surfaces:
(i) in the case of a single point charge and
(ii) in a constant electric field in Z-direction. Why the equipotential surfaces about a single charge are not equidistant?
(iii) Can electric field exist tangential to an equipotential surface? Give reason.

Sol:

An equipotential surface is a surface on which electric potential is same at every point.
(i) Equipotential surface in case of a single point charge:



In the figure, positive point charge is at the center, lines with arrows are electric field lines and dotted circles are equipotential surfaces.
(ii) Electric fields in a constant electric field in Z-direction:



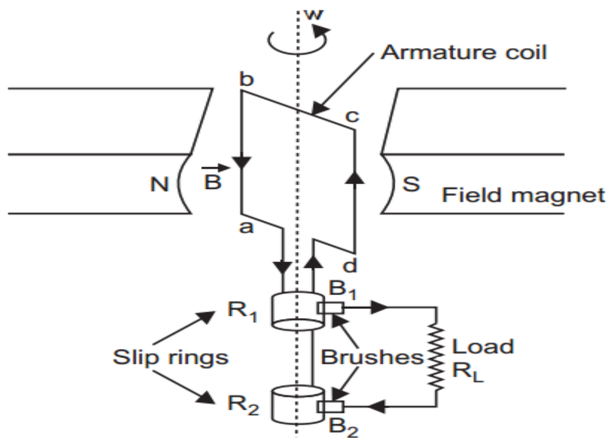
Equipotential surfaces are not equidistant in case of point charge because electric potential varies inversely with distance.
(iii) Electric field at every point is normal to the equipotential surface passing through that point because if the field were not normal to the equipotential surface, it would have non-zero component along the surface. To move a unit test charge against the direction of the component of the field, work would have to be done. But this is in contradiction to the definition of an equipotential surface: there is no potential difference between any two points on the surface and no work is required to move a test charge on the surface.
The electric field must, therefore, be normal to the equipotential surface at every point.

Question23: Ram is a student of class X in a village school. His uncle gifted him a bicycle with a dynamo fitted in it. He was very excited to get it. While cycling during night, he could light the bulb and see the objects on the road. He, however, did not know how this device works. He

asked this question to his teacher. The teacher considered it an opportunity to explain the working to the whole class.
Answer the following questions:
(*a*) State the principle and working of a dynamo.
(*b*) Write two values each displayed by Ram and his school teacher.

Sol:

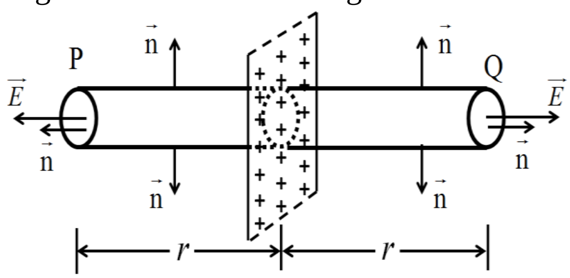
(*a*) A dynamo works on the principle of electromagnetic induction i.e. whenever amount of electromagnetic flux linked with a coil changes, an e.m.f. is induced in the coil. It lasts as long as change in the magnetic flux through the coil continues.
AC generator consists of the four main parts:



Field Magnet: It produces the magnetic field. In the case of a low power dynamo, the magnetic field is generated by a permanent magnet, while in the case of large power dynamo. The magnetic field is produced by an electromagnet.
Armature: It consists of a large number of turns of insulated wire in the soft iron drum or ring. It can revolve around an axle between the two poles of the field magnet.
Slip Rings: The slip rings R_1 and R_2 are the two metal rings to which the ends of armature coil are connected. These rings are fixed to the shaft which rotates the armature coil so that the rings also rotate along with the armature.
Brushes: These are two flexible metal plates or carbon rods (B_1 and B_2) which are fixed and constantly touch the revolving rings. The output current in external load R_L is taken through these brushes.
When the armature coil is rotated in the strong magnetic field, the magnetic flux linked with the coil changes and the current is induced in the coil, its direction being given by Fleming's right hand rule. The direction of current remains unchanged during the first half turn of armature. During the second half revolution, the direction of current is reversed. Thus, the direction of induced e.m.f. and current changes in the external circuit after each half revolution.
(*b*) The values displayed by Ram are: curiosity, observing.
The values displayed by his teacher are: knowledgeable, responsible.

Question24:(i) Use Gauss's law to find the electric field due to a uniformly charged infinite plane sheet. What is the direction of field for positive and negative charge densities?
(ii) Find the ratio of the potential differences that must be applied across the parallel and series combination of two capacitors C_1 and C_2 with their capacitances in the ratio 1:2 so that the energy stored in the two cases becomes the same.

Sol:
(i) Consider an infinite, thin plane sheet of charge.
Let σ be the surface charge density of the sheet.
By symmetry, we find that $\vec{E}$ on either side of the sheet must be perpendicular to the plane of the sheet, having same magnitude at all points equidistant from the sheet.
In order to find $\vec{E}$, at a point P distant r from the sheet, assume a cylindrical Gaussian surface of cross-sectional area *ds* of length 2*r* as shown in the figure.



Here, $\vec{n}$ is unit vector normal to the surface.
At the two cylindrical edges P and Q, $\vec{E}$ and $\vec{n}$ are parallel to each other as shown in the figure,
Therefore, electric flux over these edges = $2\vec{E}.\hat{n}\,ds = 2E\,ds.$
On the curved surface of the cylinder, $\vec{E}$ and $\vec{n}$ are perpendicular to each other so they will not contribute to the total electric flux.
Hence, total electric flux through the Gaussian surface = 2 *E ds*.
Total charge enclosed by the cylinder = σ *ds*.
By Gauss theorem in electrostatics,

Electric flux linked with the surface $= \frac{1}{\epsilon_o} \times$ (total charge enclosed by the surface)

$$2Eds = \frac{\sigma ds}{\epsilon_o}$$

$$\Rightarrow E = \frac{\sigma}{2\epsilon_o}.$$

The direction of field is away from the surface of sheet in case of positively charge sheet and towards the surface of sheet in case of negatively charge sheet.

(ii) Give, $\frac{C_1}{C_2} = \frac{1}{2} \Rightarrow C_2 = 2C_1.$

When, the capacitors are connected in parallel then, their equivalent capacitance is given as,

$C_p = C_1 + C_2 = 3C_1$.

If V_P is the potential difference applied in case of parallel capacitor then,

The energy stored in the combination is, $E_p = \frac{1}{2}C_pV_p^2 \Rightarrow E_p = \frac{3C_1V_p^2}{2}$

When, the capacitors are connected in series then, their equivalent capacitance is given as,

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} \Rightarrow C_s = \frac{C_1C_2}{C_1 + C_2} \Rightarrow C_s = \frac{2C_1}{3}.$$

If V_s is the potential difference applied in case of parallel capacitor then,

Energy stored in the combination is, $E_s = \frac{1}{2}C_sV_s^2 \Rightarrow E_s = \frac{C_1V_s^2}{3}$.

According to the question,

$$E_s = E_p$$

$$\Rightarrow \frac{C_1V_s^2}{3} = \frac{3C_1V_p^2}{2}$$

$$\Rightarrow \frac{V_s}{V_p} = \frac{3}{\sqrt{2}}.$$

OR

Question24: (i) If two similar large plates, each of area A having surface charge densities + σ and –σ are separated by a distance d in air, find the expressions for

(*a*) field at points between the two plates and on outer side of the plates.Specify the direction of the field in each case.

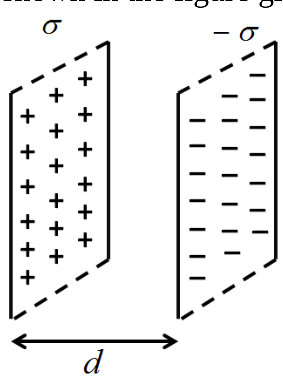
(*b*) the potential difference between the plates.

(*c*) the capacitance of the capacitor so formed.

(ii) Two metallic spheres of radii R and 2R are charged so that both of thesehave same surface charge density σ. If they are connected to each otherwith a conducting wire, in which direction will the charge flow and why?

Sol:

(i) The situation given in question is shown in the figure given below:



(*a*) Field at points between the two plates:

$E_{net} = \left(\frac{\sigma}{2\in_o}\right)+\left(\frac{\sigma}{2\in_o}\right) \Rightarrow E_{net} = \frac{\sigma}{\in_o}$ and its direction will be from positive charge to negative charge.

Electric field at outer side of the plates $= \left(\frac{\sigma}{2\in_o}\right)-\left(\frac{\sigma}{2\in_o}\right)=0.$

(b) Potential difference between the plates = (electric filed inside the plates) × (distance between the plates).

$\therefore$ Potential difference between the plates = $\frac{\sigma}{\in_o}d = \frac{Q}{A\in_o}d.$

(c) Capacitance of parallel plate capacitor so formed =

$$\frac{\text{charge on either plate}}{\text{potential difference between the plates}} = \frac{A\in_o}{d}.$$

(ii) The potential of a metallic sphere is given by, $\mathrm{V}=\frac{Q}{4\pi\in_o R}$

Where, Q is the total charge and R is the radius of the sphere.

Now, the potential of the metallic sphere of radius R is given by,

$$\mathrm{V}_1=\frac{Q}{4\pi\in_o R} \Rightarrow \mathrm{V}_1=\frac{\sigma(4\pi R^2)}{4\pi\in_o R} \Rightarrow \mathrm{V}_1=\frac{\sigma R}{\in_o}.$$

Now, the potential of the metallic sphere of radius 2R is given by,

$$\mathrm{V}_2=\frac{Q}{4\pi\in_o 2R} \Rightarrow \mathrm{V}_2=\frac{\sigma(4\pi(2R)^2)}{4\pi\in_o 2R} \Rightarrow \mathrm{V}_2=\frac{2\sigma R}{\in_o}.$$

Clearly, $V_2 > V_1$.

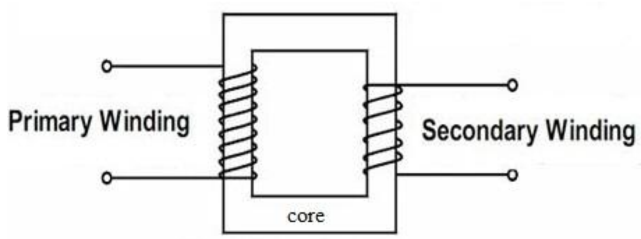
When sphere will be connected by a wire then, charge will flow from higher potential to lower potential i.e. from sphere of radius 2R to R.

Question25: (i) Draw a labelled diagram of a step-down transformer. State the principle of its working.
(ii) Express the turn ratio in terms of voltages.
(iii) Find the ratio of primary and secondary currents in terms of turn ratio in an ideal transformer.

(iv) How much current is drawn by the primary of a transformer connected to 220 V supply when it delivers power to a 110 V – 550 W refrigerator?

Sol:

(i) Labelled diagram of step-down transformer:



Step-Down Transformer

A transformer is based on the principle of electromagnetic mutual induction, i.e., whenever the amount of magnetic flux linked with a coil changes, an e.m.f. is induced in the neighbouring coil.

(ii) Let, $N_P \rightarrow$ number of turns in primary coil, $N_S \rightarrow$ number of turns in primary and secondary coil, $V_P \rightarrow$ voltage applied across primary coil, $V_S \rightarrow$ voltage obtained across secondary then,

$$\text{turn ratio} = \frac{N_s}{N_P} = \frac{V_S}{V_P}.$$

(iii) Suppose, i_p and i_s be the currents in the primary and secondary at any instant and the energy losses be zero (ideal transformer) then,

$$\text{Power in secondary} = \text{Power in primary}$$

$$\Rightarrow V_S \times i_s = V_P \times i_p$$

$$\Rightarrow \frac{V_S}{V_P} = \frac{i_p}{i_s}$$

$$\text{Turn ratio} = \frac{V_S}{V_P} = \frac{i_p}{i_s}.$$

(iv) Here, voltage in primary = V_P = 220 V, power in secondary = V_P = 550 V, current in primary = i_p= ?

$$\text{Power in secondary} = \text{Power in primary}$$

$$\Rightarrow 550 = V_P \times i_p$$

$$\Rightarrow 550 = 220 \times i_p$$

$$\Rightarrow i_p = \frac{550}{220} = 2.5 \text{ Ampere.}$$

OR

Question25: (a) Explain the meaning of the term mutual inductance. Consider two concentric circular coils, one of radius r_1 and the other of radius $r_2(r_1<r_2)$ placed coaxially with centres coinciding with each other. Obtain the expression for mutual inductance of the arrangement.

(b)A rectangular coil of area A, having number of turns N is rotated at 'f' revolution per second in a uniform magnetic field B, the field being perpendicular to the coil. Prove that the maximum emf induced in the coil is $2\pi f NBA$.

Sol:

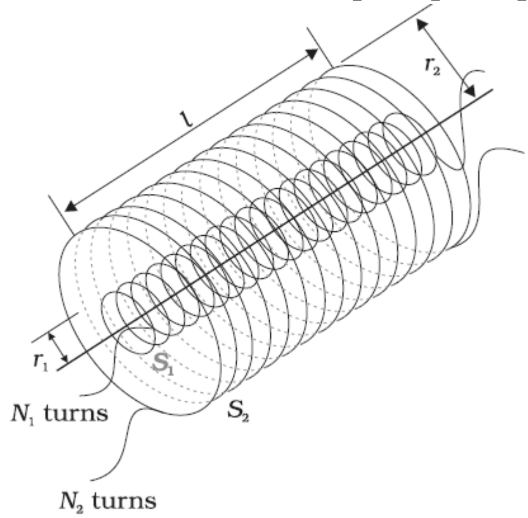
(*a*) Mutual induction is the property of two coils by virtue of which each opposes any change in the strength of current flowing through the other by developing an induced emf.

If ϕ is the amount of magnetic flux linked with one coil when a current I flows through the other coil, then $\phi = MI$, where M is the coefficient of mutual induction or mutual inductance of two coils.

Consider the figure given below, which shows two circular co-axial coils each of length *l*.

We denote the radius of the inner circular coil S_1 by r_1 and the number of turns per unit length by n_1.

The corresponding quantities for the outer circular coil S_2 are r_2 and n_2, respectively.



Let N_1 and N_2 be the total number of turns of coils S_1 and S_2, respectively.

When a current I_2 is set up through S_2, it in turn sets up a magnetic flux through S_1. Let us denote it by Φ_1.

The corresponding flux linkage with S_1 is

$N_1\Phi_1 = M_{12}I_2$…(*i*)

M_{12} is called the mutual inductance of S_1 with respect to S_2.

The magnetic field due to the current I_2 in S_2 is $\mu_0 n_2 I_2$.

The resulting flux linkage with coil S_1 is,

$N_1 \Phi_1 = (n_1 l)(\pi r_1^2)(\mu_o n_2 I_2) = \mu_o n_1 n_2 \pi r_1^2 l I_2$…(*ii*)

Where, $n_1 l$ is the total number of turns in solenoid S_1.

From equation …(*i*) and …(*ii*), $M_{12} = \mu_o n_1 n_2 \pi r_1^2 l$

We now consider the reverse case. A current I_1 is passed through the S_1 and the flux linkage with coil S_2 is, $N_2\Phi_2 = M_{21} I_1$

Where, M_{21} is called the mutual inductanceof S_2 with respect to S_1.
The flux due to the current I_1 in S_1 can be assumed to be confined solely inside S_1 since the coils are very long. Thus, flux linkage withS_2 is $N_2\Phi_2 = (n_2 l)\ (\pi r_1^2)\ (\mu_o n_1 I_1)$, where $n_2 l$ is the total number of turns of S_2.
From eq…(ii) we have, $M_{21} = \mu_o\ n_1 n_2\ \pi r_1^2\ l\ I_2$
Let $M_{12} = M_{21} = M$, then $M = \mu_o\ n_1 n_2\ \pi r_1^2\ l\ I_2$.
(*b*) If N is the number of turns in coil, fis the frequency of rotation, Ais area of coil and B is the magnetic induction then induced emf is given by,

$$e = -\frac{d\phi}{dt} = -\frac{d(N\vec{B}.\vec{A})}{dt} = -\frac{d(\text{NBAcos}\omega\text{t})}{dt} = -\frac{d}{dt}\{\text{NBA}(\cos 2\pi\text{ft}) = 2\pi\text{fNBA}\sin 2\pi f t.$$

As, maximum value of $\sin 2\pi\text{ft} = 1$, therefore maximum induced emf is given by $2\pi\text{fNBA}$.

Question26: (i) Derive the mathematical relation between refractive indices n_1 and n_2 of two radii and radius of curvature R for refraction at a convex spherical surface. Consider the object to be a point since lying on the principle axis in rarer medium of refractive index n_1 and a real image formed in the denser medium of refractive index n_2. Hence, derive lens maker's formula.
(ii) Light from a point source in air falls on a convex spherical glass surface of refractive index 1.5 and radius of curvature 20 cm. The distance of light source from the glass surface is 100 cm. At what position is the image formed?
Sol:

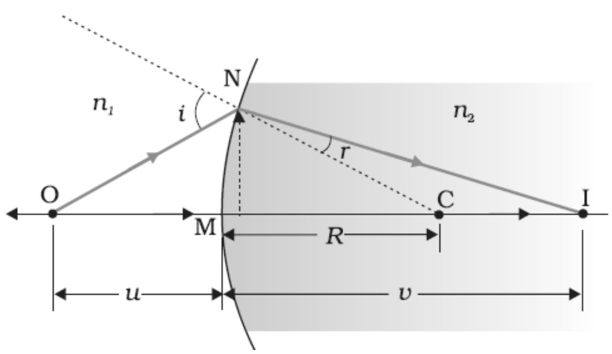


Figure given above shows the geometry of formation of image I of an object O on the principal axis of a spherical surface with centre of curvature C, and radius of curvature R.
The rays are incident from a medium of refractive index n_1, to another of refractive index n_2. As before, we take the aperture (or the lateral size) of the surface to be smallcompared to other distances involved, so that small angle approximation can be made. In particular, NM will be taken to be nearly equal to the length of the perpendicular from the point N on the principalaxis. We have, for small angles,

$$\tan \angle NOM = \frac{MN}{OM}$$

$$\tan \angle NCM = \frac{MN}{MC}$$

$$\tan \angle NIM = \frac{MN}{MI}$$

Now, for ΔNOC, i is the exterior angle. Therefore, i = ∠NOM + ∠NCM

$$\Rightarrow i = \frac{\text{MN}}{\text{OM}} + \frac{\text{MN}}{\text{MC}} \quad ...(i)$$

Similarly,

r = ∠NCM – ∠NIM

$$\Rightarrow r = \frac{\text{MN}}{\text{MC}} - \frac{\text{MN}}{\text{MI}} \quad ...(ii)$$

Now, by Snell's law, $n_1 \sin i = n_2 \sin r$, if angles are small then, $n_1 i = n_2 r$

Substituting these in equation …(i) and …(ii), we get

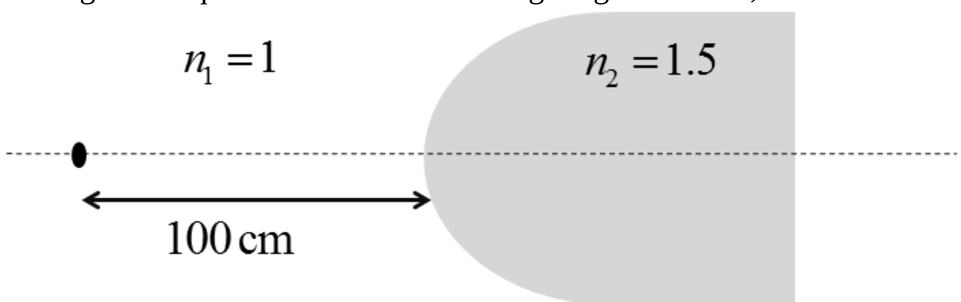
$$\frac{n_1}{OM} - \frac{n_2}{MI} = \frac{n_2 - n_1}{MC} \quad ...(iii)$$

Here, OM, MI and MC represent magnitudes of distances. Applying the Cartesian sign convention,

OM = $-u$, MI = $+v$, MC = $+R$

Substituting in equation …(iii), we get $\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$, which is the required relation.

(ii) The situation given in question is shown in the figure given below,



$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$$

Putting respective values in the formula with correct sign, we have

$$\Rightarrow \frac{1.5}{v} - \frac{1}{(-100)} = \frac{1.5 - 1}{20}$$

$$\Rightarrow \frac{1.5}{v} = 0.015 \Rightarrow v = 100 \text{ cm}.$$

Therefore, image will be formed at a distance of 100 cm from the pole in the denser medium.

OR

Question26: (a) Draw a labelled ray diagram to obtain the real image formed by an astronomical telescope in normal adjustment position. Define its magnifying power.

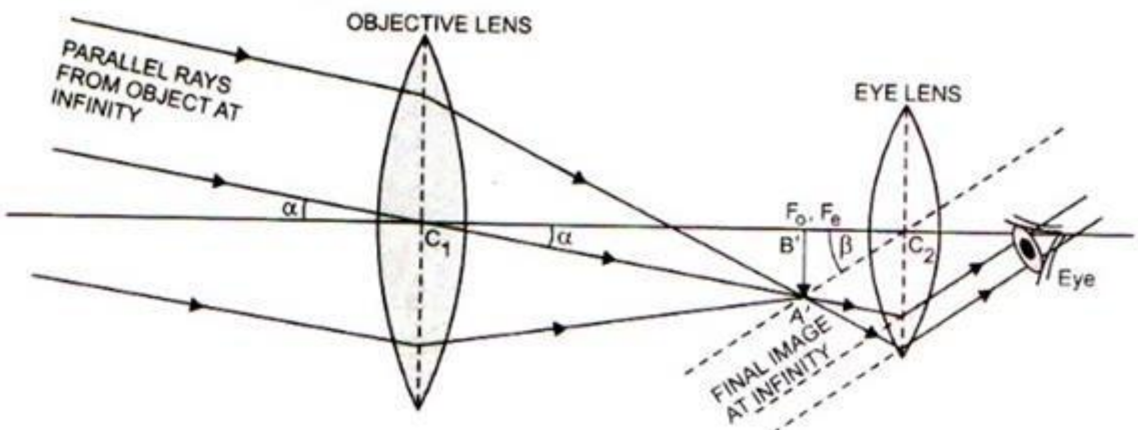
(b) You are given three lenses of power 0.5 D, 4 D and 10 D to design a telescope.

(*i*) Which lenses should he used as objective and eyepiece? Justify your answer.

(*ii*) Why is the aperture of the objective preferred to be large?

Sol:

(a) Labelled diagram showing formation of real image by an astronomical telescope in normal adjustment is given below,



Magnifying power of an astronomical telescope in normal adjustment is defined as the ratio of the angle subtended at the eye by the final image to the angle subtended at the eye, by the object directly, when the final image and the object both lie at infinite distance from the eye.

In the given figure, $m = \frac{\beta}{\alpha}$.

If f_o and f_e are focal length of objective and eyepiece then, $m = \frac{f_o}{-f_e}$.

(b) (*i*) In order to get maximum magnifying power, power of the objective lens should be large and focal length of the eye lens should be small.

Lens with smallest power (or largest focal length) should be used as the objective lens i.e. lens with power 0.5 D.

Lens with maximum power (or smallest focal length) should be used as the eye-piece i.e. lens with power 10 D.

(*ii*) Sharp image of the distant object will be formed when maximum amount of light enters the lens due to this reason the aperture of the objective is preferred to be large.