Previous Year Question Paper 2019

General Instructions:

1. All questions are compulsory. There are 27 questions in all.
2. This question paper has four sections: **Section A, Section B, Section C and Section D.**
3. Section Acontains five questions of one mark each. Section B contains seven questions of two marks each, Section C contains twelve questions of three marks each, and Section D contains three questions of five marks each.
4. There is no overall choice. However, internal choices have been provided in two questions of one mark, two questions of two marks, four questions of three marks and three questions of five marks weightage. You have to attempt only one of the choices in such questions.
5. You may use the following values of physical constants wherever necessary.

$c = 3\times10^{9}\, m/s$

$h = 6.63\times10^{-34}\, Js$

$e = 1.6\times10^{-19}\, C$

$\mu_0 = 4\pi\times10^{-7}\, TmA^{-1}$

$\frac{1}{4\pi\varepsilon_0} = 9\times10^{9}\, Nm^2C^{-2}$

$m_e = 9.1\times10^{-31}\, kg$

$mass\ of\ neutron = 1.675\times10^{-27}\, kg$

$mass\ of\ proton = 1.673\times10^{-27}\, kg$

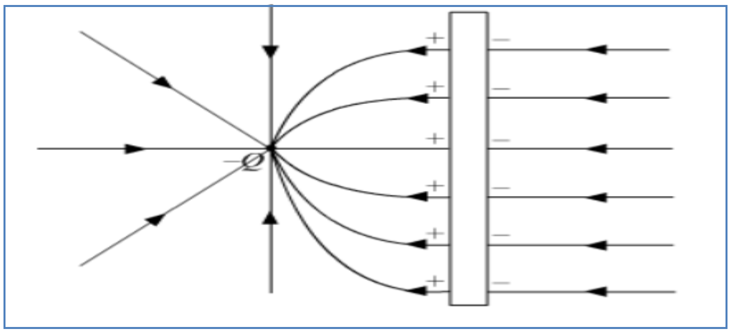
$Avagedro's\ number = 6.023\times10^{23}\ per\ gram\ mole3$

$\text{Boltmann constant} = 1.38\times10^{-23}\, JK^{-1}$

Section A

1. Draw the pattern of electric field lines, when a point charge –Q is kept near an uncharged conducting plate

Sol:-



2. **How does the mobility of electrons in a conductor change, if the potential difference applied across the conductor is doubled, keeping the length and temperature of the conductor constant?**

Sol:-

The mobility of electrons in a conductor is given by the expression, $\mu = \frac{e\tau}{m}$

As its independent of the applied potential difference, so it will not change if the applied potential difference will be doubled.

3. **Define the term "Threshold frequency", in the context of photoelectric emission.**

OR

Define the term "Intensity" in the photon picture of electromagnetic radiation.

Sol:-

For a given Photosensitive material, there is a certain minimum cut off frequency at which Photoelectric emission is possible is called Threshold frequency, i.e. At this frequency just emission of photoelectrons happens without giving them any kind of additional energy. Higher the work function of the material, greater is the Threshold frequency.
See the figure below of two different metals having different Threshold Frequency.

OR

The intensity I, is defined as the total amount of energy falling on a given surface/Region per unit time 'rand per unit area A:

If the total energy emitted $= nh\nu$

Then, $I = \frac{nh\nu}{At}$

4. **What is the speed of light in a denser medium of polarizing angle 30°?**

Sol:-

$\mu = \tan i_p$

$\mu = \tan 30^\circ = \frac{1}{\sqrt{3}}$

$\mu = \frac{c}{V} = \frac{1}{\sqrt{3}}$

$V = c \times \sqrt{3}$

$V = 3\sqrt{3} \times 10^8 \ m/s$

5. In sky wave mode of propagation, why is the frequency range of transmitting signals restricted to less than 30 MHz?

OR

On what factors does the range of coverage in ground wave propagation depend?

Sol:-

In sky wave mode of propagation, the frequency range of transmitting signals restricted to less than 30 MHz, because it is the maximum frequency below which the signals can be transmitted from one point to another point via reflection from ionosphere. Above this frequency, the signals will be transmitted through the ionosphere and are not reflected back.

OR

The ground wave propagation is preferred usually for long distance communication using frequencies below 3 MHz. The range of coverage of ground wave propagation depends on transmitted power and frequency.

Section B

6. Two bulbs are rated (P_1, V) and (P_2, V). If they are connected (i) in series and (ii) in parallel across a supply V, find the power dissipated in the two combinations in terms of P_1 *and* P_2.

Sol:-

Given Bulbs are rated as (P_1, V) &(P_2, V) respectively

The resistance of 1st bulbs $R_1 = \frac{V^2}{P_1}$

The resistance of 2nd bulbs $R_2 = \frac{V^2}{P_2}$

(i) When both are connected in Series with a power supply of voltage V.

As both the bulbs are in series connection hence both will have the same amount of current flowing through them.

$$i = \frac{V}{R_1 + R_2} = \frac{V}{\frac{V^2}{P_1} + \frac{V^2}{P_2}} = \frac{1}{V}\left(\frac{P_1 P_2}{P_1 + P_2}\right)$$

Power dissipated in the circuit

$$P_d = i^2\left(R_1 + R_2\right) = \frac{1}{V^2}\left(\frac{P_1 P_2}{P_1 + P_2}\right)^2\left(\frac{V^2}{P_1} + \frac{V^2}{P_2}\right)$$

$$P_d = \frac{P_1 P_2}{P_1 + P_2}$$

(ii) When both are connected in parallel

In this case, both bulbs will get the same voltage supply.

Hence, power dissipated

$$P_d = \frac{V^2}{R_1} + \frac{V^2}{R_2} = V^2\left(\frac{P_1}{V^2} + \frac{P_2}{V^2}\right)$$

$$P_d = P_1 + P_2$$

7. Calculate the radius of curvature of an equi-concave lens of refractive index 1.5, when it is kept in a medium of refractive index 1.4, to have a power of -5D?

OR

An equilateral glass prism has a refractive index 1.6 in the air. Calculate the angle of minimum deviation of the prism, when kept in a medium of refractive index $4\sqrt{2}/5$

Sol:-

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Using lens maker formulae for given equal concave lens,

$$\frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{-R} - \frac{1}{R}\right)$$

$$\Rightarrow \frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right)\left(-\frac{2}{R}\right)$$

Where n_2 and n_1 are refractive index of the lens and medium, respectively where

$n_2 = 1.5$ & $n_1 = 1.4$

Power of lens $-5D$

Focal length $f = \frac{1}{-5} \times 100 = -20cm$

Putting all the values in equation 1,

$$\Rightarrow \frac{1}{-20} = \left(\frac{1.5}{1.4} - 1\right)\left(-\frac{2}{R}\right)$$

$$\Rightarrow \frac{1}{20} = \left(\frac{0.1}{1.4}\right)\left(\frac{2}{R}\right)$$

$$\Rightarrow R = \frac{4}{1.4} = 2.86cm$$

When the prism is kept in another medium we have to take the refractive index of the prism with respect to the provided medium.

$$medium^{\mu} = \frac{\mu_{prism}}{\mu_{medium}} = \frac{\sin\left[\left(\frac{A+D_m}{2}\right)\right]}{\sin\left(\frac{A}{2}\right)}$$

$$\frac{1.6}{\frac{4\sqrt{2}}{5}} = \frac{\sin\left[\left(\frac{60^\circ + D_m}{2}\right)\right]}{\sin\left(\frac{60^\circ}{2}\right)}$$

$$\sqrt{2} = \frac{\sin\left[\left(\frac{60^\circ + D_m}{2}\right)\right]}{\frac{1}{2}}$$

$$\sin^{-1}\left(\frac{1}{\sqrt{2}}\right) = \left(\frac{60^\circ + D_m}{2}\right)$$

$$90^\circ = 60^\circ + D_m$$

$$D_m = 30^\circ$$

8. An a-particle and a proton of the same kinetic energy are in turn allowed to pass through a magnetic field $\vec{B}$, acting normal to the direction of motion of the particles. Calculate the ratio of radii of the circular paths described by them.

Sol:-

Mass of alpha particle $= m_a$

Charge on alpha particle = q_c,

Velocity of alpha particle = V_a

Mass of a proton = m_p

Charge on a proton = q_p

Velocity of proton = v_p

Since the KE of alpha particle and proton are equal.

$$\therefore \frac{1}{2} m_\alpha v_\alpha^2 = \frac{1}{2} m_p \cdot v_p^2$$

$$\Rightarrow \frac{(m_\alpha v_\alpha)^2}{m_\alpha} = \frac{(m_p \cdot v_p)^2}{m_p} \Rightarrow \frac{m_\alpha v_\alpha}{m_p \cdot v_p} = \left(\frac{m_\alpha}{m_p}\right)^{1/2}$$

Radius of the circle $= R = \frac{mv}{qB}$

Therefore, ratio of radii of alpha particle to proton

$$= \frac{R_\alpha}{R_p} = \frac{m_\alpha \cdot v_\alpha}{q_\alpha B} \cdot \frac{q_p B}{m_p \cdot v_p} = \left(\frac{m_\alpha}{m_p}\right)^{1/2} \cdot \frac{q_p}{q_\alpha}$$

$$Using\ \frac{m_\alpha}{m_p} = 4\ and\ \frac{q_p}{q_\alpha} = \frac{1}{2}$$

$$\therefore \frac{R_\alpha}{R_p} = (4)^{1/2}\left(\frac{1}{2}\right) = 1$$

9. State Bohr's quantization condition of angular momentum. Calculate the shortest wavelength of the Bracket series and state to which part of the electromagnetic spectrum it belongs.

OR

Calculate the orbital period of the electron in the first excited state of hydrogen atom.

Sol:-

According to Bohr's quantization, the electrons revolve around the nucleus only in those orbits for which the angular momentum is the integral multiple of

$$\frac{h}{2\pi}$$

$$L = \frac{nh}{2}$$

for bracket series $n_2 = \infty$

$$\frac{1}{\lambda} = R_H Z^2 \left\{\frac{1}{4^2} - \frac{1}{\infty}\right\}$$

$$\frac{1}{\lambda} = \frac{R_H}{16}$$

$$\lambda = \frac{16}{R_H} = 14.58 \times 10^{-7}\ m$$

This wavelength belongs to the infrared region.

OR

$r = 0.53\frac{n^2}{z}\times 10^{-10}\ m$

For first excited state $n = 2$

$r = 0.53\frac{2^2}{1}\times 10^{-10}$

$r = 2.12\times 10^{-10}\ m$

$v = v_0\times\frac{Z}{n}\ m/s$

$v = 2.188\times 10^6\times\frac{Z}{n}\ m/s$

For first excited state, n= 2, Z=1 for hydrogen atom

$\therefore\ v = 2.188\times 10^6\times\frac{1}{2}\ m/s$

$\Rightarrow\ v = 1.094\times 10^6\ m/s$

$\because$ Orbital period = $\frac{2\pi r}{v} = \frac{2\times 3.14\times 2.12\times 10^{-10}}{1.094\times 10^6}$

$\Rightarrow$ *Orbital period* $\cong 1.22\times 10^{-15}\ sec$

10. Why a signal transmitted from a TV tower cannot be received beyond a certain distance? Write the expression fc the optimum separation between the receiving and the transmitting antenna.

Sol:- Signal transmitted from a TV tower cannot be received beyond a certain distance because of the curvature of the earth. Expression for the optimum separation between the receiving and transmitting antenna:

d = $\sqrt{2hR}$

d: Optimum separation.

h: Height of the antenna

R - Radius of the curvature of Earth.

11. Why is wave theory of electromagnetic radiation not able to explain photo electric effect? How does photon picture resolve this problem?

Sol:-

There are three main drawbacks:

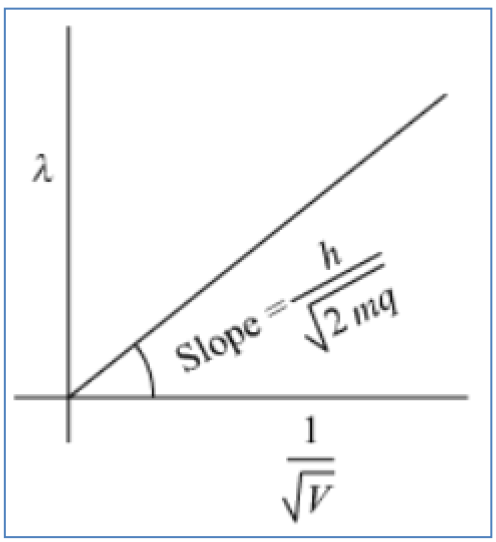
1. Intensity: If we consider light as a wave then as the intensity of the light is increased the amplitude of the oscillation of the electron will increase. Thus, as the intensity of the incident light is increased the maximum kinetic energy of the emitted electron will also increase. But it was observed that the kinetic energy of the emitted electrons does not depend on the intensity whereas the magnitude of the photoelectric current increases with the frequency.

2. Frequency: If we consider the light as a wave then the photoelectric emission should happen on any frequency, but it was observed that the electrons are emitted after a particular frequency. If the frequency of the incident light is lesser than this frequency there is no photoelectric emission observed.

3. Time Delay: According to the wave theory the energy is uniformly distributed over the wave front. As the light falls on the metallic surface, it will take some time for the electron to gain sufficient energy to get emitted. But experimentally it was observed that the electrons are emitted instantaneously as the light falls on the metallic surface.
How the photon theory can explain the photoelectric effect:
1. According to photon theory increasing the intensity means increasing the number of photons that does not change the maximum kinetic energy but changes the number of ejected electrons.
2. The energy of a photon is given as: E = hf that explains the dependence of the energy on the frequency, after a particular frequency of a photon that is threshold frequency there is photoelectric emission.
3. As soon as a photon falls on the metallic surface it is absorbed, hence the electron is ejected instantaneously. Hence, all these are in accordance with the experimental observations.

12. **Plot a graph showing variation of de Broglie wavelength (X) associated with a charged particle of mass m, versus $\frac{1}{\sqrt{V}}$ where Vis the potential difference through which the particle is accelerated. How does this graph give us the information regarding the magnitude of the charge of the particle?**

Sol:-

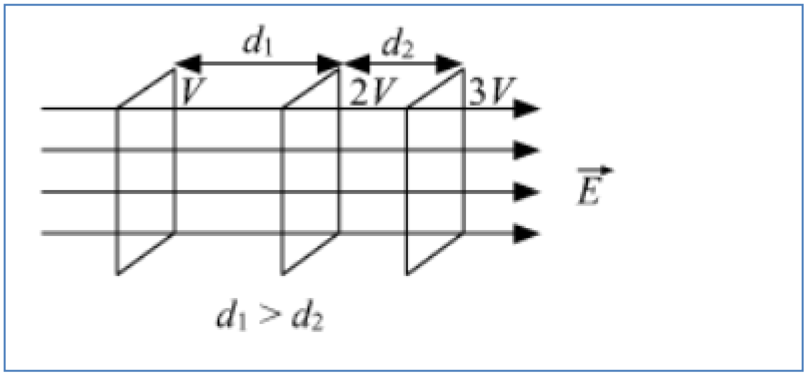


The slope of the graph is $\frac{h}{\sqrt{2mq}}$ considering we know slope and mass of the charged particle we can easily calculate the charge.

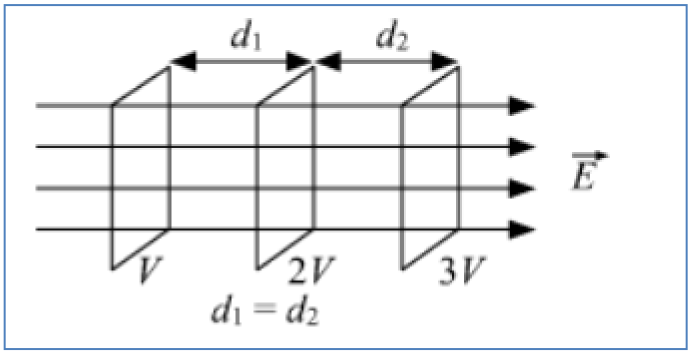
13. **(a)** Draw equipotential surfaces corresponding to the electric field that uniformly increases in magnitude along with the z-directions.
(b) Derive an expression for the electric potential at any point along the axial line of an electric dipole.

Sol:-

(a) For constant electric field vector E



For increasing electric field



Difference: For constant electric field, the equipotential surfaces are equidistant for the same potential difference between these surfaces; while for increasing electric field, the separation between these surfaces decreases, in the direction of the increasing field, for the same potential difference between them.

(b) Suppose P is a point on the axial position of the dipole.

Length of dipole = 2a

Suppose point P is at the distance 'r' from the center of the dipole.

The potential at a point is $V=\frac{1}{4\pi\varepsilon_0}.\frac{Q}{r}$

So, the potential at P due to q is $V_q=\frac{1}{4\pi\varepsilon_0}.\frac{q}{a+r}$

Potential at P due to $-q$ is $V_{-q}=\frac{1}{4\pi\varepsilon_0}.\frac{-q}{a-r}$

The total potential at P is

$$V=V_q+V_{-q}$$

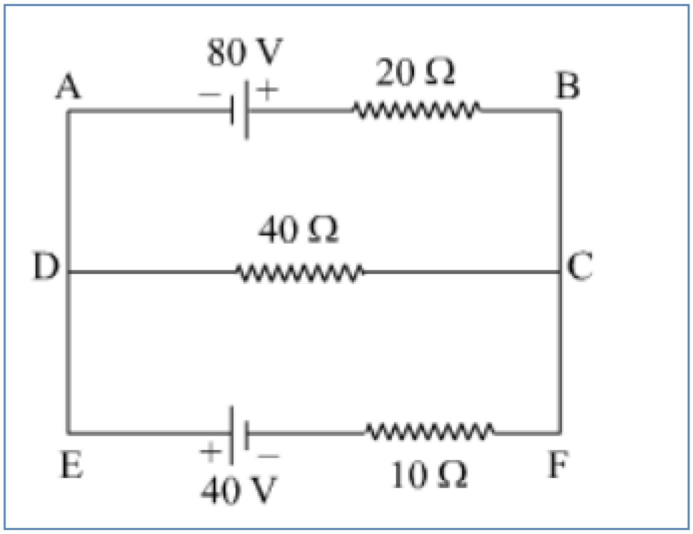
$$=\frac{1}{4\pi\in_0}.\frac{q}{(a+r)}+\frac{1}{4\pi\in_0}.\frac{-q}{(r-a)}$$

$$=\frac{q}{4\pi\in_0}\left[\frac{1}{(a+r)}+\frac{1}{(a-r)}\right]$$

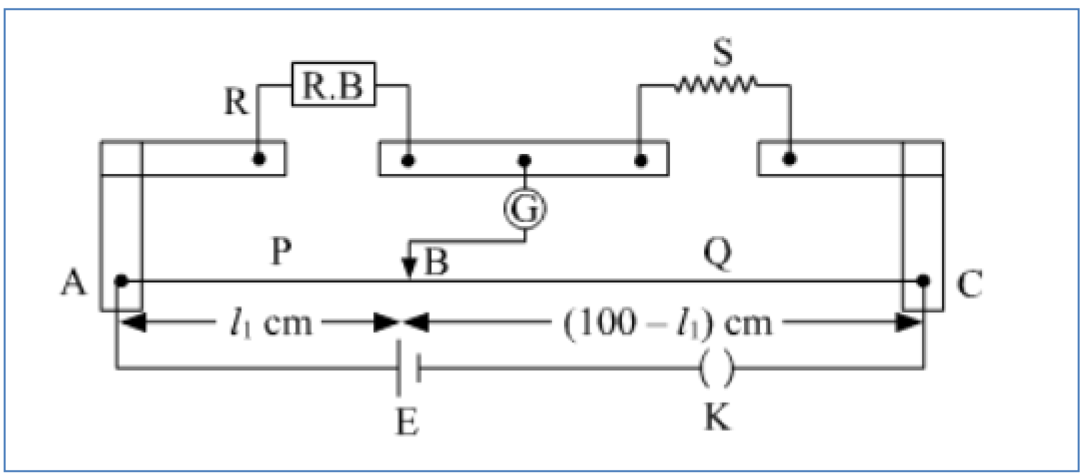
$$V=\frac{q}{4\pi\in_0}.\frac{2a}{(a^2-r^2)}$$

Section C

14. **Using Kirchhoff's rules, calculate the current through the $40\Omega\, and\, 20\Omega$ resistors in the following circuit.**

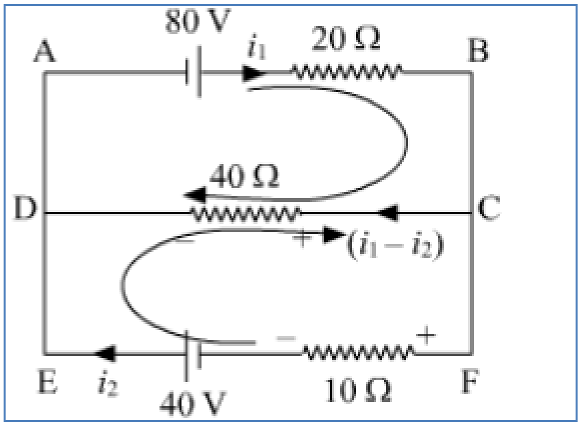


What is end error in a meter bridge? How is it overcome? The resistances in the two arms of the metre bridge are R = Ω and S respectively.
When the resistance S is shunted with an equal resistance, the new balance length found to be 1.5l_1 , where l_2 is the initial balancing length. Calculate the value of S.



Sol:-

Apply KVL through ABCDA



$80 - 20i_1 - 40(i_1 - i_2) = 0$

$80 - 60i_1 + 40i_2 = 0 \quad equation\,(1)$

Apply KVL through FEDCF

$40 + 40(i_1 - i_2) - 10i_2 = 0$

$40 + 40i_1 - 50i_2 = 0 \; equation\,(2)$

$4i_2 - 6i_1 = -8 \;\; (1)$

$-5i_2 + 4i_1 = -4 \;\; (2)$

Multiply equation $(2)\,by\,\frac{6}{4}$ and add with equation (1)

$$\begin{aligned} 4i_2 \quad &- \quad 6i_1 \quad = \quad -8 \\ -\frac{30i_2}{4} \quad &+ \quad 6i_1 \quad = \quad -6 \\ 4i_2 \quad &- \quad \frac{30}{4}i_2 \quad = \quad -14 \end{aligned}$$

$\frac{-14}{4}i_2 = -14, \; i_2 = \frac{-14}{7} \times 2$

$i_2 \; = 4\,A$

Put the value of i_2 in equation (1)

$4 \times (4) - 6i_1 = -8$

$16 - 6i_1 = -8$

$6i_1 = 16 + 8 = 24$

$i_1 = 4\,A$

$So,\ current\ through\ 40\ \Omega\ resistor \quad = \quad i_1 - i_2$

$\quad = \quad 4 - 4$

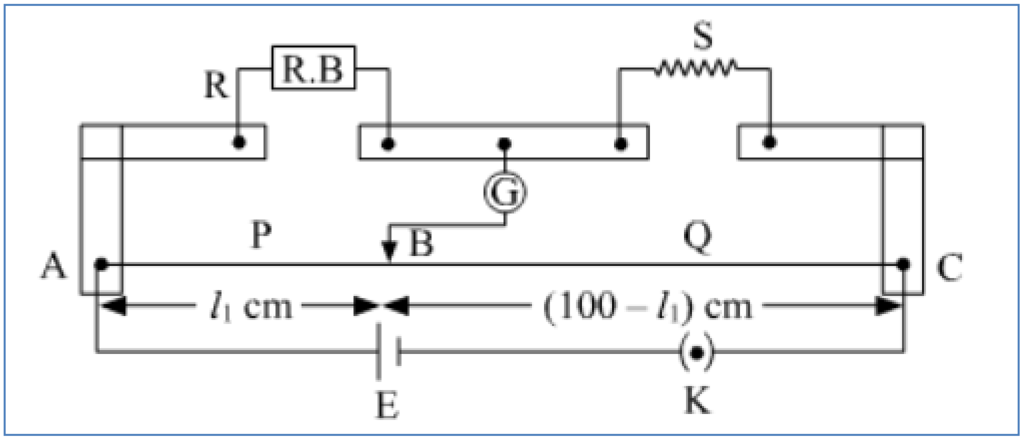
$\quad = \quad 0\,A$

Hence, current through 20Ω resistor $= 4A$

OR

The shifting of zero of the scale at different points as well as the stray resistance gives rise to the end error in meter bridge wire. This error arises due to the non-uniformity of the meter wire End corrections can be estimated by including known resistances P_1 and Q_1 in the two ends and finding the null point

We have



$R = 5\Omega$

According to wheat stone bridge principal

$$\frac{R}{l_1} = \frac{S}{100 - l_1}$$

$$\frac{5}{l_1} = \frac{S}{100 - l_1} equation(1)$$

After shunting, connect the resistance in parallel

$$S \to \frac{S}{2}$$

$$\frac{5}{1.5l_1} = \frac{S}{2(100 - 1.5l_1)} \ equation(2)$$

Thus, equation (1) can be written as

$500-5l_1 = Sl_1$ equation (3)

And equation 2 is

$10(100-1.5l_1) = 1.5Sl_1$ *equation* (4)

From equation (3) *and* (4)

$$\frac{500-5l_1}{l_1} = \frac{1000-15l_1}{1.5l_1}$$

$750-7.5l_1 = 1000-15l_1$

$-250 = -7.5l_1$

$$l_1 = \frac{100}{3}$$

$$S = \frac{500-\frac{5\times100}{3}}{\frac{100}{3}} = \frac{500-\frac{500}{3}}{\frac{100}{3}} = \frac{1000}{3}\times\frac{3}{100}$$

$S = 10\ \Omega$

15.

(a) Identify the part of the electromagnetic spectrum used in **(i)** radar and **(ii)** eye surgery. Write their frequency range.

(b) Prove that the average energy density of the oscillating electric field is equal to that of the oscillating magnetic field.

Sol:-

(a)

Microwaves are used for 'Radar' system. Frequency range of microwaves are from $1\ GHz$ to $2\ GHz$ and

(ii) Ultraviolet rays (UV rays) are used in eye surgery. Frequency range of UV rays are from 10^{15} to $10^{17} Hz$

(b)

Energy density in electric field is

$$U_E = \frac{1}{2}\epsilon_0 E^2$$

Energy density in magnetic field is

$$U_B = \frac{1}{2\mu_0} B^2$$

We know $E = Bc$

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

$$U_E = \frac{1}{2}\epsilon_0 (cB)^2 = \frac{1}{2}\epsilon_0 \left(\frac{1}{\epsilon_0 \mu_0}\right) B^2 = \frac{B^2}{2\mu_0}$$

now, $U_E = U_B$

16. Define the term wavefront. Using Huygen's wave theory, verify the law of reflection.

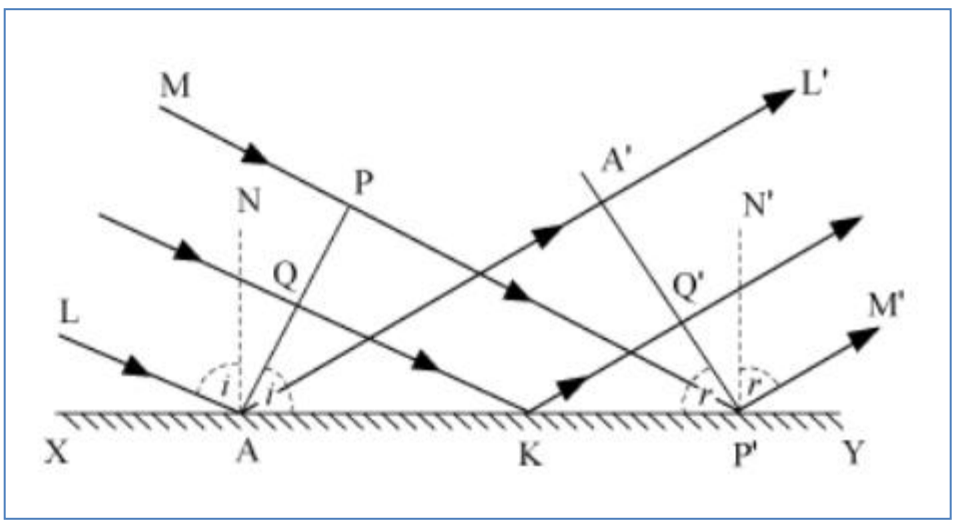
OR

Define the term, "refractive index" of a medium. Verify Snell's law of refraction when a plane wavefront is propagating from a denser to a rarer medium.

Sol:-

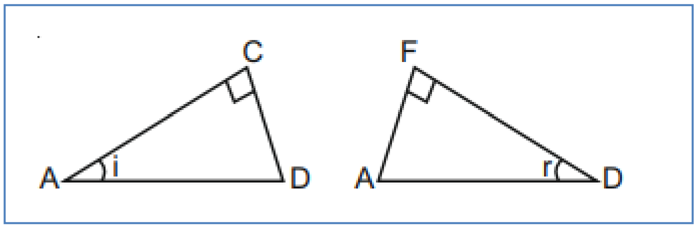
In a region where wave is propagating, geometrical structure formed by joining all the points which are vibrating in same (absolute) phase are said to be wavefront

Reflection of plane wave :



Consider a plane wave ABC incident at an angle 'i' on a reflecting surface 'AD'. If v represents the speed of the wave in medium Δt is the time taken to move from ABC to B1C1 and also from B1C1 to point 'D'. So, at the time when disturbance of point 'C' reaches to point 'D' disturbance of point 'A' must have formed a hemispherical shape of radius 2vΔt and at point 'B1' it must

have formed a hemispherical shape of radius $v\Delta t$. Drawing a common tangent from point 'D' to both of the above mentioned spherical envelope we shall have DEF as reflected wavefront.
Now, in ΔACD and ΔDFA



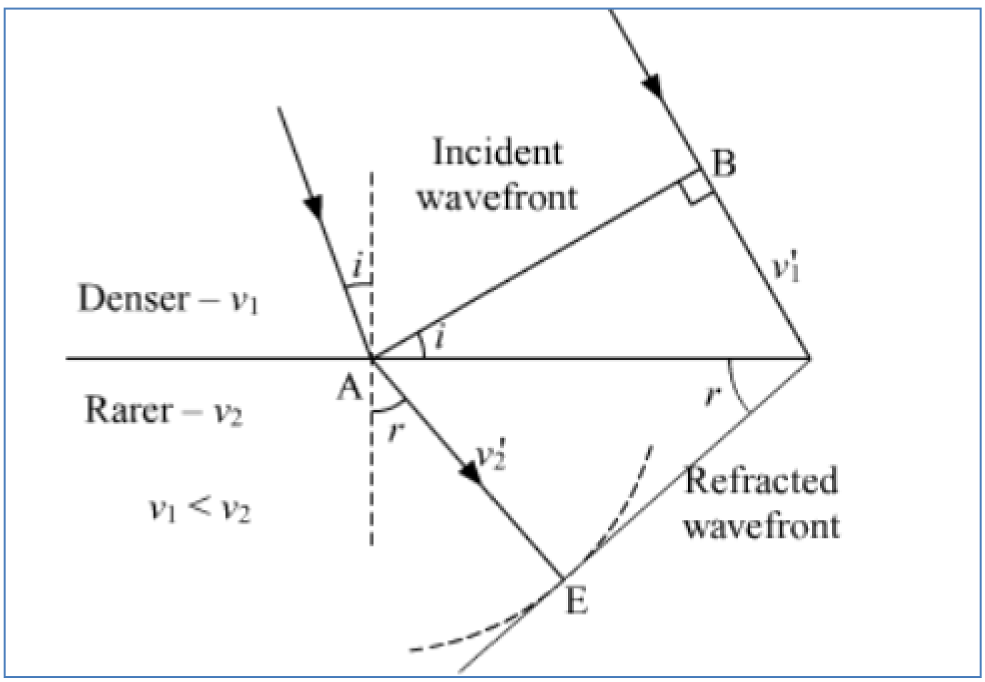
Side $AD = AD$ and side $CD = AF = 2v\Delta t$
And $\angle ACD = \angle DFA = 90^\circ$
so by RHS rule both the triangles are congruent. Hence each corresponding parameters must be same. Hence $\angle CAD = i$ (angle of incidence) Must be same as $\angle FDA = r$ (angle of reflection)
$\angle i = \angle r$

OR

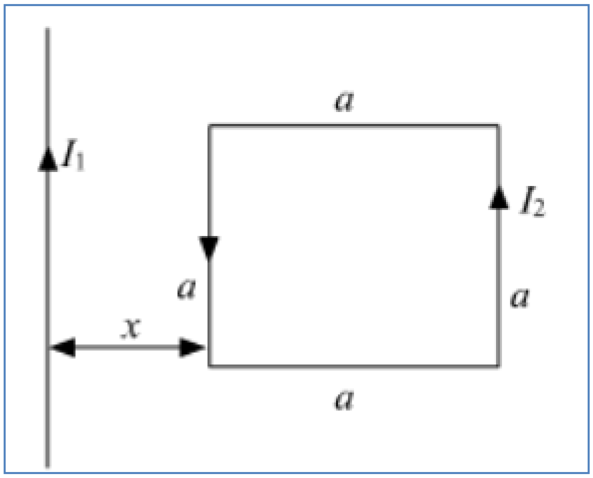
The factor by which speed of light gets reduced with respect to the "speed of light in vacuum" is said to be the refractive index for the medium.

$$\mu = \frac{c}{v} \text{ or } v = \frac{c}{\mu}$$

Here v is the speed of light in medium, c is the speed of light in vacuum and μ is the defined refractive index for the medium.



17. **(a)** Define mutual inductance and write its Si. unit.
(b) A square loop of side 'a' carrying a current 12 is kept at distance x from an infinitely long straight wire carrying a current 11 as shown in the figure. Obtain the expression for the resultant force acting on the loop.

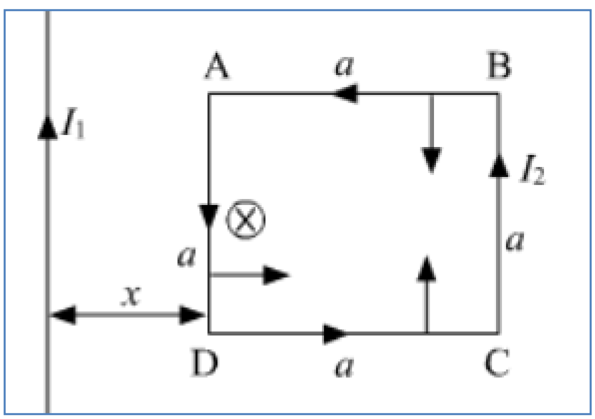


Sol:-

(a)

Mutual inductance is where the magnetic field generated by a coil of wire induces voltage in an adjacent coil of wire. A transformer is a device constructed of two or more coils in close proximity to each other, with the express purpose of creating a condition of mutual inductance between the coils. It's SI unit is : Wb/A

(b)



According to the right hand screw rule, the magnetic field will be into the plane across the loop

Force on length AD

$F = Bil$

$$F_1 = \frac{\mu_\circ I_1 I_2 a}{2\pi x}$$

Force on length BC

$F = Bil$

$$F_2 = \frac{\mu_\circ I_1 I_2 a}{2\pi(x+a)}$$

Force on AB and CD will be equal and opposite . Hence, they'll cancel out. Force on the loop

$$F_{Net} = F_1 - F_2$$

$$= \frac{\mu_\circ I_1 I_2 a}{2\pi}\left[\frac{1}{x} - \frac{1}{(x+a)}\right]$$

$$F_{Net} = \frac{\mu_\circ I_1 I_2 a}{2\pi}\left[\frac{x+a-x}{(x+a)x}\right] = \frac{\mu_\circ I_1 I_2 a^2}{2\pi(x+a)x}$$

$$F_{Net} = \frac{\mu_\circ I_1 I_2 a^2}{2\pi x(x+a)} \quad (Towards\ left)$$

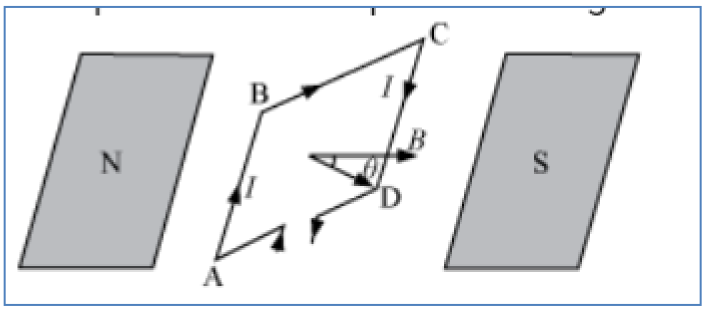
18.

(a) Derive the expression for the torque acting on a current carrying loop placed in a magnetic field.

(b) Explain the significance of a radial magnetic field when a current carrying coil is kept in it.

Sol:-

(a) The plane of the loop is not along the magnetic field but makes an angle with it.



Let the dimension of the rectangular coil ABCD, be $AB \times BC = a \times b$

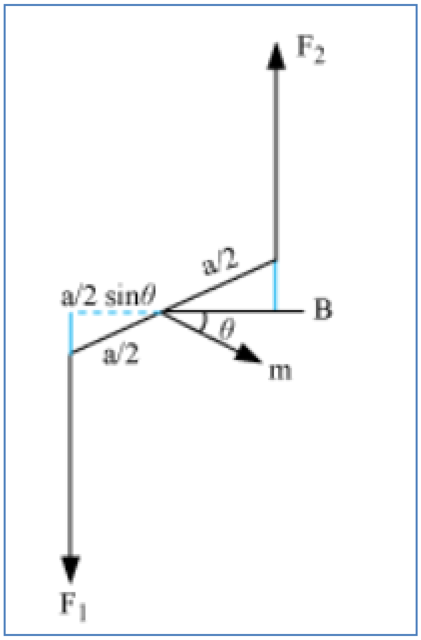
The angle between the field and the normal is θ.

Forces on BC and DA are equal and opposite and they cancel each other as they are collinear.

Force on AB is F_1 and force on CD is F_2.

$F_1 = F_2 = IbB$

The magnitude of the torque on the loop as in the figure:



$\tau = F_1 \frac{a}{2}\sin\theta + F_2 \frac{a}{2}\sin\theta$

$= IabB\sin\theta$

If there are ‘n’ such turns the torque will be $nIab\sin\theta$

The magnetic moment of the current $m = IA$

$\vec{\tau} = \vec{m}\times\vec{B}$

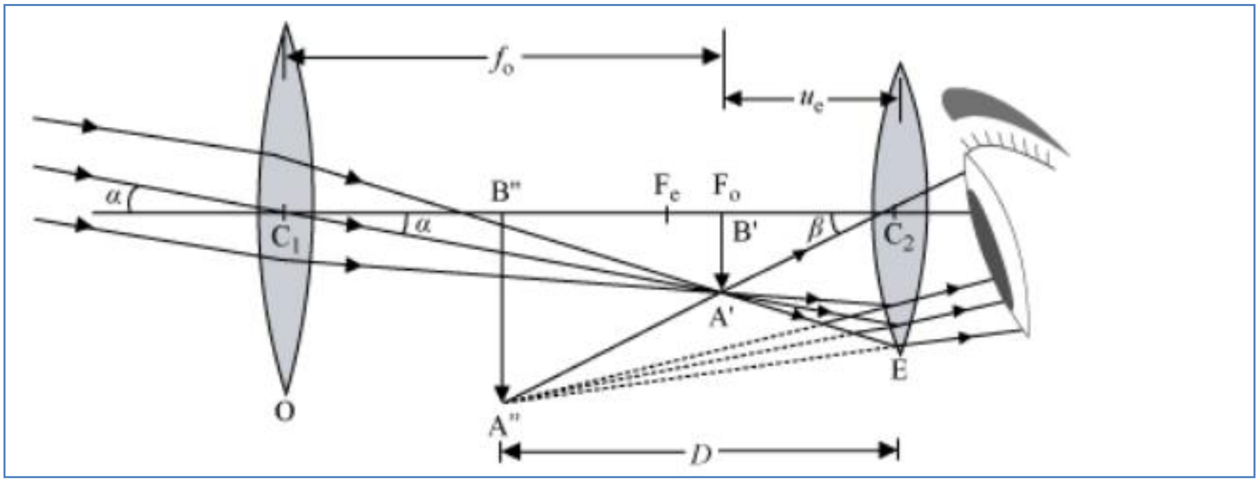
(b)

The uniform radial magnetic field keeps the plane of the coil always parallel to the direction of the magnetic field. That is, the angle between the plane of the coil and the magnetic field is zero in all the orientation of the coil.

19. Draw a labelled ray diagram of an astronomical telescope in the near point adjustment position. A giant refracting telescope at an observatory has an objective lens of focal length 15 m and an eyepiece of focal length 1.0 cm. If this telescope is used to view the Moon, find the diameter of the image of the Moon formed by the objective lens. The diameter of the Moon is $3.48\times10^6 m$, and the radius of lunar orbit is $3.48\times10^8 m$.

Sol:-

When the final image is formed at the least distance of distinct vision



Magnifying power,

$$M = \frac{\beta}{\alpha}$$

α and β are small

$$M = \frac{\tan\beta}{\tan\alpha}$$

$In\, \Delta A'B'C_2$

$$\tan\beta = \frac{A'B'}{C_1B'}$$

$In\, \Delta A'B'C_1$

$$\tan\alpha = \frac{A'B'}{C_1B'}$$

$$M = \frac{A'B'}{C_2B'} \times \frac{C_1B'}{A'B'}$$

$$= \frac{C_1B'}{C_2B'}$$

Here,

$$C_1B' = +f_0$$

$$C_2B' = -u_e$$

$$M = \frac{f_0}{-u_e}$$

Use the lens equation $\left(\frac{1}{v} - \frac{1}{u} = \frac{1}{f}\right)$ for the eyepieces, we get

$$\frac{1}{-D}-\frac{1}{-u_c}=\frac{1}{f_e}$$

$$-\frac{1}{D}+\frac{1}{u_c}=\frac{1}{f_e}$$

$$\frac{1}{u_e}=\frac{1}{f_e}+\frac{1}{D}$$

$$\frac{f_0}{u_e}=\frac{f_0}{f_e}\left(1+\frac{f_e}{D}\right)$$

$$\frac{-f_0}{u_e}=\frac{-f_0}{f_e}\left(1+\frac{f_e}{D}\right)$$

$$M=-\frac{f_0}{f_e}\left(1+\frac{f_e}{D}\right)$$

Angular magnification is:

$$m_\circ=\left|\frac{f_\circ}{f_e}\right|=\left|\frac{1500}{1}\right|=1500$$

Where, f_0 is the focal length of the objective lens and f_e is the focal length of the eye piece

Given, the diameter of the moon $3.48\times10^6 m$

The radius of the lunar orbit $3.8\times10^8 m$

The diameter of the image of the moon formed by the objective lens is given by $d=af_0$

$$d=\frac{Diameter\ of\ the\ moon}{Radius\ of\ the\ lunar\ orbit}\times f_\circ$$

$$d=\frac{3{\cdot}48\times10^6}{3{\cdot}8\times10^8}\times15=13.74\,\text{cm}$$

20. **(a)** State Gauss's law for magnetism. Explain its significance.

(b) Write the four important properties of the magnetic field lines due to a bar magnet

OR

Write three points of differences between para-, dia- and ferro- magnetic materials, giving one example for each.

Sol:-

(a) Gauss's law of magnetism states that net magnetic flux through a closed surface (Gaussian surface) is zero. Mathematically

$$\oint \vec{B}\cdot d\vec{s}=0$$

Gauss's Law for magnetism tells us that magnetic monopoles do not exist

(b) Important properties of magnetic field lines due to a bar magnet:

(i) Field lines form close loop

(ii) Field lines do not intersect

(iii) Degree of closeness of lines represents relative strength of field in regions

(iv) Direction of magnetic field at a point is along the tangent to a line at that point

Sol:-

Ferromagnetism:

These substances are strongly attracted by a magnetic field. Ferromagnetic substances can be permanently magnetized even in the absence of a magnetic field. These substances move (strongly) towards the strong field region when kept a non-uniform external magnetic field. Some examples of ferromagnetic substances are iron, cobalt, nickel, gadolinium

Paramagnetism:

The substances that are attracted by a magnetic field are called paramagnetic substances. These substances get magnetized in a magnetic field in the same direction but lose magnetism when the magnetic field is removed. Paramagnetic material moves (weakly) towards the weak field region when kept a non-uniform external magnetic field. To undergo paramagnetism, a substance must have one or more unpaired electrons.

Example O_2

Diamagnetism:

This is a form of magnetism that is only exhibited by a substance in the presence of an externally applied magnetic field. It is generally quite a weak effect in most materials, although superconductors exhibit a strong effect. Diamagnetic material moves (very weakly) away from strong field region towards the weak field region. Diamagnetic atoms have only paired electrons.

Example H_2

21. Define the term 'decay constant' of a radioactive sample. The rate of disintegration of a given radioactive nucleus is 10000 disintegrations/s and 5,000 disintegrations/s after 20 hr. and 30 hr. respectively from start. Calculate the half life and initial number of nuclei at t= 0.

Sol:-

Decay constant is the fraction of the number of atoms that decay in one second.

It is denoted by A.

Let $N_\circ$ be the initial number of nuclei,

Let λ be the decay constant

Let $t_{1/2}$ be the half life

The instantaneous activity of radioactive material is given by $A = A_0 e^{-\lambda t}$

Where, A_o is activity at t = 0

Therefore, after 20 hours is 10,000 disintegrations per second

$10,000 = A_0 e^{-\lambda(20\times3600)}$ (1)

Activity after 30 hours is 5,000 disintegrations per second

$5000 = A_0 e^{-\lambda(30\times3600)}$ (2)

On dividing (1) by (2),

$2 = e^{\lambda\times3600}$

$$\Rightarrow \lambda = \frac{\ln 2}{36000} = 1{\cdot}92\times10^{-5}$$

And half life is,

$$\frac{\ln 2}{1{\cdot}92\times10^{-5}}=36,000\,\mathrm{s}=10\,hours$$

Since,

$$\frac{dN}{dt}=\lambda N$$

$$1000=\left(1.92\times10^{-5}\right)\times N_1$$

$$\Rightarrow N_1=\frac{10,000}{1{\cdot}92\times10^{-5}}=5{\cdot}208\times10^{8}$$

Therefore, the half life is 10 hours, thus the initial number of nuclei is $N_0=10.416\times10^{8}$

22.

(a) Three photodiodes D1, D2 and D3 are made of semiconductors having band gaps of 2.5 eV, 2 eV and 3 eV respectively. Which of them will not be able to detect light of wavelength 600 nm?

(b) Why photodiodes are required to operate in reverse bias? Explain.

Sol:-

(a) Energy of the incident light

$$E = \frac{hC}{\lambda}$$

$$= \frac{\left(6.6\times10^{-34}\right)\times\left(3\times10^{8}\right)}{\left(600\times10^{-9}\right)\left(1.6\times10^{-19}\right)}$$

$$E = 2.06\ eV$$

The incident radiations can be detected by a photodiode if the energy of incident radiation photon is greater than the band gap. This is true only for D_2 (2 eV).
Hence, only D_2 will detect the light of 600 nm wavelength.

(b) The photodiode is reverse biased for operating in the photoconductive mode. As the photodiode is in reverse bias, the width of the depletion layer increases. This reduces the junction capacitance and thereby the response time. In effect, the reverse bias causes faster response times for the photodiode. The photocurrent is linearly proportional to the luminance.

23.

(a) Describe briefly the functions of the three segments of n-p-n transistor.

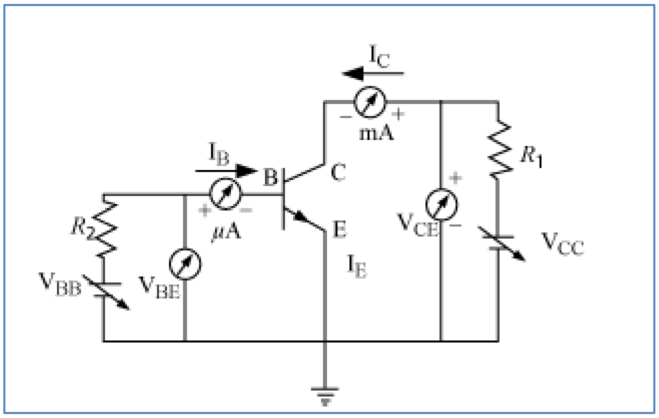
(b) Draw the circuit arrangement for studying the output characteristics of n-p- **n** transistor in CE configuration. Explain how the output characteristics is obtained.

OR

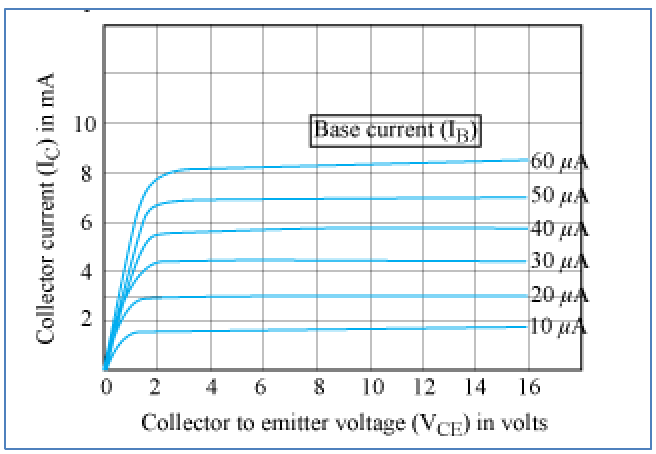
Draw the circuit diagram of a full wave rectifier and explain its working. Also, give the input and output waveforms.

Sol:-

(a) Three segments of transistor
Emitter - Segment is on one side of the transistor. It is of moderate size and heavily doped. It supplies a huge number of majority carriers for the current flow through the transistor. Base - It is the central segment. It is very thin and lightly doped. Collector - It collects a major portion of the majority carrier supplied by the emitter. It is moderately doped and large in size compared to emitter.
(b) Circuit arrangement for studying the output characteristics of n-p-n transistor in CE configuration



Variation of collector current I_c with the collector emitter voltage V_{CE} is called output characteristic.

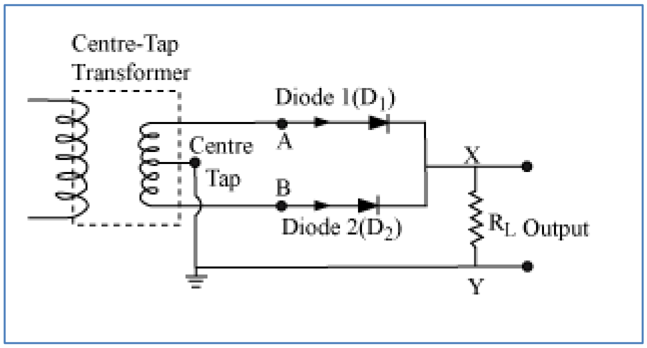


The output characteristics describe the relationship between output current (I_c) and output voltage (V_{cE}). First, draw a vertical line and a horizontal line. The vertical line represents y-axis and horizontal line represents x-axis. The output current or collector current (I_c) is taken along the y-axis (vertical line) and the output voltage (V_{cE}) is taken along the x-axis (horizontal line). To determine the output characteristics, the input current or base current 18 is kept constant at 0 pA and the output voltage V_{cE} is increased from zero volts to different voltage levels. For each level of the output voltage, the corresponding output current (I_c) is recorded. A curve is then drawn between output current I_c and output voltage V_{cE} at constant input current 18 (0 pA).

OR

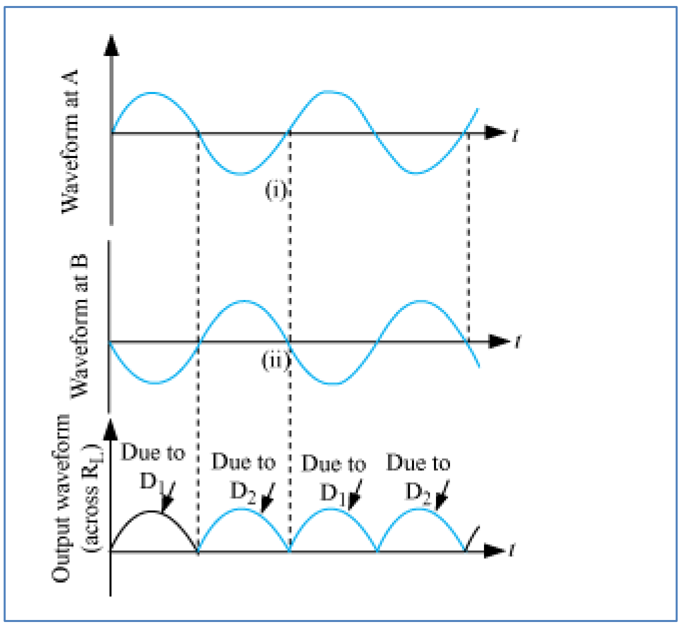
Full wave rectifier

Two diodes are used to rectified both positive and negative half cycles,



When the voltage at A with respect to the center tap is positive, and the voltage at B is negative. Then, Di is forward biased and D2 is reversed biased. Hence, Di conducts and D2 does not. When the voltage of A becomes negative, then B becomes i-ve. Therefore, Di does not conduct and D2 conducts. Hence, we obtain output voltage during both the positive as well as negative half of the cycle.

Input and Output waveforms are shown below.



24.

(a) If A and B represent the maximum and minimum amplitudes of an amplitude modulated wave, write the expression for the modulation index in terms of A and B.

(b) A message signal of frequency 20 kHz and peak voltage 10 V is used to modulate a carrier of frequency 2 MHz and peak voltage of 15 V. Calculate the modulation index. Why the modulation index is generally kept less than one?

Sol:-

(a) Modulation index for an AM wave for which the maximum amplitude is 'a' while the minimum amplitude id

Modulation index,

$a_m = \frac{E_m}{E_c}$ ... (1)

The maximum amplitude of the modulated wave, $a = Ec + Em$ (2)
The minimum amplitude of the modulated wave, $b = Ec - Em$ (3)
From the above equations,

$E_c = \frac{a+b}{2}$, $E_m = \frac{a-b}{2}$

Thus, the modulation index is $a_m = \frac{E_m}{E_c} = \frac{\frac{(a-b)}{2}}{\frac{(a+b)}{2}} = \frac{(a-b)}{(a+b)}$

(b)

$F_m = 20kHz = \text{message signal frequency}$

$V_m = 10V = \text{peak voltage do messege signal}$

$V_c = 15V = \text{peak voltage of carrier signal}$

$\text{Modulation index} = \frac{V_m}{V_c} = \frac{10}{15} = \frac{2}{3}$

To avoid distortion the modulation signal is generally kept less than 1

Section D

25.

(a) In a series LCR circuit connected across an ac source of variable frequency, obtain the expression for its impedance and draw a plot showing its variation with frequency of the ac source.
(b) What is the phase difference between the voltages across inductor and the capacitor at resonance in the LCR circuit?
(c) When an inductor is connected to a 200 V dc voltage, a current at 1A flows through it. When the same inductor is connected to a 200 V, 50 Hz ac source, only 0.5 A current flows. Explain, why? Also, calculate the self inductance of the inductor.

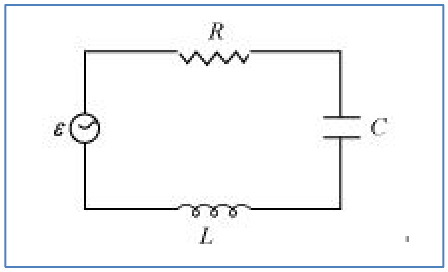
OR

(a) Draw the diagram of a device which is used to decrease high ac voltage into a low ac voltage and state its working principle. Write four sources of energy loss in this device.
(b) A small town with a demand of 1200 kW of electric power at 220 V is situated 20 km

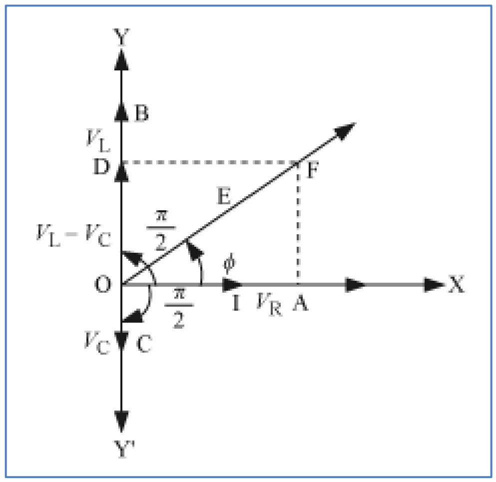
away from an electric plant generating power at 440 V. The resistance of the two wire line carrying power is 0.5 0 per km. The town gets the power from the line through a 4000-220 V step-down transformer at a sub-station in the town. Estimate the line power loss in the form of heat.

Sol:-

(a) Consider the LCR circuit



An *AC* source *E* with voltage $v = v_m \sin \omega t$ is applied across *LCR* circuit



As the inductor, capacitor and the resistor are connected in series so the current through all of them is same (same amplitude and same phase) Let the current be 1= Im sin w t The voltage across each component has a different phase relation with the current.

I. Let the maximum voltage across the resistor be $V_R = I_m R$ that is in the same phase of the current hence it is represented by OA in the phasor diagram.

II. Let the maximum voltage across the inductor be $V_L = I_m X_L$ and that leads the current by $\frac{\pi}{2}$ it is represented by OD in the phasor diagram.

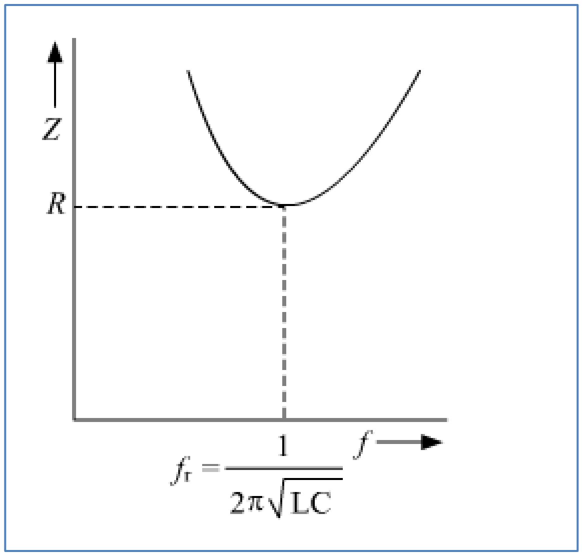
III. Let the maximum voltage across the capacitor be $V_c = I_m X_c$ and that lags behind the current by $\frac{\pi}{2}$, it is represented by OC in the phasor diagram. Resultant voltage can be found by using the vector sum of the phasors. The resultant voltage is represented by OF. It can be written as:

$$V_m = \sqrt{V_R{}^2 + (V_L - V_C)^2} = \sqrt{(I_m R)^2 + (I_m X_L - I_m X_C)^2}$$

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

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

$$Z = \frac{V_m}{I_m} = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$



(b) It can be observed from the phasor diagram that the voltage across the inductor leads the current by $\frac{\pi}{2}$ and that along capacitor leads the current by $\frac{\pi}{2}$, so in every situation the phase difference between the inductor and the capacitor is n.

(c) When the inductor is connected across the 200 V DC circuit 1 A current flows because in this case the inductor simply acts as a resistor and there is no inductive reactance. Whereas, when we connect the same inductor across 200 V AC, due to inductive reactance the overall impedance is changed and hence the value of current also changes.

When the inductor is connected across 200 V DC

The resistance of the coil

$$R = \frac{200}{1} = 200\,\Omega$$

Let the self-inductance of the inductor be L,

When the inductor is connected across 200 V A.C

Net impedance, $Z = \sqrt{(2\pi fL)^2 + R^2} = \frac{200}{0.5} = 400\,\Omega$

$$\Rightarrow (2\pi \times 50 \times L)^2 + 200^2 = 400^2$$

$$\Rightarrow (100\pi L)^2 = 160000 - 40000$$

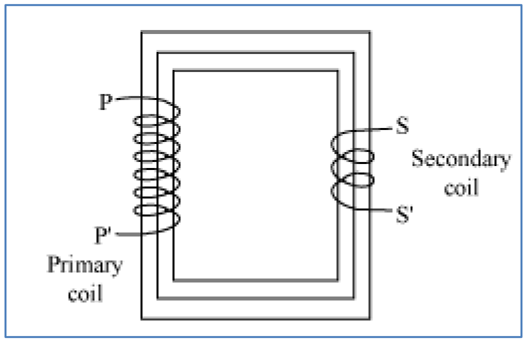
$$\Rightarrow 10000\pi^2 L^2 = 120000$$

$$\Rightarrow L^2 = \frac{12}{\pi^2}$$

$$\therefore L = \frac{\sqrt{12}}{\pi}\ H$$

OR

(a) A transformer is a device that is used to either increase or decrease the ac voltage level. In order to decrease the high ac voltage level into a low ac voltage level we need a step-down transformer, whose diagram is as follows:



Working Principle: A transformer works on the principle of electromagnetic induction. Alternating current in primary coil produces a changing magnetic flux due to this an induced current is set up in the secondary coil. Losses in a transformer: Copper loss - The windings of the transformer have finite resistance due to which some energy is lost in the form of heat. It can be diminished using thick copper wires.

Iron loss - Loss is in the bulk of iron core due to the induced eddy currents in the iron core. It is minimized by using a thin laminated core.

Hysteresis loss - Alternating magnetizing and demagnetizing of the iron core causes the loss of energy in the form of heat. It is minimized using a special alloy of the iron core with silicon that has low hysteresis loss.

Magnetic loss - All the magnetic flux due to the primary coil does not pass through the secondary coil. So there is some leakage of flux. This loss can be minimized by winding primary over the secondary coil.

(b) Total electric power required, $P = 1200\ kW = 1{,}200 \times 10^3 W$

Supply voltage, V= 220 V

Voltage at which electric plant is generating power, V = 440 V

Distance between the town and power generating station, d= 20 km

Resistance of the two-wire lines carrying power = $0.5\Omega / km$

Total resistance of the wires, $R = (20 + 20)0.5 = 20\Omega$

A step-down transformer of rating 4000-220 V is used in the sub-station.

Input voltage, V_i = 4000 V Output voltage, $V_2 = 220\ V_{Rms}$ current in the wire lines is given as:

$$I = \frac{P}{V_1} = \frac{1200 \times 10^3}{4000} = 300\,\text{A}$$

$$\text{Line power loss} = I^2 R$$

$$= 300^2 \times 20$$

$$= 1800 \times 10^3 W$$

$$= 1800 kW$$

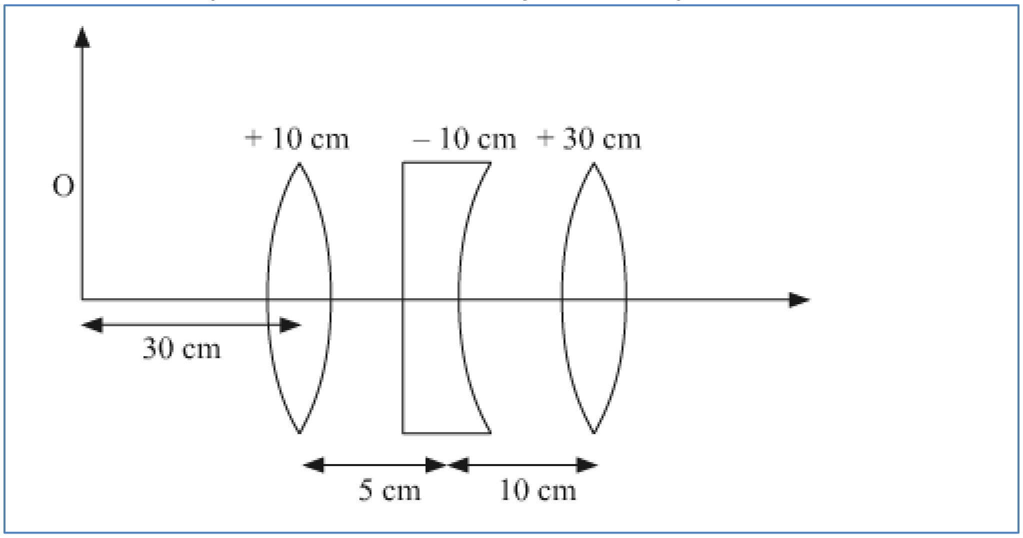
26.

(a) Describe any two characteristic features which distinguish between interference and diffraction phenomena. Derive the expression for the intensity at a point of the interference pattern in Young's double slit experiment.

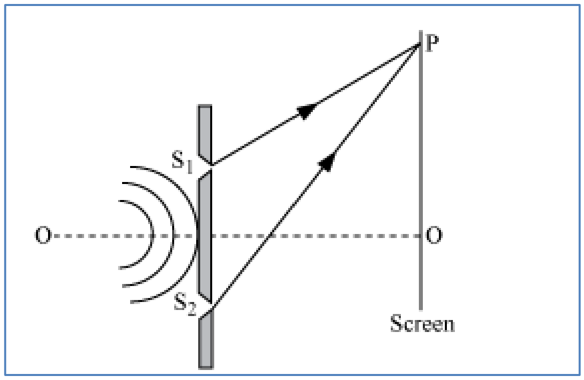
(b) In the diffraction due to a single slit experiment, the aperture of the slit is 3 mm. If monochromatic light of wavelength 620 nm is incident normally on the slit, calculate the separation between the first order minima and the 3rd order maxima on one side of the screen. The distance between the slit and the screen is 1.5 m.

OR

(a) Under what conditions is the phenomenon of total internal reflection of light observed? Obtain the relation between the critical angle of incidence and the refractive index of the medium.
(b) Three lenses of focal length +10 cm, —10 cm and +30 cm are arranged coaxially as in the figure given below. Find the position of the final image formed by the combination.



(a) Difference between interference and diffraction: In the interference pattern, the intensity of the dark fringe is completely zero. In the diffraction pattern, the intensity of secondary minima is minimum, but not completely zero. In interference pattern the width of all the interference fringes is equal. In diffraction pattern the width of central maxima is large, and on increasing distance, the width of maxima decreases. In interference pattern the intensity of all the bright bands is equal. In the diffraction pattern, the intensity of all the secondary maxima is not equal. The principle of superposition of light waves: When two or more wave trains of light travelling in a medium superpose upon each other, the resultant displacement at any instant is equal to the vector sum of the displacements due to individual waves. If $\vec{y}_1, \vec{y}_2, \vec{y}_3$, ... be the displacements due to different waves, then the resultant displacement is given by, $\vec{y} = \vec{y}_1 + \vec{y}_2 + \vec{y}_3 + \cdots$ Conditions for constructive and destructive interference:



Consider the displacement of the waves from the source S_1 and S_2 at a point P on the screen at any time *t* is:

$y_1 = a_1 \sin \omega t$

$y_2 = a_2 \sin(\omega t + \phi)$

Where ϕ is the constant phase difference between the two waves

Thus, by the superposition principal

$y = y_1 + y_2$

$= a_1 \sin \omega t + a_2 \sin(\omega t + \phi)$

$= a_1 \sin \omega t + a_2 \sin \omega t \cos \phi + a_2 \cos \omega t \sin \phi$

$y = (a_1 + a_2 \cos \phi) \sin \omega t + a_2 \sin \phi \cos \omega t$

$y = A \cos \theta \sin \omega t + A \sin \theta \cos \omega t$

$y = A \sin(\omega t + \theta)$

Squaring and adding

$A^2 \cos^2 \theta + A^2 \sin^2 \theta = (a_1 + a_2 \cos \phi)^2 + a^2{}_2 \sin^2 \phi$

$A^2 = a_1^2 + a_2^2 (\cos^2 \phi + \sin^2 \phi) + 2a_1 a_2 \cos \phi$

$A^2 = a_1^2 + a_2^2 + 2a_1 a_2$

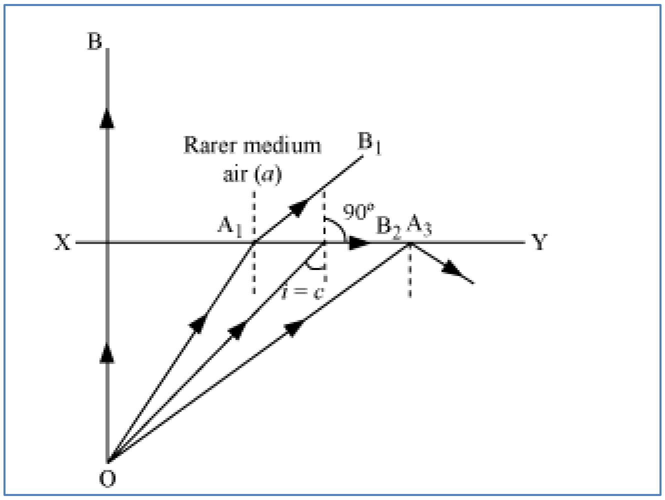
Therefore

$I = a_1^2 + a_2^2 + 2a_1 a_2 \cos \phi$

OR

(a)

Total Internal Reflection



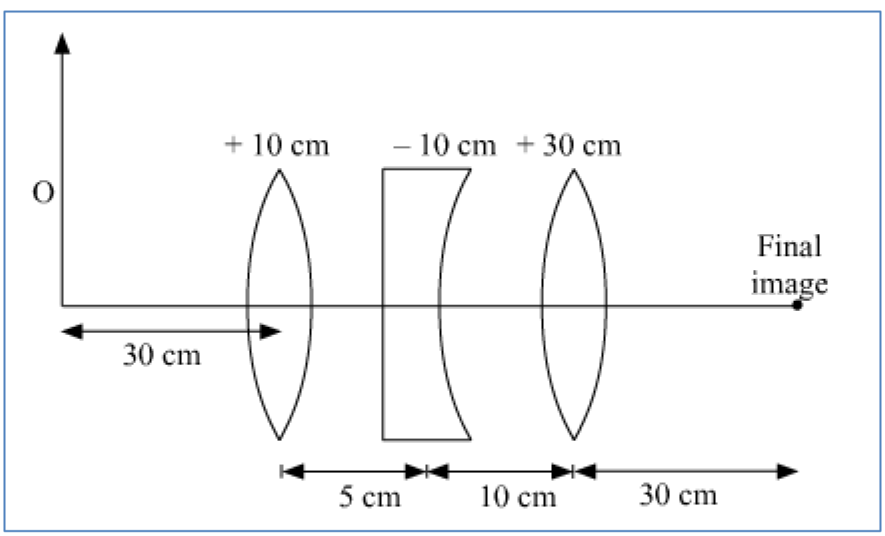
Total internal reflection is the phenomenon of reflection of light into a denser medium from an interface of the denser medium and the rarer medium. Two essential conditions for total internal reflection: Incident ray should travel in the denser medium and refracted ray should travel in the rarer medium.
The angle of incidence (i) should be greater than the critical angle for the pair of media in contact.
The relation between refractive index and critical angle (C):
When i=C and r=90
Apply Snell's law

$$\mu_b \sin C = \mu_a \sin 90^\circ = \mu_a \times 1$$

$$\frac{\mu_b}{\mu_a} = \frac{1}{\sin C}$$

$$^a\mu_b = \frac{1}{\sin C}$$

(b)



$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$$
$$u=-30\ cm$$
$$f=+10\ cm$$
$$\frac{1}{v}=\frac{1}{f}+\frac{1}{u}$$
$$\frac{1}{v_1}=\frac{1}{10}-\frac{1}{30}$$
$$\Rightarrow\frac{1}{v_1}=\frac{3-1}{30}=\frac{2}{30}$$
$$v_1=15\ cm$$
$$u=+10\ cm$$
$$f=-10\ cm$$
$$\frac{1}{v_2}=\frac{1}{f}+\frac{1}{u}=\frac{1}{10}-\frac{1}{10}$$
$$v_2=\infty$$

27.

(a) Describe briefly the process of transferring the charge between the two plates of a parallel plate capacitor when connected to a battery. Derive an expression for the energy stored in a capacitor.

(b) A parallel plate capacitor is charged by a battery to a potential difference V. It is disconnected from battery and then connected to another uncharged capacitor of the same capacitance. Calculate the ratio of the energy stored in the combination to the initial energy on the single capacitor.

OR

(a) Derive an expression for the electric field at any point on the equatorial line of an electric dipole.

(b) Two identical point charges, q each, are kept 2m apart in air. A third point charge Q of unknown magnitude and sign is placed on the line joining the charges such that the system remains in equilibrium. Find the position and nature of Q.

Sol:-

(a) Consider a parallel plate capacitor which is connected across a battery. As soon as the charges from the battery reach one plate, due to insulating gap charge is not able to move further to the other plate. Thus, positive charge is developed at one plate and negative charge is developed on the other. As the amount of charge increases on the plates a voltage is developed across the capacitor that is opposite to the applied voltage. Hence, the current flowing in the circuit decreases and gradually becomes zero. Thus, the charge is developed on the capacitor.

Energy Stored in a Charged Capacitor

The energy of a charged capacitor is measured by the total work done in charging the capacitor to a given potential.

Let us assume that initially, both the plates are uncharged. Now, we have to repeatedly remove small positive charges from one plate and transfer them to the other plate.

Let

q —Total quantity of charge transferred

V—Potential difference between the two plates

Then

$$q = CV$$

$$dW = Vdq = \frac{q}{C}dq$$

Total work done is

$$W = \int_0^Q \frac{q}{C}dq = \frac{1}{C}\int_0^Q qdq = \frac{1}{C}\left[\frac{q^2}{2}\right]_0^Q$$

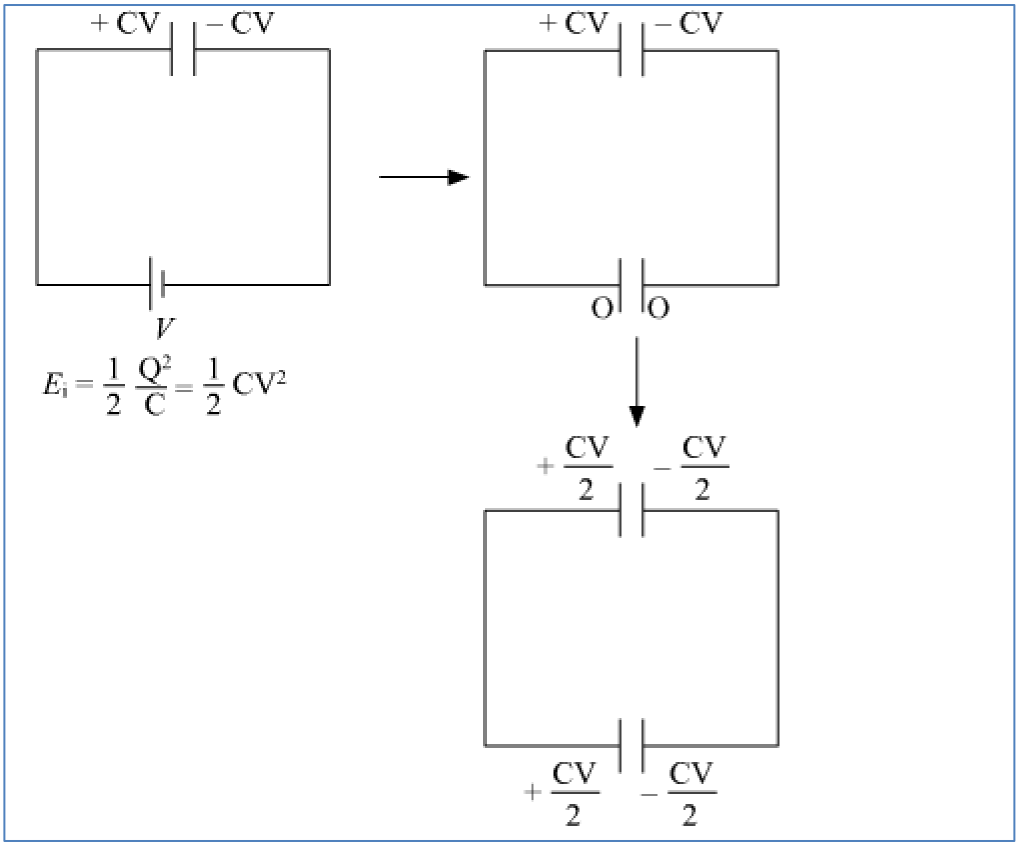
$$W = \frac{Q^2}{2C}$$

This work is stored as electrostatic potential energy *U*

$$U = \frac{Q^2}{2C}$$

$$= \frac{(CV)^2}{2C}$$

$$= \frac{1}{2}CV^2$$



(b)

$$E_f = \frac{1}{2}\frac{\left(\frac{CV}{2}\right)^2}{C} + \frac{1}{2}\frac{\left(\frac{CV}{2}\right)^2}{C}$$

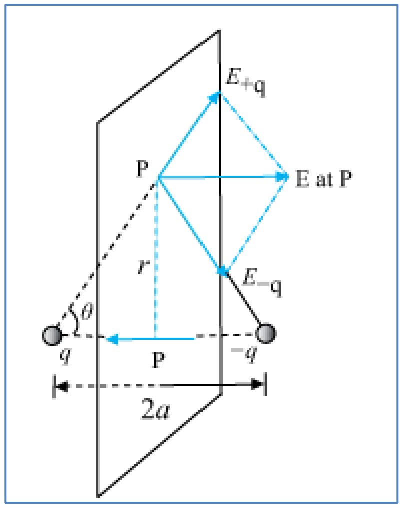
$$= \frac{C^2V^2}{4C}$$

$$E_f = \frac{1}{4}CV^2$$

$$\frac{E_f}{E_i} = \frac{\frac{1}{4}CV^2}{\frac{1}{2}CV^2} = \frac{1}{2}$$

OR

(a) Electric field for points on the equator plane



The magnitude of the electric field due to two charges +q and –q are

$$E_{+q} = \frac{q}{4\pi\varepsilon_0}\frac{1}{r^2+a^2}$$

$$E_{-q} = \frac{q}{4\pi\varepsilon_0}\frac{1}{r^2+a^2}$$

$$E_{+q} = E_{-q}$$

The directions of E_{+q} and E_{-q}, are as shown in the figure. The components normal to the dipole axis cancel away. The components along the dipole axis add up.

Total electric field, $E = -\left(E_{+q} + E_{-q}\right)\cos\theta\,\hat{p}$ (Negative sign shows that the field is opposite to $\hat{p}$

$$E = -\frac{2qa}{4\pi\varepsilon_0\left(r^2+a^2\right)^{\frac{3}{2}}}\hat{p} \qquad \text{...(iii)}$$

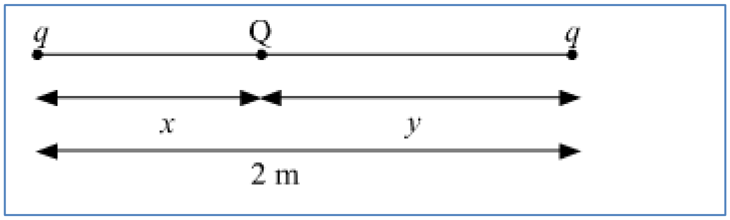
At large distances (r » a), this reduces to,

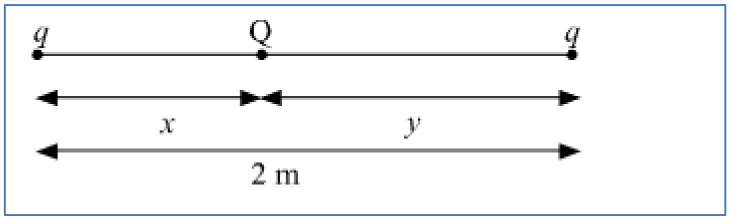
$$E = -\frac{2qa}{4\pi\varepsilon_0 r^3}\hat{p}$$

$$\vec{p} = q \times 2\vec{a}\hat{p}$$

$$E = -\frac{\vec{p}}{4\pi\varepsilon_0 r^3}$$

(b)





$$\frac{K(q)(Q)}{x} = \frac{-K(q)(q)}{2}$$

$$\Rightarrow Q = \frac{-qx}{2}$$

$$\because \frac{KqQ}{x} = \frac{KQq}{y}$$

$$x = y$$

$$x + y = 2$$

$$\therefore x = y = 1$$

$$Q = \frac{-q}{2}$$