LECTURE NOTES

ON

ENGINEERING PHYSICS

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UNIT-9 (Electrostatics & Magnetostatics)

Electrostatics (definition):

Electrostatics is the branch of physics that deals with the phenomena and properties of stationary or slow moving electric charges with no acceleration.

Since classical antiquity, it has been known that some materials such as amber attract light weight particles after rubbing.

Coulomb's law in electrostatics:

Statement: It states that the electro-static force of attraction or repulsion between two charged bodies is directly proportional to the product of their charges and varies inversely as the square of the distance between two bodies.

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Explanation:

Suppose two point charges q_1 & q_2 are situated at a distance 'r' from each other in some medium. The magnitude of the electro-static force 'F' which one exerts on the other will be given by

$$F \propto q_1 q_2 \quad \text{---(1)}$$

and $$F \propto 1/r^2 \quad \text{---(2)}$$

combining the above two equations, we get

$$F \propto \frac{q_1 q_2}{r^2}$$

$$\text{or, } \boxed{F = \beta \frac{q_1 q_2}{r^2}}$$

where β is a constant of proportionality.

Value of β:

i) In C.G.S: electrostatic system of units (e.s.u) $\beta = 1/K$

where 'K' is called the dielectric constant of the medium which is taken to be equal to one ($K = 1$) for free space (vacuum)

Therefore, Coulomb's law can be expressed in e.s.u. as:

$$F = \frac{q_1 q_2}{r^2} \quad \text{(for free space)}$$

ii) In S.I. units:

$$\beta = \frac{1}{4\pi \varepsilon_0 \varepsilon_r}$$

where 'ε_0' is the permitivity of free space (vacuum) & ε_r is the relative permitivity of the given medium.

→ Relative permitivity of a medium is defined as the ratio between absolute permitivity (ε) of the medium the the absolute permitivity (ε_0) of the free space.

$$\varepsilon_r = \varepsilon / \varepsilon_0 \quad \text{or} \quad \varepsilon = \varepsilon_0 \varepsilon_r$$

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∴ In case of S.I., coulomb's law can be written as

$$F = \frac{1}{4\pi \varepsilon_0 \varepsilon_r} \frac{q_1 q_2}{r^2} = \frac{1}{4\pi \varepsilon} \frac{q_1 q_2}{r^2}$$

value of 'ε_0' can be determined, experimentally & it has been found that

$$\varepsilon_0 = 8.854 \times 10^{-12}\ C^2 N^{-1} m^{-2}$$

Substituting for 'ε_0', we get

$$\frac{1}{4\pi \varepsilon_0} = \frac{1}{4\pi \times 8.854 \times 10^{-12}} = 8.987 \times 10^9\ N m^2 C^{-2}$$

$$\frac{1}{4\pi \varepsilon_0} \simeq 9 \times 10^9\ N m^2 C^{-2}$$

Thus, mathematically, it can be written as

$$F = \frac{1}{4\pi \varepsilon_0 \varepsilon_r} \frac{q_1 q_2}{r^2} = \frac{9 \times 10^9}{\varepsilon_r} \frac{q_1 q_2}{r^2}$$

(for any medium)

For air, $\varepsilon_r = 1$

$$F = \frac{1}{4\pi \varepsilon_0} \frac{q_1 q_2}{r^2} = 9 \times 10^9 \frac{q_1 q_2}{r^2} \quad \text{(for air)}$$

Units of 'ε_0':

According to coulomb's law,

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

$$\therefore \quad \varepsilon_0 = \frac{1}{4\pi}\frac{q_1 q_2}{F \times r^2}$$

So that $\varepsilon_0 = \dfrac{\text{coulomb} \times \text{coulomb}}{\text{Newton} \times (\text{meter})^2} = C^2 N^{-1} m^{-2}$

Dimensions of 'ε_0':

$$[\varepsilon_0] = \frac{(\text{charge})^2}{\text{force} \times (\text{distance})^2}$$

$$= \frac{[A^1 T^1]^2}{[M^1 L^1 T^{-2}] \times [L^2]} = [M^{-1} L^{-3} T^4 A^2]$$

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Unit charge:

i) In C.G.S electro-static system, the unit charge is called e.s.u of charge or statcoulomb.

In this system, force is measured in dyne & distance is measured in centimeter.

According to coulomb's law,

$$F = \frac{1}{K}\frac{q_1 q_2}{r^2}$$

For vacuum, $K = 1$.

$$\therefore \quad F = \frac{q_1 q_2}{r^2}$$

If $q_1 = q_2 = q$, $r = 1$ centimeter & $F = 1$ dyne, then

$$1 = \frac{q^2}{1} \quad \text{or} \quad q^2 = 1$$

$$\text{or,} \quad q = \pm 1 \text{ statcoulomb.}$$

Hence electro-static unit of charge or stat coulomb is that amount of charge which when placed in air at a distance of 1 cm from a similar charge repels it with a force of 1 dyne.

ii) In S.I. the unit charge is called a coulomb (C). In this system force is measured in 'newton' & distance in 'meter'.

According to coulomb's law,

$$F = \frac{1}{4\pi\epsilon_0} q_1 q_2 / r^2$$

$$= 9 \times 10^9 \; q_1 q_2 / r^2$$

If $q_1 = q_2 = q$, $r = 1$ meter & $F = 9 \times 10^9$ newton,

$$9 \times 10^9 = 9 \times 10^9 \; q^2 / 1$$

or, $1 = q^2/1$

or, $q^2 = 1$ or $q = \pm 1$ coulomb.

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Hence one coulomb of charge is defined as that charge which when placed in air at a distance of 1 meter from an equal & similar charge repels it with a force of 9×10^9 newton.

$$\boxed{1 \text{ coulomb} = 3 \times 10^9 \text{ stat coulomb}}$$

Dielectric constant (K):

Definition: It can be defined as the ratio of the force between two charges separated by some distance apart in free space to the force between the same two charges separated by the same distance apart in that medium.

Explanation: Consider two charges q_1 & q_2 placed at a distance 'r' apart. If F_1 & F_2 are the magnitudes of the force between them in medium & in a free space respectively.

i) In C.G.S.,

$$F_1 = \frac{1}{K} \frac{q_1 q_2}{r^2} \quad \text{(for any medium)}$$

$$F_2 = \frac{q_1 q_2}{r^2} \quad \text{(for free space)}$$

From the above eq^{n}s, we get

$$\frac{F_2}{F_1} = K$$

which is the dielectric constant of the medium.

ii) In S.I. units,

$$F_1 = \frac{9\times10^9}{\varepsilon_r}\,\frac{q_1q_2}{r^2} \text{ (for any medium)}$$

$$F_2 = 9\times10^9\,\frac{q_1q_2}{r^2} \text{ (for air)}$$

So, $$\frac{F_2}{F_1} = \frac{\varepsilon}{\varepsilon_0} = \varepsilon_r$$

which is the relative permitivity of the medium.

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Hence $\boxed{\varepsilon_r = K}$

Electric Potential(V):

The potential at any point in an electric field near a charged body is defined as equal to the amount of work done in bringing a unit positive charge from infinity to that point against the electric field.

i.e. $\boxed{V = \frac{W}{q}}$

→ The S.I. unit of potential is joule/coulomb. or Volt.

→ The unit of potential in c.g.s. system is statvolt.

1 volt $= \frac{1}{300}$ e.s.u. of potential or statvolt.

or, $\boxed{1 \text{ statvolt} = 300 \text{ volt}}$

Electric potential difference:

The potential difference between two points in an electric field is defined as equal to the amount of work done in moving a positive unit charge from one point to the other against the field.

i.e. $$\boxed{V_B - V_A = \frac{W_{AB}}{q}}$$

Or, $$\boxed{V_B - V_A = -\int_A^B E \cdot dl}$$

Electric Field:

It can be defined as the space around a charge in which a charged body can experience a force.

Electric field strength or intensity (E):

Electric field intensity at a given point is defined as equal to the force experienced by a positive unit charge placed at that point & represented by $\vec{E}$.

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i.e. $$\boxed{\vec{E} = \frac{F}{q_1}}$$

→ It is a vector quantity.

→ It can be measured in N/coulomb in S.I. or dyne/statcoulomb in c.g.s.

* Dimensions: $$[\vec{E}] = \frac{[\vec{F}]}{[q]} = \frac{[M^1L^1T^{-2}]}{[A^1T^1]} = [M^1L^1T^{-3}A^{-1}]$$

Capacitance (C):

capacity of a conductor is the ability to store the charges of a conductor to increase its potential to 1 volt.

Here $$\boxed{\text{capacity} = \frac{\text{charge}}{\text{potential}}}$$

i.e. $\boxed{C = \frac{Q}{V}}$

-> It is a scalar quantity.

Units

-> i) In S.I. the unit of capacity is called 1 Farad (F)

$$\boxed{1 \text{ Farad} = \frac{1\ C}{1 \text{ volt}}}$$

∴ one Farad is the capacity of a conductor to store one coulomb of charge to increase its potential to one volt.

-> ii) In C.G.S. system, it is called stat farad.

$$\boxed{1 \text{ Farad} = 9 \times 10^{11} \text{ stat farad}}$$

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Dimensions:

$$[C] = \frac{[q]}{[V]} = \frac{(\text{coulomb})^2}{\text{joule}}$$

$$= \frac{[A^2 T^2]}{[M^1 L^1 T^{-2} L]} = [M^{-1} L^{-2} T^4 A^2]$$

Grouping of capacitors:

Following two types of groupings are commonly used.

i) capacitors in parallel:

capacitors having capacities $C_1, C_2, \cdots C_n$ draw charges $q_1, q_2 \cdots q_n$ in accordance with their capacities. If Q is the total charge drawn from the source, then

$$Q = q_1 + q_2 + \cdots + q_n \quad \text{——— (1)}$$

since all the capacitors are connected between two common points A & B, therefore the potential difference across each of them is the same i.e. V. This is also potential difference across the two terminals of the source of charge.

$$V = \frac{q_1}{C_1} = \frac{q_2}{C_2} = \cdots = \frac{q_n}{C_n}$$

But $q_1 = C_1 V$,

$q_2 = C_2 V$,

$\cdots \cdots$

$q_n = C_n V$

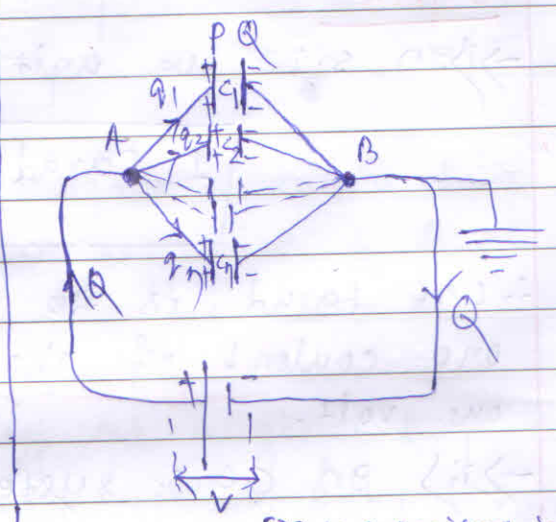

Fig.17 → capacitors in parallel

If 'C' is the capacity of the combination, then

$$V = Q/C \quad \text{or,} \quad Q = CV$$

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Substituting for Q & $q_1, q_2 \cdots q_n$ in eqn (1), we get

$$CV = C_1V + C_2V + \cdots + C_nV$$
$$= (C_1 + C_2 + \cdots + C_n)V$$

$$\boxed{C = C_1 + C_2 + \cdots + C_n}$$

Thus the resultant capacity of a number of capacitors connected in parallel is equal to the sum of their individual capacities.

ii) capacitors in series:

In series combination, each capacitor is charged with the same charge while they will be raised through different potentials in accordance with their capacities. If $V_1, V_2 \cdots V_n$ are the potential differences across various capacitors of capacities $C_1, C_2 \cdots C_n$ respectively, then,

$V = V_1 + V_2 + \cdots + V_n$ ——— (2)

where V is the potential difference between A & B.

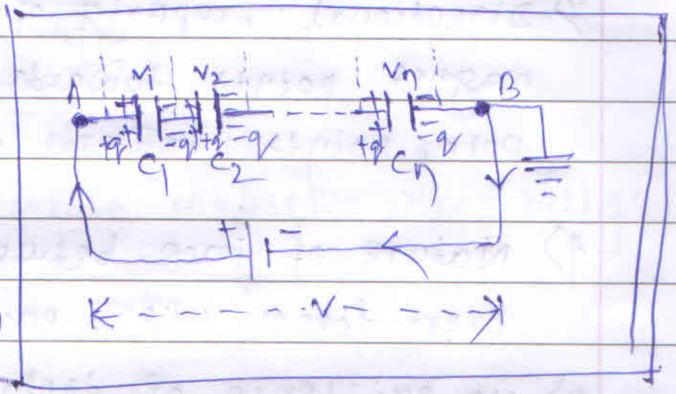

fig. -2- capacitors in series.

Now, $V_1 = \frac{q}{C_1}, V_2 = \frac{q}{C_2}, \ldots, V_n = \frac{q}{C_n}$

Again $V = q/C$

Substituting for V & $V_1, V_2 \ldots V_n$ in eqn(2), we get.

$$\frac{q}{C} = \frac{q}{C_1} + \frac{q}{C_2} + \cdots + \frac{q}{C_n}$$

$$= q\left(\frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n}\right)$$

$$\boxed{\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots \frac{1}{C_n}}$$

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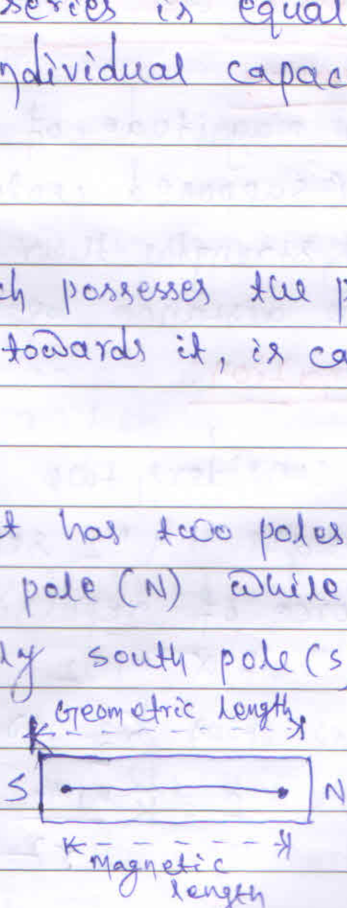
Thus, the reciprocal of the resultant capacity of a number of capacitors, connected in series is equal to the sum of the reciprocals of their individual capacities.

Magnet:

A piece of substance which possesses the property of attracting small pieces of iron towards it, is called a magnet.

properties of a magnet:

1) Two poles of a magnet: A magnet has two poles. One is 'north seeking pole' or simply north pole (N) while the second is 'south seeking pole' or simply south pole (S).



2) Attracting property of a magnet:- A magnet is capable of attracting small pieces of iron towards it.

3) Directional property of a magnet:- North pole of magnet points towards geographic north while south pole points towards geographic south.

4) Nature of force between two poles:- Magnetic poles exert forces upon each other.

5) No existence of isolated magnetic poles:- The magnetic poles exert forces upon each other.

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Magnetic field:

Magnetic field of any magnetic pole is the region or space around it in which its magnetic influence can be realised.

Coulomb's Law in Magnetism:

Statement:

The magnitude of the force between two magnetic poles (supposed isolated) varies directly as the product of the strengths their poles and inversely as the square of the distance between them.

Explanation:

Considers two magnetic poles of similar nature (n) of strengths m_1 & m_2 separated by a distance 'r' from each other. The force of repulsion between them.

$$F \propto m_1 m_2$$

$$F \propto 1/r^2 \quad \text{or} \quad F \propto \frac{m_1 m_2}{r^2}$$

$$\text{or,} \quad F = K \frac{m_1 m_2}{r^2}$$

fig. Force between two magnetic poles

where K is the constant of proportionality.

In S.I. $K = \frac{\mu_0}{4\pi}$

$$\boxed{F = \frac{\mu_0}{4\pi}\frac{m_1 m_2}{r^2}}$$

Where $\mu_0 = 4\pi \times 10^{-7}\ Wb\,A^{-1}m^{-1}$

→ μ_0 is called the 'absolute magnetic permeability' of free space.

In C.G.S. $K = 1$ $\therefore \boxed{F = \frac{m_1 m_2}{r^2}}$

Unit pole:

i) In S.I. system:

According to coulomb's law, in S.I.

$$F = \frac{\mu_0}{4\pi}\frac{m_1 m_2}{r^2}$$

$$\because \mu_0 = 4\pi \times 10^{-7}\ Wb\,A^{-1}m^{-1}$$

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$$F = \frac{4\pi \times 10^{-7}}{4\pi} \times \frac{m_1 m_2}{r^2} = 10^{-7}\frac{m_1 m_2}{r^2}$$

If $F = 10^{-7}N$, $m_1 = m_2 = m$ & $r = 1m$

$$10^{-7} = 10^{-7} \times \frac{m^2}{1}$$

$$m^2 = 1 \text{ or, } m = \pm 1 \text{ (unit pole)}$$

ii) In C.G.S system:

According to coulomb's law in C.G.S system.

$$F = \frac{m_1 m_2}{r^2}$$

If $F = 1$ dyne, $m_1 = m_2 = m$ & $r = 1$ cm

$$1 = \frac{m^2}{1} \text{ or, } m^2 = 1$$

$$m = \pm 1 \text{ (unit pole).}$$

Intensity of magnetic field!

Intensity of magnetic field at any point is defined as the force experienced by a unit north pole at that point. The direction of field is the direction in which the unit north pole would move if it were free to do so.

-> It is a vector quantity.

i) In S.I.

$$F = \frac{\mu_0}{4\pi}\frac{m_1 m_2}{r^2}$$

If $m_1 = m$, $m_2 = 1$, $F = \frac{\mu_0}{4\pi} \times \frac{m}{r^2}$

ii) In C.G.S.

$$F = \frac{m_1 m_2}{r^2}$$

If $m_1 = m$, $m_2 = 1$,

$$F = \frac{m}{r^2}$$

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Magnetic lines of force:

Line of force is the path along which a unit north pole would move if it were free to do so.

Properties:

i) Lines of force are directed away from a north pole & are directed towards south pole.

ii) Tangent at any point to the magnetic line of force gives the direction of magnetic intensity at the point.

iii) Two lines of force never cross each other.

iv) The number of lines of force per unit area is proportional to magnitude of strength of field at that point.

v) The lines of force tend to contract longitudinally or lengthwise i.e. they possess longitudinal strain.

vi) The lines of force tend to exert lateral pressure.

vii) 4π lines of force start from a unit magnetic pole.

Magnetic flux (ϕ_B):

Magnetic flux linked with the surface is defined as the product of area & the component of 'B' perpendicular to the area.

i.e. $\boxed{\phi_B = \vec{B}\cdot\vec{A} = BA\cos\theta = A(B\cos\theta)}$

Case-1 (If $\theta = 90^\circ$, $\cos\theta = 0$)

$$\therefore \phi_B = BA \times 0 = 0$$

∴ No magnetic flux is linked with the surface when the field is parallel to the surface.

Case-2 (If $\theta = 0^\circ$, $\cos\theta = 1$)

$$(\phi_B)_{max} = B \times A \times 1 = BA$$

∴ Magnetic flux linked with a surface is maximum when area is held ⊥ to the direction of field.

Units of ϕ_B:

i) In S.I.,

$\phi_B = BA$

If $B = 1$ tesla

$A = 1\ m^2$

$\phi_B = 1 \times 1 = 1$ weber.

ii) In C.G.S,

If $B = 1$ gauss,

$A = 1\ cm^2$

$\phi_B = 1 \times 1 =$ maxwell

Relation between weber & maxwell:

$$1 \text{ weber} = 1 \text{ tesla} \times 1\ m^2$$
$$= 10^4 \text{ gauss} \times (100\ cm)^2$$
$$= 10^8 \text{ gauss } cm^2$$

$$\therefore \boxed{1 \text{ weber} = 10^8 \text{ maxwell}}$$

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UNIT-10-(CURRENT ELECTRICITY)

Electric current:

Electric current is defined as the rate at which charge flows through a surface.

Electric current formula: $\boxed{i = q/t}$

where $q \rightarrow$ charge

$t \rightarrow$ time

- → It is a scalar quantity.
- → The S.I. unit of charge is coulomb and measurement of electric current happens in units of coulomb per second which is 'ampere'.

Ohm's Law:

It states that the voltage or potential difference between two points is directly proportional to the current or electricity passing through the resistance and directly proportional to the resistance of the circuit.

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Formula:

$$\boxed{V = IR}$$

where V = voltage

I = current

R = resistance

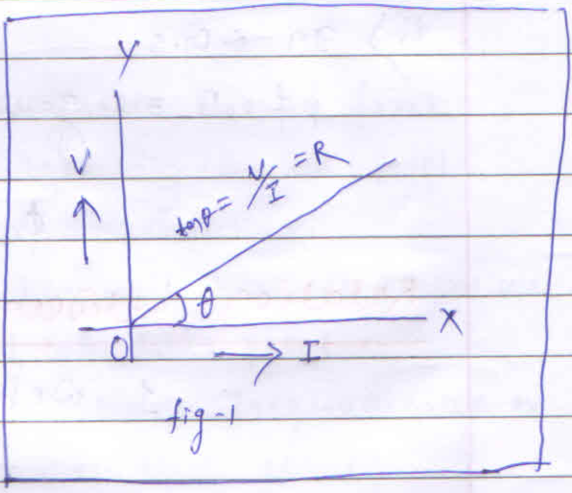

fig-1

→ The S.I. unit of resistance is 'Ohm' and is denoted by Ω.

Applications:

→ Ohm's law helps in determining either voltage, current or impedance or resistance of a linear electric circuit when the other two quantities are known.

→ It also makes power calculation simpler.

Resistors in series!

A number of resistors are said to be connected in series if the same current flows through each resistor and there is only one path for the current flow throughout.

Consider three resistors of resistances R_1, R_2 and R_3 connected in series across a battery of potential difference 'V'. Let 'I' be the circuit current.

According to Ohm's law,

$$V_1 = IR_1, \quad V_2 = IR_2, \quad V_3 = IR_3$$

Now,
$$V = V_1 + V_2 + V_3$$
$$= IR_1 + IR_2 + IR_3$$
$$= I(R_1 + R_2 + R_3)$$

or,
$$V/I = (R_1 + R_2 + R_3)$$

or,
$$\boxed{R_s = R_1 + R_2 + R_3}$$

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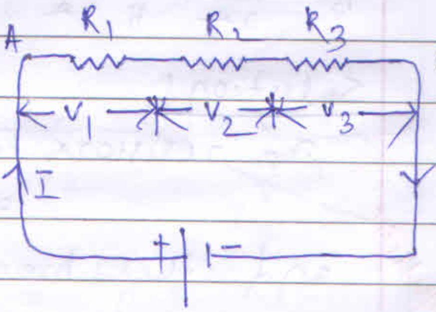

Fig-1- shows resistors connected in series.

Thus, the resultant resistance of a number of resistors connected in series is equal to the sum of their individual resistance.

Resistors in parallel!

A number of resistors are said to be connected in parallel if voltage across each resistor is same.

Consider three resistors of resistances R_1, R_2 & R_3 connected in parallel across a battery of p.d. 'V'. Note that voltage across each resistor is the same.

According to Ohm's law,

$$I_1 = \frac{V}{R_1}, \quad I_2 = \frac{V}{R_2}, \quad I_3 = \frac{V}{R_3}$$

Now,
$$I = I_1 + I_2 + I_3$$
$$= \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

or,
$$I/V = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

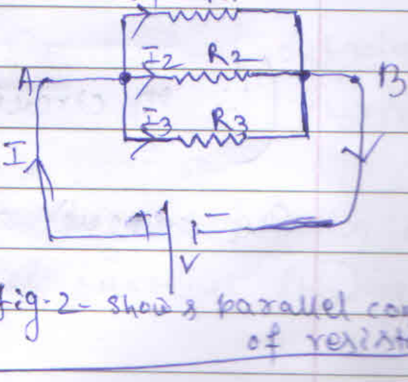

fig-2- shows parallel connection of resistors or, $\boxed{\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$

Thus, the reciprocal of resultant resistance is equal to the sum of the reciprocals of the individual resistances.

Example:-1

Determine the equivalent resistance between terminals A and B of the network shown in fig.-3.

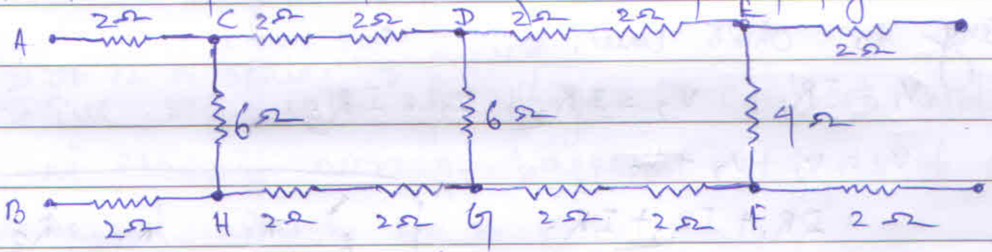

fig. 3.

Solution!

The resistors in branch DEFG are in series i.e.

$= 2+2+4+2+2 = 12\,\Omega$

and this branch is parallel with branch DG ($= 6\,\Omega$)

$\therefore$ Resistance between D & G, $\frac{1}{R_{DG}} = \frac{1}{6} + \frac{1}{12}$

$R_{DG} = \frac{12 \times 6}{12+6} = 4\,\Omega$

The circuit reduces to the circuit shown in fig-4

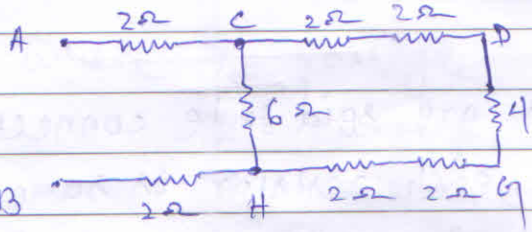

fig-5.

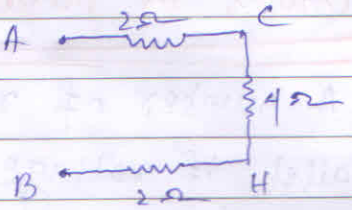

fig-6.

Resistance between C & H, $\frac{1}{R_{CH}} = \frac{1}{6} + \frac{1}{12}$

$R_{CH} = \frac{12 \times 6}{12+6} = 4\,\Omega$

($\because$ in circuit CDGH, the resistors are in series i.e.
$= 2+2+4+2+2 = 12\,\Omega$)

The circuit reduces to that shown in fig. 6

$\therefore R_{AB} = 2+4+2 = 8\,\Omega$. (Ans.)

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KIRCHHOFF'S LAWS:

Kirchhoff gave two laws to solve complex circuits, namely
1. Kirchhoff's current law (KCL)
2. Kirchhoff's voltage law (KVL)

1. Kirchhoff's current law (KCL):

first law:

"This law states that the algebric sum of the currents meeting at a junction in an electrical circuit is zero."

Explanation:

Consider four conductors carrying currents I_1, I_2, I_3 & I_4 and meeting at a point 'O'.

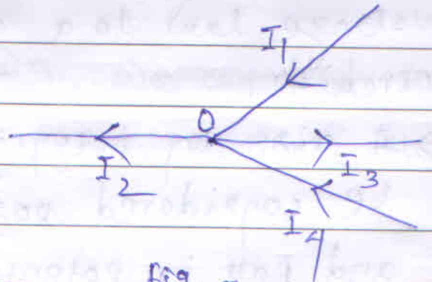

fig. 7

To determine their algebric sum of electric currents, we follow the following sign conventions

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i) The currents approaching a given point are taken as positive.

ii) The currents leaving the given point are taken as negative.

Following these sign conventions, we find that I_1 & I_4 are positive where as I_2 & I_3 are negative.

According to Kirchhoff's first law,

$$I_1 + I_4 + (-I_2) + (-I_3) = 0$$

$$\text{or, } \boxed{I_1 + I_4 = I_2 + I_3}$$

i.e. sum of incoming currents = sum of outgoing currents.

$$\text{i.e. } \boxed{\Sigma i = 0}$$

Hence the sum of currents flowing towards any junction in an electrical circuit is equal to the sum of currents flowing away from that junction.

2. Kirchhoff's voltage law (KVL):

It states that in a closed electric circuit, the algebric sum of e.m.f. is equal to the algebric sum of the products of the resistances and the currents flowing through them.

Explanation:

Sign convention:

The following sign convention may be followed while applying Kirchhoff's voltage law to a closed circuit:

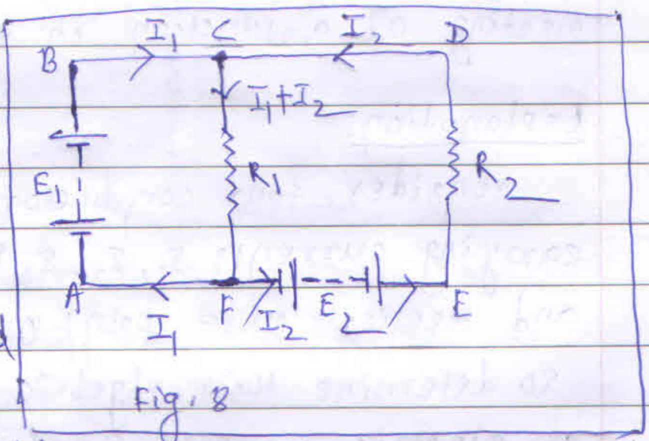

Fig. 8

→ A rise in potential should be considered positive and fall in potential should be considered negative.

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i) Thus in fig. 9 (i) as we go from A to B, there is a rise in potential. In fig. 9 (ii) as we go from A to B, there is also a rise in potential.

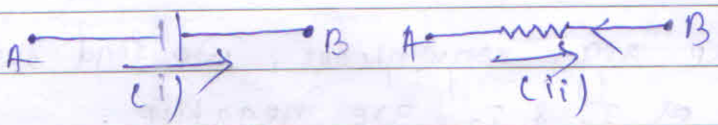

fig. 9

ii) In fig. 10 (i), as we go from C to D, there is a fall in potential In fig. 10 (ii), as we go from C to D, there is again a fall in potential.

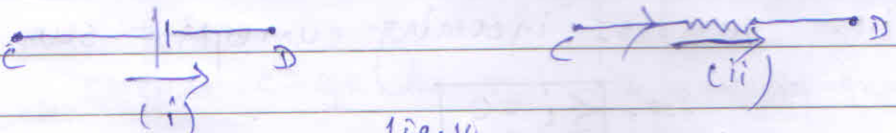

fig. 10

Loop ABCFA: In this loop as shown in fig. 8, em.f E_1 will be given positive sign because when we go from (-)ive terminal to the (+)ive terminal of the battery in the arm AB and hence there is rise in potential. The voltage drop in branch CF is $(I_1+I_2)R_1$ and shall bear (-)ve sign. according to sign convention.

Applying Kirchhoff's voltage law to the loop ABCFA, we have

$$E_1 - (I_1 + I_2) R_1 = 0$$

$$\text{or,} \quad \boxed{E_1 = (I_1 + I_2) R_1}$$

loop CDEFC: As we go round the loop CDEFC, drop I_2R_2 is +ve, e.m.f. E_2 is −ve and drop $(I_1+I_2)R_1$ is +ve. Therefore applying Kirchhoff's voltage law, we get

$$I_2R_2 - E_2 + (I_1+I_2)R_1 = 0$$

$$\text{or,} \quad I_2R_2 + (I_1+I_2)R_1 = E_2$$

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Since E_1, E_2, R_1 and R_2 are known, we can find the values of I_1 and I_2 from the above two equations. Hence the current in all branches can be determined.

WHEATSTONE BRIDGE:

Wheatstone bridge is an electrical arrangement which is used to measure accurately an unknown resistance.

It consists of four resistances P, Q, R & X connected in the four arms of a square ABCD. A cell of e.m.f. E is connected between the points A & C through a one way key K_1. A sensitive galvanometer of resistance G is connected between the terminals B & D through another one way key K_2. After closing the keys K_1 & K_2, the resistance P, Q, R & X are so adjusted that the galvanometer shows no deflection. In this position Wheatstone bridge is said to be balanced.

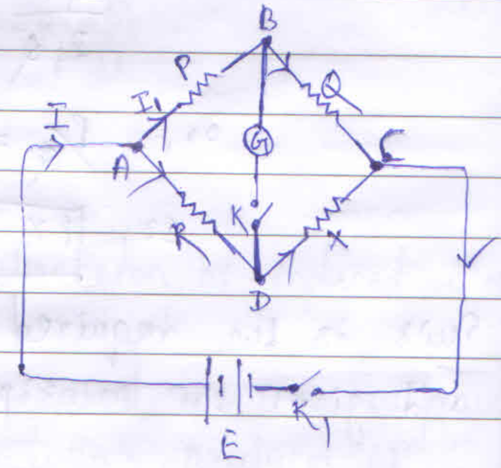

fig (11)

principle: Wheatstone bridge principle states that when the bridge is balanced, the products of the resistances of the opposite arms are equal ie

$$PX = QR \quad \text{or,} \quad X = \frac{Q}{P} \times R$$

Since the values of Q, P and R are known, the value of the unknown resistance X can be calculated.

proof: Let under balanced conditions of the bridge.

I_1 = current through P; I_2 = current through R

Since there is no current in the galvanometer.

∴ current through Q = I_1 and current through X = I_2

Since points B & D are at the same potential,

P.D. across P = P.D. across R

$$I_1 P = I_2 R \quad \text{——— (i)}$$

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Also P.D. across Q = P.D. across X

$$I_1 Q = I_2 X \quad \text{——— (ii)}$$

Dividing eqn (i) by eqn (ii), we get

$$\frac{\cancel{I_1} P}{\cancel{I_1} Q} = \frac{\cancel{I_2} R}{\cancel{I_2} X}$$

$$\text{or,} \quad P/Q = R/X$$

$$\text{or,} \quad \boxed{PX = QR}$$

This is the required condition for the bridge to be balanced and gives the principle of wheatstone bridge.

UNIT-11-(ELECTROMAGNETISM & ELECTROMAGNETIC INDUCTION)

ELECTROMAGNETISM:

definition: A current flowing through a wire produces magnetic field around itself. This phenomenon of production of magnetism due to electricity is called magnetic effect of currents or this property is known as electromagnetism.

Faraday's laws of electro-magnetic induction:

Faraday's laws deal with the induction of an e.m.f. in an electric circuit when magnetic flux linked with the circuit changes. They are stated as follows:

i) whenever magnetic flux linked with a circuit changes, an e.m.f. is induced in it.

ii) The induced e.m.f. exists in the circuit so long as the change in magnetic flux linked with it continues.

iii) The induced e.m.f. is directly proportional to the negative rate of change of magnetic flux linked with the circuit.

If '$d\phi_B$' is the change in magnetic flux linked with the circuit, that takes place in a time 'dt'.

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Rate of change of magnetic flux $= \frac{d\phi_B}{dt}$

If 'E' is e.m.f. induced in the circuit as a result of this change,

$$E \propto -\frac{d\phi_B}{dt} \quad \text{or,} \quad E = -K\frac{d\phi_B}{dt}$$

For $K = 1$,

$$\therefore \boxed{E = -\frac{d\phi_B}{dt}}$$

Where (-)ve sign is due to direction of induced e.m.f.

Lenz's law:

"It states that direction of induced e.m.f. is such that it tends to oppose the very cause which produces it."

Explanation:

Consider a coil AB, wound over a hollow wooden cylinder & having a galvanometer 'G' connected in between its free terminals through a two way key 'K' as shown in fig. 12. Let us close gap 1, keeping gap 2 open so that the course of e.m.f. sends a current through the circuit in the direction as shown in this figure.

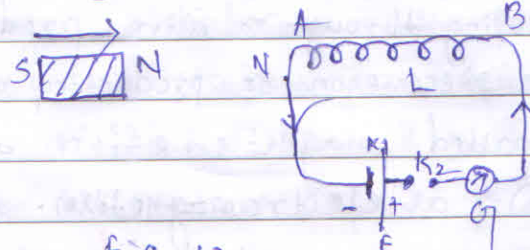

fig-12

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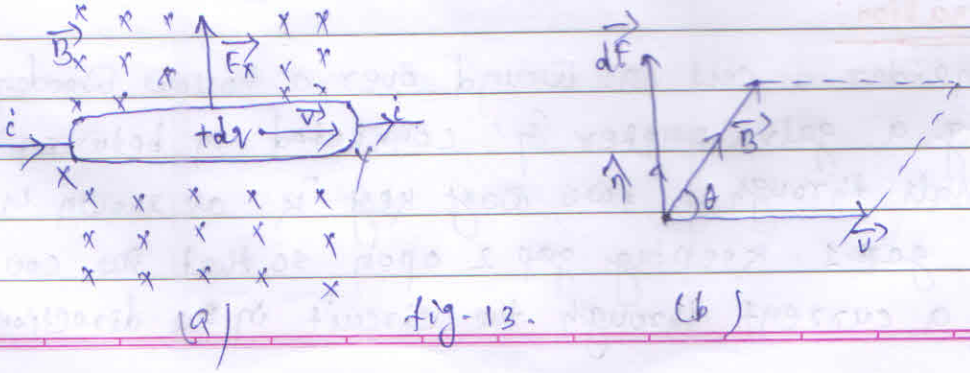
Now close gap 2 and keep gap 1 open so that battery goes out of circuit. Move a magnet N-S towards the end 'A' of coil. It will be observed that if north pole 'N' of the magnet approaches the coil, the current set up in the coil produces a deflection towards right indicating that the direction of induced current must be anti-clockwise as seen through the face 'A'. According to the rule of magnetic effects of current, face 'A' should develop a north polarity due to magnetic field of induced current. This north polarity opposes the approaching north pole of magnet i.e. the cause which produces induced e.m.f. Hence Lenz's law is verified.

Force acting on a current carrying conductor placed in a uniform magnetic field:

Consider a conductor XY placed in a uniform magnetic field $\vec{B}$ acting towards at right angle to the plane of paper. Let a current i flows through the conductor from X to Y.

Let 'dq' be a small amount of positive charge moving from X to Y with a velocity $\vec{v}$ as shown in fig. 13(a). The force $d\vec{F}$ experienced by this charge is given by



(a) fig-13. (b)

If the charge travels a small distance $\vec{dl}$ in time dt, then

$$\vec{v} = \frac{\vec{dl}}{dt}$$

$$\therefore \quad \vec{dF} = dq \times \left(\frac{\vec{dl}}{dt} \times \vec{B}\right) = \frac{dq}{dt}\left(\vec{dl} \times \vec{B}\right)$$

$$\text{or,} \quad \vec{dF} = i\left(\vec{dl} \times \vec{B}\right)$$

∴ Net force $\vec{F}$ acting on the conductor can be obtained by integrating above equation, we get

$$F = \int \vec{dF} = \int \vec{dl} \times \vec{B}$$

$$\text{or,} \quad \vec{F} = i\left(\vec{l} \times \vec{B}\right)$$

$$\text{or,} \quad \boxed{\vec{F} = ilB \sin\theta \, \hat{n}}$$

Where $\hat{n}$ is a unit vector in direction ⊥ to the plane containing $\vec{l}$ and $\vec{B}$, θ is the angle between $\vec{l}$ & $\vec{B}$.

$$\boxed{|\vec{F}| = Bil \sin\theta}$$

By: S. Mallick

Fleming's left hand rule:

"It states that stretch first finger, central finger and thumb of our left hand in mutually perpendicular directions. If the first finger points towards magnetic field, central finger points towards electric current then thumb gives the direction of force acting on the conductor."

It can be applied when the direction of motion of charged particles (current) is ⊥ to the lines of force of magnetic field. In case the charged particles move at any other angle, the direction of $\vec{F}$ can be obtained by applying the rule of cross-product.

Case-1: If the conductor is placed at right angle to the field, then

$$\theta = 90^\circ$$

$$\therefore \sin\theta = 1,$$

$$\text{so} \quad |\vec{F}| = ilB \quad (\text{maximum}).$$

Case-2: If the length of conductor is along the direction of lines of force, then

$$\theta = 0^\circ \text{ or } \theta = 180^\circ$$

$$\therefore \sin\theta = 0$$

$$\text{so, } |\vec{F}| = 0$$

Thus, no force is experienced by current carrying conductor.

Fleming's Right hand rule:

"It states that stretch first finger, central finger and the thumb of our right hand in three mutually perpendicular directions. If the first finger points towards the magnetic field, thumb points towards the direction of motion of conductor, the direction of central finger gives the direction of induced current set up in the conductor."

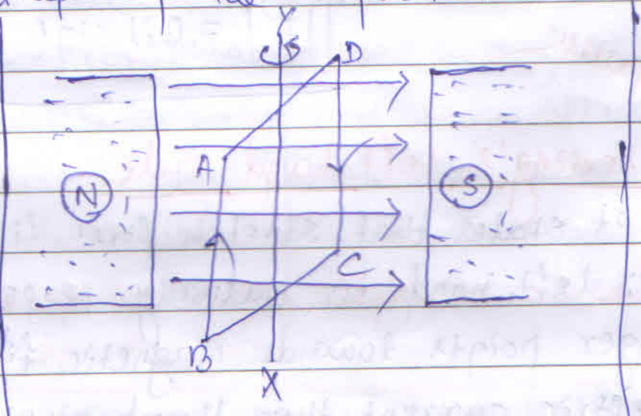


fig. 14

Consider a coil ABCD turning inbetween the two pole pieces of a magnet as shown in fig. 14. Let the direction of rotation of the coil be such that AB moves out of the plane of the paper while CD moves into. Applying Fleming's right hand rule separately on AB and CD, it can be seen that the direction of induced current is from 'B' to 'A' and 'D' to 'C'.

By: S. Mallick

Comparison between Fleming's left hand rule & Fleming's right hand rule:

FLHR	FRHR
1) In this rule, first finger, central finger and thumb of left hand mutually $\perp^r$ direction where first finger points towards magnetic field, central finger points towards electric current & thumb gives the direction of force.	1) In this rule, first finger, central finger and thumb of right hand mutually $\perp^r$ directions where first finger points towards magnetic field, central finger points towards induced current set up in conductor & thumb gives the direction of motion of conductor.
2) It applies to d.c. motor.	2) It applies to dynamo.
3) Force is produced.	3) Induced current is produced.
4) permanent magnetic field & current is provided.	4) permanent magnetic field & force is provided.

By: S. Mallick

UNIT:12- MODERN PHYSICS

LASER:

-> The name LASER is acronym of Light Amplification by Stimulated Emission of Radiation.

-> A laser beam is extremely intense, coherent and highly parallel beam of light.

-> A device which produces this kind of beam is known as Laser.

-> The term laser has grown out of "maser".

-> Maser stands for Microwave Amplification by stimulated Emission of Radiation.

Principle of LASER:

Let us consider an assembly of atoms of some kind that have metastable states of excitation energy ($h\nu$). Suppose we raise a majority of the atoms to the metastable level. If we now shine the light of frequency (ν) on the assembly, there will be more induced emission from the metastable level than induced absorption by the lower level. The result will be an amplification of light. This is the concept that produces the operation of laser.

By:- S. Mallick

Population inversion:

Under ordinary conditions of thermal equilibrium, the number of atoms in the higher energy state is smaller than the number in the lower energy state. i.e. $N_2 < N_1$. Hence there is very little stimulated emission compared with absorption. Let the atoms be initially excited so that there are more atoms in the higher energy state E_2 than in the lower energy state E_1. Then we have $N_2 > N_1$. This is known as population inversion.

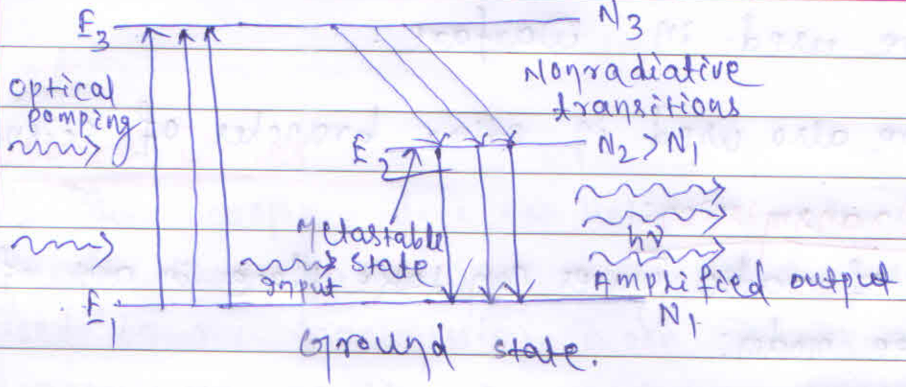


fig. 15

Pumping:

The method of producing population inversion is known as pumping. This is also called one type of "optical pumping."

Consider a material whose atoms can reside in three different states as shown in fig. 15. Atoms in ground state are pumped to state E_3 by photons of energy $h\nu = E_3 - E_1$. The excited atoms undergo non-radiative transitions & remain in metastable energy state. There will be more atoms in the higher metastable energy state E_2 than in the ground state E_1. Atoms in the metastable state E_2 are now bombarded by photons of energy resulting stimulated emission. This is the method used in ruby laser.

By: S. Mallick

Characteristics of Laser beam:

Some very important characteristics of the laser beam are

i) Directionality
ii) Intensity
iii) mono-chromaticity.
iv) coherence.

Applications of Lasers:

The following few applications are given on the basis their principle such as

1) Lasers are used in surgery.
2) They are also used in some industrial purposes.

3) They are used in warfare.

4) They are also used in other branches of science.

Wireless Transmission:

Propagation of radio waves can take place in any of the following three modes:

i) Ground Waves:

Radio waves emitted by a transmitter 'T' travel in a straight line. As such these are not able to reach distant point due to the curvature of the earth. The station situated close to the transmitter can catch these rays directly. Such waves are called ground waves.

Due to their absorption by ground, the signals received at distant station are weaker and their absorption increases with an increase in frequency of wave.

By: S. Malik

ii) Sky Waves:

The stations, which become inaccessible to ground waves due to the curvature of earth can receive waves after reflection from the ionosphere. These waves are called sky waves.

The refractive index 'μ' of the atmosphere for radio waves depends upon the frequency of radio waves as well as the di-electric constant of the medium. The dielectric constant decreases with an increase in free electron density. As we go up in ionosphere, the electron density increases, thus decreasing dielectric constant. Since the refractive index is proportional to the square root of di-electric constant, it also decreases as we move up. A radio wave finds itself travelling from denser to rare medium. It continously bends away from the normal layer after layer till its angle of incidence increases upto critical angle. Then it suffers total internal reflection & it sent back towards the earth. Thus it is able to reach distant points. These waves are called sky waves.

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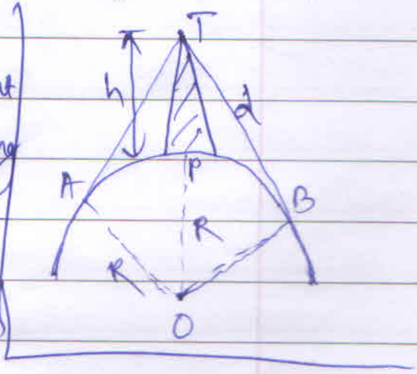
iii) Space waves!

The ionosphere does not help in reflecting wave of frequencies greater than 300 MHz. This range of frequencies is generally used in T.V. transmission. These waves can travel from transmitting station to receiving station along the line of sight. Thus, their propagation takes place in between two highly placed antennae. This is the reason that the transmission antenna is generally very high. we can calculate the distance 'd' upto which the signals from antenna of height 'h' can be recieved.



Consider a transmission antenna 'T' of height 'h' at 'P'. From 'T', draw tangents TA & TB touching earth's surface at A & B. Let 'O' be the centre of earth.

In right angled $\triangle OAT$

$$OT^2 = OA^2 + AT^2$$

Here $OT = R+h$, $OA = R$ & $AT = d$,

$$\therefore (R+h)^2 = R^2 + d^2 \quad \text{or,} \quad R^2+h^2+2Rh = R^2+d^2$$

$$\therefore d^2 = h^2 + 2Rh \quad \text{or,} \quad d = \sqrt{h(2R+h)}$$

∴ It is clear from this expression that 'd' increases with an increase in h.

In order to reach greater distances, we can make use of following methods -

1) Relay stations 2) Geostationary satellite.

By: S. Mallick