SOME IMPORTANT QUESTIONS OF PHYSICS

1. State & explain Faraday's law of electromagnetic induction. Derive an expression for the e.m.f. induced in a coil rotating in uniform magnetic field.

→ Faraday, on the basis of his experiments, gave the following two laws:

i. Whenever there is a change of magnetic flux in an electric circuit, e.m.f. is induced. The induced e.m.f. exists so long as the magnetic flux changes.
ii. The magnitude of the induced e.m.f. is directly proportional to the rate of change of magnetic flux through the circuit.

$$\text{i.e. } \varepsilon \propto \frac{d\varphi}{dt}$$

$$\therefore \varepsilon = -\frac{d\varphi}{dt}$$

<u>Explanation</u>:

i. First law: From Faraday's experiment, it is clear that when there is a relative motion between magnet and the coil, e.m.f. induces. The relative motion between magnet & the coil, as we know is equivalent to an increase or a decrease in the magnetic flux associated with the circuit. Hence magnetic flux in a circuit must change to induce current in a circuit. If we keep the magnet stationary in the coil, the magnetic flux associated with the coil is maximum. But there will be no change in magnetic flux. Hence there will be no induced e.m.f. and galvanometer shows no deflection. Thus it is change and not a mere presence of magnetic flux can induce e.m.f. Further, it is obvious that the existence of induced e.m.f. (or induced current) in the circuit is temporary. The induced current exists in the circuit so long as there is a relative motion between coil & magnet i.e. the magnetic flux keeps on changing.

ii. Second law: In the same experiment, it is observed that moving the magnet quickly into or out of the coil, the deflection of the galvanometer is large as compared to what it would be, if the motion of the magnet is slow. Moving a magnet quickly into the coil is equivalent to a larger rate of change of magnetic flux than when moving it slowly. Hence larger is the change of magnetic flux more is the induced e.m.f. and vice versa.

For a circular coil:

Consider a coil of cross section area S rotating with an angular speed ω in a uniform magnetic field B as shown in the figure.

Magnetic flux through the loop in the given position is given by:

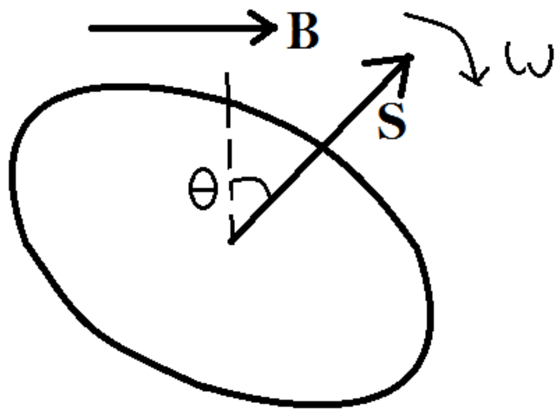
$$\varphi = \vec{B}.\vec{S}$$

$$= \mathrm{BS}\cos(\frac{\pi}{2} - \theta)$$

$$= \mathrm{BS}\sin\theta$$

Where,

$$\theta = \theta_0 + \omega t$$



& the induced e.m.f. is given by:

$$\varepsilon = \frac{d\varphi}{dt}$$

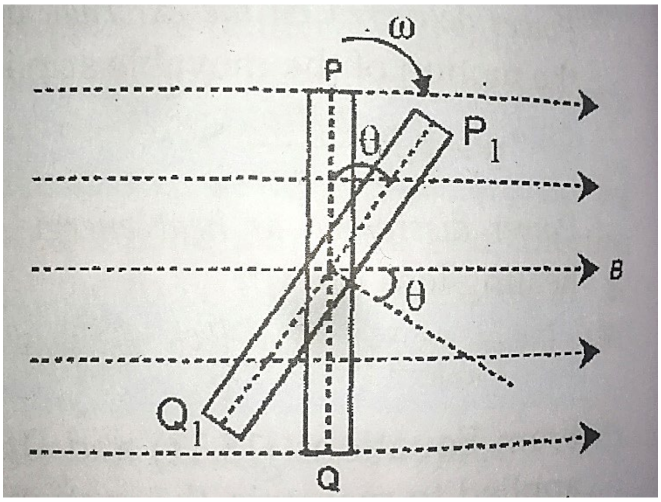
$$\varepsilon = \frac{d(BS\ \sin(\theta_0 + \omega t))}{dt}$$

$$\varepsilon = BS\ \omega\cos(\theta_0 + \omega t)$$

The rms value of induced e.m.f. is:

$$\varepsilon_{rms} = \frac{BS\omega}{\sqrt{2}}$$

For a rectangular coil:



Suppose that a coil of cross-sectional area A & number of turn n of conducting wire is rotating with a uniform angular velocity ω about an axis perpendicular to a uniform magnetic field but in the same plane. Let initially its plane is perpendicular to a uniform magnetic field of intensity B. When the coil rotates from the position PQ to P_1Q_1 in time t, it is turned through an angle 'θ'. Then we have

$$\theta = \omega t$$

In the position PQ, the plane of the coil is perpendicular to the direction of the magnetic field & magnetic flux passing through the coil is nAB. As the coil rotates, the magnetic flux passing through the coil goes on changing & therefore an induced e.m.f. is generated in the coil.

At P_1Q_1 position of the coil, total magnetic flux through the coil is,

$$\varphi = NBA\cos\theta = NBA\cos\omega t$$

From Faraday's law of electromagnetic induction, induced e.m.f. in the coil is given by,

$$E = -N\frac{d\varphi}{dt} = -NAB\frac{d(\cos\omega t)}{dt} = -NAB(-\sin\omega t)\,\omega$$

Or, $E = NBA\omega\sin\omega t$ ------------- (i)

It is clear from the above equation that e.m.f. induced in the coil is not constant as it depends upon $\sin\omega t$ which varies with the time (t). For this reason, the e.m.f. is called sinusoidal e.m.f.

As the value of $\sin\omega t$ varies between +1 & -1, the induced e.m.f. varies between +NBAω & -NBAω. Hence the maximum value of induced e.m.f. is denoted by E_0 & called the peak value of induced e.m.f. It is given by,

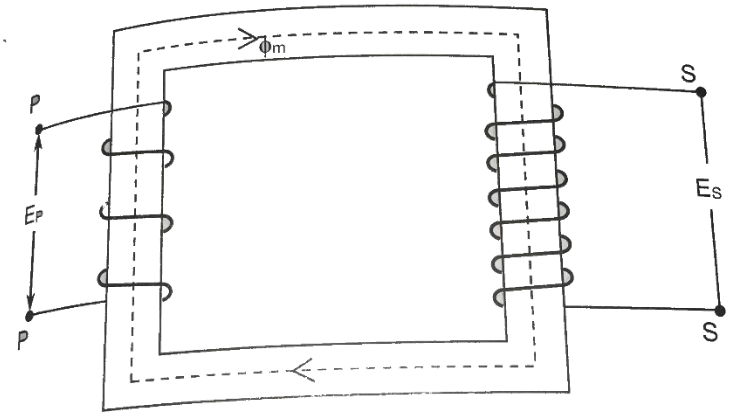
$$E_0 = NBA\omega$$

Hence, equation (i) can be written as,

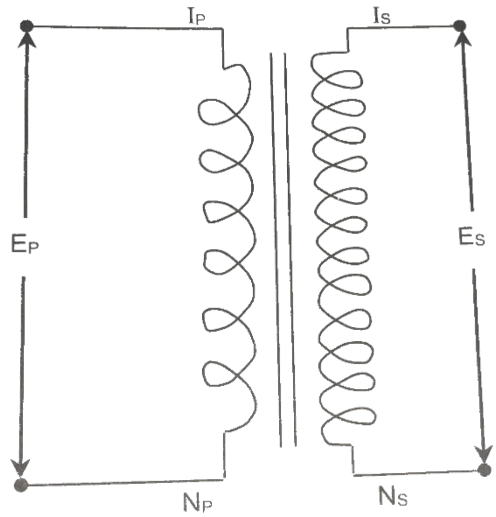
$$E = E_0\sin\omega t$$

2. Describe the structure & working principle of a transformer. Also define the efficiency of a transformer.

→ Transformer is a device used to change low AC voltage into high AC voltage & vice versa. Its working principle is based on mutual induction. When the magnitude of current associated with one circuit changes, an induced e.m.f. is generated in the neighboring circuit i.e. induced current flows in the neighboring circuit.



(a)



(b)

A transformer has four primary parts. They are the input connection, the output connection, the coils & the core. It consists of two coils PP & SS insulated from each other & wound on the arms of same magnetic core. The input alternating electrical energy is supplied through coil PP & is called primary coil whereas output electrical energy is drawn from coil SS & is called secondary coil as shown in the figure (a).

In a step up transformer, the primary coil consists of a few turns of thick insulated copper wire & the secondary coil consists of a large number of turns of fine insulated copper wire. In a step-down transformer, the case is exactly reverse. The transformer core consists of very thin strips of a special alloy of steel. These strips are insulated from one another by lamination & are grouped together. This lamination is done to avoid energy losses due to eddy currents. The coils are so wounded that the leakage of magnetic flux is minimum. The conventional circuit diagram for a transformer is shown in fig (a) & (b).

The efficiency of the transformer can be defined as the intensity or the amount of power loss within a transformer.

OR

Efficiency of transformer is defined as the ratio of output power to the input power.

$$\text{Efficiency } (\eta) = \frac{Output\ power}{Input\ power} * 100\% = \frac{E_S\, I_S}{E_P\, I_P} * 100\%$$

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3. State & explain Lenz's law of electromagnetic induction. How is it according to the law of conservation of energy?

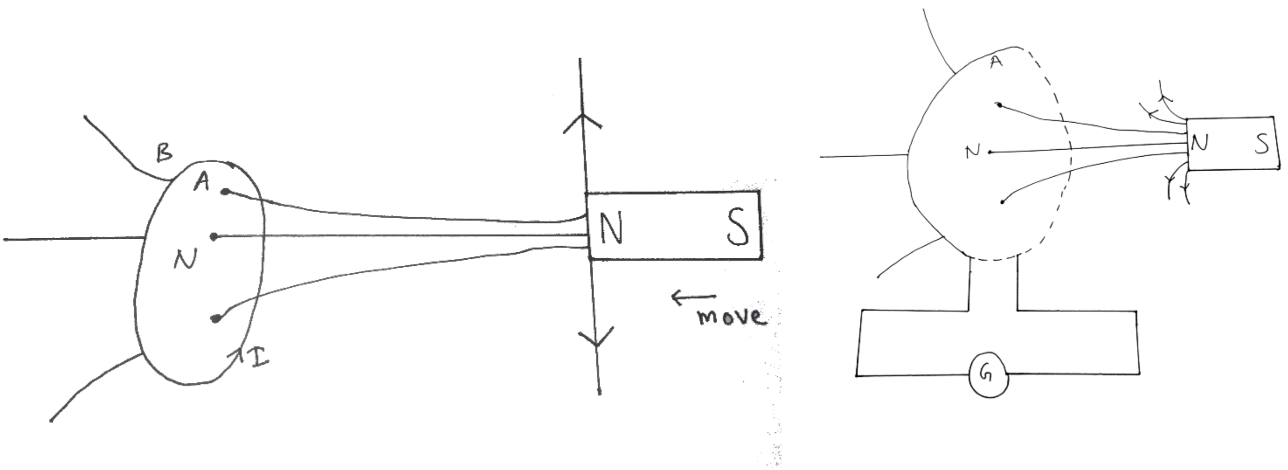
→ Lenz's law states that the direction of induced e.m.f. in any closed loop is such that it tends to produce a current that creates a magnetic flux to oppose the cause, i.e. change in magnetic flux that produces it.

If current is induced due to increase of flux then it will try to oppose that increasing flux & vice versa.

When North Pole of bar magnet is moved towards face A of the coil then flux through it increases & current is induced in it. According to Lenz law the direction of induced current should be such that it could oppose North Pole of bar magnet moving towards face A of the coil and this will be possible only when face A of coil behaves as North Pole, for which current in the coil should flow in anti-clockwise direction as viewed from face A.

Lenz's law in accordance with conservation of energy:

In the figure below when magnet is moved towards the coil flux through it changes and current is induced. Such that face A of the coil becomes North Pole. This North Pole



Creates force of repulsion on North Pole of bar magnet. In this condition in order to move magnet some external agent has to do mechanical work against force of repulsion & the work so done is converted into electrical energy (current). Hence, Lenz's law obeys the principle of conservation of energy.

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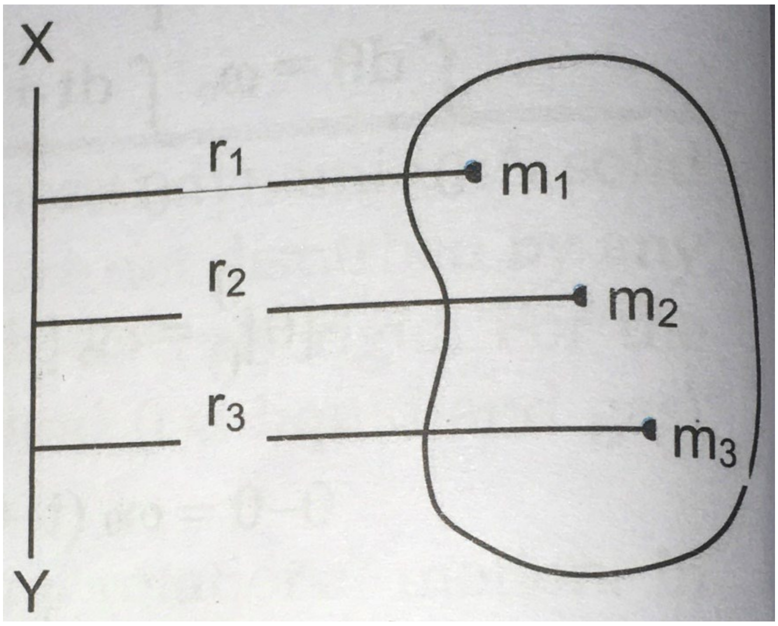
4. Kinetic energy of rotation of a rigid body.

→ Let the body rotates about the axis XY with an angular velocity ω & $v_1, v_2, v_3, \dots\dots, v_n$ be the linear velocities of particles having mass $m_1, m_2, \dots\dots, m_n$ respectively of that body as shown in the figure. Then,



Total Kinetic Energy $= \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 + \cdots + \frac{1}{2}m_nv_n^2$

$$= \frac{1}{2}m_1(\omega r_1)^2 + \frac{1}{2}m_2(\omega r_2)^2 + \cdots + \frac{1}{2}m_n(\omega r_n)^2$$

$= \frac{1}{2}\omega^2(m_1r_1^2 + m_2r_2^2 + \cdots + m_nr_n^2)$ $[\because v_1 = \omega r_1, v_2 = \omega r_2, \dots\dots, v_n = \omega r_n]$

$= \frac{1}{2}\omega^2 \sum_{i=1}^{n} m_ir_i^2$

$\therefore$ K.E. $= \frac{I\omega^2}{2}$

Where, I $= \sum_{i=1}^{n} m_ir_i^2$

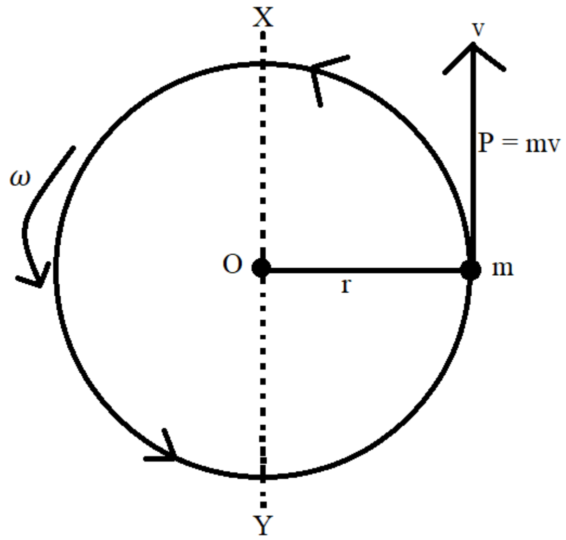
Or, I $= \frac{2 * K.E.}{\omega^2}$

If ω = 1 rad/s, then I = 2 * K.E.

Hence, moment of inertia may also be defined as twice the K.E. of a rotating body when its angular velocity is unity.

5. Angular momentum & law of conservation of angular momentum.

→ Angular Momentum:



When a body rotates about an axis, it possesses angular velocity. It is also called the moment of linear momentum. It is denoted by L. Mathematically, it is the vector product of the distance ($\vec{r}$) from the axis of the linear momentum $\vec{P}$ & the linear momentum ($\vec{P}$) of the body.

$$\therefore \vec{L} = \vec{r} * \vec{P}$$

$$\text{or, } \vec{L} = rP \sin\theta \,\hat{n}$$

Where θ is the angle between $\vec{r}$ & $\vec{P}$ & $\hat{n}$ in the unit vector which is perpendicular to both $\vec{r}$ & $\vec{P}$. Hence angular momentum is a vector & its direction is along the axis of rotation. Its unit is kgm^2s^{-1} in SI system of units.

L=P r sin θ

If $\theta = 90°$, r is the perpendicular distance of the linear momentum from the axis of rotation.

$\therefore$ L = P r

Hence the angular momentum of a body is the product of linear momentum & its perpendicular distance from the axis of rotation.

We know,

P = mv & v=ωr , where ω is the angular velocity of the body.

$\therefore$ P = m ω r

& L = m$r^2\omega$

Let the body has point masses m_1 , m_2 , ..., m_n at the distances r_1 , r_2 , ..., r_n respectively from the axis of rotation. Then, the total angular momentum of the body is given by

L = $m_1r_1^2\omega + m_2r_2^2\omega + \cdots + m_nr_n^2\omega$

= $(m_1r_1^2 + m_2r_2^2 + \cdots + m_nr_n^2)\ \omega$

$\therefore$ L = I ω

Where I = $\sum_{i=1}^{n} m_ir_i^2$ is the MI of the body about the given axis.

Angular momentum is a vector quantity. Its SI unit is "kgm^2s^{-1}". The dimensional formula of angular momentum is $[ML^2T^{-1}]$.

<u>Law of conservation of angular momentum</u>:

Statement: According to the principle of conservation of angular momentum, if no external torque acts on a rotating system, the total angular momentum of the system always remains constant.

When $\tau = 0$, then $L = I\omega$ = constant.

Proof: Suppose a system of bodies rotating about an axis with angular velocity ω. If I be the moment of inertia about the axis of rotation, then its angular momentum about the axis is given by

$L = I\omega$ .... (i)

Since the rate of change of angular momentum is torque,

$\tau = \frac{dL}{dt}$ .... (ii)

In the absence of an external torque i.e. $\tau = 0$. So, equation (ii) becomes

$\frac{dL}{dt} = 0$

Integrating on both sides, we get

$$\int \frac{dL}{dt} = \int 0$$

$\therefore L = I\omega = \text{constant}$ .... (iii)

This verifies the principle of conservation of angular momentum.

If I_1 and I_2 are the moments of inertia of a rotating body having angular velocities ω_1 & ω_2, then

$I_1\omega_1 = I_2\omega_2 = constant$ .... (iv)

Moreover, the equation (iv) can be written as

$$\frac{I_1}{I_2} = \frac{\omega_2}{\omega_1} = \frac{f_2}{f_1} = \frac{T_1}{T_2} \quad \ldots\ldots\ldots \text{(v)}$$

6. Reflection & refraction of light according to wave theory.

→ Reflection of Light Based on Wave Theory:

Suppose a plane wavefront CP incidents on a plane mirror XY with an angle of incidence i. The lines AC & BD represent incident rays. According to Huygens' principles, every point on the wavefront CP is the source of secondary wavelets. Consequently, a reflecting wavefront QD is formed as shown in the figure. Here, line CA' and DB' are reflected rays. As N'D is normal to reflecting surface at point D and ∠N'DB' = r is the angle of reflection. As N'D is normal to reflecting surface at point D & ∠N'DB' = r is the angle of reflection.

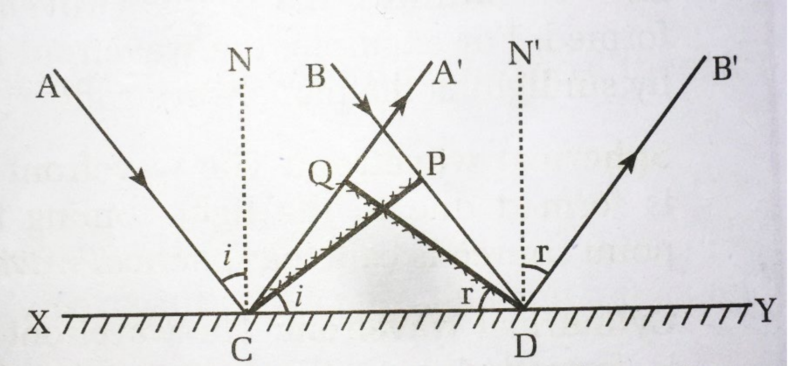


Fig: Reflection of light on a plane mirror

As the velocity of light does not change on reflection and the distances PD and CQ are traveled at the same time, we have

CQ = PD

Now, in right-angled triangles CPD and CQD, we have

CQ = PD and CD = DC

Therefore, two right-angled triangles CPD and CQD are congruent and hence

$\angle PCB = \angle QDC$ ....(i)

As the angle between two lines is same as the angle between their perpendiculars, we can write

$\angle PCD = i$ & $\angle QDC = r$

From eq^n (i), we can write

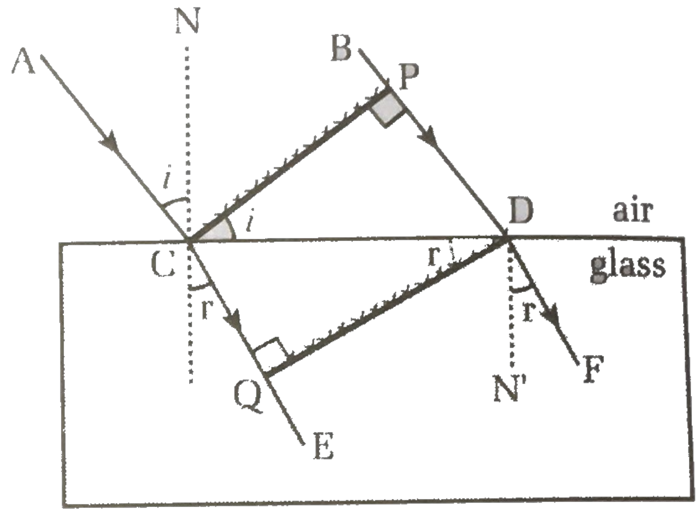
$i = r$ ....(ii)

i.e. angle of incidence is always equal to angle of reflection.

Further, the incident wavefront (CP), the reflecting surface (XY), and the reflected wavefront (QD) all are perpendicular to the plane of the paper. Therefore, the incident ray (AC), normal (NC), and reflected ray (CA'), which are respectively perpendicular to CP, XY, and QD all lie in the same plane.

Hence, the laws of reflection of light are proved based on wave theory.

<u>Refraction of light based on wave theory</u>: Suppose a plane wavefront CP incidents on a plane surface separating air from the glass. Two lines AC and BD represent the incident rays. If NC is normal to the glass surface at point C, the ∠ACN = ∠i is the angle of incidence. According to Huygens' principle, every point on the wavefront CP is the source of secondary wavelets. Consequently, a refracted wavefront QD is formed as shown in the figure. The lines CE and DF being perpendicular to the refracted wavefront QD are refracted rays of light. As DN' being normal to the surface of glass separation at point D, ∠FDN' = r is the angle of refraction.



Suppose c and v are velocities of light in air and glass respectively. As the distance PD in air and the distance CQ in glass are covered by the light at the same time, we can write

$$\frac{PD}{c} = \frac{CQ}{v}$$

Or, $$\frac{PD}{CQ} = \frac{c}{v} \qquad \text{.........(i)}$$

As the angle between two lines in same as the angle between their perpendiculars, we can write

$\angle PCD = i$ & $\angle CDQ = r$

From right angled triangle CPD, we have

$$\sin i = \frac{PD}{CD} \quad \text{.........} \text{(ii)}$$

And, from right angled triangle CQD, we have

$$\sin r = \frac{CQ}{CD} \quad \text{.........} \text{(iii)}$$

On dividing eq^n (ii) by eq^n (iii), we get

$$\frac{\sin i}{\sin r} = \frac{PD/CD}{CQ/CD} = \frac{PD}{CQ} \quad \text{.........} \text{(iv)}$$

From eq^n (i) and eq^n (iv), we have

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

$$\therefore \frac{\sin i}{\sin r} = \mu \quad \text{.........} \text{(v)}$$

This is Snell's law.

However, $\frac{c}{v} = \mu$ is a constant and is called the refractive index of a denser medium with respect to a rarer medium.

Thus, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant for the given pair of media.

Further, it is observed that the incident ray (AC), the normal (NC) and the refracted ray (CE) all lie in the same plane. That's how, the laws of refraction of light are proved based on wave theory.

7. Millikan's oil drop experiment.

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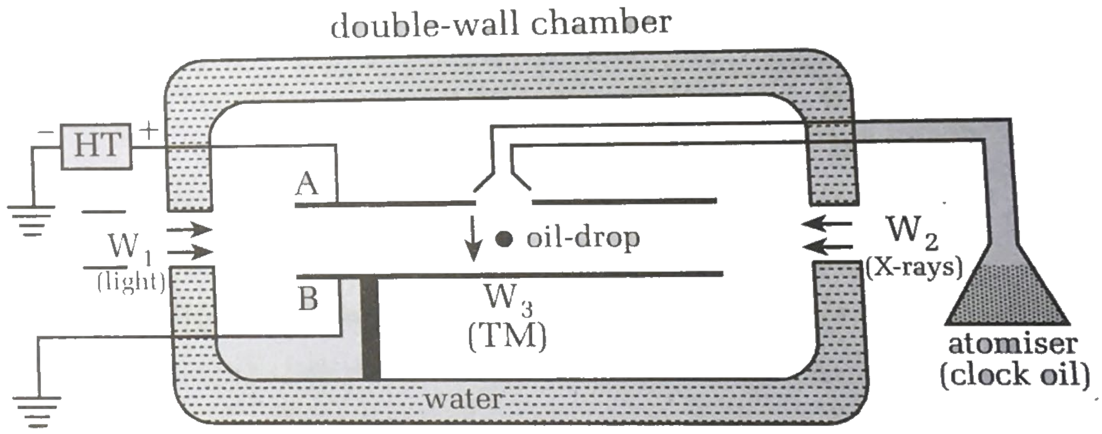

Fig.: Millikan's oil-drop experiment

Millikan's oil drop experiment is used to determine the charge of an electron. It is based on Stoke's law of viscosity. It is strong evidence of the quantization of charge.

Millikan's oil-drop experiment consists of a double-walled chamber having three windows W_1 , W_2 & W_3. The window W_1 is used to pass light, the window W_2 is used to pass x-rays for the ionization of inner gas and the window W_3 contains a traveling microscope.

There are two parallel circular metallic plates A and B each of diameter 22.0 cm and separation 3.5 cm. The upper plate A has a hole at the center and is connected with a positive terminal of high tension (H.T.) battery source. The lower plate B is connected to the earth. Clock oil can be sprayed into the hole of the upper plate with the help of an atomizer.

Water is circulated between the walls to keep the temperature of the chamber constant as shown in the figure.

Theory: The Millikan's oil-drop experiment was based upon the measurement of

(i) The terminal velocity of an oil-drop under the influence of gravity alone and

(ii) The terminal velocity under the combined action of gravity and an electric field opposing the gravity.

(a) First Part: Electric field OFF

The electric field is first switched OFF, the clock oil-drop falls under the effect of gravity alone.

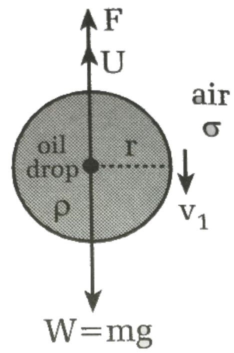

Fig.: Electric field OFF

Suppose, r = radius of oil-drop,

$$\rho = density\ of\ oil - drop, \&$$

$$\sigma = density\ of\ air$$

Now, volume of oil-drop = V = $\frac{4}{3}\pi r^3$

Mass of oil-drop = m = $V_\rho = \frac{4}{3}\pi r^3 \rho$

$\therefore$ Weight of oil-drop = W = mg = $\frac{4}{3}\pi r^3 \rho g$ ……(i)

Similarly, up thrust experienced by oil-drop is

U = weight of displaced air = $V\sigma g$

$= \frac{4}{3}\pi r^3 \sigma g$ ……(ii)

So, resultant download driving force becomes

$$F = W - U = \frac{4}{3}\pi r^3(\rho - \sigma)g \qquad \text{.........(iii)}$$

When the drop of oil moves downwards in the air, an upward viscous force arises. The magnitude of viscous force increases as the drop of oil moves down. When the viscous force becomes equals to the downward driving force, the drop starts to move with a constant velocity called terminal velocity.

If η be the coefficient of viscosity of air, then using Stoke's law, the upward viscous force F experienced by the oil-drop is

$$F = 6\pi\eta r v_1 \qquad \text{......... (iv)}$$

where v_1 is the terminal velocity of the falling oil-drop.

When the oil-drop is moving with a terminal velocity v_1, then

$$W - U = F$$

$$\text{or, } \frac{4}{3}\pi r^3(\rho - \sigma)g = 6\pi\eta r v_1 \qquad \text{......... (v)}$$

$$\therefore r = \sqrt{\frac{9\eta v_1}{2(\rho-\sigma)g}} \qquad \text{......... (vi)}$$

This eq^n (vi) gives the value of the radius of the falling oil-drop.

(b) Second Part: Electric field ON:

→ When the electric field is switched ON, the oil-drop moves with a smaller terminal velocity v_2 downwards. If E be the strength of the electric field applied and n be the number of electrons on the drop, the charge on drop q is ne and electrostatic force on oil-drop is

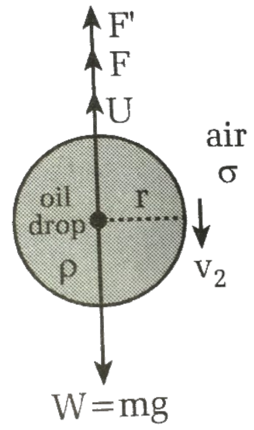

Fig.: Electric field ON

F' = qE ...... (vii)

When the oil-drop is moving with smaller terminal velocity v_2, then

W – U = F + F'

or, $\frac{4}{3}\pi r^3(\rho - \sigma)g = 6\pi\eta r v_2 + qE$

Using eq^n (v), we get

$$6\pi\eta r v_1 = 6\pi n r v_2 + qE$$

or, $6\pi\eta r(v_1 - v_2) = qE$

or, $q = \frac{6\pi\eta r(v_1 - v_2)}{E}$

$\therefore q = \frac{6\pi\eta}{E}\left(\frac{9\eta v_1}{2(\rho-\sigma)g}\right)^{1/2}(v_1 - v_2)$ ...... (viii)

The value of electronic charge from Millikan's oil-drop experiment was found to be 1.6×10^{-19} C.

8. State Kirchhoff's laws & use them to derive Wheatstone bridge principle.

→ There are two Kirchhoff's laws:

(a) First law (or Junction law): Kirchhoff's current law (KCL):

The algebraic sum of the currents at a junction of the circuit is zero.

i.e. $\sum I = 0$ …….. (i)

The current reaching a junction is taken as positive while the current leaving the junction is taken as negative.

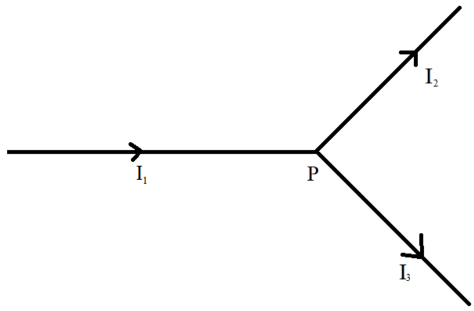

Fig. Kirchhoff's current law

This law follows the principle of conservation of charge.

Explanation: Referring to the figure, the current at the junction P is

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

$$\therefore I_1 = I_2 + I_3$$

It shows that incoming currents at a junction are always equal to outgoing currents.

(b) Second law (or loop law/mesh law): Kirchhoff's voltage law (KVL):

Kirchhoff's second law states that in any closed mesh in a circuit, the algebraic sum of the products of currents and resistances in each part of the mesh taken around in a given order is equal to the algebraic sum of e.m.f. in that mesh. In any closed loop, the algebraic sum of the e.m.f. is equal to the algebraic sum of the products of current and resistance along the loop.

i.e. $\sum E = \sum V$

$\therefore \sum E = \sum IR \quad \ldots\ldots\ldots \text{(ii)}$

This law follows the principle of conservation of energy.

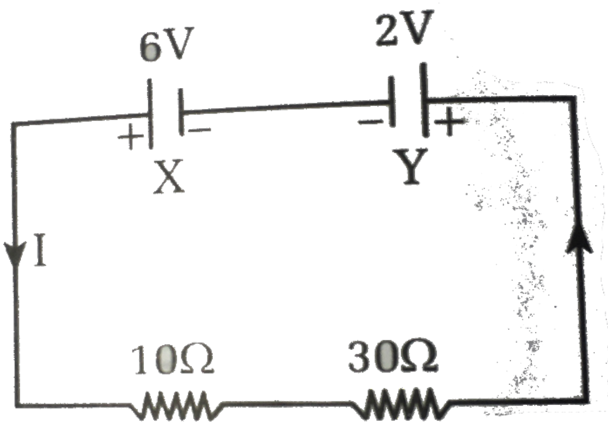

Fig.: Kirchhoff's voltage law

Explanation: Referring to the circuit diagram, we have

$$\sum E = E_1 + E_2 = 6 + (-2) = 4V$$

&

$$\sum IR = I\,(R_1 + R_2) = I\,(10 + 30) = 40I$$

<u>Wheatstone bridge</u>:

→ An electrical circuit in which four resistors are arranged as the arms of a quadrilateral that can be used for accurate measurement of resistance of a wire is called a Wheatstone bridge. The principle of the Wheatstone bridge is, when the bridge is balanced, the products of the opposite arms are equal. The device was popularized though not invented by Sir Charles Wheatstone.

Construction: The circuit diagram of the Wheatstone bridge to determine the unknown resistance is as shown in the figure. It consists of four resistances P, Q, X, and R connected in the form of a quadrilateral. A sensitive galvanometer G and its key K_1 are connected between one pair of opposite corners B and D, while a cell and its key K_2 are connected between other pairs A and C.

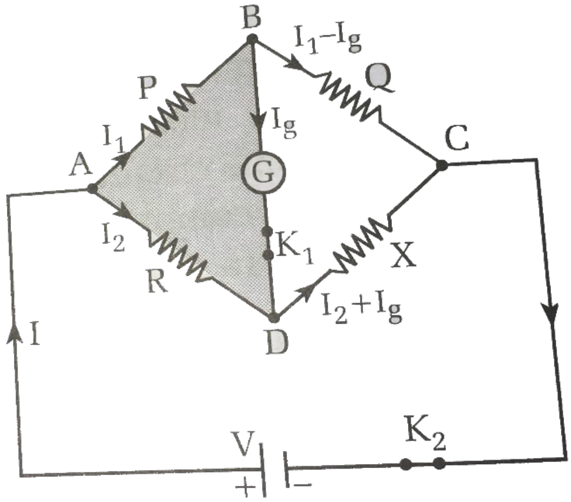

Fig.: Wheatstone bridge

Principle: The principle of the Wheatstone bridge is, when the bridge is balanced, the products of the opposite arms are equal. The current flowing through the galvanometer can be changed by varying the resistance R. For a particular value of resistance R, the current flowing through the galvanometer (I_g) becomes zero. This condition of the bridge is termed a null condition. In null deflection, the bridge is said to be balanced. The balance condition of the bridge is

$$\frac{P}{Q} = \frac{R}{X} \qquad \text{....... (i)}$$

If X is unknown resistance, then

$$\therefore X = \frac{Q}{P} \times R \qquad \text{........ (ii)}$$

Balance condition: Suppose I be the current at junction A. This current is divided at junction A. I_1 be the fraction of current flowing through resistance P, and I_2 be the current flowing through the resistance R. I_1 divides at junction B. Suppose, I_g is the current flowing through the galvanometer G.

Applying Kirchhoff's current law at the junction A, we have

$$I = I_1 + I_2 \qquad \text{........ (iii)}$$

In closed mesh ABDA, applying Kirchhoff's voltage law,

$$I_1P + I_gG - I_2R = 0 \qquad \text{........ (iv)}$$

Similarly, in closed mesh BCDB, applying Kirchhoff's voltage law,

$$(I_1 - I_g)Q - (I_2 + I_g)X - I_gG = 0 \qquad \text{...... (v)}$$

If the resistance in the circuit is suitably adjusted. the current flowing through the galvanometer can be made zero, i.e. $I_g = 0$. This is the balanced condition of the Wheatstone bridge. For this, p.d. across B and D must be zero.

With $I_g = 0$, the eq^n (iv) becomes

$$I_1P - I_2R = 0 \qquad => \qquad I_1P = I_2R \quad \text{...... (vi)}$$

With $I_g = 0$, the eq^n (v) becomes

$$I_1Q - I_2X = 0 \qquad => \qquad I_1Q = I_2X \quad \text{...... (vii)}$$

From eq^n (vi) & eq^n (vii), we get

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

$$\therefore \frac{P}{Q} = \frac{R}{X} \qquad \text{........ (viii)}$$

This is the balanced condition of the Wheatstone bridge.

Application: Some of the practical applications of the Wheatstone bridge are

(a) Meter bridge or slide Wire Bridge.

(b) Post office box.

(c) Carry Foster's bridge.

9. How did Millikan's measure the charge on electron? Describe with necessary theory & diagram. Write down the conclusion obtained from the experiment.

→ Millikan's oil drop experiment is used to determine the charge of an electron. It is based on Stoke's law of viscosity. It is strong evidence of the quantization of charge.

Millikan's oil-drop experiment consists of a double-walled chamber having three windows W_1 , W_2 & W_3. The window W_1 is used to pass light, the window W_2 is used to pass x-rays for the ionization of inner gas and the window W_3 contains a traveling microscope.

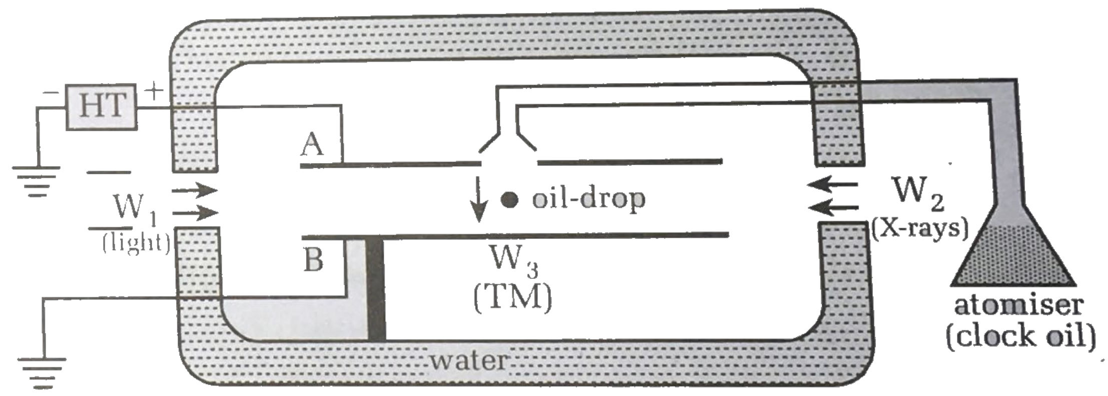

Fig.: Millikan's oil-drop experiment

There are two parallel circular metallic plates A and B each of diameter 22.0 cm and separation 3.5 cm. The upper plate A has a hole at the center and is connected with a positive terminal of high tension (H.T.) battery source. The lower plate B is connected to the earth. Clock oil can be sprayed into the hole of the upper plate with the help of an atomizer.

Water is circulated between the walls to keep the temperature of the chamber constant as shown in the figure.

Theory: The Millikan's oil-drop experiment was based upon the measurement of

(i) The terminal velocity of an oil-drop under the influence of gravity alone and

(ii) The terminal velocity under the combined action of gravity and an electric field opposing the gravity.

(a) First Part: Electric field OFF

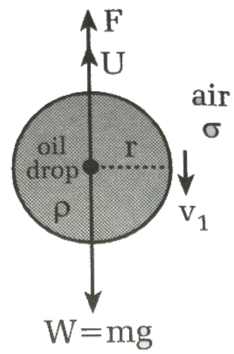

Fig.: Electric field OFF

The electric field is first switched OFF, the clock oil-drop falls under the effect of gravity alone.

Suppose, r = radius of oil-drop,

$$\rho = density\ of\ oil - drop, \&$$

$$\sigma = density\ of\ air$$

Now, volume of oil-drop = V = $\frac{4}{3}\ \pi r^3$

Mass of oil-drop = m = $V_\rho = \frac{4}{3}\ \pi r^3 \rho$

∴ Weight of oil-drop = W = mg = $\frac{4}{3}\pi r^3 \rho$g ……(i)

Similarly, up thrust experienced by oil-drop is

U = weight of displaced air = Vσg

= $\frac{4}{3}\pi r^3 \sigma$g ……(ii)

So, resultant download driving force becomes

F = W – U = $\frac{4}{3}\pi r^3 (\rho - \sigma)$g ………(iii)

When the drop of oil moves downwards in the air, an upward viscous force arises. The magnitude of viscous force increases as the drop of oil moves down. When the viscous force becomes equals to the downward driving force, the drop starts to move with a constant velocity called terminal velocity.

If η be the coefficient of viscosity of air, then using Stoke's law, the upward viscous force F experienced by the oil-drop is

$F = 6\pi\eta r v_1$ .... (iv)

where v_1 is the terminal velocity of the falling oil-drop.

When the oil-drop is moving with a terminal velocity v_1, then

W – U = F

or, $\frac{4}{3}\pi r^3(\rho - \sigma)g = 6\pi\eta r v_1$ .... (v)

$\therefore r = \sqrt{\frac{9\eta v_1}{2(\rho-\sigma)g}}$ .... (vi)

This eq^n (vi) gives the value of the radius of the falling oil-drop.

(b) Second Part: Electric field ON:

→ When the electric field is switched ON, the oil-drop moves with a smaller terminal velocity v_2 downwards. If E be the strength of the electric field applied and n be the number of electrons on the drop, the charge on drop q is ne and electrostatic force on oil-drop is

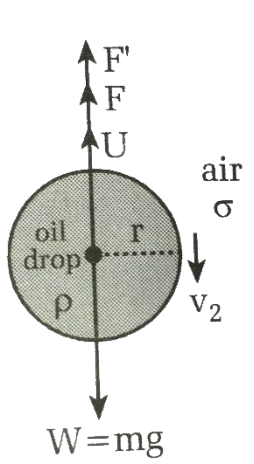

Fig.: Electric field ON

F' = qE ...... (vii)

When the oil-drop is moving with smaller terminal velocity v_2, then

W – U = F + F'

or, $\frac{4}{3}\pi r^3(\rho - \sigma)\text{g} = 6\pi\eta r v_2 + \text{qE}$

Using eq^n (v), we get

$$6\pi\eta r v_1 = 6\pi n r v_2 + qE$$

or, $6\pi\eta r(v_1 - v_2)$ = qE

or, q = $\frac{6\pi\eta r(v_1 - v_2)}{E}$

$\therefore$ q = $\frac{6\pi\eta}{E}\left(\frac{9\eta v_1}{2(\rho-\sigma)\text{g}}\right)^{1/2} \ (v_1 - v_2)$ ...... (viii)

Conclusion: The value of electronic charge from Millikan's oil-drop experiment was found to be 1.6×10^{-19} C.

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10. Discuss & derive the expression for the stationary wave. Also discuss the Newton formula for the velocity of sound in gas & its correction made by the Laplace.

→ <u>Expression for the stationary wave</u>:

The stationary wave equation can be obtained by adding the displacements of two progressive waves of equal amplitude, frequency (or time period), and wavelength traveling in the opposite direction. Energy is not carried by the stationary wave, it is redistributed.

Suppose y_1 be the displacement of a progressive wave traveling towards the positive x-direction.

$$y_1 = a\sin(\omega t - kx) \qquad \ldots\ldots\ldots \text{(i)}$$

Similarly, suppose y_2 be the displacement of another progressive wave traveling towards the negative x-direction.

$$y_2 = a\sin(\omega t + kx) \qquad \ldots\ldots\ldots \text{(ii)}$$

From the principle of superposition of waves, the resultant displacement y of the stationary wave is given by

$$y = y_1 + y_2$$

$$= a\sin(\omega t - kx) + a\sin(\omega t + kx)$$

$$= a\,[\sin(\omega t - kx) + \sin(\omega t + kx)]$$

$$= a \times 2 \times \sin\frac{\omega t - kx + \omega t - kx}{2} \times \cos\frac{\omega t - kx - \omega t - kx}{2}$$

$$= 2a \times \sin\omega t \times \cos(-kx)$$

$$= [2a\cos(kx)] \times \sin\omega t$$

$$\therefore y = A\sin\omega t \qquad \ldots\ldots\ldots \text{(iii)}$$

Where A = 2a $\cos(kx)$ gives the resultant amplitude of the stationary wave.

The eq^n (iii) is the mathematical form of the stationary wave equation.

Velocity of sound in air:

a. **Newton's formula**: Since the velocity of sound in air (or gas) is given by

$$v = \sqrt{\frac{K}{\rho}} \qquad \text{.........} \text{ (i)}$$

Where K is the bulk modulus of air and ρ is the density of air.

According to Newton, when sound waves propagate through gas, compression and rarefaction are produced in the gas medium. The temperature variations in the region of the compression and rarefaction are negligible. Therefore, the process is isothermal. The equation of state for the isothermal process is

PV = constant .... (ii)

Where P is pressure and V is the volume of the air.

On partially differentiating eq^n (ii), we get

$$P\,dV + V\,dP = 0$$

$$\text{or, } P\,dV = -V\,dP$$

$$\therefore P = -\frac{dP}{dV/V} = \frac{\text{stress}}{\text{strain}} = K_{iso} \qquad \text{... ... ... (iii)}$$

Where "K_{iso}" is the isothermal bulk modulus of elasticity. The negative sign indicates that as the pressure on air increases, its volume decreases or vice-versa, Hence, Newton's formula for the velocity of sound in air is given by

$$v = \sqrt{\frac{P}{\rho}} \qquad \text{... ... ... (iv)}$$

Where P is the pressure of air and ρ is its density.

For air, at NTP; we have

$$P = 1.013 \times 10^5 \ \mathrm{Nm^{-2}}$$

&

$$\rho = 1.293 \ \mathrm{kg/m^3}$$

With these values, eq^n (iv) gives

$$v = \sqrt{\frac{P}{\rho}} = \sqrt{\frac{1.013 \times 10^5}{1.293}} = 280 \ \mathrm{m/s}$$

However; the experimental value of the velocity of sound in air at NTP is about 331 m/s. So, the theoretical value does not agree with the experimental value. Therefore, there must be something wrong with Newton's formula. A satisfactory solution to the discrepancy in Newton's formula was given by Laplace, which is known as Laplace correction.

(b) **Laplace correction**: While deriving the above Newton's formula, Newton assumed that the propagation of sound takes place in the isothermal condition. However, according to Laplace, the propagation of sound should take place in the adiabatic condition. Laplace modified Newton’s formula assuming that the propagation of sound in air is an adiabatic change. Since the adiabatic equation of state is

$$PV^{\gamma} = \text{constant}$$

Where $\gamma = \frac{C_P}{C_V}$ is a constant. ……… (i)

On partially differentiating eq^n (i), we get

$$\gamma P V^{\gamma-1}\, dV + V^{\gamma}\, dP = 0$$

$$\gamma P V^{\gamma-1}\, dV = -V^{\gamma}\, dP$$

$$\gamma P V^{\gamma}\, V^{-1}\, dV = -V^{\gamma}\, dP$$

$$\gamma P V^{-1}\, dV = dP$$

$$\therefore \gamma P = -\frac{dP}{V^{-1}dV} = -\frac{dP}{dV/V} = -K_{adi} \quad \ldots\ldots (ii)$$

Where "K_{adi}" is the adiabatic bulk modulus of elasticity. Negative sign indicates that as the pressure on air increases, its volume decreases or vice-versa.

Hence, the velocity of sound in air is

$$v = \sqrt{\frac{K_{adi}}{\rho}}$$

$$\therefore v = \sqrt{\frac{\gamma P}{\rho}} \qquad \ldots\ldots\ldots (iii)$$

This eq^n (iii) is called the Laplace equation for the velocity of sound in air.

For air, at NTP; we have

$$\gamma = 1.4,\ \ P = 1.013 \times 10^5 Nm^{-2}\ \ \&\ \ \rho = 1.293\ kgm^{-3}$$

With these values, the eq^n (iii) gives

$$v = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\frac{1.4 \times 1.013 \times 10^5}{1.293}} = 331\ \text{m/s}$$

This value agrees with experimental value.

11. State the postulates of Huygens' Principle.

→ Huygens' Principle is a geometrical construction, which is used to determine the position of wavefront later from its position at any instant.

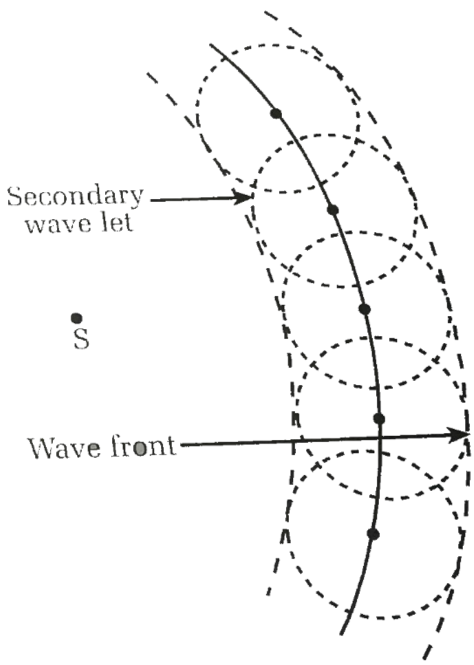

Fig: Wave front and wave let

The postulates of Huygens' Principle are listed below:

(a) Every point on the wavefront may be regarded as a source of a new disturbance.

(b) Each new source produces disturbances in all possible directions with the velocity of light & these disturbances are called secondary wavelets.

(c) An envelope to the secondary wavelets gives a new position of the wavefront at that instant.

(d) A line perpendicular to the wavefront is considered as the ray of light.

12. Explain the theory of Meter Bridge.

→ A sensitive device that is used to measure the unknown resistance is called a meter bridge. It based on the principle of a wheat-stone bridge. It consists of one meter long stretched constantan wire on a wooden board. The ends of the wire are connected to copper strips. There are two gaps between the as shown in the figure.

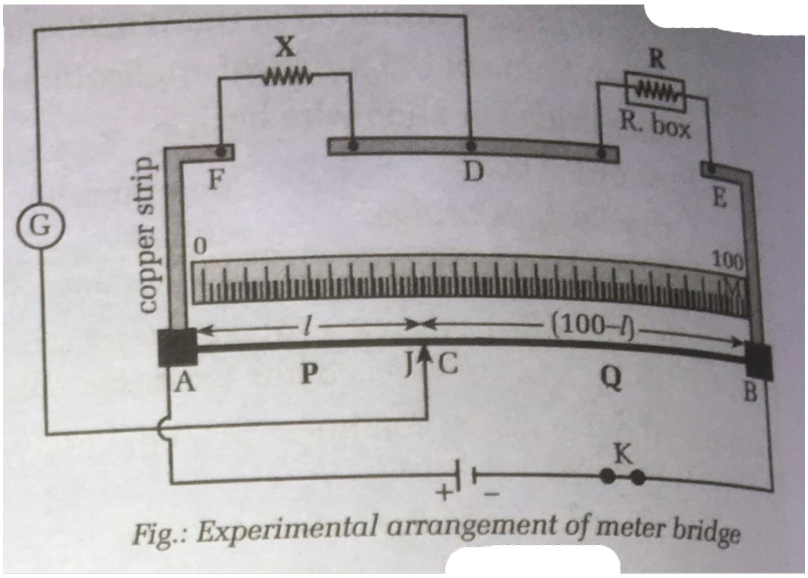

Fig.: Experimental arrangement of meter bridge

The meter bridge has a wire of length 1m soldered to the ends of two rectangular metallic strips. It can't be used to measure very high or very low resistances. The balanced position of the meter bridge is not affected by interchanging the positions of the battery and the galvanometer.

Referring to the figure, AB is a 1 meter wire of uniform cross-section. It is stretched over a wooden board provided with a meter scale so that the length of the wire can be read on it. At the ends A and B of the wire, two copper strips are provided and in between them, another straight copper strip is placed so that two gaps are left behind the two strips and the third strip. Across the two gaps, the resistors known resistor (i.e. the resistance box R) & unknown resistor (X) are connected.

According to the principle of the Wheatstone bridge, if P, Q, R, and X are four resistances arranged in the balanced conditions, then we have

$$\frac{P}{Q} = \frac{R}{X} \quad \dots\dots\dots(i)$$

If P is represented by length AC and Q is represented by length CB of the wire then

$$\frac{P}{Q} = \frac{l}{100 - l} \quad \dots\dots\dots(ii)$$

Where l is the balancing length at null deflection for resistance R.

From eq^n (i) and eq^n (ii), we obtained

$$\frac{R}{X} = \frac{l}{100 - l}$$

$$\therefore\ X = \frac{100 - l}{l} \times R \quad \dots\dots\dots(iii)$$

This eq^n (iii) gives the value of unknown resistance X.

If ρ be the resistivity of the wire of length L and cross-sectional area A, then

$$\rho = X \times \frac{\pi d^2}{4L} \quad \left(\because A = \frac{\pi d^2}{4}, \text{ where d is diameter of the wire}\right)$$

$$\therefore \rho = \frac{\pi d^2}{4L} X \quad \dots \dots \dots (iv)$$

This eq^n (iv) gives the value of resistivity of the wire X.

IMPORTANT NUMERICALS

1. Two metal plates 4 cm long are held horizontally 3 cm apart in a vacuum, one being vertically above the other. The upper plate is at a potential of 300 volt (V) & the lower is earthed. Electrons having a velocity of 10^7 m/s are injected horizontally midway between the plates & in a direction parallel to the 4 cm edge. Calculate the vertical deflection of the electron beam as it emerges from the plates. (Specific charge of an electron= 1.8×10^{11} C/kg).

→ Sol^n: Given;

Velocity (v) = $10^7\ m/s$

p.d. (V) = 300 V

Length of metal plates (x) = 4cm = 0.04 m

Separation (d) = 3 cm = 0.03 m

Specific charge of an electron (e/m) = 1.8×10^{11} C/kg

Vertical deflection (y) = ?

The vertical deflection of electron inside the electric field is

$$y = \frac{1}{2}\, at^2$$

$$= \frac{1}{2}\frac{eE}{m}\left(\frac{x}{v}\right)^2$$

$$= \frac{1}{2}\left(\frac{e}{m}\right)\frac{V}{d}\left(\frac{x}{v}\right)^2$$

$$= \frac{1}{2} \times 1.8 \times 10^{11} \times \frac{300}{0.03} \times \left(\frac{0.04}{10^7}\right)^2$$

$$\therefore y = 1.44 \times 10^{-2}\ \text{m}$$

Hence, the vertical deflection of the beam of an electron beam is 1.44×10^{-2} m.

2. An electron is revolving in a uniform magnetic field of strength 1.5×10^{-2}T. The radius of the circle describes is 1.2×10^{-2} m. Through what potential difference was the electron initially accelerated from rest? The field is perpendicular to the plane of motion.

→ Sol^n: Given;

Magnetic field strength (B) = 1.5×10^{-2} T

Radius (r) = 1.2×10^{-2} m

Angle (θ) = 90°

Potential difference (V) = ?

Inside the magnetic field, we have

$$\mathrm{Bev} = \frac{\mathrm{mv^2}}{\mathrm{r}}$$

$$\therefore \mathrm{v} = \frac{\mathrm{Ber}}{\mathrm{m}}$$

$$= \frac{1.5 \times 10^{-2} \times 1.6 \times 10^{-19} \times 1.2 \times 10^{-2}}{9.1 \times 10^{-31}}$$

$$= 3.2 \times 10^{7}\ m/s$$

Inside the electric field, we have

$$\mathrm{eV} = \frac{1}{2}\mathrm{mv^2}$$

$$\therefore \mathrm{V} = \frac{1}{2}\frac{\mathrm{m}}{\mathrm{e}}\mathrm{v^2} = \frac{1}{2}\frac{9.1 \times 10^{-31}}{1.6 \times 10^{-19}} \times (3.2 \times 10^{7})^2 = 2912\ \mathrm{V}$$

Thus, the value of the potential difference applied is 2912 volt (V).

3. In an experiment for analyzing the effect of temperature on velocity of sound a student has noted the velocity of sound at temperature 20°C & 60°C. He found that the velocity at 20°C is 330 m/s & velocity at 60°C is 280 m/s. Is the observation made by him correct?

→ Sol^n: Given;

Temperature (T_1) = 20°C = (20 + 273) K = 293 K

Velocity of sound at 20°C (v_1) = 330 m/s

Temperature (T_2) = 60°C = (60 + 273) K = 333 K

Velocity of sound at 60°C (v_2) = 280 m/s

Since, $v \propto \sqrt{T}$

We can write,

$$\frac{v_1}{v_2} = \sqrt{\frac{T_1}{T_2}}$$

$$or, \quad \frac{330}{280} = \sqrt{\frac{293}{333}}$$

$$or, \quad \frac{33}{28} = \frac{\sqrt{293}}{3\sqrt{37}} \ (False)$$

Since, the values are not equal the observation made by him are incorrect.

4. A disc of the moment of inertia 5×10^{-4} kgm^2 is rotating freely about the axis through its center at 40 rpm. Calculate the new revolution per minute (rpm) if some wax of mass 0.02 kg is dropped gently on the disc 0.08 m from the axis.

→Sol^n: Given;

Moment of inertia of disk (I_1) = 5×10^{-4} Kgm^2

Frequency of disk (f_1) = 40 rpm

Mass of wax (m) = 0.02 kg

Perpendicular distance from the axis of rotation (r) = 0.08 m

Final frequency of disc with wax (f_2) = ?

Since the moment of inertia of disc with wax is

$$I_2 = I_1 + mr^2$$

$$= 5 \times 10^{-4} + 0.02 \times (0.08)^2$$

$$= 5 \times 10^{-4} + 1.28 \times 10^{-4}$$

$$= 6.28 \times 10^{-4}\ \text{kgm}^2$$

From the principle of conservation of angular momentum, we have

$$I_1\omega_1 = I_2\omega_2$$

$$\text{or, } I_1 \times 2\pi f_1 = I_2 \times 2\pi f_2$$

$$\therefore f_2 = \frac{I_1 f_1}{I_2} = \frac{5 \times 10^{-4} \times 40}{6.28 \times 10^{-4}} = 32\ \text{rpm}$$

Hence, the new revolution per minute (rpm) of the disc with wax is 32 rpm.