2023	12	16

TS-P1

SEAT NUMBER

IIT INSPIRE
ACADEMY OF SCIENCE
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XI & XII Science (CBSE/state)
IIT- JEE (Mains + Advance)
NEET, MH-CET , NDA
Mo. No. 9595445177/9021445177

Branches : Chhatrapati Sq., Mangalmurti Sq.,

1

(4 Pages)

calculator is not allowed.
5. All symbols having their usual meanings unless otherwise stated.
6. For each MCQ, correct answer must be written along with its alphabet.
7. Evaluation of each MCQ would be done for the first attempt only.

Physical Constants:
(1) $\pi=3.142$ (2) $g=10\,m/s^2$ (3) $h=6.63\times10^{-34}\,J.s$ (4) $c=3\times10^{8}\,m/s$
(5) $e=1.6\times10^{-19}\,C$ (6) $\varepsilon_0=8.85\times10^{-12}\,C^2/N.m^2$ (7) $\mu_0=4\pi\times10^{7}\,T.m/A$,
(8) $\sigma=5.7\times10^{-8}\,W/m^2K^4$

SECTION-A

Q.1 Select and write the correct answers to the following questions: **[10]**

1) When the temperature increases, the angle of contact of a liquid __________.
   (a) increases
2) _________ gives relationship between heat transfer, work done and change in internal energy.
   (b) First law of thermodynamics
3) The average energy in one time period in a simple harmonic motion is
   (a) $\frac{1}{2}m\omega^2A^2$
4) Two capacitors of capacities C_1 and C_2 are connected in parallel. Then the equivalent capacitor is
   (a) C_1+C_2
5) Which of the following properties of a nucleus does not depend on its mass number?
   (d) density
6) A transistor is ___________.
   (c) a current device
7) In P-N-P transistor, the current produced is mainly due to _________.
   (b) holes only

8) A body of mass 'm' perform uniform circular motion along a circular path of radius 'r' with velocity 'v'. If its angular momentum is L, then the centripetal force acting on it is.

(d) L^2/mr^3

9) The logic gate which produces LOW output when one of the input is HIGH and produces HIGH output only when all of its input are LOW is called ________.

(c) NOR gate

10) An LED emits visible light when its

(c) Holes and electrons recombine

Q.2 Answer the following questions in one sentence: [8]

(1) **What is centrifugal force?**

Ans: The force acting on a particle performing UCM which is along the radius and directed away from centre of circle is called centrifugal force.

(2) **What is critical velocity?**

Ans: The velocity beyond which a streamline flow becomes turbulent is called critical velocity.

(3) **State principle of potentiometer.**

Ans: The potential difference between two points on the wire is directly proportional to the length of the wire between them provided the wire is of uniform cross section, the current through the wire is the same and temperature of the wire remains constant.

(4) **Define magnetic intensity.**

Ans: The ratio of the strength of magnetising field to the permeability of free space is called as magnetic intensity.

(5) **State law of radioactive decay.**

Ans: The number of nuclei undergoing the decay per unit time is proportional to the number of unchanged nuclei present at that instant.

(6) **Why do we need filter in power supply?**

Ans:

1. For any rectifier, the output is unidirectional but the output does not have a steady value.
2. It keeps fluctuating due to the ripple component present in it.
3. A filter circuit is used to remove the ripple from the output of a rectifier.

Hence, to get a steady output from a power supply, we need filters.

(7) **What is ideal gas equation for a mass of 7g of nitrogen gas?**

Ans: Ideal gas equation for 7 g of nitrogen gas is, $PV = \frac{RT}{4}$.

(8) **An ideal gas is taken through an isothermal process. If it does 2000 J of work on its environment, how much heat is added to it?**

Ans:

Given: $|W| = 2000\,J$

$\Delta U = 0$ ($\because$ process is isothermal)

To find: Heat added to system $(|Q|)$

Formula: $\Delta U = |Q| - |W|$

Calculation: From formula,

$$0=|Q|-2000$$
$$|Q|=2000\,J$$

SECTION-B

Attempt any eight of the following questions: [16]

Q.3 What is the difference between uniform circular motion and non-uniform circular motion?

Ans:

No.	U.C.M.	Non-U.C.M.
1	Circular motion with constant angular speed is known as uniform circular motion.	Circular motion with variable angular speed is known as non-uniform circular motion.
2	For U.C.M., $\alpha = 0$	For non-U.C.M., $\alpha \neq 0$
3	In U.C.M, work done by tangential force is zero.	In non-U.C.M, work done by tangential force is not zero.
4	Example: Motion of the earth around the sun.	Example: Motion of a body on vertical circle.

Q.4 Derive the expression for heat exchanged in case of an isobaric process.

Ans:

1. Consider an ideal gas undergoing volume expansion at constant pressure.
2. If V_i and T_i are its volume and temperature in the initial state of a system and V_f and T_f are its final volume and temperature respectively, the work done in the expansion is given by
   $W=pdV=p(V_f-V_i)=nR(T_f-T_i)$ .... (1)
3. Also, the change in the internal energy of a system is given by,
   $\Delta U=nC_v\Delta T=nC_v(T_f-T_i)$ .... (2)
   Where, C_v is the specific heat at constant volume and $\Delta T=(T_f-T_i)$ is the change in its temperature during the isobaric process.
4. According to the first law of thermodynamic, the heat exchanged is given by,
   $Q=\Delta U+W$
   Using equation (1) and (2) we get,
   $Q=nC_v(T_f-T_i)+nR(T_f-T_i)$
   $Q=(nC_v+nR)(T_f-T_i)$
   $Q=nC_p(T_f-T_i)$ .... (3)
   Where, C_p is the specific heat at constant pressure $\therefore C_p=C_v+R$.

   Note:

1. Temperature of a system changes in an isobaric process therefore, its internal energy also changes.
2. The heat exchanged is partly used for increasing the temperature and partly to do some work. The change in the temperature of the system depends on the specific heat at constant pressure C_p.

Q.5 State the laws of simple pendulum.

Ans:

Laws of Simple Pendulum:

1. **Law of Length:** Period of simple pendulum at a given place is directly proportional to square root of its length $T \propto \sqrt{L}$
2. **Law of Acceleration due to Gravity:** Period of simple pendulum (for a given length) is inversely proportional to the square root of acceleration due to gravity.
$$T \propto \frac{1}{\sqrt{g}}$$
3. **Law of Mass:** Period of simple pendulum is independent of mass of the bob.
4. **Law of Isochronous:** Period of simple pendulum is independent of the amplitude of oscillation, provided that amplitude of swing is small.

Q.6 Distinguish between free vibration and forced vibrations.

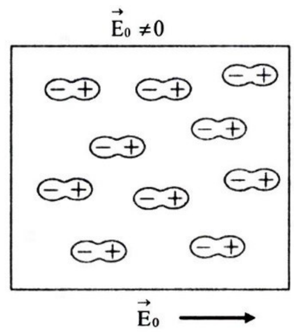
Ans:

Sr. No.	Free vibrations	Forced vibrations
1	Free vibrations are produced when a body is disturbed from its equilibrium position and released.	Forced vibrations are produced by an external periodic force of any frequency.
2	To start free vibrations only, the force is required initially.	Continuous external periodic force is required. If external periodic force is stopped, then forced vibrations also stop.
3	The frequency of free vibrations depends on the natural frequency.	The frequency of forced vibrations depends on the frequency of the external periodic force.
4	Energy of the body remains constant in the absence of friction, air resistance, etc. Due to damping forces, total energy decreases.	Energy of the body is maintained constant by the external periodic force.
5	Amplitude of vibrations decreases with time.	Amplitude is small but remains constant as long as external periodic force acts on it.
6	Vibrations stop sooner or later depending on the damping force.	Vibrations stop as soon as external periodic force is stopped.

Q.7 Explain the polarization of a non-polar dielectric in an external field.

Ans:

1. In the presence of an external electric field E_0, the centres of the positive charge in each molecule of a non-polar dielectric is pulled in the direction of E_0, while the centres of the negative charges are displaced in the opposite direction. Thus, the two centres are separated and the molecule gets distorted.
2. The displacement of the charges stops when the force exerted on them by the external field is balanced by the restoring force between the charges in the molecule.
3. Each molecule becomes a tiny dipole having a dipole moment.
4. The induced dipole moments of different molecules add up giving a net dipole moment to the dielectric in the presence of the external field.

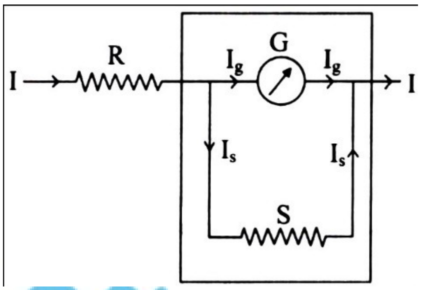


In presence of an external field

Q.8 Explain with the help of formulae how moving coil galvanometer is converted into ammeter in detail.

Ans:

1. To use a M.C.G as an ammeter, a shunt (low resistance) is connected in parallel to the coil of M.C.G.
2. In the arrangement as shown in the figure, I and I_g are the current through the circuit and galvanometer respectively.
   Therefore, the current through shunt S is, $I_s=(I-I_g)$
3. Since S and G are parallel,
   $\therefore GI_g=SI_s$
   $\therefore GI_g=S(I-I_g)$
   $\therefore S=\left[\frac{I_g}{I-I_g}\right]G$ .... (1)
   Equation (1) is useful to calculate the range of current that the galvanometer can measure.



a. If the current I is n times current I_g, then $I=nI_g$. Using this in the above expression we get
   $S=\frac{GI_g}{¿_g-I_g} \vee S=\frac{G}{n-1}$
   This is the required shunt to increase the range n times.
b. Also, if I_s is the current through the shunt resistance, then the remaining current ($I-I_g¿$ will flow through galvanometer. Hence
   $G(I-I_s)=SI_s$
   $i.e\, GI-GI_s=SI_s$
   $i.e\, SI_s+GI_s=GI$
   $\therefore \frac{I_s}{I}=\left[\frac{G}{S+G}\right]$
   This equation gives the fraction of the total current through the shunt resistance.

Q.9 Explain what do you understand by the de-Broglie wavelength of an electron. Will an electron at rest have an associated de-Broglie wavelength? Justify your answer.
Ans:
1. According to de Broglie, every particle of matter has both particle as well as wave properties associated with it.
2. The de Broglie, relation thus is given as, $\lambda=\frac{h}{p}=\frac{h}{mv}$
3. For a charged particle, like electron, of charge q, accelerated from rest, through a potential difference V, de Broglie wavelength is given as,
   $\lambda=\frac{h}{\sqrt{2mE}}=\frac{h}{\sqrt{2mqV}}$
4. For an electron at rest, as its momentum is zero, its de-Broglie wavelength would be infinite.

Q.10 Twenty-seven droplets of water, each of radius 0.1 mm coalesce into a single drop. Find the change in surface energy. Surface tension of water is 0.072 N/m.
Ans:

Given: $r = 0.1$ mm $= 10^{-4}$ m, $n = 27$,
$T = 0.072$ N/m

To find: Change in surface energy (W)

Formula: $W = TdA$

Calculation: Volume of a single drop $= \frac{4}{3}\pi R^3$ and

Volume of a single droplet $= \frac{4}{3}\pi r^3$

$\therefore$ We have, $\frac{4}{3}\pi R^3 = n\times\frac{4}{3}\pi r^3$ or $R^3 = nr^3$

$\therefore$ $R = \sqrt[3]{n}\,r = \sqrt[3]{27} \times 10^{-4} = 3 \times 10^{-4}\ m^2$

From formula,

$W = T\,(n \times 4\pi r^2 - 4\pi R^2)$

$= 4\pi T\,(nr^2 - R^2)$

$= 4 \times 3.142 \times 0.072 \times [27 \times (10^{-4})^2 - (3 \times 10^{-4})^2]$

$= 0.9049 \times 18 \times 10^{-8}$

$= \mathbf{1.629 \times 10^{-7}\ J}$

Ans: Change in the surface energy is **1.629×10^{-7} J.**

*[**Note:** The answer is calculated as per the values given in the question.]*

Q.11 Compare the rms speed of hydrogen molecules at 127^0C with rms speed of oxygen molecules at 27^0C given that molecular masses of hydrogen and oxygen are 2 and 32 respectively.

Ans:

Given: For hydrogen,

$T_{H_2} = 127\ °C = 127 + 273 = 400\ K$

$M_{H_2} = 2$

For oxygen,

$T_{O_2} = 27\ °C = 27 + 273 = 300\ K$

$M_{O_2} = 32$

To find: The ratio of rms speed of hydrogen molecules with rms speed of oxygen molecules. $(v_{H_2} : v_{O_2})$

Formula: $v_{rms} = \sqrt{\frac{3RT}{M_0}}$

Calculation:

From formula,

$v_{rms} \propto \sqrt{\frac{T}{M_0}}$

$\therefore$ $\frac{v_{H_2}}{v_{O_2}} = \sqrt{\frac{T_{H_2}}{M_{H_2}} \times \frac{M_{O_2}}{T_{O_2}}}$

$\therefore$ $\frac{v_{H_2}}{v_{O_2}} = \sqrt{\frac{400}{2} \times \frac{32}{300}} = \frac{8}{\sqrt{3}}$

$\therefore$ $v_{H_2} : v_{O_2} = \mathbf{8 : \sqrt{3}}$

Ans: The ratio of rms speed of hydrogen and oxygen molecule is **$8 : \sqrt{3}$**.

Q.12 A circular coil of a wire is made up of 100 turns, each of radius 8.0 cm. If a current of 0.40 A passes through it, what be the magnetic field at the centre of the coil?

Ans:

Given: $N = 100$, $R = 8.0\text{ cm} = 8 \times 10^{-2}\text{ m}$,
$I = 0.40\text{ A}$,
We know that, $\mu_0 = 4\pi \times 10^{-7}\text{ Tm/A}$

To find: Magnetic field at the centre of coil.

Formula: $B_c = \dfrac{\mu_0 NI}{2R}$

Calculation: From formula,

$$B_c = \frac{4\pi \times 10^{-7} \times 100 \times 0.40}{2 \times 8 \times 10^{-2}}$$

$$= \frac{160}{16}\,\pi \times 10^{-7+2}$$

$$= \pi \times 10^{-5+1}$$

$$= \mathbf{3.142 \times 10^{-4}\ T}$$

Ans: Magnetic field at the centre is $\mathbf{3.142 \times 10^{-4}\ T}$.

Q.13 Determine the series limit of Balmer, Paschen series, give the limit for Lyman series is 912 Å.

Ans:

Given: Series limit of Lyman Series = 912 Å

To find: Series limit of
i. Balmer series
ii. Paschen series
iii. Pfund series

Formula: $\dfrac{1}{\lambda} = R\left[\dfrac{1}{n^2} - \dfrac{1}{m^2}\right]$

Calculation:

From formula,
For series limit, $m = \infty$

$\therefore \quad \lambda = \dfrac{n^2}{R}$

For Lyman series, $n = 1$

$$\lambda_L = \frac{n^2}{R} = \frac{1^2}{R} = \frac{1}{R} = 912\text{ Å}$$

i. For Balmer series, $n = 2$

$$\lambda_B = \frac{2^2}{R} = \frac{4}{R} = 4 \times 912 = \mathbf{3648\ Å}$$

ii. For Paschen series, $n = 3$

$$\lambda_P = \frac{3^2}{R} = \frac{9}{R} = 9 \times 912 = \mathbf{8208\ Å}$$

iii. For Pfund series, $n = 5$

$$\lambda_{pf} = \frac{5^2}{R} = 25 \times 912 = \mathbf{22800\ Å}$$

Ans: The series limit of
i. Balmer series is **3648 Å**
ii. Paschen series is **8208 Å**
iii. Pfund series is **22800 Å**.

[Note:** Answers calculated above are in accordance with textual methods of calculation.**]

Q.14 An electron in a hydrogen atom stays in its second orbit for $10^{-8}s$. How many revolutions will it make around the nucleus in that time?

Ans:

The electron in 2^{nd} orbit will transit to 1^{st} orbit.
Energy difference between two levels,
$\Delta E = h\nu$

$$\therefore \quad \nu = \frac{\Delta E}{h}$$

$$= \frac{\left[\frac{-13.6}{2^2} - (-13.6)\right] \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}}$$

$$= \frac{(-3.4 + 13.6) \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}}$$

$$= \frac{10.2 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}}$$

$$= \frac{16.32}{6.63} \times 10^{15}$$

$$= 2.46 \times 10^{15} \text{ Hz}$$

Thus, in one second, electron completes 2.46×10^{15} revolutions.

$\therefore$ In 10^{-8} s, total revolutions performed,

$= 2.46 \times 10^{15} \times 10^{-8}$

$= \mathbf{2.46 \times 10^{7}}$

Ans: Total number of revolutions made by electron is $\mathbf{2.46 \times 10^{7}}$.

*[**Note:** Answers calculated above are in accordance with textual methods of calculation.]*

SECTION-C

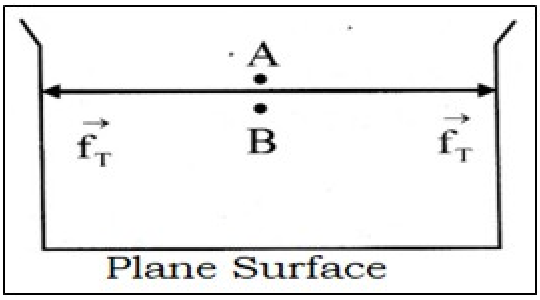
Attempt any eight of the following questions:
[24]

Q.15 Explain the excess pressure across a free surface of a liquid.

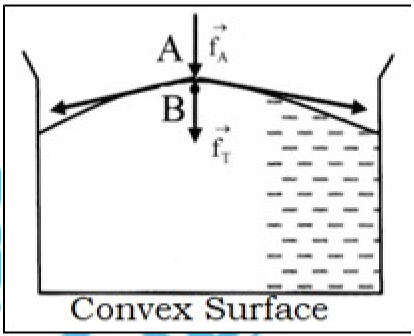
Ans:

1. Every molecule on a liquid surface experience forces due to surface tension which are tangential to the liquid surface at rest.
2. The direction of the resultant force of surface tension acting on a molecule on the liquid surface depends upon the shape of that liquid surface. This force also contributes in deciding the pressure at a point just below the surface of a liquid.
3. Let $\vec{f}_A$ be the downward force due to the atmospheric pressure. All the three figures show two molecules A and B. The molecule A is just above and the molecule B is just below it (inside the liquid).
4. Level difference between A and B is almost zero, so that it does not contribute anything to the pressure difference. In all the three figures, the pressure at the point A is the atmospheric pressure p.

   Plane liquid surface:



If the free surface of liquid is plane, the resultant force due to surface tension, $\vec{f}_T$ on the molecule at B is zero. The force $\vec{f}_A$ itself decides the pressure and the pressure at A and B is the same.

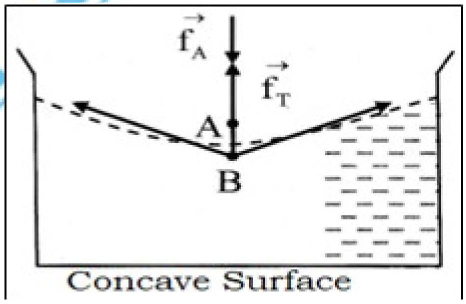


Convex liquid surface:

If the free surface of the liquid is upper convex. (Convex, when seen from above). In this case, the resultant force due to surface tension, $\vec{f}_T$ on the molecule at B is vertically downwards and adds up to the downward force $\vec{f}_A$. This develops greater pressure at point B, which is inside the liquid and on the concave side of the meniscus. Thus, the pressure on the concave side i.e., inside the liquid is greater than that on the convex side i.e., outside the liquid.

Concave liquid surface:

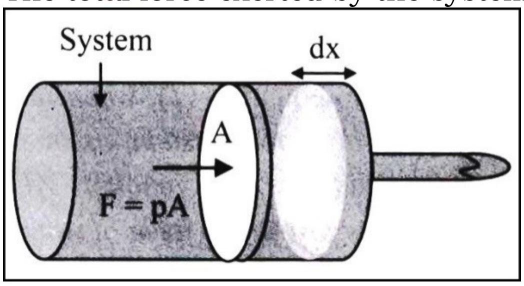
Surface of the liquid is upper concave (concave, when seen from above). In this case, the force due to surface tension $\vec{f}_T$, on the molecule at B is vertically upwards. The force $\vec{f}_A$ due to atmospheric pressure acts downwards. Forces $\vec{f}_A$ and $\vec{f}_T$ thus, act in opposite direction. Therefore, the net downward force responsible for the pressure at B is less than $\vec{f}_A$. This develops a lesser pressure at point B, which is inside the liquid and on the convex side of the meniscus. Thus, the pressure on the concave side i.e., outside the liquid, is greater than that on the convex side, i.e., inside the liquid.



Q.16 Derive the expression for the amount of work done in changing the volume of a system.

Ans:

1. Consider system enclosed in a cylinder with a movable, massless, and frictionless piston so that its volume can change.
2. Let the cross-sectional area of the cylinder (and the piston) be A, and the constant pressure exerted by the system on the piston be p.
3. The total force exerted by the system on the piston will be $F = pA$.



4. If the piston moves through an infinitesimal (very small) distance dx, the work done by this force is,

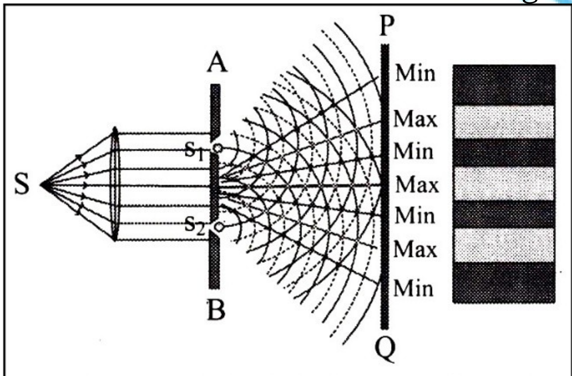
$dW = pdV$
But $Adx = dV$, the infinitesimal change in the volume of the cylinder.

5. The work done by the system in bringing out this infinitesimal change in the volume can be written as,
$dW = pdV$ .... (1)
6. If the initial volume of the cylinder is V_i and its volume after some finite change is V_f then the total work done in changing the volume of the cylinder is,
$W \int_{V_i}^{V_f} pdV = p(V_f - V_i)$ .... (2)
The change in volume in this case is small.
Note:
The internal energy of a system can be changed either by providing some heat to it (or, by removing heat from it) or, by doing some work on it (or extracting work from it).

Q.17 Describe Young's double slit interference experiment.

Ans:

1. Young performed the experiment in a dark room. He used sunlight as the source of light. Sunlight from a pin hole S is allowed to fall on two pin holes S_1 and S_2. The interference pattern was observed, which contains indistinct coloured bands. Slits are about 2-4 mm apart from each other.
2. For steady and distinct interference pattern, he replaced sunlight by the monochromatic light and pin holes by the slits. He obtained a clear and distinct interference pattern. The idea of formation of interference of light is explained in the diagram.



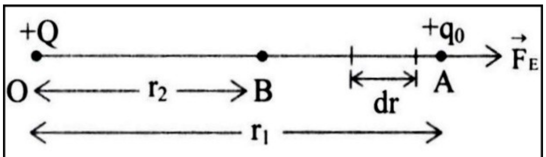
Young's double slit experiment

3. In the diagram, S is a source of light. S_1 and S_2 are the two sources, which are made using the pin holes to the partition. The light emitting from these two sources is monochromatic, coherent and of equal intensity. The crests are shown by dotted line and trough is shown by continuous lines.
4. When crest due to one wave (shown by dotted line), overlaps, the crest due to another wave, bright band is obtained, called as constructive interference. When crest due to one wave overlaps the trough (shown by continuous line) due to another wave, dark band is obtained, called as destructive interference.
5. By measuring band width [X], distance between source and screen [D] and distance between two sources [d], he obtained wavelength of monochromatic light using the relation.
$\lambda = \frac{Xd}{D}$

Q.18 Derive an expression for electrostatic potential energy.

Ans:

1. Let us consider the electrostatic field due to a source charge +Q placed at the origin O. Let a small charge $+q_0$ be brought from point A to point B at respective distance r_1 and r_2 from O, against the repulsive forces on it.



Charge +q_0 displaced by dr towards charge +Q

2. Work done against the electrostatic force $\vec{F}_e$, in displacing the charge q_0 through a small displacement $d\vec{r}$ appears as an increase in the potential energy of the system.
   $dU = \vec{F}_E . d\vec{r} = -F_E . dr$
   Negative sign appears because the displacement $d\vec{r}$ is against the electrostatic force $\vec{F}_E$.
3. For the displacement of the charge from the initial position A to the final position B, the change in potential energy ΔU, can be obtained by integration dU.
   $$\therefore \Delta U = \int_{r_1}^{r_2} dU = \int_{r_1}^{r_2} -\text{¿}\vec{F}_E . d\vec{r}\,\text{¿}$$
4. The electrostatic force (Coulomb force) between the two charge separated by distance r is
   $$\vec{F}_E = -\left[\frac{1}{4\pi\varepsilon_0}\right]\frac{Qq_0}{r^2}\hat{r}$$
   Where, $\hat{r}$ is the unit vector in the direction of $\vec{r}$. Negative sign shows $\vec{r}$ and $\vec{F}_E$ are oppositely direction.
5. $\therefore$ For a system of two-point charge,
   $$\Delta U = \int_{r_1}^{r_2} dU = \int_{r_1}^{r_2} -\left[\frac{1}{4\pi\varepsilon_0}\right]\frac{Qq_0}{r^2}\hat{r}.d\vec{r}$$
   $$\therefore \Delta U = -\left[\frac{1}{4\pi\varepsilon_0}\right]Qq_0\left[\frac{-1}{r}\right]_{r_1}^{r_2}$$
   $$\text{¿}\left[\frac{1}{4\pi\epsilon_0}\right]Qq_0\left[\frac{1}{r_2}-\frac{1}{r_1}\right]$$
6. The change in the potential energy depends only upon the end point and it independent of the actual path taken by the charge. The change in potential energy is equal to the work done W_{AB} against the electrostatic force.
   $$W_{AB} = \Delta U = \left[\frac{1}{4\pi\epsilon_0}\right]Qq_0\left[\frac{1}{r_2}-\frac{1}{r_1}\right]$$
7. So far we have defined/calculated the change in the potential energy for system of charges. It is convenient to choose infinity to be the point of zero potential energy as the electrostatic force is zero at $r=\infty$.
8. Thus, the potential energy U of the system of two-point charges q_1 and q_2 seperated by r can be obtained from the above equation by using $r_1=\infty$ and $r_2=r$. It is then given by
   $$U(r) = \left[\frac{1}{4\pi\epsilon_0}\right]\left[\frac{q_1q_2}{r}\right]$$

Q.19 Derive the relation for magnetic force acting on an arbitrarily shaped wire assuming relation for straight wire. Also calculate the value of magnetic field at a distance of 2 cm from a very long straight wire carrying a current of 5 A.

Ans:

1. Consider a segment of infinitesimal length dl along the wire.

2. If I in the current flowing, the magnetic force due to perpendicular magnetic field $\vec{B}$ (coming out of the plane of the paper) is given by,

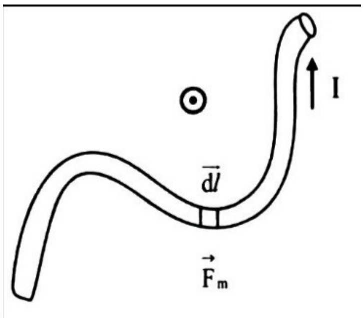
$d\vec{F}_m = I\,d\vec{l} \times \vec{B}$ .... (1)

3. The force on the total length of wire is thus,

$\vec{F}_m = \int d\vec{F}_m = I\int d\vec{l} \times \vec{B}$ .... (2)

4. If $\vec{B}$ is uniform over the whole wire,

$\vec{F}_m = I\left[\int d\vec{l}\right] \times \vec{B}$ .... (3)



Wire with arbitrary shape

Given: $I = 5\text{ A}, R = 2\text{ cm} = 2 \times 10^{-2}\text{ m}$

$\mu_0 = 4\pi \times 10^{-7}\text{ Wb/Am}$

To find: Magnitude field (B)

Formula: $B = \dfrac{\mu_0 I}{2\pi R}$

Calculation: From formula,

$$B = \frac{4\pi \times 10^{-7} \times 5}{2\pi \times 2 \times 10^{-2}} = \mathbf{5 \times 10^{-5}\ T}$$

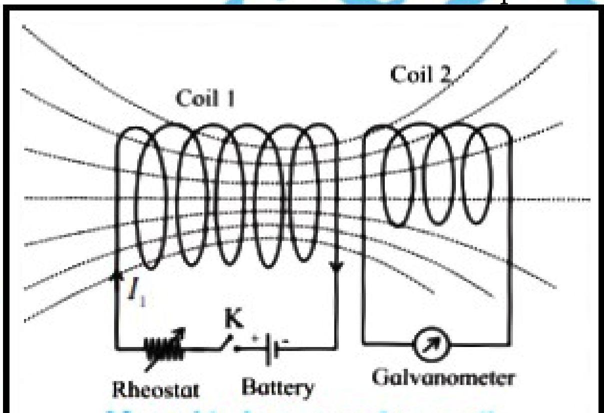
Ans: The value of magnetic field is $\mathbf{5 \times 10^{-5}}$ **T**.

*[**Note:** Answers calculated above are in accordance with textual methods of calculation.]*

Q.20 What is mutual inductance?

Ans:

1. Let us consider a case of two coils placed side by side as shown in figure.



Mutual inductance of two coils

2. Suppose a fixed current I_1 is flowing through coil 1. Due to this current a magnetic field $B_1(x, y, z)$ will be produced in the nearby region surrounding the coil 1.
3. Let ϕ_{21} be the magnetic flux liked with the surface area s_2 of the coil 2 due to magnetic field $\vec{B}_1$ and can be written as

$\phi_{21} = \int_{s_2} \vec{B}_1 . \vec{\delta a}$ .... (1)

Where, s_2 represent the effective surface (or area) enclosed by coil 2

4. If the positions of the coils are fixed in space,

Then $\phi_{21} \propto I_1$

$\phi_{21} = constant\ I_1$

Or $\phi_{21} = M_{21} I_1$ .... (2)

Where, M_{21} is a constant of proportionality and is termed as mutual inductance or coefficient of mutual induction of coil 2 (or circuit c_2) with respect to coil 1 (or circuit c_1).

5. Suppose I_1 changes slowly with time then magnetic field B_1 in the vicinity of coil 2 is related to current I_1 in coil 1 in the same way as it would be related for a steady current. The magnetic flux ϕ_{21} will change in proportion as I_1 changes.
6. The induced emf in coil 2 will be written as

$$e_{21} = \frac{-d\phi_{21}}{dt}$$

$$e_{21} = -M_{21}\frac{dI_1}{dt}$$

7. When current I_2 to flow through coil 2. Magnetic flux ϕ_{12} liked with coil 1 is obviously proportional to I_2.

That is

$\phi_{12} \propto I_2$

or $\phi_{12} = M_{12} I_2$ ...... (3)

or $M_{12} = \frac{\phi_{12}}{I_2}$ .... (4)

M_{12} is known as mutual inductance of coil 1 with respect to coil 2.

8. The induced emf in coil 1 will be

$$e_{12} = -M_{12}\frac{dI_2}{dt}$$

It may be noted that by symmetry,

$M_{12} = M_{21} = M$.

Q.21 An AC source generating a voltage $e = e_0 \sin\omega t$ is connected to a capacitor of capacitance C. Find the expression for the current I flowing through it. Plot the graph of e and i versus ωt.

Ans:

1. Consider an alternating e.m.f,

$e = e_0 \sin\omega t$ .... (1)

Is the applied across a capacitor of capacity C as shown in figure (a).

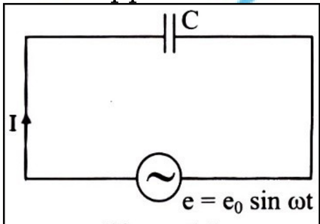


Figure (a)

2. Let 'q' be the magnitude of charge on any one plate of a capacitor at any instant. The potential difference across its plates at that instant is given by,

$$V = \frac{q}{c}$$

This p.d is equal to the instantaneous value of the applied e.m.f (e)

$\therefore e = \frac{q}{c}$ $\quad\quad \therefore q = Ce$

$\therefore q = C(e_0 \sin\omega t)$ .... (2)

3. Differentiating both sides of equation (2) w.r.t 't', we get,

$$\frac{dq}{dt} = \frac{d}{dt}(C e_0 \sin\omega t) = \omega C e_0 cos\omega t$$

$\therefore I = \omega C e_0 cos\omega t$ .... (3)

Equation (3) represents instantaneous current in the circuit.

4. Maximum current will flow through the circuit, if $cos\omega t=1$. In this condition $I_{max}=\omega C e_0$. This is called peak current through the capacitor.
   It is given by, $I_0=e_0\omega C$ .... (4)
5. From equation (3) and (4), we have,
   $I=I_0 cos\omega t=I_0 \sin\left(\omega t+\frac{\pi}{2}\right)$ .... (5)
6. Comparing $e=e_0 sin\omega t$ with equation (5), we conclude that,
   a. e.m.f or voltage across the capacitor lags behind the current by phase angle $\frac{\pi}{2}$ rad or current leads the e.m.f or voltage by $\frac{\pi}{2}$ rad.
   b. Both the current and e.m.f are sinusoidal in nature of same frequency.
7. The variation of e.m.f or current v/s ωt is shown in figure (b). It gives variation of e.m.f and current with time or ωt.

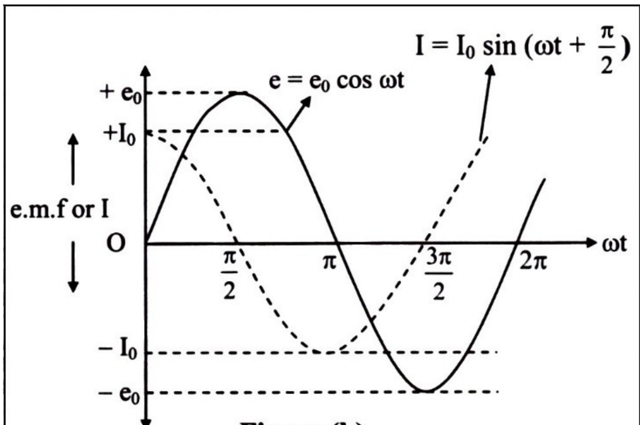


Figure (b)

8. Comparing equation (1) and equation (5) we find that in an AC circuit containing a capacitor only, the alternating current I leads the alternating emf e by phase angle of $\frac{\pi}{2}$ radian.

Q.22 Somehow, an ant is stuck to the rim of a bicycle wheel of diameter 1 m. While the bicycle is on central stand, the wheel is set into rotation and it attains the frequency of 2 rev/s in 10 seconds, with uniform angular acceleration. Calculate
(1) Number of revolutions completed by the ant in these 10 seconds.
(2) Time taken by it for the first complete revolution and the last complete revolution.
Ans:

Given: D = 1 m; r = 0.5 m, $n_0 = 0$, $\omega_0 = 0$ rad/s
n = 2 rps, $\omega = 2\pi n = 4\pi$ rad/s, t = 10 s

To find:
i. Total number of revolutions in 10 s (N)
ii. Time taken for first revolution and the last revolution (t)

Formulae: i. $\alpha = \dfrac{\omega - \omega_0}{t}$ ii. $\theta = \omega_0 t + \dfrac{1}{2}\alpha t^2$

iii. Total revolution (N) = $\dfrac{\theta}{2\pi}$

Calculation:

From formula (i),

Angular acceleration, $\alpha = \dfrac{\omega - \omega_0}{t} = \dfrac{4\pi - 0}{10}$

$= \dfrac{2\pi}{5}$ rad/s

From formula (ii),

Angle traversed by ant,

$\theta = (0)(10) - \dfrac{1}{2}\left(\dfrac{2\pi}{5}\right)(10^2) = 20\pi$ rad

From formula (iii),

Total revolutions, N = $\dfrac{20\pi}{2\pi}$ = **10 rev**.

For 1^{st} revolution, $\theta = 2\pi$ rad

From formula (ii),

$2\pi = (0)(t) + \dfrac{1}{2}\left(\dfrac{2\pi}{5}\right)t_1^2$

$\therefore$ $t_1 = \sqrt{10}$ **s**

Upto 9^{th} revolution, $\theta = 9 \times 2\pi$ rad

From formula (ii),

$9 \times 2\pi = 0(t) + \dfrac{1}{2}\left(\dfrac{2\pi}{5}\right)t_9^2$

$\therefore$ $t_9 = \sqrt{90}$ s = $3\sqrt{10}$ = 9.4868 s

Time taken for last revolution

$= t_{10} - t_9 = 10 - 9.4868$ = **0.5132 s**

Ans: i. Number of revolutions completed by the ant in is **10.**

ii. Time taken by it to complete first revolution is $\sqrt{10}$ **s** and to complete last (i.e.10^{th}) revolution is **0.5132 s.**

Q.23 A particle performing linear S.H.M. of period 2π seconds about the mean position O is observed to have a speed of $b\sqrt{3}$ m/s, when at a distance b (meter) from O. If the particles are moving away from O at that instant, find the time required by the particle, to travel a further distance b.

Ans:

Given: $T = 2\pi$ s, $v(b) = b\sqrt{3}$ m/s, $x = b$ m

To find: Time required by object to travel distance from b to 2b ($t_2 - t_1$)

Formulae: i. $\omega = \frac{2\pi}{T}$ ii. $v = \omega\sqrt{A^2 - x^2}$

iii. $v = \omega A \cos \omega t$ iv. $x = A \sin \omega t$

Calculation:

From formula (i),

$\omega = \frac{2\pi}{2\pi} = 1 \text{ rad s}^{-1}$

From formula (ii),

$b\sqrt{3} = (1) \times \sqrt{A^2 - b^2}$

Squaring both sides,

$3b^2 = A^2 - b^2$

$\therefore$ $4b^2 = A^2$

$\therefore$ $A = 2b$

From formula (iii),

$b\sqrt{3} = 1 \times 2b \times \cos(1 \times t_1)$

$\therefore$ $\frac{\sqrt{3}}{2} = \cos t_1$

$\therefore$ $t_1 = \frac{\pi}{6}$ s

From formula (iv),

$2b = 2b \sin(1 \times t_2)$

$\therefore$ $1 = \sin t_2$

$\therefore$ $t_2 = \frac{\pi}{2}$

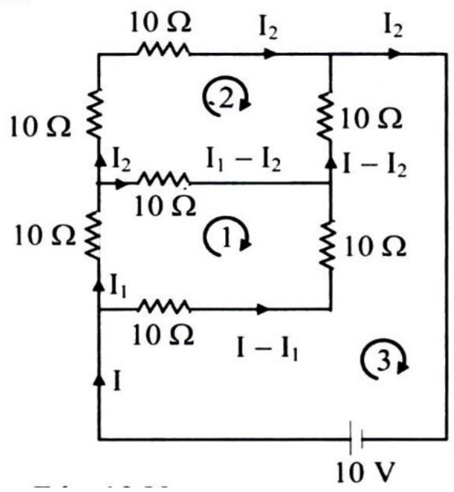
$\therefore$ $t_2 - t_1 = \frac{\pi}{2} - \frac{\pi}{6} = \boldsymbol{\frac{\pi}{3}}$ **s**

Ans: The time required by object is $\boldsymbol{\frac{\pi}{3}}$ **s.**

Q.24 Find the equivalent resistance between the terminals of F and B in the network shown in the figure below given that the resistance of each resistor is 10 ohm.

Ans:

Solution:



Let E be 10 V.
Applying KVL in loop 1,
$+20(I - I_1) - 10I_1 - 10(I_1 - I_2) = 0$

$\therefore \quad 20I - 20I_1 - 10I_1 - 10I_1 + 10I_2 = 0$

$\therefore \quad 4I_1 = 2I + I_2 \qquad \ldots(i)$

$\therefore \quad I = \dfrac{4I_1 - I_2}{2} \qquad \ldots(ii)$

Applying KVL in loop 2,
$20I_2 - 10(I_1 - I_2) - 10(I - I_2) = 0$

$\therefore \quad 40I_2 = 10I + 10I_1$

$\therefore \quad 4I_2 = I + I_1 \qquad \ldots(iii)$

Substituting (ii) in equation (iii), we get

$\therefore \quad 4I_2 = \dfrac{(4I_1 - I_2)}{2} + I_1$

$\therefore \quad 8I_2 = 4I_1 - I_2 + 2I_1$

$\therefore \quad I_1 = \dfrac{3}{2} I_2 \qquad \ldots(iv)$

Applying in KVL in loop 3,
$20(I - I_1) + 10(I - I_2) = 10$

$\therefore \quad 3I - 2I_1 - I_2 = 1$

$\therefore \quad 3\left(\dfrac{4I_1 - I_2}{2}\right) - 2 \times \dfrac{3}{2} I_2 - I_2 = 1$

$\therefore \quad 6I_1 - \dfrac{3}{2} I_2 - 4I_2 = 1$

$\therefore \quad 6 \times \dfrac{3}{2} I_2 - \dfrac{3}{2} I_2 - 4I_2 = 1$

$\left(5 - \dfrac{3}{2}\right) I_2 = 1$

$\therefore \quad \dfrac{7}{2} I_2 = 1$

$\therefore \quad I_2 = \dfrac{2}{7} A$

$\therefore \quad I_1 = \dfrac{3}{2} \times \dfrac{2}{7} = \dfrac{3}{7} A$

$I = \dfrac{4 \times \frac{3}{7} - \frac{2}{7}}{2} = \dfrac{5}{7} A$

$R_{eq} = \dfrac{V}{I} = \dfrac{10}{\frac{5}{7}} = \dfrac{10}{5} \times 7 = \mathbf{14\ \Omega}$

Ans: Equivalent resistance between the terminals of F and B is **14 Ω**.

*[**Note:** The framing of the question is modified to get conceptually right solution with respect to given condition in the question.]*

Q.25 A 100 mH inductor, a 25 μF capacitor and a 15 Ω resistor are connected in series to a 120 V, 50 Hz AC source. Calculate
(1) Impedance of the circuit at resonance
(2) Current at resonance
(3) Resonant frequency
Ans:

Given: $L = 100 \text{ mH} = 100 \times 10^{-3} \text{ H} = 10^{-1} \text{ H}$

$C = 25 \ \mu F = 25 \times 10^{-6} \text{ F}, R = 15 \ \Omega$

$e_{rms} = 120 \text{ V}, f = 50 \text{ Hz}$

To find:
i. Impedance at resonance (Z)
ii. Current at resonance (i)
iii. Resonant frequency (f_r)

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

ii. $i_{rms} = \dfrac{e_{rms}}{Z}$ iii. $f = \dfrac{1}{2\pi\sqrt{LC}}$

Calculation: At resonance,

$X_L = X_C$

From formula (i),

$Z = \sqrt{R^2 + (X_L - X_C)^2} = R = \mathbf{15 \ \Omega}$

From formula (ii),

$i_{rms} = \dfrac{120}{15} = \mathbf{8 \ A}$

From formula (iii),

$$f = \frac{1}{2 \times 3.142 \times \sqrt{10^{-1} \times 25 \times 10^{-6}}}$$

$$= \frac{\sqrt{10}}{5 \times 2 \times 3.142 \times 10^{-3}}$$

$$= \frac{3.162}{3.142} \times 10^2$$

$= 1.006 \times 10^2 \text{ Hz} = \mathbf{100.6 \ Hz}$

Ans: i. The impedance of the circuit at resonance is **15 Ω.**
ii. The current at resonance is **8 A.**
iii. The resonant frequency is **100.6 Hz.**

Q.26 Radiation of wavelength 4500 Å is incident on a metal having work function 2.0 eV. Due to the presence of a magnetic field B, the most energetic photoelectrons emitted in a direction perpendicular to the field move along a circular path of radius 20 cm. What is the value of the magnetic field B?

Ans:

Given: $\lambda = 4500 \text{ Å} = 4500 \times 10^{-10} \text{ m}$,

$\phi_0 = 2.0 \text{ eV} = 2 \times 1.67 \times 10^{-19} \text{ J}$,

$r = 20 \text{ cm} = 0.2 \text{ m}$

To find: Magnetic field (B)

Formulae: i. $E = \dfrac{hc}{\lambda} - \phi_0$ ii. $r = \dfrac{mv}{qB}$

iii. $p = mv = \sqrt{2mE}$

Calculation:

From formula (i),

$E = \dfrac{12500}{4500} - 2.0$

$= (2.78 - 2.0) \text{ eV}$

$= 0.78 \times 1.6 \times 10^{-19} \text{ J}$

$= 1.248 \times 10^{-19} \text{ J}$

From formulae (ii) and (iii),

$$r = \frac{\sqrt{2mE}}{qB} \quad \Rightarrow B = \frac{\sqrt{2mE}}{qr}$$

$$\therefore \quad B = \frac{\sqrt{2 \times 1.248 \times 10^{-19} \times 9.11 \times 10^{-31}}}{1.6 \times 10^{-19} \times 0.2}$$

$$\therefore \quad B = \frac{\sqrt{2.496 \times 9.11 \times 10^{-50}}}{3.2 \times 10^{-20}}$$

$$= \text{antilog } \{0.5 \times [\log(2.496) + \log(9.11)] - \log(3.2)\} \times 10^{-5}$$

$$= \text{antilog } \{0.5 \times (0.3973 + 0.9595) - 0.5051\} \times 10^{-5}$$

$$= \text{antilog } \{0.1733\} \times 10^{-5}$$

$$\mathbf{= 1.490 \times 10^{-5}\ T}$$

<u>SECTION-D</u>

Attempt any <u>three</u> of the following question: [12]

Q.27 Prove the relation a + r + t = 1 where symbol have their usual meaning. Compare the rates of emission of heat by the black body maintained at $727^0 C$ and at $227^0 C$, if the black bodies are surrounded by an enclosure (black) at $27^0 C$. What would be the ratio of their rates of loss of heat?

Ans:

1. Whenever thermal radiation falls on the surface of an object, some part of heat energy is reflected, some part is absorbed and the remaining part is transmitted.
2. Let Q be the total amount of thermal energy incident on the surface of an object and Q_a, Q_r and Q_t be the respective amounts of heat absorbed, reflected and transmitted by the object.
3. From law of conservation of energy,

   $Q_a + Q_r + Q_t = Q$

   Dividing by Q,

   $\therefore \frac{Q_a}{Q} + \frac{Q_r}{Q} + \frac{Q_t}{Q} = 1$
4. But by definition,

   $\frac{Q_a}{Q} = a$ ..... (Absorptance),

   $\frac{Q_r}{Q} = r$ ..... (Reflectance) and

   $\frac{Q_t}{Q} = t$ ..... (Transmittance)

   Hence,

   $a + r + t = 1$

   This is the required relation.

Given: $T_0 = 27\ °C = 27 + 273 = 300$ K
$T_1 = 727\ °C = 727 + 273 = 1000$ K
$T_2 = 27\ °C = 227 + 273 = 500$ K

To find: Ratio of rate of loss of heat ($R_1 : R_2$)

Formula: $R = \frac{dQ}{dt} = e\sigma A\,(T^4 - T_0^4)$

Calculation:

From formula,

$$R_1 = \left(\frac{dQ}{dt}\right)_1 = e\sigma A(T_1^4 - T_0^4) \quad ....(1)$$

$$R_2 = \left(\frac{dQ}{dt}\right)_2 = e\sigma A(T_2^4 - T_0^4) \quad ....(2)$$

Dividing equation (1) by equation (2),

$$\frac{R_1}{R_2} = \frac{T_1^4 - T_0^4}{T_2^2 - T_0^4} = \frac{1000^4 - 300^4}{500^4 - 300^4}$$

$$= \frac{10^4 - 3^4}{5^4 - 3^4}$$

$$= \frac{9919}{544}$$

= antilog {log (9919) – log (544)}
= antilog {3.9965 – 2.7356}
= antilog {1.2609} = **18.23**

Ans: The ratio of the rate of energy radiated is **18.23 : 1.**

Q.28 Prove that all harmonics are present in the vibrations of the air column in a pipe open at both ends.

Ans:

If longitudinal waves are sent along the air column in a pipe open at both ends by holding a vibrating tuning fork near an open end, they get reflected from the other open end. Thus, the air column contains the incident and reflected longitudinal waves which interfere with each other and longitudinal stationary waves are produced. Air at the open ends is free to vibrate so antinodes are formed at the point ends.

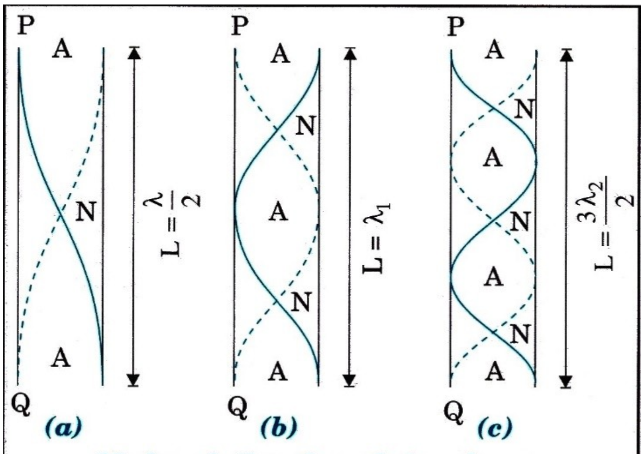
The different ways in which the air column can vibrate are called the modes of vibration of the air column.

1. The simplest mode of vibration is called the first or fundamental mode of vibration. Here, two antinodes and one node are formed.

   Length of air column $L = \frac{\lambda}{2} \quad \therefore \lambda = 2L$

   The frequency of vibration of the air column given by $n = \frac{v}{\lambda} \quad \therefore n = \frac{v}{2L} = \frac{v}{2(l+2e)}$

   This is the lowest frequency of vibration of an air column.



Modes of vibration of air column in a pipe open at both ends

2. In second mode of vibration of air column, three antinodes and two nodes are formed.

   Length of air column¿ $L=\frac{\lambda_1}{2}+\frac{\lambda_1}{2}=\lambda_1$

   $\therefore \lambda_1=L=(l+2e)$

   If n_1 and λ_1 are frequency and wavelength of second mode of vibration of air column, then

   $\therefore v=n_1\lambda_1=n_1 L$

   $\therefore n_1=\frac{v}{L}=2\left(\frac{v}{2L}\right)=\frac{v}{L}=\frac{v}{(l+2e)}$ $\qquad \therefore n_1=2n$

   This frequency is called second harmonic and first overtone.

3. In **third mode of vibration** of air column, four antinodes and three nodes are formed.

   Length of air column¿ $L=\frac{3\lambda_2}{2}$ $\quad \therefore \lambda_2=\frac{2L}{3}=\frac{2(l+2e)}{3}$

   If n_2, λ_2 are the frequency and wavelength of third mode of vibration of air column then,

   $v=n_2\lambda_2$

   $\therefore v=n_2\frac{2L}{3}$

   $\therefore n_2=\frac{3v}{2L}=3\times\left(\frac{v}{2L}\right)=\frac{3v}{2(l+2e)}=3n$ $\quad \therefore n_2=3n$

   This frequency is called the frequency of third harmonic or second overtone.

4. Similarly, frequency of p^{th} overtone,

   $n_p=(p+1)n$

   Where $p=0,1,2,3$ ......

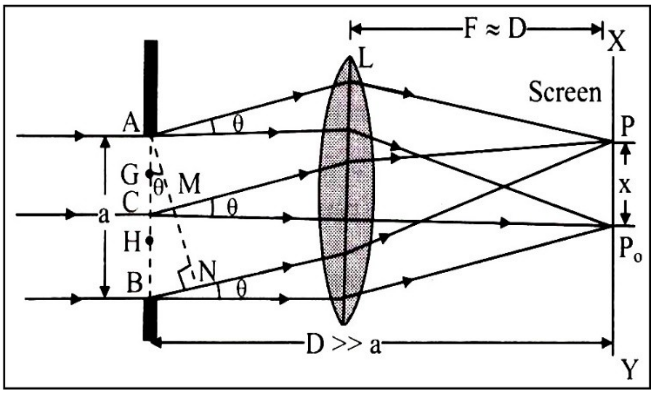
   Thus air column in a pipe open at both ends vibrate with frequency n, 3n, 5n ....

   Hence, all harmonics are present as overtone.

Q.29 Describe with neat diagram, the Fraunhofer diffraction pattern due to single slit. Derive the condition for bright and dark fringes produced due to diffraction by single slit.

Ans:

Fraunhofer diffraction due to single slit:



1. Consider a narrow-slit AB of width 'a', kept perpendicular to the plane of the paper. The slit can be imagined to be divided into extremely thin slits or slit elements. It is illuminated by a parallel beam of monochromatic light of wavelength λ i.e., a plane wavefront is incident on AB.
2. The diffracted light is focused by a converging lens L, on a screen XY.
3. The screen is kept in the focal plane of the lens and is perpendicular to the plane of the paper.
4. Let D be the distance between the slit and the screen.
5. According to Huygens' principle, each and every point of the slit acts as a source of secondary wavelets, spreading in all directions.

Position of central maxima:

1. Let C be the centre of the slit AB. The secondary wavelets travelling parallel to CP_0 come to a focus at P_0. The secondary wavelets from points equidistant from C in the upper and lower halves of the slit travel equal paths before reaching P_0.
2. The optical path difference between all these wavelets is zero and hence they interfere in the same phase forming a bright image at P_0.
3. The intensity of light is maximum at the point P_0. It is called the central or the principal maxima of the diffraction pattern.
4. For the line CP_0, angle $\theta=0^0$.

Position of secondary minima:

1. Consider a point P on the screen at which waves travelling in a direction making an angle θ with CP are brought to focus at P by the lens. This point P will be of maximum or minimum intensity because the waves reaching at P will cover unequal distance.
2. Draw AN perpendicular to the direction of diffracted rays from point A. BN is the path difference between secondary waves coming from A and B.
3. From $\Delta\, ABN$, $\sin\theta=\frac{BN}{AB}$

   $\therefore BN=AB\sin\theta=a\sin\theta$

   Since θ is very small

   $\therefore \sin\theta\approx\theta$

   $\therefore BN=a\theta$

   In figure, suppose $BN=\lambda$ and $\theta=\theta_1$then $\sin\theta_1=\frac{\lambda}{a}$
4. Such a point on the screen will be the position of first secondary minimum. It is because, if the slit is assumed to be divided into two equal halves AC and BC, then the waves from corresponding points of two halves of the slit will have a path difference of λ/2.
   It gives rise to destructive interference at P which has minimum intensity.
5. If point P on the screen is such that $BN=2\lambda$ and angle $\theta=\theta_2$, then $\sin\theta_2=\frac{2\lambda}{a}$. Such a point on the screen will be the position of the second secondary minimum.
   In general, for n^{th} minimum,

   $\sin\theta_n=\frac{n\lambda}{a}$

Where, $n = \pm 1, \pm 2, \pm 3, \ldots$

6. If y_{n_d} is the distance of n^{th} minimum from P_0, on the screen, then $(\tan\theta_{n_d}) = \frac{y_{n_d}}{D}$
7. If θ_{n_d} is very small,

   $\tan\theta_{n_d} \approx \sin\theta_{n_d} = \frac{n\lambda}{a}$

   $\therefore \frac{y_{n_d}}{D} = \frac{n\lambda}{a}$

   $\therefore y_{n_d} = \frac{n\lambda D}{a} = nW$ .... (1)

   Where, W is fringe width

   Equation (1) gives distance of n^{th} secondary minima from central maxima.

   Position of secondary maxima:

1. To obtain secondary maxima on the screen, path difference should be odd multiple of $\frac{\lambda}{2}$.

   $\therefore BN = (2n+1)\frac{\lambda}{2}$

   Where, $n = 1, 2, 3, \ldots..$

   $\sin\theta_{n_b} = (2n+1)\frac{\lambda}{2a}$ .... (2)
2. Since $\theta_{n_b} \approx \sin\theta_{n_b}$

   ¿ $\frac{(2n+1)\lambda}{2a}$ ... [From equation (2)]

   $\therefore \frac{y_{n_d}}{D} = \frac{(2n+1)\lambda}{2a}$

   $\therefore y_{n_d} = \frac{(2n+1)\lambda D}{2a} = \left(n + \frac{1}{2}\right)W$ .... (3)

   Equation (3) gives distance of n^{th} secondary maxima from the central maxima.

   Conclusion:

   The diffraction pattern of the single narrow slit consists of central bright maximum at P_0, followed by alternate secondary minima and maxima on both the sides of P_0.

   The intensity of secondary maxima is smaller than that of the central maximum and it goes on decreasing faster with increase of the distance from the central maximum. Finally, turning into uniform illumination on the screen.

Q.30 Derive the quantity for Bohr Magneton and also state its value. An electron in an atom is revolving round the nucleus in a circular orbit of radius $5.3 \times 10^{11} m$, with a speed of $2 \times 10^{6} ms^{-1}$. Find the resultant orbital magnetic moment and angular momentum of electron. (Charge on electron $e = 1.6 \times 10^{-19} C$, mass of electron $m = 9.1 \times 10^{31} kg$.)

Ans:

1. According to Bohr's theory, an electron in an atom can revolve only in certain stationary orbits in which angular momentum (L) of electron is an integral multiple (n) of $\frac{h}{2\pi}$, where h is Plank's constant.

   $\therefore L = m_e vr = \frac{nh}{2\pi}$ .... (1)
2. The orbital magnetic momentum of an electron is given as,

   $m_{orb} = \frac{eL}{2m_e}$ .... (2)

3. Substituting equation (1) and (2), we have,

$$m_{orb}=n\left(\frac{eh}{4\pi m_e}\right) \text{ .... (3)}$$

4. For the 1^{st} orbit, $n=1$,

$$\therefore m_{orb}=\frac{eh}{4\pi m_e}$$

5. The quantity $\frac{eh}{4\pi m_e}$ is called Bohr Magneton and its value is $9.274\times10^{-24}\,A\,m^2$.
6. The magnetic moment of an atom is stated in terms of Bohr magnetons (B.M.).

Given: $r = 5.3 \times 10^{-11}$ m,
$v = 2 \times 10^6$ ms^{-1},
$e = 1.6 \times 10^{-19}$ C,
$m_e = 9.1 \times 10^{-31}$ kg

To find: i. Orbital magnetic moment (m_{orb})
ii. Angular momentum of electron

Formulae: i. $m_{orb} = \frac{evr}{2}$ ii. $L = mvr$

Calculation: From formula (i),

$$m_{orb} = \frac{1.6\times10^{-19}\times2\times10^{6}\times5.3\times10^{-11}}{2}$$

$$= 1.6 \times 5.3 \times 10^{-24}$$

$$= \mathbf{8.48 \times 10^{-24}\ Am^2}$$

From formula (ii),

$$L = 9.1 \times 10^{-31} \times 2 \times 10^6 \times 5.3 \times 10^{-11}$$

$$= 96.46 \times 10^{-36}$$

$$\therefore L \approx \mathbf{9.65 \times 10^{-35}\ Nms}$$

Ans: i. Orbital magnetic moment is **8.48×10^{-24} Am^2**.
ii. Angular momentum of electron is **9.65×10^{-35} Nms.**

Q.31 Write any two application of eddy current. The value of mutual inductance of two coils is 10 mH. If the current in one of the coil changes from 5A to 1A in 0.2 s, calculate the value of emf induced in the other coil. Also calculate the value of induced charge passing through the coil if its resistance is 5 ohm.

Ans:

Applications of eddy currents:

Eddy currents are used in

1. **Dead beat galvanometer:** Normally, coil of galvanometer oscillates even though current stops flowing through it. To avoid this coil of galvanometer is wound on a metal frame made up of copper or aluminium. When coil oscillates, eddy current is setup in the metal frame of coil which opposes the motion of the coil and coil stops oscillating.
2. **Induction furnace:** In induction furnace, high frequency current is passed. Due to this eddy currents are developed in metallic blocks, in furnace and large amount of heat is generated. Therefore, metal blocks melts.
3. **Electric breaks:** A metallic drum is fixed with the wheel of train. When the train is to be stopped, a magnetic field of high intensity is applied around the drum. Eddy currents are produced in the drum which opposes the motion of drum hence wheel.
4. **Speedometers:** In speedometer an aluminium cylinder with light pointer is present. A magnet inside the cylinder rotates with the speed of vehicle. Eddy current is developed in aluminium cylinder; therefore, it deflects to oppose the current. We get the value of speed on the scale.

Solution:

Given: $M = 10 \text{ mH} = 10 \times 10^{-3}$ H,

$I_i = 5$ A , $I_f = 1$ A,

$\Delta t = 0.2$ s, $R = 5\ \Omega$

To find:
i. Induced emf
ii. Induced charge

Formulae: i. $\Delta\phi = M\,\Delta I$ ii. $e = \left|\dfrac{\Delta\phi}{\Delta t}\right|$

iii. $\Delta Q = \dfrac{e}{R} \times \Delta t = \dfrac{\Delta\phi}{R}$

Calculation: From formula (i),

$\Delta\phi = 10 \times 10^{-3} \times [\ 1 - 5\ ]$

$= -4 \times 10^{-2}$ Wb

From formula (ii),

$e = \left|\dfrac{-4\times10^{-2}}{0.2}\right| = \mathbf{0.2\ V}$

From formula (iii),

$\Delta Q = \dfrac{4\times10^{-2}}{5}$

$= 8 \times 10^{-3} = \mathbf{8\ mC}$

Ans: i. Induced emf is **0.2 V**.

ii. Induced charge is **8mC**.