UNIT 1 Wave and Optics

A. Waves

Chapter 1: Wave Motion

Short Answer Questions

1. **2076 Set B Q.No. 3a Can longitudinal wave be polarized? Explain.** **[2]**

Polarization is the phenomenon of restriction of wave to vibrate in a single direction. The transverse wave vibrates in all direction and we can cut of other directions restricting vibration in a single direction. The longitudinal waves vibrate in a single direction (in the direction of propagation of wave) i.e. this wave is already polarized. Due to this reason, longitudinal waves can not be polarized.

2. **2076 Set C Q.No. 3a How are stationary waves formed?** **[2]**

Stationary (or standing) wave: when two progressive waves of the same wavelength and amplitude travelling with the same speed through a medium in opposite directions and superimpose upon each other, they give rise to a wave which is called stationary wave.

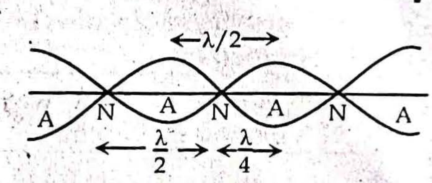

Fig: Stationary wave

In stationary wave, there are certain points where the amplitude of vibration is always zero. These points are known as nodes. Midway between these nodes, there are other points where amplitude of vibration is maximum. These points are known as antinodes. The formation of stationary wave along with nodes and antinodes is shown in figure.

3. **2075 GIE Q.No. 3a 2072 Set D Q.No. 3a Distinguish between progressive waves and stationary waves.** **[2]**

Differences between progressive wave and stationary wave are:

Progressive waves	Stationary waves
▪ The disturbance travels in forward direction.	▪ The disturbances are confined to a particular region.
▪ The amplitude of vibration of each particle is same.	▪ The amplitude is zero at nodes and maximum at antinodes.
▪ Energy is transferred forward along the waves.	▪ There is no transfer of energy in the medium.
▪ No particles in the medium are permanently at rest but momentarily at rest at the extreme positions.	▪ Particles at the nodes are permanently at rest.

4. **2075 Set A Q.No. 3a We can't hear echo in a small room. Why?** **[2]**

The minimum distance between the listener and the wall (reflecting surface) must be 17m to hear an echo. If a room is small, this requirement is not fulfilled. Due to persistence of hearing (0.1Sec), our ears cannot detect the repeated sounds i.e. we cannot hear echo.

5. **2075 Set B Q.No. 3a Frequency is the most fundamental property of a wave. Why?** **[2]**

The frequency is the most fundamental property of a wave as it is determined from the wave source. In a wave motion, its velocity and wavelength may change with the medium in which it passes but frequency does not change. Due to this reason, frequency of a wave is taken as empirical parameter.

6. **2073 Supp Q.No. 3a 2058 Q.No. 1 c If you are walking on the moon surface, can you hear the cracking sound behind you? Explain.** **[2]**

Sound wave is a mechanical wave so it requires a medium for propagation but there is no atmosphere i.e. medium on the moon surface. There is lack of atmosphere on the moon because of its weak gravity. So, due of lack of medium (i.e. atmosphere), the propagation of sound waves on moon surface is not possible. That is why we cannot hear the cracking sound behind us on the surface of moon.

7. **2069 Q.No. 3b A radio station broadcasts at 800 KHz. If the radio waves (em-waves) travel with a speed of 3×10^8 m/s, what will be the wavelength of the wave?** [2]

Frequency (f) = 800 KHz = 800×10^3 Hz
Wavelength (λ) = ?
Speed (c) = 3×10^8 m/s
We have,

$$\lambda = \frac{c}{f} = \frac{3\times10^8 \text{ m/s}}{800\times10^3} = 375\text{m}$$

8. **2069 (Set A) Old Q.No. 1d Why echo cannot be heard in a small room?** [2]

Please refer to 2075 Set A Q.No. 3a

9. **2068 Can. Q.No. 3a Distinguish between light waves and sound waves.** [2]

The main differences between sound waves and light waves are:

Light waves	Sound waves
1. Light waves are electromagnetic waves because these can travel in medium as well as in vacuum.	1. Sound waves are mechanical waves because they travel only in medium.
2. The speed of light wave is greater i.e. 3×10^8m/sec in vacuum or air.	2. The speed of sound wave is smaller i.e. 330m/sec at 0°C in air.
3. They are transverse wave.	3. They are longitudinal wave.
4. Their wavelength is short.	4. Their wavelength is long.
5. Light wave can be polarized.	5. Sound wave can not be polarized.

10. **2067 Sup Q.No. 3b Longitudinal waves cannot be polarized. Why?** [2]

Please refer to 2076 Set B Q.No. 3a

11. **2063 Q.No. 1 c Which types of wave propagate in liquid, explain.** [2]

For the propagation of transverse wave, the modulus of rigidity of the medium is responsible and for the propagation of longitudinal wave, the bulk modulus of elasticity is responsible. A solid has both modulus of rigidity and bulk modulus but liquids have only bulk modulus. Hence only longitudinal wave can propagate inside the liquid.

12. **2062 Q.No. 2 c Do sound waves undergo reflection, refraction and polarization phenomena? Explain.** [2]

Yes, sound waves undergo reflection and refraction phenomenon. Sound waves are reflected from surfaces like walls, ground, big halls etc while striking on them. During night hearing of sound is clearer than at day time due to the refraction of sound.

But sound wave does not undergo polarization phenomenon because it is a longitudinal wave, and only transverse wave undergoes the phenomenon of polarization.

13. **2055 Q.No. 1 b How are stationary waves formed?** [2]

Please refer to 2076 Set C Q.No. 3a

Long Answer Questions

14. **2074 Set B Q.No. 7a 2070 Set D Q.No. 7a How is a progressive wave different from a stationary wave? Derive an equation for a progressive wave.** [4]

Progressive wave: A wave that travels from one region of medium to another region carrying energy in the form of crest and trough or compression and rarefaction is called the progressive wave. Both transverse and longitudinal waves are progressive waves. E.g., water wave, sound wave, light wave etc. are progressive waves. The motion of progressive wave is given below.

Differences between progressive wave and stationary: Please refer to 2075 GIE Q.No. 3a

Equation of progressive wave: Let us consider a wave is travelling from left to right as shown in figure, the displacement of the vibrating particle in the medium is given by,

$y = a \sin \omega t$ ... (i)

where a is amplitude, t is time and $\omega = 2\pi f$ and f is frequency of vibration. If ϕ be the phase angle of the particle P at distance x from O, then the displacement equation given by

$y = a \sin(\omega t - \phi)$ ... (ii)

Since, for a path diff. λ, phase diff. is 2π.

And for a path diff. x, phase diff. is $\frac{2\pi}{\lambda}x$.

i.e., $\phi = \frac{2\pi}{\lambda}x$

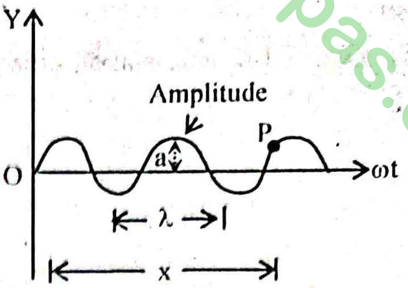

Fig: Progressive Wave

$$y = a \sin\left(\omega t - \frac{2\pi}{\lambda}x\right)$$

$$y = a \sin 2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right) = a \sin\left(\frac{2\pi}{T}t - \frac{2\pi}{\lambda}x\right)$$

$$y = a \sin(\omega t - kx) \quad \text{... (i)} \quad \left[\because k = \frac{2\pi}{\lambda}\text{, a wave number or wave vector}\right]$$

If the wave is travelling from right to left, then the displacement of the particle is given by,

$$y = a \sin 2\pi\left(\frac{t}{T} + \frac{x}{\lambda}\right) \quad \text{... (ii)}$$

These equations (i) and (ii) are the plane progressive wave equations.

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15. **2072 Set C Q.No. 7a** **What is a wave motion? Derive progressive wave equation in a medium.** **[4]**

Please refer to 2074 Set B Q.No. 7a

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16. **2072 Set E Q.No. 7a** **2066 Supp Q.No. 5a** **Define progressive waves. Derive an equation to represent this wave.** **[4]**

Please refer to 2074 Set B Q.No. 7a

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17. **2070 Sup (Set A) Q.No. 7 b** **2068 Q.No. 7 b** **What is the principle of superposition of waves? Discuss the result of superposing two waves of equal amplitude and same frequency travelling in opposite direction.** **[4]**

Principle of Superposition of Waves: It states that if two or more progress waves traveling together in a medium, converges to a point, the resulting displacement of the particle at that point is equal to the algebraic (vector) sum of individual displacements of the waves. Let $y_1, y_2, y_3, \ldots, y_n$ be the displacement at a point due to individual waves then the resultant displacement, y at the same time when the waves superpose to each other is given by

$y = y_1 + y_2 + y_3 + \ldots + y_n$

Stationary (or standing) wave: Whenever two progressive waves of the same (or nearly same) wavelength and amplitude travel in opposite directions with the same speed in a medium superpose with each other; a resultant wave is formed, such a wave is called stationary (Standing) wave.

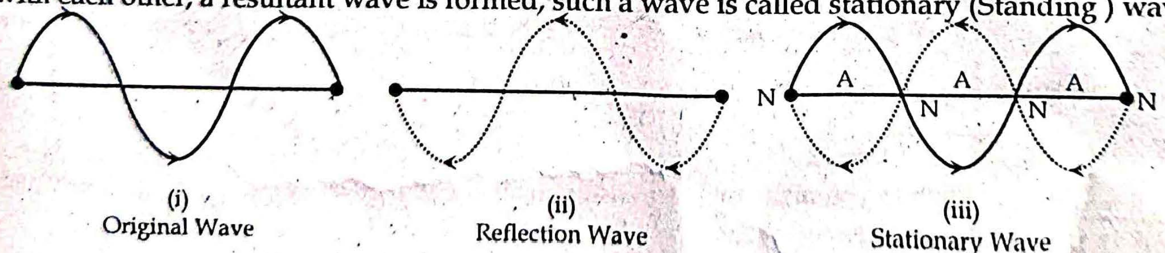

Fig: Formation of Stationary Wave

Let us consider a progressive wave of wavelength λ is travelling to right as in fig(i) strikes to a pole or reflec00tor and a reflecting wave is formed which propagate in opposite direction as in fig(ii). When these two waves combine with each other in a medium, another resultant wave is formed which is called stationary wave as fig(iii).

This wave is called stationary wave because there is no flow of energy along the wave. When a stationary wave is formed due to the superposition of two waves, the points of maximum and zero amplitude are resulted alternatively in the space. The points where the amplitude of vibration is maximum are called anti-nodes and those where the amplitude is zero are called nodes. The distance between two consecutive nodes or antinodes is equal to half of the wavelength i.e. $\frac{1}{2}\lambda$, where λ is wavelength of a wave. Also, the distance between adjacent node and antinode is equal to one quarter of wavelength i.e. $\frac{1}{4}\lambda$.

Stationary wave equation: Stationary wave equation can be obtained by opposite adding vectorically the displacements of two waves of equal amplitude, frequency (or period) and wavelength travelling in opposite directions.

Let y_1 be the displacement of the wave travelling to the positive x-direction,

$$y_1 = a \sin(\omega t - kx) \qquad \dots (i)$$

And, y_2 be the displacement of the wave travelling to the negative x-direction.

$$y_2 = a \sin(\omega t + kx) \qquad \dots (ii)$$

By using the principle of superposition of waves, the resultant displacement y is given by

$$y = y_1 + y_2$$
$$= a \sin(\omega t - kx) + a \sin(\omega t + kx)$$
$$= a [\sin(\omega t - kx) + \sin(\omega t + kx)]$$
$$= a [\sin \omega t \cos kx - \cos \omega t \sin kx + \sin \omega t \cos kx + \cos \omega t \sin kx]$$
$$= 2a \sin \omega t \cos kx \quad = 2a \sin \frac{2\pi}{T} t \cos \frac{2\pi}{\lambda} x$$

$$y = A \sin \frac{2\pi}{T} t \qquad \dots (iii)$$

where, $A = 2a \cos \frac{2\pi x}{\lambda}$ be the amplitude of resultant wave.

Equation (iii) is the equation of stationary wave equation.

Case I: For $x = 0, \frac{\lambda}{2}, \frac{2\lambda}{2}, \frac{3\lambda}{2} \dots$

then, $A = 2a$ is maximum amplitude.
Thus, these points are antinodes.

Case II: For $x = \frac{\lambda}{4}, \frac{3\lambda}{4}, \frac{5\lambda}{4} \dots$

then, $A = 0$ is minimum or zero amplitude.
Thus, these points are nodes.

$\therefore$ Distance between two consecutive nodes or antinodes is $\frac{\lambda}{2}$ and distance between any two consecutive nodes and antinodes is $\frac{\lambda}{4}$.

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18. 2070 Set C Q.No. 7 a **What are stationary waves? Prove that the distance between any two consecutive nodes in a stationary wave is $\frac{\lambda}{2}$.** [4]

Please refer to 2070 Sup (Set A) Q.No. 7 b

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19. 2068 Old Can. Q.No. 5a **What do you mean by progressive wave equation? Derive progressive wave equation in terms of its wave vector and displacement.** [1+3]

Please refer to 2074 Set B Q.No. 7a

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20. 2063 Q.No. 6 a **State and explain the stationary wave.** [4]

Please refer to 2070 Sup (Set A) Q.No. 7 b

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21. 2061 Q.No. 5 a **Use the principle of superposition of two waves to find the position of nodes and antinodes in a standing wave.** [4]

Please refer to 2070 Sup (Set A) Q.No. 7 b

Numerical Problems

22. **2053 Q.No. 3 OR** **A wave has the equation (x in metres and t in seconds) $y = 0.02 \sin(30t - 4x)$. Find**

i. Its frequency, speed and wave length.

ii. The equation of wave with double the amplitude but travelling in the opposite direction. **[4]**

Solution

Given,

The given equation is

$y = 0.02 \sin(30t - 4x)$

Comparing this equation with the standard wave equation,

$y = a \sin(\omega t - kx)$, where $k = \frac{2\pi}{\lambda}$, we have

$\omega = 30$

or, $2\pi f = 30$

or, $f = \frac{30}{2\pi} = \frac{15}{\pi}$

$\therefore$ Frequency, $f = \frac{15}{\pi} = 4.77$ Hz

$k = 4$

or, $\frac{2\pi}{\lambda} = 4$

or, $\lambda = \frac{2\pi}{4} = \frac{\pi}{2}$

$\therefore$ Wavelength, $\lambda = \frac{\pi}{2} = 1.571$m

and Speed, v = ?

We know that,

Speed, $v = \lambda f = \frac{\pi}{2} \times \frac{15}{\pi} = 7.5\ ms^{-1}$

Hence, frequency, f = 4.77 Hz

Speed, $v = 7.5\ ms^{-1}$

and wavelength, $\lambda = 1.571$ m

The equation of the wave moving in opposite direction and double the amplitude is $y = 0.04 \sin(30t + 4x)$.

❑❑❑

Misconception Alert ! *It is very difficult to identify the difference between the motion of disturbance and the motion of the water particle. The disturbance moves towards right with constant speed v, given by Eq. (1.4), while the motion of the particles is simple harmonic about mean position (Calm pond level) and their velocity changes with time as given by Eq. (1.2).*

5. The energy transfer in the medium takes place with a constant speed ($v = \lambda f$) which depends on the nature of the medium.
6. When a wave travels in a medium, the particle which meets it first begins to vibrate a little earlier than the particle immediately after it i.e. there is a continuous phase difference among the successive particles of the medium.
7. If the disturbance at the source is repetitive nature, the wave is maintained. If it is not, the amplitude of vibration of each particle becomes progressively smaller and eventually the wave ceases to exist.
8. If the disturbance at the source is simple harmonic, a plot of the displacement of the particle at a single instant of time as a distance from the source is sinusoidal.

NOTE

1. Waves transport both *energy and linear momentum* without transfer of mass but do not transfer *angular momentum.*
2. Waves may be one-dimensional (waves in guitar string), two dimensional (waves in surface of water) or three dimensional (sound waves in air).

Sample Problem - 1.1 **The FM station of Radio Nepal broadcasts at 100 MHz. What will be the wavelength of the wave?**

Sol^n: From Eq. (1.4),
Wave velocity $(v) = \lambda \times f$,
Where, $v = c = 3\times 10^8$ m/s
(speed of radio waves is equal to that of speed of light in free space)
$f = 100$ MHz $= 100 \times 10^6$ Hz
$\lambda = v/f = 3\times 10^8/100 \times 10^6 = 3$ m

Sample Problem - 1.2 **Diagnostic ultrasound of frequency 4.50 MHz is used to examine tumors in soft tissue. (a) What is the wavelength of such a sound wave in air where speed of sound is 343 m/s? (b) If the speed of sound in tissue is 1500 m/s, what is the wavelength of this wave in tissue?**

Sol^n: (a) From Eq. (1.4) $\lambda = \dfrac{v}{f} = \dfrac{343}{4.5 \times 10^6}$
or, $\lambda = 76.2 \times 10^{-6}$ m $=$ **76.2 μm**

(b) From Eq. (1.4) $\lambda = \dfrac{v}{f} = \dfrac{1500}{4.5 \times 10^6}$
$= 0.3 \times 10^{-3}$ m $=$ **0.3 mm**

Sample Problem - 1.3 **A small piece of cork in a ripple tank oscillates up and down as ripples pass through it. If the ripples travel at 0.2 ms^{-1} have a wavelength of 15 mm and amplitude of 5 mm. What is the maximum velocity of the cork?**

Sol^n: Here velocity of ripples
= wave velocity
$\therefore (v) = 0.2$ m/s
Wave length of the wave $(\lambda) = 15$ mm
$= 15 \times 10^{-3}$ m
Amplitude of oscillation of cork (A) = 5 mm
$= 5 \times 10^{-3}$ m
Since the cork executes SHM, from Eq. (1.2) ,
Velocity of the cork $(u) = A\omega \cos\omega t$ and when $\cos\omega t = 1$, u becomes maximum.

$\therefore u_{max} = A\omega = A \times 2\pi \times f = A \times 2\pi \times \dfrac{v}{\lambda}$

$u_{max} = 5 \times 10\text{-}3 \times 2\pi \times \dfrac{0.2}{15\times 10\text{-}3} =$ **0.42 m/s**

$$\therefore\ y = a \sin 2\pi \left(\frac{t}{T} - \frac{x}{\lambda}\right) \tag{1.9}$$

Equations (1.7), (1.8) and (1.9) represent a plane progressive wave. The negative sign in the bracket indicates that since the wave travels from left to right i.e. along positive x-axis. Similarly, a progressive wave travelling ih opposite direction i.e. from right to left i.e. along negative x-axis is represented by the equation,

$$y = a \sin (\omega t - kx) = a \sin \frac{2\pi}{\lambda} (vt - x) = a \sin 2\pi \left(\frac{t}{T} + \frac{x}{\lambda}\right) \tag{1.10}$$

NOTE

1. A progressive wave may be transverse or longitudinal in nature.
2. In a progressive wave, all particles of the medium have the same amplitude but different phases at a given time.
3. In differential form, above wave equation can be written as, $\frac{d^2y}{dt^2} = v^2 \frac{d^2y}{dx^2}$ (1.11)

Sample Problem - 1.5 **A wave travelling along a string is describe by y(x,t) = 0.005 sin (80.0 x - 3.0 t), in which the numerical constants are in SI units (0.005 m, 80.0 rad m^{-1}, and 3.0 rad s^{-1}_. Calculate (a) the amplitude, (b) the wavelength, and (c) the period and frequency of the wave. Also calculate the displacement y of the wave at a distance x = 30. 0 cm and time t = 20 s.**

Solution: Given y (x,t) = 0.005 sin (80.0x - 3.0t)

This displacement equation for a harmonic wave is $y(x,t) = A \sin\left(\frac{2\pi}{\lambda}x - \frac{2\pi}{T}t\right)$

On comparing the above two equations, we get

, $A = 0.005$ m, $\frac{2\pi}{\lambda} = 80.0$ rad m^{-1}, $\frac{2\pi}{T} = 3.0$ rad s^{-1}.

(a) Amplitude, A = **0.005m.**

(b) Wavelength, $\lambda = \frac{2\pi}{80.0}$ rad m^{-1}

$= 7.85 \times 10^{-2}$m = 7.85 cm.

(c) Time period, $T = \frac{2\pi \text{ rad}}{3.0 \text{ rad s}^{-1}}$ = **2.09s**

and Frequency, $f = \frac{1}{T} = \frac{1}{2.09\text{s}}$ = **0.48Hz.**

Displacement of the wave at distance x = 30.0 cm and time t = 20s,

y = (0.005m) sin (80.0 × 0.3 - 3.0 × 20)

= (0.005m) sin (-36 rad)

= **zero.**

Sample Problem-1.6 **Write the equation of a progressive wave propagating along the positive x - direction, whose amplitude is 5 cm, frequency 250 Hz and velocity 500 ms^{-1}.**

Solution: Here A =5 cm = 0.05m, f = 250 Hz, v = 500 ms^{-1}

Wavelength, $\lambda = \frac{v}{f} = \frac{500}{250}$ = 2m,

Period, $T = \frac{1}{f} = \frac{1}{250}$ s

The equation for the given wave can be written as

$y = A \sin 2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right) = 0.05 \sin 2\pi \left(250t - \frac{x}{2}\right)$

y= 0.05 sin π (500t -x) metre.

Sample Problem-1.7 **A progressive wave of frequency 5000 Hz is travelling with a velocity of 360 ms^{-1}. How far apart are the two points 60^0 out of phase?**

Sol^n: Here, velocity of wave, v = 360 ms^{-1}

Frequency of the wave, ν = 500 Hz

Therefore, wavelength of the progressive wave, $\lambda = \frac{v}{\nu} =$ = 0.72 m

The changes in phase (Δφ) and in position (Δx) are related to each other as,

$\Delta\varphi = \frac{2\pi}{\lambda}\Delta x$,where $\Delta\varphi = 60^0 = \frac{\pi}{3}$

$\therefore\ \Delta x = \frac{\lambda}{2\pi}\Delta\varphi = \frac{0.72}{2\pi} \times \frac{\pi}{3}$ = **0.12 m.**

) ***Position of Antinodes:*** At antinodes, the amplitude of the resultant wave, i.e. $A = 2a\cos kx$ hould be maximum and this is possible only when $\cos kx = \pm 1$.

or, $\cos\frac{2\pi x}{\lambda} = \pm 1$

or, $\cos\frac{2\pi x}{\lambda} = \cos n\pi$; where $n = 0, 1, 2, \ldots$

or, $\frac{2\pi x}{\lambda} = n\pi$

or, $x = \frac{n\lambda}{2}$; where $n = 0, 1, 2, \ldots$

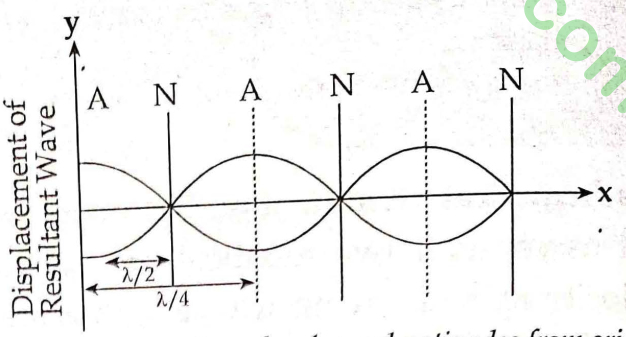


Fig- 1.14: Postion of nodes and antinodes from origin

Hence at the distances $x = 0, \frac{\lambda}{2}, \lambda, 3\frac{\lambda}{2}, \ldots$ from the boundary, antinodes are formed.

Also distance between any two consecutive antinodes $= \frac{\lambda}{2} - 0 = \frac{\lambda}{2}$ (1.15)

This concludes that the distance between two consecutive nodes or the distance between two consecutive antinodes is equal to $\frac{\lambda}{2}$ and that distance between node and antinode is $\frac{\lambda}{4}$. The points other than node and antinode, the displacement decreases gradually from their maximum value at antinode to zero value at node.

Sample Problem – 1.8 **Stationary waves are set up by the superposition of two waves given by $y_1 = 0.05\sin(5\pi t - x)$ and $y_2 = 0.05\sin(5\pi t + x)$, where x and y are in meters and t in seconds. Find the displacement of a particle situated at a distance x = 1m.**

Sol^n: According to principle of superposition, the displacement is given by

$y = y_1 + y_2$

$= 0.05\sin(5\pi t - x) + 0.05\sin(5\pi t + x)$

$= 0.05 \times 2\sin\frac{5\pi - x + 5\pi t + x}{2}\cos\frac{5\pi t + x - 5\pi t + x}{2}$

$= 0.1\cos x\sin 5\pi t$

$\therefore$ Amplitude, $A = 0.1\cos x$

At x = 1 m,

$A = 0.1\cos 1 = 0.1\cos\frac{180^0}{\pi}$

$= 0.1\cos\frac{180^0}{3.14}$

$= 0.1\cos 57.3^0 = 0.1 \times 0.5402$

$= \mathbf{0.054\ m}$

Sample Problem – 1.9. **A standing wave set up in a medium is give by $y = 4\,\mathrm{Cos}(\pi x/3)\,\mathrm{Sin}\,40\pi t$, where x and y are in cm and t in second. (i) What are the amplitude and velocity of the two component waves which produce this standing wave? (ii) What is the distance between adjacent nodes? (ii) What is the velocity of the particle of the medium at x = 3 cm and t = 1/8 s?**

Sol^n: (i) We know that the displacement equation of the stationary wave is, $y = 2a\cos kx\sin\omega t$. Comparing this eq^n with $y = 4\,\mathrm{Cos}(\pi x/3)\,\mathrm{Sin}\,\pi t$, we get

$2a = 4$ and $a = 2$ cm, $\omega = 40\pi$ and $k = \pi/3$

$\therefore$ Vel. of the component waves, $v = \omega/k =$ **1.2 m/s**

(ii) Wavelength $(\lambda) = 2\pi/k = 2\pi/(\pi/3) =$ **6 cm**

Distance between adjacent nodes $= \lambda/2 =$ **3 cm**

(iii) Particle velocity $(v) = \frac{dy}{dt}$

$v = \frac{d}{dt}[4\,\mathrm{Cos}\frac{\pi x}{3}\,\mathrm{Sin}(40\pi t)]$

or, $v = 4\,\mathrm{Cos}\frac{\pi x}{3}\,\mathrm{Cos}(40\pi t)$

for x = 3 cm and t = 1/8 cm,

$v = 4\,\mathrm{Cos}\frac{\pi 3}{3}\,\mathrm{Cos}(40\pi \times \frac{1}{8})$ **=1.6π m/s**

12. **Write down the difference between progressive wave and stationary wave.**

✍ Progressive waves and stationary waves have the following differences.

Progressive Waves	Stationary Waves
1. The disturbance travels forward with a definite velocity.	The disturbance remains confined to the region where it is produced.
2. Each particle of the medium executes SHM about its mean position with the same amplitude.	Except nodes, all particles of the medium execute SHM with varying amplitude.
3. There is a continuous change of phase from one particle to the next.	All the particles between two successive nodes vibrate in the same phase, but the phase reverse for particles between next pair of nodes.
4. No particle of the medium is permanently a rest.	The particles of the medium at nodes are permanently at rest.
5. There is no instant when all the particles are at the mean positions together.	Twice during each cycle, all particles pass through their mean positions simultaneously.
6. There is flow of energy across every plane along the direction of propagation of the wave.	Energy of one region remains confined that region.
8. All the particles have same maximum velocity which they attain while passing their mean position one after the other.	All the particles attain their individual maximum velocities at the same time as they pass through their mean positions. This velocity varies from zero at nodes to maximum at antinodes.

II. Sample Numerical Problems

Sample Problem 1.10 **If the velocity of sound in air is 340m/sec, calculate (i) the wavelength of the wave of frequency 256Hz (ii) the frequency when the wavelength is 0.85m.**

Sol^n: (i) $V = 340 m/sec$, $f = 256 Hz$, $\lambda = ?$

We know, $v = \lambda f$

or, $\lambda = v/f$

or, $\lambda = 340/256$

or, $\lambda = 1.33 m$

(ii) $V = 340 m/sec$, $\lambda = 0.85 m$

We know, $f = v/\lambda$

or, $f = 340/0.85$

or, $f = 400 Hz$

Sample Problem 1.11 **A plane progressive wave is represented by the equation ,**

$$y = 0.1 \sin\left(200\pi t - \frac{20\pi x}{17}\right),$$

Where y is the displacement in millimeters, t is in seconds and x is the distance from a fixed origin O in meters. Find (i) the frequency of the wave(ii) its wavelength (iii) its

speed (iv) the phase difference between a point 0.25 m from O and a point 1.10m from O (v) the equation of a wave with double the amplitude and double the frequency but travelling exactly in opposite direction.

Solⁿ: The given equation is

$$y = 0.1\sin\left(200\pi t - \frac{20\pi x}{17}\right)$$

Comparing this equation with the equation of a progressive wave, y= a sin (2πft - 2πx/λ), We get, (i) $2\pi f = 200\pi$

or, $f = 100$ **Hz**

(ii) $\frac{2\pi}{\lambda} = \frac{20\pi}{17}$

or, $\lambda = 1.7$ **m**

(iii) $v = \lambda f$

or, $v = 170$ **m/s**

(iv) path difference between two waves

$x = 1.1 - 0.25 = \mathbf{0.85\ m}$

Now the phase difference = $\frac{20\pi x}{17} = \pi$ **rad**

(v) The amplitude of the new wave = 2a = 0.2mm

The frequency of the new wave = 2f = 200Hz

So the wavelength of the new wave = $\frac{v}{200}$

$$= \frac{170}{200} = \frac{17}{20}\text{ m}$$

Therefore, the equation of the new wave is given by

$$\mathbf{y = 0.2 \sin\left(400\pi t + \frac{40\pi x}{17}\right)}$$

Sample Problem 1.12 **A man stationed between two parallel cliffs fires a gun. He hears the first echo after 3 secs and next after 5 secs. What is the distance between two cliffs. (velocity of sound in air = 350m/sec)**

Solⁿ: Let d_1 and d_2 are the distance of the man from the first and second cliff respectively, then ,$2d_1 = vt_1 = 350 \times 3$

or, $d_1 = 525$ m

And $2d_2 = vt_2 = 350 \times 5$

or, $d_2 = 875$ m

∴ The distance between two cliffs $= d_1 + d_2 =$ **1400 m**

Sample Problem 1.13 **A progressive and a stationary, simple harmonic wave each have the frequency of 250Hz and the same velocity of 30m/sec. Calculate (i) the phase difference between two vibrating points on the progressive wave which are 10 cm apart, (ii) the equation of motion of the progressive wave if its amplitude is 0.03m (iii) the distance between nodes in the stationary wave.**

Solⁿ: Here, frequency (f) = 250 Hz

Velocity of the wave (v) = 30 m/sec

Wavelength of the wave (λ) = $\frac{v}{f} = \frac{30}{250}$

$= \mathbf{0.12\ m}$

(i) Path difference between two points (x) = 10cm = 0.1 m

Therefore the phase difference = $2\pi x/\lambda$

$= 2\pi \times 0.1/0.12$

$= \mathbf{5\pi/3}$ **radians**

(ii) amplitude (a) = 0.03 m

So the equation of the progressive wave is given by

$$y = a\sin\left(2\pi ft - \frac{2\pi x}{\lambda}\right)$$

or, $y = 0.03 \sin\left(2\pi \times 250t - \frac{2\pi x}{0.12}\right)$

or, $y = 0.03 \sin 2\pi\left(250t - \frac{x}{0.12}\right)$

or, $\mathbf{y = 0.03 \sin 2\pi\left(250t - \frac{25x}{3}\right)}$

(iii) The distance between two nodes $= \frac{\lambda}{2}$

$$= \frac{0.12}{2} = \mathbf{0.06\ m}$$

2.3 Speed of Sound in solid

Since solid has different shape and size, it possesses different modulus of elasticity and the relations for velocity of sound for the solid of different shapes are different. Also nature of the vibration of the particles of the medium affects the speed of wave propagation.

(a) Speed of longitudinal wave in solid

In solid bar or rod: In solid rod , the Young's modulus of elasticity is taken into account. Hence speed of sound in solid rod is given by,

$$v = \sqrt{\frac{Y}{\rho}} \qquad (2.3)$$

In solid of other shape : For the bulk solid(rather than thin rod), the bulk modulus (K) and the modulus of rigidity (η) play role for propagation of sound wave and hence speed of longitudinal wave is given by,

$$v = \sqrt{\frac{K + \frac{4}{3}\eta}{\rho}} \qquad (2.4)$$

(b) Speed of transverse wave in solid

The mechanical waves travelling in solids as transverse waves are called *shear-waves* and their speed is given as,

$$v = \sqrt{\frac{\eta}{\rho}} \text{ ,where } \eta = \text{modulus of rigidity} \qquad (2.5)$$

Also for the transverse mechanical waves propagating along a string, their speed is given by the relation,

$$v = \sqrt{\frac{T}{\mu}} \qquad (2.6)$$

(For derivation, see section 4.4)

Sample Problem 2.1 **For aluminum the bulk modulus and modulus of rigidity are 7.5×10^{10} Nm^{-2} and 2.1×10^{10} Nm^{-2} respectively. Find the velocity of longitudinal waves in the medium. Density of aluminum is 2.7×10^3 kg m^{-3}.**

Sol^n: Here, $\kappa = 7.5 \times 10^{10}$ Nm^{-2},
$\eta = 2.1 \times 10^{10}$ Nm^{-2}, $\rho = 2.7 \times 10^3$ kg m^{-3}

Velocity of longitudinal waves in aluminum is

$$v = \sqrt{\frac{\kappa + \frac{4}{3}\eta}{\rho}}$$

$$= \sqrt{\frac{7.5 \times 10^{10} + \frac{4}{3} \times 2.1 \times 10^{10}}{2.7 \times 10^3}}$$

$$= \mathbf{6.18 \times 10^3\ ms^{-1}}$$

Sample Problem 2.2 For a steel rod, the Young's modulus of elasticity is 2.9×10^{11} Nm^{-2} and density is 8×10^3 kg m^{-3} Find the velocity of the longitudinal waves in the steel rod.

Sol^n: Here $Y = 2.9 \times 10^{11}$ Nm^{-2},

$\rho = 8\times 10^3$ kg m^{-3}

Velocity of longitudinal waves in steel is

$$v = \sqrt{\frac{Y}{\rho}} = \sqrt{\frac{2.9\times10^{11}}{8\times10^3}}$$

$$= 6.02\times10^3 \text{ ms}^{-1}$$

Sample Problem 2.3 For aluminum the modulus of rigidity is 2.1×10^{10} Nm^{-2} and density is 2.7×10^3 kg m^{-3}. Find the speed of transverse waves in the medium.

Sol^n: Here, $\eta = 2.1\times10^{10}$ Nm^{-2}

$\rho = 2.7\times10^3$ kgm^{-3}

Speed of transverse waves in aluminum is given by

$$v = \sqrt{\frac{\eta}{\rho}} = \sqrt{\frac{2.1\times10^{10}}{2.7\times10^3}}$$

$$= 2.79\times10^3 \text{ m s}^{-1}.$$

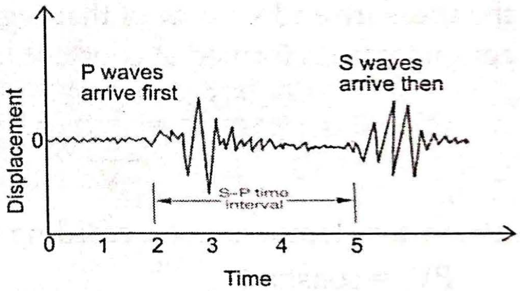
Sample Problem 2.4 Earthquake generates sound waves in earth. Unlike in a gas, there are both longitudinal (P) and transverse (S) sound waves in solid. Typically, the speed of S waves is about 4.5 km/s and that of P-waves 8.2 km/s. A seismograph records P & S waves from an earthquake. The first P waves arrive 3 minute before the first S waves. How far away did the earthquake occur?

Sol^n: Here, $v_p = 8.2$ km/s, $v_s = 4.5$ km/s and

$\Delta t = 3\times60 = 180$ s

We know that,

$$d = \frac{v_s \times v_p}{v_p - v_s}\times\Delta t = \frac{4.5\times8.2}{8.2-4.5}\times1800 = 1795 \text{ km}$$



2.4 Speed of Sound in Liquid

In case of liquids, the modulus of rigidity is negligible and the bulk modulus (K) becomes significant. Hence the speed of sound in liquid is given by the relation,

$$v = \sqrt{\frac{K}{\rho}} \qquad (2.7)$$

Sample Problem 2.5 At a pressure of 10^5 Nm^{-2}, the volume strain of water is 5×10^{-5}. Calculate the speed of sound in water. Density of water is 10^3 kg m^{-3}.

Sol^n: Bulk modulus of water is

$$k = \frac{\text{Normal stress (pressure)}}{\text{Volume strain}}$$

$$= \frac{10^5}{5\times10^{-5}}$$

$$= 2\times10^{-9} \text{ Nm}^{-2}$$

Density, $\rho = 10^3$ kg m^{-3}

Speed of sound in water is

$$v = \sqrt{\frac{k}{\rho}}$$

$$= \sqrt{\frac{2\times10^9}{10^3}}$$

$$= 1.414\times10^3 \text{ ms}^{-1}.$$

high, the velocity of sound is high and if less, the velocity is also less.

At night, the ground is cooler than the air above (air high above the ground is hotter than those at near the ground). So sound waves travelling in slanted manner will travel faster whereas those travelling near the ground will travel slowly. This makes the sound waves become more near each other near the ground but farther apart high above the ground. In addition, the wave which travelled up will head back to earth after bending, caused due to the difference in velocities. So, an observer at a distance will get sound that has travelled along the ground and also that has ascended up into the air, making the sound to be heard distinctly. Moreover, the sound seems to come from the sky rather than the ground itself.

II. Sample Numerical Problems

Sample Problem 2.6 **When a detonator is exploded on a railway line, an observer standing on the rail 2 km away hears two sounds. What is the time interval between them? (Young's modulus of steel = 2×10^{11} N/m² density of steel = 8×10^3 kg/m³, γ for air = 1.4, atmospheric pressure = 10^5 N/m²)**

Solⁿ: Here, $Y = 2 \times 10^{11}\ N/m^2$

$\rho_a = 1.4\ kg/m^3$

$\rho_s = 8 \times 10^3\ kg/m^3$

$\gamma = 1.4$

$P = 10^5\ N/m^2$

$d = 2000\ m$

Velocity of sound in air $(v_a) = \sqrt{\dfrac{\gamma P}{\rho_a}}$

or, $\dfrac{d}{t_1} = \sqrt{\dfrac{\gamma P}{\rho_a}}$

Where t_1 is the time taken by sound to travel 2 km through air.

or, $\dfrac{2000}{t_1} = \sqrt{\dfrac{1.4 \times 10^5}{1.4}}$

$t_1 = 6.32$ sec.

Now, the velocity of sound through railway line

$$(v_s) = \sqrt{\frac{Y}{\rho_s}}$$

or, $\dfrac{d}{t_2} = \sqrt{\dfrac{Y}{\rho_s}}$

Where t_2 is the time taken by the sound to travel 2 km through railway line.

$\therefore \dfrac{2000}{t_2} = \sqrt{\dfrac{2 \times 10^{11}}{8000}}$

or, $t_2 = 0.4$ sec.

∴ time interval between two sounds $= t_1 - t_2$

$= 6.32 - 0.4 =$ **5.92 sec.**

Sample Problem 2.7 **A stone is dropped into a well and a splash is heard after 2.6 second. Calculate the depth of the well. (Velocity of sound = 334m/sec)**

Solⁿ: Let t be the time taken by the stone in falling through the depth of the well. Then the depth of the well is given by

$$d = \frac{gt^2}{2}$$

$$d = \frac{9.8 \times t^2}{2} \quad \text{.................. (1)}$$

and time taken by sound to travel the distance $d = \dfrac{d}{334}$

But this time period is equal to 2.6-t.

so, $\dfrac{d}{334} = 2.6 - t$

or, $d = 334(2.6-t)$ .... (2)

From equations 1 and 2, we get

$4.9t^2 + 334t - 868.4 = 0$

On solving quadratic equation, we get

$t = 2.0504$ secs

and when we use this value of t in equation 2, we get,

$d =$ **30.73 m**

Sample Problem 2.8 **Compute the speed of sound in helium at S.T.P. [γ = 1.66, M = 4 g, R = 8.31 J mol^{-1}]**

Sol^n: Here, Ratio of SP. heats (γ) = 1.66

Mass of helium (M) = 4 g

Molar gas constant (R)= 8.31J/mole/K

Temperature (T) = 273K

Now, $v = \sqrt{\frac{\gamma RT}{M}} = \sqrt{\frac{1.66 \times 8.31 \times 273}{4 \times 10^{-3}}}$

= 970.3 m/sec.

$\therefore$ The speed of sound in helium at S.T.P. is 970.3 m/sec.

Sample Problem 2.9 **Find the wavelengths of a wave in air of sound of frequency 256 Hz at 0°C and 71°C, if the velocity of sound through air at 16°C is 340 ms^{-1}.**

Sol^n: Here,

Velocity of sound at 16°C (v_1)= 340 ms^{-1}

Temperature (T_1) = 16 + 273 K = 289 K

Temperature (T_2) = 0° C = 273 K

Temperature (T_3) = 71° C = 344 K

Frequency (f) = 256 Hz.

Wavelength (λ_2) = ?

Wavelength (λ_3) = ?

We have,

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

or, $340 = \sqrt{\frac{289}{273}} \times v_2$

or, $\frac{340}{1.029} = v_2$

$\therefore$ $v_2 = 330.42$ ms^{-1}

It is given that $v = \lambda f$

or, $330.42 = \lambda_2 \times 256$

$\therefore$ $\lambda_2 = 1.29$ m

Again, $\frac{v_1}{v_3} = \sqrt{\frac{T_1}{T_3}}$

or, $\frac{340}{v_3} = \sqrt{\frac{289}{344}}$

$\therefore$ $v_3 = 370.9$ ms^{-1}

$\therefore$ $\lambda_3 = \frac{v_3}{f} = \frac{370}{256} = $ **1.44 m.**

Sample Problem 2.10 **A source of sound of frequency 512 Hz emits waves of wave length 670 mm in air at 20°C. What is the velocity of sound in air at this temperature? What would be the wavelength of sound from the source in air at 0°C?** **[HSEB 2068]**

Sol^n: Here

Frequency of wave (f) = 512 Hz

Wave length of wave (λ) = 670mm = 0.67 m

Temperature (T) = 20°C = 293 K

Velocity of wave at 20°C (v) = ?

Wavelength of wave at 0°C (λ_0) = ?

We know,

$v = \lambda f = 0.67 \times 512 = 343.04$ m/sec.

Again, $\frac{v_0}{v} = \sqrt{\frac{273}{293}}$

Where v_0 is the velocity of sound at 0°C.

or, $\frac{v_0}{343.04} = \sqrt{\frac{273}{293}}$

$\therefore$ $v_0 = 331.125$ m/sec.

or, $\lambda_0 f = 331.125$

or, $\lambda_0 \times 512 = 331.125$

$\therefore$ $\lambda_0 =$ **0.647 m.**

Sample Problem 2.11 Calculate speed in air saturated with water vapor at 27° C. It is given that atmospheric pressure is 750 mm of mercury, S.V.P. of water at 27° C is 25 mm and velocity of sound at S.T.P. is 331 m/s.

Solⁿ: Here,

Velocity of sound (V_d) = 331 m/sec

Temperature (T_m) = 27° C = 300 K

Pressure (P_m) = 750 mm of Hg

S.V.P. at 27° C = 25 mm of Hg

We know, $\frac{V_d}{V_m} = \sqrt{\frac{P - 0.378f}{P}}$

or, $\frac{331}{V_m} = \sqrt{\frac{750 - 0.378 \times 25}{750}}$

$V_m = 333.10\ m/sec$

Now, $\frac{V_m}{V_{27}} = \sqrt{\frac{T_m}{T_{27}}}$

or, $\frac{333.10}{V_{27}} = \sqrt{\frac{273}{300}}$

$V_{27} = 349.18\ m/sec$

Sample Problem 2.12 Calculate the temperature in °C at which sound in hydrogen travels with the same velocity as in the helium at 373 K. The density of hydrogen is half that of helium.

Solⁿ: Here, from question

Velocity of sound at T in H_2 = velocity of sound at 373 in He

or, $\frac{\text{Velocity of sound at T in } H_2}{\text{Velocity of sound at 373 in He}} = 1$

$\frac{\text{Vel. of sound at T in } H_2}{\text{Vel. of sound at 373 in } H_2} \times \frac{\text{Vel. of sound at 373 in } H_2}{\text{Vel. of sound at 373 in He}} = 1$

or, $\frac{(V_{H_2})_T}{(V_{H_2})_{373}} \times \frac{(V_{H_2})_{373}}{(V_{He})_{373}} = 1$

or, $\frac{(V_{H_2})_T}{(V_{H_2})_{373}} = \frac{(V_{He})_{373}}{(V_{H_2})_{373}}$

Again, $\frac{V_1}{V_2} = \sqrt{\frac{\rho_2}{\rho_1}} = \sqrt{2}$

or, $\frac{(V_{H_2})_{373}}{(V_{He})_{373}} = \sqrt{2}$

Now,

$\frac{(V_{H_2})_T}{(V_{H_2})_{373}} = \sqrt{\frac{T}{373}}$

or, $\frac{1}{\sqrt{2}} = \sqrt{\frac{T}{373}}$

or, $\frac{373}{2} = T$

∴ $T = 186.5\ K$ or $-86.5°\ C$

Sample Problem 2.13 Find the speed of sound in a mixture of 1 mole of helium and 2 mole of oxygen at 27°C. (b) If the temperature is raised by 1K to 300 K, find the percentage change in the speed of sound in the gaseous mixture. (R = 8.31 J/mol K).

Solⁿ: (a) In terms of temperature, the speed of sound is given by

$$V = \sqrt{\frac{\gamma RT}{M}} \quad ...(1)$$

Now here as 1 mole of helium is mixed with 2 mole of oxygen,

$$M_{mix} = \frac{n_1M_1 + n_2M_2}{n_1 + n_2} = \frac{1 \times 4 + 2 \times 32}{1 + 2}$$

$$= \frac{68}{3} \times 10^{-3}\ kg/mol \quad ...(2)$$

Further as helium is monatomic $\left[C_v = \left(\frac{3}{2}\right)R\right]$ while oxygen is diatomic $\left[C_v = \left(\frac{5}{2}\right)R\right]$, so for mixture, $(C_v)_{mix}$

$$= \frac{n_1 C_{V_1} + n_2 C_{V_2}}{n_1 + n_2}$$

$$= \frac{1 \times \left(\frac{3}{2}\right)R + 2 \times \left(\frac{5}{2}\right)R}{1+2} = \frac{13}{6}R$$

Also, $(C_p)_{mix} = (C_v)_{mix} + R$

[Since $C_p - C_v = R$]

$$(C_p)_{mix} = \frac{C_p}{C_v} = \frac{19}{6}R \times \frac{6}{13R} = \frac{19}{13} \quad \ldots(3)$$

Now, substituting the value of M and γ from Eqs. (2) and (3) in (1) with T = 300 K and R = 8.31 J/mol K, we get

$$V = \sqrt{\frac{19}{13} \times \frac{8.31 \times 300}{\left(\frac{68}{3} \times 10^{-3}\right)}} = \mathbf{400.9\ m/s}$$

(b) As $v = \sqrt{\left(\frac{\gamma RT}{M}\right)}$, for a given gas,

$$\frac{\Delta v}{v} = \frac{1}{2}\frac{\Delta T}{T} = \frac{1}{2} \times \frac{1}{300} \times 100$$

$$= \mathbf{0.167\%}$$

EXERCISES-2

Short Answer Questions

2.01- What was the necessity of Laplace correction in the velocity of sound in air or gas?

2.02- The velocity of sound is greater through moist air than through dry air. Why?

2.03- The sound of a distant coming train can be easily detected by placing our ear near the rails. Why?

Long Answer Questions

2.04- Discuss the effect of pressure, temperature and density of the elastic medium on the velocity of sound. [HSEB 2052]

2.05- Derive an expression for the velocity of sound in a medium by dimensional method. Discuss the effect of change in pressure and temperature on the velocity of sound in air.

2.06- State Newton's formula for the velocity of sound in gases. What correction was done by Laplace on it? [HSEB 2061]

2.07- Explain why and how Laplace corrected the Newton's formula for the velocity of sound in air.

Numerical Problems

2.08- The audible range of frequencies lies between 20 Hz and 20 kHz. Calculate the wavelength corresponding to these extreme frequencies at NTP. (velocity of sound at NTP=330 m/sec) **[Ans: 16.5 m, 16.5 mm]**

2.09- A sound note of frequency 200 Hz is produced in hydrogen. Find the wavelength assuming velocity of sound in air as 332 m/sec and density of air as 14.4times that of hydrogen. **[Ans: 6.29 m]**

2.10- Find the temperature at which the velocity of sound in air becomes 1.5 times its value at 0°C. **[Ans: 341.25°C]**

Chapter 2: Mechanical Waves

Short Answer Questions

1. 2074 Set B Q.No. 3a **Velocity of sound in solids is more than that in liquids, why?** [2]

Sound wave is a longitudinal wave. The velocity of a longitudinal wave (in general) in a medium is given by the relation $v = \sqrt{\frac{E}{\rho}}$, where E is the modulus of elasticity and ρ is the density of the medium. From this relation, it is clear that v not only depends on ρ but also on E. So, the velocity of propagation of any longitudinal wave in any medium depends on the ratio $\frac{E}{\rho}$. For a solid, the ratio $\frac{E}{\rho}$ is much greater due to its high elasticity than that for a gas or a liquid due to its low elasticity. Hence, the velocity of longitudinal wave (e.g. sound wave) in solids is greater than in liquids and gases as $v_s > v_l > v_g$.

2. 2073 Set C Q.No. 3b **The velocity of sound in solid is generally greater than that in gas at STP. Why? Give reason.** [2]

Please refer 2074 Set B Q.No. 3a

3. 2072 Set C Q.No. 3b **When sound waves travel through a medium, does the temperature at various points remain constant? Explain.** [2]

No, when the sound waves travel in a medium, the temperature at various points does not remain same. According to Laplace, during the propagation of sound wave, the formation of compression and rarefaction is so rapid that the heat exchange is zero and the temperature at different points is different and hence the process is adiabatic process.

4. 2071 Set D Q.No. 3 a 2066 Supp Q.No. 1c **Why does sound travel faster in metals than in air?** [2]

Sound wave is a longitudinal wave. The velocity of a longitudinal wave (in general) in a medium is given by the relation $v = \sqrt{\frac{E}{\rho}}$, where E is the modulus of elasticity and ρ is the density of the medium. The modulus of elasticity for metal is Young's modulus of elasticity (Y), then velocity of sound in metal is, $v = \sqrt{\frac{Y}{\rho}}$. The value of $\frac{Y}{\rho}$ for metal is to much higher than $\frac{B}{\rho}$ for air. So, the velocity of sound wave in metal is greater than in air and hence sound travels faster in metal than in air.

5. 2070 Supp. (Set B) Q.No. 3 a **The speed of sound in humid air is more than that in dry air, why?** [2]

In the wet air, the atmospheric air becomes moist than on a dry air. So, the humidity on wet or rainy air is more than the dry air. Greater humidity present in the atmospheric air decreases its density. We know that the velocity of sound in air is inversely proportional to the square root of its density i.e. $v \propto \frac{1}{\sqrt{\rho}}$. Therefore, decrease in density causes the velocity of sound to increase. Hence, sounds heard better on a wet day than on a dry day i.e. more in damp air than in dry air.

6. 2070 Set C Q.No. 3 a 2063 Q.No. 2 a **Although the density of solid is high, the velocity of sound is greater in solid, explain.** [2]

Please refer to 2074 Set B Q.No. 3a

7. 2069 Supp Set B Q.No. 3 b **Is it possible that the velocity of sound is greater in solid than that in a gas at STP? Justify your answer.** [2]

Please refer to 2074 Set B Q.No. 3a

8. 2066 Q.No. 1c **Velocity of sound increases on a cloudy day. Why?** [2]

In a cloudy day, the air becomes moist and humidity increases in moist air which results to decrease the density of air. Since, velocity of sound is inversely proportional to square root of density of medium (i.e., $v \propto \frac{1}{\sqrt{\rho}}$), the velocity of sound increases on a cloudy day.

9. 2065 Q.No. 1 c 2060 Q.No. 2 c 2052 Q.No. 1 c **Sound at a distance can be heard distinctly at night than in the day time. Why?** **[2]**

At night, the atmospheric air becomes moist than at day time. So, density of air at night is less than at day time. But the velocity of sound is inversely proportional to the square root of density i.e., $v \propto \frac{1}{\sqrt{\rho}}$.

So, velocity of sound at night is more than at day time due to reduced density of air. Hence, sound made at a distance can be heard distinctly at night than in daytime.

10. 2064 Q.No. 2 d **Explain why the velocity of sound in solids is greater than that in gases, though the densities of solids are greater than that of gases.** **[2]**

Please refer to 2074 Set B Q.No. 3a

11. 2062 Q.No. 1 c **Do sound waves need a medium to travel from one point to other point in space? What properties of the medium are relevant?** **[2]**

Yes, sound waves are mechanical waves which need a medium to travel from one point to other point in space. In this case, the disturbance is handed over from one particle to another particle of the medium. Elastic property should be possessed by the medium. For the particle to gain kinetic energy, medium should possess inertia. The velocity of sound in the elastic medium is given by $v = \sqrt{\frac{E}{\rho}}$, where E is the elasticity of medium and ρ is its density. Thus, elasticity, pressure and inertia are the relevant properties of medium on which sound waves depend.

12. 2056 Q.No. 1 c **Why are sounds heard better on a wet day than on a dry day?** **[2]**

Please refer to 2070 Supp. (Set B) Q.No. 3 a

13. 2054 Q.No. 1 b **Is velocity of sound more in damp air or in dry air? Explain.** **[2]**

Please refer to 2070 Supp. (Set B) Q.No. 3 a

Long Answer Questions

14. 2076 Set B Q.No. 7a **Does the propagation of sound wave cause change in thermodynamic condition of medium? Derive Laplace formula of velocity of sound in air.** **[4]**

Newton's formula: The velocity of sound in any medium is given by

$v = \sqrt{\frac{E}{\rho}}$, where E is the elasticity of medium and ρ be its density.

For air medium, the modulus of elasticity is Bulk's modulus of elasticity (B). Velocity of sound in air is given by,

$$v = \sqrt{\frac{B}{\rho}}$$

Newton assumed that the formation of rarefaction and compression in the air is a slow process and the temperature is equal to the temperature of surrounding i.e. the process is the isothermal process. The gas equation is

$PV = \text{constant}$, where P is the pressure of air and V is the volume.

On differentiating, we get

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

$$P\,dV = -V\,dP$$

$$P = -\frac{dP}{\frac{dV}{V}} = \frac{\text{Volumetric stress}}{\text{Volumetric strain}} = B, \text{ Bulk modulus of elasticity of air.}$$

So, Newton's formula for velocity of sound in air is given by

$$v = \sqrt{\frac{B}{\rho}} = \sqrt{\frac{P}{\rho}},$$ where P is the pressure of air and ρ is its density.

For air, at NTP;

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

$\rho = 1.293\ kg/m^3$

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

But, the experimental value of the velocity of sound in air at NTP is about 332 m/sec. So, the theoretical value does not agree with the experimental value.

Therefore, there must be something wrong in Newton's formula. A satisfactory solution to the discrepancy in Newton's formula was given by Laplace, which is known as Laplace correction.

Laplace correction: While deriving the above formula, Newton assumed that the propagation of sound takes place in the isothermal condition. But according to Laplace, the propagation of sound should take place in rapid way so the process is adiabatic process and the temperature at rare fraction and compression is different.

Since the adiabatic equation of state is

PV^γ = constant ... (i)

where $\gamma = \frac{C_P}{C_V}$ is a constant. On differentiating equation (i), we get

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

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

$$\gamma P = -\frac{V^\gamma dP}{V^{\gamma-1}\, dV} = -\frac{dP}{V^{-1}\, dV} = -\frac{dP}{dV/V} = -B_{adi}$$

where B_{adi} is adiabatic bulk modulus of elasticity. Negative sign indicates that as the pressure increases, the volume decreases and vice versa. Hence,the velocity of sound in air is

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

$$\therefore\ v = \sqrt{\frac{\gamma P}{\rho}}$$

This equation is called Laplace equation for velocity of sound in air.

For air at NTP,

$\gamma = 1.4$

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

$\rho = 1.293\ \text{kgm}^{-3}$

$$\therefore\ v = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\frac{1.4 \times 1.013 \times 10^5}{1.293}} = 331.2\ \text{m/s}$$

This value closely agrees with experimental value 331.2 m/s.

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15. 2075 GIE Q.No. 7a | 2068 Can. Q.No. 7a | 2067 Sup Q.No. 7b **Discuss Newton's formula for the velocity of sound in a gas medium with Laplace's correction.** [4]

✍ Please refer to 2076 Set B Q.No. 7a

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16. 2074 Supp Q.No. 7a **Describe Laplace's correction in Newton's formula for velocity of sound in air. Also discuss the effect of temperature and pressure in the velocity of sound in air.** [4]

✍ **First Part:** Please refer to 2076 Set B Q.No. 7a

Second Part:

The velocity of sound in an elastic medium is given by

$v = \sqrt{\frac{E}{\rho}}$, where E is elasticity and ρ is its density.

For air medium, $E = B = \gamma P$, where γ is constant called the ratio of molar heat capacities of gas at constant pressure to that at constant volume and P is pressure.

$$\text{So, } v = \sqrt{\frac{\gamma P}{\rho}}$$

i. Effect of pressure: The velocity of sound in air is

$$v = \sqrt{\frac{\gamma P}{\rho}}$$

For one mole of gas, equation of state is

$PV = RT$

At a constant temperature,

PV = constant

Since, $V = \frac{M}{\rho}$

$\therefore P\frac{M}{\rho} = \text{const} \Rightarrow \frac{P}{\rho} = \frac{\text{const}}{M} = \text{constant}$

Hence, $v = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\gamma \times \text{constant}} = \text{constant}$

Thus, the velocity of sound in a gas is independent of the pressure of the gas provided temperature remains constant.

ii. **Effect of temperature:** For one mole of a gas, the equation of state is

PV = RT

If M and ρ be the molecular weight and density of the gas, then,

$V = \frac{M}{\rho}$

$\therefore \frac{PM}{\rho} = RT \Rightarrow \frac{P}{\rho} = \frac{RT}{M}$

Thus, $v = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\frac{\gamma RT}{M}}$

For given gas, γ, R and M are constants.

$\Rightarrow v \propto \sqrt{T}$

Hence, the velocity of sound in a gas is directly proportional to the square root of its absolute temperature.

iii. **Effect of density:** Consider two gases having same value of γ at the same pressure P but having densities ρ_1 and ρ_2 respectively. Then, the velocity of sound in them is

$v_1 = \sqrt{\frac{\gamma P}{\rho_1}}$

$v_2 = \sqrt{\frac{\gamma P}{\rho_2}}$

$\therefore \frac{v_1}{v_2} = \sqrt{\frac{\rho_2}{\rho_1}} \Rightarrow v \propto \frac{1}{\sqrt{\rho}}$

Hence, velocity of sound in a gas is inversely proportional to the square root of the density of the gas.

iv. **Effect of mass:** Let us consider M_1 and M_2 be molecular weight of the gases, then at constant temperature, the velocity of sound in them is

$v_1 = \sqrt{\frac{\gamma RT}{M_1}}$ [Here, we consider one mole of each gas such that PV = RT]

$v_2 = \sqrt{\frac{\gamma RT}{M_2}}$

Here, for a given gas at constant temperature, R, T and γ are constants.

$\therefore \frac{v_1}{v_2} = \sqrt{\frac{M_2}{M_1}} \Rightarrow v \propto \frac{1}{\sqrt{M}}$

Hence, velocity of sound in a gas is inversely proportional to the square root of the molecular mass of the gas.

17. **2074 Set A Q.No. 7a** **Describe Newton's formula for the velocity of sound in air. Explain why and how this formula is modified by Laplace.** **[4]**

Please refer to 2076 Set B Q.No. 7a

18. **2073 Set C Q.No. 7b** **What correction was made in Newton's expression for the velocity of sound? Also explain, how change of temperature and pressure affect the velocity of sound.** **[4]**

First Part: Please refer to 2076 Set B Q.No. 7a

Second Part: Please refer to 2074 Supp Q.No. 7a

19. **2072 Supp Q.No. 7a** **Write the Newton's formula for the velocity of sound in air. Explain why and how this formula is modified by Laplace.** **[4]**

Please refer to 2076 Set B Q.No. 7a

20. **2072 Set D Q.No. 7a** **2071 Supp Q.No. 7a** **Write down the Newton's formula for the velocity of sound in air. Explain why this formula has to be modified. Discuss Laplace's correction on it.** **[4]**

Please refer to 2076 Set B Q.No. 7a

21. **2071 Set C Q.No. 7 a** **Describe the Newton's formula for velocity of sound in air with Laplace's correction.** **[4]**

Please refer to 2076 Set B Q.No. 7a

22. **2070 Sup (Set A) Q.No. 7 a** **Deduce Newton's formula for velocity of sound in a gas. Why was the correction needed? What correction made by Laplace?** **[4]**

Please refer to 2076 Set B Q.No. 7a

23. **2069 Supp Set B Q.No. 7 a** **Describe Laplace's correction to find the velocity of sound and discuss how the velocity of sound is affected by different physical parameters.** **[4]**

First Part: Please refer to 2076 Set B Q.No. 7a

Second Part: Please refer to 2074 Supp Q.No. 7a

24. **2069 (Set A) Old Q.No. 5a** **What is the Newton's formula for the velocity of sound? What correction was made by Laplace?** **[1+3]**

Please refer to 2076 Set B Q.No. 7a

25. **2069 (Set B) Q.No. 7b** **Discuss the significance of Laplace's correction to Newton's formula for the velocity of sound. Also, explain how different factors affect the velocity of sound.** **[4]**

First Part: Please refer to 2076 Set B Q.No. 7a

Second Part: Please refer to 2074 Supp Q.No. 7a

26. **2068 Old Q.No. 5 a** **Write an expression for the speed of sound in an ideal gas. Discuss the effect of change in temperature on the speed of sound.** **[1+3]**

Please refer to 2074 Supp Q.No. 7a

27. **2067 Old Q.No. 5a** **Discuss the Laplace's correction for the velocity of sound in air.** **[4]**

Please refer to 2076 Set B Q.No. 7a

28. **2066 Q.No. 5 a** **Write down the factors on which the velocity of sound in air depends with necessary explanation.** **[4]**

Please refer to 2074 Supp Q.No. 7a

29. **2065 Q.No. 5 a OR** **Explain the significance of Laplace's correction of Newton's formula for the velocity of sound and derive the corrected formula.** **[1+3]**

Please refer to 2076 Set B Q.No. 7a

30. **2061 Q.No. 5 a OR** **State Newton's formula for the velocity of sound in gases. What correction was done by Laplace on it?** **[1+3]**

Please refer to 2076 Set B Q.No. 7a

31. **2060 Q.No. 5 a** **Derive an expression for the velocity of sound in a medium by dimensional method. Discuss the effect of change in pressure and temperature on the velocity of sound in air.** **[2+2]**

The velocity of sound wave in an elastic medium depends upon the elasticity and density of medium i.e., $v \propto E^x \rho^y$ where E is elasticity of medium and ρ is density of medium.

Now,

$$v = kE^x\rho^y \quad \ldots \text{(i)}$$

where k is a dimensionless proportionality constant.

Here,

Dimension of elasticity, $E = [ML^{-1}T^{-2}]$

Dimension of velocity, $v = [LT^{-1}]$

Dimension of density, $\rho = [ML^{-3}]$

From dimensional analysis, from equation (i), we get

$[LT^{-1}] = [ML^{-1}T^{-2}]^x \cdot [ML^{-3}]^y$

or, $[LT^{-1}] = [M^{x+y}\, L^{-x-3y}\, T^{-2x}]$ ...(ii)

Equating the powers of like terms, we get,

$0 = x + y$ ...(iii)

$1 = -x - 3y$ ...(iv)

$-1 = -2x$ ...(v)

Solving these equations, we get

$x = \frac{1}{2}, \quad y = -\frac{1}{2}$

$\therefore v = kE^{1/2}\rho^{-1/2} = k\sqrt{\frac{E}{\rho}}$

From mathematical analysis, k = 1, then velocity of sound in medium is $v = \sqrt{\frac{E}{\rho}}$

2nd part: Please refer to 2074 Supp. Q.No. 7a

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32. **2056 Q.No. 2 Discuss Laplace's correction and derive the formula for the velocity of sound in a gas.** **[4]**

Please refer to 2076 Set B Q.No. 7a

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33. **2055 Q.No. 2 Describe Newton's expression for the velocity of sound in a gas with Laplace correction.** **[4]**

Please refer to 2076 Set B Q.No. 7a

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34. **2053 Q.No. 2 What is Newton's formula for the velocity of sound? What correction was made by Laplace?** **[5]**

Please refer to 2076 Set B Q.No. 7a

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35. **2052 Q.No. 2 Discuss the effect of pressure, temperature and density of elastic medium on the velocity of sound.** **[5]**

Please refer to 2074 Supp Q.No. 7a

Numerical Problems

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36. **2076 Set C Q.No. 11 A source of sound of frequency 550 Hz emits waves of wavelength 60 cm in air at 20°C. What would be the wavelength of sound from the source in air at 0°C?** **[4]**

Solution

Given,

Frequency (f_{20}) = 550 Hz

Wave length (λ_{20}) = 60 cm = 0.6 m

Wave length at 0°C (λ_0) = ?

We have

Velocity $(v_{20}) = f_{20} \times \lambda_{20}$

$= 550 \times 0.6$

$= 330$ m/sec

Again,

$\frac{v_0}{v_{20}} = \sqrt{\frac{T_0}{T_{20}}}$

or, $v_0 = v_{20} \times \sqrt{\frac{T_0}{T_{20}}}$

$= 330 \times \sqrt{\frac{273}{293}}$

$= 318.54$ m/sec.

Now,

$\lambda_{20} = \frac{v_0}{f_0} = \frac{318.54}{550} = 0.58$ m

37. **2075 Set A Q.No. 11** **What is the difference between the speed of longitudinal waves in air at 27° and at − 13°C? What is the speed of 0°C?** **[4]**

Solution

Given,

Difference between velocity of sound at 27°C and − 13°C = ?

i.e., $v_{27} - v_{-13} = ?$

Velocity of sound at 0°C, $v_0 = ?$

Now, Vel. of sound in air is given by

$$v_0 = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\frac{1.4 \times 1.01 \times 10^5}{1.29}} = 331.1 \text{ m/sec}$$

Since, $v \propto \sqrt{T}$, then $\frac{v_{27}}{v_0} = \sqrt{\frac{T_{27}}{T_0}}$

$$\text{or, } v_{27} = \sqrt{\frac{T_{27}}{T_o}} \times v_o = \sqrt{\frac{273 + 27}{273}} \times 331.1 = 347.087 \text{ m/sec}$$

Also, $\frac{v_{-13}}{v_0} = \sqrt{\frac{T_{-13}}{T_0}}$

$$v_{-13} = \sqrt{\frac{T_{-13}}{T_o}} \times v_o = \sqrt{\frac{273 - 13}{273}} \times 331.1 = 323.12 \text{ m/sec}$$

Now,

$v_{27} - v_{-13} = 347.087 - 323.12 = 23.96$ m/sec

38. **2075 Set B Q.No. 11** **2058 Q.No. 5 b** **At what temperature, the velocity of sound in air is increased by 50% to that at 27°C?** **[4]**

Solution

Let, v be the velocity of sound at 27°C. Then, at T°C, the velocity of sound be

$$v_2 = \left(v + \frac{50v}{100}\right)$$

Here,

$T_1 = 27°C = 300K \qquad v_1 = v$

$T_2 = (T + 273)K$ and, $v_2 = v + \frac{50v}{100} = \frac{3v}{2}$

Now, we have,

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

$$\text{or, } \frac{v}{3v/2} = \sqrt{\frac{300}{T + 273}}$$

$$\text{or, } \frac{2}{3} = \sqrt{\frac{300}{T + 273}}$$

$$\text{or, } \frac{4}{9} = \frac{300}{T + 273}$$

or, $T + 273 = 675$

$\therefore T = 402°C$

Thus, the required temperature is 402°C.

39. **2074 Supp Q.No. 11** **In a resonance air column apparatus, the first and second resonance positions were observed at 18 cm and 56 cm respectively. The frequency of tuning fork used was 480 Hz. Calculate the velocity of sound in air and end correction of the tube.** **[4]**

Solution

Given,

First resonance length $(l_1) = 18$ cm

Second resonance length $(l_2) = 56$ cm

Frequency (f) = 480 Hz

Velocity of sound (v) = ?

End correction (e) = ?

We have,

$$v = 2f(l_2 - l_1)$$
$$= 2 \times 480\ (0.56 - 0.18)$$
$$= 364.8\ m/s$$

$$e = \frac{l_2 - 3l_1}{2}$$
$$= \frac{0.56 - 3 \times 0.18}{2}$$
$$= 0.01\ m$$

40. 2073 Set D Q.No. 11 **Calculate the bulk modulus of a liquid in which longitudinal waves with frequency of 250 Hz have the wavelength of 8 m and the density of liquid is 900 kg m^{-3}.** **[4]**

Solution

Given,

Frequency of longitudinal waves (f) = 250 Hz

Wavelength of longitudinal waves (λ) = 8m

Density of liquid (ρ) = 900 kgm^{-3}

Bulk modulus (B) = ?

We have,

$$v = f \times \lambda = 250 \times 8 = 2000\ m/sec$$

Velocity of longitudinal wave in liquid is

$$v = \sqrt{\frac{B}{\rho}}$$

$$\text{or, } 2000 = \sqrt{\frac{B}{900}}$$

$$\text{or, } B = (2000)^2 \times 900 = 3.6 \times 10^9\ N/m^2$$

41. 2072 Set E Q.No. 11 **A source of sound produces a note of 512 Hz in air at 17°C with wavelength 66.5 cm. Find the ratio of molar heat capacities at constant pressure to constant volume at NTP. Densities of air and mercury at NTP are 1.293 kg/m^3 and 13600 kg/m^3 respectively.** **[4]**

Solution

Given,

Frequency of sound (f) = 512 Hz

Wavelength of sound (λ) = 66.5 cm = 0.665 m

Temperature (T) = 17°C = 17 + 273 K = 290 K

Ratio of molar heat capacities (γ) = ?

Now,

$$v_{17} = f \times \lambda$$
$$= 512 \times 0.665$$
$$= 340.48\ m/sec$$

Now,

$$\frac{v_0}{v_{17}} = \sqrt{\frac{T_0}{T_{17}}} = \sqrt{\frac{273}{290}}$$
$$= \sqrt{0.94}$$
$$= 0.97$$

$$\text{or, } v_0 = 0.97 \times 340.48$$
$$= 330.26\ m/sec$$

Now, Velocity of sound in air is given by,

$$v_0 = \sqrt{\frac{\gamma P}{\rho}}$$

$$\text{or, } v_0 = \sqrt{\frac{\gamma \rho_m g h}{\rho_a}} \qquad [\because P = \rho_m g h]$$

or, $330.26 = \sqrt{\frac{\gamma \times 13600 \times 10 \times 0.76}{1.29}}$

or, $330.26 = \sqrt{\gamma \times 80124.03}$

or, $330.26^2 = \gamma \times 80124.03$

or, $\gamma = 1.36$

42. **2071 Set D Q.No. 11** **A Source of sound of frequency 512 Hz emits waves of wavelength 64.5 cm in air at 20°C. What would be the velocity of sound at 0°C?** **[4]**

Solution

Given,

Frequency of sound (f_{20}) = 512. Hz at 20°C

Wavelength of sound (λ_{20}) = 64.5 cm = 0.645 m at 20°C

Velocity of sound at 0°C (v_0) = ?

We have, velocity of sound at 20°C is,

$v_{20} = f_{20} \times \lambda_{20} = 512 \times 0.645 = 330.24$ m/sec

Again,

$$\frac{v_0}{v_{20}} = \sqrt{\frac{T_0}{T_{20}}}$$

$$v_0 = \sqrt{\frac{273}{293}} \times 330.24 = 318.77 \text{ m/sec}$$

43. **2070 Supp. (Set B) Q.No. 11** **In a stormy day a boy observes a lightning flash which is followed by a thunder 3 secs. later. How would you estimate the distance of the lightning strike from the boy. (given velocity of sound on that day = 332m/s, velocity of light c = 3 × 10^8m/s)** **[4]**

Solution

Given,

Time taken (t) = 3 sec

Velocity of sound (v) = 332 m/sec

Distance travelled (d) = ?

We know,

$d = v \times t$

$= 332 \times 3 = 996$ m from him.

44. **2069 (Set A) Q.No. 11** **When a detonator is exploded on a railway line, an observer standing on the rail 2 km away hears two sounds. What is the time interval between them? (Young's modulus of steel = 2 × 10^{11}Nm^{-2}, density of steel = 8× 10^3 kgm^{-3}, density of air = 1.4 kgm^{-3}, γ- for air = 1.4, atmospheric pressure = 10^5Nm^{-2})** **[4]**

Solution

Given,

Distance (d) = 2 km = 2000 m

Time interval (Δ t) = ?

Young's modules of elasticity (Y) = 2 × 10^{11} N/m²

Density of steel (ρ_s) = 8 × 10^3 kg/m³

Density of air (ρ_a) = 1.4 kg/m³

γ for air (γ) = 1.4

Pressure of air (P) = 10^5 N/m²

Velocity of sound in steel $(v_s) = \sqrt{\frac{Y}{\rho_s}} = \sqrt{\frac{2 \times 10^{11}}{8 \times 10^3}} = 5000$ m/sec

Time taken by sound in steel $(t_s) = \frac{d}{v_s} = \frac{2000}{5000} = 0.4$ sec

Again, velocity of sound in air $(v_a) = \sqrt{\frac{\gamma P}{\rho_a}} = \sqrt{\frac{1.4 \times 10^5}{1.4}} = 316.23$ m/sec

Time taken by sound in air $(t_a) = \frac{d}{v_a} = \frac{2000}{316.23} = 6.325$ sec

Then, time interval between two reports = $t_a - t_s = 6.235 - 0.4 = 5.925$ sec

45. **2064 Q.No. 5 b** **A source of sound of frequency 512 Hz emits waves of wavelength 670 mm in air at 20°C. What is the velocity of sound in air at this temperature? What would be the wavelength of sound from the source in air at 0°C?** **[4]**

Solution

Given,

Frequency of sound (f)= 512 Hz at 20°C

Wavelength of sound (λ)= 670 mm at 20°C

$= 670 \times 10^{-3}$m

Velocity of sound (v)= ? at 20°

Wavelength of sound (λ_0) = ? at 0°C

The velocity of sound at 20°C is

$v = f\lambda = 512 \times 670 \times 10^{-3} = 343.04$ m/s

Now, for the velocity of sound in at air at 0°C is

$$\frac{v}{v_0} = \sqrt{\frac{273+t}{273}}$$

$$v_0 = \sqrt{\frac{273}{273+20}} \times v = \sqrt{\frac{273}{273+20}} \times 343.04 = 331.1 \text{ m/sec}$$

Thus, the wavelength of sound at 0°C is

$$\lambda_0 = \frac{v_0}{f_0} = \frac{v_0}{f} = \frac{331.1}{512} = 0.6467 \text{ m} = 646.7 \times 10^{-3} \text{ m}$$

46. **2057 Q.No. 5 b** **A man standing at one end of a closed corridor 57 m long blow a short blast on a whistle. He found that the time from the blast to the sixth echo was 2 seconds. If the temperature was 17°C, what was the velocity of sound at 0°C?** **[4]**

Solution

Here,

The distance travelled by sound between the blast and the first echo $= 2 \times 57$ m

Time (t) = 2 sec

Temperature (θ)=17°C= 290 K

Total distance travelled in 2 sec = $6 \times 2 \times 57$ m

$\therefore$ Velocity of sound at 17°C

$$v_\theta = \frac{6 \times 2 \times 57}{2} = 342 \text{ m/s}$$

Now, let the velocity of sound at 0°C be V_0.

$$\therefore \frac{v_\theta}{v_0} = \sqrt{\frac{273+\theta}{273}} = \sqrt{\frac{273+17}{273}}$$

$$v_0 = \sqrt{\frac{273}{290}} \times v_\theta = \sqrt{\frac{273}{290}} \times 342 = 331.8 \text{ m/sec}$$

$\therefore$ The velocity of sound at 0°C = 331.8 m/sec.

47. **2052 Q.No. 3 OR** **The interval between the flash of lighting and the sound of thunder is 2 seconds, when temperature is 10°C. How far is the storm if the velocity of sound in air at 0°C is 330m s^{-1}?** **[4]**

Solution

Given, the time period (t) = 2 sec

First case:

Velocity (v_1) = 330 ms^{-1}

Temperature (T_1) = 0°C = 273 K

Second case:

Velocity (v_2) = ?

Temperature (T_2) = 10°C = 283 K

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

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

or, $\frac{330}{v_2'} = \sqrt{\frac{273}{283}}$

or, $\frac{330}{v_2} = 0.98$

$\therefore$ $v_2 = 335.98 \text{ ms}^{-1}$

Again, Using,

Distance = velocity × time

$= 335.98 \times 2 = 671.96 \approx 672\text{m}$

Thus, the storm is 672 m far.

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UNIT 2 Electricity and Magnetism

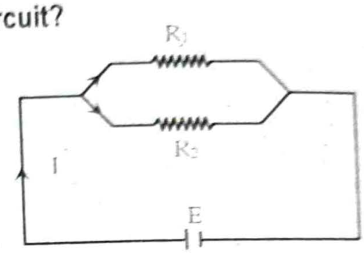
A. Current Electricity

Chapter 1: DC Circuits

Short Answer Questions

1. 2075 GIE Q.No. 1a 2074 Set B Q.No. 1a Two resistors R_1 and R_2 are connected in parallel to an emf source. What happens to the current through R_1 when R_2 is removed from the circuit? [2]

The current I flowing in the circuit is given by



$$I = \frac{E}{R}$$

Where,

$$R = \frac{R_1 \times R_2}{R_1 + R_2}$$

When, R_2 is removed, R increases and hence current through R_1 decreases.

2. 2075 Set A Q.No. 1a A wire is stretched to double its length. What will happen to its resistivity and resistance? [2]

If R be the resistance of the wire of resistivity ρ whose length is l and area of cross section is A, then its resistance R is given by, $R = \rho\frac{l}{A}$. Therefore, $R = \rho\frac{l^2}{lA} = \rho\frac{l^2}{V}$, where $Al = V$ is the volume of the conductor. If the wire is stretched to double its length, then the new length is $l' = 2l$ and new resistance R' can be written as $R' = \rho'\frac{l'^2}{V'} = \rho\frac{(2l)^2}{V}$, where $V' = V$ and $\rho' = \rho$, because resistivity and volume of the wire remain same.

$$\therefore \quad R' = 4\rho\frac{l^2}{V} = 4\rho\frac{l^2}{Al} = 4R \qquad [\because R = \rho\frac{l^2}{Al}]$$

Thus, when a wire is stretched to double its length, its resistance becomes 4 times to its original resistance and resistivity remain same .

3. 2075 Set A Q.No. 1b Differentiate between a fuse wire and a heating wire. [2]

The difference between heating wire and fuse wire are given as:

Fuse wire	Heating wire
1. Fuse wire should have the properties of melting on heating within short time.	1. Heating wire should have the properties of heating for a long time.
2. It has low resistance.	2. It has high resistance without melting.
3. It has low melting point.	3. It has high melting point.
4. It is generally soft.	4. It is generally hard.
5. It is heated for short time and immediate melted to save from firing.	5. It is heated for long time for heating purpose.

4. 2074 Supp Q.No. 1a Two wires, one of copper and another of iron, have the same diameter and carry the same current. In which wire the drift velocity of electrons will be more? [2]

The drift velocity of electrons in a conductor is given by

$$v_d = \frac{I}{neA};$$

Where,

I = current in the conductor; n = electron concentration

e = electric charge and; A = area of cross section of the wire.

For a copper and an iron wire; $n_i < n_c$; i.e. free electron density of copper is greater than free electron density of iron. So, drift velocity of electrons for iron is greater the copper wire.

5. **2074 Set A Q.No. 1a** **2058 Q.No. 10a** **You are given n wires, each of resistance r. What is the ratio of maximum to minimum resistance obtainable from these wires?** **[2]**

We know that, net resistance is maximum when a number of resistances are connected in series and it is minimum when they are connected in parallel. Let n number of identical resistors having resistances rΩ. The maximum resistance is given by

$R_{max} = r + r + r + r \ldots + r = nr \quad \ldots (i)$

The minimum resistance is given by

$$\frac{1}{R_{min}} = \frac{1}{r} + \frac{1}{r} + \frac{1}{r} + \ldots \frac{1}{r} = \frac{n}{r} \quad \ldots (ii)$$

Multiplying (i) and (ii), we get

$$\frac{R_{max}}{R_{min}} = n^2$$

Hence, the required ratio of R_{max} to R_{min} is n^2: 1.

6. **2073 Supp Q.No. 1a** **2069 Supp Set B Q.No. 1 a** **Is there any difference between 'resistance of a wire' and 'resistivity of a wire"? Explain.** **[4]**

The difference between resistance and resistivity of a wire are:

Resistance	Resistivity
▪ Resistance is the property of a wire to oppose the flow of charge (or current) through the wire.	▪ Resistivity of the wire is the resistance of the wire of unit length and unit cross section area.
▪ Resistance of the wire varies with length and cross sectional area.	▪ It is independent to the length and area of that wire.
▪ It is not constant for a metal (or conductor). It depends on shape and size.	▪ It is constant for a metal (or conductor).
▪ Its unit is Ω in S.I. system	▪ Its unit is Ω m in S.I. system.

7. **2073 Supp Q.No. 1d** **2072 Set E Q.No. 1b** **2063 Q.No. 10 a** **The element of heater is very hot while the wire carrying current are not. Why?** **[2]**

According to Joule's law of heating, the amount of heat developed per second by a wire of resistance R due to the flow of electric current I is

$H = I^2R \quad \Rightarrow H \propto R \quad$ for constant I.

So, heat developed across the wire depends on its resistance. As the resistance of the filament of heater is very high than that of connecting wire, the heat developed in the filament of heater is very high and becomes very hot whereas the heat developed in the connecting wire is very low and it is not heated.

8. **2073 Set C Q.No. 1a** **Will the drift velocity of electrons change if the diameter of a connecting wire is halved? Why?** **[2]**

The drift velocity of electrons in a metal is given by:

$$v = \frac{I}{enA}$$

where,

I = current
n = electronic concentration
e = electronic charge
A = area of cross section

Now, $A = \frac{\pi d^2}{4}$

When diameter is halved, new area of cross-section is

$$A' = \frac{\pi\left(\frac{d}{2}\right)^2}{4} = \frac{1}{4}\frac{\pi d^2}{4} = \frac{A}{4}$$

Then new drift velocity is

$$v' = \frac{I}{en\,A/4} = 4v$$

∴ v' = 4v, the drift velocity increases 4 times when diameter of wire is halved.

9. 2073 Set C Q.No. 1b **Five bulbs are connected in series across 220 volt line. If one bulb is fused, the remaining bulbs are again connected across the same line. Which one of the arrangements will be more illuminated? Justify your answer.** [2]

Five bulbs are connected in series across 220 volt line. If one bulb is fused, the remaining bulbs are again connected across the same line, the later combination will be more illuminated because the power consumed is proportional to resistance and square of the current. i.e., $P \propto I^2R$. In former case, product I^2 and R will be less than the later.

10. 2073 Set C Q.No. 1f **How can a galvanometer be converted into voltmeter? Explain.** [2]

Conversion of galvanometer into voltmeter

The galvanometer is converted into voltmeter by connecting a high resistance R in series with galvanometer. The voltage across the voltmeter is

$$V = I_g (G + R)$$

or, $R = \frac{V}{I_g} - G$

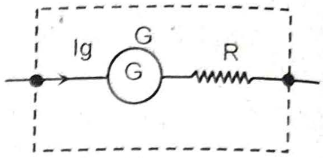


Fig: Voltmeter

Knowing the value of V, I_g and G, R can be calculated.

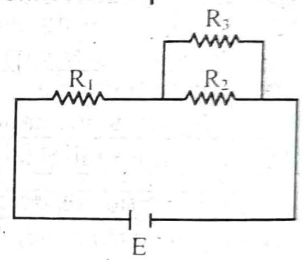
11. 2072 Supp Q.No. 1a **Explain the difference between resistance and resistivity of a wire.** [2]

Please refer to 2073 Supp Q.No. 1a

12. 2072 Set D Q.No. 1a **Resistors R_1 and R_2 are connected in series to an emf source that has negligible internal resistance. What happens to the current through R_1 when a third resistor R_3 is connected in parallel with R_2?** [2]

When two resistors R_1 and R_2 are connected in series to an emf source E of negligible internal resistance, then current following in the circuit is

$$I = \frac{E}{R_1 + R_2}$$



When a third resistor R_3 is connected parallel to the resistor R_2, then, net resistance $R_1 + R_2 \,||\, R_3$ decreases and hence current through R_1 increases.

13. 2072 Set E Q.No. 1a **Batteries are always labeled with their emf; for instance, an AA flashlight battery is labeled '1.5 volts'. Would it also be appropriate to put a label on batteries stating how much current they provide? Why or why not?** [2]

No, it would not be appropriate to put a label on batteries stating how much current they provide because current depends on both external & internal resistance as $I = \frac{E}{R + r}$; where R is external resistance & r is internal resistance.

14. 2071 Supp Q.No. 1a **Ammeters often contain fuses that protect them from large currents while voltmeters seldom do. Explain.** [2]

Since current produces more heating effect than voltage as $H = I^2Rt = IVt$. So, to protect from heating effect and damage, the ammeter contains fuses that protect from large current while voltmeter contains high resistance but in voltmeter the current flows in ideally zero.

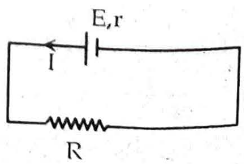
15. 2071 Set C Q.No. 1 a **What is the difference between an emf and a potential difference? Under what circumstances are the potential difference between the terminals of a battery and the emf of the battery equal to each other?** [2]

The emf of a source is defined as the work done in moving a unit positive charge from low potential to high potential end while the potential difference between two terminals of a cell in closed circuit is called terminal p.d. of the cell which is equal to the p.d. a cross external resistance of the circuit. i.e.,

$E = V + Ir$

The emf (E), terminal p.d. (V), internal resistance (r), external resistance (R) and current flowing in a circuit (I) are related as

$E = V + Ir$



If the internal resistance 'r' of the cell is zero, then emf and terminal p.d. are equal to each other.

16. **2071 Set D Q.No. 1 a** **A voltmeter has high resistance. Explain why?** **[2]**

Voltmeter is a high resistance electrical device which is connected in parallel in a circuit and measures the potential difference across any load. It has very high resistance because it is connected in parallel across any component of a circuit; it draws a very small current from the main circuit, and most of the current passes through the element. Hence, the p.d. across the component is not affected. If the resistance is small, the effective resistance is affected and most of the current passes through the voltmeter and the p.d. reduces across the component and the voltmeter cannot measure accurately.

17. **2070 Sup (Set A) Q.No. 1a** **A cylindrical rod has resistance R. If we double its length and diameter, what is its resistance interms of 'R'?** **[2]**

The resistance of a rod in terms of its length 'l' and cross sectional area 'A' is gives as,

$$R = \rho\frac{l}{A}, \ [\rho = \text{resistivity of the rod.}]$$

$$\text{or, } R = \frac{\rho l}{\frac{\pi d^2}{4}} = \left(\frac{4\rho}{\pi}\right)\frac{l}{d^2}$$

When l and d are doubled, new resistance is

$$R' = \left(\frac{4\rho}{\pi}\right)\frac{2l}{(2d)^2} = \frac{4\rho}{\pi}\ \frac{l}{2d^2}$$

$$\text{or, } \frac{R'}{R} = \frac{1}{2}$$

$$\text{or, } R' = \frac{1}{2}R$$

$\therefore$ The new resistance of the rod is $R' = \frac{1}{2}R$.

18. **2070 Sup (Set A) Q.No. 1 b** **2070 Set C Q.No. 1 b** **Why does an electric bulb nearly always burn out just as you turn on the light, almost never while the light is shining?** **[2]**

Initially the resistance of wire is small and large current flows. After some time the wire gets heated as a result, the resistance being temperature dependent $\{R_2 = R_1 (1 + \alpha\ \Delta\theta\}$ increases and hence, current decreases. Due to this reason, electric bulb nearly always burn out just as we turn on the light, but almost never while the light is shining.

19. **2070 Supp. (Set B) Q.No. 1 a** **Can the potential difference between the terminals of a battery ever be opposite in direction to the emf?** **[2]**

Yes, the potential difference between the terminals of a battery can be in opposite direction to the emf during its charging. $(V = E + Ir)$

20. **2070 Supp. (Set B) Q.No. 1 b** **"Good thermal conductors are also good electrical conductor" If so, why don't the connecting wires that are used to connect heaters get hot by conduction of heat from the heating element?** **[2]**

The heat produced in a current carrying conductor is given by $H = I^2Rt$, where R is the resistance of the wire and t is time period. The resistance of heater wire is very high while resistance of current carrying conductor is very low. Due to this, the heater wire gets heated while current carrying copper wires remain cold and do not conduct the heat for longer distance.

21. **2070 Set C Q.No. 1 a** **Two copper wires of different diameters are joined end-to-end. If a current flows in the wire combination, what happens to the drift velocity of the electrons when they move from the larger-diameter wire to the smaller-diameter wire?** **[2]**

The drift velocity of electrons in a conductor in terms of current is defined as, $I = v_d nAe$ or, $v_d = \frac{I}{neA}$, where I = current flowing in the conductor, n = no. of free electrons for unit volume and e = electronic charge. When electrons moves from larger diameter wire to smaller diameter wire, the drift velocity increases because drift velocity has inverse relationship with area of cross section.

22. 2070 Set D Q.No. 1 a **When the ends of a wire are connected to a battery, initially the current is slightly larger, but soon it decreases slowly and becomes steady at a lower value although the emf of the battery remains unchanged. Explain.** [2]

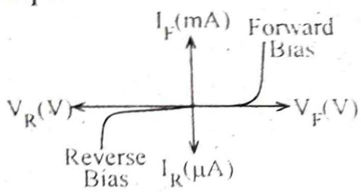
Initially the resistance of wire is small and large current flows. After some time the wire gets heated as a result, the resistance being temperature dependent $\{R_2 = R_1 (1 + \alpha \Delta\theta\}$ increases and hence, current decreases, emf remain constant (V = IR)

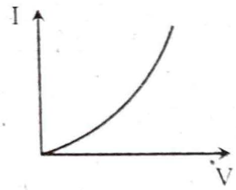
23. 2069 (Set A) Q.No. 1a **Batteries are always labeled with their emf. Would it also be appropriate to put a label on batteries stating how much current they provide? Why or why not?** [2]

Please refer to 2072 Set E Q.No. 1a

24. 2069 (Set B) Q.No. 1a **Give an example of non-ohmic conductor and present its current voltage characteristic graph.** [2]

Example of non-ohmic conductor is junction diode. The IV curve of it is given below.





25. 2069 Supp Set B Q.No. 1 b **Two bulbs of different wattage are connected in series. Which bulb will glow brighter? Why?** [2]

Let us suppose that V is the voltage on each bulb and R_1 and R_2 be the resistance of two bulbs having power P_1 and P_2 ($P_1 < P_2$) respectively. Then,

$$R_1 = \frac{V^2}{P_1} \quad \text{and } R_2 = \frac{V^2}{P_2}$$

$$\therefore \frac{R_1}{R_2} = \frac{P_2}{P_1}$$

$$\text{i.e., } R \propto \frac{1}{P}$$

From this relation, we conclude that resistance of P_1 bulb is more than P_2 bulb. Since in series combination, the same current I flows through each bulb.

Since, $H = I^2R$.; H is heat developed per unit time, i.e., power developed

$\therefore$ $H \propto R$, if current I is constant.

Therefore power developed across P_1 bulb is more than P_2 bulb. Since the brightness of the bulb is directly proportional to the power developed, P_1 bulb glows more brightly than P_2 bulb.

26. 2068 Can. Q.No. 1a **What is the ratio of maximum to minimum resistance obtainable from n wires of resistance R each?** [2]

Please refer to 2074 Set A Q.No. 1a

27. 2068 Can. Q.No. 1b **Why is it essential that the resistance of a voltmeter be very high?** [2]

Please refer to 2071 Set D Q.No. 1 a

28. 2068 Old Q.No. 10 a 2056 Q.No. 10 a **An ammeter is always connected in series. Why?** [2]

An instrument which is used to measure the electric current flowing in the circuit is called an ammeter. Ideally, the resistance of an ammeter is nearly zero. Consequently, there is no effect of ammeter on inserting in series. But, in practice, the resistance of an ammeter is not zero but very low in comparison to the other resistances. An ammeter is always connected in series of the circuit so that the total current of circuits should pass through it and then it can measure current accurately. If it is connected in parallel, the current will divide and the ammeter cannot measure accurate value. That is why, an ammeter is always connected in series.

29. 2067 Sup Q.No. 1a **The resistance of an ammeter must essentially be very small. Why?** [2]

Ammeter is a low resistance electrical device used to measure electric current in the circuit. Its resistance must essentially be very small because it is connected in series in a circuit, the net resistance of the circuit does not increase appreciably and consequently the current in the circuit remains unaffected. If the resistance of the ammeter is high, the net resistance of the circuit becomes very high and the current in the circuit reduces and hence the ammeter is not able to measure accurate current.

30. 2067 Sup Q.No. 1b **Water boils in an electric kettle in 15 minutes after being switched on. Using the same main supply, should the length of the heating element be increased or decreased if the water is to boil in 10 minutes? Explain.** **[2]**

Here in the both cases same amount of heat is to be supplied, i.e.,

$H_1 = H_2$

$\frac{V^2}{R_1}.t_1 = \frac{V^2}{R_2}.t_2 \qquad [\because H = I^2Rt]$

or, $\frac{t_1}{R_1} = \frac{t_2}{R_2}$

or, $R_1t_2 = R_2t_1$

Since, t_1 is greater than t_2 so, R_2 is less than R_1.

As we know that, resistance is directly proportional to length, the length should be decreased of the heating element in which water boil in 10 min.

31. 2067 Q.No. 1a **The energy that can be extracted from a storage battery is always less than the energy that goes into it while charging. Why?** **[2]**

The energy that can be extracted from a storage battery is always less than the energy that goes into it while charging because of loss of energy due to internal resistance. The loss of energy is converted into heat and light energy.

32. 2066 Old Q.No. 10 a **A wire is stretched to double its length. What happens to its resistance?** **[2]**

Please refer to 2075 Set A Q.No. 1a

33. 2064 Q.No. 10 a **Why heat is generated across a resistor when the electric field is applied?** **[2]**

When the electric field is applied across the ends of the resistor, the free electrons of the resistor accelerate and hence gain kinetic energy. These electrons collide with nearby electrons and loose their kinetic energy. This loss of kinetic energy is converted into heat energy.

34. 2064 Q.No. 10 b **Why do electrons acquire a steady drift velocity?** **[2]**

When the electric field is applied across the ends of the resistor, the free electrons of the resistor accelerate and hence gain kinetic energy. These electrons collide with nearby electrons and loose their kinetic energy and the other electrons also accelerate which again collide and hence this process remains continue. After some time, the electrons gain a constant speed in opposite to the electric field applied which is called drift velocity. The drift velocity in a wire is given by $I = ne\,Av_d$, where n is the no. of free electrons per unit volume, e be the electronic charge, I be the current flowing and A be the cross sectional area of wire.

35. 2064 Q.No. 10 c **Why ammeter is always connected in series?** **[2]**

Please refer to 2068 Old Q.No. 10 a

36. 2063 Q.No. 10 c **You are given 2 wires each of resistance R. What is the ratio of maximum to minimum resistance that can be obtained from these wires?** **[2]**

We know that, net resistance is maximum when a number of resistances are connected in series and it is minimum when they are connected in parallel. Let two identical resistor having resistances R. The maximum resistance is given by

$R_{max} = R + R = 2R \qquad \ldots(i)$

The minimum resistance is given by

$R_{min} = \frac{R \times R}{R + R} = \frac{R}{2} \qquad \ldots(ii)$

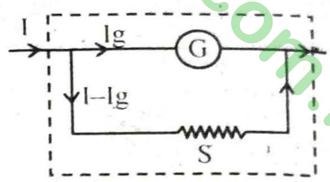
Dividing (i) by (ii), we get

$\frac{R_{max}}{R_{min}} = \frac{2R}{R/2} = 4$

Hence, the required ratio of R_{max} to R_{min} is 4: 1.

37. **2062 Q.No. 10 a** **Explain the significance of a shunt with a diagram.** **[2]**

Shunt: To convert galvanometer into an ammeter, a very low resistance is connected in parallel with galvanometer coil so that maximum current can flow through it is called a shunt. Shunt provides an alternative path for excess current.



The value of shunt resistance S to be connected in parallel with galvanometer to convert into Ammeter is $S = \frac{I_g}{I - I_g} \times G$, where G is resistance of galvanometer and I_g is current flowing through it.

38. **2061 Q.No. 10 b** **A large number of free electrons are present in metals. Why is there no current in the absence of electric field across it?** **[2]**

In the absence of electric field, the free electrons in the metal have random motions. During such motion, they collide with other atoms and electrons present in it again and again so that their direction changes. As a result, the net motion in any particular direction becomes zero and hence no current flows. But, when an external electric field is applied, the free electrons experience a force and start drifting towards the positive terminal of the source with a small drift velocity and current also starts to flow.

39. **2060 Q.No. 10 a** **Why are alloys of constantan and manganin used to make standard resistors?** **[2]**

The temperature coefficient of resistance for constantan and manganin is very small and they have high resistance. This means that there is a negligible change in the resistance due to moderate changes in temperature. Also, the melting points of these alloys are high and do not melt at high temperature. Due to these reasons, the alloys of constantan and manganin are used to make standard resistors.

40. **2059 Q.No. 10 b** **Why voltmeter is always connected in parallel with the load resistance?** **[2]**

A voltmeter is a high resistance device and measures potential difference across two points of an electrical device. When it is connected in parallel across any component of a circuit, it draws a very small current from the main circuit and the voltage does not change in parallel combination such that it can measure voltage accurately. If it is connected to series, voltage is divided and hence voltmeter cannot measure potential difference accurately.

41. **2059 Q.No. 10 c** **Two bulbs have the filament of the same length. If one is of 40 watt and the other 60 watt, which one has thicker filament?** **[2]**

The power developed across the resistor R is

$P = \frac{V^2}{R}$, where V is the p.d. applied across R.

If R_1 and R_2 are the resistances of 40 W (= P_1) and 60 W (= P_2) bulbs respectively, then: $P_1 = \frac{V^2}{R_1}$ and $P_2 = \frac{V^2}{R_2}$.

$$\Rightarrow \frac{P_1}{P_2} = \frac{V^2/R_1}{V^2/R_2} = \frac{R_2}{R_1} = \frac{\rho l / A_2}{\rho l / A_1} \qquad \left(\because R = \rho\frac{l}{A}\right)$$

$$\therefore \frac{P_1}{P_2} = \frac{A_1}{A_2} = \frac{\pi d_1^2/4}{\pi d_2^2/4} = \frac{d_1^2}{d_2^2}$$

Since $P_1 < P_2$ then, $d_1 < d_2$.

So, 60 W bulbs has thicker filament than the 40 W bulb.

42. **2058 Q.No. 10 c** **Is terminal p.d. always greater than its emf?** **[2]**

No, in general, the p.d. across a battery is smaller than its emf. But, when an electric current flows through a battery in such a way that the direction of current is opposite to the direction of emf of the battery, then p.d. across the battery is greater than its emf. In such case, the current flows from positive to negative terminal inside the battery (charging of cell). The relationship between p.d. of a battery and its emf is given by:

$E = V + (-I)\,r$, where r is the internal resistance of the battery

$E = V - Ir$ For $r \neq 0$, then $E < V$. At this condition a part of the emf is used in overcoming the internal resistance of the cell.

43. 2057 Q.No. 10 a **What are the factors on which the resistance of a conductor depends?** [2]

The resistance (R) of a conductor,

a. is directly proportional to its length (l). i.e., $R \propto l$.

b. is inversely proportional to its cross- sectional area (A) i.e., $R \propto \frac{1}{A}$

c. it depends upon the nature of the material.

d. it changes with temperature (t).

The corresponding relation which gives the relationship among above-mentioned factors is given by:

$$R = \rho \frac{l}{A},$$

where ρ is the resistivity (or specific resistance) of the conductor.

Moreover, if α be the temperature coefficient of the material of the wire, then the resistance of the wire at t_2°C is given by

$R_2 = R_1 [1 + \alpha (t_2 - t_1)]$, where R_1 is the resistance of the wire at t_1°C.

Hence: l, A, ρ, α are the factors on which the resistance of a conductor depends.

44. 2057 Q.No. 10 b **Can the potential difference across a battery be greater than its emf?** [2]

Please refer to 2058 Q.No. 10 c

45. 2057 Q.No. 10 c **Two bulbs of 60 W and 100 W are connected in series and this combination is connected across the mains. Which bulb will glow more brightly? Give reason.** [2]

Let us suppose that V is the voltage on each bulb and R_1 and R_2 be the resistance of the 60 W bulb and 100 W bulb respectively. Then,

$$R_1 = \frac{V^2}{P_1} \text{ and } R_2 = \frac{V^2}{P_2}$$

where, $P_1 = 60$ W and $P_2 = 100$ W

$$\therefore \frac{R_1}{R_2} = \frac{P_2}{P_1} \quad \text{i.e., } R \propto \frac{1}{P}$$

From this relation, we conclude that resistance of the 60 W bulb is more than 100 W bulb. Since in series combination, the same current I flows through each bulb.

Since, $H = I^2Rt$

$\therefore$ $H \propto R$, if current I and time t are constant.

Therefore heat (H) developed across 60 W bulb is more than 100 W bulb. Since the brightness of the bulb is directly proportional to the heat developed, therefore, 60 W bulb glows more brightly than 100 W bulb.

46. 2056 Q.No. 10 b **Why do we use connecting wires made of copper?** [2]

According to Joule's law of heating, the amount of heat developed per second by a wire of resistance R due to the flow of electric current I is

$H = I^2R \Rightarrow H \propto R$ for constant I. The copper wire has less resistance and resistivity i.e., high conductivity. Hence, the heat developed per sec in the wire and power loss due to heating effect is less. So, copper wires are used for connecting wires.

Long Answer Questions

47. 2076 Set B Q.No. 5a 2066 Old Q.No. 11 a 2063 Q.No. 11 a 2057 Q.No. 11 a OR **What do you mean by shunt? Describe its use in converting a galvanometer into an ammeter.** [4]

Shunt and Its Application

To convert galvanometer into an ammeter, a very low resistance is connected in parallel with galvanometer coil so that maximum current can flow through it which is called shunt. Shunt provides an alternative path for excess current. It is used to convert galvanometer into ammeter.

Conversion of galvanometer into ammeter:

Let, S be the value of shunt resistance and G be the galvanometer resistance, I be the total current through the circuit. Since resistances G and S are in parallel, the effective resistance R of the circuit is

$$\frac{1}{R} = \frac{1}{G} + \frac{1}{S}$$

$\Rightarrow R = \frac{GS}{G+S}$; since S is small, R is very small.

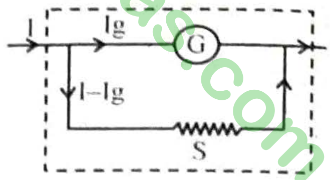


Fig. Shunt

But, potential across G = potential across S.

$$V = \frac{GS}{G+S} I$$

Current through G is $I_g = \frac{V}{G} = \frac{GS}{G(G+S)} I = \frac{S}{(G+S)} I$

Current through S is $I_S = \frac{V}{S} = \frac{GS}{S(G+S)} I = \frac{G}{G+S} I$

Since the resistance of shunt is small, the fraction of current through galvanometer, $\left(\frac{S}{G+S}\right) I$ is small.

Again, current through the shunt = $I - I_g$

Since, p.d. across S = p.d across G

or $(I - I_g)S = I_g G$

$$\Rightarrow S = \frac{I_g}{I - I_g} G$$

This is the required value of shunt which when connected in parallel with coil to convert the galvanometer into ammeter of required range.

48. $\boxed{\text{2076 Set B Q.No. 5b}}$ $\boxed{\text{2072 Supp Q.No. 5a}}$ $\boxed{\text{2061 Q.No. 11a}}$ **State Joule's law of heating and verify it experimentally.** **[4]**

When electricity is passed through the conductor, due to the applied electric field, the free electrons in the conductor are accelerated. As they move, they collide with other atoms and lose their kinetic energy which appears as heat energy in the conductor. The heat developed in the wire is discovered by Joule and formed laws as

Joule's law of heating: The amount of the heat produced in a conductor due to flow of current is;

a. directly proportional to square of current passing through it
 i.e., $H \propto I^2$

b. directly proportional to resistance R of conductor
 i.e., $H \propto R$

c. directly proportional to time 't' for which current is passed through it.
 i.e., $H \propto t$

Combining all above three relations,

$$H \propto I^2Rt$$

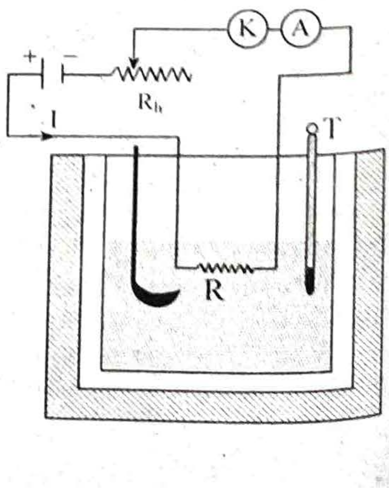
$$H = \frac{I^2Rt}{J} \qquad \text{(In CGS unit)}$$

where, J is constant.

$$H = I^2 Rt \qquad \text{[In SI unit]}$$

This is the mathematical form of Joules law of heating.

Experimental verification of Joule's law



Experimental arrangement for the verification of Joule's law of heating is shown in figure. A coil of copper is placed in a partially filled calorimeter with water. When the circuit is closed, electric current I flow in the circuit and there is rise in temperature of water. The current can be varied with the help of rheostat R_h. It is found that for constant mass of water heat produced at a fixed time is proportional to square of current flow.

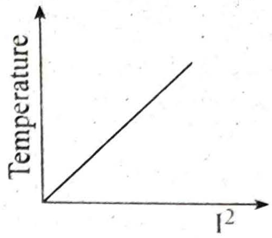
i.e., $\frac{H}{t} \propto I^2$. ... (i)

If we replace the coil of copper by another coil of different length but of same diameter. It is found that rate of heat produced, by a given current is proportional to the length of wire used. But, resistance of wire is proportional to the length of wire used. Thus,

$$\frac{H}{t} \propto R \quad \dots \text{(ii)}$$

The amount heat produced can be estimated by measuring the raise in temperature during experiment.

From equation (i) and (ii)



$$\frac{H}{t} \propto I^2R$$

$$\frac{H}{t} = \frac{I^2R}{J} \quad \text{[In CGS unit]}$$

$$H = I^2Rt \quad \text{[In S.I. unit]}$$

$$\therefore H = I^2Rt$$

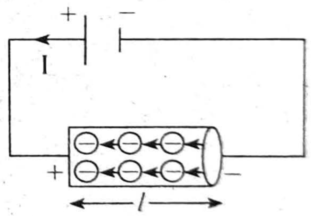
Thus, Joule's law is verified.

49. **2076 Set C Q.No. 5a** **2060 Q.No. 11 a** **Discuss how the current is established in a conductor when it is connected across a source of e.m.f. Derive the relation *J = nev*, where the symbols have their usual meanings.** **[4]**

Drift Velocity

In metal there are some loosely bound electrons. These types of electrons are called free electrons. They are in a random motion like the gas molecules confined in a container. These free electrons randomly distributed in all directions, there is no net flow of charge in any direction due to zero average velocity of electrons. But when an electric field is applied in the conductor, the electrons keep colliding with atoms with gaining and losing their kinetic energy. However, they acquire an average velocity opposite to the direction of applied field. The average velocity of free electrons with which they drift in the direction opposite to the field is called drift velocity. Thus, the average velocity of charge carriers (electrons) with which they move in a conductor under the influence of applied electric field is called drift velocity. It is denoted by v_d.

Let us consider a metallic conductor, cylindrical in shape, with cross-sectional area A and length l. If n be the number of electrons per unit volume and e be the charge of each electron.



Total free charge in a volume V is, (Q) = volume of conductor × total number of electrons x electronic charge

$\therefore$ Q = A$l$ne [$\because$ V = A × l]

Let I be the current flowing through the conductor, the free electrons drift in the direction opposite to the direction of the applied electric field is as shown in figure. Let v_d be the drift velocity of the free electrons. If t be the time required to drift total charge through length l, then current is given by

$$I = \frac{Q}{t} = \frac{neAl}{t} = neA\frac{l}{t} = neA\,v_d \qquad \left[\because \frac{l}{t} = v_d\right]$$

$$\Rightarrow I = v_d\,enA$$

$$\text{Or, } v_d = \frac{I}{neA}$$

This equation gives expression for drift velocity.

Further, current flowing per unit cross-sectional area is called current density. It is denoted by J and is given by, $J = \frac{I}{A} = \frac{v_d\,enA}{A}$

$$\Rightarrow J = ne\,v_d$$

Since, $\vec{J}$ and $\vec{v_d}$ are vector quantities, so $\vec{J} = ne\vec{v_d}$, which is the required expression of current density.

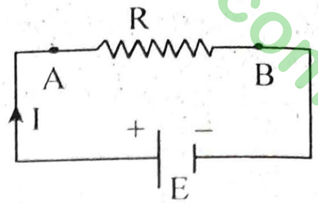
50. **2075 GIE Q.No. 5a** **2074 Set A Q.No. 5a** **2071 Set C Q.No. 5 a** **2069 (Set A) Q.No. 5b** **2068 Can. Q.No. 5a** **Describe the mechanism of metallic conduction. Deduce a relation between current density and drift velocity of the electrons.** **[4]**

Please refer to 2076 Set C Q.No. 5a

51. 2075 Set B Q.No. 5a **State and explain Joule's law of heating. Deduce an expression for heat developed in a conductor due to the passage of an electric current.** **[4]**

Joule's Law of Heating: Please refer to 2076 Set B Q.No. 5b

Second Part:



Let us consider a battery of emf E is connected across the resistance R as shown in figure. The potential across the terminals of resistance R is V = IR, where I is the total current flow in the circuit. Terminal 'A' of resistance is connected to positive terminal (higher potential) of the battery and terminal 'B' of resistance is connected to negative terminal (lower potential) of battery.

When charge moves from terminal A to terminal B, the net amount of work done for this is given by,

$W = q\,V$

Since, $q = I\,t$ and $V = IR$

$\Rightarrow\ W = I\,t \times I\,R = I^2Rt$

According to principle of conservation of energy, this amount of work done is converted into heat energy.

i.e., Heat produced in wire = W

$\therefore\ H = I^2Rt$

which is the required expression and is called Joule's law of heating.

52. 2074 Supp Q.No. 5a **What is a galvanometer? How can you convert it into a voltmeter? Why should the resistance of a voltmeter be high?** **[4]**

Galvanometer: Galvanometer is an electrical device which detects and measures small amount of current. It works on the principle of torque produced on a rectangular current carrying coil placed inside the magnetic field.

Conversion of galvanometer into voltmeter

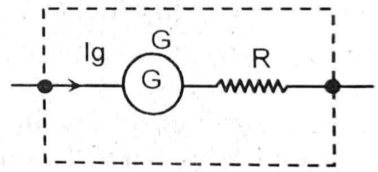


Fig: Voltmeter

The galvanometer is converted into voltmeter by connecting a high resistance R in series with galvanometer. The voltage across the voltmeter is

$V = I_g (G + R)$

or, $R = \dfrac{V}{I_g} - G$

Knowing the value of V, I_g and G, R can be calculated.

Third part: Voltmeter is a high resistance electrical device which is connected in parallel in a circuit and measures the potential difference across any load. It has very high resistance because it is connected in parallel across any component of a circuit; it draws a very small current from the main circuit, and most of the current passes through the element. Hence, the p.d. across the component is not affected. If the resistance is small, the effective resistance is affected and most of the current passes through the voltmeter and the p.d. reduces across the component and the voltmeter cannot measure accurately.

53. 2072 Set C Q.No. 5a **Define drift velocity of electrons. Establish a relation between drift velocity of electrons and current density in the conductor.** **[4]**

Please refer to 2076 Set C Q.No. 5a

54. 2072 Set D Q.No. 5b **Describe an experiment to verify Joule's Law of heating.** **[4]**

Please refer to 2076 Set B Q.No. 5b

55. 2072 Set E Q.No. 5a **Why has an ammeter a very low resistance? How can you convert a galvanometer into an ammeter?** **[4]**

Please refer to 2076 Set B Q.No. 5a

56. 2071 Supp Q.No. 5a **Define emf, terminal p.d. and internal resistance. Derive the relation between them for the circuit drawing current.** **[4]**

Electromotive Force: The electromotive force of a source is defined as the work done in moving a unit positive charge through the source from low potential end to high potential end. It is cause, independent to r. it is denoted by E and given as

$$E = \frac{W}{q}$$

where W is the work done to carry the magnitude of charge q. Its S.I. unit is joule per coulomb (JC^{-1})

Terminal Potential Difference

The work done in bringing a unit charge from one point to another point in the external circuit is called potential difference between the points. It is denoted as V and given as

$$V = \frac{W}{q_o}$$

where W is work done to carry the magnitude of charge q_o.

Difference between emf and potential difference

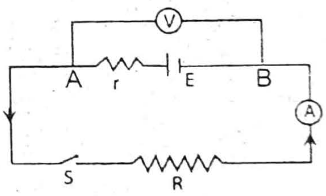
Electromotive Force(emf)	Potential Difference(p.d)
1. It is the difference of peotential between two electrodes of a cell in an open circuit.	1. It is the difference of potential between any two points in a closed circuit.
2. It is greater than p.d during discharging.	2. It is greater than emf during charging.
3. It is cause of p.d.	3. It is an effect of emf.
4. It depends internal resistance of cell.	4. It depends upon external resistance of the circuit.

Internal Resistance of a Cell

The resistance offered by a cell (source of emf) is called internal resistance of the cell. It is due to electrolyte and electrodes of the cell. It is generally denoted by r and measured in Ohm.

Relation between emf, Internal Resistance and Terminal p.d. of a Cell

Let, E be the emf of a cell, r be its internal resistance and R be the external resistor connected in series with the cell. V is voltmeter which measures p.d. between two points A and B of the circuit. S is the switch, when the circuit is open, no current flows through the circuit. The reading of the voltmeter gives emf (E) of the cell. When circuit is closed, the current I flowing through the circuit is given by



$I = \frac{E}{R + r}$ ... (i)

or, $E = IR + Ir$ ... (ii)

Terminal p.d., V = p.d. across external resistance

or, $V = IR$ ... (iii)

From equations (ii) and (iii), we can write, $E = V + Ir$

or, $V = E - Ir$ ... (iv)

where, Ir is potential drop across internal resistance of the cell. This is the required relationship between E, V and r.

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57. $\boxed{\text{2069 (Set A) Q.No. 5b}}$ **What is the difference between an electromotive force and the terminal potential difference? How are they related? [4]**

Please refer to $\boxed{\text{2071 Supp Q.No. 5a}}$

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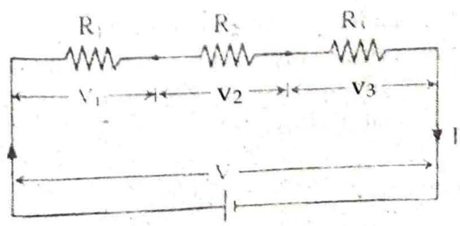
58. $\boxed{\text{2069 Supp Set B Q.No. 5 d}}$ **Explain the theory of a) series and b) parallel combinations of resistances in an electric circuit. [4]**

Combination of Resistors

There are two ways of combining two or more than two resistors; series and parallel combinations.

a. **Series Combination of Resistors:** When a number of resistors are connected end to end as shown in Fig, they are said to be in series. In this combination, the same current flows through them. Let R_1, R_2 and R_3 are three resistors connected in series. I is current flowing through them. V_1, V_2 and V_3 are the potential differences across R_1, R_2 and R_3 respectively. V be the potential difference across the whole circuit which is equal to the sum of potential differences across individual resistors. Therefore,



$V = V_1 + V_2 + V_3$ ... (i)

But $V_1 = IR_1$, $V_2 = IR_2$ and $V_3 = IR_3$ ... (ii)

From relations (i) and (ii), we have,

$V = IR_1 + IR_2 + IR_3$

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

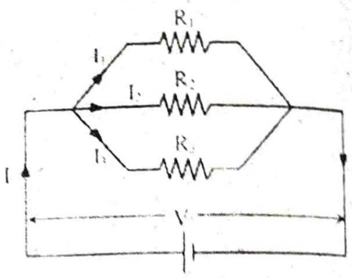
or, $V/I = R_1 + R_2 + R_3$

or, $R = R_1 + R_2 + R_3$ ... (iii)

where, $R = \frac{V}{I}$, is called effective resistance of the system. So, in series combination of the resistors, effective resistance is equal to the sum of individual resistances.

i.e., $R = R_1 + R_2 + R_3 + \ldots + R_n$ for n no. of resistors in which I is equal in each resistor.

b. **Parallel Combination of Resistors:** When one end of the number of resistors are connected to a common point and other ends are connected to an other common point as shown in Fig., it is called parallel combination. In this combination, potential difference across each resistor is the same. Let, R_1, R_2 and R_3 be three resistors connected in parallel combination. I is the current entering the system at end A and the same current leaves at end B. V is the common potential difference between common points A and B. I_1, I_2 and I_3 be the current through resistors R_1, R_2 and R_3 respectively. Here, total current, I is equal to the sum of individual current I_1, I_2 and I_3. Therefore,



$I = I_1 + I_2 + I_3$ ... (i)

But, $I_1 = \frac{V}{R_1}$, $I_2 = \frac{V}{R_2}$ and $I_3 = \frac{V}{R_3}$ ... (ii)

From relation (i) and (ii), we get, $I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$

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

or, $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ ... (iii)

where, $R = \frac{V}{I}$, is effective resistance of the system. So, in parallel combination of the resistors, reciprocal of effective resistance is equal to the sum of reciprocal of individual resistances, for n no. of resistors.

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59. 2068 Q.No. 5d **Distinguish between resistance and resistivity. Derive expression for the effective resistance of number of resistors connected in series and parallel.** **[4]**

Resistance: The property of a material or conductor to oppose the flow of charge in a conductor is called resistance. The resistance R of a conductor is defined as the ratio of potential difference V across the conductor to the current I flowing through it. Therefore,

$R = \frac{V}{I}$, or, $V = IR$, or, $I = \frac{V}{R}$

In SI system, unit of R is the Ohm (symbol Ω), the unit of current is the ampere (symbol A) and the unit of V is the volt (symbol V).

Resistivity: Experimentally, it is found that the resistance, R of a conductor is,

i. directly proportional to the length, l of the conductor, i.e., $R \propto l$ .... (i)

ii. inversely proportional to the area of cross- section, A, of the conductor. i.e.,

$R \propto \frac{1}{A}$ .... (ii)

Combining relations (i) and (ii), we have, $R \propto \frac{l}{A}$ or, $R = \rho\frac{l}{A}$ ...... (iii)

where, ρ is constant for material of conductor, called resistivity of the material. When, $l = 1\text{m}$, $A = 1\text{m}^2$ then $R = \rho$. Hence, resistivity of a material is the resistance of the material of unit length and unit cross- sectional area. SI unit of ρ is Ohm meter (Ω m).

Combination of Resistors: 2069 Supp Set B Q.No. 5 d

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60. 2064 Q.No. 11 a **State and explain Ohm's law. Two resistors are connected in parallel and third resistor be connected in series with the combination of parallel resistors. If this combination be connected with a battery of the negligible internal resistance, find the potential difference across each resistor.**

Ohm's law: The potential difference across the ends of a conductor is directly proportional to the current flowing through the conductor provided the physical conditions remains unchanged. It is Ohm's law.

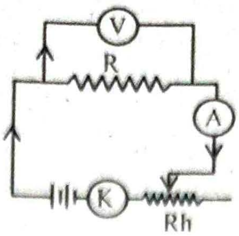
Let 'V' be the potential difference across two ends of a conductor and I be the current flowing through it. Then according to Ohm's law:

$$V \propto I$$

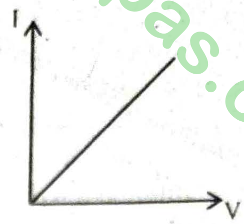
$$V = IR$$

$$\frac{V}{I} = R$$

where 'R' is a constant called resistance of the conductor. Its unit is Ohm (Ω).



(i)



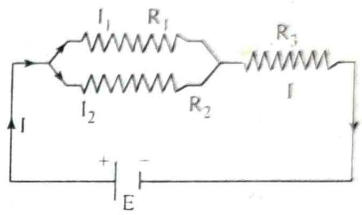
(ii)

The experimental verification of Ohm's law is shown in figure (i). The current I and p.d. across R are noted from ammeter and voltmeter by varying resistance using Rheostat (Rh). When V_1, V_2, V_3........ are the respective potential difference for the current I_1, I_2, I_3,........ then for the given conductor of constant physical conditions,

$$\frac{V_1}{I_1} = \frac{V_2}{I_2} = \frac{V_3}{I_3} = R$$

A graph between V and I is then plotted which is a straight line passing through the origin, which proves that potential difference is directly proportional to the current flowing through it.

Let us consider two resistances R_1 and R_2 be connected in parallel and the third resistance R_3 is connected to series to the combination. The resistance of the parallel combination of resistance R_1 and R_2 is given by



$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\Rightarrow R = \frac{R_1R_2}{R_1 + R_2} \quad \text{... (i)}$$

If I be the total current flow in main circuit, then

$$I = \frac{E}{R + R_3} \quad \text{... (ii)}$$

Since, in parallel resistance combination, potential across the parallel combination of R_1 and R_2 is equal. i.e.,potential across R_1 = potential across R_2

$$V' = IR$$

$$= I\frac{R_1 \; R_2}{R_1 + R_2}$$

$$= \frac{R_1 \; R_2}{(R_1 + R_2)\,(R + R_3)}E \qquad \text{[using eq}^n\text{ (ii)]}$$

$$= \frac{R_1 \; R_2\,(R_1+R_2)}{(R_1 + R_2)\,[R_3\,(R_1 + R_2) + R_1 \; R_2]}E \qquad \text{[using eq}^n\text{ (i)]}$$

$$V' = \frac{R_1 \; R_2}{R_1R_2 + R_2R_3 + R_3R_1}E$$

and potential across $R_3 = E = IR_3$.

By knowing the value of E, and resistors, we can evaluate corresponding potential difference across each resistor.

61. **2059 Q.No. 11 a** **What is drift velocity of an electron? Derive a relation between the current through a metallic conductor and the drift velocity in terms of the number of free electrons per unit volume of the conductor.[1+3]**

Please refer to 2076 Set C Q.No. 5a

62. **2056 Q.No. 11 a** **Deduce an expression for the heat developed in a wire by the passage of an electric current. [5]**

Please refer to 2075 Set B Q.No. 5a

Numerical Problems

63. **2076 Set B Q.No. 9a** **Two resistors of resistance 1000Ω and 2000Ω are joined in series with a 100 V supply. A voltmeter of internal resistance 4000Ω is connected to measure the potential difference across 1000Ω resistor. Calculate the reading shown by the voltmeter. [4]**

Solution

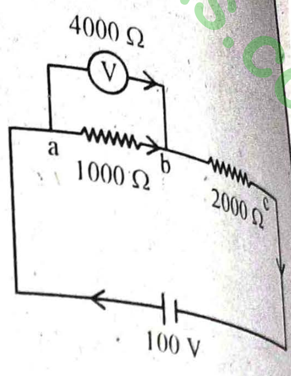
Given,

$R_1 = 1000\ \Omega$

$R_2 = 2000\ \Omega$

$E = 100$ V

Internal Resistance of Voltmeter $(R_V) = 4000\Omega$



Now,

$$R_{ab} = \frac{1000 \times 4000}{1000 + 4000} = 800\ \Omega$$

Total Resistance $R_{ac} = R_{ab} + R_{bc}$ $[\because R_2 = R_1]$

$= 800 + 2000$

$= 2800\ \Omega$

Total current in the circuit, $I = \frac{E}{R} = \frac{100}{2800} = 0.0357A$

P.D. across voltmeter $= I \times R_{ab}$

$= 0.0357 \times 800$

$= 28.57$ V

$\therefore$ Voltmeter reads 28.57V

64. $\boxed{\text{2076 Set C Q.No. 9a}}$ **The resistance of the coil of a galvanometer is 9.36Ω and a current of 0.0224 A causes to deflect full scale. The only shunt available has a resistance 0.025Ω. What resistance must be connected series with the coil to make it an ammeter of range 0 - 20A?**

Solution

Given,

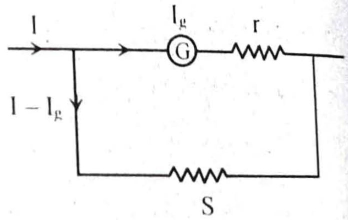
Galvanometer resistance (G) = 9.36 Ω

Galvanometer current $(I_g) = 0.224A$

Full scale current (I) = 20A

Shunt resistance (S) = 0.025 Ω

Additional resistance (r) = ?



Now,

P.D. across (G + r) = P.D. across (S)

$I_g (G + r) = (I - I_g)\ S$

or, $r = \frac{I - I_g}{I_g} . S - G = \frac{20 - 0.0224}{0.0224} \times 0.025 - 9.36 = 12.94\ \Omega$

$\therefore$ 12.94 Ω resistance is needed to connect across coil to make it ammeter.

65. $\boxed{\text{2075 Set A Q.No. 9b}}$ **Two lamps rated 25 W – 220 V and 100 W – 220 V are connected to 220 V sup... Calculate the powers consumed by the lamps.**

Solution

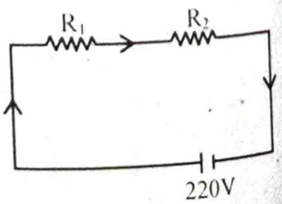
Given,

First lamp = 25 W – 220 V

Second lamp = 100 W – 220 V

Voltage (V) = 220 V

Power consumed (P) = ?



Now,

For first lamp,

$P_1 = 25$ W

$V_1 = 220$ V

$$R_1 = \frac{V_1^2}{P_1} = \frac{220 \times 220}{25} = 1936\ \Omega$$

For second lamp,

$P_2 = 100$ W

$V_2 = 220$ V.

$$R_2 = \frac{V_2^2}{P_2} = \frac{220 \times 220}{100} = 484\ \Omega$$

If two lamps are connected in series and joined to 220 V mains, the current in the circuit, I is given as,

$$I = \frac{V}{R_1 + R_2} = \frac{220}{1936 + 484} = 0.091\ A$$

Power consumed by first lamp, $I^2R_1 = (0.091)^2 \times 1936 = 16$ W

Power consumed by second lamp, $I^2R_2 = (0.091)^2 \times 484 = 4$ W

66. **2075 Set B Q.No. 9a Two resistance of 1000 Ω and 2000 Ω are placed in series with 50 V mains supply. What will be the reading on a voltmeter of internal resistance 2000 Ω when placed across the 1000 Ω resistor? What fractional change in voltage occurs when voltmeter is connected?** **[4]**

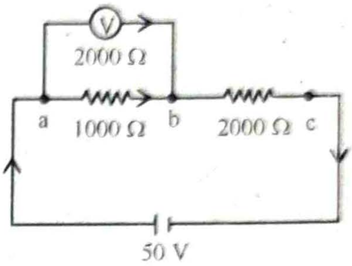
Solution

Given,

$R_1 = 1000\ \Omega$

$R_2 = 2000\ \Omega$

$E = 50$ V



Internal Resistance of Voltmeter (R_V) = 2000 V

Now,

$$R_{ab} = \frac{1000 \times 2000}{1000 + 2000}$$

$= 666.7\Omega$

Total resistance, $R = R_{ab} + R_{bc}$

$= 666.7 + 2000$

$= 2666.7\Omega$

Total current in the circuit, $I = \frac{E}{R} = \frac{50}{2666.7} = 0.01875$ A

P.d. across $1000\Omega = I \cdot R_{ab}$

$= 0.01875 \times 666.7$

$= 12.5$ V

P.d. across 1000 Ω before connecting the voltmeter, $= \frac{1000}{3000} \times 50 = 16.67$

Fraction change in voltage $= \frac{16.67 - 12.5}{16.67} = 0.25 \times 100\% = 25\%$

67. **2074 Set B Q.No. 9a A copper wire has a diameter of 1.02 mm and carries a constant current of 1.67A. If the density of free electrons in copper is $8.5\times10^{28}/m^3$, calculate the current density and the drift velocity of the electrons.** **[4]**

Solution

Given,

Diameter of wire (d) = 1.02 mm = 1.02×10^{-3} m

Current (I) = 1.67 A

Concentration of electrons (n) = $8.5 \times 10^{28}\ /m^3$

Current density (J) = ?

Drift velocity (v) = ?

We know

$J = \frac{I}{A}$; A area of cross-section

or, $J = \frac{1.67 \times 4}{\pi(1.02 \times 10^{-3})^2}$ $\left[\because A = \pi\frac{d^2}{4}\right]$

$\therefore J = 2.04 \times 10^6\ A/m^2$

Again,

$I = venA$

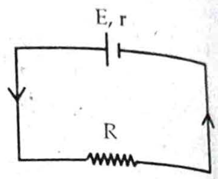
or, $v = \frac{I}{neA}$

or, $v = \frac{1.67 \times 4}{1.6 \times 10^{-19} \times 8.5 \times 10^{28} \times \pi \times (1.02 \times 10^{-3})^2} = 1.5 \times 10^{-4}$ m/sec

68. **2073 Supp Q.No. 9a** **A battery of emf 1.5 V has a terminal p.d of 1.25 V when a resistor of 25Ω is joined to it. Calculate the current flowing, the internal resistance and terminal p.d. when a resistance of 10Ω replaces 25Ω resistor.** **[4]**

Solution

Given,



E.m.f. of batter (E) = 1.5 V

Terminal P.D. (V) = 1.25 V

Resistance (R) = 25 Ω

Internal Resistance (r) = ?

Current when 25Ω is replaced by 10 Ω = ?

We have,

$E = V + Ir$

or, $1.5 = 1.25 + 0.05\, r$

or, $r = 5\Omega$

$V = IR$

or, $1.25 = I \times 25$

$I = 0.05$ A

When 25 Ω is replaced by 10 Ω resistance, then

$E = Ir + I \times 10$

or, $1.5 = I \times 5 + I \times 10$

or, $1.5 = 15\, I$

∴ $I = 0.1$ A

$V = IR$

$= 0.1 \times 10$

$= 1V$

69. **2073 Set C Q.No. 9c** **Resistance of a wire of length 1m, diameter 1 mm is 2.2Ω. Calculate its resistivity and conductivity.** **[4]**

Solution

Given,

Resistance of wire (R) = 2.2Ω

Length of a wire (l) = 1m

Diameter of wire (d) = 1mm = 10^{-3} m

Resistivety of wire (ρ)= ?

Conductivity of wire (σ) = ?

We have,

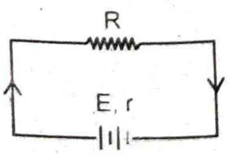
Resistivity $(\rho) = \frac{RA}{l} = \frac{R \cdot \pi d^2}{4l} = \frac{\pi \cdot (10^{-3})^2 \times 2.2}{4 \times 1} = 1.727 \times 10^{-6}\ \Omega m$

Conductivity $(\sigma) = \frac{1}{\rho} = \frac{1}{1.727 \times 10^{-6}} = 579038.8\ \Omega^{-1} m^{-1}$

70. **2073 Set D Q.No. 9a** **An electric lamp consumes 60 W at 220V. How many dry cells of emf 1.5V and internal resistance 1Ω are required to glow the lamp?** **[4]**

Solution

Given,



Power (P) = 60W

Voltage (V) = 220 V

E.M. F of cell (E) = 1.5 V

Internal resistance (r) = 1 Ω

No. of cell (n) = ?

We have,

$P = IV$

$60 = I \times 220$

$I = 0.2727$ A

Again,

$$P = \frac{V^2}{R} \Rightarrow R = \frac{V^2}{P} = \frac{220^2}{60} = 806.67\Omega$$

And,

$$I = \frac{nE}{R + nr}$$

$$\text{or, } 0.2727 = \frac{1.5n}{806.67 + n}$$

$$\text{or, } 220 = (1.5 - 0.2727)n$$

$$\text{or, } n = \frac{220}{1.2273} = 179$$

$\therefore$ No. of cell = 179

71. 2072 Supp Q.No. 9c **A copper wire has a diameter of 1.02 mm, cross-sectional area 8.2×10^{-7} m^2 and resistivity 1.72×10^{-8} Ω m. It carries a current 1.67 A. Find the electric field magnitude in the wire and the potential difference between two points in the wire 50 m apart.** [4]

Solution

Given,

Diameter of wire (d) = 1.02 mm = 1.02×10^{-3} m

Area of wire (A) = 8.2×10^{-7} m^2

Resistivity of wire (ρ) = 1.72×10^{-82} Ωm

Current in wire (I) = 1.67 A

Distance (d) = 50 m

P.D. (V) = ?

Electric field intensity (E) = ?

We have,

$$E = \rho J$$

$$= \rho \frac{I}{A} \qquad \left[J = \frac{I}{A} = \text{Current density}\right]$$

$$= \frac{1.72 \times 10^{-8} \times 1.67}{8.2 \times 10^{-7}} = 0.0350 \text{ V/m}$$

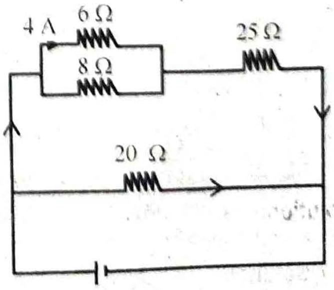
Again, V $= E \times d = 0.0350 \times 50 = 1.75$ V

72. 2072 Set C Q.No. 9a **The resistance of a galvanometer coil is 9.36Ω, and the current required for full scale deflection is 0.0224A. We want to convert this galvanometer to an ammeter reading 20A full scale. The only shunt available has a resistance of 0.025Ω. What resistance must be connected in series with the coil.** [4]

Please refer to 2076 Set C Q.No. 9a

73. 2071 Supp Q.No. 9a

Consider the figure below. The current through 6Ω resistor is 4A in the direction shown. What are the currents through the 25Ω and 20Ω resistors? [4]



Solution

Given,

Here, $R_1 = 6\Omega$, $R_2 = 8\Omega$,

$R_3 = 25\Omega$, $R_4 = 20\Omega$

Since R_1 and R_2 are parallel

P.D. across R_1 = P.D. across R_2

$I_1 \times R_1 = I_2 \times R_2$

$4 \times 6 = 8 \times I_2$

$I_2 = 3A$

Total current through path AC = 4 + 3 = 7A

So, current through 25Ω is 7A.

Now,

$R_{AC} = R_1 || R_2 + R_3 = \frac{6\times 8}{6+8} + 25 = \frac{48}{14} + 25 = 28.43\Omega$

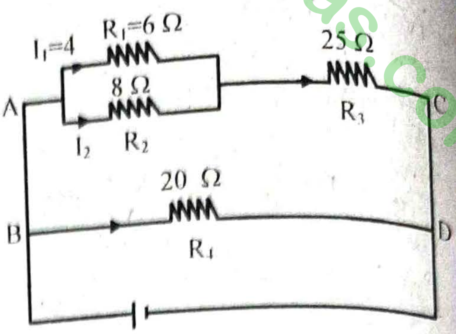
Since R_{AC} & R_{BD} are parallel,

P.D. across R_{AC} = P.D. across R_4

$28.43 \times 7 = 20 \times I_4$

or, $I_4 = \frac{28.43 \times 7}{20} = 9.95$ A

$\therefore I_4 = 9.95$ A



74. **2071 Set D Q.No. 9 b** **In the given figure, the current through the 3 Ω resistor is 0.8 A. Find the potential d... across 4 Ω resistor.**

Solution

Given,

$R_1 = 3\,\Omega$

$R_2 = 6\,\Omega$

$R_3 = 4\,\Omega$ and

$I_1 = 0.8$ A

Since, R_1 and R_2 are parallel,

potential across R_1 = potential across R_2

or, $I_1R_1 = I_2R_2$

or, $0.8 \times 3 = I_2 \times 6$

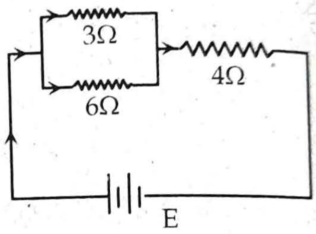
or, $I_2 = \frac{2.4}{6}$

$I_2 = 0.4$ A

Total current through the circuit is

$I = I_1 + I_2 = 0.4 + 0.8 = 1.2$ A

Potential across 4Ω = 4 × 1.2 = 4.8 V .



75. **2070 Sup (Set A) Q.No. 9 c** **A cell of emf 18 V has an internal resistance of 3 Ω. The terminal p.d. of the batt... becomes 15 V when connected by a wire. Find the resistance of the wire.**

Solution

Given,

emf of cell (E) = 18V

Internal resistance (r) = 3Ω

Potential difference (V) = 15V

Resistance of wire (R) = ?

Let I be the current flowing through the circuit, then

$E = V + Ir$

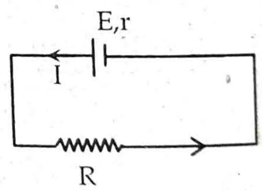
or, $I = \frac{E-V}{r} = \frac{18-15}{3} = 1$A

Again,

$V = IR$

$15 = 1 . R$

or, $R = 15\,\Omega$



76. **2070 Supp. (Set B) Q.No. 9 a** **A potential difference of 4.5 V is applied between the ends of wire that is 2.5... long and has radius of 0.654 mm. The resulting current through the wire is 17.6 A. What is the resistivity... the wire?**

Solution

Given,

Potential difference (V) = 4.5 V

Length of wire (l) = 2.5 m

Radius of wire (r) = 0.654 mm = 0.654×10^{-3}m

Current through wire (I) = 17.6A

Resistivity of wire (ρ) = ?

We know,

$$R = \frac{V}{I} = \frac{4.5}{17.6} = 0.256\ \Omega$$

Again

$$R = \rho \frac{l}{A}$$

$$\text{or, } \rho = \frac{RA}{l} = \frac{R.\pi r^2}{l} = \frac{0.256 \times \pi \times (0.654 \times 10^{-3})^2}{2.5} = 1.376 \times 10^{-7}\ \Omega m$$

77. **2070 Set C Q.No. 9 a** **A tightly coiled spring having 75 coils, each 3.50 cm in diameter, is made of insulated metal wire 3.25 mm in diameter. An ohm meter connected across its opposite ends reads 1.74 Ω. What is the resistivity of the metal? [4]**

Solution

Given,

Number of turns of coil (N) = 75

Diameter of coil (D) = 3.5 cm = 3.5×10^{-2} m

Diameter of wire (d) = 3.25 mm = 3.25×10^{-3}m

Resistance of wire (R) = 1.74 Ω

Resistivity of wire (ρ) = ?

We have,

$$\rho = \frac{RA}{L} = \frac{R.\frac{\pi d^2}{4}}{\pi D \times N} \quad [\because L = \text{length of wire} = N \times \text{circumference} = N \times \pi D]$$

$$= \frac{R\pi d^2}{4\pi DN} = \frac{Rd^2}{4DN} = \frac{1.74 \times (3.25 \times 10^{-3})^2}{4 \times (3.5 \times 10^{-2}) \times 75} = 1.75 \times 10^{-6}\ \Omega\text{ m.}$$

78. **2070 Set D Q.No. 9 a** **A voltmeter coil has resistance 50 Ω and a resistor of 1.15 K Ω is connected in series. It can read potential differences upto 12 volts. If the same coil is used to construct an ammeter which can measure currents upto 2A, what should be the resistance of the shunt used? [4]**

Solution

Given,

The voltmeter resistance (G) = 50 Ω

Series resistance (R) = 1.15 KΩ = 1.15×10^3 Ω

Voltmeter reading (V) = 12 V

Ammeter reading (I) = 2A

Shunt (S) = ?

Now, we have,

$$V = I_g (R + G)$$

$$I_g = \frac{V}{R+G} = \frac{12}{1.15 \times 10^3 + 50} = 0.01\ A$$

Again, for shunt,

$$S(I - I_g) = I_g . G$$

$$\therefore S = \frac{I_g}{I - I_g} G = \frac{0.01}{2 - 0.01} \times 50 = 0.25\ \Omega$$

79. **2069 (Set A) Q.No. 9 a** **In the given figure, when switch s is open, the voltmeter V reads 3.08V. When the switch is closed, the voltmeter reading drops to 2.97V, and the ammeter A reads 1.65A. Find the emf, the internal resistance of the battery and the resistor R. Assume that the two meters are ideal. [4]**

Solution

Given,

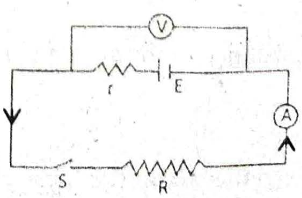
E.m.f. (E) = 3.08V

Voltage (V) = 2.97 V

Current (I) = 1.65 A

Internal resistance (r) = ? &

External resistance (R) = ?



We have, $E = V + Ir$

$3.08 = 2.97 + 1.65\ r$

or, $r = 0.067\ \Omega$

Again, $V = IR$ or, $R = \frac{V}{I} = \frac{2.97}{1.65} = 1.8\Omega$

80. **2069 (Set A) Q.No. 9 c** **The resistance of a conductor is 10 ohm at 50°C and 15 ohm at 100°C. Calculate its resistance at 0°C.** **[4]**

Solution

Given,

Temperature (t) = 50° C

Resistance (R_{50}) = 10 Ω

at 100°C, R_{100} = 15 Ω

at 0°C, R_0 = ?

We know,

$R_2 = R_1 (1 + \alpha\,\Delta\,\theta)$ [α = temp. coefficient of resistance]

so,

$R_{50} = R_0 (1 + \alpha\, 50)$

and

$R_{100} = R_0 (1 + \alpha\, 100)$

$\therefore \frac{R_{100}}{R_{50}} = \frac{1 + 100\alpha}{1 + 50\alpha}$

or, $\frac{15}{10} = \frac{1 + 100\alpha}{1 + 50\alpha}$

or, $15 + 750\alpha = 10 + 1000\alpha$

or, $5 = 250\ \alpha$

or, $\alpha = 0.02\ K^{-1}$

$\therefore R_{50} = R_0 (1 + \alpha\, 50)$

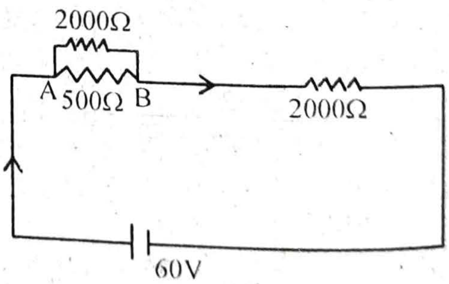
$10 = R_0 (1 + 0.02 \times 50)$

$10 = R_0 (1 + 1)$

$\therefore R_0 = 5\ \Omega$

81. **2068 Q.No. 9 a** **A resistor of 500 Ohms and one of 2000 Ohms are placed in series with a 60 volt supply. What will be the reading on a voltmeter of internal resistance 2000 Ohms when placed across (i) the 500Ω resistor and (ii) the 2000Ω resistor?** **[4]**

Solution



Given,

R_1 = 500Ω

R_2 = 2000 Ω

Emf (E)= 60V

Internal resistance of voltmeter (Rv) = 2000Ω

Now,

For (i)

When the voltmeter is placed across R_1, the equivalent resistance of the 500Ω resistor and the voltmeter is

$R_{AB} = \frac{2000 \times 500}{(2000 + 500)} = 400\Omega$

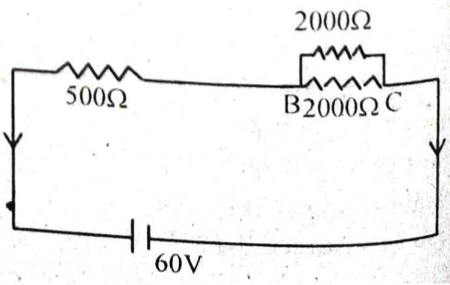
Then

Total resistance in the circuit (R) $= R_{AB} + R_2$

$= 400\Omega + 2000\Omega$

$= 2400\Omega$

$\therefore$ Current in the circuit (I) $= \frac{E}{R} = \frac{60}{2400} = \frac{1}{40}$ A



$\therefore$ Reading on voltmeter $= I \times R_{AB} = \frac{1}{40} \times 400 = 10$ V

Hence,
The required voltmeter reading in this case is 10V.

For (ii)
When the voltmeter is placed across R_2, the equivalent resistance of the 2000Ω resistor and the voltmeter is;

$$R_{BC} = \frac{2000 \times 2000}{2000 + 2000} = 1000\Omega$$

Then,
Total resistance in the circuit $= R_{BC} + R_1 = 1000 + 500 = 1500\Omega$

$\therefore$ Current in the circuit (I) $= \frac{E}{R} = \frac{60}{1500} = \frac{1}{25}$ A

$\therefore$ Reading on voltmeter $= I \times R_{BC} = \frac{1}{25} \times 1000 = 40$ V

Hence, required voltmeter reading in this case is 40 V.

82. 2068 Can. Q.No. 9a An electric heating element to dissipate 480 watts on 240V mains is to be made from nichrome wire of 1mm diameter. Calculate the length of the wire required if the resistivity of nichrome is 1.1×10^{-6} ohm-meter. [4]

Solution

Given,
Power (P) = 480 watts
Potential difference (V) = 240V
Diameter of nichrome wire (d) = 1mm = 10^{-3}m

$\therefore$ Area of cross – section (A) $= \frac{\pi d^2}{4} = \frac{\pi \times (10^{-3})^2}{4} = 7.85 \times 10^{-7} m^2$

Resistivity (ρ) $= 1.1 \times 10^{-6}\Omega$m
Length of the wire (l) = ?
Now, We have,

$$P = I \times V = \frac{V}{R} \times V = \frac{V^2}{R}$$

or, $R = \frac{V^2}{P} = \frac{(240)^2}{480} = 120\Omega$

Again, we have;

$$R = \frac{\rho l}{A}$$

or, $l = \frac{RA}{\rho} = \frac{120 \times 7.85 \times 10^{-7}}{1.1 \times 10^{-6}} = 85.6$m

Hence, the required length is 85.6m.

83. 2068 Old Q.No. 11 b An electric heating element to dissipate 1.2 KW on 240 V mains is to be made from Nichrome ribbon 1mm wide and 0.05 mm thick. Calculate the length of the ribbon required if the resistivity of nichrome is $1.1\times10^{-6}\Omega$ m. [3]

Solution

Given,
Power (P) = 1.2 KW = 1200 W
Potential difference (V) = 240 V
Wide of ribbon (b) = 1mm = 1×10^{-3} m
Thinkness of ribbon (t) = 0.05 mm= 5×10^{-5} m
Resistivity of Nidrome (ρ) = 1.1×10^{-6} Ωm
Length of ribbon (l) = ?
Now, we have

$$P = IV = \frac{V}{R} \times V = \frac{V^2}{R}$$

or, $R = \frac{V^2}{P} = \frac{240^2}{1200} = 48\Omega$

Again,

$R = \frac{\rho l}{A}$

or, $l = \frac{RA}{\rho}$ [A = b × t]

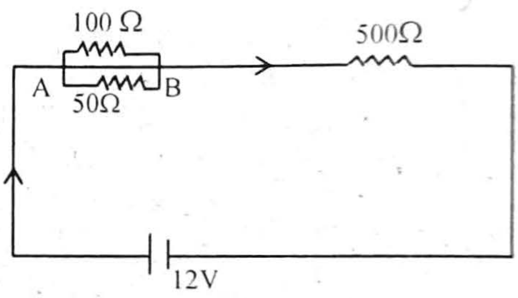
$= \frac{R \times b \times t}{\rho}$

$= \frac{48 \times 1 \times 10^{-3} \times 5 \times 10^{-5}}{1.1 \times 10^{-6}}$

$= 2.2$ m

84. 2067 Sup Q.No. 9a What is the potential difference across 100Ω resistor in the circuit given below. [4]

Solution



Given,

Emf (E) = 12V

$R_1 = 100\Omega$

$R_2 = 50\Omega$

$R_3 = 500\Omega$

$V_1 = ?$

Now,

If R be the total resistance of the circuit; we have;

$R = R_1 || R_2 + R_3$

$= \frac{100 \times 50}{(100 + 50)} + 500 = 533.33\Omega$

Then;

Total current (I) $= \frac{E}{R} = \frac{12}{533.33}$ Ampere $= 0.0225$A

We have

$I_3 = I = 0.0225$A

Then,

$V_3 = I_3R_3 = 0.0225 \times 500 = 11.25$V

Finally;

$V_1 = V_2 = (12 - 11.25) = 0.75$V

Hence, the required voltage is 0.75V.

85. 2062 Q.No. 11 b Twelve cells each of e.m.f. 2V and of internal resistance 0.5 ohm are arranged in a battery of n rows and an external resistance 0.4 ohm is connected to the poles of the battery. Estimate the current flowing through the resistance in terms of n. [3]

Solution

Given,

No. of cells (N) = 12

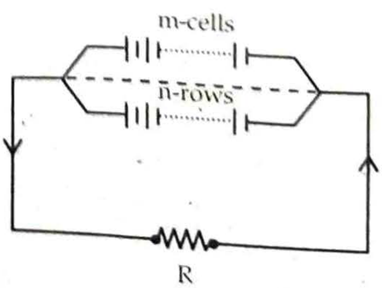
Emf (E) = 2V

Internal resistance (r) = 0.5 Ohm

No. of rows = n

External resistance (R) = 0.4Ω

Current (I) = ?



Let, 'm' be the no. of cells in each row;

Then, we have;

$m \times n = 12$

$\therefore m = \frac{12}{n}$

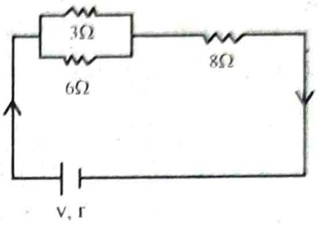
Now, we have;

$$I = \frac{mE}{\frac{mr}{n} + R} = \frac{mnE}{mr + nR} = \frac{12 \times 2}{\frac{12}{n} \times 0.5 + n \times 0.4} = \frac{24\,n}{6 + 0.4n^2} = \frac{\frac{24n}{0.4}}{\frac{6 + 0.4n^2}{0.4}} = \frac{60n}{15 + n^2}\text{ A}$$

Hence, the required current flowing through the resistance is $\frac{60n}{15 + n^2}$ Ampere.

86. **2061 Q.No. 11 b** **As shown in the figure, a battery of emf 24V and internal resistance r is connected to a circuit containing two parallel resistors of 3Ω and 6Ω in series with an 8Ω resistor. The current flowing in the 3Ω is 0.8A. Calculate the current in the 6Ω resistor and the internal resistance of the cell.** **[3]**

Solution



Given,

Emf (E)= 24V

$R_1 = 3\Omega$ $\quad R_2 = 6\Omega$

$R_3 = 8\Omega$ $\quad I_1 = 0.8A$

$I_2 = ?$

Internal resistance (r) = ?

Now,

The equivalent resistance of the circuit is given as;

$R_T = R_1//R_2 + R_3$

$= \frac{R_1R_2}{R_1 + R_2} + R_3 = \left(\frac{6 \times 3}{6 + 3} + 8\right)\Omega = 10\,\Omega$

Then,

Total current $(I_T) = \frac{E}{R_T} = \frac{24}{(10 + r)}$ A

We have, For R_1; using

$V_1 = I_1R_1 = 0.8 \times 3$

$\therefore V_1 = 2.4V$

Here, $V_1 = V_2 = 2.4V$

Then, for R_2 using;

$V_2 = I_2 \times R_2$

or, $2.4 = I_2 \times 6$

$\therefore I_2 = 0.4$ A

Here, the current in the 6Ω resistor is 0.4A.

Again, we have

$I_T = I_1 + I_2$

or, $\frac{24}{10 + r} = 0.8 + 0.4$

or, $\frac{24}{10 + r} = 1.2$

or, $10 + r = 20$

$\therefore r = 10\Omega$ which is required internal resistance.

87. **2060 Q.No. 11 b** **A battery of emf 1.5 V has a terminal p.d. of 1.25 V when a resistor of 25Ω is joined to it. Calculate the current flowing, the internal resistance and terminal p.d. when a resistance of 10Ω replaces 25Ω resistor.** **[4]**

Solution

Given,

Emf(E) = 1.5V

Terminal p.d (V) = 1.25V

Ex. Resistance (R) = 25 Ω

Current flowing (I) = ?

Internal resistance (r) = ?

Now, we have,

Current (I) $= \frac{V}{R} = \frac{1.25}{25} = 0.05A$

Hence, the required current is 0.05A.

Again, we have,

$$I = \frac{E}{R + r}$$

or, $0.05 = \frac{1.5}{25 + r}$

or, $25 + r = 30$

$\therefore$ $r = 5\,\Omega$

Hence, the required internal resistance is 5Ω.

Lastly, if a resistance of 10Ω replaces 25Ω,

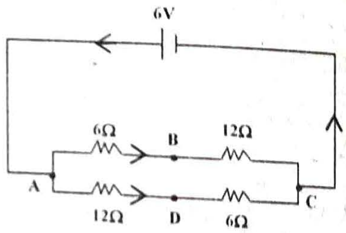
We have,

$$V' = I'R' = \frac{E}{(R' + r)} \times R' = \frac{1.5}{10 + 5} \times 10 = 1V$$

Hence, the required terminal p.d. is 1V.

88. **2058 Q.No. 11 b** **In the given circuit, calculate the potential difference between the points B and D.**

Solution



Given,

Emf of cell (E) = 6 V

Potential difference between B and D,

$(V_{BD}) = ?$

Total resistance $R_{AC} = (6 + 12) || (6 + 12)$

$= 18 || 18$

$= \frac{18 \times 18}{18 + 18} = 9\,\Omega$

Total current in the circuit (I) $= \frac{E}{R_{AC}} = \frac{6}{9} = \frac{2}{3}$ A

Then, $I_{AB} = \frac{1}{3}$ and $I_{AD} = \frac{1}{3}$

Now,

$V_{AB} = \frac{1}{3} \times 6 = 2$ V

$V_{AD} = \frac{1}{3} \times 12 = 4$ V

$\therefore$ $V_{BD} = V_{AD} - V_{AB}$

$= 4 - 2$

$= 2$ V

❑❑❑

Chapter 2: Electrical Circuits

Short Answer Questions

1. **2076 Set B Q.No. 1a State the principle of potentiometer and write down its one application.** **[2]**

Principle of potentiometer: When a constant current is passed through a wire of uniform cross-section area of potentiometer, the potential drop across any portion of wire is directly proportional to the length of that portion of wire.

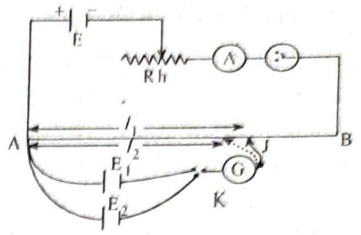
Let us consider a wire having uniform cross sectional area A length l and resistance R. If V is the potential difference across two ends of wire and I be the current flow through it, then

$$V = IR = I\rho\frac{l}{A} \qquad [\because R = \rho\frac{l}{A}]$$

$\Rightarrow V \propto l$ for constant A and I.

This is the principle of potentiometer.

Potentiometer is used to find internal resistance of a cell.



2. **2075 GIE Q.No. 1b If the current flowing in the wire of the potentiometer be decreased, what will be the effect on the position of zero deflection in potentiometer? Explain.** **[2]**

If the current flowing in the wire of potentiometer be decreased, there will be no effect on the position of zero deflection in potentiometer because the principle of potentiometer state that when constant current is passed through a wire of potentiometer, the p.d. across any segment of wire is directly proportional to length i.e. $v \propto l$ at constant I.

3. **2075 Set B Q.No. 1a 2074 Set B Q.No. 1b Why do we prefer a potentiometer with longer wire?** **[2]**

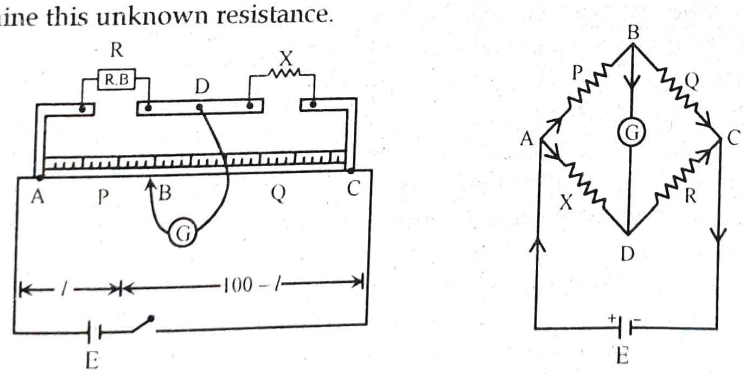
The potentiometer works on the principle that the potential difference between two ends of a wire is directly proportional to the length of wire, i.e. $V \propto l$, or $V = K\,l$, where k is constant for potentiometer. If the length of potentiometer wire be long, the potential difference per unit length K becomes small and the sensitivity of the device increases. So, we prefer a potentiometer with longer wire to take accurate data.

4. **2074 Supp Q.No. 1b 2072 Set D Q.No. 1b Draw a circuit diagram of meter bridge to determine the resistance of a wire. Write the formula used.** **[2]**

A meter bridge is an electric device used for measuring unknown resistance. It works on the principle of Wheatstone bridge which states for balanced condition of circuit as,

$$\frac{P}{Q} = \frac{R}{X};$$

where, P, Q and R are known resistance and X is unknown resistance. Meter bridge is used to determine this unknown resistance.



(a) (b)

$$\text{or,} \quad \frac{\text{Resistance of AB}}{\text{Resistance of BC}} = \frac{P}{Q}$$

Since, resistance $\propto$ length. i.e. $P \propto l$ and $Q \propto (100 - l)$

$$\text{i.e.,} \frac{P}{Q} = \frac{l}{100 - l} = \frac{R}{X}$$

$$\text{or, } X = \frac{(100 - l)R}{l}$$

Hence, the value of X is calculated at different values of R and mean is calculated.

5. 2074 Set A Q.No. 1b 2072 Set C Q.No. 1a 2070 Set D Q.No. 1 b 2069 Set A Q.No. 1 b **Why do we prefer a potentiometer to measure emf of a cell rather than a voltmeter?** [2]

Potentiometer work's on null deflection method which gives accurate value while the voltmeter works on deflection method. EMF of a cell is equal to the potential difference across the terminals of the cell when no current is drawn from the cell. Since potentiometer draws no current from the cell, it can measure the emf of the cell accurately. The deflection method gives more error than null method because on deflection the voltmeter draws some current. So, we prefer a potentiometer to measure emf of a cell rather than a voltmeter.

6. 2071 Set C Q.No. 1 b **If the length of the wire be doubled, what will be the effect on the position of zero deflection in a potentiometer?** [2]

The potentiometer works on the principle that the potential difference between two ends of a wire is directly proportional to the length of a wire. i.e., $V \propto l$. This shows that the position of zero deflection in a potentiometer increases from the initial reference point.

7. 2071 Set D Q.No. 1 b **State and explain Kirchhoff's laws of electric circuits.** [2]

Kirchhoff's laws of electric circuits:

There are two Kirchhoff's laws in electricity:

a. **Kirchhoff's current law (KCL):** It states that, the algebraic sum of the currents meeting at a junction in an electrical circuit is zero. i.e., mathematically, $\Sigma I = 0$. It means, the sum of current flowing towards any junction in an electrical circuit is equal to the sum of currents flowing away from that junction. This law is also termed as the junction law. This law is based on the principle of conservation of charge.

b. **Kirchhoff's voltage law (KVL):** It states that, in any closed electrical circuit (loop or mesh), the algebraic sum of all the emfs is always equals to the algebraic sum of voltage drops in resistors. i.e., mathematically,

$\Sigma E = \Sigma V$ or, $\Sigma E = \Sigma IR$. This law is also called as loop law. This law is based on the principle of conservation of energy.

8. 2069 (Set B) Q.No. 1 d **How would you convince that the principle of measurement of resistance of wire by meter bridge is based on Wheatstone bridge principle? Explain.** [2]

Please refer to 2074 Supp Q.No. 1b

9. 2062 Q.No. 10 c **State Kirchhoff's laws of electric circuits.** [2]

Please refer to 2071 Set D Q.No. 1 b

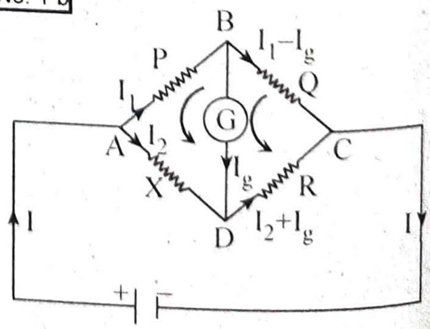
Long Answer Questions

10. 2076 Set C Q.No. 5b 2074 Set B Q.No. 5a 2070 Set C Q.No. 5 a **State and explain Kirchhoff's laws and use these laws to find the balance condition in a wheatstone bridge circuit.** [4]

Kirchhoff's laws of electric circuits: Please refer to 2071 Set D Q.No. 1 b

Balance Condition in a Wheatstone Bridge Circuit:

Wheatstone bridge: An arrangement of four resistances, three of them are known and the fourth can be determined in term of the three known resistances is called Wheatstone bridge. It is an electrical circuit which can be used for accurate measurement of resistance of conductor. The principle of Wheatstone bridge is that, when the bridge is balanced, the products of resistances of the opposite arms of circuits are equal



i.e., $\frac{P}{Q} = \frac{X}{R}$; where P, Q and R are known resistance and X is unknown resistance.

Balance Condition in a Wheatstone Bridge Circuit: The circuit diagram of wheat stone bridge to determine the resistance of unknown resistance is as shown in figure. It consists of three known resistances P, Q and R and a fourth unknown resistance X. a source of emf is connected between two points A and C and a galvanometer between B and D whose resistance is G. This circuit is called bridge because the galvanometer circuit is bridged across ABC and ADC parallel branches. If I be the current at the junction A, the current get divided at this junction.

I_1 be the fraction of current flows through resistance P, I_2 be the current through the resistance X and I_g be the current through galvanometer.

Applying Kirchoff's current law at junction A,

$$I = I_1 + I_2 \quad \dots (i)$$

Considering the closed mesh ABDA, applying Kirchoff's voltage law,(Taking anticlockwise direction as positive)

$$-I_1P - I_g G + I_2X = 0 \quad \dots (ii)$$

Similarly, considering the closed mesh BCDB, applying Kirchoff's second law, (Taking anticlockwise direction as positive)

$$-(I_1 - I_g)Q + (I_2 + I_g) R + I_g G = 0 \quad \dots (iii)$$

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

From equation (ii), we get

$$-I_1P + I_2X = 0 \Rightarrow I_1P = I_2 X \quad \dots (iv)$$

From equation (iii), we get

$$-I_1Q + I_2R = 0 \Rightarrow I_1Q = I_2R \quad \dots (v)$$

From (iv) and (v), we get

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

This is the required balance condition.

11. **2075 Set A Q.No. 5b** **2073 Supp Q.No. 5a** **2070 Sup (Set A) Q.No. 5 a** **State the principle of potentiometer. Discuss the application of potentiometer to determine the internal resistance of a cell.** **[4]**

A potentiometer is a sensitive electrical device used to measure emf of cell without drawing any current from it, find internal resistance of cell and to compare the emfs of two cells.

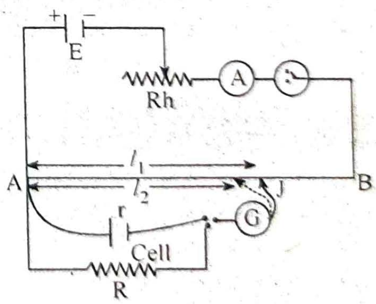
Principle of potentiometer: When a constant current is passed through a wire of uniform area of cross-section of potentiometer, the potential drop across any position of wire is directly proportional to the length of that portion of potentiometer wire.

Let us consider a wire having uniform cross sectional area A, length l and resistance R. If V is the potential difference across two ends of wire and I be the current flow through it, then

$$V = IR = I\rho\frac{l}{A} \quad [\because R = \rho\frac{l}{A}]$$

i.e., $V \propto l$ for constant A and I, which is the principle of potentiometer.

Determination of internal resistance of battery: The circuit diagram for the determination of internal resistance of battery is as shown in figure. It consists of a driving cell of emf E whose positive end is connected across the point A of the potentiometer and negative terminal is connected at B via rheostat.



A known resistance R is connected across parallel to cell whose emf is E_1 and internal resistance r (to be determined). When the key is open, i.e., open circuit, there is no current flow through resistance R and potential difference found is equal to emf of the cell. The jockey is adjusted to touch the wire at a point where there is no deflection in galvanometer. Let the balancing length is l_1, then,

$$E_1 \propto l_1 \quad \dots (i)$$

Similarly, if key is connected across known resistance R and the balancing length is l_2, then $V \propto l_2$ ... (ii)

Dividing (i) by (ii) we get

$$\frac{E_1}{V} = \frac{l_1}{l_2} \quad \dots (iii)$$

Since, $E_1 = V + Ir$ and $V = IR$, we have

$$\frac{IR + Ir}{IR} = \frac{l_1}{l_2}$$

or, $\frac{R + r}{R} = \frac{l_1}{l_2}$

or, $1 + \frac{r}{R} = \frac{l_1}{l_2} \Rightarrow \frac{r}{R} = \frac{l_1 - l_2}{l_2}$

$$\Rightarrow r = \frac{R(l_1 - l_2)}{l_2}$$

By knowing the value of R, we can calculate internal resistance of cell by using potentiometer.

12. 2075 Set B Q.No. 5b **State Kirchhoff's laws and use them to derive Wheat Stone's bridge principle.** **[4]**

Kirchhoff's laws: Please refer to 2071 Set D Q.No. 1 b

Wheat Stone's bridge principle: Please refer to 2076 Set C Q.No. 5b

13. 2073 Set C Q.No. 5a **State and apply Kirchoff's rule of electrical circuits to measure the unknown resistance of a wire by metre bridge with necessary theory and circuit.** **[4]**

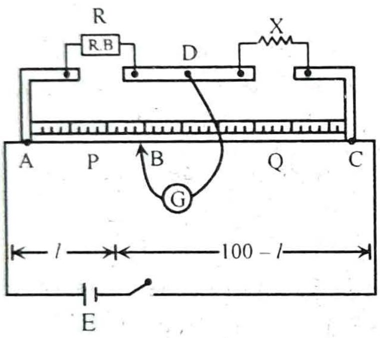
Kirchhoff's laws: Please refer to 2071 Set D Q.No. 1 b

Second part:

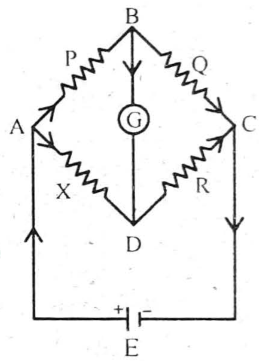
A meter bridge is the simplest practical form of the Wheatstone bridge. It consists of a resistive wire of uniform cross-sectional area so that its resistance per unit length remains constant. The length of wire is often a meter. Due to this reason the device is called meter bridge. It works on the principle of Wheatstone bridge which states for balanced condition of circuit as,

$$\frac{P}{Q} = \frac{R}{X};$$

where P, Q and R are known resistance and X is unknown resistance. Meter bridge is used to determine this unknown resistance.



(a)



(b)

Meter bridge consists of a wire AC of 1m long permanently fitted between two fixed terminals made on a wooden board having a parallel measuring scale. Points A and C are connected to a cell and B and D are connected to Galvanometer G. A resistance box is connected between A and B and an unknown resistance X is connected between D and C. A sliding jockey is connected on galvanometer as shown in figure. When the jockey is sliding on the wire at balance condition B, the galvanometer shows zero deflection. At this condition,

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

$$\text{or, } \frac{\text{Resistance of AB}}{\text{Resistance of BC}} = \frac{P}{Q}$$

Since, Resistance $\propto$ length. i.e., $P \propto l$ and $Q \propto (100 - l)$

$$\text{i.e. } \frac{P}{Q} = \frac{l}{100 - l} = \frac{R}{X}$$

$$\text{or, } X = \frac{(100 - l)R}{l}$$

Hence, the value of X is calculated at different values of R and mean R is calculated.

14. 2072 Set C Q.No. 5b **State principle of meter bridge. Describe how it is used to determine the resistance of a wire.** **[4]**

Please refer 2073 Set C Q.No. 5a

15. 2071 Set D Q.No. 5 a **What is the principle of a potentiometer? Explain with necessary theory, how you would determine the internal resistance of a cell using this principle.** **[4]**

Please refer to 2075 Set A Q.No. 5b

16. 2070 Set D Q.No. 5 a 2068 Old Q.No. 11 a 2059 Q.No. 11 a OR **What is Wheatstone bridge? Use Kirchhoff's laws of current and voltage to obtain balance condition of it.** [4]

Please refer to 2076 Set C Q.No. 5b

17. 2069 Supp Set B Q.No. 5 a **State the principle of potentiometer. How do you compare the internal resistances of two cells by using a potentiometer?** [4]

Please refer to 2075 Set A Q.No. 5b

18. 2069 (Set B) Q.No. 5c **Explain Kirchoff's laws. How are the conditions of balance in Wheatstone bridge established through these laws?** [4]

Kirchhoff's laws: Please refer to 2071 Set D Q.No. 1 b

Wheat Stone's bridge principle: Please refer to 2076 Set C Q.No. 5b

19. 2068 Can. Q.No. 5d **What is internal resistance of a cell? How can you measure the internal resistance of a cell by using potentiometer?** [4]

Internal resistance: The internal resistance of a cell is defined as the resistance offered by the electrolyte between electrodes of the cell when electric current passes through it. It is small for new cell and large for old cell.

Please refer to 2075 Set A Q.No. 5b

20. 2067 Sup Q.No. 5d **What is the principle of potentiometer? Describe a method to measure the internal resistance of a cell by using potentiometer.** [1+3]

Please refer to 2075 Set A Q.No. 5b

21. 2067 Q.No. 5a **What is potentiometer? How can you use it to measure internal resistance of a cell?** [1+3]

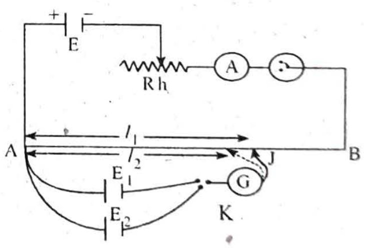
Please refer to 2075 Set A Q.No. 5b

22. 2062 Q.No. 11 a OR **Explain the principle of potentiometer. How is this used to measure the internal resistance of a cell?** [2+3]

Please refer to 2075 Set A Q.No. 5b

23. 2061 Q.No. 11 a OR **Discuss the principle of the potentiometer and use it to compare the emf's of two cells.** [2+3]

A *potentiometer* is a sensitive electrical device used to measure emf of cell without drawing any current from it, find internal resistance of cell and to compare the emfs of two cells.



Principle of potentiometer: When a constant current is passed through a wire of uniform cross-section area of potentiometer, the potential drop across any portion of wire is directly proportional to the length of that portion of wire.

Let us consider a wire having uniform cross sectional area A length l and resistance R. If V is the potential difference across two ends of wire and I be the current flow through it, then

$$V = IR = I\rho\frac{l}{A} \qquad [\because R = \rho\frac{l}{A}]$$

$\Rightarrow V \propto l$ for constant A and I.

This is the principle of potentiometer.

Comparison the emfs of two ells using a potentiometer: The circuit diagram which is used to compare the emfs of two cells having emfs E_1 and E_2 is as shown in above circuit diagram. E is driving cell whose emf must be larger than p.d. across the whole wire of potentiometer. The positive terminal of E_1 and E_2 are connected on the same end A where positive terminal of the driving cell is connected. Negative terminals are connected by two way key (K).

Galvanometer is connected in the common terminal. At first, key is connected across terminal of cell E_1. The jockey is adjusted to touch the wire at a point where there is no deflection in galvanometer.

Let the balancing length is l_1, then $E_1 \propto l_1$ ... (i) $[\because E_1 = V_{l_1}$ & $V_{l_1} \propto l_1]$

Similarly, if key is connected across terminal of cell E_2 and the balancing length is l_2, then $E_2 \propto l_2$ ... (ii) $[\because E_2 = V_{l_2}$ & $V_{l_2} \propto l_2]$

From relation (i) and (ii), we can write

$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$

By measuring the length l_1 and l_2, the ratio of E_1 and E_2 can be determined. Furthermore, if emf of one cell is known, the emf of another cell can be evaluated by using above relation.

24. 2060 Q.No. 11 a OR **Discuss the principle of potentiometer and use it to determine the internal resistance of a cell.** [2+3]

Please refer to 2075 Set A Q.No. 5b

25. 2058 Q.No. 11 a **What is a potentiometer? Explain how you compare the emfs of two cells using a potentiometer.** [1+4]

Please refer to 2061 Q.No. 11 a OR

Numerical Problems

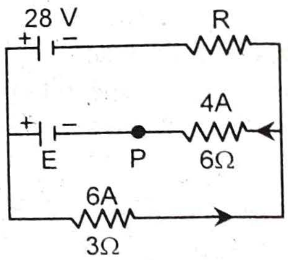
26. 2075 GIE Q.No. 9a **Using Kirchhoff's rules in the circuit, find** [4]

i. **the current in resistor R**

ii. **the resistance R**

iii. **the unknown emf E**

iv. **If the circuit is broken at P, what is the current in resistor R?**



Solution

For (i)

Using Kirchhoff's current law at junction D; we get

Current in R = (6 – 4) A = 2 A

Hence, the required current is 2 A.

For (ii)

Potential drop across 3Ω resistor = 3 × 6V = 18V

∴ Potential across $R(V_R)$ = (28 – 18)V = 10V.

Using;

$V_R = I_R \times R$

or, $10 = 2 \times R$

∴ $R = 5\Omega$

Hence, the required resistance is 5Ω.

For (iii)

Using KVL in loop ABCD; we get

$28 - E = I_R \times R - 6 \times 4$

or, $28 - E = 2 \times 5 - 24$

or, $28 - E = -14$

∴ $E = 42V$

Hence, the required emf is 42V

For (iv)

If the circuit is broken at 'P'

Total resistance in the circuit will be $R_T = (R + 3)\Omega = (5 + 3)\Omega = 8\Omega$

Then, using;

$V = I \times R$

or, $28 = I \times 8$

∴ $I = 3.5$ amp

Hence, the required current is 3.5 amp.

27. 2074 Supp Q.No. 9a **A potentiometer is 10 m long. It has a resistance of 20 Ω. It is connected in series with a battery of 3 V and a resistance of 10 Ω. What is the potential gradient along with wire?** [4]

Solution

Given,

Length of potentiometer (l_{AB}) = 10 m

Resistance of potentiometer (R_{AB}) = 20 Ω

E.m.f. of cell (E) = 3 V

Resistance of cell (r) = 10 Ω

Potential gradient $\left(\frac{V_{AB}}{l_{AB}}\right) = ?$

We have,

$$I = \frac{E}{R + r} = \frac{3}{20 + 10} = \frac{3}{30} = 0.1 \text{ A}$$

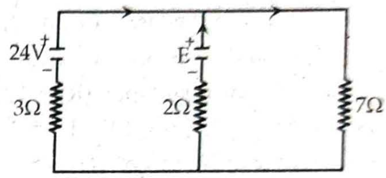
Again,

$$V_{AB} = I \times R_{AB}$$
$$= 0.1 \times 20 = 2 \text{ V}$$

Now,

$$\text{Potential gradient} = \frac{V_{AB}}{l_{AB}} = \frac{2}{10} = 0.2 \text{ V/m}$$

28. **2074 Set A Q.No. 9a** **What must be the emf E in the circuit so that the current flowing through the 7Ω resistor is 1.80A? Each emf source has negligible internal resistance. [4]**



Solution

From fig, at point E, using Kirchhoff's current law,

$I_1 + I_2 = 1.8$ ... (i)

In a closed loop AEFDA

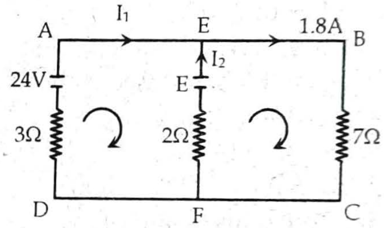
$24 - E = -2I_2 + 3I_1$

or, $24 - E = -2I_2 + 3(1.8 - I_2)$ from equation (i)

or, $24 - E = -2I_2 + 5.4 - 3I_2$

or, $18.6 - E = -5I_2$

or, $E = 5I_2 + 18.6$ ... (ii)



Again from closed loop, EBCFE

$E = 1.8 \times 7 + 2I_2$

or, $E = 12.6 + 2I_2$ ... (iii)

Solving equation (ii) and (iii), we get,

$I_2 = -2A$

Then, $I_1 = 3.8$

From equation (iii), we get

$E = 12.6 + 2(-2) = 8.6$ V

29. **2072 Supp Q.No. 9a**

A simple potentiometer circuit is setup as in fig Q(1), using a uniform wire AB, 1.0 m long, which has a resistance of 2Ω. The resistance of the 4V battery is negligible. If the variable resistor R were given a value of 2.4Ω, what would be the length AC for zero galvanometer deflection? [4]

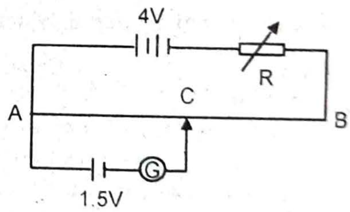


Fig. Q (1)

Solution

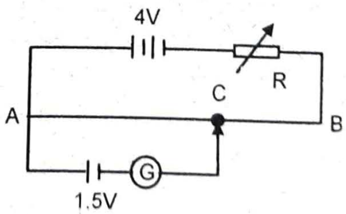
Length of wire AB (l_{AB}) = 1.0 m

Resistance of wire (R) = 2.4 Ω

E.m.f. of cell (E_1) = 4V.

Resistance across AB (R_{AB}) = 2 Ω

Length of AC (l_{AC}) = ?



For zero galvanometer deflection,

P.D. across AC = 1.5V

or, $I \cdot R_{AC} = 1.5$

$$\frac{4}{R + R_{AB}} \times R_{AC} = 1.5$$

$$\frac{4}{2.4 + 2} \times R_{AC} = 1.5$$

$$\text{or, } R_{AC} = \frac{1.5 \times 4.4}{4} = 1.65\ \Omega$$

Since, 2Ω wire AB has length 1 m.

1Ω wire AB has length $\frac{1}{2}$ m.

1.65Ω wire AB has length $\frac{1}{2} \times 1.65$ m = 0.825 m

$\therefore$ Length of AC = 0.825 m

30. **2072 Set D Q.No. 9a** **A battery of 6V and internal resistance 0.5Ω is joined in parallel with another of 10V and internal resistance 1Ω. The combination sends a current through an external resistance of 12Ω. Find the current through each battery.** **[4]**

Solution

Given,

Emf of one cell (E_1) = 6V

Emf of another cell (E_2) = 10V

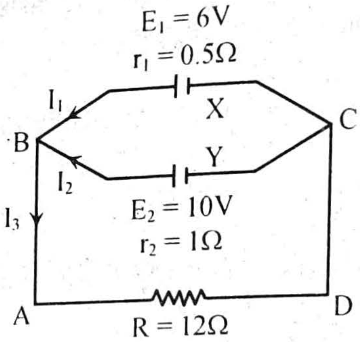
Internal resistance of one cell (r_1) = 0.5Ω

Internal resistance of another cell (r_2) = 1Ω

External resistance (R) = 12Ω

Current through E_1 (I_1) = ?

Current through E_2 (I_2) = ?



Using, KVL is closed loop ABXCDA, we've

$E_1 = I_1r_1 + I_3R$

or, $6 = I_1r_1 + (I_1 + I_2)R$

or, $6 = 0.5I_1 + 12I_1 + 12I_2$

or, $6 = 12.5\,I_1 + 12I_2$ ... (i)

Again, using KVL in closed loop ABYCDA, we've

$E_2 = I_2r_2 + I_3R$

or, $10 = I_2r_2 + (I_1 + I_2)R$

or, $10 = 12I_1 + 13I_2$ ... (ii)

Solving equations (i) and (ii), we get

$I_1 = -2.27$ A and $I_2 = 2.86$ A

31. **2072 Set E Q.No. 9a** **The total length of the wire of a potentiometer is 10m. A potential gradient of 0.0015 V/cm is obtained when a steady current is passed through this wire. Calculate,** **[4]**

i. **the distance of null point on connecting standard cell of 1.018V.**
ii. **the unknown p.d. if the null point is obtained at a distance of 940 cm, and**
iii. **the maximum p.d. which can be measured by this instrument.**

Solution

Given,

Length of potentiometer (L) = 10m

Potential gradient (K) = 0.0015 V/cm = 0.15 V/m

i. Distance of null point (l_1) = ?

Voltage of cell (V) = 1.018 V

We have,

$V \propto l$, for potentiometer,

or, $V = kl_1$

or, $1.018 = 0.15 \times l_1$

or, $l_1 = 6.8$ m

ii. P.d. (V) = ?

Length of null point (l_2) = 940 cm = 9.4 m

Again,

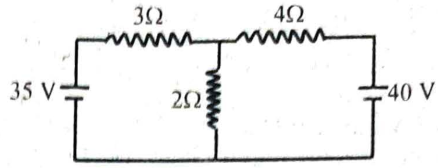
$V \propto l_2$

or, $V = kl_2 = 0.15 \times 9.4 = 1.41$ V

iii. Maximum P.d. (V_{max}) = ?

$V_{max} = K.L. = 0.15 \times 10 = 1.5$ V

32. 2071 Set C Q.No. 9 a **Using Kirchhoff's laws of current and voltage, find the current in 2Ω resistor in the given circuit:** **[4]**



Solution

From figure, in closed loop ABEFA

$3I_1 + 2I_3 = 35$ … (i)

In closed loop BCDEB

$4I_2 + 2I_3 = 40$ … (ii)

At junction B, using Kirchoff's current law

$I_1 + I_2 = I_3$ … (iii)

From (i) and (ii)

$4I_2 - 3I_1 = 5$ … (iv)

or, $4I_2 - 3(I_3 - I_2) = 5$

or, $4I_2 - 3I_3 + 3I_2 = 5$

$7I_2 - 3I_3 = 5$ … (v)

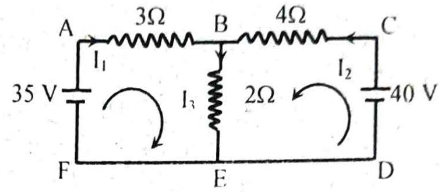
From (v) and (ii), we get

$I_3 = 10A, I_2 = 5A$

From (iii),

$I_1 = 5A$

∴ Current through 2Ω resistor is 10 A.



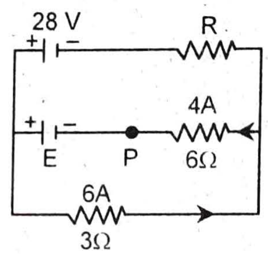
33. 2067 Q.No. 9a **In the adjacent circuit find:** **[4]**

i. the current in resistor R.

ii. resistance R,

iii. the unknown emf ε,

iv. if the circuit is broken at P, what is the current n resistor R ?



Please refer to 2075 GIE Q.No. 9a

34. 2064 Q.No. 11 b **The driver cell of a potentiometer has an e.m.f. of 2V and negligible internal resistance. The potentiometer wire has a resistance of 3 ohm. Calculate the resistance needed in series with the wire if a p.d. 5.0 mV is required across the whole wire. The wire is 100.0 cm long and a balanced length of 60 cm is obtained for a thermocouple of e.m.f. E. What is the value of E?** **[4]**

Solution

Given,

$E = 2V$ $\quad$ $R = 3\Omega$

$V = 5\ mV$ $\quad$ $R' = ?$

Suppose R' be the resistance needed in series with the wire.

From law of resistance, we can write

$R \propto l$

$$\Rightarrow \frac{R}{R'} = \frac{V}{(E - V)}$$

$$\frac{3}{R'} = \frac{5}{2 - 0.005}$$

$$\therefore R' = \frac{2 - 0.005}{0.005} \times 3 = 1197.2\Omega$$

Again,

$V = 5\ mV$ $\quad$ $d = 100\ cm$

$E = ?$ $\quad$ $l' = 60\ cm$

Using, $\frac{E}{V} = \frac{l'}{l}$

$$E = \frac{l'}{l} \times V = \frac{60}{100} \times 5 = 3mV = 3 \times 10^{-3}V$$

35. 2063 Q.No. 11 b **The driver cell of a potentiometer has an emf 2V and negligible internal resistance. The potentiometer wire has a resistance of 3Ω. Calculate the resistance needed in series with the wire if a p.d. of 5mV is required across the whole wire.** **[4]**

Solution

Given,

Emf (E) = 2V

Resistance (R) = 3Ω

p.d. (V) = 5mV = 5×10^{-3}V

Let, R′ be the resistance to be connected is series.

∴ Total resistance of the circuit (R_T) = R′ + 3

Here,

Current across the potentiometer circuit (I) = $\frac{E}{R_T} = \frac{2}{R' + 3}$

Also;

p.d. across potentiometer wire = I × R

or, $5 \times 10^{-3} = \frac{2}{R' + 3} \times 3$

or, $R' + 3 = \frac{6}{5 \times 10^{-3}}$

or, R′ + 3 = 1200

∴ R′ = 1197 Ω

Hence, the required resistance is 1197Ω.

36. 2059 Q.No. 11 b **The emf of a battery A is balanced by a length 75.0 cm on a potentiometer wire. The emf of a standard cell 1.02 volt is balanced by a length of 50.0 cm. What is the emf of A?** **[4]**

Solution

Let E_1 be the emf of a cell A.

Balancing length for A = l_1 = 75 cm

Emf of standard cell (E_2) = 1.02V

Balancing length for E_2 = l_2 = 50 cm

We know,

$$\frac{E_1}{E_2} = \frac{l_1}{l_2} \quad \Rightarrow E_1 = \frac{l_1}{l_2} \times E_2$$

$$E_1 = \frac{75}{50} \times 1.02 = 1.53 \text{ V}.$$

Hence, required emf of the cell A is 1.53 V.

37. 2056 Q.No. 11 b **The driving cell of a potentiometer has an e.m.f. of 2V and negligible internal resistance. The potentiometer wire has a resistance of 3Ω. Calculate the resistance needed in series with the wire if a p.d. of 1.5m V is required across the whole wire.** **[4]**

Solution

Given,

Emf(E) = 2V

Resistance (R) = 3Ω

p.d. (V) = 1.5 mV = 1.5×10^{-3}V

Let, R′ be the resistance to be connected in series.

∴ Total resistance of the circuit (R_T) = R′ + 3

Here,

Current across the potentiometer circuit (I) = $\frac{E}{R_T} = \frac{2}{R' + 3}$

Also;

We have,

p.d. across potentiometer wire = IR

or, $1.5 \times 10^{-3} = \frac{2}{R' + 3} \times 3$

or, R′ + 3 = 4000

∴ R′ = 3997Ω

Hence, the required resistance is 3997Ω.

□□□

Chapter 3: Waves in Pipes and Strings

Short Answer Questions

1. **2074 Set B Q.No. 3b** **2068 Can. Q.No. 3b** **The frequency of a fundamental note of a closed organ pipe and that of an open organ pipe are the same. What is the ratio of their lengths?** **[2]**

The frequency of a fundamental note of a closed pipe of length l_c is given by

$$f_c = \frac{v}{4l_c} \quad \dots (i)$$

And the frequency of a fundamental note of an open organ pipe of length l_o is given by

$$f_o = \frac{v}{2l_o} \quad \dots (ii)$$

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

$$\frac{f_c}{f_o} = \frac{l_o}{2l_c}$$

By question, $f_o = f_c$, $\frac{l_o}{l_c} = 2$, $l_o = 2l_c$. Hence, length of open pipe is double of closed pipe for same fundamental frequency.

2. **2073 Set C Q.No. 3a** **2073 Set D Q.No. 3b** **By what factor does the velocity of transverse wave in the string change when the tension in the stretched string in increased by four times.** **[2]**

The velocity of transverse wave in the string is given as

$$v = \sqrt{\frac{T}{\mu}} \quad \dots (i)$$

where T is the tension on the string, μ be the mass per unit length of the wire. If the tension in a given stretched string is increases by four times, then the velocity becomes,

$$v' = \sqrt{\frac{4T}{\mu}} \quad \dots (ii)$$

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

$\frac{v'}{v} = 2 \Rightarrow v' = 2v$. Hence, the velocity of transverse wave is increased by 2 times if the tension in a given stretched string is increased by four times.

3. **2072 Supp Q.No. 3a** **The six strings of a guitar are of the same length and are under nearly the same tension, but have different thickness. On which string do waves travel the fastest?** **[2]**

The velocity of transverse wave in a stretched string is given by

$$v = \sqrt{\frac{T}{\mu}}$$

Where,

T = Tension on string

$\mu = \frac{m}{L}$, mass per unit lengths $= \frac{\rho\pi d^2}{4}$

d = diameter of wire,

So, $v = \sqrt{\frac{4T}{\rho d^2}} = \frac{2}{d}\sqrt{\frac{T}{\rho\pi}}$

$\therefore$ $v \propto \frac{1}{d}$. Thus, velocity of wave is highest for thinnest string.

4. **2072 Supp Q.No. 3b** **How does the pitch of an organ pipe change with temperature?** **[2]**

We know that the pitch (frequency) of the organ pipe is directly proportional to the velocity of sound in air,

i.e., $f \propto v \quad \dots (i)$

Laplace equation for velocity of sound in air is

$$v = \sqrt{\frac{\gamma P}{\rho}} \quad \dots (ii)$$

For one mole of an ideal gas, we have

$PV = RT$

or, $P\dfrac{M}{\rho} = RT$

$\therefore \rho = \dfrac{PM}{RT}$

Then, Eq. (i) becomes,

$v = \sqrt{\dfrac{\gamma P}{PM}.RT}$

or, $v = \sqrt{\dfrac{\gamma . RT}{M}}$

or, $v = K\sqrt{T} \Rightarrow v \propto \sqrt{T}$ ... (iii)

Here, $K = \sqrt{\dfrac{\gamma R}{M}}$ is constant.

From Eq. (i) and (iii), we get

$f \propto \sqrt{T}$.

Hence, the frequency of the organ pipe is directly proportional to the square root of the absolute temperature. Therefore, the frequency of the organ pipe increases with increase in temperature.

5. **2071 Supp Q.No. 3a Does the frequency of sound produced by an organ pipe change with its diameter? Explain.** **[2]**

Yes, the frequency of sound wave produced by an organ pipe changes with its diameter. The fundamental frequency of an organ pipe is,

$f = \dfrac{v}{4(l + c)}$; closed pipe $\qquad f = \dfrac{v}{2(l + 2c)}$; open organ pipe

Since, $c = 0.3d$; end correction depends upon diameter 'd' of pipe, hence frequency also depends upon the diameter of organ pipe.

6. **2071 Set C Q.No. 3 b 2069 (Set A) Q.No. 2b What happens to the frequency of transverse vibration of a stretched string if its tension is halved and the area of cross section of the string is doubled?** **[2]**

The fundamental frequency of stretched string is

$f = \dfrac{1}{2l}\sqrt{\dfrac{T}{\mu}}$ [T = Tension & μ = mass per unit length]

Here,

$\mu = m/L = V.\rho /L = A.\rho$

$f = \dfrac{1}{2l}\sqrt{\dfrac{T}{A.\rho}}$

If T is halved & A is doubled,

$f = \dfrac{1}{2l}\sqrt{\dfrac{T'}{A'\rho}} = \dfrac{1}{2l}\sqrt{\dfrac{T}{2.2A.\rho}} = \dfrac{1}{2}\left(\dfrac{1}{2l}\sqrt{\dfrac{T}{A\rho}}\right) = \dfrac{1}{2}f$

Thus, the frequency is reduced to half if its tension is halved and the area of cross section of the string is doubled.

7. **2071 Set D Q.No. 3 b A tuning fork produces a feeble sound. But when it is pressed against a table, a loud sound is heard. Why?** **[2]**

A tuning fork produces a feeble sound without pressing in any obstacle because there is less mass of the vibrating particles. But when it is pressed against a table, a loud sound is heard because there is higher mass of vibrating air as the intensity of sound is directly proportional to the mass of vibrating particle.

8. **2070 Set C Q.No. 3 b Why is sounding board used in a string instrument?** **[2]**

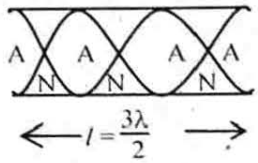
The sounding board on a stringed musical instrument is hollow inside it in which the air is set into forced vibrations along with the strings. When the frequency of vibrating air becomes equal to its natural frequency, the resonance occurs and maximum sound will be produced. Thus, the loudness of the sound is more for larger area of the vibrating body. So, stringed instruments provided with hollow boxes increases the loudness of sound.

9. **2070 Set D Q.No. 3 a When the tension in a given string is increased by four times, by what factor does the velocity of wave in the string change?** **[2]**

Please refer to 2073 Set D Q.No. 3b

10. **2069 Supp Set B Q.No. 3 a Explain, with figure, the formation of second overtone of waves in an open organ pipe.** **[2]**

Second overtone: In this mode of vibration, two antinodes are produced at both open ends and inside the pipe there are three nodes and two antinodes Figure. If λ be the wave length of the wave then the relationship between length and wave length of wave is $l = \frac{3\lambda}{2}$. If v be the velocity of sound and f_2 is the frequency of 2^{nd} overtone then, $f_2 = \frac{v}{\lambda} = \frac{3v}{2l}$.



11. **2068 Old Can. Q.No. 1c A loud sound is heard at resonance. Why?** **[2]**

When the frequency of a periodic force matches to the natural frequency of vibrating body, the body vibrates with maximum amplitude. This phenomenon is called resonance. At resonance, a compression of one wave falls on a compression of another wave and a rarefaction on a rarefaction. On account of this, the amplitude of vibrating particle increases. Since the intensity of sound is directly proportional to the square of the amplitude of the vibrating particles ($I \propto a^2$), maximum sound is heard at resonance.

12. **2067 Sup Q.No. 3a When the tension in a given stretched string is increased by four times, by what factor does the velocity of transverse wave in the string change?** **[2]**

Please refer 2073 Set C Q.No. 3a

13. **2067 Q.No. 3a Would you expect the pitch of an organ pipe to change with an increase in temperature? How?** **[2]**

Please refer to 2072 Supp Q.No. 3b

14. **2067 Q.No. 3b Is the wave speed the same as the speed of any part of the string for transverse waves? Explain the difference between these two speeds.** **[2]**

No, the wave speed is not same as the speed of any part to the string for transverse wave because of the difference of the wave velocity and particle velocity as: (i) for the transverse wave the vibration of particles and propagation of wave are perpendicular to each other. As a result the wave velocity and particle velocity are in perpendicular direction. (ii) The speed of wave is greater than the speed of the vibrating particles of the string.

15. **2066 Supp Q.No. 2c What is the use of sounding board on stringed musical instrument?** **[2]**

Please refer to 2070 Set C Q.No. 3 b

16. **2066 Q.No. 2 c Why are all string instruments provided with hollow boxes?** **[2]**

The hollow boxes are set into forced vibrations along with the strings. The loudness of sound is higher if area of the vibrating body is more. The area increased due to hollow box and consequently loudness of sound also further increased. That is why, stringed instruments are provided with hollow boxes.

17. **2061 Q.No. 2 c How does the temperature affect the frequency of an organ pipe?** **[2]**

Please refer to 2072 Supp Q.No. 3b

18. **2059 Q.No. 2 d One of the 'Nine Jewels' of Emperor Akbar, widely known as Tansen, the king of Music was able to break a glass by singing the appropriate note. What physical phenomenon could account for this?** **[2]**

This is due to resonance. The frequency of sound coming from Tansen singing may match with the natural frequency of glass and resonance may occur. The sound coming from source (i.e. the singer) may cause the vibration of glass molecules large enough to exceed their elastic limit and cause breaking. Thus, the breaking of glass by Tansen, a singer, by singing a appropriate note can be explained by resonance phenomenon.

19. **2057 Q.No. 1 d What do you mean by resonance?** **[2]**

When the natural frequency of vibrating body is equal to frequency of applied force, the body will vibrate with maximum amplitude. This type of oscillation or vibration is called resonant oscillation or vibration. This process of vibration is called resonance. It is a special case of forced vibration.

20. 2056 Q.No. 1 a **Why is sonometer box hollow from inside?** [2]

The air enclosed in the sonometer box vibrates when the stem of vibrating tuning fork is pressed on the top of sonometer box which increases the intensity of wave. To increase intensity are should be increased. Hence to increase area, the sonometer box is hollow for inside. Hence, in order to detect the resonance, the box of the sonometer is made hollow.

21. 2054 Q.No. 1 a **Why is an end correction necessary for an organ pipe?** [2]

Rayleigh found out that when an air in an organ pipe vibrates, the reflection of the sound waves takes place a little above the rim of the organ pipe because the air is free to vibrate at the open end. Due to this reason, antinode is formed above the open end of pipe. The vibrating length of the air column is greater than the actual length of the organ pipe. The distance between the actual position of antinode and the open end of pipe is called end correction. Therefore, in order to get the accurate value for frequency of vibration, the end correction is necessary. The end correction of a pipe is given by e = 0.3 d, where d is the diameter of the pipe.

22. 2053 Q.No. 1 a **The frequency of organ pipe changes with temperature. Does it increase with increase in temperature?** [2]

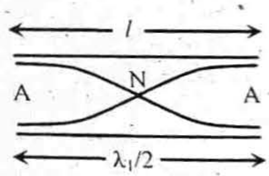
Please refer to 2072 Supp Q.No. 3b

23. 2053 Q.No. 1 c **Explain why soldiers are ordered to break steps while crossing a bridge.** [2]

Soldiers are ordered to break their steps while crossing the bridge due to resonance. When they march in steps, the frequency of marching coincides with the natural frequency of the bridge, resonance will occur in the bridge and begins to vibrate with maximum amplitude which may cause the destruction of the bridge. To avoid such a destruction of the bridge, soldiers are ordered to break their steps while crossing it.

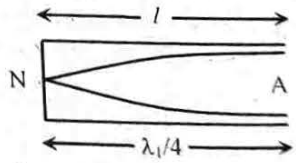
24. 2052 Q.No. 1 a **The frequency of fundamental note of an open organ pipe is double than for closed pipe of same length. Why?** [2]

If v is the velocity of sound in air and l is the length of the organ pipe. Then the fundamental frequency in an open organ pipe is



$$f_0 = \frac{v}{2l} \quad \ldots(i)$$

Also, the fundamental frequency produced in closed organ pipe whose length is same as open organ pipe is



$$f_c = \frac{v}{4l} \quad \ldots(ii)$$

∴ Dividing Eq. (i) by (ii), we get,

$$f_0 = 2\,f_c$$

Hence, the frequency of fundamental note of an open organ pipe is double than that for a closed pipe of the same length.

25. 2052 Q.No. 1 b **Differentiate between forced vibration and free vibration.**

There are following differences between forced and free vibration.

Forced vibration	Free vibration
1. When a body vibrates with the help of an external periodic force, then this type of vibration is called forced vibration.	1. When a body vibrates with its own natural frequency without the help of any external periodic force, then this type of vibration is called free vibration.
2. Examples of forced vibration are the sounding bodies i.e., a loudspeaker driven by ac signal coming from an amplifier.	2. An example of such vibration is a simple pendulum vibrating in vacuum.
3. The amplitude of vibration decreases gradually over time.	3. The amplitude of vibration remains constant for long period of time.

Long Answer Questions

26. **2076 Set C Q.No. 7a | 2074 Supp Q.No. 7b | 2070 Set C Q.No. 7 b Define end correction of a pipe. Prove that both odd and even types of harmonics can be obtained from an organ pipe open at both ends.** **[4]**

End correction in Pipes: Rayleigh found out that when air in an organ pipe vibrates, the reflection of the sound waves takes place a little above the rim of the organ pipe. Due to this reason, antinodes are formed above the open end of pipe. The vibrating length of the air column is greater than the actual length of the organ pipe. The difference in vibrating length of the air column and the actual length of the organ pipe is called end correction. Therefore, in order to get the accurate value for frequency of vibration, the end correction is necessary. The end correction for open pipe is given as $\lambda = 2(l + 2c)$ and for closed pipe it is given as $\lambda = 4(l + c)$, where c is end correction l is length of pipe and λ is wavelength of wave , also the end correction of pipe is given as 0.3d where d is diameter of the pipe.

Wave in open pipe: Open pipe is one which is open at both ends. When air is blown into the pipe through one end, a wave travels through the tube to the next end from where it is reflected. Due to superposition of the incident and reflected waves, a stationary wave is set up in air in the pipe. Since the two ends are open, they must be the positions of antinodes as shown in Fig.

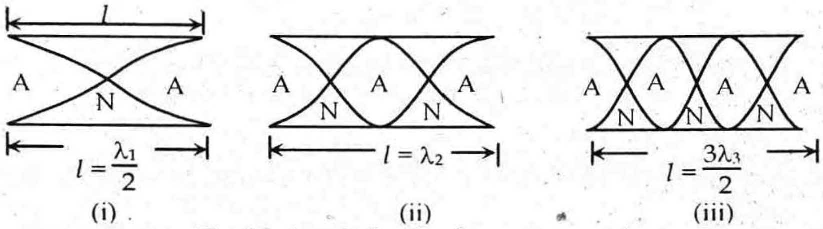


Fig. Modes of vibration in open organ pipe

Fundamental mode (First harmonic): Let length of the pipe is l and the velocity of sound in air is v. In this mode of vibration, there are antinodes at open ends and one node at the middle of the pipe as shown in Fig. (i). Let λ_1 be the wavelength of the wave. Then,

$$l = \frac{\lambda_1}{2}$$

or, $\lambda_1 = 2l$

Thus the frequency of fundamental mode or first harmonic is

$$\text{or, } f_1 = \frac{v}{\lambda_1} = \frac{v}{2l} \qquad \ldots(i)$$

Second mode (First overtone): In this mode of vibration, two antinodes are at the open ends but inside the pipe, there are two nodes and one antinode as shown in Fig. (ii). If λ_2 be the wavelength of the wave, then.

$$l = \lambda_2$$

Thus, the frequency of first overtone or second harmonic is

$$f_2 = \frac{v}{\lambda_2} = \frac{v}{l} = 2\frac{v}{2l} = 2f_1$$

$$\therefore f_2 = 2f_1 \qquad \ldots(ii)$$

Third mode (Second overtone): In this mode of vibration, two antinodes are produced at both open ends and inside the pipe; there are three nodes and two antinodes as shown in Fig. (iii). If λ_3 be the wavelength of the wave then.

$$l = \frac{3\lambda_3}{2}$$

$$\text{or, } \lambda_3 = \frac{2l}{3}$$

Thus, the frequency of second overtone or third harmonic is

$$f_3 = \frac{v}{\lambda_3} = \frac{v}{2l/3} = \frac{3v}{2l} = 3\frac{v}{2l}$$

$$\therefore f_3 = 3f_1$$

In this way, other higher modes of vibration can be obtained and the frequency of n^{th} mode of vibration is $f_n = nf_1$, where n = 1, 2, 3, ... is integer. From this, it is found that frequencies of higher modes of vibration are integral multiple of fundamental frequency f_1. So, all harmonics are possible in an open pipe as $f_1, 2f_1, 3f_1, 4f_1$... i.e., both odd and even harmonics are present.

27. 2075 GIE Q.No. 7b **State the laws of transverse vibration in a stretched string. Describe various modes of vibration in a stretched string.** **[4]**

Laws of transverse vibration of a string:

The velocity of a transverse wave travelling in a stretched string is given by $v = \sqrt{\frac{T}{\mu}}$ where T is the tension in the stretched string and μ, the mass per unit length. Since the frequency, $f = v/2l$ in fundamental mode, then

$$f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$$

From this expression, it follows that that there are three laws of transverse vibration of stretched string:

a. **The law of length:** The fundamental frequency is inversely proportional to the resonating length, l of the string.

$$f \propto \frac{1}{l}$$

b. **The law of tension:** The fundamental frequency is directly proportional to the square root of the stretching force or tension.

$$f \propto \sqrt{T}$$

c. **The law of mass:** The fundamental frequency is inversely proportional to the square root of the mass per unit length.

$$f \propto \frac{1}{\sqrt{\mu}}$$

Modes of Vibration of Stretched String

Let us consider a string which is stretched between two ends P and Q and plucked between these points produces transverse wave. The stationary waves are thus set up in the string and the wire emits vibrations of different frequencies which are called modes of vibrations as shown in figures.

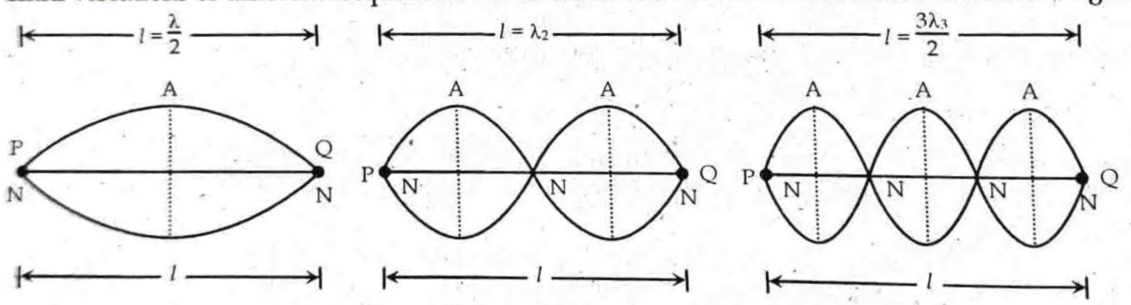


Fig: Modes of Vibration in Stretched String

First mode of vibration: Let a stretched string is plucked between two points P and Q in such a way that it forms only one segment. In this case, two modes and one antinode is formed. If l be the long of string and λ_1 be its wavelength, then its frequency is

$$f_1 = \frac{v}{\lambda_1} = \frac{v}{2l} \qquad \left[l = \frac{\lambda_1}{2} \Rightarrow \lambda_1 = 2l\right]$$

$$\text{or, } f_1 = \frac{1}{2l}\sqrt{\frac{T}{\mu}} \qquad \ldots \text{(i)} \qquad \left[\therefore v = \sqrt{\frac{T}{\mu}}\right]$$

This vibration is called fundamental mode or first harmonics and frequency is fundamental frequency.

Second mode of vibration: Let a stretched string is plucked between two points P and Q in such a way that it forms two segments. In this case, three nodes and two antinodes are formed. If l be the length of string and λ_2 be its wavelength, then its frequency is

$$f_2 = \frac{v}{\lambda_2} = \frac{v}{l} \qquad [\therefore\ l = 2l]$$

or, $f_2 = \frac{1}{2}\sqrt{\frac{T}{\mu}}$ $\left[\because v = \sqrt{\frac{T}{\mu}}\right]$

$\therefore$ $f_2 = 2f_1$ ... (ii)

This vibration is called second mode of vibration or second harmonics or first overtone. The frequency in the mode is twice the frequency of fundamental frequency.

Third mode of vibration: Let a stretched string is plucked between two points P and Q in such a way that it forms three segments. In this case, four nodes and three antinodes are formed. If l be the length of string and λ_2 be its wavelength, then its frequency is

$$f_3 = \frac{v}{\lambda_3} = \frac{3v}{2l} \qquad \left[\because \lambda_3 = \frac{2l}{3}\right]$$

or, $f_3 = \frac{3}{2l}\sqrt{\frac{T}{\mu}}$ $\left[\because v = \sqrt{\frac{T}{\mu}}\right]$

$\therefore$ $f_3 = 3f_1$ ... (iii)

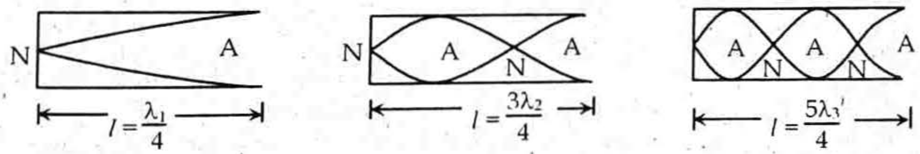
This vibration is called third mode of vibration or third harmonics or second overtone. The frequency in three times the fundamental frequency. In general, for n^{th} mode of vibration, the frequency of vibration in $f_n = nf_1 = f_1, 2f_1, 3f_1, 4f_1, \ldots$

28. **2075 Set A Q.No. 7a** **2065 Q.No. 5 a** **What do you understand by harmonics and overtones in the case of organ pipes? Prove that only odd harmonies are produced in closed organ pipes.** **[4]**

Harmonics and overtones: All the modes of vibrations other than the fundamental tones are called overtones. When the overtones have frequencies in exact multiples of the fundamental tone, they are called harmonics.

Organ pipe: A hollow wooden or metallic tube used to produce sound is called an organ pipe. It is a wind instrument such as a flute, whistle, violin, clarinet etc.

Wave in closed pipe: The organ pipe which is closed to one end is called closed organ pipe. Consider a closed organ pipe of length l as shown in figure. A blast of air is blown into it at the open end and a wave thus travels through the pipe and is reflected at the next end. Due to superposition of incident and reflected waves, stationary wave is produced. In the simplest mode of vibration, there is a displacement node, N at the closed end as the air is at rest and displacement antinodes, A at the open end as the air can vibrate freely. The different modes of vibration in closed organ pipe are given below.



(i) (ii) (iii)

Fig. Modes of vibration in closed organ pipe

Fundamental mode: In this mode of vibration, the pipe has one node at its closed end and one antinode at its open end. As observed in Fig. (i), the length, l of the pipe is equal to distance between a node and an antinode which is $\lambda_1/4$, where λ is the wavelength of the stationary wave. Then

$$l = \frac{\lambda_1}{4}$$

or, $\lambda_1 = 4l$

If v is the velocity of sound and f_1 is its frequency of vibration, then we have

$v = \lambda_1 f_1$

or, $f_1 = \frac{v}{\lambda_1} = \frac{v}{4l}$

$\therefore$ $f_1 = \frac{v}{4l}$ ... (i)

It is the lowest frequency produced in the pipe. It is called fundamental frequency or first harmonic.

Second mode (First overtone): In this mode of vibration, there are two antinodes and two nodes within the pipe as shown in Fig (ii). If λ_2 is the wavelength of the wave, then we have

$$l = \frac{3\lambda_2}{4}$$

or, $\lambda_2 = \frac{4l}{3}$

The frequency of vibration, f_2 is given by

$v = \lambda_2 f_2$

or, $f_2 = \frac{v}{\lambda_2} = \frac{v}{4l/3} = \frac{3v}{4l} = 3f_1$

$\therefore\ f_2 = 3f_1$ ... (ii)

This is the frequency of first overtone or third harmonic.

Third mode (Second overtone): In this mode of vibration, there are three nodes and three antinodes within the pipe as shown in Fig. (iii). If λ_3 is wavelength of the wave, then

$l = \frac{5\lambda_3}{4}$

or, $\lambda_3 = \frac{4l}{5}$

If f_3 is frequency of second overtone, then

$v = \lambda_3 f_3$

or, $f_3 = \frac{v}{\lambda_3} = \frac{v}{4l/5} = 5\frac{v}{4l} = 5f_1$

$\therefore\ f_3 = 5f_1$ ... (iii)

This is the frequency of second overtone or fifth harmonic.

Similarly the n^{th} mode of vibration, the frequency of vibration is $f_n = (2n+1)\ f_1$. In this way, other higher modes of vibration can be obtained. From Equation (i), (ii) and (iii), it is observed that the frequency of higher modes of vibration is odd integral multiple of fundamental frequency f_1. That is, f $= f_1, 3f_1, 5f_1, 7f_1, \ldots$ only odd harmonics are present in closed organ pope.

29. **2075 Set B Q.No. 8a** **2069 (Set A) Old Q.No. 5a OR** **What are harmonics? Explain the formation of overtones in an open and a closed organ pipe.** **[4]**

All the modes of vibrations other than the fundamental tones are called overtones. When the overtones have frequencies in exact integral multiples of the fundamental frequency, they are called as harmonics.

Closed organ pipe: Please refer to 2075 Set A Q.No. 7a

Open organ pipe: Please refer to 2076 Set C Q.No. 7a

30. **2074 Set A Q.No. 7b** **2073 Supp Q.No. 7a** **2067 Q.No. 7a** **Describe an experiment with the necessary theory by which the speed of sound in air is determined by using resonance tube method.** **[4]**

Measurement of velocity of sound in air and end-correction of the tube (Resonance tube experiment):

Resonance Tube: It is a tube which is used to measure the velocity of sound in air, end correction of tube, to compare the frequencies of the two given tuning forks. It consists of a metallic tube about 1m in length, about 3-5 cm in diameter whose upper end is open and lower is closed with a large reservoir of water. The tube and reservoir are connected by a rubber tube. A meter scale is attached by the side of tube which measures the length of air column in the tube. The length of air column is adjusted by raising or lowering the reservoir as shown in figure (a).

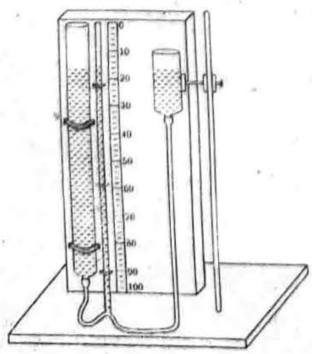


Fig a

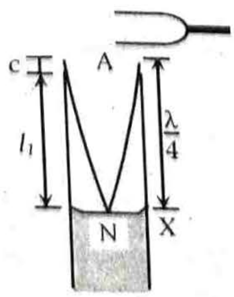


Fig b

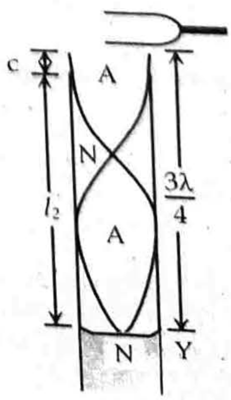


Fig c

Working Principle: To find the velocity of sound in air, the water level in the tube is brought close to the open end of the tube by raising the reservoir. A sounding tuning fork is held horizontally at the mouth of the tube filled with water. A wave travels in air column of the tube reflects from the water surface and a stationary wave is formed as shown in fig.(b), a sound is heard, the condition is called first resonance. Let resonance is obtained at some position say X.

Let l_1 be the length of air column in the tube for first resonance, c be the end - correction of the tube, λ be the wavelength of the wave in the tube. So,

$$l_1 + c = \frac{\lambda}{4} \quad \ldots \text{(i)}$$

Now, the water level is lowered further from position X until second resonance is again obtained and sound is heard at position Y as in fig (c). If l_2 be length of air column for this second resonance, then,

$$l_2 + c = \frac{3\lambda}{4} \quad \ldots \text{(ii)}$$

Subtracting equation (i) from (ii), we have,

$$l_2 - l_1 = \frac{\lambda}{2}$$

or, $\lambda = 2(l_2 - l_1)$

Velocity of sound $v = f\lambda = 2f(l_2 - l_1)$ ... (iii)

Where, f is frequency of the tuning fork. Knowing l_1, l_2 and f, v can be calculated at a given temperature.

Substituting the value of $\frac{\lambda}{4}$ from (i) in (ii), we get,

$l_2 + c = 3.(l_1 + c)$

or, $l_2 + c = 3l_1 + 3c$

or, $2c = l_2 - 3l_1$

$$\therefore c = \frac{l_2 - 3l_1}{2} \quad \ldots \text{(iv)}$$

Thus, knowing l_1 and l_2, c can be calculated using equation (iv).

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31. **2073 Set D Q.No. 7a What is the difference between an open and a close pipe? Explain with proper sketches for the formation of second overtones in each case. Also, express the length of pipes in terms of the wavelength of sound.** **[4]**

First Part: Please refer to 2075 Set A Q.No. 7a

Second Part: Please refer to 2076 Set C Q.No. 7a

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32. **2072 Set D Q.No. 7b What is end correction of a pipe? Describe the different modes of vibration of air column in an organ pipe closed at one end.** **[4]**

First Part: Please refer to 2076 Set C Q.No. 7a

Second Part: Please refer to 2075 Set A Q.No. 7a

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33. **2071 Supp Q.No. 7b Prove, with necessary diagrams, that both types of harmonics odd and even can be produced in an organ pipe open at both ends.** **[4]**

Please refer to 2076 Set C Q.No. 7a

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34. **2071 Set D Q.No. 7 a What is resonance? Describe an experiment to determine the velocity of sound in air and end correction of the tube by resonance method.** **[4]**

Please refer to 2074 Set A Q.No. 7b

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35. **2069 Supp Set B Q.No. 7 b Write the laws of transverse vibration of string. Explain how the law of length is verified experimentally.** **[4]**

Laws of transverse vibration of a string: Please refer to 2075 GIE Q.No. 7b

Verification of the laws of transverse vibration

To verify the laws of vibration of a string, a sonometer is used. This device consists of a wire under tension which is arranged in a hollow wooden board as shown in Fig. The vibration of the wire are passed by the movable bridges to the box and then, to the air inside it.

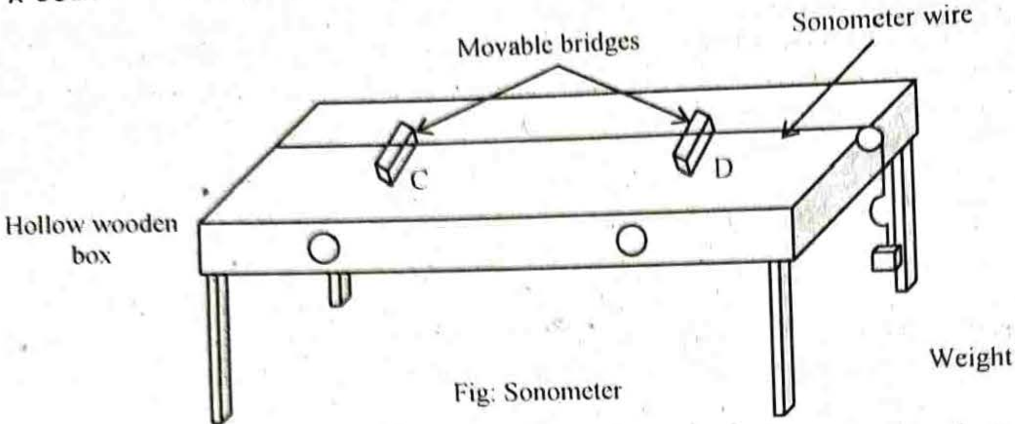


Fig: Sonometer

a. **To verify $f \propto 1/l$:** To verify this law, take a tuning fork of known frequency. Taking a load of 1 kg on the string, find the resonating length of the wire between the bridges C and D. Let l_1 be the resonating length for this tuning fork. The same process is repeated for next tuning fork having different frequency. Let l_2 be the resonating length for the second tuning fork. It will be found that the product $f_1 \times l_1 = f_2 \times l_2$ at constant tension and mass per unit length of the string. This follows that $f \propto \frac{1}{l}$.

b. **To verify $f \propto 1/\sqrt{\mu}$:** To verify this law, the wires of different diameters and materials are used under same vibrating length and same tension. Taking a load of 1 kg on the string, find the resonating length of the wire between the bridges C and D. Let l be the resonating length for this tuning fork. Take another tuning fork of different frequency and another wire of different diameter. Taking a load of 1 kg on the string, find the resonating length of the wire between the bridges C and D. Now draw a graph between frequency and $1/\sqrt{\mu}$ a straight line is obtained. This verifies that $f \propto \frac{1}{\sqrt{\mu}}$.

36. 2069 (Set A) Q.No. 7a **Show that both harmonics, odd and even can be produced in an open organ pipe? What is end correction?** **[4]**

Please refer to 2076 Set C Q.No. 7a

37. 2068 Q.No. 7 a **What is meant by resonance? Explain in detail how you would use sonometer to determine frequency of a given tuning fork.** **[4]**

Resonance: When a body capable of vibration is displaced and then allowed to vibrate freely, it will vibrate with a frequency which is called the natural frequency. If an external periodic force is applied on the body and the body vibrates with the frequency of the force, the motion is called the forced vibration. In a forced vibration, if the frequency of the periodic force is equal to the natural frequency of the body, the amplitude of vibration becomes very large and the vibration of the body is called **resonance.**

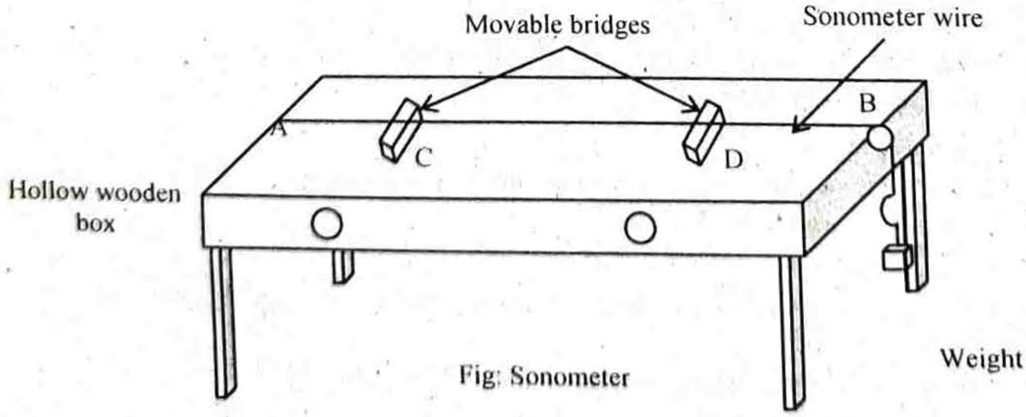


Fig: Sonometer

A sonometer consists essentially of a thin metallic wire stretched across two bridges A and B on the top of a hollow, wooden sounding box about 1 meter long. One end of the wire is fastened to a peg at one end of the box. Its other end passes over a smooth frictionless pulley fixed at the other end of the box, and carries a scale pan so that it can be loaded to have any desired tension. There are two bridges C and D between the two fixed bridges A and B sliding over a scale to adjust the length of the vibrating potion of the string.

To obtain the frequency of the tuning fork, take a resonance vibration of the string, a small 'V' shaped piece of paper is placed on the string between bridges C and D. Some weight (W) is put on the scale pan to produce tension in the string. A tuning fork is struck against a rubber pad and placed on the box close to the segment CD of the wire. When the string between the bridges vibrates, the piece of paper on it flutters. By varying the resonating length of the string by moving C or D, if the frequency of vibration of the string given by equation $f = \frac{1}{2l}\sqrt{\frac{T}{m}}$ becomes equal to the frequency of the tuning fork, the string segment CD vibrates with maximum amplitude. As a result, the piece of paper may fall. This is how the resonant condition is detected. At this condition, the resonant length and weight on the pan are noted. By knowing the value of mass per unit length of the wire we can calculate the frequency of the tuning fork.

38. **2068 Old Can. Q.No. 5a OR** **What is a closed pipe? Describe the natural modes of vibration of air in an organ pipe closed at one end. Also explain the term 'end correction'.** **[1+2+1]**

First part: Please refer to Please refer to 2075 Set A Q.No. 7a

End correction in Pipes: Please refer to 2076 Set C Q.No. 7a

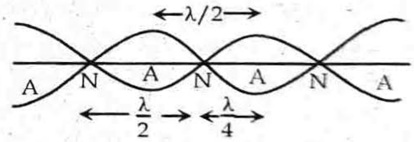
39. **2067 Old Q.No. 5a OR** **Describe the resonance tube experiment to determine the velocity of sound in Laboratory and obtain the expression of end correction.** **[4]**

Please refer to 2074 Set A Q.No. 7b

40. **2064 Q.No. 5 a OR** **State and explain principle of superposition and formation of stationary waves. Show that the frequency of the fundamental note of a closed organ pipe is half as compared to that of an open pipe of the same length.** **[2+2]**

Principle of Superposition of Waves: It states that if two or more progress waves traveling together in a medium, converges to a point, the resulting displacement of the particle at that point is equal to the algebraic (vector) sum of individual displacements of the waves. Let $y_1, y_2, y_3, \ldots, y_n$ be the displacement at a point due to individual waves then the resultant displacement, y at the same time when the waves superpose to each other is given by

$y = y_1 + y_2 + y_3 + \ldots + y_n$



Stationary (or standing) wave: Whenever two progressive waves of the same wavelength and amplitude travel in opposite directions with the same speed, they are superimposed; a single wave is formed such wave is called stationary wave.

This is formed as given by superposition principle which states that the vector sum of displacements of individual waves is equal to the displacement of resultant wave. When a stationary wave is formed due to the superposition of two waves, the points of maximum and zero amplitude are resulted alternatively in the space. The points where the amplitude of vibration is maximum are called antinodes and those where the amplitude is zero are called nodes. The distance between two consecutive nodes or antinodes is equal to half of the wavelength i.e. $\frac{1}{2}\lambda$, where λ is wavelength of a wave. Also, the distance between adjacent node and antinode is equal to one quarter of wavelength i.e. $\frac{1}{4}\lambda$.

Stationary wave equation: Stationary wave equation can be obtained by adding vectorically the displacements of two waves of equal amplitude, frequency (or period) and wavelength travelling in apposite directions.

Let y_1 be the displacement of the wave travelling to the positive x-direction, then

$y_1 = a \sin(\omega t - kx)$ ... (i)

And, y_2 be the displacement of the wave travelling to the negative x-direction. Then

$y_2 = a \sin(\omega t + kx)$ ... (ii)

By using the principle of superposition of waves, the resultant displacement y is given by

$y = y_1 + y_2$

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

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

$= a [\sin \omega t \cos kx - \cos \omega t \sin kx + \sin \omega t \cos kx + \cos \omega t \sin kx]$

$= 2a \sin \omega t \cos kx \quad = 2a \sin \frac{2\pi}{T} t \ \cos \frac{2\pi}{\lambda} x$

$$y = A \sin \frac{2\pi}{T} t \qquad \ldots \text{(iii)}$$

Where $A = 2a \cos \frac{2\pi x}{\lambda}$ be the amplitude of resultant wave.

Equation (iii) is the equation of stationary wave.

If v is the velocity of sound in air and l is the length of the organ pipe, then the fundamental frequency in an open organ pipe is

$$f_0 = \frac{v}{2l} \qquad \ldots \text{(i)}$$

Also, the fundamental frequency produced in closed organ pipe whose length is same as open organ pipe is

$$f_c = \frac{v}{4l} \qquad \ldots \text{(ii)}$$

∴ Dividing Eq. (i) by (ii), we get

$$f_c = \frac{1}{2} f_o$$

Hence, the frequency of the fundamental mode of a closed organ pipe is half as compared to that of an open pipe of the same length.

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41. 2063 Q.No. 6 a OR 2057 Q.No. 5 a OR **Discuss the different modes of vibrations of air column in closed pipe. [4]**

Please refer to 2075 Set A Q.No. 7a

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42. 2062 Q.No. 6 a OR **State the laws of transverse vibration of string. Describe an experiment to verify the law of mass, and law of length. [4]**

Please refer to 2069 Supp Set B Q.No. 7 b

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43. 2059 Q.No. 5 a OR **State the laws of transverse vibrations of string. Using only dimensions show that the speed of propagation of a transverse wave depends only on tension and mass per unit length. [1+3]**

Laws of transverse vibrations of string: Please refer to 2075 GIE Q.No. 7 b

A string is a flexible wire of uniform area of cross section. It is observed that the velocity of transverse waves in a stretched string depends on

(a) Tension T (b) Mass m and (c) Length l

Here, $v \propto T^x$, $v \propto m^y$ and $v \propto l^z$

On combining, $v \propto T^x m^y l^z$

$$\therefore \ v = k T^x m^y l^z \qquad \ldots \text{(i)}$$

where k, x, y and z are numbers.

Since, the dimension of velocity (v) = $[LT^{-1}]$

the dimension of tension (T) = $[MLT^{-2}]$

the dimension of mass (m) = $[M]$

On substituting

$[LT^{-1}] = [MLT^{-2}]^x\, [M]^y\, [L]^z$

$[LT^{-1}] = [M^{x+y} L^{x+z} T^{-2x}]$

Equating the indices of M, L, T on both sides, we have

For M, $x + y = 0$

For L, $x + z = 1$

For T, $-2x = -1$

$\therefore \ x = \frac{1}{2}, \quad y = -\frac{1}{2}$ and $z = \frac{1}{2}$

Thus, equation (i) becomes,

$v = kT^{1/2} m^{-1/2} L^{1/2}$

$$\therefore \ v = k\sqrt{\frac{Tl}{m}} = k\sqrt{\frac{T}{m/l}}$$

Sine $\frac{m}{l} = \mu$, is the mass per unit length of the string, then

$$v = k\sqrt{\frac{T}{\mu}}$$

Experimentally it is observed that, k = 1

$$\therefore v = \sqrt{\frac{T}{\mu}}$$

Thus, the speed of propagation of a transverse wave depends only on tension and mass per unit length.

44. **2058 Q.No. 5 a OR Prove that both types of harmonics, odd and even, can be produced in an organ pipe open at both ends.** **[4]**

Please refer to 2076 Set C Q.No. 7a

Numerical Problems

45. **2076 Set B Q.No. 11 A wire whose mass per unit length is 10^{-3} kg/m is stretched by a load of 4 kg over the two bridges of a sonometer wire 1 m apart. It is struck at its middle point, what would be the wavelength and frequency of its fundamental vibration?** **[4]**

Solution

Given,

Mass per unit length = 10^{-3} kg/m

Load (m) = 4 kg

Fundamental frequency of vibration (f) = ?

Length of wire (l) = 1 m

We have

$$f = \frac{1}{2l}\sqrt{\frac{T}{\mu}} \qquad [\therefore T = mg = 4 \times 10N]$$

$$= \frac{1}{2 \times 1}\sqrt{\frac{4 \times 10}{10^{-3}}} = 100 \text{ Hz}$$

46. **2074 Set B Q.No. 11 A steel wire of length 20 cm and mass 5 gram is under the tension of 500N and is tied down at both ends. Calculate the frequency of fundamental mode of vibration.** **[4]**

Solution

Given,

Length of steel wire (l) = 20 cm = 20×10^{-2} m = 0.2 m

Mass of wire (m) = 5 gm = 5×10^{-3} kg

Tension on the wire (T) = 500 N

Frequency of fundamental mode (f_0) = ?

We have, for fundamental frequency

$$f_0 = \frac{1}{2l}\sqrt{\frac{T}{\mu}} \qquad \left(\because \mu = \frac{m}{l} = \frac{5 \times 10^{-3}}{0.2} = 0.025 \text{ kg/m}\right)$$

$$\text{or, } f_1 = \frac{1}{2 \times 0.2}\sqrt{\frac{500}{0.025}} = 353.55 \text{ Hz}$$

47. **2073 Supp Q.No. 11 2069 Supp Set B Q.No. 11 A pianofort wire having a diameter of 0.90 mm is replaced by another wire of the same material but with diameter 0.93 mm. If the tension of the wire is as before. What is percentage change in the frequency of fundamental note?** **[4]**

Solution

Given,

1st diameter (d_1) = 0.9 mm = 0.9×10^{-3} m

2nd diameter (d_2) = 0.93 mm = 0.93×10^{-3} m

Fundamental frequency of vibration of wire is given as;

$$f = \frac{1}{l.d}\sqrt{\frac{T}{\pi\rho}}$$

So,

$$f_1 = \frac{1}{l.d_1}\sqrt{\frac{T}{\pi\rho}}$$

And,

$$f_2 = \frac{1}{l.d_2}\sqrt{\frac{T}{\pi\rho}}$$

Percentage change in frequency $= \frac{f_1 - f_2}{f_1} \times 100\ \%$

$$= \frac{\frac{1}{ld_1}\cdot\sqrt{\frac{T}{\pi\rho}} - \frac{1}{ld_2}\sqrt{\frac{T}{\pi\rho}}}{\frac{1}{ld_1}\sqrt{\frac{T}{\pi\rho}}} = \frac{\frac{1}{d_1} - \frac{1}{d_2}}{\frac{1}{d_1}} \times 100\ \%$$

$$= \frac{d_2 - d_1}{d_1 . d_2} \times d_1 \times 100\ \% = \frac{0.93 - 0.9}{0.93} \times 100\ \% = 3.2\%$$

Thus, the required percentage change is 3.2%.

48. **2072 Supp Q.No. 11** **On a day when the speed of sound is 345 m/s, the fundamental frequency of a closed organ pipe is 220 Hz. The second overtone of this pipe has the same wave length as the third harmonic of an open pipe. How long is the open pipe?** **[4]**

Solution

Given,

Speed of sound (v) = 345 m/sec

Fundamental frequency of closed pipe (f_c) = 220 Hz

Length of open pipe (l_0) = ?

Here, given that,

Wave length of second overtones of closed pipe (λ_3) = third harmonics of open pipe (λ'_3)

or, $\frac{v}{\lambda_3} = \frac{v}{\lambda'_3}$

or, f_3 for closed pipe = f_3 for open pipe, $\left(\because f = \frac{v}{\lambda}\right)$

or, $5f_1 = \frac{v}{\lambda'_3}$

or, $\lambda'_3 = \frac{v}{5f_1} = \frac{345}{5 \times 220} = 0.3136$ m

Now, for open organ pipe,

$f_3 = \frac{v}{\lambda'_3} = \frac{3v}{2l_0}$ $\quad (\because \lambda'_3 = 2l_0)$

or, $\frac{v}{\lambda'_3} = \frac{3v}{2l_0}$

or, $l_0 = \frac{3\lambda'_3}{2} = \frac{3 \times 0.3136}{2} = 0.47$ m

$\therefore$ Length of open pipe (l_0) = 0.47 m

49. **2072 Set C Q.No. 11** **A wire with mass 40 g is stretched so that its ends are tied down at points 80 cm apart. The wire vibrates in its fundamental mode with frequency 60 Hz. Calculate the speed of propagation of transverse waves in the wire and the tension in the wire.** **[4]**

Solution

Given,

Mass of wire (m) = 40 gm = 40×10^{-3} kg

Length of wire (l) = 80 cm = 80×10^{-2} m

Fundamental frequency (f) = 60 Hz

Speed of wave (v) = ?

Tension in the string (T) = ?

We have, fundamental frequency in the stretched wire is

$$f = \frac{v}{2l}$$

or, $v = f \times 2l = 60 \times 2 \times 80 \times 10^{-2}$

$\therefore$ $v = 96$ m/sec

Again,

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{T}{(m/l)}} \qquad [\because \mu = \frac{m}{l}]$$

or, $T = v^2 \times \frac{m}{l} = \frac{96^2 \times 40 \times 10^{-3}}{80 \times 10^{-2}} = 460.8$ N

50. 2071 Supp Q.No. 11 **A cord of length 1.5 m is fixed at both ends. Its mass per unit length is 1.2g/m and the tension is 12N.**

a. What is the frequency of fundamental oscillation?

b. What tension is required if the n = 3 mode has frequency of 0.50 kHz? **[4]**

Solution

Given,

Length of cord (l) = 1.5 m

Mass per unit length (μ) = 1.2 g/m = $\frac{1.2}{1000}$ kg/m

Tension on cord (T) = 12N

a. Fundamental frequency (f) = ?

Now,

$$f = \frac{1}{2l}\sqrt{\frac{T}{\mu}} = \frac{1}{2 \times 1.5}\sqrt{\frac{12 \times 1000}{1.2}} = 33.33 \text{ Hz.}$$

Again, for n = 3 mode, let f_0 the fundamental frequency. Here,

$3f_0 = 0.5$ KHz = 0.50×1000 Hz

$f_0 = 500/3$ Hz

T = ?

Now,

$$f_0 = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$$

or, $\frac{500}{3} = \frac{1}{2 \times 1.5}\sqrt{\frac{T \times 1000}{1.2}}$

or, $T = \frac{1.2}{1000} \times \left(\frac{500 \times 2 \times 1.5}{3}\right)^2 = \frac{1.2}{1000} \times (500)^2 = 300$ N

$\therefore$ T = 300 N

51. 2071 Set C Q.No. 11 2070 Set D Q.No. 11 **In a resonance tube experiment the first and the second resonance positions were observed at 17cm and 52.6cm respectively. The tuning fork used was frequency 512Hz and the temperature was 27°C. Calculate the velocity of sound in air at 0°C and the end correction of the tube. [4]**

Solution

Given,

First resonance length (l_1) = 17cm = 0.17m

Second resonance length (l_2) = 52.6cm = 0.526 m

Velocity of sound at 0°C (v_o) = ?

Frequency of tunning fork (f) = 512 Hz

We have,

At 27°C

$v_{27} = 2f(l_2 - l_1)$

$= 2 \times 512 (0.526 - 0.17) = 364.5$ m/sec

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

$$\frac{v_o}{v_{27}} = \sqrt{\frac{T_o}{T_{27}}} = \sqrt{\frac{273}{273 + 27}}$$

$$v_o = \sqrt{\frac{273}{300}} \times 364.5 = 347.75 \text{ m/sec}$$

Again,

$$\text{End correction (c)} = \frac{l_2 - 3l_1}{2} = \frac{0.526 - 3 \times 0.17}{2} = 0.008\text{m}$$

Thus, the required values are 347.75 m/s and 0.008 m respectively.

52. 2069 Set B Q.No. 11 2067 Sup Q.No. 11 An open pipe 30 cm long and a closed pipe 23 cm long, both of the same diameter, each sounds their first overtone. If they are in resonance, find the end correction of these pipes. [4]

Solution

Let, c be the end correction of both pipes having same diameter. Since their vibrations are in unison, so they must have same frequency and same wavelength.

For the first overtone in the open pipe, we have:

$\lambda = l + 2c$; where l be the length of open pipe.

or, $\lambda = 30 + 2c$ ... (i)

For the first overtone in the closed pipe,

$\frac{3\lambda}{4} = l' + c$; where l' be the length of closed pipe.

or, $\frac{3\lambda}{4} = 23 + c$

or, $\lambda = \frac{4}{3}(23 + c)$ ... (ii)

From equation (i) and (ii), we get

$30 + 2c = \frac{4}{3}(23 + c)$

or, $90 + 6c = 92 + 4c$

or, $2c = 2$

$\therefore$ $c = 1\text{cm}$

Hence, the required end correction is 1cm= 0.01m.

53. 2068 Can. Q.No. 11 A piano string 1.5m long is made of steel of density 7800 kg/m^3 and Young's modulus 2×10^{11}N/m^2. It is maintained at a tension which produced an elastic strain of 1% in the string. Calculate the frequency of transverse vibration of the string when it is vibrating in second mode of vibration. [4]

Solution

Given,

Length of string (l) = 1.5m

Density of steel (ρ) = 7800kg/m^3

Young's modulus (Y) = 2×10^{11}N/m^2

Strain = 1% = $\frac{1}{100}$

Frequency of second mode of vibration (f_1) = ?

Now, we have

$Y = \frac{\text{stress}}{\text{strain}}$

or, stress = Y × strain

or, $\frac{\text{Tension}}{\text{Area}} = 2 \times 10^{11} \times \frac{1}{100}$

or, $\frac{T}{A} = 2 \times 10^9$ ... (i)

Then, for fundamental mode, we have

$$f = \frac{1}{2l}\sqrt{\frac{T}{M/L}} = \frac{1}{2l}\sqrt{\frac{LT}{M}} = \frac{1}{2l}\sqrt{\frac{LT}{A \times L \times \rho}} = \frac{1}{2l}\sqrt{\frac{T}{A \times \rho}}$$

$$= \frac{1}{2 \times 1.5}\sqrt{\frac{2 \times 10^9}{7800}} \quad [\because \text{ from equation (i)}]$$

$= 168.79$ Hz

Hence, the required frequency is 168.79Hz

For second mode of vibration

$f_2 = 2f$

$= 2 \times 168.79$ Hz

$= 337.6$ Hz

54. **2066 Supp Q.No. 5b A steel wire of length 40 cm and the diameter 0.25 mm vibrates in unison with a tube, open at both ends and of effective length 60 cm, when each is sounding its fundamental notes. The air temperature is 27° C. Find the tension in the wire. Given – velocity of sound in air at 0°C = 332 ms^{-1} and density of steel = 7800 kg m^{-1}.** **[4]**

Solution

Given,

Length of wire (l_w) = 40cm = 0.4m

Diameter of wire (d) = 0.25mm = 0.25×10^{-3} m

Length of pipe (l_p) = 60cm = 0.6m

Density of steel (ρ) = 7800 kgm^{-1}

Let,

$v_1 = 332\text{ms}^{-1}$

$T_1 = 0°C = 273$ k

$v_2 = ?$

$T_2 = 27°C = 300$k

Now, using;

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

or, $\frac{332}{v_2} = \sqrt{\frac{273}{300}}$

$\therefore$ $v_2 = 348.03$ ms^{-1}

Then,

Fundamental frequency of vibration of wire is given as

$$f = \frac{1}{2l_w}\sqrt{\frac{T}{\mu}}$$

$$= \frac{1}{2l_w}\sqrt{\frac{T}{V \times \rho}} \quad \text{where, V is the volume per unit length}$$

$$= \frac{1}{2l_w}\sqrt{\frac{T}{\frac{\pi d^2 l}{4l} \times \rho}} = \frac{1}{2l_w}\sqrt{\frac{4T}{\pi d^2 \rho}} = \frac{1}{2l_w} \times \frac{2}{d}\sqrt{\frac{T}{\pi\rho}} = \frac{1}{l_w d}\sqrt{\frac{T}{\pi\rho}}$$

Again;

Fundamental frequency of vibration in open pipe is given as:

$$f' = \frac{v}{2l_0}$$

When the steel wire & the open pipe vibrates in unison, we have

$f = f'$

or, $\frac{1}{l_w d}\sqrt{\frac{T}{\pi\rho}} = \frac{v}{2l_0}$

or, $\frac{1}{0.4 \times 0.25 \times 10^{-3}}\sqrt{\frac{T}{\pi \times 7800}} = \frac{348.03}{2 \times 0.6}$

or, $\sqrt{\frac{T}{7800\pi}} = 0.029$

or, $\frac{T}{7800\pi} = 8.41 \times 10^{-4}$

$\therefore$ T = 20.6 N

Hence, the required tension is 20.6N

55. **2066 Q.No. 5 b** **A uniform tube 60 cm long stands vertically with its lower end dipping into water. When the length above the water is 14.8cm and again when it is 48 cm, the tube resounds to a vibrating tuning fork of frequency 512Hz. Find the lowest frequency to which the tube will resound when it is open at both ends.** **[4]**

Solution

Given,

First resonating length (l_1) = 14.8cm

Second resonating length (l_2) = 48cm

Length of the tube (L) = 60cm

Frequency of tuning fork (f) = 512Hz

Lowest frequency (f_o) = ?

Now, we have,

Velocity (v) $= 2f(l_2 - l_1)$

$= 2 \times 512 (48 - 14.8)$

$\therefore$ v = 33996.8 cm/s = 339.97 m/s

End correction (c) $= \frac{l_2 - 3l_1}{2} = \frac{48 - 3 \times 14.8}{2} = 1.8$cm

Here, as the tube is open at both ends, we have for the lowest frequency,

$\frac{\lambda_o}{2} = L + 2c$

or, $\lambda_o = 2(L + 2c) = 2(60 + 2 \times 1.8) = 127.2$ cm

Again, we have

$v = \lambda_o f_o$

or, $f_o = \frac{v}{\lambda_o} = \frac{33996.8}{127.2} = 267.27$ Hz

56. **2061 Q.No. 5 b** **2055 Q.No. 3** **A piano string has a length of 2.0m and a density of 800 kgm^{-3}. When the tension in the string produces a strain of 1%, the fundamental note obtained from the string in transverse vibration is 170 Hz. Calculate the Young's modulus value for the material of string.** **[4]**

Solution

Given,

Length of string (l) = 2m

Density (ρ) = 800kg/m^3

Strain = 1% $= \frac{1}{100}$

Frequency (f) = 170Hz

Young's Modulus (Y) = ?

Now, we have,

$Y = \frac{\text{stress}}{\text{strain}}$

or, stress $= Y \times$ strain

or, $\frac{\text{Tension}}{\text{Area}} = Y \times \frac{1}{100}$

or, $\frac{T}{A} = \frac{Y}{100}$ ... (i)

Then,

For fundamental mode of vibration of string; we have,

$f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$

$$= \frac{1}{2l}\sqrt{\frac{T}{M/L}} \qquad \left[\because \mu = \frac{M}{L}\right]$$

$$= \frac{1}{2l}\sqrt{\frac{LT}{M}} = \frac{1}{2l}\sqrt{\frac{LT}{V\times\rho}} = \frac{1}{2l}\sqrt{\frac{LT}{A\times L\times\rho}}$$

$$\text{or, } f = \frac{1}{2l}\sqrt{\frac{T}{A\times\rho}} \qquad \ldots \text{(ii)}$$

Putting the value of $\frac{T}{A}$ from equation (ii), we get,

$$f = \frac{1}{2l}\sqrt{\frac{Y}{100}\times\frac{1}{\rho}}$$

$$\text{or, } 170 = \frac{1}{2\times 2}\sqrt{\frac{Y}{100}\times\frac{1}{800}}$$

$$\text{or, } 680 = \sqrt{\frac{Y}{80000}}$$

$$\text{or, } 462400 = \frac{Y}{80000}$$

$\therefore$ Y $= 3.7 \times 10^{10}$ Nm^{-2}

Here, the required value of Young's Modulus is 3.7×10^{10}Nm^{-2}.

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57. **2060 Q.No. 5 b** **2053 Q.No. 3** **A wire of diameter 0.04 cm and made of steel of density 8000 kgm^{-3} is under a constant tension of 80N. What length of this wire should be plucked to cause it to vibrate with a frequency of 840 Hz?** **[4]**

Solution

Given,

Diameter of wire (d) = 0.04 cm = 0.04×10^{-2}m

Density of wire (ρ) = 8000 kgm^{-3}

Tension in wire (T) = 80 N

Frequency (f) = 840 Hz

Length of wire (l) = ?

We know that frequency of vibration (f) is given by

$$f = \frac{1}{2l}\sqrt{\frac{T}{m}} = \frac{1}{2l}\sqrt{\frac{T}{\frac{\rho\,\pi d^2}{4}}} \qquad \left[\therefore m = \frac{\text{mass}}{\text{length}} = \rho \times \frac{\pi d^2}{4}\right]$$

$$f = \frac{1}{ld}\sqrt{\frac{T}{\pi\rho}} \Rightarrow l = \frac{1}{fd}\sqrt{\frac{T}{\pi\rho}}$$

$$= \frac{1}{840 \times 0.04 \times 10^{-2}}\sqrt{\frac{80}{\pi \times 8000}}$$

$$= 0.168 \text{ m}$$

Hence, the length of the wire is 0.168 m.

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58. **2056 Q.No. 3 OR** **An organ pipe is turned to a frequency of 440 Hz when the temperature is 27°C. Find its frequency when the temperature drops to 0°C. Assume both ends of the pipe open.** **[4]**

Solution

Given,

Frequency (f_1) = 440 Hz

Temperature T_1) = 27°C = 27 + 273 = 300 K

Frequency (f_2) = ?

Temperature (T_2) = 0°C = 0 + 273 = 273 K

For open organ pipe, we have

$$f_1 = \frac{v_1}{2l} \qquad \ldots \text{(i)}$$

$$\text{and } f_2 = \frac{v_2}{2l} \qquad \ldots \text{(ii)}$$

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

$$\frac{f_2}{f_1} = \frac{v_2}{2l} \times \frac{2l}{v_1} = \frac{v_2}{v_1} = \sqrt{\frac{T_2}{T_1}} \qquad \left[\because v \propto \sqrt{T} \Rightarrow \frac{v_2}{v_1} = \sqrt{\frac{T_2}{T_1}}\right]$$

$$f_2 = \sqrt{\frac{273}{300}} \times 440 = 419.73 \text{ Hz}$$

$\therefore$ $f_2 = 419.73$ Hz

Hence, the frequency at 0°C is 419.73 Hz.

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59. $\boxed{\text{2052 Q.No. 3}}$ **A steel wire 2m long whose mass is 3g is under tension of 500N and is tied down at both ends. Calculate the frequency and wavelength for fundamental mode of vibration.** **[4]**

Solution

Given,

Length of wire (l) = 2m

Mass of wire (M) = 3g = 3×10^{-3}kg

$\therefore$ Mass per unit length (m) = $\frac{3 \times 10^{-3}}{2}$ kg

Tension (T) = 500N

Frequency of fundamental mode of vibration (f) = ?

Wavelength of fundamental mode of vibration (λ) =?

Now,

For fundamental mode of vibration; we have,

$$f = \frac{1}{2l}\sqrt{\frac{T}{m}} = \frac{1}{2\times2}\sqrt{\frac{500}{\frac{3 \times 10^{-3}}{2}}} = \frac{1}{4} \times \sqrt{\frac{1000}{3 \times 10^{-3}}} = \frac{1}{4} \times \sqrt{\frac{10^6}{3}}$$

$\therefore$ f = 144.3 Hz

Also,

In this case, we have

$$\frac{\lambda}{2} = l$$

or, $\lambda = 2l = 2 \times 2 = 4$m

Hence, the required values of frequency and wavelength are 144.3Hz and 4 m respectively.

❑❑❑

Chapter 4: Acoustic Phenomena

Short Answer Questions

1. 2076 Set B Q.No. 3b | 2073 Supp Q.No. 3b | 2070 Set D Q.No. 3 b | 2058 Q.No. 2 d **An empty vessel sounds more than a filled one when it is struck. Why? [2]**

An empty vessel contains more air due to greater empty area than the filled one. When an empty vessel is struck, greater mass of air is set into vibration. We know that greater is the intensity of sound if the greater mass of air is set into motion. This means the intensity of sound is more in empty vessel than the filled one by the relation $I \propto a^2$. Hence, the empty vessel produces more intense sound than a filled one.

2. 2076 Set C Q.No. 3b **Sound waves are called pressure waves. Why? [2]**

Sound wave is longitudinal wave in a medium. Generally, it can be represented by displacement wave equation as

$y = a \sin(\omega t - kx)$ ... (i)

where a = amplitude, k = wave vector and ω is angular frequency. Sound wave can be expressed in terms of pressure variation at various points in a medium. In air, the pressure fluctuation occurs sinusoidally above and below the atmospheric pressure during the formation of compression and rarefaction. The human ear can sense such fluctuations. The compression portion has greater pressure where as rarefaction portion has less pressure. In this way, sound wave can be expressed in terms of pressure wave.

3. 2075 GIE Q.No. 3b | 2074 Set A Q.No. 3b | 2072 Set E Q.No. 3b **What is the threshold of hearing? Define one bel. [2]**

The lowest intensity of sound that can be perceived by a normal ear is called the threshold of hearing. A sound wave of given intensity produces different amount of hearing sensation in different ranges of frequency. Moreover, the threshold of hearing at a frequency may vary from ear to ear as well. Hence, for a normal ear, the threshold of hearing is taken as 10^{-12} W/m^2 of a pure tone of frequency 1 KHz.

Bel and decibel: The unit of intensity level given by the equation $L = \log_{10}\frac{I}{I_o}$ is the bel. One bel is defined as loudness of 1000 Hz tone whose intensity is ten times the threshold of a hearing. It is denoted by B. Its smaller unit is decibel (dB). 1 dB is ten times smaller than 1B. So equation (i) is given in terms of dB as $L = (10\text{ dB})\log_{10}\frac{I}{I_o}$.

4. 2075 Set A Q.No. 3b **Justify the proverb "An empty vessel makes much noise". [2]**

Please refer to 2076 Set B Q.No. 3b

5. 2075 Set B Q.No. 3b **Why is the voice of a woman more intelligible than that of a man? [2]**

The pitch of sound depends upon the frequency. The sound with low frequency is identified as low pitch and sound with high frequency is identified high pitch sound. The tone of high frequency is interpreted as shrill or intelligent sound. The sound produced by a woman has higher frequency than the sound produced by a man. So, the sound produced b a woman is more intelligence than the sound produced by a man.

6. 2074 Supp Q.No. 3a | 2074 Set A Q.No. 3a **Why are longitudinal waves called pressure waves? [2]**

Please refer to 2076 Set C Q.No. 3b

7. 2074 Supp Q.No. 3b | 2054 Q.No. 1 c **What are ultrasonic and infrasonic waves? [2]**

Sound waves of frequency above the audible range (i.e., above 20 KHz) are called ultrasonic waves or ultrasonics. These sound waves are not audible to normal human ears. Such waves can be generated by vibrating crystals e.g. quartz crystal. The bats can produce and hear ultrasonic waves.

The sound waves of frequency below the audible range (i.e., below 20 Hz) are called infrasonic waves or infrasonics. The infrasonic waves are produced by the vibration of large object. For example, an earthquake waves are infrasonic waves. These sounds are not audible to normal human ears.

8. 2073 Set D Q.No. 3a **Explain the difference in characteristics between ultrasonic and supersonic waves. [2]**

Sound waves of frequency above the audible range (i.e., above 20 KHz) are called ultrasonic waves. These sounds are not audible to normal human ears. Such waves can be generated by vibrating crystals e.g., quartz crystal. The bats can produce and hear ultrasonic waves.

The objects which travel with the speed greater than the speed of sound in air are called supersonics. E.g. super jets, rockets etc.

9. 2072 Set C Q.No. 3a | 2060 Q.No. 1 c | 2071 Set C Q.No. 3 a **Whistle of an approaching train is shriller, why?** [2]

According to Doppler effect, the pitch of the source when it is approaching towards the stationary observer changes due to relative motion between the listener and the source as by relation: $f' = \frac{v}{v - v_s} f$, where v is velocity of sound and v_s is velocity of moving source. When the train is approaching, there is relative motion between stationary listener outside the train and the train. Hence, the pitch increases for the stationary listener outside the train. That's why; whistle of an approaching train is shriller.

10. 2072 Set D Q.No. 3b **If the pressure amplitude of a sound wave is halved, by what factor does the intensity of the wave change?** [2]

The intensity (I) of a sound wave of pressure amplitude (ΔP_m) is given by

$$I = \frac{\Delta P_m^2}{2\rho v}$$

where ρ is density of medium and v be velocity of wave. When ΔP_m is halved, then,

$$I' = \frac{(\Delta p'_m)^2}{2\rho v} = \frac{1}{2^2}\left(\frac{\Delta p_m^2}{2\rho v}\right) = \frac{1}{4} I$$

Thus, intensity is reduced by 4 times.

11. 2072 Set E Q.No. 3a **A tuning fork has two prongs. Why?** [2]

A tuning fork has two prongs to produce vibration for longer time. When two prongs vibrate simultaneously, they communicate the vibrations between themselves to produce vibration for longer time than a single prongs. So, a tuning for has two prongs.

12. 2071 Supp Q.No. 3b **How can we consider sound waves as pressure waves?** [2]

Please refer to 2076 Set C Q.No. 3b

13. 2070 Sup (Set A) Q.No. 3 a **'An empty vessel makes much noise'. How would you justify the proverb?** [2]

Please refer to 2076 Set B Q.No. 3b

14. 2070 Sup (Set A) Q.No.3 b **Bats catch their prey in the dark even when they don't see the prey. How can this happen?** [2]

Bats have no eyes for vision. They produce and hear ultrasonic waves or ultrasound. The ultrasonic waves produced by a bat spread out in all direction. These waves after reflecting from a prey, say an insect reach the bat. Hence, the bat can easily locate its prey.

15. 2070 Supp. (Set B) Q.No. 3 b **How can we recognize a person just by hearing her voice without seeing her face?** [2]

Due to the quality of sound, one can recognize a friend from his voice without seeing him. The quality of sound emitted by a person depends on the presence of overtones. The quality of sound helps us to distinguish between two sounds having same loudness and pitch. The overtones present in different voices are different whatever they produce the same frequency and the same intensity of sound. In this way, one can recognize a friend from his voice without seeing her/his face.

16. 2069 Set A Q.No. 3a **An empty vessel sounds more than a filled one. Why?** [2]

Please refer to 2076 Set B Q.No. 3b

17. 2069 Set B Q.No. 3a **Is there a physical difference between intensity and intensity level of a wave? How are these quantities related?** [2]

Yes, there is difference between the intensity and intensity level of a sound wave. The intensity of sound wave is the amount of sound energy passing through a surface per unit surface area per unit time when the surface is perpendicular to the propagation of the wave, while the intensity level is the relative value of the intensity with the reference to the threshold of hearing. These two terms are related by the formula, $L = \log_{10}\frac{I}{I_0}$, where I is the intensity of a sound wave and I_0 is the threshold of hearing and L is intensity level. I is measured in Wm^{-2} while L is in bel. The absolute intensity cannot be measured and avoided internationally and relative value of intensity is measured which is called intensity level.

18. 2069 (Set A) Old Q.No. 2c 2053 Q.No. 1 b **How are beats produced? What is beat frequency?** [2]

The process of alternate rising and falling the intensity of sound in the resultant wave formed due to superposition of two sound waves of slightly frequency difference (less than 10 Hz) is called beat. Each 'rise and fall' in intensity of sound is called a beat. The time between a 'rise and fall' is called beat period, while the number of beats per second is called *beat frequency*. The beat frequency is given by $f_b = |f_1 - f_2|$ which is less than 10Hz.

19. 2068 Q.No. 3 a **Which has a more direct influence on the loudness of a sound wave: the displacement amplitude or the pressure amplitude? Explain your reasoning.** [2]

Pressure amplitude has direct influence on the loudness of sound wave. This is because the value of pressure amplitude has greater value than the displacement amplitude and the intensity depends upon the pressure amplitude as

$I = \frac{\Delta P_m^2}{2\rho v}$. This shows that intensity is influenced by pressure amplitude.

20. 2068 Old Can. Q.No. 2c **Two notes, one produced by violin and the other by a sitar, may have the same frequency, yet we can distinguish between them. Why?** [2]

The quality of a sound is determined by the number of overtones present in the note. The fundamental note of violin and sitar may be the same but they are accompanied by a different number of overtones. As a result, the quality of the two sounds is different and we can distinguish the two notes.

21. 2067 Old Q.No. 1d **Why are the bells made of metal not of wood?** [2]

There is high damping of sound waves in wood but very low damping in metals. If the damping is high, sound produced has low intensity and can travel for short distance but if the damping is less, sound produced has high intensity and can travel for long distances for longer duration and sound can be heard at greater distances. That is why, bells are made of metals but not of wood.

22. 2065 Q.No. 2 d **Explain with a figure, the meaning of beats.** [2]

Beats: When two sound waves of slightly different frequencies are sounded together, there occurs a periodic rise and fall of sound intensity. Such a phenomenon is known as beat. The time between a rise and a fall is called beat period. The number of beats heard per second is called beat frequency. It is given by, $(f_b) = f_2 - f_1$

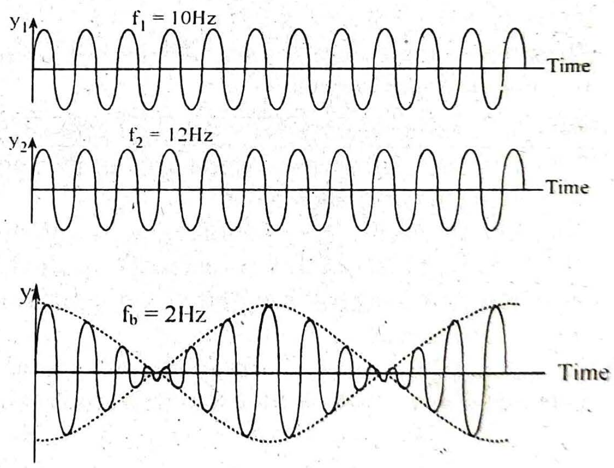


Fig. Formation of beats

23. 2064 Q.No. 1 c **Bells are made of metal and not of wood, why?** [2]

Please refer to 2067 Old Q.No. 1d

24. 2061 Q.No. 1 c **Define beats and beat frequency.** [2]

Please refer to 2069 (Set A) Old Q.No. 2c

25. 2059 Q.No. 1 c **What do you mean by the term threshold of hearing?** [2]

Please refer to 2075 GIE Q.No. 3b

26. 2057 Q.No. 2 d **Why is the roaring of a lion different than the sound of a mosquito?** [2]

Sound produced by a body differs from that produced by another body, basically, by its pitch. Sound produced by a lion is of low pitch (frequency) but high intensity while the sound produced by a mosquito has high pitch but low intensity. Hence, roaring of a lion is different from that of a mosquito.

27. 2056 Q.No. 1 b **How is it that one can recognize a friend from his voice without seeing him?** [2]

Please refer to 2070 Supp. (Set B) Q.No. 3 b

28. 2055 Q.No. 1 c **Distinguish between ultrasonics and supersonics.** [2]

Please refer to 2073 Set D Q.No. 3a

Long Answer Questions

29. 2076 Set B Q.No. 7b 2057 Q.No. 5 a **What is Doppler's effect? Derive an expression for the apparent frequency received by a stationary observer when a source of sound is moving away from the observer.** [4]

Doppler's Effect: "The phenomenon of variation in the pitch of sound due to the relative motion of the source and the observer (listener) is called Doppler effect." Due to this effect, the pitch emitted by the siren of an approaching ambulance appears increased. Similarly, the pitch appears to drop when it is moving away.

Source is moving away from the stationary observer:

Suppose v is the velocity of sound in air and f is its true frequency. When both source and observer are at rest, the distance occupied by f waves is v per second. Suppose source moves with velocity u_s away from stationary observer O. Therefore, distance occupied by f waves sent out towards O in one second is $v + u_s$. Thus, the wavelength increases as

$$\lambda' = \frac{v + u_s}{f}$$

The apparent frequency is given by,

$$f' = \frac{\text{velocity of sound wave relative to O}}{\text{wavelength of wave reaching to O}}$$

$$f' = \frac{v}{\lambda'} = \frac{v}{\frac{v + u_s}{f}} = \frac{v}{v + u_s} f$$

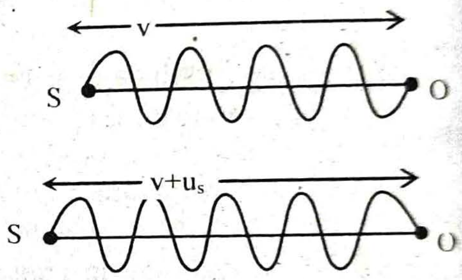


Fig: Source moving away from stationary observer

Since, $(v + u_s) > v \Rightarrow f' < f$

Thus, the pitch of the sound decreases if source is moving away from stationary observer.

30. 2076 Set C Q.No. 7b 2075 Set B Q.No. 8b 2074 Set B Q.No. 7b 2073 Set D Q.No. 7b 2072 Supp Q.No. 7b **What is Doppler's effect? Derive an expression for the apparent frequency when a source of sound and the observer are moving towards each other.** [4]

Doppler's Effect: "The phenomenon of variation in the pitch of sound due to the relative motion of the source and the observer (listener) is called Doppler effect." Due to this effect, the pitch emitted by the siren of an approaching ambulance appears increased. Similarly, the pitch appears to drop when it is moving away.

The change in apparent frequency of sound as heard by the listener due to the relative motion between source and listener was first studied by Doppler and is called Doppler's effect.

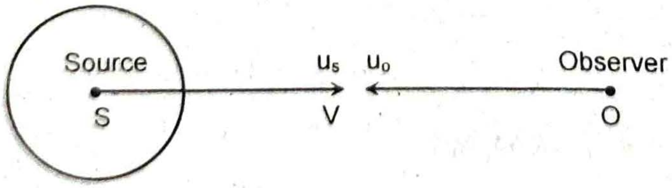


Fig: Observer and source are moving towards each other

Let us consider, source S is moving towards observer with velocity u_s and observer O is moving towards source with velocity with u_0, then

Velocity of wave relative to observer, $v' = v + u_0$

and

Apparent wavelength, $\lambda' = \frac{v - u_s}{f}$

But, we have,

$$f' = \frac{v'}{\lambda'} = \frac{v + u_0}{(v - u_s)/f} = \left(\frac{v + u_0}{v - u_s}\right) \times f$$

$$f' = \left(\frac{v + u_0}{v - u_s}\right) \times f$$

So, the frequency of wave increases. In such case as $v + u_0 > v - u_s$.

31. **2075 Set A Q.No. 7b What is Doppler's effect? Obtain an expression for the apparent pitch when a source moves away from a stationary observer. [4]**

Please refer to 2076 Set B Q.No. 7b

32. **2073 Supp Q.No. 7b 2064 Q.No. 5 a Define intensity of sound. Show that the intensity of sound for a given frequency is directly proportional to the square of amplitude of vibration. [4]**

Intensity of sound: The intensity of sound wave at a place is defined as the rate of flow of energy per unit area held normally to the direction of wave propagation. It is denoted by I and given by

$$I = \frac{E_o}{A \times t}$$

where, E_o is sound energy, A is area on which it passes, and t is time.

The displacement y of a vibrating layer of air due to the wave propagation is given by

$$y = a \sin \omega t \qquad \dots \text{(i)}$$

where, a is the amplitude of vibration. Then the velocity v at any instant is

$$v = \frac{dy}{dt} = \frac{d}{dt}(a \sin \omega t)$$

$$v = a\omega \cos \omega t \qquad \dots \text{(ii)}$$

Kinetic energy E of the layer is given as,

$$E = \frac{1}{2} mv^2 = \frac{1}{2} m\, \omega^2 a^2 \cos^2 \omega t \qquad [\because v = \omega a] \qquad \dots \text{(iii)}$$

where, m is the mass of the layer. When the KE becomes maximum, the PE becomes zero and vice versa, for an oscillating system. Thus, the maximum value of KE is equal to total energy E_o of the system.

In equation (iii), E will be maximum, when $\cos \omega t = 1$.

$$\therefore E_o = \frac{1}{2} m\omega^2 a^2$$

Then, intensity of sound is given by

$$I = \frac{1}{2}\frac{m\omega^2 a^2}{A \times t}$$

$$= \frac{1}{2}\frac{\rho V\omega^2 a^2}{A \times t}$$

$$= \frac{1}{2}\frac{\rho A l\omega^2 a^2}{A \times t}$$

$$= \frac{1}{2}\rho v\omega^2 a^2 \qquad \left(\because m = V\rho,\ V = A \times l \text{ and } v = \frac{l}{t}\right)$$

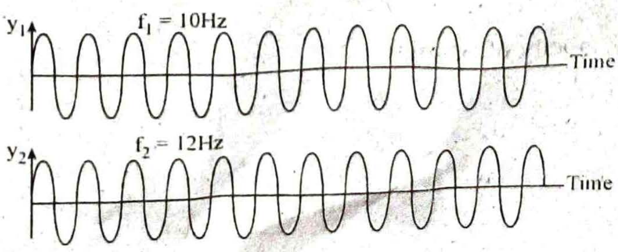
$$\text{or, } I = \frac{1}{2} v\rho (2\pi f)^2 a^2 = 2\pi^2 f^2 v\rho a^2 \qquad (\because \omega = 2\pi f)$$

From definition, this is the intensity of the wave

i.e., $I = 2\pi^2 f^2 v\rho a^2 \Rightarrow I \propto a^2$

In words, the intensity of a sound wave of given frequency is directly proportional to the square of amplitude of vibration.

33. **2073 Set C Q.No. 7a How are beats formed when two waves are superimposed? Deduce expression for the frequency of beats so formed. [4]**



Beats: When two sound waves of slightly different frequencies are sounded together, there occurs a periodic rise and fall of sound intensity. Such a phenomenon is known as beats. The time between a rise and a fall is called beat period. The number of beats heard per second is called beat frequency. It is given by $(f_b) = f_2 - f_1$

Let us consider two waves of equal amplitude 'a' but of slightly different frequencies. Let the frequencies of the waves be f_1 and f_2 where $f_1 > f_2$.

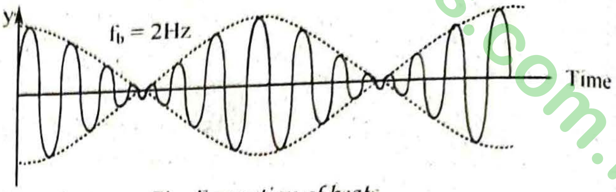


Fig. Formation of beats

Consider y_1 and y_2 are the individual displacement of the medium at a time t due to these waves, then

$y_1 = a \sin \omega_1 t = a \sin 2\pi f_1 t$

and $y_2 = a \sin \omega_2 t = a \sin 2\pi f_2 t$

Applying the principle of superposition of waves, the resultant displacement of the vibrating particle is given by

$y \ = y_1 + y_2 = a \sin 2\pi f_1 t + a \sin 2\pi f_2 t$

$y \ = a \ \sin 2\pi f_1 t + \sin 2\pi f_2 t$

$= 2a \sin 2\pi \left(\frac{f_1 + f_2}{2}\right) t \cos 2\pi \left(\frac{f_1 - f_2}{2}\right) t \qquad [\because \sin A + \sin B = 2 \sin \frac{A+B}{2} . \cos \frac{A-B}{2}]$

or, $y = A \sin 2\pi f t$; ... (i)

where, $A = 2a \cos 2\pi \left(\frac{f_1 - f_2}{2}\right) t$ is called the amplitude of resultant wave (or amplitude factor) and $f = \left(\frac{f_1 + f_2}{2}\right)$ is resultant frequency.

So, the equation (i) represents the equation of the harmonic wave whose frequency is f and amplitude A which varies with time.

Condition of maxima and minima;

Condition for maxima;

A beat (loud sound) is detected when amplitude is maximum. Amplitude 'A' will be maximum when $\cos 2\pi \left(\frac{f_1 - f_2}{2}\right) t$ is maximum.

i.e., $\cos 2\pi \left(\frac{f_1 - f_2}{2}\right) t = +1 \text{ or } -1$

or, $\cos 2\pi \left(\frac{f_1 - f_2}{2}\right) t = \cos n\pi$

or, $2\pi \left(\frac{f_1 - f_2}{2}\right) t = n\pi$

or, $t = \frac{n}{f_1 - f_2}$

when, n = 0, 1, 2, 3, ...

$t = 0, \frac{1}{f_1 - f_2}, \frac{2}{f_1 - f_2}, \frac{3}{f_1 - f_2}, \ldots$

The time interval between two consecutive maxima is the period and is given by

$T = \frac{1}{f_1 - f_2}$

Hence frequency of maxima is $f = \frac{1}{T} = f_1 - f_2$

Condition for minima;

Resultant amplitude is minimum when $\cos 2\pi \left(\frac{f_1 - f_2}{2}\right) t$ is minimum.

i.e. $\cos 2\pi \left(\frac{f_1 - f_2}{2}\right) t = 0$

or, $\cos 2\pi \left(\frac{f_1 - f_2}{2}\right) t = \cos (2n + 1) \frac{\pi}{2}$

or, $t = \frac{2n+1}{2(f_1 - f_2)}$

when, n = 0, 1, 2, 3, ...

or, $t = \frac{1}{2(f_1 - f_2)}, \frac{3}{2(f_1 - f_2)}, \frac{5}{2(f_1 - f_2)}, \ldots$

The time interval between two consecutive minima i.e. beat period is given as

$$T = \frac{3}{2(f_1 - f_2)} - \frac{1}{2(f_1 - f_2)} = \frac{1}{f_1 - f_2}$$

Hence frequency of minima is $f = \frac{1}{T} = f_1 - f_2$

Hence frequency of maxima = $f_1 - f_2$ = frequency of minima = beat frequency = f. thus, beat frequency is equal to the difference of the frequencies of individual superposing waves.

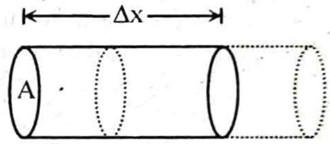
34. **2072 Set C Q.No. 7b Describe sound wave as a pressure wave and deduce an expression for the pressure amplitude. [4]**

Pressure Amplitude: Sound wave is a longitudinal wave in a gaseous medium. This wave generally can be represented by displacement wave equation as,

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

Where, a = amplitude, ω = angular frequency, t = time, k = wave number. Here x and y are parallel. Sound waves can be expressed in terms of pressure variations at various points in a medium. In air, the pressure fluctuates sinusoidally above and below the atmospheric pressure 'P' during the formation of compression and rare fraction. The human air can sense such fluctuations.

Let ΔP be the instantaneous pressure fluctuation in a sound wave at a point X at time t. Consider an imaginary air cylinder of cross section area A and length Δx, such that change in volume V = A.Δx when there is no wave. When wave is produced, the size of cylinder disturbed. Let left cross section is displaced by y_1 and right cross section is displaced by y_2. If $y_2 > y_1$, volume increases and pressure decreases and vice versa.



Now,

$$\Delta V = A(y_2 - y_1) = A\Delta y$$

In the limit $\Delta x \to 0$,

$$\frac{dV}{V} = \lim_{\Delta x \to 0} \frac{A\Delta y}{A\Delta x} = \frac{dy}{dx}$$

$$\therefore P = -B\frac{\Delta V}{V}, \text{ B = Bulk modulus of air,}$$

$$\text{or, } P = -B\frac{dy}{dx} = Bak\cos(\omega t - kx)$$

$$\text{or, } P = P_m\cos(\omega t - kx) \qquad \ldots \text{(ii)}$$

Where,

P_m = Bak, is pressure amplitude

$\therefore P_m = v^2\rho ak \qquad \left[\because v = \sqrt{\frac{B}{\rho}} \text{ or, } B = v^2\rho\right]$

The equation (ii) is pressure amplitude which is directly proportional to displacement amplitude. From equation (i) and (ii) we can differentiate that the displacement wave is out of phase by 90° with pressure wave. It means that, when the displacement at a point is zero, the pressure change is a maximum, and vice-versa.

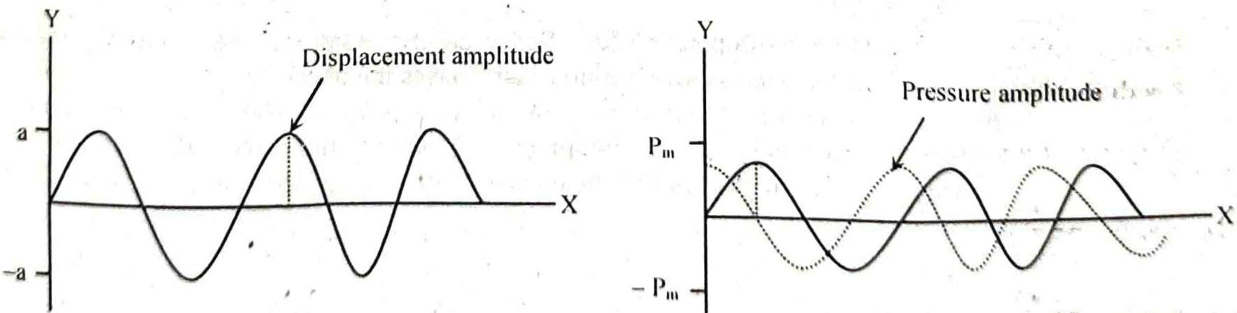


Fig: Displacement and Pressure amplitude of sound wave in air

35. 2072 Set E Q.No. 7b **What is Doppler effect? Find the change in frequency when an observer moves towards a stationary source and then moves away from the source.** [4]

Doppler's Effect: "The phenomenon of variation in the pitch of sound due to the relative motion of the source and the observer (listener) is called Doppler effect." Due to this effect, the pitch emitted by the siren of an approaching ambulance appears increased. Similarly, the pitch appears to drop when it is moving away.

Suppose v is the velocity of sound in air and f is its true frequency. Since the source is stationary, f waves occupy distance v in one second. So the wavelength λ of the wave reaching observer O is

$\lambda = \frac{v}{f}$ which remains unchanged.

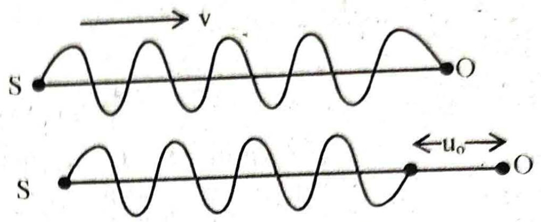


Fig: Observer moving towards stationary source

Suppose the observer is moving towards the stationary source with velocity u_o as shown in figure. Here, sound waves are moving towards O with velocity v and O is moving towards S with velocity u_o. Therefore, velocity of sound waves relative to O is

$v' = v + u_o$

The apparent frequency is given by,

$$f' = \frac{\text{velocity of sound wave relative to O}}{\text{wavelength of wave reaching to O}}$$

$$f' = \frac{v'}{\lambda} = \frac{v + u_o}{\frac{v}{f}} = \frac{v + u_o}{v} f$$

Since, $(v + u_o) > v \Rightarrow f' > f$

Thus, the pitch of the sound increases if observer is moving towards stationary sound source.

When observer moves away from the stationary source, the velocity of the waves relative to observer is $v - u_o$, then apparent frequency f' is given by

$$f' = \frac{v'}{\lambda'} = \frac{v - u_o}{v} f.$$

$$\therefore \ f' = \frac{v - u_o}{v} f$$

Since $v - u_o < v$, $f' < f$

Thus, the pitch of the sound decreases if observer is moving away from stationary sound source.

36. 2071 Set C Q.No. 7 b **Define intensity of sound. Prove that it is proportional to the square of the amplitude of vibration for the given source of sound.** [4]

Please refer to 2073 Supp Q.No. 7b

37. 2071 Set D Q.No. 7 b **What is Doppler's effect in sound? Obtain an expression for the apparent frequency of the sound when an observer moves towards a stationary source of sound.** [4]

Please refer to 2072 Set E Q.No. 7b

38. 2070 Supp. (Set B) Q.No. 7 a 2067 Sup Q.No. 7a **What are beats? Obtain an expression for the beat frequency produced by the superposition of two waves of slightly different frequencies.** [4]

Please refer 2073 Set C Q.No. 7a

39. 2070 Supp. (Set B) Q.No. 7 b **Define Doppler's effect. Derive an expression for the change in frequency observed by a stationary observer when a moving source just crosses the observer.** [4]

Doppler's Effect: "The phenomenon of variation in the pitch of sound due to the relative motion of the source and the observer (listener) is called Doppler effect." Due to this effect, the pitch emitted by the siren of an approaching ambulance appears increased. Similarly, the pitch appears to drop when it is moving away.

When source is not crossing the stationary observer:
Suppose v is the velocity of sound in air and f is its true frequency. When both source and observer are at rest, the distance occupied by f waves is v per second. Suppose source moves with velocity u_s towards stationary observer O.
Therefore, distance occupied by f waves sent out towards O in one second is v - u_s. Thus, the wavelength decreases as

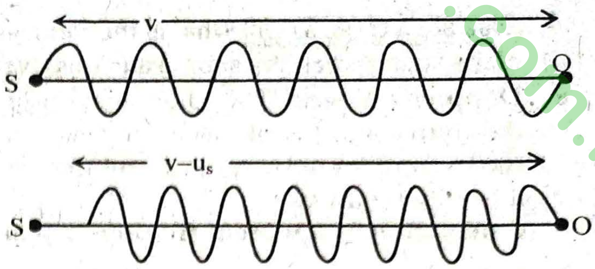


Fig: Source moving towards stationary observer

$$\lambda' = \frac{v - u_s}{f}$$

The apparent frequency is given by,

$$f' = \frac{v}{\lambda'} = \frac{v}{\frac{v - u_s}{f}} = \frac{v}{v - u_s} f$$

Since, $(v - u_s) < v \Rightarrow f' > f$
Thus, the pitch of the sound increases if source is moving towards stationary observer.

When the source is crossing the stationary observer:
Suppose v is the velocity of sound in air and f is its true frequency. When both source and observer are at rest, the distance occupied by f waves is v per second.
Suppose source moves with velocity v_s away from stationary observer O. Therefore, distance occupied by f waves sent out towards O in one second is v + v_s. Thus, the wavelength increases as

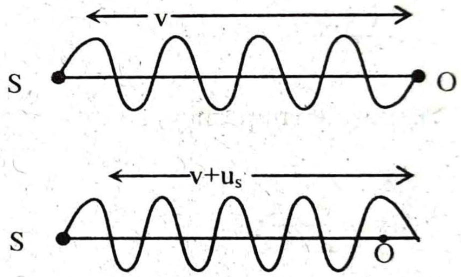


Fig: Source moving away from stationary observer

$$\lambda' = \frac{v + u_s}{f}$$

The apparent frequency is given by,

$$f' = \frac{\text{Velocity of sound wave relative to O}}{\text{wavelength of wave reaching to O}}$$

$$f' = \frac{v}{\lambda'} = \frac{v}{\frac{v + u_s}{f}} = \frac{v}{v + u_s} f$$

Since, $(v + u_s) > v \Rightarrow f' < f$
Thus, the pitch of the sound decreases if source is moving away from stationary observer.

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40. 2070 Set D Q.No. 7 b | 2060 Q.No. 5 a OR **What are beats? Show that the number of beats heard per second is equal to the difference between the frequencies of two superposing waves.** **[4]**

Please refer 2073 Set C Q.No. 7a

41. 2069 (Set A) Q.No. 7b **What is Doppler's effect? Obtain an expression for the apparent pitch when an observer moves towards a stationary source.** **[4]**

Please refer to 2072 Set E Q.No. 7b

42. 2069 (Set B) Q.No. 7a **How does the frequency of sound change when sound source is moving:**
i. towards the stationary listener and
ii. away from the stationary listener. **[4]**

Please refer to 2070 Supp. (Set B) Q.No. 7 b

43. 2068 Can. Q.No. 7b **What is Doppler's effect? Deduce an expression for the apparent frequency heard by a stationary observer when a source approaches towards him.** **[4]**

Please refer to 2070 Supp. (Set B) Q.No. 7 b

44. 2067 Q.No. 7b **Define intensity and deduce it in terms of amplitude of vibration, density of medium, angular velocity and velocity of the wave.** **[4]**

Please refer to 2073 Supp Q.No. 7b

45. **2066 Supp Q.No. 5a OR What is the Doppler effect in sound. Obtain an expression for the apparent frequency of the sound when the source and observer both move in the same direction.** **[1+3]**

Doppler's Effect: "The phenomenon of variation in the pitch of sound due to the relative motion of the source and the observer (listener) is called Doppler effect." Due to this effect, the pitch emitted by the siren of an approaching ambulance appears increased. Similarly, the pitch appears to drop when it is moving away.

Calculation of apparent frequency when both source and observer are moving:

If both the source and observer are moving then apparent frequency f' is given by, $f' = \frac{v'}{\lambda'}$ where, v' is velocity of sound waves relative to observer O and λ' is wavelength of the waves reaching O. This is general formula to calculate f', when source and observer move along a straight line. So, we can use this to find the apparent frequency in any of the cases considered before. Suppose, v is velocity of sound in air, f is true frequency of the source, u_o is velocity of the observer O and u_s is velocity of the source S.

i. **When source S and observer O are moving in the same direction as shown in figure:**

The velocity of sound wave v and velocity of observer u_o are in the same direction. Therefore, velocity of sound waves relative to O is,

$$v' = v - u_o$$

Since, the source is moving towards observer O, wavelength of the wave reaching O is

$$\lambda' = \frac{v - u_s}{f}$$

$$\therefore \text{ Apparent frequency, } f' = \frac{v'}{\lambda'} = \frac{v - u_o}{\frac{v - u_s}{f}}$$

or, $$f' = \frac{v - u_o}{v - u_s} f$$

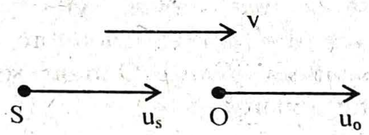

Fig: Source follows the observer

Here, if $u_o = u_s$ then $f' = f$.

ii. **If the source and observer are moving in the same direction as shown in figure:**

If the source and observer are moving in the same direction as shown in figure, v and u_o are in the opposite directions, so the velocity of sound waves relative to O is, $v' = v + u_o$

Since, the source is moving away from the observer, wavelength of the wave reaching O is

$$\lambda' = \frac{v + u_s}{f}$$

$$\therefore f = \frac{v'}{\lambda'} = \frac{v + u_o}{\frac{v + u_s}{f}}$$

or, $$f' = \frac{v + u_o}{v + u_s} . f$$

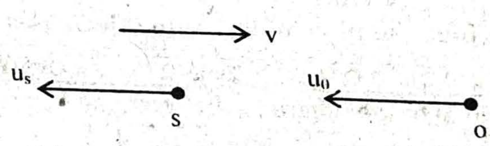

Fig: Observer follows the source

Here, if $u_o = u_s$ then $f' = f$.

46. **2066 Q.No. 5 a OR Define the intensity of sound and prove that $I = \frac{1}{2} \rho V r^2 \omega^2$ where the symbols have their usual meaning.**

Please refer to 2073 Supp Q.No. 7b **[1+3]**

47. **2062 Q.No. 6 a Discuss the phenomenon of Doppler's effect. Find the change in frequency when a moving source of sound passes a stationery observer.**

Please refer to 2070 Supp. (Set B) Q.No. 7 b **[4]**

48. **2059 Q.No. 5 a What is Doppler's effect? Derive the change in frequency when an observer moves towards stationary source.**

Please refer to 2072 Set E Q.No. 7b **[1+3]**

49. **2058 Q.No. 5 a What do you mean by intensity and intensity level of sound? Define bel and decibel.** **[4]**

Intensity: Please refer to 2073 Supp Q.No. 7b

Intensity level: The intensity level L of a sound wave is defined as the ratio of intensity of sound to the standard intensity. Mathematically it is given by the equation,

$$L = \log_{10}\frac{I}{I_o} \quad \dots (i)$$

where, I is the intensity of the wave and I_o is called the threshold value of hearing. It is ratio of same quantity and has no dimension although it is measured in the unit to bel.

Bel and decibel: The unit of intensity level given by the equation $L = \log_{10}\frac{I}{I_o}$ is the bel. One bel is defined as loudness of 1000Hz tone whose intensity is ten times the threshold of a hearing. It is denoted by B. Its smaller unit is decibel (dB). 1 dB is ten times smaller than 1B. So equation (i) is given in terms of dB as $L = (10\ \text{dB})\log_{10}\frac{I}{I_o}$.

50. **2055 Q.No. 2 OR** **Deduce the expression for the frequency heard by an observer, when the observer is approaching the stationary sound source.**

Please refer to 2072 Set E Q.No. 7b

Numerical Problems

51. **2075 GIE Q.No. 11** **A train is approaching a cliff at 20 m/s. The driver sounds a whistle of frequency 800 Hz. What will be the frequency of echo as heard by the driver? Velocity of sound in air is 350 m/s.** **[4]**

Solution

Given

Velocity of train (v_0) = 20 m/sec

Frequency (f) = 800 Hz

Velocity of sound (v) = 350 m/sec

Frequency of echo (f') = ?

Now,

$$f' = \frac{v + v_0}{v - v_S} \times f \qquad [\because v_s = v_0]$$

$$= \frac{350 + 20}{350 - 20} \times 800$$

$$= 896.97 \text{ Hz}$$

52. **2074 Set A Q.No. 11** **A car is approaching towards a cliff at a speed of 20m/s. The driver sounds a whistle of frequency 800 Hz. What will be the frequency of the echo as heard by the car driver? Velocity of sound in air = 350m/s.** **[4]**

Please refer to 2075 GIE Q.No. 11

53. **2073 Set C Q.No. 11** **A car travelling with a speed of 60 Kmhr^{-1} sounds a horn of frequency 500Hz. The sound is heard in another car travelling behind the first car in the same direction with a speed of 80 Kmhr^{-1}. What frequencies will the driver of the second car hear before an after overtaking the first car if the velocity of sound is 340ms^{-1}?** **[4]**

Solution

Given,

Velocity of sounding car (v_s) = 60 kmhr^{-1} = $\frac{60 \times 1000}{60 \times 60}$ = 16.67 m/sec

Velocity of observing car (v_0) = 80km/hr = $\frac{80 \times 1000}{60 \times 60}$ = 22.22 m/sec

Frequency of sound (f) = 500 Hz

Velocity of sound (v) = 340 m/sec

Apparent frequency before overtaking the car,

$$f' = \frac{v + v_0}{v + v_s} \times f = \frac{340 + 22.22}{340 + 16.67} \times 500 = 507.8 \text{ Hz}$$

Apparent frequency after overtaking the car

$$f' = \frac{v - v_0}{v - v_s} \times f = \frac{340 - 22.22}{340 - 16.67} \times 500 = 491.4 \text{ Hz}$$

54. **2072 Set D Q.No. 11** **A stationary motion detector sends sound waves of 150 KHz towards a truck approaching at a speed of 120 km/hr. What is the frequency of wave reflected back to detector? (Velocity of sound in air = 340 m/s)** **[4]**

Solution

Given,

Frequency of sound (f) = 150 KHz = 150000 Hz

Velocity of observer (u_0) = 120 km/hr = $\frac{120 \times 1000}{3600}$ m/sec = 33.33 m/sec

Velocity of sound (v) = 340 m/sec

Apparent frequency (f') = ?

We have, the apparent frequency as observed by the truck is,

$$f' = \frac{v + u_0}{v} = \frac{340 + 33.33}{340} \times 150000 = 164704.41 \text{ Hz} = 164.7 \text{ KHz}$$

Again, the truck acts as a source with frequency f' and the observer is the detector. So, the frequency of wave reflected back to detector is,

$$f'' = \left(\frac{v}{v - v_s}\right) . f' = \frac{340}{340 - 33.34} \times 164.7 = 182.6 \text{ KHz}$$

55. **2070 Sup (Set A) Q.No. 11** **A car travelling at $20ms^{-1}$ blows its horn which has a frequency of 600Hz. A stationary observer notices that the frequency of the horn changes considerably as the car passes by him. Calculate the change in frequency heard by the observer as the car approaches and moves away from the observer. (given velocity of sound = $330ms^{-1}$)** **[4]**

Solution

Given,

Speed of car (Vs) = 20m/sec

Frequency of sound (f) = 600 Hz

Velocity of sound (v) = 330 m/sec

Change in frequency (Δf) = ?

When the car approaches towards stationary observer,

$$f' = \frac{v}{v - vs} . f = \frac{330}{330 - 20} \times 600 = 638.7 \text{ Hz}$$

When the car passes the stationary observer,

$$f'' = \frac{v}{v + vs} . f = \frac{330}{330 + 20} \times 600 = 565.7 \text{ Hz}$$

Change in frequency heard by the observer as car approaches and passes him is,

$\Delta f = f' - f'' = 638.7 - 565.7 = 73$ Hz

56. **2069 Set A Old Q.No. 5b** **When a jet plane is flying on elevation of 1000m the sound level on the ground is 4.0db. What would be the intensity level on the ground when its elevation is as low as 100m?** **[3]**

Solution

Given,

r_1 = 1000m β_1 = 4dB

r_2 = 100m β_2 = ?

Now, we have

Intensity (I) $\propto \frac{1}{r^2}$

Then,

$$\frac{I_2}{I_1} = \frac{r_1^2}{r_2^2} = \frac{1000^2}{100^2}$$

$$\therefore \frac{I_2}{I_1} = 100$$

Again, we have,

The difference of intensity level at these two points is;

$\Delta\beta = \beta_2 - \beta_1$

$= 10\log_{10}\left(\frac{I_2}{I_1}\right) = 10 \log (100) = 20 \text{ dB}$

$\therefore \Delta\beta = 20\text{dB}$

Hence,

$\beta_2 = \beta_1 + \Delta\beta$

$= (4 + 20) \text{ dB} = 24\text{dB}$

Hence, the required intensity level is 24 dB

57. **2068 Old Q.No. 5 b** **When a jet plane is flying at an elevation of 1000m the sound level on the ground is 4.0 dB. What would be the intensity level on the ground when its elevation is as low as 50 m?** **[4]**

Solution

Given,

$r_1 = 1000\text{m}$ $\quad\beta_1 = 4\text{dB}$

$r_2 = 50\text{m}$ $\quad\beta_2 = ?$

Now, we have

Intensity (I) $\propto \frac{1}{r^2}$

Then,

$\frac{I_2}{I_1} = \frac{r_1^2}{r_2^2} = \frac{1000^2}{50^2}$

$\therefore \frac{I_2}{I_1} = 400$

Again, we have,

The difference of intensity level at these two points is;

$\Delta\beta = \beta_2 - \beta_1$

$= 10\log_{10}\left(\frac{I_2}{I_1}\right) = 10 \log (400) = 26.02 \text{ dB}$

$\therefore \Delta\beta = 26.02\text{dB}$

Hence,

$\beta_2 = \beta_1 + \Delta\beta$

$= (4 + 26.02) \text{ dB} = 30.02\text{dB}$

Hence, the required intensity level is 30.02 dB

58. **2068 Old Can. Q.No. 5b** **A source of sound generates sound waves which travel with a speed of 340ms^{-1}. The frequency of the source is 500 Hz. Find the frequency of the sound heard if:**

i. The source is moving towards the stationary observer with a speed of 30 ms^{-1}.

ii. The observer is moving towards the stationary source with a speed of 30ms^{-1}.

iii. Both source and observer move with a speed of 30ms^{-1} and approach one another. **[4]**

Solution

Given,

Speed of sound (v) = 330m/s

Frequency of source (f) = 500Hz

Now,

For (i)

$u_s = 30\text{m/s}^{-1}$ $\quad u_o = 0$

Then, using

$f' = \frac{v}{v - u_s} \times f = \frac{330}{330 - 30} \times 500 = 550 \text{ Hz}$

Hence, the required frequency in this case is 550Hz.

Again, for (ii) we have,

$u_o = 30\text{ms}^{-1}$ $\quad u_s = 0$

Then, using

$$f' = \left(\frac{v + u_o}{v}\right) f = \left(\frac{330 + 30}{330}\right) \times 500 = 545.45 \text{ Hz}$$

Hence, the required frequency in this case is 545.45Hz.

Again,

for (iii), we have,

$u_o = 30m/s$ $\quad\quad u_s = 30m/s$

Then, using

$$f' = \left(\frac{v + u_o}{v - u_s}\right) \times f = \left(\frac{330 + 30}{330 - 30}\right) \times 500 = 600\text{Hz}$$

Hence, the required frequency in this case is 600Hz.

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59. **2067 Q.No. 11 | 2067 Old Q.No. 5b An observer travelling with constant velocity of 20 m/s, passes close to a stationary source of sound and notices that there is a changes of frequency of 50 HZ as he passes the source. What is the frequency of the source? Speed of the sound in air = 340 m/s.** **[4]**

Solution

Given,

Velocity of observer (u_o) = 20m/s

Velocity of source of sound (u_s) = 0

Change of frequency = 50Hz

Speed of sound in air (v) = 340m/s

Frequency of the source (f) = ?

Now, we have,

$$f_1' = \frac{v \pm u_o}{v \pm u_s} \times f$$

In the condition, when the observer approaches the source,

We have

$$f_1' = \frac{v + u_o}{v} \times f = \frac{340 + 20}{340} \times f = \frac{360}{340} \times f$$

$$\text{or, } f_1' = \frac{18f}{17}$$

Again,

when observer passes the source, we have

$$f_2' = \frac{v - u_o}{v} \times f = \frac{340 - 20}{340} \times f = \frac{320}{340} \times f$$

$$\text{or, } f_2' = \frac{16f}{17}$$

Then, according to the question,

$$f_1' - f_2' = \frac{18f}{17} - \frac{16f}{17} = 50$$

$$\text{or, } 50 = \frac{18f - 16f}{17}$$

$$\text{or, } \frac{2f}{17} = 50$$

$$\therefore f = 425\text{Hz}$$

Hence, the required frequency is 425Hz.

---

60. **2065 Q.No. 5 b A car is moving away from a stationary listener with a velocity of 20m/s. If the horn is sounding at frequency 512 Hz, calculate the change in pitch of the sound received by the listener. (velocity of sound in air = 330ms^{-1})** **[4]**

Solution

Given,

Velocity of source (u_s) = 20m/s

Velocity of observer (u_o) = 0
Frequency of horn (f) = 512 Hz
Velocity of sound in air (v) = 330ms^{-1}
Change in pitch = ?
Now,
We have,

$$f' = \frac{v \pm u_o}{v \pm u_s} \times f$$

In this condition, we can use

$$f' = \frac{v}{v + u_s} \times f = \frac{330}{330 + 20} \times 512$$

$\therefore$ $f' = 482.74\text{Hz}$
Hence,
Change in Pitch = $f - f' = (512 - 482.7)\text{Hz} = 29.26\text{Hz}$

61. **2063 Q.No. 6 b** **The intensity level from a loud speaker is 100 dB at a distance of 10m. What is its intensity level at a distance of 200m?** **[4]**

Solution

Given,
For first case: distance (d_1) = 10m, intensity level (I_1) = 100 dB
For second case: distance (d_2) = 200m, intensity level (I_2) = ?

Since, $I \propto \frac{1}{d^2} \Rightarrow \frac{I_2}{I_1} = \left(\frac{d_1}{d_2}\right)^2 \Rightarrow \frac{I_2}{I_1} = \left(\frac{10}{200}\right)^2 = 0.0025$ ...(i)

Again, the difference of intensity level at these two points is;

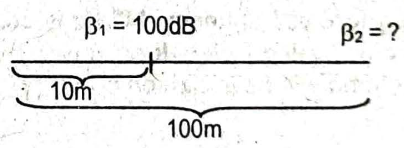
$$\beta_2 - \beta_1 = (10\text{ dB}) \log_{10}\left(\frac{I_2}{I_1}\right) = -26\text{ dB}$$

$\therefore$ $\beta_2 = -26 + \beta_1 = (-26 + 100)\text{ dB} = 74\text{ dB}$
Hence, the required intensity level is 74 dB.

62. **2062 Q.No. 6 b** **The intensity level from a loud speaker is 100 dB at a distance of 10 m. What is its intensity level at a distance of 100 m?** **[4]**

Solution

Given
β_1 = 100dB r_1 = 10m
β_2 = ? r_2 = 100m



Now, we have

$$\text{Intensity (I)} \propto \frac{1}{r^2}$$

Then,

$$\frac{I_2}{I_1} = \frac{r_1^2}{r_2^2}$$

or, $\frac{I_2}{I_1} = \left(\frac{r_1}{r_2}\right)^2 = \left(\frac{10}{100}\right)^2$

$\therefore$ $\frac{I_2}{I_1} = 0.01$

Again, the difference of intensity level at these two points is;

$$\beta_2 - \beta_2 = 10\log_{10}\left(\frac{I_2}{I_1}\right) = 10 \times \log_{10}(0.01) = -20\text{ dB}$$

$\therefore$ $\beta_2 = \beta_1 - 20$
$= (100 - 20)\text{ dB} = 80\text{ dB}$

Hence, the required intensity level is 80 dB.

63. **2059 Q.No. 5 b** **A note produces 2 beat/s with a tuning fork of frequency 480 Hz and 6 beats/s with a tuning fork of 472 Hz. Find the frequency of the note.** **[4]**

Solution

Given,
Note produced by a tuning fork of frequency 480 Hz = 2 beat/ s
Note produced by a tuning fork of frequency 472 Hz = 6 beat/ s
Since, the note produces 2 beats with the tuning fork of frequency 480 Hz, the frequency of the note
$= 480 \pm 2 = 482$ or 478 Hz.
Also, the note produces 6 beat/s with the tuning fork of 472 Hz, the frequency of the note
$= 472 \pm 6 = 478$ or 466 Hz.
As the frequency of 478 Hz is common in both cases, the frequency of the note is 478 Hz.

64. **2056 Q.No. 3** **The noise from an airplane engine 25.0 m from an observer is found to have an intensity of 45.0 dB. What will be the intensity in decibel when the plane flies overhead at an attitude of 2.0 km?** **[4]**

Solution

Given,
$d_1 = 25.0$ m, $d_2 = 2.0$ km $= 2000$ m, $I_1 = 45.0$ dB, $I_2 = ?$
Let I_1 and I_2 be the intensities on the ground when the airplane is at an elevation of 200m and 25 m respectively.

We have, $\frac{I_2}{I_1} = \frac{d_1^2}{d_2^2} = 1.56 \times 10^{-4}$

Here, intensity level at 25m,

$$\beta_1 = (10 \text{ dB}) \log_{10} \frac{I_1}{I_0} \quad \ldots \text{(i)}$$

and intensity level at 2km,

$$\beta_2 = (10 \text{ dB}) \log_{10} \frac{I_2}{I_0} \quad \ldots \text{(ii)}$$

Now, equation (i) – equation (ii), we get

$$\beta_2 - \beta_1 = (10 \text{ dB}) \log_{10} \frac{I_2}{I_1} - (10 \text{ dB}) \log_{10} \left(\frac{d_1^2}{d_r^2}\right)$$

$$\therefore \beta_2 = \beta_1 + (10 \text{ dB}) \log_{10} (1.56 \times 10^{-4}) = 6.94 \text{ dB}$$

65. **2054 Q.No. 3** **A column of air is set into vibration and the note emitted gives 10 beats per second when a tuning fork of frequency 440 Hz is sounded, the temperature being 20°C. The frequency of beats decreases when the tuning fork is loaded with a small piece of wax. At what temperature will the unloaded fork and the air column will be in unison?** **[4]**

Solution

Given,
Beats per second =10
So, the frequency of the pipe = 440 ± 10 Hz = 430 Hz or 450 Hz
When the fork is loaded with a small piece of wax, the beat frequency decreases, so the air column must have the lower frequency.
i.e., f = 430 Hz
Let t°C be the temperature at which the air column will be in unison.
At this temperature, the frequency of air column = 440 Hz

$$\therefore v_t = 440 \times \lambda \quad \ldots \text{(i)}$$

And at 20°C the frequency of air column is given by

$$\therefore v_{20} = 430 \times \lambda \quad \ldots \text{(ii)}$$

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

$$\frac{v_t}{v_{20}} = \frac{440 \times \lambda}{430 \times \lambda} = \frac{44}{43} \quad \ldots \text{(iii)}$$

Since, $v \propto \sqrt{T}$, so the equation (iii) can be written as

$$\frac{\sqrt{273 + t}}{\sqrt{273 + 20}} = \frac{44}{43} \Rightarrow \frac{273 + t}{293} = \left(\frac{44}{43}\right)^2$$

$\therefore$ $t = \left(\frac{44}{43}\right)^2 \times 293 - 273 = 33.73°C = 306.33K$

Hence, the required temperature is 306.33K

66. **2054 Q.No. 3 OR Two observers A and B are provided with source of sound of frequency 500 Hz. A remains stationary and B moves away from him at a velocity of 18ms^{-1}. How many beats per second are observed by B, the velocity of sound in air being 330 ms^{-1}? [4]**

Solution

Given,
Frequency of the source (f) = 500 Hz
Velocity of sound (v) = 330 ms^{-1}
Velocity of observer (v_0) = 18 ms^{-1}
Velocity of source (v_s) = 0 ms^{-1}
Observer B is moving away from the source i.e., observer A. Apparent frequency heard by B is given by.

$$f_1 = \left(\frac{v - v_0}{v}\right) \times f = \frac{330 - 18}{330} \times 500 = 472.8 \text{ Hz}$$

$\therefore$ Beat frequency (B) = $f - f_1$ = 500 – 472.8 = 27.2 Hz ≈ 27 Hz
Hence, 27 beats per second are observed by B.

❑❑❑

B. Physical Optics

Chapter 1: Nature and Propagation of Light

Short Answer Questions

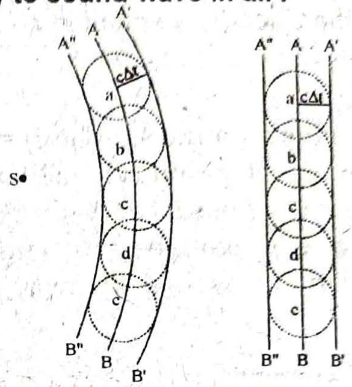
1. **2076 Set B Q.No. 4a** **2067 Sup Q.No. 4a** **State Huygen's principle. Does it apply to sound wave in air?** [2]

Huygens principle is a geometrical construction of a wavefront which is used to determine the position of wavefront at a later time from its position at any instant. The principle is based on the following assumptions:

a. Each point on the primary (given) wavefront acts as a source of secondary wavelets, the light waves sending out from secondary sources travel in all direction with the speed of light.

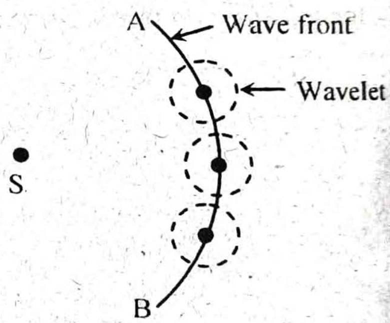
b. The new position of the wavefront at any instant is given by the forward envelope of the secondary wavelets at that instant.

Yes, it can be applied to sound wave.



2. **2076 Set C Q.No. 4a** **2075 Set A Q.No. 4a** **2075 Set B Q.No. 4a** **2074 Supp Q.No. 4a** **2072 Set C Q.No. 4a** **2070 Set C Q.No. 4 b** **2056 Q.No. 2 c** **Differentiate wave front and wavelet.** [2]

Wavefront at any instant is defined as the locus of the particles of the medium vibrating in the same phase. Every point on the wavefront acts a source of a disturbance; these disturbances from the points are called wavelets. Each point on a wave surface can act like a new source of smaller spherical waves which are called wavelets. The wavelets may originate from the primary as well as secondary source of light. Wavefronts are the envelope of these wavelets.

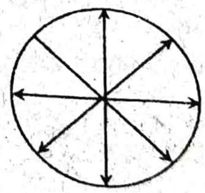


3. **2074 Set A Q.No. 4a** **2072 Set E Q.No. 4a** **Explain with proper sketch, the differences between wavefronts and wavelets.** [2]

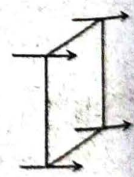
Please refer to 2076 Set C Q.No. 4a

4. **2073 Supp Q.No. 4a** **2062 Q.No. 2 d** **Differentiate between a plane wavefront and a spherical wavefront.** [2]

A wavefront is the continuous locus of vibrating particles of the medium which are in the same state of vibration or phase. If a point source in an isotropic medium (i.e. a medium in which the waves travel with the same speed in all directions) is sending out waves in three dimensions, the wavefronts are spheres centered on the source as shown in Fig. (i), such a wavefront is called a spherical wavefront. At a large distance from a source of any kind, the wavefront will appear plane as shown in Fig. (ii), such a wavefront is called plane wavefront.



(i)



(ii)

5. **2073 Set D Q.No. 4a** **What is the difference between wavefront and wavelets in the explanation of Huygen's wave theory?** [2]

Please refer to 2076 Set C Q.No. 4a

6. **2071 Supp Q.No. 4a** **If light travels from one medium to another, its velocity changes? Is it due to change in frequency or wavelength? Explain.** [2]

The velocity of light is given by $v = \lambda \times f$, where λ is wavelength of light in that medium & f is frequency. Since, frequency is fundamental or empirical parameter of a wave & it does not change with medium. So, the velocity of light wave changes on changing wavelength when light passes from one medium to another medium.

7. **2071 Set C Q.No. 4 a** **Distinguish between wavefronts and wavelets.** [2]

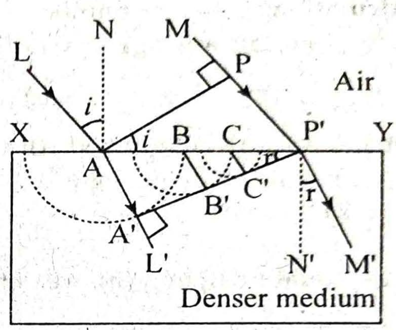
Please refer to 2076 Set C Q.No. 4a

8. **2070 Supp. (Set B) Q.No. 4 a A normally incident wavefront does not deviate, when it travels from one medium to another. Explain.** **[2]**

According to Snell's law of refraction, the refractive index of a medium is given by, $\mu = \frac{\sin i}{\sin r}$, where i is incident angle and r is refracted angle. For normal incidence, i = 0, then r = 0 as $\mu \neq 0$, the minimum value of μ is 1 but never is equal to 0. So, a normally incident wavefront does not deviate, when it travels from one medium to another.

9. **2069 Supp Set B Q.No. 4 b Can Snell's law be verified from wave theory? Explain with figure only.** **[2]**

Yes, snell's law can be verified from wave theory.



From right angled triangle APP',

$\sin i = \frac{PP'}{AP'} = \frac{ct}{AP'}$;

c = vel. of light in air

From right angled triangle AA'P',

$\sin r = \frac{AA'}{AP'} = \frac{vt}{AP'}$;

v = vel. of light in denser medium

Now, $\frac{\sin i}{\sin r} = \frac{ct}{vt} = \frac{c}{v} = \mu$

$\therefore \mu = \frac{\sin i}{\sin r}$ which is Snell's law.

10. **2069 (Set A) Old Q.No. 2g 2068 Q.No. 4 b What is wavefront?** **[2]**

Wavefront is the locus of all vibrating particles which are in same phase. The shape of wavefront is different according to the nature and distance from the source of light.

11. **2067 Q.No. 4b What is Huygens's principle?** **[2]**

Please refer to 2076 Set B Q.No. 4a

12. **2067 Old Q.No. 2c When monochromatic light incidents on a surface, the reflected and refracted wave will have same frequency, why?** **[2]**

When monochromatic light incidents on a surface, the reflected and refracted wave will have same frequency because frequency of a wave is empirical parameter and does not change with reflection and refraction.

13. **2063 Q.No. 2 c Which parameter of light does not change on refraction?** **[2]**

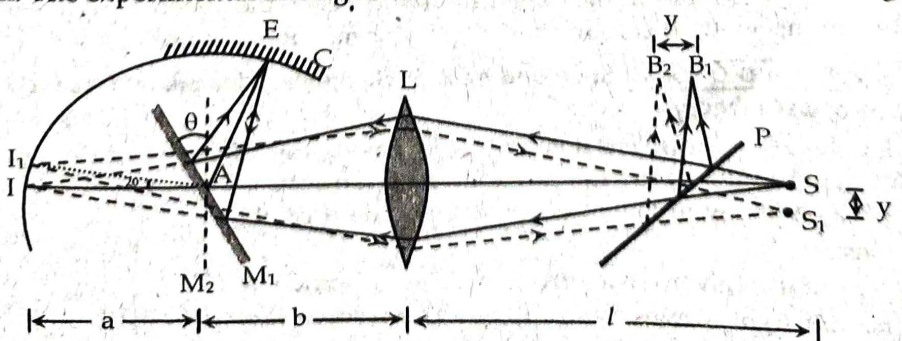
During the refraction of light, velocity and wavelength of light wave are changed but frequency is not changed because frequency is fundamental parameter of light wave. It is the characteristics of the source that produce the wave.

Long Answer Questions

14. **2076 Set B Q.No. 8b 2075 Set A Q.No. 8b 2070 Sup (Set A) Q.No. 8 a 2069 (Set A) Q.No. 8a Describe Foucault's method of determining the speed of light.** **[4]**

Measurement of velocity of light by Foucault's Method:

Construction: The experimental arrangement of Foucault's method is shown in figure.



It consists of a bright source of light S, placed in front of a partially silvered glass plate P which is kept at an angle of 45° to the axis of lens L, which is kept between the glass plate and a rotating mirror M_1. A concave mirror is kept at distance equal to the radius of curvature of the concave mirror from point A. The whole apparatus are arranged as shown in figure.

The light from source S is incident on a convex lens L. The light after passing through L will converges at the point I. If a mirror M_1 is placed at A, light after reflection from the surface of the mirror M_1 converges at the pole E of concave mirror C. The distance between the two mirror is equal the radius of curvature of the concave mirror. The light reflected back from E along its original paths finally the image is formed on the source S. As there is half silvered glass plate P inclined at an angle 45° to the axis of lens, a part of light is reflected by the glass plate and forms an image B_1 of the source. If the mirror M_1 is rotated by an angle θ to new position M_2, the rays reflected in this position of the mirror are converged by the lens at point S_1, then the position of I shift to I_1 and B_1 to B_2 as shown in figure.

Calculation: Let, n = number of revolutions per second made by the mirror, then time taken by mirror to rotate an angle of θ radian is

$$t_1 = \frac{\theta}{\omega} = \frac{\theta}{2\pi n} \quad \ldots \text{(i)}$$

Let, c = velocity of light and AE = a

∴ Also, time taken by the light to travel from A to E and back to A is,

$$t_2 = \frac{2a}{c} \quad \ldots \text{(ii)}$$

Thus, equating (i) and (ii), we obtain

$$\frac{\theta}{2\pi n} = \frac{2a}{c}$$

$$c = \frac{4\pi na}{\theta} \quad \ldots \text{(iii)}$$

Therefore, knowing n, a and θ, the velocity of light c can be calculated.

Again, if the mirror is rotated through an angle θ, the reflected ray is rotated through an angle 2θ. It is clear from the figure that

$II_1 = a(2\theta)$

Since the points S, I and S_1, I_1 are conjugate points for the lens L,

$$\frac{SS_1}{II_1} = \frac{\text{object distance}}{\text{image distance}}$$

or, $$\frac{SS_1}{II_1} = \frac{l}{a+b}$$

Since, $SS_1 = B_1B_2 = y$,

$$\frac{y}{2a\theta} = \frac{l}{a+b} \quad \ldots \text{(iv)}$$

Putting the value of θ from equation (iii) to (iv) we get,

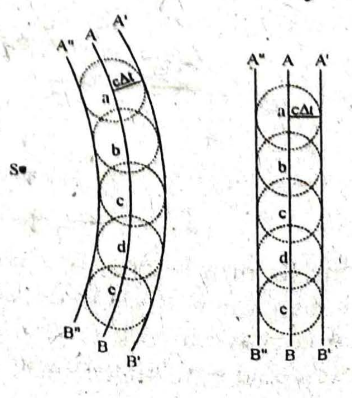
$$\frac{yc}{8\pi na^2} = \frac{l}{a+b}$$

$$\therefore \quad c = \frac{8\pi na^2 l}{y(a+b)}$$

This is required expression to determine the speed of light by Foucault's method. All the quantities on the right hand side can be measured in the experiment and hence the speed of light can be calculated. The speed of light from this method is found to be 2.98×10^8 ms^{-1} in vacuum.

15. **2076 Set C Q.No. 8a** **2072 Set D Q.No. 8a** **State and explain Huygen's principle and use it to verify laws of reflection on the basis of wave theory.** **[4]**

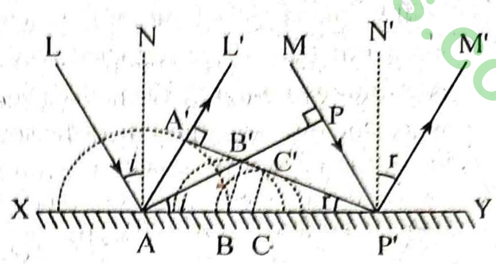
➢ **Huygen's principle:** Huygens principle is a geometrical construction of a wavefront which is used to determine the position of wavefront at a later time from its position at any instant. The principle is based on the following assumptions:



a. Each point on the primary (given) wavefront acts as a source of secondary wavelets, the light waves sending out from secondary sources travel in all direction with the speed of light.

b. The new position of the wavefront at any instant is given by the forward envelope of the secondary wavelets at that instant.

Reflection on basis of wave theory: Let XY be a reflecting surface and AP be a plane wavefront just incident on it. The lines LA and MP which are perpendicular to the incident wavefront AP, represent incident rays. If AN is normal to reflecting surface at A, then ∠LAN = i is the angle of incidence as shown in figure.



The wavefront arrives at point A first of all and will arrive at points B, C ... later in time, but in this order. Thus, different points on the reflecting surface will become source of secondary wavelets at different instants of time. When the disturbance from point P on incident wavefront has reached point P′ on the surface, the secondary wavelets from A, on the surface will have acquired radius, say equal to AA′ and those from points B, C, ... equal to BB′, CC′, ... respectively. The reflected wavefront will be the tangent plane A′P′ touching all the secondary wavelets. The lines A′L′ and P'M' perpendicular to the reflected wavefront A'P' are reflected rays. If P'N' is normal to reflecting surface at P', then ∠N'P'M' = r is the angle of reflection.

Now, in right angled triangles APP' and AA'P'

∟APP′ = ∟AA′P′ (both are right angles)

AA' = PP' (distance travelled by light in same time)

AP' = AP' (common side)

Therefore, two triangles are congruent and hence

∠PAP' = ∠A'P'A ... (i)

As the angle between two lines is same as the angle between their perpendiculars, therefore,

∠PAP' = i and ∠A'P'A = r

From equation (i), we have

$i = r$

i.e., angle of incidence is equal to angle of reflection. Further, as the incident wavefront (AP), the reflecting surface (XY) and the reflected wavefront (A'P') are all perpendicular to the plane of the paper, therefore the incident ray (LA), normal (AN) and reflected ray (AA'L'), which are respectively perpendicular to AP, XY and A'P' all lie in the same plane. This proves the second law of reflection. Hence, the laws of reflection are proved on the basis of wave theory.

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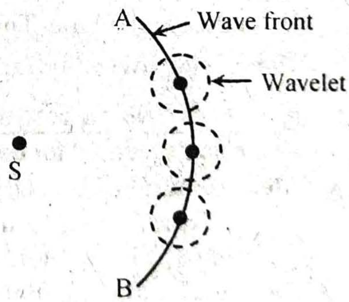
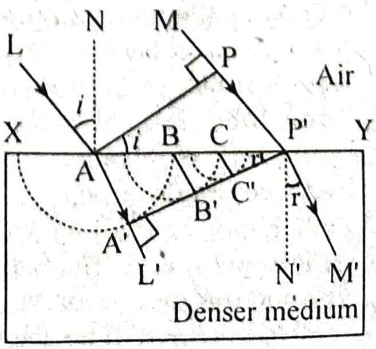
16. **2075 GIE Q.No. 8a** **2071 Supp Q.No. 8a** **What is meant by wave front? Verify Snell's law on the basis of wave theory.** **[4]**

Wave Front: Wavefront at any instant is defined as the locus of the particles of the medium vibrating in the same phase. Every point on the wavefront acts a source of a disturbance; these disturbances from the points are called wavelets. Each point on a wave surface can act like a new source of smaller spherical waves which are called wavelets. The wavelets may originate from the primary as well as secondary source of light. Wavefronts are the envelope of these wavelets.



Refraction on basis of wave theory: Let XY be a plane surface separating air form a denser medium and AP be a plane wavefront just incident on it. The lines LA and MP which are perpendicular to the incident wavefront AP, represent incident rays. If AN is normal to the surface at A, then ∠LAN = i is the angle of incidence as shown in figure. Again the wavefront arrives at point A first of all and will arrive at points B, C,... later in time but in this order.



Therefore, different points on the surface XY will become source of secondary wavelets at different instants of time. When the disturbance from point P on incident wavefront has reached point P' on the surface, the secondary wavelets from point A on the surface will have acquired a radius, say equal to AA' and those from points B, C ... equal to BB', CC'... respectively. The refracted wavefront will be the tangent plane A'P' touching all the secondary spherical wavelets. The lines A'L' and P'M' perpendicular to the refracted wavefront A'P' are refracted rays. If P'N' is normal to the surface of separation at point P', then ∠N'P'M' = r is the angle of refraction.

Let c be velocity of light in air and v, the velocity in denser medium. As the distance PP' in air and the distance AA' in denser medium are covered by the light in same time, therefore

$$\frac{PP'}{AA'} = \frac{c \times t}{v \times t} = \frac{c}{v} \quad \ldots (i)$$

As the angle between two lines is same as the angle between their perpendiculars, therefore,

∠PAP' = i and ∠AP'A' = r

From right angled triangle APP',

$$\sin i = \frac{PP'}{AP'}$$

And from right angled triangle AA'P',

$$\sin r = \frac{AA'}{AP'}$$

$$\therefore \mu = \frac{\sin i}{\sin r} = \frac{PP'}{AP'} \cdot \frac{AP'}{AA'}$$

$$\frac{\sin i}{\sin r} = \frac{PP'}{AA'} \quad \ldots (ii)$$

From equation (i) and (ii), we have

$\frac{\sin i}{\sin r} = \frac{c}{v} = \mu$ which is Snell's law.

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

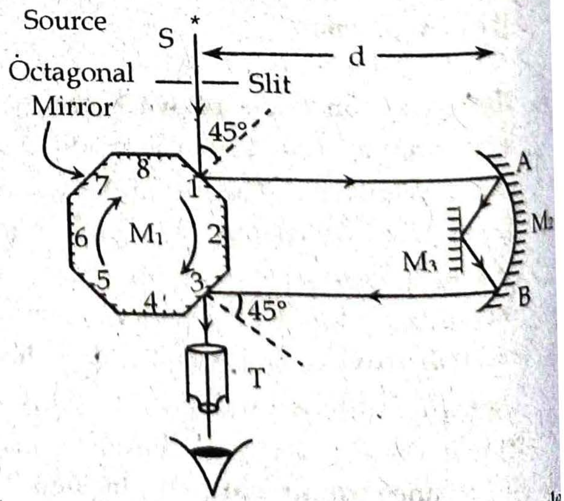
Further, it can be proved that the incident ray (LA), the normal (AN) and the refracted ray (AA'L) all lie in the same plane. This proves another law of refraction.

Hence, the laws of refraction are proved on the basis of wave theory.

17. **2075 Set B Q.No. 7a** **2072 Set E Q.No. 8a** **2071 Set C Q.No. 8 a** **2069 Supp Set B Q.No. 8b** **2067 Q.No. 8a** **Describe Michelson's method for determining the speed of light.** **[4]**

Measurement of velocity of light by Michelson's Method:

The experimental arrangement of Michelson's experiment for determination of velocity of light consists of an octagonal mirror M_1, a bright source S, a concave mirror M_2, a plane mirror M_3, a telescope T. These apparatus are arranged as shown in figure.



A collimated beam of light from source via slit falls on the first face of the octagonal mirror at an angle of 45°. This beam of light reflects by mirrors M_1, M_2 and M_3 and again returned back on face 3 of the octagonal mirror M_1 again at an angle of 45°. The light reflected by this face is then collected by a telescope T and the eye at the position. At this rest position of the mirror M_1, an image of the light source can be observed in the telescope.

If the mirror M_1 is rotated, the light returning to it from the mirror M_2 will not be incident at an angle of 45°, and hence will not enter the telescope. When the speed of rotation of mirror M_1 is so adjusted that the face 2 of mirror occupies exactly the same position as was occupied by face 3 earlier (in 1/8th revolution, of mirror M_1) during this time light travels from M_1 to M_2 and back to M_1, then the image of source will reappear continuously.

If d is the distance between the mirror M_1 and M_2 and c be the speed of light, then the time taken by the light to travel from M_1 to M_2 and back to M_1 is

$$t = \frac{2d}{c}$$

If n is the number of revolutions per second of mirror M_1 and m is the number of faces of this mirror, then the angle rotated by the mirror during the time t is

$\theta = \frac{2\pi}{m}$ and $t = \frac{\theta}{\omega}$; ω is angular velocity of rotating mirror M_1.

or, $t = \frac{\theta}{2\pi f} = \frac{2\pi}{2\pi nm} = \frac{1}{mn}$ $\quad (\because \omega = 2\pi n)$

or, $\frac{2d}{c} = \frac{1}{mn}$

$\therefore$ $c = 2mnd$

This is required formula to calculate speed of light by using Michelson's method. In his original experiment, the speed of the motor was about 528 rev/s and d was about 35 km. He obtained a value of 2.99775×10^8 ms^{-1} for speed of light in vacuum.

18. **2074 Set B Q.No. 8a** **What is a wavefront? Using Huygen's principle proves that for a parallel beam of light incident on a reflecting surface, the angle of incidence is equal to angle of reflection.** **[4]**

Wave Front: Please refer to 2075 GIE Q.No. 8a

Reflection on basis of wave theory: Please refer to 2076 Set C Q.No. 8a

19. **2073 Set C Q.No. 8b** **Describe Huygen's principle with figure to prove the laws of reflection and refraction of light.** **[4]**

Please refer to 2076 Set C Q.No. 8a

20. **2072 Supp Q.No. 8a** **What is Huygen's principle? Show how refraction of light at a plane interface can be explained on the basis of wave theory of light.** **[4]**

Please refer to 2075 GIE Q.No. 8a

21. **2071 Set D Q.No. 8 a** **State and explain Huygen's principle and use it to verify Snell's law.** **[4]**

Huygen's principle: Please refer to 2076 Set B Q.No. 4a

Refraction on basis of wave theory: Please refer to 2075 GIE Q.No. 8a

22. **2070 Sup (Set A) Q.No. 8 b** **State Huygen's principle of wave theory of light and also use this principle to verify the laws of reflection of light.** **[4]**

Please refer to 2076 Set C Q.No. 8a

23. **2070 Supp. (Set B) Q.No. 8 b** **State and use Huygen's principle of wave theory of light to verify the laws of refraction of light.** **[4]**

Huygen's principle: Please refer to 2076 Set B Q.No. 4a

Refraction on basis of wave theory: Please refer to 2075 GIE Q.No. 8a

24. **2070 Set D Q.No. 8 a** **State and explain Huygen's principle. Use it to prove Snell's law.** **[4]**

Huygen's principle: Please refer to 2076 Set B Q.No. 4a

Refraction on basis of wave theory: Please refer to 2075 GIE Q.No. 8a

25. **2069 (Set B) Q.No. 8b** **Describe Foucault's experimental method for the measurement of the velocity of light with necessary theory.** **[4]**

Please refer to 2076 Set B Q.No. 8b

26. **2068 Can. Q.No. 8a** **2066 Supp Q.No. 6a** **State and explain Huygen's principle. Use the principle to show that a plane wave incident obliquely on a plane mirror is reflected as a plane wave so that the angle of incidence is equal to the angle of reflection.** **[4]**

Please refer to 2076 Set C Q.No. 8a

27. 2067 Sup Q.No. 8b **Describe Michelson's method to determine the speed of light. Write advantages of the method over foucault's method.** [3+1]

Michelson's method: Please refer to 2075 Set B Q.No. 7a

Advantage of Michelson's Method

i. This is a null method and so, there is no measurement of the displacement of the image.
ii. The image is very bright and so its position can be located with accuracy.
iii. The appearance and disappearance of the image is quite abrupt so that it coincides with the cross wires in the telescope only for a particular constant speed of the mirror.
iv. The distance between two mirrors is very large about 35 km so as to measure the speed of light accurately.

28. 2064 Q.No. 6 a **State and explain Huygen's principle. Use the principle to verify the laws of refraction of light on the basis of wave theory.** [1+3]

Huygen's principle: Please refer to 2076 Set B Q.No. 4a

Refraction on basis of wave theory: Please refer to 2075 GIE Q.No. 8a

29. 2063 Q.No. 5 a OR **Define Huygen's principle and prove Snell's law by the help of wave theory of light.** [4]

Huygen's principle: Please refer to 2076 Set B Q.No. 4a

Refraction on basis of wave theory: Please refer to 2075 GIE Q.No. 8a

30. 2061 Q.No. 6 a **Prove the laws of reflection of light using the wave theory.** [4]

Please refer to 2076 Set C Q.No. 8a

31. 2060 Q.No. 6 a **State and explain Huygen's principle. Use the principle to show that a plane wavefront incident obliquely on a plane mirror is reflected as a plane wavefront so that the angle of incidence is equal to the angle of reflection.** [2+2]

Please refer to 2076 Set C Q.No. 8a

Numerical Problems

32. 2074 Supp Q.No. 12 **In Michelson's rotating prism method, the distance between the rotating prism and the distant mirror is 45 km. A minimum speed of 416.7 revolutions per second is needed to view the source in the same position as when the prism is at rest. Calculate the speed of light.** [3]

Solution

Given,

Distance between mirrors (d) = 45 km = 45000 m

Speed of prism (n) = 416.7 rev/ sec

Faces of prism (m) = 8

Speed of light (c) = ?

We have,

$$c = 2mnd = 2 \times 8 \times 416.7 \times 45000 = 300024000 \text{ m/s} = 3 \times 10^8 \text{ m/s}$$

33. 2074 Set A Q.No. 12 **A plane mirror is placed at the centre of a concave mirror having radius of curvature 40 m. The plane mirror rotates at the speed of 2600 revolutions per second. Calculate the angle between ray incidents on the plane mirror and then reflected from it after the light has travelled to the concave mirror and back to the plane mirror. Given -speed of light is 3×10^8 m/s.** [3]

Solution

Given,

Radius of curvature (R) = 40 m

Frequency (f) = 2600 rev/sec

Angle (2θ) = ?

Velocity of light (c) = 3×10^8 m/sec

We have,

$$\theta = \frac{4\pi fR}{c} = \frac{4\pi \times 2600 \times 40}{3 \times 10^8} = 4.35 \times 10^{-3} \text{ rad} = \left(4.35 \times 10^{-3} \times \frac{180}{\pi}\right)^\circ = 0.25^\circ$$

Then angle between incident and reflected ray

$2\theta = 0.25 \times 2 = 0.5^\circ$

34. **2073 Supp Q.No. 12** **The radius of curvature of the curved mirror is 200m and the plane mirror is rotated at 20 rev s^{-1}. Calculate the angle in degrees between ray incidents on the plane mirror and then reflected from it after the light has travelled to the curved mirror and back to the plane mirror. (C = 3 × 10^8 ms^{-1})** **[3]**

Solution

Given,

Radius of curvature (R) = 200 m

Rotation of mirror (f) = 20 rev/s

Velocity of light (c) = 3×10^8 ms^{-1}

Angle (θ) = ?

We have,

$$\theta = \frac{4\pi fR}{c} = \frac{4\pi \times 20 \times 200}{3 \times 10^8} = 1.67 \times 10^{-4} \text{ rad} = (9.57 \times 10^{-3}) \text{ degree}$$

Angle between incident and reflected ray is 2θ

$\therefore 2\theta = 2 \times 9.5 \times 10^{-3}$ degree = 0.0192 degree

35. **2072 Set C Q.No. 12** **2070 Supp. (Set B) Q.No. 12** **A beam of light after reflection at a plane mirror, rotating 2000 times per minute, passes to a distant reflector. It returns to the rotating mirror from which it is reflected to make an angle of 1° with its original direction. If the distance between the mirrors is 6250 m, calculate the velocity of light.** **[3]**

Solution

Given,

Frequency of rotation (n) = 2000/min $= \frac{2000}{60} = 33.33$ rev/sec

Angle (2θ) = 1°, $\theta = 0.5^\circ$

or, $\theta = 0.5 \times \frac{\pi}{180}$

$= 8.73 \times 10^{-3}$rad

Distance between mirrors (d) = 6250m

Velocity of light (c) = ?

We have,

$$c = \frac{4\pi nd}{\theta} = \frac{4\pi \times 33.33 \times 6250}{8.73 \times 10^{-3}} = 3 \times 10^8 \text{ m/sec}$$

36. **2071 Supp Q.No. 12** **In a Michelson experiment for measuring speed of light, the distance travelled by light between two reflections from the rotating mirror is 4.8km. The rotating mirror has a shape of regular octagon. At what frequency of rotation of mirror the image is formed at the position where non-rotating mirrors forms it?** **[3]**

Solution

Given,

Speed of light (c) = 3×10^8 m/sec

No. of face of mirror (m) = 8

No. of rotation per sec (n) = ?

Distance travelled (D) = 4.8 km

$\therefore$ Distance between two mirrors, $d = \frac{D}{2} = \frac{4800}{2} = 2400$ m

We have,

$c = 2mnd$

or, $3 \times 10^8 = 2 \times 8 \times n \times 2400$

$\therefore n = 7812.5$ rev/sec

37. 2070 Set C Q.No. 12 2067 Old Q.No. 6b **A beam of light is reflected by a rotating mirror on to a fixed mirror, which sends it back to the rotating mirror which it is again reflected making an angle of 18° with its original direction. The distance between the two mirrors is 10 km and the rotating mirror is making 375 revolutions per second. Calculate the velocity of light.** [4]

Solution

Given,

The deviation of reflected ray from the original direction,

$2\theta = 18°$

or, $\theta = 9° = 9 \times \frac{\pi}{180}$ rad

distance between two mirrors (d) = 10^4 m

frequency of rotating mirror (n) = 375 rev/sec

velocity of light (c) = ?

We have,

$$c = \frac{4\pi nd}{\theta} = \frac{4 \times \pi \times 375 \times 10^4 \times 180}{9 \times \pi} = 3 \times 10^8 \text{ m/sec}$$

Hence, the velocity of light (c) is 3×10^8 m/s.

38. 2063 Q.No. 5 b **A beam of light is reflected by a rotating mirror onto a fixed mirror which sends back to the rotating mirror from which it is again reflected and then makes an angle of 3.6° with the original direction. The distance between the two mirror is 1 km and the rotating mirror is make 750 revs^{-1}. Calculate the velocity of light.** [4]

Solution

Given,

Frequency of rotating mirror

n = 750 rev s^{-1}

Deviation of the beam after reflection from the rotating mirror

$2\theta = 3.6°$

$\therefore \theta = \frac{3.6°}{2} = 1.8° = 1.8 \times \frac{\pi}{180}$ radian

Distance between two mirrors (d) = 1km = 1000m

Velocity of light (c) = ?

We have, relation for velocity of light as

$$c = \frac{4\pi nd}{\theta} = \frac{4\pi \times 750 \times 1000 \times 180}{1.8 \times \pi} = 3 \times 10^8 \text{ m/s}$$

Hence, the velocity of light (c) is equal to 3×10^8 m/s.

39. 2053 Q.No. 6 b **The radius of curvature of the curved mirror is 20 m and the plane mirror is rotated at 20 revs^{-1}, calculate the angle in degrees between a ray incident on the plane mirror and then reflected from it after the light has travelled to the curved mirror and back to the plane mirror ($c = 3 \times 10^8$ m s^{-1}).** [4]

Solution

Given,

The distance between the plane mirror and the curved mirror (d) = 20m

Velocity of light (c) = 3×10^8 ms^{-1}

Frequency of mirror (n) = 20 revs^{-1}

Angle (2θ) = ?

Now,

$$c = \frac{4\pi nd}{\theta}$$

or, $\theta = \frac{4\pi nd}{c} = \frac{4\pi \times 20 \times 20}{3 \times 10^8} = 1.675 \times 10^{-5}$ rad

$\theta = 9.6 \times 10^{-4}$ degree

$2\theta = 2 \times 9.6 \times 10^{-4}$ degree

$= 1.92 \times 10^{-3}$ degree

□□□

Check your understanding **A large number of free electrons are present in metals. Why is there no current in the absence of electric field across it?**

Sol^n: In the absence of electric field across a conductor, the free electrons move in random direction. During their motion, an electron collide with other electrons and ions in the metal and it will have net displacement zero making drift velocity zero. We know I = nevA where I is the current and v is the drift velocity. Since, v = 0m/s, I will be zero.

Sample Problem –10.1 **A copper wire of diameter 1.02mm carries a constant current of 1.67A The density of free electrons is 8.5 $\times 10^{28}$ electron per cubic meter. Find the magnitudes of the current density and the drift velocity.**

Sol^n:

The cross sectional area is

$$A = \frac{\pi d^2}{4} = \frac{\pi}{4} \times (1.02 \times 10^{-3})^2$$

$$= 8.17 \times 10^{-7}\ m^2$$

The magnitude of the current density is

$$J = \frac{I}{A} = \frac{1.67}{8.17 \times 10^{-7}} = 2.04 \times 10^6\ Am^{-2}$$

The drift velocity $v = \frac{J}{ne}$

$$= \frac{2.04 \times 10^6}{8.5 \times 10^{28} \times 1.6 \times 10^{-19}}$$

$$v = \mathbf{1.5 \times 10^{-4}\ m/s}$$

10.11 Relation Between $\vec{J}$ and $\vec{E}$.

Here,

$$V = IR$$

$$\text{or, } I = \frac{V}{R}$$

$$\text{or, } I = \frac{V}{\rho l} \times A \quad [\because R = \rho l/A]$$

$$\text{or, } \frac{I}{A} = \frac{1}{\rho}\left(\frac{V}{l}\right)$$

$$\vec{J} = \sigma\vec{E}$$

This is known as vector form of Ohm's law.

Sample Problem -10.2 The 18-guage copper wire has a diameter of 1.02mm and a cross sectional area of $8.20 \times 10^{-7} m^2$. It carries a current of 1.67 A. find:

(a) The electric field magnitude in the wire.
(b) The potential difference between two points in the wire 50m apart.
(c) The resistance of a 50m length of this wire.

*Sol^n^*: Diameter (d) = 1.02×10^{-3}m

Cross sectional area (A) = $8.2\times10^{-7}m^2$

Current (I) = 1.67A

Electric field magnitude (E) = ?

Potential difference (V) = ?

Length (ℓ) = 50m

Resistance (R) = ?

We have, $\rho = 1.272 \times 10^{-8}\Omega m$

$$J = \sigma E$$

$$\text{or, } E = \frac{I}{A} \times \rho$$

$$\text{or, } E = 0.0259 Vm^{-1}$$

Again,

$$V = E \times d = 1.295V$$

$$\text{Then, } R = \frac{\rho\ell}{A} = 1.272 \times 10^{-8} \times \frac{50}{8.2\times10^{-7}}$$

$$= 0.77\Omega.$$

Sample Problem -10.3 The resistance of a conductor at 20^0C is 3.15 Ω and at 100^0C is 3.75 Ω. Determine the temperature coefficient of resistance of the conductor. What will be the resistance of the conductor at 0^0C?

*Sol^n^*: $R_1 = R_o(1 + \alpha\theta_1)$ and $R_2 = R_o(1 + \alpha\theta_2)$

On dividing,

$$\frac{R_1}{R_2} = \frac{1 + \alpha\theta_1}{1 + \alpha\theta_2}$$

$$\text{or, } R_1(1 + \alpha\theta_2) = R_2(1 + \alpha\theta_1)$$

$$\text{or, } \alpha = \frac{R_2 - R_1}{R_1\theta_2 - R_2\theta_1}$$

Here, $\theta_1 = 20^0C$, $R_1 = 3.15\Omega$

$\theta_2 = 100^0C$, $R_2 = 3.75\ \Omega$

$$\therefore \quad \alpha = \frac{3.75 - 3.15}{(3.15 \times 100) - (3.75 \times 20)}$$

$$= \frac{0.60}{315 - 75} = \frac{0.60}{240} = 0.0025^0C^{-1}$$

$$\text{and } R_o = \frac{R_1}{1 + \alpha\theta_1} = \frac{3.15}{1 + 0.0025 \times 20} = 3.0\Omega$$

Chapter 2: Interference

Short Answer Questions

1. **2075 GIE Q.No. 4a What happens on the interference fringes in a Young's double slit experiment when (i) the screen is moved away (ii) the source is replaced by another source of shorter wavelength? [2]**

We know that fringe width (β) in Young's double slit experiment is given by $\beta = \frac{\lambda D}{d}$, where D is distance between slit and screen, d is separation of slits and λ be wave length of light used.

i. When the screen is moved away, the D increases and fringe width increases and better interference fringes are seen.

ii. If the source is replaced by another source of shorter wavelengths, then the fringe width decreases and interference bands are not seen clearly.

2. **2074 Set B Q.No. 4a What are coherent sources of light? Can two different bulbs, similar in all respects, act as coherent sources? [2]**

Coherent sources are a pair of sources of light which emit light waves of the same wavelength and frequency which are always in the phase with each other or have a constant phase difference. Two independent sources of light cannot be coherent sources because they may emit the light wave of same wavelength and frequency but they never are in same phase or at a constant phase difference. So, two different bulbs, similar in all respects, can not act as coherent sources.

3. **2073 Set C Q.No. 4a Two waves are represented in usual notation as $y_1 = a_1 \sin wt$ and $y_2 = a_2 \cos wt$. Their intensities are I_1 and I_2. What would be the ratio of their amplitudes when $I_1 = 2I_2$? [2]**

Given waves, $y_1 = a_1 \sin \omega t$

and $y_2 = a_2 \sin \omega t$

Let I_1 and I_2 be their intensities, then

$$I_1 \propto a_1^2$$

$$I_2 \propto a_2^2$$

or, $\frac{I_1}{I_2} = \frac{a_1^2}{a_2^2}$

When, $I_1 = 2I_2$

Then, $\frac{2I_2}{I_2} = \left(\frac{a_1}{a_2}\right)^2$

or, $2 = \left(\frac{a_1}{a_2}\right)^2$

or, $\frac{a_1}{a_2} = \sqrt{2}$

i.e., $\frac{a_1}{a_2} = \sqrt{2} : 1$

Thus, the ratio of this amplitudes would be $\sqrt{2} : 1$

4. **2072 Supp Q.No. 4a A two-slit interference experiment is setup and the fringes are displayed on a screen. Then the whole apparatus is immersed in water. How does the fringe pattern change? [2]**

In a Young's two-slit experiment, the fringe width denoted by β and given by

$$\beta = \frac{\lambda D}{d}$$

where, λ = wavelength of light in air, D = distance between slits and screen and d be the distance between two slits. When the whole apparatus is kept in water, the wavelength of light changes. So, β_w in water is given as,

$$\beta_w = \lambda_w \frac{D}{d}$$

Here, $\frac{\beta_w}{\beta} = \frac{\lambda_w}{\lambda} = \frac{1}{\mu_w}$ $\left[\because \mu_w = \frac{c}{v_w} = \frac{\lambda . f}{\lambda_w . f} = \frac{\lambda}{\lambda_w}\right]$

or, $\beta_w = \frac{1}{\mu_w} . \beta$

The fringe width decreases to a factor of $\frac{1}{\mu_w}$ times that in air.

5. **2072 Set D Q.No. 4a Does the interference of light wave obey the law of conservation of energy? Explain.**

Yes, the law of conservation of energy obeyed in case of interference of light. During interference of light wave, there is unequal energy distribution. There is greater energy at bright fringe and minimum energy at dark fringe. This means that the energy of dark fringe transfers to energy of bright fringe and total energy remains same. Hence interference phenomenon obeys law of conservation of energy.

6. **2071 Set C Q.No. 4 b What are the conditions for constructive and destructive interference of light waves? [2]**

For constructive interference, the path difference between two interfering waves should be integral multiple of wavelength of wave i.e., path difference = $n\lambda$, n = 0, 1, 2, 3, ... and λ is wavelength of wave.

For destructive interference, the path difference between interfering waves should be half of odd number integral multiple of wavelength i.e., path difference = $(2n + 1)\frac{\lambda}{2}$, n = 0, 1, 2, 3 ...

7. **2070 Sup (Set A) Q.No. 4 b Is the law of conservation of energy obeyed in case of interference of light? Explain. [2]**

Please refer to 2072 Set D Q.No. 4a

8. **2070 Set C Q.No. 4 a What should be the path difference between two interfering waves for constructive interference and destructive interference? [2]**

Please refer to 2071 Set C Q.No. 4 b

9. **2068 Can. Q.No: 4a 2066 Supp Q.No. 2d In Young's double slit experiment, how is the fringe width altered if the separation between the slits is doubled and the distance between the slits and the screen is halved? [2]**

In a Young's double slit experiment, the fringe width denoted by β and given as $\beta = \frac{\lambda D}{d}$

where, λ is the wavelength of light used, D be the distance between the slits and screen and d be the slit width. If the separation between the slits is doubled and the distance between the slits and the screen is halved, then the fringe width is given as $\beta' = \frac{\lambda D/2}{2d} = \frac{\lambda D}{4d} = \frac{1}{4}\beta$

Thus, the fringe width is altered by $\frac{1}{4}$ times if the separation between the slits is doubled and the distance between the slits and the screen is halved.

10. **2068 Old Q.No. 1d 2065 Q.No. 2c What do you mean by coherent sources of light? [2]**

Coherent sources are a pair of sources of light which emit light waves of the same wavelength and frequency which are always in the phase with each other or have a constant phase difference. Two independent sources of light cannot be coherent sources because they may emit the light wave of same wavelength and frequency but they never be in same phase or at a constant phase difference. So, it is difficult to make the coherent sources. However, two sources of light obtained from a single source can be considered as coherent sources.

11. **2067 Old Q.No. 1c What are the conditions for sustained interference of light? [2]**

Conditions to produce Interference

- The two interfering sources must be coherent.
- The two interfering waves must have same amplitude or nearly equal amplitude.
- The waves should have a certain path difference.
- The light source used must be monochromatic.
- The two sources must be very close to each other.
- The two sources should be very narrow.
- For constructive interference, path difference = $n\lambda$, and for destructive interference, path difference = $\left(n + \frac{1}{2}\right)\lambda$, where n is the integer and λ is the wavelength of light used.

12. 2064 Q.No. 1 d **Distinguish between interference and diffraction.** **[2]**

Difference between the interface and diffraction are

Interference	Diffraction
a. It is due to superposition of wavelets of different wavefronts.	a. It is due to superposition of wavelets of the different parts of same wavefront.
b. In interference bands may of equal width.	b. Diffraction fringes are not of the same width.
c. Points of minimum intensity are perfectly dark.	c. Points of minimum intensity are not perfectly dark.
d. All bright bands are of uniform intensity.	d. All bright bands are not of the same intensity.
e. Bands are large in number.	e. Bands are few in number.

13. 2058 Q.No. 2 c **Why have the two sources of light to be close to each other for the production of good interference pattern?** **[2]**

We know that, fringe width (β) in interference pattern is given by: $\beta = \frac{\lambda D}{d}$ where D is the distance between slits and the screen, d is separation between the slits and λ be the wavelength of light.

From above expression, it is clear that, $\beta \propto \frac{1}{d}$

If the coherent sources are close to each other i.e., for small d, the fringe width will be large and hence good interference patterns are obtained.

14. 2057 Q.No. 2 c **Can two independent sources of light produce interference?** **[2]**

No, two sources of light cannot produce interference. The light wave emitted by two identical but independent sources, even though have same frequency and wavelength do not have constant phase difference i.e. they may not be coherent. So the sustained interference pattern will not be obtained. Due to rapid change in phase difference the intensity of bright and dark fringes will change rapidly. But as the time of persistence of fringes is smaller than the time of persistence of human vision, we will be unable to see the interference pattern formed by the independent source of light. So, two sources of light cannot produce interference.

Long Answer Questions

15. 2076 Set B Q.No. 8a **Describe Newton's ring experiment and derive expression for wavelength of light.** **[4]**

Newton's Ring Experiment (Determination of Wavelength of light)

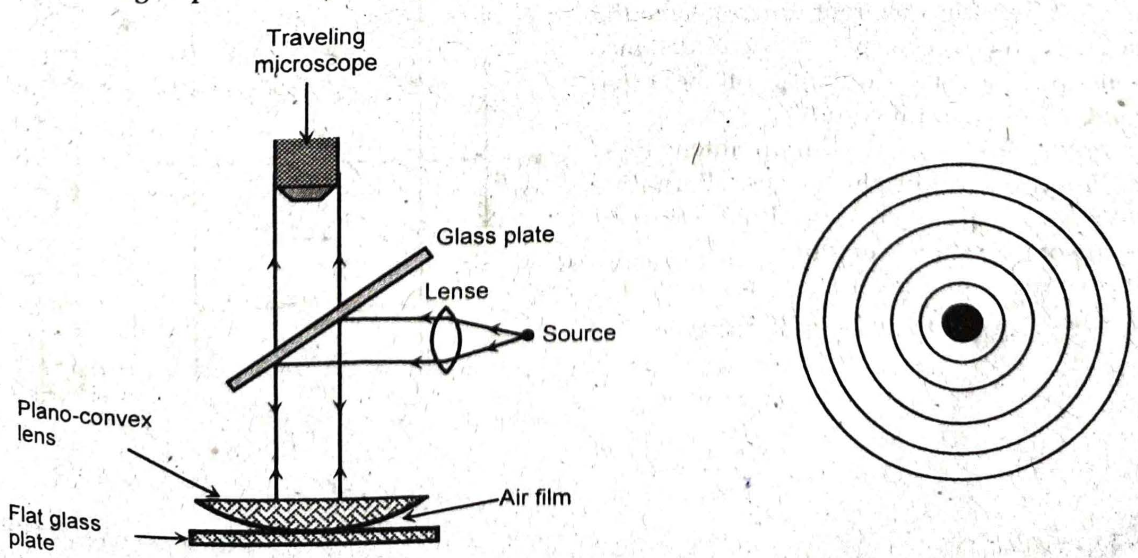


Fig (i) Newton's Ring Experiment

Fig (ii) Newton's Ring

Newton's Ring experimental apparatus for determination of wavelength of light consists of a plano-convex lens placed on a flat glass plate, a source of light (generally sodium light), a glass plate kept at 45° to the incident beam and a traveling microscope. The apparatus are arranged as shown in figure. A source of light S is plated at focus of convex lens. The ray of light after passing through this lens become parallel and strike to the glass plate which is partially silvered. These rays get reflected and strikes to the plano-convex lens. The air film is formed between the flat glass plate and lower face of plano-convex lens. The air film is formed circular and width varies from zero to infinity. The light rays reflected from upper surface of glass plate and lower surface of plano-convex lens has some path difference. These reflected rays get superimpose and form interference pattern in the form of ring called Newton's ring. The central ring is dark and then alternate dark and bright rings are formed as shown in figure (ii). These rings are formed due to the superposition of reflected beam of light. Here, the radius of n^{th} bright ring is $r_n = \sqrt{\left(\frac{2n-1}{n}\right)\lambda R}$ and n^{th} dark ring is $r_n = \sqrt{n\lambda R}$ where λ is wavelength of light used and R is radius of plano-convex lens.

Determination of Wavelength of Light:

If D_n be the diameter of n^{th} dark ring, then $r_n = \frac{D_n}{2}$

$\therefore \frac{D_n}{2} = \sqrt{n\lambda R}$

or, $D_n^2 = 4n\lambda R$

Similarly, if D_{n+m} be the diameter $(n+m)^{th}$ dark ring, then we can write,

$D^2_{n+m} = 4(n+m)\lambda R$

$\therefore D^2_{n+m} - D^2_n = 4m\lambda R$

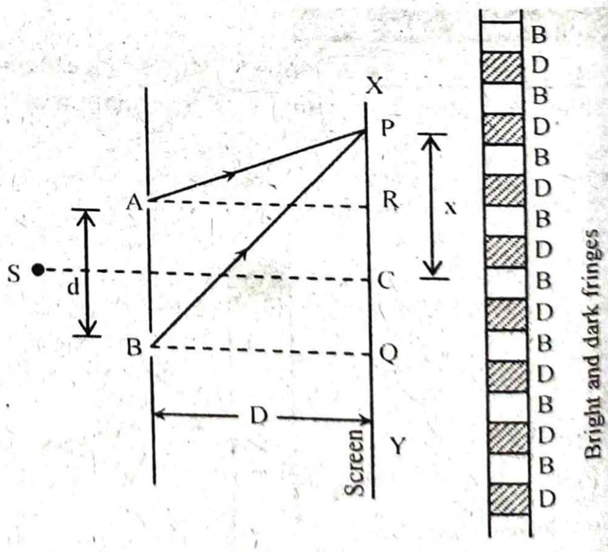
or, $\lambda = \frac{D^2_{n+m} - D^2_n}{4mR}$

From this formula we can calculate the wavelength of light by using Newton's Ring.

16. **2075 Set A Q.No. 8a** **Discuss the Young's double slit experiment and show that the width of bright and dark fringes are equal.** **[4]**

Young's double slit experiment: Let us consider S be the monochromatic source of light. A and B are two slits which act as the coherent sources, d be the distance between them. Let a screen is placed at a distance D from the coherent sources, C be the central point on the screen, which is equidistance from A and B. The path difference of the wave reaching at C from A and B is zero.

Hence, a bright fringe of maximum intensity is observed. From central bright fringes, alternative dark and bright fringes of equal width are formed on either side of it as shown in figure.



To find the n^{th} bright or dark fringe, let us consider a point P which lies at a distance x from C.

Here, $PR = \left(x - \frac{d}{2}\right)$

and $PQ = \left(x + \frac{d}{2}\right)$

Now, $AP^2 = \left(x - \frac{d}{2}\right)^2 + D^2$

And $BP^2 = \left(x + \frac{d}{2}\right)^2 + D^2$

So, $BP^2 - AP^2 = \left(x + \frac{d}{2}\right)^2 - \left(x + \frac{d}{2}\right)^2$

$\therefore\ BP - AP = \frac{2xd}{BP + AP}$

If the point P lies very near to C, then
$BP \simeq AP \simeq D$.

$\therefore\ BP - AP = \frac{2xd}{2D}$

i.e., path difference $= \frac{dx}{D}$

Since, phase difference $= \frac{2\pi}{\lambda}$. (path difference)

$$= \frac{2\pi}{\lambda}\left(\frac{xd}{D}\right) \qquad \ldots \text{(i)}$$

The point P may be bright or dark fringes depending upon the path difference (BP – AP).

Case (I): Bright fringes (or Constructive interference)

When the path difference between the two paths is integral multiple of wavelength (λ), the bright fringes are obtained.

i.e. Path difference = $n\lambda$. where n = 1, 2, 3, ...

or, $\frac{xd}{D} = n\lambda$

$\therefore\ x = \frac{n\lambda D}{d}$

When n = 0, it gives the zero order which indicates central bright fringe and n = 1, 2, 3, 4 ... gives the 1st, 2nd, 3rd... order bright fringes and so on.

Thus, for, $n = 1,\ x_1 = \frac{\lambda D}{d}$

for, $n = 2,\ x_2 = \frac{2\lambda D}{d}$

for, $n = 3,\ x_3 = \frac{3\lambda D}{d}$

and for, $n = n,\ x_n = \frac{n\lambda D}{d}$

The distance between the two consecutive bright fringes called fringe width (β), is given by

$\beta = x_2 - x_1 = \frac{\lambda D}{d}$

Case (II): Dark fringes (or Destructive interference)

When the path difference between two paths is half of odd integral of wavelength, then the dark fringes are obtained.

i.e., path difference $= \left(\frac{2n+1}{2}\right)\lambda,\ \ n = 0, 1, 2, 3, \ldots$

or, $\frac{xd}{D} = \left(\frac{2n+1}{2}\right)\lambda$

$\therefore\ x = \left(\frac{2n+1}{2}\right)\frac{\lambda D}{d}$

This equation gives the distance of the dark fringes from the point C.

for, $n = 0,\ x_0 = \frac{\lambda D}{2d}$

for, $n = 1$, $x_1 = \frac{3\lambda D}{2d}$

for, $n = 2$, $x_2 = \frac{5\lambda D}{2d}$

for, $n = n$ $x_n = \left(\frac{2n+1}{2}\right)\frac{\lambda D}{d}$

The distance between two consecutive dark fringes called fringe width (β), is given by

$\beta = x_2 - x_1 = \frac{\lambda D}{d}$

Thus, both dark and bright fringes are of equal width.

This shows that the fringe width β is:

a. Directly proportional to the wavelength of the light used.
i.e., $\beta \propto \lambda$

b. Directly proportional to the distance between the screen from the coherent sources.
i.e., $\beta \propto D$

c. Inversely proportional to the distance between he slits.
i.e., $\beta \propto \frac{1}{d}$

d. Independent of the order of the fringes. So, all the interference fringes are of equal width.
The intensity distribution in Young's double slit experiment is given as figure.

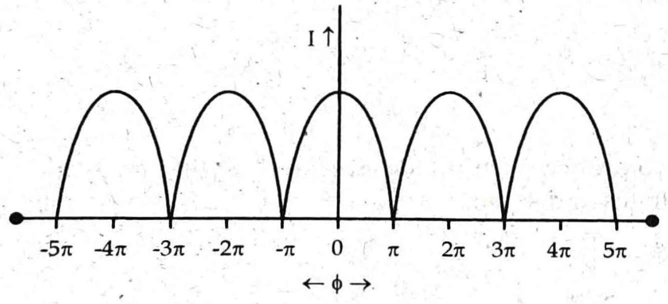


Fig: Intensity Distribution Graph in Interference

17. 2074 Supp Q.No. 8a 2071 Set D Q.No. 8 b **Describe Young's double slit experiment and obtain an expression for the fringe width.** **[4]**

Please refer to 2075 Set A Q.No. 8a

18. 2074 Set A Q.No. 8a **Define coherent sources of light. Prove that the dark and bright fringes are equally spaced in Young's double slit experiment.** **[4]**

Coherent sources of light: Coherent sources are a pair of sources of light which emit light waves of the same wavelength and frequency which are always in the phase with each other or have a constant phase difference. Two independent sources of light cannot be coherent sources because they may emit the light wave of same wavelength and frequency but they never be in same phase or at a constant phase difference. So, it is difficult to make the coherent sources. However, two sources of light obtained from a single source can be considered as coherent sources.

Second part: Please refer to 2075 Set A Q.No. 8a

19. 2073 Supp Q.No. 8a 2069 (Set A) Q.No. 8b 2068 Old Can. Q.No. 6a OR 2067 Sup Q.No. 8a **Prove analytically that the bright and dark fringes in Young's double slit experiment are equally spaced.** **[4]**

Please refer to 2075 Set A Q.No. 8a

20. 2073 Set C Q.No. 8a 2072 Set C Q.No. 8a 2070 Set D Q.No. 8 b **What are coherent sources of light? Describe double slit experiment to find the fringe width from the experiment performed with light waves.** **[4]**

Coherent Sources: Please refer 2068 Old Q.No. 1d

Young's double slit experiment: Please refer to 2075 Set A Q.No. 8a

21. 2072 Supp Q.No. 8b What are the conditions for constructive and destructive interference of light waves? Show that in Young's double slit experiment, the dark and bright fringes are equally spaced. [4]

Please refer to 2075 Set A Q.No. 8a

22. 2070 Supp. (Set B) Q.No. 8 a Discuss the Young's double slit experiment and determine the expression for fringe width. [4]

Please refer to 2075 Set A Q.No. 8a

23. 2069 Supp Set B Q.No. 8 a Describe Young's double slit experiment of interference to estimate the fringe width of the pattern. [4]

Please refer to 2075 Set A Q.No. 8a

24. 2069 (Set B) Q.No. 8a What are the main characteristics of coherent sources? Describe Young's double slit interference experiment to determine the wavelength of the source of light. [4]

Coherent sources of light are the sources of light waves which produce the light waves having same frequency, wavelength and they have same phase or constant phase difference.

Characteristics

- They are monochromatic.
- They have same frequency and wavelength.
- They have constant phase difference or same phase.
- They are close to each other.

Young's double slit experiment: Please refer to 2075 Set A Q.No: 8a

25. 2069 (Set A) Old Q.No. 6a What do you mean by constructive and destructive interference of light? Describe Young's double slit experiment for the measurement of wavelength of monochromatic source of light. [1+3]

First Part: Please refer to 2071 Set C Q.No. 4b

Second Part: Please refer to 2075 Set A Q.No. 8a

26. 2066 Q.No. 6 a Describe Young's double slits experiment for the interference of light and show that width of bright and dark fringes are the same. [1+3]

Please refer to 2075 Set A Q.No. 8a

27. 2062 Q.No. 5 a What do you understand by interference of light? Derive an expression for the fringe width in a Young's double slit experiment. [4]

Interference of light: When two waves coming from two coherent sources of light overlap with each other, then the amplitude of resultant wave is different from the amplitude of individual waves. The resultant amplitude is either more or less than the amplitude of individual waves. This phenomenon of light wave is called interference of light.

Young's double slit experiment: Please refer to 2075 Set A Q.No. 8a

28. 2057 Q.No. 6 a Derive the fringe width for Young's double slit experiment. [4]

Please refer to 2075 Set A Q.No. 8a

Numerical Problems

29. 2076 Set C Q.No. 12 2074 Set B Q.No. 12 In a Young's double slit experiment, the separation of four bright fringes is 2.5 mm. The wavelength of light used is 6.2×10^{-7} m. If the distance from the slits to the screen is 80 cm, calculate the separation of two slits. [3]

Solution

Given,

Wave-length of light (λ) = 6.2×10^{-5} cm = 6.2×10^{-7} m

Distance between the slits and screen (D) = 80 cm = 0.8 m

Separation of slits (d) = ?

Separation of four bright fringes (y) = $3\beta = 2.5 \times 10^{-3}$ m

Here, $\beta = \dfrac{\lambda D}{d}$ is the fringe width.

Now,

$$y = 3\beta = \frac{3\lambda D}{d}$$

or, $d = \frac{3\lambda D}{y}$

or, $d = \frac{3 \times 6.2 \times 10^{-7} \times 0.8}{2.5 \times 10^{-3}}$

$\therefore$ $d = 5.95 \times 10^{-4}$ m

Thus, the required distance is 5.95×10^{-4} m.

30. **2075 GIE Q.No. 12** **The distance between two coherent sources in Young's double slit experiment is 0.3 mm and the interference pattern is observed on a screen 60 cm from the sources. If the wavelength of light used is 6×10^{-7} m, calculate the fringe width of the interference pattern.** **[3]**

Solution

Given,

Distance between two slits (d) = 0.3 mm = 0.3×10^{-3}m

Distance between slits and the screen (D) = 60 cm = 0.6 m

Wavelength of light (λ) = 600 nm = 600×10^{-9} m = 6×10^{-7}m

Fringe width (β) = ?

We have

$$\beta = \frac{\lambda D}{d} = \frac{6 \times 10^{-7} \times 0.6}{0.3 \times 10^{-3}} = 1.2 \times 10^{-3}\text{m}$$

Hence, the fringe width is 1.2×10^{-3} m

31. **2075 Set B Q.No. 12** **In a Newton' rings experiment, the diameter of 15th ring was found as 0.590 cm and that of 5th ring was 0.336 cm. Calculate the radius of curvature of the plano-convex lens if the wavelength of light used is 5880Å.** **[3]**

Solution

Given,

Diameter of 15th ring (D_{15}) = 0.590 cm

Diameter of 5th ring (D_5) = 0.336 cm

Wavelength of light (λ) = 5880 Å = 5880×10^{-8} cm

Radius of curvature (R) = ?

m = 15

n = 5

We have,

$$R = \frac{D_m^2 - D_n^2}{4\lambda(m-n)}$$

$$= \frac{D_{15}^2 - D_5^2}{4 \times \lambda \times (15-5)} = \frac{0.590^2 - 0.336^2}{4 \times 5880 \times 10^{-8} \times 10}$$

= 100 cm

= 1 m

$\therefore$ Therefore, the radius of curvature of plano-convex lens is 1 m.

32. **2073 Set D Q.No. 12** **The separation between the consecutive dark fringes in a Yourn's double slit experiment is 1 mm. The screen is placed at a distance of 2 m from the slits 1.0 mm separation. What is the wavelength of light used in the experiment?** **[4]**

Solution

Given,

Fringe width (β) = 1 mm = 10^{-3} m

Slit width (d) = 1.0 mm = 10^{-3} m

Distance (D) = 2m

Wavelength (λ) = ?

we have,

$$\beta = \frac{\lambda D}{d}$$

or, $\lambda = \frac{\beta d}{D} = \frac{10^{-3} \times 10^{-3}}{2} = 5 \times 10^{-7}$ m

33. **2072 Set D Q.No. 12 In young's double slit experiment, the slits are 0.03 cm apart and the screen is placed 1.5 m away. The distance between the central bright fringe and fourth bright fringe is 1 cm. Calculate the wave length of light used.** **[3]**

Solution

Given,

Distance between slit (d) = 0.03 cm = 0.03×10^{-2} m

Distance between slit and screen (D) = 1.5 m

Distance between central bright fringe and fourth bright fringe is,

$4\beta = 1 \text{ cm} = 1 \times 10^{-2}$ m

or, $\beta = 0.25 \times 10^{-2}$m

Wavelength (λ) = ?

Now, we have

$$\beta = \frac{\lambda D}{d}$$

$$\text{or, } \lambda = \frac{\beta d}{D}$$

$$= \frac{0.25 \times 10^{-2} \times 0.03 \times 10^{-2}}{1.5} = 5 \times 10^{-7} \text{ m}$$

34. **2072 Set E Q.No. 12 Two coherent sources A and B of radio waves are 5m apart. Each source emits waves with wavelength 6m. Consider points along the line between two sources, at what distances, if any, from A is the interference constructive.** **[3]**

Solution

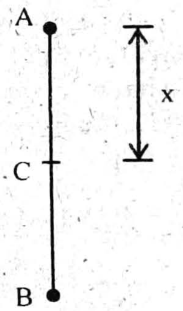
Given,

Distance between coherent sources A and B (d) = 5 m

Wavelength of source (λ) = 6 m

We have, for constructive interference,

Path difference = $n\lambda$; n = 0, 1, 2 ... ... (i)



Here, in the case, it is impossible to have path difference of λ or more because sources separation is less than the wave length of the radio waves. So, only n = 0 is possible.

Then, from equation (i),

$AC - BC = 0.\lambda$ [$\because$ Path difference = AC – BC]

or, $x - (5 - x) = 0$

$\therefore$ $x = 2.5$ m

i.e., Maximum brightness point between A and B is 2.5 m away from A towards B.

35. **2068 Can. Q.No. 12 Two slits spaced 0.45 mm apart are placed 75 cm from a screen. What is the distance between the second and third dark lines of the interference pattern on the screen when the slits are illuminated with monochromatic light of wavelength 500 nm?** **[3]**

Solution

Given,

Distance between two slits (d) = 0.45 mm = 0.45×10^{-3}m

Distance between slits and the screen (D) = 75 cm = 0.75 m

Wavelength of light (λ) = 500 nm = 500×10^{-9} m = 5×10^{-7}m

Fringe width (β) = ?

Since, in the interference pattern due to the slits, all the fringes are equally spaced, the distance between the second and third dark lines is the fringe width which is given by,

$$\beta = \frac{\lambda D}{d} = \frac{5 \times 10^{-7} \times 0.75}{0.45 \times 10^{-3}} = 0.833 \times 10^{-3}\text{m}$$

Hence, the distance between the second and third dark lines of the interference pattern is 0.833×10^{-3}m.

36. **2068 Q.No. 12** **In a Young's slits experiment, the separation of four bright fringes is 2.5 mm when the wavelength used is 6.2×10^{-7}m. The distance from the slits to the screen is 0.80m. Calculate the separation of the two slits.** **[3]**

Solution

Given,

The separation between the first and fifth bright fringes (x_n)

$= 2.5 \text{ mm} = 2.5 \times 10^{-3}\text{m}, n = 4$

Wavelength of light used (λ) = 6.2×10^{-7} m

Distance between slits and the screen (D) = 0.8 m

The separation of slits (d) = ?

We have, $x_n = \frac{n\lambda D}{d}$

$$\therefore d = \frac{n\lambda D}{x_n} = \frac{4 \times 6.2 \times 10^{-7} \times 0.8}{2.5 \times 10^{-3}} = 7.9 \times 10^{-4} \text{ m}$$

Thus, the separation of slits (d) = 7.9×10^{-4} m.

37. **2067 Q.No. 12** **In a two-slit interference experiment, the slits are 0.200 mm apart, and the screen is at a distance of 1.00 m. The third bright fringe is found at 9.49 mm from the central fringe. Find wavelength of the light used.** **[3]**

Solution

Given,

Slit width (d) = 0.200 mm = 0.2×10^{-3} m

Distance between screen & slit (D) = 1.00 m

Distance of 3rd bright fringe from centre

$y = 9.49$ mm

$= 9.49\times10^{-3}$m

Wave length of light (λ) = ?

We have,

If β be the fringe width,

$y = 3\beta$

$y = 3 \times \frac{\lambda D}{d}$

$$\text{or, } \lambda = \frac{y \times d}{3 \times D} = \frac{9.49 \times 10^{-3} \times 0.2 \times 10^{-3}}{3 \times 1}$$

$\lambda = 6.33 \times 10^{-7}$ m

38. **2064 Q.No. 6 b** **In a Young's double slit experiment, the separation between the first and fifth bright fringes is 2.5 mm when the wavelength of light used is 6.2×10^{-4} mm. The distance from the slits to the screen is 80 cm. Calculate the separation of the two slits.** **[4]**

Please refer to 2068 Q.No. 12

39. **2060 Q.No. 6 b** **In an experiment using Young's slits the distance between the centre of the interference pattern and the tenth bright fringe on either side is 3.44 cm. Distance between the slits and the screen is 2.0 m. If the wavelength of the light used is 5.89×10^{-7} m, determine the slit separation and the angle made by the central bright fringe at the slit.** **[4]**

Solution

Given,

Distance between the centre of the interference pattern and the tenth bright fringe (y) = 3.44 cm = 3.44×10^{-2}m

Distance between slits and screen (D) = 2 m

Wavelength of light used (λ) = 5.89×10^{-7}m

Slit separation (d) = ?

Angle subtended by the central bright fringe (α) = ?

We have the relation,

$y = \frac{n\lambda D}{d}$

$d = \frac{n\lambda D}{y} = \frac{10 \times 5.89 \times 10^{-7} \times 2}{0.0344} = 3.42 \times 10^{-4}$ m

Also, we have,

$\alpha = \frac{\beta}{D} = \frac{\lambda D}{dD}$ $\left(\because \beta = \frac{\lambda D}{d}\right)$

$\alpha = \frac{\lambda}{d} = \frac{5.89 \times 10^{-7}}{3.42 \times 10^{-4}} = 1.72 \times 10^{-3}$ radian

Hence, separation between slits is 3.42×10^{-4} m and angle made is 1.72×10^{-3} radian.

40. **2059 Q.No. 6 b Two slits are 0.3 mm apart and placed 50 cm from a screen. What is the distance between the second and third dark lines of the interference pattern when the slits are illuminated with a light of 600 mm wavelength? [4]**

Solution

Given,

Distance between two slits (d) = 0.3 mm = 0.3×10^{-3}m

Distance between slits and the screen (D) = 50 cm = 0.5 m

Wavelength of light (λ) = 600 nm = 600×10^{-9} m = 6×10^{-7}m

Fringe width (β) = ?

Since, in the interference pattern due to the slits, all the fringes are equally spaced; the distance between the second and third dark lines is the fringe width which is given by,

$$\beta = \frac{\lambda D}{d} = \frac{6 \times 10^{-7} \times 0.5}{0.3 \times 10^{-3}} = 1.0 \times 10^{-3}\text{m}$$

Hence, the distance between the second and third dark lines of the interference pattern is 1.0×10^{-3}m.

❑❑❑

Chapter 3: Diffraction Light

Short Answer Questions

1. **2074 Supp Q.No. 4b 2069 (Set A) Q.No. 4a Why is diffraction of sound waves easier to observe than that of light waves?** **[2]**

For diffraction to take place, the wavelength of the wave must comparable the size of the obstacle. The sound waves have longer wavelength of order of 1m. The light wave has wavelength of order 10^{-6}m. The size of obstacle of this order is rare in real nature. Due to this reason, sound waves are more evident in daily experience than that of light waves.

2. **2072 Supp Q.No. 4b Light waves undergo diffraction around an edge. Can sound wave diffract around an edge? Explain.** **[2]**

Yes, sound waves can diffract around an edge like light waves. The sound waves diffract when the width of edge is comparable to wavelength of sound wave. The wavelength of sound wave is long and there are more possibilities to occur the diffraction.

3. **2071 Set D Q.No. 4 a 2068 Old Can. Q.No. 2d The diffraction of sound waves is more evident in daily experience than that of light waves. Why?** **[2]**

Please refer to 2074 Supp Q.No. 4b

4. **2070 Sup (Set A) Q.No. 4 a Why can we readily observe diffraction effects for sound waves but not for light?** **[2]**

Please refer to 2074 Supp Q.No. 4b

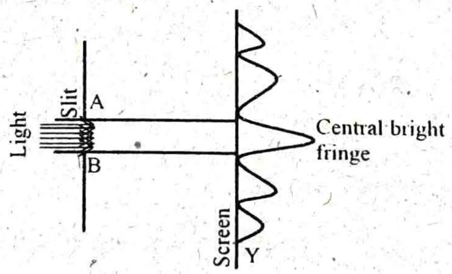
5. **2070 Set D Q.No. 4 a 2067 Sup Q.No. 4b Radio waves diffract around buildings but not light waves, why?** **[2]**

For diffraction to take place, the wavelength of the wave must be of the order of the size of the obstacle. The radio waves have long wavelength which is the order of the size of the corner of building, hence they get diffracted. On the other hand, the wavelength of light wave is very small (order of 10^{-6}m), thus they are not diffracted by the building.

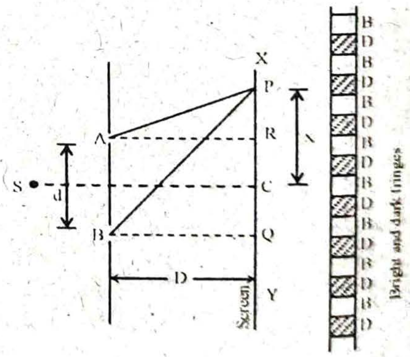
6. **2069 Supp Set B Q.No. 4 a What is the fundamental physical difference between interference and diffraction? Explain with figures.** **[2]**

Interference is due to superposition of wavelets of different wavefronts in which dark and bright fringes are equally spaced.

Diffraction is due to superposition of wavelets of the different parts of same wavefront in which central bright fringes has maximum intensity and the intensity of other bright fringes reduce on outwards.



Diffraction of light



Interference of light

7. **2069 (Set B) Q.No. 4a What are the characteristic elements associated with a diffraction grating? How is plane transmission grating constructed?** **[2]**

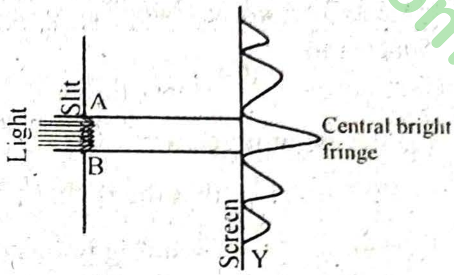
The diffraction grating consists of large number of equidistant narrow slits. If the slits are parallel to each other then the grating is called plane diffraction grating or plane transmission grating. It can be made by drawing a large number of straight and equidistant parallel lines or scratches over a thin glass plate by means of a fine sharp diamond point. These lines are called rulings which act as opaque and the transparent regions between rulings serve as slits. If a be the width of the transparent part and b be the width of the opaque portion, then grating element is, $d = a + b = 1/N$; N number of lines per unit length.

8. **2068 Q.No. 4 a Describe what happens to the single slit diffraction pattern when the width of the slit is less than the wave length of the wave.** **[2]**

For diffraction of light, the slit width should be comparable to the wavelength of light used. When the width of the slit is less than the wavelength of wave, no diffraction pattern on the single slit.

9. **2062 Q.No. 1 d What is diffraction of light?** **[2]**

In general, light wave travels in the straight line. A very careful study's shows that light will bend when it is passed through an edge of an obstacle or small opening. "The phenomenon of bending of the light around the corners of an obstacle and the spreading into the region of geometrical shadow is called diffraction." The diffraction of light produces the dark and bright fringes known as diffraction bands or diffraction fringes. Moreover, diffraction is shown by all kinds of waves. The necessary condition for it is that the size of the obstacle must be comparable to the wavelength of the wave.



10. **2059 Q.No. 2 c Diffraction grating is better than a two-slit set up for measuring the wave length of a monochromatic light. Explain.** **[2]**

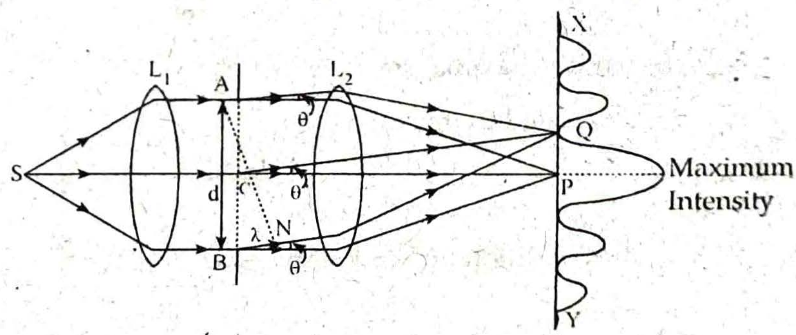
Diffraction gratings are used to produce spectra and for measuring wavelength. The spectrum produced in fine grating is sharp and can be separated easily and more accurately are measurable. Further, in a two-slit set up for measuring the wavelength of light which produces interference fringes and are modulated by the diffraction produced by individual slits. Thus, diffraction grating is better than two slits.

Long Answer Questions

11. **2076 Set C Q.No. 8b 2075 GIE Q.No. 8b 2075 Set B Q.No. 7b 2074 Set B Q.No. 8b 2071 Set C Q.No. 8 b Discuss Fraunhofer diffraction at a single slit.** **[4]**

Fraunhofer diffraction at a single slit:

Suppose a parallel beam of light incident normally on a slit AB of width d after refraction through the lens L_1. These rays diffract and after diffraction the beam is focused on to the screen XY by means of lens L_2.



Result: A wide control central bright fringe of maximum intensity is obtained at the centre P of the screen and on either side of the central fringe, dark and bright fringes of decreasing intensity are observed. These bands are referred to as secondary minima and maxima respectively. It is found that–

a. The width of central maxima is double to that of secondary maxima and
b. The intensity of the secondary maxima goes on decreasing.

Explanation: According to Huygen's hypothesis, when light falls on the slit, it becomes a source of secondary wavelets. These wavelets are initially in phase and spread out in all directions.

a. **Central maxima:** Consider a point P at the centre of the screen as shown in figure. Light travel equal optical paths to reach the point P and are in same phase. Thus, P is the position of maximum intensity which is known as the central (or principal) maxima.

b. **Position of secondary maxima and minima:** Suppose a point Q on the screen at which wavelets travelling in a direction making angle θ with CP are brought to focus by the lens. The wavelets from different parts of the slit will not reach at point Q in phase, although, they are initially in phase. This is because they cover unequal distances in reaching point Q. The wavelets from points A and B will have a path difference BN.

i.e., $BQ - AQ = BN = d \sin\theta$ i.e. $\lambda = d \sin\theta$ $\left(\because \sin\theta = \frac{BN}{d}\right)$

a. For n^{th} secondary minima, we have

Path difference $= n\lambda$ $(n = 1, 2, 3 \ldots)$

$\Rightarrow d \sin\theta_n = n\lambda$

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

Since θ is small, $\sin\theta \simeq \theta_n$

$\therefore \theta_n = \frac{n\lambda}{d} \quad (n = 1, 2, 3 ...)$

For first minima, $n = 1 \Rightarrow \theta_1 = \frac{\lambda}{d}$

This indicates that the path difference between wavelets from A and B is λ and therefore the wavel[e]
from the corresponding points of the two halves AC and CB will have a path difference of $\frac{\lambda}{2}$.

For second minima, $n = 2, \Rightarrow \theta_2 = \frac{2\lambda}{d}$

For n^{th} minima, $n = n \Rightarrow \theta_n = \frac{n\lambda}{d}$

b. For n^{th} secondary maxima (bright fringe), we have

Path difference $= (2n + 1)\frac{\lambda}{2}$

$\Rightarrow d\sin\theta_n = (2n + 1)\frac{\lambda}{2} \Rightarrow \sin\theta_n = \frac{(2n+1)\lambda}{2d}$

Since, θ is small, $\sin\theta \simeq \theta$

$\therefore \theta_n = \frac{(2n+1)\lambda}{2d} \quad (n = 1, 2, 3, ...)$

For first order maxima, $n = 1 \Rightarrow \theta_1 = \frac{3\lambda}{2d}$

For second maxima, $n = 2 \Rightarrow \theta_2 = \frac{5\lambda}{2d}$

For n^{th} secondary maxima, $n = n$

$$\theta_n = \frac{(2n+1)\lambda}{2d} \quad (n = 1, 2, 3 ....)$$

Hence, the condition for secondary maxima is $\theta_n = \frac{(2n+1)\lambda}{2d}$ and that of secondary minima is $\theta_n = \frac{n\lambda}{d}$.

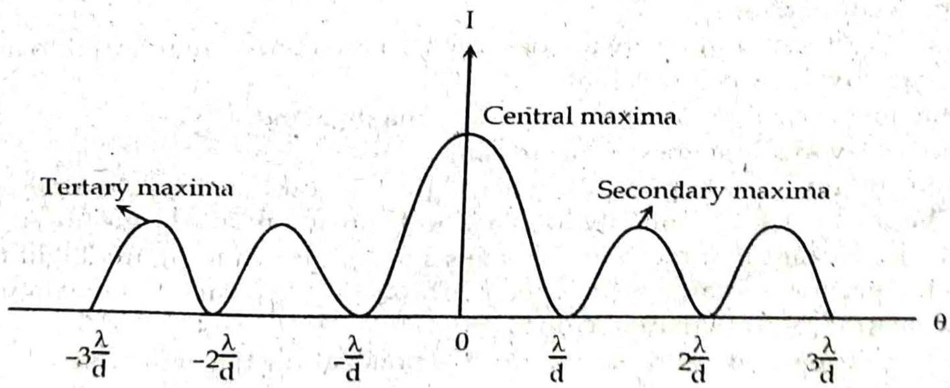


Figure: Intensity Distribution

12. **2074 Set A Q.No. 8b What is diffraction grating? Discuss the formation of diffraction pattern due to a diffraction grating.** **[4]**

Diffraction Grating: An arrangement of a large number of very narrow equidistant slits is called a diffraction grating. If the slits are parallel to each other then the grating is called plane diffraction grating or plane transmission grating. It can be made by drawing a large number of straight and equidistant parallel lines or scratches over a thin glass plate by means of a fine sharp diamond point. These lines are called rulings which act as opaque and the transparent regions between rulings serve as slits. If a be the width of the transparent part and b be the width of the opaque portion, then grating element is, $d = a + b = 1/N$; N number of lines per unit length.

Theory of Diffraction Grating: The figure shows the section of grating whose slits are perpendicular to the plane of paper.

Let,

a = the width of each slit

b = the distance between two slits (or width of opaque portion).

The distance (a + b) is known as grating element or grating space.

If N is the number of lines per inch of the grating then,

$$(a + b) = \frac{1\text{ inch}}{N} = \frac{2.54}{N}\text{ cm}$$

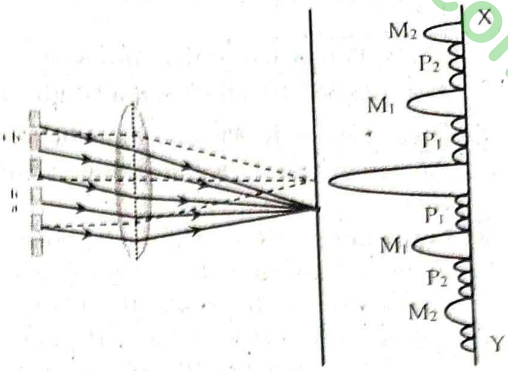


Fig: Diffraction Gratings

$(a+b) \sin \theta_n = n\lambda$

where n can take any integral value like 1, 2, 3, 4,5, ……

If n = 0, the central maxima is formed.

13. 2073 Supp Q.No. 8b **Describe the diffraction of light at a single slit and find the condition for secondary maxima and minima.** **[4]**

Please refer to 2076 Set C Q.No. 8b

14. 2073 Set D Q.No. 8a **What is diffraction of light? Explain the case of diffraction at a single slit. Hence show the intensity distribution in the figure.** **[4]**

First Part: Please refer to 2062 Q.No. 1d

Second Part: Please refer to 2076 Set C Q.No. 8b

15. 2072 Set C Q.No. 8b **Define Fraunhofer diffraction. How is transmission grating constructed? Describe necessary theory of diffraction grating.** **[4]**

Fraunhofer diffraction: The diffraction in which the source and screen are placed at a greater distance (i.e., may be infinite) from the obstacle is called Fraunhoffer diffraction. A converging lens is used to focus the light coming from infinite source to the obstacle and another converging lens is used to focus the diffracted light on the screen. In this type of diffraction, the incident as well as the diffracted wavefronts are plane.

Diffraction Grating: Please refer to 2074 Set A Q.No. 8b

16. 2072 Set D Q.No. 8b **Discuss the formation of maxima and minima due to Fraunhofer diffraction at a single slit.** **[4]**

Please refer to 2076 Set C Q.No. 8b

17. 2072 Set E Q.No. 8b **What do you mean by diffraction of light? Explain the diffraction pattern due to a single slit to find the angular width of the central band.** **[4]**

First Part: Please refer to 2062 Q.No. 1d

Second Part: Please refer to 2076 Set C Q.No. 8b

18. 2071 Supp Q.No. 8b **Explain the formation of maxima and minima due to diffraction through a single slit.** **[4]**

Please refer to 2076 Set C Q.No. 8b

19. 2070 Set C Q.No. 8 a **Discuss the theory of diffraction of light at single slit.** **[4]**

Please refer to 2076 Set C Q.No. 8b

20. 2068 Can. Q.No. 8b **What is the basic difference between interference and diffraction? Discuss Fraunhofer diffraction at a single slit.** **[4]**

Difference between the interface and diffraction

Interference	Diffraction
a. It is due to superposition of wavelets of different wavefronts.	a. It is due to superposition of wavelets of the different parts of same wavefront.
b. In interference bands may of equal width.	b. Diffraction fringes are not of the same width.

c. Points of minimum intensity are perfectly dark.	c. Points of minimum intensity are not perfectly dark.
d. All bright bands are of uniform intensity.	d. All bright bands are not of the same intensity.
e. Bands are large in number.	e. Bands are few in number.

Fraunhofer diffraction at a single slit: Please refer to 2076 Set C Q.No. 8b

21. 2068 Q.No. 8 b What is Fraunhoffer diffraction? Explain the formation of maxima and minima due to diffraction? Show that the width of central maxima is inversely proportional to the distance between the two slits. **[4]**

Fraunhofer diffraction: The diffraction in which the source and screen are placed at a greater distance (i.e. may be infinite) from the obstacle is called Fraunhofer diffraction. A converging lens is used to focus the light coming from infinite source to the obstacle and another converging lens is used to focus the diffracted light on the screen. In this type of diffraction, the incident as well as the diffracted wavefronts are plane in nature.

Second Part: Please refer to 2076 Set C Q.No. 8b

22. 2067 Q.No. 8b Describe diffraction of light through a single slit. **[4]**

Please refer to 2076 Set C Q.No. 8b

23. 2065 Q.No. 6 a OR What are the differences between interference and diffraction? Explain the theory of diffraction of light through a single slit. **[1+3]**

Difference between the interface and diffraction: Please refer to 2068 Can. Q.No. 8b

Second Part: Please refer to 2076 Set C Q.No. 8b

24. 2061 Q.No. 6 a OR Describe the diffraction of light at a single slit and find the condition for secondary maxima and minima. **[2+2]**

Please refer to 2076 Set C Q.No. 8b

25. 2058 Q.No. 6 a OR What is diffraction of light? How does it differ from interference of light? **[4]**

Diffraction of light: Please refer to 2072 Set E Q.No. 8b

Types of diffraction: There are two types of diffraction;

a. **Fresnel diffraction:** The diffraction in which the source and the screen are at finite distance from the obstacle, is known as Fresnel's diffraction. Usually, no lens is required to observe it. In this type of diffraction, the incident as well as the diffracted wavefronts are spherical in nature.

b. **Fraunhofer diffraction:** The diffraction in which the source and screen are placed at a greater distance (i.e. may be infinite) from the obstacle is called Fraunhofer diffraction. A converging lens is used to focus the light coming from infinite source to the obstacle and another converging lens is used to focus the diffracted light on the screen. In this type of diffraction, the incident as well as the diffracted wavefronts are plane in nature.

Difference between the interface and diffraction: Please refer to 2068 Can. Q.No. 8b

Numerical Problems

26. 2076 Set B Q.No. 12 How wide is the central diffraction peak on a screen 5 m behind a 0.01 mm slit illuminated by 500 nm light source? **[3]**

Solution

Given,

Width of slit (d) = 0.01 mm = 10^{-5} m

Distance between slit and screen (D) = 5 m

Wave length of light used (λ) = 500 nm = 500×10^{-9} m

Width of central diffraction peak (x) = ?

We know,

$$x = \frac{2\lambda D}{d} = \frac{2 \times 500 \times 5 \times 10^{-9}}{10^{-5}} = 0.5\text{m}$$

27. [2075 Set A Q.No. 12] [2062 Q.No. 5 b] **How wide is the central diffraction peak on a screen 3.5 m behind a 0.01 mm slit illuminated by 500 nm light source?** **[3]**

Solution

Given,

Width of slit (d) = 0.01 mm $= 10^{-5}$ m

Distance between slit and screen (D) = 3.5 m

Wavelength of light used (λ) = 500 nm $= 500 \times 10^{-9}$ m

Width of central diffraction peak is given by

$$x = \frac{2\lambda D}{d} = \frac{2 \times 500 \times 10^{-9} \times 3.5}{10^{-5}} = 0.35 \text{ m}$$

Hence, required width of central diffraction peak is 0.35 m.

28. [2073 Set C Q.No. 12] **A plane transmission grating having 500 lines per mm is illuminate normally by light source of 600 nm wavelength. How many diffraction maxima will be observed on a screen behind the grating?** **[4]**

Solution

Given,

Number of lines = 500 lines/mm = 500000 lines/m

$$d = \frac{1}{N} = \frac{1}{500000} = 2 \times 10^{-6} \text{ m}$$

Wavelength (λ) = 600 nm $= 600 \times 10^{-9}$ m

We have,

$d \sin\theta = n\lambda$

For maximum number of spectra, $\theta = 90^\circ$

$$\therefore \; n = \frac{d}{\lambda} = \frac{2 \times 10^{-6}}{600 \times 10^{-9}} = 3.33 \approx 3$$

29. [2071 Set D Q.No. 12] [2069 (Set B) Q.No. 12] **A parallel beam of sodium light is incident normally on a diffraction grating. The angle between the two first order spectra on either side of the normal is 27°42'. Assuming that the wavelength of light is 5.893×10^{-7}m, find the number of rulings per mm on the grating?** **[3]**

Solution

Given,

Wavelength (λ) = 589.3 nm $= 589.3 \times 10^{-9}$m

$$\text{Angle } (2\theta_1) = 27^\circ 42' = 27^\circ + \frac{42^\circ}{60} = 27.27^\circ$$

$\therefore \; \theta = 27.7/2 = 13.85^\circ$

No. of lines per mm (N) = ?

We have,

$d \sin\theta = \lambda$ (for first order)

$$\frac{1}{N}\sin\theta = \lambda$$

$$\text{or, } N = \frac{\sin\theta}{\lambda} = \frac{\sin 13.85}{589.3 \times 10^{-9}}$$

= 406212.18 lines/m = 406 lines per mm

30. [2069 (Set A) Q.No. 12] **A diffraction grating has 400 lines per mm and is illuminated normally by a monochromatic light of wavelength 6000 Å. Calculate the grating spacing, the angle at which first order maximum is seen and the maximum number of diffraction maxima obtained.** **[3]**

Solution

Given,

Grating spacing (d) = ?

No. of lines (N) = 400 lines/mm = 400000 lines/m

$d = \frac{1}{N} = \frac{1}{400000} = 2.5\times10^{-6}$ m

Wavelength (λ) = 6000A° = 6000×10^{-10}m

We have,

$d \sin\theta = n\lambda$

$d \sin\theta_1 = \lambda$ [for first order]

$2.5\times10^{-6}\times\sin\theta_1 = 6000\times10^{-10}$

$\theta_1 = 13.88^\circ$

For maximum number of diffraction maxima, $\theta = 90^\circ$

$$n = \frac{d}{\lambda} = \frac{2.5\times10^{-6}}{6000\times10^{-10}} = 4.17 \approx 4$$

---

31. **2068 Old Can. Q.No. 6b** **A Parallel beam of sodium light of wavelength 5.893×10^{-7}m is incident normally on a diffraction grating. The angle between the two first order spectra on either side of the normal is 28°. Find the number of ruling lines per mm on the grating.** **[3]**

Solution

Given,

Wavelength (λ) = 589.3 nm = 589.3×10^{-9}m

Angle (2θ) = 28° $\Rightarrow \theta = 14^\circ$

No. of lines per mm (N) = ?

We have,

$d \sin\theta = \lambda$ (for first order)

$$\frac{1}{N}\sin\theta = \lambda$$

$$\text{or, } N = \frac{\sin\theta}{\lambda} = \frac{\sin 14}{589.3\times10^{-9}} = 410524.17 \text{ lines/m} = 410 \text{ lines per mm}$$

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Chapter 3: Thermoelectric Effect

Short Answer Questions

1. 2076 Set B Q.No. 1b | 2059 Q.No. 10 a | **What is thermoelectric effect?** [2]

If two different metal wires are joined to form a closed circuit and two junctions are kept at different temperatures, a small emf is set up in the circuit and small current flows in the circuit in a definite direction. This effect is called thermoelectric effect or Seebeck effect which is discovered by a German physicist Thomas J Seebeck. This thermoelectric effect is defined as the phenomenon of conversion of heat energy into electrical energy when the junction of two dissimilar certain metals (thermocouple) are kept at different temperatures. The emf developed in the circuit is called thermo emf and the current is called thermoelectric current. Thus the electromotive force developed in the thermoelectric effect is called thermoelectric emf or thermo emf or Seebeck emf. The value of thermo emf depends on:

(a) the temperature of hot junction of thermocouple and

(b) the nature of material chosen from the thermoelectric series.

2. 2076 Set C Q.No. 1b | **If the temperature of cold junction of a thermocouple is lowered, what will be the effect on neutral temperature and the temperature of inversion?** [2]

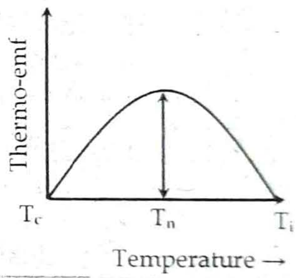
When the temperature of hot junction increases, the thermo-emf increases at first, reaches to a maximum value called neutral temperature and then reduces to zero called temperature of inversion. The temperature of the hot junction at which thermo-emf is reduced to zero and changes its polarity is called temperature of inversion. The temperature of inversion is shown in the given graph. The temperature of inversion depends upon the temperature of cold junction and the nature of metals used in the thermocouple.

The temperature of cold junction, temperature of inversion and neutral temperature are related as

$$T_n = \frac{T_c + T_i}{2}$$

or, $T_i = 2T_n - T_c$.

If temperature of cold junction decreases, then temperature of inversion increases and neutral temperature decreases.



3. 2075 Set A Q.No. 1c | 2073 Supp Q.No. 1b | 2070 Sup (Set A) Q.No. 1 f | 2068 Q.No. 1 b | **Does the thermoelectric effect obey the law of conservation of energy? Justify?** [2]

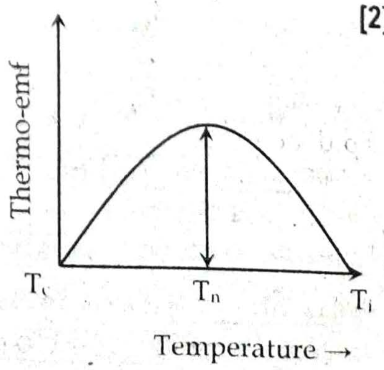
Yes, the thermoelectric effect obeys the law of conservation of energy. The thermoelectric effect is defined as the process of production of small emf in the circuit when the two dissimilar metals are joined end to end and two ends are kept at different temperature. Here, the heat energy is converted to electrical energy and hence obey the law of conservation of energy.

4. 2075 Set B Q.No. 1b | **Why is Lead (Pb) used as a standard reference metal in thermo-electricity?** [2]

From experimental investigation, Seeback became able to arrange a number of metals in a series in thermoelectricity called thermoelectric series. The series is given as Ag, Au, Cr, Sn, Pb, Cu, Co, Ni, Bi. The series was made in such a way that if any two of them form a thermo-couple, the current will flow from the metal which is earlier in the series to the metal which is later in the series through out the cold junction. The lead (Pb) lies in middle and taken as standard references metal in thermo-electricity as the thermo emf of lead is almost zero.

5. 2074 Supp Q.No. 1c | 2069 (Set A) Q.No. 1c | 2068 Can. Q.No. 1c | **What is temperature of inversion? On what factors does it depend?** [2]

When the temperature of hot junction increases, the thermo-emf increases at first, reaches to a maximum value called neutral temperature and then reduces to zero called temperature of inversion. The temperature of the hot junction at which thermo-emf is reduced to zero and changes its polarity is called temperature of inversion. The temperature of inversion is shown in the given graph. The temperature of inversion depends upon the temperature of cold junction and the nature of metals used in the thermocouple.



6. **2074 Set B Q.No. 1c What is temperature of inversion? How does it change, if temperature of cold junction decreases?** [2]

Please refer to 2074 Supp Q.No. 1c

7. **2073 Set C Q.No. 1d Point out the difference between Peltier and Seebeck effect in brief.** [2]

Seebeck's Effect: When two different metals are joined end to end to form a closed circuit such that two ends are kept at different temperatures, a small emf is developed in the circuit and small current flows in the circuit. This effect is called Seebeck effect. The amount of emf (current) depends up on the nature of two metals and temperature of hot junction. Heat energy is converted into electrical energy.

Peltier Effect: When a current is passed through a thermocouple whose junctions are at same temperature, heat is evolved at one junction and heat is absorbed at other junction and cooled. This effect is known as Peltier effect. The temperature difference of two junctions depends upon the amount of current flowing through the circuit. In Peltier effect, electrical energy is converted into heat energy. So, Peltier effect is inverse of Seebeck effect.

8. **2073 Set D Q.No. 1f What is Seebeck effect? How is this effect different from Peltier effect? Explain.** [2]

Please refer 2073 Set C Q.No. 1d

9. **2072 Supp Q.No. 1e On what factors does the temperature of inversion depend?** [2]

Please refer to 2074 Supp Q.No. 1c

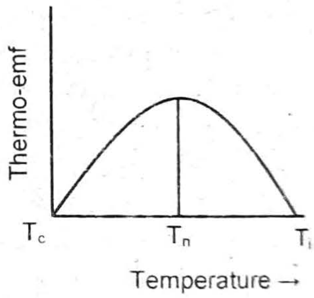
10. **2072 Set E Q.No. 1d Is Seebeck effect reversible effect? Explain.** [2]

Yes, Seebeck effect is reversible effect. This is because on changing the hot and cold junction, the direction of thermo-current reverses its direction in Seebeck experiment.

11. **2071 Set D Q.No. 1 c What is neutral temperature? On what factors does it depend?** [2]

When the temperature of hot junction increases in the thermocouple, the thermo-emf increases at first, reaches to maximum value called neutral temperature and then reduces to zero called temperature of inversion. Neutral temperature depends on the temperature of cold junction and nature of material of thermocouple. The relation between temperature of cold junction, neutral temperature and temperature inversion is given as

$$T_n = \frac{T_c + T_i}{2}$$



12. **2070 Set C Q.No. 1 c Define temperature of inversion. If the temperature of cold junction of a thermocouple is lowered, what will be the effect on it?** [2]

Please refer to 2076 Set C Q.No. 1b

13. **2069 Supp Set B Q.No. 1 f 2069 (Set B) Q.No. 1c Peltier effect is the converse of Seebeck effect. Explain** [2]

Please refer 2073 Set C Q.No. 1d

14. **2067 Q.No. 1b What are the factors on which thermo-emf depends?** [2]

If we keep the junctions of two dissimilar metals making a loop at different temperatures, a current flows through it. An emf appears across the junction and is responsible for this current. This emf is called thermoelectric emf or thermo emf. The value of thermo emf depends on:

a. the temperature of hot junction of thermocouple and
b. the nature of material chosen from the thermoelectric series.

15. **2066 Old Q.No. 10 c How does thermo emf change in a thermocouple when the temperature of the hot junction is changed?** [2]

Please refer to 2071 Set D Q.No. 1 c

16. **2062 Q.No. 10 b How is Seebeck effect different from Peltier effect? Explain.** [2]

Please refer to 2073 Set C Q.No. 1d

17. 2061 Q.No. 10 a **What are the factors on which the thermo emf produced in a thermocouple depends?** **[2]**

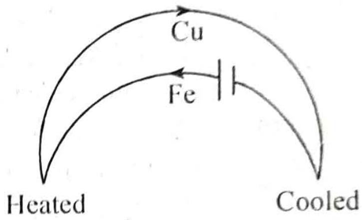
Please refer to 2067 Q.No. 1b

18. 2060 Q.No. 10 c **Why is Sb-Bi thermocouple preferred to Fe-Cu thermocouple?** **[2]**

The device, which is made by two different metal wires with their junction at different temperature is known as thermocouple. The value of thermo emf produced between two junctions of thermocouple depends on the position of metal in the thermoelectric series. The more distant the two elements in the thermoelectric series, the larger is the thermoelectric emf (or current) for a given differences of temperatures between the junctions of the couple. In the thermoelectric series, the position of Fe and Cu is at middle which have some common electrical properties but the position of Sb and Bi is at end. As a result, large amount of thermo electric current is produced by Sb-Bi thermocouple than that by Fe-Cu thermocouple. That's why Sb-Bi thermocouple is preferred to Fe-Cu thermocouple.

19. 2058 Q.No. 10 b **What do you mean by Peltier's effect?** **[2]**

When a current is passed through a thermocouple whose junctions are at the same temperature, heat is evolved at one junction and gets thus heated and heat is absorbed at the other junction and thus gets cooled. This effect is known as Peltier's effect. Thus Peltier's effect is defined as the phenomenon of generation or absorption of heat at the two junctions of thermocouple due to passing the current through it. This is the inverse of Seebeck effect. If the direction of the current is reversed, the previous cold junction becomes hot and vice versa.



Long Answer Questions

20. 2075 GIE Q.No. 5b **What is Seebeck effect? How does the thermo emf vary with the increase in temperature of hot junction, keeping cold junction at 0°c? Explain.** **[4]**

Seebeck Effect: If two dissimilar metals are joined at their ends so as to form a closed conducting circuit and if a difference of temperature is maintained at the two junctions, a small emf is produced, this effect in which heat can be converted into electricity is called seeback effect.

The thermocouple can be formed by using the metals such as Antimony, Iron, Zinc, Lead copper, Platinum, Bismuth, etc.

Variation of thermo–emf with temperature: Let us consider a Cu-Fe junction. Galvanometer is connected in the copper wire. Junction A is placed in hot water and B is placed in ice cold water as shown in figure. Keeping the junction B at 0°C and temperature of junction A is heated, the deflection in galvanometer is noted. For different temperature of hot junction, the variation of emf with temperature is shown in figure (i).

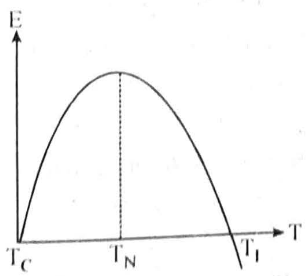


Figure (i)

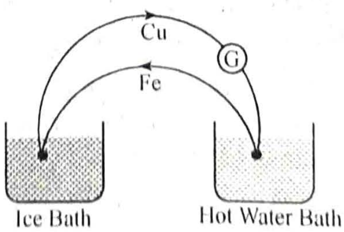


Figure (ii)

As the temperature of hot junction increases keeping cold junction at constant temperature(T_C), the thermo emf increases with the increase in temperature and has maximum at particular temperature called neutral temperature (T_N). If the temperature of hot junction is further increased beyond T_N, thermo emf decreases and becomes zero at particular temperature called temperature of inversion (T_I).

The temperature of inversion and neutral temperature are constant for a given thermocouple and neutral temperature independent of temperature of cold junction but inversion temperature depends upon cold junction. It is found that neutral temperature is equal to arithmetic mean of inversion temperature and the temperature of cold junction.

i.e., $T_N = \frac{T_I + T_C}{2}$

If E is the thermo emf and T be the temperature of hot junction, then E and T are related as

E = a T + b T^2 where a and b are constants.

21. **2074 Set A Q.No. 5b What is Seebeck effect? Explain the variation of thermo emf with gradual increase in the temperature of hot junction, keeping the cold junction at 0^0c.** **[4]**

Please refer to 2075 GIE Q.No. 5b

22. **2072 Set D Q.No. 5a What is thermoelectric effect? How does the thermo emf of a thermocouple vary with increase in temperature of hot junction, keeping cold junction at 0°C? Explain.** **[4]**

Please refer to 2075 GIE Q.No. 5b

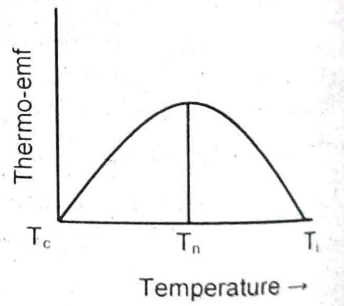
23. **2071 Supp Q.No. 5b What is seebeck effect? How does the emf of thermocouple vary with temperature of the hot junction?** **[4]**

Please refer to 2075 GIE Q.No. 5b

24. **2071 Set C Q.No. 5 b What is a thermocouple? Define neutral temperature and temperature of inversion of a thermocouple. Are they constant for a given thermocouple?** **[4]**

Thermocouple: The device, which is made by two different metal wires with their junction at different temperature is known as thermocouple. The value of thermo emf produced between two junctions of thermocouple depends on the position of metal in the thermoelectric series. The more distant the two elements in the thermoelectric series, the larger is the thermoelectric emf (or current) for a given differences of temperatures between the junctions of the couple. In the thermoelectric series, the position of Fe and Cu is at middle which have some common electrical properties but the position of Sb and Bi is at end. As a result, large amount of thermo electric current is produced by Sb-Bi thermocouple than that by Fe-Cu thermocouple. That's why Sb-Bi thermocouple is preferred to Fe-Cu thermocouple.

When the temperature of hot junction increases in the thermocouple, the thermo-emf increases at first, reaches to maximum value called neutral temperature and then reduces to zero called temperature of inversion. Neutral temperature depends on the temperature of cold junction and nature of material of thermocouple. The relation between temperature of cold junction, neutral temperature and temperature inversion is given as



$T_n = \frac{T_c + T_i}{2}$

They are not constant for a thermocouple because they depends upon the temperature of cold junction.

25. **2070 Supp. (Set B) Q.No. 5 a What is thermo electric effect? Discuss the variation of thermo emf with the change in temperature of the hot junction.** **[4]**

Please refer to 2075 GIE Q.No. 5b

26. **2070 Set D Q.No. 5 b Define Seebeck effect. Discuss the variation of thermoelectric emf in a thermocouple with the increase of temperature of hot junction.** **[4]**

Please refer to 2075 GIE Q.No. 5b

27. **2067 Sup Q.No. 5a What is thermoelectric effect? Discuss the variation of thermo-emf with the change in temperature of the hot junction.** **[1+3]**

Please refer to 2075 GIE Q.No. 5b

28. **2063 Q.No. 11 a OR What is Seebeck effect? How does the thermo emf of a thermocouple vary with temperature of the hot junction?**

Please refer to 2075 GIE Q.No. 5b

29. 2057 Q.No. 11 a What is Seebeck effect? How does the emf of a thermocouple vary with the temperature of the hot junction? [2+3]

Please refer to 2075 GIE Q.No. 5b

30. 2056 Q.No. 11 a OR Explain what do you mean by Seebeck Effect? How thermoelectric e.m.f. does vary with the temperature? [1+3]

Please refer to 2075 GIE Q.No. 5b

Numerical Problems

31. 2073 Set D Q.No. 9c The thermo-emf E and the temperature of hot junction θ satisfy a relation $E = a\theta + b\theta^2$, where $a = 4.1 \times 10^{-5}$ V $(^\circ C)^{-1}$ and $b = -4.1 \times 10^{-8}$ V$(^\circ C)^{-2}$. If the cold junction temperature is 0°C find the neutral temperature. [4]

Solution

The given equation is

$E = a\theta + b\theta^2$ ....(i)

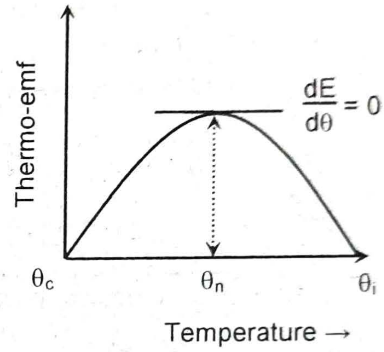
where, a & b are constant, θ = temperature of hot junction.

$a = 4.1 \times 10^{-5}$ V $(^\circ C)^{-1}$, $b = -4.1 \times 10^{-8}$ V$(^\circ C)^{-2}$

and temperature of cold junction is 0°C.

Now,

$$\frac{dE}{d\theta} = a + 2b\theta.$$



The neutral temperature is temperature of hot junction at which, thermo-emf is maximum i.e.

$$\frac{dE}{d\theta} = 0 \text{ or } a + 2b\theta_n = 0$$

or, $a = -2b\theta_n$

or, $\theta_n = \frac{a}{-2b} = \frac{4.1 \times 10^{-5}}{-2 \times (-4.1 \times 10^{-8})} = 500\ ^\circ C$

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Chapter 4: Chemical Effect of Current

Short Answer Questions

1. **2076 Set B Q.No. 1c** **2067 Sup Q.No. 1c** **Distinguish between ionic and electronic conduction.** [2]

The differences between the ionic and electronic conduction are given below;

Electronic conduction	Ionic conduction
1. The conduction of electricity takes place due to drifting of free electrons in metals is called electronic conduction.	1. The conduction of electyricity takes place due to movement of ions is called ionic conduction.
2. No chemical change takes place when the current passes through metal in electronic conduction.	2. The chemical decomposition takes place when current passes through the electrolyte.
3. No matter is transformed during electric conduction in metals.	3. Matter is transported in the form of positive and negative ions in case of electrolytes.
4. Eg. Electricity passing through copper wire.	4. Eg. Electricity passing through copper sulphate solution.
5. The resistance is less in electronic conduction.	5. The resistance is more in ionic conduction.

2. **2076 Set C Q.No. 1a** **2074 Set B Q.No. 1f** **2072 Set C Q.No. 1b** **The conductivity of an electrolyte is low as compared to that of metal at room temperature. Why?** [2]

The conductivity of an electrolyte is low as compared to a metal because of following reasons.

i. The number of ions in an electrolyte is small as compared to the number of free electrons in the metallic conductors. The drift velocity is given by the relation $I = v_d neA$, since n is more in metal than that of electrolyte, then the current is more in metal.

ii. The mobility of ions in an electrolyte is small as compared to the mobility of free electrons in metallic conductors.

iii. The resistance offered by the electrolyte to ions is more than resistance offered by metal to free electrons.

3. **2075 GIE Q.No. 1c** **A voltameter measures current more accurately than an ammeter, why?** [2]

The current flowing in a voltameter can be measured by using the relation, $I = \frac{m}{zt}$. All quantities of this relation can be accurately measured upto three decimal places. But in case of ammeter due to the presence of certain resistance in it, current can never be measured accurately. That's why, a voltameter measures electric current more accurately than an ammeter.

4. **2075 Set B Q.No. 1c** **2071 Set C Q.No. 1 e** **Why is the conductivity of an electrolyte low in comparison to that of metal?** [2]

Please refer to 2076 Set C Q.No. 1a

5. **2073 Set C Q.No. 1e** **State the Faraday's laws of electrolysis.** [2]

Faraday gave two laws of electrolysis, they are stated as:

a. **Faraday's first law of electrolysis:** The mass of a substance liberated or deposited in electrolysis is directly proportional to the electric charge that passes through the electrolyte.

i.e., $m \propto Q \quad \Rightarrow m = Z\,Q$

where Z is electrochemical equivalent (ECE).

$\therefore \quad m = Z\,It \qquad (Q = I\,t)$

b. **Faraday's second law of electrolysis:** The mass of different substances liberated in electrolysis by the passage of same quantity of electric charge, is directly proportional to their respective chemical equivalent.

$$\frac{m}{E} = \text{constant}$$

6. 2072 Supp Q.No. 1b **Explain electrochemical equivalent of a substance.** **[2]**

Electrochemical equivalent: From Fraday's first law of electrolysis, the amount of ions deposited or liberated at an electrode in electrolysis is directly proportional to the quantity of electricity passed through the electrolysis.

i.e., $m \propto Q$ or, $m = ZQ$

Where, $Z = \frac{m}{Q}$ is electrochemical equivalent of a substance. Thus, electrochemical equivalent of a substance is defined as the mass of ions deposited or liberated at the electrode when one coulomb of charge is passed through electrolyte. Its unit is KgC^{-1}.

7. 2072 Set E Q.No. 1c **Why is the conductivity of an electrolyte very low as compared to a metal at room temperature?** **[2]**

Please refer to 2076 Set C Q.No. 1a

8. 2071 Supp Q.No. 1f 2056 Q.No. 10 c **What is meant by Faraday constant?** **[2]**

Faraday's constant (F): From Faraday's first and second laws of electrolysis, we get a combined equation

$$m \propto QE$$

where m is the mass of ions or substance liberated or deposited, Q is amount of charge deposited or liberated and E be chemical equivalent.

$$\text{Or, } m = \frac{1}{F}QE$$

where F is a universal constant called Faraday's constant. If m = E (numerically), then F = Q. thus, Faraday constant is defined as the quantity of charge required to liberate the mass of substance equal to its gram equivalent. Its value is equal to 96500Cmol-1.

9. 2070 Set C Q.No. 1 e **The conductivity of an electrolyte is low as compared to a metal. Why?** **[2]**

Please refer to 2076 Set C Q.No. 1a

10. 2070 Set D Q.No. 1 e **State and explain Faraday's laws of electrolysis.** **[2]**

Please refer to 2073 Set C Q.No. 1e

11. 2066 Old Q.No. 10 b **Define one Faraday.** **[2]**

Please refer to 2071 Supp Q.No. 1f

12. 2063 Q.No. 10 b **Why does voltameter measure current more accurately than an ammeter?** **[2]**

Please refer to 2075 GIE Q.No. 1c

Long Answer Questions

13. 2075 Set A Q.No. 5c 2071 Set D Q.No. 5 b 2069 (Set A) Q.No. 5c **State Faraday's laws of electrolysis. How will you verify Faraday's second law experimentally?** **[4]**

Faraday gave two laws of electrolysis, they are stated as:

a. **Faraday's first law of electrolysis:** The mass of a substance liberated or deposited in electrolysis is directly proportional to the electric charge that passes through the electrolyte.

i.e., $m \propto Q \quad \Rightarrow m = Z Q$

where Z is electrochemical equivalent (ECE).

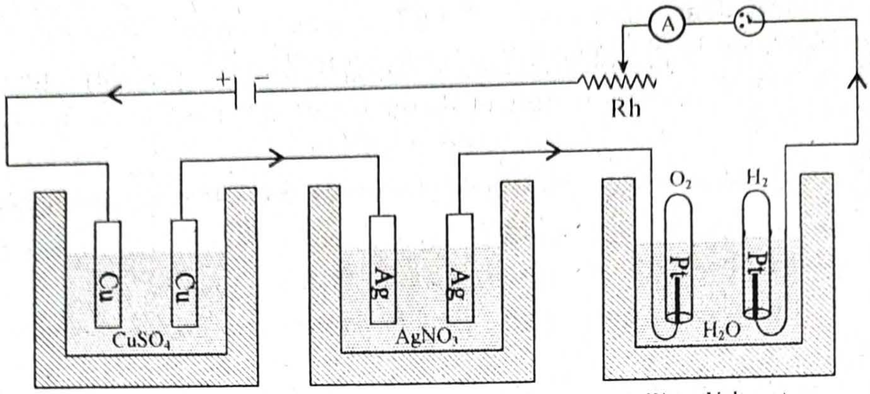
$\therefore \quad m = Z It \qquad (Q = I t)$

b. **Faraday's second law of electrolysis:** The mass of different substances liberated in electrolysis by the passage of same quantity of electric charge, is directly proportional to their respective chemical equivalent.

$$\frac{m}{E} = \text{constant}$$

Experimental verification:

Second law:



The experimental arrangement for the verification of Faraday's second law is as shown in figure. There are three voltameters containing $CuSO_4$, $AgNO_3$ and acidified water as electrolytes and Cu, Ag and Pt are as respective electrodes. If I be the constant current flow in circuit, then in time 't', the mass of hydrogen gas liberated, silver and copper deposited on electrodes are calculated. If m_1, m_2 and m_3 are masses of copper, silver and hydrogen deposited at the respective cathodes and E_1, E_2 and E_3 are their chemical equivalents respectively, then, experimentally it is found that,

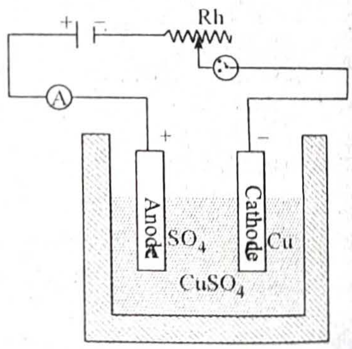
$\frac{m_1}{E_1} = \frac{m_2}{E_2} = \frac{m_3}{E_3}$ i.e., $m \propto E$. This verifies Faraday's second law of electrolysis.

14. 2070 Sup (Set A) Q.No. 5 c 2062 Q.No. 11 a **State Faraday's laws of electrolysis and verify second law.** **[4]**

Please refer to 2075 Set A Q.No. 5c

15. 2069 (Set B) Q.No. 5a **Verify Faraday laws of electrolysis.** **[4]**

First law: The experimental arrangement to verify Faraday's first law of electrolysis in copper voltameter is as shown in figure. A clean and dry cathode plate is weighed and then it is placed in the voltameter. The electric circuit is completed by the series combination of voltameter with the battery, ammeter and a rheostat as shown in figure. When steady current I is passed for a certain time 't', the electrolyte $CuSO_4$ solution of electrolyte decompose into Cu^{++} and SO_4^{--}.



Let m_1 be the mass of copper deposited on cathode in time t with the passage of current I_1, then

$m_1 = Z I_1 t$ ... (i)

The experiment is repeated with current I_2 at same time t, the mass of copper deposited on cathode is m_2, then

$m_2 = Z I_2 t$ ... (ii)

From (i) and (ii), we get

$$\frac{m_1}{m_2} = \frac{I_1 t}{I_2 t} \Rightarrow \frac{m_1}{m_2} = \frac{Q_1}{Q_2}$$

i.e., $m \propto Q$, Similar procedure can be repeated by keeping current constant and varying time. This verifies the first law.

Statement and Second Law: Please refer to 2075 Set A Q.No. 5c

16. 2068 Old Q.No. 11 a or 2058 Q.No. 11 a OR **State and explain Faraday's Laws of electrolysis and hence define Faraday's constant.** **[3+2]**

First law: Please refer to 2069 (Set B) Q.No. 5a

Statement and Second Law: Please refer to 2075 Set A Q.No. 5c

Faraday's constant (F): From fist law of electrolysis, we have

$m \propto Q$, where E is constant

From second law of electrolysis, we have

$m \propto E$, where Q is constant

Combining these two laws we get,

$m \propto QE$ where Q and E both vary.

Or, $m = \frac{1}{F}QE$

where F is a universal constant called Faraday's constant. If m = E (numerically), then F = Q. Thus, Faraday constant is defined as the quantity of charge required to liberate the mass of substance equal to its gram equivalent. Its value is equal to $96500 Cmol^{-1}$.

17. **2064 Q.No. 11 a OR State Faraday's law of electrolysis. Discuss the experiment to verify them.** **[4]**

First law: Please refer to 2069 (Set B) Q.No. 5a

Statement and Second Law: Please refer to 2075 Set A Q.No. 5c

Numerical Problems

18. **2074 Supp Q.No. 9b It is desired to deposit 0.254 kg of copper on the cathode of a copper voltameter. How long will it take to deposit this amount if a steady current of 100 A is maintained? Relative Atomic mass of copper = 63.5 and Faraday's constant, F = 96500 C/mol.** **[4]**

Solution

Given,

Mass of copper deposited (m) = 0.254 kg = 254 g

Time (t) = ?

Current (I) = 100 A

Relative Atomic mass of copper (M) = 63.5

Faraday's constant (F) = 96500 C/mol

We have,

$m = ZIt$

or, $m = \frac{M}{VF} \times I \times t$

or, $t = \frac{m \cdot V \cdot F}{M \cdot I}$

$= \frac{254 \times 2 \times 96500}{63.5 \times 100}$

$= 7720$ s

19. **2069 Supp Set B Q.No. 9 a Assuming Faraday constant to be 96500 C $(mole)^{-1}$ and relative atomic mass of copper is 63, calculate the mass of copper liberated by 2 A current in 5 minutes.** **[4]**

Solution

Given,

Faraday constant (F) = $96500 C mol^{-1}$

Relative atomic mass of copper (M) = 63

Current (I) = 2A

Time (t) = 5 min = 5 × 60 = 300 sec.

Valency of copper (V) = 2

Mass of copper deposited (m) = ?

We have,

$m = ZIt$

$= \frac{E}{F}It$

$= \frac{M}{VF}It = \frac{63 \times 2 \times 300}{2 \times 96500} = 0.196$ gm

20. **2066 Old Q.No. 11 b In a copper plating system, an electrolysis current of 3 A is used. How many atoms of Cu^{2+} are deposited in 1.5 h? ($e = -1.6 \times 10^{-19}C$).** **[5]**

Solution

Given,

Current (I) = 3A

Time (t) $= 1.5h = 1.5 \times 3600 = 5400$ s

e $= 1.6 \times 10^{-19}$C

Now, Charge passed in 1.5 hour (Q) = It $= 3 \times 5400 = 16200$ C

Also, Charge carried by each Cu^{2+} atoms $= 2 \times 1.6 \times 10^{-19}C = 3.2 \times 10^{-19}C$

Then, No. of atoms deposited $= \dfrac{16200}{3.2 \times 10^{-19}} = 5.06 \times 10^{22}$

Hence, the required number of atoms is 5.06×10^{22}.

21. 2057 Q.No. 11 b Calculate the charge needed to deposit 2g of Oxygen in the electrolysis of water.(Relative molecular mass of Oxygen is 32, Faraday constant F is 965,000 C mol^{-1}). [5]

Solution

Given,

Mass of oxygen (m) = 2gm

Molecular mass of oxygen (M) = 32; Atomic mass $= \dfrac{32}{2} = 16$gm

Faraday constant (F) $= 96500$Cmol^{-1}

Charge needed (Q) = ?

Now,

Valency of oxygen (V)= 2

Then, we have

Chemical equivalent (E) = F × Z

or, $\dfrac{\text{Atomic mass}}{\text{Valency}} = F \times Z$

or, $\dfrac{16}{2} = 96500 \times Z$

$\therefore$ Z $= 8.29 \times 10^{-5}$ gmC^{-1}

Again, we have

m = Z × Q

or, $2 = 8.29 \times 10^{-5} \times Q$

$\therefore$ Q = 24125.45C

Hence, the required amount of charge is 24125.45C

❑❑❑

B. Magnetic Field of Current

Chapter 1: Magnetic Effect of Current

Short Answer Questions

1. 2076 Set B Q.No. 1d | 2068 Q.No. 1 e | **An electron beam and a proton beam are moving parallel to each other in the beginning. Do they always maintain this status? Justify your answer.** [2]

An electron beam and a proton beam are moving parallel to each other in the beginning, the path of beam depends on the speed of charged particles. Protons and electrons are opposite charge particles. In the lower speed, the electrostatic force dominates the magnetic force and attract to each other. As a result, they come close to each other. If the speed is high, the magnetic force dominates to electrostatic force and they behave as two currents carrying infinitely long conductor carrying current in opposite direction. So, they diverse to each other and become far from each other.

2. 2076 Set B Q.No. 1e | **Define one ampere current in terms of force.** [2]

The force per unit length between two current carrying conductors is written as,

$$F = \frac{\mu_0 I_1 I_2}{2\pi r}$$

when, $I_1 = I_2 = 1A$ and $r = 1$ m, then

$$F = \frac{4\pi \times 10^{-7} \times 1 \times 1}{2 \times r} = 2 \times 10^{-7} N$$

Hence, one ampere of current is defined as the current which when passed through two infinitely long parallel conductors separated by a distance 1m in vacuum which produces a force 2×10^{-7} N per unit length between the conductors.

3. 2076 Set C Q.No. 1c | **How will the magnetic field intensity at the centre of a circular coil carrying current change, if the current through the coil is doubled and the radius of the coil is halved?** [2]

The magnetic field intensity at the centre of the circular current carrying coil is,

$$B = \frac{\mu_0 NI}{2r}$$

where,

μ_0 = Magnetic permeability of free space,

N = No. of turns of coil,

r = Radius of coil

If current in the coil is doubled and radius of coil is halved, then magnetic field intensity is

$$B' = \frac{\mu_0 NI'}{2r'} \qquad [\because I' = 2I, r' = \frac{r}{2}]$$

$$= \frac{\mu_0 N(2I)}{2\left(\frac{r}{2}\right)}$$

$$= 4\frac{\mu_0 NI}{2r}$$

$$= 4B$$

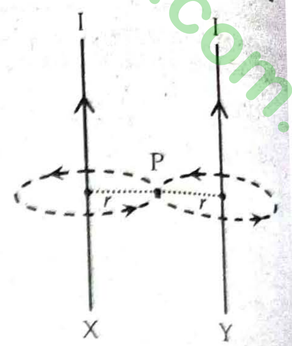
Thus, the magnetic field intensity changes by four times if the current through coil is doubled and radius is halved.

4. 2076 Set C Q.No. 1d | 2072 Set C Q.No. 1f | **Can a charged particle move through a magnetic field without experiencing any force? Explain.** [2]

Yes, a charged particle moving through a uniform magnetic field B experience a force in a straight line is given by F = Bqv sinθ where θ is angle between velocity v and magnetic field B. If the velocity and field are parallel, the charged particle moves without experiencing any force.

5. [2075 GIE Q.No. 1d] **Equal currents are flowing through two infinitely long parallel wires. What will be the magnetic field at a point mid-way, when the currents are flowing (i) in the same direction (ii) in the opposite direction?** [2]

Let two conductors X and Y carrying equal current I in same direction. The magnetic field at point P due to conductor X is $B = \frac{\mu_0 I}{2\pi r}$. By right hand thumb rule, the field is inward to the plane of paper. Similarly, the magnetic field at P due to conductor Y is $B = \frac{\mu_0 I}{2\pi r}$ at a direction outward to the plane of paper (right hand thumb rule). The magnetic field midway between two conductors is equal but opposite in direction. So, cancelled each other.



But when current is flowing in opposite direction, then the magnetic field at the middle of wire is double is 2B, i.e. $\left(\frac{\mu_0 I}{\pi r}\right)$

6. [2075 Set A Q.No. 1d] [2075 Set B Q.No. 1d] [2067 Sup Q.No. 1d] **A solenoid tends to contract when a current passes through it. Why?** [2]

Solenoid is made by winding large number of insulated wires. Thus, the turns of wire act as parallel conductors carrying current in same direction. There exists a force of attraction between two parallel current carrying conductors ($F = \frac{\mu_o I_1 I_2}{2\pi r}$). Hence, the conductors attract each other. Due to the attractive forces between the two parallel conductors the solenoid tends to contract its length.

7. [2073 Supp Q.No. 1e] [2060 Q.No. 2 e] **Define one Ampere in terms of the force between current carrying conductors.** [2]

Please refer to [2076 Set B Q.No. 1e]

8. [2073 Set C Q.No. 1c] **How can the sensitivity of moving coil galvanometer be increased? Explain.** [2]

The sensitivity of galvanometer can be increased by:

i. making the pole pieces of magnet concave.
ii. using the cylindrical soft iron core.
iii. making radial magnetic field.

9. [2073 Set D Q.No. 1b] **A charge particle carrying a change 'q' moves in an electric field E. If its specific charge is 'S', write an expression of its acceleration in terms of above entities.** [2]

A charge particle carrying a charge q moves in an electric field E. If its specific charge is S, then force is given as

$F = qE$

and acceleration, $a = \frac{F}{m} = \frac{qE}{m} = SE$ [since, $\frac{q}{m} = S$, given]

$\therefore$ acceleration, $a = SE$

10. [2073 Set D Q.No. 1c] **Magnetic field at the centre of a solenoid is double than that at its ends. Why?** [2]

The magnetic field at a point on the axis of solenoid is

$$B = \frac{\mu_o nI}{2}[\text{Cos}\,\theta_1 - \text{Cos}\,\theta_2]\ \text{Tesla}$$

Where, $\mu_o = 4\pi \times 10^{-7}$ H/m, I = current in solenoid and θ_1 and θ_2 be the angles made by small element of solenoid.

At the centre, $\theta_1 = 0$, $\theta_2 = \pi$, then

$$B_C = \frac{\mu_o nI}{2}[1 - (-1)]$$

$$B_C = \mu_o nI$$

At the end, $\theta_1 = 90°$, $\theta_2 = \pi$, then

$$B_E = \frac{\mu_o nI}{2}.1$$

$$B_E = \frac{\mu_0 nI}{2}$$

$$B_C = 2B_E$$

Hence, the magnetic field at the centre of solenoid is double than at ends.

11. 2072 Supp Q.No. 1c **Hall voltages are much larger for semi-conductors than for good conductors for comparable currents, fields and dimensions. Why?** **[2]**

The Hall Voltage developed in a specimen kept in a magnetic field is given by,

$$V_H = \frac{BI}{net} \quad \dots (i)$$

Where, B = magnetic field,
I = current in a specimen
n = no. of charge carriers,
e = electronic charge,
t = thickness of specimen.

Thus the Hall voltage is,

$V_H \propto \frac{1}{n}$ for same, B, I and t,

n for conductor is much larger than semiconductor. So, V_H is larger for semiconductor than conductor.

12. 2072 Set D Q.No. 1c **Does a charged particle moving through a magnetic field always experience a force? Explain.** **[2]**

No, a charged particle moving though a magnetic field does not experienced force on any time. The magnetic force experienced by a moving charge particle in a magnetic field B is given as,

$F = B qv \sin\theta$,

where q is charge particle and θ is angle between velocity and B. When θ = 0° i.e., velocity is parallel to magnetic field, the force experienced is zero.

13. 2072 Set E Q.No. 1e **How will an electron move in a homogeneous magnetic field if the velocity of the electron at the initial moment forms an angle 'θ' with the force lines of the field?** **[2]**

The magnetic force acting on an electron moving in a homogeneous magnetic field when the velocity of the electron at the initial moment forms an angle θ is,

$F = Bev \sin\theta$, here B = Magnetic flux density, hence, the path of this electron in the filed is spiral.

14. 2071 Supp Q.No. 1d **A uniform magnetic field directed upward exists in some region of space. In what directions could an electron be moving if its trajectory is a) a straight line? b) a circle?** **[2]**

A uniform magnetic field directed upward exists in some region of space. When an electron moves in straight line, then its path is circular and if the trajectory of the electron is circular then it moves in helical path.

15. 2071 Set C Q.No. 1 c **A current was sent through a helical coil spring. The spring contracted, as if it had been compressed. Why?** **[2]**

Please refer to 2075 Set A Q.No. 1d

16. 2070 Sup (Set A) Q.No. 1 c **If a magnetic force does no work on charged particles, how can it have any effect on the particles' motion?** **[2]**

When a charged particle moves in a uniform, magnetic field (B), it experience a force F as $F = Bqv \sin\theta$, where q is charge of particle, v be its velocity and θ is angle between B and v. This force is acting towards the centre of circle or the motion is circular. The direction of force F and the distance covered s are always perpendicular to each other such that, work done W = FS cos 90 = 0. So, the magnetic force does no work done but moves the particle in circular motion.

17. 2070 Supp. (Set B) Q.No. 1 c **Can a charged particle move through a magnetic field without experiencing any force? Explain the reason.** **[2]**

Please refer to 2076 Set C Q.No. 1d

18. 2069 Supp Set B Q.No. 1 c **Two straight current carrying rods are replaced parallel to each other. How can 1(one) ampere of current be defined from this arrangement?** **[2]**

Please refer to 2076 Set B Q.No. 1e

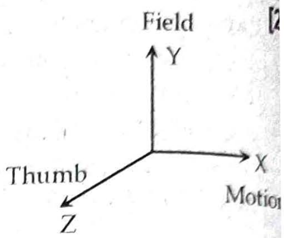
19. **2068 Old Can. Q.No. 2e** **What will be the effect if the magnetic field in a moving coil galvanometer is no radial?** [2

If the magnetic field in a moving coil galvanometer is not radial, the plane of coil does not becom parallel to the magnetic field and the torque (τ = BINA cosθ) does not become same in all cases. Hence, following effects can be seen; th sensitivity of the galvanometer decreases, it does not make galvanometer dead beat and th galvanometer does not measure accurate current.

20. **2067 Q.No. 1e** **2067 Old Q.No. 1e** **2066 Supp Q.No. 2e** **A current carrying solenoid tends to contract. Why?** [2

Please refer to 2075 Set A Q.No. 1d

21. **2065 Q.No. 2 e** **Explain how the direction of Lorentz force is determined.** [2



The direction of Lorentz force is determined by using Fleming's left hand rule which states that when the fore finger, middle finger and thumb of the left hand are stretched mutually perpendicular to each other in such a way that if the fore finger points the direction of field (B) and the middle finger points in the direction of motion of charge particle then the direction of thumb gives the direction of the force.

22. **2061 Q.No. 2 e** **How magnetic field is made radial in a moving coil galvanometer?** [2

In a moving coil galvanometer, magnetic field is made radial by using concave pole pieces of magne and putting a soft iron cylindrical core between the pole pieces. The advantage of radial magneti field is that the deflection θ becomes directly proportional to the current I flowing through the coil As a result, the scale showing the current values is a uniform one.

23. **2060 Q.No. 1 e** **Why is the cylindrical core of soft iron used in moving coil galvanometer?** [2

An instrument which is used to detect and measure small amount of electric current flowing through the circuit is called moving coil galvanometer. When a cylindrical core of soft iron is used in it, a radial magnetic field is produced so that the deflection θ becomes directly proportional to the current I flowing through the coil. As a result, the scale showing the current value is uniform one i.e., equal division along the calibrated scale represents equal steps in current.

i. It makes radial field B so that linearly scaled galvanometer can be made.
ii. It makes dead beat galvanometer.
iii. It increases sensitivity of galvanometer.

That's why, the cylindrical core of soft is iron used in moving coil galvanometer.

24. **2057 Q.No. 2 e** **A proton moving in a straight line enters a strong magnetic field along the field direction. How will its path and velocity change?** [2]

When a proton enters to a strong magnetic field along the field direction, the force experienced by a proton is given by F = Bqv sinθ. In this case, proton is moving along the field, i.e. θ =0°, then F = Bqv sin 0 = 0. Here, force experienced by the proton is zero. So, its path and velocity remains unchanged.

25. **2055 Q.No. 7 a** **Does a charged particle moving through a magnetic field experience a force? Express with conditions, maximum, and minimum force it experiences.** [2]

Yes, a charged particle moving through a magnetic field experiences a force. The amount of force experienced by a charge q moving with velocity v inside the magnetic field B is given by, F = Bqv sin θ, where θ is the angle between the direction of v and B.

a. When θ = 0°, then F = Bqv sin 0 = 0 (minimum or zero force).

b. When θ = 90°, then F = Bqv sin 90 = Bqv (maximum force).

26. **2054 Q.No. 7 d** **Under what conditions does a charge affect a magnet?** [2]

When a fast moving charge particle enters to a magnetic field, a magnetic field as well as force is developed in the charge which is F = Bqv sinθ, where B is magnetic field intensity, q is the charge, v be the velocity of charge particle and θ be the angle between the velocity and magnetic field. Due to this reason, the fast moving charge particle affects the magnet.

$$B = \int dB = \frac{\mu_0 I}{4\pi a}\int_0^{\pi} \sin\theta \, d\theta = \frac{\mu_0 I}{4\pi a}\left[-\cos\theta\right]_0^{\pi} = \frac{\mu_0 I}{4\pi a}\left[\cos 0 - \cos\pi\right] = \frac{\mu_0 I}{4\pi a}.2$$

$$\therefore \; B = \frac{\mu_0 I}{2\pi a}$$

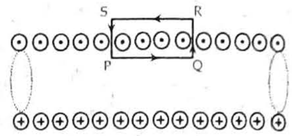
This is required magnetic field intensity.
This indicates that magnetic field of a long straight wire is inversely proportional to the distance of the point from the wire (i.e., $B \propto \frac{1}{a}$).

29. 2075 GIE Q.No. 5c 2074 Supp Q.No. 5b State Ampere's law and use it to find the magnetic field intensity due to a long solenoid. [4]

Ampere's Theorem (Ampere's Circuital law): Ampere's Circuital law state that the line integral of magnetic flux density $\vec{B}$ in a closed loop is equal to μ_0 times the net current bounded by the area of closed surface (in SI system).

i.e., $\oint \vec{B}.\vec{dl} = \mu_0 I$, where dl is a small element of the loop.

The magnetic field intensity due to a long current carrying solenoid:
Consider a long solenoid having n number of turns per unit length & carrying current I in the clockwise direction. Then, the magnetic field outside the solenoid is very small or almost zero & that inside is uniform. The direction of magnetic field is along the axis of the solenoid.
Let us take a rectangular close path PQRSP to calculate the magnetic field intensity B inside the solenoid as shown in figure. Let PQ = l. Then the number of turns enclosed by the close path is $N = n.l$



Thus, the current enclosed by the closed path is
$I' = N \times I = n\,l \times I = n\,I\,l$

The line integral of $\vec{B}$ around the close path is given by

$$\vec{B}.\vec{dl} = \int_P^Q \vec{B}.\vec{dl} + \int_Q^R \vec{B}.\vec{dl} + \int_R^S \vec{B}.\vec{dl} + \int_S^P \vec{B}.\vec{dl}$$

As angle between $\vec{B}$ and $\vec{dl}$ is 90^0, so $\int_Q^R \vec{B}.\vec{dl} = \int_S^P \vec{B}.\vec{dl} = 0$

Also as $\vec{B}$ outside the solenoid is zero, so $\int_R^S \vec{B}.\vec{dl} = 0$

Therefore, $\oint \vec{B}.\vec{dl} = \int_P^Q \vec{B}.\vec{dl} = \int_P^Q B\,dl\cos 0° = B\int_P^Q dl = Bl$ [Because $l = \int_P^Q dl$]

Therefore $\oint B.\vec{dl} = Bl$ ... (i)

Applying Ampere circuital theorem, we have

$\oint \vec{B}.\vec{dl} = \mu_0 \times$ current enclosed $= \mu_0 \times I' = \mu_0 (n\,I\,l)$ ...(ii)

So, equations (i) and (ii) give,

$B\,l = \mu_0 (n\,I\,l)$

$\therefore \; B = \mu_0\,n\,I$

This is the required expression for magnetic field intensity due to long current carrying solenoid.

30. 2075 Set A Q.No. 5a State Biot's and Savart's law and used it to obtain an expression for the magnetic field at the center of a circular coil. [4]

Biot's and Savart's law: Please refer to 2076 Set B Q.No. 5c

Magnetic field B at the centre of narrow coil: Let us consider a narrow circular coil of radius r having N-turns carries current I through it. The flux density dB at the centre of the coil due to a small element dl is given by

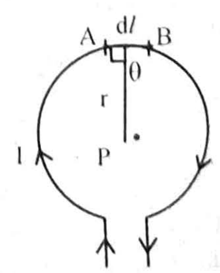


Fig: Narrow circular coil

$$dB = \frac{\mu_0}{4\pi}\frac{Idl\sin\theta}{r^2}$$

Since, $\theta = 90^0$

$$\Rightarrow dB = \frac{\mu_0}{4\pi}\frac{Idl}{r^2}$$

Thus, the total magnetic field B at the centre of narrow circular coil is given by

$$B = \int dB = \frac{\mu_0}{4\pi}\int_0^{2\pi r}\frac{Idl}{r^2} = \frac{\mu_0 I}{4\pi r^2}(2\pi r) = \frac{\mu_0 I}{2r}$$

For N number of turns, the magnetic field intensity at the center of the circular current carrying coil is

$$B = \frac{\mu_0 NI}{2r}$$

This is required magnetic field intensity at the centre of circular current carrying coil.

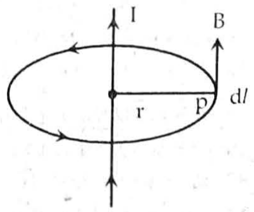
31. **2075 Set B Q.No. 5c** **State Ampere's law and use it to find magnetic field due to a long straight current carrying conductor and toroid.** **[4]**

Ampere's Laws: Ampere's circuital law states that the line integral of a magnetic field B around any closed path in vacuum is equal to μ_0 time total current enclosed by the path. If I be the total current enclosed by a closed path around which the line integral of B is $\oint \vec{B}\cdot\vec{dL} = \mu_o I$ [Ampere's Law]

Application of Ampere's Law

i. **Magnetic field due to a long straight current carrying conductor**

Let us consider a long straight conductor carrying current I as shown in figure. A current carrying conductor produces a magnetic field around it. We want to find out the magnetic field B at a point P at a distance r from the conductor. Let us draw a circle of radius r around the wire or conductor B be the magnetic field at P and dl be small element of circle which are in same direction. According to Ampere's Law,



$$\oint \vec{B}\cdot\vec{dl} = \mu_o I$$

or, $\oint Bdl\cos 0 = \mu_0 I$

or, $B\oint dl = \mu_0 I$

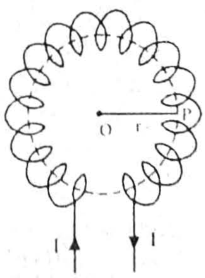
or, $B \,.\, 2\pi r = \mu_0 I$

$\therefore\ B = \dfrac{\mu_0 I}{2\pi r}$

This is required magnetic field at P.

ii. **Magnetic field due to a current carrying toroid**

A toroid is an endless solenoid which is bent into a circular form and whose ends are kept closer as shown in figure. This has infinite number of turns. Consider a torroid of mean radius r, number of turns per unit length n, and carrying current I, as shown in figure. Let us consider a point P inside the solenoid at which we want to find the magnetic field B. Draw a circle of a radius r as shown dotted line in the figure. Each and every point in the dotted circle $\vec{B}$ and $\vec{dl}$ are in same direction. Now from Ampere's law,



$\oint \vec{B}\cdot\vec{dl} = \mu_o I'$ [I' = total current enclosed]

or, $\oint Bdl\cos 0 = \mu_0 I'$ [$\therefore$ I' = N.I = n.2.πr.I]

or, $B\oint dl = \mu_0 I'$ [$\therefore$ N = n . 2πr]

or, $B \,.\, 2\pi r = \mu_0 \,.\, n2\pi r \,.\, I$

$\therefore\ B = \mu_0 nI$

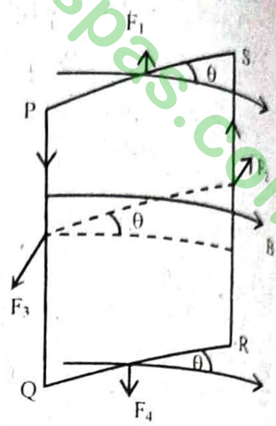
This is required magnetic field.

32. **2074 Supp Q.No. 5d** **A rectangular coil of N turns is placed in a uniform magnetic field B with its plane parallel to the field. Derive an expression for the torque produced on the coil when a current I is passed through it. Define magnetic moment in terms of torque.** **[4]**

Torque on a rectangular coil in a uniform magnetic field:

Let us consider a rectangular coil PQRS of length l and breadth b carrying current I and having N number of turns is placed in a uniform magnetic field of flux density B. Suppose the plane of the coil makes an angle θ with the field as shown in figure.

The face PS of length b making an angle θ with the direction of magnetic field, then the force acting on this face is $F_1 = BIb\sin\theta$ in upward direction (By Fleming's left hand rule).



Similarly, the force acting on face QR is $F_4 = BIb\sin\theta$ acts downward. The force acting on face PQ carrying current I of length l is $F_3 = BIl$ [since, angle between the length of the coil and magnetic field is 90°] which acts outward from the plane of paper. Similarly the force acting at face RS is $F_2 = BIl$ acting inward from the plane of the paper.

Since, the forces F_1 and F_4 are equal and opposite acting on a same line of action and hence vanish. The forces F_2 and F_3 are equal and opposite acting at different line of action so produced torque on the coil.

The torque exerted on the rectangular coil is given by

τ = force × perpendicular distance

The perpendicular distance between forces is given by $= b\cos\theta$

Thus, the torque exerted on the rectangular coil is given by

$\tau = BIlN \times b\cos\theta$

$\tau = BINA\cos\theta$, where $A = l \times b$ is the area of the coil.

This is required torque produced in the rectangular coil carrying currents.

Special Cases:

a. When $\theta = 0^0$, then $\tau = BINA\cos 0^0 = BINA$

i.e., when the plane of the coil is parallel to B, the maximum value of the torque is acting on the coil.

b. When $\theta = 90^0$, then $\tau = BINA\cos 90^0 = 0$

i.e., no torque acts on the coil, if the plane of the coil is perpendicular to B.

Magnetic Moment: Two equal and opposite forces produced in a rectangular current carrying coil in different line of action which produce the turning effect of coil are called magnetic moment.

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33. 2074 Set A Q.No. 5c 2071 Set C Q.No. 5 c 2069 (Set A) Q.No. 5b **State Biot-Savart law. Use this law, to find the magnetic field due to a current carrying circular coil at any point on the axis of the coil.** [4]

Biot's and Savart's law: Please refer to 2076 Set B Q.No. 5c

Magnetic field strength at a point on the axis of circular current loop:

Consider a circular coil of radius a and centre O carrying current I in the direction shown in Fig. Let the plane of the coil be perpendicular to the plane of the paper. It is desired to find the magnetic field at a point P on the axis of the coil such that OP = x. Let AB be a small element of length dl at a distance r from point P.

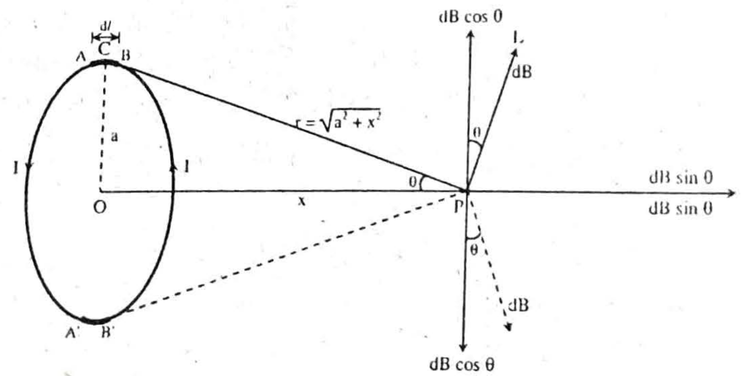


Fig. Field on the axis of circular coil.

According to Biot-Savart law, magnetic field due to element AB at point P is given by,

$$dB = \frac{\mu_0 I\, dl \sin\alpha}{4\pi\, r^2} \quad \dots (i)$$

Angle α between dl and r can be taken as $\pi/2$ because radius of coil is small, so Eq. (i) can be written as

$$dB = \frac{\mu_0 I\, dl \sin \pi/2}{4\pi\, r^2} = \frac{\mu_0 I\, dl}{4\pi\, r^2} \quad \dots (ii)$$

The direction of dB is perpendicular to the plane formed by dl and r and is along PL which is perpendicular to PC. Resolving dB along two components, we get $dB\cos\theta$ along perpendicular to the axis of the coil and $dB\sin\theta$ along the axis of the coil and away from centre of the coil. The components $dB\cos\theta$ is cancelled by another components $dB\cos\theta$ due to element A'B'. So, total magnetic field at point P due to the whole coil is equal to the sum of the dB sinθ components of magnetic field due to each element

i.e., $B = \int_0^{2\pi a} dB \sin\theta = \int_0^{2\pi a} \frac{\mu_0}{4\pi}\frac{Idl}{r^2}\sin\theta \quad \left[\because dB = \frac{\mu_0}{4\pi}\frac{Idl}{r^2} \text{ from Eq. (ii)}\right]$

or, $B = \frac{\mu_0 I \sin\theta}{4\pi r^2}\int_0^{2\pi a} dl = \frac{\mu_0 I \sin\theta}{r\pi r^2}[l]_0^{2\pi a} = \frac{\mu_0 I \sin\theta}{4\pi r^2}[2\pi a - 0]$

$= \frac{\mu_0 I \sin\theta}{4\pi r^2} 2\pi a$

$= \frac{\mu_0 I}{2 r^2}\sin\theta\, a = \frac{\mu_0 I}{2 r^2} a \frac{a}{r} \quad \left[\because \sin\theta = \frac{a}{r} \text{ from figure}\right]$

$$B = \frac{\mu_0 I a^2}{2(a^2 + x^2)^{3/2}} \quad \ldots\text{(iii)}$$

$[\because r^2 = a^2 + x^2, \text{ from figure}]$

If the coil has n turns, then

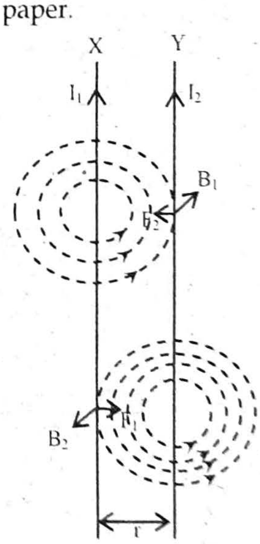
$$B = \frac{\mu_0 n I a^2}{2(a^2 + x^2)^{3/2}} \text{ Tesla} \quad \ldots\text{(iv)}$$

This is required formula for the magnetic field intensity at the axis of current carrying solenoid.

34. 2074 Set B Q.No. 5b **Derive an expression for the force per unit length between two infinitely long parallel straight wires carrying current in the same direction. Hence define one ampere.** **[4]**

Force Between Two Parallel Current Carrying Conductors:

When two parallel current carrying conductors are placed close together, they exert forces to each other. Consider, two infinitely long parallel conductors X and Y carrying currents I_1 and I_2 respectively in the same direction. Let the two conductors are separated at distance r in the plane of paper.



The magnitude of magnetic field at any point P on the conductor Y due to current I_1 in conductor X is

$$B_1 = \frac{\mu_0 I_1}{2\pi r} \quad \ldots\text{(i)}$$

According to right hand grip rule, the direction of magnetic field is perpendicular to the plane of the paper and is directed inwards shown in figure.

Now, conductor Y carrying current I_2 is placed in the magnetic field B_1 produced by conductor X. So, force experience per unit length of conductor Y is given by

$$F_Y = \frac{B_1 I_2 l}{l} = B_1 I_2 \quad [\because F = BIl]$$

Putting value of B_1, we get

$$F_Y = \frac{\mu_0 I_1}{2\pi r} I_2 \text{ per unit length}$$

According to right hand rule, the force F_Y is in the plane of the paper and is directed towards the conductor X.

Similarly, force per unit length on conductor X is

$$F_x = \frac{\mu_0 I_1 I_2}{2\pi r}$$

Again, by right hand rule, this force is in the plane of the paper and is directed towards conductor Y as shown in figure. Clearly, the force is such that conductors attract each other and the force of attraction per unit length is

$$F = \frac{\mu_0 I_1 I_2}{2\pi r}$$

This is required force acting between two parallel current carrying conductors.

One Ampere Current: Please refer to 2076 Set B Q.No. 1e

35. 2073 Supp Q.No. 5b 2072 Set D Q.No. 5c **State and explain Biot-Savart law and use it to find magnetic field due to a long straight current carrying conductor.** [4]

Please refer to 2076 Set B Q.No. 5d

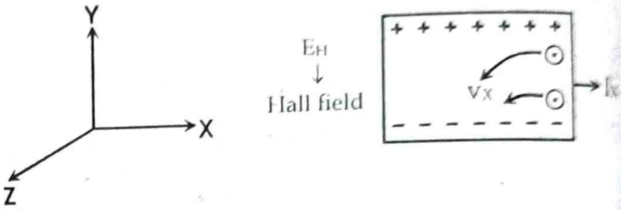
36. 2073 Set C Q.No. 5c **State Ampere's law and deduce an expression for the force between two parallel current carrying wires.** [4]

First Part: Please refer to 2075 GIE Q.No. 5d

Second part: Please refer to 2074 Set B Q.No. 5b

37. 2073 Set C Q.No. 5d 2073 Set D Q.No. 5d **What is Hall effect? Explain and deduce expressions for Hall voltage and Hall electric field.** [4]

Hall Effect: When a magnetic field is applied to a current carrying conductor, a transverse voltage is developed across the specimen in the direction perpendicular to both the current and the magnetic field. This effect is called Hall Effect.



Let us consider a rectangular conductor in which current is passed in x-axis and magnetic field is applied in z-axis, then hall voltage or hall field is developed in y-axis as shown in figure.

Let, current is passing along x-axis and no magnetic field is applied, the electrons drift in opposite to the x-axis. When magnetic field is applied, the electrons bends downwards due to Lorentz force. As a result, electron accumulates in the lower surface while positive charges are accumulated in upper surface producing the field in y-axis called hall field. The accumulation of electrons continues until the Lorentz force is cancelled by Hall field i.e.,

Hall force = Lorentz force

$$e E_H = ev_x B_z$$

or, $E_H = v_x B_z$

From Ohm's law, current density,

$$J_x = -nev_x$$

or, $v_x = \dfrac{J_x}{-ne}$

$$\therefore \quad E_H = -\frac{B_z J_x}{ne} \qquad \ldots(i)$$

This is required hall field. If t be the thickness of specimen, then, hall voltage V_H is

$$V_H = t \cdot E_H = -\frac{B_z J_x \cdot t}{ne} \qquad \ldots(ii)$$

which is required hall voltage.

38. 2073 Set D Q.No. 5a **Explain the magnetic effect on a current carrying rectangular coil. Hence obtain expression for the torque on the coil.** [4]

Please refer to 2074 Supp Q.No. 5d

39. 2072 Supp Q.No. 5b **Find an expression for the magnetic field on the axial line of a current carrying circular coil.** [4]

Please refer to 2074 Set A Q.No. 5c

40. 2072 Set C Q.No. 5c **Derive an expression for the force per unit length acting on each of the two straight parallel metallic conductors carrying current in the same direction and kept near each other. Why do such current carrying conductors attract each other?** [4]

First Part: Please refer to 2074 Set B Q.No. 5b

Second Part: The current carrying conductors in same direction attract each other due to magnetic force produced between them.

41. 2072 Set E Q.No. 5b **Derive an expression for the force per unit length between two parallel current carrying conductors.** [4]

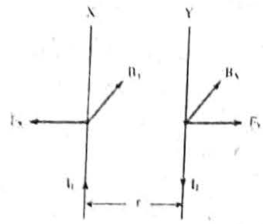
Please refer to 2074 Set B Q.No. 5b

42. 2071 Supp Q.No. 5d **Derive an expression for the force per unit length between parallel conductors carrying current in the opposite direction.** **[4]**

Force between two unlike parallel current carrying conductors

When two parallel current carrying conductors are placed close together, they exert forces to each other. Consider two infinitely long parallel conductors X and Y carrying currents I_1 and I_2 respectively in the opposite direction. Let the two conductors are separated at distance r in the plane of paper.

The magnitude of magnetic field at any point on the conductor Y due to current I_1 in conductor X is



$$B_x = \frac{\mu_0 I_1}{2\pi r} \quad \text{... (i)}$$

According to right hand grip rule, the direction of magnetic field is perpendicular to the plane of the paper and is directed outwards as shown in figure.

Now, conductor Y carrying current I_2 is placed in the magnetic field Bx produced by conductor X. So, force experience per unit length of conductor Y is given by

$$F_Y = \frac{B_x I_2 l}{l} = B_x I_2 \quad [\because F = BIl]$$

Putting value of B_x, we get

$$F_Y = \frac{\mu_0 I_1}{2\pi r} I_2$$

According to right hand rule, the force F_Y is in the plane of the paper and is directed opposite of the conductor X.

Similarly, force per unit length on conductor X is

$$F_x = \frac{\mu_0 I_1 I_2}{2\pi r}$$

Again, by right hand rule, this force is in the plane of the paper and is directed opposite conductor Y as shown figure. Clearly, the force is such that conductors repel to each of the other and the force of repulsion per unit length is

$$F = \frac{\mu_0 I_1 I_2}{2\pi r}$$

which is force of repulsion per unit length acting between two long current carrying wires.

43. 2071 Set D Q.No. 5 c **State and explain Ampere's theorem and use it to calculate the magnetic field due to a long solenoid.** **[4]**

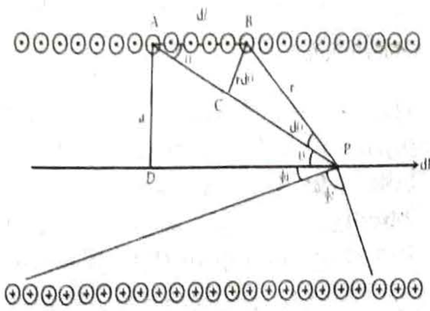
Please refer to 2075 GIE Q.No. 5c

44. 2070 Sup (Set A) Q.No. 5 b **Deduce an expression for a magnetic field at a point along the axis of a solenoid and at the mid point of the solenoid.** **[4]**

Magnetic field on the centre of a long solenoid: Consider a long solenoid of radius a having n number of turns per unit length. When current I flows through it, magnetic field is produced inside it. To find out magnetic field produced by it at a point P on the axis of the solenoid, let us consider an element AB of length dl which makes angle θ with AP = r.

Let the element dl makes angle dθ at P which is as shown in figure. Since, magnetic field produced by single coil is, $dB = \frac{\mu_0 I a}{2r^2} \sin\theta$. So, magnetic field produced by the element $n dl$ at point P is given by

$$dB = \frac{\mu_0 I a}{2r^2} \sin\theta \, n \, dl \quad \text{... (i)}$$



From ΔABC, $\sin\theta = \frac{BC}{AB}$

$$\sin\theta = \frac{r\,d\theta}{dl} \quad \left(\because d\theta = \frac{BC}{r} \quad \therefore BC = r d\theta \right)$$

$\therefore \quad dl = \dfrac{r\,d\theta}{\sin\theta}$

Using value of dl in Eq. (i), we get

$$dB = \frac{\mu_0 I a}{2 r^2} \sin\theta\, n \frac{r\,d\theta}{\sin\theta}$$

$$dB = \frac{\mu_0 I a}{2 r} n\, d\theta \qquad \text{... (ii)}$$

Again, from ΔADP,

$\sin\theta = \dfrac{a}{r}$ [If point A is close to point B, AP $\approx$ BP = r]

or, $r = \dfrac{a}{\sin\theta}$

Putting value of r in Eq. (ii), we get

$$dB = \frac{\mu_0 I a n\, d\theta}{2a} \sin\theta = \frac{\mu_0 n I \sin\theta\, d\theta}{2} \qquad \text{... (iii)}$$

If the radii of the coil at its ends subtend angles ϕ_1 and ϕ_2 at P, then to find out total magnetic field produced by the solenoid at point P, we have to integrate Eq. (iii) from ϕ_1 to ϕ_2.

i.e., $B = \int_{\phi_1}^{\phi_2} \dfrac{\mu_0 n I \sin\theta\, d\theta}{2} = \dfrac{\mu_0 n I}{2} \int_{\phi_1}^{\phi_2} \sin\theta\, d\theta = \dfrac{\mu_0 n I}{2} [-\cos\theta]_{\phi_1}^{\phi_2}$

$$= \frac{\mu_0 n I}{2} (\cos\phi_1 - \cos\phi_2) \qquad \text{... (iv)}$$

If the point P inside a very long solenoid is so long that we may regard, it is an infinite, then $\phi_1 = 0°$ and $\phi_2 = \pi$. So, Eq. (iv) becomes,

$$B = \frac{\mu_0 n I}{2} (\cos 0° - \cos\pi) = \frac{\mu_0 n I}{2} (1 + 1)$$

$\therefore$ B $= \mu_0 n I$ Tesla

This is required magnetic field due to long solenoid.

At the end, $\theta_1 = 90°$, $\theta_2 = \pi$, then

$$B_E = \frac{\mu_o n I}{2} . 1 = \frac{\mu_o n I}{2}$$

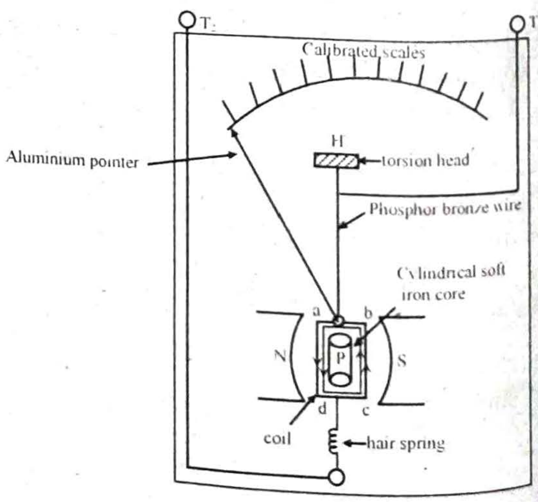
45. 2070 Supp. (Set B) Q.No. 5 b **State Biot Savart law. Use this law to find the magnetic field intensity due to a current carrying straight conductor at a distance 'd' from it.** **[4]**

Please refer to 2076 Set B Q.No. 5c

46. 2070 Set C Q.No. 5 d **Describe with the help of a diagram, the principle, construction and working of a moving coil galvanometer.** **[4]**

Moving coil galvanometer

Galvanometer: Moving coil galvanometer is a device which detects and measures small current. It works on the principle of torque produced on a rectangular current carrying coil placed inside the magnetic field.



Construction: It consists of a rectangular coil abcd of length l and breath x and having N number of turns of insulated copper wire, wound on a non- magnetic metallic frame. The coil is suspended in a strong radial magnetic field, B set up by two cylindrical strong permanent magnetic poles, NS. A cylindrical core of soft iron is fixed to the frame at the centre of the coil.

The current is passed into and out of the coil through the suspension coil at the top and the bottom as shown in figure.

Theory: If current, I, is flowing in the coil, the two forces are acting in the coil such that they produce torque on the coil. If l is the length of coil, then F is given by,

$F = BIl$ ($\because l$ is perpendicular to B)

These forces F, at two sides are perpendicular to the plane of the coil and acting in opposite directions. So, they produce torque, the torque acting on each turn of the coil is Torque = one of the force × perpendicular distance between two forces.

$= F . x,$ ($\because$ x is width of the coil)

$= BIl\,x = BIA;$ ($\because lx = A$ is area of the coil)

Therefore, total deflecting torque, acting on N turns of coil is = BINA.

A restoring torque, due to the twist in the suspension wire, acts on the coil. Let, K be the restoring torque per unit twist (or torsional constant) of the suspension wire. Then, the total restoring torque for twist, θ, is $K\theta$.

For the equilibrium of the coil,

deflecting torque = restoring torque

or, $BINA = K\theta$

or, $I = \frac{K}{BAN}\theta$

$\therefore \theta \propto I$, since K, B, N and A are constant for a galvanometer.

i.e., deflection, θ, is proportional to the current, I. Therefore, the equal divisions in scale show the equal steps in current. Thus, the deflection over the scale can measure current values.

47. **2070 Set C Q.No. 5 c** **What is Ampere's circuital law? Use this law to derive an expression for the magnetic field due to a long solenoid carrying current.** **[4]**

Please refer to 2075 GIE Q.No. 5d

48. **2070 Set D Q.No. 5 c** **Find an expression for the force per unit length between two long parallel conductors carrying currents and hence define one ampere.** **[4]**

Please refer to 2074 Set B Q.No. 5b

49. **2069 Supp Set B Q.No. 5 c** **State and explain Biot Savart law to find the magnetic field due to a current carrying solenoid at its centre.** **[4]**

Biot's and Savart's law: Please refer to 2076 Set B Q.No. 5d

Second Part: Please refer to 2070 Sup (Set A) Q.No. 5 b

50. **2069 (Set B) Q.No. 5d** **State and explain Biot-Savart law to find magnetic field due to a long straight current carrying conductor.** **[4]**

Please refer to 2076 Set B Q.No. 5d

51. **2068 Can. Q.No. 5c** **State and explain Ampere's theorem and hence use it to find the magnetic field due to a long solenoid carrying current I.** **[4]**

Please refer to 2075 GIE Q.No. 5d

52. **2068 Old Can. Q.No. 7a OR** **State and explain Biot-Savart law and hence use this law to find the magnetic field due to a long straight current carrying conductor.** **[1+3]**

Please refer to 2076 Set B Q.No. 5d

53. **2067 Sup Q.No. 5b** **State and explain Biot-savart law and use it to find magnetic field due to a long straight current carrying conductor.** **[1+3]**

Please refer to 2076 Set B Q.No. 5d

54. **2067 Q.No. 5b** **Find an expression for the magnetic field on the axis of a solenoid, carrying current, using Ampere's law.** **[2]**

Please refer to 2075 GIE Q.No. 5d

55. **2067 Old Q.No. 7a** **Obtain magnetic field strength at a point on the axis of circular current loop by using Biot and Savart law.** **[4]**

Please refer to 2074 Set A Q.No. 5d

56. **2066 Supp Q.No. 7a State and explain Biot-savart law. Use it to find the magnetic field at the center of a circular coil of N turns and carrying current I.** [1+3]

Please refer to 2075 Set A Q.No. 5a

57. **2066 Q.No. 7 a Derive an expression of force per unit length between two parallel conductors separated by a distance 'r' and carrying currents I_1 and I_2 in the same direction.** [4]

Please refer to 2074 Set B Q.No. 5b

58. **2065 Q.No. 7 a OR State and explain Biot-Savart law with a case of its application.** [2+2]

Please refer to 2075 Set A Q.No. 5a

59. **2064 Q.No. 7 a State and explain Biot-Savart law. Use this law to find the magnetic field intensity at any point due to a long straight current carrying conductor.** [1+3]

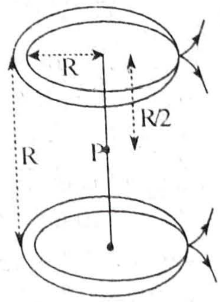
Please refer to 2076 Set B Q.No. 5c

60. **2063 Q.No. 7 a Find an expression for torque on rectangular coil in a uniform magnetic field.** [4]

Please refer to 2074 Supp Q.No. 5d

61. **2063 Q.No. 7 a OR 2058 Q.No. 7 a OR What is a Helmholtz coil? Derive an expression for the magnetic field due to this coil.** [4]

Helmholtz coil: Helmholtz coil is a combination of two coaxial parallel coils having same radius, same number of turns & same current in the same direction.



The field along the axis of a single coil varies with the distance x from the coil. In order to obtain a uniform field, Helmholtz used two coaxial parallel coils of radius R, separated by a distance R. In this case, when the same current flows around each coil in the same direction, the resultant field B is uniform for same distance on either side of the point on their axis midway between the same coils.

For two coils, the magnitude of the resultant magnetic field B at the midpoint P can be given as

$$B = 2 \times \frac{\mu_o N I R^2}{2\left[\left(\frac{R}{2}\right)^2 + R^2\right]^{3/2}} = \frac{\mu_o N I R^2}{\left(\frac{R^2+4R^2}{4}\right)^{3/2}} = \frac{4}{5}^{3/2}\frac{\mu_o N I}{R} = 0.72\frac{\mu_o N I}{R}$$

Discussion on Helmholtz coil:

The variation of B on the two sides of the coil with x is as shown in figure (i). Thus, the magnetic field due to a coil is not uniform.

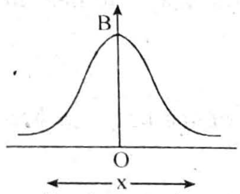


Fig. for a single coil

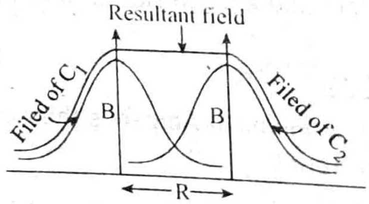


Fig. for a helmholtz coil

But for Helmholtz coil, the resultant field B is uniform for some distance on either side of the point on their axis midway between the coils.

Here the decrease in the field due to one coil is balanced by the increase of the field due to the other coil.

Hence the field remains uniform over a considerable region on either side of the point $x = \frac{R}{2}$.

62. **2062 Q.No. 7 a State and explain Biot-Savart law and hence use it to find the magnetic field intensity at any point due to a long straight conductor.**

Please refer to 2076 Set B Q.No. 5c

63. **2061 Q.No. 7 a Derive the formula for the magnetic field at a point due to a long straight current carrying conductor using Biot-Savart law.** [4]

Please refer to 2076 Set B Q.No. 5c

64. 2060 Q.No. 7 a **State and explain Ampere's theorem and hence use it to find the magnetic field intensity due to a long current carrying solenoid.** **[1+3]**

Please refer to 2075 GIE Q.No. 5c

65. 2059 Q.No. 7 a **Derive the formula for the magnetic field at the centre of a circular coil carrying current. Explain why the magnetic field at the centre of the coil disappears when the circular coil is made infinitely large.** **[4]**

First part: Please refer to 2075 Set A Q.No. 5a

The magnetic field at the center of a circular current carrying coil is given as $B = \frac{\mu_o NI}{2r}$, i.e., $B \propto \frac{1}{r}$.

This shows that if the coil is infinitely large, the radius becomes infinite and B becomes zero.

66. 2057 Q.No. 7 a **Derive an expression for the magnetic field at a point due to a long straight conductor carrying current.** **[4]**

Please refer to 2076 Set B Q.No. 5c

67. 2056 Q.No. 7 c **Explain in brief, the motion of an electron moving normal to a magnetic field.** **[2+3]**

Force on an electron moving in a uniform magnetic field:

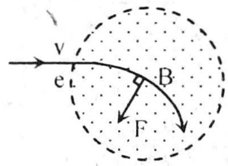
When an electron moves in a magnetic field, it experiences a force called Lorentz force as it was given by Lorenz. Let an electron of charge e is moving with velocity v making an angle θ with magnetic field B then the magnitude of the force F on the electron is directly proportional to the strength of the magnetic field B, i.e., $F \alpha B$; directly proportional to the electronic charge; i.e., $F \alpha e$ directly proportional to the speed of charge; i.e., $F \alpha v$; directly proportional to the sine of the angle between v and B; i.e, $F \alpha \sin\theta$.

Combining all equations we get,

$F \alpha eBv\sin\theta$

$F = keBv\sin\theta$, where k is proportionality constant whose value is found to be 1.

so, $F = eBv\sin\theta$



Vectorically $\vec{F} = e(\vec{v} \times \vec{B})$

Special Cases:

i. When electron is moving in perpendicular direction to the magnetic field
$\theta = 90°$, $F = Bev \sin 90° = Bev$; maximum force.

ii. When electron is moving in the direction of the magnetic field
$\theta = 0°$, $F = Bev \sin 0 = 0$, minimum force.

Direction of Force (Fleming's left-hand rule): It states that, "If the thumb, fore finger and middle finger of our left hand are stretched mutually perpendicular to each other such that the middle finger points to the current direction, the fore finger points to the direction of magnetic field, then the thumb points to the direction of the force experienced by the conductor."

68. 2056 Q.No. 8 **Derive an expression for the magnitude of the magnetic flux density at the center of a narrow circular coil.** **[4]**

Please refer to 2075 Set A Q.No. 5a

69. 2055 Q.No. 9 OR **State Biot-Savart's law and obtain the expression for the magnetic field at the centre of the circular coil.** **[5]**

Please refer to 2075 Set A Q.No. 5a

Numerical Problems

70. 2076 Set B Q.No. 9b **Two galvanometers, which are otherwise identical, are fitted with different coils. One has a coil of 50 turns and resistance 10Ω while the other has 500 turns and a resistance of 600Ω. What is the ratio of the deflection when each is connected in turns to a cell of e.m.f. 25 V and internal resistance 50Ω?** **[4]**

Solution

Given,

$N_1 = 50$ turns $\quad R_1 = 10\Omega$

$N_2 = 500$ turns $\quad R_2 = 600\Omega$

E = 25 U   r = 50Ω

$\theta_1 : \theta_2 = ?$

We know that for a galvanometer at equilibrium condition,

Deflecting torque = Restoring torque

i.e. BINA = Kθ

where,

B = Magnetic field intensity

I = Current in the galvanometer

N = Number of turns

A = Area of coil of galvanometer

θ = Deflection

K = Torsional constant

For first galvanometer,

$BI_1N_1A = K\theta_1$ and $E = I_1(R_1 + r)$

or, $I_1 = \dfrac{K\theta_1}{BN_1A}$ or, $I_1 = \dfrac{E}{R_1 + r}$

$$\therefore \frac{K\theta_1}{BN_1A} = \frac{E}{R_1 + r} \quad \text{... (i)}$$

Similarly for second galvanometer

$$\therefore \frac{K\theta_2}{BN_2A} = \frac{E}{R_2 + r} \quad \text{... (ii)}$$

Dividing equation (i) and (ii) we get

$$\frac{\dfrac{K\theta_1}{BN_1A}}{\dfrac{K\theta_2}{BN_2A}} = \frac{\dfrac{E}{R_1 + r}}{\dfrac{E}{R_2 + r}}$$

or, $\dfrac{\theta_1}{\theta_2} \times \dfrac{N_2}{N_1} = \dfrac{R_2 + r}{R_1 + r}$

or, $\dfrac{\theta_1}{\theta_2} = \left(\dfrac{R_2 + r}{R_1 + r}\right) \times \dfrac{N_2}{N_1}$

$= \left(\dfrac{600 + 50}{10 + 50}\right) \times \dfrac{50}{500}$

$= 13 : 12$

71. **2076 Set C Q.No. 9b** **A flat silver strip of width 1.5cm and thickness 1.5mm carries a current of 150A. A magnetic field of 2T is applied perpendicular to the flat face of the strip. The emf developed across the width of the strip is measured to be 17.9μV. Calculate the free electron density in the silver.** [4]

Solution

Given,

Width of silver strip (b) = 1.5 cm = 1.5×10^{-2} m

Thickness of silver strip (t) = 1.5 mm = 1.5×10^{-3} m

Current (I) = 150 A

Magnetic field (B) = 2T

Hall voltage (V_m) = 17.9 μV = 17.9×10^{-6} V

Electron density (n) = ?

Charge (e) = -1.6×10^{-19} C

We have,

$$V_M = -\frac{B\,J\,t}{ne}$$

or, $n = -\dfrac{B \cdot I \cdot t}{V_M \cdot e \cdot A} = \dfrac{2 \times 150 \times 1.5 \times 10^{-3}}{17.9 \times 10^{-6} \times 1.6 \times 10^{-19} \times 1.5 \times 10^{-2} \times 1.5 \times 10^{-3}} = 6.98 \times 10^{27}\ m^{-3}$

72. $\boxed{\text{2075 GIE Q.No. 9b}}$ **A Silver wire has 1×10^{30} free electrons per cubic meter, a cross sectional area of 2 mm^2 and carries a current of 5A. Calculate the force acting on each electron if the wire is now placed in a magnetic field of flux density 0.15T which is perpendicular to the wire.** **[4]**

Given,

No. of free electrons (n) = 1×10^{30} /m^3

Cross-section area (A) = $2mm^2 = 2 \times 10^{-6}\ m^2$

Current (I) = 5A

Flux density (B) = 0.15 T

Force on electron (F) = ?

Now,

Dift velocity, $v_d = \frac{I}{neA}$ A and

$$\text{Force, } F = Bev_d$$

$$= Be\frac{I}{enA} = \frac{BI}{nA}$$

$$= \frac{0.15 \times 5}{1 \times 10^{30} \times 2 \times 10^{-6}}$$

$$= 3.75 \times 10^{-25}\ N$$

73. $\boxed{\text{2075 Set B Q.No. 9b}}$ $\boxed{\text{2061 Q.No. 7 b}}$ **A horizontal straight wire 5 cm long weighing 1.2 gm^{-1} is placed perpendicular to a uniform horizontal magnetic field of flux density of 0.6 T. If the resistance per unit length of the wire is 3.8 $\Omega\ m^{-1}$, calculate the p.d. that has to be applied between the ends of the wire to make it just self-supporting.** **[4]**

Solution

Given,

Length of wire (l) = 5cm = 5×10^{-2}m

Weight per meter = 1.2gm

$\therefore$ Total mass of wire (m) $= 1.2 \times 5 \times 10^{-2}$gm

$= 0.06$gm

$= 0.06 \times 10^{-3}$kg

Flux density (B) = 0.6T

Resistance per meter = 3.8Ω

$\therefore$ Total resistance of wire (R) = $3.8 \times 5 \times 10^{-2}\Omega$

$= 0.19\Omega$

Potential difference (V) = ?

Now,

To make the wire just self supporting,

Weight of wire = Magnetic force

or, $mg = BIl \sin 90°$ [$\because \theta = 90$]

or, $0.06 \times 10^{-3} \times 9.8 = 0.6 \times \frac{V}{R} \times 5 \times 10^{-2}$

or, $0.588 \times 10^{-3} = 0.03 \times \frac{V}{0.19}$

$\therefore$ V $= 3.7 \times 10^{-3}$V

Hence, the required potential is 3.7×10^{-3} Volt.

74. $\boxed{\text{2074 Set A Q.No. 9b}}$ **A straight horizontal rod of length 20 cm and mass 30 gm is placed in a uniform horizontal magnetic field perpendicular to the rod. If a current of 2A through the rod makes it self supporting in the magnetic field, calculate the magnetic field.** **[4]**

Solution

Given,

Length of rod (l) = 20 cm = 0.2 m

Mass of rod (m) = 30 gm = 0.03 kg

Current (I) = 2A

Angle (θ) = 90°

Magnetic field (B)= ?

For self supporting, magnetic force is equal to the weight of the wire,

i.e.

Magnetic force = Weight

or, $BI\, l\sin\theta = mg$

or, $B \times 2 \times 0.2 \times \sin 90° = 0.03 \times 10$

$\therefore$ $B = 0.75$ T

75. **2074 Set B Q.No. 9b** **A coil consisting of 100 circular loops with radius 60 cm carries a current of 5A. Find the magnetic field at a point along the axis of the coil, 80 cm from the centre. ($\mu_0 = 4\pi \times 10^{-7}$Tm/A)** [4]

Solution

Given,

Number of circular loops (N) = 100

Radius (R) = 60 cm = 0.6 m

Current (I) = 5A

Distance (x) = 80 cm = 0.8 m

Magnetic field (B) = ?

We know,

$$B = \frac{\mu_0 NIa^2}{2(x^2 \times a^2)^{3/2}}$$

$$= \frac{4\pi \times 10^{-7} \times 100 \times 5 \times 0.6^2}{2(0.8^2 + 0.6^2)^{3/2}} = 1.13 \times 10^{-4}\text{ T}$$

76. **2073 Supp Q.No. 9b** **A straight conductor of length 5cm carries current of 1.5A. The conductor experiences a magnetic force of 4.5×10^{-3}N when it is placed in a magnetic field of 0.9T. What angle the conductor makes with magnetic field?** [4]

Solution

Given,

Length of conductor (l) = 5 cm = 0.05 m

Current in conductor (I) = 1.5 A

Magnetic force (F) = 4.5×10^{-3} N

Magnetic field (B) = 0.9 T

Angle (θ) = ?

We have,

$F = BIl\sin\theta$

or, $4.5 \times 10^{-3} = 0.9 \times 0.05 \times 1.5 \times \sin\theta$

or, $\sin\theta = 0.067$

$\therefore$ $\theta = 3.84°$

77. **2073 Set D Q.No. 9b** **A circular coil has 100 turns and a mean diameter of 20 cm. It carries a current of 5A. Find the strength of the magnetic field at a point on its axis at a distance of 15 cm from the centre of the coil.**

Solution

Given,

No. of turns of coil (n) = 100 turns.

Diameter of coil (D) = 20 cm

Radius of coil (r) = $\frac{20}{2}$ = 10 cm = 0.1 m

Current in coil (I) = 5A

Distance (x) = 15cm = 0.15m

Magnetic field (B) = ?

$$B = \frac{\mu_0 nIr^2}{2(x^2 + r^2)^{3/2}} = \frac{4\pi \times 10^{-7} \times 100 \times 5 \times (0.1)^2}{2(0.15^2 + 0.1^2)^{3/2}} = \frac{6.28 \times 10^{-6}}{0.0117} = 5.37 \times 10^{-4}\text{ T}$$

78. 2072 Set C Q.No. 9b **A horizontal wire, of length 5 cm and carrying a current of 2A, is placed in the middle of a long solenoid at right angles to its axis. The solenoid has 1000 turns per meter and carries a steady current I. Calculate I if the force on the wire is equal to 10^{-4} N. ($\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}).** **[4]**

Solution

Given,

Length of wire (l) = 5cm = 5×10^{-2} m

Current on wire (I_w) = 2A

No. of turns of solenoid (n) = 1000 turns/ meter

Force on wire (F) = 10^{-4} N

Current on solenoid (I_s) = ?

We have,

$F = B.I_s.\, l$

or, $F = \mu_0\, n\, I_s.\, I_w\, l$ $\quad [\because B = \mu_0\, n\, I_w]$

or, $10^{-4} = 4\pi \times 10^{-7} \times 1000 \times I_s \times 2 \times 10^{-2} \times 5$

or, $I_s = 0.8$ A

79. 2072 Set D Q.No. 9b 2071 Supp Q.No. 9b 2067 Q.No. 6b **The coil of a moving coil galvanometer has 50 turns and its resistance is 10Ω. It is replaced by a coil having 100 turns and resistance 50Ω. Find the factor by which the current and voltage sensitivities change.** **[4]**

Solution

Given,

For Initial condition;

No. of turns(N_1) = 50

Resistance (R_1) = 10Ω

Similarly

For final condition;

No. of turns (N_2) = 100

Resistance (R_2) = 50Ω

Now, current sensitivity of first coil is,

$$\left(\frac{\alpha}{I}\right)_1 = \frac{BN_1A}{k}$$

Also, current Sensitivity of second coil is;

$$\left(\frac{\alpha}{I}\right)_2 = \frac{BN_2A}{k}$$

Then,

$$\frac{\left(\frac{\alpha}{I}\right)_2}{\left(\frac{\alpha}{I}\right)_1} = \frac{\frac{BN_2A}{k}}{\frac{BN_1A}{k}} = \frac{N_2}{N_1} = \frac{100}{50} = 2$$

∴ The current sensitivity will increase by 2 times.

Again, voltage sensitivity of first coil is:

$$\left(\frac{\alpha}{V}\right)_1 = \frac{BN_1A}{k \times R_1}$$

Also, voltage sensitivity second coil:

$$\left(\frac{\alpha}{V}\right)_2 = \frac{BN_2A}{k \times R_2}$$

Then;

$$\frac{\left(\frac{\alpha}{V}\right)_2}{\left(\frac{\alpha}{V}\right)_1} = \frac{N_2}{R_2} \times \frac{R_1}{N_1} = \frac{100}{50} \times \frac{10}{50} = \frac{2}{5}$$

Hence, the voltage sensitivity will increase by $\frac{2}{5}$ times.

80. **2072 Set E Q.No. 9c** **A 60 cm long wire of mass 10 g is suspended horizontally in a transverse magnetic field of flux density 0.4T through two springs at its two ends. Calculate the current required to pass through the wire so that there is zero tension in the springs.** **[4]**

Solution

Given,

Length of wire (l) = 60 cm = 0.6 m

Mass of wire (m) = 10g = 10×10^{-3} kg

Magnetic flux density (B) = 0.4 T

Current in the wire (I) = ?

For no tension in the wire, the weight of wire must be equal to the magnetic force i.e.,

Weight of wire = Magnetic force

or, $mg = BIl$

or, $10 \times 10^{-3} \times 10 = 0.4 \times I \times 0.6$

or, $0.1 = 0.24\, I$

or, $I = \frac{0.1}{0.24}$

$\therefore$ $I = 0.42$ A

81. **2071 Set C Q.No. 9 b** **A horizontal straight wire of mass 0.12 gm and length 10cm is placed perpendicular to a uniform horizontal magnetic field of flux density 0.6T. If the resistance per unit length of the wire is 3.8Ωm⁻¹ calculate the potential difference that has to be applied between the end of the wire to make it just self supporting.** **[4]**

Solution

Length of wire (l) = 10 cm = 0.1m

Mass of wire (m) = 0.12 gm = 0.12×10^{-3} kg

Magnetic flux density (B) = 0.6 T

Resistance of wire (R) = $3.8 \times 0.1\ \Omega = 0.38\ \Omega$

p.d. between ends of wire (V) = ?

We have, for self supporting,

$mg = BIl \sin 90°$

$$0.12 \times 10^{-3} \times 10 = 0.6 \times \frac{V}{R} \times 0.1 \times 1$$

or, $0.12 \times 10^{-2} = 0.06 \times \frac{V}{0.38}$

or, $V = 7.6 \times 10^{-3}$ V

82. **2071 Set D Q.No. 9 a** **A copper wire has 10^{29} free electrons per cubic meter, a cross sectional area of 2mm² and carries a current of 5 A. Calculate the force acting on each electron if the wire is now placed in a magnetic field of flux density 0.15 T which is perpendicular to the wire.** **[4]**

Solution

Given,

No. of free electrons (n) = 1×10^{29} /m³

Cross section area (A) = 2mm² = (2×10^{-6}) m²

Current (I) = 5A

Flux density (B) = 0.15 T

Force on electron (F) = ?

Now,

Drift velocity (V_d) $= \frac{I}{enA}$

$$F = BeV_d = Be\frac{I}{enA} = \frac{BI}{nA} = \frac{0.15 \times 5}{1 \times 10^{29} \times 2 \times 10^{-6}} = 3.75 \times 10^{-24}\ N$$

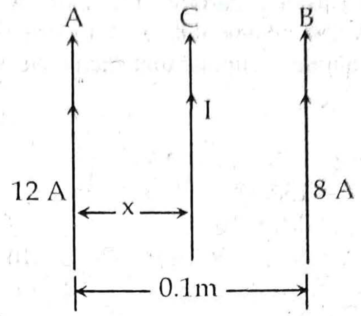
83. **2070 Sup (Set A) Q.No. 9 a** **Two long parallel conductors carry respectively currents of 12A and 8A in the same direction. If the wires are 10cm apart, find where a third parallel wire also carrying a current must be placed so that the force experienced by it will be zero.** **[4]**

Solution

Given,

Current in first wire (I_1) = 12 A
Current in second wire (I_2) = 8A
Distance between wires = 10 cm = 0.1m
Position of third wire = ?
Let us consider A and B are two wires carrying currents 12A and 8A are placed at distance 0.1m part. A third conductor C is placed at x distance from A such that force on it is

$F_1 = \frac{\mu_0 I_1 I}{2\pi x}$ and $F_2 = \frac{\mu_0 I_2 I}{2\pi(0.1 - x)}$



According to question, $F_1 - F_2 = 0$

or, $F_1 = F_2$

$$\frac{\mu_0 I_1 I}{2\pi x} = \frac{\mu_0 I_2 I}{2\pi(0.1 - x)}$$

$$\frac{I_1}{x} = \frac{I_2}{0.1 - x}$$

$$\frac{12}{x} = \frac{8}{0.1 - x}$$

or, $1.2 - 12x = 8x$

or, $1.2 = 20x$

or, $x = \frac{1.2}{20} = 0.06$ m

∴ The third wire is kept at 0.06 m from first wire A such that it experiences no force.

84. **2070 Supp. (Set B) Q.No. 9 b** **An electron of K.E. 10 eV is moving in a circular orbit of radius 11 cm, in a plane at right angles to a uniform magnetic field. Determine the value of the flux density. (mass of an electron = 9.1 × 10^{-31} kg, e = 1.6 × 10^{-19}C)** **[4]**

Solution

Given,
KE of electron (E_k) = 10 eV = 10 × 1.6 × 10^{-19} J
Radius of orbit (r) = 11 cm = 11 × 10^{-2} m
Flux density of magnetic field (B) = ?
Now,

$$E_k = \frac{1}{2}mv^2$$

or, $v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2 \times 10 \times 1.6 \times 10^{-19}}{9.1 \times 10^{-31}}} = 1.87 \times 10^6$ m/sec

Again,

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

or, $B = \frac{mv}{er} = \frac{9.1 \times 10^{-31} \times 1.875 \times 10^6}{1.6 \times 10^{-19} \times 11 \times 10^{-2}} = 9.7 \times 10^{-5}$ T

85. **2070 Set D Q.No. 9 b** **A slab of copper, 2 mm thick and 1.50 cm wide, is placed in a uniform magnetic field of flux density 0.40 T, so that maximum flux pass through the slab. When a current of 75 A flows through it, a potential difference of 0.81 μV is developed between the edges of the slab. Find the concentration of the mobile electrons in copper.** **[4]**

Solution

Given,
Thickness of slab (t) = 2mm = 2 × 10^{-3}m
Width of slab (b) = 1.50cm = 1.5 × 10^{-2}m
Magnetic flux density (B) = 0.40 T
Current in slab (I) = 75 A
Induced voltage (V_H) = 0.81μV = 0.81 × 10^{-6}V
No. of electron (n) = ?

We have,

$$V_H = \frac{IB}{net}$$

or, $n = \frac{IB}{V_H et} = \frac{75 \times 0.40}{0.81 \times 10^{-6} \times 1.6 \times 10^{-19} \times 2 \times 10^{-3}} = 1.15 \times 10^{29}/m^3$

86. **2069 Supp Set B Q.No. 9 c** **2069 (Set A) Q.No. 9b** **2067 Sup Q.No. 9b** **A slice of indium antimonide is 2.5 mm thick and carries a current of 150 mA. A magnetic field of flux density 0.5 T, correctly applied, produces a maximum Hall voltage of 8.75 mV between the edges of the slice. Calculate the number of free charge carriers per unit volume assuming that each have a charge of 1.6×10^{-19} C.** [4]

Solution

Given,

Thickness (t) = 2.5mm = 2.5×10^{-3}m

Current (I) = 150mA = 150×10^{-3}A

Magnetic field (B) = 0.5T

Hall voltage (V_H) = 8.75mV = 8.75×10^{-3}V

Electronic charge (e) = -1.6×10^{-19}C

Electron density (n) = ?

Now,

We have,

$$\frac{E_H}{BJ} = -\frac{1}{ne}$$

or, $\frac{V_H}{t \times B \times J} = -\frac{1}{ne}$ $\quad [\because E = \frac{V}{d}]$

or, $\frac{V_H t^2}{t \times B \times I} = -\frac{1}{ne}$ $\quad [\because J = \frac{I}{A} = \frac{I}{t^2}]$

or, $n = -\frac{BI}{V_H et} = \frac{0.5 \times 150 \times 10^{-3}}{8.75 \times 10^{-3} \times (-1.6 \times 10^{-19}) \times 2.5 \times 10^{-3}} = \frac{75}{35 \times 10^{-22}}$

$\therefore$ n $= 2.14 \times 10^{22}$

Hence, the required number of free charge carriers is 2.14×10^{22} m^{-3}.

87. **2069 Supp Set B Q.No. 9 b** **A copper wire has 1×10^{29} free electrons per cubic meter and crossectional area 2mm^2 carries a current of 6 A. Calculate the force acting on each electron if the wire is now placed in uniform magnetic field of flux density 0.1 T perpendicularly.** [4]

Solution

Given,

No. of free electrons (n) = 1×10^{29} /m^3

Cross section area (A) = 2mm^2 = (2×10^{-6}) m^2

Current (I) = 6A

Flux density (B) = 0.1 T

Force on electron (F) = ?

Now,

Drift velocity (V_d) $= \frac{I}{enA}$

$$F = BeV_d = Be\frac{I}{enA} = \frac{BI}{nA} = \frac{0.1 \times 6}{1 \times 10^{29} \times 2 \times 10^{-6}} = 3 \times 10^{-24} \text{ N}$$

88. **2069 (Set B) Q.No. 9a** **An alpha particle makes a full rotation in a circle of radius 1.0 meter in 2.0 sec. Calculate the value of magnetic field induction at the centre of the circle. ($\mu_0 = 4\pi \times 10^{-7}$H m^{-1})** [4]

Solution

Given,

Charge of α particle (q) = 2e

Time (t) = 2.0 sec

Radius (r) = 1.0m

Magnetic induction at centre (B) = ?

We have,

$$B = \frac{\mu_0 I}{2r} = \frac{\mu_0}{2r} \cdot \frac{q}{t} = \frac{\mu_0 2e}{2r\,t} = \frac{4\pi\times10^{-7}\times2\times1.6\times10^{-19}}{2\times2\times1} = 10^{-25}\ T$$

89. **2069 (Set A) Old Q.No. 7b A copper wire 28m long is wound into a flat circular coil 8.0cm in diameter. If the current of 4.50 A flows through the coil, what is the magnetic induction at the centre?** **[1+2+1]**

Solution

Given,
Length of copper wire (l) = 28 m
Diameter of circle (d) = 8.0 cm = 0.08 m
Current (I) = 4.5 A
Magnetic field intensity (B) = ?
Now,
Length of circumference

$$C = \pi . d = \frac{22}{7} \times 0.08 = 0.251\ m$$

$$\text{No. of turns of coil (N)} = \frac{l}{c} = \frac{28}{0.251} = 112$$

$$\text{Then, } B = \frac{\mu_0 NI}{2r} = \frac{4\pi \times 10^{-7} \times 112 \times 4.5}{2 \times 0.04} = 7.8 \times 10^{-3}\ T$$

90. **2068 Q.No. 9 b A coil consisting of 100 circular loops with radius 0.60m carries a current of 5 A. At what distance from the center, along the axis, the magnetic field of magnitude 1/8 as great as it is at the center? [4]**

Solution

Given,
No. of circular loops (N) = 100
Radius (a) = 0.6m
Current (I) = 5ampere
Now, we have,

$$\text{Magnetic field at the centre} = \frac{\mu_o NI}{2a}$$

Also;

$$\text{Magnetic field at distance x from the centre} = \frac{\mu_o NIa^2}{2(a^2 + x^2)^{3/2}}$$

According to the question;

$$\frac{\mu_o NIa^2}{2(a^2 + x^2)^{3/2}} = \frac{1}{8} \times \frac{\mu_o NI}{2a}$$

or, $8a^3 = (a^2 + x^2)^{3/2}$

or, $(2a)^3 = \left(\sqrt{a^2 + x^2}\right)^3$

or, $2a = \sqrt{a^2 + x^2}$

or, $2\times0.6 = \sqrt{0.36 + x^2}$

or, $x^2 = 1.08$

$\therefore$ $x = 1.04m$

Hence, the required distance is 1.04m.

91. **2068 Can. Q.No. 9b A long wire carrying a current of 10 A is placed perpendicular to magnetic field of flux density 5 Tesla. Calculate the force acting on 2m of the wire.** **[4]**

Solution

Given,
Current (I) = 10A
Magnetic field (B) = 5Tesla
Length (l) = 2m
Force (F) = ?

We have,

$F = BIl\sin 90° = 5 \times 10 \times 2 \times 1 = 100N$

Hence, the required force is 100N.

92. **2065 Q.No. 7 b** **A wire carrying current of 10A and 2 m in length is placed in a field of flux density 0.34 Tesla. What is the force on the wire if it is placed at 60° to the field?**

Solution

Given,

Current (I) = 10A

Length (l) = 2m

Magnetic field (B) = 0.34T

Angle (θ) = 60°

Force (F) = ?

Now, we have;

$F = BIl \sin\theta$

$= 0.34 \times 10 \times 2 \times \sin 60°$

$\therefore F = 5.88N$

Hence, the required force is 5.88 N.

Chapter 2: Magnetic Properties of Matters

Short Answer Questions

1. 2075 GIE Q.No. 1e | 2074 Set A Q.No. 1d **Why is soft iron preferred for making the core of a transformer?** [2]

The soft iron has narrow hysterisis loop and hence low coercivity and high remanence which means that it can be easily magnetized and demagnetized. That is why, soft iron is preferred to make core of transformer of high efficiency.

2. 2075 Set B Q.No. 1e **What is the significance of the area of a hysteresis loop?** [2]

A broad hysteresis loop with high values of retentively and coercivity is characteristic of suitable material for a permanent magnet as a greater work must be done to change its magnetization i.e. more energy is required to damage its magnetic properties. For example, steel.

3. 2074 Supp Q.No. 1d **Permanent magnets are made of steel. Why?** [2]

The shape and size of hysteresis loop is characteristic of each magnetic material. A broad hysteresis loop with high values of retentivity and coercive force is characteristic of suitable material for a permanent magnet as a greater work must be done to change its magnetization. This property is observed in steel and so, steel is used to make permanent magnets. However, a material having narrow hysteresis loop is suitable for transformer cores which undergoes many cycles of magnetization. Soft iron has smaller hysteresis loop, it has very low coercivity and high remanence which means that it can be easily magnetized and demagnetized. So, soft iron core is used in transformer core as the loss of energy is less and the efficiency of transformer is higher.

4. 2074 Set A Q.No. 1c **What is angle of dip? How is it related with components of earth's magnetic field?** [2]

Angle of Dip: The angle made by a freely suspended magnet or magnetic needle with horizontal component of earth magnetic field at a place is called angle of dip. It is denoted as δ and given by

$$\tan\delta = \frac{V}{H};$$

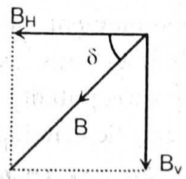
where V and H are vertical and horizontal components of earth magnetic field respectively. If $V = H$, $\delta = 45°$.

5. 2073 Supp Q.No. 1c | 2069 (Set A) Q.No. 1d **Steel is used in making permanent magnets where as soft iron is preferred for making the core of transformer. Why?** [2]

Please refer to 2074 Supp Q.No. 1d

6. 2073 Set D Q.No. 1a **How do you expect about the directions of horizontal and vertical components of earth's magnetic intensity at pole and at equator? Give justification in terms of angle of dip.** [2]

The horizontal component (B_H) and vertical component (B_v) of earth magnetic field in terms of total earth magnetic filed (B) and dip angle δ are given as;



$B_H = B\cos\delta$ ... (i)

$B_V = B\sin\delta$ ... (ii)

At equator, $\delta = 0°$, $B_H = B$; maximum value

$B_V = 0$; minimum or zero

At pole; $\delta = 90°$, $B_H = 0$; minimum or zero

$B_V = B$; maximum value.

This shows that the horizontal component of earth magnetic field is maximum at equator and minimum at pole while vertical component is maximum at pole and minimum at equator.

7. 2072 Supp Q.No. 1d | 2071 Set D Q.No. 1 d **Why should the permeability of a paramagnetic material be expected to decrease with increasing temperature?** [2]

The degree to which the magnetic lines of force can penetrate the magnetic substance placed inside to magnetizing field is called permeability of that substance. The permeability (μ) of the substance is given as $\mu = \frac{B}{H}$, where B is magnetic induction and H is magnetizing field. When the temperature of paramagnetic material increased, the alignment of molecular magnet disturbed and the value of magnetic induction B decreases as a result, μ also decrease.

8. 2072 Set C Q.No. 1c What is retentivity and coercivity of a ferromagnetic material? [2]

Retentivity: The induced magnetic field in the ferromagnetic material at which the magnetizing field is reduced to zero is called retentivity or remanance of ferromagnetic material. In the given figure of hysteresis loop, OR or OE at which external magnetic field or magnetising field is zero but induced magnetic field is not zero. So, OR or OE is the retentivity.

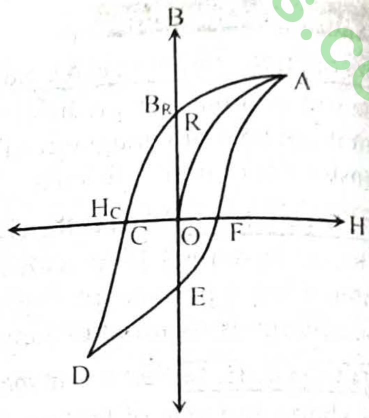


Fig: Hysteresis Loop

Coercivity: The coercivity is the reverse magnetic field to make the induced magnetic field zero of ferromagnets. In the given figure, OC = H_C is the coercive force or coercivity.

9. 2072 Set D Q.No. 1d Define angle of dip. What will be its value at a place where the horizontal and vertica components of earth's magnetic field are equal? [2

Please refer to 2074 Set A Q.No. 1c

10. 2071 Supp Q.No. 1e What is the role of hysteresis loop in choosing a material for making permanen magnets? [2

Please refer to 2075 Set B Q.No. 1e

11. 2070 Sup (Set A) Q.No. 1 d Distinguish between dia and para magnetic substances on the basis o susceptibility. [2

The magnetic susceptibility of a magnetic material is defined as the ratio of the intensity o magnetization (I) to the strength of magnetizing field (H). It is denoted by χ and is given b $\chi = \frac{I}{H}$.

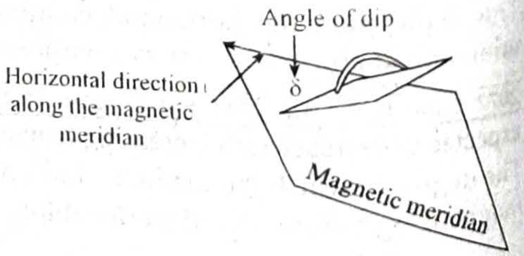
The magnetic susceptibility of a diamagnetic substance is small and negative, paramagnetic materia is small and positive while that of ferromagnetic material is very high and positive.

12. 2070 Set D Q.No. 1 c The magnetic susceptibility of a paramagnetic material is quite strongly temperatur dependent, but that of diamagnetic material is nearly independent of temperature. Why? [2

The magnetic susceptibility of magnetic material depends upon the magnetic moments. Th paramagnetic materials have permanent magnetic moment whereas the diamagnetic materials hav zero magnetic moment. In paramagnets, the alignment of magnetic moment gets disturbed due t increase in temperature. As result, the paramagnet loses its magnetic properties. Due to this reaso the magnetic susceptibility of a paramagnetic material is quite strongly temperature dependent, bu that of diamagnetic material is nearly independent of temperature.

13. 2069 Supp Set B Q.No. 1 e Define an angle of dip. What will be its value at the pole of the earth? [2

The angle made by a freely suspended magnet or magnetic needle with horizontal component of earth magnetic field at a place is called angle of dip. The resultant magnetic field is along the inclined direction of the magnet so the angle of dip is the angle between the resultant field and the horizontal. It is denoted by δ. At equator, the value of angle of dip is zero and the angle of dip at poles is 90°. Thus, value of angle of dip increases from equator (where it's value is zero) to poles.



14. 2068 Old Q.No. 8 a XI **What are the characteristics of a fero-magnetic substance?** [2]

Ferromagnetic substances: The substances which are strongly attracted towards the magnet are called ferromagnetic substances. For e.g. iron, cobalt, gadolinium, and their alloys such as gadolinium are ferromagnetic substances.

Properties of Ferromagnetic substances:

The properties of ferromagnetic substances are similar to that of paramagnetic substances but are exhibited in a large scale.

i. These substances are strongly attracted by a magnet. This is due to the reason that when a ferromagnetic material is placed inside a magnetic field, it gets magnetized strongly in the direction of the magnetic field.

ii. In a non uniform magnetic field, ferromagnetic substance moves from weaker part of the magnetic field to stronger part.

iii. When a rod of a ferromagnetic substance is freely suspended in a uniform magnetic field, it rotates and aligns itself parallel to the applied field.

iv. The relative permeability of the ferromagnetic substance is much greater than 1.

v. The intensity of magnetization of ferromagnetic substance has positive value much greater than 1.

vi. The susceptibility of a ferromagnetic substance has a large positive value because $\chi = I/H$ and I has large positive value.

vii. The susceptibility of the ferromagnetic substance decreases with a rise of temperature. For i.e., the ferromagnetism decreases. At a critical temperature called Curie point, all the ferromagnetic substances become paramagnetic.

15. 2068 Q.No. 1 c **A permanent magnet can be used to pick up a string of nails, tacks or paper clips, even though these are not magnets by themselves. How can this be?** [2]

When a magnet is taken near a string of nails, tacks or paper clips, they get magnetized due to the magnetizing field of permanent magnet. The magnetic field produced in opposite direction in the magnetic material. Hence, the magnetic material like string of nail, paper clip are attracted by a permanent magnet, even through these are note magnets themselves.

16. 2068 Can. Q.No. 1e 2063 Q.No. 8 a **Above curie temperature a ferromagnetic material becomes paramagnetic. Why?** [2]

According to the Curie's law, the magnetic susceptibility (χ) of paramagnetic material is inversely proportional to its absolute temperature (T) i.e., $\chi \propto \frac{1}{T}$. The susceptibility of ferromagnetic material decreases with the rise of temperature in a complicated manner. A ferromagnetic material starts behaving as a paramagnetic material at a certain temperature which is called Curie temperature. Due to increase in temperature, the alignment of molecular magnet in the magnetic domain distributed and they lose their magnetic properties. Above curie temperature, the alignment of domain is completely random and the ferromagnetic substance becomes paramagnet.

17. 2067 Sup Q.No. 1e **Permanent magnets are made of steel while the core of transformer is made of soft iron. Why?** [2]

Please refer to 2074 Supp Q.No. 1d

18. 2067 Q.No. 1c **Why does a magnet lose its magnetism when heated to high temperature?** [2]

When a magnet is heated, due to thermal energy, the tiny molecular magnet gains kinetic energy and orients itself in any direction. As temperature increases up to the melting point of the material of the magnet, the orientation is completely random and it completely loses its magnetic properties and hence not retains its magnetism.

19. 2066 Old Q.No. 8 a **The angle of dip in Britain is greater than that in Kathmandu. Why?** [2]

The angle made by a freely suspended magnet or magnetic needle with horizontal component of earth magnetic field at a place is called angle of dip. It is denoted by δ. At equator, the value of angle of dip is zero and the angle of dip at poles is 90°. Thus, value of angle of dip increases from equator (where it's value is zero) to poles. Kathmandu lies near to equator than the Britain, so the angle of dip in Britain is greater than that in Kathmandu.

20. 2064 Q.No. 8 a **Why does a bar magnet not retain its magnetism when it is melted?** [2]

Please refer to 2067 Q.No. 1c

21. 2059 Q.No. 8 c **How does dip vary from place to place on earth's surface?** [2]

Please refer to 2069 Supp Set B Q.No. 1 e

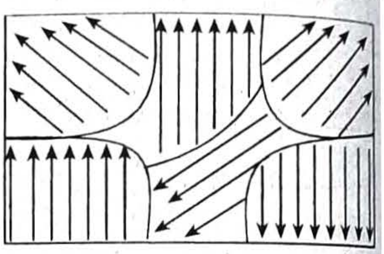
22. 2058 Q.No. 8 c **Define angle of dip and angle of declination at a place.** [2]

The angle made by a freely suspended magnet or magnetic needle with horizontal component of earth magnetic field at a place is called angle of dip. The value of this angle varies from zero at the equator to 90° at the geomagnetic pole. The angle of declination is the angle between the magnetic meridian and the geographic meridian.

23. 2057 Q.No. 8 b **What are magnetic domains?** [2]

The atoms of a ferromagnetic material possess non-zero magnetic moment. According to atomic view of magnetism, an atom acts as a small magnet due to the orbital and spinning motion of its electrons. In small regions, there are large numbers of atoms.

These small regions in which all-atomic magnets align along same direction and have very strong magnetism inside the ferromagnetic material are called magnetic domains. There are very large numbers of domains, which align along various directions. Hence, net magnetic moment is zero but inside the domains there exist strong magnets.



Magnetic domain

24. 2057 Q.No. 8 c **What is angle of dip? How does it vary from the equator to the poles?** [2]

Please refer to 2069 Supp Set B Q.No. 1 e

Long Answer Questions

25. 2076 Set C Q.No. 5c **Define angle of dip. If δ is the true dip at a place, δ_1 and δ_2 are the apparent dips observed in two vertical planes at right angles to each other at that place, then prove the relation, $\cot^2\delta = \cot^2\delta_1 + \cot^2\delta_2$.** [4]

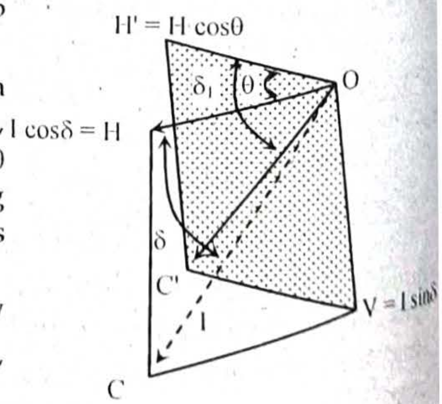
Angle of Dip: The angle made by a freely suspended magnet or magnetic needle with horizontal component of earth magnetic field at a place is called angle of dip. It is denoted as δ and given by

$$\tan\delta = \frac{V}{H};$$

where V and H are vertical and horizontal components of earth magnetic field respectively.

The angle of dip measured by keeping the dip circle in magnetic meridian is called true angle of dip.

The angle of dip at a place measured without bringing the dip circle in the magnetic meridian is called apparent dip.



Let OVCH represents the magnetic meridian & the shaded area OH'C'V represent a plane which is not in magnetic meridian, obtained after rotation of the OVCH plane through an angle θ along the vertical axis OV, the resulted intensity I acts along the OC and makes an angle δ with the horizontal line OH. This angle δ is the true dip at the plane.

In figure, OH represents the horizontal component and OV represents the vertical component of I, so that, $H = OH = I\cos\delta$ and $V = OV = I\sin\delta$.

After rotation of the plane to the position OVC'H', the angle made by the resultant intensity OC' with the horizontal line OH' is δ_1. This angle δ_1 is called apparent dip at that plane. For the new plane, OH' represents the horizontal component and OV represents the vertical component of I, so that, $OH' = H\cos\theta$ and $OV = I\sin\delta$. Now, from right angled $\Delta OC'H'$,

$$\tan\delta_1 = \frac{C'H'}{OH'} = OV/OH' = I\sin\delta / H\cos\theta$$

But, we have, $H = I \cos\delta$

So, $\tan\delta_1 = I \sin\delta / I \cos\delta \cos\theta = \tan\delta/\cos\theta$

or, $1/\tan^2\delta_1 = \cos^2\theta/\tan^2\delta$ ... (i)

Let the plane OVC'H' is rotated through an angle 90° from its position.

Suppose, at that place, angle of apparent dip is δ_2, so that

$\tan\delta_2 = \tan\delta/\cos(90+\theta) = \tan\delta/-\sin\theta$

or, $1/\tan^2\delta_2 = \sin^2\theta/\tan^2\delta$ ... (ii)

Now adding (i) and (ii) we get,

$1/\tan^2\delta_1 + 1/\tan^2\delta_2 = \cos^2\theta/\tan^2\delta + \sin^2\theta/\tan^2\delta$

or, $1/\tan^2\delta_1 + 1/\tan^2\delta_2 = (\cos^2\theta + \sin^2\theta)/\tan^2\delta = 1/\tan^2\delta$

$\therefore \cot^2\delta_1 + \cot^2\delta_2 = \cot^2\delta$ **Proved**

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26. 2074 Set B Q.No. 5c Define permeability and susceptibility of magnetic materials. Derive a relation between them. [4]

Permeability (μ): The degree to which the magnetic lines of force can penetrate in a substance placed in magnetising field is called the permeability of the substance. It is a property of magnetic substance. It is also defined as the ratio of the magnetic induction to the strength of magnetizing field. It is denoted by μ. By definition, $\mu = B/H$, where B is value of magnetic induction and H is the value of magnetizing field and value of μ in free space is $\mu_0 = 4\pi \times 10^{-7}\ WbA^{-1}m^{-1}$

Relative Permeability (μ_r): It is defined as the ratio of the permeability of a medium to that in vacuum. So, by definition, $\mu_r = \mu/\mu_0$. Since, it is a pure ratio, it has no unit.

Magnetic Susceptibility(χ): The magnetism induced in a material when it is placed in a magnetic field depends upon the magnetising field and nature of the material. Thus, when two identical pieces of the same volume and size of different materials are placed in the magnetising field H, they would be magnetized to different extents.

This property of the magnetic substance also defined as the ratio of the intensity of magnetisation to the strength of the magnetising field. It is denoted by χ.

By definition, $\chi = I/H$

Relation between μ_r and χ

When a magnetic material is magnetized in a magnetising field vacuum, the magnetic induction developed in the material is due to the magnetizing field H and induced magnetism in the material i.e., the intensity of magnetization. Hence, the total magnetic induction is the sum of these two quantities and we have,

$B = B_1$ (magnetic field inside material) + B_2 (Magnetic field due to material)

or, $B = \mu_0 H + \mu_0 I$

or, $\mu H = \mu_0 H + \mu_0 I$

or, $\dfrac{\mu}{\mu_0} = 1 + \dfrac{I}{H}$

or, $\mu_r = 1 + \chi$

This is the required relationship between the relative permeability and magnetic susceptibility.

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27. 2073 Set C Q.No. 5b Relate magnetic permeability and susceptibility features of a magnetic material. Can hysteresis curve be drawn in the case of diamagnetic material? Explain on the basis of above features. [4]

First Part: Please refer to 2074 Set B Q.No. 5c

Second Part

No, hysteresis curve cannot be drawn in the case of diamagnetic material because hysteresis is the phenomena of ferromagnetic material which is easily magnetized and demagnetized by external magnetic field. The causes are:

i. The permeability (μ) of diamagnet is less than 1.

ii. The intensity of magnetization has a small negative value.

iii. Susceptibility has value less then one.

iv. They are feebly repelled by magnets.

28. **2072 Set E Q.No. 5c** **What do you mean by true dip and apparent dip? Show that $\cos^2\delta = \cot^2\delta_1 + \cot^2\delta_2$ where symbols have usual meanings.** [4]

Please refer to 2076 Set C Q.No. 5c

29. **2070 Supp. (Set B) Q.No. 5 d** **Prove that $\cot^2\delta = \cot^2\delta_1 + \cot^2\delta_2$, where symbols have usual meanings.** [4]

Please refer to 2076 Set C Q.No. 5c

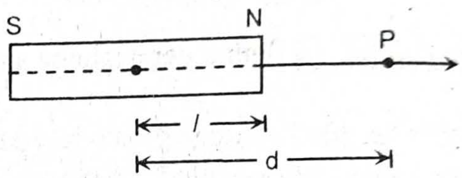
30. **2070 Set C Q.No. 5 b** **Define magnetic susceptibility and relative permeability and establish a relation between them.** [4]

Please refer to 2074 Set B Q.No. 5c

Numerical Problems

31. **2075 Set A Q.No. 9c** **A bar magnet, 10 cm in length, has pole strength of 10 AM. Determine the magnetic field at a point on its axis at a distance of 15 cm from the center of the magnet. ($\mu_0 = 4\pi \times 10^{-7}$ H/m)** [4]

Solution



Given,

Length of bar magnet ($2l$) = 10cm

or, l = 5 cm = 0.05 m

Pole strength (m) = 10Am

Magnetic moment (M) = $m.2l = 10 \times 0.1 = 1$ Am^2

Distance (d) = 15 cm = 0.15 m

Magnetic permeability (μ_0) = $4\pi \times 10^{-7}$ H/m

Magnetic field (B) = ?

We have,

$$B = \frac{\mu_0}{4\pi} \times \frac{2Md}{(d^2 - l^2)^2}$$

$$= \frac{4 \times \pi \times 10^{-7}}{4\pi} \times \frac{2 \times 3 \times 0.15}{(0.15^2 - 0.05^2)^2}$$

$$= \frac{3 \times 10^{-8}}{4 \times 10^{-4}}$$

$$= 7.5 \times 10^{-5} \text{ T}$$

32. **2062 Q.No. 9 b** **The needle of a dip circle shows an apparent dip of 45° in a particular position and 53° when the circle is rotated through 90°. Find the true dip.** [4]

Solution

Given,

Apparent dip at one place (δ_1) = 45°

Apparent dip at another place right angle to the first place (δ_2) = 53°

True value of dip (δ) = ?

If δ be the true value of dip, then, $\cot^2\delta = \cot^2\delta_1 + \cot^2\delta_2$

$$\frac{1}{\tan^2\delta} = \frac{1}{\tan^2\delta_1} + \frac{1}{\tan^2\delta_2} \quad \Rightarrow \frac{1}{\tan^2\delta} = \frac{1}{\tan^2 45^\circ} + \frac{1}{\tan^2 53^\circ}$$

$$\frac{1}{\tan^2\delta} = 1 + 0.57 \quad \Rightarrow \delta = 38.7^\circ$$

Hence, the required true angle of dip is 38.7°.

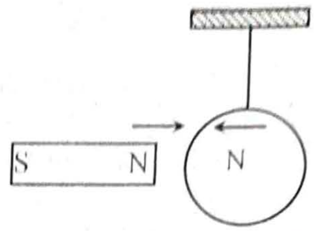
□□□

Chapter 3: Electromagnetic Induction

Short Answer Questions

1. 2076 Set C Q.No. 1e 2070 Set C Q.No. 1 d A copper ring is suspended by a thread in a vertical plane. One end of a magnet is brought horizontally towards the ring. How will the position of the ring be affected? [2]

When a copper ring is suspended in a vertical plane and one end say north pole N of the magnet is brought horizontally towards the ring, the ring will move away from the magnet. This is because if the N pole of magnet is approaching the ring, then face of the ring towards the magnet will become N pole due to current induced in it (Lenz's law) which repels the ring.



2. 2075 Set A Q.No. 1e A bar magnet falls through copper ring. Will its acceleration be equal to 'g'? Justify. [2]

No, the acceleration of a bar magnet will not equal to acceleration due to gravity 'g' when it falls through copper ring. When bar magnet falls through copper ring, at first its acceleration increases due to gravity but after some time, eddy current is produced in the copper ring which opposes the cause of it i.e. motion of magnet and hence its acceleration decreases. After some time it gains steady state velocity.

3. 2075 Set B Q.No. 1f Birds sitting on a high tension line wire fly off when current is switched on. Why? [2]

When a high tension current is switched on, induced current is set up in the body of the birds. The induced currents flow in opposite direction (Lenz's law) through the wings of the birds which produces repulsive force and hence the wings spread and the birds fly away.

4. 2074 Supp Q.No. 1e State and explain Faraday's law of electromagnetic induction. [2]

Faraday's Laws of electromagnetic induction

First law: "Whenever magnetic flux linked with a circuit changes, induced emf is produced. The induced emf lasts as long as the change in the magnetic flux continues". So, first law gives the state in which the induced emf is obtained.

Second Law: "The magnitude of induced emf in a coil (or a conductor) is directly proportional to the rate of change of magnetic flux and number of turns in the coil."

Let ϕ_1 & ϕ_2 be the magnetic flux linked with a coil (or conductor) initially & after time t, then, the rate of change of magnetic flux is

$$\varepsilon = N\frac{\phi_1 - \phi_2}{t} = -N\frac{d\phi}{dt}$$

Thus, Faraday's second law of electromagnetic induction gives the measurement of induced emf.

5. 2074 Set A Q.No. 1e 2072 Set C Q.No. 1d If the number of turns of a solenoid is doubled, keeping the other factors constant, how does the self inductance of the solenoid change? [2]

The self inductance of a solenoid is given by, $L = \mu_0 \frac{N^2}{l} A$, where N is number of turns of solenoid, l is length of solenoid and A be its area of cross section. If the number of turns N is made doubled, then self inductance of solenoid is increased by four times.

6. 2074 Set B Q.No. 1d What are eddy currents? How can these be reduced in a transformer? [2]

When a metallic piece is placed in a changing magnetic field, the induced currents are set up in the metal piece. These currents are called eddy currents or Foucault's currents. The direction of eddy currents is given by Lenz law. Eddy currents produce heat due to which there is loss of power. The eddy currents can be reduced by using laminated sheet of soft iron core of transformer.

7. 2073 Set D Q.No. 1d 2069 Supp Set B Q.No. 1d Lenz law follows the principle of conservation of energy. Explain. [2]

Lenz law & Conservation of Energy: Lenz's Law is an example of the principle of Conservation of Energy. When the magnet is moved towards the coil, it produces induced current in the coil whose direction opposite to the motion of the magnet as given by the Lenz's law. Hence there is a force of repulsion between the magnet and the coil and to overcome this repulsive force, an external work must be done. This work done (mechanical energy) must be converted into electrical energy which is according to the law of conservation of energy. Similar case arises when the magnet is removed away from the coil. That's why, the Lenz's law is in accordance with the law of conservation of energy.

8. **2072 Set C Q.No. 1e A transformer gets heated up while in use. Why?** [2]

A transformer is made up of sheets of the soft iron. When the transformer is in use, the core of transformer gets magnetized and demagnetized with the cycle of a.c. which induces eddy current in the sheet. The circulation of eddy current heats the transformer.

9. **2072 Set D Q.No. 1e Why does acceleration of a magnet falling through a long solenoid decrease?** [2]

If a magnet is dropped through a long solenoid, at first acceleration increases due to gravity but after some time, eddy current is produced in the solenoid which opposes the cause of it (Lenz's law) i.e., motion of magnet and hence its acceleration decreases.

10. **2071 Set C Q.No. 1 d 2067 Q.No. 1d A sheet of copper is placed between the poles of an electromagnet with the magnetic field perpendicular to the sheet. When it is pulled out, a considerable force is required, and the force required increases with speed. Explain.** [2]

When a sheet of copper is placed between the poles of an electromagnet with the magnetic field perpendicular to the sheet and pulled out, eddy currents are produced which also produce the magnetic field. The direction of these current opposes the motion of sheet and a considerable force is required to pull it. When the motion or velocity of sheet increases, the magnetic field produced also increases and more force is required to pull it.

11. **2071 Supp Q.No. 1c A vertical magnetic field is perpendicular to the vertical plane of a loop. When the loop is rotated about a horizontal axis in the plane, the current produced in the loop reverses directions twice per rotation. Explain why there are two reversals for one rotation.** [2]

A vertical magnetic field is perpendicular to the vertical plane of loop. When the loop is rotated about a horizontal axis in a plane, the current produced in a loop reverses twice per rotation due to Fleming's right hand rule. The current produced in half cycle is in one direction and reverses in next half cycle of rotation.

12. **2071 Set D Q.No. 1 e A long, straight conductor passes through the centre of a metal ring, perpendicular to its plane. If the current in the conductor increases, does current get induced in the ring? Explain.**

Yes, when a long straight conductor passes through the centre of a metal ring, perpendicular to its plane and the current through the conductor increases, it increases the magnetic flux linked to the ring (as $B = \frac{\mu_0 I}{2\pi r}$). This change in magnetic flux linked produces an emf and hence current in the ring is produced.

13. **2070 Sup (Set A) Q.No. 1 e Can a transformer be used with dc? Why? Why not?** [2]

A transformer is device for converting ac current at low voltage to high voltage or vice-versa. It works on the principle of mutual induction which is only possible by a.c. but not by d.c.. When primary coil of the transformer is connected to a dc current, this produces constant magnetic flux. Consequently, the flux linked with the secondary coil of the transformer is not changed. If there is no change in magnetic flux, emf is not induced in the secondary coil. That's why a transformer can't be used to change the value of dc voltage.

14. **2070 Supp. (Set B) Q.No. 1 d Pairs of conductors carrying current into or out of the power supply components of electronic equipments are twisted together. Why?** [2]

Pairs of conductors carrying current into or out of the power supply components of electronic equipments are twisted together because this decreases the self induction. The current in every part of coil is equal and opposite in direction. So, the magnetic field around the one part is cancelled by the magnetic field around the opposite part. This self induction becomes minimum and the power loss will be minimum.

15. **2070 Supp. (Set B) Q.No. 1 e Does Lenz law violate principle of conservation of energy? Explain.** [2]

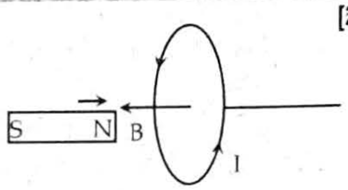
No, Lenz law doesn't violate principle of conservation of energy. Lenz's Law is an example of the principle of Conservation of Energy. When the magnet is moved towards the coil, it produces induced current in the coil whose direction opposite to the motion of the magnet as given by the Lenz's law. Hence there is a force of repulsion between the magnet and the coil and to overcome this repulsive force, an external work must be done. This work done (mechanical energy) must be converted into electrical energy which is according to the law of conservation of energy. Similar case arises when the magnet is removed away from the coil. That's why, the Lenz's law is in accordance with the law of conservation of energy.

16. **2070 Set D Q.No. 1 d A copper ring is held horizontally and a bar magnet is dropped through the ring with its length along the axis of the ring. Will the acceleration of the falling magnet be equal to the acceleration due to gravity? Explain.** **[2]**

✍ If a permanent magnet is dropped down a vertical copper pipe, eddy currents are produced in pipe which opposes the motion of the magnet (by Lenz law) and the speed ultimately decreases. At a certain condition, the weight of the magnet and the upward force become equal and hence attain terminal velocity.

17. **2069 Set A Q.No. 1f State and explain the lenz's law.** **[2]**

✍ Lenz's law states that "the direction of an induced current is such as to oppose the cause producing it." The cause of current may be the motion of a conductor in a magnetic field or it may be change of magnetic flux through a stationary circuit.



Explanation:

Consider a coil to which a magnet with its north pole is moved toward it. The induced emf in the coil will sends current in such a direction in the coil that it will produce magnetic field from right to left so as to oppose (repel) the magnet. When the magnet is moved back, the magnetic field will be produced due to induced current from left to right & the current will flow in the opposite direction. In this way, the induced emf produced in the coil opposed the cause which produced it.

18. **2069 (Set B) Q.No. 1e Explain Faraday laws of electromagnetic induction.** **[2]**

✍ Please refer to 2074 Supp Q.No. 1e.

19. **2069 (Set A) Old Q.No. 1h A bar magnet falls through a metal ring, will its acceleration be equal to 'g'?** **[2]**

✍ Please refer to 2075 Set A Q.No. 1 e

20. **2068 Q.No. 1 d If a permanent magnet is dropped down a vertical copper pipe, it eventually reaches a terminal velocity even if there is no air resistance. Why should this be?** **[2]**

✍ Please refer to 2070 Set D Q.No. 1 d

21. **2068 Can. Q.No. 1d A student asserted that if a permanent magnet is dropped down a vertical copper pipe, it eventually reaches a terminal velocity even if there is no air resistance. Why should this be?** **[2]**

✍ Please refer to 2070 Set D Q.No. 1 d

22. **2066 Q.No. 1e A sheet of copper is placed between the poles of an electromagnet with the magnetic field perpendicular to the sheet. When it is pulled out, a considerable force is required, and the force required increases with speed, why?** **[2]**

✍ Please refer to 2071 Set C Q.No. 1 d

23. **2065 Q.No. 1 e State Faraday's laws of electromagnetic induction.** **[2]**

✍ Please refer to 2074 Supp Q.No. 1e

24. **2064 Q.No. 2 e A transformer cannot be used in dc circuits, why?** **[2]**

✍ Please refer to 2070 Sup (Set A) Q.No. 1 e

25. **2063 Q.No. 1 e 2061 Q.No. 1 e Why can't a transformer be used to step up or down the d.c. voltage?** **[2]**

✍ Please refer to 2070 Sup (Set A) Q.No. 1 e

26. **2063 Q.No. 2 e What is eddy current? Write down its uses.** **[2]**

✍ When a metallic piece is placed in a changing magnetic field, the induced currents are set up in the metal piece. These currents are called eddy currents or Foucault's currents. The direction of eddy currents is given by Lenz law. Eddy currents produce heat due to which there is loss of power which can be reduced by use of laminated core.

Following are some useful uses of eddy currents:

- Eddy current damping
- Induction heating
- Energy meters

- Electromagnetic brakes
- Induction motors.

27. 2062 Q.No. 2 e What are different power losses in a transformer? What measures do you take to minimize these losses? [2]

A practical transformer has efficiency less than one due to following types of power losses:

- **Copper loss:** It can be minimized by taking wires of suitable thickness.
- **Hysteresis loss:** This can be minimized by using core materials having narrow hysteresis loop.
- **Iron (or eddy current) loss:** It can be minimized by using laminated soft iron core.
- **Humming loss:** It can be reduced by using proper materials with low vibration.
- **Flux loss:** It is minimized by designing the core for maximum linkage between the primary and secondary coils.

28. 2059 Q.No. 2 e Two closely wound circular coils have the same number of turns, but one has twice the radius of the other. What is the ratio of self inductances of the two coils? [2]

Since, the self-inductance of a closely wounded circular coil (i.e. toroidal coil) is given by

$$L = \mu_0 N^2 \frac{A}{l} = \mu_o N^2 \frac{(\pi r^2)}{l}.$$

where N is the number of turns, $A = \pi r^2$ is the area of the coil, I is the current flowing in the windings and l is the mean length.

This means, $L \propto r^2$ keeping other parameter constant. This shows that the value of self inductance changes by four times when the radius is doubled. Thus one has twice the radius of the other, the ratio of the self-inductions of two coils is 4:1.

29. 2058 Q.No. 1 e Show that Lenz's law is an example of conservation of energy. [2]

Please refer to 2073 Set D Q.No. 1d

30. 2056 Q.No. 7 e State Lenz's law. [2]

Please refer to 2069 Set A Q.No. 1f

31. 2055 Q.No. 7 c Mention two types of loss in a transformer. [2]

Two types of loss in a transformer are:

a. **Copper Losses:** Energy lost in winding the wire of transformer is known as copper loss. This is due to the resistance R of copper wire, when current flows through these wires, power loss (I^2 R) takes place. This loss appears as heat produced in the primary and secondary coils. Copper losses can be reduced by using thick wires for the windings.

b. **Flux losses:** In actual transformer, the coupling between primary and secondary coils is not perfect. It means the magnetic flux linked with the primary coil is not equal to the magnetic flux linked with the secondary coil. So, certain amount of electrical energy supplied to the primary coil is wasted. It is minimized by designing the core for maximum linkage between the primary and secondary coils.

32. 2053 Q.No. 7 g What is lenz's law? [2]

Please refer to 2069 Set A Q.No. 1f

Long Answer Questions

33. 2076 Set C Q.No. 5d 2075 GIE Q.No. 5d 2067 Sup Q.No. 5c 2064 Q.No. 7 a OR State and explain Faraday's laws of electromagnetic induction and derive an expression for the emf induced in a rectangular coil rotating in a uniform magnetic field. [4]

Faraday's Laws of electromagnetic induction

First law: "Whenever magnetic flux linked with a circuit changes, induced emf is produced. The induced emf lasts as long as the change in the magnetic flux continues". So, first law gives the state in which the induced emf is obtained.

Second Law: "The magnitude of induced emf in a coil (or a conductor) is directly proportional to the rate of change of magnetic flux and number of turns in the coil."

Let ϕ_1 & ϕ_2 be the magnetic flux linked with a coil (or conductor) initially & after time t, then, the rate of change of magnetic flux is

$$\varepsilon = N\frac{\phi_1 - \phi_2}{t} = -N\frac{d\phi}{dt}$$

Thus, Faraday's second law of electromagnetic induction gives the measurement of induced emf.

Second part: Induced EMF in a coil rotating in Magnetic Field:

We consider a rectangular coil of area A and number of turns N is rotating in a magnetic field. The field is provided by two pole pieces N and S of a strong magnet. Let the normal to the plane of the coil makes an angle θ with the direction of magnetic field as shown in figure. The component of field B at right angles to the plane of the coil is B cosθ. The total flux through the coil is

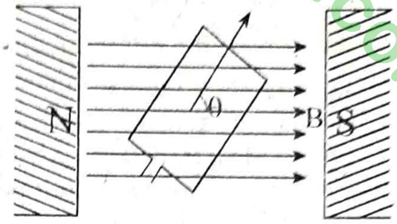


Fig. Induced emf in a rotating coil

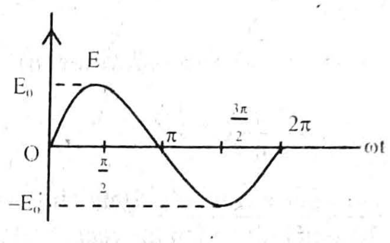
$$\phi = NAB\cos\theta \quad \dots (i)$$

If the coil turns about an axis perpendicular to the field direction with a constant angular velocity ω $(=\frac{\theta}{t})$, then emf induced in the coil is

$$E = -\frac{d\phi}{dt} = -\frac{d}{dt}(NAB\cos\theta) = -NAB\frac{d(\cos\omega t)}{dt}$$

$$= NAB\sin\omega t\frac{d(\omega t)}{dt}$$

$$= NAB\omega\sin\omega t \quad \dots (ii)$$



Therefore, $E = E_o \sin\omega t$,

where, $E_o = \omega NAB$ is the peak value of E.

This sinusoidal varying emf is called induced emf in the coil rotating in the magnetic field.

The instantaneous induced current in the circuit is given by,

$$I = \frac{E}{R} = \frac{E_0\sin\omega t}{R}$$, where R is resistance of the coil

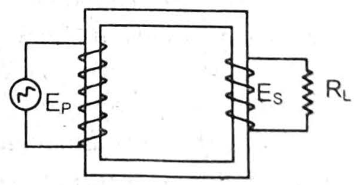
$$\therefore \quad I = I_0\sin\omega t \quad \dots (iii)$$

where $E_0/R = I_0$ is maximum value of the induced current.

The equations (ii) and (iii) are the required equations of the induced emf and induced current in a rotating coil of area A, no. of turns N and rotating in a magnetic field B with speed ω.

34. 2074 Supp Q.No. 5c **Describe the structure and working principle of a transformer. Define the efficiency of a transformer.** **[4]**

Structure and Working Principle of a Transformer: Transformer is a device used to convert low alternating voltage at high current into high alternating voltage at low current and vice versa. The transformer works on the principle of mutual induction i.e. when there is change in the current of the primary coil, magnetic flux linkage with the secondary coil changes and hence induced emf is produced in the secondary coil. There are two types of transformer i.e., step up transformer and step down transformer.



A simple construction of transformer is as shown in above figure. The primary and secondary coils are wounded on a common laminated soft iron core. The coil connected to a.c. is primary coil and coil connected to load is secondary coil. When an a.c. source of emf E_P is connected to primary coil, an alternating current flows through it so that alternating magnetic field is produced and hence magnetic flux linked with secondary coil is changed. This change in magnetic field induces an alternating emf in the secondary coil. Let N_P and N_S be number of turns in primary coil and secondary coil respectively. From Faradays law of electromagnetic induction,

$$E_P = -N_P\frac{d\phi}{dt} \quad \dots (i)$$

The induced emf is secondary is given by

$$E_S = -N_S\frac{d\phi}{dt} \quad \dots (ii)$$

Dividing equation (ii) by (i)

$$\frac{E_S}{E_P} = \frac{N_S}{N_P}$$

where, $\frac{N_S}{N_P} = \sqrt{\frac{L_S}{L_P}}$ = k is called transformation ratio.

where L_S is the self induction for secondary coil and L_P is the self induction for primary coil.

For step down transformer, k < 1 so that $N_S < N_P$ and $E_S < E_P$.

For step up transformer, k > 1 so that $N_S > N_P$ and $E_S > E_P$.

For an ideal transformer, on which there is no loss of energy,

Output power = Input power

$E_S I_S = E_P I_P$

$$\frac{E_S}{E_P} = \frac{I_P}{I_S}$$

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

$$\text{Efficiency of a transformer } (\eta) = \frac{\text{Output power}}{\text{Input power}} \times 100\%$$

$$\text{or, } \eta = \frac{E_S I_S}{E_P I_P} \times 100\%$$

35. 2074 Set A Q.No. 5d **State and explain Faraday's law of electromagnetic induction. Obtain an expression for the emf induced in the rectangular coil rotating in a uniform magnetic field.** [4]

Please refer to 2076 Set C Q.No. 5d

36. 2073 Supp Q.No. 5c **State and explain Faraday's law of electromagnetic induction. Obtain an expression for the emf induced in the rectangular coil moving in the magnetic field.** [4]

Please refer to 2076 Set C Q.No. 5d

37. 2073 Set D Q.No. 5c **Explain how the concept of self and mutual inductances are used in the working principle of a transformer.** [4]

Self inductance is the property of a coil by which it opposes the growth or decay of the current flowing through it. In the given figure, when the switch is on, the current in the coil increasing due to which flux linkage around the coil also increases, as a result, induced emf is step up in the coil. The direction is such that it opposes the growth of current in the coil. When the key is off, current in the coil starts decreasing due to which magnetic flux around coil changes and induced emf is set up that oppose the decay of current. Such property of coil is called self induction.

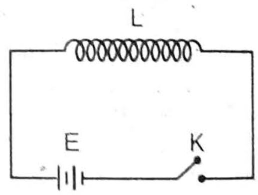


Fig: Diagram of self inductance

Mutual induction is the phenomenon of inducing emf in a given coil due to rate of change of current or change in magnetic flux linked with the near of coil.

In the figure, primary coil P is connected with battery and secondary coil S is connected to a galvanometer. When the key is pressed, current increases in the coil and magnetic field around primary coil also increases. As a result, magnetic flux linked with secondary coil changes. Due to this, emf is induced in secondary coil and current flows through coil. This phenomenon of inducing emf is called mutual induction.

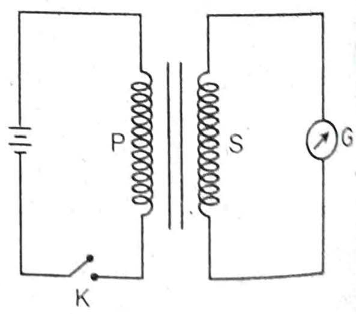


Fig: Mutual induction between coil

Structure and Working Principle of a Transformer: Please refer to 2074 Supp Q.No. 5c

38. 2072 Supp Q.No. 5c **Describe the phenomena of self and mutual induction. Describe the construction and explain the action of a transformer.** [4]

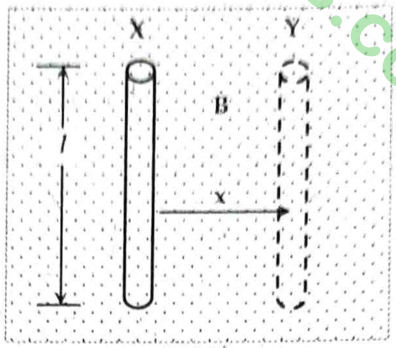
Please refer to 2073 Set D Q.No. 5c

39. 2072 Set C Q.No. 5d **What is Lenz's law? Deduce an expression for the emf induced in a straight conductor moving in a uniform magnetic field.** [4]

Lenz's Law: Please refer to 2069 Set A Q.No. 1f

Second part:

Let us consider a uniform conducting rod of length l is placed inside the magnetic field of flux density B in a direction perpendicular to the direction of magnetic field. Suppose, this conductor moves from X to Y covering a distance x. Then, total flux linkage in the conductor change by



$\phi = B.A = B.l.x$

Now, from Faraday's law of electromagnetic induction,

$$E = \frac{d\phi}{dt} = \frac{d(B.l.x)}{dt} = B.l.\frac{dx}{dt} = B.l.v$$

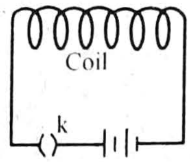
$\therefore$ $E = B.l.v$

This is required expression for emf induced in a conductor moving in a magnetic field.

40. **2071 Set C Q.No. 5 d** **Define self inductance. An inductor having self inductance L is used in a ac power supply. Calculate the energy stored in it.** **[4]**

Self inductance: Self inductance is the property of a coil by virtue of which it opposes the growth or decay of the current flowing through it.

Consider a coil connected to a battery through a key (k) as shown in figure. As the key is on, current in the coil starts increasing. Due to it, the magnetic field and hence flux linkage around the coil also increases. As a result, induced e.m.f. is set up in the coil. According to Lenz's law, the direction of induced e.m.f. is such that it opposes the growth of current in the coil. This delays the current to acquire the maximum value.



When the key (k) is off, the current in the coil starts decreasing. So, the magnetic flux linked with the coil decreases. As a result of this change in magnetic flux, induced e.m.f. is set - up in the coil itself. According to Lenz's law, the direction of induced e.m.f. is such that it opposes the decay of current in the coil. This delays the current to acquire minimum or zero value.

Such property of the coil which opposes the growth or decay of the current is called self induction. It is also known as inertia of elasticity as it opposes the growth or decay of the current in the circuit.

Coefficient of Self Induction or Self Inductance

Let I be the current flowing through a coil, then the magnetic flux (ϕ) linked with the coil is found to be proportional to the strength of the current (I).

i.e., $\phi \propto I$

or, $\phi = LI$

where L is proportionality constant called coefficient of self induction or self inductance.

Energy Stored in an Inductor

Let us consider an inductor of inductance L having initially zero current. It is assumed that an inductor has zero resistance so that there is no dissipation of energy within the inductor. Let I be the current at any instant of time so that dI/dt is the rate of change of current. Here, current is increasing. The voltage between the two terminals of the inductor at this instant is, V = L dI/dt and the rate P at which energy is being delivered to the inductor is given by,

$$P = VI = LI\frac{dI}{dt}$$

The energy supplied to the inductor in small amount of time is small which is written as

$$dU = P\,dt$$
$$= LI\frac{dI}{dt}dt$$
$$dU = LI\,dI \quad \text{.... (i)}$$

To obtain total amount of energy stored in the inductor, we have to integrate it from 0 to I_0.

i.e., $U = \int_0^{I_0} L.I.dI$

or, $U = L\int_0^{I_0} I\,dI$

or, $U = L\left[\frac{I_0^2}{2}\right]_0^I = \frac{1}{2}L\,I_0^2$

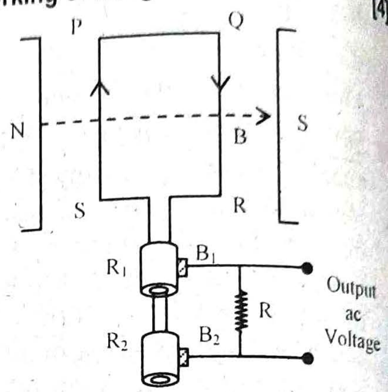
$\therefore$ Total energy stored in an inductor, $U = \frac{1}{2}L\,I_0^2$

41. 2070 Sup (Set A) Q.No. 5 d **What is meant by self inductance? Derive an expression for energy stored in an inductor.** **[4]**

✍ Please refer to 2071 Set C Q.No. 5 d

42. 2070 Supp. (Set B) Q.No. 5 c 2068 Q.No. 5b **Describe the principle and working of a.c. generator.** **[4]**

✍ **A.C. Generator (Alternator / A.C. Dynamo)**



An electrical machine used to convert mechanical energy into electrical energy is known as A.C. generator.

Principle: It works on the principle of electromagnetic induction i.e., when a coil is rotated in a uniform magnetic field, an e. m. f. is induced in it.

Construction: The a. c. generator consists of following components as shown in Fig. below.

i. **Armature:** Armature coil (PQRS) consists of a large number of turns of insulated copper wire wound over soft iron core of area A and N turns.

ii. **Strong field magnet:** The armature is rotated in a strong uniform magnetic field provided by powerful permanent magnet NS. The axis of rotation is perpendicular to the field.

iii. **Slip rings:** The two ends of the armature coil are connected to two brass slip rings R_1 and R_2. These rings rotate along with the armature coil.

iv. **Brushes:** The two carbon brushes (B_1 and B_2) are pressed against the slip rings. The brushes remain fixed while slip rings rotate along with the armature. These brushes are connected to the load through which output is obtained.

Working: When the armature coil PQRS rotates in the magnetic field provided by the strong field magnet, it cuts the magnetic lines of force. The magnetic flux linked with the coil changes due to the rotation of the armature and hence e.m.f. is induced in the coil. The direction of induced e.m.f. or the current in the coil is determined by Fleming's right hand rule.

The current flows out through the brush B_1 in one direction of half of the revolution and through the brush B_2 in the next half revolution in the reverse direction. This process is repeated. Therefore, e.m.f. produced is of alternating nature.

Theory: Consider the plane of the coil to be perpendicular to the magnetic field $\vec{B}$. Let the coil be rotated anticlockwise with a constant angular velocity ω. Then, the angle between the normal to the coil and $\vec{B}$ at any time t is given by, $\theta = \omega t$. The component of magnetic field normal to the plane of the coil = $B\cos\theta = B\cos\omega t$.

Magnetic flux linked with a single coil = $A.B\cos\omega t$, where A is area of the coil. So, magnetic flux linked with N coils, $\phi = NBA\cos\omega t$.

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

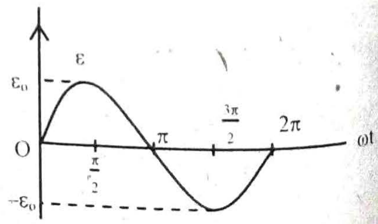
$$E = -\frac{d\phi}{dt} = -\frac{d(NBA\cos\omega t)}{dt}$$

$$= -NBA\frac{d}{dt}(\cos\omega t) = NBA(\sin\omega t)\,\omega$$

$$E = NBA\,\omega\sin\omega t \qquad \dots\text{(i)}$$

The magnitude of induced e.m.f. will be maximum i.e., (E_0), when $\sin\omega t = 1$, so,

$$E_0 = NBA\omega$$



Thus, Eq. (v) becomes,

$$E = E_0\sin\omega t \qquad \dots\text{(ii)}$$

Instantaneous current in the circuit is given by,

$I = \frac{E}{R} = \frac{E_0 \sin \omega t}{R}$, where R is resistance of the coil

$\therefore \quad I = I_0 \sin \omega t$

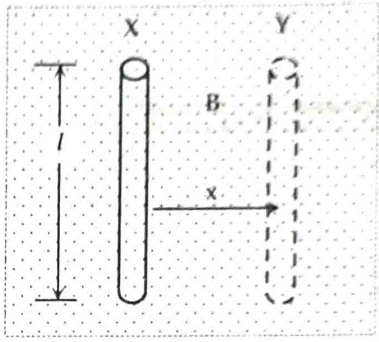
where $E_0/R = I_0$ is maximum value of current.

when the coil is rotated from its position at right angle to the magnetic field through 180°, the induced e.m.f. and current increases from zero to maximum (E_0) and then decreases from maximum to zero in the same direction. When the coil is further rotated through the next 180°, the e.m.f. and current rises from zero to maximum and then decreases from maximum to zero in the opposite direction shown in figure.

43. 2069 (Set A) Old Q.No. 7a **What do you mean by electromagnetic induction? Obtain an expression for the e.m.f. induced in the conductor moving in the magnetic field.** [1+3]

The process of induction of emf in a coil when the magnetic flux linkage in a coil changed is called electromagnetic induction.

Let us consider a uniform conducting rod of length l is placed inside the magnetic field of flux density B in a direction perpendicular to the direction of motion or rod. Suppose, this conductor moves from X to Y covering a distance x. Then, total flux linkage in the conductor changes by



$\phi = B.A = B.l.x$

Now, from Faraday's law of electromagnetic induction,

$$E = \frac{d\phi}{dt} = \frac{d(B.l.x)}{dt} = B.l.\frac{dx}{dt} = B.l.v$$

$\therefore \quad E = B.l.v$

This is required expression for emf induced in a conductor moving in a magnetic field.

44. 2068 Can. Q.No. 5b **State and explain Faraday's laws of electromagnetic induction. Deduce an expression for the induced emf in a coil rotating uniformlyin a uniform magnetic field.** [4]

Please refer to 2076 Set C Q.No. 5d

45. 2068 Old Can. Q.No. 7a **State Faraday's law of electromagnetic induction. Derive an expression for the e.m.f. induced in a straight conductor moving at right angle to the direction oif a uniform magnetic field.** [1+3]

Faraday's Laws of electromagnetic induction: Please refer to 2076 Set C Q.No. 5d

Second part: Please refer to 2072 Set C Q.No. 5d

46. 2067 Q.No. 5c **State Faraday's laws of electromagnetic induction. Derive an expression for induced emf in a coil rotating in a magnetic field.** [4]

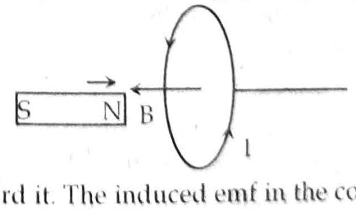
Please refer to 2076 Set C Q.No. 5d

47. 2066 Supp Q.No. 7a OR **State Faraday's laws of electromagnetic induction. Deduce an expression for induced emf in a coil rotating in a magnetic field.** [1+3=4]

Please refer to 2076 Set C Q.No. 5d

48. 2062 Q.No. 7 a OR **State Lenz's law and explain how this law leads to the conservation of energy principle.** [4]

Lenz's law: Lenz's law states that "the direction of an induced current is such as to oppose the cause producing it." The cause of current may be the motion of a conductor in a magnetic field or it may be change of magnetic flux through a stationary circuit.



Explanation:

Consider a coil to which a magnet with its north pole is moved toward it. The induced emf in the coil will sends current in such a direction in the coil that it will produce magnetic field from right to left so as to oppose (repel) the magnet. When the magnet is moved back, the magnetic field will be produced due to induced current from left to right & the current will flow in the opposite direction. In this way, the induced emf produced in the coil opposed the cause which produced it.

Lenz law & Conservation of Energy: Lenz's Law is an example of the principle of Conservation of Energy. When the magnet is moved towards the coil, it produces induced current in the coil whose direction opposite to the motion of the magnet as given by the Lenz's law. Hence there is a force of repulsion between the magnet and the coil and to overcome this repulsive force, an external work must be done. This work done (mechanical energy) must be converted into electrical energy which is according to the law of conservation of energy. Similar case arises when the magnet is removed away from the coil. This proves that the Lenz's law leads to the law of conservation of energy.

49. 2059 Q.No. 7 a OR **State and explain Lenz's law.** **[4]**

Please refer to 2062 Q.No. 7 a OR

50. 2057 Q.No. 7 a OR **Deduce an expression for induced emf in a coil rotating in a magnetic field.** **[4]**

Please refer to 2076 Set C Q.No. 5d

51. 2053 Q.No. 10 **State the laws of electromagnetic induction. Derive an expression for the emf induced in a conductor moving in a magnetic field.** **[4]**

Faraday's Laws of electromagnetic induction: Please refer to 2076 Set C Q.No. 5d

Second part: Please refer to 2072 Set C Q.No. 5d

52. 2052 Q.No. 8 **Obtain the expression for the emf induced in the conductor moving in a magnetic field.** **[4]**

Please refer to 2069 (Set A) Old Q.No. 7a

Numerical Problems

53. 2076 Set B Q.No. 9c **The magnetic flux passing perpendicular to the plane of coil is given by $\phi = 4t^2 + 5t + 2$ where ϕ is in Weber and t is in second. Calculate the magnitude of instantaneous emf induced in the coil when t = 2 sec.** **[4]**

Solution

Given,

Flux (ϕ) = $4t^2 + 5t + 2$

Time (t) = 2 sec

E.m.f. (E) = ?

We know that

$$E = \left|\frac{-d\phi}{dt}\right|$$

Now,

$$\frac{d\phi}{dt} = \frac{d(4t^2 + 5t + 2)}{dt} = 8t + 5$$

Now,

$$E = \left|\frac{-d\phi}{dt}\right|_{t = 2\,sec} = |\,8 \times 2 + 5\,| = 21\text{ V}$$

54. 2075 Set A Q.No. 9a **A straight conductor of length 25 cm is moving perpendicular to its length with a uniform speed of 10 m/s making an angle of 45° with a uniform magnetic field of 10 T. Calculate the emf induced across its length.** **[4]**

Solution

Given,

Length of conductor (l) = 25 cm = 0.25 m

Velocity of conductor (v) = 10 m/s

Angle (θ) = 45°

Magnetic field (B)= 10T

Induced emf (E) = ?

We have,

$$E = Blv\sin\theta = 10 \times 0.25 \times 10 \times \sin 45° = 17.68\text{ V}$$

55. 2075 Set B Q.No. 9c 2067 Old Q.No. 7b A coil of 100 turns, each of area 2×10^{-3} m² has a resistance of 12 Ω. It lies in a horizontal plane in a vertical magnetic flux density of 3×10^{-3} Wbm^{-2}. What charge circulates through the coil if its ends are short-circuited and the coil is rotated through 180° about a diametrical axis? [4]

Solution

Given,

No. of turns (N) = 100

Area (A) = $2 \times 10^{-3} m^2$

Resistance (R) = 12Ω

Magnetic flux density (B) = 3×10^{-3} Tesla

Charge (Q) = ?

Now, we know that,

Mag. Flux (ϕ) = NAB cosθ

Then,

$\Delta\phi = \phi_1 - \phi_2$

$= NAB\cos\theta_1 - NAB\cos\theta_2$

$= NAB\cos 0° - NAB\cos 180°$

$= NAB + NAB = 2\,NAB = 2 \times 100 \times 2 \times 10^{-3} \times 3 \times 10^{-3} = 0.0012$

$= 1.2 \times 10^{-3}$ wb

Then, we have;

$$\text{Charge (Q)} = \frac{\Delta\phi}{R} = \frac{1.2 \times 10^{-3}}{12}$$

∴ $Q = 10^{-4}$C

Hence, the required charge is 10^{-4}C.

56. 2074 Set B Q.No. 9c An aircraft with a wingspan of 40 m files with a speed of 1080 km hr^{-1} in the eastward direction at a constant altitude in the northern hemisphere. Where the vertical component of earth's magnetic filed is 1.75×10^{-5} T. Find the emf that develops between the tips of the wings. [4]

Solution

Given,

Length of wings (l) = 40 m

Speed of span (v) = 1080 Km/hr $= \dfrac{1080 \times 1000}{3600}$ m/s

Vertical component of earth magnetic field (B_v) = 1.75×10^{-5} T

Induced e.m.f. (E) = ?

We have

$E = B_V . l . v$

$= 1.75 \times 10^{-5} \times 40 \times \dfrac{1080 \times 1000}{3600} = 0.21$ V

57. 2073 Set C Q.No. 9a A straight conductor of length 15 cm is moving with uniform speed of 10 ms^{-1} making an angle of 30° with uniform magnetic field of 10^{-4} Tesla. Calculate the emf induced across the length. [4]

Solution

Given,

Length of conductor (l) = 15 cm = 0.15 m

Velocity of conductor (v) = 10 ms^{-1}

Angle (θ) = 30°

Magnetic field (B) = 10^{-4} T

Induced emf (E) = ?

We have,

$E = Blv \sin\theta$

$= 10^{-4} \times .15 \times 10 \times \sin 30°$

$= 7.5 \times 10^{-5}$ V/m

58. 2072 Supp Q.No. 9b A jet plane is flying due west at the speed of 1800 km/hr. What is the voltage difference developed between the ends of the wings 25m long of the earths' magnetic field at that location is 5×10^{-4} T and the angle of dip is 45°? [4]

Solution

Given,

Velocity (v) = 1800 Km/hr = $\frac{1800 \times 1000}{60 \times 60}$ m/sec = 500 m/sec.

P.D. between end of wire (v) = ?

length of wings (l) = 25m

Horizontal component magnetic field (B_H) = 5×10^{-4} T

Angle of dip (δ) = 45°

Now, we have,

$$\tan\delta = \frac{B_V}{B_H}$$

$$\text{or, } B_V = B_H \times \tan\delta$$

$$= 5 \times 10^{-4} \times \tan 45 = 5 \times 10^{-4}\ \text{T}$$

From Farraday's laws of electromagnetic induction,

$$E = B_V \cdot l \cdot v$$

$$= 5 \times 10^{-4} \times 25 \times 500 = 6.25\ \text{V}$$

59. 2072 Set D Q.No. 9c A long solenoid of 1000 turns and cross sectional area 2×10^{-3} m^2 carries a current of 2A and produces a flux density 52×10^{-3} T inside it. Calculate the self inductance of the coil. [4]

Solution

Given,

No. of turns (N) = 1000

Area (A) = 2×10^{-3} m^2

Current (I) = 2A

Magnetic field (B) = 52×10^{-3} T

Self-inductance (L) = ?

Now, we have,

$$L = \frac{\phi}{I}$$

$$= \frac{NAB}{I} \qquad [\because \theta = 90°]$$

$$= \frac{1000 \times 2 \times 10^{-3} \times 52 \times 10^{-3}}{2}$$

$$\therefore L = 0.052\text{H}$$

Hence, the required self inductance is 0.052H.

60. 2072 Set E Q.No. 9b The magnetic flux passing perpendicular to the plane of a coil is given by $\phi = 4t^2 + 5t + 2$ where ϕ is in Weber and t is in seconds. Calculate the magnitude of instantaneous emf induced in the coil when t = 3 sec. [4]

Solution

Given,

Flux in a coil (ϕ) = $4t^2 + 5t + 2$

Time (t) = 3 sec.

E.m.f. induced (E) = ?

We have,

$$E = -\frac{d\phi}{dt} = -\frac{d(4t^2 + 5t + 2)}{dt}$$

$$\text{or, } E = -(8t + 5)$$

$$\text{or, } E_{t=3} = -(8 \times 3 + 5) = -29\ \text{V}$$

$\therefore$ –ve sign indicates that e.m.f. induces has opposing nature.

61. 2071 Supp Q.No. 9c A plane circular coil has 200 turns and its radius is 0.10m. It is connected to a battery. After switching on the circuit a current of 2A is set up in the coil. Calculate the energy stored in the coil. ($\mu_0 = 4\pi \times 10^{-7}$ Hm^{-1}) **[4]**

Solution

Given,

No. of turns of coil (n) = 200

Radius of coil (r) = 0.10 m

Set up current (I) = 2A

Energy stored in the oil (U) = ?

Now,

$$U = \frac{1}{2} LI^2$$

$$= \frac{1}{2}\mu.\ nA\ I^2 = \frac{1}{2}\mu.\ n\pi r^2.\ I^2$$

$$= \frac{1}{2} \times 4 \times 10^{-7} \times 200 \times \frac{22}{7} \times (0.10)^2 \times 2^2 = 1.6 \times 10^{-5} J$$

$$\left(\begin{array}{ll} \because & \phi = LI \\ \& & \phi = \mu.nIA \\ \text{or,} & L = \mu.nA \end{array}\right)$$

62. 2071 Set D Q.No. 9 c Find the emf induced in a straight conductor of length 25 cm, on the armature of a dynamo and 12 cm from the axis, when the conductor is moving in a uniform radial magnetic field of 0.5 T. The armature is rotating at 1000 revolutions per minute. **[4]**

Solution

Given,

Induced emf (E) = ?

Length of conductor (l) = 25 cm = 0.25 m

Distance from axis (r) = 12 cm = 0.12 m

Magnetic flux density (B) = 0.5 T

Frequency (f) = 1000 rev/min = 1000/60 rev/sec

We have,

$$E = Blv = B.l.\omega.r = B.l.\ 2\pi f.\ r = 0.5 \times 0.25 \times 2\pi \times 1000/60 \times 0.12 = 1.57\ V.$$

63. 2070 Set C Q.No. 9 b A metal aircraft with a wing span of 40 m flies with a speed 1000 km hr^{-1} in a direction due east at constant altitude in a region of the northern hemisphere where the horizontal component of the earth's magnetic field is 1.6×10^{-5}T and the angle of dip is 41°. Find the potential difference developed between the tips of the wing. **[4]**

Solution

Given,

Length of span (l) = 40m

Speed of span (v) = 1000 Km/hr $= \frac{1000 \times 1000}{60 \times 60}$ m/sec

Horizontal component of earth magnetic field (B_H) = 1.6×10^{-5} T

Dip angle (δ) = 41°

Induced p.d (V) = ?

Now,

Vertical component of earth magnetic field is calculated as,

$$\tan\delta = \frac{B_V}{B_H}$$

or, $B_V = B_H \times \tan\delta = 1.6 \times 10^{-5} \times \tan 41°$

Again,

$$V = B_V \times l \times v = 1.6 \times 10^{-5} \times \tan 41 \times 40 \times \frac{1000 \times 1000}{60 \times 60} = 0.154 \text{ volts.}$$

64. 2070 Set D Q.No. 9 c A rectangular coil of 100 turns has dimensions 15 × 10 cm². It is rotated at the rate of 300 revolutions per minute in a uniform magnetic field of flux density 0.6 T. Calculate the maximum emf induced in it. **[4]**

Solution

Given,

No. of turns (N) = 100

Dimension of coil (A) = $15 \times 10\ cm^2 = 15 \times 10 \times 10^{-4}\ m^2 = 150 \times 10^{-4}\ m^2$

Frequency (f) = 300 rev/min = 300/60 = 5 Hz

Magnetic flux density (B) = 0.6 T

Maximum emf induced (E_0) = ?

We have,

$E_0 = B\omega NA = B.\ 2\pi f\ .\ NA = 0.6 \times 2\pi \times 5 \times 100 \times 150 \times 10^{-4} = 28.27$ V.

65. **2069 (Set A) Old Q.No. 9 c** **A long solenoid with 15 turns per cm has a small loop of area 2cm² placed in normal to the axis of the solenoid. If the current carried by the solenoid changes steadily from 2 A to 4 in 0.1 second, what is the induced voltage in the loop, while the current is changing?**

Solution

Given,

No. of turns (n) = 15 turns/ cm = 15×100/m

Area (A) = $2cm^2 = 2\times10^{-4}m^2$

Change in current (dI) = $I_2 - I_1 = 4 - 2 = 2A$

Time (dt) = 0.1 sec

Induced emf (E) = ?

Now,

$$\frac{dI}{dt} = \frac{2}{0.1} = 20\ A/sec$$

$$E = \frac{d\phi}{dt} = \frac{d}{dt}(BA) = \frac{d}{dt}(A\mu_0 nI) = A\mu_0 n\frac{dI}{dt} = 2 \times 10^{-4} \times 4\pi \times 10^{-7} \times 15 \times 100 \times 20 = 7.5 \times 10^{-6}\ V$$

66. **2067 Q.No. 6c** **Two plane coils having number of turns 1000 and 2000, and radii 5 cm and 10 cm respectively are placed co-axially in the same plane. Calculate their mutual inductance. ($\mu_0 = 4\pi \times 10^{-7}$ H/m).**

Solution

Given,

No. of turns in first coil (N_1) = 1000

No. of turns is second coil (N_2) = 2000

Radius of 1st coil (r_1) = 5cm = 0.05m

Radius of 2nd coil (r_2) = 10cm = 0.1m

Mutual inductance (M) = ?

Now, we have,

Magnetic field due to 1st coil i.e., $B_1 = \frac{\mu_0 N_1 I}{2r_1}$

Then,

Flux linked with 2nd coil (ϕ_2) = $B_1N_2A_2 = \frac{\mu_0 N_1 I}{2r_1} \times N_2 \times A_2 = \frac{\mu_0 N_1 N_2 I \pi r_2^2}{2r_1}$

Again, we have,

$$\text{Mutual inductance (M)} = \frac{\phi_2}{I} = \frac{\mu_0 N_1 N_2 I \pi r_2^2}{2r_1 I} = \frac{\pi}{2} \times \frac{\mu_0 N_1 N_2 r_2^2}{r_1}$$

$$= \frac{\pi}{2} \times \frac{4\pi \times 10^{-7} \times 1000 \times 2000 \times (0.1)^2}{0.05} = 0.79\ H$$

Hence, the required mutual inductance is 0.79H.

67. **2066 Q.No. 7 b** **A long solenoid of 1000 turns and cross-sectional area 2×10^{-3} m² carries a current of 2A produces a flux density 52×10^{-3} T in the middle of the coil. Assuming this value of flux density at sections of the solenoid, calculate its self-inductance.**

Please refer to 2072 Set D Q.No. 9c

68. **2060 Q.No. 7 b** **A transformer has 500 turns in the primary coil and 100 turns in the secondary coil. What is the output voltage if the input voltage is 4000 volts? If the transformer is assumed to have an efficiency of 100%, what primary current is required to draw 2000 watts from the secondary?** **[4]**

Solution

Given,

No. of turns in primary coil (N_p) = 500

No. of turns in secondary coil (N_S) = 100

Input voltage (ε_P) = 4000 V

Output voltage (ε_s) = ?

Efficiency (η) = 100%

Power output = 2000 watt

Current in primary coil (I_p) = ?

Now, we have,

$$\frac{N_P}{N_s} = \frac{\varepsilon_P}{\varepsilon_s}$$

or, $\frac{500}{100} = \frac{4000}{\varepsilon_s}$

$\therefore$ $\varepsilon_s = 800V$

Again; we have,

$$\eta = \frac{\text{output power}}{\text{Input power}} \times 100\%$$

or, $100 = \frac{2000}{\text{Input power}}$

or, Input Power = 20W

or, $E_P \times I_P = 20$

or, $4000 \times I_P = 20$

$\therefore$ $I_P = 0.005$ A

Hence, the required current is 0.005A & output voltage is 800V.

69. **2058 Q.No. 7 b** **A jet plane is traveling due west at the speed of 1800km/h. What is the voltage difference developed between the ends of the wings 25m long, if the earth's magnetic field at the location is 5.0×10^{-4} T and the dip angle is 30°?** **[4]**

Solution

Given,

Speed of jet plane, v = 1800 km/h = $\frac{1800 \times 1000}{3600}$ m/s

v = 500 m/s

Length of wings, l = 25m

Earth's magnetic field, $B_H = 5 \times 10^{-4}$ T

Angle of dip., $\delta = 30°$

p.d. developed i.e., induced e.m.f., ε = ?

We know,

$$\tan\delta = \frac{B_V}{B_H}$$

or, $B_V = B_H \tan\delta = 5 \times 10^{-4} \times \tan 30° = 2.8 \times 10^{-4}$ T

$\varepsilon = B_V.l.V = 5 \times 10^{-4} \times \tan 30° \times 25 \times \frac{1800 \times 1000}{3600}$

So, ε = 3.5 volt

$\therefore$ Voltage developed between the ends, ε = 3.5 volt.

70. **2054 Q.No. 9** **When a wheel with metal spokes 1.2m long is rotated in a magnetic field of flux density 5×10^{-5} T normal to the plane of wheel, an emf of 10^{-2}V is induced between the rim and axle. Find the rate of rotation of the wheel.** **[4]**

Solution

Given,

Length of metal spokes, $r = 1.2$ m

Magnetic flux density, $B = 5 \times 10^{-5}$ T

Induced e.m.f., $E = 10^{-2}$ V

Rate of rotation, f = ?

In such case, we have

$$E = B.l.\ v_{av.} = B.\ r.\left(\frac{0+v}{2}\right) = B.\ r.\ \frac{\omega r}{2} = B.\ r.\ \frac{2\pi f r}{2} = B.\ \pi r^2 f = BA f$$

$$f = \frac{E}{BA} = \frac{E}{B\pi r^2} = \frac{10^{-2}}{5 \times 10^{-5} \times \pi \times (1.2)^2} = 44.2 \text{ rev/sec}$$

$\therefore$ f = 44.2 rev/sec

71. **2052 Q.No. 11** **A circular metal disc of area 3.0×10^{-3} m² is rotated at 50 rev/s about an axis through its centre perpendicular to its plane. The disc is in a uniform magnetic field of flux density 5.0×10^{-3}T in the direction of the axle. What is the value of induced emf?** **[4]**

Solution

Here,

Area of metal disc (A) = 3×10^{-3} m²

Rate of revolutions (f) = 50 rev/sec

Magnetic flux density (B) = 5×10^{-3} T

Induced e.m.f. (E) = ?

In such case, we have

$$E = B.l.\ v_{av.} = B.\ r.\left(\frac{0+v}{2}\right) = B.\ r.\ \frac{\omega r}{2} = B.\ r.\ \frac{2\pi f r}{2} = B.\ \pi r^2 f$$

or, E = B A f

$= 5 \times 10-3 \times 3 \times 10^{-3} \times 50$

or, E $= 75 \times 10^{-5}$ volt

$\therefore$ Induced e.m. f., E $= 75 \times 10^{-5}$ volt

72. **2052 Q.No. 11 OR** **A step down transformer transforms a supply line voltage 220 volts into 100 volts. Primary coil has 500 turns. The efficiency and power transmitted by the transformer are 80% and 80KW. Find (a) the number of turns in the secondary coil (b) power supplied.** **[4]**

Solution

Given,

No. of turns in primary coil (N_p) = 500

No. of turns in secondary coil (N_S) = ?

Input voltage (ε_p) = 220 V

Output voltage (ε_s) = 100V

Efficiency (η) = 80%

Power transmitted = 80 KW = 80000W

Power supplied = ?

Now, we have,

$$\frac{N_p}{N_s} = \frac{\varepsilon_p}{\varepsilon_s}$$

or, $\frac{500}{N_s} = \frac{220}{100}$

$\therefore$ $N_s = 227$

Again; we have

$$\eta = \frac{\text{power transmitted}}{\text{power supplied}} \times 100\%$$

or, $80\% = \frac{80000}{\text{power supplied}} \times 100\%$

$\therefore$ Power supplied = 10^5 watt.

□□□

Chapter 4: AC Circuits

Short Answer Questions

1. 2076 Set B Q.No. 1f 2070 Set C Q.No. 1f **220 V A.C. is more danger than 220 V D.C., why?** [2]

The root mean square voltage and peak value of voltage are related as

$$V_{rms} = \frac{V_p}{\sqrt{2}}$$

or, $V_p = \sqrt{2}\ V_{rms}$

So, the peak value of 220 V a.c. is $\sqrt{2}$ times greater than 220V d.c. Hence, a 220V a.c. is more dangerous than 220 V d.c.

2. 2076 Set C Q.No. 1f 2069 (Set B) Q.No. 1f 2068 Old Can. Q.No. 1e **A choke coil is preferable to a resistor in an ac circuit. Why?** [2]

Choke coil is a coil of wire with high inductance and low resistance. It is used in ac circuit to control the current without significant loss of electrical energy in the form of heat. The power consumed in choke coil is $P_{av} = I_{rms} \times V_{rms} \times \cos\theta$. Since, $\theta = 90°$, then $P_{av} = I_{rms} \times V_{rms} \times \cos 90° = 0$. It means the current in a choke is wattless. If a resistor is used for limiting current in a circuit, there is always wastage of power by Joule's law of heating. The power loss is given by $P = I^2R$. Also, there is gradual potential drop across the resistor. Hence, choke coil is preferred to a resistance in an ac circuit to change the magnitude of the current without consuming power from the source.

3. 2075 GIE Q.No. 1f **The emf of an ac source is given by the expression, E = 300 sin 314t volts. Write the values of peak voltage and frequency of that source. What will be the rms voltage of source?** [2]

Given E = 300 sin(314t)

R.M.S. voltage (E) = ?

Frequency (f) = ?

Comparing this equation with

$E = E_0 \text{ Sin wt}$

Here, $E_0 = 300$ V & $\omega = 314$

$$\therefore \quad Vrms = \frac{E_0}{\sqrt{2}} = \frac{300}{\sqrt{2}} V$$

& $2\pi f = 314$

$\therefore \quad f = 50$ Hz

4. 2075 Set AQ.No. 1f 2073 Supp Q.No. 1f 2071 Set D Q.No. 1 f 2068 Can. Q.No. 1f 2062 Q.No. 1e 2057 Q.No. 1 e 2056 Q.No. 7 d 2053 Q.No. 7 e **Why is choke coil preferred over a resistance in a.c.?** [2]

Please refer to 2076 Set C Q.No. 1f

5. 2074 Supp Q.No. 1f 2072 Set D Q.No. 1f 2071 Set C Q.No. 1 f **What is wattless current?** [2]

The electrical power consumed in an ac circuit is given by,

$P_{av} = I_{rms} \times V_{rms} \times \cos\theta$, where, $\cos\theta = \frac{R}{Z}$.

Here, Z is impedance, cosθ is called the power factor and θ is the phase difference between the current and voltage. Since, the value of phase angle in pure capacitor and inductor is 90°, the power consumed is $P_{av} = I_{rms} \times V_{rms} \times \cos 90° = 0$. And hence, current flowing in pure capacitor and inductor is called wattles current. So, current of any ac circuit is said to be wattless current when it does not consume any power.

6. 2074 Set A Q.No. 1f **The emf of an ac source is given by the expression, E=300 sin 314 t volts. Write the values of peak voltage and frequency of source.** [2]

Please refer to 2075 GIE Q.No. 1f

7. **2074 Set B Q.No. 1e Define rms value of ac. How is it related with the peak value of ac?** [2]

The r.m.s. value of ac is the steady current (dc), which on passing through a resistance for a given time will produce the same amount of heat as the alternating current does in the same resistance for the same time. It is also called as virtual or effective value. If I_0 be the peak value of ac, then its rms value is given by $I_{rms} = \frac{I_0}{\sqrt{2}}$

Similarly the r.m.s value of ac voltage is $V_{rms} = \frac{V_0}{\sqrt{2}}$.

8. **2073 Set D Q.No. 1e Alternating current passes through a capacitor whereas direct current does not. Explain this fact on the basis of capacitative reactance.** [2]

The capacitative reactance of a capacitor is given as,

$X_C = \frac{1}{2\pi fC}$, where f = frequency of current and C is capacitance of a capacitor.

For a dc current, f = 0, $X_C = \infty$ i.e., for d.c. current the reactance of a capacitor becomes infinite and acts as insulator which blocks current. For alternating current, f is more & X_C is less i.e., the capacitor has low reactance for alternating current. So, a.c. easily passes through it and d.c is blocked by capacitor.

9. **2072 Supp Q.No. 1f How does the resonance frequency of an L.C.R. series circuit change if the plates of the capacitor are brought closer together?** [2]

The resonance frequency of an L.C.R series circuit is

$$f = \frac{1}{2\pi}\sqrt{\frac{1}{LC}} = \frac{1}{2\pi\sqrt{LC}}$$

where, L is inductance of inductor and C is the capacitance of a capacitor. The capacitance of a parallel plate capacitor is given as

$$C = \frac{\epsilon A}{d}$$

where, ϵ = permittivity of the substance kept inside the capacitor,

A = area of plate and d is distance between plate.

when distance decreases by taking the plate closer, the capacitance of capacitor increases, as a result, the resonance frequency decreases.

10. **2072 Set E Q.No. 1f What are the advantages of A.C. over D.C.?**

The advantages of a.c over d.c. are given as:

- The a.c. can be easily converted into d.c. but reverse is little bit difficult.
- The voltage of a.c. can be changed from lower voltage to higher and vice versa with the help of transformer but voltage of d.c. can not be changed.
- The a.c. can be transferred easily over long distances without any loss of energy but not d.c.
- Many electrical appliances like electrical fan, washing machine, electric motor are run by only a.c but not by d.c.
- Production of ac is easy and economical.

11. **2071 Supp Q.No. 1b For a capacitor in an a.c. circuit, explain why there is a phase difference between current and voltage.** [2]

When an a.c. is passing through a capacitor, current leads voltage by a phase angle 90°. This is due to the charge storing nature of capacitor. When a.c. is passing through a capacitor, it stores charges & response current but voltage produces after storing charges and hence current leads voltage by a phase angle of 90°.

12. **2070 Supp. (Set B) Q.No. 1 f 2068 Q.No. 1 f 2067 Sup Q.No. 1f 2064 Q.No. 1 e Define rms values of alternating current.** [2]

Please refer to 2074 Set B Q.No. 1e

13. 2070 Set D Q.No. 1 f 2059 Q.No. 1 e **Fluorescent lights often use an inductor, to limit the current through the tubes. Why is it better to use an inductor rather than a resistor for this purpose?** **[2]**

The electrical power consumed in an ac circuit is given by

$P_{av} = I_{rms} \times V_{rms} \times \cos\theta$, where $\cos\theta = \frac{R}{Z}$.

Here, Z is impedance, $\cos\theta$ is called the power factor and θ is the phase difference between the current and voltage. Since, the value of phase angle in pure inductor is 90°, the power consumed is $P_{av} = I_{rms} \times V_{rms} \times \cos 90° = 0$. Due to this reason, an inductor is used to limit the current through the tube of fluorescent light. But, if a resistor is used for this purpose, there is wastage of power ($P = I^2R$) by Joule's law of heating due to zero phase difference between the voltage and current. Thus, unlike resistor, inductor plays a significant role for controlling the current without loss of any power. That's why, inductor is better to use than a resistor in fluorescent tubes.

14. 2069 (Set A) Q.No. 1e **At high frequencies, a capacitor becomes a short-circuit and an inductor becomes an open circuit. Explain.** **[2]**

The capacitative reactance if a capacitor X_C is given by

$X_C = \frac{1}{2\pi fC}$, where f is frequency & C is capacitance of a capacitor.

If $f = \infty$, $X_C = 0$, So, capacitor acts as short circuit.

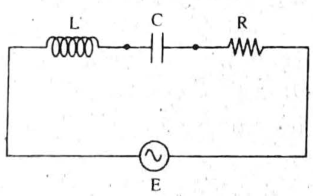
The inductive reactance for inductor X_L is given by,

$X_L = 2\pi fL$, L = inductance of inductor.

If, $f = \infty$, $X_L = \infty$, so inductor act as open circuit.

15. 2069 (Set B) Q.No. 1a **Sketch the symbols of "capacitor", "an inductor", "emf of a cell" and "a resistor".** **[2]**

The symbols of a capacitor (C), an inductor (L), emf (E) and a resistor (R) are shown in the circuit



16. 2067 Q.No. 1f **What do you mean by wattless current?** **[2]**

Please refer to 2074 Supp Q.No. 1f

17. 2067 Old Q.No. 2e **What are the advantages of a.c. over d.c.?** **[2]**

Please refer to 2072 Set E Q.No. 1f

18. 2066 Supp Q.No. 1e **Define rms value of a.c.** **[2]**

Please refer to 2074 Set B Q.No. 1e

19. 2066 Q.No. 2 e **Fluorescent lamps often use an inductor, called a ballast, to limit current through the tubes. Why is it better to use an inductor rather than a resistor for this purpose?** **[2]**

Please refer to 2070 Set D Q.No. 1 f

20. 2058 Q.No. 2 e **What is meant by wattles current?** **[2]**

Please refer to 2074 Supp Q.No. 1f

21. 2056 Q.No. 7 h **What do you mean by r.m.s value of an A.C. current?** **[2]**

Please refer to 2074 Set B Q.No. 1e

22. 2055 Q.No. 7 e **Why is choke coil preferable to resistor?** **[2]**

Please refer to 2076 Set C Q.No. 1f

23. 2054 Q.No. 7 g **What is meant by impedence of an a.c. circuit?** **[2]**

The net resistance or opposition offered by the ac circuit to the alternating current is called *impendence* of an ac circuit. When an ac current passes through a LCR circuit i.e., circuit containing inductor, capacitor and resistor, then each of the components offers different resistances which differ from each other. Inductor (L) offers reactance X_L which is directly proportional to the frequency (f) of ac. Similarly, capacitor (C) offers reactance X_C which is inversely proportional to the frequency (f) of ac, and resistance offered by resistor does not depend upon frequency.

Hence, the net resistance offered by LCR circuit is given by,

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2} \quad (\text{where } \omega = 2\pi f)$$

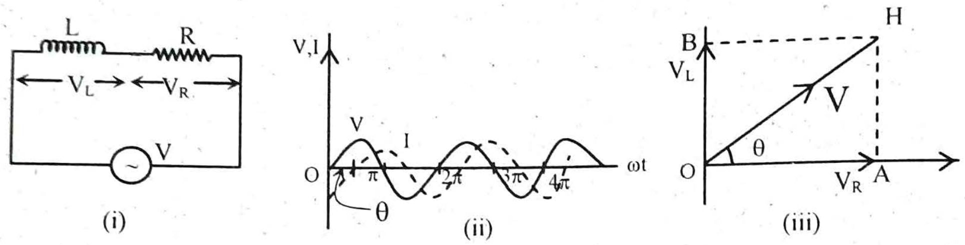
which is known as impedance of an ac circuit. It plays same role as played by resistance in dc circuit.

Similarly, the impedance of LR circuit is $Z = \sqrt{R^2 + X_L^2}$ and CR circuit is $Z = \sqrt{R^2 + X_C^2}$.

Long Answer Questions

24. **2076 Set B Q.No. 5d** **2058 Q.No. 7 a** **An alternating current passes through a circuit containing an inductor and a resistor in series. Derive expressions for the current flowing and phase relation between the current and the voltage.** **[4]**

Suppose a pure resistor of resistance R and a pure inductor of inductance L are connected in series to a source of alternating e.m.f. as shown in figure (i). Let V be the r.m.s. value of applied alternating e.m.f. and I be the r.m.s. value of current flowing in the circuit.



(i) A.C. through resistor & inductor (ii) Phase relationship between Voltage & Current in LR circuit (iii) Phasor diagram

The potential difference across inductor, $V_L = IX_L$ (leads current I by an angle of $\pi/2$). The potential difference across R, $V_R = I.R$ (in phase with the current). Since V_R and I are in phase. So, V_R is represented by OA in the direction of I (figure (iii)). The current lags behind the potential difference V_L by angle of $\pi/2$ so, V_L is represented by OB perpendicular to the direction of I. So resultant of V_R and V_L is given by OH. The magnitude of OH is given by

$$OH = \sqrt{OA^2 + OB^2} = \sqrt{V_R^2 + V_L^2}$$

or, $V = \sqrt{I^2 R^2 + I^2 X_L^2}$

or, $V = I\sqrt{R^2 + X_L^2}$

or, $\frac{V}{I} = \sqrt{R^2 + X_L^2} = \sqrt{R^2 + \omega^2 L^2}$

But $\frac{V}{I} = Z$, is the effective opposition of LR circuit to a.c. called impedance of LR circuit.

The impedance of L–R circuit is given by

$$Z = \sqrt{R^2 + X_L^2}$$

Again, $I = \frac{V}{Z} = \frac{V}{\sqrt{R^2 + X_L^2}}$

$\therefore \; I = \frac{V}{\sqrt{R^2 + (L\omega)^2}} \quad [\because X_L = L\omega]$

Let θ be the angle between V and I, so from figure (iii), we have,

$$\tan\theta = \frac{V_L}{V_R} = \frac{IX_L}{IR}$$

or, $\tan\theta = \frac{X_L}{R} = \frac{L\omega}{R} \qquad \therefore \tan\theta = \frac{L\omega}{R}$

If the values of X_L and R are known, θ can be calculated. Current lags behind the applied voltage or e.m.f. by an angle θ. The phase relationship between current and voltage is given in fig. (ii).

The power factor in this circuit is given by

$$\cos\theta = \frac{R}{\sqrt{R^2 + (L\omega)^2}}$$

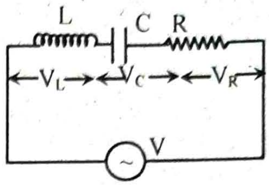
25. **2075 Set A Q.No. 5d What is an LCR circuit? Derive the condition for resonant frequency for an LCR series circuit with an a.c. supply.** **[4]**

LCR Circuit: The electrical circuit which contains a resistor, an inductor and a capacitor connected with an a.c. mains is called LCR circuits.

Electrical Resonance and resonance in Series LCR Circuit

Let us consider a pure resistor of resistance R, a pure inductor of inductance L and an ideal capacitor of capacitance C be connected in series to a source of alternating e.m.f. as shown in figure. As R, L and C are in series, current at any instant through the three elements has the same amplitude and phase.

However, voltage across each element bears different phase relationship with the current. Let V be the r.m.s. value of the applied alternating e.m.f. to LCR circuit and I be the r.m.s. value of current flowing through all the circuit elements which is given by



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

where, $Z = \sqrt{R^2 + (X_L - X_C)^2}$ is the impedance of the series LCR circuit.

Electrical resonance is said to take place in a series LCR circuit when the circuit allows maximum current for a given frequency of the source of alternating supply for which capacitive reactance becomes equal to the inductive reactance (i.e., $X_C = X_L$).

$$\text{Now, } I = \frac{E}{Z} = \frac{E}{\sqrt{R^2 + \left(L\omega - \frac{1}{C\omega}\right)^2}}$$

At low frequency, $X_L = L\omega = L2\pi f$ is very small and $X_C = \frac{1}{C\omega} = \frac{1}{C2\pi f}$ is very large. At high frequency, $X_L = L\omega$ is very large and $X_C = \frac{1}{C\omega}$ is very small. If $X_L = X_C$ for a particular frequency f_0, then the impedance of LCR circuit is given by

$z = \sqrt{R^2 + 0} = R$ (minimum)

i.e., Impedance of LCR circuit is minimum and hence current becomes maximum. This frequency (f_0) is called resonant frequency and the phenomenon is called electrical resonance.

Hence, for electrical resonance, we have

$$X_L = X_C$$

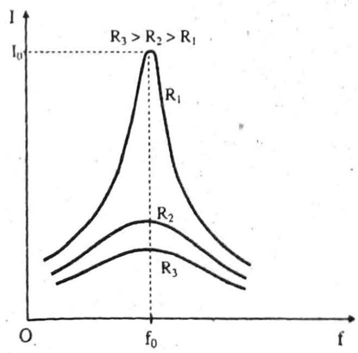
$$\text{or, } L\omega = \frac{1}{C\omega}$$

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

$$\text{or, } \omega = \frac{1}{\sqrt{LC}}$$

$$\text{or, } 2\pi f_0 = \frac{1}{\sqrt{LC}}$$

$$\therefore f_0 = \frac{1}{2\pi\sqrt{LC}}$$

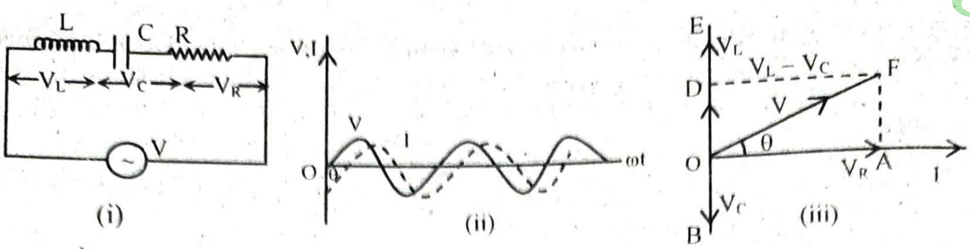


This is the expression for resonant frequency.

The resonant frequency is independent of the resistance R in the circuit. However, the sharpness of resonance decreases with increase in resistance as shown in figure.

26. **2075 Set B Q.No. 5d Derive an expression for the impedance of an a.c. circuit containing a resistor an inductor and a capacitor. Hence derive resonance frequency. Also, draw the phase diagram.** **[4]**

Impedance of an a.c. Circuit: Let a pure resistor of resistance R, a pure inductor of inductance L and an ideal capacitor of capacitance C be connected in series to a source of alternating e.m.f. as shown in following figure. As R, L and C are in series, current at any instant through the three elements has the same amplitude and phase. However, voltage across each element bears different phase relationship with the current. Let V be the r.m.s. value of the applied alternating e.m.f. to LCR circuit and I be the r.m.s. value of current flowing through all the circuit elements.



(i) A.C. through LCR series circuit (ii) Phase relationship between V & I in series LCR circuit (iii) Phase diagram

The potential difference across inductor, $V_L = IX_L$ leads current I by an angle of $\pi/2$)
The potential difference across C, $V_C = IX_C$ (lags behind the current I by an angle $\pi/2$)
The potential difference across R, $V_R = IR$ (in phase with the current)
Since, V_R and I are in phase so, V_R is represented by OA in the direction of I as shown in figure (iii). The current lags behind the potential difference V_L by angle of $\pi/2$, so V_L is represented by OE perpendicular to the direction of I. The current leads the potential difference V_C by an angle of $\pi/2$ so V_C is represented by OB perpendicular to the direction of I. Since V_L and V_C are in opposite phase, so their resultant $(V_L - V_C)$ is represented by OD (Here, $V_L > V_C$).
The resultant of V_R and $(V_L - V_C)$ is given by OF. The magnitude of OF is given by

$$OF = \sqrt{(OA)^2 + (OD)^2} = \sqrt{V_R^2 + (V_L - V_C)^2}$$

or, $V = \sqrt{I^2 R^2 + (I X_L - I X_C)^2} = I\sqrt{R^2 + (X_L - X_C)^2}$

or, $\dfrac{V}{I} = \sqrt{R^2 + (X_L - X_C)^2}$

But $\dfrac{V}{I}$ = Z is the effective opposition of LCR circuit to A.C. called impedance of the circuit. So, we get

$$Z = \frac{V}{I} = \sqrt{R^2 + (X_L - X_C)^2} \quad \ldots(i)$$

This is required impedance of LCR series circuit.

Resonance frequency:

At low frequency, $X_L = L\omega = L2\pi f$ is very small and $X_C = \dfrac{1}{C\omega} = \dfrac{1}{C2\pi f}$ is very large. At high frequency, $X_L = L\omega$ is very large and $X_C = \dfrac{1}{C\omega}$ is very small. If $X_L = X_C$ for a particular frequency f_0, then the impedance of LCR circuit is given by

$$z = \sqrt{R^2 + 0} = R \text{ (minimum)}$$

i.e., Impedance of LCR circuit is minimum and hence current becomes maximum. This frequency (f_0) is called resonant frequency and the phenomenon is called electrical resonance.
Hence, for electrical resonance, we have

$$X_L = X_C$$

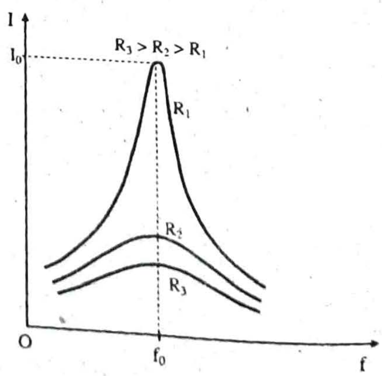
or, $L\omega = \dfrac{1}{C\omega}$

or, $\omega^2 = \dfrac{1}{LC}$

or, $\omega = \dfrac{1}{\sqrt{LC}}$

or, $2\pi f_0 = \dfrac{1}{\sqrt{LC}}$

$\therefore \quad f_0 = \dfrac{1}{2\pi\sqrt{LC}}$



This is the expression for resonant frequency.
The resonant frequency is independent of the resistance R in the circuit. However, the sharpness of resonance decreases with increase in resistance as shown in figure.

27. 2074 Set B Q.No. 5d **Derive an expression for the impedance of an ac circuit with an inductor L, a capacitor C and a resistor R in series. Draw the phase diagram if the voltage across the inductor is greater than that across the capacitor.** **[4]**

Please refer to 2075 Set B Q.No. 5d

28. 2073 Supp Q.No. 5d **Derive expression for the impedance of an ac circuit containing a resistor and an inductor. Also draw the phase diagram.** **[4]**

Please refer to 2076 Set B Q.No. 5d

29. 2073 Set D Q.No. 5b **Find expression for current in the case of alternating LCR series circuit and explain the phase relation between voltage and current.** **[4]**

Let a pure resistor of resistance R, a pure inductor of inductance L and an ideal capacitor of capacitance C be connected in series to a source of alternating e.m.f. as shown in following figure. As R, L and C are in series, current at any instant through the three elements has the same amplitude and phase. However, voltage across each element bears different phase relationship with the current. Let V be the r.m.s. value of the applied alternating e.m.f. to LCR circuit and I be the r.m.s. value of current flowing through all the circuit elements.

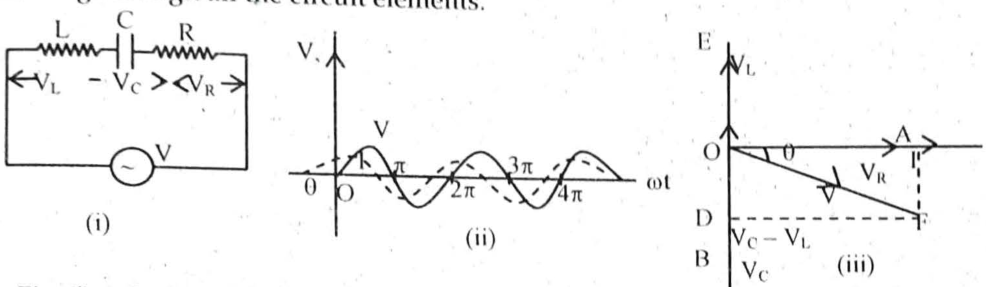


Fig: (i) A.C. through LCR series circuit (ii) Phase relationship between V & I in series LCR circuit (iii) Phase diagram

The potential difference across inductor, $V_L = IX_L$ (leads current I by an angle of $\pi/2$)
The potential difference across C, $V_C = IX_C$ (lags behind the current I by an angle $\pi/2$)
The potential difference across R, $V_R = IR$ (in phase with the current)
Since V_R and I are in phase so, V_R is represented by OA in the direction of I as shown in figure (iii).

The current lags behind the potential difference V_L by angle of $\pi/2$, so V_L is represented by OE perpendicular to the direction of I. The current leads the potential difference V_C by an angle of $\pi/2$ so V_C is represented by OB perpendicular to the direction of I.

Since V_L and V_C are in opposite phase, so their resultant $(V_C - V_L)$ is represented by OD (Here $V_C > V_L$).

The resultant of V_R and $(V_C - V_L)$ is given by OF. The magnitude of OF is given by

$$OF = \sqrt{(OA)^2 + (OD)^2} = \sqrt{V_R^2 + (V_C - V_L)^2}$$

or $V = \sqrt{I^2 R^2 + (I X_C - I X_L)^2} = I\sqrt{R^2 + (X_C - X_L)^2}$

or, $\dfrac{V}{I} = \sqrt{R^2 + (X_C - X_L)^2}$

But $\dfrac{V}{I}$ = Z is the effective opposition of LCR circuit to A.C. called impedance of the circuit. So, we get

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

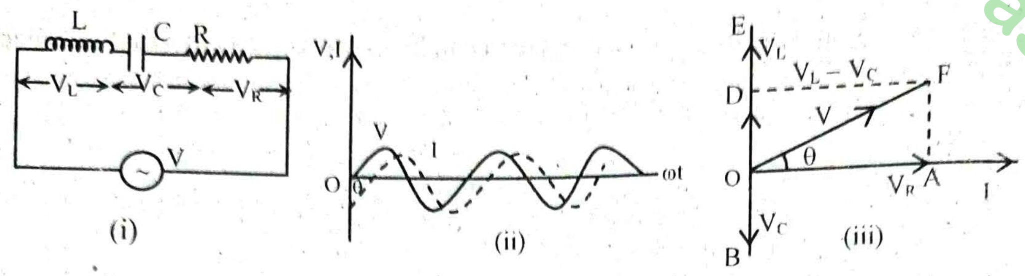
or, $I = \dfrac{V}{Z} = \dfrac{V}{\sqrt{R^2 + (X_C - X_L)^2}}$ ...(i)

This is required current of LCR series circuit.

Now,

$$\tan\theta = \frac{V_C - V_L}{V_R} = \frac{IX_C - IX_L}{I_R} = \frac{X_C - X_L}{R}$$

or, $\tan\theta = \dfrac{\dfrac{1}{\omega C} - \omega L}{R}$



(i) A.C. through LCR series circuit (ii) Phase relationship between V & I in series LCR circuit (iii) Phase diagram

The potential difference across inductor, $V_L = IX_L$ leads current I by an angle of $\pi/2$)
The potential difference across C, $V_C = IX_C$ (lags behind the current I by an angle $\pi/2$)
The potential difference across R, $V_R = IR$ (in phase with the current)
Since, V_R and I are in phase so, V_R is represented by OA in the direction of I as shown in figure (iii). The current lags behind the potential difference V_L by angle of $\pi/2$, so V_L is represented by OE perpendicular to the direction of I. The current leads the potential difference V_C by an angle of $\pi/2$ so V_C is represented by OB perpendicular to the direction of I. Since V_L and V_C are in opposite phase, so their resultant $(V_L - V_C)$ is represented by OD (Here, $V_L > V_C$).
The resultant of V_R and $(V_L - V_C)$ is given by OF. The magnitude of OF is given by

$$OF = \sqrt{(OA)^2 + (OD)^2} = \sqrt{V_R^2 + (V_L - V_C)^2}$$

or, $V = \sqrt{I^2 R^2 + (I X_L - I X_C)^2} = I\sqrt{R^2 + (X_L - X_C)^2}$

or, $\dfrac{V}{I} = \sqrt{R^2 + (X_L - X_C)^2}$

But $\dfrac{V}{I} = Z$ is the effective opposition of LCR circuit to A.C. called impedance of the circuit. So, we get

$$Z = \frac{V}{I} = \sqrt{R^2 + (X_L - X_C)^2} \quad \dots(i)$$

This is required impedance of LCR series circuit.

Resonance frequency:

At low frequency, $X_L = L\omega = L2\pi f$ is very small and $X_C = \dfrac{1}{C\omega} = \dfrac{1}{C2\pi f}$ is very large. At high frequency, $X_L = L\omega$ is very large and $X_C = \dfrac{1}{C\omega}$ is very small. If $X_L = X_C$ for a particular frequency f_0, then the impedance of LCR circuit is given by

$$z = \sqrt{R^2 + 0} = R \text{ (minimum)}$$

i.e., Impedance of LCR circuit is minimum and hence current becomes maximum. This frequency (f_0) is called resonant frequency and the phenomenon is called electrical resonance.
Hence, for electrical resonance, we have

$$X_L = X_C$$

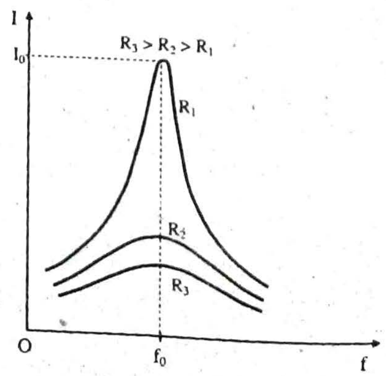
or, $L\omega = \dfrac{1}{C\omega}$

or, $\omega^2 = \dfrac{1}{LC}$

or, $\omega = \dfrac{1}{\sqrt{LC}}$

or, $2\pi f_0 = \dfrac{1}{\sqrt{LC}}$

$\therefore$ $f_0 = \dfrac{1}{2\pi\sqrt{LC}}$



This is the expression for resonant frequency.
The resonant frequency is independent of the resistance R in the circuit. However, the sharpness of resonance decreases with increase in resistance as shown in figure.

2074 Set B Q.No. 5d **Derive an expression for the impedance of an ac circuit with an inductor L, a capacitor C and a resistor R in series. Draw the phase diagram if the voltage across the inductor is greater than that across the capacitor.** **[4]**

Please refer to 2075 Set B Q.No. 5d

2073 Supp Q.No. 5d **Derive expression for the impedance of an ac circuit containing a resistor and an inductor. Also draw the phase diagram.** **[4]**

Please refer to 2076 Set B Q.No. 5d

2073 Set D Q.No. 5b **Find expression for current in the case of alternating LCR series circuit and explain the phase relation between voltage and current.** **[4]**

Let a pure resistor of resistance R, a pure inductor of inductance L and an ideal capacitor of capacitance C be connected in series to a source of alternating e.m.f. as shown in following figure. As R, L and C are in series, current at any instant through the three elements has the same amplitude and phase. However, voltage across each element bears different phase relationship with the current. Let V be the r.m.s. value of the applied alternating e.m.f. to LCR circuit and I be the r.m.s. value of current flowing through all the circuit elements.

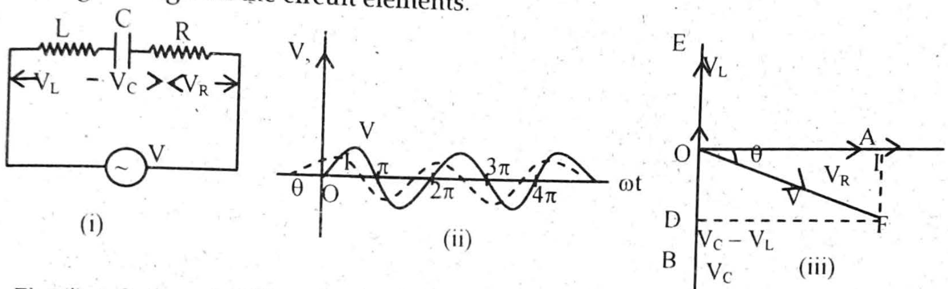


Fig: (i) A.C. through LCR series circuit (ii) Phase relationship between V & I in series LCR circuit (iii) Phase diagram

The potential difference across inductor, $V_L = IX_L$ (leads current I by an angle of $\pi/2$)
The potential difference across C, $V_C = IX_C$ (lags behind the current I by an angle $\pi/2$)
The potential difference across R, $V_R = IR$ (in phase with the current)
Since V_R and I are in phase so, V_R is represented by OA in the direction of I as shown in figure (iii).

The current lags behind the potential difference V_L by angle of $\pi/2$, so V_L is represented by OE perpendicular to the direction of I. The current leads the potential difference V_C by an angle of $\pi/2$ so V_C is represented by OB perpendicular to the direction of I.

Since V_L and V_C are in opposite phase, so their resultant $(V_C - V_L)$ is represented by OD (Here $V_C > V_L$).

The resultant of V_R and $(V_C - V_L)$ is given by OF. The magnitude of OF is given by

$$OF = \sqrt{(OA)^2 + (OD)^2} = \sqrt{V_R^2 + (V_C - V_L)^2}$$

$$\text{or } V = \sqrt{I^2 R^2 + (I X_C - I X_L)^2} = I\sqrt{R^2 + (X_C - X_L)^2}$$

$$\text{or, } \frac{V}{I} = \sqrt{R^2 + (X_C - X_L)^2}$$

But $\frac{V}{I} = Z$ is the effective opposition of LCR circuit to A.C. called impedance of the circuit. So, we get

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

$$\text{or, } I = \frac{V}{Z} = \frac{V}{\sqrt{R^2 + (X_C - X_L)^2}} \quad \ldots(i)$$

This is required current of LCR series circuit.

Now,

$$\tan\theta = \frac{V_C - V_L}{V_R} = \frac{IX_C - IX_L}{I_R} = \frac{X_C - X_L}{R}$$

$$\text{or, } \tan\theta = \frac{\frac{1}{\omega C} - \omega L}{R}$$

$$\text{or, } \theta = \tan^{-1}\frac{\frac{1}{\omega C} - \omega L}{R}$$

This is required phase relationship between current and voltage.

30. 2072 Supp Q.No. 5d **Derive an expression for the impedance of a LCR series a.c. circuit. Show graphically how impedance varies with the variation of applied frequency.** **[4]**

Please refer to 2075 Set B Q.No. 5d

31. 2072 Set D Q.No. 5d **An alternating current passes through a circuit containing a resistor, a capacitor and an inductor in series. Derive an expression for the phase relation between the current and the voltage.** **[4]**

Please refer to 2073 Set D Q.No. 5b

32. 2072 Set E Q.No. 5d **Derive the condition for resonant frequency of LCR alternating current circuit.** **[4]**

Please refer to 2075 Set A Q.No. 5d

33. 2071 Supp Q.No. 5c **Define a.c. power. Derive an expression for it. Also define power factor.** **[4]**

Power consumed in an circuit

Let the alternating e.m.f. applied to LCR circuit be

$$E = E_0 \sin\omega t \quad \dots \text{(i)}$$

The current in the circuit be,

$$I = I_0 \sin(\omega t - \theta) \quad \dots \text{(ii)}$$

Power at any instant t is given by

$$\frac{dW}{dt} = EI = E_0 \sin\omega t \times I_0 \sin(\omega t - \theta) = E_0I_0 \sin\omega t\,(\sin\omega t \cos\theta - \cos\omega t \sin\theta)$$

$$= E_0I_0 \sin^2\omega t \cos\theta - E_0I_0 \sin\omega t \sin\theta \cos\omega t = E_0I_0 \sin^2\omega t \cos\theta - \frac{E_0I_0}{2}\sin 2\omega t \sin\theta$$

If this instantaneous power is assumed to remain constant for a small time dt, then small amount of work done in this time is,

$$dW = \left(E_0I_0 \sin^2\omega t \cos\theta - \frac{E_0I_0}{2}\sin 2\omega t \sin\theta\right) dt \quad \dots \text{(iii)}$$

Total work done over a complete cycle is calculated by integrating equation (iii) from time t = 0 to t = T.

$$W = \int_0^T E_0I_0 \sin^2\omega t \cos\theta\, dt - \int_0^T \frac{E_0I_0}{2}\sin 2\omega t \sin\theta\, dt$$

$$= E_0I_0\cos\theta\int_0^T \sin^2\omega t\, dt - \frac{E_0I_0}{2}\sin\theta\int_0^T \sin 2\omega t\, dt \quad \left[\because \int_0^T \sin^2\omega t\,dt = \frac{T}{2},\ \int_0^T \sin 2\omega t\,dt = 0\right]$$

$$\therefore W = E_0I_0\cos\theta\,\frac{T}{2}$$

Now, Average power,

$$P = \frac{W}{T} = \frac{E_0I_0}{2}\cos\theta = \frac{E_0}{\sqrt{2}}\frac{I_0}{\sqrt{2}}\cos\theta$$

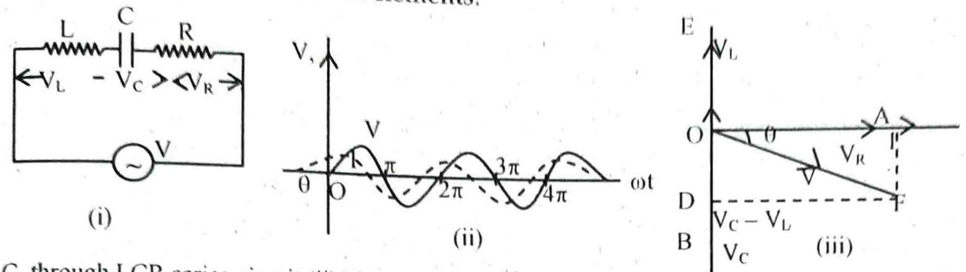
$$\therefore P = I_{rms}\,.\,E_{rms}\cos\theta \quad \dots \text{(iv)}$$

This is required expression for power in ac circuit. The power in ac is defined as the product of the virtual current and virtual potential difference with power factor $\cos\theta$. Here, $\cos\theta$ is power factor which is defined as the ratio of true power to apparent (or virtual power) in an ac circuit.

i.e., Power factor, $\cos\theta = \dfrac{P}{I_{rms}.\,E_{rms}}$

34. 2071 Set D Q.No. 5 d **Derive an expression for the impedance of an ac circuit with an inductor L, a capacitor C and a resistor R in series. Draw the phase diagram if the voltage across the capacitor is greater than that across the inductor.** **[4]**

Let a pure resistor of resistance R, a pure inductor of inductance L and an ideal capacitor of capacitance C be connected in series to a source of alternating e.m.f. as shown in following figure. As R, L and C are in series, current at any instant through the three elements has the same amplitude and phase. However, voltage across each element bears different phase relationship with the current. Let V be the r.m.s. value of the applied alternating e.m.f. to LCR circuit and I be the r.m.s. value of current flowing through all the circuit elements.



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The resultant of V_R and $(V_C - V_L)$ is given by OF. The magnitude of OF is given by

$$OF = \sqrt{(OA)^2 + (OD)^2} = \sqrt{V_R^2 + (V_C - V_L)^2}$$

or $V = \sqrt{I^2 R^2 + (I X_C - I X_L)^2} = I\sqrt{R^2 + (X_C - X_L)^2}$

or, $\frac{V}{I} = \sqrt{R^2 + (X_C - X_L)^2}$

But, $\frac{V}{I}$ = Z is the effective opposition of LCR circuit to A.C. called impedance of the circuit. So, we get

$$Z = \frac{V}{I} = \sqrt{R^2 + (X_C - X_L)^2} \quad \ldots(i)$$

This is required impedance of LCR series circuit.

35. 2070 Set D Q.No. 5 d An ac passes through a circuit containing a resistor and an inductor in series. Derive an expression for the current and phase relation between the current and voltage. [4]

Please refer to 2076 Set B Q.No. 5d

36. 2069 Supp Set B Q.No. 5 b Derive expression for the impedance of an ac circuit containing a resistor and an inductor. Also draw the phase diagram. [4]

Please refer to 2076 Set B Q.No. 5d

37. 2069 (Set A) Q.No. 5d 2052 Q.No. 10 OR Discuss the phase relationship between the voltage and current in the ac circuit containing an inductor and a resistor in series. What is power factor of the circuit? [4]

Please refer to 2076 Set B Q.No. 5d

38. 2067 Q.No. 5d 2060 Q.No. 7 a OR Discuss the phase relationship between the current and voltage in A.C. circuit containing capacitor and resistor in series and hence derive an expression for the impedance of the circuit. [4]

Suppose a pure resistor of resistance R and a pure capacitor of capacitance C are connected in series to a source of alternating e.m.f. as shown in figure (i). Let V be the r.m.s. value of applied alternating e.m.f. and I be the r.m.s. value of current flowing in the circuit.

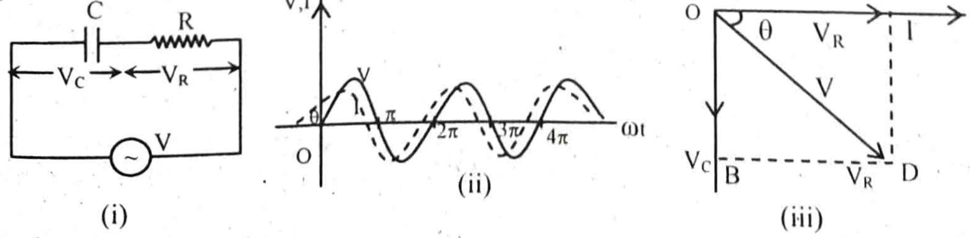


Fig: (i) A.C. through capacitor and resistor in series (ii) Phase relationship between V & I in CR circuit (iii) Phasor diagram

The potential difference across capacitor, $V_C = IX_C$ (lags behind the current I by angle of $\pi/2$). The potential difference across R, $V_R = I.R$ (in phase with the current). Since, V_R and I are in phase so V_R is represented by OA in the direction of I as shown in figure (iii). The current leads the potential difference V_C by angle of $\pi/2$ so V_C is represented by OB perpendicular to the direction of I. So, resultant of V_R and V_C is given by OD. The magnitude of OD is given by,

$$OD = \sqrt{OA^2 + OB^2} = \sqrt{V_R^2 + V_C^2}$$

$$\text{or, } V = \sqrt{I^2 R^2 + I^2 X_C^2}$$

$$\text{or, } V = I\sqrt{R^2 + X_C^2}$$

$$\text{or, } \frac{V}{I} = \sqrt{R^2 + X_C^2} = \sqrt{R^2 + \frac{1}{\omega^2 C^2}}$$

But $\frac{V}{I}$ =Z, is the effective opposition of CR circuit to a.c. called impedance of CR circuit.

The impedance of CR circuit is given by

$$Z = \sqrt{R^2 + X_C^2}$$

$$\text{Again, } I = \frac{V}{Z} = \frac{V}{\sqrt{R^2 + X_C^2}}$$

$$\therefore\ I = \frac{V}{\sqrt{R^2 + \frac{1}{\omega^2 C^2}}} \quad [\because X_c = \frac{1}{\omega^2 C^2}]$$

Where, $Z = \sqrt{R^2 + (1/\omega C)^2}$ is impendence of the circuit

Let θ be the angle between E and I, so from figure (c), we have,

$$\tan\theta = \frac{V_C}{V_R} = \frac{IX_C}{IR}$$

$$\text{or, } \tan\theta = \frac{X_C}{R} = \frac{1}{\omega CR} \quad \therefore\ \tan\theta = \frac{1}{\omega CR}$$

If the values of X_C, and R are known θ can be calculated. This shows that the voltage lags the current or current leads the voltage or e.m.f by an angle θ. The phase relationship between V and I is shown in fig (ii).

39. **2067 Old Q.No. 7a OR** **2066 Q.No. 7 a OR** **Derive an expression for the current flowing through an a.c. circuit containing a resistor and capacitor. Obtain the expression of power factor of this circuit.** [3+

Please refer to 2067 Q.No. 5d

40. **2065 Q.No. 7 a** **Derive the condition for resonant frequency of an L-C-R alternating current series circuit.** [

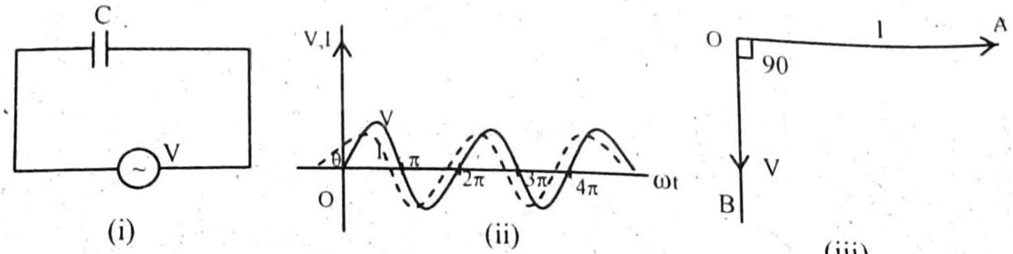
Please refer to 2075 Set A Q.No. 5d

41. **2061 Q.No. 7 a OR** **Find an expression for impedance of an a.c. circuit containing a resistance and capacitor in series. Also discuss the phase relation of current and emf in that circuit.** [3+

Please refer to 2067 Q.No. 5d

42. **2056 Q.No. 9** **An alternating emf is applied across a capacitor. Show that the current in it leads to the applied emf by 90°.** [

AC circuit containing a capacitor:



(i) A.C. through capacitor (ii) Phase relationship between V & I (iii) Phasor diagram

Let us consider a pure capacitor of capacitance C connected across an alternating source of emf V as shown in figure. The emf at any instant in the circuit is

$V = V_o \sin \omega t$ ... (i)

Now, the charge q on the capacitor at the instant is given by

$q = C V = C V_o \sin \omega t$

Thus, the current flowing in the circuit at any instant is

$$I = \frac{dq}{dt} = \frac{d}{dt}(C V_o \sin\omega t) = C\omega V_o \cos \omega t = \frac{V_o}{1/C\omega} \sin\left(\omega t + \frac{\pi}{2}\right)$$

$$I = I_o \sin\left(\omega t + \frac{\pi}{2}\right) \quad \text{...(ii)}$$

where, $I_o = C\omega V_o = \frac{V_o}{1/C\omega} = \frac{V_o}{X_C}$ is the peak value of current. The equation (i) & (ii) show that the current leads the applied voltage by $\frac{\pi}{2}$.

The phase relation between V & I is shown in the wave diagram in (ii) and (iii). The phasor diagram (iii) also shows that I lead V by 90^0.

43. 2055 Q.No. 9 **Find the impendence of LCR circuit in series.** **[4]**

Please refer to 2075 Set B Q.No. 5d

Numerical Problems

44. 2076 Set C Q.No. 9c **A circuit consists of a capacitor of 2μF and a resistor of 1000Ω. An alternating emf of 12V and frequency 50Hz is applied. Find the voltage across the capacitor and the phase angle between the applied emf and the current.** **[4]**

Solution

Given,

Capacitance of capacitor (C) = 2μ F = 2×10^{-6} F

Resistance of resistor (R) = 1000 Ω

emf (V) = 12 V (rms)

Frequency (f) = 50 Hz

Current (I) = ?

Voltage across capacitor (V_C) = ?

Phase angle (ϕ) = ?

We have

$$I = \frac{V}{\sqrt{R^2 + X_C^2}} = \frac{V}{\sqrt{R^2 + \left(\frac{1}{2\pi fC}\right)^2}} = \frac{12}{\sqrt{1000^2 + \left(\frac{1}{2\pi \times 50 \times 2 \times 10^{-6}}\right)^2}} = 6.38 \times 10^{-3}\ \text{A}$$

$$V_C = IX_C = I\frac{1}{2\pi fC} = \frac{6.38 \times 10^{-3}}{2\pi \times 50 \times 2 \times 10^{-6}} = 10.2\ \text{V}$$

$$\phi = \tan^{-1}\left(\frac{V_C}{V_R}\right) = \tan^{-1}\left(\frac{V_C}{IR}\right) = \tan^{-1}\left(\frac{10.2}{6.38 \times 10^{-3} \times 1000}\right) = 57.9°$$

45. 2075 GIE Q.No. 9c **An ac source of 220 V, 50 Hz is connected to series circuit containing a resistor R and inductor L and a capacitor C. If R = 200 Ω, L = 0.5 H and C = 10 μF, calculate, (i) the current in the circuit, (ii) the phase angle and (iii) the power consumed in the circuit.** **[4]**

Solution

Given,

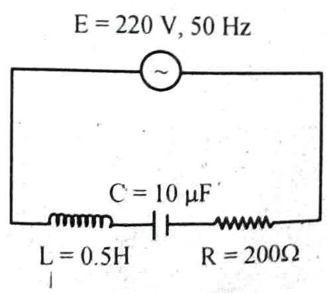
E.m.f. of source (V) = 220 V

Frequency of source (f) = 50 Hz

Resistance (R) = 200 Ω

Inductance (L) = 0.5 H

Capacitance (C) = 10 μF = 10×10^{-6} F



i. Current (I) = ?
ii. Phase angle (ϕ) = ?
iii. Power consumed (P) = ?
We have,

i. $V = I\sqrt{R^2 + (X_L - X_C)^2}$

or, $V = I\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$

or, $I = \frac{V}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$

$= \frac{220}{\sqrt{200^2 + \left(2\pi \times 50 \times 0.5 - \frac{1}{2\pi \times 50 \times 10 \times 10^{-6}}\right)^2}}$

$= \frac{220}{257}$

$= 0.856A$

ii. Let ϕ be phase angle,

$\tan\phi = \frac{X_L - X_C}{R}$

or, $\phi = \tan^{-1}\left(\frac{\omega L - \frac{1}{\omega C}}{R}\right)$

$= \tan^{-1}\left(\frac{2\pi fL - \frac{1}{2\pi fL}}{R}\right)$

$= \tan^{-1}\left(\frac{2\pi \times 50 \times 0.5 - \frac{1}{2\pi \times 50 \times 0.5}}{200}\right)$

$= \tan^{-1}(-0.807)$

$= -38.9°$ [$\because$ – ve sign indicate that current leads voltage]

iii. Power consumed P is

$P = IV\cos\phi$

$= 0.856 \times 220 \times \cos(-38.9)$

$= 146.56$ W

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46. **2074 Supp Q.No. 9c** **An iron cored coil of inductance 2 H and resistance 50 Ω is connected in series with a resistor of 950 Ω. A 220 V, 50 Hz ac supply is connected across the arrangement. Find the current flowing in the circuit and the voltage across the coil.** **[4]**

Solution

Given
Introduction (L) = 2H
Resistance of inductor (R_L) = 50Ω
Resistance of resistor (R_R) = 950 Ω
Emf (V) = 220V
Frequency (f) = 50Hz
Current (I) = ?
Voltage across coil (V_L) = ?
Now, we have,

$X_L = \omega L$

$= 2\pi fL = 2\pi \times 50 \times 2 = 628.32\Omega$

Then, using

$$I = \frac{E}{\sqrt{(R_R + R_L)^2 + X_L^2}} = \frac{220}{\sqrt{(950+50)^2 + (628.32)^2}} = \frac{220}{1181.01} = 0.186 \text{ ampere}$$

Hence, the required current is 0.186 ampere.

Again, we have

$V_L = IX_L$

$= 0.186 \times 628.32 = 116.87$ V

Hence, the required voltage is 116.87V.

---

47. **2074 Set A Q.No. 9c** **A coil of inductance 0.1 H and negligible resistance is in series with a resistance 40 Ω. A supply voltage of 50v (rms) is connected to them. If the voltage across L is equal to that across R, calculate the voltage across the inductor and frequency of the supply.** **[4]**

Solution

Given,

Voltage (V) = 50V

Voltage across resistor (V_R) = voltage across inductor (V_L)

L = 0.1H R = 40Ω

Now, in case of L–R circuit, we have

$V^2 = V_R^2 + V_L^2$

or, $V^2 = V_R^2 + V_R^2$ $[\because V_R = V_L]$

or, $V^2 = 2V_R^2$

or, $V_R^2 = \frac{V^2}{2}$

or, $V_R = \frac{V}{\sqrt{2}} = \frac{50}{\sqrt{2}} = 35.35$V

$\therefore$ $V_R = 35.35$ Volt

Hence, the required voltage across R is 35.35 volt.

Again using,

$V_R = V_L$

or, $IR = IX_L$

or, $R = X_L$

or, $R = \omega L$

or, $R = 2\pi fL$

or, $f = \frac{R}{2\pi L} = \frac{40}{2\pi \times 0.1}$

$\therefore$ $f = 63.7$Hz

Hence, the required frequency is 63.7Hz

---

48. **2073 Supp Q.No. 9c** **2053 Q.No. 11** **An iron cored coil of inductance 3 H and 50 Ω resistance is placed in series with a resistor of 550 Ω and a 100 v, 50 Hz ac supply is connected across the arrangements. Find the current flowing in the coil and voltage across the coil.** **[4]**

Solution

Given,

Inductance (L) = 3H

Resistance of inductor (R_L) = 50Ω

Resistance of resistor (R_R) = 550Ω

Emf (E) = 100V

Frequency (f) = 50Hz

Current (I) = ?

Voltage across coil (V_L) = ?

Now, we have,

$X_L = \omega L$

$= 2\pi fL = 2\pi \times 50 \times 3 = 942.47\ \Omega$

51. 2071 Set C Q.No. 9 c A circuit consists of a capacitor of 2μF and a resistor of 1000Ω. An alternating emf of 12V (rms) and frequency 50Hz is applied. Find the current flowing, the voltage across capacitor and the phase angle between the applied emf and current. [4]

Please refer to 2076 Set C Q No. 9c

52. 2070 Sup (Set A) Q No. 9 b A.C. mains of 200 volts and 50 Hz is joined to a circuit containing an inductance of 100mH and a resistance of 20Ω in series. Calculate the power consumed. [4]

Solution

Given,

Voltage of A.C. mains (V) = 200 V

Frequency of A.C. mains (f) = 50 Hz

Inductance of coil (L) = 1000 mH = 100×10^{-3} H

Resistance of resister (R) = 20 Ω

Power consumed (P) = ?

Now, impedance of circuit

$$Z = \sqrt{R^2 + X_L^2} = \sqrt{R^2 + (2\pi fL)^2} = \sqrt{20^2 + (2\pi \times 50 \times 100 \times 10^{-3})^2} = 37.24 \text{ A}$$

$$\text{Current in the circuit (I)} = \frac{V}{Z} = \frac{200}{37.24} = 5.37 \text{ A}$$

$$\text{Power consumed (P)} = I^2R = 5.37^2 \times 20 = 576.8 \text{ Watt}$$

53. 2070 Supp. (Set B) Q.No. 9 c An iron cored coil of 2 H and 50 Ω resistance placed in series with a resistor of 450 Ω and 200 V, 50H z a.c. supply is connected across the arrangement, find

i. The current flowing the coil,
ii. Its phase angle relative to the voltage supply
iii. The voltage across the coil. [4]

Solution

Given,

Inductance (L) = 2 H

Resistance of wire (R) = 450 Ω

Frequency of a.c. (f) = 50 Hz

Phase angle (ϕ) = ?

Resistance of coil (r) = 50 Ω

Emf (V) = 200 V

Current (I) = ?

Voltage a cross coil (V_L) = ?

Now,

$$I = \frac{V}{\sqrt{(R + r)^2 + X_L^2}} = \frac{V}{(R + r)^2 + (2\pi fL)^2} = \frac{200}{\sqrt{(450 + 50)^2 + (2\pi \times 50 \times 2)^2}} = 0.25\text{A}$$

Now,

$$V_L = IX_L = 0.25 \times 2\pi \times 50 \times 2 = 156.5 \text{ V}$$

$$\phi = \tan^{-1}\left(\frac{V_L}{V_R}\right) = \tan^{-1}\left(\frac{156.5}{0.25 \times 450}\right) = 54.3°$$

54. 2070 Set C Q.No. 9 c A 50 V a.c. supply is connected to a resistor having resistance 50 Ω, in series with a solenoid whose inductance is 0.25 H. The potential difference between the ends of the resistor is 25 V. Find the resistance of the wire of the solenoid. Take frequency of the ac source is 50 Hz. [4]

Solution

Given,

Emf (V) = 50 V

Frequency (f) = 50 Hz

Resistance (R) = 50 Ω

Inductance (L) = 0.25 H

P.d. across resistor (V_R) = 25 V

Resistance of the solenoid (R_s) = ?

Now, for LR circuit, we have

$$I = \frac{V}{\sqrt{(R_s + R)^2 + X_L^2}} = \frac{50}{\sqrt{(R_s + 50)^2 + (\omega L)^2}} = \frac{50}{\sqrt{(R_s + 50)^2 + (2\pi fL)^2}}$$

$$= \frac{50}{\sqrt{(R_s + 50)^2 + 4\pi^2 f^2 L^2}} = \frac{50}{\sqrt{(R_s + 50)^2 + 4 \times \pi^2 \times 50^2 \times 0.25^2}}$$

$$\therefore \quad I = \frac{50}{\sqrt{(R_s + 50)^2 + 6168.5}} \quad \ldots (i)$$

Also, we have

$$I = \frac{V_R}{R} = \frac{25}{50}$$

$$\therefore \quad I = 0.5 \text{ Ampere}$$

From equation (i) we get,

$$0.5 = \frac{50}{\sqrt{(R_s + 50)^2 + 6168.5}}$$

or, $\sqrt{(R_s + 50)^2 + 6168.5} = 100$

or, $(R_s + 50)^2 + 6168.5 = 10000$

or, $(R_s + 50)^2 = 3831.497$

or, $R_s + 50 = 61.89$

$\therefore$ $R_s = 11.89\Omega$

Here, the required resistance is 11.89Ω

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55. **2069 (Set B) Old Q.No. 9b** **Alternating voltage in an ac circuit is represented by $V = 100\sqrt{2}\ \sin(100\ \pi t)$ volts. Find its roots mean square value and the frequency.** **[4]**

Solution

Given,

$V = 100\sqrt{2}\,\text{Sin}(100\pi\ t)$

R.M.S. voltage (V) = ?

Frequency (f) = ?

Compare this eq^n with

$V = V_0 \text{ Sin } wt$

Here, $V_0 = 100\sqrt{2}$ & $w = 100\ \pi$

$$\therefore \quad V_{rms} = \frac{V_0}{\sqrt{2}} = 100V$$

& $2\pi f = 100\pi$

$\therefore$ $f = 50$ Hz

---

56. **2068 Q.No. 9 c** **A circuit consists of an inductor of 200 μ H and resistance of 10Ω in series with a variable capacitor and a 0.10V (r.m.s.), 1.0 MHz supply. Calculate (i) the capacitance to give resonance (ii) the quality factor of the circuit at resonance.** **[4]**

Solution

Given,

Inductance (L) = $200\mu H = 200 \times 10^{-6}$H

Resistance (R) = 10Ω

Emf (E) = 0.10V

Frequency (f) = 1MHz = 10^6Hz

Now, For (i); we have

$X_L = \omega L$

$= 2\pi fL = 2\pi \times 10^6 \times 200 \times 10^{-6} = 1256.6\Omega$

In resonance condition; we have

$X_C = X_L$

or, $\dfrac{1}{\omega C} = 1256.6$

or, $\dfrac{1}{2\pi f C} = 1256.6$

or, $\dfrac{1}{2\pi \times 10^6 \times C} = 1256.6$

$C = 1.26 \times 10^{-10}F$

Hence, the required capacitance is $1.26 \times 10^{-10}F$.

Again, we have,

$$\text{Quality factor (Q)} = \frac{1}{R}\sqrt{\frac{L}{C}} = \frac{1}{10}\sqrt{\frac{200 \times 10^{-6}}{1.26 \times 10^{-10}}} = 125.97 \approx 126$$

Hence, required value of quality factor is 126.

57. **2068 Can. Q.No. 9c** **A 100 V, 50Hz AC source is connected to an LCR circuit containing L= 8.1 mH, C=12.5μ F and R=10 Ω all connected in series. Find the potential difference across the resistor.** **[4]**

Solution

Given

Emf(V) = 100V

Frequency (f) = 50Hz

$L = 8.1mH = 8.1 \times 10^{-3}H$

$C = 125\mu F = 12.5 \times 10^{-6}F$

$R = 10\Omega$

P.d. across the resistor (V_R) = ?

Now, we have

$X_L = \omega L$

$= 2\pi fL = 2\pi \times 50 \times 8.1 \times 10^{-3} = 2.5\ \Omega$

Also,

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 50 \times 12.5 \times 10^{-6}} = 254.65\Omega$$

Then,

$$\text{Current (I)} = \frac{V}{\sqrt{R^2 + (X_L - X_C)^2}} = \frac{100}{\sqrt{10^2 + (2.5 - 254.65)^2}} = \frac{100}{\sqrt{63679.6}} = 0.39 \text{ ampere}$$

Then,

$V_R = IR = 0.39 \times 10 = 3.9V$

Hence, the required p.d. is 3.9V.

58. **2068 Old Can. Q.No. 7b** **An alternating voltage 10V (rms) and 4 KHz frequency is applied to a resistor of resistance 5Ω in series with a capacitor of capacitance 10μF. Calculate the r.m.s. potential differences across the resistor and the capacitor.** **[4]**

Solution

Given,

Voltage (V_{rms}) = 10V

Frequency (f) = 4KHz = 4 × 1000Hz

Resistance (R) = 5Ω

Capacitance (C)= 10μF = $10 \times 10^{-6}F$

p.d. across resistor (V_R) = ?

p.d. across capacitor (V_C) = ?

Now, we have,

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 4 \times 1000 \times 10 \times 10^{-6}} = 3.98\ \Omega$$

Then, in case of R.C. circuit, we have

$$I_V = \frac{V_{rms}}{\sqrt{R^2 + X_C^2}} = \frac{10}{\sqrt{5^2 + (3.98)^2}} = \frac{10}{6.39} = 1.56A$$

Then,

p.d. across resistor (V_R) = $I_V \times R$

$= 1.56 \times 5 = 7.8$ V

Also, p.d. across capacitor (V_C) = $I_V \times X_C$

$= 1.56 \times 3.98 = 6.2V$

Here, the required p.d across resistor & capacitor are 7.8 & 6.2V respectively.

59. 2068 Old Q.No. 7 b A 50V, 50Hz, a.c. supply is connected to a resistor, of resistance 40Ω, in series with a solenoid whose inductance is 0.20H. The p.d. between the ends of the resistor is found to be 20 V. What is the resistance of the wire of the solenoid? (Assume $\pi^2 = 10$) [3]

Solution

Given

Emf (V) = 50V

Frequency (f) = 50Hz

Resistance (R) = 40Ω

Inductance (L) = 200mH = $\frac{200}{1000}$ = 0.2H

P.d. across resistor (V_R) = 20V

Resistance of the solenoid (R_s) = ?

Now, for LR circuit, we have

$$I = \frac{V}{\sqrt{(R_s + R)^2 + X_L^2}} = \frac{50}{\sqrt{(R_s + 40)^2 + (\omega L)^2}} = \frac{50}{\sqrt{(R_s + 40)^2 + (2\pi f L)^2}}$$

$$= \frac{50}{\sqrt{(R_s + 40)^2 + 4\pi^2 f^2 L^2}} = \frac{50}{\sqrt{(R_s + 40)^2 + 4 \times \pi^2 \times 50^2 \times 0.2^2}}$$

$$\therefore I = \frac{50}{\sqrt{(R_s + 40)^2 + 3947.84}} \quad \ldots(i)$$

Also, we have

$$I = \frac{V_R}{R} = \frac{20}{40}$$

$\therefore$ I = 0.5 Ampere

From equation (i) we get,

$$0.5 = \frac{50}{\sqrt{(R_s + 40)^2 + 3947.84}}$$

or, $\sqrt{(R_s + 40)^2 + 3947.84} = 100$

or, $(R_s + 40)^2 + 3947.84 = 10000$

or, $(R_s + 40)^2 = 6052.16$

or, $R_s + 40 = 77.79$

$\therefore$ R_s = 37.79Ω

Here, the required resistance is 37.79Ω

60. 2067 Sup Q.No. 9c An iron cored coil of inductance 2H and of resistance 50Ω is connected in series with a resistor of 950Ω, and a 220V, 50 Hz ac supply. Find the current flowing in the circuit and the voltage across the coil. [4]

Please refer to 2074 Supp Q.No. 9c

61. 2066 Supp Q.No. 7b A coil of inductance 0.1H and negligible resistance is in series with a resistance R. A supply voltage of 40 V (rms) is connected to them. If a voltage across L is equal to that across R, calculate the voltage across R and the frequency of the supply? [4]

Solution

Given,

Voltage (V) = 40V

Voltage across resistor (V_R) = voltage across inductor (V_L)

L = 0.1H   R = 40Ω

Now, in case of L-R circuit, we have

$V^2 = V_R^2 + V_L^2$

or, $V^2 = V_R^2 + V_R^2$ [$\because V_R = V_L$]

or, $V^2 = 2V_R^2$

or, $V_R^2 = \frac{V^2}{2}$

or, $V_R = \frac{V}{\sqrt{2}} = \frac{40}{\sqrt{2}}$

$\therefore$ $V_R = 28.3$volt

Hence, the required voltage across R is 28.3 volt.

Again using,

$V_R = V_L$

or, $IR = IX_L$

or, $R = X_L$

or, $R = \omega L$

or, $R = 2\pi fL$

or, $f = \frac{R}{2\pi L} = \frac{40}{2\pi \times 0.1}$

$\therefore$ $f = 63.7$Hz

Hence, the required frequency is 63.7Hz

---

62. 2064 Q.No. 7 b **A 50V, 50 Hz, ac supply is connected to a resistor of resistance 40Ω in series with a solenoid having inductance 200 mH with same resistance. The potential difference across the ends of the 40Ω resistor is found to be 20V. Find the resistance of the wire of the solenoid.** **[4]**

Please refer to 2068 Old Q.No. 7 b

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63. 2063 Q.No. 7 b **An inductor, a resistor and a capacitor are connected in series across an a.c. circuit. A voltmeter reads 60 V when connected across the inductor, 16V across the resistor and 30 V across the capacitor:**

i. **What will the voltmeter read when placed across the series circuit?**
ii. **What is the power factor of the circuit?** **[4]**

Solution

Given,

Voltage across inductor, $V_L = 60$ volt

Voltage across resistor, $V_R = 16$ volt

Voltage across capacitor, $V_C = 30$ volt

i. Voltmeter reading across the series, V = ?

ii. Power factor = ?

We know,

$V = I\sqrt{R^2 + (X_L - L_C)^2}$

or, $V^2 = I^2 R^2 + (IX_L - IX_C)^2$

$= (16)^2 + (60-30)^2 = 16^2 + 30^2$

$V^2 = 1156$

$\therefore$ $V = 34$ volt

Again, we know

Power factor $(\cos\theta) = \frac{R}{\sqrt{R^2 + (X_L - L_C)^2}} = \frac{IR}{I\sqrt{R^2 + (X_L - X_C)^2}} = \frac{V_R}{\sqrt{V_R^2 + (V_L - V_C)^2}} = \frac{V_R}{V} = \frac{16}{34} = 0.47$

---

64. 2062 Q.No. 7 b **In a series LCR circuit, R = 25Ω, L = 30mH and C = 10μF and these elements are connected to 240 ac (rms) 50 Hz source. Calculate the current in the circuit and voltmeter reading across a capacitor.** **[4]**

Solution

Given,

Resister (R) = 25Ω

Inductor (L) = 30mH

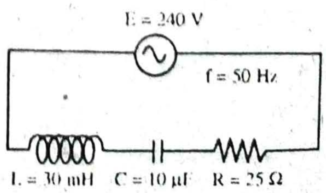
Capacitor (C) = 10μF

Voltage (V) = 240 V

Frequency = 50Hz

Current in the circuit, I = ?

Voltmeter reading across the capacitor, V_C = ?



In such case, we have,

$$V = I\sqrt{R^2 + (X_L - X_C)^2}$$

$$\text{or, } V = I\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

$$\text{or, } I = \frac{V}{\sqrt{R^2 + \left(2\pi f L - \frac{1}{2\pi fC}\right)^2}} = \frac{240}{\sqrt{(25)^2 + \left(2\pi \times 50 \times 30 \times 10^{-3} - \frac{1}{2\pi \times 50 \times 10 \times 10^{-6}}\right)^2}}$$

$I = 0.774$ Amp

And, p.d. across capacitor,

$$V_C = I X_C = I\frac{1}{2\pi fC} = 0.774 \times \frac{1}{2\pi \times 50 \times 10 \times 10^{-6}} = 246.37 \text{ volt.}$$

65. **2059 Q.No. 7 b** **The maximum capacitance of a variable capacitor is 33 pF. What should be the self-inductance to be connected to this capacitor for the natural frequency of the LC circuit to be 810 KHz. Corresponding to A.m. broadcast band of Radio Nepal?** **[4]**

Solution

Given,

Capacitance (C) = 33pF = 33×10^{-12} F

Let, L be the self-inductance connected with the capacitance, so the natural frequency of this LC circuit is, f = 810KHz = 810×10^3Hz.

Now, using

$$f = \frac{1}{2\pi\sqrt{LC}}$$

$$\text{or, } L = \frac{1}{4\pi^2 f^2 C} = \frac{1}{4\pi^2 (810 \times 10^3)^2 \times 33 \times 10^{-12}} = 1.17 \times 10^{-3}\text{H}$$

Hence, the required inductance is 1.17×10^{-3}H.

66. **2057 Q.No. 7 b** **A circuit consists of a capacitor of 10 μF and a resistor of 1000Ω. An alternating emf of 12V (rms) and frequency 50Hz is applied. Calculate the current flowing and voltage across the capacitor.** **[4]**

Solution

Given,

Capacitance of capacitor, (C) = 10μF = 10×10^{-6}F

Resistance (R) = 1000Ω

emf (V) = 12V (rms)

Frequency (f) = 50Hz

Now, impedance of the circuit is given by

$$Z = \sqrt{R^2 + X_C^2}$$

$$= \sqrt{R^2 + \frac{1}{C^2\omega^2}} = \sqrt{R^2 + \frac{1}{(C \times 2\pi f)^2}} \quad (\because \omega = 2\pi f)$$

$$= \sqrt{(1000)^2 + \frac{1}{\left(10 \times 10^{-6} \times 2 \times \frac{22}{7} \times 50\right)^2}} = \sqrt{1000000 + \frac{1}{9.86 \times 10^{-6}}}$$

$= 1049.4\ \Omega$

Then,

$$\text{Current flowing (I)} = \frac{V}{Z} = \frac{12}{1049.4} = 0.0114 \text{ A}$$

Now,

$$\text{Voltage across the capacitor } (V_C) = I \times X_C = I \times \frac{1}{2\pi fC} = 0.0114 \times \frac{1}{2 \times \frac{22}{7} \times 50 \times 10 \times 10^{-6}} = 3.63 \text{ V}$$

Hence, the required current is 0.0114 ampere & voltage is 3.63 V.

67. **2054 Q.No. 11** **A constant A.C. supply is connected to a series circuit consisting of a resistance of 300Ω in series with a capacitance 6.67 μF, the frequency of the supply being 3000/2π Hz. It is desired to reduce the current in the circuit to half its value. Show how this could be done by placing an additional resistance.** **[4]**

Solution

Given,

Resistance (R) = 300Ω

Capacitance (C) = 6.67μF = 6.67×10^{-6}F

Frequency (f) = $\frac{3000}{2\pi}$ Hz

Let, I_1 & I_2 be the current in the 1st & 2nd condition then, according to the question.

$$I_2 = \frac{I_1}{2}$$

We have,

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi fC} = \frac{1}{2\pi \times \frac{3000}{2\pi} \times 6.67 \times 10^{-6}} = 49.97\ \Omega$$

Now,

For 1st condition, we have,

$$I_1 = \frac{V}{\sqrt{R^2 + X_C^2}} \quad \ldots(i)$$

Again, Let, (R') be the resistance in 2nd case, then

$$I_2 = \frac{V}{\sqrt{R'^2 + X_C^2}}$$

$$\text{or, } \frac{I_1}{2} = \frac{V}{\sqrt{R'^2 + X_C^2}} \quad \ldots(ii)$$

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

$$\frac{I_1}{\frac{I_1}{2}} = \frac{\frac{V}{\sqrt{R^2 + X_C^2}}}{\frac{V}{\sqrt{R'^2 + X_C^2}}}$$

$$\text{or, } 2 = \frac{\sqrt{R'^2 + X_C^2}}{\sqrt{R^2 + X_C^2}}$$

$$\text{or, } 2 = \frac{\sqrt{R'^2 + (49.97)^2}}{\sqrt{(300)^2 + (49.97)^2}}$$

$$\text{or, } 2 = \frac{\sqrt{R'^2 + 2497}}{304.13}$$

$$\text{or, } 608.26 = \sqrt{R'^2 + 2497}$$

$$\text{or, } 369980.22 = R'^2 + 2497$$

$$\text{or, } R'^2 = 369783.22$$

$$\therefore R' = 606.1\Omega$$

Hence, the resistance to be added = R' – R = (606.1 – 300)Ω = 306.1 Ω

□□□

UNIT 3 Modern Physics

Chapter 1: Electrons and Photons

Short Answer Questions

1. 2076 Set B Q.No. 2a **Why discharge does not take place at very low pressure?** [2]

At lower pressure, the ionized particles (ions and electrons) have higher mean free path and easily reach to electrodes. The discharge thus takes place. But at very low pressure, no particles are sufficient for discharging or ionizing and discharge does not take place.

2. 2075 GIE Q.No. 2a 2071 Supp Q.No. 2a **Explain why electric discharge through a gas takes place at low pressure.** [2]

At high pressure and low voltage, due to presence of more atoms, the positively charged particles (or ions) and electrons can move freely for short distance only. The particles present in the tube are not able to travel to cathode or anode but soon recombine. Thus further ionization by the initial ions is prevented. But at low pressure and high voltage, ionized particles (ions and electrons) have larger mean free path and can move towards electrodes with high energy and, in their way, can ionize other gas atoms. Thus, more ions will be produced and gas becomes conducting. Hence, for the gas in the discharge tube kept at low pressure and high potential difference become conducting.

3. 2075 GIE Q.No. 2b **If the wavelength of electromagnetic radiation is doubled, what will happen to the energy of the photons?** [2]

According to Einstein Photoelectric equation the kinetic energy of photon is given as

$$= \frac{1}{2}mv^2 = hf - \phi_0$$

where ϕ_0 is work function of a metal, h is Planck's constant and if is frequency of radiation.

Now,

$$\frac{1}{2}mv^2 = \frac{hc}{\lambda} - \phi_0$$

or, $E \propto \frac{1}{\lambda}$ at constant ϕ_0.

When wavelength of radiation doubled the energy of photon is reduced to half.

4. 2075 Set A Q.No. 2a 2068 Can. Q.No. 2a **Gases are insulators at ordinary pressure and start conducting at low pressure. Why?** [2]

At ordinary pressure, due to presence of more atoms, the positively charged particles (or ions) and electrons can move freely for short distance only. The particles present in the tube are not able to travel to cathode or anode but soon recombine. Thus, further ionization by the initial ions is prevented. But at low pressure ionized particles (ions and electrons) have greater mean free path and can move towards electrodes with high energy and in their way can ionize other gas atoms. Thus, more ions will be produced and gas becomes conducting. Hence, for the gases in the discharge tube kept at normal pressure are insulators and at low pressure becomes conducting.

5. 2075 Set A Q.No. 2c 2070 Supp. (Set B) Q.No. 2 b **What happens to the kinetic energy of photo electrons when intensity of light is doubled?** [2]

The kinetic energy of photoelectrons is given by, $hf = \phi + \frac{1}{2}mv^2$, where ϕ is work function, f is frequency of incident radiation, m is the mass of photoelectron and v be the speed. Here, the speed or K.E. depends upon the frequency of radiation but does not depend on the intensity of radiation. So, there is no effect to the kinetic energy of photoelectron when the intensity of incident light is doubled.

6. 2075 Set B Q.No. 2a **Why is a magnetic field used to deflect electron beam but not an electric field in a T.V. picture tube?** [2]

The motion of electron in electric field is parabolic while in magnetic field is circular. In a television picture tube, if an electric field is used to deflect the electron beam, either very high voltage is to be applied or a very long tube is to be used. However, if a magnetic field is used, even a small field can produce large deflection. On the other hand, size of picture tube is reduced. Therefore, the magnetic field is used to deflect electron beam in a television picture tube instead of electric field.

7. 2074 Supp Q.No. 2a **Gases become conducting at low pressure. Why?** [2]

Please refer to 2075 Set A Q.No. 2a

8. 2074 Set A Q.No. 2b 2071 Set C Q.No. 2 a 2069 (Set A) Q.No. 2a **The value of e/m is constant for cathode rays but not for positive rays, why?** [2]

The value of e/m is constant for cathode rays because cathode rays are the beam of electrons. The mass and charge of electrons are constant and hence e/m for electrons is universal constant. But the positive rays are made up of positive ions which are different for different substance because of their different masses. So, values of e/m are different for different ions.

9. 2073 Supp Q.No. 2a 2069 Supp Set B Q.No. 2 a **An electron and a proton move with the same speed in a uniform magnetic field of equal magnitude. Compare the radii of their circular path.** [2]

The radius of circular path covered by a charged particle moving in a magnetic filed of flux density B is given by

$$r = \frac{mv}{Bq},$$

where m is the mass of charged particle, v be velocity and q be the charge of particle. Or, $r \propto m$. Since, mass of proton is greater than mass of electron; the radius of proton is greater than the radius of electron for same speed and charge in a magnetic field.

10. 2072 Supp Q.No. 2b **Human skin is relatively insensitive to visible light, but ultra violet radiation can cause severe burns. Does this have anything to do with photon energies? Explain.** [2]

The energy of photon is given by

$E = hf = h\frac{c}{\lambda}$. Since, $\lambda_V > \lambda_{uv}$, $E_V < E_{UV}$.

The wavelength of visible light is greater than the wavelength of ultraviolet light and the energy of ultraviolet ray is greater than visible light. So, UV radiation can cause severe burns to human skin and the skin is insensitive to visible light.

11. 2072 Set C Q.No. 2a **If we go on increasing the wavelength of light incident on a metal surface, what changes take place in the number of electrons and energy of the electrons?** [2]

The no. of photo-electrons emitted from the surface of metal surface depends up on the intensity of light but not depends upon the wavelength of light. So, number of photo-electrons emitted remains constant when the wavelength of incident light increases.

The energy of electron emitted is,

$$hf = \phi + \frac{1}{2}mv^2$$

$$\text{or, } \frac{1}{2}mv^2 = hf - \phi$$

$$\text{or, } \frac{1}{2}mv^2 = \frac{hc}{\lambda} - \phi$$

When wavelength (λ) of light increases, the K.E. of photo-electrons emitted decreases.

12. 2072 Set E Q.No. 2a **Beams of electrons and protons having the same initial K.E. enter normally into an electric field, which beam will be more curved? Justify.** [2]

The kinetic energy K.E. of a charged particle is given as,

$$K.E. = \frac{1}{2}mv^2$$

or, $v^2 = 2\,K.E./m$.

The deflection of a charged particle in an electric field is given as,

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

$$= \frac{1}{2}\frac{F}{m}t^2 \qquad [a = F/m, \text{ or, } F = ma]$$

$$= \frac{1}{2}\frac{e}{m}E\left(\frac{l}{v}\right)^2 = \frac{1}{2}\frac{e}{m}E\frac{l^2}{v^2} = \frac{1}{2}\frac{e}{m}E\frac{l^2}{2K.E.}\cdot m = \frac{1}{2}\frac{e}{m}.E.\frac{l^2}{2K.E.}$$

Hence, for same K.E. and electric field intensity E, the electron has less mass and hence greater curve than that of proton.

13. **2071 Set D Q.No. 2 a** **A gas at lower pressure conducts electricity but the same gas at higher pressure does not. Explain.** **[2]**

Please refer to 2075 Set A Q.No. 2a

14. **2070 Sup (Set A) Q.No. 2 b** **Gases at normal pressure are insulators; how do they become conducting at low pressure?** **[2]**

Please refer to 2075 Set A Q.No. 2a

15. **2070 Set C Q.No. 2 a** **A charged particle is fired into a cubical region of space where there is uniform magnetic field. Outside this region, there is no magnetic field. Is it possible that the particle will remain inside the cubical region? Explain.** **[2]**

Yes, it is possible that the particle will remain inside the cubical region if it enters perpendicularly to the magnetic field and the diameter of circular path is less than the side of the cube.

16. **2070 Set D Q.No. 2 a** **A charged particle moves through a region of space with constant velocity. If the external magnetic field is zero in this region, can we conclude that the external field in the region is also zero? Explain.** **[2]**

Yes, the velocity is constant only in the region of zero electric field because the velocity of charged particle will be constant in a field free space and in cross-field space. Here, magnetic field is zero and hence for constant velocity electric field also be zero.

17. **2069 (Set B) Q.No. 2f** **Write down expressions for acceleration of a moving charge Q in parallel and perpendicular magnetic fields.** **[2]**

The force experienced by a charge Q of mass m moving in a magnetic field of intensity B with velocity v and making an angle θ with the field is F = BQvsinθ. Then the expression for acceleration of a moving charge Q in parallel and perpendicular magnetic field are; $a = \frac{BQv \sin 0}{m} = 0$, as $\theta = 0^o$ and $a = \frac{BQv \sin 90}{m} = \frac{BQv}{m}$, as $\theta = 90^o$ respectively.

18. **2068 Q.No. 2 a** **What property of the cathode rays indicates that they consist of electrons?** **[2]**

The value of charge (e) and specific charge (e/m) for cathode rays is same as that of electrons. Hence, the cathode rays must consists of electrons.

19. **2067 Sup Q.No. 2a** **Why does electric discharge take place at low pressure and high potential difference?** **[2]**

Please refer to 2075 GIE Q.No. 2a

20. **2067 Q.No. 2a** **What is the importance of Millikan's oil drop experiment?** **[2]**

Importance of Millkan's Experiment

i. Millikan's experiment shows that electronic charge is the smallest possible charge on a charged particle or ion.

ii. Millikan's experiment has proved the quantization of charge i.e., a charged body can carry an integral multiple of minimum charge e.
i.e., Q = ± n e, where n = 1, 2, 3....

iii. There is no direct method to find the mass of an electron. Knowing the charge of an electron and specific charge, the mass of the electron can be determined as

$$m = \frac{e}{e/m} = \frac{1.6 \times 10^{-19} C}{1.75 \times 10^{11} C/kg} = 9.11 \times 10^{-31} kg$$

21. 2065 Q.No. 2 f **Compare the specific charge of an electron with that of a proton.** [2]

The specific charge of an electron of mass m_e and charge e is e/m_e, whereas the specific charge of a proton of mass m_p and charge e is e/m_p. Then,

$$\frac{e/m_e}{e/m_p} = \frac{e}{m_e} \times \frac{m_p}{e} = \frac{m_p}{m_e} = \frac{1.67 \times 10^{-27}}{9.1 \times 10^{-31}} \approx 1840$$

So, specific charge of electron is nearly 1840 times the specific charge of proton.

22. 2060 Q.No. 1 g **Cathode rays cannot be regarded as electromagnetic waves. Why?** [2]

Cathode rays are not electromagnetic waves, which is clear from the following reasons:

a. Cathode rays are fast moving electrons but electromagnetic waves consist of oscillating electric and magnetic fields.

b. The speed of cathode rays is about $(1/10)^{th}$ of speed of light, but the speed of electromagnetic wave is as the speed of light.

c. Cathode rays are produced normally from the surface of a cathode, but electromagnetic waves can be emitted in all directions from the cathode.

d. Cathode rays are deflected inside the electric and magnetic field in such a way that it confirms the negatively charged particle nature of cathode rays. But, electromagnetic waves have no effect on electric and magnetic field.

23. 2056 Q.No. 12 a **Why a glowing gas, such as that in a neon tube, gives only certain wavelengths of light?** [2]

Neon tube is a discharge tube containing neon gas at low pressure and high potential difference between the anode and cathode. Due to high potential difference between the anode and cathode, electrons are accelerated towards the anode and colliding with neon atoms, ionize them which excite the positive ions. When these exciting particles return to lower energy level, emit the characteristic pink light. There is only one neon gas but not other gas, so a glowing gas such as that in a neon tube, gives only certain wavelength of light.

24. 2056 Q.No. 12 c **What is meant by stopping potential?** [2]

The minimum retarding potential applied to the anode at which photoelectric current becomes zero is called stopping potential and denoted by V_0. Stopping potential V_0 stops the photoelectrons with maximum kinetic energy reaching the anode and hence name stopping potential. If m is mass of emitted photoelectron and v_{max} is its maximum velocity, then

$$K.E._{max} = e V_0 = \frac{1}{2} m v^2_{max}$$

25. 2055 Q.No. 13 **Discuss the physical principles involved in Millikan's experiment for the determination of the charge of an electron.** [2]

The principle of Millikan's experiment is to measure the terminal velocity (by Stoke's law) of the charged oil drops (i) under the action of gravity alone and (ii) under the combined action of gravity and electric field opposed to gravity. Knowing the terminal velocities under these conditions, we can easily find the charge on each droplet. It will be found that every charged droplet has a charge equal to integral multiple of basic charge e (i.e., 2e, 3e, 4e, etc.).

26. 2054 Q.No. 12 d **Explain why photoelectric effect cannot be observed with all wavelengths of light.** [2]

The wavelength corresponding to threshold frequency is known as threshold wavelength λ_0. The photoelectrons will be emitted with some kinetic energy, for emission of photoelectron the wavelength of the incident radiation should be less than the threshold wavelength. The energy of the radiation should be more than the work function of the metal. Hence, photoelectric effect cannot be observed with all wavelengths of light.

27. 2053 Q.No. 12 e **What is threshold frequency?** [2]

The minimum frequency of incident radiation required to eject an electron (i.e., with zero velocity) from the surface of a metal is known as threshold frequency (f_0) for that metal. Different metals have different threshold frequencies. Illumination of a surface with light of frequency less than f_0 will not cause ejection of photoelectrons.

Long Answer Questions

28. 2076 Set B Q.No. 6a **What is quantization of charge? Describe the theory of Millikan's oil drop experiment to determine the number of charges on an oil drop.** [4]

Millikan's Oil Drop Experiment: Millikan determined the value of charge on an electron using oil drop method which is discussed below.

The experimental arrangement used by Millikan to determine the charge on an electron is shown in a Fig. It consists of two metal circular plates A and B about 20 cm in diameter and 1.5 cm apart with a small hole H in the centre of the upper plate A.

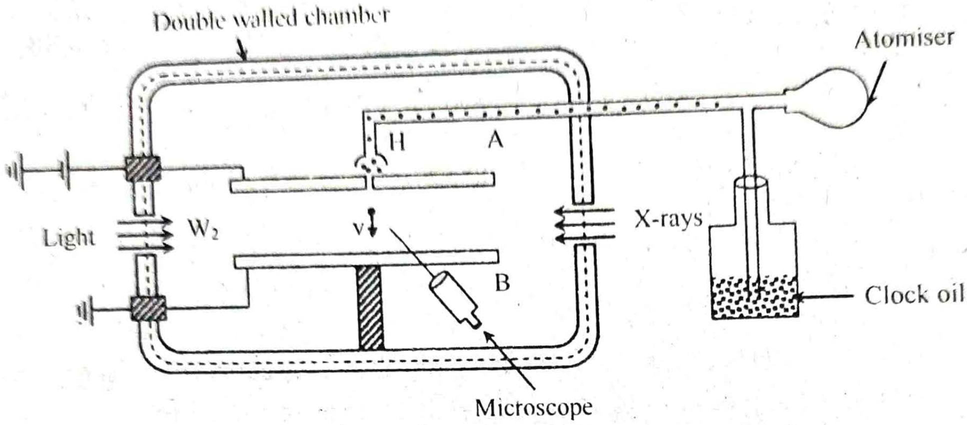


Fig. Millikan's experimental apparatus

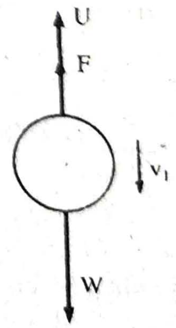
The upper plate A is connected to a positive of high tension battery while the lower plate B is earthed or upper plate is connected to the positive terminal and lower plate is connected to negative terminal of high tension battery. The plates are arranged inside a double walled chamber.

Through hole in the upper plate H, clock oil (a non volatile liquid) is sprayed by means of atomizer. These drops get charged due to friction and carry a few electronic charges. The window W_1 (not seen in figure) is used to illuminate the oil drops by providing enough light. The window W_2 is used to let X-rays pass in to the space between the plates in order to ionize the oil drops in case the oil drops are not ionized by friction. The microscope is provided with a crosswire and a micrometer scale so that the motion of the drop can be observed and measured.

Theory 1:

Motion of oil drop under gravity alone: Suppose the electric field is not applied. As the oil drop falls under gravity, its velocity goes on increasing. A stage comes when the viscous force on the oil drop becomes equal to its resultant weight. The oil drop now moves with a constant velocity v_1 called terminal velocity.

Let, r = radius of oil drop
m = mass of oil drop
ρ = density of the oil
σ = density of air



Then, Volume of the oil drop $= \frac{4}{3}\pi r^3$

Weight of the oil drop (W) $= \frac{4}{3}\pi r^3 \rho g$

Upthrust due to the air, U = weight of the air displaced by the drop

$= \frac{4}{3}\pi r^3 \sigma g$

The viscous force on the oil drop in upward direction, $F = 6\pi \eta r v_1$

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

F + U = W

$$6\pi \eta r v_1 + \frac{4}{3}\pi r^3 \sigma g = \frac{4}{3}\pi r^3 \rho g$$

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

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

Knowing the values of ρ, σ, η, v_1 and g, the radius of the oil drop can be calculated.

Theory 2:

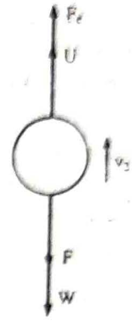
Motion of the oil drop under electric field: A strong electric field is applied between the plates in such a direction that force on the negatively charged oil drop due to the electric field acts in the vertically upward direction. Now, the oil drop starts moving upward and soon attains a terminal velocity v_2 in upward direction.

Let, E be the strength of the electric field. As the drop carries a charge Q, then, electrostatic force on oil drop in

Upward direction $(F_e) = QE$

Viscous force in downward direction $(F) = 6\pi \eta r v_2$

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



When the oil drop attains terminal velocity v_2, then

$$F_e + U = F + W$$

or, $F_e = (W - U) + F$

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

or, $QE = 6\pi\eta r v_1 + 6\pi \eta r v_2$

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

or, $Q = 6\pi \eta \frac{(v_1 + v_2)}{E} \times \sqrt{\frac{9 \eta v_1}{2(\rho - \sigma) g}}$ ...(ii)

Knowing all the quantities on the right hand side, the value of charge Q on the oil drop can be determined. By repeating the experiment for different drops, Millikan fount that all charges turned out to the integral multiple of unique value of 1.6×10^{-19}C, which is the charge associated with an electron.

Importance of Millkan's Experiment

i. Millikan's experiment shows that electronic charge is the smallest possible charge on a charged particle or ion.

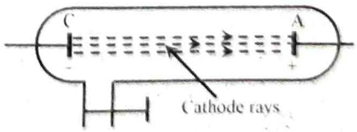
ii. Millikan's experiment has proved the quantization of charge i.e., a body can carry an integral multiple of minimum charge e. The value of e is 1.6×10^{-19}C.
i.e., $Q = \pm n e$, where n = 1, 2, 3....

iii. There is no direct method to find the mass of an electron. Knowing the charge of an electron and specific charge, the mass of the electron can be determined as

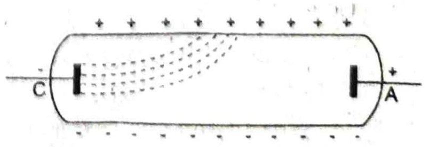
$$m = \frac{e}{e/m} = \frac{1.6 \times 10^{-19} c}{1.75 \times 10^{11} c/kg} = 9.11 \times 10^{-31} \text{ kg}$$

29. **2076 Set C Q.No. 6a** **2068 Old Q.No. 9** **What are cathode rays? How are they produced? Mention the properties of cathode rays.** **[4]**

Ans. The invisible rays, emerging normally from the cathode of a discharge tube, kept at a pressure of 0.01 mm of Hg and under a very high potential difference of the order of 10–15 KV, supplied from an induction coil, are called cathode rays. These rays are independent of the nature of the gas and their propagation is independent of the position of anode.



Properties of Cathode Rays



1. Cathode rays are emitted normally from the surface of the cathode.
2. Cathode rays can penetrate small thickness of matter such as sheets of aluminum foil.
3. Cathode rays travel in straight line and cast sharp shadows of the objects placed in their path.
4. Cathode rays carry negative charge. So they are deflected by electric and magnetic fields.
5. Cathode rays carry momentum and kinetic energy.

6. They produce heat when they fall upon matter.
7. When cathode rays are suddenly stopped by a target, X – rays are produced.
8. Cathode rays can ionize the gas through which they pass.
9. They affect the photographic plate.
10. They travel with 1/10th the velocity of light.
11. Cathode rays produce fluorescence when they fall on certain substance like phosphorus.
12. Cathode rays can exert mechanical pressure.

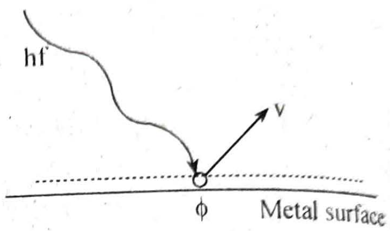
30. 2076 Set C Q.No. 6c What is photoelectric effect? Discuss Einstein's photoelectric equation. Write some applications of photoelectric effect. [4]

Photoelectric effect: The process of emission of electrons from metal surface when the light radiation of suitable frequency falls on it is called photoelectric effect. The electrons emitted in this process are called photoelectrons.

Einstein's photoelectric equation: According to Planck's quantum theory of radiation, the energy associated with each photon of light with frequency f is given by

E = hf, where h is the Planck's constant and f is frequency of photon.

When a photon of energy hf is incident on a metal surface, it is used in two ways:



a. A part of this energy 'ϕ' is used to knock out an electron from surface of metal. The minimum energy 'ϕ' required just to liberate an electron from the surface of metal without imparting any KE to it is called work function of the metal.

b. The rest of the energy is used to impart the KE of ejected photo electrons (E_k). If m is the mass & v is the velocity of the photoelectron after the emission, the KE of the electron is given by,

$$E_k = \frac{1}{2} mv^2$$

Thus, the Einstein photoelectric electric is

Energy of photon= work function+ kinetic energy of emitted electrons

or, $hf = \phi + E_k$

$\therefore \quad hf = \phi + \frac{1}{2}mv^2$

Energy of photon = work function + K.E. of emitted electrons

This equation is known as *Einstein's photoelectric equation*.

Some applications of photoelectric effect

Photoelectric effect (photo-electricity) is used in photoelectric cells called photocells. A photoelectric cell is a device which converts light energy into electric energy. There are three types of photo electric cells; photo-emissive cell, photovoltaic cell and photoconductive cell. They are used in TV camera, TV receivers, cinematography to re-produce sound, photography as exposure meter etc.

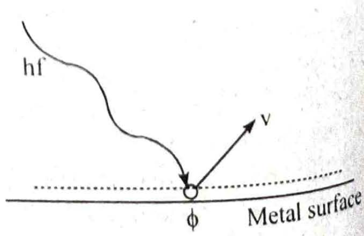
31. 2075 GIE Q.No. 6b Describe Millikan's experiment to determine the value of Plank's constant. Explain how Einstein's photoelectric equation is verified from this experiment. [4]

Photoelectric effect: The process of emission of electrons from metal surface when the light radiation of suitable frequency falls on it is called photoelectric effect. The electrons emitted in this process are called photoelectrons.

Einstein's photo electric equation: According to Planck's quantum theory of radiation, the energy associated with each photon of light with frequency f is given by

E = hf, where h is the Planck's constant and f is frequency of photon.

When a photon of energy hf is incident on a metal surface, it is used in two ways:



a. A part of this energy 'ϕ' is used to knock out an electron from surface of metal. The minimum energy 'ϕ' required just to liberate an electron from the surface of metal without imparting any KE to it is called work function of the metal.

b. The rest of the energy is used to impart the KE of ejected photo-electrons (E_k). If m is the mass & v is the velocity of the photoelectron after the emission, the KE of the electron is given by $E_k = \frac{1}{2} mv^2$

Thus, the Einstein photoelectric equation is

Energy of photon= work function+ kinetic energy of emitted electrons

or, $hf = \phi + E_k$

or, $hf = \phi + \frac{1}{2} mv^2$

or, $hf = hf_0 + \frac{1}{2} mv^2$

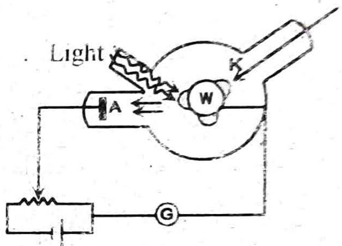
$\therefore \frac{hc}{\lambda} = \frac{hc}{\lambda_0} + \frac{1}{2} mv^2$

Energy of photon = work function + K.E. of emitted electrons.

This equation is known as *Einstein's photoelectric equation*.

Experimental verification of Einstein's Photoelectric Emission

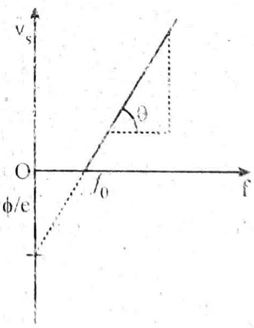
Millikan performed an experiment to verify Einstein's photo electric equation & hence to determine the value of Planck's constant. The experimental arrangement has been shown in the figure. It consists of an evacuated glass flask with window and a rotating wheel W. The alkali metals like lithium, sodium and potassium are used to emit the photoelectrons.



These metals are connected with a rotating wheel W which is made cathode by connecting it with negative terminal of battery. A knife K is connected with this to clean the metal surface. A radiation of suitable frequency falls on a given metal surface at a time through window of an evacuated glass flask which emits the photoelectrons from the metal surface. These photoelectrons are attracted towards the anode and we can see the anode current on the galvanometer or ammeter connected to it.

Theory:

Let negative potential to the anode increases with the help of rheostat. The negative potential at anode repels the electrons reaching to it. On increasing the negative anode potential, anode current decreases. At a certain negative anode potential the anode current becomes zero called stopping potential. The frequency of incident radiation is changed by color filter and the corresponding stopping potential V_s is noted. A set of observations is taken for different values of incident frequency and corresponding stopping potential.



At stopping potential, we have

$eV_s = \frac{1}{2} mv^2$

Since the photo electric equation is,

$\frac{1}{2} mv^2 = hf - \phi$

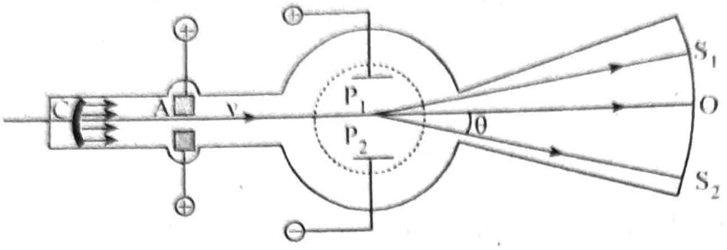
Thus, $eV_s = hf - \phi$

$\therefore V_s = \frac{h}{e} f - \frac{\phi}{e}$

This equation represents a straight line between stopping potential V_s and frequency of incident radiation f [i.e., of the form of y = m x + c]. When Millikan plotted an experimental graph between stopping potential and frequency of incident light, he found that the nature of graph is straight line with negative intercept along y-axis as shown in figure. This straight line graph verifies the Einstein's photoelectric equation. Millikan experimentally found the slope of the straight line m = tanθ = h/e implies h = e tanθ = 6.625×10^{-34}Js. In this way, Einstein photoelectric equation is verified and value of Planck's constant is calculated.

32. **2075 Set A Q.No. 6b Discuss J.J Thomson's experiment to determine the specific charge of an electron. [4]**

A. **Determination of specific charge $\frac{e}{m}$ of an electron by J.J. Thomson Method:** The apparatus designed in J.J. Thomson method consists of a discharge tube containing concave cathode C & a cylindrical anode A with high positive potential. The discharge tube is connected with a fluorescent tube. When a high voltage of the order of 10 to 15 kV is applied between the electrodes of the discharge tube containing gas at 0.01 mm of Hg, cathode rays are produced. These rays are rendered into a beam by the cylindrical anode, which meets with the screen at its center O. Electric field is applied by the horizontal plates P_1 & P_2 so that the beam of cathode ray is deviated to S_1. A perpendicular magnetic field is represented by the dotted circle deviates the beam to S_2. When both fields of equal magnitude are applied in perpendicular directions with each other then the beam of electrons or cathode rays does not deviate and again meet at point O.



Theory:

When a high potential difference (V_o) is applied between cathode and cylindrical anode, the beam of electrons is highly accelerated and gain a velocity v whose kinetic energy is given by

$$eV_o = \frac{1}{2}mv^2$$

or, $\dfrac{e}{m} = \dfrac{1}{2}\dfrac{v^2}{V_o}$ ... (i)

When both magnetic and electric fields are applied perpendicular to each other such that the beam of electrons does not bend, then the magnetic force and electric force are equal.

i.e., Electric force = Magnetic force

or, $Bev = eE$

or, $v = \dfrac{E}{B}$

where, E is the electric field intensity and B is the magnetic field intensity. The electric field E is given by E=V/d, where V is the p.d. between the plates P_1 and P_2 & d is their separation. Then, from equation (i),

or, $\dfrac{e}{m} = \dfrac{E^2}{2B^2 V_o}$

or, $\dfrac{e}{m} = \dfrac{V^2}{2B^2d^2 V_o}$

By knowing the value of V, B, d and V_o, we can find value of e/m. The value of e/m for an electron from J.J. Thomson method is $1.76\times 10^{11} \text{Ckg}^{-1}$. This ratio of electric charge to mass of an electron is called its specific charge.

33. 2075 Set B Q.No. 6a | 2074 Set B Q.No. 6a | 2071 Set D Q.No. 6 a | 2069 (Set A) Q.No. 6a | 2068 Can. Q.No. 6a

Describe the theory of Milikan's oil drop experiment to determine the charge of an electron. [4]

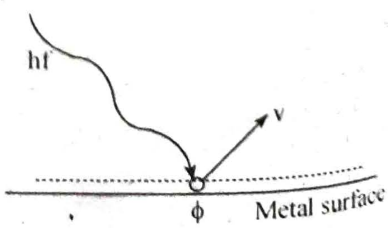
Please refer to 2076 Set B Q.No. 6a

34. 2074 Supp Q.No. 6b **What is photoelectric effect? Explain the effect of increase of (i) frequency (ii) intensity of the incident radiation on photoelectrons emitted by a phototube.** [4]

The process of emission of electrons from a metal surface when the light radiation of suitable frequency falls on it is called photoelectric effect. The electrons emitted in this process are called photoelectrons and the current of the electrons is called photocurrent.

Einstein's photoelectric equation: According to Planck's quantum theory of radiation, the energy associated with each photon of light with frequency f is given by

E = hf, where h is the Planck's constant and f is frequency of photon.



When a photon of energy hf incidents on a metal surface, it is used in two ways:

a. A part of this energy 'ϕ' is used to knock out an electron from surface of metal. The minimum energy 'ϕ' required just to liberate an electron from the surface of metal without imparting any KE to it is called work function of the metal.

b. The rest of the energy is used to impart the KE of ejected photo-electrons (E_k). If m is the mass & v is the velocity of the photoelectrons after the emission, the KE of the electron is given by,

$$E_k = \frac{1}{2} mv^2$$

Thus, the Einstein photoelectric electric is

Energy of photon= work function+ kinetic energy of emitted electrons

or, $hf = \phi + E_k$

$\therefore$ $hf = \phi + \frac{1}{2} mv^2$

Energy of photon = work function + K.E. of emitted electrons

This equation is known as *Einstein's photoelectric equation*.

No, the work function of a metal does not depend on intensity of light.

The above Einstein photoelectric equation shows that the energy of the photoelectrons depends upon the frequency of the incident radiation but not the intensity of radiation. If the frequency of the radiation increases, the kinetic energy of the photoelectron increases and intensity of photoelectrons remain same. But the kinetic energy remains same and intensity of photoelectrons increases on increasing the intensity of incident radiation.

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35. **2074 Set A Q.No. 6b 2072 Set D Q.No. 6a Discuss photoelectric effect and derive Einstein's photoelectric equation. What is stopping potential? [4]**

First parts: Please refer to 2074 Supp Q.No. 6b

Second Part: Please refer to 2056 Q.No. 12c

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36. **2073 Supp Q.No. 6a 2070 Supp. (Set B) Q.No. 6 a 2054 Q.No. 15 Describe an experiment to determine the specific charge of an electron. [4]**

Please refer to 2075 Set A Q.No. 6b

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37. **2073 Set C Q.No. 6a Explain photoelectric effect to write Einstein's photoelectric equation. Describe Millikan's laboratory method to determine Planck's constant. [4]**

Please refer to 2075 GIE Q.No. 6b

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38. **2073 Set D Q.No. 6d Describe the laboratory method to determine the specific charge of an electron by J.J. Thomson's method. [4]**

Please refer to 2075 Set A Q.No. 6b

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39. **2072 Supp Q.No. 6b Describe an experiment to determine the ratio of the charge to mass (e/m) for an electron. Show how the result is derived from the observations. [4]**

Please refer to 2075 Set A Q.No. 6b

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40. **2072 Set C Q.No. 6a Describe with necessary theory of Thomson's method to determine specific charge of an electron. [4]**

Please refer to 2075 Set A Q.No. 6b

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41. **2072 Set E Q.No. 6d 2067 Q.No. 6a Explain Millikan's experiment for the verification of Einstein's photoelectric equation. [4]**

Please refer to 2075 GIE Q.No. 6b

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42. **2071 Supp Q.No. 6a Verify quantization of charge using Millikan's oil drop experiment. [4]**

Please refer to 2076 Set B Q.No. 6a

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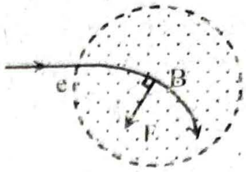
43. **2071 Set C Q.No. 6 a Discuss the motion of an electron in a uniform magnetic field and show that if a free electron moves at right angle to a magnetic field, the path is a circle and the time period of revolution is independent of the speed of the electron. [4]**

Deflection of electron in Magnetic field:

Suppose a beam of electrons moving with velocity v enters into a region of uniform magnetic field B which is perpendicular to the motion of electron as shown in figure. Then, force on electron in the field is F = Bev. This force is perpendicular to both B & v and direction of the force is given by

Fleming's left hand rule. Due to this, the electron moves in circular path. If m is the mass of the electron & r be the radius of its circular path inside the magnetic field, then the force Bev provides the necessary centripetal force.

Thus, Magnetic force = Centripetal force



or, $Bev = \frac{mv^2}{r}$

or, $r = \frac{mv}{Be}$

As the magnetic force acting on the moving electron acts tangentially, the motion of the electron becomes circular with radius r.

Moreover, $Bev = \frac{mv^2}{r}$

$Be = \frac{mv}{r} = \frac{m.r\omega}{r}$ $\quad (\because v = r\omega)$

$\omega = \frac{Be}{m}$

So, the frequency of electron moving inside the magnetic field is given by

$f = \frac{\omega}{2\pi} = \frac{Be}{2\pi m}$

Also, the time period (T) of electron moving inside the magnetic field is given by

$T = \frac{1}{f} = \frac{2\pi m}{Be}$

Hence the frequency (f) and the time period (T) of the electron in the circular path is independent of the speed of electron (v).

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44. **2070 Sup (Set A) Q.No. 6 a Discuss the trajectory of a charged particle when it is moving in a uniform magnetic field and hence discuss how the specific charge of the particle is obtained.** **[4]**

Please refer to 2075 Set A Q.No. 6b

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45. **2070 Sup (Set A) Q.No. 6 d What is work function of a metal? Does it depend on the intensity of incident light? Discuss Einstein's photoelectric equation.** **[4]**

The minimum energy of incident photon or radiation required to liberate an electron from metal surface without gaining any kinetic energy of emitted electron is called work function of a metal. This is denoted as ϕ and given as $\phi = hf_0$, where h is Planck's constant and f_0 is threshold frequency of a metal.

No, the work function of a metal does not depend on the intensity of incident of light. It is constant for a metal and different for different metals.

Einstein's photoelectric equation: Please refer to 2075 GIE Q.No. 6b

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46. **2069 Supp Set B Q.No. 6 a Describe J.J. Thomson's experiment with necessary theory behind the determination of specific charge of electron.** **[4]**

Please refer to 2075 Set A Q.No. 6b

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47. **2069 Supp Set B Q.No. 6 d Explain photoelectric effect and present the necessary theory to determine the value of Planck's constant.** **[4]**

Please refer to 2075 GIE Q.No. 6b

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48. **2069 (Set B) Q.No. 6a Describe Millikan's oil drop experiment with necessary theory. Estimate the specific charge of an electron from it.** **[4]**

Please refer to 2076 Set B Q.No. 6a

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49. **2069 (Set A) Old Q.No. 8a What is photoelectric effect? Derive Einstien's photoelectric equation. Define various terms used in it.** **[3]**

Photoelectric effect and Einstien's photoelectric equation: Please refer to 2076 Set C Q.No. 6c

Various terms

1. **Stopping potential:** The minimum retarding potential applied to the anode at which photoelectric current becomes zero is called stopping potential and denoted by V_0. Stopping potential V_0 stops the

photoelectrons with maximum kinetic energy reaching the anode and hence name stopping potential. If m is mass of emitted photoelectron and v_{max} is its maximum velocity, then

$$K.E._{max} = e\,V_0 = \frac{1}{2} m\,v^2_{max}$$

2. **Work function:** The minimum energy 'ϕ' required just to liberate an electron from the surface of metal without imparting any KE to it is called work function of the metal. It is denoted by ϕ and given as $\phi = h\,f_0$, where f_0 threshold frequency.
3. **Threshold frequency:** The minimum frequency of incident radiation required to eject an electron (i.e., with zero velocity) from the surface of a metal is known as threshold frequency (f_0) for that metal. The corresponding wave length is called threshold wave length. Different metals have different threshold frequencies. Illumination of a surface with light of frequency less than f_0 will not cause ejection of photoelectrons.

50. 2068 Q.No. 6 a **Describe the phenomenon of electrical discharge through gases.** [4]

➤ **Electric Discharge through gases:** On normal pressure, gas does not conduct electricity and behaves almost like insulator. When the pressure of gas is reduced and applying very high voltage near about 30kV/cm, it starts to conduct electricity. For the study of electric discharge, a gas is taken in a tube and the tube called as discharge tube. Discharge tube is a glass tube of 30 cm to 50 cm length & 3 cm to 5 cm in diameter. The tube contains an anode A and a cathode C by making respectively positive and negative terminal of the induction coil (10 kV to 15 kV). The pressure of the gas inside the tube can be reduced with a vacuum pump. The walls of the vacuum tube are coated with fluorescent material.

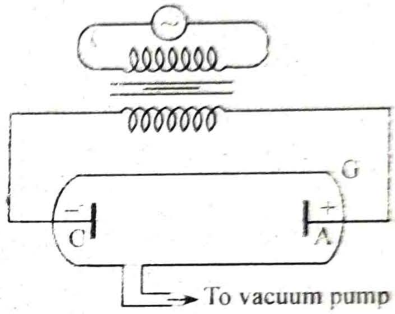
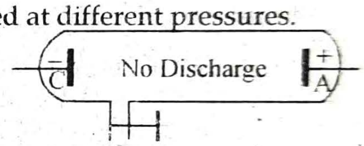


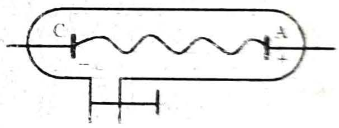
Fig. Discharge tube

When the pressure of the gas is reduced, following results are obtained at different pressures.

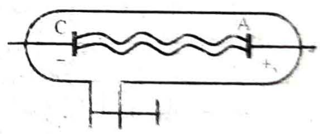
Pressure above 10mm of Hg: When the pressure is above 10mm of Hg, the electric discharge does not take place. It is so because the ions and electrons are unable to reach their collisions with gas atoms due to low mean free path.



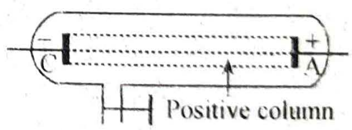
Pressure at 10mm of Hg: When the pressure inside the discharge tube is reduced to 10mm of Hg, discharge takes place. Its path is zigzag with crackling sound and bluish in color.



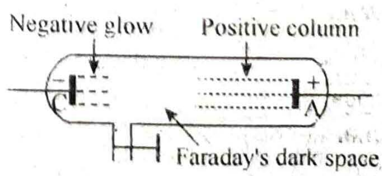
Pressure at 5mm of Hg: When pressure of tube is reduced to 5 mm of Hg, the blue streaks broaden out in to a luminous column which is bright and steady. The luminous column is called Geissler's discharge. The color of discharge depends on the nature of the gas taken.



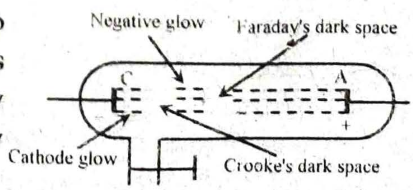
Pressure at 2mm of Hg: At 2mm of Hg pressure, a luminous column appears from anode which extends almost to cathode called the positive column. Colour of the discharge depends upon the nature of the gas. For e.g., it is red for air and blue for hydrogen.

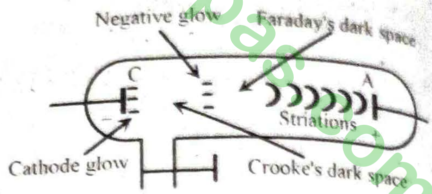


Pressure at 1mm of Hg: When the pressure of gas is reduced to 1 mm of Hg, positive column detaches from the cathode and shortens towards anode. A blue luminous glow appears at the cathode called negative glow. The space between positive column & negative glow is comparatively dark called Faraday's dark space.

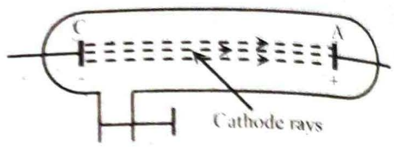


Pressure at 0.5mm of Hg: When the pressure of gas is reduced to 0.5 mm of Hg, the negative glow leaves the cathode and moves towards the anode. At the cathode, at the same time, another glow called cathode glow appears. A dark space between negative glow and cathode glow is appears called Crooke's dark space.





Pressure at 0.05 mm of Hg: At 0.05mm of Hg pressure, the positive column shortens and breaks into alternative bright and dark space called striations.



Pressure at 0.01 mm of Hg: At 0.01mm of Hg pressure, striations, Faraday's dark space, negative glow & cathode glow are disappeared. The whole tube is filled with Crooke's dark space. Then, the cathode emits invisible radiations towards anode, called cathode rays. When they are allowed to fall on fluorescent coating of the glass tube, fluorescent light is produced.

Pressure below 0.01 mm of Hg: When the pressure is reduced below 0.01 mm of Hg, the tube behaves like a vacuum tube & it is impossible to maintain discharge. The discharge stops beyond pressure of 10^{-4} mm of Hg.

51. **2067 Sup Q.No. 6a What is photoelectric effect? Discuss Einstein's Photo-electric equation. Does the work function of a metal depend on intensity of light?** [1+2+1]

First parts: Please refer to 2076 Set C Q.No. 6c

No, the work function of a metal does not depend on intensity of light.

52. **2067 Old Q.No. 8a Describe J.J. Thomson's experiment to determine the specific charge of an electron.** [4]

Please refer to 2075 Set A Q.No. 6b

53. **2066 Supp Q.No. 9 Or Describe with necessary theory to determine the ratio of charges to mass (e/m) of an electron by J.J. Thomson method.** [4]

Please refer to 2075 Set A Q.No. 6b

54. **2065 Q.No. 9 a OR Describe an experimental method to determine the specific charge of an electron.** [2+2]

Please refer to 2075 Set A Q.No. 6b

55. **2064 Q.No. 9 What is specific charge of an electron? Describe and give necessary theory of J.J. Thomson's method to determine the specific charge of an electron.** [1+3]

Please refer to 2075 Set A Q.No. 6b

56. **2063 Q.No. 8 a OR Describe the theory of Millikan's oil drop experiment to determine the number of charge on oil drop.** [4]

Please refer to 2076 Set B Q.No. 6a

57. **2063 Q.No. 9 OR Show that electron motion in magnetic field is circular. Prove that frequency and time period are independent with the velocity of electron.** [4]

Please refer to 2071 Set C Q.No. 6 a

58. **2060 Q.No. 8 a Write down Einstein's photoelectric equation and describe an experiment to verify it.** [1+3]

Please refer to 2075 GIE Q.No. 6b

59. **2057 Q.No. 8 a What are cathode rays? State their six properties.** [4]

Please refer to 2076 Set C Q.No. 6a

60. **2056 Q.No. 13 Explain the phenomena of discharge of electricity through gases at low pressure.** [4]

Please refer to 2068 Q.No. 6 a

61. **2055 Q.No. 13 Discuss the physical principles involved in Millikan's experiment for the determination of the charge of an electron.** [4]

Please refer to 2076 Set B Q.No. 6a

62. **2052 Q.No. 15 Describe with necessary theory, Millikan's oil drop experiment to determine the value of the charge associated with an electron.** [4]

Please refer to 2076 Set B Q.No. 6a

Numerical Problems

63. 2076 Set B Q.No. 10a 2069 (Set B) Q.No. 10c An ion for which the charge per unit mass is 4.40×10^7 c/kg has velocity of 3.52×10^5 m/s and moves in a circular orbit in a magnetic field of flux density 0.4T. What will be the radius of this orbit? [4]

Solution

Given,

Charge per unit mass of ion, $\left(\frac{e}{m}\right) = 4.40 \times 10^7$ C/kg

Velocity of ion (v) = 3.52×10^5 m/s

Magnetic flux density (B) = 0.4T

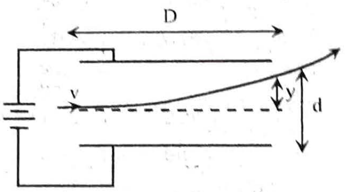
Radius of orbit (r) = ?

We know that,

$$r = \frac{mv}{Be} = \frac{v}{B \times \frac{e}{m}} = \frac{3.52\times10^5}{0.4 \times 4.40 \times 10^7} = 0.02 \text{ m}$$

64. 2075 GIE Q.No. 10a 2068 Can. Q.No. 10a 2060 Q.No. 8 b OR Two plane 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 V and the lower plate is earthed. Electrons having a velocity 10^7 m/s are injected horizontally midway between the plates and in a direction parallel to 4 cm edge. Calculate the vertical deflection of the electron beam as it emerges from the plates. (e/m for the electron = 1.8×10^{11} Ckg^{-1}) [4]

Solution



Given,

Potential difference (V) = 300V

Separation between plates (d) = 3cm = 3×10^{-2}m

Velocity of electron (v) = 10^7m/s

Length of each plate (D) = 4cm = 4×10^{-2}m

$\frac{e}{m} = 1.8 \times 10^{11}$ C kg^{-1}

Vertical deflection (y) = ?

Now,

For vertical motion of beam of electrons, we have,

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

$$= \frac{1}{2} \times \frac{F}{m} \times t^2 \quad [\because F = ma]$$

$$= \frac{1}{2} \times \frac{e\times E}{m} \times t^2 \quad [\because F = e.E]$$

$$= \frac{1}{2}\frac{eV}{md} \times t^2 \quad [\because E = \frac{V}{d}]$$

$$= \frac{1}{2} \times \frac{e}{m} \times \frac{V}{d} \times \left(\frac{D}{v}\right)^2 \quad [\because t = \frac{D}{v}]$$

$$= \frac{1}{2} \times 1.8 \times 10^{11} \times \frac{300}{3 \times 10^{-2}} \times \left(\frac{4 \times 10^{-2}}{10^7}\right)^2$$

$$= 1440 \times 10^{-5}$$

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

Hence, the required vertical deflection is 1.44×10^{-2} m.

65. 2075 Set A Q.No. 10b A clean nickel surface of work function 5.1 eV is exposed to light of wavelength 235 nm. What is the maximum speed of the photoelectrons emitted from its surface? [4]

Solution,

Given,

Work function of nickel (ϕ) = 5.1 eV = $5.1 \times 1.6 \times 10^{-19}$ J = 8.16×10^{-19} J

Wavelength (λ) $= 235$ nm $= 235 \times 10^{-9}$ m

Maximum speed of emitted electrons (v) = ?

We have, from Einstein's photoelectric equation,

$$hf = \phi + \frac{1}{2}mv^2$$

$$\text{or,} \quad \frac{1}{2}mv^2 = \frac{hc}{\lambda} - \phi = \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{235 \times 10^{-9}} - 8.16 \times 10^{-19} = 2.91 \times 10^{-20}\ \text{J}$$

$$\therefore \quad v = \sqrt{\frac{2 \times 2.91 \times 10^{-20}}{9.1 \times 10^{-31}}} = 2.52 \times 10^5\ \text{m/sec}$$

66. $\boxed{\text{2075 Set A Q.No. 10c}}$ **An electron moving with a speed of 10^7 m/s is passed into a magnetic field of intensity 0.1 T normally. What is the radius of the path of the electron inside the field? If the strength of the magnetic field is doubled, what is the radius of the new path? (e/m = 1.8×10^{11}C/kg)** **[4]**

Solution

Given,

Speed of electron (v) $= 10^7$ m/sec

Magnetic flux density (B) = 0.1 T

Specific charge of electron $(\frac{e}{m}) = 1.8 \times 10^{11}\ \text{C kg}^{-1}$

Radius of path (r) = ?

We have,

$$r = \frac{mv}{Be} = \frac{v}{B\, e/m} = \frac{10^7}{0.1 \times 1.8 \times 10^{11}} = 5.6 \times 10^{-4}\ \text{m}$$

Again on doubling magnetic field,

$$r' = \frac{mv}{B'e} = \frac{v}{B'\, e/m} = \frac{10^7}{2 \times 0.1 \times 1.8 \times 10^{11}} = 2.78 \times 10^{-4}\ \text{m}$$

67. $\boxed{\text{2075 Set B Q.No. 10a}}$ **Sodium has a work function of 2 eV. Calculate the maximum energy and speed of the emitted electrons when sodium is illuminated by a radiation of 150 nm. What is the threshold frequency of radiation for which electrons are emitted from sodium surface?** **[4]**

Solution

Given,

Work function (ϕ) $= 2$ eV $= 2 \times 1.6 \times 10^{-19}$ J

Maximum Kinetic Energy ($K.E_{max}$) = ?

Speed of electron (v_{max}) = ?

Threshold frequency (f_0) = ?

Wavelength of light (λ) $= 150$ nm $= 150 \times 10^{-9}$m

From

Einstein photo-electric equation

$$hf = \phi + K.E_{max}$$

$$\text{or,} \quad K.E_{max} = h\frac{c}{\lambda} - \phi$$

$$= \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{150 \times 10^{-9}} - 2 \times 1.6 \times 10^{-19}$$

$$= 1.004 \times 10^{-18}\text{J}$$

$$v_{max} = \sqrt{\frac{2 \times K.E_{max}}{m}}$$

$$= \sqrt{\frac{2 \times 1.004 \times 10^{-18}}{9.1 \times 10^{-31}}}$$

$$= 1.483 \times 10^6\ \text{m/s}$$

Again, For threshold frequency

$$\phi = hf_0$$

$$\text{or,} \quad f_0 = \frac{\phi}{h} = \frac{2 \times 1.6 \times 10^{-19}}{6.62 \times 10^{-34}} = 4.8 \times 10^{14}\ \text{Hz}$$

68. 2074 Supp Q.No. 10a **Calculate the potential difference to be maintained between two horizontal conducting plates separated by a distance of 10 mm so that a small charged oil drop of mass 1.31×10^{-14} kg will remain in equilibrium. Charge in the oil drop is 6.4×10^{-19} C.** **[4]**

Solution

Given,

Potential difference (V) = ?

Distance between Plates (d) = 10 mm = 10×10^{-3} m

Mass of oil drop (m) = 1.31×10^{-14} kg

Charge of oil drop (q) = 6.4×10^{-19} C

From question, at equilibrium position of oil drop between the two plates,

Weight of oil drop = Electric force acting on it

$mg = q.E$

or, $mg = q \cdot \frac{V}{d}$ $\quad [\because E = \frac{V}{d}]$

or, $V = \frac{m \cdot g \cdot d}{q}$

$= \frac{1.31 \times 10^{-14} \times 10 \times 10^{-3} \times 10}{6.4 \times 10^{-19}}$

$= 2046.87$ V

69. 2074 Set A Q.No. 10a **An electron moves in a circular path of radius 20 cm in a uniform magnetic field of 2×10^{-3}T. Find the speed of the electron and period of revolution. Mass of electron $= 9.1 \times 10^{-31}$kg.** **[4]**

Solution

Given,

Radius of circle (r) = 20 cm = 0.2 m

Magnetic field (B) = 2×10^{-3} T

Velocity (v) = ?

Frequency (f) = ?

We have,

$Be\, v = \frac{mv^2}{r}$

or, $v = \frac{Be\, r}{m} = \frac{2 \times 10^{-3} \times 1.6 \times 10^{-19} \times 0.2}{9.1 \times 10^{-31}} = 7.03 \times 10^7$ m/sec

Again

$f = \frac{Be}{2\pi m} \left(Be = \frac{mv}{r} = \frac{mwr}{r} = mw = 2\pi fm \right)$

$= \frac{2 \times 10^{-3} \times 1.6 \times 10^{-19}}{2\pi \times 9.1 \times 10^{-31}} = 5.6 \times 10^7$ Hz

70. 2074 Set B Q.No. 10a **Radiations of wavelength 5400 Å fall on a metal whose work function is 1.9 eV. Find the energy of the photoelectrons emitted and their stopping potential. Planck's constant $= 6.62 \times 10^{-34}$ Js.** **[4]**

Solution

Given,

Wave-length of light (λ) = 5400×10^{-10} m

Work function (ϕ) = 1.9 eV = $1.9 \times 1.6 \times 10^{-19}$ J

K.E. of photoelectrons (E_K) = ?

Stopping potential (V_s) = ?

We have, from Einstein's photoelectric equation,

$hf = \phi + E_K$

or, $E_K = h\frac{c}{\lambda} - \phi = \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{5400 \times 10^{-10}} - 1.9 \times 1.6 \times 10^{-19}$

$\therefore E_K = 6.38 \times 10^{-20}$ J

Also,

$E_K = eV_s$

or, $V_s = \frac{E_K}{e}$

or, $V_s = \frac{6.38 \times 10^{-20}}{1.6 \times 10^{-19}}$

$\therefore$ $V_s = 0.4$ V

71. **[2073 Supp Q.No. 10a] [2068 Q.No. 10 b] [2066 Supp Q.No. 8b] [2053 Q.No. 14] Light of frequency 5×10^{14}Hz librates electrons with energy 2.3×10^{-19}J from a certain metallic surface. What is the wavelength of ultraviolet light which librates electrons of energy 8.93×10^{-19}J from the same surface? (Given $h = 6.62 \times 10^{-34}$ Js, $c = 3 \times 10^8$ m/s)** **[4]**

Solution

Given,

1st case: K.E. of electron $(E_1) = 2.31\times10^{-19}$J

Frequency of radiation $(f_1) = 5.0\times10^{14}$Hz

2nd case: K.E. of electron $(E_2) = 8.93 \times10^{-19}$ J

Frequency of radiation (f_2) = ?

Wavelength of radiation (λ_2) = ?

From Einstein photo electric equation,

$\therefore$ $E_1 = hf_1 - \phi$ ... (i)

and $E_2 = hf_2 - \phi$ ... (ii)

On subtracting equation (i) from (ii), we get

$E_2 - E_1 = h(f_2 - f_1)$

$\therefore$ $f_2 - f_1 = \frac{E_2 - E_1}{h} = \frac{8.93 \times10^{-19} - 2.31\times10^{-19}}{6.62 \times10^{-34}} = 10 \times10^{14}$ Hz

or, $f_2 = 10 \times10^{14} + f_1$

$= 10\times10^{14} + 5\times10^{14} = 15 \times10^{14}$ Hz

$\therefore$ $\lambda_2 = \frac{c}{f_2} = \frac{3\times10^8}{15\times10^{14}} = 2.0\times10^{-7}$ m

72. **[2073 Set C Q.No. 10b] An electron having 500 eV energy enters at right angle to a uniform magnetic filed of 10^{-4} Tesla. If its specific charge is 1.75×10^{11} Ckg^{-1}, calculate the radius of its circular orbit.** **[4]**

Solution

Given,

Energy, $\frac{1}{2}mv^2 = eV = 500$ eV $= 500 \times 1.6 \times 10^{-19}$ J

or, $v = \sqrt{\frac{2 \times 500 \times 1.6 \times 10^{-19}}{9.1 \times 10^{-31}}} = 1.32 \times 10^7$ m/sec

Magnetic field (B) = 10^{-4} T

Specific charge (e/m) = 1.75×10^{11} C kg^{-1}

Radius of orbit (r) = ?

We have,

$r = \frac{mv}{Be} = \frac{v}{B \cdot e/m} = \frac{1.32 \times 10^7}{10^{-4} \times 1.75 \times 10^{11}} = 0.75$ m

73. **[2073 Set D Q.No. 10a] 400 nm wavelength of light falls on a photo sensitive material of work function 2.3 eV. Compute the maximum energy of photoelectrons.** **[4]**

Solution

Given,

Wavelength (λ) = 400 nm = 400×10^{-9}m

Work function (ϕ) = 2.3 eV = $2.3 \times 1.6 \times 10^{-19}$ J

Maximum energy (E_k) = ?

We have, from Einstein's photoelectric equation,

$hf = \phi + E_k$

$h\frac{c}{\lambda} = \phi + E_k$

$\therefore E_k = \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{400 \times 10^{-9}} - 2.3 \times 1.6 \times 10^{-19} = 1.285 \times 10^{-19}\ J = 0.803\ eV$

74. **2072 Supp Q.No. 10b Sodium has a work function of 2 eV. Calculate the maximum energy and speed of the emitted electrons when sodium is illuminated by radiation of wave length 150 nm. (Given: mass of electron = 9.1×10^{-31} Kg)** **[4]**

Solution

Given,

Work function (ϕ) = 2eV

$= 2 \times 1.6 \times 10^{-19}\ J = 3.2 \times 10^{-19}\ J$

Maximum energy (E_{max}) $= \frac{1}{2} mv^2_{max} = ?$

Maximum speed (v_{max}) = ?

Wavelength of light (λ) = 150×10^{-9} m

Mass of electron (m_e) = 9.1×10^{-31} Kg

We have, from Einstein's photo electric equation;

$E = \phi + \frac{1}{2} mv^2_{max}$

or, $hf = \phi + \frac{1}{2} mv^2_{max}$

or, $\frac{1}{2} mv^2_{max} = \frac{hc}{\lambda} - \phi$

or, $\frac{1}{2} \times 9.1 \times 10^{-31} \times v^2_{max} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{150 \times 10^{-9}} - 3.2 \times 10^{-19}$

or, $v_{max} = 1.48 \times 10^6$ m/sec

Max. Energy (E_{max}) $= \frac{1}{2} mv^2_{max} = \frac{1}{2} \times (1.48 \times 10^6)^2 \times 9.1 \times 10^{-31} = 9.96 \times 10^{-19}$ J

75. **2072 Set C Q.No. 10a The work function for the surface of aluminum is 4.2 eV. How much potential difference will be required to stop the emission of maximum energy of electrons emitted by light of wavelength 2000 Å ? (Planck's constant, h = 6.61×10^{-34} Js)** **[4]**

Solution

Given,

Work function (ϕ) = 4.2 eV = $4.2 \times 1.6 \times 10^{-19}$ J

Stopping potential (V_s) = ?

Wavelength (λ) = 2000 Å = 2000×10^{-10} m

Now, from Einstein's photoelectric equation,

$hf = \phi + \frac{1}{2} mv^2 \qquad [\because eV_s = \frac{1}{2} mv^2]$

or, $hf = \phi + eV_s$

or, $eV_s = h\frac{c}{\lambda} - \phi, \qquad [\because f = \frac{c}{\lambda}]$

or, $eV_s = \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{2000 \times 10^{-10}} - 4.2 \times 1.6 \times 10^{-19}$

or, $eV_s = 9.93 \times 10^{-19} - 6.72 \times 10^{-19}$

or, $eV_s = 3.21 \times 10^{-19}$

or, $V_s = \frac{3.21 \times 10^{-19}}{1.6 \times 10^{-19}}$

$\therefore V_s = 2V$

76. **2072 Set D Q.No. 10a** **In a Millikan's oil drop experiment, a drop is observed to fall with a terminal speed of 1.4 mm/s in the absence of electric field. When a vertical electric field of 4.9×10^5 V/m is applied, the droplet is observed to continue to move downward at a lower terminal speed 1.21 mm/s. Calculate the charge on the drop. (Density of oil = 750 kg/m³, viscosity of air = 1.81×10^{-5} kg/m.s, density of air = 1.29 kg/m³)** [4]

Solution

Given,

First terminal velocity (v_1) = 1.4 mm/sec = 1.4×10^{-3} m/sec

Second terminal velocity (v_2) = 1.21 mm/sec = 1.21×10^{-3} m/sec

Electric field intensity (E) = 4.9×10^5 V/m

Charge on oil drop (q) = ?

Density of Oil (ρ) = 750 kg/m³

Density of air (σ) = 1.29 kg/m³

Viscosity of air (η) = 1.81×10^{-5} kg/m.s

We have,

$$q = \frac{6\pi\eta(v_1 - v_2)}{E}\sqrt{\frac{9\eta v_1}{2(\rho-\sigma)g}}$$

$$= \frac{6\pi \times 1.81 \times 10^{-5}(1.4 - 1.21) \times 10^{-3}}{4.9 \times 10^5}\sqrt{\frac{9 \times 1.81 \times 10^{-5} \times 1.4 \times 10^{-3}}{2(750 - 1.29) \times 10}}$$

$= 5.16 \times 10^{-19}$ C

77. **2072 Set E Q.No. 10b** **A beam of electrons, moving with velocity of 10^7 m/s, enters midway between two horizontal parallel plates in the direction parallel to the plates which are 5 cm long and 2 cm apart and have a p.d. of V volts between them. Calculate V if the beam is deflected so that it just grazes the edge of the plate. (Assume e/m = 1.76×10^{11} C/kg).** [4]

Solution

Given,

Velocity (v) = 10^7m/s

Length of each plate (D) = 5cm = 0.05m

Separation between two plates (d) = 2cm= 0.02m

$\frac{e}{m} = 1.76 \times 10^{11} C\, kg^{-1}$

Potential difference (V) = ?

Now,

As the electron beam enters mid-way between two plates, the vertical distance moved by the electron beam is, $y = \frac{d}{2} = \frac{0.02m}{2} = 0.01m$

But, we have,

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

or, $0.01 = \frac{1}{2} \times \frac{F}{m} \times \left(\frac{D}{v}\right)^2$ $\quad [\because a = \frac{F}{m}$ and $t = \frac{D}{v}]$

or, $0.02 = \frac{E \times e}{m} \times \left(\frac{D}{v}\right)^2$ $\quad [\because F = E \times e]$

or, $0.02 = \frac{V}{d} \times \frac{e}{m} \times \left(\frac{D}{v}\right)^2$ $\quad [\because E = \frac{V}{d}]$

or, $0.02 = \frac{V}{0.02} \times 1.76 \times 10^{11} \times \left(\frac{0.05}{10^7}\right)^2$

or, $0.00040 = V \times 1.76 \times 10^{11} \times 0.25 \times 10^{-16}$

or, $V = 90.9$ V

Hence, the required value of V is 90.9 V.

78. **2071 Set C Q.No. 10 a** **Light of wavelength 5×10^{-7} m falls on a sensitive metal plate with photo electric work function 1.90 eV. Find kinetic energy of the photoelectrons emitted and stopping potential. (given $h = 6.62 \times 10^{-34}$ Js)** **[4]**

Solution

Given,

Wavelength of light (λ) = 5×10^{-7} m

Work function (ϕ) = 1.9 eV = $1.9 \times 1.6 \times 10^{-19}$ J

K.E. of photoelectrons (E_K) = ?

Stopping potential (V_s) = ?

We have, Einstein photoelectric equation as,

$$hf = \phi + E_k$$

$$\text{or, } \frac{hc}{\lambda} - \phi = E_k$$

$$\text{or, } E_k = \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{5 \times 10^{-7}} - 1.90 \times 1.6 \times 10^{-19} = 9.32 \times 10^{-20}\ \text{J}$$

$$E_k = 0.58\ \text{eV}$$

Again,

$$E_k = eV_S$$

$$\text{or, } V_S = \frac{E_k}{e} = \frac{9.32 \times 10^{-20}}{1.6 \times 10^{-19}}$$

$$\therefore V_S = 0.58\ \text{V}$$

79. **2071 Set D Q.No. 10 a** **Ultraviolet light of wavelength 3.5×10^{-7} m is made to fall on a smooth surface of potassium. The wok function of potassium is 2eV. Determine maximum energy of emitted photoelectrons and stopping potential.** **[4]**

Solution

Given,

Work function (ϕ) = 2.0eV = $2 \times 1.6 \times 10^{-19}$ J = 3.2×10^{-19}J

Wavelength (λ) = 350 nm = 350×10^{-9} m

Stopping potential (V_S) = ?

Now,

From Einstein's photoelectric equation, we have,

$$eV_s = \frac{1}{2}mv^2 = hf - \phi$$

$$\text{or, } eV_s = hf - \phi$$

$$\text{or, } eV_s = \frac{hc}{\lambda} - \phi$$

$$\therefore V_s = \frac{hc}{e\lambda} - \frac{\phi}{e} = \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 10^{-19} \times 350 \times 10^{-9}} - \frac{3.2 \times 10^{-19}}{1.6 \times 10^{-19}} = 3.5 - 2 = 1.5\ \text{V}$$

Hence, the required value of stopping potential is 1.5V.

Again,

To find the kinetic energy, we have,

$K.E_{max} = eV_s = 1.6 \times 10^{-19} \times 1.5 = 2.4 \times 10^{-19}$ J

Hence, the required kinetic energy is 2.4×10^{-19} J.

80. **2071 Set D Q.No. 10 c** **An electron is accelerated through a potential difference of 2000V and then it enters a uniform magnetic field of 0.02 Tesla in a direction perpendicular to it. Find the radius of the path of the electron in the magnetic field. Mass of an electron is 9.1×10^{-31} kg, charge of an electron is 1.6×10^{-19}C.** **[4]**

Solution

Given,

Potential difference (V) = 2000V

Flux density (B) = 0.02T

Proton mass (m) = 9.1×10^{-31}kg

Electronic charge (e) = -1.6×10^{-19}C

Radius of the path (r) = ?

Now, the kinetic energy acquired by the proton is equal to the work done on it. So,

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

or, $v^2 = 2\frac{e}{m}V$

or, $v = \sqrt{2\frac{e}{m}V}$

For the proton to be in the circular orbit, the force on electron due to magnetic field BeV provides the necessary centripetal force.

i.e., $Bev = \frac{mv^2}{r}$

or, $r = \frac{mv}{Be}$

Substituting the value of v from Eq. (i) in Eq. (ii), we get,

$r = \frac{m}{Be}\sqrt{\frac{2eV}{m}} = \frac{1}{B}\sqrt{2V\frac{m}{e}} = \frac{1}{0.02}\sqrt{\frac{2\times2000\times9.1\times10^{-31}}{1.6\times10^{-19}}} = 7.5\times10^{-3}m$

Hence, the radius of the path is $7.5\times10^{-3}m$.

81. 2070 Sup (Set A) Q.No. 10 a Calculate the radius of a water drop which would just remain suspended in an electric field of 300 V/cm and charged with one electron. [4]

Solution

Given,

Radius of water drop (r) = ?

Electric field (E) = 300 V/cm = 30000 V/m

In this case, electrostatic force = Weight of drop

i.e., $F_e = W$

$qE = mg$ $\quad [\because F_e = qE]$

or, $neE = \frac{4}{3}\pi r^3\rho g$ $\quad [\because q = ne]$

$1\times1.6\times10^{-19}\times30000 = \frac{4}{3}\pi r^3\times1000\times10$

$r^3 = 1.1459\times10^{-19}$

$\therefore r = 4.9\times10^{-7}m$

82. 2070 Supp. (Set B) Q.No. 10 a Electrons with maximum kinetic energy of 3 eV are ejected from a metal surface by ultra-violet radiation of wavelength 1.5×10^{-7} m. Determine work function, threshold wavelength and the stopping potential for the metal. (Planck's constant, $h = 6.62\times10^{-34}$ Js) [4]

Solution

Given,

Maximum kinetic energy of ejected electron (E_k) = 3 eV = $3\times1.6\times10^{-19}$ J

Wavelength of incident radiation (λ) = 1.5×10^{-7} m

Work function (ϕ) = ?

Threshold wavelength (λ_0) = ?

Stopping potential (V_s) = ?

Now, from Einstein photoelectric equation,

$hf = \phi + E_k$

or, $h\frac{c}{\lambda} = \phi + E_k$

or, $\phi = \frac{6.62\times10^{-34}\times3\times10^8}{1.5\times10^{-7}} - 3\times1.6\times10^{-19} = 8.44\times10^{-19}J = 5.275 eV$

Again,

$\phi = \frac{hc}{\lambda_0}$

$$\text{or, } \lambda_0 = \frac{hc}{\phi} = \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{8.44 \times 10^{-19}} = 2.35 \times 10^{-7} \text{ m}$$

Also,

$$E_k = eV_S$$

$$\text{or, } V_S = \frac{3 \times 1.6 \times 10^{-19}}{1.6 \times 10^{-19}} = 3V$$

83. **2070 Set C Q.No. 10 a** **An electron beam after being accelerated from rest through a potential difference of 5 KV in vacuum is allowed to impinge normally on a fixed surface. If the incident current is 50μ A, determine the force exerted on the surface assuming that it brings the electrons to rest. Take mass of electron is 9.1 ×10^{-31} Kg.** **[4]**

Solution

Given,

Potential difference (V) = 5 KV = 5000 V

Incident current (I) = 50μA = 50×10^{-6} A

Force (F) = ?

We have,

$$\frac{1}{2} m_e v^2 = eV$$

$$\text{or, } v = \sqrt{\frac{2eV}{m_e}}$$

Also,

$$F = \frac{mv}{t} = \frac{m}{t} v$$

$$= \frac{n\, m_e\, v}{t} \qquad [\because m = n.\, m_e]$$

$$= \frac{I}{e} . m_e \sqrt{\frac{2eV}{m_e}}$$

$$\left[\begin{aligned} &\because\ q = ne \\ &\text{or, } I = \frac{q}{t} = \frac{ne}{t} \\ &\text{or, } \frac{n}{t} = \frac{I}{e} \end{aligned}\right]$$

$$= I \times \sqrt{\frac{2\, m_e}{e} V}$$

$$= 50 \times 10^{-6} \sqrt{\frac{2 \times 9.1 \times 10^{-31} \times 5000}{1.6 \times 10^{-19}}}$$

$$= 1.19 \times 10^{-8} \text{ N.}$$

84. **2070 Set C Q.No. 10 b** **The photoelectric threshold wavelength of a tungsten surface is 272 nm. Calculate the maximum velocity of the electrons ejected from this tungsten surface by ultraviolet radiation of frequency 1.45 ×10^{15} Hz. (h =6.62 × 10^{-34} Js, c = 3 × 10^8m/s, m_e = 9.1 × 10^{-31}kg)** **[4]**

Solution

Given,

Threshold wavelength (λ_0) = 272 nm = 2.72 ×10^{-7} m

Maximum velocity of electrons (v_{max}) = ?

Frequency of radiation (f) = 1.45 × 10^{15} Hz

We have, from Einstein photoelectric equation

$$hf = \phi + \frac{1}{2} m\, v^2_{max}$$

$$\text{or, } \frac{1}{2} mv^2_{max} = hf - \frac{hc}{\lambda_0}$$

$$\text{or, } v_{max} = \sqrt{\frac{2h}{m}\left(f - \frac{c}{\lambda_0}\right)} = \sqrt{\frac{2 \times 6.62 \times 10^{-34}}{9.1 \times 10^{-31}}\left(1.45 \times 10^{15} - \frac{3 \times 10^8}{2.72 \times 10^{-7}}\right)} = 7.11 \times 10^5 \text{ m/sec}$$

5. **2070 Set D Q.No. 10 a** **A beam of electrons, moving with a velocity of 10^7m/s, enters midway between two horizontal parallel plates in a direction parallel to the plates. Each plate is 5 cm long. These plates are kept 2 cm apart and a potential difference of 90 V is applied between them. Calculate the velocity of the electron beam with which it just grazes the edge of the positive plate. (e/m = 1.8 × 10^{11} C/kg)** **[4]**

Solution

Given,

Velocity of electron (v) = 10^7 m/sec

Length of plates (l) = 5 cm = 0.05m

Distance between plates (d) = 2cm = 0.02 m

Potential difference (V) = 90 V

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

Final velocity (v_f) = ?

Now,

$v_x = v = 10^7$ m/sec $\quad [\because u_x = v \text{ and } a_x = 0 \text{ as } v_x = u_x + a_x t]$

$v_y = at = \frac{e}{m} \frac{V}{d} \cdot \frac{l}{v} \quad [\because u_y = 0 \text{ and } a_y = \frac{F}{m} = \frac{eE}{m} = \frac{e}{m} \cdot \frac{V}{d}]$

$= 1.8 \times 10^{11} \times \frac{90}{0.02} \times \frac{0.05}{10^7} = 4.05 \times 10^6$ m/sec

So, $v_f = \sqrt{v_x^2 + v_y^2} = \sqrt{(10^7)^2 + (4.05 \times 10^6)^2} = 1.079 \times 10^7$ m/sec

Also,

$\tan\theta = \frac{v_y}{v_x}$

or, $\theta = \tan^{-1}\left(\frac{v_y}{v_x}\right) = \tan^{-1}\left(\frac{4.05 \times 10^6}{10^7}\right) = 22.04°$

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86. **2070 Set D Q.No. 10 b** **When ultraviolet light with a wavelength of 400 nm falls on a certain metal surface, the maximum kinetic energy of the emitted electrons is 1.10 eV. What is the maximum kinetic energy of the photoelectrons when light of wavelength 300 nm falls on the same surface?** **[4]**

Solution

Given,

Wavelength of UV light (λ_1) = 400nm = 400×10^{-9} m

The maximum K.E. of electron (K.E.$_1$) = 1.10 eV = $1.10 \times 1.6 \times 10^{-19}$ J

Wavelength for another light (λ_2) = 300nm = 300×10^{-9} m

Maximum energy of electron (K.E$_2$) = ?

We have, from Einstein's photoelectric equation,

$hf = \phi + KE$

So, $\frac{hc}{\lambda_1} = \phi + KE_1 \quad \ldots \text{(i)}$

and, $\frac{hc}{\lambda_2} = \phi + KE_2 \quad \ldots \text{(ii)}$

Subtracting equation (i) from (ii), we get

$KE_2 - KE_1 = hc\left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right)$

$KE_2 = KE_1 + hc\left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right)$

$= 1.10 \times 1.6 \times 10^{-19} + 6.62 \times 10^{-34} \times 3 \times 10^8 \left(\frac{1}{300 \times 10^{-9}} - \frac{1}{400 \times 10^{-9}}\right)$

$= 3.42 \times 10^{-19}$ J

$= \frac{3.42 \times 10^{-19}}{1.6 \times 10^{-19}}$ eV = 2.13 eV

---

87. **2069 Supp Set B Q.No. 10 a** **2067 Sup Q.No. 10a** **In a Millikan apparatus the horizontal plates are 1.5 cm apart. With the electric field is switched off, an oil drop is observed to fall with the steady velocity 2.5×10^{-2} cms^{-1}. When the field is switched on, the upper plate being positive, the drop just remains stationary when the potential difference between the plates is 1500 V. Calculate the radius of the drop and the number of electronic charges neglecting air density. (Given: density of oil =900 kgm^{-3} and viscosity of air = 1.8×10^{-5} Nsm^{-2})** **[4]**

Solution

Given,

Distance (d) = 1.5 cm = 1.5×10^{-2}m

Terminal velocity (v_t) = 2.5×10^{-2} cm/s = 2.5×10^{-4}m/s

Potential difference (V) = 1500V

Now,

For (a):

We have,

$$r = \sqrt{\frac{9}{2}\frac{\eta v_t}{(\rho - \sigma)g}} = \sqrt{\frac{9}{2} \times \frac{1.8 \times 10^{-5} \times 2.5 \times 10^{-4}}{(900 - 0) \times 9.8}} = \sqrt{2.29 \times 10^{-3} \times 10^{-5} \times 10^{-4}} = \sqrt{2.29 \times 10^{-12}}$$

$= 1.5 \times 10^{-6}$m

Hence, the radius of the drop is 1.5×10^{-6}m.

Again,

For (b): we have,

$$E = \frac{V}{d} = \frac{1500}{1.5 \times 10^{-2}} = \frac{1500 \times 10^2}{1.5} = 10^5 \text{ V/m}$$

Again, we have,

$$q = \frac{6\pi\eta r v_t}{E} = \frac{6 \times \pi \times 1.8 \times 10^{-5} \times 1.5 \times 10^{-6} \times 2.5 \times 10^{-4}}{10^5} = 127.23 \times 10^{-20} \text{ C}$$

But,

$q = ne$

or, $12.723 \times 10^{-19} = n \times 1.6 \times 10^{-19}$

$\therefore$ n = 8

Hence, the required number of electrons is 8.

88. **2069 (Set A) Q.No. 10a An electron is accelerated through a potential difference of 2KV and then it enters a uniform magnetic field of 0.02T, in a direction perpendicular to it. Find the radius of the path of the electron in the magnetic field. (mass of electron = 9.1×10^{-31}kg) [4]**

Solution

Given,

P.D. (V) = 2 KV = 2000V

Magnetic flux (B) = 0.02T

Mass of electron (m) = 9.1×10^{-31}kg

Radius of path (r) = ?

We have, $Bev = \frac{mv^2}{r}$

or, $Be = \frac{mv}{r}$

or, $r = \frac{mv}{Be} = \frac{m}{Be}\sqrt{\frac{2eV}{m}}$ $\left[\because \frac{1}{2}mv^2 = eV \text{ or, } v = \sqrt{\frac{2eV}{m}}\right]$

or, $r = \frac{1}{B}\sqrt{2.\frac{m}{e}V} = \frac{1}{0.02}\sqrt{\frac{2\times9.1\times10^{-31}}{1.6\times10^{-19}} \times 2000} = 7.5\times10^{-3}$m

89. **2069 Set A Old Q.No. 8bOR In a Thomson experiment, voltage across the plates is 50V and the distance between them is 3 cm. The magnetic field applied to make the beam undeflected is 10^{-4}T. What is the velocity of the electron passing between the plates? [4]**

Solution

Given,

Voltage across the plates (V) = 50 V

Distance between the plates (d) = 3 cm = 3×10^{-2} m

Applied magnetic field (B) = 10^{-4} T

Velocity of the electron (v) = ?

We have, for the undeflected beam in electric and magnetic field,

$F_B = F_e$

or, $Bev = eE$

or, $v = \frac{E}{B}$

or, $v = \frac{V}{Bd}$ $\quad [\because E = \frac{V}{d}]$

or, $v = \frac{50}{10^{-4} \times 3 \times 10^{-2}}$

$\therefore v = 1.67 \times 10^{7}$ m/s

Hence, the required velocity of electron is 1.67×10^{7} m/s.

90. **2068 Q.No. 10 a** **An electron having 450 eV of energy moves at right angles to a uniform magnetic field of density 1.50×10^{-3}T. Find the radius of its circular orbit. [Given: specific charge of the electron $1.76 \times 10^{+11}$C/kg]**

Solution

Given,

Energy of electron (E) = 450 eV = $450 \times 1.6 \times 10^{-19}$J

Magnetic flux density (B) = 1.50×10^{-3} T

Specific charge (e/m) = 1.76×10^{11} C/kg

Radius of the orbit (r) = ?

We have,

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

or, $r = \frac{mv}{Be}$

or, $r = \frac{m}{Be} \cdot \sqrt{\frac{2E}{m}} = \frac{1}{B.(e/m)} \cdot \sqrt{\frac{2E}{m}}$ $\quad \left[\because E = \frac{1}{2}mv^2 \text{ or, } v = \sqrt{\frac{2E}{m}}\right]$

or, $r = \frac{1}{1.5 \times 10^{-3} \times 1.76 \times 10^{11}} \cdot \sqrt{\frac{2 \times 450 \times 1.6 \times 10^{-19}}{9.1 \times 10^{-33}}} = 0.048$m

91. **2068 Old Q.No. 8 b** **Light of wavelength 6000 Å falls on a photosensitive plate of work function 1.9 eV. Find the speed of the photoelectrons emitted. ($h = 6.62 \times 10^{-34}$ Js and $m_e = 9.1 \times 10^{-31}$kg)**

Solution

Given,

Wavelength of light (λ) = 6000Å = 6000×10^{-10} m

Work function (ϕ) = 1.9 eV = $1.9 \times 1.6 \times 10^{-19}$ J

Planck's constant (h) = 6.62×10^{-34} Js

Mass of electron (m) = 9.1×10^{-31} Kg,

Speed of photoelectrons (v) = ?

We have, from Einstein's photoelectric equation,

$hf = \phi + K.E.$

or, $\frac{hc}{\lambda} = \phi + \frac{1}{2}mv^2$

or, $v = \sqrt{\frac{2}{m}\left(\frac{hc}{\lambda} - \phi\right)} = \sqrt{\frac{2}{9.1 \times 10^{-31}}\left(\frac{6.62 \times 10^{-34} \times 3 \times 10^{8}}{6000 \times 10^{-10}} - 1.9 \times 1.6 \times 10^{19}\right)} = 2.44 \times 10^{5}$ m/s

92. **2068 Can. Q.No. 10c** **What will be the change in the stopping potential for photoelectrons emitted from source if the wavelength of incident light is reduced from 400 nm to 360 nm?**

Solution

Given,

$\lambda_1 = 400\text{nm} = 400 \times 10^{-9}$m

$\lambda_2 = 360\text{nm} = 360 \times 10^{-9}$m

Change in stopping potential (ΔV) = ?

Now,

For 1st condition, we have

$$eV_1 = \frac{hc}{\lambda_1} - \phi_o \quad \ldots(i)$$

For 2nd condition, we have

$$eV_2 = \frac{hc}{\lambda_2} - \phi_o \quad \ldots(ii)$$

Subtracting equation (i) from (ii), we get

$$e(V_2 - V_1) = hc\left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right)$$

or, $e.\Delta V = 6.64 \times 10^{-34} \times 3 \times 10^8 \left(\frac{1}{360 \times 10^{-9}} - \frac{1}{400 \times 10^{-9}}\right)$

or, $1.6 \times 10^{-19} \times \Delta V = \frac{19.92 \times 10^{-26}}{10^{-9}}\left(\frac{1}{360} - \frac{1}{400}\right)$

or, $\Delta V = 12.45 \times 10^2 \left(\frac{40}{360 \times 400}\right)$

$\therefore \Delta V = 0.34V$

Hence, the required change in the stopping potential is 0.34V.

93. **2068 Old Can. Q.No. 8b** **A beam of electrons, moving with a velocity of 10^6 m/s enters midway between two horizontal parallel plates in a direction parallel to the plates. Each plate is 4cm long. These plates are kept 2cm apart and a potential difference V is applied between them. Calculate V if the beam is deflected so that it just grazes the edge of positive plate. (Given: e/m for the electron is 1.8×10^{11}C kg^{-1}.)** **[4]**

Solution

Given,

Velocity (v) = 10^6m/s

Length of each plate (D) = 4cm = 0.04m

Separation between two plates (d) = 2cm= 0.02m

$\frac{e}{m} = 1.8 \times 10^{11}$C kg^{-1}

Potential difference (V) = ?

Now,

As the electron beam enters mid-way between two plates, the vertical distance moved by the electron beam is, $y = \frac{d}{2} = \frac{0.02}{2} = 0.01$m

But, we have,

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

or, $0.01 = \frac{1}{2} \times \frac{F}{m} \times \left(\frac{D}{v}\right)^2 \quad [\because a = \frac{F}{m} \text{ and } t = \frac{D}{v}]$

or, $0.02 = \frac{E \times e}{m} \times \left(\frac{D}{v}\right)^2 \quad [\because F = E \times e]$

or, $0.02 = \frac{V}{d} \times \frac{e}{m} \times \left(\frac{D}{v}\right)^2 \quad [\because E = \frac{V}{d}]$

or, $0.02 = \frac{V}{0.02} \times 1.8 \times 10^{11} \times \left(\frac{0.04}{10^6}\right)^2$

or, $0.02 = V \times 0.144 \times 10^{11} \times 10^{-12}$

$\therefore V = 1.39V$

Hence, the required value of V is 1.39V.

94. **2068 Old Can. Q.No. 8b OR** **The maximum energy of photoelectrons emitted from a metal plate is 1.2 eV. If the threshold wavelength is 2.48×10^{-9}m, calculate the wavelength of incident light. (Given: Planck's constant is 6.62×10^{-34}Js.)** **[4]**

Solution

Given,

Maximum energy of photoelectrons ($K.E_{max}$) = 1.2 eV = $1.2 \times 1.6 \times 10^{-19}$ J = 1.92×10^{-19}J

Threshold wavelength (λ_0) = 2.48×10^{-9} m

Wavelength of incident light (λ) = ?

Planck's constant (h) = 6.62×10^{-34}Js

Now,

From Einstein's photoelectric equation, we have

$hf = \phi + K.E_{max} = hf_0 + K.E_{max}$

or, $K.E_{max} = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right)$

or, $1.92 \times 10^{-19} = 6.62 \times 10^{-34} \times 3 \times 10^8 \left(\frac{1}{\lambda} - \frac{1}{2.48 \times 10^{-9}}\right)$

or, $9.67 \times 10^5 = \frac{1}{\lambda} - \frac{1}{2.48 \times 10^{-9}}$

or, $9.67 \times 10^5 + \frac{1}{2.48 \times 10^{-9}} = \frac{1}{\lambda}$

or, $\frac{23.98 \times 10^{-4} + 1}{2.48 \times 10^{-9}} = \frac{1}{\lambda}$

or, $\lambda = \frac{2.48 \times 10^{-9}}{1.002}$

$\therefore$ $\lambda = 2.47 \times 10^{-9}$ m

Hence, the required wavelength is 2.47×10^{-9} m.

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95. **2067 Q.No. 10a** **A beam of electrons is under potential difference of 1.36×10^4V applied across two parallel plates 4 cm apart and a magnetic field 2×10^{-3} T at right angles to each other. If two fields produce no deflection in the electronic beam, calculate (i) the velocity of electrons (ii) the radius of the orbit in which the beam will move, if the electric field is made zero.**

[Given; mass of electron = 9.1×10^{-31} kg.] **[4]**

Solution

Given,

Potential difference (V) = 1.36×10^4 V

Distance between two plates (d) = 4cm = 0.04m

Magnetic field (B) = 2×10^{-3}T

Mass of electron (m) = 9.1×10^{-31}kg

Velocity of elections (v) = ?

Radius of the orbit (r) = ?

Now,

For (i):

Since, the electron beam is not deflected, the magnetic force is equal to the electric force i.e.,

Bev =eE

or, $v = \frac{E}{B} = \frac{V}{d \times B} = \frac{1.36 \times 10^4}{0.04 \times 2 \times 10^{-3}}$

$\therefore$ $v = 1.7 \times 10^8$m/s

Hence, the required velocity is 1.7×10^8 m/s.

Again,

For (ii):

If electric field is made zero, the magnetic force provides the centripetal force. i.e.,

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

or, $r = \frac{mv}{Be} = \frac{9.1 \times 10^{-31} \times 1.7 \times 10^{8}}{2 \times 10^{-3} \times 1.6 \times 10^{-19}}$

$\therefore r = 0.48m$

Hence, the required radius of circular path is 0.48 m.

96. **2066 Q.No. 8 b OR In Millikan-type apparatus, the horizontal plates are 1.5 cm apart. With the electric field switched off an oil drop is observed to fall with the steady velocity 2.5×10^{-2} cm/s. When the electric field is switched on the upper plate being positive, the drop just remains stationary when the p.d. between plates is 1500V. (a) Calculate the radius of the drop (b) How many electronic charges does it carry? [4]**
(Given – density of oil = 900 kg m^{-3} and viscosity of air = $1.8 \times 10^{-5} Nsm^{-2}$, Neglect air density)

Please refer to 2069 Supp Set B Q.No. 10 a

97. **2064 Q.No. 8 b 2063 Q.No. 8 b 2056 Q.No. 15 When a light of frequency 5.4×10^{14} Hz is incident on a metal surface, the maximum energy of the electrons emitted is 1.2×10^{-19} J. If the same surface is illuminated with light of frequency 6.6×10^{14} Hz, the maximum energy of the electrons is 2×10^{-19} J. Find the value of Planck's constant. [4]**

Solution

Given,
1^{st} case:
Frequency of radiation $(f_1) = 5.4 \times 10^{14}$ Hz
K.E. $(E_1) = 1.2 \times 10^{-19}$ J
2^{nd} case:
Frequency of radiation $(f_2) = 6.6 \times 10^{-14}$ Hz
K.E. $(E_2) = 2.0 \times 10^{-19}$J
Planck's constant (h) = ?
Now, we have,

$E_1 = hf_1 - \phi$ ... (i)

and, $E_2 = hf_2 - \phi$ ... (ii)

From equation (i) and (ii) by subtraction, we have,

$E_2 - E_1 = h(f_2 - f_1)$

$\therefore h = \frac{E_2 - E_1}{f_2 - f_1} = \frac{2.0 \times 10^{-19} - 1.2 \times 10^{-19}}{6.6 \times 10^{14} - 5.4 \times 10^{14}} = \frac{0.8 \times 10^{-19}}{1.2 \times 10^{14}} = 6.67 \times 10^{-34}$ Js

Hence, the required value of Plank's constant is 6.67×10^{-34}Js.

98. **2061 Q.No. 8 b A beam of proton is accelerated from rest through a potential difference of 2000V and then enters a uniform magnetic field which is perpendicular to the direction of the proton beam. If the flux density is 0.2T, calculate the radius of the path which the beam describes. (proton mass = 1.7×10^{-27} kg, Electronic charge = -1.6×10^{-19} C) [4]**

Solution

Given,
Potential difference (V) = 2000V
Flux density (B) = 0.2T
Proton mass (m) = 1.7×10^{-27}kg
Electronic charge (e) = -1.6×10^{-19}C
Radius of the path (r) = ?
Now, the kinetic energy acquired by the proton is equal to the work done on it. So,

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

or, $v^2 = 2\frac{e}{m}V$

or, $v = \sqrt{2\frac{e}{m}V}$

For the proton to be in the circular orbit, the force on electron due to magnetic field BeV provides the necessary centripetal force.

i.e., $Bev = \frac{mv^2}{r}$

or, $r = \frac{mv}{Be}$

Substituting the value of v from Eq. (i) in Eq. (ii), we get,

$$r = \frac{m}{Be}\sqrt{\frac{2eV}{m}} = \frac{1}{B}\sqrt{2V\frac{m}{e}} = \frac{1}{0.2}\sqrt{\frac{2\times2000\times1.7\times10^{-27}}{1.6\times10^{-19}}} = 0.033m$$

Hence, the radius of the path is 0.033m.

99. **2059 Q.No. 8 b** **A UV light of 400 nm strikes a cesium surface of work function 1.9 eV. Find the velocity of electron emitted from the cesium surface. ($m_e = 1.9 \times 10^{-31}$kg, $c = 3 \times 10^8$ m/s, $h = 6.62 \times 10^{-34}$ Js)** **[4]**

Solution

Given,

Wavelength (λ) = 400nm = 400×10^{-9}m

Work function (ϕ) = 1.9eV = $1.9 \times 1.6 \times 10^{-19}$J = 3.04×10^{-19}J

$m_e = 9.1 \times 10^{-31}$kg

$c = 3 \times 10^8$ m/s

$h = 6.62 \times 10^{-34}$Js

velocity of election (v) = ?

Now,

From Einstein's photoelectric equation, we have

$$\frac{1}{2}m_ev^2 = \frac{hc}{\lambda} - \phi$$

or, $\frac{1}{2} \times 9.1 \times 10^{-31} \times v^2 = \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{400 \times 10^{-9}} - 3.04 \times 10^{-19}$

or, $4.55 \times 10^{-31} \times v^2 = 4.96 \times 10^{-19} - 3.04 \times 10^{-19}$

or, $4.55 \times 10^{-31} \times v^2 = 1.92 \times 10^{-19}$

or, $v^2 = 4.22 \times 10^{11}$

$\therefore$ $v = 6.5 \times 10^5$ m/s

Hence, the required velocity is 6.5×10^5m/s.

100. **2058 Q.No. 8 b OR** **Calculate the p.d. in volt necessary to be maintained between two horizontal conducting plates, one 5 mm above the other, so that a small oil drop of mass 1.31×10^{-14} kg with two electrons attached to it remains in equilibrium. (g = 9.8ms^{-2}, charge of electron = -1.6×10^{-19}C).** **[4]**

Solution

Given,

Mass of oil drop (m) = 1.31×10^{-14} kg

Distance between plates (d) = 5mm = 5×10^{-3} m

Potential difference (V) = ?

Charge on oil drop (q) = 2e = $2\times1.6\times10^{-19}$ C

For the drop to be in equilibrium,

$F_e = F_g$

or, $qE = mg$

or, $q\frac{V}{d} = mg$

$$V = mg.\frac{d}{q} = \frac{1.31\times10^{-14}\times9.8\times5\times10^{-3}}{2\times1.6\times10^{-19}} = 2005.94 \text{ volt}$$

101. **2057 Q.No. 8 b** **The photoelectric work function of potassium is 2eV and the surface is illuminated with radiation of wavelength 350 nm. What potential difference have to be applied between a potassium surface and the collecting electrode in order just to prevent collection of electrons? What would be the kinetic energy of the electrons?** **[4]**

✍ Please refer to 2071 Set D Q.No. 10 a

102. **2056 Q.No. 16 OR** **Find the electric field required to keep a water drop of radius 10^{-5} cm just suspended in vacuum when charged with one electron. (electronic charge = -1.6×10^{-19}C, density of water = 1000 kg/m^3)** **[4]**

Solution

Given,

Radius of water drop (r) = 10^{-5} cm = 10^{-7} m

Electronic charge (e) = – 1.6×10^{19} C
Density of water (ρ) = 1000 kg/m³
Electric field (E) = ?
Now,
To keep water drop just suspended, we have,
Electric force = weight of water drop

or, $E \times e = mg$ [since, water drop is charged with 1 electron]

or, $E \times e = \rho \times V \times g$ [$\because \rho = \frac{m}{V}$]

or, $E \times e = \rho \times \frac{4\pi r^3}{3} \times g$ [$\because V = \frac{4\pi r^3}{3}$]

or, $E \times 1.6 \times 10^{-19} = 1000 \times \frac{4}{3} \times \pi\,(10^{-7})^3 \times 9.8$

or, $E \times 1.6 \times 10^{-19} = 41050.14 \times 10^{-21}$

$\therefore$ E $= 256.56\ \text{Vm}^{-1}$

Hence, the required electric field is 256.56Vm^{-1}.

---

103. **2055 Q.No. 15 OR** The maximum kinetic energy of the electrons emitted from a metallic surface is 1.6×10^{-19}J when the frequency of the radiation is 7.5×10^{14} Hz. Calculate the minimum frequency of the radiation for which electrons will be emitted. Assume that $h = 6.6 \times 10^{-34}$ Js. [4]

Solution

Given,
$K.E._{max} = 1.6 \times 10^{-19}$J
Frequency of incident radiation (f) = 7.5×10^{14}Hz
Plank constant (h) = 6.6×10^{-34} Js
Threshold frequency (f_o) = ?

Now, we have, from photoelectric equation,

$hf = \phi + K.E.max$

or, $K.E_{max} = h\,(f - f_o)$ [$\because \phi = hf_0$]

or, $1.6 \times 10^{-19} = 6.6 \times 10^{-34}\,(7.5 \times 10^{14} - f_o)$

or, $0.24 \times 10^{15} = 7.5 \times 10^{14} - f_o$

or, $2.4 \times 10^{14} = 7.5 \times 10^{14} - f_o$

$\therefore$ $f_o = 5.1 \times 10^{14}$ Hz

Hence, the required frequency is 5.1×10^{14} Hz.

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104. **2054 Q.No. 14** A beam of proton is accelerated from rest through a p.d. of 2000V and then enters a uniform magnetic field which is perpendicular to the direction of the proton beam. If the flux density is 0.4T, calculate the radius of the path which the beam describes. (Proton mass = 1.7×10^{-27} kg, charge = 1.6×10^{-19}C). [4]

Solution

Given,
Potential difference (V) = 2000 V
Flux density (B) = 0.4 T
Proton mass (m) = 1.7×10^{-27} kg
Charge (e) = 1.6×10^{-19} C
Radius (r) = ?
Now,
The kinetic energy acquires by the proton is equal to the work done on it. So, we can write,

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

or, $v^2 = 2\frac{e}{m}V$

$\therefore$ $v = \sqrt{2\frac{e}{m}V}$ ...(i)

For the proton to be in the circular orbit, the force on electron due to magnetic field Bev provides the necessary centripetal force. So,

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

or, $r = \frac{mv}{Be}$ ...(ii)

Substituting the value of v from equation (i) in equation (ii), we get,

$r = \frac{m}{Be}\sqrt{2\frac{e}{m}V} = \frac{1}{B}\sqrt{2 \times \frac{m^2}{e^2} \times \frac{e}{m} \times V} = \frac{1}{B}\sqrt{2 \times \frac{m}{e} \times V}$

$= \frac{1}{0.4}\sqrt{2 \times \frac{1.7 \times 10^{-27} \times 2000}{1.6 \times 10^{-19}}} = \frac{1}{0.4}\sqrt{4250 \times 10^{-8}}$

$\therefore$ $r = 1.629 \times 10^{-2}$ m

Hence, the required radius is 1.629×10^{-2}m.

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105. 2053 Q.No. 16 An oil drop of mass 3.25×10^{-15} kg falls vertically with uniform velocity, through the air between vertical parallel plates which are 2cm apart. When a p.d. of 1000V is applied to the plates the drop moves to the positively charged plate being inclined at 45° to the vertical. Calculate the charge on the drop. [4

Solution

Given,

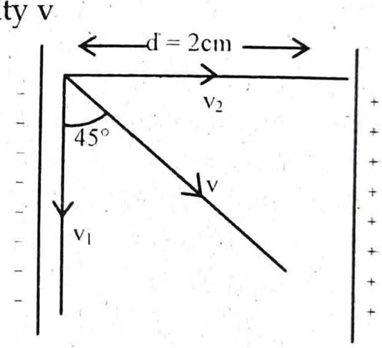
Mass of oil drop (m) = 3.25×10^{-15}kg

Distance between two plates (d) = 2cm = 0.02m

Potential difference (V) = 1000V

Let, v_1 & v_2 be the vertical & horizontal components of the velocity v

Now,



For vertical motion, we have

$mg = 6\pi\eta rv_1$ ...(i)

For horizontal motion, we have

$QE = 6\pi\eta rv_2$ ...(i)

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

$\frac{QE}{mg} = \frac{v_2}{v_1}$

or, $\frac{QE}{mg} = \frac{v\sin 45°}{v\cos 45°}$

or, $Q = \frac{mg}{E} = \frac{mg \times d}{V} = \frac{3.25 \times 10^{-15} \times 9.8 \times 0.02}{1000}$

$\therefore$ $Q = 6.37 \times 10^{-19}$C

Hence, the required charge on the drop is 6.37×10^{-19}C.

❑❑❑

26. An electron and a proton move with the same speed in a uniform magnetic field of equal magnitude. Compare the radii of their circular path. **[HSEB 2069]**

✍ The radius of circular path covered by a charged particle moving in a magnetic field of flux density B is given by

$r = \frac{mv}{Bq}$, where m is the mass of charged particle, v be velocity and q be the charge of particle. Since mass of proton is greater than mass of electron, the radius of proton is greater than the radius of electron for same speed and charge in a magnetic field.

27. Write down expressions for acceleration of a moving charge Q in parallel and perpendicular magnetic fields.

✍ The acceleration of a moving charge Q in a magnetic field is given by

$$a = \frac{BQv \sin\theta}{m}$$

Where, B is magnetic flux density, v is velocity of charged particle, m is mass of charged particle and θ is angle between B and v

When a charge is moving parallel to the direction of magnetic field, then $\theta = 0^0$

$$\therefore \quad a = \frac{BQv \sin 0}{m} = 0$$

When a charge is moving perpendicular to the direction of magnetic field, then $\theta = 90^0$

$$\therefore \quad a = \frac{BQv \sin 90}{m} = \frac{BQv}{m}$$

28. A charged particle moves through a region of space with constant velocity. If the external magnetic field is zero in this region, can we conclude that the external field in the region is also zero? Explain. **[HSEB 2070]**

✍ Yes, the velocity is constant only in the region of zero electric field because the velocity of charged particle will be constant in a field free space and in cross field space. Here, magnetic field is zero and hence for constant velocity electric field also be zero.

II. Sample Numerical Problems

Sample Problem 20.5 **Specific charge of a particle is $4.4 \times 10^7 Ckg^{-1}$. It is moving in a circular orbit with a velocity 3.52×10^5 ms^{-1} in a magnetic flux density 0.4T. Find the radius of its orbit.** **[HSEB 2069 Set B]**

Sol^n:

Specific charge of a particle (e/m) $= 4.4 \times 10^7 Ckg^{-1}$

Velocity of a particle (v) = 3.52×10^5 ms^{-1}

Magnetic flux density (B) = 0.4T

Radius of the circular orbit (r) = ?

When a charged particle is moving in a circular path in magnetic field, then

Centripetal force = Magnetic force

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

$$\text{or,} \quad \frac{mv}{r} = Be$$

$$\text{or,} \quad r = \frac{mv}{Be} = \frac{v}{Be/m}$$

$$= \frac{3.52 \times 10^5}{0.4 \times 4.4 \times 10^7}$$

$$= \mathbf{0.02m}$$

Hence, the radius of the circular orbit is 0.02m.

Sample Problem 20.6 **In a Thomson's experiment voltage across the plates is 50V and the distance between them is 3 cm. The magnetic field applied to make the beam undeflected is 10^{-4} T. What is the velocity of the electron passing between the plates?**

[HSEB 2069 Set A Old]

Sol^n:

Potential difference (V) = 50V

Distance between two plates (d) = 3cm $= 3 \times 10^{-2}$ m

Magnetic flux density (B) = 10^{-4} T

Velocity of the electron beam (v) =?

Since, the path of the beam is undeflected

$\therefore$ Magnetic force on electron = electric force on it

or, $Bev = eE$

or, $v = \frac{E}{B} = \frac{V}{dB} = \frac{50}{3 \times 10^{-2} \times 10^{-4}}$ $\left[\because E = \frac{V}{d}\right]$

Hence the velocity of electron beam passing between the plate is **1.67×10^7 ms^{-1}**

Sample Problem 20.7 **Electron is accelerated through a potential difference of 2kV and then it enters a uniform magnetic field of 0.02T, in a direction perpendicular to it. Find the radius of the path of the electron in the magnetic field. (Mass of electron = 9.1×10^{-31} kg)**

[HSEB 2069 Set A]

Sol^n:

Potential difference (V) = 2kV = 2000V

Magnetic flux density (B) = 0.02T

Mass of electron (m) = 9.1×10^{-31} kg

Radius of the path (r) = ?

$\because$ Let v be the velocity of electron, K.E. gained by electron = Work done on it

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

$$\text{or, } v = \sqrt{\frac{2eV}{m}}$$

$$= \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 2000}{9.1 \times 10^{-31}}} = 2.65 \times 10^7 \text{ ms}^{-1}$$

When an electron enters a uniform magnetic field perpendicular to it, then it deflects in a circular path.

Here,

Centripetal force = magnetic force

$$\text{or, } \frac{mv^2}{r} = Bev$$

$$\text{or, } r = \frac{mv}{Be}$$

$$= \frac{9.1 \times 10^{-31} \times 2.65 \times 10^7}{0.02 \times 1.6 \times 10^{-19}} = \mathbf{7.5 \times 10^{-3}\ m}$$

Hence the radius of circular or path of electron is 7.5×10^{-3} m.

Sample Problem 20.8 **In the ionosphere electrons execute 1.4×10^6 revolution in a second. Find the strength of the magnetic flux density B in this region. (Mass of an electron = 9.1×10^{-31} kg, electronic charge = 1.6×10^{-19} C).**

Sol^n:

Frequency (f) = 1.4×10^6 rev/sec

Strength of the magnetic flux density (B) =?

Mass of an electron (m) = 9.1×10^{-31} kg

Charge of an electron (e) = 1.6×10^{-19} C

For the electrons to be in the circular path, the force on electron due to magnetic field provides the necessary centripetal force.

$$\text{i.e. } Bev = \frac{mv^2}{r}$$

$$\text{or, } Be = \frac{mv}{r} = m\omega \quad Be = m2\pi f$$

$$\text{or, } B = m\frac{2\pi f}{e}$$

$$= \frac{9.1 \times 10^{-31} \times 2\pi \times 10^6}{1.6 \times 10^{-19}} = 0.5 \times 10^{-4}\ T$$

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

Hence the strength of the magnetic flux density is 5×10^{-5}T

Sample Problem 20.9 **An electron having 450 eV of energy moves at right angles to a uniform magnetic field of flux density 1.50×10^{-3} T. Find the radius of its circular orbit. Assume that the specific charge of the electron is 1.76×10^{11} C kg^{-1}.** **[HSEB 2068]**

Sol^n:

Energy of an electron (E) = 450 eV

$\therefore$ Potential difference (V) = 450 V

Sp charge of electron $\left(\frac{e}{m}\right) = 1.76 \times 10^{11}$ C Kg^{-1}

Magnetic flux density (B) = 1.5×10^{-3} T

As the electron moves with velocity v, then energy of the electron is

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

$$\therefore \quad v = \sqrt{\frac{2eV}{m}}$$

For the electron to be in the circular orbit, the force on electrons due to magnetic field provides the necessary centripetal force.

$$\text{i.e. } Bev = \frac{mv^2}{r}$$

$$\text{or, } r = \frac{m}{e}\frac{v}{B}$$

$$\text{or, } r = \frac{m}{e}\frac{1}{B}\sqrt{\frac{2eV}{m}}$$

$$\text{or, } r = \frac{1}{B}\sqrt{\frac{2mV}{e}}$$

$$\text{or, } r = \frac{1}{1.5 \times 10^{-3}}\sqrt{\frac{2 \times 450}{1.76 \times 10^{11}}}\ m$$

$$= \mathbf{4.8 \times 10^{-2}\ m}$$

Hence, the radius of the circular orbit is 4.8×10^{-2} m

Sample Problem 20.10 **In an evacuated tube electrons are accelerated from the rest through a potential difference of 3600 V and then travel in a narrow beam through a field free space before entering a uniform magnetic field the flux lines of which are perpendiculars to the beam. In the magnetic field the electrons describe a circular are of radius 0.10m. Calculate (i) the speed of the electrons entering the magnetic field (ii) the magnitude of the magnetic flux density. (iii) If an electron described a complete revolution in a magnetic field, how much energy would it acquire (e/m = 1.8×10^{11} C kg^{-1}).**

Sol^n:

p.d. (V) = 3600 V

Radius (r) = 0.10 m

Specific charge $\left(\frac{e}{m}\right) = 1.8 \times 10^{11}$ C Kg^{-1}

(i) Since, the kinetic energy acquired by the electrons is equal to the work done on it.

$$\text{i.e. } \frac{1}{2}m v^2 = eV$$

$$\text{or, } v^2 = \frac{2eV}{m} \Rightarrow v = \sqrt{\frac{2eV}{m}}$$

$$= \sqrt{2 \times 1.8 \times 10^{11} \times 3600}$$

$$\therefore \quad v = 3.6 \times 10^7\ ms^{-1}$$

ii) Magnetic flux density, B =?

For the electron to be in the circular arc of radius r, the force on electron due to the magnetic field provides the necessary centripetal force.

$$\text{i.e. } Be\,v = \frac{mv^2}{r}$$

$$\therefore B = \frac{mv}{er} = \frac{v}{\frac{e}{m} \times r}$$

$$= \frac{3.6 \times 10^7}{1.8 \times 10^{11} \times 0.10} = \mathbf{2 \times 10^{-3}T}$$

iii) If an electron described a complete revolution in a magnetic field the total work done is zero, so the energy acquired by electron would be zero.

Sample Problem 20.11 **Taking the electronic charge to be -1.6×10^{-19} C, calculate the potential difference in volt necessary to be maintained between two horizontal conducting plates, one 5mm above the other, so that a small oil drop of mass 1.31×10^{-14} kg with two electrons attached to it, remains in equilibrium between them. Which plate would be at the positive potential? ($g = 9.8\ ms^{-2}$)**

Solⁿ:

Charge of an electron (e) = -1.6×10^{-19}, $g = 9.8 m s^{-2}$,

Distance between two plates (d) = 5mm $= 5 \times 10^{-3}$ m,

Mass of an electron (m) = 1.31×10^{-14} kg

Acceleration due to gravity (g) = 9.8 m/s²

Number of electrons attached to the drop (n) = 2

∴ Charge (q) = 2e

Potential difference (V) =?

For the oil drop to remain in equilibrium, the force on oil drop due to electric field must to equal to the weight of the drop.

i.e. $qE = mg$

i.e. $\frac{qV}{d} = mg$

or, $V = \frac{mgd}{q}$

or, $V = \frac{mgd}{2e} = \frac{1.31 \times 10^{-4} \times 9.8 \times 5 \times 10^{-3}}{2 \times 1.6 \times 10^{-19}}$

$= \mathbf{2006\ V}$

The upper plate would be at positive potential. Hence, the required potential difference is 2006 volt.

Sample Problem 20.12 **A beam of protons is accelerated form rest through a potential difference of 2000 V and then enters a uniform magnetic field which is perpendicular to the direction of the proton beam. If the flux density is 0.2 T calculate the radius of the path which the beam describes. (Proton mass = 1.7×10^{-27} kg., Electronic charge = -1.6×10^{-19}C) [HSEB 2061]**

Solⁿ:

Potential difference (V) = 2000 V

Magnetic flux density (B) = 0.2 T,

Mass of proton (m) = 1.7×10^{-27} kg

Electronic charge (e) = 1.6×10^{-19} C

Radius of the path (r) = ?

Since, the kinetic energy acquired by the proton is equal to the work done on it.

i.e. $\frac{1}{2} mv^2 = eV$

or, $v^2 = \frac{2eV}{m}$

or, $v = \sqrt{\frac{2eV}{m}}$ .... (i)

For the proton to be in the circular orbit, the force on electron due to magnetic field is B ev provides the necessary centripetal force

i.e. $Bev = \frac{mv^2}{r}$

or, $r = \frac{mv}{Be}$

Substituting the value of v from Eq. (i) in Eq. (ii) we get,

$r = \frac{m}{Be}\sqrt{\frac{2eV}{m}}$

or, $r = \frac{1}{B}\sqrt{2V\frac{m}{e}}$

or, $r = \frac{1}{0.2}\sqrt{\frac{2 \times 2000 \times 1.7 \times 10^{-27}}{1.6 \times 10^{-19}}}$

or, $r = 0.033$ m $=$ **33mm**

Hence, the radius of the path is 33mm.

Sample Problem 20.13 **Two plane metal plates 4.0 cm long are held horizontally 3.0 cm apart in a vacuum, one being vertically above the other. The upper plate is at a potential of 300V and the lower is earthed. Electrons having a velocity of 1.0×10^7 m s^{-1} are injected horizontally midway between the plates and in a direction parallel to the 4.0 cm edge. Calculated the vertical deflection of the electron beam as it emerges from the plates. (e/m for electron 1.8×10^{11} C kg^{-1})** **[HSEB 2060]**

Sol^n:

Length of each plate (D) = 4 cm = 4×10^{-2} m,

Distance between two plates (d) = 3cm

$= 3 \times 10^{-2}$ m

P.d.(V) = 300 V

Velocity (v) $=1.0 \times 10^7$ m s^{-1}

Specific charge $\left(\frac{e}{m}\right) = 1.8 \times 10^{11}$ C kg^{-1}

Vertical deflection of the electron beam (y) =?

As we know,

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

$$y = \frac{eE}{m}t^2$$

$$y = \frac{1}{2}\frac{eE}{m}\left(\frac{D}{v}\right)^2 \qquad [\because t = \frac{D}{v}]$$

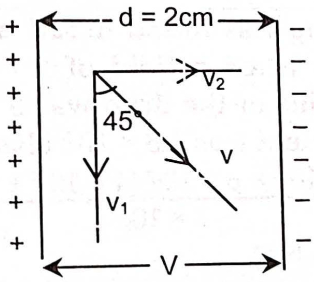
$$= \frac{1}{2}\frac{eV}{md}\left(\frac{D}{v}\right)^2$$

$$= \frac{1}{2} \times 1.8 \times 10^{11} \times \frac{300}{3 \times 10^{-2}} \times \left(\frac{4 \times 10^{-2}}{1.0 \times 10^7}\right)^2$$

$$= \mathbf{1.44 \times 10^{-2}\ m}$$

Sample Problem 20.14 **An oil drop of mass 3.25×10^{-15} kg falls vertically with uniform velocity, through the air between vertical parallel plates which are 2 cm apart. When a p.d. of 1000V is applied to the plates the drop moves towards the negatively charged plate, its path being inclined at 45°to the vertical. Calculate the charge on the drop.** **[HSEB 2053]**

Sol^n:



Mass of oil drop (m) = 3.25×10^{-15} kg,

Distance between two plates (d) = 2cm

$= 2 \times 10^{-2}$ m,

Potential difference (V) = 1000 volt

Inclination of path to the vertical (θ) = 45°

Let us consider v_1 and v_2 be the vertical and horizontal components of the velocity when the field is applied and q be the changed on the drop.

Here,

$$mg = 6\pi\eta\ rv_1 \quad \text{......... (i)}$$

and $qE = 6\pi\eta rv_2$ ....(ii)

Dividing Eq. (ii) by (i), we get

$$\frac{qE}{mg} = \frac{v_2}{v_1} = \frac{v \sin 45°}{v \cos 45°}$$

$$\text{or, } q = \frac{mg}{E}$$

$$= \frac{mg \times d}{V} = \frac{3.25 \times 10^{-15} \times 9.8 \times 0.02}{1000}$$

$$= \mathbf{6.37 \times 10^{-19}\ C}$$

Hence, the charge on oil drop is 6.37×10^{-19} C

Sample Problem 20.15 In a Millikan- type apparatus the horizontal plate are 1.5 cm part. With the electric field switched off and oil drop is observed to fall with the steady velocity 2.5×10^2 cm s^{-1}. When the field is switched on the upper plate being positive, the drop just remains stationery when the p.d. between the two plates is 1500V.(a) Calculate the radius of the drop. (b) How many electronic charged does it carry? (c) If the p.d. between the two remains unchanged, with what velocity will the drop move when it has collected two more electrons as a result of exposure to ionizing radiation?(Oil density = 900 kgm^{-3}, viscosity of air = 1.8×10^{-5} NS m^{-2})

Soln:

Distance between two plates (d) = 1.5 cm $= 1.5 \times 10^{-2}$m,

Steady velocity (v) $= 2.5 \times 10^{-2}$ cms^{-1} $= 2.5 \times 10^{-4}$ ms^{-1}

Potential difference (V) = 1500 V

Density of oil (ρ) = 900 kgm^{-3}

Viscosity of air (η) = 1.8×10^{-5} Ns m^{-2}

a. When the electric field is switched off, then

Weight of the drop = viscous force.

$$mg = 6\pi\eta rv$$

$$\text{or, } \frac{4}{3}\pi r^3 \rho g = 6\pi\eta rv \Rightarrow \frac{2}{3} r^2 \rho g = 3\eta v$$

$$\text{or, } r^2 = \frac{9\eta v}{2\rho g} \Rightarrow r = \left(\frac{9\eta v}{2\rho g}\right)^{1/2}$$

$$= \left(\frac{9 \times 1.8 \times 10^{-5} \times 2.5 \times 10^{-4}}{2 \times 900 \times 9.8}\right)^{1/2}$$

$$= \mathbf{1.5 \times 10^{-6}\ m}$$

b. When the drop is stationary then force on oil drop due to electric field must be equal to the weight of the drop.

i.e. $qE = mg$

$$\text{or, } q = \frac{mg}{E} = \frac{4}{3}\pi r^3 \rho g \times \frac{d}{V}$$

$$\text{or, } q = \frac{4}{3}\frac{\pi(1.5 \times 10^{-6})^3 \times 900 \times 9.8 \times 1.5 \times 10^{-2}}{1500}$$

$$= \mathbf{12.5 \times 10^{-19} C}$$

$\therefore$ no of electrons on the drop $(n) = \frac{q}{e}$

$$= \frac{12.5 \times 10^{-19}}{1.6 \times 10^{-19}} = 8$$

c. When the drop collects two more electrons, the electrostatic force is greater than weight of an oil drop and hence the drop moves up.

Here, $(2 + 8)\, eE - mg = 6\pi\eta rv$

or, $2\, eE + 8\, eE - mg = 6\pi n rv$

$2\, eE = 6\pi\eta rv$ $\quad [\because 8\, eE = mg]$

$$v = \frac{2eE}{6\pi\eta r} = \frac{eV}{3\pi\eta rd}$$

$$= \frac{1.6 \times 10^{-19} \times 1500}{3\pi \times 1.8 \times 10^{-5} \times 1.5 \times 10^{-6} \times 1.5 \times 10^{-2}}$$

$$= \mathbf{6.28 \times 10^{-5} ms^{-1}}$$

Sample Problem 20.16 In an experiment a single charged drop was found to fall under gravity at a terminal velocity of 0.004 cm/s and rise at 0.012 cm/s when a field of 2×10^5v/m was applied. calculate the electronic is charge given that the radius of the drop was 6×10^{-7} m and coefficient of viscosity of gas under the conditions of experiment was 1.8×10^{-5} Nsm^{-2}.

Soln:

Terminal velocity of a drop in absence of field (v_1) = 0.004 cm/s $= 4 \times 10^{-5}$ m/s

Terminal velocity of a drop in presence of field (v_2) = 0.012 cm/s $= 12 \times 10^{-5}$ m/s

Electric field (E) = 2×10^5 v/m.

Radius of drop (r) = 6×10^{-7} m

Coefficient of viscosity of gas (η) = $1.8 \times 1\text{-}0^5$ Nsm^{-2}

Electronic charge (e) = ?

When the electric field is applied, the drop moves up and attains terminal velocity.

Then,

$$\text{charge on the drop } (q) = \frac{6\pi\eta r\,(v_1 + v_2)}{E}$$

$$= \frac{6\pi \times 1.8 \times 10^{-5} \times 6 \times 10^{-7}\,(4 \times 10^{-5} + 12 \times 10^{-5})}{2 \times 10^5}$$

$= 1.628 \times 10^{-19}$ C

$= 1.6 \times 10^{-19}$C

Since, $q = ne$

or, electronic charge $(e) = \frac{q}{n}$

According to question, the drop contains single charge i.e. n = 1

$\therefore$ e = q

or, e = $\mathbf{1.6 \times 10^{-19}}$ **C**

Hence, the electronic charge is 1.6×10^{-19} C.

Sample Problem 20.17 **An electron having charge 1.8 × 10^{11} C/kg with a velocity of 10^7 ms^{-1} enters a region of uniform magnetic field of strength 0.1 T, the angle between the direction of the field and the initial path of the electron being 25°. Find the (a) radius of path (b) the axial distance traveled between two consecutive turns (or pitch of the helix) (c)the no. of revolutions made per sec.**

Sol^n:

Velocity (v) = 10^7m/s,

angle (θ) = 25°

Component of velocity perpendicular to the field (v_y) = v sinθ

The vertical component of velocity is responsible to describe the helical path.

a. Radius of path (r) = $\frac{mv_y}{Be} = \frac{mv\sin\theta}{Be}$

$$= \frac{v\sin\theta}{B\left(\frac{e}{m}\right)} = \frac{10^7 \sin 25°}{0.1 \times 1.8 \times 10^{11}}$$

$= 2.35 \times 10^{-4}$ **m**

b. Velocity along the field(v_x) = v cosθ

The horizontal component of velocity is responsible for the axial distance.

∴ Axial distance between two consecutive turns = linear distance travelled in 1 complete rotation.

= Horizontal velocity × Time period

= v_x T

$$= v\cos\theta\frac{2\pi r}{v_y} = v\cos\theta\frac{2\pi r}{v\sin\theta}$$

$$= \frac{2\pi r}{\tan\theta} = \frac{2\pi \times 2.35\times 10^{-4}}{\tan 25°}$$

= **2.86 × 10^{-4} m**

c. No. of revolutions per second is

$$f = \frac{1}{T} = \frac{v\sin\theta}{2\pi r} = \frac{10^7 \times \sin 25°}{2\pi(3.14 \times 10^{-4})}$$

= **2.14 × 10^9/s**

EXERCISES-20

Short Answer Questions

20.01- Why is a gas at normal pressure a bad conductor of electricity?

20.02- Why does electric discharge take place of low pressure and high potential difference? **[HSEB 2067 Sup]**

20.03- A gas at lower pressure conducts electricity but the same gas at higher pressure does not. Explain. **[HSEB 2071 Set D]**

20.04- Electric discharge stops at very low pressure, why? or Discharge tube appears dark when evacuated to very low pressure, why ?

20.05- Lighting discharge takes place at high attitude, why?

20.06- Cathode rays cannot be regarded as electromagnetic waves. Why? **[HSEB 2060]**

20.07- What property of cathode rays indicates that they consist of electrons? **[HESB 2068]**

20.08- Explain an evidence for the particle nature of electricity.

20.09- State the principle of working of Millikan's oil drop experiment. **[HSEB 2067]**

20.10- What is the importance of Millikan's oil drop experiment ?

20.11- Why is the path of a moving electron in et magnetic field is circular ?

Chapter 2: Solids and Semiconductors

Short Answer Questions

1. 2076 Set B Q.No. 2b | 2052 Q.No. 12 f **What do you mean by hole in a semiconductor?** **[2]**

At absolute zero temperature, in a pure semiconductor, all the electrons lie in a valance band. As a result, the valance band is completely filled by electrons and conduction band is empty. When temperature of semiconductor increases, the valance electrons get thermal energy and jump to the conduction band creating a vacant space in valance band. This vacant space in valence band is called hole in semiconductor. This hole acts as positive charge.

When a trivalent impurity atom is added to a pure semiconductor, the three valance electrons of trivalent atom form three covalent bonds with sharing three electrons of semiconductor atom and the fourth covalent bond has a deficiency of electron. This vacant space is also called hole in semiconductor.

2. 2076 Set C Q.No. 2b | 2068 Old . Q.No. 1f **Why is the emitter region of a transistor doped heavily?** **[2]**

A transistor consists of three terminals called emitter, base and collector. The function of emitter is to emit the charges, base is to supply charge and collector is to collect the charge. For emission of charge, doping is needed high for emitter. Due to this reason, the emitter of transistor is doped heavily.

3. 2075 GIE Q.No. 2c | 2071 Set D Q.No. 2 d **What is nanotechnology? Explain.** **[2]**

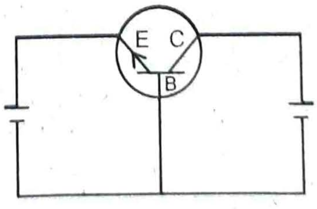
Nanotechnology: Nanotechnology is the study of control of matter in atomic and molecular size i.e., in nanometer scale in the range of 100 nanometer or smaller. One nanometer (nm) is one billionth, i.e. $1\ nm = 10^{-9}\ m$. This helps to develop the devices like nano-tubes, quantum dots of very small in size. It has the potential to create many new and small devices which are used in nano-medicine diagnosis, drug delivery, tissue engineering, nano-batteries, opto-electronics, semiconductor devices, quantum computer, etc.

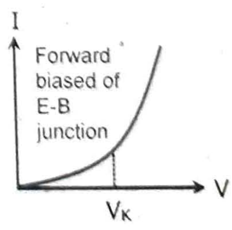
4. 2075 Set A Q.No. 2d **A semiconductor has electrons and holes as charge carriers. Do conductors also have the holes as charge carriers? Justify.** **[2]**

At absolute zero temperature, in a pure semiconductor, all the electrons lie in a valance band. As a result, the valance band is completely filled by electrons and conduction band is empty. When temperature of semiconductor increases, the valance electrons get thermal energy and jump to the conduction band creating a vacant space in valance band. This vacant space in valence band is called hole in semiconductor. This hole acts as positive charge. Thus, in semiconductor hole in valance band and electron in conduction band act as charge carriers.

No, hole can't be created in a metal because the conduction band and valance band overlap with each other, so that there is no possibility of jumping of electrons from valance band into conduction band so as to create the holes in valance bands.

5. 2075 Set B Q.No. 2b **In a transistor, emitter-base junction is always forward biased. Why?** **[2]**





The proper application of d.c. voltage across three terminals of a transistor (Emitter, Base and Collector) is called biasing of transistor. The voltage is applied either in emitter-base junction or in collector-base junction in such a manner that emitter-base junction is forward biased and collector-base junction is reverse biased. When emitter-base junction is made forward biased its resistance decreases. The current flows through the junction beyond the knee voltage i.e. charge cross base from emitter to collector. Hence, emitter-base junction is always forward biased in transistor to pass change carriers (electrons and holes) towards base.

6. 2074 Set A Q.No. 2c **The output of two-input AND gate is fed to a NOT gate. Give its logic symbol and write down its truth table. Identify the new logic gate formed.** **[2]**

NAND gate is the combination of AND and NOT gate in such a way that the output of AND gate is connected to the input of a NOT gate. The symbolic representation of the NAND gate is shown in fig. This gate produces high output if any one of the input is low.

If A and B represent the inputs and Y represents the output of NAND gate, then $Y = \overline{A.B}$. Thus truth table for NAND gate is given by:

Inputs		A·B	Output
A	B		$Y = \overline{A.B}$
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0

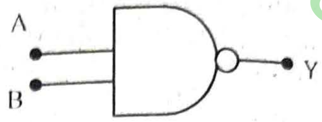


Fig. Symbol of NAND gate

7. 2074 Set B Q.No. 2a Draw a circuit diagram for p-n junction diode in forward bias. Sketch the voltage versus current graph for it. [2]

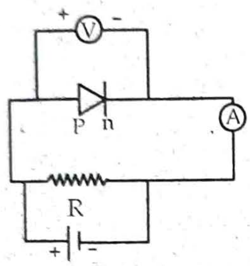


Fig: Forward biasing of p-n junction

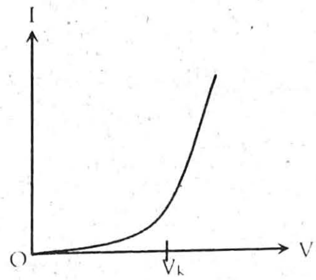
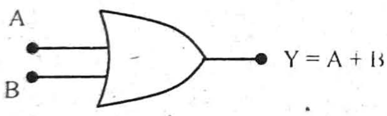


Fig: I-V curve in forward biasing

8. 2073 Supp Q.No. 2b 2070 Set C Q.No. 2 c What is a logic gate? Give logic symbol and truth table for an OR gate. [2]

The logic gate is the electronic circuit which gives the logic decisions.

OR gate is an electronic circuit which gives high (1) output when any or all inputs are high (1). It has two or more inputs and single output. Logic symbol, Boolean expression and truth table of two inputs OR gate are as follows:

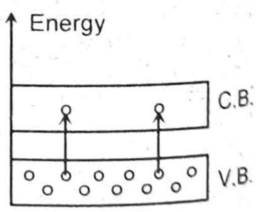


Symbol of OR Gate

Inputs		Output
A	B	Y = A + B
1	1	1
1	0	1
0	1	1
0	0	0

9. 2073 Set C Q.No. 2b How does the conductivity of semiconductor vary with temperature? Explain. [2]

At absolute zero temperature the valance band is completely filled and conduction band is empty and semiconductor acts as insulator. When temperature of semiconductor increases, some of the covalent bonds of valance band break down and the electrons jump to the conduction band where the electrons become free to conduct electricity. At higher temperature, more covalent bonds break down & more electrons are knocked to conduction band creating more number of in valance band electrons in conduction band. Hence, electrical conductivity increases on increasing temperature.



10. 2073 Set D Q.No. 2a Explain how the conductivity of a semiconductor varies with temperature? [2]

Please refer 2073 Set C Q.No. 2b

11. 2072 Supp Q.No. 2c Explain the essential characteristics for an element to serve as (i) a donor impurity (ii) an acceptor impurity in a semiconductor. [2]

The essential characteristics for an element to serve as a donor impurity is pentavalent or has five valence electrons which provides one free electron while doping to a semiconductor crystal and an acceptor impurity is trivalent or having three valance electrons which provides one hole which accept an electron.

12. 2072 Set C Q.No. 2b What are logic gates? Give a truth table for a two input NOR gate. [2]

The logic gates are electronic circuits which give logic decisions. The output of such circuits is either high or low but not intermediate value.

NOR gate: NOR gate is the electronic circuit which gives the high output when all of the inputs are low. It is the combination of OR and NOT gate. The output of OR gate is connected to input of NOT gate. The truth table and symbol of NOR gate is given below.

Inputs		Output of OR gate $Y = A+B$	Output of NOR gate $Y = \overline{A+B}$
A	B		
0	0	0	1
0	1	1	0
1	0	1	0
1	1	1	0

13. 2072 Set D Q.No. 2a The output of two-input AND gate is fed to a NOT gate. Draw the logic circuit of the combination of gates. Write down its truth table. [2]

Please refer to 2074 Set A Q.No. 2c

14. 2072 Set E Q.No. 2b What is meant by a charge carrier hole in a semi conductor? Can it be created in a conductor? [2]

Please refer to 2075 Set A Q.No. 2d

15. 2071 Supp Q.No. 2b When examining a circuit diagram, how is it possible to tell whether a transistor is PNP or NPN? [2]

The arrow in the circuit symbol of the transistor can be used to differentiate an N-P-N transistor from P-N-P transistor. If the arrow in the emitter terminal pointed in (pointed in means P-N-P) as shown in the figure (b), the transistor is recognized as a P-N-P transistor. If the arrow in the emitter terminal points out (not pointed in means N-P-N) as shown in the figure (a), the transistor is known as an N-P-N transistor.

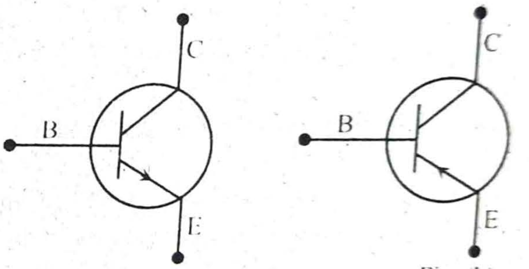


Fig. (a) NPN transistor

Fig. (b) PNP transistor

16. 2071 Set C Q.No. 2 b Draw a circuit diagram for a p-n junction diode in forward bias. Sketch the voltage-current graph for the same. [2]

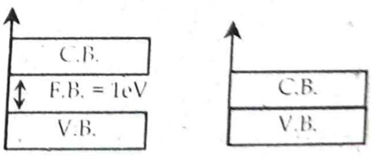
Please refer to 2074 Set B Q.No. 2a

17. 2071 Set C Q.No. 2 d What is truth table? Write down the truth table for a two-input NAND gate. [2]

Please refer to 2074 Set A Q.No. 2c

18. 2070 Sup (Set A) Q.No. 2 e Based on the band theory of solids, how would you distinguish between conductors and semi conductors? [4]

According to band theory of solids, there are three types of bands. They are; valance band, conduction band and forbidden band. The valance band is energy related to valance electrons, conduction band is energy related to conduction electrons or free electrons and forbidden band is energy gap between valance band and conduction band. For semiconductor, the energy gap between conduction band and valance band is small (nearly 1 eV) while for conductor, the gap is zero i.e., two bands are overlapped to each other as shown is figure.



Semiconductor Conductor

19. 2070 Supp. (Set B) Q.No. 2 d 2067 Sup Q.No. 2b An n-type semiconductor has a large number of free electrons at room temperature, yet it is said to be electrically neutral. Why? [2]

An n-type semiconductor is obtained by doping pure semiconductor with pentavalent impurity. As the impurity atoms enter into the configuration of the pure semiconductor, its four electrons take part in covalent bonding, while the fifth electron is left free. Since, an intrinsic semiconductor is made up of neutral atoms and hence it is electrically neutral and in n-type semiconductor, neutral pentavalent atoms are added to pure semiconductor crystal. Due to this reason, the number of electrons and protons are not changed in n-type semiconductor and hence it is electrically neutral even it has large number of free electrons.

20. **2070 Set D Q.No. 2 c** **2067 Sup Q.No. 2c** **What is a logic gate? Give logic symbol and truth table for a two-input AND gate.** **[2]**

The logic gates are the electronic circuits which give the logic decisions. AND gate is an electronic circuit which gives high output when all of the inputs are high. The symbol of two inputs AND gate is given below which consists of two inputs named A and B and one output say Y.

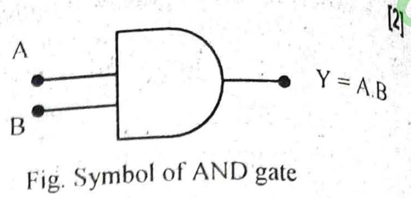


Fig. Symbol of AND gate

The truth table for two-inputs AND gate is given below:

Inputs		Output
A	B	$Y = A \cdot B$
0	0	0
0	1	0
1	0	0
1	1	1

21. **2069 Supp Set B Q.No. 2 d** **What is doping? Discuss its significance in semiconductor studies.** **[2]**

Doping is the process of adding impurity atoms to pure semiconductor crystal of silicon or germanium. The impurity atoms are either pentavalent atoms like phosphorus or trivalent atoms like aluminium. When pentavalent atoms are added to a pure semiconductor crystal, the no. of free electrons increase in conduction band. While the addition of trivalent impurity atoms increases the holes in valance band. Hence, the addition of impurity atoms to the pure semiconductor crystal increases the conductivity of semiconductor by increasing charge carriers.

22. **2069 (Set A) Q.No. 2b** **A p-type semiconductor has a large number of holes but still it is electrically neutral. Explain.** **[2]**

A p-type semiconductor is made by doping trivalent atom to a pure semiconductor crystal of silicon or germanium. The three valance electron of trivalent atom form covalent bond with the tree valance electron of semiconductor atom and the forth bond has deficiency of electron and a hole is created. An intrinsic semiconductor is made up of neutral atoms and hence it is electrically neutral and a p-type semiconductor is also made by doping the neutral trivalent impurity atoms in neutral intrinsic semiconductor. Hence, p-type semiconductor has equal number of electrons and protons as a whole and it is electrically neutral even it has large number of holes.

23. **2069 (Set B) Q.No. 2d** **What is a logic gate? Draw the truth table for an AND gate.** **[2]**

Please refer to 2070 Set D Q.No. 2 c

24. **2068 Q.No. 2b** **Would there be any advantage to adding n-type or p-type impurities to copper? Why or why not?** **[2]**

No, there would be no any advantage to adding n-type or p-type impurities to copper because copper has already large number of free electrons in its conduction band and there is no meaning of adding the impurity atoms.

25. **2068 Can. Q.No. 2c** **How does the suitable impurity increase the conductivity of a semiconductor?** **[2]**

In a pure semiconductor, there are no more free electrons in the conduction band and holes in valance band and hence there is low conductivity of semiconductor. When pentavalent impurity atoms are added to the pure semiconductor crystal, the number of free electrons in the conduction band increased. Similarly, the number of free holes increases on adding the trivalent impurity atoms to the pure semiconductor crystal. This increase in holes in valance band and free electrons in conduction band increases the conductivity of semiconductor. Thus, presence of impurity atoms in semiconductor increases its conductivity.

26. **2067 Q.No. 2b** **A student asserts that Si and Ge became good conductors at very high temperatures and good insulators at very low temperature. Do you agree? Explain your reasoning.** **[2]**

I agree with the statement that Si and Ge become good conductors at very high temperatures and good insulators at very low temperature. At very low temperature, all the electrons lie in the valance band and there are no free electrons in the conduction band and holes in valance band. Due to this reason, the semiconductors become insulators. When temperature increases and reaches to room temperature, some of the valance electrons jump to the conduction band by gaining thermal energy which creates holes in the valance band and these electrons become free in the conduction band. Hence, the number of holes in the valance band and the electrons in the conduction band increase on increasing temperature. Hence, the conductivity of semiconductor increases on increasing temperature and become conductor at high temperature.

27. 2065 Q.No. 1 f **How is p-type semiconductor formed? Explain.** **[2]**

➤ When a trivalent impurity atom (like boron, gallium etc) is added to pure semiconductor crystal of Silicon or Germanium, P-type semiconductor is formed. The three valance electrons of trivalent impurity atoms form covalent bond by sharing with three valence-electrons of pure semiconductor atoms and the forth covalent bond of semiconductor atom has a deficiency of electron. This deficiency of one electron in valance band creates a hole. On dopping large number of impurity atoms, more number of holes is created. Due to this reason, there are large number of holes and small number of free electrons in conduction band in P-type semiconductor.

28. 2063 Q.No. 1 f **Give the circuit symbol and truth table of NAND gate.** **[2]**

➤ Please refer to 2074 Set A Q.No. 2c

29. 2062 Q.No. 1 f **What do you mean by biasing a transistor?** **[2]**

➤ The proper application of dc voltage across the three terminals of transistor is called biasing of the transistor. The voltage is applied either in emitter-base junction or in collector-base junction in such a manner that the emitter-base junction is always forward-biased and the collector-base junction is always reverse-biased. So, the resistance of the emitter-base junction is low while the resistance of the collector-base junction is high. This is why, the forward bias voltage applied to the emitter-diode is very small whereas reverse bias voltage applied to the collector-diode is larger.

30. 2062 Q.No. 2 g **When P and N type materials are interfaced, there exists a depletion layer at the interface. Explain** **[2]**

➤ When a P-type of semiconductor is joined with a N-type of semiconductor, the free electron from the N-type is diffused into the P-type. This is because the concentration of free electrons in the N-side of material is greater than that in the P-side of material. Thus, there will be a layer of positive and negative ions at the junction - called depletion layer. In the depletion layer, there is net positive charge on the N-side and negative charge on the P-side. These collections of positive and negative charges at the junction produce an electric field which opposes further diffusion. This region is called barrier region and corresponding potential produced is called barrier potential.

31. 2059 Q.No. 1 f **What factors determine whether a material is a semiconductor or an insulator?** **[2]**

➤ The solid substance which has small energy gap between the valence band and conduction band is known as semiconductor. The energy gap in insulator is large. At lower temperature (0 K), the semiconductor also acts like insulator because both have the empty conduction band and filled valence band. But at room temperature, conduction band is partially filled for semiconductor but still empty for insulator. Thus, the factors like energy gap, temperature, conductivity and resistivity of the material determine whether the material is a semiconductor or an insulator.

32. 2058 Q.No. 1 f **A p-n diode conducts electricity when forward biased and does not conduct when reserve biased. Explain.** **[2]**

➤ When a positive terminal of the source is connected with P-type and negative terminal to N-type of a p-n junction diode, then it is said to be forward biased. In such biasing, electrons are repelled by negative terminal of battery in the N-region and holes are repelled by positive terminal of battery in the P-region. So, the width of barrier potential decreases and charges cross the junction and conducts the flow of current (switch ON).

When a positive terminal of the source is connected with N-type and negative terminal to P-type of P-N junction diode, then it is said to be reverse biasing. In this biasing, holes are attracted by negative terminal and electrons are attracted by positive terminal being opposite charges. Consequently, the barrier potential of the P-N junction diode increases and the flow of charges through the junction become impossible. As no charge flows in reverse biasing, conduction of electricity also does not take place (switch OFF).

33. **2057 Q.No. 2 f The base region of a transistor is made very thin as compared with emitter and collector regions, why? [2]**

A transistor is taken as good amplifier as it can deliver large collector current for very small base current. The base and collector currents are related with emitter current as $I_E = I_C + I_B$. So, at constant emitter current (I_E), the base current (I_B) should be very small for large collector current (I_C). This condition is satisfied only when very small number of majority charges carriers from emitter recombines with the opposite charge carriers at the base. The chances of combination in the base will be less if the number of opposite charge carriers is very low there. This number is reduced by making the base thin and doping it lightly. Thus, the base region of a transistor is made very thin as compared with emitter and collector regions to increase the collector current. If base is made heavy, large number of charges recombines and collector current decreases.

34. **2056 Q.No. 12 b How the conductivity of a semiconductor changes with the presence of impurities? [2]**

Please refer to 2068 Can Q No. 2d

35. **2055 Q.No. 12 a How is it possible to rectify an AC? [2]**

Rectification is the process of conversion of AC signal into DC signal by using a device which is called rectifier. There are two types of rectifier: Half wave and full wave rectifier. In half wave rectifier, only half cycle of AC is rectified because there is only one diode and it rectifies only in forward bias. In full wave rectifier, there are two diodes which rectifies both (positive and negative) half cycle at once because these diodes are so adjusted that one diode become forward biased during positive half cycle and another during negative half cycle. Thus, AC can be rectified by using semiconductor diode.

36. **2055 Q.No. 12 d When examining a circuit diagram, how is it possible to tell whether a transistor is a n-p-n or p-n-p? [2]**

Please refer to 2071 Supp Q.No. 2b

37. **2054 Q.No. 12 e Why may the addition of small quantities of suitable impurities to an intrinsic semiconductor result in a considerable decrease in its resistivity? [2]**

In a pure semiconductor crystal, there are equal number of free electrons in conduction band and holes in valance band. When small quantities of impurity atoms (either pentavalent atoms or trivalent atoms) are added to the pure semiconductor crystal, there is excess of electrons in conduction band by addition of pentavalent atoms and holes in valance band by addition of trivalent atoms. It means the number of charge carriers increases and hence conductivity increases. The resistivity is the reciprocal of conductivity ($\rho = 1/\sigma$). Thus, on increasing impurity, the resistivity decreases.

Long Answer Questions

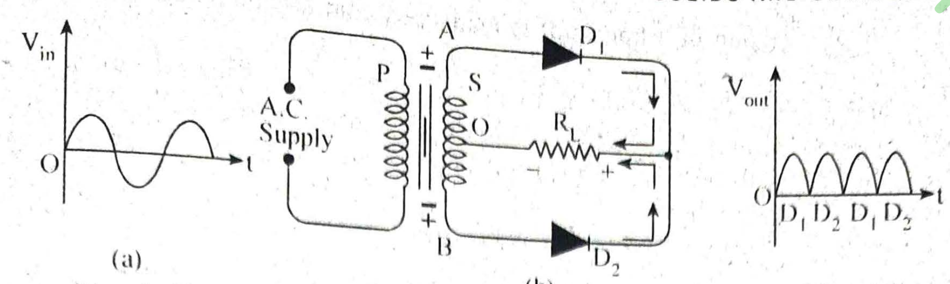
38. **2076 Set B Q.No. 6b What is P-N junction diode? Discuss its applications as full wave rectifier. [4]**

P-N Junction Diode: It is a semiconductor device in which P-type semiconductor is in contact with a N-type semiconductor. It has two terminals namely anode and cathode. The anode refers to the P-type region and cathode refers to the N-type region. Its symbol is as shown in figure.

Semiconductor Diode as Full wave rectifier

When current passes through the diode, it gains the unidirectional property i.e. the current moves in one direction. This characteristic of the diode is used in rectification. The conversion of the alternating current (or voltage) to direct current (or voltage) is called rectification. The device which is used for rectification is called rectifier. There are two types of rectifiers: Half wave and Full wave rectifiers. The half wave rectifier rectifies only half cycle of ac into dc while full wave rectifier converts both half cycle (positive half cycle and negative half cycle) of ac into dc.

The circuit diagram of the full wave rectifier is shown in the figure. It consists of a transformer with center tapped secondary coil. Two diodes D_1 and D_2 are connected at the upper and lower ends of the secondary coil of the transformer respectively. The center tap of the transformer and a common point of the n-region of diodes are connected to the load resistance from which output is taken.



(a) (b) (c)

During the positive half cycle of secondary voltage, the upper diode D_1 is forward biased and the lower diode D_2 is reverse-biased. Thus, the current flows through the diode D_1 and load resistor. During the negative half cycle of secondary voltage, the upper diode D_1 is reverse biased and the lower diode D_2 is forward biased. Thus, current flows through D_2 and the load resistor R_L. Figure shows the output voltage obtained at the load resistor R_L in both half cycle. The current flows through R_L for both half cycle of the input voltage. The voltage through the resistor R_L is in the same direction in both cases. Thus, the output current through the load is said to be unidirectional current. We can consider that a full-wave rectifier is like two back to back half wave rectifiers with one rectifier working in the first half cycle and the other working in the alternate half cycle.

39. **2076 Set C Q.No. 6b** **2071 Set D Q.No. 6 d** **Distinguish between intrinsic and extrinsic semiconductors. Explain the formation of potential barrier and depletion region in a PN junction. [4]**

Intrinsic semiconductor: An extremely pure semiconductor is called an intrinsic semiconductor. Pure silicon and germanium are examples of intrinsic semiconductor.

Extrinsic semiconductor: A pure semiconductor doped with trivalent or pentavalent impurities is called extrinsic semiconductor. Pure silicon or germanium doped with arsenic or indium is example of extrinsic semiconductor.

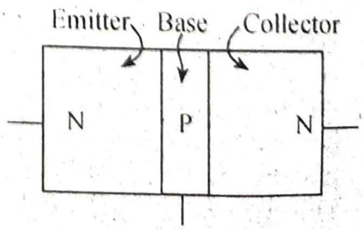
The main differences between intrinsic and extrinsic semiconductor are:

Intrinsic Semiconductor	Extrinsic semiconductor
It is pure semiconductor.	It is impure semiconductor.
The no. of holes in valance band and no. of electrons in conduction band are equal.	The no. of electrons in conduction band is greater in N-type semiconductor and no. of holes in valance band is greater in P-type semiconductor.
Its electrical conductivity is less.	Its conductivity is high.
Its electrical conductivity is only function of temperature.	It electrical conductivity is function of temperature and quantity of impurity atoms.
No impurity atoms are added.	Trivalent and pentavalent impurity atoms are added.
Eg. pure silicon and germanium.	Eg. pure silicon and germanium with arsenic and indium.

Second part: Please refer to 2062 Q.No. 2 g

40. **2075 GIE Q.No. 6a** **2068 Can. Q.No. 6b** **What is transistor? Discuss the input and output characteristics of a transistor in common emitter configuration. [4]**

NPN transistor: A NPN transistor is composed of two n-type semiconductors separated by a very thin p-type section. Thus, in a NPN transistor, there are three different regions: Emitter, Base and collector.Here, *emitter* is a heavily doped region and it supplies charge to the base region. *Base* is a lightly doped and very thin region situated in between emitter and collector region. It passes most of the charges injected form emitter to the collector. And *collector* is a moderately doped section of a transistor, which lies on the other side of the base. It collects the charge carriers from the base.



The input and output characteristics of the transistor in CE configuration: The electric circuit diagram of NPN transistor in CE configuration is as shown in figure below:

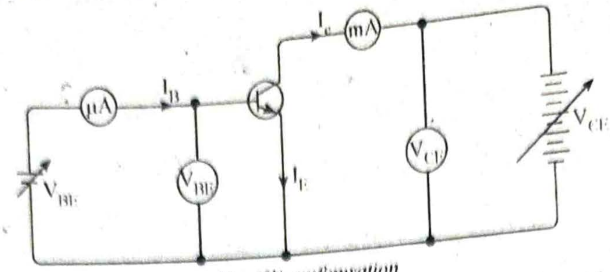
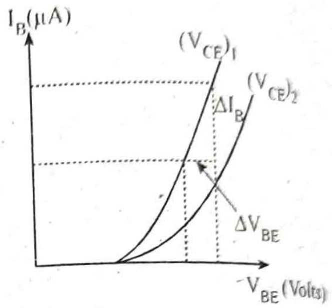


Fig. CE configuration

In CE configuration, the input is applied between the base and emitter terminals and output is taken between the collector and emitter terminals. Here, base current I_B is the input current and collector current I_C is the output current. Also, voltage source V_{BE} is used to forward bias on the input and V_{CE} is used to reverse bias on the output circuit.

Input characteristic:

The variation of the base current I_B against the corresponding values of the base-emitter voltage V_{BE} for a constant collector-emitter voltage V_{CE} is called input characteristics curve, which is as shown in graph.



The following informations can be obtained from the input characteristic.

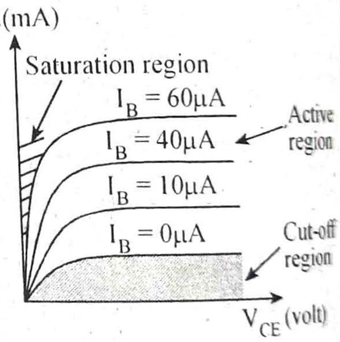
a. As long as V_{BE} is less than the knee voltage, the current I_B is small. But, when V_{BE} is increased to a value greater than knee voltage, the current I_B increased sharply. It is similar to the forward characteristics of junction diode.

b. The slope of the characteristic curve at a given fixed point gives the value of the input resistance (R_{in}).

i.e., $R_{in} = \dfrac{\Delta V_{BE}}{\Delta I_B}$ (at constant V_{CE})

Output characteristic:

The variation of the collector current I_C against the corresponding collector-emitter voltage V_{CE} for a constant value of base current I_B is called output characteristics curve, which is as shown in graph.



The following informations can be obtained from the output characteristics.

a. The collector current I_C increases rapidly when the V_{CE} increased from zero. After a certain value of V_{CE}, I_C remains almost constant.

b. When the base current $I_B = 0$, a small collector current still flows in the circuit, it is called leakage current.

c. The slope of this characteristic curve at a given fixed point gives the value of the output resistance (R_{out}).

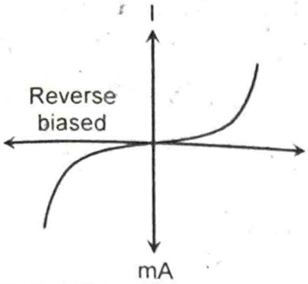
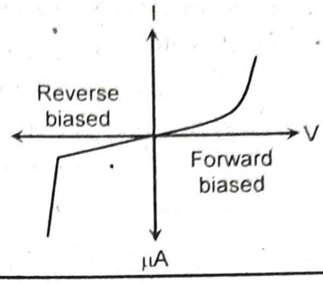
i.e., $R_{out} = \dfrac{\Delta V_{CE}}{\Delta I_C}$ (at constant I_B)

d. Output characteristic curves shows that there exist three operating regions as cut-off region, saturation region and active region.

41. 2075 Set A Q.No. 6c What is the difference between a zener diode and a common diode? Discuss the function of Zener diode as a voltage regulator. [4]

The difference between zener diode and a ordinary diode are given as:

Ordinary diode	Zener diode
1. Ordinary diode is a semiconductor device made up of N-type and P-type semiconductor with two terminals and commonly doped.	1. It is diode with property of diode having sharp breakdown region.
2. It words on forward biased.	2. It works on reversed biased.
3. Symbol:	3. Symbol:

4. Characteristics curve: 	4. Characteristics curve: 

Use of Zener Diode as Voltage Regulator

Voltage regulation is the ability of circuit to maintain constant output voltage irrespective of the variation of input voltage and load resistance. From the reverse characteristics of zener diode it is clear that if the current is increased, the voltage remains constant in the breakdown region which is the principle behind the action of zener diode as a voltage regulator. The circuit (or device) used to regulate voltage is called voltage regulator. It is connected between filter and load resistor of a power supply to obtain constant output voltage.

The above figure shows the circuit diagram of zener diode as a voltage regulator. As the zener diode is connected parallel to the load resistor, the regulator is also called zener diode shunt regulator.

A resistor R_S connected in series with the diode limits the current through the circuit and is called series current limiting resistor. For the proper operation, the input voltage must be greater than the zener voltage ($V_{in} > V_Z$) which ensures that the zener diode operates in reverse breakdown region. The total current in the circuit is given by

$$I = I_L + I_Z$$

where I_L is the load current and I_Z is the zener current

Also $$V_{in} = V_R + V_Z$$

and the current through the resistor R_s is given by

$$I = \frac{V_{In} - V_Z}{R_s}$$

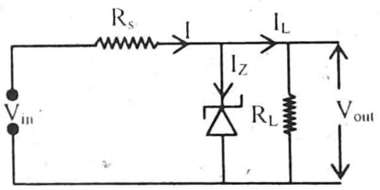


Fig. Zener diode as voltage regulator

Also, $V_z = V_L$ or V_0

If the input voltage (V_{in}) increased, then I also increases. Since R_L is kept constant which means I_L will have to remain constant. So when I is increased, the additional increased current passes through the zener diode. Thus I_Z increases. But the output voltage (V_o) remains constant. In this way we see that as the input voltage increases, the voltage across load ($V_L = I_L R_L$) remains constant. So a constant voltage is obtained from the varying input source voltage.

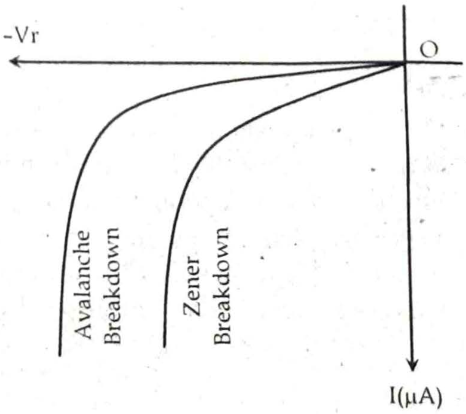
42. 2075 Set B Q.No. 6b **What are avalanche effect and Zener effect? How can a Zener diode be used as a voltage regulator?** **[4]**

Zener Diode: A zener diode is a properly doped crystal diode having sharp breakdown voltage. It is designated to operate in reverse breakdown region without damage. It words on reverse biased condition.

Zener Effect (Zener Breakdown): If the diode is heavily doped and has narrow depletion layer, a small reverse voltage can set up very high electric field across the junction. If the electric field becomes very height (10^8 V/m), it breaks down the covalent bonds producing large number of electron-hole pairs. Hence current rises very sharply. This effect is called Zener effect or zener breakdown.

Avalanche Effect (Avalanche Breakdown):

If the diode is lightly doped and the depletion layer is wide, the reverse electric field unable to create zener breakdown. However, the minority charge carriers in the diode are accelerated due to electric field. These highly energetic accelerated charges collide with the semiconductor atoms and breakdown the covalent bonds creating large number of electron-hole pairs. The newly generated electrons-holes gain energy and again accelerated, which produce large number of electron-hole pairs by breaking the covalent bond of



semiconductor atoms. This leads to an avalanche of charge carriers called avalanche effect or avalanche breakdown.

Second part: Please refer to 2075 Set A Q.No. 6c

43. 2074 Supp Q.No. 6a **Distinguish between intrinsic and extrinsic semiconductors. Explain the information of potential barrier and depletion region in a p-n junction.** [4]

Distinguish between intrinsic and extrinsic semiconductors:

Please refer to 2076 Set C Q.No. 6b

Second Part: Please refer to 2062 Q.No. 2 g

44. 2074 Set A Q.No. 6a **What is zener diode? Explain its use as a voltage regulator.** [4]

Zener diode: A zener diode is a properly doped crystal diode having sharp breakdown voltage. It is designed to operate in reverse breakdown region without damage. It is exclusively used in reverse biased condition.

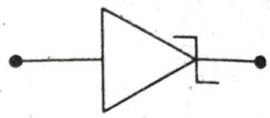


Fig: Symbol of zener diode

Use of Zener Diode as Voltage Regulator:

Please refer to 2075 Set A Q.No. 6c

45. 2074 Set B Q.No. 6b **What is rectification? With the help of a circuit diagram, explain full wave rectification by using junction diodes.** [4]

Please refer to 2076 Set B Q.No. 6b

46. 2073 Supp Q.No. 6b **Explain the characteristic of a diode and discuss its application as a half wave rectifier.** [4]

Half wave rectifier: The device which converts ac voltage or current to dc voltage or current is called rectifier. There are two types of rectifiers; half wave rectifier and full wave rectifier. The half wave rectifier rectifies only half cycle of the ac input into dc output while full wave converts both half cycle into dc output. A half wave rectifier is as shown in the figure which contains a transformer, a diode and a load resistor. The diode is connected at the secondary coil through a load resistor R_L. An alternating voltage is supplied to the transformer through the primary coil.

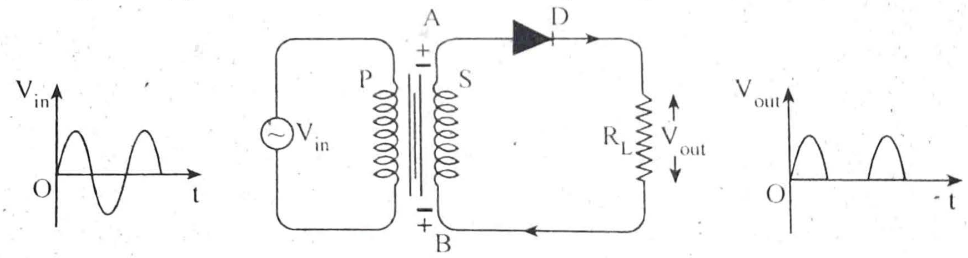


Fig. Half wave rectifier

During the positive half cycle of secondary voltage, the diode is forward-biased. Therefore, the current passes through the load resistor. During the negative half cycle of secondary voltage, the diode is reverse-biased. Therefore, no current passes through the load resistor R_L.

Thus, only during the positive half cycle of a.c., the diode conducts and voltage is developed in the load resistor. The voltage developed across the load resistor is shown in the figure. This clearly shows why the circuit shown in the figure is called half wave rectifier.

47. 2073 Set C Q.No. 6b **How are intrinsic and extrinsic semiconductors conceptualized? Explain the biasing characteristics of a junction diode.** [4]

Intrinsic semiconductor: An extremely pure semiconductor is called an intrinsic semiconductor. Pure silicon and germanium are examples of intrinsic semiconductor.

Extrinsic semiconductor: A pure semiconductor doped with trivalent or pentavalent impurities is called extrinsic semiconductor. Pure silicon or germanium doped with arsenic or indium is example of extrinsic semiconductor.

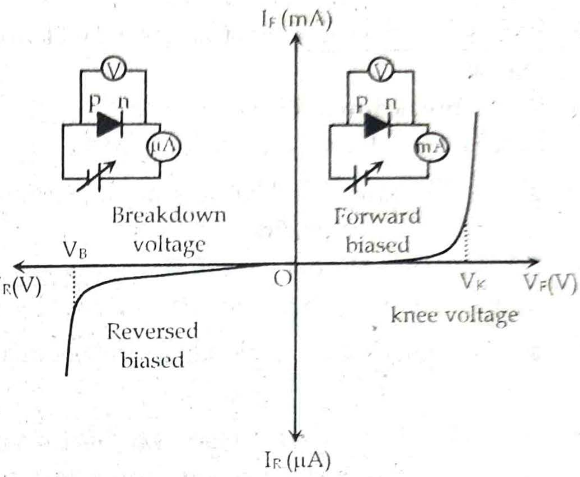
When pentavalent atoms are added to the pure semiconductor, the impure semiconductor thus formed is called **N-type semiconductor**. In N-type semiconductor, there are large numbers of free electrons in conduction band than the number of holes in valance band.

When trivalent atoms are added to the pure semiconductor, the impure semiconductor thus formed is called **P-type semiconductor.** In P-type semiconductor, there are large numbers of holes in valance band than the number of free electrons in conduction band.

Characteristics of a p-n junction diode:

The proper supply of external voltage to a p-n junction diode to get it ready for operation is called the biasing of a p-n diode. There are two types of biasing of diode; forward biasing and reversed biasing. When positive terminal of a battery is connected to the P-region and negative terminal is connected to the N-region then it is called forward biasing of the diode. During this biasing, diode properly works. If positive terminal of a battery is connected to the N-region and negative terminal is connected to the P-region then it is called reverse biasing of the diode. During this biasing, diode does not work.

When a junction diode is joined in forward biased, a large amount of current flows through it. But, when it is connected in the reverse biased, practically no current flows. The variation of current through a diode with the applied external voltage can be represented by drawing a graph. This graph is called **characteristic curve**. Such a graph is drawn by taking voltage along the x-axis and the current along the y-axis. In order to determine the characteristics of a semiconductor diode, a circuit arrangement is made as shown in the figure.



When the external voltage applied is zero, the potential barrier at the junction does not permit the flow of current. Thus, the circuit current is zero as depicted by point O in the characteristic curves.

When the forward voltage is gradually increased in steps and corresponding milli-ammeter reading shows that no current flows until the barrier voltage is overcome. Once the external voltage exceed the barrier potential, the current increases rapidly. The forward voltage beyond which the diode current increases rapidly is known as knee voltage V_k. V_K for Si diode is 0.7 K and 0.3 for Ge diode.

When the reverse biasing voltage is gradually increased in steps and corresponding micro-ammeter reading shows that the small current flows over a long range, increasing slightly with increasing bias voltage as shown in figure. If the reverse bias voltage is gradually increased, at one point the current suddenly rises. This voltage where the reverse current suddenly increases sharply is called reverse break down voltage V_B.

48. 2073 Set D Q.No. 6c **What is a rectifier? Describe the working principle of a full wave rectifier.** **[4]**

Please refer to 2076 Set B Q.No. 6b

49. 2072 Supp Q.No. 6c **Describe the common emitter configuration in a n-p-n transistor. Draw and explain input, output and transfer characteristics.** **[4]**

Please refer to 2075 GIE Q.No. 6a

50. 2072 Set C Q.No. 6b **What is an extrinsic semiconductor? Explain the formation of potential barrier and depletion region in p-n junction.** **[4]**

First Part: Please refer to 2076 Set C Q.No. 6b

Second Part: Please refer to 2062 Q.No. 2 g

51. 2072 Set D Q.No. 6b **Explain the use of a p-n junction diode as a rectifier. Draw the circuit diagram of a full wave rectifier using diodes and explain its working.** **[4]**

Please refer to 2076 Set B Q.No. 6b

52. 2072 Set E Q.No. 6a **What is rectification? How can you construct a full wave rectifier using two semiconductor diodes? Explain their working.** **[4]**

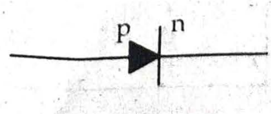
Please refer to 2076 Set B Q.No. 6b

53. 2071 Supp Q.No. 6b **What is a semiconductor diode? Explain the working of a full wave rectifier.** **[4]**

Please refer to 2076 Set B Q.No. 6b

54. 2071 Set C Q.No. 6 d **What is p-n junction? Describe forward biased and reverse biased condition of p-n junction.**

P-N Junction Diode: It is a semiconductor device in which P-type semiconductor is in contact with a N-type semiconductor. It has two



terminals namely anode and cathode. The anode refers to the P-type region and cathode refers to the N-type region. Its symbol is as shown in figure.

Characteristics of a p-n junction diode: Please refer to 2073 Set C Q.No. 6b

55. **2070 Sup (Set A) Q.No 6 c** **2070 Supp. (Set B) Q.No. 6 d** **2067 Sup Q.No. 6b** **2067 Q.No. 6b** **2066 Q.No. 8 a** **What is a rectifier? Explain how two diodes can be used as a full wave rectifier.** **[4]**

Please refer to 2076 Set B Q.No. 6b

56. **2070 Set C Q.No. 6 a** **What is Zener breakdown? Describe how a Zener diode can be used as a voltage regulator?** **[4]**

Zener breakdown: Please refer to 2074 Set A Q.No. 6a

Second Part: Please refer to 2075 Set A Q.No. 6c

57. **2070 Set D Q.No. 6 a** **What is a p-n a junction diode? Explain the characteristics of it in the forward and reversed biased condition.** **[4]**

P-N Junction Diode: Please refer to 2071 Set C Q.No. 6 d

Characteristics of a p-n junction diode: Please refer to 2073 Set C Q.No. 6b

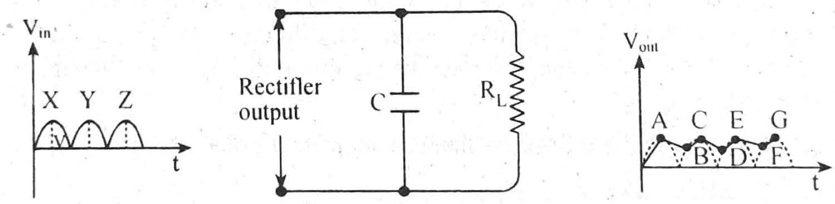
58. **2069 Supp Set B Q.No. 6 c** **What is rectifier? Describe the working of a full wave rectifier.** **[4]**

Please refer to 2076 Set B Q.No. 6b

59. **2069 (Set A) Q.No. 6b** **Explain with neat diagram, the working mechanism of a full wave rectifier using junction diodes. How the output changes when a filter circuit is used?** **[4]**

First Part: Please refer to 2076 Set B Q.No. 6b

The process of conversion of a.c. into d.c. is called rectification. The a.c. variation from the rectifier voltage can be filtered or smoothed out using a circuit called filter circuit. Thus, by using filter circuit, a constant d.c. voltage can be obtained. Figure shows a shunt capacitor filter circuit, the filter circuit contains a capacitor C parallel with the resistor R_L. The pulsating direct voltage of the rectifier is applied across the capacitor.



When the rectifier voltage increases, it charges the capacitor, as soon as the quarter cycle is completed (i.e., point X is reached in figure), the capacitor is charged to peak value of V_{in} of the rectifier voltage. Now, as the peak point X crosses over, the rectifier voltage starts to decrease. During this time, the capacitor discharges through the load R_L and voltage across it decreases slightly as shown by the line AB in figure.

Immediately after it, another peak voltage Y comes and recharges the capacitor. This process is repeated again and again resulting in wave form of the output voltage as in the figure.

60. **2069 (Set B) Q.No. 6b** **What is a Zenor diode? Explain how it regulates the constant voltage in the electronic circuit.** **[4]**

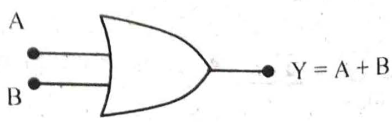
Please refer to 2075 Set A Q.No. 6c

61. **2068 Q.No. 6 b** **What are Logic gates? Describe, with truth tables, three basis gates: OR, AND and NOT.** **[4]**

Logic gates: The logic gate is the electronic circuit which gives the logic decisions.

OR Gate: OR gate is an electronic circuit which gives high (1) output when any or all inputs are high (1). It has two or more inputs and single output. Logic symbol, Boolean expression and truth table of two inputs OR gate are as follows:

Inputs		Output
A	B	Y = A + B
1	1	1
1	0	1
0	1	1
0	0	0



Symbol of OR Gate

AND Gate: The logic gates are the electronic circuits which give the logic decisions. AND gate is an electronic circuit which gives high output when all of the inputs are high. The symbol of two inputs AND gate is given below which consists of two inputs named A and B and one output say Y.

The truth table for two-inputs AND gate is given below:

Inputs		Output
A	B	$Y = A \cdot B$
0	0	0
0	1	0
1	0	0
1	1	1

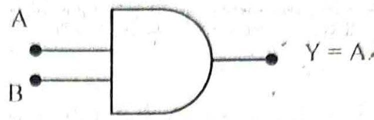


Fig. Symbol of AND gate

NOT Gate: NOT gate is an electronic circuit which gives output which is not of input i.e. high output (1) when input is low (0) and vice-versa.

Input (A)	Output (B)
1	0
0	1

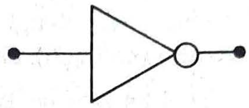


Fig. Symbol of NOT gate

62. 2068 Old Can. Q.No. 8a **What is a p-n junction diode? With the help of a circuit diagram, explain the working of a junction diode as a full- wave rectifier.** [1+3]

Please refer to 2076 Set B Q.No. 6b

63. 2067 Old Q.No. 9 OR **What do you mean by rectifier? Describe the working of full wave rectifier using semiconductor diodes.** [1 + 3]

Please refer to 2076 Set B Q.No. 6b

64. 2066 Supp Q.No. 8a **What are N-type and P-type semiconductors? Discuss how the semiconductor diodes are used as a full-wave rectifier.** [2+2]

First Part: Please refer 2073 Set C Q.No. 6b

Second Part: Please refer to 2076 Set B Q.No. 6b

65. 2065 Q.No. 9 a **What do you understand by zener diode? How can this be used as voltage regulator?** [4]

Please refer to 2075 Set A Q.No. 6c

66. 2061 Q.No. 9 **What is a junction diode? Explain its working as a half wave rectifier.** [1+3]

Junction Diode: Please refer to 2074 Set A Q.No. 6a

Half Wave Rectifier: Please refer to 2073 Supp. Q.No. 6b

67. 2060 Q.No. 9 OR **How is a NPN transistor formed? Discuss the input and output characteristics of the transistor in CE configuration.** [1+3]

Please refer to 2075 GIE Q.No. 6a

68. 2059 Q.No. 9 a **What are N-type and P-type semiconductors? Describe with a neat diagram the working mechanism of a full wave rectifier for a junction diode.** [1+3]

First Part: Please refer 2073 Set C Q.No. 6b

Second Part: Please refer to 2076 Set B Q.No. 6b

69. 2056 Q.No. 14 OR **Explain the action of a diode valve as a full wave rectifier.** [4]

Please refer to 2076 Set B Q.No. 6b

70. 2055 Q.No. 13 OR **Explain the characteristics of a diode and discuss its application as a full wave rectifier.** [4]

Please refer to 2076 Set B Q.No. 6b

71. 2054 Q.No. 15 OR **What is a junction diode? Explain full wave rectification produced by a filter circuit.** [4]

Please refer to Please refer to 2069 (Set A) Q.No. 6b

72. 2053 Q.No. 15 OR **What is a junction diode? Discuss its applications as full wave rectifier.** [4]

Please refer to 2076 Set B Q.No. 6b

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Chapter 3: Quantization of Energy

Short Answer Questions

1. **2076 Set B Q.No. 2c** **2054 Q.No. 12 b** **Which has more energy- a photon in the infrared or photon in the ultraviolet? Given reasons.** [2]

We know, energy of photon is given by

$$E = hf = \frac{hc}{\lambda}$$

where h is Planck's constant, c is the velocity of light and λ is the wavelength of radiation.

$$\text{or, } E \propto \frac{1}{\lambda} \quad \dots (i)$$

It means energy of photon is inversely proportional to its wavelength.
Again, we know, wavelength of infrared photon is greater than wavelength of ultra-violet photon.
Hence, according to Eq. (i), energy of ultraviolet photon is more than infrared photon.

2. **2076 Set C Q.No. 2a** **2074 Set B Q.No. 2b** **2073 Supp Q.No. 2c** **2068 Can. Q.No. 2b** **2068 Old Can. Q.No. 1f** **An electron and a proton have the same kinetic energy. Which one of them has the longer wavelength?** [2]

If E_k be the kinetic energy of a particle, then its wavelength λ is given by, $\lambda = \frac{h}{p}$, where h is Planck's constant.

or, $\lambda = \frac{h}{\sqrt{2mE_k}}$. This shows that the wavelength of a moving particle is inversely proportional to the square root of its mass.
Since, the mass of the electron is less than the mass of the proton, for same kinetic energy, the electron has greater wavelength than the proton by $\sqrt{1840}$.

3. **2075 Set A Q.No. 2b** **A photon and an electron have got the same de-Broglie wavelength. Which one has greater total energy? Explain.** [2]

According to question, an electron and a photon has same de-Broglie wavelength, $\lambda = \frac{h}{mv}$

Energy of electron, $E_1 = mc^2 \quad \dots (i)$

Energy of photon, $E_2 = \frac{hc}{\lambda} = hc\frac{mv}{h}$

or, $E_2 = mcv \quad \dots (ii)$

Dividing (i) by (ii), we get

$$\frac{E_1}{E_2} = \frac{mc^2}{mcv} = \frac{c}{v}$$

Since, $c > v$, $E_1 > E_2$
Hence, energy of photon is greater than energy of electron for same de-Broglie wavelength.

4. **2073 Set C Q.No. 2a** **The accelerating voltage of a proton is increased to twice. How will its de-Broglie wavelength change? Explain.** [2]

Let V be the accelerating potential of a partice, then its de Brogile wavelength is

$$\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2meV}}, \qquad h = \text{planck's constant.}$$

When accelerating potential of proton increases twice, then new wavelength is,

$$\lambda' = \frac{h}{\sqrt{2me2V}} = \frac{1}{\sqrt{2}}\frac{h}{\sqrt{2meV}} = \frac{\lambda}{\sqrt{2}}$$

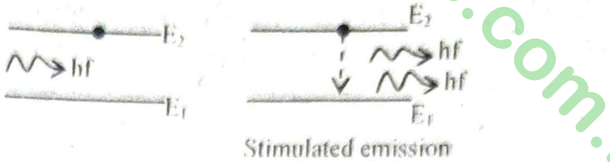
The de Brogile wavelength is reduced by $\sqrt{2}$.

. **2073 Set C Q.No. 2d** **Can X-ray diffraction experiment be performed by an ordinary grating? Why?** [2]

No, X-ray diffraction experiment cannot be performed by an ordinary grating. For diffraction, the grating element must be order of wavelength of light. The X-ray has wavelength of order of $\left(\frac{1}{1000}\right)^{th}$ of ordinary visible light. So, for diffraction of X-ray crystal grating is needed.

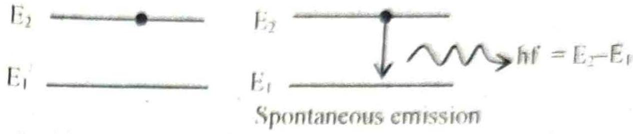
6. 2073 Set D Q.No. 2f **Explain the difference between stimulated and spontaneous emissions of radiation.** [2]

The process of emission of radiation by an excited atom during its returning back to ground state by the induction of photon of the suitable energy is called *stimulated emission*. Thus, emitted photon is always in phase with the stimulating photon of same frequency and in same direction as shown in first figure. This is the working principle of LASER.



Stimulated emission

The process of emission of radiation by an excited atom during its returning to the ground state without any external influence is known as *spontaneous emission*. Such emission is non-coherent to the photons of light which are sent in all directions with random phase as shown in second figure.



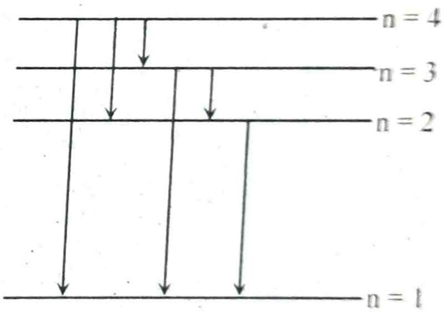
Spontaneous emission

7. 2072 Supp Q.No. 2f **If a proton and an electron have the same speed, which has the longer de-Broglie wavelength? Explain.** [2]

The de-Broglie wavelength of a moving particle is given as $\lambda = h/mv$, where h is Planck's constant, m be the mass of the particle and v be its velocity. Since mass of proton is greater than mass of electron, the wavelength of electron is longer than proton.

8. 2072 Set C Q.No. 2c **Even if a hydrogen atom contains an electron, its spectrum consists of a large number of lines. Explain how.** [2]

A hydrogen atom consists of one electron and one proton. A single hydrogen atom has infinitely large number of stationary orbits even it has a single electron. Even it has an electron; it can emit large no. of spectrums when electron jumps from higher orbits to lower possible orbits. Suppose an electron lies in fourth orbit ($n = 4$) then possible transitions are $n = 4$ to $n = 3$, $n = 4$ to $n = 2$, $n = 4$ to $n = 1$, $n = 3$ to $n = 2$, $n = 3$ to $n = 1$ and $n = 2$ to $n = 1$. All together there are six possible transitions and give six lines to spectrum.



9. 2072 Set D Q.No. 2b **What is optical pumping in the production of laser?** [2]

The process by which population inversion is carried out by light is called optical pumping. This is done by applying the photon of suitable frequency to the atoms of ground state. It is commonly used in laser production so as to achieve population inversion.

10. 2072 Set E Q.No. 2d **Production of X-ray is the inverse phenomenon of photoelectric effect. Justify it.** [2]

When fast moving electrons (particles) strike on a metal target having high atomic mass, then X-rays (waves) are produced. In photoelectric effect, when radiations (waves) of suitable frequency incident on the surface of metal, then photoelectrons (particles) are emitted from it. In other words, in photoelectric emission, the energy of photon transformed into kinetic energy of electron where as in the production of X- rays, kinetic energy of electron is transformed into the energy of photon. Also, the production of X-ray, hard metals are used as target metal whereas soft metals are used in for production of X-ray. That's why, the production of x-rays is the reverse or inverse phenomenon of photoelectric effects. That's why, the production of x-rays is the reverse or inverse phenomenon of photoelectric effect.

11. 2072 Set E Q.No. 1f **"The total energy of an electron of an atom in an orbit is negative". What does this negative energy indicate?** [2]

The total energy of an electron in an orbit is

$$E = -\frac{13.6}{n^2}\ \text{eV}$$

The –ve sign indicates that the total energy of an electron in an orbit as negative which means the electron in bound to the nucleus and some work should be done to separate it from the atomic orbit.

12. **2071 Supp Q.No. 2c An electron and proton are accelerated through the same potential, which one has higher de-Broglie's wavelength? Justify your answer.** **[2]**

Let V be the potential through which a charged particle is accelerated, then its de-Broglie wavelength is,

$$\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2meV}}; \text{ h = Planck's constant}$$

For same potential and different masses,

$$\lambda \propto \frac{1}{\sqrt{m}}$$

Since, mass of electron is less than mass of proton, wavelength of electron is longer than the wavelength of proton accelerating in a same potential.

13. **2071 Set C Q.No. 2 c An electron and a proton have same kinetic energy, which of the two has greater de-Broglie wavelength? Justify your answer.** **[2]**

Please refer to 2076 Set C Q.No. 2a

14. **2071 Set D Q.No. 2 b A proton and an electron have same de-Broglie wavelengths, which of the two has greater kinetic energy? Justify your answer.** **[2]**

Let E_K be kinetic energy and λ be the de-Borglie wavelength, then, we have

$$\lambda = \frac{h}{\sqrt{2mE_K}}$$

$$\text{or, } \lambda^2 = \frac{h^2}{2mE_K}$$

$$\text{or, } E_K = \frac{h^2}{2m\lambda^2}$$

According to question, wavelength of electron and proton has same. Since $m_e < m_p$ than $E_{Ke} > E_{Kp}$. Hence, energy of proton is less than energy of electron for same de-Broglie wavelength.

15. **2071 Set D Q.No. 2 c Distinguish between stimulated emission and spontaneous emission.** **[2]**

Please refer to 2073 Set D Q.No. 2f

16. **2070 Sup (Set A) Q.No. 2 a If a proton and an electron have the same kinetic energy which has the longer de-Broglie wavelength?** **[2]**

Please refer to 2076 Set C Q.No. 2a

17. **2070 Sup (Set A) Q.No. 2 c Why is the gravitational force not taken into consideration while evaluating the energy of an electron in an atom?** **[2]**

The gravitational force is not taken into consideration while evaluating the energy of an electron in an atom because the mass of electron is 9.1×10^{-31} kg which very small, as a result i.e. the gravitational force is very small compared to the atomic energy caused by electrostatic force.

18. **2070 Supp. (Set B) Q.No. 2 c Can X-rays be produced from gases? Explain.** **[2]**

No, X-rays can not be produced from gases. The spectrum produced by gases lies in ultraviolet, visible and infrared range, but not in the X-ray region. X-rays are produced only in the electron transition in the metals of high atomic number and high melting like tungsten.

19. **2070 Set C Q.No. 2 b A proton and an electron have the same speed. Which has longer wavelength?** **[2]**

Please refer to 2072 Supp Q.No. 2f

20. **2070 Set D Q.No. 2 b The wave nature of particles is not observable in daily life. Why?** **[2]**

According to de-Broglie wave theory, the wavelength associated with wave of moving particle of mass m and velocity v is given by, $\lambda = \frac{h}{mv}$, where h is Planck's constant. Since, the value of Planck's constant is 6.62×10^{-34}Js i.e., very small and mass of the particles which are daily observable in our eyes are very large, then de-Broglie wavelength becomes very small. So, matter has a wave nature, but not observable in our daily experiences.

21. 2069 Supp Set B Q.No. 2 c **Can Bragg's law of x-ray diffraction be verified with yellow light of wavelength 600 nm? Explain.** [2]

Bragg's law depends upon the X-ray diffraction experiments on crystals. For diffraction of any wave, the wavelength of the wave should be comparable to the size of the width of the slit i.e. opening. Bragg's diffraction experiment is done by using metal crystal. The spacing between the atoms in crystal is about 10^{-10} m which very narrower than the wavelength of yellow light 600nm (10^{-6}m). So, Bragg's law of X-ray diffraction cannot be verified by using yellow light of wavelength 600nm.

22. 2069 Supp Set B Q.No. 2 b **Draw schematic diagram to show the difference between spontaneous and stimulated emissions of radiation.** [2]

Please refer to 2073 Set D Q.No. 2f

23. 2069 (Set A) Q.No. 2c **A stone is dropped from the top of a building. How does its de-Broglie wavelength change?** [2]

The de-Broglie wavelength of a moving particle (dropping stone) is given as $\lambda = h/mv$, where h is Planck's constant, m be the mass of the particle and v be its velocity. When a stone is dropped from the top of the building, its velocity increases and hence its wavelength gradually decreases.

24. 2069 (Set B) Q.No. 2c **Compare the wavelengths of an electron with that of a proton if their kinetic energies are equal. Mass of a proton is nearly equal to 1840 times the mass of an electron.** [2]

Please refer to 2076 Set C Q.No. 2a

25. 2068 Q.No. 2 f **When x-rays are produced only about 10% of the initial input energy appears as x-ray energy. Explain what has happened to the other 90% of the energy.** [2]

X-rays are produced when fast moving electrons strikes a target of high atomic number like platinum, tungsten, molybdenum, etc. When rapidly moving electrons strike the target metal, about 10% of the initial input energy appears of X-ray energy and remaining 90% of input energy is converted into heat energy.

26. 2068 Can. Q.No. 2d **Define population inversion and optical pumping.** [2]

Population Inversion

Let N_1 and N_2 be the number of atoms lying in the ground state E_1 and E_2 excited state respectively. Under ordinary conditions of thermal equilibrium, the number of atoms in the higher energy state is considerably smaller than the number of atoms in the lower energy state i.e. $N_2 < N_1$. In such a situation, if a light of frequency $f = E_2 - E_1/h$ is incident on a large collection of such atoms, the atoms are excited due to absorption of photons and rise to the excited state E_2. So that there are more atoms in the higher energy sate E_2 than in the lower energy state E_1 i.e., $N_2 > N_1$. This phenomenon of having more number of atoms in the excited state by any means than in the ground state is called population inversion.

Optical Pumping: Please refer to 2072 Set D Q.No. 2b

27. 2067 Q.No. 2c **What are the differences between matter wave and electromagnetic wave?** [2]

The differences between matter wave and electromagnetic wave are given below:

Matter Waves	Electromagnetic waves
1. The matter waves are produced when material body of certain mass moves.	1. The electromagnetic waves are produced when charged particles move.
2. The wave velocity depends upon the velocity of the moving body which is less.	2. The velocity of the electromagnetic wave does not depend upon the motion of the charged particles which is more.
3. They are not associated with electric and magnetic field.	3. They are associated with electric and magnetic field.
4. The wavelength of electromagnetic radiations are much large and given by the relation $\lambda = \frac{c}{f}$ where f is frequency and c be speed of electromagnetic wave.	4. The matter waves have shorter wavelength given by de-Broglie equation, $\lambda = \frac{h}{mv}$ where mv is the momentum of the particle and h is planck's constant.

28. 2067 Old Q.No. 1f 2066 Supp Q.No. 2f **Why is the production of x-rays called inverse of photoelectric effect?** [2]

Please refer to 2072 Set E Q.No. 2d

29. 2066 Q.No. 1f The phenomenon of x-rays production is also called an inverse of photoelectric effect. Why? [2]

Please refer to 2072 Set E Q.No. 2d

30. 2066 Q.No. 2 f If matter has a wave nature, why is this not observable in our daily experiences? [2]

Please refer to 2070 Set D Q.No. 2 b

31. 2062 Q.No. 2 f What do you mean by matter waves? [2]

According to de-Broglie, every moving particle is associated with a wave which controls the particle in every respect. The wave associated with a moving particle is called matter wave or de-Broglie wave. According to him, wavelength of a material particle would be related to it's momentum in the same way as for a photon (i.e., $P = h/\lambda$). That is, for a particle of mass m moving with speed v, de-Broglie wave length is given by, $\lambda = h/mv$, where h is Planck's constant.

32. 2061 Q.No. 1 g Production of X-rays is the reverse phenomenon of photoelectric effect. Justify this statement. [2]

Please refer to 2072 Set E Q.No. 2d

33. 2060 Q.No. 2 f Distinguish between stimulated emission and spontaneous emission. [2]

Please refer to 2073 Set D Q.No. 2f

34. 2058 Q.No. 1 g Can aluminum be used as a target in X-ray tube? [2]

No, Aluminum cannot be used as a target in X-ray tube. The anode of Coolidge tube is the target where the emitted electrons from the filament strikes and hence huge amount of heat is produced which can melt the anode. To prevent it from melting, the anode should have high melting point and a metal of high atomic number has high melting point. But, aluminum has low melting point and low atomic number. So, it cannot be used as a target in X-ray tube.

35. 2056 Q.No. 12 d Differentiate between stimulated and spontaneous emission of radiation. [2]

Please refer to 2073 Set D Q.No. 2f

36. 2056 Q.No. 12 e What do you mean by uncertainty principle? [2]

According to Heisenberg uncertainty principle, it is impossible to measure the two canonically conjugate variables simultaneously and exactly. There arises some errors which is of the order of $\frac{h}{2\pi}$.

For example, it is impossible to measure simultaneously the exact position of an electron in an orbit and its momentum accurately. If the position uncertainty is Δx and momentum (mass × velocity) uncertainty is Δp, then the Heisenberg's uncertainty principle can be mathematically defined as

$(\Delta x) \times (\Delta p) \geq \frac{h}{2\pi}$, where h is Planck's constant.

37. 2055 Q.No. 12 f Point out the importance of a de-Broglie waves. [2]

Importance of de-Broglie waves are as follows:

i. A matter particle will have a wavelength associated with it only if it is in motion. The greater is the momentum, the shorter will be the wave-length.

ii. Two different velocities are associated with a material particle in motion – one refers to the mechanical motion of the particle (v) and other refers to the propagation of the associated wave (u).

iii. It justifies Bohr's quantum condition of hydrogen atom.

iv. It has broken down the barrier between the matter and wave and established them as two aspects of the same thing.

38. 2054 Q.No. 12 a What do you meant by de-Broglie waves? [2]

Please refer to 2062 Q.No. 2 f

39. 2053 Q.No. 12 a An electron is in the third excited state. How many different photon-wave lengths are possible? [2]

Suppose E_1, E_2, E_3 and E_4 are energy of an electron in ground state, first excited state, second excited state and third excited state respectively. So, possible transitions of an electron which is in third excited state are:

E_4 to E_1
E_4 to E_2
E_4 to E_3
E_3 to E_2
E_3 to E_1
and E_2 to E_1

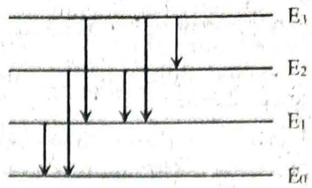


Fig: Energy Level

Hence, there are six possible different wave lengths when the electron is in third excited state.

40. **2052 Q.No. 12 c** **In the production of X-ray, how will you control the penetrating power of X-rays?** **[2]**

Penetrating power of X-ray, which represents its quality, depends on its energy or frequency. The frequency and energy of X-ray depends on applied potential difference across the target and the filament ($\because hf = eV = \frac{1}{2}mv^2$). So, as potential difference is increased, penetrating power of X-ray is also increased and vice versa. Hence, penetrating power of X-ray can be controlled by controlling the applied potential difference between the two electrodes in X-ray tube.

41. **2052 Q.No. 12 e** **How Paschen series in originated in Hydrogen spectra?** **[2]**

Wave length of lines in each group in hydrogen spectra can be calculated from Bohr's formula,

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

where λ is wave length of the lines.
R is Rydberg's constant. n_1 is lower energy level and n_2 is higher every level.
The Paschen series is obtained when electrons jump from any outer orbits (n_2 = 4, 5, 6, . . .) to third orbit (n_1 = 3). This series lies in the infrared region.

42. **2052 Q.No. 15 b** **Differentiate between excitation potential and ionization potential.** **[2]**

The minimum energy required for electron to jump from ground state to any higher state is called excitation energy and the corresponding potential is called excitation potential.
First excitation energy = $E_2 - E_1$

and first excitation potential = $\frac{E_2 - E_1}{e}$ volt, where e is electronic charge.

Second excitation energy = $E_3 - E_1$, and second excitation potential = $\frac{E_3 - E_1}{e}$ volt

Hence, n^{th} excitation potential = $\frac{E_{n+1} - E_1}{e}$

The minimum energy required for electron to knock out of the atom is called the ionization energy and the corresponding potential is called ionization potential.
For just escape, electron jumps from n = 1 to n = ∝.

So, ionization energy = $E_\propto - E_1$, and ionization potential = $\frac{E_\propto - E_1}{e}$ volt.

The ionization potential is greater than excitation potential. The excitation potential for the first excited state of hydrogen atom is 10.2 V while ionization potential is 13.6 V.

Long Answer Questions

43. **2075 Set A Q.No. 6a** **Stating the Bohr's postulates, deduce an expression for the total energy of an electron in n^{th} orbit of hydrogen atom.** **[4]**

Bohr's Postulate: According to Bohr's theory of atomic model, following are the postulates:

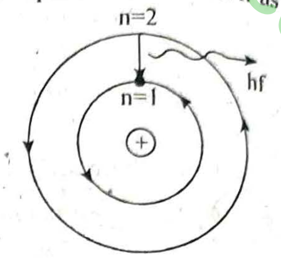
a. An electron in an atom revolves in certain stable orbit without radiation of energy i.e. an atom has certain specific energy state and has definite total energy. These are called stationary states of the atom.

b. An electron can move only in those orbits in which its angular momentum is integral multiple of $\frac{h}{2\pi}$, where h is the Planck's constant. If an electron of mass m is moving with a constant velocity v in a stable orbit of radius r, then its angular momentum,

$mvr = n\frac{h}{2\pi}$ Where n = 1,2,3,.....integers.

This is called Bohr's quantization condition. The orbits given by the above equation are known as stationary orbits.

c. An electron revolving in any stationary orbit doesn't radiate energy at all. The electron emits energy when it jumps from outer orbit to inner orbit. Similarly, it absorbs radiation energy when it jumps from the inner orbit to the outer orbit.



If E_n & E_o are the energies associated with excited & ground state energy levels, then the energy released is given by

$hf = E_n - E_o$,where f is the frequency of radiation.

Energy of Electron in the nth orbit: The total energy of the electron in the nth orbit is the sum of kinetic energy due to motion of the electron & potential energy due to the position of electron near the nucleus.

a. **Kinetic energy (KE):** Let v_n be the velocity of electron in nth orbit and m be its mass then its K.E. is given by

$$K.E_n = \frac{1}{2}mv_n^2$$

$$= \frac{1}{2}m\left(\frac{e^2}{2\epsilon_o nh}\right)^2 \qquad \left[\because v_n = \frac{e^2}{2\epsilon_o nh}\right]$$

$$= \frac{me^4}{8\epsilon_o^2 n^2h^2} \qquad \ldots(i)$$

b. **Potential Energy (PE):** The potential energy of an electron of charge -e is

$$PE_n = \frac{1}{4\pi\epsilon_0}\frac{e.(-e)}{r_n}$$

$$= -\frac{1}{4\pi\epsilon_0}\frac{e^2}{r_n}$$

$$= -\frac{1}{4\pi\epsilon_o}\frac{e^2}{\left(\frac{\epsilon_o n^2h^2}{\pi me^2}\right)} \qquad \left[\because r_n = \frac{\epsilon_o n^2h^2}{\pi me^2}\right]$$

$$= -\frac{me^4}{4\epsilon_o^2 n^2h^2} \qquad \ldots(ii)$$

c. **Total Energy (E_n):** Total energy is the sum of KE and PE in nth orbit,

$$E_n = K.E_n + P.E_n$$

$$= \frac{me^4}{8\epsilon_o^2 n^2h^2} + \left(-\frac{me^4}{4\epsilon_o^2 n^2h^2}\right) = -\frac{me^4}{8\epsilon_o^2 n^2h^2}$$

This is required expression for energy of electron in nth orbit.

The negative sign shows that electron is bounded to the nucleus.

44. $\boxed{\text{2075 Set B Q.No. 6c}}$ **Describe coolidge tube for the production of X-rays. How do you control (i) the intensity (ii) the penetrating power of the emitted X-rays?** **[4]**

Production of X-rays by Coolidge Tube

When fast moving electrons strike on a very hard target of high atomic number, e.g., platinum, tungsten, molybdenum etc., X-rays are produced. Dr. William Coolidge, in 1913, designed a tube for the production of X-rays. This tube is known as Coolidge tube or modern x-ray tube.

The Coolidge tube consists of a glass tube G exhausted to nearly, perfect vacuum of about 10^{-5} mm of mercury provided with cathode and the target T. The cathode consists of a tungsten filament (F) heated by a low tension battery. The filament is placed inside a metal cup C to focus the electrons on to the target. The target is made of a metal like tungsten or molybdenum having a high melting point and high atomic weight held at an angle of 45° to the horizontal. The target T held by a copper rod is projected outside the X-rays tube. Water is continuously circulated around the copper rod outside the tube. The anode (i.e., target) is connected to the positive and cathode to the negative terminal of a high tension power supply.

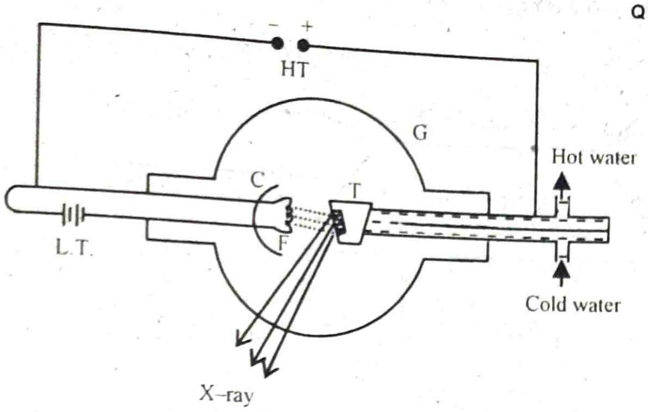


Fig. Production of X-rays in collidge tube

Working:

The filament F is heated by passing a suitable current through it. The electrons emitted from the filament are focused at a point on the target with the help of a metal cup C. Due to the extremely high potential difference between the cathode and the anode; the electrons arrive at the target (i.e., anode) with high speed. The speed of the electrons can be further increased by increasing the accelerating voltage. On striking the anode, the electrons are stopped. Nearly 98% of the energy of the incident electrons is converted in to heat. The remaining energy appears in the form of x-rays. However, intense heat is produced, which may melt the target. Therefore, the target is cooled by circulating water in the copper tube continuously as shown in figure.

Intensity control: The intensity of X-ray's produced depends up on the number of electrons striking to the target. The more number of electrons can be generated by the heating of cathode by passage of electric current. Hence, intensity of X-ray can be controlled by varying the tube current i.e. by varying the rheostate (Rn) in the circuit.

Penetrating Power Control: Penetrating power of X-ray, which represents its quality, depends on its energy or frequency. The frequency and energy of X-ray depends on applied potential difference across the target and the filament ($\because hf = eV = \frac{1}{2}mv^2$). So, as potential difference is increased, penetrating power of X-ray is also increased and vice versa. Hence, penetrating power of X-ray can be controlled by controlling the applied potential difference between the two electrodes in X-ray tube.

45. **2074 Set B Q.No. 6c State Bohr's postulates. Using these postulates obtain an expression for the total energy of an electron in the n^{th} orbit of hydrogen atom.** **[4]**

Please refer to 2075 Set A Q.No. 6a

46. **2073 Supp Q.No. 6c 2063 Q.No. 9 What are Bohr's postulates? Derive an expression for the total energy of electron in n^{th} orbit of H-atom.** **[4]**

Please refer to 2075 Set A Q.No. 6a

47. **2073 Set C Q.No. 6d Explain the working principle of a gas laser. How is population inversion achieved for lasing action?** **[4]**

Laser stands for Light Amplification by Stimulated Emission of Radiation. It is an intense beam of radiation of light.

Helium – Neon Laser

The following figure shows the basic features of He–Ne laser. The laser tube is about 0.5 m long and 5 mm in diameter. The tube is filled with a mixture of helium and neon gas in the ratio 5 : 1 at a total pressure of about 1 torr. The ends of the tube are cut in Brewster's angle as shown in figure. The tube has two parallel mirrors at its two ends. One of the mirrors is partially transparent and 99% reflecting while other is completely reflecting. The spacing of the mirrors is equal to an integral number of half wave length of the laser light. There are two electrodes connected to power supply to create discharge in the gas. The mixture of the gas is ionized by passing electric current through it.

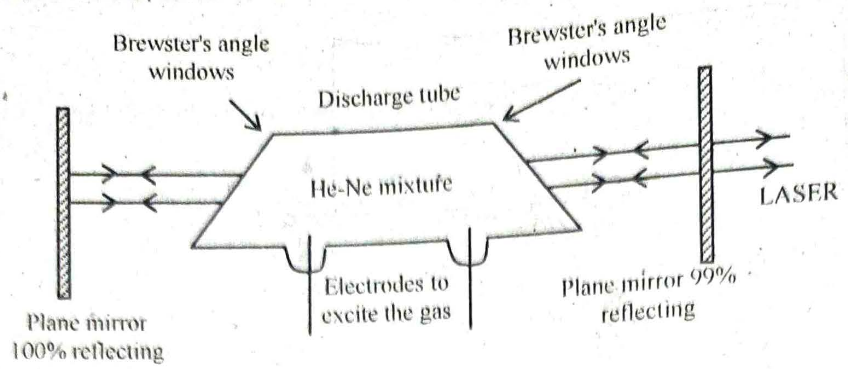


Fig. He - Ne Laser

Working

The following figure shows an energy level diagram for the system. Helium atoms are excited very efficiently by electron impact into the 2s level while the neon atoms are much less readily excited by the electrons. Helium atoms with an electron excited to a 2S state with energy 20.61 eV has a longer life time and the energy of the 5S level is 20.66 eV in neon. Similarly, the energy of 3P energy level of Ne is 18.70 eV. When the excited He atoms collide the Ne atoms, their energy is transferred into the Ne atoms. The excited Ne atoms in the 5S energy state undergo stimulated transition to 3P state giving rise to laser light of wavelength 632.8 nm.

Photons travelling parallel to the tube are reflecting back and forth between the mirrors placed at the ends, and rapidly build up into intense beam which escape through the end with the lower reflectivity.

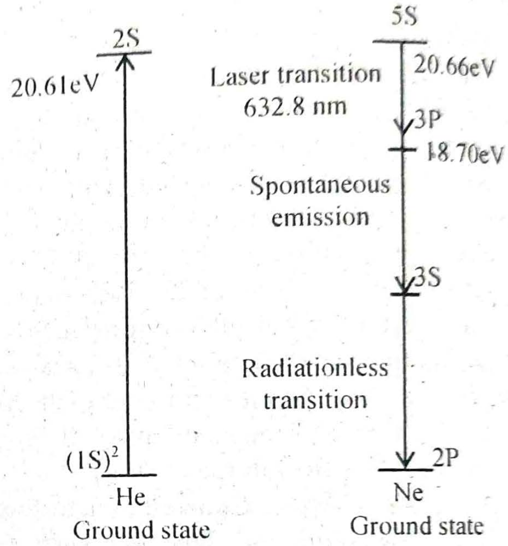


Fig: Energy level diagram of He - Ne Laser

Uses of Laser

Laser has a large number of applications. Some of them are given below:

i. The laser is used in radio communication in outer space.
ii. It is used in holography.
iii. It is used in piercing holes in metals.
iv. It is used in detecting and ranging objects at great distances.
v. It is used in welding.
vi. It is used in medicine.
vii. It is used in scientific research.

Properties of Laser

The characteristic properties of laser beam are

i. The light is nearly monochromatic.
ii. The laser beam diverges hardly at all.
iii. The light is coherent and are in phase with each other.
iv. The beam is extremely intense.

48. $\boxed{\text{2073 Set D Q.No. 6a}}$ **Write down the postulates of Bohr's hydrogen atom. Hence derive expression for energy of the third electron orbit.** **[4]**

Please refer to $\boxed{\text{2075 Set A Q.No. 6a}}$

49. $\boxed{\text{2072 Set D Q.No. 6c}}$ **State Bohr's postulates of hydrogen atom and use them to calculate the radius of n^{th} orbit of the hydrogen atom.** **[4]**

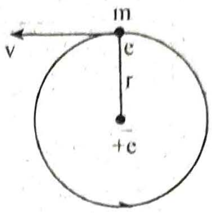
Bohr's postulates: Please refer to $\boxed{\text{2075 Set A Q.No. 6a}}$

Bohr's Theory of Hydrogen Atom (Radius of Bohr's orbit): Consider a hydrogen atom which has positive charge 'e' in the nucleus & negative charge '-e' moving round in an orbit of the radius r as shown in figure. Suppose, the electron is revolving in the n^{th} orbit whose radius is r_n with velocity v_n. From Coulomb's Law, the force of attraction between the nucleus & the electron is given by,

$F = \frac{1}{4\pi \in_0} \frac{e.e}{r_n^2}$, where $\in_0$ is permittivity of free space.

If m is the mass of the electron, the centripetal force acting on the electron is given by

$F = \frac{mv_n^2}{r_n}$



The centripetal force is provided by electrostatic force.

Thus, $\frac{mv_n^2}{r_n} = \frac{1}{4\pi \in_0} \frac{e.e}{r_n^2}$

or, $mv_n^2 r_n = \frac{1}{4\pi \in_0} e^2$ ...(i)

Applying the second postulate of Bohr's atomic model,

$mv_n r_n = n\frac{h}{2\pi}$ (n=1,2,3,...)

or, $m^2 v_n^2 r_n^2 = n^2 \frac{h^2}{4\pi^2}$ ...(ii)

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

$m\, r_n = n^2 \frac{\in_0 h^2}{\pi e^2}$

$r_n = n^2 \frac{\in_0 h^2}{\pi m e^2}$

$\therefore r_n = n^2 r_1 = n^2 a_0 \Rightarrow r_n \propto n^2$ ... (iii)

Where, $r_1 = \frac{\in_0 h^2}{\pi m e^2} = a_0$ is called Bohr's orbit.

Here, $\in_0 = 8.85\times 10^{-12}\, C^2N^{-1}m^{-2}$

$h = 6.62\times10^{-34}$ Js

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

$m = 9.1\times10^{-31}$ kg

$\therefore a_0 = \frac{(8.85 \times 10^{-12}) \times (6.62 \times 10^{-34})^2}{\pi \times (9.1 \times 10^{-31}) \times 1 \times (1.6 \times 10^{-13})^2} = 0.53\times10^{-10}\text{ m} = 0.53\text{ Å}$

$\therefore r_n = n^2\,(0.53\times10^{-10})$ meter

This equation is used to find the radius of various orbits of hydrogen atom. i.e., putting n=1 gives the radius of first orbit (a_0), putting n = 2 gives the radius of second orbit (r_2) & so on.

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50. **2072 Set E Q.No. 6b Explain the working of He-Ne laser.** **[4]**

Please refer 2073 Set C Q.No. 6d

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51. **2071 Supp Q.No. 6d Derive Bragg's equation and explain how this equation is used to determine the crystal plane spacing.** **[4]**

Bragg's law: When the path difference between two reflected beams of X-rays from two different layers of crystal is an integral multiple of wavelength of X-rays, intensity of the reflected beam at a certain angle will be maximum. i.e., the intensity of reflected beam will be maximum, when path difference = n λ (n=1, 2, 3, 4 ,...)

Derivation: Let us consider AB & CD are two layers of a crystal plane with spacing d. Two parallel X-rays EF & GH are two incident beams which fall on the layers AB & CD at a glancing angle θ and are reflected along FK & HL from the atoms F & H respectively as shown in the figure.

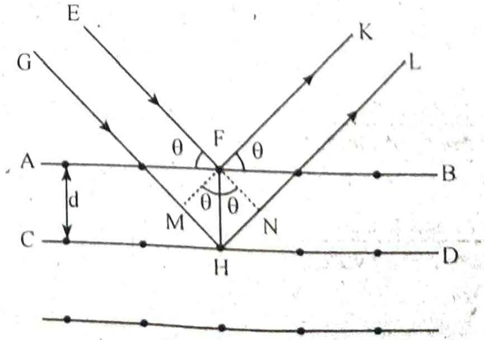


Fig. Bragg's law

Now, FM perpendicular to GH and FN perpendicular to HL are drawn so that

$\angle MFH = \angle NFH = \theta$ ($\because$ angles between two lines and angle between their perpendiculars are equal)

In Δ FMH, we have

$\sin\theta = \frac{MH}{FH} = \frac{MH}{d} \Rightarrow MH = d\sin\theta$

Similarly, in Δ FNH, we have

NH = d $\sin\theta$

Thus, the path difference between the two rays EFK & GHL is given by;

Path difference = MH + HN = d $\sin\theta$ + d $\sin\theta$

= 2d $\sin\theta$

Since for maximum intensity,

path difference = n λ (n=1,2,3,...)

Hence, 2d $\sin\theta$ = n λ

This equation is the mathematical expression for Bragg's law & is called Bragg's equation.

∴ For first order reflection, n=1,

If θ_1 is the corresponding grazing angle, then from Bragg's equation

$$\lambda = 2d\sin\theta_1 \Rightarrow d = \frac{\lambda}{2\sin\theta_1}$$

Thus, by knowing the wavelength of X-rays used & grazing angle (θ_1) at which X-rays are incident, crystal plane spacing (Lattice constant) 'd' of the crystal can be calculated.

52. **2071 Set C Q.No. 6 b** **What are x-rays? Describe the modern Coolidge tube method to produce x-rays.** **[4]**

Introduction of X-rays

X-rays are highly penetrating electromagnetic waves of wavelength range from 10^{-12} m to 10^{-9}m. The X-rays are produced when fast moving electrons strike a target of high atomic number like Platinum, Tungsten, and Molybdenum etc.

Production of X-rays by Coolidge tube: Please refer to 2075 Set B Q.No. 6c

53. **2071 Set D Q.No. 6 b** **State Bohr's postulates of hydrogen atom. Use these postulates to derive an expression for the radius of the n^{th} orbit of the hydrogen atom.** **[4]**

Please refer to 2072 Set D Q.No. 6c

54. **2070 Supp. (Set B) Q.No. 6 b** **State Bohr's postulates of atomic structure. Use the postulates to determine the total energy of an electron in n^{th} orbit of hydrogen atom.** **[4]**

Please refer to 2075 Set A Q.No. 6a

55. **2070 Set C Q.No. 6 b** **State Bohr's postulates and hence derive expression for the radius of n^{th} orbit of hydrogen atom.** **[4]**

Please refer to 2072 Set D Q.No. 6c

56. **2070 Set D Q.No. 6 b** **Describe the construction and working of a Helium-Neon laser.** **[4]**

Please refer 2073 Set C Q.No. 6d

57. **2069 (Set A) Q.No. 6d** **Describe the construction and working principle of He-Ne laser. Write some important uses of laser.** **[4]**

Please refer 2073 Set C Q.No. 6d

58. **2069 (Set B) Q.No. 6d** **Describe the construction and working principle of He-Ne laser. Also write its important uses.** **[4]**

Please refer 2073 Set C Q.No. 6d

59. **2068 Q.No. 6 d** **Describe the modern method of productions of x-rays. Discuss crystal diffraction.** **[4]**

First Part: Please refer to 2075 Set B Q.No. 6c

Second Part: Please refer to 2071 Supp Q.No. 6d

60. **2068 Old Can. Q.No. 9 OR** **Starting from Bohr's postulates, obtain an expression for the energy of the electron in n^{th} orbit of the hydrogen atom.** **[4]**

Please refer to 2075 Set A Q.No. 6a

61. **2067 Sup Q.No. 6c** **What is laser? Describe the construction and working principle of He-Ne laser.** **[1+3]**

Please refer 2073 Set C Q.No. 6d

62. **2067 Q.No. 6d** **2066 Q.No. 9 OR** **Obtain an expression for the energy of electron in n^{th} orbit of hydrogen atom.**

Please refer to 2075 Set A Q.No. 6a

63. 2067 Old Q.No. 8a OR What do you mean by laser? Describe the He-Ne laser. [1 + 3]

Please refer 2073 Set C Q.No. 6d

64. 2067 Old Q.No. 9 Explain Bragg's law of diffraction of x-rays. [4]

Please refer to 2071 Supp Q.No. 6d

65. 2066 Q.No. 9 Derive Bragg's law. [4]

Please refer to 2071 Supp Q.No. 6d

66. 2065 Q.No. 8 a Write down the postulates of Bohr's model of hydrogen atom and obtain expression for the energy of the n^{th} orbit of electron. [1+3]

Please refer to 2075 Set A Q.No. 6a

67. 2062 Q.No. 8 a X-ray diffraction has been very useful in determining the structure of a crystalline substance. Use this concept to determine the distance between two planes. [4]

Please refer to 2071 Supp Q.No. 6d

68. 2059 Q.No. 8 a What are Bohr's postulates? Derive the formula for the radius of the third Bohr's orbit. [4]

Please refer to 2072 Set D Q.No. 6c

69. 2058 Q.No. 9 Derive Bragg's law and explain how this law is used to determine the crystal plane spacing. [4]

Please refer to 2071 Supp Q.No. 6d

70. 2057 Q.No. 9 Derive an expression for the energy of an electron in a hydrogen atom.

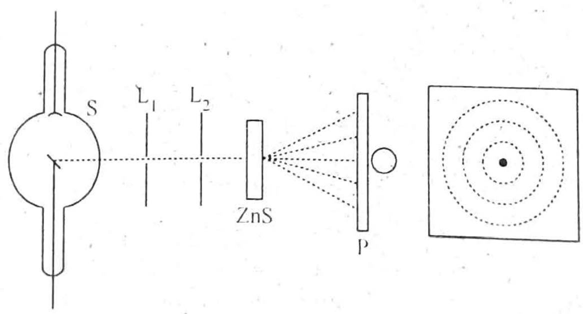
Please refer to 2075 Set A Q.No. 6a

71. 2055 Q.No. 14 What are the X-rays? Confirm with experiment the wave nature of X-rays. [4]

X-rays are the electromagnetic waves of very much shorter wavelength ranging from 1Å to 100 Å. When highly energetic electron strikes on a target metal of high atomic number, the electromagnetic radiation is emitted which are X-rays. The X-rays have the following important properties:

1. X-rays are the electromagnetic waves of very short wavelength (1 Å to 100 Å).
2. They travel in straight line with the speed of light in air.
3. They affect the photographic plate.
4. They can ionize the gas through which they pass.
5. They exhibit the properties of reflection, refraction, interference, diffraction & polarization.
6. They are highly penetrating. They can penetrate through flesh, wood, paper, etc.
7. They can cause photoelectric effect like light.
8. They are not deflected by electric & magnetic field.
9. They produce fluorescence in substance like ZnS, Calcium compounds, Uranium glass etc.

An experiment to confirm the wave nature of X-rays: X-rays, produced from modern X-ray tube, are changed into a fine beam by thin slits L_1 & L_2. The X-rays beam is then incident on a zinc sulphide (Zns) crystal behind which a photographic plate is placed.



After a long exposure, the photographic plate is developed. Many concentric spots are observed around a central black spot on the plate. The spots obtained in the photographic plate are known as Laue's spots. This shows that X-rays are diffracted from ZnS crystal.

From this experiment, it was concluded that X-rays are electromagnetic waves of very short wavelength.

72. 2053 Q.No. 15 What are Bohr's postulates of hydrogen atom? Derive an expression for the radius of Bohr's orbit. [4]

Please refer to 2072 Set D Q.No. 6c

73. 2052 Q.No. 15 a OR **State and explain uncertainty principle.** [4]

Heisenberg's Uncertainty Principle: It states that it is impossible to determine precisely and simultaneously the values of both the members of pair of physical variables which describe the motion of an atomic system. Such pairs of variables are called canonically conjugate variables. According to this principle, the position and momentum of a particle cannot be determined simultaneously to any desired degree of accuracy.

If a coordinate x has an uncertainty Δx and if the corresponding momentum component p_x has an uncertainty Δp_x, then uncertainties are found to be related in general by the inequality

$$\Delta x \, \Delta p_x \geq \hbar \quad \ldots(i)$$

This is the Heisenberg uncertainty principle for position and momentum.

where $\hbar = \dfrac{h}{2\pi}$

This Eq. (i) is one form of the Heisenberg uncertainty principle for position and momentum, first discovered by the German physicist Werner Heisenberg (1901–1976). Similarly, the uncertainty ΔE depends on the time interval Δt during which the system remains in the given state. The relation is

$$\Delta E \, \Delta t \geq \hbar$$

which is uncertainty principle for energy and time interval.

Numerical Problems

74. 2076 Set B Q.No. 10b 2066 Supp Q.No. 8b Or 2058 Q.No. 8 b **Obtain the de Broglie wavelength of neutron of kinetic energy 150 eV. (mass of neutron = 1.675×10^{-27} kg. Planck's constant = 6.6×10^{-34} Js. 1eV = 1.6×10^{-19} J.)** [4]

Solution

Given,

Kinetic energy of neutron (K.E) = 150eV = $150 \times 1.6 \times 10^{-19}$ J = 240×10^{-19} J

Mass of neutron (m) = 1.675×10^{-27} kg

de-Broglie wave length (λ) = ?

Now,

If the Neutron acts as a photon, we have

$$\lambda = \frac{h}{p} \quad \ldots(i)$$

Also,

If it behaves as a matter, we can use;

$$E = \frac{P^2}{2m}$$

$$\text{or, } P = \sqrt{2mE} \quad \ldots(ii)$$

From equation (i) & (ii), we get

$$\lambda = \frac{h}{\sqrt{2mE}} = \frac{6.62 \times 10^{-34}}{\sqrt{2 \times 1.675 \times 10^{-27} \times 240 \times 10^{-19}}} = \frac{6.62 \times 10^{-34}}{\sqrt{804 \times 10^{-46}}} = \frac{6.62 \times 10^{-34}}{28.35 \times 10^{-23}} = 2.33 \times 10^{-12}\text{m}$$

Hence, the required wavelength is 2.33×10^{-12}m.

75. 2076 Set C Q.No. 10a 2069 (Set A) Q.No. 10b **An x-ray tube, operated at a dc potential difference of 10kV, produces heat at the target at the rate of 720 watt. Assuming 0.5% of the incident electrons is converted into x-radiation, calculate the number of electrons striking per second at the target and velocity of the incident electrons. (given, e/m = 1.8×10^{11} Ckg^{-1})** [4]

Solution

Given,

P.d (V) = 10KV = 10000V

Power (P) = 720 W

Current (I) = ?

Velocity (v) = ?

Here,

$P = (100-0.5)\% \times$ of IV

or, $720 = \frac{99.5}{100} \times I \times 10000$

or, $I = \frac{720\times100}{995000} = 0.072$ A

Again,

$I = \frac{q}{t} = \frac{ne}{t}$

or, $\frac{n}{t} = \frac{I}{e} = \frac{0.072}{1.6\times10^{-19}} = 4.5\times10^{17}$ number/sec.

Again, we have,

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

$\therefore v = \sqrt{\frac{2eV}{m}} = \sqrt{2\times1.8\times10^{11}\times10000} = 6\times10^7$ m/sec

76. 2075 GIE Q.No. 10b **Calculate the wavelength of an electron which has been accelerated through a potential difference of 200 V. Take mass of the electron as 9.1×10^{-31} kg and Plank's constant as 6.6×10^{-34} JS.** **[4]**

Solution

Given,

Accelerating voltage (V) = 200 V

Wave length (λ) = ?

We have,

$$\lambda = \frac{h}{\sqrt{2meV}} = \frac{6.6\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times1.6\times10^{-19}\times200}} = 8.6\times10^{-11}\text{ m}$$

77. 2075 Set B Q.No. 10b **A hydrogen atom is in ground state. What is the quantum number to which it will be excited absorbing a photon of energy 12.75 eV?** **[4]**

Solution

Given,

Energy of absorption (ΔE) = 12.75 eV

Quantum number (n) = ?

We know,

The energy of hydrogen atom in n^{th} state, $E_n = \frac{-13.6\text{ eV}}{n^2}$ ... (i)

The energy gap between n^{th} state and the ground state of hydrogen atom is,

$\Delta E = E_n - E_1$

Here,

$\Delta E = 12.75$ eV and

$E_1 = -13.6$ eV

Then,

$12.75 = E_n - (-13.6)$

or, $E_n = 12.75 - 13.6 = -0.85$ eV

$\therefore E_n = -0.85$ eV

Also, from (i),

$E_n = -\frac{13.6}{n^2}$ eV

or, $-0.85 = -\frac{13.6}{n^2}$

or, $n^2 = \frac{13.6}{0.85} = 16$

$\therefore n = 4$

Hence, the quantum number is 4.

78. 2074 Supp Q.No. 10b **Determine the wavelength of a proton that has been accelerated through a potential differences of 20 kV. Mass of proton = 1.67×10^{-27} kg and Planck's constant = 6.62×10^{-34} Js.** [4]

Solution

Given,

Potential difference (V) = 20 kV = 20×10^3 V

Mass of proton (m_p) = 1.67×10^{-27} kg

Planck constant (h) = 6.62×10^{-34} Js

Electric charge (e) = 1.6×10^{-19} C

Wave length (λ) = ?

We have,

$$\lambda = \frac{h}{\sqrt{2m_peV}} = \frac{6.62 \times 10^{-34}}{\sqrt{2 \times 1.67\times 10^{-27} \times 1.6 \times 10^{-19} \times 20 \times 10^3}} = 2.02 \times 10^{-13} \text{ m}$$

79. 2074 Supp Q.No. 10c 2073 Set C Q.No. 10c **The first member of Balmer series of hydrogen atom has a wavelength of 6563 Å. Calculate the wavelength of its second member.** [4]

Solution

Given,

Wavelength of first line of Balmer series (λ_1) = 6563 Å = 6563×10^{-10} m

Wavelength of second line of Balmer series (λ_2) = ?

For Balmer series, $n_1 = 2$

For first line of Balmer series, $n_2 = 3$

For second line of Balmer series, $n_3 = 4$

We have,

$$\frac{1}{\lambda_1} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

or, $\frac{1}{\lambda_1} = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right)$, for first line of Balmer Series

or, $\frac{1}{\lambda_1} = R\left(\frac{1}{4} - \frac{1}{9}\right)$

$$\frac{1}{\lambda_1} = R \cdot \frac{5}{36} \qquad \ldots(i)$$

Similarly,

$\frac{1}{\lambda_2} = R\left(\frac{1}{4} - \frac{1}{16}\right)$, for second line of Balmer Series

$$= R\frac{3}{16} \qquad \ldots(ii)$$

Dividing (i) by (ii), we get

$$\frac{\frac{1}{\lambda_1}}{\frac{1}{\lambda_2}} = \frac{R\frac{5}{36}}{R\frac{3}{16}}$$

$$\frac{\lambda_2}{\lambda_1} = \frac{5}{36} \times \frac{16}{3}$$

$$\lambda_2 = \frac{5 \times 16}{36 \times 3} \times 6563 \times 10^{-10} = 4861.48 \times 10^{-10} \text{ m} = 4861.48 \text{ Å}$$

80. 2074 Set A Q.No. 10b **Calculate de-Broglie wavelength of an electron which has been accelerated through a potential difference of 200V. Given-mass of electron =9.1×10^{-31}kg and Planck's constant, h=6.6×10^{-34}Js.** [4]

Please refer to 2075 GIE Q.No. 10b

81. **2073 Set D Q.No. 10c** **Calculate the de-Broglie wavelength of electron having kinetic energy of 400 eV.**

Solution

Given,

de-Broglie wavelength (λ) = ?

Kinetic energy (E_k) = 400 eV = $400 \times 1.6 \times 10^{-19}$ J

We have,

$$\lambda = \frac{h}{\sqrt{2mE_k}} = \frac{6.62 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 400 \times 1.6 \times 10^{-19}}} = 6.13 \times 10^{-11} \text{ m}$$

82. **2072 Supp Q.No. 10a** **Calculate the wave length of electromagnetic radiation emitted by a hydrogen atom which undergoes a transition between energy levels of -1.36×10^{-19} J and -5.45×10^{-19} J. (Given Planck's constant = 6.6×10^{-34} Js).** **[4]**

Solution

Given,

First energy level (E_1) = -1.36×10^{-19} J

Second energy level (E_2) = -5.45×10^{-19} J

Planck's constant (h) = 6.6×10^{-34} Js

Wavelength (λ) = ?

We have,

Transition energy = $E_1 - E_2$

$$hf = E_1 - E_2$$

$$h\frac{c}{\lambda} = E_1 - E_2$$

$$\text{or, } \lambda = \frac{hc}{E_1 - E_2} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{-1.36 \times 10^{-19} - (-5.45 \times 10^{-19})} = 4.841 \times 10^{-7} \text{ m} = 4841 \text{ Å}$$

83. **2072 Set C Q.No. 10b** **2072 Set D Q.No. 10b** **An X-ray tube works at a dc potential difference of 50 kV. Only 0.4% of the energy of the cathode rays is converted into x- rays and heat is generated in the target at the rate of 600 watt. Estimate the current passed into the tube and the velocity of the electrons striking the target (Mass of electron = 9×10^{-31} kgm charge of electron = 1.6×10^{-19} C)** **[4]**

Solution

Given,

Potential difference (V) = 50 kV = 50000 V

Heat generation power (P) = 600 W

Tube current (I) = ?

Velocity of electron (v) = ?

According to question, 0.4% of energy is converted into x-radiatoin & 99.6% of electrical energy is converted into heat. i.e.

$$P = 99.6\% \text{ of } IV$$

$$\text{or, } 600 = \frac{99.6}{100} \times I \times 50000$$

$$\text{or, } I = 0.012 \text{ A}$$

Again,

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

$$\text{or, } v = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 50000}{9.10 \times 10^{-31}}} = 1.3 \times 10^8 \text{ m/sec}$$

$\therefore I = 0.012\text{A}, v = 1.3 \times 10^8$ m/sec

84. **2072 Set E Q.No. 10a** **An X-ray spectrometer has a crystal of rock salt for which atomic spacing is 2.82 Å set at an angle of 14° to the beam coming from a tube operated at a constantly increasing voltage. An instense first line appears when the voltage across the tube is 9045 V. Calculate the value of Planck's constant.** **[4]**

Solution

Given,

Atomic spacing (d) = 2.82Å = 2.82×10^{-10} m

Glancing angle (θ_1) = 14°

Voltage (V) = 9045 V
Planck's constant (h) = ?
We have,
$2d\sin\theta_n = n\lambda$; $n = 1, 2, 3, \ldots$
$2d\sin\theta_1 = \lambda$ for $n = 1$,
$2 \times 2.82 \times 10^{-10} \times \sin 14° = \lambda$
$\lambda = 1.36 \times 10^{-10}$ m
Again,
$hf = eV$

or, $h\dfrac{c}{\lambda} = eV$

or, $h = \dfrac{eV\lambda}{c}$

or, $h = \dfrac{1.6 \times 10^{-19} \times 9045 \times 1.36 \times 10^{-10}}{3 \times 10^8} = 6.56 \times 10^{-34}$ Js

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85. **2071 Supp Q.No. 10a** **An x-ray tube works at a dc potential difference of 50KV and the current through the tube is 0.5mA. Find (i) the number of electrons hitting the target per second, (ii) the energy falling on the target per second as the kinetic energy of electrons, (iii) the cut off wavelength of x-ray emitted. (The charge of electron = 1.6×10^{-19}C, velocity of light c = 3×10^8 m/s, Planck's constant = 6.62×10^{-34}Js)** **[4]**

Solution

Given,
D.C. Potential difference (V) = 50 KV = 50,000 V
Tube current (I) = 0.5 mA = 0.5×10^{-3} A

i. No. of electron per sec $\left(\dfrac{n}{t}\right) = ?$

Now,

$I = \dfrac{q}{t} = \dfrac{ne}{t}$

or, $\dfrac{n}{t} = \dfrac{I}{e} = \dfrac{0.5 \times 10^{-3}}{1.6 \times 10^{-19}} = 3.125 \times 10^{15}$ number/sec

ii. Energy per second (Power) = ?
We have,
$P = IV = 0.5 \times 10^{-3} \times 50{,}000 = 25$ J/sec = 25 watt

iii. Cut-off wavelength (λ_c) = ?
We have,
$hf = eV$

or, $\dfrac{hc}{\lambda_c} = eV$

or, $\lambda_c = \dfrac{hc}{eV} = \dfrac{6.62 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 10^{-19} \times 50{,}000} = 2.48 \times 10^{-11}$ m

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86. **2071 Supp Q.No. 10c** **Determine the energy that must be given to a hydrogen atom so that it can emit second line of Balmer series. (Rydberg's constant R = 1.097×10^7m⁻¹)** **[4]**

Solution

For second line of Balmer series, $n_1 = 2$ and $n_2 = 4$. Then, wavelength of radiation emitted when electron jumps from 4th orbit to 2nd orbit is,

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{4^2}\right) = 1.097 \times 10^7 \times \left(\frac{1}{4} - \frac{1}{16}\right) = 1.097 \times 10^7 \times \frac{3}{16} = 2.057 \times 10^6$$

Now,

$E = hf = h\dfrac{c}{\lambda} = 6.62 \times 10^{-34} \times 3 \times 10^8 \times 2.05 \times 10^6 = 4.08 \times 10^{-19}$ J = 2.55 eV

7. 2070 Sup (Set A) Q.No. 10 c Find the wavelength of the radiation emitted from a hydrogen atom when an electron jumps from 4th orbit to the second orbit. (Given $\epsilon_0 = 8.85 \times 10^{-12}\ C^2N^{-1}\ m^{-2}$, $h = 6.62 \times 10^{-34}$ Js, $m_e = 9.1 \times 10^{-31}$ kg) (where the symbols have their usual meanings.) [4]

Solution

Given,

Permittivity of free space (ϵ_0) = $8.854 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$

Planck's constant (h) = 6.62×10^{-34} Js

Electronic mass (m_e) = 9.1×10^{-31} kg

Velocity of light (c) = 3×10^8 m/sec

Here, $n_1 = 2$, $n_2 = 4$

Now,

$$\frac{1}{\lambda} = \frac{me^4}{8ch^3\epsilon_0^2}\left(\frac{1}{2^2} - \frac{1}{4^2}\right)$$

$$\text{or, } \frac{1}{\lambda} = \frac{9.1 \times 10^{-31} \times (1.6 \times 10^{-19})^4}{8 \times 3 \times 10^8 (6.62 \times 10^{-34})^3 \times (8.85 \times 10^{-12})^2} \times \frac{3}{16}$$

$$\text{or, } \frac{1}{\lambda} = 1.09 \times 10^7 \times \frac{3}{16}$$

$$\therefore \lambda = 4.89 \times 10^{-7}\ m$$

8. 2070 Supp. (Set B) Q.No. 2 a A cricket ball is moving with a speed of 120 km/hr. What would be its de-Broglie wavelength if its mass is 400gms. [2]

Solution

Given,

Speed of cricket ball (v) = 120 km/hr = $\frac{120 \times 1000}{60 \times 60}$ = 33.33 m/sec

Mass of cricket ball (m) = 400 gms = 0.4 Kg

de- Broglie wavelength (λ) = ?

We have,

$$\lambda = \frac{h}{p} = \frac{h}{mv} \quad [\because h = 6.62 \times 10^{-34}\ Js]$$

$$\text{or, } \lambda = \frac{6.62 \times 10^{-34}}{0.4 \times 33.33}$$

$$\therefore \lambda = 4.96 \times 10^{-35}\ m$$

9. 2070 Supp. (Set B) Q.No. 10 b X-rays are incident on the zinc sulphide crystal of crystal spacing 3.08×10^{-8}cm such that first order reflection takes place at glancing angle 12°. Calculate the wavelength of X-rays and glancing angle for second order maximum. [4]

Solution

Given,

Wavelength of x-ray beam (λ) = ?

Angle of diffraction (θ) = 12°

Order of diffraction (n) = 1

Spacing between planes (d) = 3.08×10^{-8} cm = 3.08×10^{-10} m

Now,

From Bragg's law, we have,

$2d\sin\theta = n\lambda$

$$\text{or, } \lambda = 2d \sin\theta = 2 \times 3.08 \times 10^{-10} \times \sin 12$$

$$d = 1.28 \times 10^{-10} m$$

Hence, the required spacing between the planes is 1.28×10^{-10}m.

10. 2069 (Set B) Q.No. 10b X-rays are incident on the zinc sulphide crystal. It's crystal spacing is 3.08×10^{-8} cm and the first order reflection takes place at a glancing angle of 12°. Calculate the wavelength of incident X-rays. [4]

Please refer to 2070 Supp. (Set B) Q.No. 10 b

91. **2069 (Set A) Old Q.No. 8b 2052 Q.No. 16 OR X-ray beam of wavelength 2.9AU (Å) is diffracted from the plane of cubic crystal. The first order diffraction is obtained at an angle of 35°. Calculate the spacing between the planes.** [4]

Solution

Given,

Wavelength of x-ray beam (λ) = 2.9Å = 2.9×10^{-10} m

Angle of diffraction (θ) = 35°

Order of diffraction (n) = 1

Spacing between planes (d) = ?

Now,

From Bragg's law; we have;

$d\sin\theta = n\lambda$

or, $d = \frac{n\lambda}{\sin\theta} = \frac{1 \times 2.9 \times 10^{-10}}{\sin 35}$

$\therefore$ $d = 5 \times 10^{-10}$m

Hence, the required spacing between the planes is 5×10^{-10}m.

92. **2069 Supp Set B Q.No. 10 b 2067 Sup Q.No. 10b Find the wavelength of radiation emitted from hydrogen atom when an electron jumps from third orbit to second orbit. (Given: $\epsilon_0 = 8.854 \times 10^{-12}$ C²N⁻¹m⁻², h = 6.62×10^{-34} Js and mass of electron, $m_e = 9.1 \times 10^{-31}$ kg.)** [4]

Solution

Given,

Permittivity of free space (ϵ_0) = 8.854×10^{-12} $C^2 N^{-1} m^{-2}$

Planck's constant (h) = 6.62×10^{-34} Js

Electronic mass (m_e) = 9.1×10^{-31} kg

$n_1 = 2$

$n_2 = 3$

Now,

According to Bohr's it postulate, we have

$E_2 - E_1 = hf$

or, $-\frac{me^4}{8n_2^2 h^2 \epsilon_0^2} + \frac{me^4}{8n_1^2 h^2 \epsilon_0^2} = hf$

or, $\frac{me^4}{8 h^2 \epsilon_0^2}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) = \frac{hc}{\lambda}$

or, $\frac{me^4}{8 ch^3 \epsilon_0^2}\left(\frac{1}{2^2} - \frac{1}{3^2}\right) = \frac{1}{\lambda}$

or, $\frac{9.1 \times 10^{-31} \times (1.6 \times 10^{-19})^4}{8 \times 3 \times 10^8 \times (6.62 \times 10^{-34})^3 \times (8.854 \times 10^{-12})^2} \times \frac{5}{36} = \frac{1}{\lambda}$

or, $1.517 \times 10^6 = \frac{1}{\lambda}$

$\therefore$ $\lambda = 6.59 \times 10^{-7}$m

Hence, the required wavelength is 6.59×10^{-7} m.

93. **2067 Q.No. 10b An x-ray tube operated at a d.c. potential difference of 40 KV, produces heat at the rate of 720 W. Assuming 0.5% of the energy of the incident electrons converted into x-radiation, calculate (i) number of electrons per second striking the target. (ii) the velocity of the incident electrons. [Given *e/m* = 1.8×10^{11} C/kg].** [4]

Solution

Given,

Potential difference (V) = 40KV = 40,000V

Power (P) = 720 watt

Now,

For (i), we have

Here, Total p.d. used for producing heat energy $= (100 - 0.5)\%$ of V

$= 99.5\ \%$ of V

If I be the total current produced in the filament.

Then, we can use

$P = I \times 99.5\%$ of V

or, $720 = \frac{q}{t} \times \frac{99.5}{100} \times 40{,}000$

or, $720 = \frac{ne}{t} \times 39800$

or, $\frac{n}{t} = \frac{720}{39800 \times e}$

or, $\frac{n}{t} = \frac{720}{39800 \times 1.6 \times 10^{-19}}$

$\therefore \frac{n}{t} = 1.13 \times 10^{17}$

Hence, the required number of electrons per second is 1.13×10^{17}.

Again,

For (ii), we have,

$eV = \frac{1}{2} m v^2$ (Where v is the velocity of electrons)

or, $v = \sqrt{\frac{2eV}{m}} = \sqrt{2 \times 1.8 \times 10^{11} \times 40000}$

$= 1.2 \times 10^{8}$ m/s

Hence, the required velocity is 1.2×10^{8} m/s.

94. 2065 Q.No. 8 b X-rays of wavelength 0.36 Å are diffracted by a Bragg's crystal spectograph at a glancing angle of 4.8°. Find the spacing of the atomic planes in the crystal. [4]

Solution

Given,

Wavelength of X-ray (λ) = 0.36Å = 0.36×10^{-10}m

Glancing angle (θ) = 4.8°

Spacing of atomic planes (d) = ?

Now,

From Bragg's law, we have

$2d\sin\theta = n\lambda$ n = 1, 2, 3, ...

for n = 1; we have

$2d\sin\theta = \lambda$

or, $d = \frac{\lambda}{2\sin\theta} = \frac{0.36 \times 10^{-10}}{2 \times \sin 4.8}$

$\therefore d = 2.15 \times 10^{-10}$m

Hence, the required spacing is 2.15×10^{-10} m

95. 2062 Q.No. 8 b If an electron position can be measured to an accuracy of 10^{-9} m. How accurately can its velocity be measured? ($m_e = 9.1 \times 10^{-31}$ kg.) [4]

Solution

Given,

$\Delta x = 10^{-9}$m

$\Delta v = ?$

We know;

$m_e = 9.1 \times 10^{-31}$kg

$h = 6.6 \times 10^{-34}$Js

Now,

From uncertainty principle; we can write,

$\Delta x \times \Delta P = \frac{h}{2\pi}$

or, $\Delta x \times m \times \Delta v = \frac{h}{2\pi}$

or, $\Delta v = \frac{h}{2\pi \times \Delta x \times m} = \frac{6.6 \times 10^{-34}}{2 \times \pi \times 10^{-9} \times 9.1 \times 10^{-31}}$

$\therefore \Delta v = 1.16 \times 10^{5}$ m/s

Hence, it's velocity can be measured to an accuracy of 1.16×10^{5}m/s

96. **2061 Q.No. 8 b OR Obtain the de-Broglie wave length of the electron having the kinetic energy of 3600eV. (mass of electron = 9.1×10^{-31} kg, Electronic charge = 1.6×10^{-19} C, Planck's constant = 6.6×10^{-34} Js)** [4]

Solution

Given,

Energy of election (E) = 3600 eV = $3600 \times 1.6 \times 10^{-19}$ J = 5760×10^{-19} J

Mass of electron (m) = 9.1×10^{-31} kg

Electronic charge (e) = 1.6×10^{-19}C

Plancks constant (h) = 6.6×10^{-34}Js

de-Broglie wavelength (λ) = ?

Now,

If electron behaves as photon; we have

$\lambda = \frac{h}{p}$ ...(i)

Also,

If it behaves as a matter, we can use;

$E = \frac{P^2}{2m}$

or, $P = \sqrt{2mE}$ ...(ii)

From equation (i) & (ii), we get

$\lambda = \frac{h}{\sqrt{2mE}} = \frac{6.6 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 5760 \times 10^{-19}}} = \frac{6.6 \times 10^{-34}}{\sqrt{1.05 \times 10^{-45}}} = \frac{6.6 \times 10^{-34}}{3.24 \times 10^{-23}}$

$\therefore \lambda = 2.04 \times 10^{-11}$m

Hence, the required value of wavelength is 2.04×10^{-11}m.

97. **2060 Q.No. 8 b Calculate energy in electron volts of a quantum of x-radiation of wavelength 0.15nm. Take e = 1.6×10^{-19}C, h = 6.5×10^{-34} Js, c = 3×10^{8} ms^{-1}.** [4]

Solution

Given,

Wavelength (λ) = 0.15nm = 0.15×10^{-9}m

Electronic charge (e) = 1.6×10^{-19}C

Planck's constant (h)= 6.5×10^{-34}Js

Speed of light (c) = 3×10^{8} ms^{-1}

Energy (E) = ?

Now, we have,

$E = hf = \frac{hc}{\lambda} = 6.5 \times 10^{-34} \times \frac{3 \times 10^{8}}{0.15 \times 10^{-9}} = 130 \times 10^{-17}$ joules

$= \frac{130 \times 10^{-17}}{1.6 \times 10^{-19}}$ eV [$\because$ 1 eV = 1.6×10^{-19}J]

$\therefore E = 8125$ eV

Hence, the required energy is 8125 eV.

98. **2055 Q.No. 15 An electron of energy 20eV comes into collision with a hydrogen atom in its ground state. The atom is excited into a higher state and the electron is scattered with reduced velocity. The atom subsequently returns to its ground state with the emission of photon of wavelength 1.216×10^{-7}m. Determine the velocity of the scattered electron. (mass of electron = 9.1×10^{-31} kg).** [4]

Solution

Given,

Energy of electron before collision (E) = 20eV = $20 \times 1.6 \times 10^{-19}$J = 32×10^{-19} J

Wavelength of photon emitted (λ) = 1.216×10^{-7}m

Mass of electron (m) = 9.1×10^{-31}kg

Velocity of scattered electrons (v) = ?

Now, we have,

Energy of electron before collision = Energy of emitted photon + energy of scattered electrons

or, $32 \times 10^{-19} = \frac{hc}{\lambda} + \frac{1}{2}mv^2$

or, $32 \times 10^{-19} = \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{1.216 \times 10^{-7}} + \frac{1}{2} \times 9.1 \times 10^{-31} \times v^2$

or, $32 \times 10^{-19} = 16.35 \times 10^{-19} + \frac{1}{2} \times 9.1 \times 10^{-31} \times v^2$

or, $\frac{1}{2} \times 9.1 \times 10^{-31} \times v^2 = 15.65 \times 10^{-19}$

or, $v^2 = 3.44 \times 10^{12}$

$\therefore$ v $= 1.85 \times 10^6$ m/s

Hence, the required velocity is 1.85×10^6m/s.

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99. 2054 Q.No. 16 **Calculate the wavelength of the first line of the Balmer series, if the wavelength of the second line of this series is 4.86×10^{-7}m.** **[4]**

Solution

Given,

Wavelength of the 2nd line (λ_2) = 4.86×10^{-7} m

Wavelength of the 1st line (λ_1) = ?

Now,

For 2nd line of Balmer series, we have,

$n_1 = 2$; $n_2 = 4$

Then, using

$\frac{1}{\lambda_2} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$

or, $\frac{1}{\lambda_2} = R\left(\frac{1}{2^2} - \frac{1}{4^2}\right)$

or, $\frac{1}{\lambda_2} = R\left(\frac{1}{4} - \frac{1}{16}\right)$

$\frac{1}{\lambda_2} = R\frac{3}{16}$ ... (i)

For 1st line of Balmer series,

$n_1' = 2$, $n_2' = 3$

Then using;

$\frac{1}{\lambda_1} = R\left(\frac{1}{n_1'^2} - \frac{1}{n_2'^2}\right) = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right)$

or, $\frac{1}{\lambda_1} = R\frac{5}{36}$ ... (ii)

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

$\frac{\lambda_1}{\lambda_2} = \frac{3}{16} \times \frac{36}{5}$

or, $\lambda_1 = \frac{3}{16} \times \frac{36}{5} \times 4.86 \times 10^{-7} = 6.56 \times 10^{-7}$ m

Hence, the required value of wavelength is 6.56×10^{-7}m.

□□□

Chapter 4: Nuclear Physics

Short Answer Questions

1. 2076 Set C Q.No. 2c **Neutron is considered the most effective bombarding particle in a nuclear reaction. Why?** [2]

The neutrons are uncharged particle and can hit the target nucleus without being repelled by the nucleus or electrons. Inside the nucleus, it increases the neutron to proton ratio of the nucleus and makes the nucleus unstable and hence causes nuclear reaction releasing large amount of energy. Due to this reason, the neutrons are used to initiate fission reaction.

2. 2075 Set A Q.No. 2e **A nucleus consists of positively charged protons and electrically neutral netutrons in a small volume. How can this be possible as the like charges repel each other?** [2]

According to properties of charges, like charges repel each other. But the protons in a nucleus stay together due to binding energy. The binding energy binds the like charges of protons and chargeless neutrons. The source of binding energy is mass defect.

3. 2075 Set B Q.No. 2d 2066 Q.No. 1g **All nuclei have nearly the same density. Why?** [2]

The mass per unit volume of a nucleus is called its density.

i.e., Nuclear density, $\rho = \dfrac{\text{Nuclear mass}}{\text{Nuclear volume}} = \dfrac{Am_N}{4/3\,\pi R^3}$

or, $\rho = \dfrac{Am_N}{4/3\,\pi (r_0A^{1/3})^3} = \dfrac{3Am_N}{4\pi r_0^3 A} = \dfrac{3m_N}{4\pi r_0^3} = \dfrac{3 \times 1.66 \times 10^{-27}}{4\pi(1.2 \times 10^{-15})^3}$ kg/m^3

$= 2.3 \times 10^{17}$ kgm^{-3}

This shows that the nuclear density is very high and is independent with A i.e., all the nuclei have same density.

4. 2074 Supp Q.No. 2b **The nuclear density is almost constant for all nuclei. Why?** [2]

Please refer to 2075 Set B Q.No. 2d

5. 2074 Set A Q.No. 2a 2070 Set C Q.No. 2 d **Why is neutron considered the most effective bombarding particle in a nuclear reaction?** [2]

Please refer to 2076 Set C Q.No. 2c

6. 2074 Set B Q.No. 2c **According to properties of charges, like charges repel each other. Then, how do the protons in a nucleus stay together?** [2]

Please refer to 2075 Set A Q.No. 2e

7. 2073 Supp Q.No. 2d 2067 Q.No. 2d **Why is the mass of a nucleus slightly less than the mass of constituent nucleons?** [2]

The total binding energy of a nucleus represents the amount of energy that must be put into a nucleus in order to break it apart into its constituent protons and neutrons. According to Eisenstein's mass-energy relation ($E = mc^2$), change in energy is associated with changes in mass. Therefore, one should expect that mass of a nucleus is less than the sum of the rest masses of its separated nucleons which expenses to bind the nucleons inside the nucleus.

8. 2073 Set C Q.No. 2c **Define atomic mass unit (amu). Hence convert the mass of a neutron, (1840 Me), into amu where Me is the mass of 'an electron'.** [2]

Atomic mass unit refers to the mass of neutral atom including mass of all the nucleons. One atomic mass unit is defined as 1/12 of the mass of one $_6C^{12}$ atom.

i.e., $1\text{ amu} = \dfrac{1}{12}\left(\dfrac{12}{6.023 \times 10^{23}}\right) g = 1.66 \times 10^{-24}\ g = 1.66 \times 10^{-27}$ kg

Now according to Einstein's mass energy relation,

$E = \Delta mc^2 = 1.66 \times 10^{-27} \times (3 \times 10^8)^2\ J = 1.49 \times 10^{-10}\ J$

$= \dfrac{1.49 \times 10^{-10}}{1.6 \times 10^{-19}}\ eV = 0.931 \times 10^9\ eV = 931$ MeV

$\therefore$ 1 amu = 931 MeV

2073 Set D Q.No. 2b **Diameter of Al^{27} nucleus is D_{Al} How can one express the diameter of Cu^{64} in terms of D_{Al}? Explain.** **[2]**

The Radius of a nucleus is given as

$R = R_o A^{1/3}$, where R_o = constant & A = atomic mass unit for Al^{27}, $R = R_o(27)^{1/3} = 3\,R_o$.

Then, Diameter $(D_A) = 2 \times R = 6R_o$.

For Cu^{64}, $R = R_o\,(64)^{1/3} = Ro\,(4^3)^{1/3} = 4R_o$

Then Diameter. $(D_{cu}) = 8\,R_0$

Now,

$$\frac{D_{cu}}{D_{Al}} = \frac{8R_0}{6R_0} = \frac{8}{6} = \frac{4}{3}$$

$$D_{cu} = \frac{4}{3} D_{Al}.$$

1. 2072 Supp Q.No. 2d **By what factor must the mass number of a nucleus increase to double its volume? Explain.** **[2]**

The volume of a nucleus is given by

$$V = \frac{4}{3}\pi R^3$$

Where, R = radius of nucleus = $R_0A^{1/3}$, R_0 = constant parameter,

A = Atomic mass number. Then,

$$V = \frac{4}{3}\pi(R_0A^{1/3})^3 = \frac{4}{3}\pi\,R_0^3\,A$$

i.e., $V \propto A$

The mass number doubles when volume becomes double.

11. 2072 Set D Q.No. 2c **All the nuclei have nearly the same density. Justify.** **[2]**

Please refer to 2075 Set B Q.No. 2d

12. 2071 Supp Q.No. 2d **What is the significance of binding energy per nucleon?** **[2]**

The minimum energy required to bind the constituents of the nucleus inside it is called binding energy. This is given as,

$$B.E. = \Delta mc^2,$$

where Δm is mass defect and c is speed of light. Binding energy per nucleon is average binding energy given as,

$$\text{B.E. per nucleuon} = \frac{\text{B.E.}}{\text{Mass number}} = \frac{\text{B.E.}}{A}$$

It gives the stability of nucleus against disintegration which is shows in give figure.

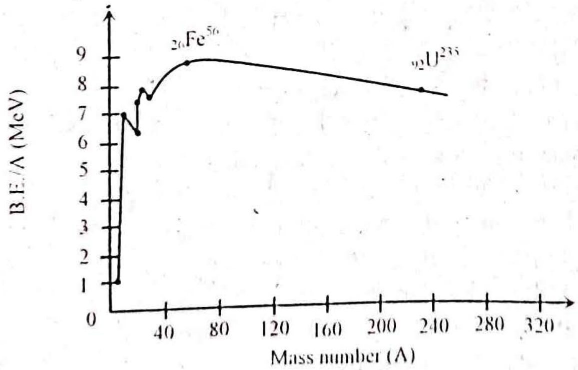


Fig. Variation of binding energy per nucleon with mass number

13. 2070 Supp. (Set B) Q.No. 2 e **Find the value of 1 amu in terms of MeV.**

Please refer 2073 Set C Q.No 2c

14. 2070 Set D Q.No. 2 d **Does a nucleus contain electrons? Explain.** **[2]**

Electron is not constituent of nucleus. To exist inside the nucleus, the uncertainity in position should not exceed the radius of nucleus. i.e., $\Delta x \leq 10^{-14}$ m. Then, from Heisenberg uncertainty principle, uncertainty in momentum is

$\Delta P = \frac{h}{2\pi\Delta x} = \frac{6.62 \times 10^{-34}}{2\pi \times 10^{-14}} = 5.3 \times 10^{-21}$ kgms^{-1}.

Since mass of electron is 9.1×10^{-31} kg, velocity of electron comes out to be 58c, where c is speed of light. But no material particle moves with speed greater than the speed of light. So, electron can't exist inside the nucleus.

15. 2069 Supp Set B Q.No. 2 e **What does the energy balance (Q–value) of a nuclear reaction signify? Explain.** **[2]**

The general scheme of a nuclear reaction is giving by

$$A + B \rightarrow C + D + Q$$

where A and B are reactants and C and D are products. It was found that in nuclear reaction initial mass (mass of A + B) is not equal to final mass (mass of C + D). The difference in mass is converted into energy (according to Einstein's mass energy relation, $E = mc^2$). The Q–value balances this mass or energy in the nuclear reaction.

So, Q-value in a nuclear reaction signifies that either energy is released or absorbed during the nuclear reaction.

16. 2068 Old Can. Q.No. 1g **Why are the neutrons used to initiate fission reaction?** **[2]**

Please refer to 2076 Set C Q.No. 2c

17. 2067 Old Q.No. 2f **Why does a mountain of uranium not explode as a bomb?** **[2]**

The uranium atom undergoes nuclear fission reaction releasing large amount of energy as ${}_{92}U^{235} + {}_{0}n^1 \rightarrow ({}_{92}U^{236})^* \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3{}_{0}n^1 + Q$

This shows that to initiate the nuclear fission reaction of uranium, a slow bombarding neutron must be required. Without this bombarding particle, a mountain of uranium does not explode as a bomb.

18. 2066 Supp Q.No. 1f **Write difference between nuclear fission and fusion.** **[2]**

The differences between the nuclear fission and fusion are given below:

Nuclear Fission	Nuclear Fusion
1. If a heavy nucleus is splitted into two or more light nuclei releasing large amount of energy is called nuclear fission reaction.	1. If two or more light nuclei fused together to form a heavy nucleus releasing large amount of energy is called nuclear fusion reaction.
2. Slow neutrons are required to initiate reaction.	2. High temperature and pressure are required for this reaction to take place.
3. Example: ${}_{92}U^{235} + {}_{0}n^1 \rightarrow [{}_{92}U^{236}]^* \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3{}_{0}n^1 + Q$	3. Example: ${}_{1}H^2 + {}_{1}H^2 \rightarrow {}_{2}He^4 + Q$
4. 200 MeV energy is released per fission.	4. 24 MeV energy is released per fusion.
5. It can be used to make nuclear bomb.	5. It can be used to make hydrogen bomb.

19. 2065 Q.No. 1 g **Explain the significance of Einstein's mass energy equivalence relation.** **[2]**

According to Einstein, mass and energy are inter-convertible. In a nuclear reaction, sum of initial rest mass is not equal to the final rest mass after reaction. The difference between the rest masses is equal to the nuclear energy released. According to Einstein's equation expressing the equivalence of mass and energy is given as $E = \Delta m\, c^2$ where Δm is the mass difference between the sum of the masses of the nucleons and the mass of single nucleus and c be the velocity of light. Thus, Einstein's mass energy equivalence relation views as the law of energy conservation and mass conservation are no more independent laws but single law called law of mass-energy conservation.

20. 2065 Q.No. 2 g **Define atomic mass unit and convert it into MeV.** **[2]**

Please refer 2073 Set C Q.No. 2c

21. 2061 Q.No. 1 f **Define mass defect and packing fraction of a nucleus.** **[2]**

The difference between the actual mass of the nucleus and the sum of masses of the constituent nucleons is called mass defect. It is denoted by ΔM and given by

Δm = mass of constituent nucleus–actual mass of the nucleus

$\Delta m = [Z\, m_p + (A - Z)\, m_n] - M$

where m_p and m_n are the masses of a proton & a neutron respectively.

When the nucleus grouped together to form a nucleus, they loss a small amount of mass i.e., there is always a mass defect during the formation of a nucleus..

The mass defect of a nucleus per nucleon is called packing fraction. If Δm is the mass defect, then packing fraction 'f' may be given as

$$f = \frac{\text{mass defect}}{\text{mass number}} = \frac{\Delta m}{A}$$

Thus, packing fraction indicates that when individual nucleons packed together, their mass will be different from their mass number A.

2059 Q.No. 2 f **Distinguish between isotopes and isobar?** [2]

The differences between isotopes and isobar are given below:

Isotopes are the atoms which have same atomic number (Z) but different mass number (A). But, isobars are the atoms which have same mass number (A) but different atomic number (Z).

Isotopes contain different number of neutrons and the same number of protons. Isobars contain different number of both neutrons and protons.

All the isotopes have different physical properties but have identical chemical properties. But, all the isobars have different chemical and physical properties.

Examples of isotopes are $_1H^1$, $_1H^2$ and $_1H^3$. But the examples of isobars are $_6C^{14}$, $_7N^{14}$ and $_8O^{14}$.

2056 Q.No. 12 f **Explain why the mass of a nucleus is always less then the combined masses of its constituent particles.** [2]

Please refer to 2073 Supp Q No. 2d

2055 Q.No. 12 b **Explain binding energy in terms of packing fraction.** [2]

Experimentally it has been found that the rest mass of the nucleus of a stable atom is always less than the sum of the masses of its constituent nucleons i.e., protons and neutrons in free state. The difference between the sum of the masses of nucleons constituting a nucleus and the rest mass of the nucleus is called mass defect, denoted by Δm. The energy equivalent of this mass defect is called binding energy of the nucleus. This energy is defined as the minimum energy required to bind the nucleons inside the nucleus. The binding energy is given by

B.E. = $\Delta m\, c^2$; where c is velocity of light. The mass defect per nucleon is known as packing fraction.

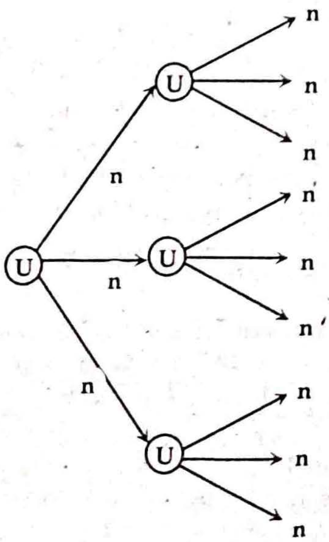
i.e., Packing fraction = $\Delta m/A$ where A is total mass number.

2055 Q.No. 12 c **Point out the difference between nuclear fission and fusion.** [2]

Please refer to 2066 Supp Q No. 1f

2053 Q.No. 12 b **What is meant by chain reaction?** [2]

When a slow neutron is bombarded on a $_{92}U^{235}$ nucleus, it undergoes fission and it splits into two lighter nuclei $_{56}Ba^{141}$ and $_{36}Kr^{92}$ with three neutrons. Again three neutrons can further bombard other three uranium atoms giving 3 × 3 = 9 neutrons. Further 9 neutrons can bombard other nine uranium atoms to give 9 × 3 = 27 neutrons with the release of energy. This process will continue till all the uranium atoms take part in the reaction with the release of a huge amount of energy. This reaction is known as chain reaction.



2052 Q.No. 12 d **Distinguish between fission and fusion reaction.** [2]

Please refer to 2066 Supp Q No. 1f

Long Answer Questions

28. 2075 GIE Q.No. 6c Define binding energy and binding energy per nucleon. How does binding energy per nucleon vary with mass number? What is its significance? [4]

It was found that the rest mass of the nucleus of a stable atom is always less than the sum of the masses of its constituent nucleons i.e., protons and neutrons in free state. The difference between the sum of the masses of nucleons constituting a nucleus and the rest mass of the nucleus is called mass defect. It is denoted by Δm. This difference in mass of the nucleus is used to bind the constituents of the nucleus. The minimum energy required to bind the constituent particles into the nucleus is called binding energy. In other words, the energy equivalent of this mass defect is called binding energy of the nucleus.

B.E. = Δmc^2

Here, Δm = mass of constituent nucleus – actual mass of the nucleus

$= [Z\, m_p + (A - Z)\, m_n] - M$

where m_p and m_n are the masses of a proton & a neutron respectively and M be the rest mass of the nucleus ${}_ZX^A$. Then the binding energy is given by

B.E. = $[\{Z\, m_p + (A - Z)\, m_n\} - M]\, c^2$J (Here, mass in kg)

B.E. = $[\{Z\, m_p + (A - Z)\, m_n\} - M] \times 931$MeV (Here, mass in amu)

The variation of binding energy of different elements with atomic mass is studied in terms of binding energy per nucleon which is average binding energy given as:

$$\text{Average Binding Energy } (\overline{\text{B.E.}}) = \frac{\text{Total Binding Energy}}{\text{Mass Number}} = \frac{\text{B.E.}}{A}$$

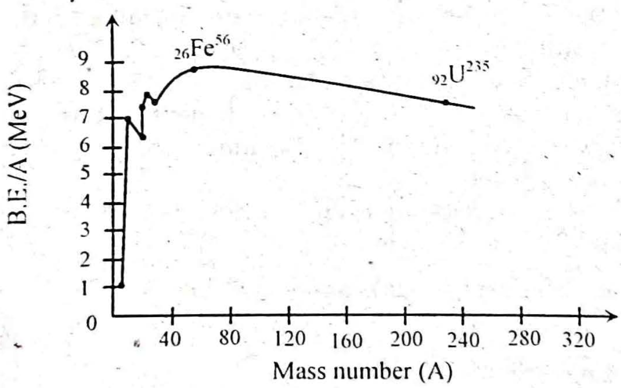


Fig. Variation of binding energy per nucleon with mass number

It determines the major of the stability of the nucleus against disintegration. The greater the value of average binding energy, the higher will be the stability of nucleus and vice-versa. The variation of binding energy per nucleon with mass number is given in the graph. The graph shows the maximum value of 8.79 MeV per nucleon of ${}_{26}Fe^{56}$. So, iron is stable than the higher nuclei like ${}_{92}U^{235}$.

29. 2075 Set A Q.No. 6d Differentiate between nuclear fission and fusion. Explain the production of energy in the Sun. [4]

Differences between the nuclear fission and fusion:

The differences between the nuclear fission and fusion are given below:

Nuclear Fission	Nuclear Fusion
1. If a heavy nucleus is splitted into two or more light nuclei releasing large amount of energy is called nuclear fission reaction.	1. If two or more light nuclei fused together to form a heavy nucleus releasing large amount of energy is called nuclear fusion reaction.
2. Slow neutrons are required to initiate reaction.	2. High temperature and pressure are required for this reaction to take place.
3. Example: ${}_{92}U^{235} + {}_0n^1 \rightarrow [{}_{92}U^{236}]^* \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_0n^1 + Q$	3. Example: ${}_1H^2 + {}_1H^2 \rightarrow {}_2He^4 + Q$
4. 200 MeV energy is released per fission.	4. 24 MeV energy is released per fusion.
5. It can be used to make nuclear bomb.	5. It can be used to make hydrogen bomb.

6. Products of fission are radioactive.	6. Products of fusion are not radioactive.
7. Nuclear reactor is based on controlled fission chain reaction.	7. No controlled fusion discovered till now.
8. For fission reaction, critical mass is needed.	8. For fusion reaction, critical mass is not needed.
9. The sources (fuel) of fission are limited.	9. The sources of fusion are unlimited.
10. It is single stage reaction.	10. It is multistage reaction.
11. Fuel is either in solid or liquid state and can be stored for long time.	11. Fuel is in plasma state and can not be stored for long time because it requires high temperature.
12. Fission is induced by neutrons.	12. Fusion is induced by protons.

Nuclear fusion: The combination of two or more lighter nuclei to form a heavy nucleus with the release of large amount of energy is called nuclear fusion reaction. For example,

$$ {}_1H^1 + {}_1H^1 + {}_1H^1 + {}_1H^1 \rightarrow {}_2He^4 + 2\,{}_{+1}e^0 + Q $$

Now,

Mass of helium, ${}_2He^4$ = 4.0038744 amu

Mass of proton, ${}_1H^1$ = 1.007825 amu

Now, total mass on reactant side = 4.0313 amu

Total mass on product side = 4.0038744 amu

Mass defect (Δm) = 4.0313 – 4.0038744= 0.0274256 amu

Energy released = 0.0274256 × 931 MeV = 25.5 MeV

Like this reaction, energy is produced in the sun.

30. 2074 Supp Q.No. 6c **Discuss fission and fusion reaction with one example of each. In which reaction is the energy released greater?** **[4]**

Ans: **Nuclear fission:** The process of splitting up of a heavy nucleus into two or more lighter nuclei with the release of a large amount of energy is known as nuclear fission.

When ${}_{92}U^{235}$ is bombarded with a slow neutron, an unstable compound nucleus is formed which may break up into barium and krypton as follows:

$$ {}_{92}U^{235} + {}_0n^1 \rightarrow ({}_{92}U^{236})^* \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3{}_0n^1 + Q $$

Where Q is the energy released in the nuclear fission.

Nuclear Fusion: The process of formation of a heavy nucleus from two lighter nuclei with the release of a large amount of energy is known as nuclear fusion. For example, two deuterons (${}_1H^2$) can fuse together to form a helium nucleus with the liberation of energy as follows:

$$ {}_1H^2 + {}_1H^2 \rightarrow {}_2He^3 + {}_0n^1 + Q $$

Energy Released in Nuclear Fission:

A large amount of energy is released in a nuclear fission reaction because the mass of product nucleus is less than the masses of the reactant nuclei.

The fission reaction for U-235 is given as

$$ {}_{92}U^{235} + {}_0n^1 \rightarrow ({}_{92}U^{236})^* \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3{}_0n^1 + Q $$

Given, Mass of ${}_{92}U^{235}$ = 235.0439334 u

Mass of ${}_0n^1$ = 1.0086654 u

Mass of ${}_{56}Ba^{141}$ = 140.91394 u

Mass of ${}_{36}Kr^{92}$ = 91.89734 u

Avogadro's number (N_A) = 6.02×10^{23} mol^{-1}

Therefore, total mass of reactant part = mass of [${}_{92}U^{235} + {}_0n^1$]

= 235.049933 + 1.008665

= 236.052984 u

& total mass of product part = mass of [${}_{56}Ba^{141} + {}_{36}Kr^{92} + 3{}_0n^1$]

=140.9139 + 91.89373 + 3×1.018665

= 235.8373 U

So, decrease in mass = 236.05 - 235.8373 = 0.21534 u

We have, 1 u = 931 MeV

Therefore, total energy released = 0.2153 × 931 =200.2 MeV

Energy Released in Nuclear Fusion:

Mass of the two deuteron = 2 × 2.014102 u = 4.028204 u

Mass of $_2He^4$ = 4.002604 u
Decrease in mass = 0.025600 u
Energy released = 0.0256 × 931 MeV = 23.84 MeV
The Q-value of nuclear reaction indicates the energy release or absorb during the nuclear reaction. This shows that energy released for fission is greater than energy release for fusion.

31. **2074 Set A Q.No. 6c** **Define mass defect and binding energy of a nucleus. Draw a graph showing the variation of binding energy per nucleon and atomic number of the elements. Also, interpret the graph.** **[4]**

Please refer to 2075 GIE Q.No. 6c

32. **2073 Set C Q.No. 6c** **Write down the representative nuclear fission and fusion reactions. Explain, how the energy release in the case of four protons fused into doubly ionized helium can be estimated?** **[4]**

Nuclear fission: The process of splitting up of a heavy nucleus into two or more parts with the release of a large amount of energy is known as nuclear fission reaction. For example,

$$_{92}U^{235} + {}_0n^1 \rightarrow ({}_{92}{}^{236})^* \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + {}_{30}n^1 + Q$$

Nuclear fusion: Please refer to 2075 Set A Q.No. 6d

33. **2072 Set C Q.No. 6c** **Discuss four important properties of nuclei.** **[4]**

Nucleus: An atom consists of positively charged protons, negatively charged electrons and charge less neutrons. The electrons are revolving round the central part of atom in possible orbit while protons and neutrons are located at the central part of atom called nucleus. So, constituents of nucleus are protons and neutrons. It is generally represented by $_ZX^A$, where Z no. of electrons = no. of protons i.e., atomic number, A = Z + N (N = No. of neutrons) is atomic mass.

Four general properties of Nuclei are:

1. **Size:** The size of nucleus is very small. According to Rutherford (who discovered nucleus), the size of nucleus (i.e. radius) is 10^{-14} m to 10^{-15}m while that of atom is abut 10^{-10} m. The empirical formula for nuclear radius is $R = r_o A^{1/3}$, where A is mass number and $r_o = 1.2 \times 10^{-15}$ m = 1.2 Fm.
2. **Charge:** The nuclei consist of protons & neutrons. Protons are positively charged and neutrons are chargeless or neutral. So, nuclei are positively charged.
3. **Mass:** Since the nucleus consists of protons and neutrons. So, the mass of nucleus is the sum of mass of protons and mass of neutrons.

   Assumed Nuclear mass = $Zm_p + Nm_n$

   where Z = No. of protons, N = No. of neutrons, m_p = mass of proton and m_n is mass of a neutron.
4. **Nuclear density:** The density of nucleus is given by

$$\text{Nuclear density} = \frac{\text{mass of a nucleus}}{\text{volume of nucleus}}$$

$$= \frac{Am_n}{\frac{4}{3}\pi R^3} = \frac{Am_n}{\frac{4}{3}\pi (r_0 A^{1/3})^3} \qquad [\because R = r_0 A^{1/3}]$$

$$= \frac{m_n}{\frac{4}{3}\pi r_0^3} = \frac{3 \times 1.66 \times 10^{-27}}{4 \times \pi \times (1.2 \times 10^{-15})^3}$$

$\therefore \sigma = 2.3 \times 10^{17}$ kg/m^3

This shows that nuclear density is independent to atomic mass number and is very high. So, it is said that a large crane is required to lift the microscopic size of nucleus.

34. **2071 Supp Q.No. 6c** **What are meant by mass defect and binding energy per nucleon? Draw a graph showing the relation between binding energy per nucleon and atomic number. Explain its significances.** **[4]**

Please refer to 2075 GIE Q.No. 6c

35. **2071 Set C Q.No. 6 c** **Define binding energy. How does binding energy per nucleon vary with mass number? What is its significance?** **[4]**

Please refer to 2075 GIE Q.No. 6c

36. **2070 Set C Q.No. 6 c** **Discuss fission and fusion with an example of each. In which reaction is the energy released greater?** **[4]**

Please refer to 2074 Supp Q.No. 6c

37. 2070 Set D Q.No. 6 d What is nuclear fusion? Discuss the sources of the energy released during fusion. [4]

Please refer to 2075 Set A Q.No. 6d

38. 2069 Set A Q.No. 6c How does nuclear fusion differ from nuclear fission? How is the energy released estimated in the fusion reaction? [4]

Please refer to 2075 Set A Q.No. 6d

39. 2068 Q.No. 6 c What is nuclear fission? Compare the energy released from nuclear fission with that of fusion. [4]

Please refer to 2074 Supp Q.No. 6c

40. 2067 Sup Q.No. 6d Write down the schemes for nuclear fusion and nuclear fission. How can the release energy in any of these reactions estimated? What do you mean by Q-value of a nuclear reaction? [1+2+1]

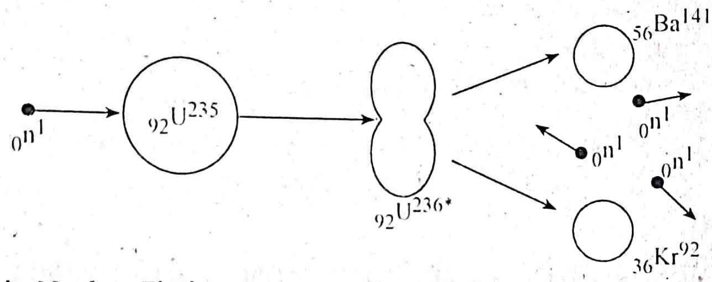
Please refer to 2074 Supp Q.No. 6c

41. 2063 Q.No. 8 a What is nuclear fission? How energy is released in nuclear fission reaction? [4]

Nuclear fission: The process of splitting up of a heavy nucleus into two, more or less equal parts with the release of a large amount of energy is known as nuclear fission.

When ${}_{92}U^{235}$ is bombarded with a slow neutron, an unstable compound nucleus is formed which may break up into barium and krypton as follows: ${}_{92}U^{235} + {}_0n^1 \rightarrow ({}_{92}U^{236})^* \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3{}_0n^1 + Q$

where Q is the energy released in the nuclear fission.



Energy Released in Nuclear Fission:

A large amount of energy is released in a nuclear fission reaction because the mass of product nucleus is less than the masses of the reactant nuclei.

The fission reaction for U-235 is given as;

${}_{92}U^{235} + {}_0n^1 \rightarrow ({}_{92}U^{236})^* \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3{}_0n^1 + Q$

Given, Mass of ${}_{92}U^{235}$ = 235.0439334 u

Mass of ${}_0n^1$ = 1.0086654 u

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Mass of ${}_{36}Kr^{92}$ = 91.89734 u

Avogadro's number (N_A) = 6.02×10^{23} mol^{-1}

Therefore, total mass of reactant part = mass of $[{}_{92}U^{235} + {}_0n^1]$

= 235.049933 + 1.008665

= 236.052984 u

& total mass of product part = mass of $[{}_{56}Ba^{141} + {}_{36}Kr^{92} + 3{}_0n^1]$

=140.9139 + 91.89373 + 3x1.018665 = 235.8373 u

So, decrease in mass = 236.05 – 235.8373 = 0.21534 u

We have, 1 u = 931 MeV

Therefore, total energy released = 0.2153×931 =200.2 MeV

Thus in the process of fission of one nucleus of Uranium, about 200 MeV energy is released.

42. 2062 Q.No. 2 h What is nuclear fusion? Write a representative equation of fusion reaction? [4]

Please refer to 2075 Set A Q.No. 6d

43. 2061 Q.No. 9 OR 2057 Q.No. 9 OR Distinguish between nuclear fusion and fission with examples. [4]

Please refer to 2075 Set A Q.No. 6d

44. 2058 Q.No. 8 a What do you mean by fission? How energy is released in fission of uranium nucleus? [4]

Please refer to 2063 Q.No. 8 a

45. 2056 Q.No. 14 What is nuclear fission? Give an example of nuclear reaction. [4]

Please refer to 2063 Q.No. 8 a

46. **2052 Q.No. 13 State and explain Einstein's mass energy relation with example.** **[4]**

According to Einstein, mass and energy are inter-convertible. In a nuclear reaction, sum of initial rest mass is not equal to the final rest mass after reaction. The difference between the rest masses is equal to the nuclear energy released. According to Einstein's equation expressing the equivalence of mass and energy is given as $E = \Delta m\, c^2$ where Δm is the mass difference between the sum of the masses of the nucleons and the mass of single nucleus and c be the velocity of light. If the sum of the final rest mass exceeds the sum to the initial rest masses, the energy is absorbed in the reaction. Similarly, if the sum is less than the initial sum, then the energy is released as K.E. of the final particles. Thus, Einstein's mass energy equivalence relation views as the law of energy conservation and mass conservation are no more independent laws but single law called law of mass-energy conservation.

For example:

Nuclear fusion: Combing two or more lighter nuclei into a heavy nucleus with release of energy is called nuclear fusion. As an example, consider a fusion reaction in which a proton $({}_1H^1)$ and a neutron $({}_0n^1)$ combines to form a deuterium $({}_1H^2)$. That is

$${}_1H^1 + {}_0n^1 \rightarrow {}_1H^2 + \gamma$$

Here, the mass of ${}_1H^1$ = 1.007825 amu

The mass of ${}_0n^1$ = 1.008665 amu

The mass of ${}_1H^2$ = 2.014102 amu

∴ The mass defect (Δm) = (1.007825+1.008665-2.014102) amu

= 0.002388 amu

Therefore, the energy released is given by

$E = \Delta m \text{ (in amu)} \times 931 \text{ MeV} = 0.002388 \times 931 \text{ MeV} = 2.22\text{MeV}$.

Numerical Problems

47. **2076 Set B Q.No. 10c 2070 Set D Q.No. 10 c Calculate the binding energy per nucleon of ${}_{26}Fe^{56}$. Atomic mass of ${}_{26}Fe^{56}$ is 55.9349u and that of ${}_1H^1$ is 1.00783u. Mass of ${}_0n^1$ = 1.00867u and 1u = 931 MeV.** **[4]**

Solution

Given,

Mass of proton (m_p) = 1.007825 amu

Mass of neutron (m_n) = 1.008665 amu

Mass of ${}_{26}Fe^{56}$ (M) = 55.934939 amu

Atomic mass A = 56, atomic number Z = 26, No. of neutron N = A – Z = 30

Binding energy per nucleon of ${}_{26}Fe^{56}$ (B.E./A) = ?

We have,

$\Delta m = (Zm_p + Nm_n - M)$

$= (26 \times 1.007825 + 30 \times 1.008665 - 55.934939) = 0.7555$ amu

Now,

$$\overline{B.E.} = \frac{B.E.}{A} = \frac{0.7555 \times 931}{56} \text{ meV/nucleon} = 8.78 \text{ MeV/nucleon}$$

48. **2076 Set C Q.No. 10b Calculate the binding energy per nucleon of calcium nucleus $({}_{20}Ca^{40})$.** **[4]**

Given:

mass of ${}_{20}Ca^{40}$ = 39.962589 u

mass of neutron, m_n = 1.008665 u

mass of proton, m_p = 1.007825 u

1u = 931 MeV

Solution

Given,

Mass of ${}_{20}Ca^{40}$ = 39.962589 u

Mass of neutron, m_n = 1.008665 u

Mass of proton, m_p = 1.007825 u

1u = 931 MeV

Binding Energy per nucleon $\left(\frac{B.E.}{A} = \overline{B.E.}\right) = ?$

We know,

Binding energy is given by

$$B.E. = [\{Z m_P + (A - Z)m_n\} - M] \times 931 \text{ MeV}$$

$$= [\{20 \times 1.007825 + (40 - 20) \times 1.008665\} - 39.962589] \times 931 \text{ MeV}$$

$$= 341.873441 \text{ MeV}$$

$$\overline{B.E.} = \frac{B.E.}{A} = \frac{341.873441}{40} = 8.54 \text{ MeV/ nucleon}$$

49. 2075 Set A Q.No. 10a A city requires 10^7 watts of electrical power on the average. If this is to be supplied by a nuclear reactor of efficiency 20%. Using $^{92}U_{235}$ as the fuel source, calculate the amount of fuel required per day (Energy released per fission $^{92}U_{235}$ = 200 MeV). **[4]**

Solution

Given,

Output power (P_{out}) = 10^7 watts

Efficiency (η) = 20%

Input power (P_{in}) = ?

Mass required = ?

Time (t) = 1 day = 24 × 60 × 60 = 86400 sec

Energy, released per fission of $^{235}_{92}U$ = 200 MeV

Mass of $^{235}_{92}U$ = ?

We have,

$$\eta = \frac{P_{out}}{P_{in}}$$

$$\text{or, } 0.20 = \frac{10^7}{P_{in}}$$

$$\text{or, } P_{in} = \frac{10^7}{0.20} = 5 \times 10^7 \text{ watt}$$

Energy $E = P_{in} \times t = 5 \times 10^7 \times 86400 = 4.32 \times 10^{12}$ J

Again,

235 amu $= 235 \times 1.66 \times 10^{-27}$ kg $= 3.9 \times 10^{-25}$ kg

Energy released per fission of $^{235}_{92}U$ = 200MeV

$= 200 \times 10^6 \times 1.6 \times 10^{-19} = 3.2 \times 10^{-11}$J

∴ 3.2×10^{-11} J energy is released by 3.9×10^{-25} kg of uranium.

or, 4.32×10^{12} J energy is released by $\frac{3.9 \times 10^{-25}}{3.2 \times 10^{-11}} \times 4.32 \times 10^{12}$ kg of uranium.

$= 0.0527$ kg

∴ Mass of $^{235}_{92}U$ required = 0.0527 kg

50. 2075 Set B Q.No. 10c 2067 Q.No. 10c A nucleus of $_{92}U^{238}$ disintegrates according to **[4]**

$_{92}U^{238} \rightarrow {}_{90}Th^{234} + {}_2He^4$.

Calculate:

i. the total energy released in the disintegration process.

ii. the k.e. of the α particle, the nucleus at rest before disintegration.

[Mass of $_{92}U^{238} = 3.859 \times 10^{-25}$ kg

Mass of $_{90}Th^{234} = 3.787 \times 10^{-25}$ kg

Mass of $_2He^4 = 6.648 \times 10^{-27}$ kg]

Solution

Given,

Mass defect = Decrease of mass in reaction

$= 238.12492 - (234.11650 + 4.00387)$
$= 0.004554.$

Equivalent energy in MeV = $0.00455 \times 931 = 4.236$ MeV

a. Hence, total energy released = 4.236 MeV

b. K.E. of the α – particle. $= \frac{m_{th}}{m_{th} + m_{\lambda}} \times E = \frac{234.11650}{234.11650 + 4.00387} \times 4.236 = 4.16$ MeV

51. **2074 Set B Q.No. 10b** **The mass of $_{17}CL^{35}$ is 34.9800 amu. Calculate its binding energy and binding energy per nucleon. Mass of one proton = 1.007825 amu and mass of one neutron =1.00865 amu.** [4]

Solution

Given,

Mass of Cl^{35} (M) = 34.9800 amu

Mass of one proton (m_P) = 1.007825 amu

Mass of one neutron (m_n) = 1.008665 amu

Binding energy (B.E.) = ?

Binding energy per nucleon ($\overline{B.E.}$) = ?

We know,

Binding energy is given by,

$B.E. = [\{zmp + (A - Z)m_n\} - M] \times 931$ MeV

or, $B.E. = [\{17 \times 1.007825 + 18 \times 1.008665\} - 34.9800] \times 931$

$\therefore$ B.E. = 287.67 MeV

Again,

$$\overline{B.E.} = \frac{BE}{A} = \frac{287.66}{35}$$

$\therefore$ $\overline{B.E.}$ = 8.2 MeV/ nucleon

52. **2073 Supp Q.No. 10b** **2072 Set D Q.No. 10c** **2070 Sup (Set A) Q.No. 10 b** **2068 Can. Q.No. 10b** **The energy librated in the fission of single uranium –235 atom is 3.2×10^{-11}J. Calculate the power production corresponding to the fission of 1g of uranium per day. Assume Avogadro constant as 6.02×10^{23} mole^{-1}.** [4]

Solution

Given,

Energy liberated by the fission of a U^{235} atom = 3.2×10^{-11} J

Avogardo's constant (N_A) = 6.023×10^{23} mol^{-1}

Time (T) = 1 day = $24 \times 60 \times 60$ secs = 86400 secs

Now,

we have;

1 mole = 235 gm of Uranium = 6.023×10^{23} atoms

$\therefore$ 1 gm of Uranium = $\frac{6.023 \times 10^{23}}{235}$ atoms = 2.56×10^{21} atoms

$\therefore$ Total energy released by the fission of 1 gm Uranium

$= 3.2 \times 10^{-11} \times 256 \times 10^{21}$ J = 8.19×10^{10}J

Again, we know,

$$\text{Power produced} = \frac{\text{Energy released}}{\text{Time taken}} = \frac{8.19 \times 10^{10}}{86400} = 9.47 \times 10^5 \text{ watt}$$

Hence, the required power is 9.47×10^5 watt.

53. **2073 Set D Q.No. 10b** **What will be the amount of energy released in the fusion of three alpha particles into a C^{12} nucleus if mass of He^4 and C^{12} nuclei are respectively 4.00263 amu and 12 amu.** [4]

Solution

Given,

Mass of $_2He^4$ = 4.00263 amu

Mass of C^{12} = 12 amu

Energy released = ?

Given reaction,

$$3 \times {}_2He^4 \Rightarrow C^{12} + Q$$

Mass defect (Δm) = $3 \times 4.00263 - 12 = 0.00789$ amu

Energy released = 0.00789×931 MeV ($\because$ 1 amu = 931 MeV)

= 7.35 MeV

54. **2072 Supp Q.No. 10c The mass of the nucleus of the isotope Lithium (7Li) is 7.014351 u. Find its binding energy and binding energy per nucleon. (Given mass of proton = 1.007275 u, mass of neutron = 1.008665 u) [4]**

Solution

Given,

Mass of proton (m_P) = 1.007275 u

Mass of neutron (m_n) = 1.008665 u

Binding energy (B.E.) = ?

Binding energy per nuclean ($\overline{B.E.}$) = ?

Mass of Lithium (M) = 7.01435 u

Here, for ${}_3Li^7$; Z = 3, N = A - Z = 7 - 3 = 4

A = 7

Mass defect (Δm) = $(Z \cdot mp + N.m_n) - M = (3 \times 1.007275 + 4 \times 1.008665) - 7.01435 = 0.042135$ u

B.E. = $\Delta m \times c^2 = 0.042135 \times 931 = 39.22$ MeV

B.E. per neclon ($\overline{B.E.}$) = $\frac{B.E.}{A} = \frac{39.22}{7} = 5.60$ MeV/ nucleon.

55. **2072 Set E Q.No. 10c ${}_{28}Ni^{62}$ may be described as the most strongly bound nucleus because it has the highest B.E. per nucleon. Its neutral atomic mass is 61.928349 amu. Find its mass defect, its total binding energy and binding energy per nucleon.**

Given, mass of neutron = 1.008665 amu

mass of porton = 1.007825 amu

1 amu = 931.5 MeV.

Solution

Given,

Atomic mass of nickel (M) = 61.928349 amu

Mass of proton (m_p) = 1.007825 amu

Mass of neutron (m_n) = 1.008665 amu

1 amu = 931.5 MeV

Mass defect (Δm) = ?

Binding energy (B.E.) = ?

Binding energy per nucleon ($\overline{B.E.}$) = ?

We have,

$\Delta m = Z m_p + N m_n - M$

$= 28 \times 1.007825 + 34 \times 1.008665 - 61.928349 = 0.585361$ amu

B.E. $= \Delta m \times 931.5$ MeV

$= 0.585361 \times 931.5$ MeV = 545.26 MeV

$\overline{B.E.} = \frac{B.E.}{A} = \frac{545.26}{62} = 8.8$ MeV per nucleon

56. **2071 Set C Q.No. 10 c The energy released by fission of one U^{235} atom is 200 MeV. Calculate the energy released in KWh, when one gram of uranium undergoes fission. [4]**

Solution

Given,

Energy liberated by the fission of a U^{235} atom = 200 MeV = $200 \times 10^6 \times 1.6 \times 10^{-19} = 3.2 \times 10^{-11}$ J

Avogardo's constant (N_A) = 6.023×10^{23} mol^{-1}

Time (T) = 1 day = $24 \times 60 \times 60$ secs = 86400 secs

Now,

we have;

1 mole = 235 gm of Uranium = 6.023×10^{23} atoms

$\therefore$ 1 gm of Uranium = $\frac{6.023 \times 10^{23}}{235}$ atoms = 2.56×10^{21} atoms

∴ Total energy released by the fission of 1 gm Uranium
$= 3.2 \times 10^{-11} \times 256 \times 10^{21}$ J $= 8.19 \times 10^{10}$J

Energy released $= 8.19 \times 10^{10}$ Ws $= 8.19 \times 10^{7}$ KWs $= \dfrac{8.19 \times 10^{7}}{60 \times 60}$ KWh $= 2.275 \times 10^{4}$ KWh

57. $\boxed{\text{2071 Set D Q.No. 10 b}}$ **Calculate the binding energy per nucleon for a helium nucleus. Given that mass of helium nucleus = 4.001509 amu, mass of proton = 1.007277 amu and mass of neutron = 1.008666 amu.** **[4]**

Solution

Given,
Binding energy per nucleon ($\overline{BE}$) = ?
Mass of helium (M) = 4.001509 amu
Mass of proton (m_p) = 1.007277 amu
Mass of neutron (m_n) = 1.008666 amu
A = 4, Z = 2, N = 2
Now,
Mass defect (Δm) $= Zm_p + Nm_n - M = 2 \times 1.007277 + 2 \times 1.008666 - 4.001509 = 0.030377$ amu
Binding energy $= 0.030377 \times 931$ MeV $= 28.281$ MeV
Binding energy per nucleon $= \dfrac{B.E.}{A} = \dfrac{28.281}{4} = 7.07$ MeV/nucleon

58. $\boxed{\text{2070 Supp. (Set B) Q.No. 10 c}}$ **The most common isotope of uranium $^{238}_{92}U$, has atomic mass 238.050783u. Calculate the a) mass defect, b) binding energy, c) Binding energy per nucleon** **[4]**
(Mass of proton = 1.007825u, mass of neutron = 1.008665u)

Solution

Given,
Mass of $_{92}U^{238}$ (M) = 238.050783u
Mass of proton (M_p) = 1.007825u
Mass of neutron (M_n) = 1.008665u
Mass defect (Δm) = ?
Binding energy (BE) = ?

Binding energy per nucleon ($\overline{BE}$) = ?
[A = 238, Z = 92, N = 238 – 92 = 146]
Now,
Mass defect (Δm) $= Zm_p + Nm_n - M$
$= 92 \times 1.007825 + 146 \times 1.008665 - 238.050783$
$= 1.9342$u
B.E. $= 1.9342 \times 931$ MeV $= 1800.75$ MeV
$\overline{B.E.} = \dfrac{B.E.}{A} = \dfrac{1800.75}{238} = 7.566$ MeV/nucleon

59. $\boxed{\text{2069 (Set B) Q.No. 10a}}$ **Estimate the binding energy per nucleon of $_3Li^7$. Mass of $_3Li^7$, a proton and a neutron are respectively 7.01435 amu, 1.00728 amu and 1.00867 amu.** **[4]**
✍ Please refer to $\boxed{\text{2072 Supp Q.No. 10c}}$

60. $\boxed{\text{2068 Old Q.No. 8 b OR}}$ **Assuming that about 200 MeV energy is released per fission of $_{92}U^{235}$nuclei, what would be the mass of U^{235} consumed per day in the fission reactor of power 1MW approximately?** **[4]**

Solution

Given,
Energy released per fission of U-235 = 200 MeV $= 200 \times 1.6 \times 10^{-13}$ J
Power of the reactor (P) = 1 MV $= 10^6$ W
Time (t) = 1 day $= 24 \times 60 \times 60$ sec.
Mass of U-235 consumed (m) = ?
We know,

Power (P) $= \dfrac{\text{Total energy released (E)}}{\text{Time (t)}}$

$E = P \times t = 10^6 \times 24 \times 3600 = 8.64 \times 10^{10}$ J

Since, $200 \times 1.6 \times 10^{-13}$ J energy is released by the fission of 1 U^{235} atom

8.64×10^{10} J energy is released by the fission of

$$\frac{1}{200 \times 1.6 \times 10^{-13}} \times 8.64 \times 10^{10} \text{ atoms} = 2.7 \times 10^{21} \text{ atoms}$$

Also, 235 gm of U-235 contains 6.023×10^{23} atoms

i.e., 6.023×10^{23} atoms have mass (m) $= \frac{235}{6.023 \times 10^{23}} \times 2.7 \times 10^{21}$ gm $= 1.05$ gm

Thus, mass of U-235 consumed per day is 1.05 gm.

61. **2064 Q.No. 8 b OR** **The energy liberated in the fission of a single uranium – 235 atom is 3.2×10^{-11} J. Calculate the power production corresponding to the fission of 1.5 kg of uranium per day.** **[4]**

Solution

Given,

Energy liberated by the fission of a U^{235} atom $= 3.2 \times 10^{-11}$J

Avagardo's constant (N_A) $= 6.023 \times 10^{23}$ mol^{-1}

Time (T) = 1 day = $24 \times 60 \times 60$ secs = 86400 secs

Now, we have,

1 mole = 235 gm of Uranium = 6.023×10^{23} atoms

$\therefore$ 1.5 kg ie, 1500gm of Uranium $= \frac{6.023 \times 10^{23}}{235} \times 1500$ atoms $= 38.44 \times 10^{23}$ atoms

$\therefore$ Total energy released by the fission of 1.5 Kg Uranium $= 38.44 \times 10^{23} \times 3.2 \times 10^{-11}$ J

$= 1.23 \times 10^{14}$J

Again, we know

$$\text{Power produced} = \frac{\text{Energy released}}{\text{Time taken}} = \frac{1.23 \times 10^{14}}{86400} = 1.42 \times 10^9 \text{ watt}$$

Hence, the required power is 1.42×10^9 watt.

62. **2054 Q.No. 16 OR** **The energy liberated in the fission of a single uranium – 235 atom is 3.2×10^{-11} J. Calculate the power production corresponding to the fission of 1 kg of uranium per day. (Avogadro's constant = 6.0×10^{23} $mole^{-1}$)** **[4]**

Solution

Given,

Energy liberated by the fission of a U^{235} atom $= 3.2 \times 10^{-11}$ J

Avogardo's constant (N_A) $= 6.0 \times 10^{23}$ mol^{-1}

Time (T) = 1 day = $24 \times 60 \times 60$ secs = 86400 secs

Now, we have;

1 mole = 235 gm of Uranium which contains 6.0×10^{23} atoms.

$\therefore$ 1 kg i.e., 1000 gm of Uranium $= \frac{6.0 \times 10^{23}}{235} \times 1000$ atoms $= 2.55 \times 10^{24}$ atoms

$\therefore$ Total energy released by the fission of 1 kg Uranium $= 2.55 \times 10^{24} \times 3.2 \times 10^{-11}$ J

$= 8.16 \times 10^{13}$J

Again, we know;

$$\text{Power produced} = \frac{\text{Energy released}}{\text{Time taken}} = \frac{8.16 \times 10^{13}}{86400} = 9.4 \times 10^8 \text{ watt}$$

Hence, the required power is 9.4×10^8 watt.

63. **2052 Q.No. 16** **Calculate the speed of particle if the mass of it is equal to 5 times its rest mass.** **[4]**

Solution

Given,

Mass of moving particle (m) $= 5m_0$; m_0 = rest mass of the particle

Speed of the particle (v) = ?

Now, the relativistic formulae for the variation of mass with velocity is given by,

$$m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}} \quad ; c = \text{velocity of light} = 3 \times 10^8 \text{ m/s}$$

$$\text{or, } 5m_0 = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$\text{or, } 1-\frac{v^2}{c^2} = \left(\frac{1}{5}\right)^2$$

$$\text{or, } 1-\frac{1}{25} = \frac{v^2}{c^2}$$

$$\text{or, } v^2 = \frac{24}{25}\cdot c^2 = \frac{24}{25} \times (3 \times 10^8)^2$$

$$\therefore\ v = \sqrt{\frac{24}{25}} \times 3 \times 10^8 = 2.94 \times 10^8 \text{ m/s}$$

64. **2052 Q.No. 14** **Calculate the Q-value of the reaction and mention the type of reaction (endothermic or exothermic)** [4]

$_2He^4$ = 4.00377 amu **$_8O^{17}$ = 17.00450 amu**

$_7N^{14}$ = 14.00783 amu **$_1H^1$ = 1.00814 amu**

Solution

Given,

The concerned reaction is

$_7N^{14} + {_2He^4} \longrightarrow {_8O^{17}} + {_1H^1} + Q$

Where, Q is the Q-value of the reaction

Then, Mass of reactants = (14.00783 + 4.00377) amu = 18.0116 amu

Also,

Mass of products = (17.00450 + 1.00814) amu = 18.01264 amu

$\therefore$ Difference in mass between reactants & products (Δm)=(18.0116–18.01264)amu =–0.00104 amu

Then, Q–value of the reaction $= \Delta m \times c^2$

$= (-0.00104)\text{amu} \times 931$ MeV

$= -0.96824$ MeV

$= -0.96824 \times 1.6 \times 10^{-13}$J

$= -1.55 \times 10^{-13}$J

Hence, the required Q-value is – 0.97 Mev. Here, since Q-value is negative, the given reaction is endothermic.

❑❑❑

Chapter 5: Radioactivity

Short Answer Questions

1. 2076 Set B Q.No. 2d **All the radioactive series terminate at lead as their final product. Why?** **[2]**

When the radioactive elements become unstable they emit radiations like α, β–particles and γ–radiations. As they emit radiation, they tend to be stable. Lead is a common element having 82 protons and 126 neutrons. The elements having protons greater than 82 require more neutrons to be stable. Due to inadequacy of sufficient neutrons, they become unstable and undergo radioactivity phenomena. The process of emission of radiation occurs until the element becomes stable which is lead. The lead is a first stable isotope. The half life of lead is billions of times greater than the current age of the Universe. So, the radioactive elements having protons greater than 83 becomes lead as their final product.

2. 2076 Set C Q.No. 2d **How does a daughter nucleus differ from its parent nucleus when it emits an α-particle?** **[2]**

The α-particle is a helium nucleus consisting of two protons and two neutrons. When an α-particle is emitted from a nucleus, then the new nucleus will have two less protons and two less neutrons than the parent nucleus. In other words, the mass number (A) decreases by 4 units and the atomic number (z) decreases by 2 units. For example, when $_{92}U^{235}$ atom emits an α-particle ($_2He^4$), it forms $_{90}Th^{231}$ as shown in the following equation:

$$_{92}U^{235} \longrightarrow {}_{90}Th^{231} + {}_2He^4 \text{ (}\alpha\text{-particle)}$$

3. 2075 GIE Q.No. 2d **How does a daughter nucleus differ from its parent nucleus when it emits** **[2]**
   i. **an α particle** ii. **γ-rays**

When a nucleus $_ZX^A$ (Z = proton number and A = mass number) emits α-particle and γ-ray, it changes as,

$_ZX^A \longrightarrow {}_{Z-2}Y^{A-4} + {}_2He^4$; for α-particle emission, where $_{Z-2}Y^{A-4}$ is the daughter nucleus.

$(_ZX^A)^* \longrightarrow {}_ZX^A + \gamma$-radiation, for γ-ray emission

4. 2074 Supp Q.No. 2c **What change takes place in the nucleus when** **[2]**
   i. **an α particle is emitted.**
   ii. **a γ-ray is emitted.**

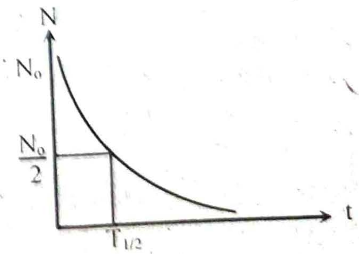
Please refer to 2075 GIE Q.No. 2d

5. 2074 Set A Q.No. 2d **How does a daughter nucleus differ from its parent nucleus when it emits i) an α-particle and ii) a β- particle?** **[2]**

For alpha decay $_ZX^A \rightarrow {}_{Z-2}Y^{A-4} + {}_2He^4$,

For Beta decay $_ZX^A \rightarrow {}_{Z+1}Y^A + {}_{-1}e^0$

6. 2074 Set B Q.No. 2d **If a radioactive nucleus has a half life of one year, will it be completely decayed at the end of two year? Explain.** **[2]**



No, a radioactive nucleus will not completed at the ends of two years if its half life is one year because it decays in exponential manner as shown in figure by the relation,

$$N = N_0e^{-\lambda t}$$

where, No be the initial number of atoms and $T_{1/2}$ be its half life.

7. 2073 Set D Q.No. 2d **Characteristic features of X- rays and Y-rays are similar in many aspects. Write two important features that explain the differences between these rays.** **[2]**

Two important differences between x-rays & γ-rays are:

X – rays	γ – rays.
1. The wavelength of X– rays is more and frequency is less than γ –rays. 2. The ionization power is more & penetrating power is less than γ–rays.	1. The wavelength of γ-rays is less and frequency is more than X–rays. 2. The ionization power is less and penetrating power is more than x–rays.

8. **2072 Set C Q.No. 2e A nucleus contains no electrons, yet it ejects them. Explain.** **[2]**

The β-particles are emitted from the nucleus during the radioactive disintegration although there are no electrons inside the nucleus. When the nucleus emits the β-particles, it becomes more stable. During the process of emitting these particles, a neutron in the nucleus is converted into a proton by emitting a beta particle and an anti-neutrino as: ${}_0n^1 \rightarrow {}_1H^1 + {}_{-1}\beta^0 + \nu$. Hence, β-particles are emitted from nucleus by converting neutrons into protons.

9. **2072 Set D Q.No. 2d How do the mass number and atomic number of a radioactive element change in an α-decay?** **[2]**

Please refer to 2076 Set C Q.No. 2d

10. **2071 Supp Q.No. 2e There are no electrons inside the nucleus, but they are emitted from an unstable nucleus. Why?** **[2]**

Please refer to 2072 Set C Q.No. 2e

11. **2070 Sup (Set A) Q.No. 2 d How are half life and average life of a radioactive substance related?** **[2]**

The half life and average life of a radioactive elements are given as

$$T_{1/2} = \frac{0.693}{\lambda} \text{ and } T_{mean} = \frac{1}{\lambda}$$

$$\therefore T_{mean} = \frac{T_{1/2}}{0.693} = 1.44\, T_{1/2}$$

$$\therefore T_{mean} = 1.44\, T_{1/2}$$

This is the relationship between mean life and half of radioactive substance.

12. **2069 (Set A) Q.No. 2d Beta particles penetrate through a matter easily than that of alpha-particle of the same energy. Why?** **[2]**

Beta particles are light particles, their velocity is very high and hence their energy is high. So, their penetrating power is very high and hence they can penetrate through a matter easily. While alpha-particles are heavy particles, their energy and penetrating power is less. So, they cannot penetrate the matter easily.

13. **2069 (Set B) Q.No. 2b Write down the decay schemes separately for alpha and beta decays from a nucleus $_ZX^A$.** **[2]**

Please refer to 2074 Set A Q.No. 2d

14. **2069 Set A Old Q.No. 2d 2052 Q.No. 12 a What do you mean by curie?** **[2]**

Curie is the unit of radioactivity. It is defined as the activity of a radioactive substance which gives 3.7×10^{10} disintegration per second. It is equal to the activity of 1g of pure radium. i.e., $1Ci = 3.7 \times 10^{10}$ disintegration/second.

15. **2068 Q.No. 2 d Heavy unstable nuclei usually decay by emitting an α or β particle. Why do they not usually emit a single proton or neutron?** **[2]**

During the emission of α-particle from an atom, it loses atomic number by 2 units and mass number by 4 units. But, during the emission of β-particle from an atom, it gains atomic number by one but the mass number remains same. There is no phenomenon occurred in which increasing and decreasing of atomic number simultaneously found. So, a nucleus either emits a α-particle or a β-particle at an instant but never both or more than one of each kind simultaneously. However, r-ray is emitted after each emission of α- or β-particle if the atom is initially in the excited state.

16. **2068 Old Q.No. 1 h Explain the term "decay constant".** **[2]**

The rate of disintegration of radioactive substances at any time is directly proportional to the number of atoms present at that instant.

Let N be the number of atoms present in a particular radioactive element at any instant t. If dN is the number of disintegration in time dt, then rate of disintegration is directly proportional to the number of atoms present at that instant.

$$\text{i.e., } \frac{dN}{dt} \propto N \Rightarrow \frac{dN}{dt} = -\lambda N$$

where 'λ' is a proportionality constant and is called disintegration (or decay) constant. The negative sign shows that the number of present atoms is continuously decreasing. Thus decay constant λ is defined as the disintegration per second per unit atom.

17. 2064 Q.No. 2 g **How do you get emission of β-particles from the nucleus, although there are no electrons within it?** [2]

Please refer to 2072 Set C Q.No. 2e

18. 2060 Q.No. 2 g **What is the result if a α-particle is emitted from a nucleus? Give an example.** [2]

Please refer to 2076 Set C Q.No. 2d

19. 2058 Q.No. 2 f **Can a single nucleus at a time emit α-particle, β-particle and gamma ray?** [2]

Please refer to 2068 Q.No. 2 d

20. 2057 Q.No. 1 f **How do β-particles differ from electrons?** [2]

The differences between β-particles and electrons are given below:

β-particles	Electrons
1. β-particles are emitted from the nucleus during radioactive decay.	1. Electrons are emitted during thermionic emission or photoelectric emission from outer shell.
2. They have high velocity.	2. They have less velocity.
3. Their K.E. is high.	3. Their K.E. is less.

21. 2054 Q.No. 12 c 2053 Q.No. 12 d **Explain the term artificial radio isotopes.** [2]

The atoms of the same element having different mass numbers is called isotope. The artificially produced isotopes, which exhibit radioactivity, are called artificial radioisotopes. For example: Iodine-131, Cobalt-60, Sodium-24 etc are artificial radioisotopes. These isotopes are made in laboratory and used for various purposes.

22. 2053 Q.No. 13 **What are beta and gamma rays? State three properties of each.** [2]

Beta particles are the negatively charged particles (or electrons) emitted from the nucleus during the radioactive decay of a nucleus. The three properties of beta particles are:

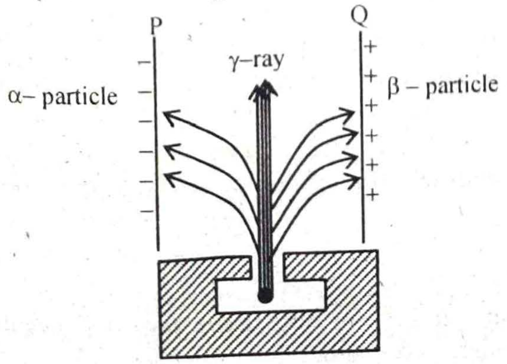
a. They are negatively charged particles having charge -1.6×10^{-19}C.
b. Their rest mass is equal to 9.0×10^{-31} kg.
c. They are deflected by electric and magnetic field.

Gamma rays are the electromagnetic waves of short wavelength which are emitted during the radioactive disintegration of a radioactive substance. The three properties of the gamma rays are given below:

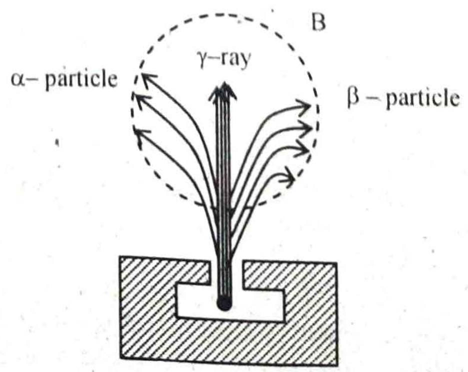
a. They move with the velocity of light.
b. They are not deflected by electric and magnetic field.
c. They can affect the photographic plate.

23. 2052 Q.No. 12 b **How will you identity α, β and γ radiation by simple experiment?** [2]

A simple experiment which is shown below determines the different types of radiations (α, β and γ) emitted by a radioactive substance. A small hole is made in a lead block in which a piece of radioactive sample such as radium is placed and a narrow beam of radiation emerges out of the hole. The nature of the radiation is studied by applying electric field and magnetic field. In both cases, the narrow beam of radiation is splitted into three components. The beam which deviates towards the negative plate P of electric field is α–particles and the beam which deviates towards positive plate Q are termed as β–particles whereas the beam which does not deflect towards any plate is termed as γ–rays as shown in figure (i). In magnetic field, the β–particles deviate more than α–particles and γ–rays travels straight as shown in figure (ii).



(i)



(ii)

Long Answer Questions

24. 2076 Set B Q.No. 6c **List out the laws of radioactive disintegration. Deduce the expression $N = N_o e^{-\mu}$ where symbols have their usual meaning.** **[4]**

Laws of Radioactive Disintegration: The laws of radioactive disintegration are:

a. In all known radioactive disintegration either an α - particle or a β-particle is only emitted, but it is never that both the particles are ejected simultaneously. γ-rays are emitted after each emission of α or β particle if the atom is already in excited state.

b. The rate of disintegration is independent of external factors like temperature, pressure etc.

c. The rate of disintegration of radioactive substances at any time is directly proportional to the number of atoms present at that instant.

Let N be the number of atoms present in a particular radioactive element at any instant t. If dN is the number of disintegration in time dt, then rate of disintegration is directly proportional to the number of atoms present at that instant.

i.e., $\frac{dN}{dt} \propto N \Rightarrow \frac{dN}{dt} = -\lambda N$

where 'λ' is a proportionality constant and is called disintegration (or decay) constant. The negative sign shows that the number of present atoms is continuously decreasing.

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

On integrating, we get

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

or, $\ln N = -\lambda t + C$, Where C is a integration constant.

At first t = 0, $N = N_o$ (intial number of atoms)

$\ln N_o = C$

On substitution, we get

or, $\ln N = -\lambda t + \ln N_o$

$\ln N - \ln N_o = -\lambda t$

$\ln \frac{N}{N_0} = -\lambda t$

$\frac{N}{N_0} = e^{-\lambda t}$

$N = N_0 e^{-\lambda t}$

$N = N_o e^{-\mu}$, where $\mu = \lambda t$

This equation gives the disintegration law and indicates that radioactive substances decrease with time.

25. 2075 Set B Q.No. 6d 2073 Supp Q.No. 6d 2072 Set D Q.No. 6d **State the laws of radioactive disintegration. Derive the relation between half life and decay constant.** **[4]**

Laws of Radioactive Disintegration: The laws of radioactive disintegration are:

a. In all known radioactive disintegration either an α - particle or a β-particle is only emitted, but it is never that both the particles are ejected simultaneously. γ-rays are emitted after each emission of α or β particle if the atom is already in excited state.

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c. The rate of disintegration of radioactive substances at any time is directly proportional to the number of atoms present at that instant.

Let N be the number of atoms present in a particular radioactive element at any instant t. If dN is the number of disintegration in time dt, then rate of disintegration is directly proportional to the number of atoms present at that instant.

i.e., $\frac{dN}{dt} \propto N \Rightarrow \frac{dN}{dt} = -\lambda N$

where 'λ' is a proportionality constant and is called disintegration (or decay) constant. The negative sign shows that the number of present atoms is continuously decreasing.

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

On integrating, we get

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

or, $ln N = -\lambda t + C$, Where C is a integration constant.

At first t =0, N=N_o (initial number of atoms)

$ln N_o = C$

On substitution, we get

or, $ln N = -\lambda t + ln N_o$

$ln N - ln N_o = -\lambda t$

$ln \frac{N}{N_0} = -\lambda t$

$\frac{N}{N_0} = e^{-\lambda t}$

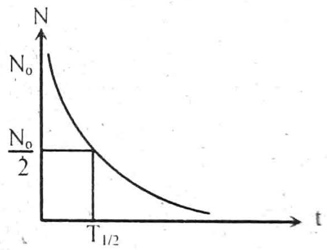
$N = N_o e^{-\lambda t}$

This equation gives the disintegration law and indicates that radioactive substances decrease with time.

Relation between half-life and decay constant:

The half-life of a radioactive element is defined as the time interval during which half the radioactive atoms disintegrate.

If $T_{1/2}$ is the half-life period of a radioactive substance, then



$N = \frac{N_0}{2}$ at $t = T_{1/2}$

Since, $N = N_0 e^{-\lambda t}$

$\therefore \frac{N_0}{2} = N_0 e^{-\lambda T_{1/2}}$

or, $\frac{1}{2} = e^{-\lambda T_{1/2}} \Rightarrow 2 = e^{\lambda T_{1/2}}$

or, $ln 2 = \lambda T_{1/2}$

or, $T_{1/2} = \frac{\ln 2}{\lambda}$

$\therefore T_{1/2} = \frac{0.693}{\lambda}$

This is required half life of a radioactive material.

26. **2074 Supp Q.No. 6d State the laws of radioactive disintegration. What is half life period of a radioactive substance? Derive an expression for it.** **[4]**

Please refer to 2075 Set B Q.No. 6d

27. **2073 Set D Q.No. 6b Deduce the law of radioactivity and hence define half life of a radioactive sample. How much is one Curie?** **[4]**

Please refer to 2075 Set B Q.No. 6d

1 curie = 3.7×10^{10} dis/sec.

28. **2072 Supp Q.No. 6d State the laws of radioactive disintegration. Derive disintegration equation. Using the equation find a relation between the half life and decay constant.** **[4]**

Please refer to 2075 Set B Q.No. 6d

29. **2072 Set E Q.No. 6c What are different units of radio activity? Describe "carbon dating".** **[4]**

Units of Radioactivity: The activity of radio-active substance is measured in disintegration per second. The other units are:

i. Curie (Ci) = It is defined as the activity of a substance which gives 3.7×10^{10} dis/sec. It is equal to activity of 1g of pure radium.

1 Ci = 3.7×10^{10} dis/sec

ii. Rutherford (rd): It is defined as the activity of a substance which gives 10^6 dis/sec.
i.e., 1 rd = 10^6 dis/sec.

iii. Becquerel (Bq): It is S.I. unit of radioactivity.
i.e., 1 Bq= 1 dis/sec

$\therefore$ 1 Curie = 3.7×10^{10} dis/sec = 3.7×10^{10} Bq = 3.7×10^4 rd

Radio Carbon Dating

Estimating the age of archeological and geological objects like rocks, the idols by measuring the proportion of $_6C^{14}$, $_6C^{12}$ in the specimen is called carbon dating.

In archeological dating C^{14} is used as radio-isotope whose half life is about 5730 years. The C^{14} is produced in the atmosphere by the bombardment of the neutrons present in the cosmic rays on the nitrogen present in the atmosphere according to the following nuclear reaction.

$_7N^{14} + {_0n^1} \rightarrow {_6C^{14}} + {_1H^1}$

The $_6C^{14}$ thus produced is absorbed by living organism (the plants and animals which eat plants). When the living organisms die, the intake of $_6C^{14}$ stops and the decay of $_6C^{14}$ contained in them starts with the half life of 5730 years. Then the determination the number of atoms of $_6C^{14}$ and $_6C^{12}$ in a sample of the dead organism present at a time, its age can be estimated.

Suppose, the activity of some dead material was R_0 at the time of death and it has been reduced to R after t years. Then, according to the law of radioactive decay, we have,

$$R = R_0 e^{-\lambda t}$$

$$e^{\lambda t} = \frac{R_0}{R}$$

$$\text{or, } \lambda t = \log\left(\frac{R_0}{R}\right)$$

$$\text{or, } t = \frac{1}{\lambda} \log\left(\frac{R_0}{R}\right)$$

But, $\lambda = \frac{0.693}{T_{1/2}}$, with $T_{1/2}$ = 5730 years.

Then,

$$t = \frac{T_{1/2}}{0.693} \log\left(\frac{R_0}{R}\right)$$

Hence, by measuring the activity R_0 of living plant and activity R of its dead material, the age t of that object can be determined.

30. 2071 Set D Q.No. 6 c **State the laws of radioactive disintegration. What is half life period of a radioactive substance? Derive an expression for it.** **[4]**

Please refer to 2075 Set B Q.No. 6d

31. 2070 Sup (Set A) Q.No. 6 b **Define decay constant for a radioactive substance and deduce the expression $N=N_0 e^{-\lambda t}$, where the symbols have their usual meanings. How can we estimate the age of some fossils using such equation?** **[4]**

Please refer to 2076 Set B Q.No. 6d

32. 2070 Supp. (Set B) Q.No. 6 c **Discuss radioactive decay law. Deduce an expression for the number of atoms after a time 't' has elapsed and hence write an expression for half life of the radioactive substance.** **[4]**

Please refer to 2075 Set B Q.No. 6d

33. 2070 Set D Q.No. 6 c **State the laws of radioactivity and derive the decay equation.** **[4]**

Please refer to 2076 Set B Q.No. 6d

34. 2069 Supp Set B Q.No. 6 b **Explain the difference between natural and artificial radioactivity and obtain the decay law of radioactivity. Also find a relation between the decay constant and half life of a radioactive isotope.** **[4]**

The radioactive elements like uranium which are found in nature are called natural radioactivity while the radioactivity elements like Iodine-131, Cobalt – 60, Sodium 24, etc. which are artificially made by man in the lab are called artificially radioactivity.

2nd part: Please refer to 2075 Set B Q.No. 6d

35. 2068 Can. Q.No. 6c Write down laws of radioactive disintegration and establish a relation between half life and decay constant. [4]

Please refer to 2075 Set B Q.No. 6d

36. 2068 Old Can. Q.No. 9 2066 Supp Q.No. 9 2061 Q.No. 8 a Define half- life and decay constant of a radioactive substance. Establish a relation between them. [2+2]

Please refer to 2075 Set B Q.No. 6d

37. 2067 Q.No. 6c Derive the decay equation and establish the relationship between decay constant and half life of radio-active element. [2+2]

Please refer to 2075 Set B Q.No. 6d

38. 2065 Q.No. 8 a OR What do you understand by the activity of a radioactive material? Write its unit. Also derive the law of radioactive disintegration. [1+3]

Please refer to 2076 Set B Q.No. 6c

39. 2064 Q.No. 9 OR State laws of radioactive disintegration and show that the number of atoms of a given radioactive substance decreases exponentially with time. Also, derive a relation between decay constant and half life of a radioactive substance. [2+2]

Please refer to 2075 Set B Q.No. 6d

40. 2060 Q.No. 9 What is radioactivity? Obtain its exponential decay law and hence derive an expression for half life period. [1+2+1]

The process of spontaneous emission of radiations (α, β, and γ) by the unstable nuclei like uranium, thorium, etc. is called radioactive emission or radioactivity.

2nd part: Please refer to 2075 Set B Q.No. 6d

41. 2054 Q.No. 13 State the laws of radioactive disintegration. Derive a relation between half-life and decay constant. [4]

Please refer to 2075 Set B Q.No. 6d

Numerical Problems

42. 2076 Set C Q.No. 10c 2075 GIE Q.No. 10c Find the half life of U^{238}, if 1 gm of it emits 1.24×10^4 α-particles per-second Avogadro's number = 6.025×10^{23}. [4]

Solution

Given,

$\frac{dN}{dt} = 1.24\times10^4$

Half life $(T_{1/2}) = ?$

But, 238 g of U contains 6.023×10^{23} atoms

$\therefore$ 1 g of U contains $\frac{6.023\times10^{23}}{238}$

$\therefore N = 2.51\times 10^{21}$ atoms

We have,

$$\frac{dN}{dt} = \lambda N = \frac{0.693}{T_{1/2}}.N$$

$$\therefore T_{1/2} = \frac{0.693\times N}{dN/dt} = \frac{0.693\times2.51\times10^{21}}{1.24\times10^4} = 1.41\times10^{17}\text{sec} = 4.5\times10^9 \text{ years}$$

43. 2074 Set A Q.No. 10c The isotope Ra-226 undergoes α decay with a half life of 1620 years. What is the activity of 1 g of Ra-226? Avogadro number = 6.023×10^{23}/mole. [4]

Solution

Given,

Halt life $(T_{1/2})$ = 1620 years = $1620\times365\times24\times60\times60$ sec = 5.1×10^{10} sec

Mass of Ra−226 = 1 gm

Activity of Ra-266 $\left(\frac{dN}{dt}\right) = ?$

Now,

$\lambda = \frac{0.693}{T_{1/2}} = \frac{0.693}{5.1 \times 10^{10}} = 1.36 \times 10^{-11}\ sec^{-1}$

226 gm of Ra-226 contains 6.023×10^{23} atoms

1 gm of Ra-226 contains $\frac{6.023 \times 10^{23}}{226}$ atoms = 2.66×10^{21} atoms

Now,

$\frac{dN}{dt} = \lambda N = 1.36 \times 10^{-11} \times 2.66 \times 10^{21} = 3.6 \times 10^{10}$ dis/sec

44. **2074 Set B Q.No. 10c** **Calculate the mass in grams of a radioactive sample Pb-214 having an activity of 3.7×10^4 decays / s and a half life of 26.8 minutes. Avogadro number = 6.02×10^{23} /mole.** **[4]**

Solution

Given,

Half life ($T_{1/2}$) = 26.8 min = 26.8 × 60 sec

Activity $\left(\frac{dN}{dt}\right) = 3.7 \times 10^4$ dis/ sec

Avogadro No. (N_A) = 6.02×10^{23} /mol

Mass of sample (m) = ?

We have,

$\frac{dN}{dt} = \lambda N$ (Magnitude only)

or, $\frac{dN}{dt} = \frac{0.693}{T_{1/2}} \times N \quad \left[\therefore \lambda = \frac{0.693}{T_{1/2}}\right]$

or, $N = \frac{dN}{dt} \times \frac{T_{1/2}}{0.693}$

or, $N = \frac{3.7 \times 10^4 \times 26.8 \times 60}{0.693}$

$= 8.585 \times 10^7$ atoms

Now,

6.02×10^{23} atoms of Pb are present in 214 gm of it.

$\therefore$ 8.585×10^7 atoms of Pb are present in $\frac{214 \times 8.585 \times 10^7}{6.023 \times 10^{23}}$ gm

i.e., (mass (m) = 3.05×10^{-14} gm

45. **2073 Supp Q.No. 10c** **A radioactive source has decayed to one tenth of one percent of its initial activity in one hundred days. What is its half life period?** **[4]**

Solution

Given,

Time period (T) = 100 days

Let A_0 be the initial activity, then according to the question, activity after one hundred days is given by,

$A = \frac{1}{10}$ of 1% of $A_0 = \frac{1}{10} \times \frac{1}{100} \times A_0 = \frac{A_0}{1000}$

Now, we have

$A = A_0 e^{-\lambda t}$

or, $\frac{A_0}{1000} = A_0 e^{-\lambda \times 100}$

or, $\frac{1}{1000} = e^{-\lambda \times 100}$

Talking $\log_e$ on both sides, we get,

$\log_e\left(\frac{1}{1000}\right) = -\lambda \times 100$

or, $-6.9 = \frac{-0.693}{T_{1/2}} \times 100$

$\therefore$ $T_{1/2} = 10$ days

Hence, the required half-life period is 10 days.

46. 2073 Set C Q.No. 10a **Half life of Ra^{226} is 1620 years. Estimate its mass when its activity is 0.5 Curie.** **[4]**

Solution

Given,

Half life $(T_{1/2}) = 1620$ years $= 1620 \times 365 \times 24 \times 60 \times 60 = 5.1 \times 10^{10}$ sec

Activity $\left(\frac{dN}{dT}\right) = 0.5$ curie $= 0.5 \times 3.7 \times 10^{10} = 1.85 \times 10^{10}$ dis/sec

Now,

$\frac{dN}{dt} = \lambda N$ (in magnitude)

or, $\frac{dN}{dt} = \frac{0.693}{T_{1/2}} N$

or, $1.85 \times 10^{10} = \frac{0.693}{5.1 \times 10^{10}} N$

or, $N = \frac{1.85 \times 5.1 \times 10^{20}}{0.693} = 1.36 \times 10^{21}$ atoms

But, 6.023×10^{23} atoms $= 226$ gm of Ra^{226}

$\therefore$ 1.36×10^{21} atoms $= \frac{226}{6.023 \times 10^{23}} \times 1.36 \times 10^{21} = 0.51$ gm $= 0.51 \times 10^{-3}$ kg

47. 2072 Set C Q.No. 10c **After a certain lapse of time, the fraction of radioactive polonium undecayed is found to be 12.5% of the initial quantity. What is the duration of this time lapse if half of polonium is 139 days.** **[4]**

Solution

Given,

Fraction of undecayed polonium $\left(\frac{N}{N_0}\right) = 12.5\%$

Half life of polonium $(T_{1/2}) = 139$ days

Total life time (t) = ?

Now,

$N = N_0 e^{-\lambda t}$

or, $\frac{N}{N_0} = e^{-\lambda t} = e^{-\frac{0.693}{T_{1/2}} t}$ $\left[\because \lambda = \frac{0.693}{T_{1/2}}\right]$

or, $\frac{12.5}{100} = e^{-\frac{0.693}{T_{1/2}} t}$

Taking ln on both sides, we get

$\ln\left(\frac{12.5}{100}\right) = -\frac{0.693}{T_{1/2}} \times t$

or, $-2.08 = -\frac{0.693}{T_{1/2}} \times t$

or, $t = \frac{139 \times 2.08}{0.693}$

$\therefore$ $t = 417.2$ days

48. 2071 Supp Q.No. 10b **If 15% of the radioactive material decays in 5 days, what would be the percentage of amount of original material left after 25 days?** **[4]**

Solution

If 15% of radioactive material decays in 5 days. Then remain material is 85% of original material. Then,

$\frac{N_5}{N_0} = 85\% = \frac{85}{100} = e^{-\lambda 5}$

or, $e^{-\lambda 5} = \frac{85}{100}$

or, $\ln\left(\frac{85}{100}\right) = -\lambda 5$

or, $\lambda = \ln\left(\frac{85}{100}\right)/5 = 0.0325/\text{days}$

Again,

$\frac{N_{25}}{N_0} = e^{-\lambda 25} = e^{-\frac{0.0325}{5} \times 25}$

or, $\frac{N_{25}}{N_0} = 0.44$

i.e., $\frac{N_{25}}{N_0} = 44\%$

$\therefore$ 44% of original material left after 25 days.

49. 2071 Set C Q.No. 10 b **The mass of the radium is 226. It is observed that 3.67×10^{10} $\propto$-particles are emitted per second from 1g of radium. Calculate the half life of radium. (Avogadro number = 6.023×10^{23} mole)** [4]

Solution

Given,

Rate of disintegration $\left(\frac{dN}{dt}\right) = 3.67 \times 10^{10}$ dis/sec

Half life $(T_{1/2})$ = ?

Mass of radium = 1gm

From mole concept,

226 gm of radium contains 6.023×10^{23} atoms.

1 gm of radium $= \frac{6.023 \times 10^{23}}{226} = 2.665 \times 10^{21}$ atoms

$\therefore$ $N = 2.665 \times 10^{21}$ atoms

Now,

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

or, $3.67 \times 10^{10} = \lambda \times 2.665 \times 10^{21}$

or, $\lambda = 1.377 \times 10^{-11}$ sec^{-1}

Again

$T_{1/2} = \frac{0.693}{\lambda} = \frac{0.693}{1.377 \times 10^{-11}} = 5 \times 10^{10}$ sec $= 1586$ years

50. 2070 Set C Q.No. 10 c **Measurements on certain isotope show that the decay rate decreases from 8318 decays/min. to 3091 decays/min. in 4 days. What is the half life of this isotope?** [4]

Solution

Given,

Initial activity $(A_0) = 8318$ decays/min $= \frac{8318}{60}$ decays/sec

Final activity $(A) = 3091$ decays/min $= \frac{3091}{60}$ decays/sec

Time taken (t) = 4 days $= 4 \times 24 \times 60 \times 60 = 345600$ sec

Half life $(T_{1/2})$ = ?

We have,

$A = A_0 e^{-\lambda t}$

or, $\frac{A}{A_0} = e^{-\lambda t}$

or, $\frac{\frac{3091}{60}}{\frac{8318}{60}} = e^{-\lambda \times 34600 \text{ sec}}$

or, $0.37 = e^{-\lambda \times 34600\,sec}$

Taking ln on both side we get,

$ln\,(0.37) = \lambda \times 345600$

or, $\lambda = \dfrac{-0.994}{-345600} = 2.87 \times 10^{-6}$

Then,

$T_{1/2} = \dfrac{0.693}{\lambda} = \dfrac{0.693}{2.87 \times 10^{-6}} = 2.8$ days

51. **2069 Supp Set B Q.No. 10 c** **At a certain instant, a piece of radioactive material contains 10^{12} atoms. The half life of the material is 40 days. Calculate the number of disintegrations in first one second.** **[4]**

Solution

Given,

Initial no. of atoms $(N_0) = 10^{12}$ atoms

Half life $(T_{1/2})$ = 40 days = $40 \times 24 \times 60 \times 60 = 3456000$ sec

Time taken (t) = 1 sec

No. of disintegration per second $\left(\dfrac{dN}{dt}\right) = ?$

We have,

$N = N_0\, e^{-\lambda t} = N_0\, e^{-\lambda \times 1} = N_0 e^{\frac{-0.693}{T1/2}} = N_0 e^{\frac{-0.693}{3456000}} = 10^{12} \times 0.999 = 9.99 \times 10^{11}$

Again,

$\dfrac{dN}{dt} = \lambda\, N$

or, $\dfrac{dN}{dt} = \dfrac{0.693}{3456000} \times 9.99 \times 10^{11}$

$\therefore \dfrac{dN}{dt} = 2 \times 10^5$ dis/sec

52. **2069 (Set A) Q.No. 10c** **Find the half life of $_{92}U^{238}$, if one gram of it emits 1.24×10^4 α- particles per second. (Avogadro's number = 6.023×10^{23})** **[4]**

Please refer to 2076 Set C Q.No. 10c

53. **2068 Q.No. 10 c** **At a certain instant, a piece of radio active material contains 10^{12} atoms. The half-life of the material is 30 days. Calculate the number of disintegrations in the first second.** **[4]**

Solution

Given,

Initial no. of atoms $(N_0) = 10^{12}$ atoms

Half life $(T_{1/2})$ = 30 days = $30 \times 24 \times 60 \times 60 = 2592000$sec

Time taken (t) = 1 sec

No. of disintegration per second $\left(\dfrac{dN}{dt}\right) = ?$

We have,

$N = N_0\, e^{-\lambda t} = N_0\, e^{-\lambda \times 1} = N_0 e^{\frac{-0.693}{T_{1/2}}} = N_0\, e^{\frac{-0.693}{2592000}} = 10^{12} \times 0.999 = 9.99 \times 10^{11}$

Again,

$\dfrac{dN}{dt} = \lambda\, N$

or, $\dfrac{dN}{dt} = \dfrac{0.693}{2592000} \times 9.99 \times 10^{11}$

$\therefore \dfrac{dN}{dt} = 2.7 \times 10^5$ dis/sec

54. 2067 Sup Q.No. 10c **The initial number of atoms in a radioactive element is 6×10^{20} and its half life is 10 hours. Calculate the number of atoms which have decayed in 30 hours and the amount of energy liberated if the energy liberated per atom decay is 4×0^{-13} J.** [4]

Solution

Given,

Initial no. of atoms $(N_0) = 6 \times 10^{20}$

Half life $(T_{1/2})$ = 10 hours

Time period (t) = 30 hours

Energy liberated per atom (E) = 4×10^{-13} J

No. of atoms decayed (N') = ?

Total energy liberated = ?

Now, we have,

$\frac{N}{N_0} = \left(\frac{1}{2}\right)^{\frac{t}{T}}$ where N is the no. of atoms remained undecayed after 30 hours

[Note: You can also use the relation, $N = N_0e^{-\lambda t}$]

or, $\frac{N_0 - N'}{N_0} = \left(\frac{1}{2}\right)^{\frac{30}{10}}$

or, $\frac{6 \times 10^{20} - N'}{6 \times 10^{20}} = 0.125$

or, $6 \times 10^{20} - N' = 0.75 \times 10^{20}$

$\therefore$ $N' = 5.25 \times 10^{20}$ atoms

Hence, the required number of atoms decayed is 5.25×10^{20}.

Again,

Total energy liberated = $N' \times E = 5.25 \times 10^{20} \times 4 \times 10^{-13} = 21 \times 10^7$ J

55. 2067 Old Q.No. 8b **If the half life period of a radioactive substance is 2 days, after how many days will $\frac{1}{64}$ th part of the substance be left behind?** [4]

Solution

Given,

$N = \frac{1}{64}$ of N_o

or, $\frac{N}{N_o} = \frac{1}{64}$

Half life $(T_{1/2})$ = 2 days

Time (t) = ?

Now, we know,

$N = N_0e^{-\lambda t}$

$\frac{N}{N_o} = e^{-\frac{0.693}{T_{1/2}} \times t}$

$\frac{1}{64} = e^{-\frac{0.693}{T_{1/2}} \times t} = e^{-\frac{0.693}{2} \times t}$

taking natural log on both side, we get

$\log_e\left(\frac{1}{64}\right) = -\frac{0.693}{2} \times t$

$\therefore$ t = 12 days.

56. 2066 Q.No. 8 b **A small volume of a solution which contain a radioactive isotope of sodium had an activity of 12000 disintegrations per minute when it was injected into the blood stream of a patient. After 30 hours, the activity of 1cm³ of the blood was found to be 0.5 disintegration per minute. If the half life of the sodium isotope is 15 hours, estimate the volume of the blood in the patient.** [4]

Solution

Given,

Initial activity (A_0) = 12,000 dis/minute

Final activity per cm³ volume (A) = 0.50 dis/minute

Time (t) = 30 hrs

Half life($T_{1/2}$) = 15 hrs

Now, if V be the total volume of blood.

then, we have;

Activity of Vcm^3 of blood = 12,000 dis/minute

$\therefore$ Activity of 1 cm^3 of blood (A_0) = $\frac{12000}{V}$ dis/minute

Then using

$$\frac{A}{A_0} = \left(\frac{1}{2}\right)^{\frac{t}{T}}$$ *[Note: Also you can use; $A = A_0e^{-\lambda t}$]*

$$\text{or, } \frac{0.50}{\frac{12000}{V}} = \left(\frac{1}{2}\right)^{\frac{30}{15}}$$

$$\text{or, } \frac{0.5V}{12000} = 0.25$$

$\therefore$ V = $6000cm^3$

Hence, the required volume is 6000 cm^3.

57. **2063 Q.No. 8 b OR A sample of Ra-226 has half life of 1620 years. What is the mass of the sample which undergoes 20000 disintegrations per second?** **[4]**

Solution

Given,

Half life ($T_{1/2}$) 1620 yrs = (1620 × 12 × 30 × 24 × 60 × 60) sec = 5.04×10^{10} sec

No. of disintegrations per second $\left(\frac{dN}{dt}\right)$ = 20000 dis/sec

Avogadro's no. = 6.02×10^{23} mol^{-1}

Now, we have;

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

$$\text{or, } \frac{dN}{dt} = \frac{0.693}{T_{1/2}} \times N$$

$$\text{or, } 20000 = \frac{0.693}{5.04 \times 10^{10}} \times N$$

$\therefore$ N = 1.45×10^{15} atoms

Again, we have

6.02×10^{23} number of atoms of Ra are present in 226 gm of it.

$\therefore$ 1.45×10^{15} number of atoms of Ra are present in $\frac{226}{6.02 \times 10^{23}} \times 1.45 \times 10^{15}$gm

$= 5.44 \times 10^{-7}$gm

$= 5.44 \times 10^{-10}$kg

Hence, the required mass of sample is 5.44×10^{-10} kg.

58. **2062 Q.No. 8 b OR The isotope 14C has a half life 5700 yrs. If the sample contains 1×10^{22} carbon 14 nuclei. What is the activity of the sample?** **[4]**

Solution

Given,

Half-life ($T_{1/2}$) = 5700 yrs = (5700 × 12 × 30 × 24 × 60 × 60)sec = 1.77×10^{11} secs.

No. of atoms (N) = 1×10^{22}

Activity $\left(\frac{-dN}{dt}\right)$ = ?

Now, we have;

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

$= \frac{0.693}{T_{1/2}} \times N \qquad [\because \lambda = \frac{0.693}{T_{1/2}}]$

$= \frac{0.693}{1.77 \times 10^{11}} \times 1 \times 10^{22} = 3.9 \times 10^{10}$ dis/sec

$\approx 4 \times 10^{10}$ dis/sec

Hence, the required activity is 4×10^{10} dis/sec.

59. **2059 Q.No. 8 b OR** **The unstable isotope of potassium – 40 has a half life of 2.4×10^8 yrs. How many decays occur per second in a sample containing 2×10^{-6} gm of potassium – 40?** **[4]**

Solution

Given,

Half life ($T_{1/2}$) = 2.4×10^8 yrs = $(2.4 \times 10^8 \times 365 \times 24 \times 3600)$ sec = 7.57×10^{15} sec

Initial mass (m) = 2×10^{-6} gm

Here,

40 gm of potassium contains 6.023×10^{23} atoms of it.

$\therefore$ 2×10^{-6} gm of potassium contains $\frac{6.023 \times 10^{23}}{40} \times 2 \times 10^{-6}$ atoms of it.

$= 3.01 \times 10^{16}$ atoms

Let, $N = 3.01 \times 10^{16}$

Then,

Decay per second $\left(\frac{dN}{dt}\right) = ?$

Now, we have;

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

$= \frac{0.693}{T_{1/2}} \times N \qquad [\because \lambda = \frac{0.693}{T_{1/2}}]$

$= \frac{0.693}{7.57 \times 10^{15}} \times 3.01 \times 10^{16}$

$\therefore \frac{dN}{dt} = 2.76$ dis/sec

Here, the required no. of decay per second is 2.76 dis/sec.

60. **2057 Q.No. 8 b OR** **A radioactive source which has the half life of 130 days, contains initially 1×10^{20} radioactive atoms, and the energy released per disintegration is 8×10^{-13} J, calculate the activity of the source after 260 days have elapsed and total energy released during this period.** **[4]**

Solution

Given,

Half life ($T_{1/2}$) = 130 days

Initial no. of atoms (N_0) = 1×10^{20}

Energy released per disintegration (E) = 8×10^{-13} J

Time period (t) = 260 days; Half life ($T_{1/2}$) = 130 days

Activity after 260 days $\left(-\frac{dN}{dt}\right) = ?$

Now,

If N be the number of atoms remaining after 260 days, we have

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

$= \lambda \times N_0 \times e^{-\lambda t} \qquad [\because N = N_0 e^{-\lambda t}]$

$= \frac{0.693}{T_{1/2}} \times N_0 e^{-\frac{0.693}{T_{1/2}} \times t} \qquad [\because \lambda = \frac{0.693}{T_{1/2}}]$

$= \frac{0.693}{130} \times 1 \times 10^{20} \times e^{-\frac{0.693}{130} \times 260}$

$= 5.33 \times 10^{17} \times 0.25$

or, $\frac{dN}{dt} = 1.33 \times 10^{17}$ dis/day

or, $-\frac{dN}{dt} = \frac{1.33 \times 10^{17}}{24 \times 60 \times 60}$ dis/sec

$\therefore \frac{dN}{dt} = 1.54 \times 10^{12}$ dis/sec

Hence, the required activity is 1.54×10^{12} dis/sec

Again, we have

$N = N_0 \times e^{-\lambda t} = 1 \times 10^{20} \times e^{-\frac{0.693}{130} \times 260} = 2.5 \times 10^{19}$

Hence, the required energy released $= (N_0 - N) \times E$

$= (1 \times 10^{20} - 2.5 \times 10^{19}) \times 8 \times 10^{-13} J = 6 \times 10^7 J$

61. 2056 Q.No. 16 **A radio-active source has decayed to one tenth of one percent of its initial activity in one hundred days. What is its half-life period?** **[4]**

Please refer to 2073 Supp Q.No. 10c

62. 2055 Q.No. 16 **If 4g of radio active material of half life period of 10 years disintegrates, find out mean life of the given sample.** **[4]**

Solution

Given,

Half life $(T_{1/2}) = 10$ years

Mean life (T) = ?

Now,

We know;

$T_{1/2} = \frac{0.693}{\lambda}$

or, $\lambda = \frac{0.693}{T_{1/2}} = \frac{0.693}{10} = 0.0693 \text{ yr}^{-1}$

Then, we have,

Mean life $(T) = \frac{1}{\lambda} = \frac{1}{0.0693} = 14.43$ years

Hence, the required mean life is 14.43 years.

63. 2053 Q.No. 16 OR **At certain instant a piece of radio active material contained 10^{12} atoms. The half life of the material is 15 days. Calculate the rate of decay after 30 days have elapsed.** **[4]**

Solution

Given,

Initial no. of atoms $(N_o) = 10^{12}$ atoms

Half life $(T_{1/2}) = 15$ days

Time (t) = 30 days

Now,

We know,

$N = N_0 e^{-\lambda t}$

$= N_0 e^{-\frac{0.693}{T_{1/2}} \times t} = 10^{12} e^{-\frac{0.693}{15} \times 30} = 10^{12} . e^{-0.693 \times 2}$

$\therefore N = 2.5 \times 10^{11}$ atoms

Again,

Rate of decay after 30 days is given by,

$\frac{dN}{dt} = \lambda N = \frac{0.693}{T_{1/2}} \times N = \frac{0.693}{15} \times 2.5 \times 10^{11} = 1.15 \times 10^{10}$ dis/sec

Hence, the required rate of decay is 1.15×10^{10} dis/sec

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Chapter 6: Nuclear and Other Sources of Energy

Short Answer Questions

1. 2076 Set B Q.No. 2e What do you mean by greenhouse effect? Write its effects. [2]

The house whose walls are made up of green glasses is called a green house. It allows entering the sun rays through it but does not allow escaping out of it. Thus a green house makes the radiation in its trap.

Earth is comparable to green house having walls of air. Solar radiations can enter into the atmosphere but can't escape out from the layer of green house gases. So the radiations are trapped in the earth due to which heating of earth surface takes place. Thus the heating up of earth's atmosphere due to trapped radiation is called green house effect. Main sources of green house effect are the various activities releasing green house gases and deforestation.

The effects of greenhouse effect are:

- Global warming
- Desertification
- Increased melting of snow and ice
- Sea level rise
- Stronger storms and extreme events
- Ocean Acidification
- Changes to plant growth and nutrition levels
- Smog and ozone pollution
- Ozone layer depletion

2. 2076 Set C Q.No. 2e What is acid rain? Write its any two effects. [2]

The rain that contains harmful chemicals like carbonic acid, sulphuric acid, nitric acid which damages trees, crops and buildings is called acid rain. The harmful gases like carbon dioxide, sulpher dioxide, nitric oxide coming from industries and other sources mix with water during the rain and the rain falls in the form of the acid which is called acid rain. Acid rain has adverse effect on different things on the earth which are given as:

- The acidity of water in ponds, lakes and seas increases due to which aquatic animals are affected.
- It reduces crop yield due to the increases of soil acidity.
- Acid rain corrodes building, bridges, monuments etc.
- Respiratory and skin diseases are caused.
- It causes bacterial diseases.

3. 2075 GIE Q.No. 2e 2072 Set D Q.No. 2f 2071 Set D Q.No. 2 f 2070 Set C Q.No. 2 e 2068 Can. Q.No. 2f What is acid rain? Explain. [2]

Please refer to 2076 Set C Q.No. 2e

4. 2075 Set A Q.No. 2f 2068 Q.No. 2 e If energy is conserved, why is there an energy crisis? [2]

The world population increases day by day. There is increasing demand of energy throughout the world due to over population growth. There has been an over exploitation of the non-renewable sources of energy. The non-renewable energy sources like coal, petroleum are being finished in their mines. Forests are being reduced and water sources are being dried. In this way the useful form of energy is converted to non-useful form of energy. If the energy consumption rate is being continued in the present rate, the world will face the energy crises even the energy be conserved.

5. 2075 Set B Q.No. 2c Define acid rain and write it's adverse effects. [2]

Please refer to 2076 Set C Q.No. 2e

6. 2074 Supp Q.No. 2e What do you mean by degradation of energy? Explain. [2]

Conservation of energy refers to reduce the use of excess energy. For this, some steps should be taken as: renewable sources of energy should be used in place of non-renewable source of energy, the population should be controlled, solar and electrical vehicles should be used, deforestation should be stopped, awareness about the importance of energy conservation should be created in people.

Degradation of energy refers to degrade or deplete or to be shortage of energy due to changing the energy from useful form to unuseful form. For example; conversion of fuel to heat energy. Now a days, energy is depleting due to various causes like over population growth and we have to conserve energy.

7. 2074 Supp Q.No. 2f Explain how acid rain in formed. [2]

Please refer to 2076 Set C Q.No. 2e

8. 2074 Set A Q.No. 2f 2074 Set B Q.No. 2f What is energy crisis? Explain. [2]

The shortage of essential energy of the earth is called "energy crisis." Due to this energy crisis, the human being has to face several difficulties & the development of society will be slowed down. Because of these reasons, an energy crisis has become an important issue of the world. In order to get rid of the problem of energy crisis, alternative sources of energy should be developed.

9. 2073 Supp Q.No. 2e 2067 Old Q.No. 1h 2065 Q.No. 1 h What do you mean by energy crisis? [2]

Please refer to 2074 Set A Q.No. 2f

10. 2072 Supp Q.No. 2e Which type of renewable energy is most useful to our country? Give reasons. [2]

Hydro-electricity is the best renewable useful energy to our country because of following reasons.

- Nepal is second richest country for water in the world.
- Nepal has large water resources which are capable to produce electricity. There are 600 small and large rivers which can produce 83000 MW electricity.
- Hydro-electricity is pollutionless.
- It can run large machinery.
- It is cheap.

11. 2072 Set C Q.No. 2f What do you mean by global warming? [2]

The concentration of the green house gases including carbon dioxide, carbon monoxide, sulpher dioxide is increasing significantly each year. The enormous human activities including industrialization and transportation are enhancing the production rate of green house gases. This increase in the concentration of green house gases results in the increase in temperature on the surface of the earth trapping more and more infrared radiations. These radiations increase the temperature of the earth. This increase in the temperature on the surface of the earth is called global warming.

12. 2071 Set C Q.No. 2 e Write the meaning of conservation of energy and degradation of energy. [2]

Please refer to 2074 Supp Q.No. 2e

13. 2071 Set C Q.No. 2 f 2070 Set D Q.No. 2 e What is global warming? Explain. [2]

Please refer to 2072 Set C Q.No. 2f

14. 2069 (Set B) Q.No. 2e What is global warming? Give two examples of its effect. [2]

Please refer to 2072 Set C Q.No. 2f

Two effects of global warming are:

i. It affects seasonal crops.
ii. Melting of polar ice.

15. 2069 (Set A) Old Q.No. 1g Name some of major air pollutants. [2]

The major air pollutants are:

i. Smoke coming from old vehicles.
ii. Dust particles from stone crusher industry.
iii. Bad smell coming from garbage.

16. 2068 Old Can. Q.No. 1h State the two main effects on the earth due to ozone depletion? [2]

The main effects on the earth due to ozone depletion are given below:

The most harmful ultraviolet rays of sun reaches to the earth and causes skin cancer as well as eye etching of human.

The ultraviolet rays cause mutation and damage the ecosystem.

17. 2068 Old Can. Q.No. 2h What are the main energy sources in Nepal? [2]

The main energy sources of Nepal are given: Biomass, firewood, hydropower, wind power, fossil fuels etc.

18. 2068 Old Q.No. 2 g **Explain what are solar flares.** [2]

A brief eruption of intense high-energy radiation from the sun's surface, associated with sunspots and causing radio and magnetic disturbances on the earth is called solar flares. Powerful flares are often, but not always, accompanied by a coronal mass ejection. Even the most powerful flares are barely detectable in the total solar irradiance. Solar flares can temporarily alter the upper atmosphere creating disruptions with signal transmission from, say, a GPS satellite to Earth causing it to be off by many yards. Another phenomenon produced by the sun could be even more disruptive. Known as a coronal mass ejection or CME these solar explosions propel bursts of particles and electromagnetic fluctuations into Earth's atmosphere. Those fluctuations could induce electric fluctuations at ground level that could blow out transformers in power grids.

19. 2068 Old Q.No. 2 h **Mention the major sources of Noise Pollution.** [2]

Any unwanted sound, which produces displeasing effect in our ear, is called the noise. The adverse effect of noise in living & working environment is called noise pollution. The main sources of noise pollution are means of transportation, manufacturing industries, Construction activities, Social noises and military activities.

20. 2067 Q.No. 2f **What is global warming?**

Please refer to 2072 Set C Q.No. 2f

21. 2066 Supp Q.No. 2h **What do you mean by radiation hazard?** [2]

The nuclear radiations such as α- rays, β -rays, γ- rays, neutrons, x- rays can cause harm to the living beings by ionizing complex organic molecules, the danger of our exposure to these radiations is called *radiation hazard*. The radiation damage produced in biological organisms is due to ionization produces in life cells. The main damage to the genetic material, DNA is particularly serious one since it can damage not only the individual but also future generations as well.

22. 2065 Q.No. 2 h 2064 Q.No. 2 h **What do you understand by green house effect?** [2]

Please refer to 2076 Set B Q.No. 2e

23. 2063 Q.No. 1 h **What is radiation hazard?** [2]

Please refer to 2066 Supp Q.No. 2h

24. 2063 Q.No. 2 e **Which bomb is more explosive, hydrogen bomb or atom bomb?** [2]

Hydrogen bomb is more explosive than atom bomb because hydrogen bomb is based under the principle of nuclear fusion while atom bomb is based on nuclear fission reaction. It is noted that energy released per nucleus during nuclear fission is 0.9 MeV and that during in nuclear fusion is 5.96 MeV.

25. 2063 Q.No. 2 f **What is the source of energy of sun?** [2]

The source of solar energy is thermo-nuclear fusion reaction. In nuclear fusion reaction, lighter nuclei fuse to form heavy nuclei along with release of tremendous amount of energy. The nuclear reaction takes place in the sun is as $4\,({}_1H^1) \rightarrow {}_2He^4 + 2\,{}_1e^0 + 26.7$ MeV

Since there is a huge amount of Hydrogen present in sun, large numbers of such nuclear reactions take place. As a result sun can emit light & heat energy.

26. 2062 Q.No. 1 h **What is Ozone depletion?** [2]

When the gases like CFCs, Co, oxides of nitrogen, etc. reach into the stratosphere of earth's atmosphere, they are decomposed by ultraviolet radiation and form chlorine. This chlorine helps to decompose ozone and hence the amount of ozone is drastically reduced there. This is called ozone depletion.

27. 2062 Q.No. 10 OR **Discuss energy crisis in a modern society.** [2]

Please refer to 2074 Set A Q.No. 2f

28. 2060 Q.No. 2 h **What is water pollution?** [2]

Contamination of water by foreign matter such as microorganisms, chemicals, industrial or other wastes which deteriorates the quality of the waste and renders it unfit for its intended use is called water pollution. The major pollutants of water are Oxygen demanding wastes, water soluble inorganic chemicals such as acids, salts, heavy metals etc. The water pollution can be minimized by awareness of water pollution should be brought in people.

29. 2059 Q.No. 1 h **What is noise pollution?** [2]

Any unwanted sound, which produces displeasing effect in our ear, is called the noise. The adverse effect of noise in living & working environment is called noise pollution. The main sources of noise pollution are means of transportation, manufacturing industries, Construction activities, Social noises and military activities.

Noise pollution can be controlled by running loudspeaker, radio and other music system at low volume and by using silencers with the automobiles and machines in the industries.

30. 2059 Q.No. 2 h **Why is solar energy more preferable than fossil-fuel energy? Explain.** [2]

The energy obtained from the sun is called solar energy. It is the main source of energy of the world. Solar energy is the everlasting source of energy. It can never be ended up by continuous use. But fossil fuel energy will end up in future due to its continuous use. Using solar energy, there will not be any kind of pollution but use of fossil-fuel energy can lead to several types of pollutions such as air pollution, water pollution, etc. Also, solar energy can be used in different ways more conveniently than fossil fuel energy. Solar energy can be easily used in vehicles, factories, generating emf, heating and cooking and many more important works.

Hence, solar energy is more preferable than fossil-fuel energy.

31. 2058 Q.No. 1 h **What is ozone-hole?** [2]

The region in the ozone layer where there is deficiency of ozone is called ozone hole. Ozone hole is made by the depletion of ozone in the stratosphere through which the uv rays can directly enter the earth causing harmful effects. It is estimated that 5% reduction of ozone in the ozone layer could result in nearly 10 % increase in the skin cancer on the earth. When chlorofloro carbons (CFCs) reach the stratosphere, it destroys ozone.

32. 2057 Q.No. 1 g **What are renewable sources of energy?** [2]

The sources of energy which can be reproduced in short time & can be used continuously for long time are called renewable sources of energy .For example, bio-mass energy, hydro-energy, nuclear energy, solar energy, wind energy, tidal energy, geothermal energy, etc are major sources of renewable sources of energy. Scientists are making several researches to develop the cheapest & the most convenient alternative sources of energy.

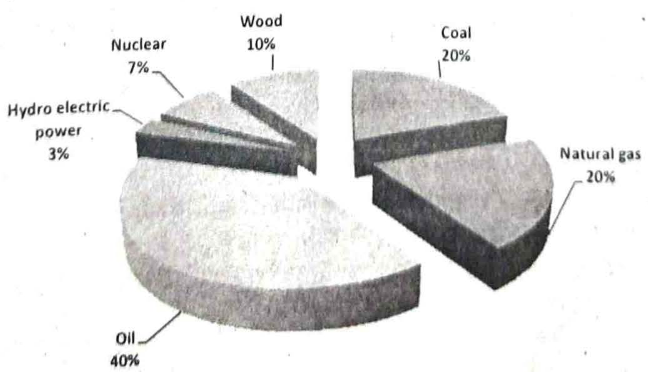
Long Answer Questions

33. 2076 Set B Q.No. 6d **What are sources of energy? Discuss global energy consumption pattern and demands.** [4]

The major energy sources are coal, biomass, nuclear energy, hydro- power, mineral oil, natural gas etc.

Global Energy Consumption Pattern and Demands

Amount of energy consumed by a country depends on the living standard of its citizens and the degree of its industrialization. The average energy required for a man to maintain his daily activities require about 20 k cal per day. This energy is supplied by food he/she eats. In addition, man uses more energy for capital per day is about 2000 times the 20 k calorie he needs for maintaining life.



The main energy sources being used by us are: coal, biomass, nuclear energy, hydro- power, mineral oil, natural gas etc. At present, about 40 % of the demand for energy in the world is obtained from oils. Similarly, about 20 % of the total energy consumptions provided by coal, about 20 % by natural gas, wood 10 %, nuclear fission 7 % and hydroelectric power 3%. Other energy required by the world is fulfilled by other energy sources like solar energy, tidal energy, wind energy etc. Given figure shows a clear picture of the world's present energy consumption.

34. 2076 Set C Q.No. 6d **What are the major energy sources? Discuss the global energy consumption pattern and demands.** **[4]**

Please refer to 2076 Set B Q No. 6d

35. 2075 GIE Q.No. 6d **What are the major energy sources in Nepal? Suggest some measures to reduce energy crisis in the future.** **[4]**

Energy sources of Nepal

The consumption of energy is increasing in Nepal every year. The population growth accompanied by rapid expansion of economic activities is the main cause responsible for the increasing of the consumption of energy. However, the consumption of alterative energy sources is very negligible. The following are the major sources of energy in Nepal.

a. **Fuel wood:** Fuel wood is the major source of energy in Nepal. That is, it is vital source of energy and serves the larger population than any other source of energy does. It is reported that fuel wood consumed in household cooking purposes represents 97% for all rural areas and 75% for all the country as a whole.

b. **Bio-mass energy:** Bio-mass energy such as animal waste, agricultural residue is also become a major source of energy. Recently, government of Nepal has been given high priority to biogas programs and has purposed to construct 2000 plants in various sectors of the country.

c. **Hydro-energy:** Hydroelectric Energy is the most potential sources of energy in Nepal. However, it has not been used sufficiently yet. At present time, the use of hydropower energy has increased drastically. In the world's list, Nepal is rich in hydropower next to Brazil. Out of total population only about 20% people has been facilitated by hydroelectric power.

d. **Solar Energy:** It is a new type of energy, which has been recently introduced in Nepal. But its use is limited to heating water. It is also used to generate electricity on a small scale for telecommunication purpose and domestic purposes in some villages of the county. Even though the potentiality of solar power in Nepal is quite enormous, due to the lack of technological knowledge, only small amount of solar energy has been installed.

e. **Coal:** Coal is considered as a major source of industrial energy. In average, 1,60,000 tons of coal is consumed per year in Nepal. Being a mountainous country, Nepal has been supposed to be fairly rich in coal resources, but it actually has not seen to be so.

f. **Petroleum oil and natural gases:** Petroleum products such as petrol, diesel, kerosene, natural gases are the other major sources of the energy in Nepal. The petroleum products cover about 3.5% of the total energy consumption.

g. **Wind energy:** Wind Energy can be used as a source of energy for operating windmills. Terai and some of the interior locations such as Palpa, Ramechhap, Karnali, Chishapani, Jumla and Namche are identified for providing wind energy. Electricity is being generated from wind power in Kagbeni of Mustang district.

Among the principal sources of energy, hydro energy is the only alternative source of energy available abundantly in Nepal.

Energy Crisis in Modern Society: The shortage of essential energy of the earth is called "energy crisis." Due to this energy crisis, the human being has to face several difficulties & the development of society will be slowed down. Because of these reasons, an energy crisis has become an important issue of the world. In order to get rid of the problem of energy crisis, alternative sources of energy should be developed.

Now-a-days, the development of a nation is measured in terms of production, investment and conservation of energy. In our villages, fuel wood, crop waste and animal dung are still used as sources of energy for cooking, heating and lighting. The sources of energy, which are exhaustible and cannot be replaced in the nature quickly when exhausted, are called non-renewable sources of energy. Fossil fuels and nuclear energy are examples. It has been estimated that fossil fuels will last not more than 200 years at the present rate of consumptions. Similarly, it is estimated that nuclear materials (uranium and thorium) will last at least for 100 years at the present rate of consumption. That's why, we should conserve energy to avert the energy crisis.

36. 2074 Set A Q.No. 6d **Explain renewable and non-renewable source of energy with examples. Give an account of the energy consumption scenario in Nepal.** **[4]**

Renewable and Non renewable sources of energy:

The sources of energy which can be reproduced in short time & can be used continuously for long time are called renewable sources of energy. For example, bio-mass energy, hydro-energy, nuclear energy, solar energy, wind energy, tidal energy, geothermal energy, etc are major sources of renewable sources of energy. Scientists are making several researches to develop the cheapest & most convenient alternative sources of energy.

The sources of energy which can't be reproduced in short time & can't be used continuously for long time are called non-renewable sources of energy. These energy sources are finished after exhausted. For example, fuel energy, coal energy, firewood, petrol energy etc are major sources of non-renewable sources of energy.

Energy consumption scenario in Nepal

The use of energy is increasing in Nepal every year. The development efforts and rapid development of living standards demand ever increasing use of energy. However, the conventional energy sources which are non-renewable sources are limited. In Nepal, existing energy sources are classified into two categories: conventional and alternative energy sources. Nepal is not industrially developed country. So, the biomass energy source such as burning of wood, agriculture products and animal waste products are the most important source of energy in Nepal. Petroleum products such as petrol, diesel, kerosene etc are the other energy sources used in Nepal. Another major source of energy in Nepal is hydropower. According to the Energy Systems Planning and Analysis Center for Energy Studies, IOE/TU, the major energy consumption pattern in 2015 is given below:

Energy consumption scenario in Nepal in 2015

Types of Energy Source	Consumption %
Biomass	78
Electricity	3
Coal	4
Petroleum products	12
Modern renewable energy	3
Total	100

The above tabled shows that the most used energy source is biomass such as firewood, animal dung, methane gas, agriculture products and second most used energy source is petroleum products.

37. 2074 Set B Q.No. 6d **What is green house effect? Discuss its effects, sources and the controlling measures. [4]**

The house whose walls are made up of green glasses is called a green house. It allows entering the sun rays through it but does not allow escaping out of it. Thus, a green house makes the radiation in its trap.

Earth is comparable to green house having walls of air. Solar radiations can enter into the atmosphere but can't escape out from the layer of green house gases. So, the radiations are trapped in the earth due to which heating of earth surface takes place. Thus, the heating up of earth's atmosphere due to trapped radiation is called green house effect. Main sources of green house effect are the various activities releasing green house gases and deforestation

Effects of Green House Effects

- Global warming
- Desertification
- Increased melting of snow and ice
- Sea level rise
- Stronger storms and extreme events
- Ocean Acidification
- Changes to plant growth and nutrition levels
- Smog and ozone pollution
- Ozone layer depletion

Sources of Greenhouse Gases

- Carbondioxide(CO_2) and carbonmonoxide(CO) coming from the running vehicle, industries, burning of gases, petroleum and firewood
- Methane gas(CH_4) coming from the animal dung
- Low level ozone gas can be produced from chemical reaction between car exhaust pollutants like CO and NO
- Halogenated carbon like CCl_4 and CFCs gases
- Nitrous Oxide (NO_2) from soil.

Solutions of Greenhouse Gases

- Reduce, reuse, recycle
- Use less heat and air conditioning
- Replace your light bulbs
- Drive less and drive smart
- Buy energy-efficient products
- Use less hot water
- Use the "Off" switch
- Plant a tree
- Use alternative use of energy
- encourage Others to Conserve

38. 2072 Supp Q.No. 6a **What are the environmental implications of the following energy sources: (i) fossil fuels and (ii) nuclear fuels?** **[4]**

Environmental implications of fossils fuels and nuclear fuels are:

i. **Fossil fuels:** Fossil fuels were formed from the fossilized remains of plants and animals. They are used in industries like iron and steel. Coal is used in railway engines. Mineral oils like petrol, diesel, and kerosene are used in transportation, lighting etc. The fossil fuel has following effect in the environment.

a. Environmental pollution is the major disadvantages of fossil fuels. It is a known fact that CO_2, gas released when fossils are burnt in one of primary gas responsible for global warming.

b. Middle east countries have huge reserve of oil and gas and many other countries are fully dependent on them. This leads increasing marketing price.

c. SO_2 is one of pollutant that is released when fossil fuels are burnt and is a main cause of acid rain.

d. It directly as well as indirectly affects human health.

ii. **Nuclear fuels:** the splitting up of a heavy nucleus into two or more nuclei of nearly equal or comparable masses with liberation of energy is called nuclear fission. From nuclear fission large amount of heat and light energy is produced. Uranium is the source of nuclear energy. The nuclear fuels has following advantages as well as disadvantages on environment.

Advantages:

- Nuclear power plant could produce more electricity after coal and oil become scarce.
- Nuclear power plant needs less fuel than one which burns fossil fuels.
- They do not produce environmental pollution.

Disadvantages:

- Nuclear explosions produce radiation like γ- rays, α- rays, β -rays, neutrons, x- rays. The nuclear radiations harm the cells of the body which can make people sick or even kill.
- Incase of an accident, the fission reaction goes out of control, leading to a nuclear explosion and emission of great amount of radiation.
- Nuclear reactors only last for about forty to fifty years.

39. 2072 Set C Q.No. 6d **What are renewable and non renewable sources of energy? Write with examples. Describe the necessity of conservation of natural resources of energy to reduce energy crisis in the future. [4]**

Renewable and Non renewable sources of energy: Please refer to 2074 Set A Q.No. 6d

Energy Crisis in Modern Society: Please refer to 2075 GIE Q.No. 6d

40. 2070 Set C Q.No. 6 d **What are the major energy sources? Discuss the global energy consumption pattern. [4]**

Please refer to 2076 Set B Q.No. 6d

41. 2068 Can. Q.No. 6d **What are major energy sources? Give a brief account on the global energy consumption pattern and demands.** **[4]**

Please refer to 2076 Set B Q.No. 6d

42. 2068 Old Can. Q.No. 10 **What is air pollution? Discuss the adverse effects of it on the human beings. Write some measures to control it.** **[4]**

Air pollution: Air pollution is the contamination of the atmosphere by gaseous, liquid or solid wastes than can endanger human health and the health & welfare of plants& animals or can attack materials, reduce visibility, or produce undesirable odor.

Type of pollutants:

Air is said to be polluted when solid& harmful substances are accumulated in the atmosphere and such harmful substances are called air pollutants. There are two major types of pollutants:

a. **Gaseous pollutant:** These pollutants are in gaseous state like carbon monoxide, carbon dioxide, nitrogen dioxide, surplus dioxide etc.
b. **Particulate Pollutant:** These pollutants are on solid or liquid state like dust particle aerosols & fumes etc

Sources of air pollution:

a. **Industrial pollution:** Industries like cement industries, chemical industries, fertilizer factories, bricks factories, etc contribute a lot to air pollution.
b. **Vehicular emission:** The emission from motor vehicles is a major source of air pollution in urban areas.
c. **Burning of solid fuel:** Burning of fuel like firewood, agricultural residues, coal etc for domestic & industrial purpose s also contribute to the air pollution.

Control of air pollution:

Following measures can be used to control air pollution:

a. Industries should be established far from the settlement areas.
b. There should be proper chimneys in factories & mills. If possible dust & smoke controller should be used.
c. Two stroke engines are to be replaced by four stroke engines.
d. The use of fossil fuels, firewood & coke should be minimized.
e. Affareotration should be encouraged. Plants can be used for removing some pollutants.
f. Alternative sources of energy should be used in vehicles& also in industries in place of combustible fuels e.g. solar power, wind power, electric power etc.
g. Population growth is the main cause of all types of pollutant. We should check the population growth rate
h. Nuclear testing & explosion should be avoided.

Effects of air pollution:

The following are the major effects of air pollution:

a. Increasing CO_2 concentration causes global warming due to green house effect.
b. Increase of Chloroforo carbon (CFC) & nitrogen oxide causes ozone depletion & ozone hole.
c. The oxides of sulphur & nitrogen in air combine with water vapor & cause acid rain.
d. Particulate matters usually absorb sunlight as a result road & air accidents may increases.
e. Carbon monoxide combines with haemoglobin of blood reducing oxygen carrying capacity of blood. It causes laziness, exhaustion, nervousness, cardiac disorders, vision effect etc.
f. Oxides of nitrogen cause eye initiation & pulmonary troubles in human beings.
g. Dust irritation & smoke cause initiation in respiratory system. It also may cause asthma, bronchitis, and allergies in human beings.

43. 2068 Old Can. Q.No. 10 OR **Discuss the role of physics in the development of a nation.** **[4]**

Role of Physics for Development of Nation

In the eighteenth century, the hydro energy brought about a revolution in water transport in Britain, which helped it to establish itself as one of the world. So we see that every fact required for the development of a nation is based in the law of physics. Physics and society are complementary to each other.

Hoping for the development of a nation without physics is like crying for the moon. Knowledge of physics increases the efficiency & confidence in a physical world, study of physics makes the

individual of a nation more realistic & thus, they contribute much to the nation's social & infrastructure development. So a noble laureate (famous) has rightly said, "If you want to develop your nation you must give more priority to the study of physics."
It has been clear that physics is very important for development of a society & hence for the development of a nation. The following are the importance of physics for the development of a nation (like Nepal):

a. In physics, we study the laws of nature. Knowing the laws of nature, our society can understand how to live in harmony with nature.
b. The study of environmental physics creates awareness in people towards the importance of healthy environment.
c. All technologies, which have been facilitating our societies, are basically developed on the basis of laws of physics.
d. Being fundamental science, physics is used in other disciplines of science.
e. Searching new technology for the development of the societies is possible only by studying physics.
f. The knowledge of physics increases the efficiency & the confidence in a physical work.
g. Studying physics makes the individuals of a society more realistic.
h. Searching study of extraterrestrial bodies have been made possible for us by the study of physics.

Please refer to 2068 Old Can. Q.No. 10 OR

44. 2067 Old Q.No. 10 **Discuss the importance of physics for the development of nation.** **[4]**

Please refer to 2068 Old Can. Q.No. 10 OR

45. 2067 Old Q.No. 10 OR **What is ozone hole? Mention the causes and effects of depletion of ozone layer.** **[1+3]**

The ozone (O_3) is a pale blue gas formed in the stratosphere. Ozone always has tendency to convert back into oxygen. It is an allotropic form of oxygen present in the atmosphere. Due to the absorption of certain radiation from the sun, O_2 molecules dissociates into the nascent oxygen to make ozone (O_3)

O_2 + h f (radiation) $\rightarrow$ [O] + [O]

O_2 + [O] $\rightarrow$ O_3

Ozone hole: The region in the ozone layer where there is deficiency of ozone is called ***ozone hole***. Ozone layer is the thicker concentration of ozone found in the lower stratosphere between the altitude 30 km to 50 km. A complete ozone layer stops most of the sun's ultraviolet (uv) radiation as well as radiations of wavelengths less then 3×10^{-7} m. If the uv rays are not absorbed by the ozone layer, the existence of life on the earth would be impossible.

Ozone hole is made by the depletion of ozone in the stratosphere through which the uv rays can directly enter the earth causing harmful effects. It is estimated that 5% reduction of ozone in the ozone layer could result in nearly 10% increase in the skin cancer on the earth. When chlorofloro carbons (CFCs) reach the stratosphere, it destroys ozone according to the following reaction:

CF_2Cl_2 + hf (uv- radiation) $\rightarrow$ CF_2 Cl + Cl,

Cl + O_3 $\rightarrow$ ClO + O_2

2ClO $\rightarrow$ Cl_2 + O_2

This chain reaction occurs rapidly & destroys the ozone. One CFCs destroys more than one lakh ozone in the stratosphere during its life time.

When the ozone in the certain areas of an ozone layer is converted into the oxygen due to the effect of CFCs, ozone hole is formed in that area of the ozone layer.

Effects of the ozone depletion: The depleted ozone layer cannot absorb the UV radiation from the sun. Therefore, UV rays easily penetrate to the surface of the earth causing many harmful effects.

a. The UV rays bring cataract on the eyes. It can ultimately lead to blindness.
b. The UV rays can cause skin cancer.
c. The UV rays damage the DNA & bring generation alternation.
d. The UV rays reduce the rate of photosynthesis of plants & bring downfall in the crop yields.
e. The UV rays damage the phytoplankton of water ecosystem & affect the food chain of marine life.

46. 2066 Supp Q.No. 10 **What is ozone hole? Discuss the impacts of ozone depletion on living beings.** **[4]**

Please refer to 2067 Old Q.No. 10 OR.

47. 2066 Supp Q.No. 10 Or **Write an essay on the role of physics in the development of nation.** **[4]**

Please refer to 2068 Old Can. Q.No. 10 OR

48. 2064 Q.No. 10 **What is water pollution? Discuss its adverse effects and give some measures to control it.** **[4]**

Water Pollution: Water is the important constituent of life support system. No one can live and even dream to live without water. When contaminated bodies are mixed into water, it becomes polluted. Most of our water bodies have become polluted due to industrial growth; urbanization and man-made problems mainly the result of population growth. Poor sanitation and contaminated drinking water arising from human activity and natural phenomena create serious problems in human health. The chief sources of water pollution are sewage and other waste, industrial effluents, agricultural discharges and industrial wastes from chemical industries, fossils fuel plants and nuclear power plants. They create a larger problem of water pollution rendering water no longer fit for drinking, agriculture and, as well as for aquatic life. As a result thousands of children die everyday from diarrhoea and other water, sanitation and hygiene related diseases and many suffer and are weakened by illness.

Cause of Water Pollution;

Surface water in the Kathmandu Valley is severely polluted by industrial effluence, domestic waste, and by the discharge of untreated sewage from residential areas.

i. **Domestic pollution:** Important source of water pollution is domestic sewage system, which pollutes well and rivers, which are important source of drinking water. It is estimated that Kathmandu produces 150 tons of waste each day, nearly half of which is dumped into the river. More than 40 million liters a day of wastewater is generated in Kathmandu and a whopping over 80 percent of this is generated by households.

ii. **Industrial pollution:** Sewage is not the only cause of water pollution; industrial waste is also a significant polluter - giving rise to contamination with heavy metals. A recent research conducted by the Community Development Organization has concluded that the chemicals discharged by the factories are more harmful than the sewerage that flows into the river9. Out of the 4,271 industrial establishments around the country, 72 percent are concentrated in the capital city. Most of them discharge untreated water into the river. The effluent discharged by the factories contains detergents, non-biodegradable materials and toxic chemicals hazardous to health and hygiene.

iii. **River state:** The poor water quality of the river has numerous detrimental effects from the ecological, social, cultural and health aspects. Domestic sewage, industrial effluents and agricultural residues and chemicals are the most significant wastes causing urban rivers pollution in Kathmandu valley. All kinds of pollutants are discharged without pre-treatment directly through the public sewerage system or indirectly through runoff and open drainage into rivers.

Consequences on health: Poor sanitation and contaminated drinking water are two of the most common environmental hazards in many countries of the world. Inadequate water, sanitation and hygiene account for a large part of the burden of illness and death in developing countries. Lack of clean water and sanitation is the second most important risk factor in terms of the global burden of disease, after malnutrition. There are many reports on the impact of waterborne diseases in countries worldwide revealing thousands of outbreaks due to bacterial, viral, and parasitic micro-organisms associated with the consumption of untreated or improperly treated drinking waste. An important fraction of the burden of water-related diseases, in particular: water-related vector-borne diseases, is attributable to the way water resources are developed and managed. In many parts of the world the adverse health impacts of dam construction, irrigation development and flood control may lead to in an increased incidence of malaria, Japanese encephalitis, schistosomiasis, lymphatic filariasis. Water polluted by source of inorganic substances like mercury, lead, arsenic etc. much harmful to the health. Aquatic lives also affected by the water pollution.

How to solve the problem: Water pollution is the most serious environmental quality issues in Nepal. It is caused by the disposal of solid and liquid wastes on land and surface water. The most significant waste is sewage, industrial effluent and agricultural residues and chemicals. Research findings on the relative public health importance of providing safe drinking water supplies, sanitation and hygiene education may seem counter intuitive. Improved hygiene and sanitation have more impact than drinking water quality on health outcomes, specifically reductions in diarrhoea, parasitic infections, morbidity and mortality, and increases in child growth. Solid waste is also an aesthetic or visual pollutant. There is no systematic management of solid waste in industrial districts.

The municipalities are helping a lot in solving the problem of solid wastes but the services are not as effective as expected. There are numerous technical options for excreta management, many of which, if properly designed, constructed, operated and maintained will provide adequate and safe service as well as health benefits.

49. 2064 Q.No. 10 OR Write an essay on the role of physics in the development of a developing country like Nepal. [4]

Please refer to 2068 Old Can. Q.No. 10 OR

50. 2063 Q.No. 10 What are the roles of physics in the development of nation? [4]

Please refer to 2068 Old Can. Q.No. 10 OR

51. 2063 Q.No. 10 OR Describe the present sources of energy being used in our country. [4]

Please refer to 2065 GIE Q.No. 6d

52. 2062 Q.No. 10 What is a ozone layer? Describe the effects of ozone depletion on the plants and animal life on earth. What steps should we take to avoid ozone depletion in our atmosphere? [4]

Please refer to 2067 Old Q.No. 10 OR

53. 2061 Q.No. 10 What are the causes of air pollution? Mention its effects and ways to minimize it. [4]

Please refer to 2068 Old Can. Q.No. 10

54. 2061 Q.No. 10 OR Write an essay on major sources of energy in Nepal. [4]

Please refer to 2075 GIE Q.No. 6d

55. 2060 Q.No. 10 Give a brief account on "Energy sources of Nepal". [4]

Please refer to 2075 GIE Q.No. 6d

56. 2060 Q.No. 10 OR What is air pollution? Discuss major sources of air pollution and suggest some ways of controlling it. [1+2+1]

Please refer to 2068 Old Can. Q.No. 10

57. 2059 Q.No. 10 What do you mean by ozone-hole? What various agents are responsible for ozone layer depletion in the stratosphere? What measures should we take to stop the depletion of ozone layer? [1+2+1]

Please refer to 2067 Old Q.No. 10 OR

58. 2059 Q.No. 10 OR What is renewable source of energy? Nepal is rich in hydro power next to Brazil. Comment on it. [1+3]

Please refer to 2075 GIE Q.No. 6d

59. 2058 Q.No. 10 What is water pollution? What degree of water pollution do you think exists in Kathmandu valley? [4]

Please refer to 2064 Q.No. 10

60. 2058 Q.No. 10 OR What do you mean by radiation hazard? What are its safety measures? [4]

The nuclear radiations such as γ- rays, α- rays, β -rays, neutrons, x- rays can cause harm to the living beings by ionizing complex organic molecules, the danger of exposure to these radiations is called radiation hazards. Moreover, the presence of radiations on an environment is called the radiation pollutions. The main pollutants of radiation are:

a. The radioactive elements such as uranium, radium etc.

b. The cosmic rays.

Effects:

The radiation damage produced in biological organisms is primarily due to ionization produces in life cells. The main damage to the genetic material, DNA is particularly serious one since it can damage not only the individual but also future generations as well. The possible damages are:

a. Over exposure to radiation can cause lung cancer.

b. Radiation can cause genetic damage by dividing the reproductive cells.

c. The exposure to radiation can cause blindness.

d. The exposure to radiation may cause start of leukemia (death of RBC in the blood).

e. The radiation can cause skin burn & can ultimately lead to skin cancer.

Safety:

The following safety precautions should be taken while using radioactive source:

a. Radioactive sources must be handled with the help of remote control devices.
b. Radioactive source should be placed in thick walled lead containers so that the lead may absorb the radiations.
c. The worker must wear a lead apron while working in the hazardous areas.
d. The radioactive waste must be avoided from the working areas.
e. Nuclear explosion should be carried far away from the public areas.

61. 2057 Q.No. 10 **What is the role of physics in the development of a nation?** **[4]**

✎ Please refer to 2068 Old Can. Q.No. 10 OR

62. 2057 Q.No. 10 OR **What is ozone hole? Discuss the impacts of ozone depletion on living things.** **[4]**

✎ Please refer to 2067 Old Q.No. 10 OR

❑❑❑

Check Your Understanding An electron is not defected in passing through a certain region of space. Can we be sure that there is no magnetic field in the region?

Sol^n: We cannot be sure about the absence of magnetic field because if the electron moves parallel or anti parallel to the magnetic field, it will not experience any force and obviously will not be deflected.

Sample Problem 15.1 A test charge of 1.6×10^{-29}C is moving with a velocity of $V = (2\hat{i} + 3\hat{j})\text{ms}^{-1}$ in a magnetic field. $\vec{B} = (3\hat{i} + 4\hat{j})\text{wbm}^{-2}$. Find the force acting on the test charge.

Sol^n: $v = (2\hat{i} + 3\hat{j})$ and $B = (3\hat{i} + 4\hat{j})$

Now, $F = q(\vec{V} \times \vec{B})$

$= q(2\hat{i} + 3\hat{j}) \times (3\hat{i} + 4\hat{j})$

$= q(8\hat{k} - 9\hat{k})$

$F = q(-\hat{k})$

$= -1.6 \times 10^{-19}\,\hat{k}$

$\therefore$ Force acting on the test charge is 1.6×10^{-19} N along negative z-axis.

15.5 Magnetic Force on a Current-Carrying Conductor

A conductor possesses a large number of free electrons. These free electrons are drifted along the conductor when electric field is applied across it. Hence if a current carrying conductor is placed in a magnetic field, each of the drifting electrons experiences a Lorentz force. Sum of all Lorentz forces is equal to force experienced by current carrying conductor in a magnetic field.

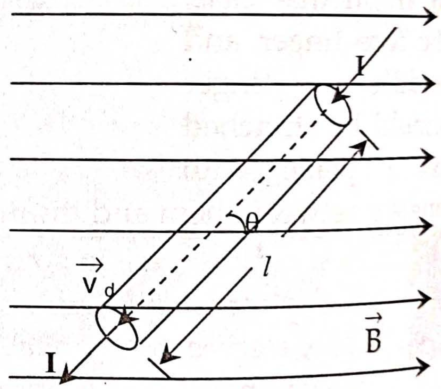


Fig-15.9: Force on a conductor in magnetic field

Let us consider a straight conductor of length l carrying current I, placed in a magnetic field $\vec{B}$ making an angle θ with the direction of $\vec{B}$ as shown in Fig-15.9. Let 'n' be the number of free electrons per unit volume (free electron density) in the conductor. If 'v_d' be drift velocity of electron in the conductor, then, force on each electron known as Lorentz force,

$$\vec{F_e} = e(\vec{v_d} \times \vec{B})$$

Total number of free electrons in the conductor N = n × volume of the conductor

= nAl {Al = volume of the conductor}

Where A = area of cross-section of the conductor

Total force acting on the conductor, $\vec{F} = N\vec{F_e} = nAle(\vec{v_d} \times \vec{B})$

Magnitude of total force, $F = (nAle)\, v_d B \sin\theta = (nAev_d)\,(l B \sin\theta) = I\,l\,B \sin\theta$

Since $nAev_d = (ne)Av_d = I$

$$\therefore \quad F = BIl \sin\theta \qquad (15.4)$$

vector form, above relation can be written as,

$$\vec{F} = I\left(\vec{l} \times \vec{B}\right) \qquad (15.5)$$

Direction of force is perpendicular to the plane containing $\vec{l}$ and $\vec{B}$ and may be given by Fleming's left hand rule.

Special Cases:

i. When $\theta = 0°$ or $180°$, $\sin\theta = 0$ so that $F = 0$ N

This means if a current carrying conductor is placed parallel or antiparallel to the magnetic field, no force is experienced by it.

ii. When $\theta = 90°$, $\sin\theta = 1$ so that $F = BIl$ = max. value of force

This means a current carrying conductor if placed perpendicular to the magnetic field, maximum force is experienced by it.

Check Your Understanding **Why does a force act on a conductor in a magnetic field only when a current flows through it and not earlier , even though there are large no. of free electrons?**

Sol^n: When flow of current in a conductor is zero, the motion of electrons produce no net displacement due to which no force is experienced by them.

Sample Problem 15.2 **A vertical straight conductor X of length 0.5 m is situated in a uniform horizontal magnetic field of 0.1 T. (i) Calculate the force on X when a current of 4A is passed into it. (ii) Through what angle must X be turned in a vertical plane so that the force on X is halved?**

Sol^n:

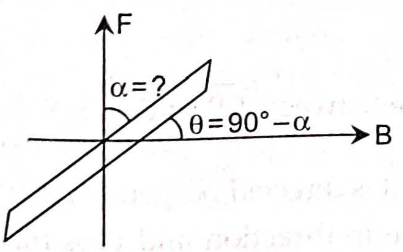
(i) Given,

L = 0.5 m,

B = 0.1 T,

I = 4A, $\theta = 90°$

F = ?



$F = BIL \sin\theta$

$= 0.1 \times 4 \times 0.5 \times 1 = \mathbf{0.2\ N}$

(ii) Let α be the required angle, The force on the conductor

$$F' = \frac{1}{2} F = \frac{0.2}{2} = 0.1 \text{ N}$$

$$F' = BIL \sin\theta$$

or, $\frac{1}{2} BIL = BIL \sin(90° - \alpha)$

or, $\frac{1}{2} = \cos\alpha$

or, $\alpha = \cos^{-1}\left(\frac{1}{2}\right) = \mathbf{60°}$

Sample Problem 15.3 The plane of a 5cm × 8cm rectangular loop of wire is parallel to a 0.19T magnetic field. The loop carries a current of 6.2A (a) What torque acts (b) what is the maximum torque that can be obtained with the same total length of wire carrying the same current in this magnetic field?

Sol^n : Given,

$A = 5cm \times 8\ cm$

$A = 40 \times 10^{-4}\ m^2$

$B = 0.19T$

$\theta = 0°$

$I = 6.2\ A$

(a) Torque acting (τ) = ?

$\tau = BIA \cos\theta$

$\tau = 0.19 \times 6.2 \times 40 \times 10^{-4} \cos 0°$

$\therefore \tau = 4.7 \times 10^{-3}$ Nm

(b) Maximum torque (τ_{max}) = ?

Torque will be maximum, when angle between the plane of the coil and field is zero. So,

Maximum torque (τ_{max}) = BIA Cos0°

$= 4.7 \times 10^{-3}$ Nm

15.7 Moving Coil Galvanometer

The moving coil galvanometer was introduced first of all by Kelvin and modified later by d' Arsonval. That is why this galvanometer is also known as d' Arsonval galvanometer.

[A] Principle: When a coil is placed in a magnetic field, it experiences a torque due to the forces acting on the coil according to Fleming's left hand rule.

[B] Construction: A moving coil galvanometer consists of a coil PQRS, containing of a large number of turns of the fine insulated copper wire. The coil is wound over light, non-magnetic,

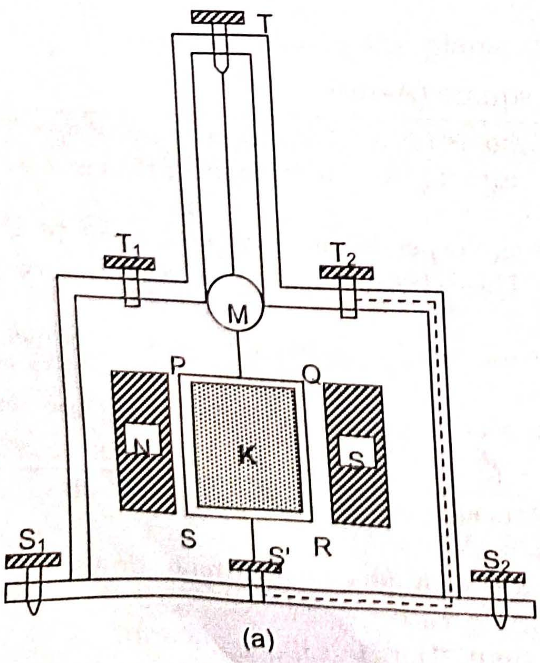


Fig-15.11(a): Moving coil Galvanometer

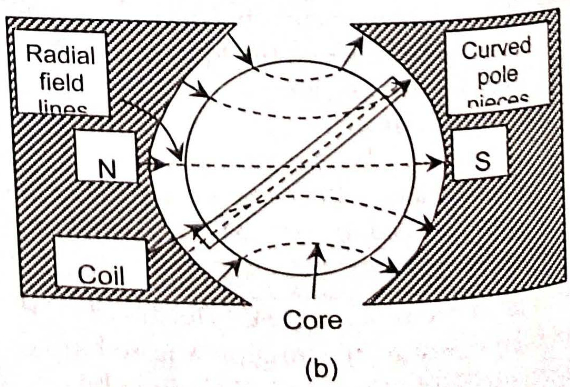


Fig-15.11(b): Coil in the radial magnetic field

metallic frame (usually brass) which may be circular or rectangular in shape. Rectangular

15.8 Hall Effect

When a magnetic field is applied to a current carrying conductor, a voltage is devel across the specimen in the direction perpendicular to both the current and the magnetic This effect is called Hall effect. The Hall Effect was discovered in 1997 by Edwin He Hall while working on his doctoral degree at the Johns Hopkins University in Baltin Maryland, USA.

The transverse voltage produced in this effect is called Hall voltage, denoted by V_H.

Explanation: As shown in Fig-15.12, a current I is passing through a flat strip of metal in a given direction. A magnetic field B is applied at right angle to the strip which is directed in to the page due to which the strip experiences a force which in turn is due to the force experienced by the charge carriers, i.e free electrons for metal. The magnetic force acting on the charge carriers havin the magnitude of charge e each moving with a drift velocity v is Bev in the direction fron AG to CD according to Fleming left hand rule. So, electrons accumulate at upper side CD o the strip, leaving positive charge at its lower side AG which makes the side AG at positive (higher) potential and the side CD at negative potential. In this way, a potential difference is set up. This particular potential difference between these two sides of the strip which opposes further flow of charges is called Hall potential difference or Hall voltage V_H.

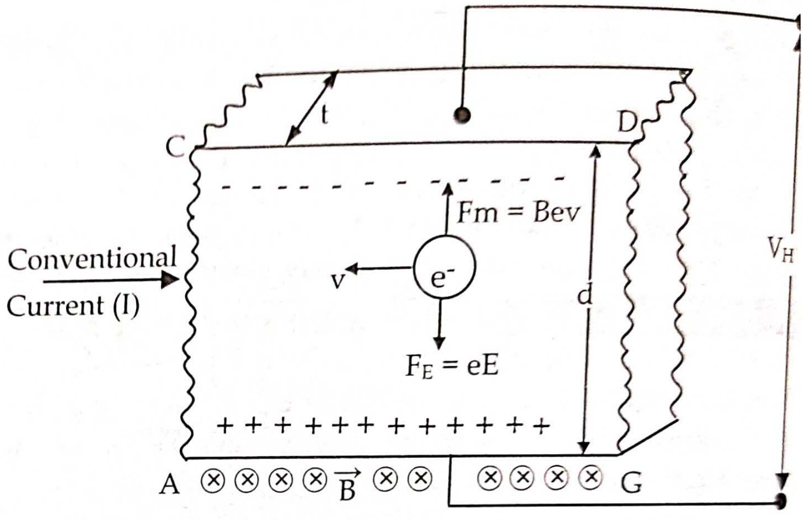


Fig-15.12: Hall effect

The accumulation of free electrons to upper face CD continue until the magnetic force F_m is cancelled out by the force due to electric field F_E.

For the steady flow of electrons,

$$F_m = F_E$$

$$B\cancel{e}\, v \sin 90^\circ = \frac{\cancel{e}\varepsilon}{d}$$

$$\frac{BI}{enA} = \frac{V_H}{d} \qquad [\because I = venA]$$

$$\frac{BI}{en(\cancel{d}t)} = \frac{V_H}{\cancel{d}} \qquad [\because A = dt]$$

$$\therefore \quad V_H = \frac{BI}{ent} \qquad (15.11)$$

Also, Hall resistance (R_H) of metal strip is given by

$$R_H = \frac{V_H}{I} = \frac{BId}{nAq \times I}$$, where q = e for metallic conductor

$$R_H = \frac{Bd}{nAq}$$ (15.12)

The quantity $\frac{1}{nq}$ is called Hall coefficient (H_C).

$$H_C = \frac{1}{nq}$$ (15.13)

(a) Hall effect in metal

Let $B = 1T$ $\quad I = 10A$

$e = 1.6 \times 10^{-19}$ C $\quad t = 1mm = 1 \times 10^{-3}m$

$n \simeq 10^{29}$ electron $1m^3$ (Copper)

$\therefore \quad V_H = \frac{B1}{net} = \frac{1 \times 10}{10^{29} \times 1.6 \times 10^{-19} \times 1 \times 10^{-3}} = 0.625\mu v$

(b) Hall effect in semiconductor

Let $B = 1T$ $\quad I = 10A$

$e = 1.6 \times 10^{-19}C$ $\quad t = 1mm = 1 \times 10^{-3}m$

$n \simeq 10^{25}$ electron/m^3 (for semiconductor)

$V_H = \frac{BI}{net} = \frac{1 \times 10}{10^{25} \times 1.6 \times 10^{-19} \times 10^{-3}} = 6.25mV$

Hence, Hall voltage (V_H) is much more measurable in semiconductor than in metallic conductor.

Check Your Understanding **Hall effect is more measurable in semiconductor than in metal, why?**

Sol^n: Since $V_H \propto 1/n$, and density of free electrons in metal($n \approx 10^{28}$ electrons/m^3) is greater than that of semiconductor ($n \approx 10^{25}$ electrons/m^3), Hall effect is more measurable in semiconductor.

Sample Problem 15.5 **A slice of indium antimonide is 2.5mm thick and carries a current of 150 mA. A magnetic field of flux density 0.5T, correctly applied produces a maximum hall voltage of 8.75 mv between the edges of the slice. Calculate the density of free charge in the slice, assuming they each have a charged of 1.6×10^{-19} C.**

Sol^n:

Given,

Thickness (t) =2.5mm = 2.5×10^{-3}m

Current (I) = 150mA = 150×10^{-3}A

Magnetic flux density (B) = 0.5T

Hall voltage (V_H) = 8.75mv = 8.75×10^{-3}V

No. of free electron (n) = ?

Electron charge (e) = 1.6×10^{-19}C

Now, $V_H = \frac{BI}{net}$

$n = \frac{BI}{V_H et}$

$= \frac{0.5 \times 150 \times 10^{-3}}{8.75 \times 10^{-3} \times 1.6 \times 10^{-19} \times 25 \times 10^{-3}}$

$= \mathbf{2.14 \times 10^{22}\ m^{-3}}$

$\therefore$ No. of free electron inside that slice of indium is $2.14 \times 10^{22}\ m^{-3}$.

Sample Problem 15.6 A copper strip 2cm wide and 1mm thick is placed in a magnetic field B = 1.5T. if a current of 200A is set is set up in the strip what Hall voltage appears across the strip? Electron concentration = $8.5 \times 10^{28} m^{-3}$.

Sol^n^:

Thickness (t) = 1mm = 1×10^{-3}m

Magnetic flux density (B) = 1.5T

Current (I) = 200A

Free electron (n) = 8.5×10^{28}

Hall voltage (V_H) = ?

We know that,

$$V_H = \frac{BI}{net} = \frac{1.5 \times 200}{8.5 \times 10^{28} \times 1.6 \times 10^{-19} \times 1 \times 10^{-3}}$$

$$= \frac{300}{13600000}$$

$= 2.20 \times 10^{-5}$ V

∴ Hall voltage inside a copper strip is 2.20×10^{-5} V

~~Right~~ Right hand thumb rule → B

15.9 Biot Savart's Law

Whenever current is passed through a conductor, a magnetic field is set up around it. To find the magnetic field at any point Laplace and Ampere gave a law which is known as Laplace's law or Ampere's law. But this law is first explained by Jean-Baptise Biot and proved by Felix Savart. As such this law is now commonly known as Biot-Savart's law.

Consider a current element AB of a thin curved conductor XY shown in Fig-15.13 through which a constant current I is maintained. Let dB be the magnitude of the magnetic field $\vec{dB}$ at point P at radial distance 'r' due to this current element of length d*l*.

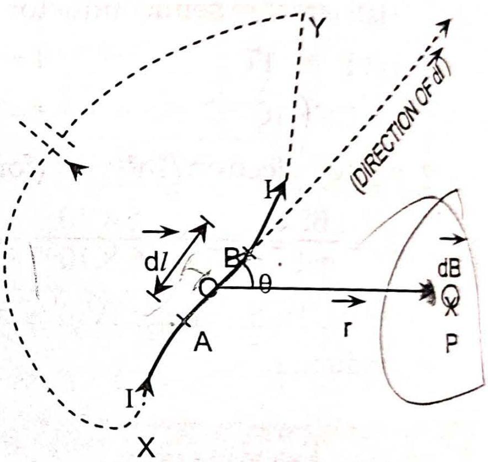


Fig-15.13: Biot-Savart's law

According to Biot-Savart's law

i. $dB \propto I$ (The magnetic field is directly proportional to current).

ii. $dB \propto dl$ (The magnetic field is directly proportional to the length of the current element).

iii. $dB \propto \sin\theta$, (The magnetic field is directly proportional to the sine of the angle between current element and position vector), where θ is the angle between $\vec{r}$ and $\vec{dl}$. $\vec{r}$ is the position vector of the observation point P with respect to the centre O of the current element. The direction of $\vec{dl}$ is the direction of flow of current.

iv. $dB \propto \frac{1}{r^2}$, (The magnetic field is inversely proportional to the square of the distance between the source of the field and the point at which the field is to be measured. It is also called inverse square law.), where r is the distance of the observation point P from the mid-point O of the current element.

Combining all the four factors, we get

$$dB = \frac{\mu_0 I}{4\pi}\frac{(r\sec^2\alpha\, d\alpha)\cos\alpha}{r^2\sec^2\alpha} = \frac{\mu_0 I}{4\pi r}\cos\alpha\, d\alpha$$

The magnetic field at point P due to the whole of the conductor XY is given by integrating dB

$$\text{i.e. } B = \int dB = \int_{-\phi_1}^{\phi_2}\frac{\mu_0 I}{4\pi r}\cos\alpha\, d\alpha = \frac{\mu_0 I}{4\pi r}\int_{-\phi_1}^{\phi_2}\cos\alpha\, d\alpha = \frac{\mu_0 I}{4\pi r}[\sin\alpha]_{-\phi_1}^{\phi_2}$$

$$\text{or, } B = \frac{\mu_0 I}{4\pi r}[\sin\phi_2 - \sin(-\phi_1)]$$

$$B = \frac{\mu_0 I}{4\pi r}(\sin\phi_1 + \sin\phi_2) \qquad (15.19)$$

If the conductor is infinitely long, then $\phi_1 = \frac{\pi}{2}$ and $\phi_2 = \frac{\pi}{2}$

Thus for infinitely long straight conductor

$$B = \frac{\mu_0 I}{4\pi r}\left[\sin\frac{\pi}{2} + \sin\left(\frac{\pi}{2}\right)\right] = \frac{\mu_0 I}{4\pi r}[1+1]$$

$$\text{or, } B = \frac{\mu_0}{4\pi}\frac{2I}{r}$$

$$\therefore \quad B = \frac{\mu_0 I}{2\pi r} \qquad (15.20)$$

Sample Problem 15.10 **Fig below shows a right-angled isosceles ΔPQR having its base equal to a. A current of 1 ampere is passing downwards along a thin straight wire cutting the plane of paper normally as shown at Q. Likewise a similar wire carries an equal current passing normally upwards at wire carries an equal current passing normally upwards at R. Find the magnitude and direction of the magnetic induction B at P. Assume the wire to be infinitely long.**

Sol^n: Let PQ = QR = r. In right ΔPQR,

$A^2 = r^2 + r^2 = 2r^2$ or, $r = \frac{1}{\sqrt{2}}$

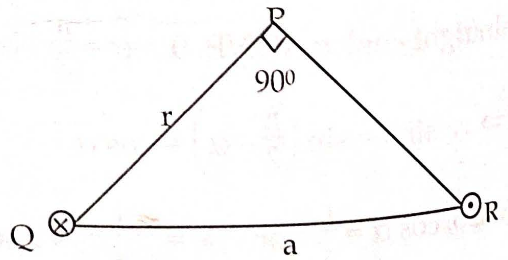
Magnetic induction at point P due to the conductor passing through Q,

$$B_1 = \frac{\mu_0 I}{2\pi r} = \frac{\sqrt{2}\mu_0 I}{2\pi a} = \frac{\mu_0 I}{\sqrt{2}\pi a}, \text{ acting}$$

along PR

Magnetic induction at point P due to the conductor passing through R,

$$B_2 = \frac{\mu_2 I}{\sqrt{2}\pi a}, \text{ acting along PQ}$$



As the two fields at point P are acting along perpendicular directions, the resultant magnetic induction at point P is

$$B = \sqrt{B_1^2 + B_2^2} = \frac{\mu_0 I}{\pi a}$$

This field acts towards the midpoint of QR.

II. Sample Numerical Problems

Sample Problem 15.14 A straight horizontal rod X, of mass 50 g and length 0.5 m is placed in uniform horizontal magnetic field of 0.2 T perpendicular to X. Calculate the current in X if the force acting on it just balances its weight. ($g = 10$ N kg^{-1})

Soln:

Given,

m = 50 g = 0.050 kg, l = 0.5 m, $\theta = 90°$

B = 0.2 T, I = ?

For the weight of the rod to be balanced by the force on the conductor due to the current flowing through it.

$$BIl\sin\theta = mg$$

$$I = \frac{mg}{Bl\sin\theta} = \frac{0.050 \times 10}{0.2 \times 0.5 \times 1} = 5 \text{ A}$$

Sample Problem 15.15 An electron beam, moving with a velocity of 10^6 ms^{-1} through a uniform magnetic field of 0.1 T, which is perpendicular to the direction of the beam. Calculate the force on an electron if the electron charge is 1.6×10^{-19} C.

Soln:

Given, $v = 10^6$ ms^{-1}, B = 0.1 T, $q = 1.6 \times 10^{-19}$ C, $\theta = 90°$

Now, $F = Bqv\sin\theta$

$= 0.1 \times 10^6 \times 1.6 \times 10^{-19} \times 1$

$= 1.6 \times 10^{-14}$ N

Sample Problem 15.16 A narrow vertical rectangular coil is suspended from the middle of its upper side with its plane parallel to a uniform horizontal magnetic field of 0.02 T. The coil has 10 turns and the lengths of its vertical and horizontal sides are 0.1 m and 0.05 m respectively. Calculate the torque on the coil when a current of 5A is passed into it. What would be the new value of the torque if the plane of the vertical coil was initially at 60° to the magnetic field and a current of 5A was passed into the coil.

Soln:

Given,

B = 0.02 T, N = 10 turns, A = $l \times b = 0.1 \times 0.05 = 0.005$ m^2

I = 5A, $\theta = 0°$

Now,

Torque = BINA $\cos\theta$ = $0.02 \times 5 \times 10 \times 0.005 \times 1 = 0.005$ Nm

$= 5 \times 10^{-3}$ Nm

New value of the torque when the plane of the vertical coil was at 60° to the magnetic field.

$= \text{BINA}\cos\theta$

$= 5 \times 10^{-3}\cos 60°$

$= 5 \times 10^{-3} \times \frac{1}{2}$

$= 2.5 \times 10^{-3}$ Nm

Sample Problem 15.17 A rectangular coil of 50 turns hangs vertically in a uniform magnetic field of magnitude 10^{-2} T, so that the plane of the coil is parallel to the field. The mean height of the coil is 5 cm and its mean width 2 cm. Calculate the strength of the current that must pass through the coil in order to deflect it 30° if the torsional constant of the suspension is 10^{-9} Nm per degree.

Soln:

Given,

N = 50 turns, B = 10^{-2} T, $\theta = 30°$

c = 10^{-9} Nm per degree, A $= 5 \times 2$ $cm^2 = 10cm^2$

$= 10 \times 10^{-4}$ $m^2 = 10^{-3}$ m^2

We know, $\text{BINA}\cos\theta = c\,\theta$

$$\therefore \quad I = \frac{c\,\theta}{\text{BNA}\cos\theta} = \frac{10^{-9} \times 30}{10^{-2} \times 50 \times 10^{-3}\cos 30°}$$

$= 6.9 \times 10^{-5}$ A $= 69$ μA

Sample Problem 15.18 A copper wire has 1.0×10^{29} free electrons per cubic metre, a cross sectional area of 2.0 mm² and carries a current of 5.0 A. Calculate the force acting on each electron if the wire is now placed in a magnetic field of flux density 0.15 T which is perpendicular to the wire. ($e = -1.6 \times 10^{-19}$ C)

Solⁿ:

Given,

$n = 1.0 \times 10^{29}\ m^{-3}$ $A = 2.0\ mm^2 = 2 \times 10^{-6}\ m^2$, $\theta = 90°$

$I = 5.0$ A, $B = 0.15$ T, $F = ?$

Now, $I = nevA$ or $v = \dfrac{I}{neA}$

We know, $F = Bev \sin\theta$

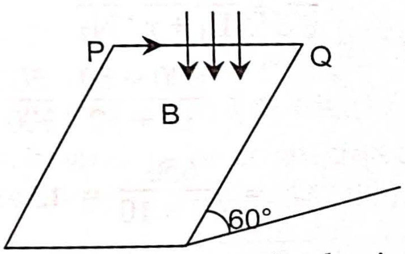
$$= \frac{Be \sin\theta \times I}{neA} = \frac{BI \sin\theta}{nA}$$

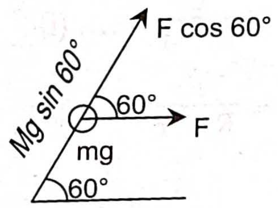
$$= \frac{0.15 \times 5 \times 1}{1.0 \times 10^{29} \times 2 \times 10^{-6}}$$

$$= 3.75 \times 10^{-24}\ N$$

Sample Problem 15.19 A horizontal rod PQ of mass 10 g and length 0.10 m, is placed on a smooth plane incident at 60° to the horizontal. A uniform vertical magnetic field of value B is applied in the region of PQ. Calculate B if the rod remains stationary on the plane when a current of 1.73 A flows in the rod. What is the direction of the current in the rod?

Solⁿ:





Force on the rod along the horizontal direction $F = BIl$ [$\theta = 90°$]

Component of force up the plane = $BIl \cos 60°$

Component of the weight of the rod down the plane = $mg \sin 60°$

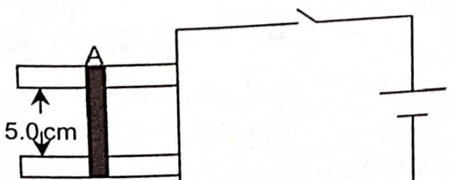
For the rod to be stationary

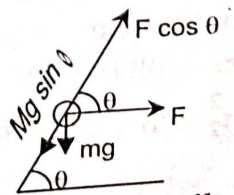
$BIl \cos 60° = mg \sin 60°$

or, $B = \dfrac{mg}{Il} \tan 60° = \dfrac{10 \times 10^{-3} \times 9.8\sqrt{3}}{1.73 \times 0.1} = 0.98$ T

As the force is to the right of PQ, applying Fleming's left hand rule, the direction of current should be from P to Q.

Sample Problem 15.20 A cylindrical aluminum bar A resting on two horizontal aluminum rails which can be connected to a battery to drive a current through A. A magnetic field of flux density 0.10 T, acts perpendicularly to the paper and into it. In which direction will A move if the current flows?





Calculate the angle to the horizontal to which the rails must be tilted to keep A stationary if its mass is 5.0 g, the current in it is 4.0 A and the direction of the field remains unchanged. (g = 10 ms⁻²)

Solⁿ:

Applying Fleming's left hand rule, the direction of the force is to the right. Hence A moves towards right.

Let θ be the angle through which the rails must be tilted to the horizontal so as to keep it stationary, then

$$mg\sin\theta = F\cos\theta = BIl\cos\theta$$

$\{F = BIl\sin 90° = BIl\}$

$$\text{or } \tan\theta = \frac{BIl}{mg} = \frac{0.1\times 4\times 5\times 10^{-2}}{5\times 10^{-3}\times 10} = 0.4$$

$$\text{or } \theta = \tan^{-1}(0.4) = \mathbf{21.8°}$$

Sample Problem 15.21 Two galvanometers, which are otherwise identical are fitted with different coils. One has a coil of 50 turns and resistance 10 Ω while the other has 500 turns and a resistance of 600 Ω. What is the ratio of the deflection when each is connected in turns to a cell of e.m.f. 2.5 V and internal resistance 50 Ω ?

Solⁿ:

Given,

$N_1 = 50, R_1 = 10\ \Omega, N_2 = 500, R_2 = 600\ \Omega$

$V = 2.5\ V, \theta_1 : \theta_2 = ?$

$$I_1 = \frac{c}{N_1 BA}\theta_1 = \frac{E}{R_1 + r} \quad \ldots\ldots \text{(i)}$$

$$I_2 = \frac{c}{N_2 BA}\theta_2 = \frac{E}{R_2 + r} \quad \ldots\ldots \text{(ii)}$$

From (i) and (ii)

$$\frac{N_2}{N_1}\frac{\theta_1}{\theta_2} = \frac{R_2 + r}{R_1 + r}$$

$$\text{or,} \quad \frac{\theta_1}{\theta_2} = \frac{R_2 + r}{R_1 + r}\cdot\frac{N_1}{N_2}$$

$$= \frac{600 + 50}{10 + 50}\cdot\frac{50}{500}$$

$$= \frac{650}{60\times 10} = \mathbf{13:12}$$

Sample Problem 15.22 A circular coil of 50 turns and area 1.25×10^{-3} m² is pivoted about a vertical diameter in a uniform horizontal magnetic field and carries a current of 2A. When the coil is held with its plane in a north-south direction, it experiences a couple of 0.04 Nm. When its plane is east-west, the corresponding couple is 0.03 Nm. Calculate the magnetic flux density.

Solⁿ:

Let the plane of the coil makes an angle θ with the magnetic field when it is in the north-south direction.

At this position

Torque $\tau_1 = BINA\cos\theta$

When the plane of the coil is in the east-west direction

Torque $\tau_2 = BINA\sin\theta$

$$\tau_1^2 + \tau_2^2 = B^2 I^2 N^2 A^2(\cos^2\theta + \sin^2\theta)$$

$$\therefore \quad B^2 = \frac{\tau_1^2 + \tau_2^2}{I^2 N^2 A^2}$$

$$= \frac{(0.03)^2 + (0.04)^2}{(2\times 50\times 1.25\times 10^{-3})^2}$$

$$= \frac{0.0025}{(2\times 50\times 1.25\times 10^{-3})^2}$$

$$\therefore \quad B = \frac{0.05}{2\times 50\times 1.25\times 10^{-3}} = 0.4\ T$$

Sample Problem 15.23 A galvanometer, with a scale divided into 150 equal divisions, has a current sensitivity of 10 divisions per miliampere and a voltage sensitivity of 2 divisions per millivolt. How can the instrument be adapted to serve (a) as an ammeter reading to 6A, (b) as a voltmeter in which each division represents 1 volt?

Soln: Given,

Current sensitivity $(\theta/I) = 10$ div/mA

Max. current that the galvanometer can measure, I_g = Current corresponding to 150 divs

$$= \frac{150}{10} = 15 \text{ mA}$$

Voltage sensitivity $(\theta/V) = 2$ div/mV

∴ Maximum Voltage corresponding to the full scale deflection, $V_g = \frac{150}{2} = 75$ mV

∴ Galvanometer resistance $G = \frac{V_g}{I_g}$

$$= \frac{75 \text{ mV}}{15 \text{ mA}} = 5\ \Omega$$

(a) Current to be measured I = 6A

Let S be the resistance to be connected across the galvanometer so as to read 6A, then

$$I_g = I\frac{S}{G+S}$$

$$15 \times 10^{-3} = 6\frac{S}{5+S}$$

or, $75 \times 10^{-3} + 15 \times 10^{-3} S = 6S$

or, $75 \times 10^{-3} = (6 - 0.015) S$

$$\therefore \quad S = \frac{75 \times 10^{-3}}{5.985} = 12.5 \times 10^{-3}\ \Omega$$

(b) Voltage to be measured $V = 150 \times 1 = 150$ V

Let R be the resistance to be connected in series with the galvanometer so as to read 150 V, then

$$150 = I_g (G + R)$$

or, $150 = 15 \times 10^{-3} (5 + R)$

or, $5 + R = \frac{150}{15 \times 10^{-3}} = 10{,}000$

or, $R = 10{,}000 - 5 = $ **9995 Ω**

Sample Problem 15.24 A wire 28 m long is bent into N turns of circular coil of diameter 14 cm forming a solenoid of length 60 cm. Calculate the flux density inside it when a current of 5 amp passes through it. ($\mu_o = 12.57 \times 10^{-7}$ m^{-1})

Soln:

Given,

$l = 60$ cm $= 0.6$ m

$d = 14$ cm $= 0.14$ m,

From question, $N \times \pi d = 28$ m

$N \times \pi \times 0.14 = 28$

$$\therefore \quad N = \frac{28}{0.14 \times \pi} = 63.66 \text{ turns}$$

$$B = \mu_o nI = \mu_o \frac{N}{l} I = 12.57 \times 10^{-7} \times \frac{63.66}{0.6} \times 5 = \mathbf{6.67 \times 10^{-4}\ T}$$

Sample Problem 15.26 A horizontal wire, of length 5 cm and carrying a current of 2 A is placed in the middle of a long solenoid at right angles to its axis. The solenoid has 1000 turns per metre and carries a steady current I. Calculate I if the force on the wire is vertically downwards and equal to 10^{-4} N.

Soln:

Given, $l = 5$ cm $= 5 \times 10^{-2}$ m, $I_{wire} = 2$A

$n = 1000$ m^{-1}, $F = 10^{-4}$ N

If I be the current through the solenoid, then

$B = \mu_o nI$

Force $= B I_{wire} l$

or $10^{-4} = \mu_o nI \times I_{wire}\, l$

or $10^{-4} = 4\pi \times 10^{-7} \times 1000 \times I \times 2 \times 5 \times 10^{-2}$

$= 4\pi \times 10^{-5}$ I

$$\therefore \quad I = \frac{10^{-4}}{4\pi \times 10^{-5}} = \frac{10}{4\pi} = \mathbf{0.8\ A}$$