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UG TRB PHYSICS 2023-2024



UNIT-1 Mechanics

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UG TRB PHYSICS – 2023-24

UNIT 1

MECHANICS



1.1. NEWTON'S LAW

Introduction:

- ❖ An object is said to be in motion if its position changes with respect to its surroundings in a given time while on the other hand, if the position of the object does not change with respect to its surroundings, it is said to be at rest. A motorbike speeding on road, a bird flying through air, a ship sailing on water, the graceful movements of a dancer are the examples of objects in motion while on the other hand, a pen lying on the table is at rest because its position with respect to the table does not change with time.
- ❖ To study the motion of an object, we have to study the change in the position of the object with respect to its surroundings. In space, the position of an object is specified by the three coordinates x, y and z. The position of the object changes due to change in one or two or all the three coordinates. The motion of an object is said to be one-dimensional when one of the three coordinates specifying the position of the object changes with time. The motion of a bus on the road, the motion of a train on railway track or an object falling freely under gravity are examples of one-dimensional motion. The motion of an object is said to be two-dimensional when two of the three coordinates specifying the position of the object change with time. Among the well-known examples of two-dimensional motion that we have studied are circular motion and projectile motion. However, our study was limited to the motion along a straight line (one-dimensional motion) and in a two-dimensional plane (two-dimensional motion). But you know that our world is three-dimensional in space. Therefore, we shall begin by studying motion

in three dimensions. The motion of an object is said to be three-dimensional when all the three coordinates specifying the position of the object change with time. The motion of a flying kite, gas molecules or the motion of a bird in the sky are some examples of three-dimensional motion.

- ❖ We shall first understand what we mean when we say that an object is moving. We shall learn how to describe the motion of a particle in terms of displacement, velocity and acceleration. In this unit, we shall also study the factors affecting the motion. For this, we shall study Newton's laws of motion and apply them to a variety of situations. We shall use the familiar concept of linear momentum to study the motion of systems having more than one particle and establish the principle of conservation of linear momentum.

What is Motion?

- Can we imagine what your life would be like if you were confined to some place, unable to move from one position to another as time passed? This sentence possesses the answer to the question. What is motion? If an object occupies different positions at different instants of time, then we say that it is moving or it is in motion. Thus the study of motion deals with questions - where? And when? Let us recall some definitions relating to motion.

Distance and Displacement:

- The position of a moving object goes on changing with respect to time. The length of the actual path covered by a body in a time-interval is called 'distance' while the difference between the final and the initial positions of an object is known as 'displacement'. We know that the position of an object is always expressed with respect to some reference point. If the initial position of an object with respect to a reference point is x_1 and after some time it becomes x_2 , then the magnitude of the displacement of the object is $x_2 - x_1$.

Speed:

- The distance travelled by an object in unit interval of time is called the 'speed' of the object i.e.

$$SPEED = \frac{DISTANCE}{TIME}$$

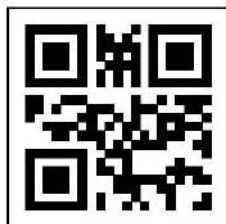
- The speed is represented by 'v' and it has unit meter/second. It is a scalar quantity.

Velocity:

- The displacement of an object in a particular direction in unit interval of time is called the 'velocity' of the object i.e.

$$\text{velocity} = \frac{\text{displacement}}{\text{Time}}$$

$$\bar{v} = \frac{x_2 - x_1}{t_2 - t_1}$$



- For expressing the difference in a quantity, we use the symbol Δ (delta). Therefore, we can write the average velocity of the object as-

$$V = \frac{\Delta x}{\Delta t}$$

- If we go on decreasing the time-interval Δt and when Δt becomes infinitesimally small ($\Delta t \rightarrow 0$), then from the above formula, we shall be knowing the velocity of the object at a particular instant of time. This velocity is called the 'instantaneous velocity' of the object

$$V = \lim_{\Delta t \rightarrow 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

Acceleration:

- You should know that if the velocity of a moving object is changing then its motion is known as 'accelerated motion'. It is obvious that change in velocity means the change in magnitude (i.e. speed) or in direction or in both. Thus, the time-rate of change of velocity of an object is called the 'acceleration' of that object, i.e

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{Time taken}}$$

- Acceleration is generally represented by 'a' and it has unit meter/second². It is also a vector quantity.
- Let us suppose that the velocity of a moving object at time t_1 is v_1 and at time t_2 , it becomes v_2 . It means that in the time-interval $(t_2 - t_1)$, the change in the velocity of the

object is $(v_2 - v_1)$. Therefore, the average acceleration of the object in time-interval $(t_2 - t_1)$ is

$$a = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\Delta v}{\Delta t}$$

- If the time-interval Δt is infinitesimally small (i.e. $\Delta t \rightarrow 0$), then at a particular time, the instantaneous acceleration is given by

$$a = \lim_{\Delta t \rightarrow 0} \frac{v_2 - v_1}{t_2 - t_1} = \frac{\Delta v}{\Delta t}$$

Causes of Motion:

- What makes things move? Let us understand this question. The answer of this question was suggested by the great physicist Aristotle, way back in the fourth century B.C. Most of the people believed in his answer that a force which is described as push or pull, was needed to keep something moving. And the motion ceased when the force was removed. This idea made a lot of common sense. But these ideas were first critically examined by Galileo who performed a series of experiments to show that no cause or force is required to maintain the motion of an object.
- Let us try to understand some common examples. From our daily experience, we know that the motion of a body is a direct result of its interactions with the other bodies around it which form its environment when a cricketer hits a ball, his or her bat interacts with the ball and modifies its motion. The motion of a freely falling body or of a projectile is the result of its interaction with earth. When an ox stopped pulling an ox-cart, the cart quickly comes to a stop.
- An interaction is quantitatively expressed in terms of a concept called 'force' - a push or a pull. When we push or pull a body, we are said to exert a force on it. Earth pulls all bodies towards its centre and is said to exert a force (gravitational) on them. A locomotive exerts a force on the train, it is either pulling or pushing. In this way every force exerted on a body is associated with some other body in the environment.
- We should also remember that it is not always that an application of force will cause motion or change motion. For example, we may push a wall i.e. there is an interaction between us and the wall and hence there is a force, but the wall may not move at all.

- Thus, force may be described as push or pull, resulting from the interaction between bodies which produces or tends to produce motion or change in motion. The analysis of the relation between force and motion of a body is based on Newton's laws of motion. We will now discuss these laws.

Newton's Laws of Motion:

- Galileo concluded that any object in motion, if not obstructed, will continue to move with a constant speed along a horizontal line. Therefore, there would be no change in the motion of an object, unless an external agent acted on it to cause the change. That was Galileo's version of inertia. Inertia resists changes, not only from the state of rest, but also from motion with a constant speed along a straight line. Therefore, the interest shifted from the causes of motion to the causes for changes in motion. Galileo's version of inertia was formalized by Newton in a form that has come to be known as Newton's first law of motion.

Newton's First Law:

- This law states – **“If a body is at rest then it will remain at rest or if it is moving along a straight line with a uniform speed then it will continue to move as such unless an external force is applied on it to change its present state”**. This property of bodies showing a reluctance to change their present state is called “inertia”. Hence, Newton's first law is also known as the “law of inertia” This law is also called “Galileo law”. Newton's first law makes no distinction between a body at rest and one moving with a constant velocity. Both states are ‘natural’ when no net external force or interaction acts on the body.

Example:

- (i) when a carpet or a blanket is beaten with a stick then the dust particles separate out from it
- (ii).fast moving vehicles suddenly stops then the passengers inside the vehicle bend outward.

Newton's Second Law:

- Newton's second law tells us what happens to the state of rest or of uniform motion of a body when a net external forces acts on the body i.e. when the body interacts with other surroundings bodies. This law states – **“The time-rate of change of linear momentum**

of a particle is directly proportional to the force applied on the particle and it takes place in the direction of the force".

- Mathematically

$$F \propto dp / dt$$

$$F = k dp / dt$$

$$F = k d / dt (mv)$$

- Where k is a constant of proportionality and its value is only SI and CGS system

$$F = m .dv / dt$$

$$F = ma$$

- Newton's second law can also be written as-

$$F = m .dv / dt$$

- If the unit of mass m is kg and the unit of acceleration a is meter/second², then the unit of force F is called 'newton'.
- If m=1 kg and a= 1 meter/second²
- Then magnitude of force $F = ma = 1 \times 1 = 1$ Newton

i.e. 1 newton force is the force which produces an acceleration of 1 meter/second² in a body of mass 1 kg.

Examples:

(i) It is easier for a strong adult to push a pull shopping cart then it is for a baby to push the same cart. (This is depending on the net force acting on the object)

Newton's Third Law of Motion :

- A force acting on a body arises as a result of its interaction with another body surrounding it. Thus, any single force is only one feature of a mutual interaction between two bodies. We find that whenever one body exerts a force on a second body, the second body always exerts on the first a force which is equal in magnitude but opposite in direction and has the same line of action. A single isolated force is therefore an impossibility.

- The two forces involved in every interaction between the bodies are called an 'action' and a 'reaction'. Either force may be considered the 'action' and the other the 'reaction'. This fact is made clear in Newton's third law of motion. This law states-**"To every**

Action there is always an equal and opposite reaction":

- Here the words 'action' and 'reaction' mean forces as defined by the first and second laws.
- If a body A exerts a force on a body B, then the body B in turn exerts a force $F_{AB} = -F_{BA}$ on A, such that

$$F_{AB} = -F_{BA}$$

So, we have $F_{AB} = -F_{BA}$ (15)

- Notice that Newton's third law deals with two forces, each acting on a different body. This law is also known as 'Law of action-reaction'.
- There are two important points regarding Newton's third law. Firstly, we cannot say that this particular force is action and the other one is reaction. Any one may be action and the other reaction. Secondly, action and reaction act on different bodies.
- Out of three laws, Newton's second law is most general as first and third law may be derived from second law.

Examples:

- swimming become possible because of third law of motion
- jumping of a man from a boat on to the bank river
- the jerk is produced in a gun when Bullet is fired from it
- pulling of cart by a horse

Weight and Mass:

- The weight of a body is simply the gravitational force exerted by earth on the body. It is a vector quantity whose direction is the direction of the gravitational force i.e. towards the centre of the earth.
- Let us understand the concept of weight in a better way. When a body of mass m falls freely, its acceleration is g and the force acting on it is its weight \vec{w} . Thus, by using Newton's second law,

$$F = Ma \quad \text{We get}$$

- Since both weight w and acceleration due to gravity g are directed towards the centre of the earth, we can write

$$w = mg$$

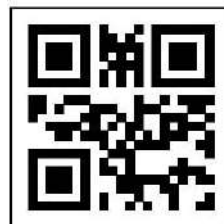
- The mass m of a body is an intrinsic property of the body while the weight of a body is different in different localities because acceleration due to gravity g varies from point to point on the earth. The unit of mass is kg while that of weight is kg m/sec^2 or Newton.

Applications of Newton's Laws Of Motion:

- Newton's laws of motion give us the means to understand most aspects of motion. Let us now apply them to a variety of physical situation involving objects in motion. To apply Newton's laws, we must identify the body whose motion interests us. Then we should identify all the forces acting on the body, draw them in the figure and find the net force acting on the body. Newton's second law can then be used to determine the body's acceleration

Exercise Questions - I:

- What causes the motion of a body which is initially in the state of rest?
 (A) Force (B) Displacement
 (C) Speed (D) Velocity
- People sitting in a moving bus experience a jerk when the bus stops. This is due to ____
 (A) Inertia of motion (B) Inertia of rest
 (C) Inertia of turning (D) Inertia of acceleration
- Passengers sitting in a stationary car experience a jerk when the car suddenly starts. This is due to ____
 (A) Inertia of motion (B) Inertia of rest
 (C) Inertia of turning (D) Inertia of acceleration
- Inertia is ____
 (A) Property of mass to remain unchanged
 (B) Property of mass to change continuously
 (C) Property of mass to accelerate
 (D) Tendency of mass to accelerate
- What is the force applied on a body with 5 kg of mass and an acceleration of 7 m/s^2 ?
 (A) 35 N (B) 5 N (C) 7 N (D) 0 N



6. Unit of force is ____
 (A) Newton (B) Pascal (C) Byte (D) Gram
7. The unit 'Newton' is equivalent to ____
 (A) $\text{Kg} - \text{m} / \text{s}^2$ (B) $\text{Kg} - \text{m} / \text{s}$ (C) $\text{Kg} / \text{m} / \text{s}^2$ (D) $\text{Kg}^2 - \text{m} / \text{s}^2$
8. If the force acting on a body is 10 N, and the acceleration is 4 m/s^2 , what can be the mass of the body?
 (A) 2.5 Kg (B) 25 Kg (C) 0.25 Kg (D) 5 Kg
9. If the force acting on a body is 50 N, and the mass is 5 kg, what can be the acceleration of the body?
 (A) 10 m/s^2 (B) 80 m/s^2 (C) 8 m/s^2 (D) 0.8 m/s^2
10. How do we calculate force in a variable mass constant velocity system?
 (A) $F = ma$ (B) $F = mv$ (C) $F = v(dm/dt)$ (D) $F = m/t$

1.2. IMPULSE:

- You can see many occasions in your daily life when a large force is applied on a body for a short time-interval: for example, hitting a cricket-ball by a bat or a ping-pong ball by a stick, striking a nail by a hammer etc. In such cases, the product of the force and the time-interval is called the 'impulse' of the force.
- If a constant force F is applied on a body for a short interval of time Δt , then the impulse of this force will be $F \times \Delta t$.
- Impulse is a vector quantity having the direction of force. It may be found by calculating net change in linear momentum.
- The impulse I of a constant force F acting for a time t is defined as $F \times t$.
- By Newton's second law, $F = ma$.

The unit of impulse is Newton -sec:

- If u and v are the initial and final velocities of the particle,

$$a = (v - u) / t$$

$$\therefore I = Ft = mat = m \left(\frac{v - u}{t} \right) t = m(v - u)$$

- Thus, the impulse of a force is equal to the change in momentum produced.
- Two directions of projections for a given velocity and range

Example 6:

- A ball of mass 0.35 kg moving horizontally with a velocity 10 m/sec is struck by a bat. The duration of contact is 10^{-3} sec. After leaving the bat, the speed of the ball is 30 m/sec in a direction opposite to its original direction of motion. Calculate the average force exerted by the bat.

Solution:

- Given mass of the ball $m = 0.35 \text{ kg}$, initial velocity of ball $v_1 = 10 \text{ m/sec}$, final velocity of ball $v_2 = 30 \text{ m/sec}$, duration of contact $\Delta t = 10^{-3} \text{ sec}$

- Change in momentum of ball $\Delta p = p_2 - p_1$

$$= mv_2 - mv_1 = m(v_2 - v_1)$$

$$= 14 \text{ kg m/sec}$$

We know that, Impulse = change in momentum

$$\text{i.e. } F \times \Delta t = \Delta p$$

$$\text{or } F = \Delta p / \Delta t = 14 / 10^{-3} = 14000 \text{ Newton}$$

Impulsive Force:

Definition:

- An impulsive force is an infinitely great force acting for a very short interval of time, such that their product is finite.
- The force and the time cannot be measured because one is too great and the other is too small.
- The impulse of the impulsive force is equal to the change in momentum produced.
- Hence an impulsive force is always measured by the change in momentum produced.
- In practice, the conditions of an impulsive force are never realized.
- Some approximate examples of impulsive force are:

(1) The blow of a hammer on a nail and

(2) The force exerted by the bat on a cricket ball.



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UNIT 2

THERMAL PHYSICS

2.1. Kinetic Theory of Gases

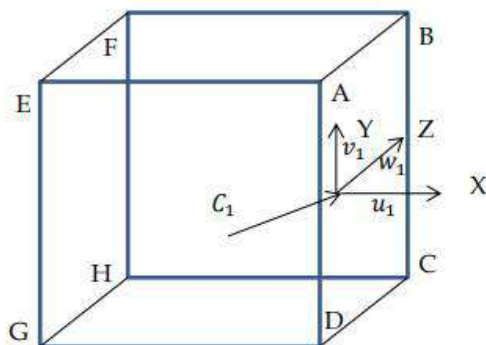
- ❖ The kinetic theory of gases is the study that relates the microscopic properties of gas molecules (like speed, momentum, kinetic energies etc..) with the macroscopic properties of gas molecules (like pressure, temperature and volume).

Fundamental Postulates of Kinetic Theory

1. The molecules of a gas are considered to be rigid, perfectly elastic, identical in all respects. They are solid spheres. Their size is negligible compared to intermolecular distances.
2. The molecules are in random motion in all directions with all possible velocities.
3. The molecules collide with each other and with the walls of the container. At each collision, velocity changes but the molecular density is constant in steady state.
4. As the collisions are perfectly elastic, there is no force of attraction or repulsion between the molecules. Thus the energy is only kinetic.
5. Between any two successive collisions, molecules travel with uniform velocity along a straight line.

Expression for Pressure of the Gas:

- Consider a gas contained in a cubical vessel of side l with perfectly elastic walls containing a large number of molecules. Let c_1 be the



velocity of a molecule in a direction as shown. This can be resolved into three components u_1, v_1 and w_1 along X, Y and Z directions as shown.

- Then

$$c_1^2 = u_1^2 + v_1^2 + w_1^2 \text{ ————— (1)}$$

- The momentum of this molecule that strikes the wall ABCD of the vessel is equal to mu_1 where m is its mass. As the collision is elastic, the molecule will rebound with same momentum i.e. mu_1 . The change in momentum due to impact is equal to $mu_1 - (-mu_1) = 2mu_1$. It strikes the wall EFHG and returns back to ABCD after travelling a distance $2l$. The time between the successive collisions (time for one collision) on ABCD is $\frac{2l}{u_1}$.

- Thus, the number of collisions per second, this molecule makes with ABCD is $\frac{u_1}{2l}$

- Hence the rate of change of momentum = change in momentum \times number of collisions per second is equal to $2mu_1 \times \frac{u_1}{2l} = \frac{mu_1^2}{l}$

- From Newton's second law, rate of change of momentum = impressed force

- If f_1 is the force, then $f_1 = \frac{mu_1^2}{l}$ along X- direction.

- Similarly, the force on another molecule of velocity c_2 , whose components are u_2, v_2 and w_2 due

- to impact is $f_2 = \frac{mu_2^2}{l}$ along X- direction.

- Hence the total force F_x on the face ABCD due to impact of all the n molecules in the X- direction is given by $F_x = \frac{m}{l}(u_1^2 + u_2^2 + u_3^2 \dots + u_n^2) \dots (2)$

- Since pressure is force per unit area, the pressure P_x on ABCD is given by

$$P_x = \frac{F_x}{l^2} = \frac{m}{l^3}(u_1^2 + u_2^2 + u_3^2 \dots + u_n^2) \dots (3) \quad (\text{since } P = \frac{F}{A} \text{ and } A = l^2)$$

- Similarly, if P_y and P_z are the pressure on faces EFBA and FBCH, then

$$P_y = \frac{F_y}{l^2} = \frac{m}{l^3} (v_1^2 + v_2^2 + v_3^2 \dots v_n^2) \dots (4)$$

$$P_z = \frac{F_z}{l^2} = \frac{m}{l^3} (w_1^2 + w_2^2 + w_3^2 \dots w_n^2) \dots (5)$$

- As the pressure exerted by the gas is same in all directions, the average pressure P of the gas is

$$P = \frac{P_x + P_y + P_z}{3} \dots (6)$$

$$P = \frac{m}{3l^3} (u_1^2 + u_2^2 + u_3^2 \dots u_n^2) + (v_1^2 + v_2^2 + v_3^2 \dots v_n^2) + (w_1^2 + w_2^2 + w_3^2 \dots w_n^2)$$

$$P = \frac{m}{3l^3} (u_1^2 + v_1^2 + w_1^2) + (u_2^2 + v_2^2 + w_2^2) \dots + (u_n^2 + v_n^2 + w_n^2) \dots (7)$$

- Since $l^3 = V$, the volume of the cube and

$$c_1^2 = u_1^2 + v_1^2 + w_1^2$$

$$P = \frac{m}{3l^3} (c_1^2 + c_2^2 + c_3^2 \dots + c_n^2) \dots (8)$$

- Or where $P = \frac{1}{3} \frac{mn}{V} C^2$ $C^2 = \frac{c_1^2 + c_2^2 + c_3^2 + \dots + c_n^2}{n}$ known as the mean square velocity of the molecules

- If M is the total mass of the gas, i.e. $M = n m$, then $P = \frac{1}{3} \frac{M}{V} C^2 \dots (9)$

To Derive the Relation $U = \frac{3}{2} RT$

- The pressure exerted by a gas n molecule occupying volume V is given by

$$P = \frac{1}{3} \frac{mn}{V} C^2 \quad \text{Or} \quad P V = \frac{1}{3} m n C^2$$

- If V is the volume occupied by a gram molecule of the gas and M is the molecular weight of the gas, then $M = m N_A$ where is the Avogadro number.
- From the perfect gas equation $PV = RT$ _____ (2)
- From (1) and (2) we get $\frac{1}{3} M C^2 = RT$

$$\text{Or } MC^2 = 3RT$$

- Dividing the above equation on both the sides by 2 we get $= \frac{1}{2} MC^2 = \frac{3}{2} RT$ _____ (3)

$$\text{Or } U = \frac{3}{2} RT \text{ _____ (4) where } U = \frac{1}{2} MC^2 \text{ is called the internal energy of the gas.}$$

- Dividing both sides of equation (3) by N_A , which is the number of molecules in one gram molecule of the gas or one mole, called Avogadro number, we get $\frac{1}{2} \frac{M}{N_A} C^2 = \frac{3}{2} \frac{R}{N_A} T$

$$\text{As } \frac{M}{N_A} = m \text{ and } \frac{R}{N_A} = k, \text{ where } k \text{ is Boltzmann constant.}$$

$$\frac{1}{2} mC^2 = \frac{3}{2} kT \text{ _____ (5)}$$

- Thus, the mean kinetic energy per molecule in a given mass of gas is proportional to the absolute temperature of the gas. **Deduction of perfect gas equation**
- From kinetic theory of gases, the expression for pressure of a gram molecular of the gas is

$$P = \frac{1}{3} \frac{mn}{v} C^2 \quad \text{Or } PV = \frac{1}{3} mN_A C^2 \text{ _____ (1)}$$

$$\text{Or } PV = \frac{2}{3} \times \frac{1}{2} mN_A C^2 = \frac{2}{3} N_A \times \frac{1}{2} mC^2 \text{ _____ (2)}$$

- The average kinetic energy of 1-gram molecule of a gas at absolute temperature T is given by

$$KE = \frac{1}{2} MC^2 = \frac{1}{2} mN_A C^2$$

- Average kinetic energy of a molecule

$$\frac{1}{2} MC^2 = \frac{3}{2} kT \text{ _____ (3)}$$

- Comparing equations (2) and (3) $PV = \frac{2}{3} N_A \times \frac{3}{2} kT$

$$\text{Or } PV = N_A kT \text{ or } PV = RT \text{ where } R = N_A k$$

- R is called universal gas constant given by $R = 8.31 J mol^{-1} K^{-1}$

Derivation of Gas laws

(1) Boyle's Law:

- From the kinetic theory of gases, the pressure exerted by a gas is given by

$$P = \frac{1}{3} \frac{M}{C} C^2 \quad \text{Or } PV = \frac{1}{3} MC^2$$

- At a constant temperature C^2 is a constant. Thus for a given mass of a gas, from the above equation, **P V = Constant**. Hence Boyle's law.

(2) Charle's Law

- The pressure of a gas is $P = \frac{1}{3} \frac{M}{V} C^2$ or $V = \frac{1}{3} \frac{m n}{p} C^2$
- Thus, for a given mass of gas, at constant pressure $V \propto C^2$
- As, $C^2 \propto T$ we get $V \propto T$. Hence the Charle's law
- Similarly, it can be shown that $P \propto T$ at constant volume called the Regnault's law.

(3) Avogadro's Law

- This law states that at the same temperature and pressure equal volumes of all gases contain the same number of molecules.
- Let n_1 and n_2 be the number of molecules of two different gases, m_1 and m_2 their masses and C_1 and C_2 the respective root mean square velocities. Since the two gases have the same pressure and for unit volume the gases,

$$P = \frac{1}{3} m_1 n_1 C_1^2 = \frac{1}{3} m_2 n_2 C_2^2 \quad \text{--- (1)}$$

- As the temperature of the two gases is the same, there is no change in temperature when they are mixed. This is possible only if the mean kinetic energy per molecule in the two gases is the same, i.e. $\frac{1}{2} m_1 C_1^2 = \frac{1}{2} m_2 C_2^2$ --- (2)

- Based on the equation (2) equation (1) reduces to the condition $n_1 = n_2$. Hence the Avogadro law.

Exercise – 1

1. On which factor does the average kinetic energy of gas molecules depend?

A) Nature of the gas	B) Temperature
C) Volume	D) Mass
2. What is the average velocity of the molecules of an ideal gas?

A) Infinity	B) Constant
C) Unstable	D) Zero
3. Cooking gas containers are kept in a lorry moving with uniform speed. The temperature of the gas molecules inside will _____.

A) Increase	B) Decrease
C) Remain the same	D) Decreases for some, while the increase for others
4. At Boyle's temperature?

A) Joule's effect is positive	B) Van der Waal's equation becomes zero
C) Gases obey Boyle's law	D) Water solidifies
5. For Boyle's law to hold good, the gas should be _____.

A) Perfect and of constant mass and temperature	B) Real and of constant mass and temperature
C) Perfect and at constant temperature but variable mass	D) Real and at constant temperature but variable mass
6. A gas behaves as an ideal gas at _____.

A) Low pressure and high temperature	B) Low pressure and low temperature
C) High pressure and low temperature	D) High pressure and high temperature
7. The temperature of gas is held constant, while its volume is decreased. The pressure exerted by the gas on the wall of the container increases, because of its molecules _____.

A) Strike the walls with higher velocities	B) Strike the walls with large force
C) Strike the walls more frequently	D) Are in contact with the walls for a shorter time
8. Statement: The root mean square and most probable speeds of the molecules in a gas is symmetrical.

Reason: The Maxwell distribution for the speed to molecules in a gas is symmetrical.

- A) Both statement and reason are true and the reason is the correct explanation of the statement
- B) Both statement and reason are true but the reason is not a correct explanation of the statement
- C) Statement it true but the reason is false
- D) Both statement and reason are false
9. The degree of freedom of a triatomic gas is?
- A) 1 B) 2 C) 6 D) 8

2.2. Mean Free Path

- The average distance travelled by a molecule in a gas between any two successive collisions is called mean free path of the molecule. It is denoted by λ . If the total path travelled in N collisions is S , then the mean free path is given by $\lambda = S/N$ Expression for mean free path
- Consider n as the number of molecules per unit volume of a gas and let σ be the diameter of each of these molecules. The assumption made here is that only the molecule under consideration is in motion, while all other molecules are at rest. The moving molecule will collide with all those molecules whose centres lie within a distance σ from its centre as shown in the figure. If v is the velocity of the molecule, in one second it will collide with all the molecules the centres of which lie in a cylinder of radius σ and length v , and hence in a volume $\pi\sigma^2 v$. The number of molecules in this cylindrical volume is $\pi\sigma^2 v n$. Thus the number of collisions N made by the moving molecule is also $\pi\sigma^2 v n$. or $N = \pi\sigma^2 v n$.
- As the distance S traversed by the molecule in one second is its velocity v , the mean free path λ is given by $\lambda = \frac{S}{N} = \frac{v}{\pi\sigma^2 v n} = \frac{1}{\pi\sigma^2 n}$
- Thus $\lambda = \frac{1}{\pi\sigma^2 n}$ ————— (1) This equation connecting the mean free path with the molecular diameter and the number of molecules per unit volume was deduced by Clausius.
- Boltzman, assuming that all the molecules have the same average speed deduced the equation

$$\lambda = \frac{3}{4\pi\sigma^2 n} \text{-----} (2)$$

- Maxwell, based on the exact law of distribution of velocities, obtained a more correct equation

$$\lambda = \frac{1}{\sqrt{2}\pi\sigma^2 n} \text{-----} (3)$$

- From the above equation it is clear mean free path is inversely proportional to the square of the molecular diameter.
- From the perfect gas equation $P V = R T$ or $P V = N_A R T$ Where $R = N_A k$
- We get $P = \frac{N_A k T}{V}$ or $n = \frac{P}{k T}$
- Substituting for n in equation (3) $\lambda = \frac{k T}{\sqrt{2}\pi\sigma^2 P}$. Thus, mean free path is directly proportional to the absolute temperature and inversely proportional to the pressure.

Exercise -2

- What is meant by mean free path?
 - It is the average distance a molecule travels without colliding
 - Average distance between 2 molecules
 - Average distance travelled by a molecule before colliding with a wall of the container
 - Sum of distance travelled by all molecules
- Which of the following states of matter has the maximum value of mean free path?
 - Gas
 - Solid
 - Liquid
 - Plasma
- John Dalton said that atoms are the smallest constituents of elements. True or False?
 - True
 - False
- The mean free path l for a gas molecule depends upon the diameter, d of the molecule as,
 - $l \propto \frac{1}{d^2}$
 - $l \propto d$
 - $l \propto d^2$
 - $l \propto \frac{1}{d}$
- If the mean free path of atoms is doubled, then the pressure of the gas will become
 - $\frac{p}{4}$
 - $\frac{p}{2}$
 - $\frac{p}{8}$
 - p

6. If the pressure in a closed vessel is reduced by drawing out some gas, the mean free path of the molecules:
- A) Decreases B) Increases
- C) Remains unchanged D) Increases or decreases according to the nature of the gas
7. When the gas in an open container is heated, the mean free path
- A) Decreases B) Increases
- C) Remains unchanged D) Any of the above depending on the molar mass

2.3. Ideal Gas Equation

What is Ideal Gas Equation?

- In thermodynamics, Ideal gas law is a well-defined approximation of the behaviour of many gases under diverse conditions. Ideal Gas Equation is the combination of empirical laws like Charle's law, Boyle's law, Gay-Lussac's law, and Avogadro's law.
- Ideal Gas Equation is the equation defining the states of the hypothetical gases expressed mathematically by the combinations of empirical and physical constants. It is also called the **general gas equation**. It can be defined as:

"The ideal gas law is the equation of state of a hypothetical ideal gas. It is a good approximation of the behaviour of many gases under many conditions, although it has several limitations".

Equation of Ideal Gas Law

- The state of an ideal gas is determined by the macroscopic and microscopic parameters like pressure, volume, temperature.
- *Thus, the ideal gas equation is often written as:*

$$PV=nRT$$

Where,

- ✓ P is the pressure of the ideal gas.
- ✓ V is the volume of the ideal gas.
- ✓ n is the amount of ideal gas measured in terms of moles.

✓ R is the gas constant.

✓ T is the temperature.

- The ideal gas concept is useful because it obeys the ideal gas law, a simplified equation of state, and is amenable to analysis under statistical mechanics.

Ideal Gas Equation Units

- The Ideal gas equation units, terms, and corresponding definitions can be expressed as follows:

Terms	Symbol	Definition	Units
Pressure	P	Force per unit area	Pa or N/m ²
Volume	V	3D space enclosed by the closed surface	m ³
Amount of substances/ no. of moles	N	The ratio of the mass of the gas to its molar mass.	Mole
Ideal gas constant	R	Physical constant relates the average kinetic energy of an ideal gas with temperature. it is expressed in units of energy per temperature increment per mole	8.3144598 JK ⁻¹ mol ⁻¹
Temperature	T	Measure of heat.	K or °C

What is Ideal gas?

- Ideal gas does not exist in reality. It is a hypothetical gas proposed to simplify the calculations.
- An ideal gas is a theoretical gas composed of a set of randomly-moving point particles that interact only through elastic collisions.
 - ✓ In Ideal gas, the gas molecules move freely in all directions, and collision between them is considered to be perfectly elastic, which implies no loss in the kinetic energy due to the collision.



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UG TRB PHYSICS 2023-2024



UNIT-3

Properties of Matter and Acoustics

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UG TRB PHYSICS – 2023-24

UNIT 3

PROPERTIES OF MATTER AND ACOUSTICS

3.1. Stress

- When a body is deformed by external force, internal reactionary forces are developed between the molecules of the body to oppose the action of the deforming force, which tend to restore the body to its original condition. The internal restoring force developed unit area of the body when subjected to external deforming force is called stress. Being a disturbed force, it is measured in the same manner as fluid pressure (i.e.,) in terms of load on deforming force applied / unit area of the body, being equal in magnitude but opposite in direction to it, until a permanent change has been brought about in the body. These forces are self-adjusting forces. As deforming force increases restoring force also increases. When deforming force is equal to restoring force, body attains equilibrium. Due to this, at equilibrium, stress can be measured by the deforming force applied on a unit area of the body.

$$\text{Stress} = \frac{\text{Restoring force}}{\text{area}} = \frac{\text{Deforming force}}{\text{area}} = \frac{F}{A}$$

- Unit of stress is Newton per metre ² (N / m²) and its dimensional formula is [ML⁻¹T⁻²].
The stress developed in a body depends upon how the external forces are applied over it. Depending on these three types of stress, are as follows

Types of Stress

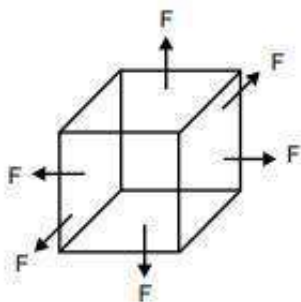
(a) Longitudinal Stress (or) Tensile Stress :

- If the deforming force acting on a body is along its longitudinal axis and produces a change in its length, then the deforming force / unit area acting normal to the surface is called longitudinal or normal or tensile stress.



- If the applied force is a thrust or produces a compression, then the stress is called normal compressive stress. F . Thus, Tensile stress = force / unit area = F/A Tensile stress = F/A

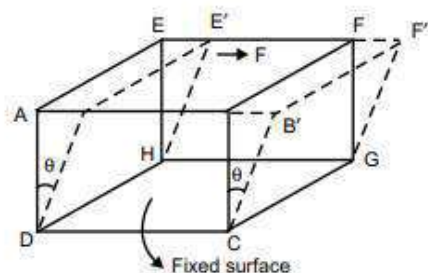
(b) Volume or Bulk



- If the equal deforming forces can be applied uniformly on each 6 faces of a cube in outward direction, then the cube suffers an increase in its volume. Under equilibrium, the applied force/unit area is called volume or bulk stress.

(c) Shearing Stress (or) Tangential Stress :

- If the deforming forces are applied tangentially over the top surface of a cube and bottom surface being kept fixed then, the top face gets displaced towards the direction of applied force.



- The tangential force/unit area or the stress which tends to make one part of the body slide across the other part is termed as shearing stress or tangential stress.

3.1.1. Strain

- A body under deforming forces undergoes a change in length, volume or shape. Then the body is said to be under strain. The strain produced in the body is measured in terms of the fractional change produced in the dimensions of a body. Under a system of forces in equilibrium strain is also measured as the ratio of change in dimension of the body to its original dimension. As strain is just a ratio, it is a dimensionless quantity, having no units.

Types of Strain

(a) Longitudinal strain or Tensile strain $L \Delta L$:

- If the deforming force is of the nature of pull or a tension and acting along the longitudinal axis of a wire of length L , and produces a change in length ΔL without any change in shape, then this fractional change $\Delta L/L$, is called longitudinal strain.

$$\text{Longitudinal Strain} = \frac{\text{change in length}}{\text{original length}} = \frac{\Delta L}{L}$$

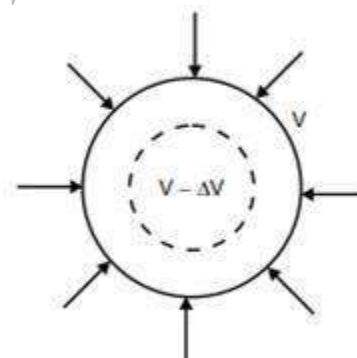


- If length increases from its natural length, then it is tensile strain. If in case there is decrease in length then it is compressive strain.

(b) Volume Strain

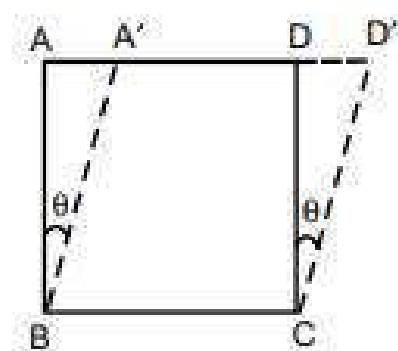
- When the forces or pressure are applied uniformly and normally inwards (or outwards) over the whole surface of a body of volume V , then its volume gets decreased (or increased) by an amount ΔV without any change in shape. The ratio of this change in volume to its original volume is called volume strain.

$$\text{Volume Strain} = \frac{\text{change in volume}}{\text{original volume}} = \frac{\Delta V}{V}$$



3.1.2. Shearing Strain or Shear

- **Fig.** When the deforming forces are applied tangentially over the top surface of the body, it suffers a change in shape without any change in volume or length and is said to be sheared. Shear is numerically equal to the ratio of the displacement of any layer in the direction of applied tangential force to its distance from the fixed surface.
- The strain produced is measured by an angle which a tilted surface makes with original vertical surface.



$$\frac{AA'}{AB} = \theta$$

- Strain produced by stretching or compressing force, both volume & shape of the body may alter, while the strain produced by shearing forces only the shape of the body is altered though the volume remains constant.

3.1.3. Elastic limit

- The maximum stress which produces maximum amount of recoverable deformation is called Elastic limit. If the stress applied exceeds the elastic limit, then the substance does not return to its original state when the stress is removed. The substance is then said to have acquired permanent set.

3.1.4. Hooke's Law

- If a substance is subjected to a stress below the elastic limit, it recovers completely when the stress is removed or within elastic limit, the stress is directly proportional to strain produced. The linear relationship between the stresses and deformations produced below elastic limit is called Hooke's law. (i.e.,) $\text{Stress} \propto \text{Strain}$
- $\text{Stress} / \text{Strain} = \text{Constant} = E \rightarrow \text{Modulus of elasticity (coefficient of elasticity)}$ The value of modulus of elasticity depends upon the type of stress and strain produced.

3.2. Young's Modulus

- If the strain is longitudinal then the modulus of elasticity is called "Young's Modulus" (Y).

$$Y = \frac{\text{Longitudinal stress}}{\text{Longitudinal strain}} = \frac{F/A}{\Delta L/L} = \frac{FL}{A\Delta L}$$

- Within elastic limit, the ratio of longitudinal stress to the corresponding longitudinal strain is called Young's modulus of elasticity.

3.2.1 Bulk Modulus

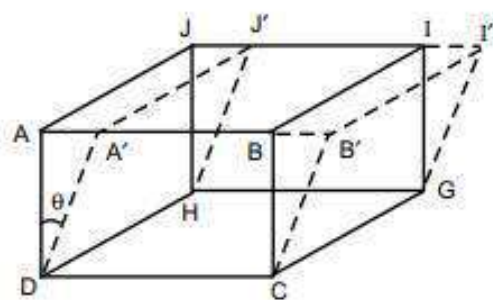
- When a uniform pressure (normal force) is applied normally over the whole surface of a body of an isotropic material, it suffers a change in its volume though its shape remains unchanged within elastic limit. The ratio of the volume stress to the volume strain is called bulk modulus of elasticity of the material.

$$K = \frac{\text{Volume stress}}{\text{Volume strain}} = \frac{F/A}{\Delta V/V} = \frac{FV}{A\Delta V}$$

- Reciprocal of K is called compressibility. Unit N/m^2 and its dimensional formula N/m^2
 $[ML^{-1}T^{-2}]$

3.2.2 Modulus of Rigidity

- When a body is subjected to tangential deforming force, it suffers a change in shape but volume remains unchanged. Then body is said to be sheared. The stress developed in this case is called shearing stress, due to which a shearing strain is developed. Within the elastic limit, the ratio of shearing stress or tangential stress to shearing strain is called modulus of rigidity of the material. If θ is angle of shear, then
- If θ is angle of shear, then



$$\tan \theta = \frac{BB'}{BC}$$

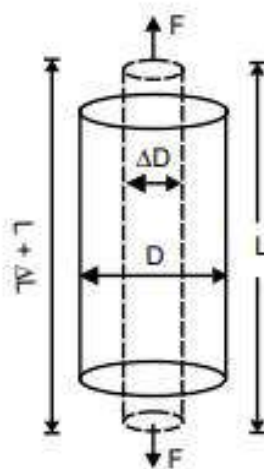
$$= \frac{\text{displacement of top surface}}{\text{displacement of top surface from fixed surface}}$$

$$n = \frac{\text{shearing stress}}{\text{shearing strain}} = \frac{F/A}{\theta}$$

Unit of n is N/m^2 and dimensional formula is $[ML^{-1}T^{-2}]$

3.2.3 Poisson's Ratio

- In the Fig, a wire of original length L and diameter D is acted upon by two equal and opposite force F along the length. Its length increases by ΔL , while its diameter decreases by ΔD .
- When a wire is pulled, it not only becomes longer but also thinner. If a force produces elongation or extension in its own direction, a contraction also occurs in a direction perpendicular to it, that is in lateral direction or vice versa. The fractional change in the direction of applied force is longitudinal strain, fractional change in perpendicular direction is lateral strain. Within elastic limit, ratio of lateral strain to longitudinal strain is constant for a given material and is called poisson's ratio (σ).



$$\alpha = \frac{\Delta L}{L}; \beta = \frac{\Delta D}{D}$$

$$\sigma = \frac{\beta}{\alpha} = \frac{\text{lateral strain}}{\text{longitudinal strain}} = \frac{-\left(\frac{\Delta D}{D}\right)}{\Delta L / L}$$

$$= -\frac{L \Delta D}{D \Delta L}$$

σ as a differential coefficient,

$$\sigma = \frac{L dD}{D dL}$$

- Minus sign indicates that increase in the direction of force would be accompanied by decrease in the direction perpendicular to the force. σ is dimensionless and has no units.

3.3. Relation Between the Three Moduli of Elasticity (Y, K and n)

- To arrive at the relation between Young's modulus, bulk modulus and rigidity modulus, the three moduli need to be expressed in terms of longitudinal strain (α) and lateral strain (β) and hence in terms of σ (Poisson's ratio) must be known

(i) Relation between Young's modulus and α

$$Y = \frac{1}{\alpha}$$

(ii) Bulk modulus in terms of α and β

$$K = \frac{1}{3(\alpha - 2\beta)}$$

(iii) Rigidity modulus in terms of α and β

$$K = \frac{1}{2(\alpha + \beta)}$$



(iv) Relation between Y, K and σ

$$\sigma = \frac{\beta}{\alpha} \quad Y = \frac{1}{\alpha}$$

$$K = \frac{1}{3(\alpha - 2\beta)}$$

$$\text{now } K = \frac{1}{3\alpha(1-2(\beta/\alpha))} = \frac{1/\alpha}{3(1-2\sigma)} = \frac{Y}{3(1-2\sigma)} \quad \left(\because Y = \frac{1}{\alpha} \right)$$

$$(\text{or}) \quad \boxed{Y = 3K(1-2\sigma)} \quad (1)$$

(v) Relation between n, Y and σ

$$n = \frac{1}{2(\alpha + \beta)}$$

$$= \frac{1}{2\alpha(1 + \beta/\alpha)} = \frac{1/\alpha}{2(1 + \sigma)} = \frac{Y}{2(1 + \sigma)}$$

$$(\text{or}) \quad \boxed{Y = 2n(1 + \sigma)} \quad (2)$$

(vi) Relation between Y, K, n and σ and Relation between the three moduli of Elasticity

Now from (1) and (2)

$$Y = 3K(1-2\sigma) \text{ and } Y = 2n(1 + \sigma)$$

$$(\text{or}) \quad \frac{Y}{3K} = 1 - 2\sigma \quad (3)$$

$$\text{and } \frac{Y}{n} = 2(1 + \sigma) \quad (4)$$

Adding the two equations (3) and (4)

$$\frac{Y}{3K} + \frac{Y}{n} = 3 \quad (\text{or}) \quad \boxed{Y = \frac{9Kn}{n + 3K}}$$

$$(\text{or}) \quad \boxed{\frac{9}{Y} = \frac{1}{K} + \frac{3}{n}}$$

Now, Dividing equations (3) and (4)

$$\frac{n}{3K} = \frac{1-2\sigma}{2(1+\sigma)} \quad (\text{or}) \quad 2n(1+\sigma) = 3K(1-2\sigma)$$

$$(\text{or}) \quad 2n + 2n\sigma = 3K - 6K\sigma$$

$$(or) \quad \sigma = \frac{3K - 2n}{2n + 6K} = \frac{3K - 2n}{2(n + 3K)}$$

Limiting values of poisons ratio

We know $Y = 3K(1 - 2\sigma)$ & $Y = 2n(1 + \sigma)$

$$3K(1 - 2\sigma) = 2n(1 + \sigma)$$

(i) If σ is positive, RHS is positive

LHS must be positive.

It will be only when $2\sigma < 1$

$$\sigma < \frac{1}{2}$$

$$\sigma < 0.5$$

(ii) If σ is negative, LHS is positive

RHS to be positive.

$$1 + \sigma > 0$$

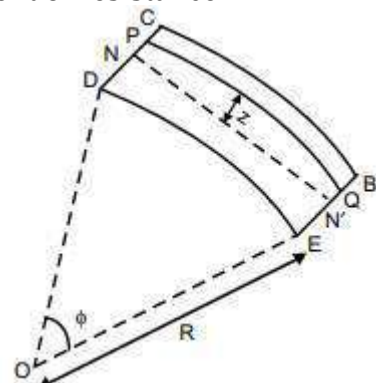
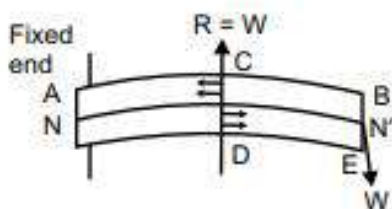
$$\sigma < -1$$

$$-2 < \sigma < -\frac{1}{2}$$

3.4. Bending Moment

- When a beam is bent under the action of a pair of two equal and opposite couples acting at its ends, to oppose this bending, an internal bending (restoring) couple is developed at each cross section of the beam, due to its elastic properties. In equilibrium, the restoring couple is equal and opposite to the external bending couple. The moment of the restoring couple is called bending moment or moment of resistance.

3.4.1. Expression for Bending Moment



- Assume weight of the beam is negligibly small as compared to the load suspended and its cross section remains unaltered by the action of applied forces. The Fig., shows longitudinal section of a beam, whose one end is clamped and other end is depressed by a load W . Let the beam be divided into two parts by a plane CD and NN' is neutral surface. Consider the equilibrium of part CD . Filaments above neutral surface are extended and below are compressed. Filaments above are in tensile stress and their portions to the left of CD exerts a pulling force on their portions to the right of CD . Filaments below are in compressive stress and their portions to the left of CD exert a pushing force on their portions to the right of CD . The tensile stress developed in the upper half of beam and compressive stress in the lower half of the beam constitute a couple called restoring couple (in the direction opposite to the bending couple). To find the magnitude of this restoring couple or bending moment, consider the part CB of the bent beam and forces acting over the section D as shown in fig. Let the portion $BCDE$ subtend an angle ϕ at the centre of curvature 'O' of the arc and R be the radius of curvature of the neutral axis NN' . Consider a filament PQ at a distance z above the neutral axis. Then from Fig.,

$$PQ = (R + z)\phi$$

$$NN' = R\phi$$

- Before bending, each filament was of the same length as neutral filament.

$$(i.e) PQ = NN' = R\phi$$

$$\therefore \text{Extension in } PQ \text{ on bending} = PQ - NN' = (R + z)\phi - R\phi = z\phi$$

- Longitudinal strain for this filament

$$= \frac{\text{Increase in length}}{\text{Original length}} = \frac{z\phi}{R\phi} = \frac{z}{R}$$

- If f be the force acting longitudinally on the filament under consideration, a area of cross section and Y Young's modulus of the beam, then

$$Y = \frac{\text{longitudinal stress}}{\text{longitudinal strain}} = \frac{f/a}{z/R}$$

$$f = \frac{Ya}{R} z$$

- Moment of this force about the neutral axis is

$$fz = \frac{Ya}{R} z^2$$

- Sum of moments of all these elementary forces of push and pull acting over entire cross section CD of the beam is the magnitude of the bending moment at this section.

∴ Bending moment

$$= \sum fz = \sum \frac{Ya}{R} z^2 = \frac{Y}{R} \sum az^2$$

- The quantity $\sum az^2$ is analogous to $\sum mr^2$, known as geometrical moment of inertia I_g

$\text{Bending moment} = \frac{YI_g}{R}$
--

- Geometrical moment of inertia for

- Rectangular cross section = $\frac{bd^3}{12}$ (breadth – b, thickness of the beam – d)

- Bending moment = $\frac{Ybd^3}{12R}$

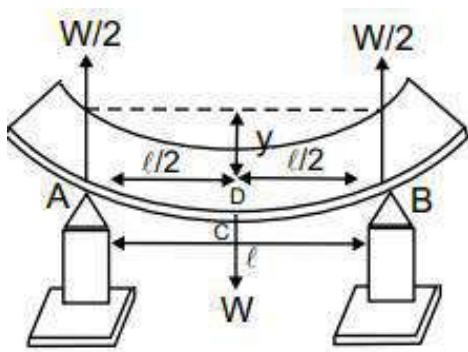
- For circular cross section of radius r

$$I_g = \frac{\pi r^4}{4}$$

- Bending moment = $\frac{Y\pi r^4}{4R}$

3.5. Non-Uniform Bending - Depression at the Mid-Point of a Beam Loaded at The Middle

- Consider a beam of length 'l' (distance between two knife edges) supported on the two knife edges A and B. A load of weight 'W' is suspended at the center 'C'. It is found that the beam bends and the maximum displacement is at the point 'D', where the load is given. Due to load (W) applied, at the middle of the beam the reaction W/2 is acted vertically upwards at each knife edges - The bending is called non uniform bending. The beam may be considered as two cantilevers, whose free end carries a load W/2 each of length l/2 and fixed at the point 'D'.



- Hence, we can say the elevation of A above D as the depression of D below A. We know, Depression of cantilever.

$$\frac{wl^3}{3YI_g} = y$$

Therefore substituting $l = \frac{l}{2}$ & $W = \frac{W}{2}$ we get

$$\frac{wl^3}{48YI_g} = y$$

3.5.1. Experimental Determination of Young's Modulus - Non-Uniform Bending

- It consists of a beam, symmetrically supported on the two knife edges A and B. A weight hanger is suspended at the center (C) of the beam by means of a loop. A pin is fixed vertically at 'C' by some wax. The tip of the pin is focussed by a travelling microscope. Taking weight hanger as a dead load (W) the microscope is adjusted & the tip is made to coincide with horizontal cross wire. The readings is noted from the vertical scale of the microscope. Weights are added in steps of m, 2m, 3m kg and corresponding readings are taken. Same procedure is repeated for unloading and readings are tabulated.

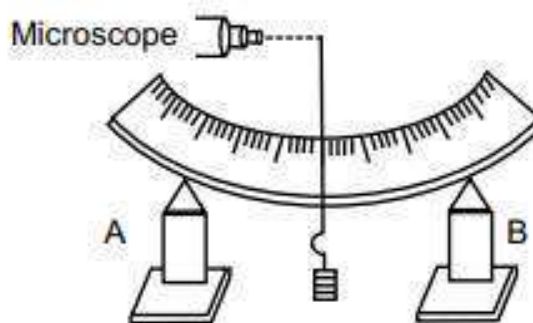


Fig. 19

The mean depression y is found for a load of m kg.



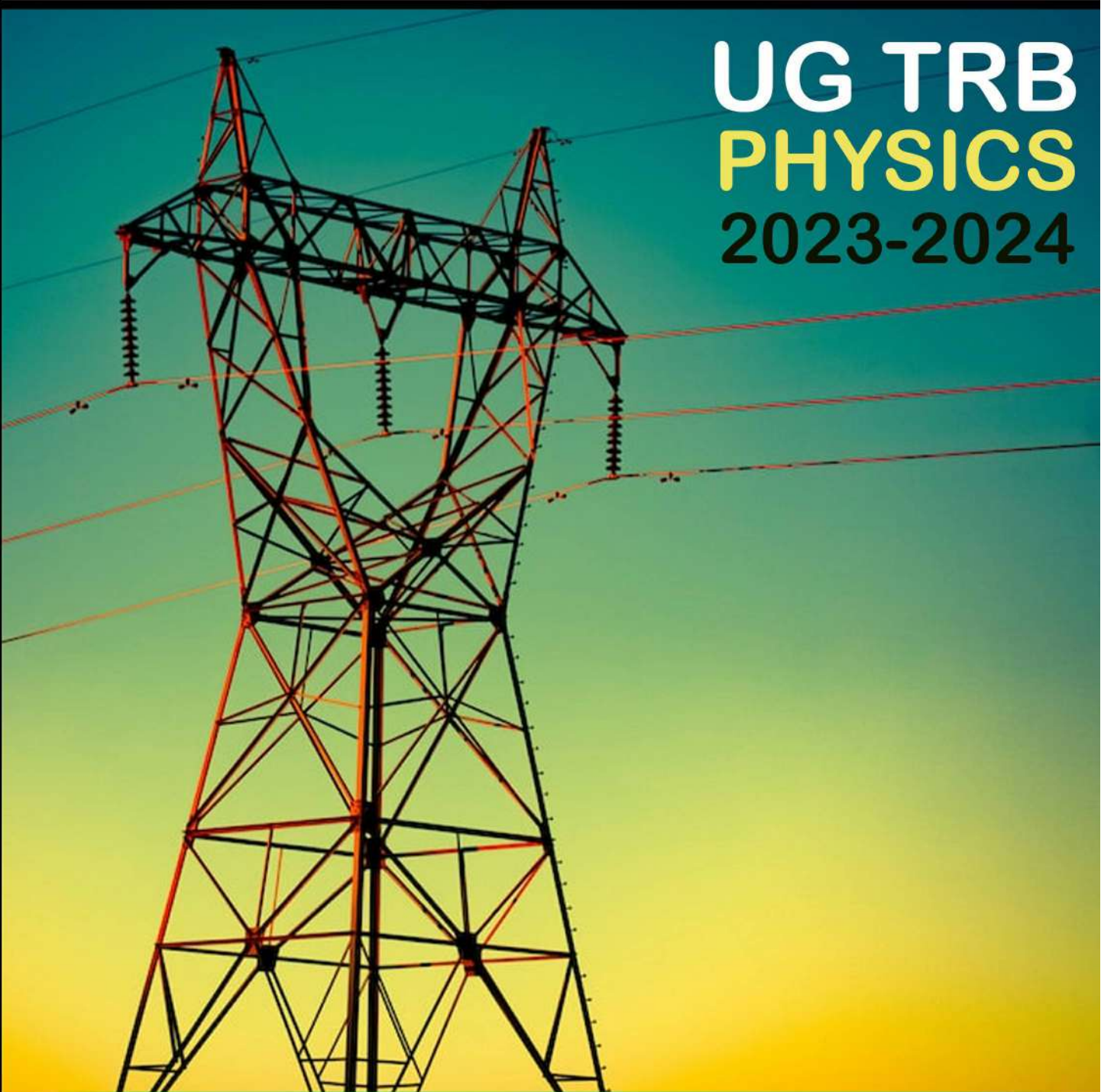
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UNIT-4

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UG TRB PHYSICS – 2023-24

UNIT 4

ELECTRICITY AND MAGNETISM

4.1. Introduction

Electrostatics:

- Electromagnetics is the branch of physics in which electric, magnetic fields and interaction of electric, magnetic fields are studied
- Electrostatics is a branch of physics in which static **electric field** produced by static **electric charges** are studied.
- The computer peripheral devices include liquid crystal display (LCD), keyboard, touch pads works on the principle of electrostatics.

Electric Charge:

- Electric charge is the property of sub-atomic particles particularly includes electrons and protons. Electrons have negative charge, protons have positive charge and neutrons do not have any charge.
- The charge of electrons and protons is measured in coulombs, represented by C. Electron has a charge of -1.602×10^{-19} Coulombs (c) and proton has a charge of $+1.602 \times 10^{-19}$ Coulombs (C). The charge of an electron is equal to the charge of a proton. However, electron has a negative value of charge and proton has a positive value of charge.
- The number of electrons and protons in the atom are equal in number. Due to the opposite charges of electrons and protons the charges get cancel each other and the atom remains neutral.

- If the atom has unequal number of electrons and protons, then the atom is said to be a charged atom. If the atom has more number of electrons (negative charges) than protons (positive charges), then it is said to be negatively charged. Similarly, if the atom has more number of protons than electrons, then it is said to be positively charged.

Properties of electric charge:

- The various properties of electric charge include:
 - Additivity of charges
 - Charge is conserved
 - Quantization of charge

Additivity of charges:

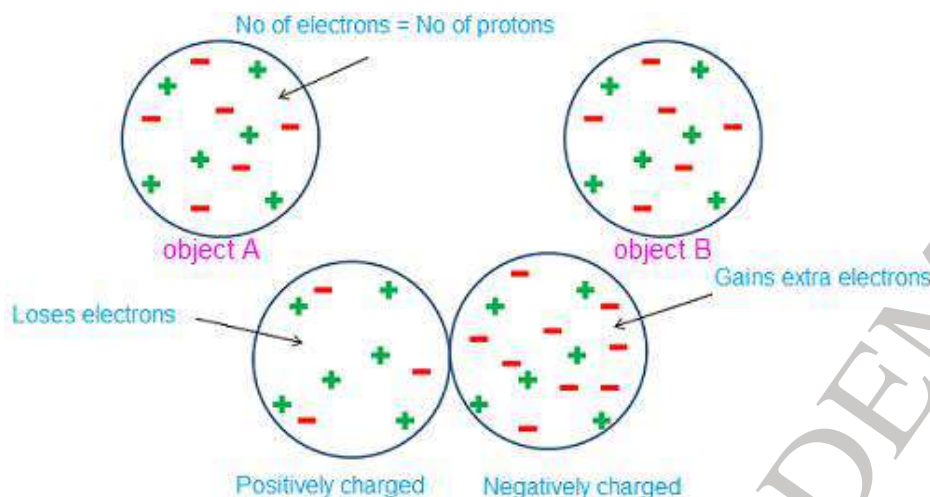
- If a system contains two point charges q_1 and q_2 , then the total charge of the system is obtained by simply adding q_1 and q_2 , i.e., charges add up like real numbers.
- If a system contains n number of charges $q_1, q_2, q_3, q_4, \dots, q_n$, then the total charge of the system is $q_1 + q_2 + q_3 + q_4 + \dots + q_n$.
- Charge is a scalar quantity; it has magnitude but no direction, similar to mass. However, there is one difference between charge and mass. Mass of a body is always positive whereas charge can be either positive or negative.
- Let us take for example, the system containing four charges $q_1 = +2C, q_2 = +3C, q_3 = -3C, q_4 = +4C$, then the total charge of the system is

$$\begin{aligned} q &= q_1 + q_2 + q_3 + q_4 \\ &= (+2) + (+3) + (-3) + (+4) \\ &= +6C \end{aligned}$$

- Therefore, the total charge of the system is $+6C$ and it is positively charged.

Charge is Conserved

- The law of conservation of charge states that charge cannot be created or destroyed. However, a charge can be transferred from one object to other.
- Let us consider two objects, object A and object B. Object A has equal number of electrons and protons. So, it is electrically neutral. Similarly, object B has equal number of electrons and protons. So, it is also electrically neutral.



- When object A and object B are rubbed with each other, negative charges from object A can be transferred to object B. Hence, object B has more number of electrons than protons due to gaining of extra electrons. Similarly, object A has lesser number of electrons than protons due to losing of some electrons.
- Therefore, object A becomes positively charged and object B becomes negatively charged. However, the total charge of an isolated system remains constant.

Quantization of Charge

- The charge of any object is equal to integer multiples of the elementary charge. This is known as quantization of charge. It is given by

$$q = ne \quad (\text{or}) \quad n(-e)$$

Where q = electric charge of any object or body

n = any integer positive or negative

$-e$ = elementary charge = charge carried by single electron.

e = elementary charge = charge carried by single proton.

- The charge on an electron is written as $-e$ and charge on a proton is written as $+e$. The quantization of charge was first suggested by the experimental laws of electrolysis discovered by Faraday. It was experimentally proved by Millikan. The total charge on a object is equal to the algebraic sum of individual charges present within the object.
- If an object contains n_1 electrons and n_2 protons, then the total charge on the object is $n_1 \times (-e) + n_2 \times e$. For example, if the object contains 150 electrons and 200 protons, then the total charge on the object is $-150e + 200e = 50e$. Hence, the object is positively charged. The object charge can be exactly $0e$ or $1e, 2e \dots$ or $-1e, -2e \dots$ but not $\frac{1}{2}, \frac{1}{4}$ etc.

4.2. Coulomb's Law:

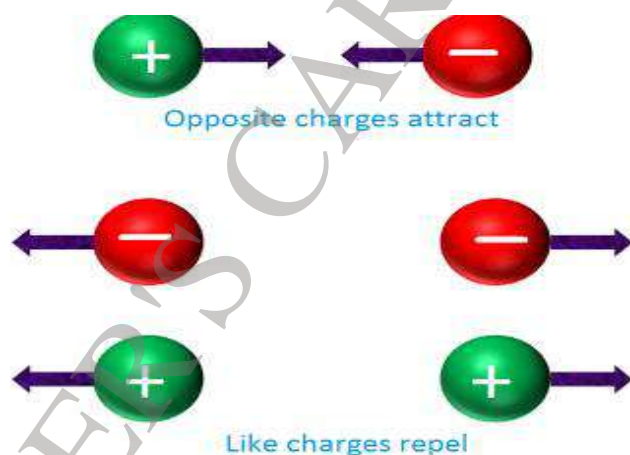
- The study of electrostatics begins with the Coulomb's law. Coulomb's law is an experimental law published in 1785 by French physicist Charles Augustin de Coulomb. This law is very important for the development of theory of electromagnetism.
- Charles Coulomb observed that when two electric charges are placed close to each other, they experience a force. He used a torsion balance to measure the repulsive and attractive forces between charged particles.

Statement of Coulomb's law

- Charles coulomb has developed the two laws on the basis of his experiments, which are known as Coulomb's law of electrostatics.

First law

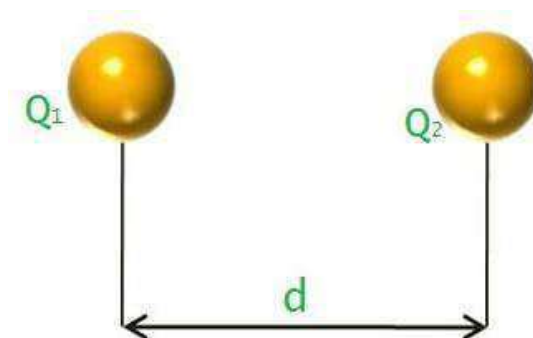
- Coulomb's first law states that two charged particles of same charge (positive or negative) will repel each other and two charged particles of opposite charges (one positive and one negative) will attract each other.



- If two positively or negatively charged particles are placed close to each other, they get repelled. On the other hand, if one positively charged particle and one negatively charged particle is placed close to each other, they get attracted.

Second law

- Coulomb's second law states that, the force of attraction or repulsion between the two electrically charged particles is directly proportional to the product of magnitudes of two charges and inversely proportional to the square of the distance between two charges.
- This force of attraction or repulsion between two charges is also depends on the medium in which charges are placed.



- If we increase the distance between two-point charges, the force of attraction or repulsion present between them will decrease. In the similar way, if we decrease the distance between two-point charges, the force of attraction or repulsion present between them will increase.

Coulomb's law can be Mathematically Written as

$$F \propto \frac{Q_1 Q_2}{d^2} \text{ (or) } F = k \frac{Q_1 Q_2}{d^2}$$

Where,

F = Force of attraction or repulsion between the charges

Q_1, Q_2 = Magnitude of charge 1 and charge 2

d = Distance between two charges.

k = Constant whose value depends on the medium in which charges are placed.

$$k = \frac{1}{4\pi\epsilon}$$

Where $\epsilon = \epsilon_0 \epsilon_r$

$$k = \frac{1}{4\pi\epsilon_0 \epsilon_r}$$

Where,

ϵ_0 = permittivity of vacuum = $8.854 \times 10^{-12} \text{ F/m or } \text{C}^2$

ϵ_r = relative permittivity of medium with respect to free space.

4.3. Relative Permittivity:

For vacuum, the relative permittivity $\epsilon_r = 1$,

Hence $\epsilon = \epsilon_0$

Therefore, the force of attraction or repulsion between two electric charges that are placed in vacuum and medium is given by

$$F = \frac{Q_1 Q_2}{4\pi \epsilon_0 d^2} \text{ in vacuum}$$

$$F = \frac{Q_1 Q_2}{4\pi \epsilon_0 \epsilon_r d^2} \text{ in medium}$$

Units and Dimensions of Permittivity of Free Space:

Dimension Analysis :

$$\begin{aligned} \epsilon_0 &= \frac{[TA]^2}{[MLT^{-2}][L^2]} \\ &= \frac{[TA]^2}{[ML^3T^{-2}]} \\ &= [M^{-1}L^3T^4A^2] \end{aligned}$$

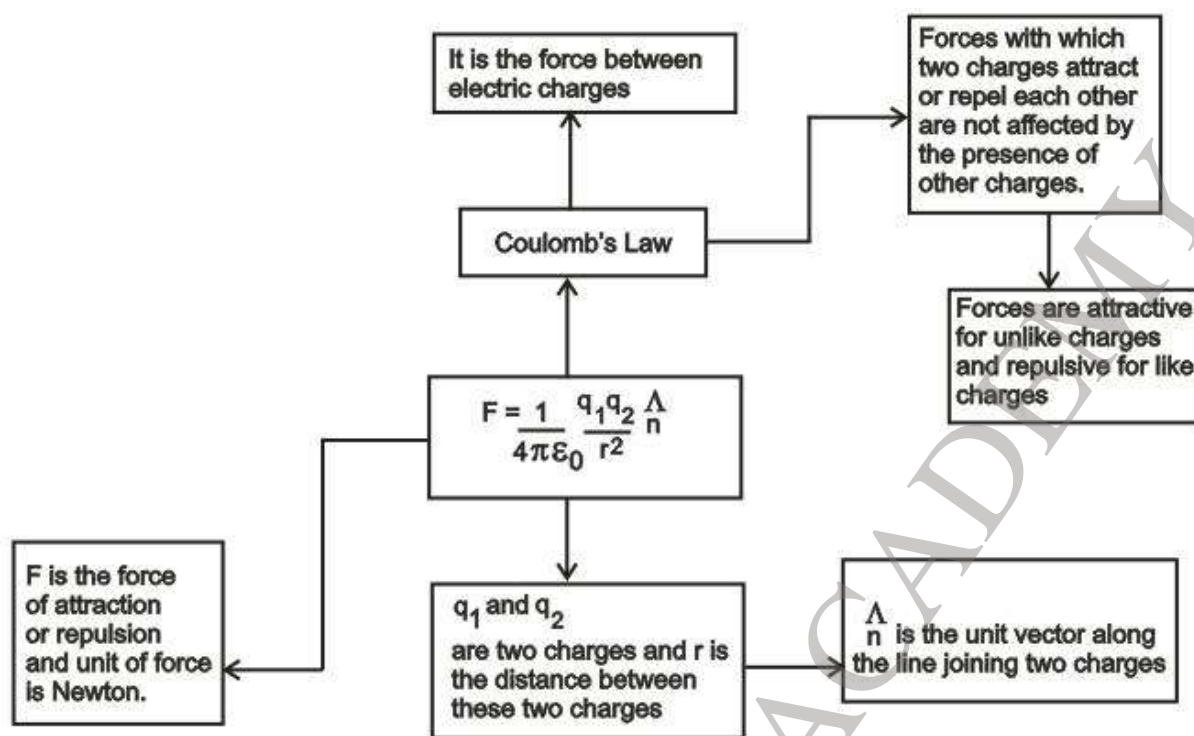
Where $[A]$ is the dimension of electric current

Unit:

$$F = \frac{1}{4\pi\epsilon_0} \frac{q^2}{r^2} \quad \epsilon_0 = \frac{1}{4\pi} \frac{q^2}{Fr^2} = C^2 / N-m^2$$

4.3.1. Applications:

- To calculate the force between two charges
- To calculate the distance between two charges
- To study the motion of electrons around an orbit in an atom
- To calculate the electrostatic potential and hence the work done in moving a charge from one point to another.
- To calculate the relative permittivity (dielectric constant) of a medium.



4.4. Electric field or electric field intensity:

- If we place a test body carrying a positive electric charge q near a charged rod, an electrostatic force F will act on it.

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

- Electric field at a point is defined as the force that acts on a unit positive charge placed at that point. The direction of the vector E is that of vector F .
- SI unit of electric field is Newton/ Coulomb Wc^{-1} or volt/metre (Vm^{-1})

Dimensions of electric field strength

$$E = \frac{\text{Dimension of force}}{\text{Dimension of charge}} = \frac{[MLT^{-2}]}{AT}$$

$$= [MLT^{-3}A^{-1}]$$

$$F = qE$$

- The force F exerted on a charge q at a point where the electric field is E equals the product of the electric field and the charge.

- For a configuration which has a number of discrete stationary charges, the net electric field at a point is the vector sum of the individual electric fields due to each charge.

$$E = E_1 + E_2 + E_3 + \dots$$

$$= \sum E_i$$

$$= \frac{1}{4\pi\epsilon_0} \left[\frac{q}{r_1^2} \hat{r}_1 + \frac{q_2}{r_2^2} \hat{r}_2 + \frac{q_3}{r_3^2} \hat{r}_3 + \dots \right]$$

$$E = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i^2} \hat{r}_i$$

For a continuous charge distribution, the electric field E at any point is given by,

$$E = \frac{1}{4\pi\epsilon_0} \int \frac{dq}{r^2} \hat{r}$$

4.4.1. Continuous Charge Distributions

- Three types of charge distributions namely,
 - Linear charge distribution
 - Surface charge distribution
 - Volume charge distribution

(i) Line charge:

$\lambda \rightarrow$ charge per unit length.

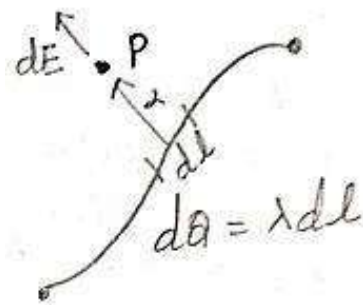
- If a charge is distributed over a line, each differential charge dQ along the line produces a differential electric field at P .

$$dE = \frac{dQ}{4\pi\epsilon_0 r^2} \hat{r}$$

- The total electric field at P ,

$$E(P) = \frac{1}{4\pi\epsilon_0} \int_{line} \frac{\hat{r}}{r^2} \lambda dl$$

- $r \rightarrow$ distance from the element of charge dl to the point P .



(ii) Surface Charge:

Charge may also be distributed over a surface.

σ - Charge per unit area.

$$dQ = \sigma da$$

$da \rightarrow$ small element of surface area

$$dE = \frac{dQ}{4\pi\epsilon_0 r^2} \hat{r}$$

The total electric field at P is

$$E(P) = \frac{1}{4\pi\epsilon_0} \iint \frac{\hat{r}}{r^2} \sigma da$$

(iii) Volume charge:

Charge spread throughout a volume is described by ρ

ρ - charge per unit volume

$$dQ = \rho d\tau$$

$d\tau \rightarrow$ small element of volume

The total electric field at P is obtained by integration over the volume.

$$E(P) = \frac{1}{4\pi\epsilon_0} \iiint \frac{\hat{r}}{r^2} \rho d\tau$$

$r \rightarrow$ distance from the element of charge $d\tau$ to the point P.

4.5. Electric Field Due to a Point Charge:

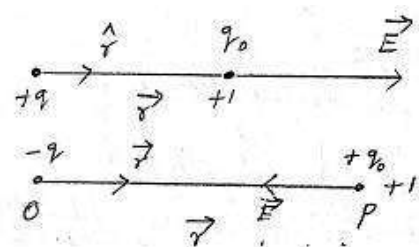
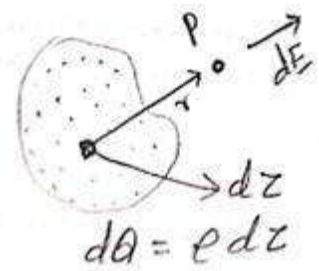
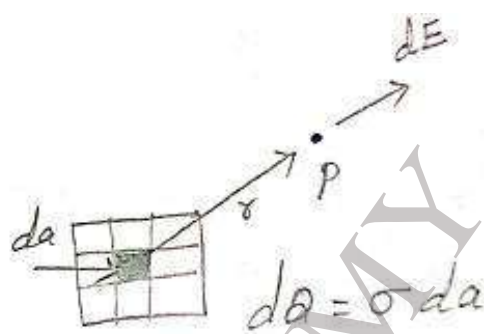
P \rightarrow point lying in vacuum at a distance r from a point charge q lying at O.

According to Coulomb's law, the force F acting on q_0 due to q is,

$$F = \frac{1}{4\pi\epsilon_0} \frac{q q_0}{r^2} \hat{r}$$

$q_0 \rightarrow$ Test charge placed at P.

The electric field at the point P is,



The electric field is given by the force per unit test charge $E = \frac{F}{q_0}$

$$= \frac{1}{4\pi\epsilon_0 q_0} \frac{q q_0}{r^2} \hat{r}$$

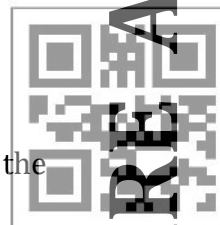
$$E = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{r}$$

The direction of E is along the line joining O and P, pointing outward if q is positive and inward if q is negative.

Exercise - 1

- Coulomb is the unit of which quantity?
 - Field strength
 - Charge
 - Permittivity
 - Force
- Coulomb law is employed in
 - Electrostatics
 - Magnetostatics
 - Electromagnetics
 - Maxwell theory
- Two charges 1 C and – 4 C exists in air. What is the direction of force?
 - aways from 1 C
 - From 1 C to – 4 C
 - away from – 4 C
 - From – 4 C to 1 C
- The Coulomb law is an implication of which law?
 - Ampere law
 - Gauss law
 - Biot Savart law
 - Lenz law
- For a charge Q_1 , the effect of charge Q_2 on Q_1 will be
 - $F_1 = F_2$
 - $F_1 = -F_2$
 - $F_1 = F_2 = 0$
 - F_1 and F_2 are not equal
- Coulomb's law is valid for _____.
 - only point charge
 - for both point charge and distributed charge

- (C) only distributed charge
- (D) neither distributed nor point charge
7. Which one of the following is similar between electrostatic force and gravitational force?
- (A) Force can be attractive or repulsive
- (B) The force depends on the medium between the bodies
- (C) Both the forces are strong forces
- (D) Force is inversely proportional to the distance between the bodies
8. Two 1 coulomb charges are kept at 1 m distance in air medium. Force of attraction or repulsion between them will be ____.
- (A) $9 \times 10^9 \text{ N}$ (B) 1 dyne
- (C) 1 N (D) $3 \times 10^3 \text{ N}$
9. Two charges q_1, q_2 exert some amount of force on each other. What will happen to the force on q_1 if another charge q_3 is brought close to them?
- (A) The force will increase
- (B) The force will decrease
- (C) The force remains the same
- (D) The force may increase or decrease depending on whether q_3 is positive or negative
10. Two negative charges are kept at a certain distance in the air medium. What will happen if a dielectric slab is inserted between them?
- (A) The slab will get heated
- (B) Current will flow through the slab
- (C) Two charges will be attracted each other
- (D) The net force between the charges will be reduced
11. Unlike charges can ____ each other.
- (A) attracts each other (B) repels each other
- (C) either attracts or repels (D) neither attracts nor repels





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UNIT-5

Atomic and Nuclear Physics

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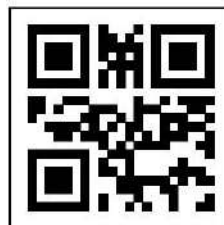
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UNIT 5– ATOMIC &NUCLEAR PHYSICS

5.1. Bohr Atom Model

Atom Models:

- There has been a variety of atomic models throughout history of atomic physics, that refers mainly to a period from the beginning of 19th century to the first half of 20th century, when a final model of atom which is being used nowadays was invented. The basic atom models are,
 - Dalton's Billiard Ball Model,
 - J.J Thomson's "plum pudding" model
 - Rutherford's Planetary model
 - Bohr's Atomic model
 - Sommerfeld Relativistic atom model
 - Vector Atom model



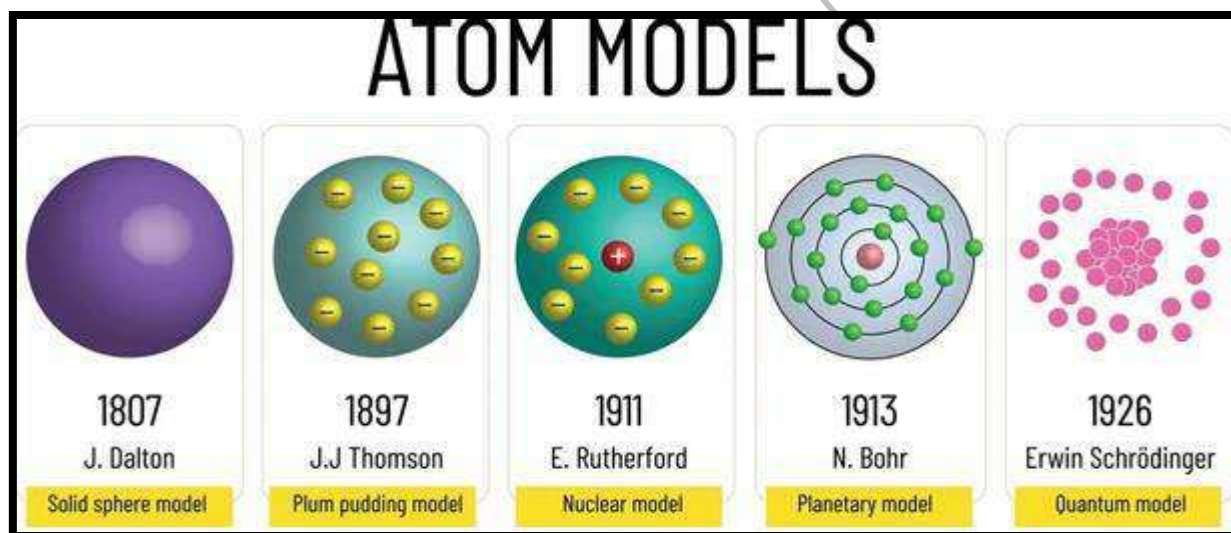
John Dalton's Atomic Model:

- John Dalton was an English scientist, who came up with an idea that all matter is composed of very small things. It was the first complete attempt to describe all matter in terms of particles. He called these particles atoms and formed an atomic theory. In this theory he claims that:
 - All matter is made of atoms. Atoms are indivisible and indestructible
 - All atoms of a given element are identical in mass and properties
 - Compounds are formed by a combination of two or more different kinds of atoms
 - A chemical reaction is a rearrangement of atoms

- Parts of his theory had to be modified based on the discovery of subatomic particles and isotopes. We now also know that atoms are not indivisible, because they are made up of neutrons, electrons and protons.

J.J. Thomson's Plum Pudding Model:

- After discovery of an electron in 1897, people realized that atoms are made up of even smaller particles. In 1904 J. J. Thomson proposed his famous "plum pudding model". In this model, atoms were known to consist of negatively charged electrons, however the atomic nucleus had not been discovered yet. Thomson knew that atom had an overall neutral charge. He thought that there must be something to counterbalance the negative charge of an electron. He came up with an idea that negative particles are floating within a soup of diffuse positive charge. His model is often called the plum pudding model, because of his similarity to a popular English dessert.

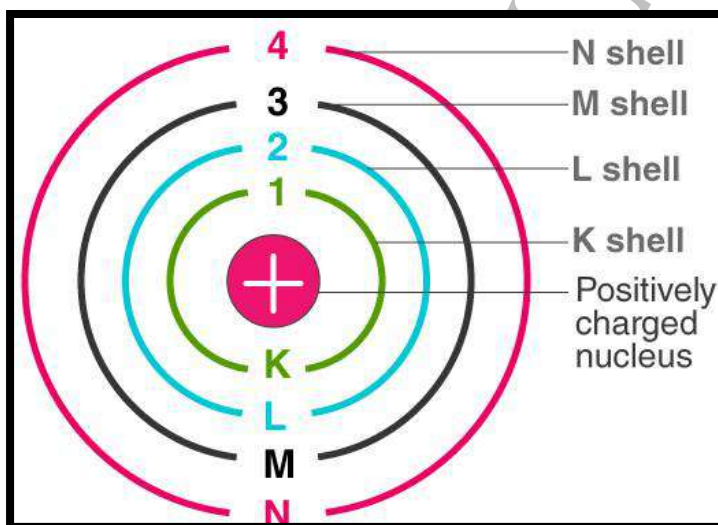


Rutherford's Planetary Model :

- Rutherford overturned Thomson's model in 1911 with his well-known gold foil experiment in which he demonstrated that the atom has a tiny and heavy nucleus. Rutherford designed an experiment to use the alpha particles emitted by a radioactive element as probes to the unseen world of atomic structure. If Thomson was correct, the beam would go straight through the gold foil. Most of the beams went through the foil, but a few were deflected.
- Rutherford presented his own physical model for subatomic structure, as an interpretation for the unexpected experimental results. In it, the atom is made up of a central charge surrounded by a cloud of orbiting electrons. Rutherford only committed himself to a small central region of very high positive or negative charge in the atom.

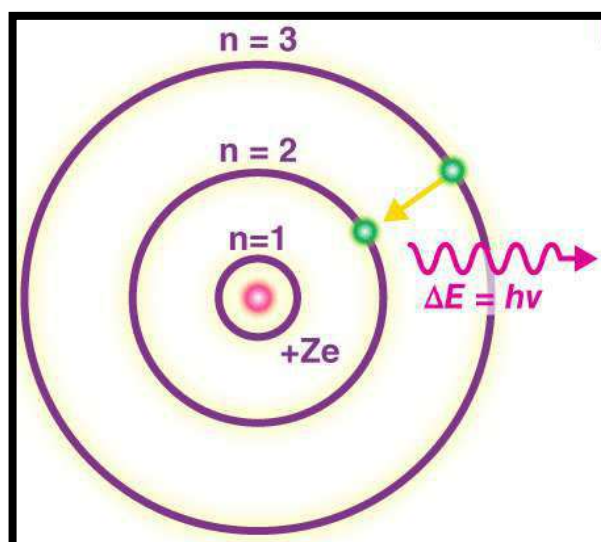
Bohr's Atom Model:

- Bohr model of the atom was proposed by Neil Bohr in 1915. Bohr theory Applicable to modified the atomic structure model by explaining that electrons move in fixed orbitals (shells) and not anywhere in between and he also explained that each orbit (shell) has a fixed energy level. Rutherford basically explained the nucleus of an atom and Bohr modified that model into electrons and their energy levels.
- Bohr's model consists of a small nucleus (positively charged) surrounded by negative electrons moving around the nucleus in orbits. Bohr found that an electron located away from the nucleus has more energy, and electrons close to the nucleus have less energy.



Postulates of Bohr's Model of an Atom:

- In an atom, electrons (negatively charged) revolve around the positively charged nucleus in a definite circular path called orbits or shells.
- Each orbit or shell has a fixed energy and these circular orbits are known as orbital shells.
- The energy levels are represented by an integer ($n=1, 2, 3, \dots$) known as the quantum number. This range of quantum number starts from nucleus side with $n=1$ having the lowest energy level. The orbits $n=1, 2, 3, 4, \dots$ are assigned as K, L, M, N.... shells and when an electron attains the lowest energy level, it is said to be in the ground state.
- The electrons in an atom move from a lower energy level to a higher energy level by gaining the required energy and an electron moves from a higher energy level to lower energy level by losing energy.



Limitations of Bohr's Model of an Atom:

- Bohr's model of an atom failed to explain the Zeeman Effect (effect of magnetic field on the spectra of atoms).
- It also failed to explain the Stark effect (effect of electric field on the spectra of atoms).
- It violates the Heisenberg Uncertainty Principle.
- It could not explain the spectra obtained from larger atoms.
- It does not explain fine structure of spectral lines.

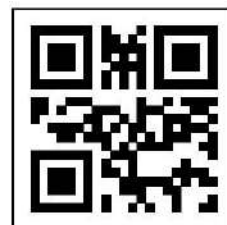
Exercise Questions: I

1. Who was the first to discover that electrons revolve around the nucleus?

- A) Dalton B) Rutherford C) Bohr D) Thomson

2. Electrons revolving in an orbit have fixed

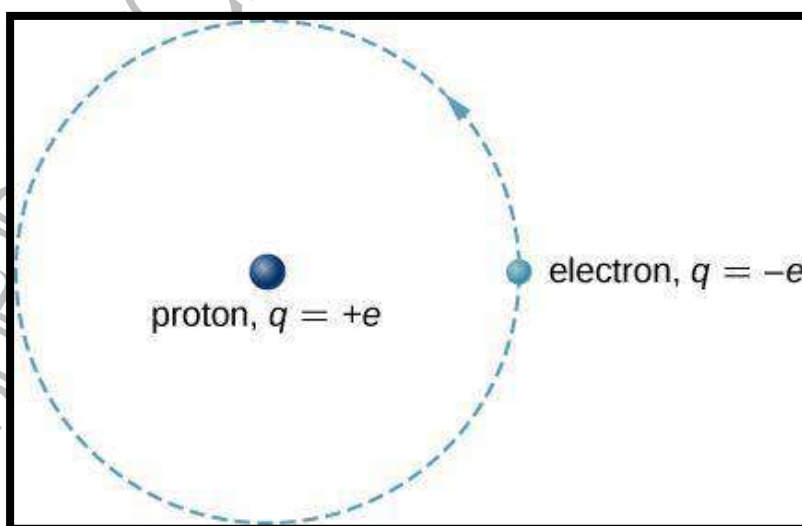
- A) Thickness B) Shape C) Angular momentum D) Route



5.2. Hydrogen Atom:

- ❖ The hydrogen atom is the simplest atom in nature and, therefore, a good starting point to study atoms and atomic structure. The hydrogen atom consists of a single

negatively charged electron that moves about a positively charged proton. In Bohr's model, the electron is pulled around the proton in a perfectly circular orbit by an attractive Coulomb force. The proton is



approximately 1800 times more massive than the electron, so the proton moves very little in response to the force on the proton by the electron. (This is analogous to the Earth-Sun system, where the Sun moves very little in response to the force exerted on it by Earth.) An explanation of this effect using Newton's laws is given in Photons and Matter Waves.

- With the assumption of a fixed proton, we focus on the motion of the electron.
- In the electric field of the proton, the potential energy of the electron is

$$U(r) = -ke^2 / r,$$

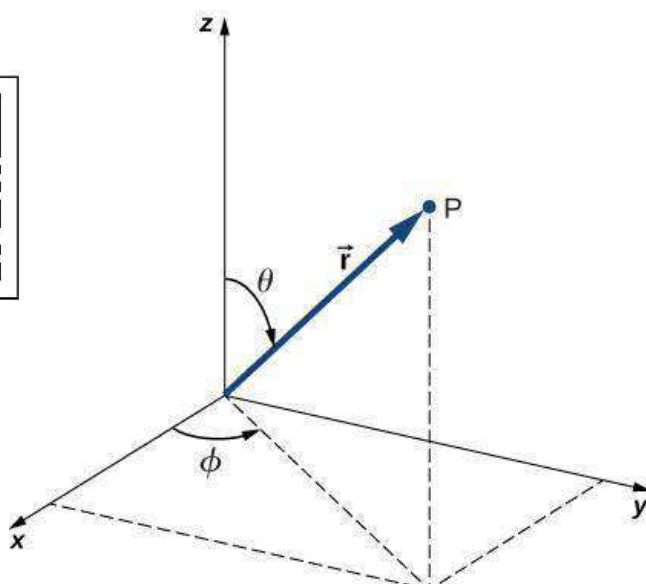
Where $k = 1 / 4\pi \epsilon_0$

- and r is the distance between the electron and the proton. As we saw earlier, the force on an object is equal to the negative of the gradient (or slope) of the potential energy function. For the special case of a hydrogen atom, the force between the electron and proton is an attractive Coulomb force.
- Notice that the potential energy function $U(r)$ does not vary in time. As a result, **Schrödinger's equation** of the hydrogen atom reduces to two simpler equations: one that depends only on space (x, y, z) and another that depends only on time (t). (The separation of a wave function into space- and time-dependent parts for time-independent potential energy functions is discussed in Quantum Mechanics.) We are most interested in the space-dependent equation:

$$-\frac{h}{2m_e} \left(\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} + \frac{\partial^2 \psi}{\partial z^2} \right) - k \frac{e^2}{r} \psi = E\psi$$

- where $\psi = \psi(x, y, z)$ is the three-dimensional wave function of the electron, m_e is the mass of the electron, and E is the total energy of the electron. Recall that the total wave function $\psi(x, y, z, t)$, is the product of the space-dependent wave function $\psi = \psi(x, y, z)$ and the time-dependent wave function $\phi = \phi(t)$
- In addition to being time-independent, $U(r)$ is also spherically symmetrical. This suggests that we may solve Schrödinger's equation more easily if we express it in terms of the spherical coordinates (r, θ, ϕ) instead of rectangular coordinates (x, y, z) . A spherical coordinate system is shown in below Figure 8.2.2. In spherical coordinates, the variable r is the radial coordinate, θ is the polar angle (relative to the vertical z -axis), and ϕ is the azimuthal angle (relative to the x -axis). The relationship between spherical and rectangular coordinates is

$$x = r \sin \theta \cos \phi, \quad y = r \sin \theta \sin \phi, \quad z = r \cos \theta$$



5.3. Spectra of Hydrogen Atom and Hydrogen like Atoms:

- ❖ Whenever an electron in a hydrogen atom jumps from higher energy level to the lower energy level, the difference in energies of the two levels is emitted as a radiation of particular wavelength. It is called a spectral line. As the wavelength of the spectral line depends upon the two orbits (energy levels) between which the transition of electron takes place, various spectral lines are obtained. The different wavelengths constitute spectral series which are the characteristic of the atoms emitting them. The following are the spectral series of hydrogen atom.

(i) Lyman Series:

- When the electron jumps from any of the outer orbits to the first orbit, the spectral lines emitted are in the ultraviolet region of the spectrum and they are said to form a series called Lyman series (Fig).

Here, $n_1 = 1, n_2 = 2, 3, 4 \text{ etc}$

The wave number of the Lyman series is given by,

$$\nu = R \left(1 - \left(\frac{1}{n_2^2} \right) \right)$$

(ii) Balmer Series:

- When the electron jumps from any of the outer orbits to the second orbit, we get a spectral series called the Balmer series. All the lines of this series in hydrogen have their wavelength in the visible region. Here $n_1 = 2, n_2 = 3, 4, 5$

The wave number of the Balmer series is,

$$\nu = R \left(\frac{1}{2^2} - \frac{1}{n_2^2} \right) = R \left(\frac{1}{4} - \frac{1}{n_2^2} \right)$$

- The first line in this series ($n_2 = 3$), is called the H_{α} line, the second ($n_2 = 4$), the H_{β} line and so on.

(iii) Paschen Series:

- This series consists of all wavelengths which are emitted when the electron jumps from outer most orbits to the third orbit. Here $n_2 = 4, 5, 6$ and $n_1 = 3$. This series is in the infrared region with the wave number given by

$$\nu = R\left(1/3^2 - 1/n_2^2\right) = R\left(1/9 - 1/n_2^2\right)$$

(iv) Brackett Series:

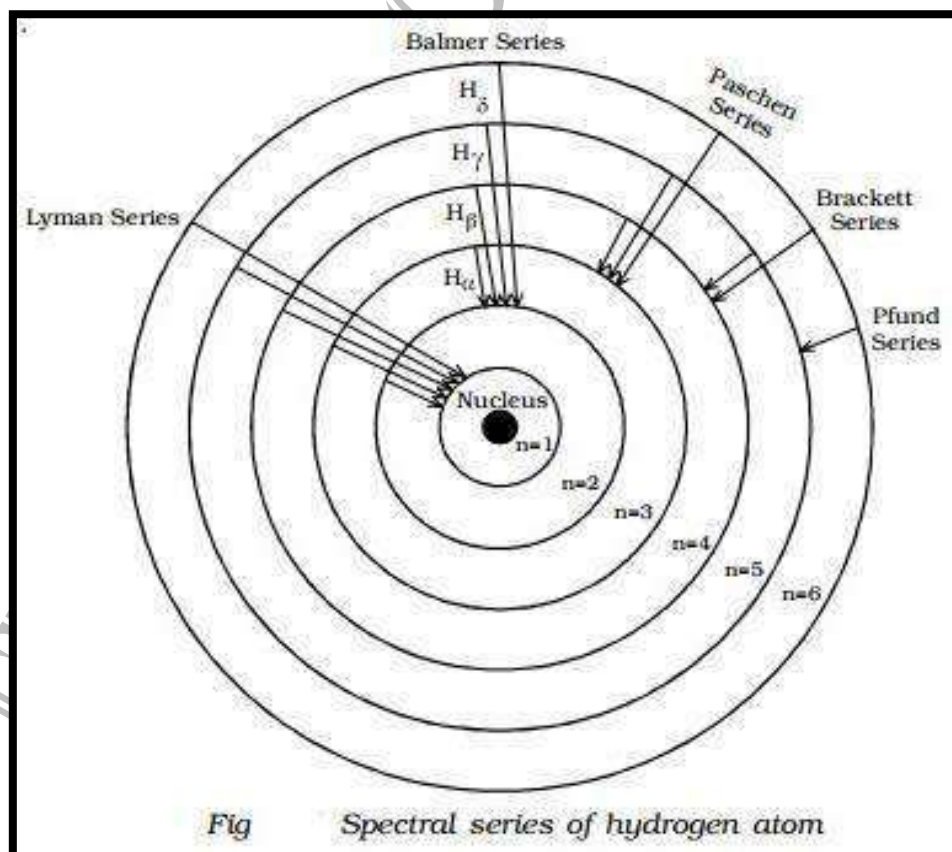
- The series obtained by the transition of the electron from $n_2 = 5, 6 \dots$ to $n_1 = 4$ is called Brackett series. The wavelengths of these lines are in the infrared region. The wave number is,

$$\nu = R\left(1/4^2 - 1/n_2^2\right) = R\left(1/16 - 1/n_2^2\right)$$

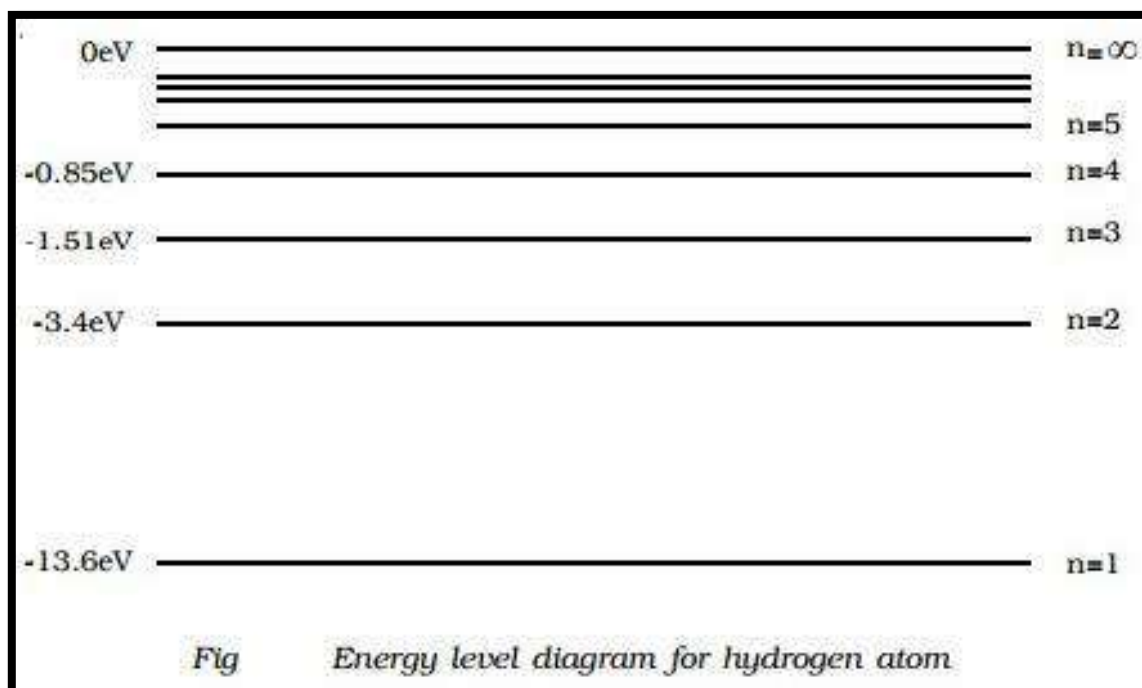
(v) Pfund Series:

- The lines of the series are obtained when the electron jumps from any state $n_2 = 6, 7 \dots$ to $n_1 = 5$. This series also lies in the infrared region. The wave number is,

$$\nu = R\left(1/5^2 - 1/n_2^2\right) = R\left(1/25 - 1/n_2^2\right)$$



Energy Level Diagram:



- The energy of the electron in the n^{th} orbit of the hydrogen atom is given by,

$$E_n = -13.6 / n^2 \text{ eV}$$
- Energy associated with the first orbit of the hydrogen atom is,

$$E_1 = -13.6 / 1^2 = -13.6 \text{ eV}$$
- It is called ground state energy of the hydrogen atom. Energy associated with the second orbit is given by,

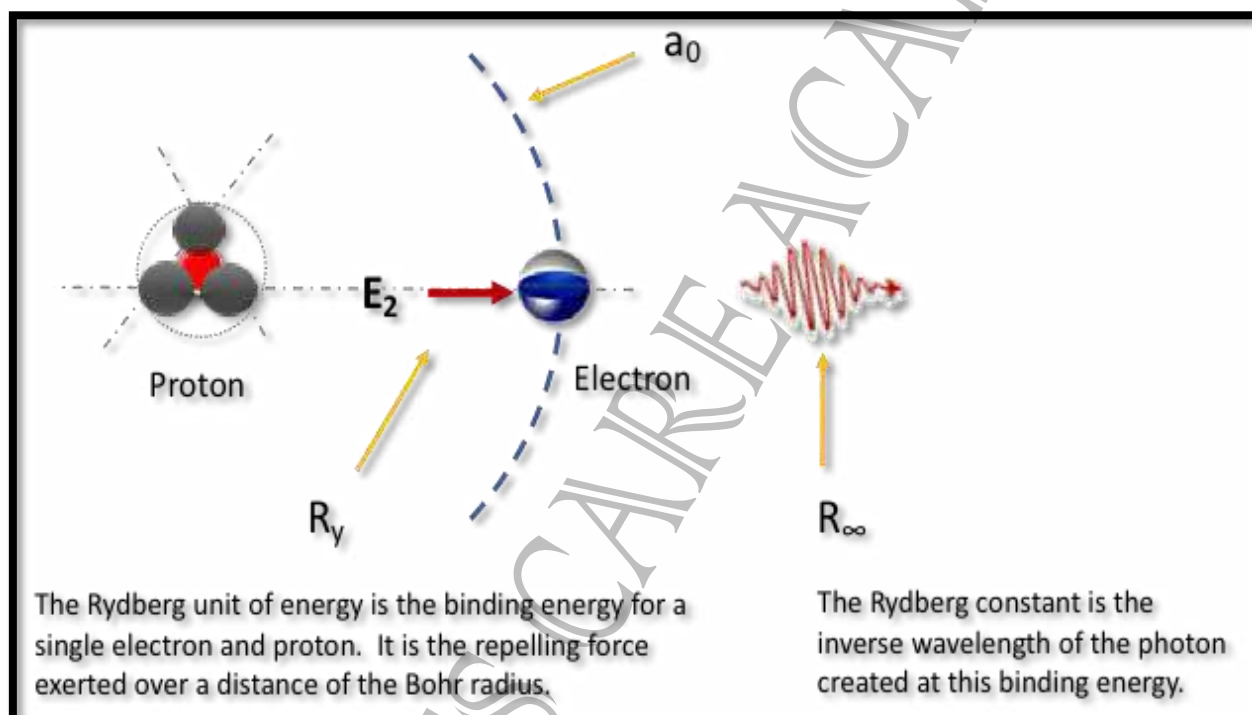
$$E_2 = -13.6 / 2^2 = -3.4 \text{ eV}$$
- It is called energy of first excited state of the hydrogen atom. The energy of second, third, fourth, excited states of the hydrogen atom are,

$$E_3 = -1.51 \text{ eV}, E_4 = -0.85 \text{ eV}, E_5 = -0.54 \text{ eV} \dots$$

when $n = \infty, E_{\infty} = -13.6 / \infty^2 = 0$
- Therefore, it is seen from the above values, that, the energy associated with a state becomes less negative and approaches closer and closer to the maximum value zero corresponding to $n = \infty$.
- Taking these energies on a linear scale, horizontal lines are drawn which represent energy levels of the hydrogen atom (Fig). This diagram is known as energy level diagram.

5.4. Rydberg's Constant:

- The value of the Rydberg constant R_∞ is **10,973,731.56816 per metre**. When used in this form in the mathematical description of series of spectral lines, the result is the number of waves per unit length, or the wavenumbers. Multiplication by the speed of light yields the frequencies of the spectral lines.
- The Rydberg constant is used **to calculate the wavelengths in the hydrogen spectrum** – energy which is absorbed or emitted in the form of photons as electrons move between shells in the hydrogen atom.



- Hydrogen atoms inside a discharge lamp emit a series of lines in the visible part of the spectrum. This series was named after the Swiss teacher Johann Balmer and called the Balmer series. In 1885, Balmer found a way to describe the wavelengths of these lines by a trial and error method.

$$1/\lambda = R(1/4 - 1/n)$$

- Here n are integers starting from 3, 4, 5 and go till infinity. R is the rydberg constant. This article will look closely into rydberg or R constant, a unit of rydberg constant, and also discuss the rydberg constant derivation.

Rydberg Constant and its Importance:

- The Rydberg constant holds high importance in atomic physics as it is connected to fundamental atomic constants, i.e. e , h , c , and m_e . The constant can be derived with

a high level of accuracy. The Rydberg constant first came into existence in 1890 when Swedish physicist Johannes Rydberg analyzed several spectra. Rydberg found that many of the Balmer line series could be explained by the equation:

$$n = n_0 - N_0 / (m + m')^2$$

- where m is a natural number, m' and n_0 are quantum defects specific for a particular series. N_0 is the Rydberg constant. Rydberg is used as a unit of energy.

Speed of Light:

- It is the speed of light waves that propagate through different materials. In a vacuum, the speed of light is given as 3×10^8 meters per second. The speed of light is the fundamental concept of nature. In a famous equation $E = mc^2$, the speed of light (c) serves as constant linking energy (E) and mass of the particles.
- In terms of speed of light, the Rydberg constant (R) is given as Rhc , where h is Planck's constant and c is the speed of light. The dimensional formula of Rhc is equal to the dimensional formula for energy.

Explanation of Rydberg Constant

- When an electron changes its position from one atomic orbit to another, there is a change in the electron's energy. If the electron shifts from a higher energy state to a lower energy state, then a photon of light gets created. If the electron goes from a low energy state to a higher one, the atom absorbs a photon of light. A distinct spectral fingerprint characterizes every element.
- R_∞ or R_H denotes the rydberg constant, and it is a wavenumber associated with the atomic spectrum of each element. The value of rydberg constant in cm^{-1} ranges from $109,678 \text{ cm}^{-1}$ to $109,737 \text{ cm}^{-1}$. The first value of the constant is the value of the rydberg constant for hydrogen, and the last value is for the heaviest element. The value of the rydberg constant is based on the fact that the nucleus of an atom that is emitting light is exceedingly huger than the single orbiting electron.

Dimensional Formula of Rydberg Constant:

- The Rydberg formula is expressed as a mathematical formula that denotes the wavelength of light emitted by an electron that moves between energy levels within an atom. Findings of Rydberg, along with Bohr's atomic model, give in below formula:

$$1/\lambda = RZ^2 \left(1/n_1^2 - 1/n_2^2 \right)$$

5.43. Multiple Choice Questions (Important)

- The minimum energy required by the electrons to escape from the orbit is known as a __
 - potential energy
 - kinetic energy
 - binding energy
 - gravitational potential energy
- The binding energy required for removing an electron from first Bohr's orbit is ____
 - 13.6 eV
 - 13.6 eV
 - 27.6 eV
 - 27.6 eV
- Binding energy of an electron is _____
 - directly proportional to n
 - directly proportional to n^2
 - inversely proportional to n
 - inversely proportional to n^2
- As the binding energy of the nucleus increases the energy required to separate the nucleons
 - increases
 - decreases
 - constant
 - neither decreases nor increases
- Which of the following is the main result of nuclear fission?
 - Helium
 - Strontium
 - Krypton
 - Barium
- Who measured the size of the nucleus first?
 - Bohr
 - Einstein
 - Rutherford
 - Geiger and Marsden
- When a radioactive substance emits an α -particle, its position in the periodic table is lowered by which of the following?
 - One place
 - Two places
 - Three places
 - Four places
- Which is a non-central force?
 - Electrostatic force
 - Nuclear force
 - Gravitational force
 - Spring force
- Which of the following substances cannot be emitted by radioactive substances during their decay?
 - Protons
 - Neutrinos
 - Helium nuclei
 - Electrons
- What is the reaction responsible for the production of light energy from the sun?
 - Fusion
 - Fission
 - Nuclear
 - Emission



11. In a nuclear reaction, there is the conservation of which of the following?

- A) Mass only
- B) Energy only
- C) Momentum only
- D) Mass, energy, and momentum

12. Which of the following is used as a moderator in a nuclear reactor?

- A) Cadmium
- B) Plutonium
- C) Uranium
- D) Heavy water

13. In nuclear reactors, what are the controlling rods made of?

- A) Cadmium
- B) Graphite
- C) Stainless steel
- D) Plutonium

14. The operation of a nuclear reactor is said to be critical if the multiplication factor (k) has a value of what?

- A) 1
- B) 0
- C) 1.5
- D) 2.1

15. In which of the following process are Neutrons emitted?

- A) Inverse beta Decay
- B) Nuclear fission
- C) Spontaneous Fission
- D) Nuclear fusion

16. Atoms of different chemical elements that have the same number of nucleons are called as?

- A) Isobars
- B) Isotones
- C) Isomers
- D) Isotopes

17. Most of the energy released in fission process is in process of _____

- A) Kinetic Energy
- B) Thermal Energy
- C) Light Energy
- D) Heat Energy

18. Fusion reactions are called _____

- A) Thermonuclear
- B) Thermoduric
- C) Thermo Uric
- D) Compound reactions

19. What is the most attractive part of nuclear energy?

- A) Supports countries development
- B) Causes no pollution
- C) Has high efficiency of energy production
- D) Is available in abundance

20. The atom as a whole is electrically charged.

- A) True
- B) False

90. Fission occurs because the average binding energy per nucleon for the fission fragments is higher than that for the original nucleus. The change in binding energy per nucleon is approximately

- A) 0.20 MeV B) 1.0 MeV C) 7.0 MeV D) 28 MeV

91. The conservation law violated by the reaction $p \rightarrow \pi_0 + e^+$ is the conservation of

- A) charge. B) energy
C) linear momentum. D) lepton number and baryon number.

92. The fact that the binding energy per nucleon is roughly a constant over most of the range of stable nuclei is a consequence of the fact that the nuclear force

- A) short range B) long range C) weak D) strong

93. The interaction that describes the forces among nucleons that hold nuclei together is

- A) the strong nuclear interaction. B) the electromagnetic interaction.
C) the weak nuclear interaction. D) the gravitational interaction.

94. Which of the following is used to detect fission reaction:

- A) Mass spectrograph B) Microscope
C) Through penetration D) Thermometer

95. Which of the following is correct during fusion of hydrogen into helium:

- A) Mass is increased B) Mass is reduced
C) Energy is absorbed D) Energy is released

96. The density of atom is uniform, Who proposed this law?

- A) Rutherford's model B) Bohr's model
C) J.J. Thomson model D) None of these

97. The mass will _____, when the energy is released from a system.

- A) Increases B) Decreases C) Constant D) Zero

98. If the internal energy of a nucleus is high, then it is radioactive.

- A) True B) False

99. A nucleus at rest splits into two nuclear parts having radii in the ratio of 1:3. Find the ratio of their velocities.

- A) 1:9 B) 3:1 C) 1:27 D) 27:1

100. Which of the following has the highest neutron ratio?

- A) ${}^1_0\text{O}^{16}$ B) ${}^4_2\text{He}$ C) ${}^{56}_{26}\text{Fe}$ D) ${}^{235}_{92}\text{U}$



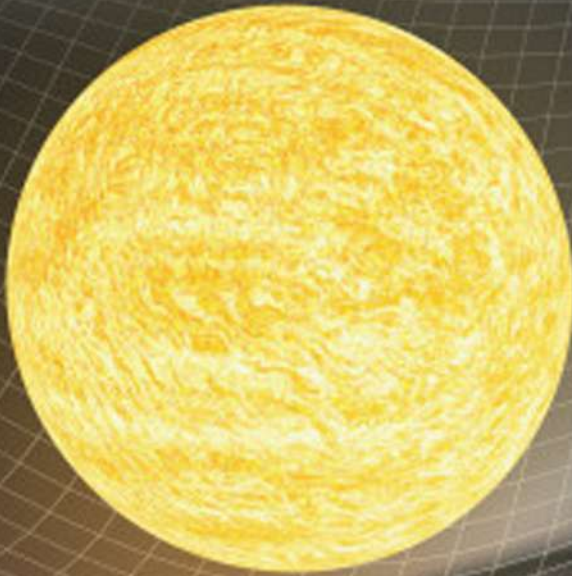
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UNIT-6

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UG TRB PHYSICS – 2023-24

UNIT 6

QUANTUM MECHANICS AND RELATIVITY

6.1. Wave Nature of Particles:

Explanation:

- ❖ The theory that radiation travels in space in the form of waves got established as it successfully explained the optical phenomena like reflection, refraction, interference, diffraction and polarization.
- ❖ However, to explain photoelectric effect and Compton Effect one needs the particle or corpuscular nature of radiation. Thus, radiation possesses wave-particle duality. Sometimes it behaves like a wave and at times like a particle.
- ❖ The wave nature of electrons was first proved by Davison and Germer experiment.

6.1.1. Inadequacy of Classical Mechanics:

- ❖ According to the classical mechanics, if we consider the case of an electron moving round the nucleus, its energy should decrease (because the accelerated charged particle loses energy in the form of electromagnetic waves) and therefore its velocity should decrease continuously.
- ❖ The ultimate result is that the electron comes closer and closer to the nucleus until it collapses. This shows the instability of the atom; it is in contradiction to the observed fact of the stability of an atom.
- ❖ The number of photoelectrons emitted per second from a metal surface increases when: the intensity of incident light increases.
- ❖ Thus the classical mechanics fails to explain the stability of an atom. The classical

mechanics also failed to explain the spectrum of the hydrogen atom. According to the classical theory, the excited atoms of hydrogen emit electromagnetic radiations of all wavelengths continuously, while it is observed that they emit the radiation of certain wavelengths only.

6.1.2. Classical mechanics failed to explain the following phenomena:

- (i) It does not hold in the region of atomic dimensions, i.e., it cannot explain the non-relativistic motion of atoms, electrons, protons etc.
 - It could not explain the stability of atoms.
 - It could not explain the origin of discrete spectra of atoms since, according to classical mechanics, the energy changes are always continuous.
- (ii) It could not explain observed spectrum of black body radiation.
- (iii) Classical mechanics could not explain observed phenomena like photoelectric effect, Compton Effect etc.
- (iv) It could not explain the observed variation of specific heat capacity of solids.
 - The inadequacy of classical mechanics led to the development of Quantum Mechanics.

(i) The Hydrogen Atom and the Bohr Model:

- As the first example of the failure of classical physics to account for observed phenomena, we consider the case of the hydrogen atom. Rutherford model failed to explain two main observational features of the hydrogen atom:
 - (a) Its stability and (b) the spectrum of its radiation. Let us consider these one at a time.
 - (a) An electron in a curved orbit is accelerated and hence must radiate. As it radiates its energy away, the radius of its orbit must decrease until eventually it collapses into the nucleus. Thus, the atom cannot be stable. But most of the atoms are stable.
 - (b) The second discrepancy involves the observed radiation spectrum. The frequency of the radiated energy should be the same as the orbiting frequency. As the electron orbit collapses, its orbiting frequency increases continuously. In contrast, the experimentally observed spectrum consists of families of discrete lines.
- Bohr provided an explanation for both the spectral discreteness and the observed stability. He proposed that in solving for the orbital motion of the electron in its hydrogenic orbit one should impose an added condition:

- The angular momentum of the electron must be equal to some integer multiple of \hbar .

$$l = n\hbar \quad (n = 1, 2, 3, \dots)$$

(ii) Black Body Radiation:

- The observed variation of the spectral intensity $I(\nu)$ (power per unit area per unit frequency) of blackbody radiation as a function of frequency ν is shown in fig. From the curves we note that
 - The intensity reaches a maximum at some frequency ν_m .
 - The frequency ν_m , as well as the height of the peak, increase with temperature.

Multiple Choice Questions:

- Rutherford model failed to explain -----two main observational features of the hydrogen atom?
 - Its stability
 - the spectrum of its radiation
 - Both (A) & (B)
 - None of the above
- The Quantum Mechanical Model of the atom was proposed by
 - Louis de Broglie
 - Erwin Schrodinger
 - Neil Bohr
 - Werner Heisenberg
- The wavelength of the matter waves is independent of
 - Mass
 - Velocity
 - Charge
 - Momentum
- The wave nature of electrons was first proved by by whom?
 - Photoelectric effect
 - G. B. Thompson experiment
 - Compton Effect
 - Davison and Germer experiment
- What type of nature do electromagnetic waves have?
 - Dual nature
 - Wave nature
 - Particle nature
 - Photon nature
- Waves are associated with matter only?
 - When it is stationary
 - When it is in motion with the velocity of light only
 - When it is in motion with any velocity.
 - None of the above

- 7) The number of photoelectrons emitted per second from a metal surface increases when?
- The energy of incident photons increases
 - The frequency of incident light increases
 - The wavelength of incident light increases
 - The intensity of incident light increases
- 8) (i) The frequency of the radiated energy should be the same as the orbiting frequency
(ii) As the electron orbit collapses, it's orbiting frequency increases continuously.
- (i) and (ii) is true
 - (i) is true (ii) is false
 - (i) false (ii) is true
 - (i) and (ii) is false
- 9) A photosensitive substance emits _____ when illuminated by light.
- only protons
 - only neutrons
 - electrons and protons
 - only electrons
10. The photoelectric current does not depend upon the (i) frequency of incident light (ii) work function of the metal (iii) stopping potential (iv) intensity of incident light
- (i) and (iv) only
 - (ii) and (iii) only
 - (iii) only
 - (ii) only

6.2. Matter Waves or De Broglie Waves

Explanation:

- ❖ According to de Broglie a moving particle, whatever its nature, has wave properties associated with it.
- ❖ He proposed that the wavelength λ associated with any moving particle of momentum p (mass m and velocity v) is given by
$$\lambda = \frac{h}{p} = \frac{h}{mv}$$
- ❖ Where h is Planck's constant. Such waves associated with the matter particles are called *matter waves* or *de Broglie waves*.
- ❖ Bohr's Theory of the hydrogen atom led de Broglie to the conception of matter waves. According to Bohr's theory, the stable states of electrons in the atom are governed by –integer rules.

- Substituting this in equation (1), we get

$$\frac{\partial^2 \Psi}{\partial x^2} + \frac{\partial^2 \Psi}{\partial y^2} + \frac{\partial^2 \Psi}{\partial z^2} = -\frac{\omega^2}{u^2} \Psi \quad \dots\dots (4)$$

- But $\omega = 2\pi\nu$

$$= \frac{2\pi u}{\lambda},$$

$$\text{i.e.} \quad \frac{\omega}{u} = \frac{2\pi}{\lambda} \quad \dots\dots (5)$$

$$\text{Also} \quad \frac{\partial^2 \Psi}{\partial x^2} + \frac{\partial^2 \Psi}{\partial y^2} + \frac{\partial^2 \Psi}{\partial z^2} = \nabla^2 \Psi \quad \dots\dots (6)$$

- Using (5) and (6), equation (4) becomes

$$\nabla^2 \Psi + \frac{4\pi^2}{\lambda^2} \Psi = 0. \quad \dots\dots (7)$$

- So far we have not introduced wave mechanical concept and so the treatment is general. For introducing the concept of Wave Mechanics we must put from de Broglie equation.

$$\lambda = \frac{h}{mv} \quad \dots\dots (8)$$

- Substituting this in equation (7), we get

$$\nabla^2 \Psi + \frac{4\pi^2 m^2 v^2}{h^2} \Psi = 0 \quad \dots\dots (9)$$

- If E and V are the total energy and potential energy of the particle respectively, then its kinetic energy $\frac{1}{2}mv^2$ is given by

$$\frac{1}{2}mv^2 = E - V.$$

- Which gives $m^2 v^2 = 2m(E - V)$.
- Substituting this in equation (9), we get

$$\nabla^2 \Psi + \frac{8\pi^2 m}{h^2} (E - V) \Psi = 0 \quad \dots\dots (10)$$

- The above equation is called Schrodinger time independent wave equation. The quantity ψ is usually referred as wave function.
- Let us now substitute in equation (10),

$$\hbar = \frac{h}{2\pi} \quad \dots\dots (11)$$

- Then the Schrodinger time-independent wave equation, in usually used form, may be written as

$$\nabla^2 \Psi + \frac{2m}{h^2} (E - V) \Psi = 0 \quad \dots\dots (12)$$

6.13.2. Schrodinger Equation for a Free Particle:

- For a free particle $V = 0$; therefore if we put $V = 0$ in equation (12), it will become the Schrodinger equation for a free particle, i.e.

$$\nabla^2 \Psi + \frac{2mE}{\hbar^2} \Psi = 0 \quad \dots\dots\dots (13)$$

6.13.3. Time Independent Schrodinger Equation:

- Time – dependent Schrodinger equation may be obtained by eliminating E from Equation (12).
- Differentiating equation (3) with respect to t , we get

$$\begin{aligned} \frac{\partial \Psi}{\partial t} &= -i\omega \Psi_0(r) e^{-i\omega t} \\ &= -i(2\pi\nu) \Psi_0(r) e^{-i\omega t} \quad (\text{Since } \omega = 2\pi\nu) \\ &= -2\pi i\nu \Psi(r) \quad \text{using (3)} \\ &= -\frac{2\pi i E}{h} \Psi \quad \left(\text{Since } E = h\nu \text{ i.e. } \nu = \frac{E}{h} \right) \end{aligned}$$

$$\text{Or} \quad E\Psi = -\frac{h}{2\pi i} \frac{\partial \Psi}{\partial t} = -\frac{i}{\hbar} \left(\frac{h}{2\pi} \right) \frac{\partial \Psi}{\partial t}$$

- Using (11), we get

$$E\Psi = i\hbar \frac{\partial \Psi}{\partial t} \quad \dots\dots\dots (14)$$

- Substituting value of $E\Psi$ from above equation in (12), we get

$$\nabla^2 \Psi + \frac{2m}{\hbar^2} \left[i\hbar \frac{\partial \Psi}{\partial t} - V\Psi \right] = 0$$

$$\text{Or} \quad \nabla^2 \Psi = -\frac{2m}{\hbar^2} \left[i\hbar \frac{\partial \Psi}{\partial t} - V\Psi \right]$$

$$\text{i.e.,} \quad -\frac{\hbar^2}{2m} \nabla^2 \Psi + V\Psi = i\hbar \frac{\partial \Psi}{\partial t} \quad \dots\dots\dots (15)$$

- This equation contains the time and hence is called the time – dependent Schrodinger equation.
- Equation (15) may be written as

$$\left(-\frac{\hbar^2}{2m} \nabla^2 + V \right) \Psi = i\hbar \frac{\partial \Psi}{\partial t} \quad \dots\dots\dots (16)$$

- The operation $\left(-\frac{\hbar^2}{2m}\nabla^2 + V\right)$ is called Hamiltonian and is represented by H; while operator $i\hbar\frac{\partial}{\partial t}$, operated on ψ , gives E which may be seen from (14). Thus equation (16) may be written as $H\Psi = E\Psi$ (17)
- The above forms of the Schrodinger's equation describe the motion of a non-relativistic material particle.

Multiple Choice Questions:

- Find the function, $f(x)$, for which $X f(x) = -\frac{i}{\hbar} a^2 p_x f(x)$, where a is the real quantity.
 A) ke^{-x^2} B) $ke^{-x^2/2a}$ C) $ke^{-x^2/2a^2}$ D) none of the above
- $d\psi/dx$ must be zero.
 A) Statement is true B) statement is false C) not sure D) none of the above
- The time domain can be ---- in Schrodinger wave equation?
 A) Dependent B) Independent C) Zero D) Both A and B
- The Schrodinger is a differential equation.
 A) Statement is true B) statement is false C) not sure D) none of the above
- A Schrodinger equation is a ----- form of equation?
 A) Linear B) Partial differential C) Non linear D) Both A and B
- A Schrodinger equation governs ----- form of quantum mechanics?
 A) Wave B) Air C) Noise D) All the above
- Schrodinger equation is a part of ----- law?
 A) Newton's B) Charl's C) Ohms D) None of the above
- Schrodinger based equation provides the evolution over data related to?
 A) Wave function B) Quantum mechanics
 C) Physical system isolation D) All the above
- Which of the following is the mathematical methods of Schrodinger?
 A) Matrix mechanism B) Path integral formula C) Differentiation D) both A & B
- Which of the following is the domain in which Schrodinger equations are expressed in?
 A) Time domain B) Frequency domain C) Phase domain D) All the above

6.14. Probability Amplitude:

Introduction:

- We have seen that the wave-function is to be interpreted as a particle probability amplitude, the motion of the particle is clearly to be associated with the motion of the wave-function. This general idea may be made quantitative by the introduction of probability current density.
- In quantum mechanics, Newton's familiar equations of motion are replaced by Schrödinger's equation. We shall not discuss this equation in any detail, nor indeed even write it down, but one important aspect of it must be mentioned.
- When Newton's laws of motion are applied to a system, we obtain both the energy and an equation of motion. The equation of motion allows us to calculate the position or coordinates of the system at any instant of time.
- However, when Schrödinger's equation is solved for a given system we obtain the energy directly, but not the probability distribution function the function which contains the information regarding the position of the particle. Instead, the solution of Schrödinger's equation gives only the amplitude of the probability distribution function along with the energy.
- The probability distribution itself is obtained by squaring the probability amplitude. (Click here for note.) Thus for every allowed value of the energy, we obtain one or more (the energy value may be degenerate) probability amplitudes.

Explanation:

- The probability amplitudes are functions only of the positional coordinates of the system and are generally denoted by the Greek letter ψ (psi). For a bound system the amplitudes as well as the energies are determined by one or more quantum numbers. Thus for every E_n we have one or more ψ_n 's and by squaring the ψ_n 's we may obtain the corresponding P_n 's.
- Let us look at the forms of the amplitude functions for the simple system of an electron confined to motion on a line. For any system, ψ is simply some mathematical function of the positional coordinates.
- In the present problem which involves only a single coordinate x , the amplitude functions may be plotted versus the x -coordinate in the form of a graph. The functions ψ_n are particularly simple in this case as they are sin functions.

$$\psi_n(x) = \sqrt{2/L} \sin(n\pi x/L)$$

The first few ψ_n 's are shown plotted in Fig.

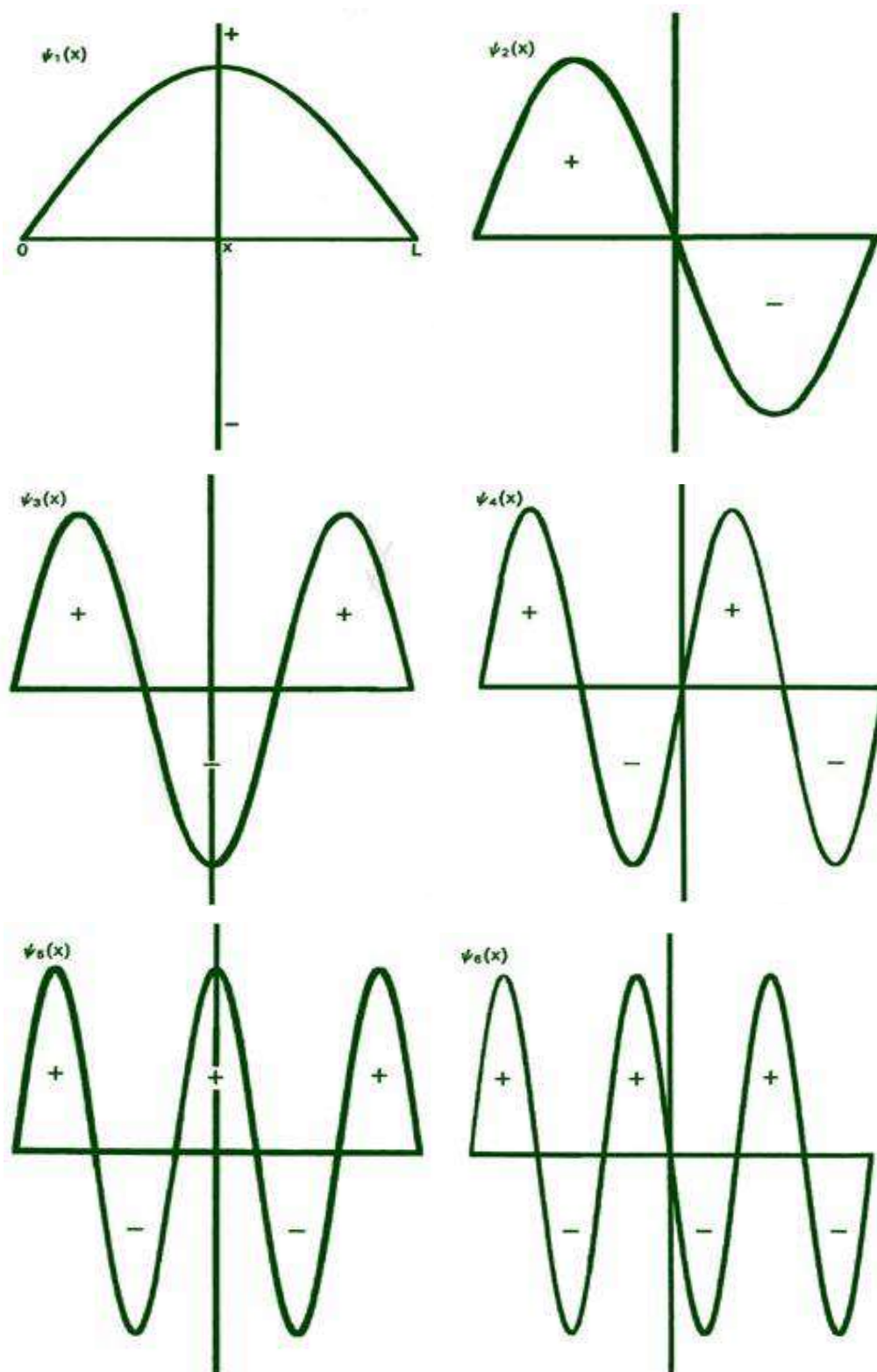


Fig. The first six probability amplitudes $\psi_n(x)$ for an electron moving on a line of length L .

- Note the $\psi_n(x)$ may be negative in sign for certain values of x . The $\psi_n(x)$ are squared to obtain the probability distribution functions $P_n(x)$, which are, therefore, positive for all values of x . Wherever $\psi_n(x)$ crosses the x -axis and changes sign, a node appears in the corresponding $P_n(x)$.

- Each of these graphs, when squared, yields the corresponding P_n curves shown previously. When $n = 1$,

$$\psi_1(x) = \sqrt{2/L} \sin(\pi x/L)$$

- When $x = 0$,

$$\psi_1(0) = \sqrt{2/L} \sin(0) = 0$$

- When $x = L$,

$$\psi_1(L) = \sqrt{2/L} \sin(\pi) = 0$$

- When $x = L/2$,

$$\psi_1(L/2) = \sqrt{2/L} \sin(\pi/2) = \sqrt{2/L}$$

- Thus y equals zero at $x = 0$ and $x = L$ and is a maximum when $x = L/2$. When this function is squared, we obtain:

$$P_1(x) = (2/L) \sin^2(\pi x/L)$$

and the graph (Fig. 2-4) previously given for $P_1(x)$.

- As illustrated previously in Fig. 2-4, the value of $y_n^2(x)$ or $P_n(x)$ multiplied by Dx , $y_n^2(x)Dx$, or $P_n(x)Dx$, is the probability that the electron will be found in some particular small segment of the line Dx . The constant factor of $\sqrt{2/L}$ which appears in every $y_n(x)$ is to assure that when the value of $y_n^2(x)Dx$ is summed over each of the small segments Dx , the final value will equal unity.
- This implies that the probability that the electron is somewhere on the line is unity, i.e., a certainty. Thus the probability that the electron is in any one of the small segments Dx (the value of $y_n^2(x)Dx$ or $P_n(x)Dx$ evaluated at a value of x between 0 and L) is a fraction of unity, i.e., a probability less than one. (Click here for note.)
- Each y_n must necessarily go to zero at each end of the line, since the probability of the electron not being on the line is zero.
- This is a physical condition which places a mathematical restraint on the y_n . Thus the only acceptable y_n 's are those which go to zero at each end of the line.
- A solution of the form shown in Fig. 2-9 is, therefore, not an acceptable one. Since there is but a single value of the energy for each of the possible y_n functions, it is clear that only certain discrete values of the energy will be allowed.

- The physical restraint of confining the motion to a finite length of line results in the quantization of the energy.
- Indeed, if the line is made infinitely long (the electron is then free and no longer bound), solutions for any value of n , integer or non-integer, are possible; correspondingly, all energies are permissible. Thus only the energies of bound systems are quantized.

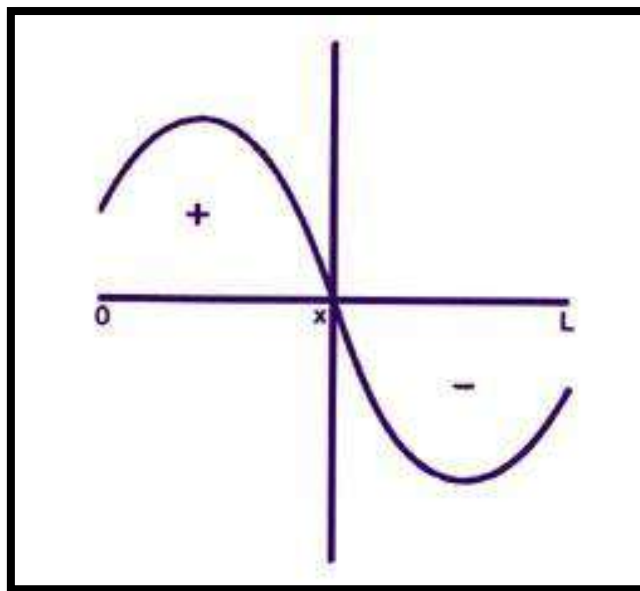


Fig. An unacceptable form for $y_n(x)$.

- The y_n 's have the appearance of a wave in that a given value of $y_n(x)$ is repeated as x is increased. They are periodic functions of x . We may, if we wish, refer to the wavelength of y_n . The wavelength of y_1 is $2L$ since only one half of a wave fits on the length L .
- The wavelength for y_2 , is L since one complete wave fits in the length L . Similarly $\lambda_3 = (2/3)L$ and $\lambda_4 = (2/4)L$. In general:

$$\lambda_n = 2L/n$$

- Because of the wave-like nature of the y_n 's, the new physics is sometimes referred to as wave mechanics, and the y_n functions are called wave functions.
- However, it must be stressed that a wave function itself has no physical reality. All physical properties are determined by the product of the wave function with itself.
- It is the product $y_n(x) y_n(x)$ which yields the physically measurable probability distribution. Thus y_n^2 may be observed but not y_n itself.
- A y_n does not represent the trajectory or path followed by an electron in space. We have seen that the most we can say about the position of an electron is given by the probability function y_n^2 .

- We do, however, refer to the wavelengths of electrons, neutrons, etc. But we must remember that the wavelengths refer only to a property of the amplitude functions and not to the motion of the particle itself.
- A number of interesting properties can be related to the idea of the wavelengths associated with the wave functions or probability amplitude functions.
- The wavelengths for our simple system are given by $\lambda = 2L/n$. Can we identify these wavelengths with the wavelengths which de Broglie postulated for matter waves and which obeyed the relationship:

$$\lambda = h/p ?$$

- The absolute value for the momentum (the magnitude of the momentum independent of its direction) of an electron on the line is $nh/2L$. Substituting this into de Broglie's relationship gives:

$$\lambda = h/p = \frac{h}{nh/2L} = 2L/n$$

- So indeed the wavelengths postulated by de Broglie to be associated with the motions of particles are in reality the wavelengths of the probability amplitudes or wave functions.
- There is no need to postulate "matter waves" and the results of the electron diffraction experiment of Davisson and Germer for example can be interpreted entirely in terms of probabilities rather than in terms of "matter waves" with a wavelength $\lambda = h/p$.
- It is clear that as n increases, λ becomes much less than L . For $n = 100$, $\lambda \ll L$ and P_{100} would appear as in Fig. 2-10. When $L \gg \lambda$, the nodes in P_n are so close together that the function appears to be a continuous function of x .
- No experiment could in fact detect nodes which are so closely spaced, and any observation of the position of the electron would yield a result for P_{100} similar to that obtained in the classical case.
- This is a general result. When λ is smaller than the important physical dimensions of the system, quantum effects disappear and the system behaves in a classical fashion.
- This will always be true when the system possesses a large amount of energy, i.e., a high n value. When, however, λ is comparable to the physical dimensions of the system, quantum effects predominate.

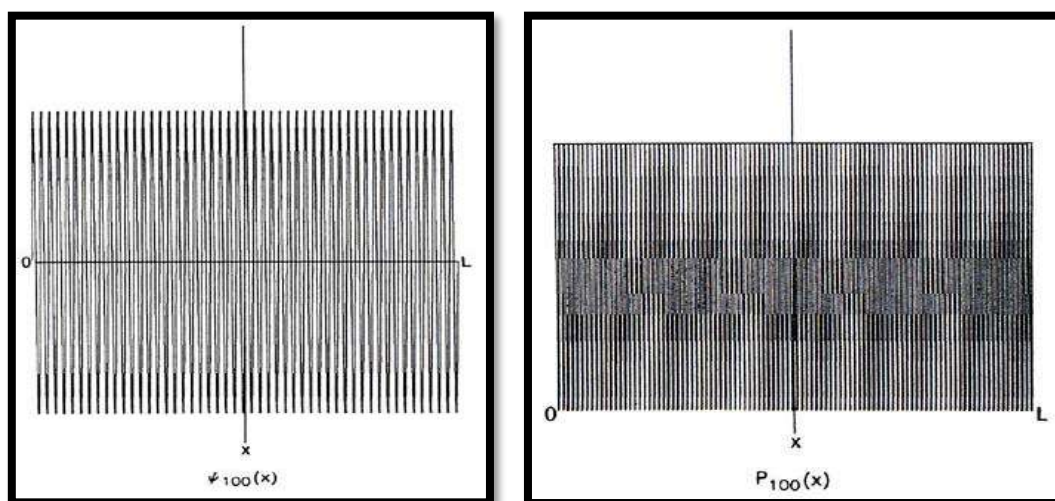


Fig. The wave function and probability distribution for $n = 100$.

- Let us check to see whether or not quantum effects will be evident for electrons bound to nuclei to form atoms. A typical velocity of an electron bound to an atom is of the order of magnitude of 109 cm/sec. Thus:

$$\lambda = \frac{6.6 \times 10^{-27}}{9.1 \times 10^{-28} \times 1 \times 10^9} = 10^{-8} \text{ cm}$$

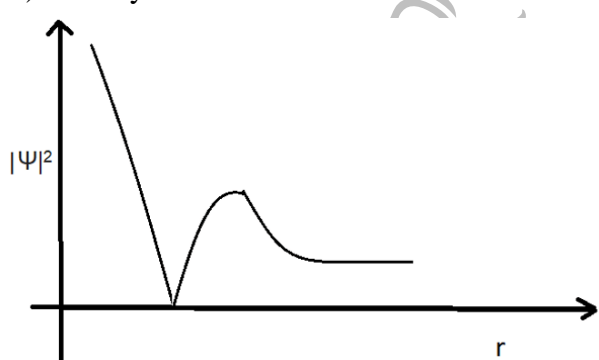
- This is a short wavelength, but it is of the same order of magnitude as an atomic diameter. Electrons bound to atoms will definitely exhibit quantum effects because the wavelength which determines their probability amplitude is of the same size as the important physical dimension the diameter of the atom.
- We can also determine the wavelength associated with the motion of the mass of 1 g moving on a line 1 m in length with a velocity of, say, 1 cm/sec:

$$\lambda = \frac{6.6 \times 10^{-27}}{1 \times 1} = 6.6 \times 10^{-27} \text{ cm}$$

- This is an incredibly short wavelength, not only relative to the length of the line but absolutely as well. No experiment could detect the physical implications of such a short wavelength.
- It is indeed many, many times smaller than the diameter of the mass itself. For example, to observe a diffraction effect for such particles the spacing's in the grating must be of the order of magnitude of 1×10^{-27} cm. Such a grating cannot be made from ordinary matter since atoms themselves are about 10^{19} times larger than this.
- Even if such a grating could be found, it certainly wouldn't affect the motion of a mass of 1 g as the size of the mass is approximately 10^{28} times larger than the spacing's in the grating. Clearly, quantum effects will not be observed for massive particles. It is also clear that the factor which determines when quantum effects will be observed and when they will be absent is the magnitude of Planck's constant h .

- The very small magnitude of h restricts the observation of quantum effects to the realm of small masses.

Multiple Choice Questions:

- The electron probability density is greatest at _____.
 A) $r = 0$ B) $r = n$ C) $r = 1$ D) $r = me$
- Which of the following is the correct expression for the total number of nodes?
 A) $n - 1$ B) $l - 1$ C) $l + 1$ D) $n + 1$
- If Ψ is the wave function, the probability density function is given by _____.
 A) $|\Psi|$ B) $|\Psi|^2$ C) $|\Psi|^3$ D) $|\Psi|^4$
- For a 3p orbital, what are the total number of nodes?
 A) 3 B) 2 C) 1 D) 0
- The probability of finding an electron is along two directions in which orbital?
 A) s B) p C) d D) p
- Which of the following can be the quantum numbers for an orbital?
 A) $n = 4, l = 4, m = 3$ B) $n = 2, l = 3, m = 1$
 C) $n = 3, l = 2, m = -1$ D) $n = 3, l = 0, m = -3$
- For which quantum number, the probability of finding an electron is most?
 A) 1 B) 2 C) 3 D) 4
- Identify the orbital for the following probability density graph.


A) 1s B) 2s C) 2p D) 3s
- The probability of finding an electron is zero in p_{xy} along _____.
 A) x-axis B) y-axis C) z-axis D) never zero
- What orbital never has a zero probability of finding electrons?
 A) s B) p_x C) d_{xy} D) d_{z^2}

56. Heisenberg's uncertainty principle is

- A) $\Delta x. \Delta p_y \geq \frac{h}{2\pi}$ B) $\Delta x. \Delta y \geq \frac{h}{2\pi}$
 C) $\Delta E. \Delta t \geq \frac{h}{2\pi}$ D) $\Delta x. \Delta E \geq \frac{h}{2\pi}$

57. The momentum operator \hat{P} =-----.

- A) $-i\hbar\nabla$ B) $i\hbar\nabla$ C) $\frac{i}{\hbar}\nabla$ D) $-\frac{i}{\hbar}\nabla$

58. What the Uncertainty of the Electron is?

- A) $\Delta P = 5.2745 \times 10^{-20} \text{kgm/sec}$ B) $\Delta P = 3.2745 \times 10^{-20} \text{kgm/sec}$
 C) $\Delta P = 5.2745 \times 10^{-21} \text{kgm/sec}$ D) $\Delta P = 5.2745 \times 10^{-23} \text{kgm/sec}$

59. The operator ∇^2 is called ----- operator.

- A) Hamiltonian B) Laplacian C) Poisson D) vector

60. The operator operating on the wave function should always standing on ----- side.

- A) Middle B) Right C) Left D) Upper

61. Schrodinger's time independent equation is

- A) $\frac{\partial^2 y}{\partial x^2} + \frac{2m}{\hbar^2} (E - V)\Psi = 0$ B) $\frac{\partial^2 y}{\partial x^2} + \frac{2m}{\hbar^2} (E + V)\Psi = 0$
 C) $\frac{\partial^2 y}{\partial x^2} + \frac{2m}{v^2} (E - V)\Psi = 0$ D) $\frac{\partial^2 y}{\partial x^2} + \frac{2m}{\hbar^2} (V - E)\Psi = 0$

62. Which of the following is the correct expression for the Schrodinger wave equation?

- A) $i\hbar \frac{\partial \Psi}{\partial t} = -i \frac{\hbar}{2m} \frac{\partial \Psi}{\partial x} + U\Psi$ B) $i\hbar \frac{\partial \Psi}{\partial t} = -i \frac{\hbar}{2m} \frac{\partial^2 \Psi}{\partial x^2} + U\Psi$
 C) $i\hbar \frac{\partial \Psi}{\partial t} = i \frac{\hbar}{2m} \frac{\partial \Psi}{\partial x} + U\Psi$ D) $i\hbar \frac{\partial \Psi}{\partial t} = -i \frac{\hbar^2}{2m} \frac{\partial \Psi}{\partial x} + U\Psi$

63. The values of energy for which Schrodinger's steady state equation can be solved is Called as -----.

- A) Eigen vectors B) Eigen values C) Eigen functions D) Operators

64. What is the minimum energy possessed by the particle in a box?

- A) 0 B) $\frac{\hbar^2}{2m}$ C) $\frac{\pi^2 \hbar^2}{2m}$ D) $\frac{\pi \hbar^2}{2m}$

65. The wave function of a particle in a box is given by -----

- A) $A \sin(kx)$ B) $A \cos(kx)$
 C) $A \sin(kx) + B \cos(kx)$ D) $A \sin(kx) - B \cos(kx)$

66. Which of the following can be a wave function?

- A) $\tan x$ B) $\sin x$ C) $\cot x$ D) $\sec x$

67. A charged particle in an electromagnetic field experience a force called -----.

- A) Gravitational force B) Lorentz force
C) Frictional force D) restoring force

68. In the classical mechanics the kinetic expression of a particle of mass m and -----.

- A) Force B) moving with velocity u
C) Momentum D) acceleration

69. Lorentz transformation of momentum for Y component -----.

- A) $P'y = Py$ B) $P'y = Pz$ C) $P'y = Ex$ D) $P'y = Bx$

70. the speed of light is -----.

- A) E B) m C) Q D) C

71. According to Einstein's special theory of relativity, laws of physics can be formulated based on -----.

- A) Inertial frame of reference B) Non inertial frame of reference
C) Both Non and Inertial frame of reference D) Quantum state

72. In relativity an electric field and magnetic fields are -----.

- A) Dependent B) Independent C) Interdependent D) Acceleration

73. The net force between two moving charges is -----.

- A) Zero B) One C) Infinite D) C

74. Einstein's Mass-Energy relation $E =$

- A) mc^2 B) m^2c C) $\frac{1}{2}mc^2$ D) mv^2

75. The unifies mass unit $u =$

- A) $1.66 \times 10^{-29}k$ B) $1.91 \times 10^{-29}kg$
C) $1.91 \times 10^{-27}kg$ D) $1.66 \times 10^{-27}kg$

76. Length Contraction $l =$

- A) $\frac{l_0}{\sqrt{1-\frac{v^2}{c^2}}}$ B) $\frac{l_0^2}{\sqrt{1-\frac{v^2}{c^2}}}$ C) $\frac{l}{\sqrt{1-\frac{v^2}{c^2}}}$ D) $l_0 \times \sqrt{1-\frac{v^2}{c^2}}$

77. Length contraction happens only

- A) perpendicular to direction of motion B) along the direction of motion
C) parallel to the direction of motion D) both A and B

78. A rod of length 5 m is moving at a speed of $0.6c$. To an observer sitting perpendicular to the direction of motion, the length appears to be _____

- A) 5 m B) 4 m C) 3 m D) 2 m

79. If an object reaches the speed of light, its length changes to _____

- A) Infinite B) Double of the value
C) Half of the value D) Zero

80. A 20-year-old person goes at a high speed in a rocket on his birthday. when he comes back to earth after 1 earth year, he would be _____

- A) 1 year older B) 2 years older
C) A few months older D) Same age

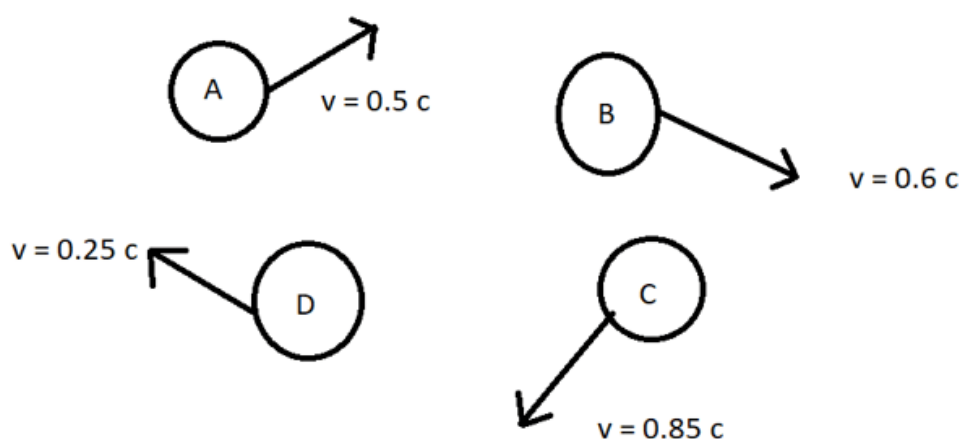
81. An object of length 1 m is moving at speed $0.5c$. To an observer at rest relative to the object, the length of the object seems to be _____

- A) 0.86 m B) 0.5 m C) 1 m D) 0.14 m

82. A particle with a lifetime of 2×10^{-6} s moves through the laboratory with a speed of $0.9c$. Its lifetime, as measured by an observer in the laboratory, is _____

- A) 2×10^{-6} s B) 3.2×10^{-6} s C) 4.6×10^{-6} s D) 5.4×10^{-6} s

83. All the given particles have a lifetime of 1 microsecond. Which of them will survive the longest?



- A) A B) B C) C D) D

84. A meter stick, at an angle of 30 degrees with the x-axis, is traveling at $0.6c$ in the direction of the positive y-axis. To a stationary observer, how long does the meter stick appear to be?

- A) 1m B) $\frac{1}{5}\sqrt{\frac{29}{2}}\text{m}$ C) $\frac{\sqrt{91}}{10}\text{m}$ D) $\frac{4}{5}\text{m}$

85. Two particles approach each other with a speed $0.8c$ with respect to the laboratory. Their relative speed is _____

- A) $0.912c$ B) $0.95c$ C) $0.975c$ D) $0.85c$

86. What would be the mass of the body at rest, if it explodes into two objects of mass 2 kg each moving with a speed $0.8c$ relative to the original body?

- A) 4 Kg B) 5.4 Kg C) 6.2 Kg D) 6.7 Kg

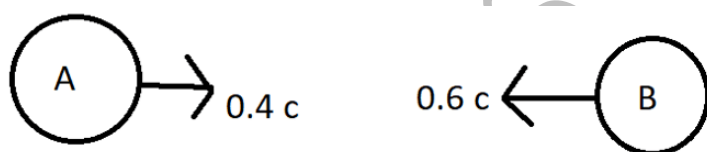
87. In the case $v \ll c$, Lorentz transformation is the same as _____

- A) Einstein's transformation B) Galilean transformation
C) Maxwell's transformation D) Planck's transformation

88. When a particle is moving with a velocity of light c relative to S, its velocity as observed by an observer in the frame S' is _____

- A) Zero B) $0.5c$ C) $0.75c$ D) c

89. From the graph, what should be the velocity as observed from frame S?



- A) $0.6c$ B) $0.7c$ C) $0.8c$ D) $0.9c$

90. An atom A, moving relative to the observer, with velocity $2 \times 10^8 \text{ m/s}$ emits a particle B which moves with a velocity of $2.8 \times 10^8 \text{ m/s}$ with respect to the atom. The velocity of the emitter particle relative to the scientist is _____

- A) $0.8 \times 10^8 \text{ m/s}$ B) $2.4 \times 10^8 \text{ m/s}$ C) $3 \times 10^8 \text{ m/s}$ D) $2.95 \times 10^8 \text{ m/s}$

91. The basic theorem/principle used to obtain mass-energy relation is _____

- A) Heisenberg's Uncertainty Principle B) Work-Energy Theorem
C) Momentum Conservation Theorem D) Maxwell Theorem

92. Which of the following is Einstein's mass energy relation?

- A) $E_k = (m - m_0)c^2$ B) $E = mc^2$
 C) $E^2 - p^2c^2 = m_0^2c^4$ D) $E_k = mv^2/c^2$

93. For Pair Production phenomenon to occur to photon must have energy, greater than or equal to _____

- A) 0.51 MeV B) 1.02 MeV C) 0.32 MeV D) 0.85 MeV

94. What will be the rest energy of an electron?

- A) 0.41 MeV B) 0.51 MeV C) 0.61 MeV D) 0.71 MeV

95. In the probabilistic interpretation of wave function Ψ , the quantity $|\Psi|^2$ is:

- A) a probability density. B) a probability amplitude.
 C) a negative probability. D) 0.

96. A physical requirement on wave functions is that they should be:

- A) reliable. B) friable. C) certifiable. D) normalizable

97. During Einstein's Photoelectric Experiment, what changes are observed when the frequency of the incident radiation is increased?

- A) The value of saturation current increases
 B) No effect
 C) The value of stopping potential increases
 D) The value of stopping potential decreases

98. What is the relation between the interaction parameter, 'b', and atomic radius, R, for the Photoelectric effect?

- A) $b > R$ B) $b \approx R$
 C) $b < R$ D) no relation between b and R

99. What is the time lag between the incidence of photons and the ejection of photoelectrons?

- A) Greater than 10^{-5} s B) Between 10^{-5} s and 10^{-9} s
 C) Less than 10^{-9} s D) 1 second



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UG TRB PHYSICS 2023-2024

UNIT-7

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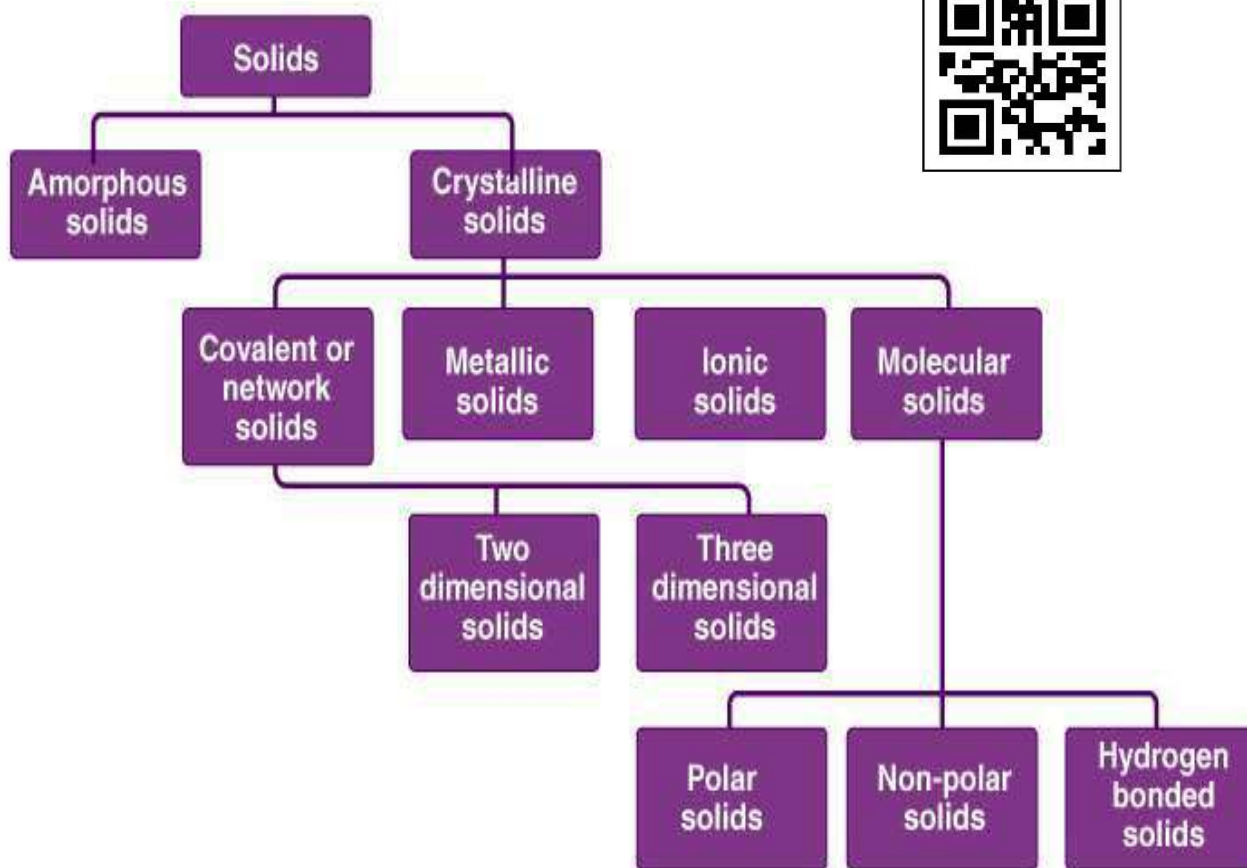
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UG TRB PHYSICS – 2023-24

UNIT 7– SOLID STATE PHYSICS

7.1. Classification of Solids:

- ❖ The constituents of the solids are arranged in two different ways. This means that they either tend to form a regular and repetitive 3D structure which is known as a crystal lattice, which produces a crystalline solid, or they tend to aggregate without any specific order and produce an amorphous solid. There is a vast difference between crystalline and amorphous solids and here, we will learn about the comparison of amorphous vs. Crystalline.



The solid-state has the following distinguishing characteristics:

- They are distinguished by their mass, volume, and shape.
- The intermolecular distances are short.
- The intermolecular forces are extremely powerful.
- Atoms, molecules, and ions (constituent particles) have fixed positions in space and can only oscillate around their mean positions.
- They are rigid and inflexible.

Based on the arrangement of constituent particles, solids are classified into two types:

- Crystalline solid
- Amorphous Solid

7.1.1. Crystalline Solids:

- ❖ Crystalline solids consist of particles that are arranged in a three-dimensional manner. The intermolecular forces between them are equal. They are anisotropic and have a well-defined melting point as well. They are referred to as the true solids. Examples of crystalline solids are diamond, benzoic acid, etc. The application of diamond includes the making of beautiful jewellery, cutting of glass, etc.

7.1.2. Amorphous Solids:

- ❖ Amorphous refers to being shapeless. Amorphous solids have an irregular arrangement of solid particles. The intermolecular forces between them are not equal. Also, the distance between every two particles tends to vary. They do not possess a defined geometric shape. Amorphous solids are also known as supercooled liquids and are isotropic. Examples of amorphous solids include glass, naphthalene, etc

Applications of Glass are as Follows.

- It is widely used for the construction of buildings.
- It is also used in the packaging of cosmetics such as cosmetics boxes and the packing of food items such as in making food jars.

To better understand the difference between amorphous solids and crystalline solids better, let us take a look at the table given below. It showcases the crystalline and amorphous differences in detail.

7.1.3. Difference between Crystalline Solid and Amorphous Solid:

Let us look at the difference between crystalline and amorphous solids in detail

Difference between Crystalline and Amorphous

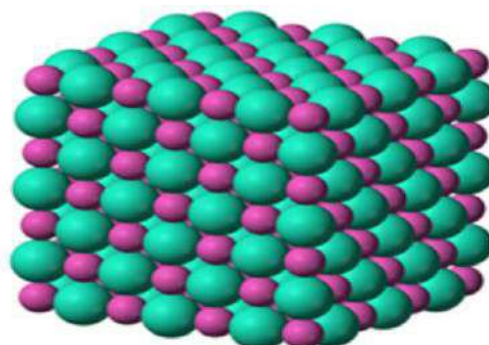
CRYSTALLINE SOLIDS	AMORPHOUS SOLIDS
Atoms are arranged in regular 3 dimension	They do not have regular arrangement
Sharp melting point	No particular melting point
Anisotropic	Isotropic
True solid	Pseudo solid
Symmetrical	Unsymmetrical
More rigid	Less rigid
Long range order	Short range order
Example: Potassium nitrate, copper	Example: Cellophane, polyvinyl chloride

7.2. What is Crystal Structure?

- ❖ A crystal structure is made of atoms. A crystal lattice is made of points. A crystal system is a set of axes. In other words, the structure is an *ordered array of atoms, ions or molecules*.
- ❖ Crystal Structure is obtained by attaching atoms, groups of atoms or molecules. This structure occurs from the intrinsic nature of the constituent particles to produce symmetric patterns. A small group of a repeating pattern of the atomic structure is known as the unit cell of the structure. A unit cell is the building block of the crystal structure and it also explains in detail the entire crystal structure and symmetry with the atom positions along with its principal axes. The length, edges of principal axes and the angle between the unit cells are called lattice constants or lattice parameters.

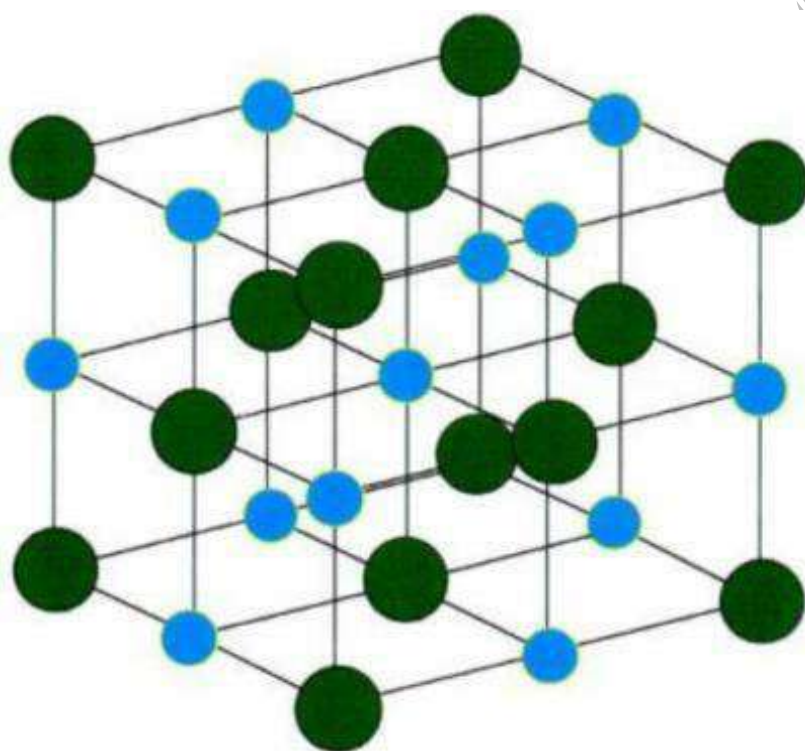
7.3. Unit Cell:

- ❖ Crystals use x-rays, which excite signals from the atom. The signals given by these atoms have different strengths, and they usually



depend upon the electron density distribution in closed shells. The signals released by the atoms varies. Lighter the atoms, weaker is their signals. The mutual arrangement of atoms is also known as crystal structures. Crystal structures are derived from the physical density and chemical formulas of solids.

- ❖ Unit cell can be defined as the smallest part of a component of the crystal. A group of atoms, ions or molecules, which are arranged together in a pure manner to build the crystal. The unit cells are structured in three-dimensional space, which describes the bulk arrangement of atoms of the crystal.
- ❖ Unit Cell is the smallest part (portion) of a crystal lattice. It is the simplest repeating unit in a crystal structure. The entire lattice is generated by the repetition of the unit cell in different directions.

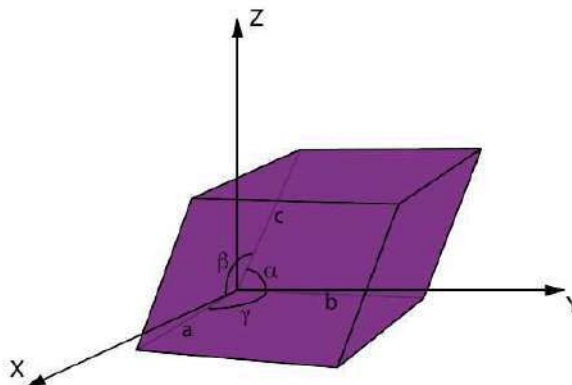


The sodium chloride crystal structure. Each atom has six nearest neighbours, with octahedral geometry. This arrangement is known as *cubic close packed (ccp)*.

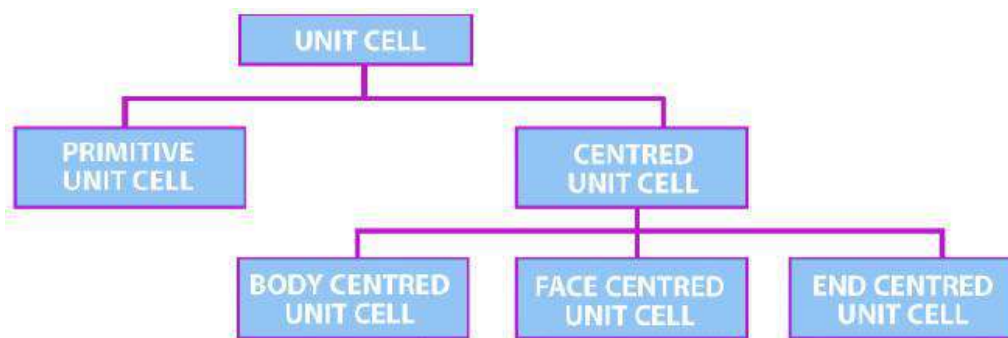
Light blue = Na^+
Dark green = Cl^-

7.3.1. Parameters of a Unit Cell:

- ❖ There are six parameters of a unit cell. These are the 3 edges which are a , b , c and the angles between the edges which are α , β , γ . The edges of a unit cell may be or may not be perpendicular to each other.



7.3.2. Types of Unit Cell:



7.3.2.1. Primitive Unit Cells:

- When the constituent particles occupy only the corner positions, it is known as Primitive Unit Cells.

7.3.2.2. Centered Unit Cells:

- When the constituent particles occupy other positions in addition to those at corners, it is known as Centred Unit Cell. There are 3 types of Centred Unit Cells:
 - Body Centred: When the constituent particle at the centre of the body, it is known as Body Centred Unit cell.
 - Face Centred: When the constituent particle present at the centre of each face, it is known as Face Centred Unit cell.
 - End Centred: When the constituent particle present at the centre of two opposite faces, it is known as an End Centred Unit cell.

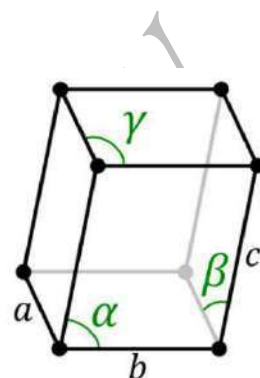
7.4. Crystal System:

- ❖ A Crystal System refers to one of the many classes of crystals, space groups, and lattices. In crystallography terms, lattice system and crystal, the system are associated with each other with a slight difference. Based on their point groups crystals and space groups are divided into seven crystal systems.
- ❖ The Seven Crystal Systems is an approach for classification depending upon their lattice and atomic structure. The atomic lattice is a series of atoms that are organized in a symmetrical pattern. With the help of the lattice, it is possible to determine the appearance and physical properties of the stone. It is possible to identify which crystal system they belong to. In a Cubic System crystals are said to represent the element earth. They are Seven Crystal Systems and are stated below with illustrated examples.

7.4.1. The Seven Crystal Systems

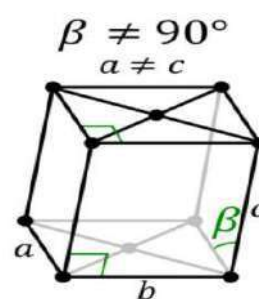
1. Triclinic System:

- It is the most unsymmetrical crystal system. All three axes are inclined towards each other, and they are of the same length. Based on the three inclined angles the various forms of crystals are in the paired faces. Some standard Triclinic Systems include Labradorite, Amazonite, Kyanite, Rhodonite, Aventurine Feldspar, and Turquoise.



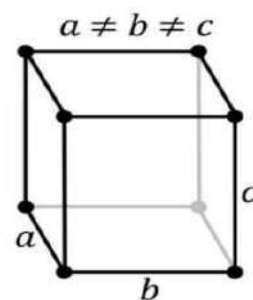
2. Monoclinic System:

- It comprises three axes where two are at right angles to each other, and the third axis is inclined. All three axes are of different length. Based on the inner structure the monoclinic system includes Basal pinacoids and prisms with inclined end faces. Some examples include Diopside, Petalite, Kunzite, Gypsum, Hiddenite, Howlite, Vivianite and more.



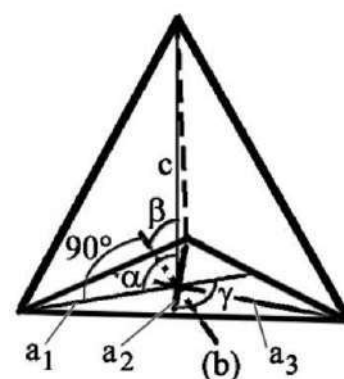
3. Orthorhombic System:

- It comprises three axes and is at right angles to each other. There are different lengths. Based on their Rhombic structure the orthorhombic system includes various crystal shapes namely pyramids, double pyramids, rhombic pyramids, and pinacoids. Some common orthorhombic crystals include Topaz, Tanzanite, Iolite, Zoisite, Danburite and more.



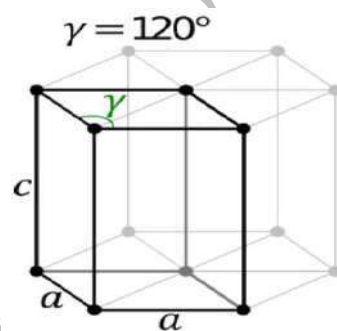
4. Trigonal System:

- Angles and axis in a trigonal system are similar to Hexagonal Systems. At the base of a hexagonal system (cross-section of a prism), there will be six sides. In the trigonal system (base cross-section) there will be three sides. Crystal shapes in a trigonal system include three-sided pyramids, Scalenohedral and Rhombohedra. Some typical examples include Ruby, Quartz, Calcite, Agate, Jasper, Tiger's Eyes and more.



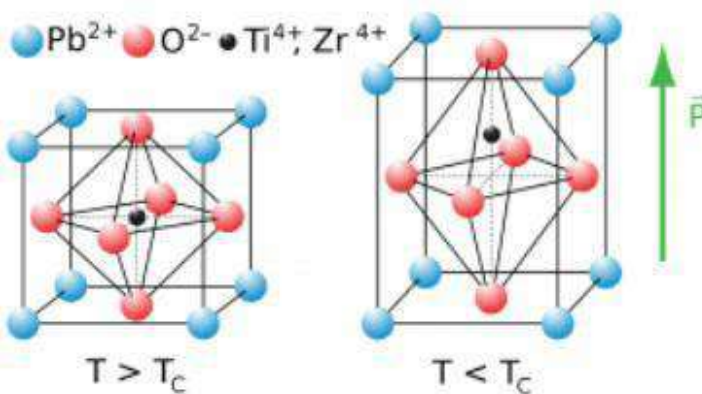
5. Hexagonal System:

- It comprises four axes. The three a_1 , a_2 and a_3 axes are all contained within a single plane (called the basal plane) and are at 120° . They intersect each other at an angle of sixty degrees. The fourth axis intersects other axes at right angles. Crystal shapes of hexagonal systems include Double Pyramids, Double-Sided Pyramids, and Four-Sided Pyramids. Example: Beryl, Cancrinite, Apatite, Sugilite, etc.



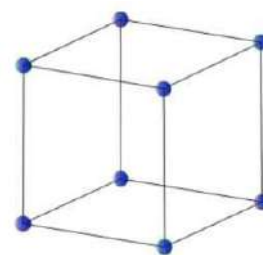
6. Tetragonal Systems:

- It consists of three axes. The main axis varies in length; it can either be short or long. The two-axis lie in the same plane and are of the same length. Based on the rectangular inner structure the shapes of crystal in tetragonal include double and eight-sided pyramids, four-sided prism, trapezohedrons, and pyrite.



7. Cubic System:

- Cubic system is the most symmetrical one out of the seven crystal system. All three angles intersect at right angles and are of equal length. Crystal shapes of a cubic system based on inner structure (square) include octahedron, cube, and Hexacisohedron. Example: Silver, Garnet, Gold, and Diamond.

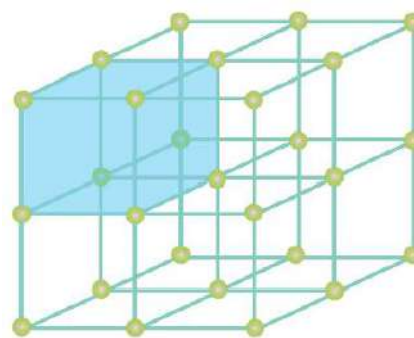


7.5. Crystal Lattices and Unit Cells:

- ❖ The 'crystal lattice' is the pattern formed by the points and used to represent the positions of these repeating structural elements. The periodic structure of an ideal crystal is most easily described by a lattice. The crystal lattice is the array of points at the corners of all the unit cells in the crystal structure.

7.5.1. What is Crystal Lattice?

- The crystal lattice is the symmetrical three-dimensional structural arrangements of atoms, ions or molecules (constituent particle) inside a crystalline solid as points. It can be defined as the geometrical arrangement of the atoms, ions or molecules of the crystalline solid as points in space.



7.5.2. Characteristics of Crystal Lattice:

- In a crystal lattice, each atom, molecule or ions (constituent particle) is represented by a single point.
- These points are called lattice site or lattice point.
- Lattice sites or points are together joined by a straight line in a crystal lattice.
- When we connect these straight lines we can get a three-dimensional view of the structure. This 3D arrangement is called Crystal Lattice also known as **Bravais Lattices**.

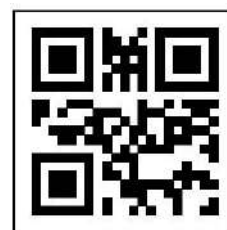
7.6. Bravais lattice:

- ❖ There are 14 types of three-dimensional lattices are present in crystals. These types are known as Bravais lattice. These lattices are named after the French physicist Auguste Bravais.
- ❖ Bravais Lattice indicates the 14 different 3-dimensional arrangements into which atoms can be arranged in crystals. The smallest group of symmetrically arranged atoms that can be repeated in an array to make up the entire crystal is called a unit cell. The most fundamental classification is known as the Bravais lattice. In other words, a Bravais lattice is an array of discrete points with an arrangement and orientation that look exactly the same from any of the discrete points, that is the lattice points are indistinguishable from one another.

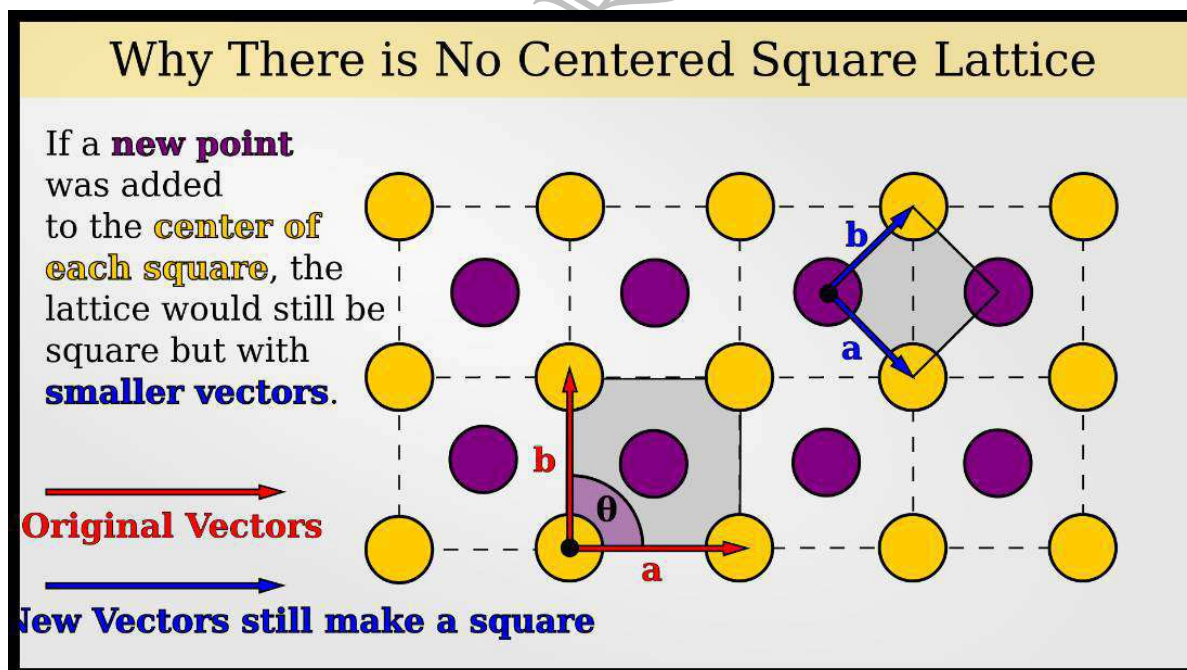
7.6.1. 2D Bravais Lattices:

There are five basic 2D Bravais lattices.

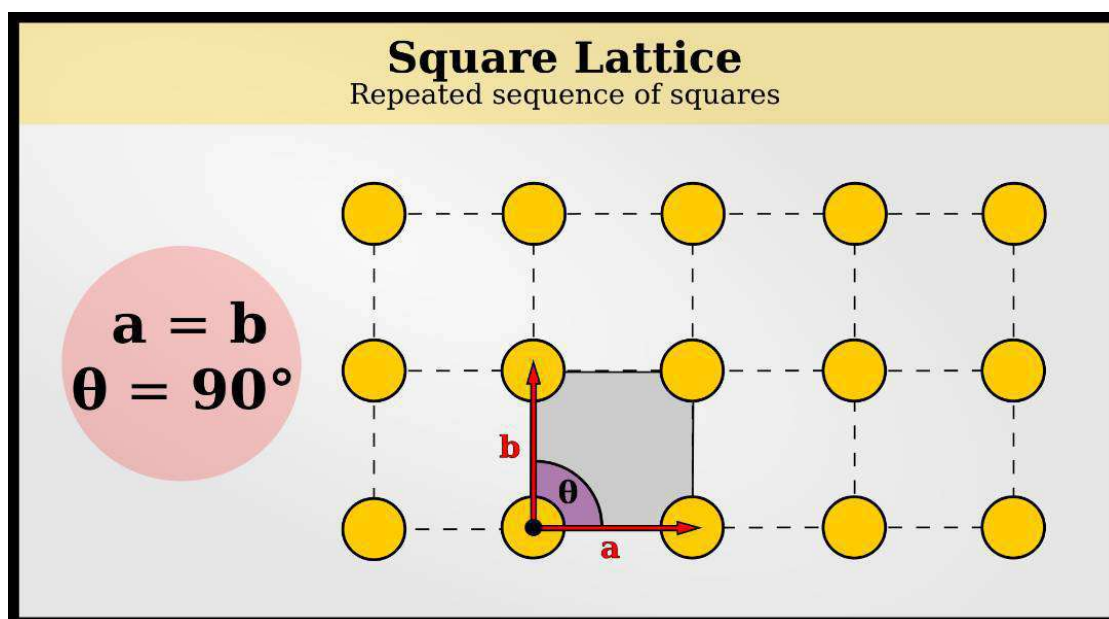
1. Square, $a = b, \theta = 90^\circ$



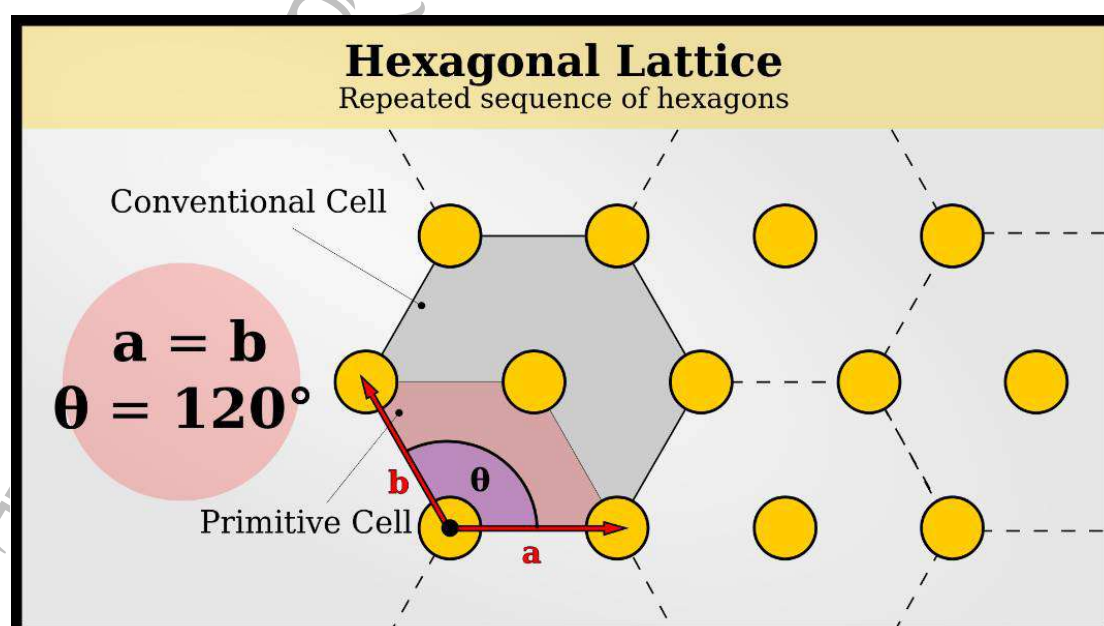
2. Hexagonal, $a = b, \theta = 120^\circ$
 3. Rectangular, $a \neq b, \theta = 90^\circ$
 4. Centered Rectangular
 - **Note:** the primitive cell is like hexagonal or square but less symmetry
 - **Note:** only centered, not face body or base
 5. Rhomboidal, $a \neq b, \theta \neq 90^\circ$
- If you tried to think of another pattern that fully covered a 2D space, such as centered square or off-centered rectangular, it could be reduced to one of these 5 2D lattices. A mathematician might like to prove this, but as an engineer I accept that the proof has already been performed. But I encourage you to think of a few examples of more complex arrangements, and consider which basic lattice you have. For example, you may notice that there is a centered-rectangular lattice, but not a **Centered-Square Lattice**. That's because if you added a centered atom to the **square lattice**, it would actually still be a square lattice, but smaller.



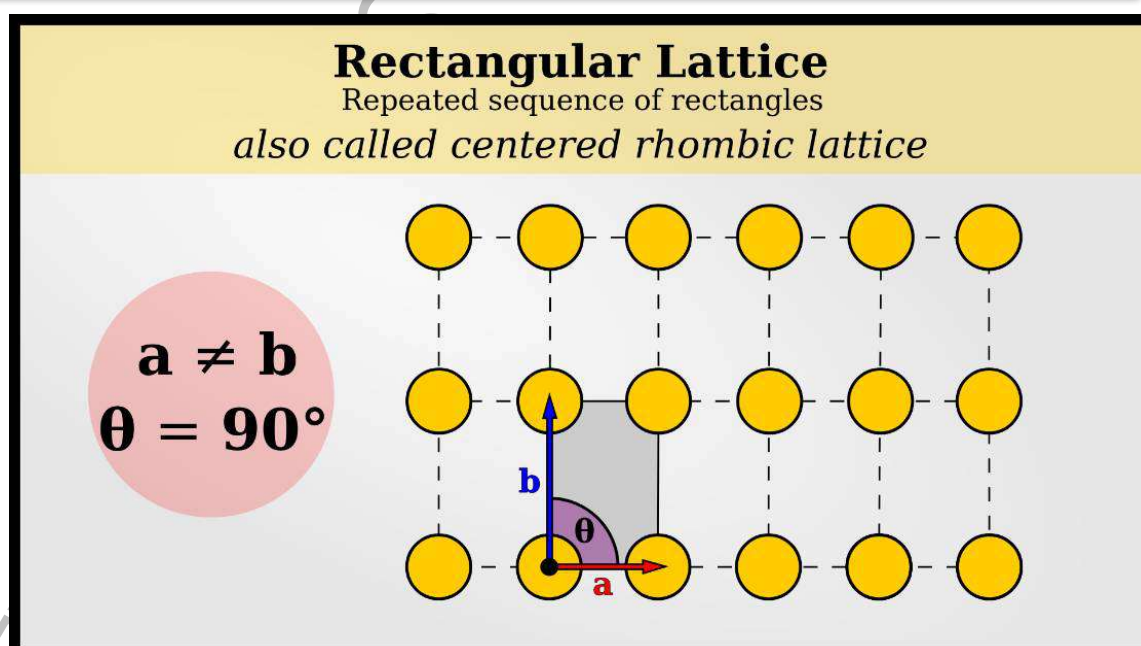
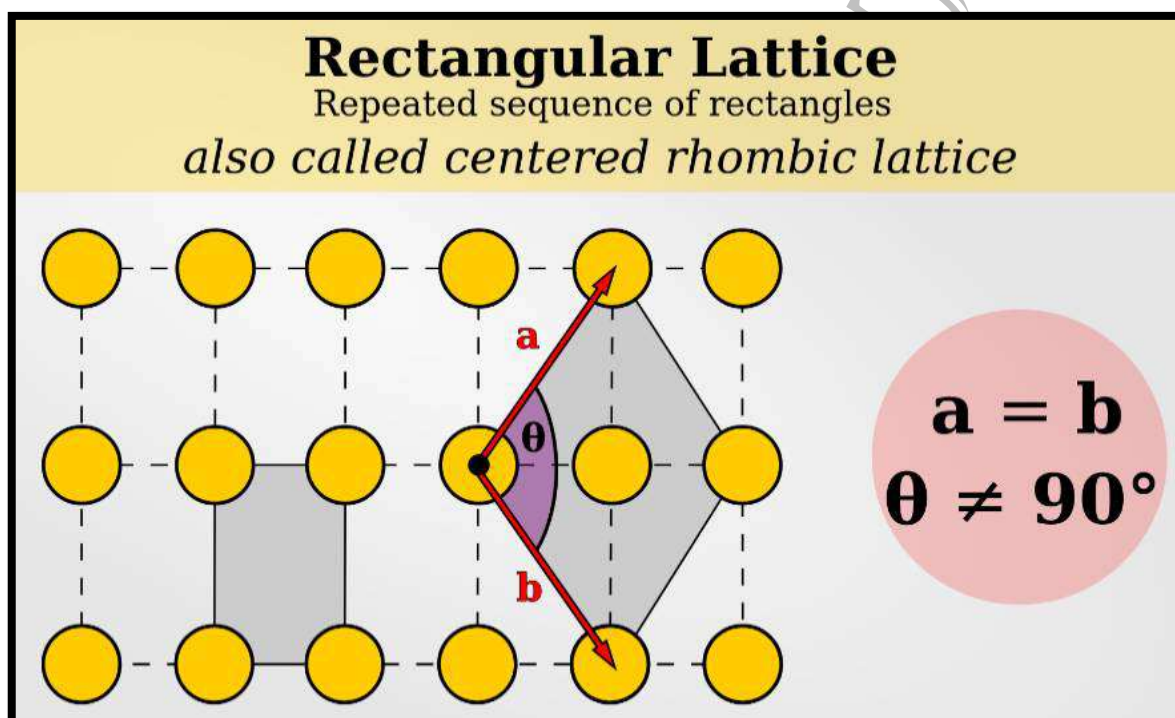
- On the other hand, adding a centered atom to rectangular means that the new crystal has a parallelogram-shaped lattice with $a=b$ and $\theta \neq 90^\circ$. Similarly, adding a centered atom to *this* lattice would give you back a rectangular lattice. Because rectangles have higher symmetry I prefer to describe them as rectangular and centered-rectangular lattices.



- I bring up the 2D lattices because I want to give you an opportunity to play with them in your head. Once we get to complicated 3D lattices, which matter because of crystallography, you'll probably just have to take my word that these are all 14 possible lattices.
- The **square 2D Bravais lattice** completely tiles a space with squares. The vectors a and b are equal to each other and are at right angles.
- The **hexagonal 2D Bravais lattice** might also be described as rhombic. You may like to think of them as triangular, although it actually requires 2 triangles (one up, the other down) to maintain translational symmetry. This lattice tiles a space with hexagons or rhombuses (I prefer "hexagonal" because it indicates higher symmetry). The vectors a and b are equal to each other and at an angle of 120° .

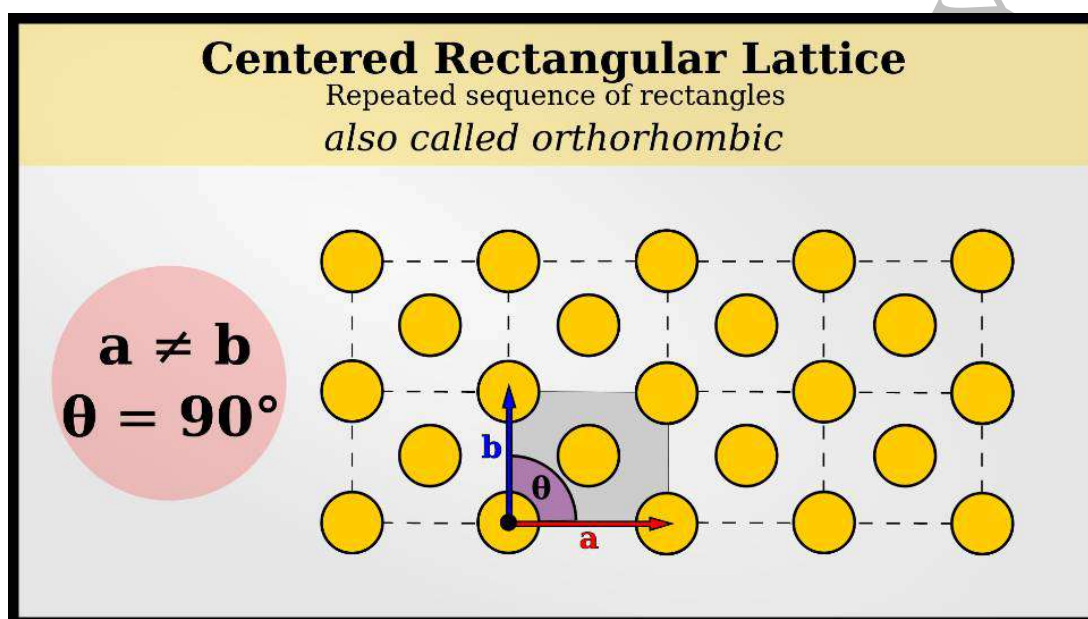


- (In principle, the hexagonal Bravais lattice is a subset of the centered-rectangular lattice, but it gets a special name because the perfect 120° angle has higher symmetry and makes hexagons).
- The **Rectangular 2D Bravais lattice** tiles a space with rectangles. The vectors a and b are at right angles but have different magnitudes.
- Notice that another way to imagine this lattice is if you had a and b with the same length, but not at right angles, with another lattice point in the center.

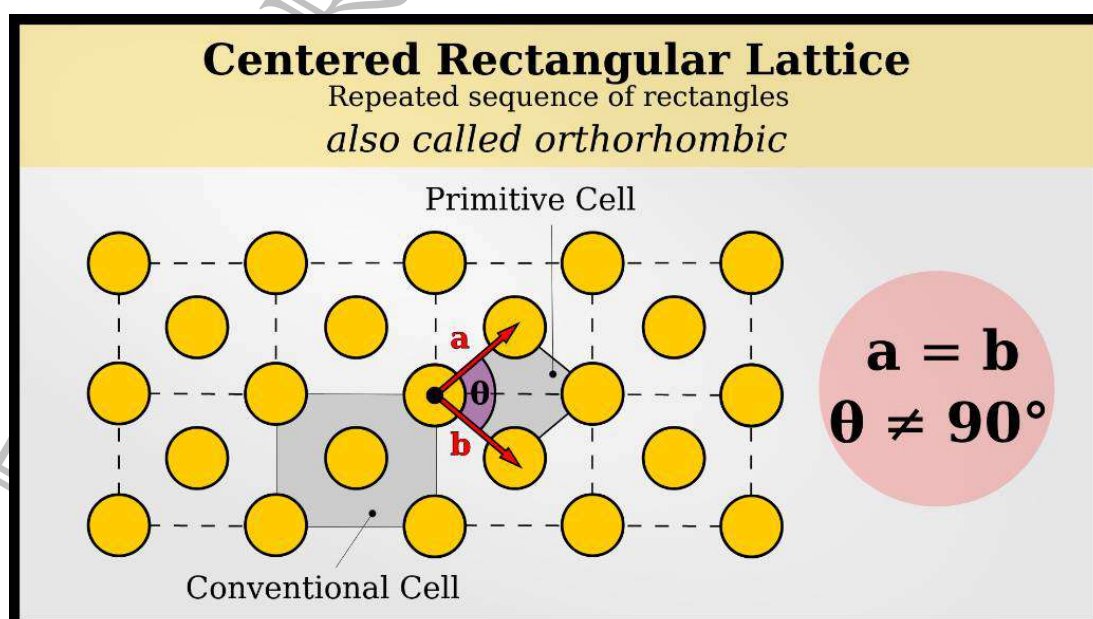


- I mention this just to help you think of the relationships between lattices, and how easily two seemingly-different lattices might end up being identical.

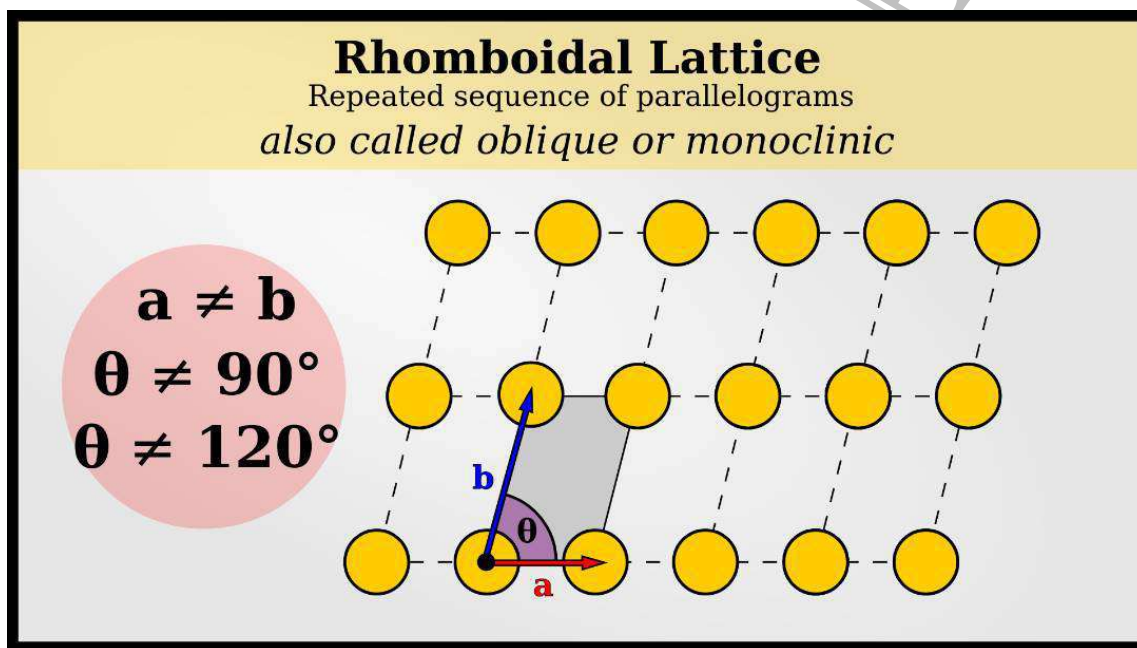
- The **Centered-Rectangular 2D Bravais lattice** tiles a space with rectangles that have an extra lattice point in the center. The vectors a and b are at right angles and have different lengths; one extra point is at the center.



- You may realize that it's possible to make a different lattice without requiring an atom in the center.
- This lattice has vectors a and b of the same length, at non- 90° angles.
- From one perspective, this lattice is simpler than the original one I showed you, because the unit cell has less area and lattice points inside. Since this one is the simplest possible lattice, we call it the **primitive lattice**.
- However, this depiction of the primitive lattice does not show the full symmetry, so we tend to use the non-primitive, centered-rectangular depiction instead.



- The **rhomboidal 2D Bravais lattices** tile a space with rhomboids. This lattice has vectors a and b of different lengths at non- 90° angles.
- This lattice is actually called “oblique” in most places I looked, but I thought it would make more sense if I actually called it by the proper shape. Rhomboids are parallelograms with non- 90° angles and 2 different side lengths. There is no such 2D shape as “oblique.”

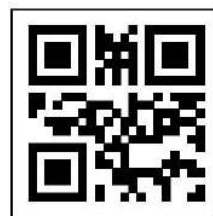


7.6.2. 3D Bravais Lattices:

- ❖ Now we get into the Bravais lattices which are useful to materials science. There are 14 3D Bravais lattices. Remember that the Bravais lattices come by considering **translational symmetry**. Other symmetries, like reflection or inversion, are captured in point groups and space groups, not Bravais lattices.
- ❖ I'll provide a short description of each lattice, and list some common materials with that structure. For a more in-depth look at each kind of lattice, I have written a dedicated article for each one. You can find those linked at the top or bottom of this article.
- ❖ Each lattice is a polyhedron with 6 faces, 12 edges, and 8 vertices. We can describe these polyhedrons using 3 vectors which correspond to 3 of the 12 edges (because of the 4-sided nature of the polygon, there will be 3 sets of 4 matching edges. That's why we only need to describe 3 different vectors, as long as they come from 3 different edge sets). The cube is the highest-symmetry lattice shape. All 12 edges are the same length and they all have the same angle to each other (90°), which can be represented as 3 vectors of identical length, at 90° to each other.

7.17. Multiple Choice Questions (Important):

- Prompt emission of X-ray by an atom ionised by a higher energy X-ray is a type of which of the following phenomena?
 - Luminescence
 - Fluorescence
 - Phosphorescence
 - Spontaneous emission
- The measurement of intensity of fluorescent X-rays provide a simple and _____ way of _____ analysis.
 - Destructive, quantitative
 - Non-destructive, quantitative
 - Destructive, qualitative
 - Non-destructive, qualitative
- The energy of the emitted X-rays depends upon the _____ of the atom and their intensity depends upon the _____.
 - Atomic number, amount of sample
 - Mass number, amount of sample
 - Mass number, concentration of atoms
 - Atomic number, concentration of atoms
- Which of the following is Mosely's equation if 'C' is the speed of light, 'a' is proportionality constant, ' σ ' is a constant which depends on electronic transition series, 'Z' is the atomic number and ' λ ' is the wavelength?
 - $C\lambda = a(Z - \sigma)^2$
 - $C/\lambda = a(Z - \sigma)^2$
 - $C(Z - \sigma)^2 = a\lambda$
 - $C(Z - \sigma)^2 = a/\lambda$
- In X-ray fluorescence spectrometer, the relationship between the excitation intensity and the intensity of fluorescence does not depend on which of the following?
 - Spectrum of the incident radiation
 - Angle of radiance
 - Molecular weight
 - Incident angle
- Absorption meter is _____ and _____ of the chemical state of the element concerned.
 - Non-destructive, independent
 - Destructive, independent
 - Non-destructive, dependent
 - Destructive, dependent



7. X-ray absorption meters have which of the following major disadvantages?
A) Low accuracy B) Low range C) Low sensitivity D) It is destructive
8. In absorption meter, which of the following is placed between the cell and the X-ray tube?
A) Collimator B) Filter C) Chopper D) Attenuator
9. In absorption meter, which of the following is placed between the chopper and the reference cell?
A) Collimator B) Filter
C) Photomultiplier tube D) Attenuator
10. In absorption meter, the two halves of the X-ray beam are allowed to fall on which of the following components?
A) Collimator B) Filter
C) Photomultiplier tube D) Attenuator
11. The photomultiplier tube used in absorption meter is coated with which of the following materials?
A) Sodium B) Potassium C) Phosphorous D) Chlorine
12. In absorption meter, which of the following is adjusted until the absorption of two X-ray beams are brought into balance?
A) Collimator B) Filter
C) Photomultiplier tube D) Attenuator
13. In absorption meter, the change in thickness of aluminium required for different samples is a function of the difference in which of the following parameters?
A) Amount B) Concentration C) Colour D) Composition.
14. Photographs made with X rays are known as _____
A) X-graphs B) Gamma-graphs C) Radiographs D) Scanned Photos
15. X-rays are used with computer in _____
A) CT Scan B) CAT Scan C) CA Scan D) AT Scan
16. Which of the following disease can be detected by X-Ray?
A) Bladder infection B) Pneumonia C) Diarrhea D) Fever



90. Stacking sequence in hexagonal close packed (HCP) structure is?
 A) AAAAAA B) ABABAB C) ABCABC D) AABBA
91. Stacking sequence in face centered cubic (FCC) close packed structure is?
 A) AAAAAA B) ABABAB C) ABCABC D) AABBA
92. For plane (1 1 1) of FCC having a lattice parameter 'a', planar atomic density is given by?
 A) $2.31/a^2$ B) $2.31/a^3$ C) $1.31/a^2$ D) $1.31/a^3$
93. For plane (1 1 1) of BCC having a lattice parameter 'a', planar atomic density is given by?
 A) $1.07/a^2$ B) $0.58/a^2$ C) $2.07/a^2$ D) $0.78/a^2$
94. For plane (1 0 0) of BCC having a lattice parameter 'a', planar atomic density is given by?
 A) $\frac{1}{a^3}$ B) $\frac{2}{a^2}$ C) $\frac{3}{a^4}$ D) $\frac{1}{a^2}$
95. For plane (1 1 0) of BCC having a lattice parameter 'a', planar atomic density is given by?
 A) $\frac{3.690}{a^2}$ B) $\frac{2.312}{a^2}$ C) $\frac{1.414}{a^2}$ D) $\frac{0.580}{a^2}$
96. For plane (1 1 0) of SC having a lattice parameter 'a', planar atomic density is given by?
 A) $\frac{0.580}{a^2}$ B) $\frac{0.707}{a^2}$ C) $\frac{0.707}{a^3}$ D) $\frac{0.508}{a^3}$
97. For plane (1 1 1) of SC having a lattice parameter 'a', planar atomic density is given by?
 A) $\frac{0.58}{a^2}$ B) $\frac{0.78}{a^3}$ C) $\frac{0.68}{a^2}$ D) $\frac{0.88}{a^2}$
98. Which of the following equation describes Bragg's law of diffraction? (Assume that all symbols have their usual meaning.)
 A) $2d \sin\theta = \lambda$ B) $2d = n\lambda$ C) $2d = n\lambda \sin\theta$ D) $2d \sin\theta = n\lambda$
99. Miller indices for Octahedral plane in cubic crystal
 A) (100) B) (110) C) (111) D) None



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UNIT-8

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UNIT 8 - OPTICS AND SPECTROSCOPY

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UG TRB PHYSICS – 2023-24

UNIT 8 - OPTICS AND SPECTROSCOPY

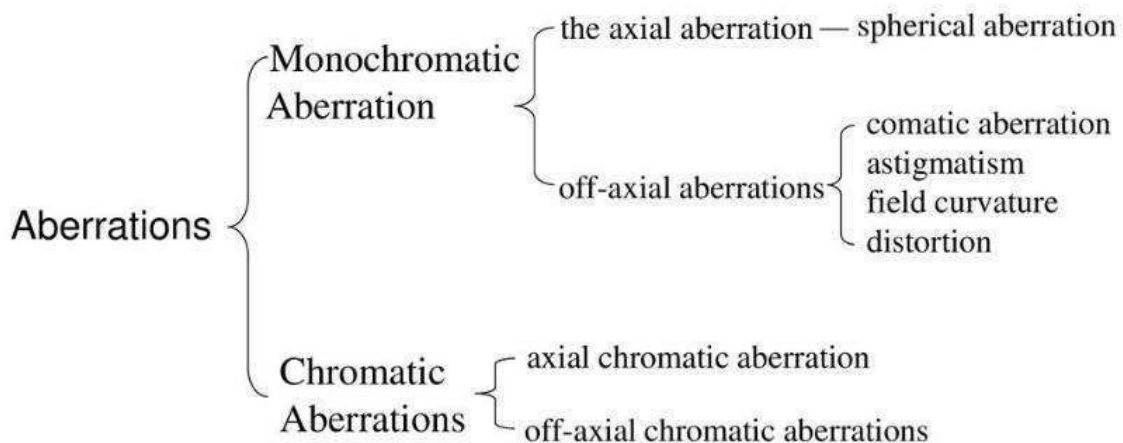
8.1. DEFECTS OF IMAGES FORMED BY LENSES:

- ❖ The defects in images formed by lenses are called aberrations. Images formed by a lens are defective because of the following reasons.
 - 1) Lens maker's formula is derived on the assumptions that incident rays are paraxial and aperture of the lens is small.
 - 2) Object may be extended and need not have point size always.
 - 3) Due to dispersion, the focal length of the lens changes with color.
 - 4) Refractive index of the lens changes with wavelength of the incident light.

8.2. ABERRATION:

- ❖ Aberrations are of two types

- 1) Monochromatic aberrations
- 2) Chromatic aberrations

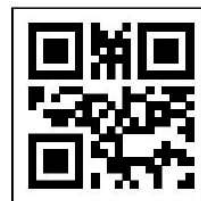


8.2.1. Spherical and Chromatic Aberration in a Lens:

- According to geometric optics, the image of a point object formed in a lens is a point image. In reality, the image of a point object is not a point image, but it is spread in to a region in space both along and perpendicular to the axis of the lens. The deviation of an optical image in size, shape and position formed by a lens is known as aberration of an optical image.
- The aberration of an image is not due to any defect in the construction of the lens, but it is due to the reasons mentioned below:
 - (1) The phenomenon of refraction in the lens and
 - (2) Variation of refractive index of the material of a lens with the wavelength of light.

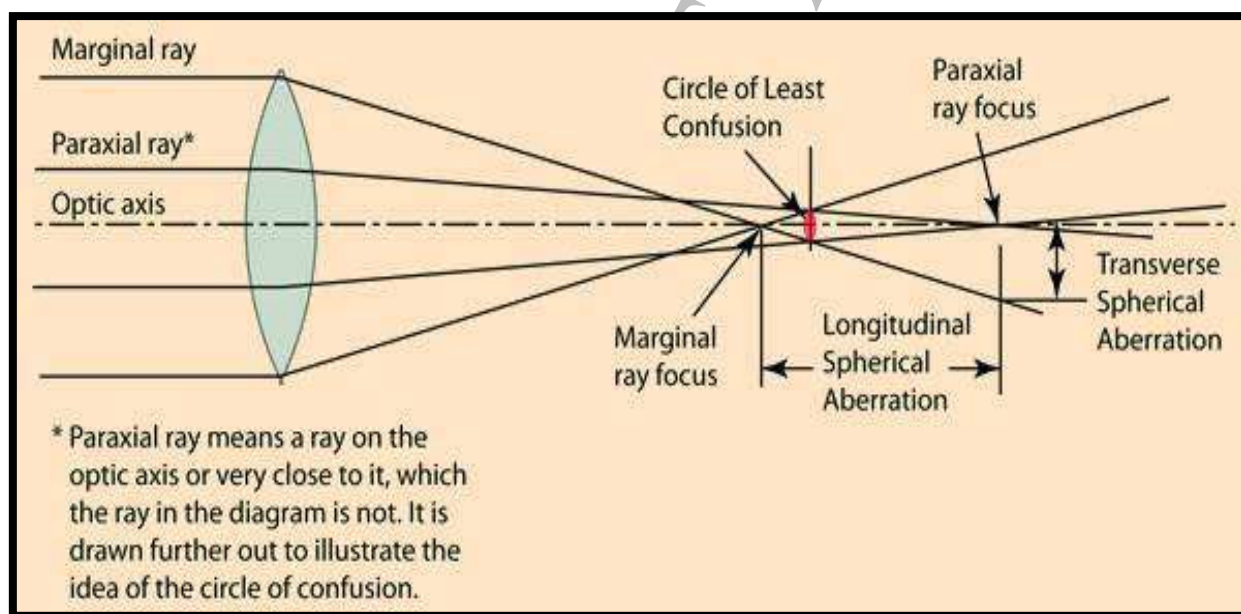
8.2.2. Monochromatic Aberration:

- The aberration of optical image even when monochromatic light is used is known as **monochromatic aberration**.
- There are five different types of monochromatic aberrations. They are,
 - (1) Spherical aberration
 - (2) Coma
 - (3) Astigmatism
 - (4) Curvature of the field and
 - (5) Distortion
- When the concept of principal focal length is used, the presumption is that all parallel rays focus at the same distance, which is of course true only if there are no aberrations. The use of the lens equation likewise presumes an ideal lens, and that equation is practically true only for the rays close to the optic axis, the so-called paraxial rays. For a lens with spherical aberration, the best approximation to use for the focal length is the distance at which the difference between the paraxial and marginal rays is the smallest. It is not perfect, but the departure from perfect focus forms what is called the "circle of least confusion". Spherical aberration is one of the reasons why a smaller aperture (larger f-number) on a camera lens will give a sharper image and greater depth of field since the difference between the paraxial and marginal rays is less.



8.2.3. Spherical Aberration and its Minimization:

- The rays of light from the distant object after passing through the lens at the margin of the lens [known as marginal rays] converge at a point I_m close to the lens. Similarly, the rays of light passing through a region close to the axis [known as paraxial rays] converge at a point I_p , away from the lens. This results in an image that spreads into a region from I_m to I_p along the axis and from A to B perpendicular to the axis. This defect of the image due to the rays passing through different section of the lens, even with monochromatic light, is known as **spherical aberration of the lens**. The spread of the image along the axis, $[dx]$ is known as longitudinal spherical aberration.
- The image formed at AB is a circle with least diameter and at this position the best image is formed. This circle is called the **circle of least confusion**. The radius of the circle of least confusion measures lateral spherical aberration

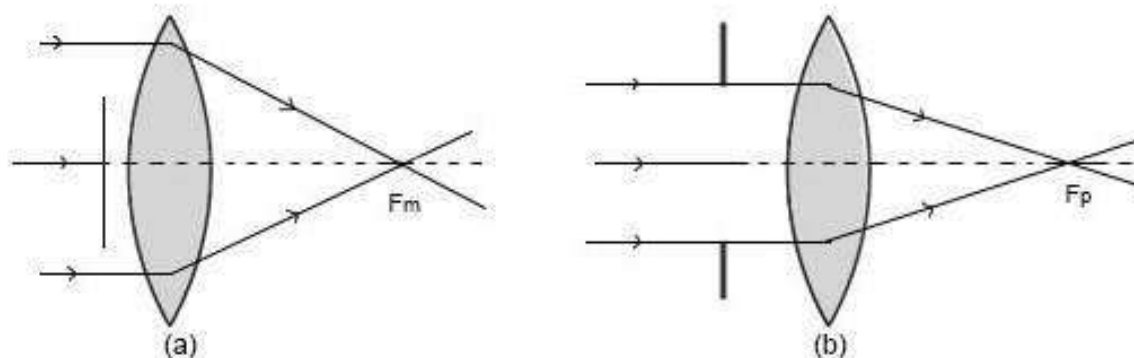


- Monochromatic aberration is also called as spherical aberration. The failure of paraxial and marginal rays to form a common image for pointed object in front of a lens on the principal axis is called spherical aberration.
- Spherical aberration is the blurriness at the edge of an image. Using a spherical lens on a camera **causes light near the edge of the lens (farther from the optical axis) to converge closer to the lens.** "Positive" spherical aberration means peripheral rays are bent too much. "Negative" spherical aberration means peripheral rays are not bent enough.

8.3. METHODS OF REDUCING SPHERICAL ABERRATION:

(1) By using stops:

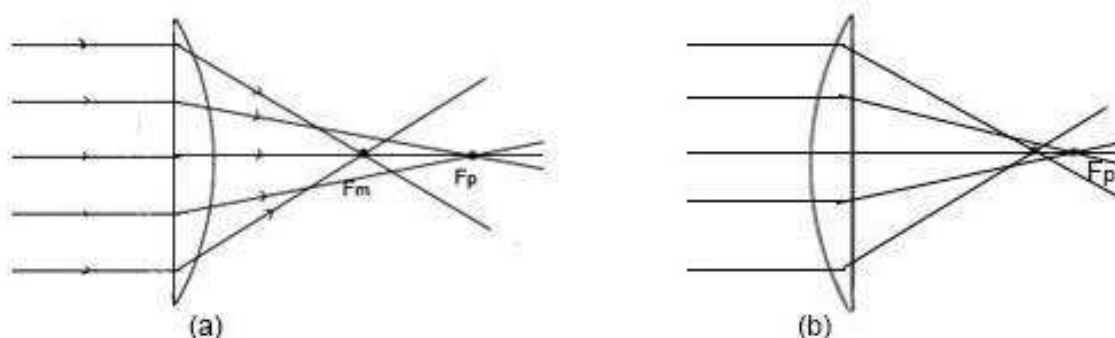
In this case, the stops used will either allow the paraxial rays or marginal rays. Usually the stop is used to avoid the marginal rays. This brings paraxial and marginal images close to one another thereby reducing the spherical aberration.



Reduction of spherical aberration by using stops in different positions.

(2) By the use of Plano-convex lens:

In a lens, the deviation produced by the lens is minimum, when the deviation is shared equally between the two surfaces of the lens. This is achieved in a Plano-convex lens by arranging convex side facing the incident or emergent rays whichever are more parallel to the axis as shown in the following figure.



Reduction of spherical aberration by using plano - convex lens in different positions.

(3) By the use of crossed lenses:

It is theoretically known that the lenses have minimum spherical aberration when the parallel rays fall on the lens having their radii of curvature r_1 and r_2 bearing a ratio, which satisfies the following condition.

$$\frac{r_1}{r_2} = \frac{\mu(2\mu-1)-4}{\mu(2\mu+1)} \dots\dots (1)$$

In the above equation, μ is the refractive index of the material of the lens. For a lens of $\mu = 1.5$, the

$$\frac{r_1}{r_2} = -\frac{1}{6}$$

A lens having its radii of curvature satisfying this condition is known as a crossed lens.

(4) By using two Plano-convex lenses separated by a suitable distance:

Math When the two plano-convex lenses are separated at a suitable distance, the total deviation is divided equally between the two lenses and the total deviation is minimum. This reduces the spherical aberration to minimum. The necessary condition is derived as follows

With reference of figure (4) , we can write,

$$\angle BAK = \angle BF_2O_2 = \delta, \text{ Also } \angle F_1BF_2 = \angle BF_2F_1 = \delta, \text{ so that}$$

$$F_1F_2 = F_1B = F_1O_2 \text{ or } O_2F_1 = \frac{1}{2} F_2O_2F_2.$$

Since F_2 is the virtual object of the real image F_1 and using the lens formula for the second lens,

We can write the equation

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f^2} \dots (2)$$

$$\text{In this equation } u = f_1 - d \text{ \& } v = \frac{f_1 - d}{2} \dots (3)$$

Substituting for 'u' and 'v' and simplifying , we get

$$\frac{2}{f_1 - d} - \frac{1}{f_1 - d} = \frac{1}{f_1} \Rightarrow \frac{1}{f_1 - d} = \frac{1}{f_2} = \frac{1}{f_1 - d} = \frac{1}{f_1} \Rightarrow f_2 = f_1 - d$$

Equation (4) gives the condition for minimum spherical aberration.

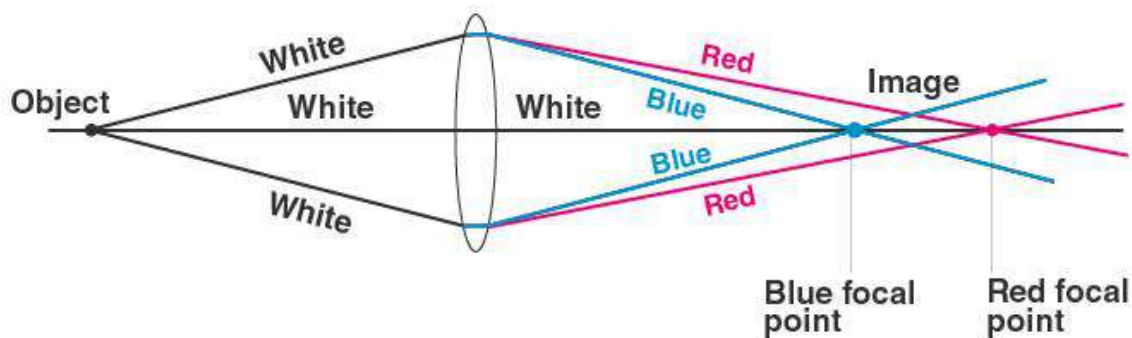
5) By using suitable concave and convex lenses in contact:

Since spherical aberration produced by convex lens is positive and that produced by a concave lens is negative, a suitable combination of convex and concave lens will minimize the spherical aberration.



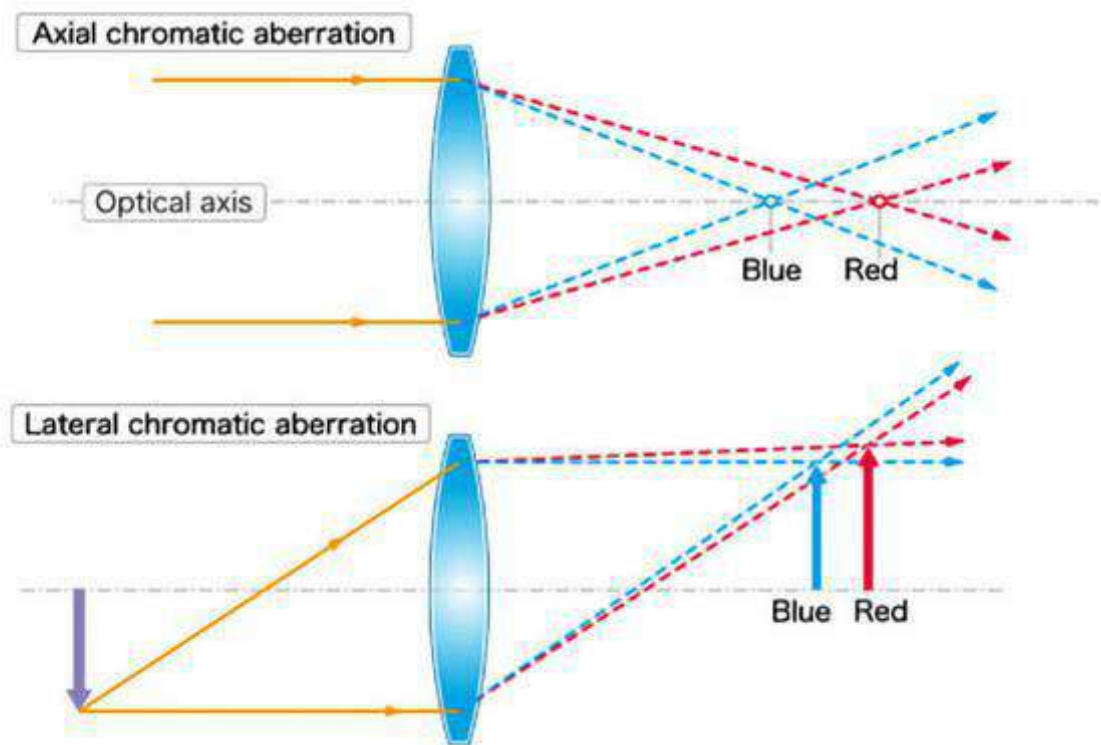
8.4. CHROMATIC ABERRATION:

- ❖ Aberration of optical images formed in a lens due to the variation of refractive index with the wavelength of light is known as chromatic aberration.
- ❖ **Chromatic aberrations** (present when using **more than one wavelength** of light) and **monochromatic aberrations** (present with a **single wavelength** of light). Monochromatic aberrations are **aberrations that occur in quasimonochromatic light**.



Chromatic Aberration

8.4.1. Longitudinal or Axial Chromatic Aberration:



- When a parallel beam of white light is passed through a lens, blue rays are brought to focus at a point near the lens and red rays are brought to focus at a

point away from the lens and other coloured foci are formed in between them. Thus, the image spread over a distance 'x' from blue focus to red focus and this distance $x = f_r - f_b$, is called the **longitudinal or Axial Chromatic Aberration**. An equation for axial chromatic aberration is derived as follows

- The focal length of a lens is given by,

$$\frac{1}{f} = (\mu - 1) \left[\frac{1}{R_1} - \frac{1}{R_2} \right] \dots (1)$$

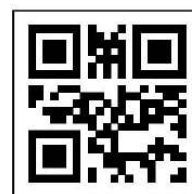
$$\text{or } \left[\frac{1}{R_1} - \frac{1}{R_2} \right] = \frac{1}{f(\mu - 1)} \dots (2)$$

- similarly, the focal length for the blue and red rays is given by ,

$$\frac{1}{f_b} = (\mu_b - 1) \left[\frac{1}{R_1} - \frac{1}{R_2} \right] = \frac{(\mu_b - 1)}{(\mu - 1)f} \dots (3)$$

- Also

$$\frac{1}{f_r} = (\mu_r - 1) \left[\frac{1}{R_1} - \frac{1}{R_2} \right] = \frac{(\mu_r - 1)}{(\mu - 1)f} \dots (4)$$



- Subtracting equation (4) from equation (3), we get,

$$\frac{1}{f_b} - \frac{1}{f_r} = \frac{(\mu_b - 1 - \mu_r + 1)}{(\mu - 1)f} \Rightarrow \frac{f_r - f_b}{f_r f_b} = \frac{(\mu_b - \mu_r)}{(\mu - 1)f} \dots (5)$$

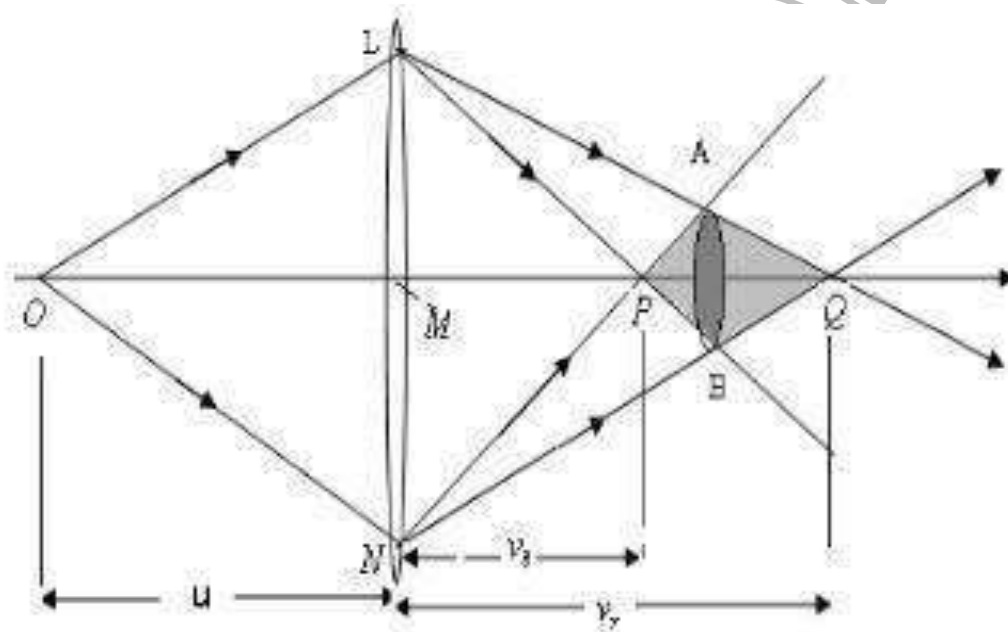
- Taking $f_r f_b = f^2$ (where f is the mean focal length), we can write equation (5) as

$$\frac{f_r - f_b}{f^2} = \frac{(\mu_b - \mu_r)}{(\mu - 1)f} \Rightarrow f_r - f_b = \left[\frac{(\mu_b - \mu_r)}{(\mu - 1)} \right] f = \omega \times f$$

- Thus $f_r - f_b = \omega f \dots (6)$
- In equation (6) 'ω' is the dispersive power of the material of the lens and f is the focal length of the mean ray. Therefore, axial chromatic aberration is equal to the product of the dispersive power of the material of the lens and the focal length of the lens. As ω and f are constant for a lens, a single lens cannot be used to minimize axial chromatic aberration. As a concave lens forms virtual focus, the focal length of the lens for mean ray is negative and hence a suitable combination of a convex and a concave lens can minimize axial chromatic aberration.

8.4.2. Circle of Least Confusion, a Measure of lateral Chromatic Aberration:

- Let a point object illuminated by white light is situated on the axis at a distance “u” from the lens and the blue and red images are formed on the axis at positions P and Q such that the coloured images spread from P to Q. A screen placed at AB has an image with least lateral chromatic aberration. The diameter of the circle of least confusion gives a measure of lateral chromatic aberration and equation for is calculated as follows.



Let ‘u’ be the object distance and ‘v_r’ and ‘v_b’ denote the image distance for red and blue images. If f_r and f_b represent the focal lengths for the red and blue rays of light, then

$$\frac{1}{v_b} - \frac{1}{u} = \frac{1}{f_b} \dots (1)$$

And $\frac{1}{v_r} - \frac{1}{u} = \frac{1}{f_r} \dots (2)$



- Subtracting equation (2) from (1), we get

$$\frac{1}{v_b} - \frac{1}{v_r} = \frac{1}{f_b} - \frac{1}{f_r} \Rightarrow \frac{v_r - v_b}{v_r v_b} = \frac{f_r - f_b}{f_r f_b}$$

- Taking $v_r v_b = v^2$ and $f_r f_b = f^2$ (where f is the mean focal length),

$$\frac{v_r - v_b}{v^2} = \frac{f_r - f_b}{f^2} = \frac{w f}{f^2} = \frac{w}{f} \text{ (Because, } f_r - f_b = w f \text{)}$$

- Therefore $v_r - v_b = \frac{wv^2}{f} \dots\dots(3)$
- From similar triangles LQN and AQB we can write, $\frac{CQ}{AB} = \frac{MQ}{LN} \dots\dots(4)$
- Also, from similar triangles LPN and APB we can write, $\frac{CQ}{AB} = \frac{MP}{LN} \dots\dots(5)$
- Adding equations (4) and (5), we get,

$$\frac{PC + CQ}{AB} = \frac{MQ + MP}{LN} \Rightarrow \frac{PQ}{AB} = \frac{MQ + MP}{LN} \dots\dots(6)$$

- Methods

But , $PQ = v_r - v_b$; $AB = d$, in the diameter of the circle of least confusion and $LN = D$ is the diameter of the lens aperture and $MQ + MP = v_r + v_b = 2v$ approximately. Substituting these values in equation (6), we get

$$= \frac{v_r - v_b}{d} = \frac{2v}{D} \Rightarrow D \times \left[\frac{(v_r - v_b)}{2v} \right] = d$$

- Using equation (3), we can write ,

$$d = D \times \left[\frac{1}{2v} \right] \frac{wv^2}{f} = \frac{1}{2} \cdot Dw \cdot \frac{v}{f} \dots\dots(7)$$



- For a parallel beam of incident light, and hence equation (7) reduces to the form ,

$$d = \frac{1}{2} \cdot Dw \cdot \frac{f}{f} = \frac{1}{2} Dw \dots\dots(8)$$

- Thus, the lateral chromatic aberration on the diameter of the lens aperture and the dispersive power of the material, but it is independent of the focal length of the lens.

8.5. METHODS OF MINIMIZING CHROMATIC ABERRATION:

8.5.1. Condition for achromatism of two lenses placed in contact:

- Let a convex lens C made of crown glass and a concave lens F made of flint glass in contact act as achromatic combination. Let μ_b, μ, μ_r and μ'_b, μ', μ'_r represent the refractive indices for blue, yellow and red rays of light of the two

materials of the lenses. Let f_b, f, f_r and f'_b, f', f'_r are corresponding focal lengths of the two lenses and ω and ω' are the dispersive powers for crown and flint glass respectively. Let R_1 and R_2 be the radii of curvature of the Crown glass lens and let R'_1 and R'_2 be the radii of curvature of the Flint glass lens.

- Then using lens maker's formulae, we can write for the Crown glass lens

$$\frac{1}{f} = (\mu - 1) \left[\frac{1}{R_1} - \frac{1}{R_2} \right] \Rightarrow \left[\frac{1}{R_1} - \frac{1}{R_2} \right] = \frac{1}{(\mu - 1)f} \dots (1) \text{ (for yellow ray)}$$

$$\frac{1}{f_r} = (\mu_r - 1) \left[\frac{1}{R_1} - \frac{1}{R_2} \right] \Rightarrow \frac{1}{f_r} = \frac{(\mu_r - 1)}{(\mu - 1)f} \dots (2) \text{ (for red ray)}$$

$$\text{also } \frac{1}{f_b} = (\mu_b - 1) \left[\frac{1}{R_1} - \frac{1}{R_2} \right] \Rightarrow \frac{1}{f_b} = \frac{(\mu_b - 1)}{(\mu - 1)f} \dots (3) \text{ (for blue ray)}$$

- In the same way, for the flint concave lens, we can write

$$\frac{1}{f'} = (\mu' - 1) \left[\frac{1}{R'_1} - \frac{1}{R'_2} \right] \Rightarrow \left[\frac{1}{R'_1} - \frac{1}{R'_2} \right] = \frac{1}{(\mu' - 1)f'} \dots (4) \text{ (for yellow ray)}$$

$$\frac{1}{f'_r} = (\mu'_r - 1) \left[\frac{1}{R'_1} - \frac{1}{R'_2} \right] \Rightarrow \frac{1}{f'_r} = \frac{(\mu'_r - 1)}{(\mu' - 1)f'} \dots (5) \text{ (for red ray)}$$

$$\frac{1}{f'_b} = (\mu'_b - 1) \left[\frac{1}{R'_1} - \frac{1}{R'_2} \right] \Rightarrow \frac{1}{f'_b} = \frac{(\mu'_b - 1)}{(\mu' - 1)f'} \dots (6) \text{ (for blue ray)}$$

- If F_b and F_r denote the focal length of the combination for blue and red rays of light, then, we can write,

$$\frac{1}{F_r} = \frac{1}{f_r} + \frac{1}{f'_r} = \frac{(\mu_r - 1)}{(\mu - 1)f} + \frac{(\mu'_r - 1)}{(\mu' - 1)f'} \dots (7)$$

$$\text{Similarly, } \frac{1}{F_b} = \frac{1}{f_b} + \frac{1}{f'_b} = \frac{(\mu_b - 1)}{(\mu - 1)f} + \frac{(\mu'_b - 1)}{(\mu' - 1)f'} \dots (8)$$

- For the combination to be achromatic, the focal length F_b and F_r must be equal, thus

$$F_r = F_b \text{ or } \frac{1}{F_b} = \frac{1}{F_r} \Rightarrow \frac{(\mu_r - 1)}{(\mu - 1)f} + \frac{(\mu'_r - 1)}{(\mu' - 1)f} = \frac{(\mu_b - 1)}{(\mu - 1)f} + \frac{(\mu'_b - 1)}{(\mu' - 1)f}$$

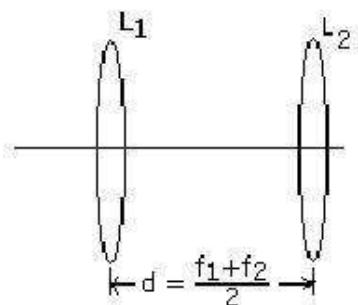
$$\Rightarrow \frac{(\mu_b - \mu_r)}{(\mu - 1)f} - \frac{(\mu_r - 1)}{(\mu - 1)f} + \frac{(\mu'_b - \mu'_r)}{(\mu' - 1)f'} - \frac{(\mu'_r - 1)}{(\mu' - 1)f'} = 0 \Rightarrow \frac{(\mu_b - \mu_r)}{(\mu - 1)f} + \frac{(\mu'_b - \mu'_r)}{(\mu' - 1)f'} = 0$$

Using $\frac{(\mu_b - \mu_r)}{(\mu - 1)} = \omega$ and $\frac{(\mu'_b - \mu'_r)}{(\mu' - 1)} = \omega'$, we get $\frac{\omega}{f} + \frac{\omega'}{f'} = 0$ or

$$\frac{\omega}{f} = -\frac{\omega'}{f'} \Rightarrow \boxed{f = -f' \frac{\omega}{\omega'}} \dots (9)$$

- Since ω and ω' are positive quantities, f' is negative if f is positive. Thus if crown glass is used to make convex lens, then flint glass lens must be concave. The ratio of the dispersive powers of the material of the lenses must be equal to the ratio of the focal lengths of the two lenses.

8.5.2. Condition for achromatism of two thin lenses separated by finite distance:



- Let f_1 and f_2 be the two convex lenses separated by a distance 'd' such that they act as achromatic combination. Let the two lenses are made of the same material and let μ , μ_b and μ_r denote the refractive indices for the mean ray, blue rays and red rays respectively.
- Let f_r, f_r' and f_b, f_b' are the focal lengths of the two lenses for red and blue rays of light. Then, the equivalent focal length of the two lenses for mean ray, red ray and blue ray are respectively given by the following equations.

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2} \dots (1) \text{ (for mean ray)}$$

$$\frac{1}{F_r} = \frac{1}{f_r} + \frac{1}{f_r'} - \frac{d}{f_r f_r'} \dots (2) \text{ (for red rays)}$$

$$\frac{1}{F_b} = \frac{1}{f_b} + \frac{1}{f_b'} - \frac{d}{f_b f_b'} \dots (3) \text{ (for blue rays)}$$

- In the above F, F_r and F_b are the combined focal length for the mean rays, red rays and blue rays.

$$\text{But } \frac{1}{f_r} = \frac{(\mu_r - 1)}{(\mu - 1)f_1'} \frac{1}{f_r'} = \frac{(\mu_r - 1)}{(\mu - 1)f_2} \quad \& \quad \frac{1}{f_b} = \frac{(\mu_b - 1)}{(\mu - 1)f_1'} \frac{1}{f_b'} = \frac{(\mu_b - 1)}{(\mu - 1)f_2} \dots (4)$$

- using equation (4) in equation (2) and (3), we get

$$\frac{1}{F_r} = \frac{(\mu_r - 1)}{(\mu - 1)f_1} + \frac{(\mu_r - 1)}{(\mu - 1)f_2} - \frac{(\mu_r - 1)^2}{(\mu - 1)^2} \times \frac{d}{f_1 f_2} \dots (5)$$

$$\text{and } \frac{1}{F_b} = \frac{(\mu_b - 1)}{(\mu - 1)f_1} + \frac{(\mu_b - 1)}{(\mu - 1)f_2} - \frac{(\mu_b - 1)^2}{(\mu - 1)^2} \times \frac{d}{f_1 f_2} \dots (6)$$

- for the combination to be achromatic $F_r = F_b$; or $\frac{1}{F_r} = \frac{1}{F_b}$
- The material of the lenses must be equal to the ratio of the focal lengths of the two lenses.
- Using equation (5) and (6), we can write,

$$\frac{(\mu_r - 1)}{(\mu - 1)f_1} + \frac{(\mu_r - 1)}{(\mu - 1)f_2} - \frac{(\mu_r - 1)^2}{(\mu - 1)^2} \frac{d}{f_1 f_2} = \frac{(\mu_b - 1)}{(\mu - 1)f_1} + \frac{(\mu_b - 1)}{(\mu - 1)f_2} - \frac{(\mu_b - 1)^2}{(\mu - 1)^2} \times \frac{d}{f_1 f_2}$$

$$\frac{(\mu_r - 1)}{(\mu - 1)} \left[\frac{1}{f_1} + \frac{1}{f_2} \right] - \frac{(\mu_r - 1)^2}{(\mu - 1)^2} \frac{d}{f_1 f_2} = \frac{(\mu_b - 1)}{(\mu - 1)} \left[\frac{1}{f_1} + \frac{1}{f_2} \right] - \frac{(\mu_b - 1)^2}{(\mu - 1)^2} \times \frac{d}{f_1 f_2}$$

- Re arranging, the above equation, we get

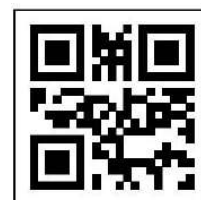
$$\frac{(\mu_b - \mu_r)}{(\mu - 1)} \left[\frac{1}{f_1} + \frac{1}{f_2} \right] = \frac{d}{(\mu - 1)^2 f_1 f_2} \left((\mu_b - 1)^2 - (\mu_r - 1)^2 \right) = \frac{d}{(\mu - 1)^2 f_1 f_2} (\mu_b - \mu_r) [\mu_b + \mu_r - 2]$$

$$= \frac{d}{(\mu - 1)^2 f_1 f_2} (\mu_b - \mu_r) 2[\mu - 2] \quad (\text{taking } \mu_b + \mu_r = 2\mu)$$

$$\frac{(\mu_b - \mu_r)}{(\mu - 1)} \left[\frac{1}{f_1} + \frac{1}{f_2} \right] = \frac{d}{(\mu - 1)^2 f_1 f_2} (\mu_b - \mu_r) 2[\mu - 1] = \frac{2d(\mu_b - 1)}{(\mu - 1)f_1 f_2}$$

$$\text{Thus, we get } \frac{1}{f_1} + \frac{1}{f_2} = \frac{2d}{f_1 f_2} \quad \text{or} \quad \frac{f_1 + f_2}{f_1 f_2} = \frac{2d}{f_1 f_2} \Rightarrow d = \frac{f_1 + f_2}{2}$$

Equation (7) gives the condition for the two thin convex lenses separated by a distance for them to act as achromatic combination of lenses.



9. Coherent sources are those sources for which
- A) Phase difference remain constant
 - B) Frequency remains constant
 - C) Both phase difference and frequency remain constant
 - D) None of these
10. Interference of light is evidence that:
- A) The speed of light is very large
 - B) light is a transverse wave
 - C) light is electromagnetic in character
 - D) Light is a wave phenomenon
11. In Newton's Ring experiments, the diameter of bright rings is proportional to
- A) Square root of Odd Natural numbers
 - B) Natural Number
 - C) Even Natural Number
 - D) Square root of natural number
12. Extended source is needed in
- A) Young's double slit experiment
 - B) Bi prism Experiment
 - C) Newton's Ring Experiment
 - D) None of them
13. The phenomenon of diffraction can be understood using
- A) Huygens principle
 - B) Fraunhofer
 - C) Uncertainty principle
 - D) Fresnel
14. What is the name of the process whereby waves travel around corners and obstacles in their paths?
- A) Reflection
 - B) Refraction
 - C) Interference
 - D) Diffraction
15. In Fraunhofer diffraction, the incident wave front should be _____
- A) elliptical
 - B) Plane
 - C) Spherical
 - D) Cylindrical
16. The wave nature of light is demonstrated by which of the following?
- A) The photoelectric effect
 - B) Color
 - C) The speed of light
 - D) Diffraction
17. In Fresnel diffraction _____
- A) source of light is kept at infinite distance from the aperture
 - B) source of light is kept at finite distance from the aperture

113. In Young's double slit experiment if the slit widths are in the ratio 1:9, the ratio of the intensity at minima to that at maxima will be:

- A) 1 B) $\frac{1}{9}$ C) $\frac{1}{4}$ D) $\frac{1}{3}$

114. In interference with two coherent sources, the fringe width varies:

- A) directly as wavelength
B) inversely as wavelength
C) directly as the separation between slits
D) inversely as the distance between the slits and screen

115. The sources of light are said to be coherent if the waves produced by them have the same:

- A) wavelength
B) amplitude
C) wavelength and a constant phase difference
D) amplitude and the same wavelength

116. When light suffers reflection at the interface between water and glass, the change of phase in the reflected wave is

- A) zero B) π C) $\frac{\pi}{2}$ D) 2π





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UNIT-9

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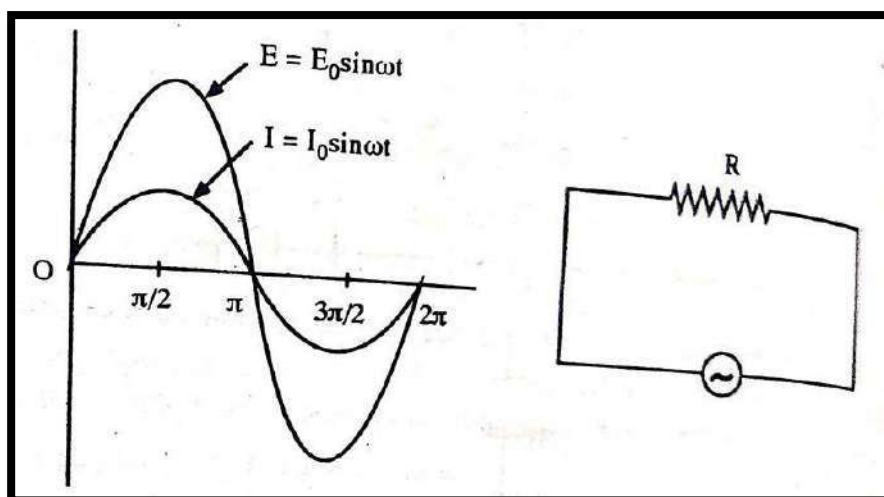
UNIT 9

ELECTRICAL CIRCUITS & ELECTRONICS

9.1. AC Circuits with R, L and C:

9.1.1. AC circuits Containing Only Resistance:

- When the circuit is non-inductive and contains a resistance R the current at any instant $I = E/R$.



- Suppose, the EMF at any instant $E = E_0 \sin \omega t$

$$I = \frac{E_0 \sin \omega t}{R}$$

When,

$$\omega t = \frac{\pi}{2}, \sin \omega t = 1$$

$$I = \frac{E_0}{R} = I_0 \sin \omega t$$



- Thus, the current is represented by a sine wave in phase with the EMF.

9.1.2. AC Circuits Containing Only Inductance:

- When an AC circuit contains only an inductance the current at any instant

$$I = I_0 \sin \omega t \text{ and } E = L \frac{dI}{dt}$$

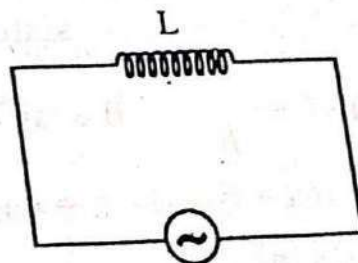
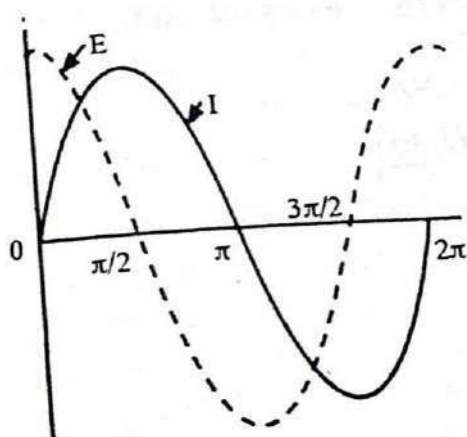
$$E = L \frac{d(I_0 \sin \omega t)}{dt} = L \omega I_0 \cos \omega t$$

When $\cos \omega t = 1, E = E_0$

$$E_0 = L \omega I_0, \quad I_0 = \frac{E_0}{L \omega}$$

$$E = E_0 \cos \omega t = E_0 \sin(\omega t + \pi/2)$$

i.e., EMF is ahead of current by $\pi/2$ or it is said that the current lags behind the EMF by $\pi/2$.



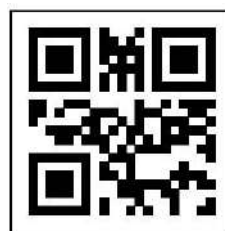
When $\omega t = 0, I = 0, E = E_0$

When $\omega t = \pi/2, I = I_0, E = E_0$

When $\omega t = \pi, I = I_0, E = -E_0$

When $\omega t = 3\pi/2, I = -I_0, E = 0$

When $\omega t = 2\pi, I = 0, E = E_0$



$L\omega$ is known as inductive reactance and has the same effect in AC circuits as resistance R in DC circuits.

Note:

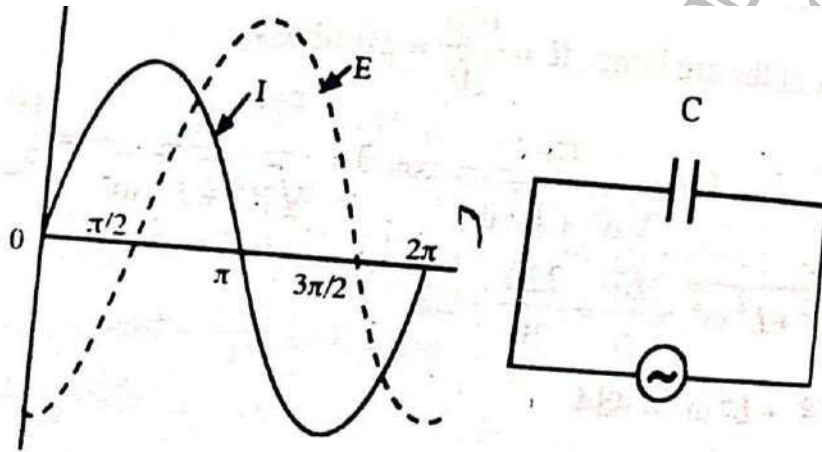
- In a circuit containing only inductance, the EMF is ahead of the current by $\pi/2$.
Using operator j , $E_0 = j[L\omega I_0]$
- The inductive reactance $= L\omega$.

9.1.3. AC Circuits Containing Only Capacitance:

- Consider a condenser of capacity C joined to an AC source. The current at any instant

$$I = I_0 \sin \omega t$$

- The PD across the condenser at any instant $E = \frac{Q}{C}$



- The current at any instant $I = \frac{dQ}{dt}$

$$dQ = I dt$$

$$Q = \int dQ = \int I dt = \int I_0 \sin \omega t dt$$

$$E = \frac{\int I_0 \sin \omega t dt}{C}$$

$$E = -\frac{I_0 \cos \omega t}{C\omega} = \frac{I_0 \sin(\omega t - \frac{\pi}{2})}{C\omega}$$

- When $\sin(\omega t - \pi/2) = 1$, $E = E_0 \frac{I_0}{C\omega}$

$$E = E_0 \sin(\omega t - \pi/2)$$

- Therefore the EMF lags behind the current by $\pi/2$ or the current is a head of EMF by $\pi/2$.

- Moreover, $E_0 = \frac{I_0}{C\omega}$, $I_0 = \frac{E_0}{\frac{1}{C\omega}}$

$\frac{1}{C\omega}$ is known as capacitive reactance.

- As $\omega = 2\pi f$, capacitive reactance $= \frac{1}{2\pi f C}$



Note:

- In a circuit containing only a capacitor, the EMF lags behind the current by $\pi/2$. Using operator j .

$$E_0 = -j \left[\frac{I_0}{C\omega} \right] = I_0 = \left[\frac{-j}{C\omega} \right]$$

- The capacitive reactance $= \frac{1}{C\omega}$
- It is necessary to distinguish between the two kinds of reactance. Inductive reactance is represented by X_L and capacitive reactance by X_C .

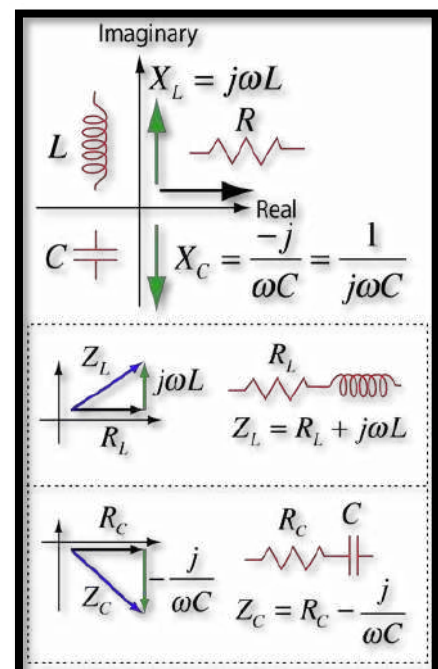
$$1) X_L = 2\pi fL \text{ and } X_C = \frac{1}{2\pi fC}$$

Two points should be noted

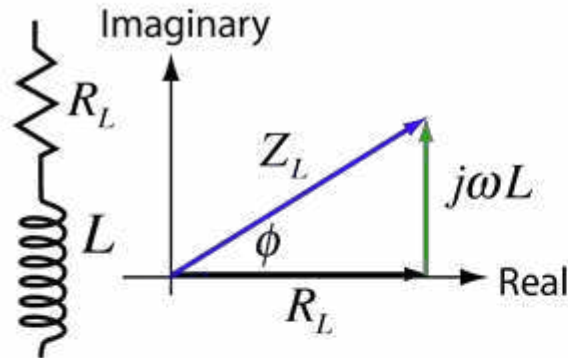
- Inductive reactance, X_L is directly proportional to both inductance and frequency.
 - Capacitive reactance X_C is inversely proportional to both capacitance and frequency.
- 2) Relative to the same current, the PD across an inductance is ahead of the current by $\frac{\pi}{2}$, whereas the PD across a capacitance lags behind the current by $\frac{\pi}{2}$. Due to this reason, the phase difference between the two PDs is π and X_L is taken as +ve and X_C is taken as -ve.

9.2. Complex Impedance and Phase Diagram:

- Using complex impedance is an important technique for handling multi-component AC circuits. If a complex plane is used with resistance along the real axis then the reactances of the capacitor and inductor are treated as imaginary numbers. For series combinations of components such as RL and RC combinations, the component values are added as if they were components of a vector. Shown here is the cartesian form of the complex impedance. They can also be written in polar form. Impedances in this form can be used



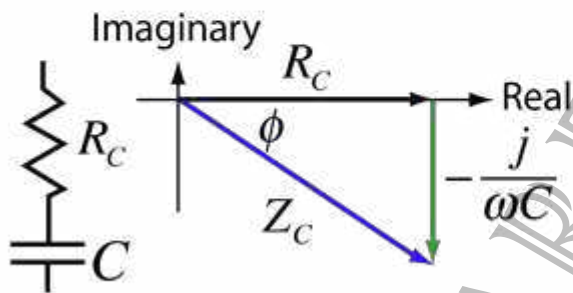
as building blocks for calculating the impedances of combination circuits like the RLC parallel circuit. This depicts the phasor diagrams and complex impedance expressions for RL and RC circuits in polar form. They can also be expressed in Cartesian form.



Cartesian form: $Z_L = R_L + j\omega L$

Polar form: $Z_L = |Z_L| e^{j\phi}$

where $|Z_L| = \sqrt{R_L^2 + \omega^2 L^2}$
 $\phi = \tan^{-1} \frac{\omega L}{R_L}$



Cartesian form: $Z_C = R_C - \frac{j}{\omega C}$

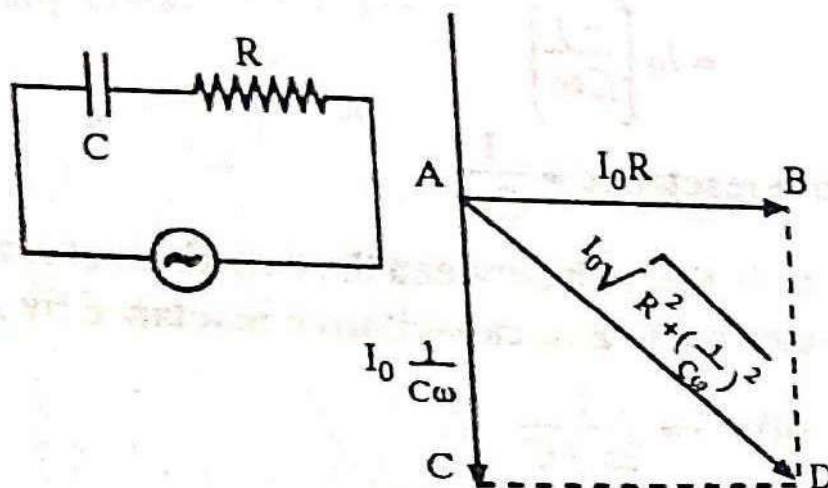
Polar form: $Z_C = |Z_C| e^{j\phi}$

where $|Z_C| = \sqrt{R_C^2 + \left[\frac{-1}{\omega C} \right]^2}$
 $\phi = \tan^{-1} \frac{-1}{\omega C R_C}$

9.3. R-L and R-C circuits:

AC circuit containing resistance and capacitance:

- Consider an AC circuit containing a resistance R and a capacitance C joined in series let the current at any instant be given by ,



$$I = I_0 \sin \omega t \text{ _____ (1)}$$

E.M.F at any instant , $E = RI + Q/C$

But ,

$$Q = \int I_0 \sin \omega t \, dt$$

$$E = RI_0 \sin \omega t + \frac{\int I_0 \sin \omega t \, dt}{C}$$

$$E = RI_0 \sin \omega t - \frac{I_0}{C} \cos \omega t$$

$$E = I_0 \sqrt{R^2 + \left(\frac{1}{C\omega}\right)^2} \times \left(\sin \omega t \frac{R}{\sqrt{R^2 + \left(\frac{1}{C\omega}\right)^2}} - \cos \omega t \frac{\frac{1}{C\omega}}{\sqrt{R^2 + \left(\frac{1}{C\omega}\right)^2}} \right)$$

Taking, $\frac{R}{\sqrt{R^2 + \left(\frac{1}{C\omega}\right)^2}} = \cos \theta$

$$\frac{R}{\sqrt{R^2 + \left(\frac{1}{C\omega}\right)^2}} = \cos \theta \text{ and } \frac{\frac{1}{C\omega}}{\sqrt{R^2 + \left(\frac{1}{C\omega}\right)^2}} = \sin \theta \text{ and } \tan \theta = \frac{\frac{1}{C\omega}}{R}$$

$$E = I_0 \sqrt{R^2 + \left(\frac{1}{C\omega}\right)^2} (\sin \omega t \cos \theta - \cos \omega t \sin \theta)$$

$$= I_0 \sqrt{R^2 + \left(\frac{1}{C\omega}\right)^2} \sin(\omega t - \theta)$$

When $\sin(\omega t - \theta) = 1$

$$E = E_0 = I_0 \sqrt{R^2 + \left(\frac{1}{C\omega}\right)^2}$$

$$E = E_0 \sin(\omega t - \theta)$$

Therefore , the E.M.F lags behind the current by θ

$$\theta = \tan^{-1} \frac{\frac{1}{C\omega}}{R}$$

Also , $E_0 = I_0 \sqrt{R^2 + \left(\frac{1}{C\omega}\right)^2}$

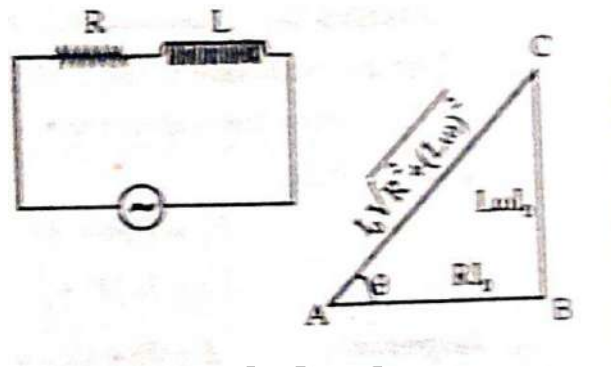


$$I_0 = E_0 / \sqrt{R^2 + \left(\frac{1}{C\omega}\right)^2}$$

The impedance of the circuit, $Z = \sqrt{R^2 + \left(\frac{1}{C\omega}\right)^2}$

Ac Circuit Containing Resistance and Inductance :

- When an AC circuit contains a resistance R and an inductance L in series, the current at any instant t,



$$I = I_0 \sin \omega t$$

EMF at any instant, $e = RI + L di/dt$

$$\begin{aligned} E &= R \sin \omega t + L \frac{d(I_0 \sin \omega t)}{dt} \\ &= R I_0 \sin \omega t + L \omega I_0 \cos \omega t \\ &= I_0 [R \sin \omega t + L \omega \cos \omega t] \\ &= I_0 [R \sin \omega t + L \omega \cos \omega t] \\ &= I_0 \sqrt{R^2 + (L\omega)^2} \left[\frac{R}{\sqrt{R^2 + (L\omega)^2}} \sin \omega t + \frac{L\omega}{\sqrt{R^2 + (L\omega)^2}} \cos \omega t \right] \end{aligned}$$

Taking $\frac{R}{\sqrt{R^2 + (L\omega)^2}} = \cos \theta$, and $\frac{L\omega}{\sqrt{R^2 + (L\omega)^2}} = \sin \theta$

$$E = I_0 \sqrt{R^2 + (L\omega)^2} [\cos \theta \sin \omega t + \sin \theta \cos \omega t]$$

$$E = I_0 \sqrt{R^2 + (L\omega)^2} \sin(\omega t + \theta)$$

$$E = I_0 \sqrt{R^2 + (L\omega)^2} \sin(\omega t + \theta)$$

Where $\tan \theta = L\omega/R$, or $\theta = \tan^{-1}(L\omega/R)$

When $\sin(\omega t + \theta) = 1, E = E_0$

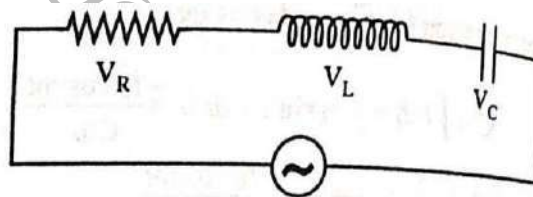
$$E_0 = I_0 \sqrt{R^2 + (L\omega)^2}$$

$$E = E_0 \sin(\omega t + \theta)$$

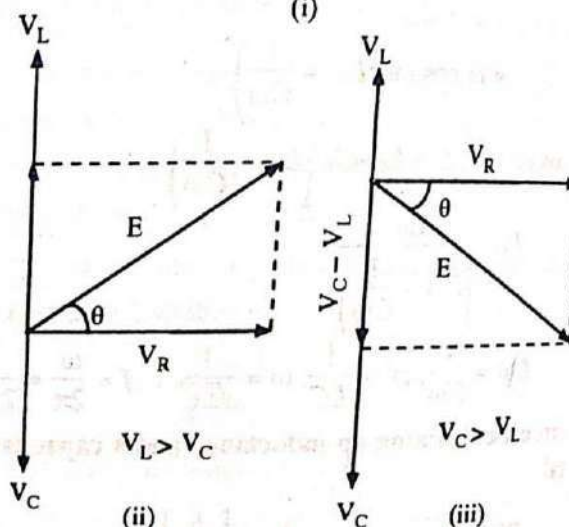
- $\sqrt{R^2 + (L\omega)^2}$ is called as impedance of the circuit and has the same meaning of resistance in a DC circuit . thus impedance is also called as the effective resistance of an AC circuit as $\omega = 2\pi f$, where f is the frequency impedance = $\sqrt{R^2 + (L2\pi f)^2}$ from the equation (i) and (iii) it is clear the EMF is ahead of current by θ where $\theta = \tan^{-1}(L\omega/R)$ or the current lags behind the EMF by an angle θ .
- The impedance can also be calculate from the impedance triangle . taken AB representing RI_0 and BC representing $L\omega I_0$ the PD
- RI_0 is in phase with the current where as $L\omega I_0$ is ahead of the current by $\frac{\pi}{2}$.
- The total PD equal to $I_0 \sqrt{R^2 + (L\omega)^2}$ is represented by AC . therefore w, impedance = $\sqrt{R^2 + (L\omega)^2} = \sqrt{R^2 + (L2\pi f)^2}$.

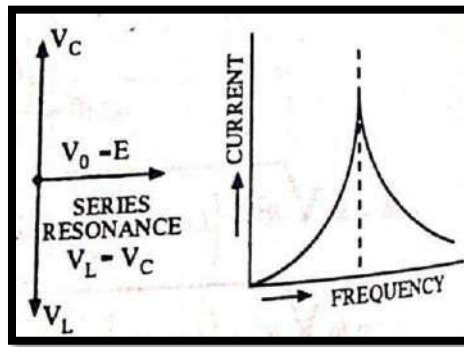
9.4. Series and Parallel Resonant- LCR circuits:

LRC Circuit (series resonance circuit)



(i)





- Consider, a circuit containing an inductance L , a capacitor C and a resistance R joined series. This series circuit is connected to an AC supply given by

$$E = E_0 e^{j\omega t}$$

- The total impedance of the circuit is given by

$$Z = R + j(L\omega - 1/c\omega)$$

- The current I at any instant is

$$I = E/Z$$

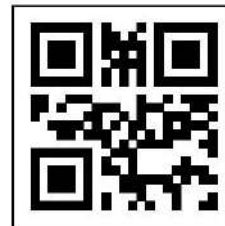
$$I = E_0 e^{j\omega t} / R + j(L\omega - 1/c\omega)$$

$$I = E_0 e^{j\omega t} / \sqrt{R^2 + j(L\omega - 1/c\omega)^2}$$

$$I = \frac{E_0 e^{j\omega t}}{\sqrt{R^2 + (L\omega - 1/c\omega)^2}} < \tan^{-1} \frac{L\omega - 1/c\omega}{R}$$

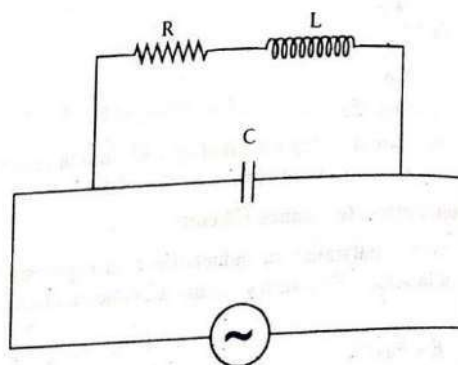
$$\tan \delta = \frac{L\omega - 1/c\omega}{R}$$

$$I_0 = E_0 / \sqrt{R^2 + (L\omega - 1/c\omega)^2}$$



Parallel Resonance Circuit (Reject for Circuit):

- In parallel circuit, capacitor C is connected in parallel to the series combination of resistance R and inductance L . The combination is connected across the AC source.



$$Z_1 = R + jL\omega$$

$$Z_2 = \frac{1}{jC\omega}$$

- Z_1 and Z_2 are in parallel

$$\frac{1}{Z} = \frac{1}{Z_1} + \frac{1}{Z_2}$$

$$\frac{1}{Z} = \frac{1}{R + jL\omega} + \frac{1}{\frac{1}{jC\omega}}$$

$$Y = \frac{1}{R + jL\omega} + jC\omega$$

$$Y = \frac{R - jL\omega}{R^2 + (jL\omega)^2} + jC\omega$$

$$Y = \frac{R}{R^2 + (L\omega)^2} + j \left[C\omega - \frac{L\omega}{R^2 + (L\omega)^2} \right]$$

$$Z = \frac{1}{Y} = \frac{1}{\frac{R}{R^2 + (jL\omega)^2} + j \left[C\omega - \frac{L\omega}{R^2 + (jL\omega)^2} \right]}$$

- Current :

$$I = \frac{E}{Z} = EY$$

$$I = E \left[\frac{R}{R^2 + (jL\omega)^2} + j \left[C\omega - \frac{L\omega}{R^2 + (jL\omega)^2} \right] \right]$$

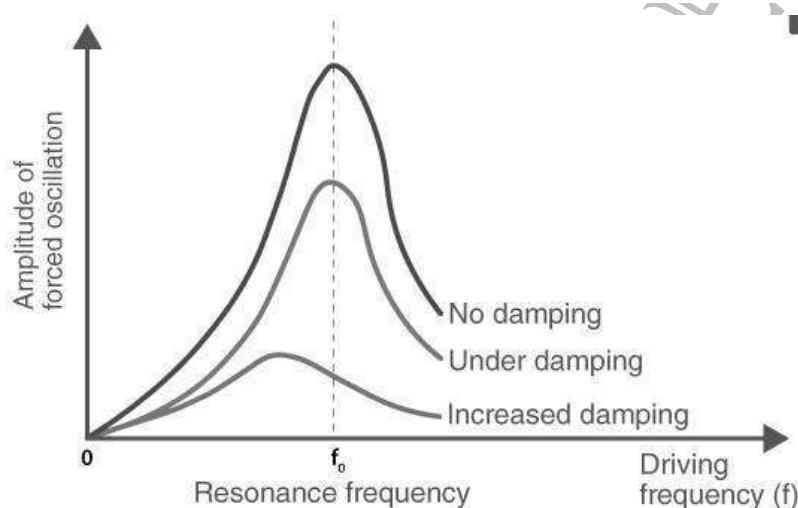
9.5. Sharpness of Resonance Q factor:

- ❖ Resonance is defined as the tendency of a system to vibrate with an increase in amplitude at the excitation of frequencies. Resonance frequency or resonant frequency is the maximum frequency at which the amplitude is relatively maximum. The Q factor is used to define the sharpness of the resonance.

What is Sharpness of Resonance?

- The sharpness of resonance is defined using the Q factor which explains how fast energy decay in an oscillating system. The sharpness of resonance depends upon:

- **Damping:** Effect due to which there is a reduction in amplitude of vibrations.
- **Amplitude:** Maximum displacement of a point on a vibrating body which is measured from its equilibrium position.
- The sharpness of resonance increases or decreases with an increase or decrease in damping and as the amplitude increases, the sharpness of resonance decreases.



What is Q Factor?

- Q factor or quality factor is a dimensionless parameter that is used to describe the underdamped resonator and characterizes the bandwidth and centre frequency of the resonator.
- The mathematical representation is:

$$Q = E_{\text{stored}} / E_{\text{lost per cycle}}$$

- The Q factor of an RF resonant circuit is given as:

$$Q = F_0 / F_{3dB}$$

What is Q Factor of Coil?

- Q factor for a coil is defined for a given frequency as the ratio of inductance L to the resistance R of a coil.

$$Q = \omega L / R$$

What is Q Factor of RLC Circuit?

- Q factor in a series circuit is:

$$Q = \frac{1}{R} \sqrt{\frac{L}{C}} = \frac{\omega_0 L}{R}$$

9.17. Multiple Choice Questions:

- Addition of trivalent impurity to a semiconductor creates many _____.
 A) holes
 B) free electrons
 C) valence electrons
 D) bound electrons
- A hole in a semiconductor is defined as _____.
 A) a free electron
 B) the incomplete part of an electron pair bond
 C) a free proton
 D) a free neutron
- The impurity level in an extrinsic semiconductor is about _____ of pure semiconductor.
 A) 10 atoms for 10^8 atoms
 B) 1 atom for 10^8 atoms
 C) 1 atom for 10^4 atoms
 D) 1 atom for 100 atoms
- As the doping to a pure semiconductor increases, the bulk resistance of the semiconductor _____.
 A) remains the same
 B) increases
 C) decreases
 D) none of the above
- A hole and electron in close proximity would tend to _____.
 A) repel each other
 B) attract each other
 C) have no effect on each other
 D) none of the above
- In a semiconductor, current conduction is due _____.
 A) only to holes
 B) only to free electrons
 C) to holes and free electrons
 D) none of the above
- The random motion of holes and free electrons due to thermal agitation is called _____.
 A) diffusion
 B) pressure
 C) ionisation
 D) none of the above



8. When the temperature of an extrinsic semiconductor is increased, the pronounced effect is on _____
- A) junction capacitance B) minority carriers
C) majority carriers D) none of the above
9. With forward bias to a pn junction, the width of depletion layer _____
- A) decreases B) increases C) remains the same D) none of the above
10. The leakage current in a pn junction is of the order of _____
- A) A B) mA C) kA D) μ A
11. In an intrinsic semiconductor, the number of free electrons _____
- A) equals the number of holes B) is greater than the number of holes
C) is less than the number of holes D) none of the above
12. At room temperature, an intrinsic semiconductor has _____
- A) many holes only B) a few free electrons and holes
C) many free electrons only D) no holes or free electrons
13. At absolute temperature, an intrinsic semiconductor has _____
- A) a few free electrons B) many holes
C) many free electrons D) no holes or free electrons
14. At room temperature, an intrinsic silicon crystal acts approximately as _____
- A) a battery B) a conductor
C) an insulator D) a piece of copper wire.
15. A light emitting diode is _____
- A) Heavily doped B) Lightly doped
C) Intrinsic semiconductor D) Zener diode
16. Which of the following is not a characteristic of LED?
- A) Fast action B) High Warm-up time
C) Low operational voltage D) Long life
17. Which of the following materials can be used to produce infrared LED?
- A) Si B) GaAs C) CdS D) PbS

97. The frequency of Colpitts oscillator is expressed as _____

(Where L is inductance and C is the effective capacitance)

- A) $1/(4\pi\sqrt{LC})$ B) $1/(2\pi\sqrt{LC})$
C) $1/(3\pi\sqrt{LC})$ D) $\sqrt{3}/(2\pi\sqrt{LC})$

98. How many capacitors are there in the tank circuit of Colpitts oscillator?

- A) 1 B) 2
C) 3 D) 0

99. Active element used in Colpitts oscillator is _____

- A) Cell B) Voltage regulator
C) Diode D) Transistor

100. Colpitts oscillator provides more performance than Hartley oscillator because of its _____ elements.

- A) Capacitive B) Resistive
C) Inductive D) Active





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UNIT-10

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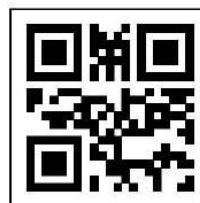
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UNIT 10

EXPERIMENTAL PHYSICS



10.1. Errors and Approximation:

10.1.1 Errors:

- Errors are difference between the measured value and expected value calculated.
- When a single measurement is compared to another single measurement of the same experiment, the values are usually not identical.
- Errors are not always happened by the mistakes.
- It causes results that are inaccurate or misleading and can misrepresent nature.
- A precise experiment also has some small error.
- Errors cannot be completely ignored, but it can be reduced by being aware of common sources of errors and by using thoughtful and careful methods.
- All the scientific measurements suffer from uncertainty which results from unavoidable errors.
- All of these errors can be either random or systematic depending on how they affect the results.
- To find the true values of the experiments, we attempt to find this ideal quantity to the best of our ability with the time and resources available.
- The main strategy in dealing with these errors is to minimize them, but at the same time be honest about them and report truthfully.
- Common sources of error include instrumental, environmental procedural and human.

10.1.1.1 Instrumental Error:

- It happens when the instruments (apparatus) are being used are inaccurate, such as a balance that does not work. Instrumental errors can be classified as,
 - i. Shortcoming of instruments: Friction in bearing of various moving parts, irregular spring tension.
 - ii. Misuse of instruments: A good instrument is not properly used leads to giving abnormal readings.
 - iii. Loading instruments: When the input given to instrument is exceeded the limit, the instruments may affect with the overloading and it leads to show error in next measurements.

Figure: Instrumental errors on pressure meter and weighing balance.



Example: A tape may be too long or an angle measuring instrument may be out of adjustment.

10.1.1.2 Environmental Errors:

- These errors are happening when some external factors in the environment such as an uncommon event, leads to the error.
- Ambient parameters such as temperature, pressure, humidity, dust, external magnetic and electrostatic fields, and frequency sensitivity of the instrument.
- These errors can be avoided by providing air conditioning, cleaning the instruments, housing the instruments in a proper protecting cover.
- The effects of electromagnetic or effects of the external field can be avoided by providing magnetic or electrostatic shields or screens.

Example: If you trying to measure the mass of some object on a scale, and your lab is windy, windy may cause the scale to read incorrectly.

10.1.1.3 Procedural Errors:

- These errors occur when the experimenter does not follow the proper methodological procedures during the measurements.
- There is no solution but can delete the measurements and redo the experiments carefully followed by the proper instructions.
- All the measurement should be done by the procedures which was developed by the manufacturer/professional users.

10.1.1.4 Human Errors:

- These errors due to carelessness or to the limitations of human ability.
- Two types of human error are transcriptional and estimation errors.

Transcriptional errors occur when the data is recorded or written down incorrectly.

Example: The measured reading value is copied incorrectly or when a number is skipped when typing the data into a computer from data sheet.

Estimation errors can occur when reading the measurements on some instruments.

Example: When reading a ruler, you may read the length of a pencil as being 10.3 cm, while other person read it as 10.4 cm.

10.1.2 Approximation:

- Approximation is an estimation value based on prior and reasoning.
- On many scenarios, physicist, engineers and other researchers need to make approximations or guesstimates for a particular quantity.
- The scientific theory predictions can differ from the actual measuring due to there are factors in the real situation that are not included in the theory.
- It is most often applied to numerical problems, also frequently applied in mathematical functions, shapes and physical laws.
- Many approximation numbers are based on formulae in which the input quantities are known only to a limited accuracy.
- The reason for the necessity of approximation is that real systems in nature are far too complex for physics to analyze them exactly in every detail.
- In general, a macroscopic system such as lengths, mass and time scales will need a large number of variables to describe it fully, even if we ignore for the moment its microscopic constitution.

- The sign of approximately (\approx) was introduced by Alfred Greenhill a British mathematician.
- The drawback of the approximation is that it reduces accuracy of measurements. This can cause severe problems in sensitive experimental.

Example (1): Physicist often approximate the shape of the Earth as sphere even though more accurate representation are possible, because many physical properties such as gravity are much easier to calculate for a sphere than other shapes.

Example (2): If our aim of the experiment is finding the motion of the rocket as a whole, we need to know some particular mechanical variables such as original mass, the rate of mass depletion, the exhaust velocity relative to the rocket and gravitational acceleration.



Questions:

- 1) Temperature causes _____ of error.
A) Instrumental B) Procedural C) Environmental D) Human
- 2) Zero error is a type of _____ error.
A) Systematic B) Instrumental C) Random D) Human
- 3) The best method to deal the error is _____.
A) Ignoring B) Minimizing C) Repeat the experiment D) Accepting
- 4) If the length of the object is measured by two observers as 7.86 cm and 8.24. 1.2cm of length already broken in scale. What is the approximate length of the object?
A) 9.2 cm B) 9.3 cm C) 8.1 cm D) 8.7 cm
- 5) The difference between _____ is known as error of measurement.
A) True value and measurement B) Precision and True value
C) Measured value and Precision D) None of the above
- 6) Poor calibration of the instrument leads to _____.
A) Systematic error B) Random error C) Gross error D) Precision error
- 7) Which one of the following is not a systematic error type?
A) Gross error B) Environmental error
C) Observational error D) Instrumental error
- 8) Careless handling of instruments leads to _____.
A) Gross error B) Systematic error C) Environmental error D) Random error

9) The deviation between the measured quantity's actual value and the value displayed by the instrument under various conditions is known as ____.

- A) Dynamic error B) Static error C) Absolute error D) Zero error

10) In a measuring systems random errors caused by ____.

- A) Unpredictable effects B) Poor cabling setup
C) Calibration effects D) Environmental changes

10.2. Types of Errors:

There are two types of errors in experimental measurements.

1. Random errors
 2. Systematic errors
- Random error varies changeable from one to another measurements while the systematic error has same values for every measurement.
 - Random errors are unavoidable, but cluster around the true value.
 - Systematic error can often be avoided by calibrating instruments.

10.2.1 Random Errors:

- Random error affects the last significant digit of a measurement.
- It refers to random fluctuations in the measured data due to limitations of instruments, environmental factors, slight variations in procedures and effects of something changing in the surrounding between measurements. Such as,
 - When weighing yourself on a scale, your position angle will be slightly different each time.
 - When taking a volume reading in a flask, you may read the value from a different angle each time.
 - Measuring the mass of a sample on an analytical balance may produce different values as air currents affects the balance or as water enters and leaves the specimen.
 - Measuring your height is affected by minor posture changes.
 - Measuring wind velocity depends on the height and time at which a measurement is taken. Multiple readings must be taken and averaged because gusts and changes in direction affect the value.

- Readings must be estimated when they fall between marks on a scale or when the thickness of a measurement marking is taken into account.
- For the reason that random error always occurs and cannot be predicted, it's important to take multiple data points and average them to get a sense of the amount of variation and estimate the corrected value.

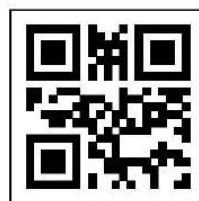
10.2.2 Systematic Errors:

- Systematic error is predictable and either constant or else proportional to the measurement. These errors primarily influence a measurement's accuracy.
- It refers to reproducible fluctuations consistently in the same direction due to an equipment being wrongly calibrated, an equipment with zero error.
- Systematic errors cannot be detected or reduced by taking more measurements.
- Typical causes of systematic error include observational error, imperfect instrument calibration and environmental interference. Such as,
 - Forgetting to tare or zero a balance produces mass measurements that are always off by the same amount. An error caused by not setting an instrument to zero prior to its use is known as offset error.
 - Not reading the curve at eye level for a volume measurement will always result in an inaccurate reading. The value will be consistently low or high, depending on whether the reading is taken from above or below the mark.
 - Measuring length with a metal ruler will give a different result at a cold temperature than at a hot temperature, due to thermal expansion of the material.
 - An improperly calibrated thermometer may give accurate readings within a certain temperature range, but become inaccurate at higher or lower temperatures.
 - Measured distance is different using a new cloth measuring tape versus an older, stretched one. Proportional errors of this type are called scale factor errors.
 - Drift occurs when successive readings become consistently lower or higher over time. Electronic equipment tends to be susceptible to drift. Many other instruments are affected by (usually positive) drift, as the device warms up.
- Once its cause is identified, systematic error may be reduced to an extent. Systematic error can be minimized by routinely calibrating equipment, using controls in experiments, warming up instruments prior to taking readings, and comparing values against standards.

- While random errors can be minimized by increasing sample size and averaging data, it's harder to compensate for systematic error. The best way to avoid systematic error is to be familiar with the limitations of instruments and experienced with their correct use.

Questions:

- 1) Systematic errors can be fixed by _____.
 A) Calibrating
 B) Repeated readings
 C) Changing the scales
 D) Changing of inputs
- 2) Metal ruler may give the different results due to _____.
 A) Thermal expansion
 B) Conductivity nature
 C) Zero error
 D) None of the above
- 3) Random errors can be fixed by _____.
 A) Multiple data's
 B) Calibration
 C) Changing the instruments
 D) Changing of inputs
- 4) An error caused by not setting an instrument to zero prior to its use is known as _____.
 A) Offset error
 B) Random error
 C) Environment error
 D) Zero error
- 5) Random errors can be assessed _____.
 A) Statistically
 B) Empirically
 C) Experimentally
 D) By sensitivity analysis
- 6) When an instrument is not properly aligned with the direction of the desired measurement, an error occurs that is referred to as _____.
 A) Alignment error
 B) Characteristic error
 C) Environment error
 D) Reading error
- 7) The discrepancy between a quantity's true value and its measured value is referred to as _____.
 A) Static correction
 B) Change over
 C) Dynamics correction
 D) None of the above
- 8) The error which occurs due to carelessness of the operator is known as _____.
 A) Observational error
 B) Random error
 C) Systematic error
 D) Instrumental error



9) The parallax errors happened due to ____.

- A) Error in reading of an operator B) Static error of the instrument
C) Dynamic error of the instrument D) Environmental conditions

10) Errors result from circumstances outside of the measuring device is known as ____.

- A) Environmental error B) Random error
C) Observational error D) Systematic error

10.3. Absolute, Relative and Percentage of Errors

10.3.1. Absolute Error:

- The magnitude of the difference between the true value of the quantity and the individual measurement value is called the absolute error of the measurement. That is the absolute value of the deviation is known as absolute error.
- The absolute error $|\Delta a|$ is always will be positive.

$$|\Delta a_1| = |\Delta a_{mean} - a_1|,$$

$$|\Delta a_2| = |\Delta a_{mean} - a_2|,$$

$$|\Delta a_n| = |\Delta a_{mean} - a_n|$$

10.3.1.1 Mean Absolute Error

- The arithmetic mean of all the absolute errors is taken as the final or mean absolute error of the value of the physical quantity (a).
- Mean absolute error is represented by Δa_{mean} .

$$\Delta a_{mean} = \frac{(|\Delta a_1| + |\Delta a_2| + |\Delta a_3| + \dots + |\Delta a_n|)}{n}$$

$$\Delta a_{mean} = \frac{\sum_{i=1}^n |\Delta a_i|}{n}$$

- If only a single measurement of the physical quantity a is done by someone else, it is expected to be in the range,

$$a_{mean} \pm \Delta a_{mean}$$

$$i.e. a = a_{mean} \pm \Delta a_{mean}$$

the result is expected to be in the range

$$a_{mean} + \Delta a_{mean} \leq a \leq a_{mean} - \Delta a_{mean}$$



10.3.2 Relative and Percentage Error:

- The relative error is the ratio of the mean absolute error Δa_{mean} to the mean value a_{mean} of the quantity measured.

$$\text{Relative error} = \frac{\Delta a_{mean}}{a_{mean}}$$

- When the relative error is expressed in percent, it is called the percentage error (δa).
- Thus, Percentage error is,

$$\delta a = \frac{\Delta a_{mean} \times 100\%}{a_{mean}}$$

Problems:

- Calculate absolute error when the actual value is 22.13 and the measured value is 24.09.
- Calculate the absolute and relative errors of the approximation 122.67 to the value 116.66.

Questions:

1) An analogue indicating device with a 0–2.5 V range displays a voltage of 1.46 V even though the voltage has a true value of 1.5 V. The proportional error is ____.

- A) -2.66 % B) -26.6 % C) -0.4 % D) -4.0 %

2) The sample size of 100 with a mean age of 34.25 from a population with a standard deviation of 10 and the 95% confidence interval of the average age of accidents in any city during the previous year are ____.

- A) [32.29, 36.21] B) [32.29, 36.58] C) [32.605, 35.895] D) [31.92, 36.58]

3) While a metre reads 125 V, the actual voltage is 125.5 V. Find the instrument's static error ____.

- A) 0.5 V B) 125 V C) 125/0.5 V D) 0.5/125 V

4) The discrepancy between a quantity's indicated value and true value is ____.

- A) Absolute error B) Gross error C) Dynamic error D) Relative error

5) Improper zero adjustment is a type of ____.

- A) Instrument error B) Random error C) Operator error D) None of the above

6) The span of a zero-centered voltmeter with a scale from – 5 V to + 5 V is ____.

- A) 10 V B) 5 V C) 0 V D) -5 V

7) When an instrument's absolute static error is 2.5 V and its true value is 125 V, relative static error ____.

- A) 2 % B) 4 % C) 5 % D) 10 %

8) Determine the relative error when the capacitor's true value is 201.4 F and its measured value is 204.3 F.

- A) 1.43 % B) 1.23 % C) 1.68 % D) 1.94 %

9) When a capacitor's measured value is 195.5 F and its true value is 200 F, what is the relative static error?

- A) 2.25 % B) 2.30 % C) 4.5 % D) 22.5 %

10) When a resistor's measured value is 105 and its true value is 100, what is the relative static error?

- A) 5 % B) 10 % C) 2.5 % D) 6.25 %



10.4. Significant Figures:

- As significant figures are given in the form of digits, it is also called as significant numbers.
- The number of significant digits is found by counting all values from the first non-zero digit from the left side.
- These are important and reliable to display the quantity of a length, volume, mass, etc.
- Arithmetic operations such as addition, subtraction, multiplication and division are used when the significant number calculation.
- When the number of significant numbers increases, the accuracy will be increases.
- Significant figures are defined as the number of digits which is required to give the precise result of any experiment or a calculation.
- Significant figures are number of digits which is known reliably and also number which is uncertain.

10.4.1. Rules for the Significant Figures:

- Some of the rules are used to determine the significant figures, such as
 - All non-zero digits are significant figures.
 - Zeros which lie between to non-zero digits are also significant numbers.

- A trailing zero or final zero in the decimal portion only are significant.
- All zeros after decimal but before a non – zero digit is not considered a significant figure. E.g., 0.00465 has only 3 three significant figures.
- When the given number does not contain a decimal point, then the final zeroes are ambiguous and they are not considered as significant figures. E.g., 94000 has two significant figures. But when the number which is obtained on the basis of actual (real) measurement, then all zeroes which are to the right of the last non zero digit are also considered as significant figures. E.g., 9080 has four significant figures.
- When a decimal is present at the end of a whole number, then all zeros which are at the right end just before the decimal are considered as significant figures. E.g., 42200. Has five significant figures.
- When the number contains both an integral part as well as a decimal part, then all zeros in the number are considered as significant figures. E.g., 25.34 has four significant figures.

Example: When a period of oscillation of a simple pendulum is determined as 3.25 seconds. Then the digits 3 and 2 are reliable and certain, and the digit 5 is uncertain. Therefore, the calculated value has three significant figures.

10.4.2. Rules for rounding Significant Figures:

- A number is rounded to the needed number of significant digits by leaving one or more digits to the right. If the first digit on the left is less than the number 5, then the last digit must remain constant. If the first digit is more than the number 5, then the last digit of the significant figure is rounded up. If the remaining digit is exactly equal to the number 5, then the retained number is rounded up or down to get an even number. If more than one digit remains, round as a whole rather than one digit.
 - When the digit after the last significant digit is more than the number 5, then the last digit of the significant figure (or significant digit) is raised by one (1).
 - When the digit after the last significant digit is less than the number five (5), then the last digit of the significant figure (or significant digit) is left without making any changes.
 - When the digit after the last significant digit is equal to the number five (5), then the last digit of the significant figure (or significant digit) is not altered when the number is even and is increased by 1 when it is odd.

10.5. Advantages of Average:

- It is most widely applied measure because it can be calculated very easily and can be understood without any complication.
- The result of average is always fixed as it is defined by rigid formula.
- Averages can be used for further study especially for algebraic calculation and statistical analysis.
- It is less affected by sampling fluctuations.
- It doesn't require the arrangements of data values and dividing data like other measurements of central tendencies.
- Completely based on observation; it represents the data not the terms positions.
- The average of a collected data is obtained by adding all the values and dividing the sum by total number of values that are added.

$$\text{Average } \bar{X} = \frac{X_1 + X_2 + X_3 + \dots + X_n}{n}$$

- Arithmetic mean is simple to understand and easy to calculate.
- It is rigidly defined.
- It is suitable for further algebraic treatment.
- It is least affected fluctuation of sampling.
- It takes into account all the values in the series.
- If a variate X takes values $x_1, x_2, x_3, \dots, x_n$ with corresponding frequencies $f_1, f_2, f_3, \dots, f_n$ respectively, then the arithmetic average of these values is,

$$\bar{X} = \frac{f_1x_1 + f_2x_2 + \dots + f_nx_n}{f_1 + f_2 + \dots + f_n}$$

$$\bar{X} = \frac{\sum_{i=1}^n f_i x_i}{N}$$

$$N = \sum_{i=1}^n f_i = f_1 + f_2 + \dots + f_n$$



Example Problem:

Find out the average of the given distribution.

x:	4	6	9	10	15
f:	5	10	10	7	8

Solution:

x_i	4	6	9	10	15
f_i	5	10	10	7	8
$x_i f_i$	20	60	90	70	120

$$N = \sum f_i = 40$$

$$\sum f_i x_i = 360$$

Therefore,

$$\bar{X} = \frac{360}{40} = 9$$

Questions:

1) The average of data set is obtained by ____ all the data values and ____ the sum by total number of the values.

A) Adding, Dividing

B) Subtracting, Dividing

C) Adding, Multiplication

D) Subtracting, Multiplication

2) The average of the set {12, -24, 25, -19} is ____.

A) 2.5

B) -2.5

C) 3

D) -3

3) The average of 6, 9, 11, 12, x, 20 is 11. Find x.

A) 6

B) 8

C) 9

D) 7

4) Find the average of the following distribution.

x	10	30	50	70	89
f	7	8	10	15	10

A) 55

B) 54

C) 65

D) 64

5) Find the missing frequencies in the following frequency distribution if it is known that the mean of the distribution is 1.46.

x	0	1	2	3	4	5	Total
f	46	?	?	25	10	5	200

A) 76 & 38

B) 78 & 36

C) 66 & 48

D) 37 & 75

10.33. Multiple Choice Questions (Important)

- Errors that occur during measurement of the quantities are of
 - 2 types
 - 3 types
 - 4 types
 - 5 types
- Systematic error occurred due to the poor calibration of the instrument that can be corrected by
 - Taking several readings
 - replacing instruments
 - Taking mean of values
 - taking median of values
- Error that occurs due to equally affected measurements is called
 - random error
 - systematic error
 - frequent error
 - precision
- Error that occurs during the measurement of quantities is
 - random error
 - systematic error
 - frequent error
 - both A and B
- What is the reason for the occurrence of systematic in an instrument?
 - No use for a long-time
 - High use
 - Manufacturing fault
 - Delivery fault
- How are systematic errors removed usually for an instrument?
 - By-replacing it
 - By re- calibrating it
 - By using a repairing service
 - By not using it for some time
- If the error in the measurement of the radius of a sphere is 2%, then the error in the determination of the volume of the sphere will be
 - 4%
 - 6%
 - 8%
 - 2%
- The mean length of an object is 5 cm. Which of the following measurements is most accurate?
 - 4.9 cm
 - 4.805 cm
 - 5.25 cm
 - 5.4 cm
- | Column A | Column B |
|------------------------------|----------------------|
| i) Length | 1) Burette |
| ii) Volume | 2) Vernier callipers |
| iii) Diameter of a thin wire | 3) Screw gauge |
| iv) Mass | 4) Common balance |



- A) i) 2); ii) 1); iii) 3); iv) 4)
 B) i) 4); ii) 2); iii) 3); iv) 1)
 C) i) 3); ii) 2); iii) 4); iv) 1)
 D) i) 4); ii) 2); iii) 1); iv) 3)



10. The magnitude of the difference between the individual measurement and true value of the quantity is called

- A) Absolute error B) Percentage error C) Relative error D) None of these

11. systematic errors can be

- A) negative only B) positive only
 C) either positive or negative D) none of these

12. The _____ is a measure of how closed the measured value is to the true value of quantity

- A) Accuracy B) Precision C) Error D) none of these

13. If $Z = A^3$, then $\frac{\Delta Z}{Z} =$ _____

- A) $\frac{\Delta A^3}{A}$ B) $3\left(\frac{\Delta A}{A}\right)$ C) $\left(\frac{\Delta A}{A}\right)^3$ D) $\left(\frac{\Delta A}{A}\right)^{\frac{1}{3}}$

14. If $X = a - b$, then the maximum percentage error in the measurement of X will be

- A) $\left(\frac{\Delta a}{a-b} + \frac{\Delta b}{a-b}\right) \times 100 \%$ B) $\left(\frac{\Delta a}{a} + \frac{\Delta b}{b}\right) \times 100 \%$
 C) $\left(\frac{\Delta a}{a-b} - \frac{\Delta b}{a-b}\right) \times 100 \%$ D) $\left(\frac{\Delta a}{a} - \frac{\Delta b}{b}\right) \times 100 \%$

15. The most suitable instrument for measuring the size of an atom is:

- A) Electron microscope B) Vernier calliper
 C) optical microscope D) screw gauge

16. The method used to measure the distance of a planet from the earth is:

- A) Parallax method B) Archimedes method
 C) Newtons method D) Galileos method

17. which of the following is caused by careless handling?

- A) Systematic error B) Gross error
 C) Random error D) None of these

- C) Taking average value of resistances determined using (B)
D) Both (B) and (C)
92. The best instrument for accurate measurement of EMF of a cell is
A) Potentiometer
B) Metre bridge
C) Voltmeter
D) Ammeter and Voltmeter
93. Basically a potentiometer is a device for
A) Comparing two voltages
B) Measuring a current
C) Comparing two currents
D) Measuring a voltage
94. In order to achieve high accuracy, the slide wire of a potentiometer should be
A) As long as possible
B) As short as possible
C) Neither too small not too large
D) Very thick
95. A series LCR circuit ($R = 30 \text{ ohm}$, $X_L = 40 \text{ ohm}$, $X_C = 80 \text{ ohm}$) is connected to an AC source of 200 V and 50 Hz. The power dissipated in the circuit is :
A) 480 W
B) 240 W
C) 48 W
D) 24 W
96. The Power factor of a Series LCR circuit at resonance is
A) 0.707
B) 0.50
C) 0.00
D) 1.00
97. Calculate the quality factor Q for an RLC circuit having $R = 10 \text{ ohm}$, $C = 30 \text{ Mf}$, and $L = 27 \text{ mH}$.
A) 3
B) 6
C) 9
D) 15
98. What is a recirculating register?
A) Serial out connected to serial in
B) All Q outputs connected together
C) A register that can be used over again
D) Parallel out connected to Parallel in
99. In a 4-bit Johnson counter sequence, there are a total of how many states or bit patterns?
A) 1
B) 3
C) 4
D) 8
100. How much storage capacity does each stage in a shift register represent?
A) One bit
B) Two bits
C) Four bits
D) Eight bits



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