

## B.Sc. VI SEM PHYSICS

**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.

**Unit Cell:** 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.

**X-Ray Diffraction:** X-ray diffraction is a non-destructive solid technique for delineating crystalline materials.

**X-Ray Diffraction Analysis:** X-ray diffraction analysis (XRD) is a method used in materials science to determine the material's crystallographic structure. XRD operates by measuring the X-rays' intensities and scattering angles that leave the material.

**X-ray Diffraction and its applications:** 1. The phenomena by which X-rays are reflected from the atoms in a crystalline solid is called diffraction. The diffracted X-rays generate a pattern that reveals structural orientation of each atom in a given compound. 2. X-ray diffraction is extensively used in chemistry for the characterization of organic and inorganic compounds that are made for pharmaceutical companies or making batteries of the cell phones.

**The principle of XRD:** 1. XRD finds the geometry or shape of a molecule using X-rays. 2. XRD techniques are based on the elastic scattering of X-rays from structures that have long range order.

**X-ray Crystallography:** X-ray crystallography is a method of determining the arrangement of atoms within in a crystal, in which a beam of X-rays strikes a crystal and scatters into many different directions. Since very many materials can form crystals - such as salts, metals, minerals, semiconductors, and various inorganic, organic and biological molecules.

**Bragg's Law:** When the X-ray is incident onto a crystal surface, its angle of incidence,  $\theta$ , will reflect with the same angle of scattering,  $\theta$ . And, when the path difference,  $d$  is equal to a whole number,  $n$ , of wavelength,  $\lambda$ , constructive interference will occur. Bragg Equation:  $n\lambda = 2d \sin\theta$

**Applications of Bragg's Law:** It has some useful applications. 1. In X-ray diffraction, the interplanar spacing of a crystal is used for the identification purposes. 2. It is useful for conducting the measurements of the wavelength of different families of crystals.

**Bragg's Diffraction:** Bragg's diffraction was first proposed by William Henry Bragg and William Lawrence Bragg, in 1913. Bragg's diffraction occurs when a subatomic particle or electromagnetic radiation waves have wavelengths that are comparable to atomic spacing in a crystal lattice.

**Bragg's Law importance:** Bragg law is useful for measuring wavelengths and for determining the lattice spacings of crystals.

**Conclusions on Bragg's Law:** The primary takeaways from Bragg's law are: 1. The diffraction has three parameters: the wavelength of X rays,  $\lambda$ . 2. The crystal orientation, defined by the angle  $\theta$ . 3. The spacing of the crystal planes,  $d$

**Crystalline Solid:** A crystalline solid is a homogeneous solid in which the constituent particles, atoms, ions or molecules are arranged in a definite repeating pattern.

**Properties of Crystalline Solids:** The properties of crystalline solids are: They have definite shapes and symmetries, These are hard and rigid and They have a high melting point.

**Classification of Crystalline Solids:** Crystalline solids are conveniently classified into four main types.

**Molecular solids:** The constituent particles of molecular solids are molecules of the same compound. The molecular solids are classified into three types according to the type of molecules involved in crystal formation and the nature of the intermolecular force of attraction between the neighboring molecules.

**Polar molecular solids:** The covalently bonded molecules of the substances like HCl, SO<sub>2</sub>, etc. exist in a gaseous state as discrete molecules under normal conditions of temperature and pressure. On cooling and subjecting to high pressures the gases first liquefy and then solidify to yield polar molecular solids. Polar molecules possess permanent dipole moments.

**Non-polar Molecular Solids:** Non-polar molecules like CO<sub>2</sub>, H<sub>2</sub>, Cl<sub>2</sub>, CH<sub>4</sub>, and weakly polar molecules like CO and other hydrocarbons form non-polar molecular solids at relatively lower temperatures. The melting points of non-polar molecular solids are very low, lower than polar molecular solids.

**Hydrogen bonded molecular solids:** If a hydrogen atom in a molecule is bonded covalently to any of the strongly electronegative atoms like oxygen, nitrogen or fluorine then the hydrogen atom acquires an additional positive charge and shows the ability to form an additional bond with strongly electronegative atoms in the vicinity. The additional bond formed is called a hydrogen bond.

**Ionic Solids:** All salts are crystalline in nature and are called ionic solids. The ionic salts are formed by molecules containing positively charged, smaller in size cations and negatively charged relatively bigger anions.

**Metallic Solids:** Metallic solids are crystalline solids formed by atoms of the same metallic element. The bonding electrons are delocalized over the space of the crystal and have the freedom to move from one end to the other. The metal atoms in the crystal are in the form of positive ions.

**Covalent Solids:** Covalent solids are formed by chemical bonds i.e. covalent bonds between the neighboring constituent atoms of non-metallic solids. They are also called giant solids. Examples are three allotropic modifications of carbon i.e. diamond, graphite and fullerene.

### **Factors Influencing Lattice Enthalpy:**

**1. Ion Charge:** The ions within the lattice crystal are drawn to each other due to the electrostatic force of attraction. This force is directly proportional to the charge magnitude, meaning the higher the charge, the stronger the lattice enthalpy.

**2. Atom Size:** Smaller atoms, due to their reduced interatomic distances, have stronger binding forces, leading to higher lattice enthalpy.

**Decoding Lattice Structure and Lattice Enthalpy:** Ionic compounds are known for their robust molecular force of attraction, which is why they are typically found in solid states. In these ionic solids, the molecules form a three-dimensional grid-like pattern, commonly referred to as a **lattice structure**. The lattice enthalpy of an ionic solid is the energy needed to separate one mole of the solid ionic compound into gaseous ions entirely.

**Free Electron Theory:** We can categorize Free Electron Theory as follows: Classical free electron theory and Quantum free electron theory

**Classical Free Electron Theory:** Drude and Lorentz gave classical free electron theory of metals theory in 1900. Another name for this theory is Drude–Lorentz theory of metals. Classical theory says that the metals having free electrons obey the laws of classical mechanics.

**Success:**

1. It verifies ohm's law.
2. This explains electrical conductivity and thermal conductivity of metals.
3. It derives the Widemann – Franz law. Widemann – Franz law gives the relation between electrical and thermal conductivity.

**Drawbacks:**

1. Theory does not explain the Compton Effect, photoelectric effect and black body radiation.
2. This theory is not explaining electrical conductivity of semiconductors and insulators.
3. At lower temperatures Widemann – Franz law ( $K/\sigma T = \text{constant}$ ) is not applicable.

**Quantum Free Electron Theory:** The failure of classical theory created the way for Quantum free electron theory. However, Sommerfeld introduced this in 1928. Quantization of electrical energy levels is added here. He also used the Pauli Exclusion Principle in restricting the energy values of electron. His theory is famous as Quantum Free Electron Theory.

**FREE ELECTRON THEORY**

1. Classical free electron theory: The first theory was developed by Drude and Lorentz in 1900. According to this theory, metal contains free electrons which are responsible for the electrical conductivity and electrons obey the laws of classical mechanics.

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**Merits of quantum free electron theory:**

1. It successfully explains the electrical and thermal conductivity of metals.
2. It can explain the Thermionic phenomenon.
3. It explains temperature dependence of conductivity of metals.

**Demerits of quantum free electron theory:**

1. It is unable to explain the metallic properties exhibited by only certain crystals.
2. It is unable to explain why the atomic arrays in metallic crystals should prefer certain structures only.
3. This theory fails to distinguish between metal, semiconductor and Insulator.

**Nuclear Force:** The nuclear force is one of the four fundamental forces of nature, the others being gravitational and electromagnetic forces. The nuclear force is a force that acts between the protons and neutrons of atoms. This force is the force that binds the protons and neutrons in a nucleus together.

**Properties of Nuclear Force:** 1. It is attractive in nature but with a repulsive core. That is the reason that the nucleus is held together without collapsing in itself. 2. The range of a nuclear force is very short. At 1 Fermi, the distance between particles in a nucleus is tiny. At this range, the nuclear force is much stronger than the repulsive Coulomb's force that pushes the particles away. However, if the distance is anything more than 2.5 Fermi, nuclear force is practically non-existent.

**Deuteron:** The deuteron is a stable particle composed of a neutron and a proton. It is denoted by symbol **D** or **<sup>2</sup>H** or **Hydrogen-2**. Deuteron mass is expressed using the atomic mass unit (amu) or electron volts (eV). Deuteron has a charge +1e.

**Deuteron ground state properties:** Deuteron is the simplest of two nucleon – bound system. It consists of one proton and one neutron. Therefore, deuteron is two body problem. deuteron is a system of two particles –neutron and proton , of nearly equal masses (each of mass  $m$  say) .i.e. ,  $m_1 = m_2 = M$

$$\mu = \frac{\text{The reduced mass of system}}{m_1 + m_2} = \frac{m_1 m_2}{M + M} = \frac{M}{2}$$

**Nuclear fusion:** The process in which two lighter nuclei combine to form a heavier nucleus is termed as 'nuclear fusion'. E.g.:  ${}_1\text{H}^2 + {}_1\text{H}^2 \rightarrow {}_2\text{He}^4 + Q$  (Energy)

**Accelerators:** Particle accelerators are machines used exclusively to propel charged particles or ions to great speed or energy using electromagnetic fields. Large accelerators are used for fundamental research in particle physics.

**Types of Particle Accelerator:** The particle accelerator is basically of two types, Electrostatic and electrodynamic accelerators.

**The Electrodynamic or Electromagnetic particle accelerator:** The Electrodynamic particle accelerator are of two types they are-

1. **Linear accelerator:** - Linear particle accelerator in short linac accelerate particles along the straight line. Here the subatomic particle or ion which is to be accelerated is subjected to a series of oscillating electric potential along the linear beamline.
2. **Circular accelerator:** - The accelerating particles are made to take a circular path or roughly circular path using a magnetic field.

**Electrostatic accelerator:** They use the static electric field to accelerate particles. In this class, achievable kinetic energy for the particle is dependent on the accelerating voltage, which is limited by electrical breakdown. The simple small-scale example of this class of accelerator is Cathode-Ray-Tube. The most common examples are Van de Graaff generator and Cockcroft Walton generator.

**Applications of Particle Accelerator:** 1. They are also used by industrial and technical fields. 2. Rest is used for industrial processing, biomedical, low-energy, and high energy research.

### 1. High Energy Physics:

- For a most fundamental understanding of space and time, structure of matter, dynamics, physicists seek into simple kind of interaction at the highest possible energies (hundreds of GeV).
- The highest energy and the largest particle accelerator of this class is Large Hadron Collider (LHC) at CERN.

### 2. Isotope production and Nuclear Physics applications:

- The beam of bare atomic nuclei is used to investigate interaction, structure, and properties of nuclei themselves of condensed matter at very high temperatures and densities.
- The largest of this class is Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory.

### 3. Particle therapy and Low-energy machines:

At low energies, the beam of accelerated particles is used in the treatment of cancers (Radiotherapy). Low energy particle accelerators like,

- Cathode-Ray-Tubes are used in display machines.
- Ion implanter used to manufacture Integrated Circuits.
- Cockcroft Walton generator used to convert AC to High energy DC etc.
- **Synchrotron radiation:** The Synchrotron accelerates the electrons in the magnetic field to very high energy to emit a bright and coherent beam of high energy photons.

**Van De Graaff Accelerators:** R. J. Van de Graaff built the Van de Graaff accelerator in 1929. A Van de Graaff generator uses a moving belt to accumulate a large electric charge on a hollow metal sphere situated atop an insulated column.

**Elementary Particles:** Elementary particles are quarks, leptons and bosons. These particles then join together to create the more well-known particles, such as the neutron and the proton. Such particles are known as composite particles, as they are composed of two or more of these elementary particles.

**Classification of Elementary Particles:** Elementary particles are categorized on the basis of their nature and properties. They are classified on the basis of mass, charge, average lifetime, spin, interaction etc.

