

WEEK-01

Crystal structure, Types of crystal structures – Crystalline & Non-crystalline, Structure of metal –unit cell, BCC, FCC and HCP structures, Mechanical Properties. Atomic Packing factor for BCC, FCC and HCP crystal structure (no derivations)

CRYSTAL STRUCTURE:

A crystalline structure is any structure of ions, molecules, or atoms that are held together in an ordered, three-dimensional arrangement.

Examples: Table Salt, Sugar, Iron, Copper and Aluminium

Types of Crystal Structures:

1. Crystalline structure
2. Non-Crystalline(Amorphous) Structure

CRYSTALLINE STRUCTURE:

Crystalline materials are materials in which atoms are arranged in a regular and repeating pattern through the materials.

Examples: Iron, Copper, Aluminium, Steel, Salts, Diamond etc

Characteristics of Crystalline materials:

1. Atoms are arranged in a orderly manner
2. Definite geometrical shape and structure
3. High strength
4. Sharp melting point
5. Good mechanical properties

Advantages of Crystalline Materials:

1. More resistant to damage than amorphous solids
2. Strong and durable
3. Good load carrying capacity
4. Suitable for engineering applications

Disadvantages of Crystalline Materials:

1. Less ductile and can display brittle behavior, particularly under high strain rates
2. Cracks may propagate along crystal boundaries
3. Their chemical stability makes them hard to solvent-weld, paint

NON-CRYSTALLINE STRUCTURE:

Non-Crystalline materials are materials in which atoms are arranged in randomly or irregularly, without any regular pattern. These materials do not have a crystal structure. It is also called as amorphous solid.

Examples: Glass, Plastics, Rubber, Polymers, Wax etc

Characteristics of Non-Crystalline materials:

1. Do not have long-rang, regular atomic order
2. No definite sharp melting point
3. No definite shape or form a irregular shape
4. Low strength
5. Soften over a range of temperatures depending on their composition
6. Usually brittle

Advantages of Non- Crystalline Materials:

1. Easy to mould and shape
2. Good electrical insulation
3. Low cost

Disadvantages of Non-Crystalline Materials:

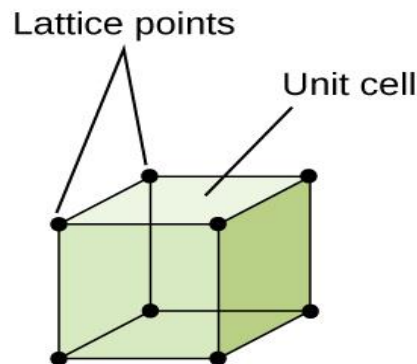
1. Low strength
2. Not suitable for heavy load applications

DIFFERENCE BETWEEN CRYSTALLINE & NON- CRYSTALLINE MATERIALS:

Sl no	Crystalline materials	Non- crystalline materials
1	Regular atomic arrangement	Random/Irregular atomic arrangement
2	Definite crystal structure	No crystal structure
3	High strength	Low strength
4	They have sharp melting point	They do not have sharp melting point
5	They are most stable	They are less stable
6	Examples: Iron, Copper, Aluminium, Steel, Salts, Diamond etc	Examples: Glass, Plastics, Rubber, Polymers, Wax etc

STRUCTURE OF METALS:

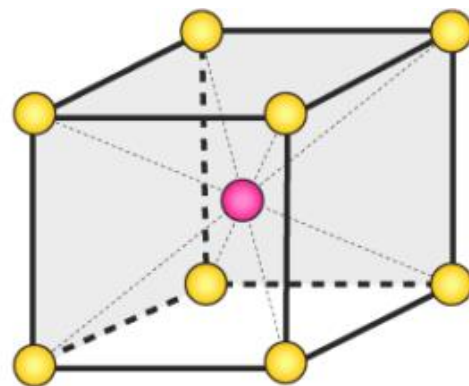
Metals are made up of atoms arranged in a regular, repeating 3D pattern which is called as crystal lattice. The way atoms are packed in unit cell affects the density, strength, ductility and other mechanical properties of the metal.

Unit cell:

A unit cell is the smallest part of the crystal structure which repeats again and again to form the entire metal. A unit cell is the basic building block of a metal crystal. When this unit cell repeats in all directions, it forms the complete 3D crystal structure of the metal. Different metals have different types of unit cells.

Types of Crystal Structures in metals:

1. BCC-Body centered cubic.
2. FCC- Face centered cubic.
3. HCP-Hexagonal close packed.

BCC-Body centered cubic.

Body-centered Cubic Unit Cell (BCC)

- In BCC structure ,atoms are arranged in a 3D cubic pattern.
- There are 8 atoms at the corners of the cube and 1 atoms at the ventre of the cube. Each corner atom is shared among 8 adjacent unit cell.

Examples: Iron, Chromium, Tungsten,sodium, vanadium etc.

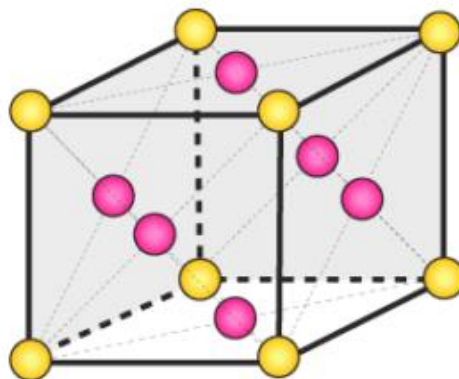
Properties of BCC Metals:

- High strength.
- Harder and Malleable.
- Less ductile
- Stronge but difficult to shape.
- Resistance to defoemation under shock load.

Applications:

- Machine components.
- Cutting and drilling tools.
- Armor plates.
- Shafts and Gears.
- Construction steels(beam, frames, tools).

Face-centered cubic(FCC) structure:



Face-centred Cubic Unit Cell (FCC)

In the FCC structure,atoms are arranged in a 3D cubic pattern. There are 8 atoms at the corners of the cube and 1 atom at the center of each face of the cube. Each corner atom is shared among 8 adjacent unit ceells.

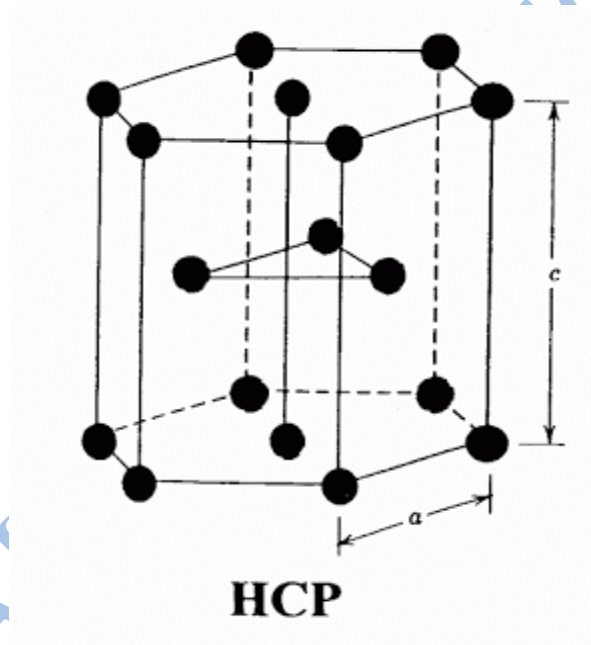
Examples: Aluminium, Copper, Gold, Silver, Nickel etc.

Properties:

- High ductility and Malleable.
- Higher atomic packing factor (74% for FCC).
- Bending or shaping without cracking.

Applications:

- Electrical wires and cables(Copper, Aluminum).
- Metal foils and sheeys(Aluminum foil).
- Kitchen untensils and cookware.
- Automotive and aircraft body panels.

Hexagonal Close-packed(HCP):

In the HCP structure, atoms are arranged in a hexagonal 3D pattern. There are 12 atoms at the corners of the hexagonal prism and 2 atoms inside the prism(one at the center of the top face and one at the center of the bottom face). Additionally, there are 3 atoms in the middle layer forming a trigonal arrangement.

Example: Magnesium, Titanium, Zinc, Cobalt, Cadmium etc

Properties:

- High Strength to weight ratio.
- Low ductility.

Applications:

- Aerospace and aircraft components(Titanium, Magnesium alloys).
- Automotive wheels and frames.
- Biomedical implants(Titanium).
- Batteries(Zinc).
- Coating and galvanizing (Zinc).

MECHANICAL PROPERTIES OF METALS:

The following properties are:

1. **Elasticity:** It is the property of metal by virtue of which metals are able to regain their original shape and size after removal of load.
2. **Plasticity:** It is the property of metal by virtue of which metal takes place permanent deformation without fracture whenever it is subjected to the action of external load.
3. **Ductility:** It is the property of metal by virtue of which metal can be drawn into wires
4. **Brittleness:** It is the property of metal by virtue of which metal to break easily without bending
5. **Hardness:** It is the property of metal by virtue of which metal resists to indentation.
6. **Toughness:** it is defined as that property by virtue of which a metal can absorb maximum energy before fracture takes place.
7. **Resilience:** it is defined as the property by virtue of which a metal stores energy and resists shock or impact loads.
8. **Malleability:** It is the ability of metal to be hammered in to thin sheets.
9. **Strength:** strength may be defined as the property of a metal by virtue of which can withstand a load without fracture.

ATOMIC PACKING FACTOR:

It is also packing efficiency. The ratio of actual volume of atoms in a unit cell to total volume of unit cell is known as atomic packing factor.

$$APF = \frac{\text{volume of atoms in a unit cell}}{\text{total unit cell volume}}$$

1. Body centred cubic structure:

APF: 0.68(68%). It means 68% of the total volume of the unit cell is actually occupied by atom and the remaining 32% is empty space between atoms.

2. Face centred cubic structure:

APF: 0.74(74%). It means 74% of the total volume of the unit cell is actually occupied by atom and the remaining 26% is empty space between atoms.

3. Hexagonal close packed structure:

APF: 0.74(74%). It means 74% of the total volume of the unit cell is actually occupied by atom and the remaining 26% is empty space between atoms.

EXERCISES**MULTIPLE CHOICE QUESTIONS AND ANSWERS**

1. When each atom in a crystal structure is replaced by a point, then it is known as

- a) Lattice Spacing c) Crystal Lattice
b) Atomic Spacing d) None of the above

Ans: b)

2. In FCC, the unit cell shares _____ atoms, with the neighbouring unit cells.

- a) 8 b) 14 c) 12 d) 20

Ans: c)

3. What does BCC stands for in crystal structures?

- a) Brave-cubic crystal c) Body-centred cubic
b) Bond-centred crystal d) Base-centred cubic

Ans: c)

4. What is the approximate atomic packing factor(APF) for a face centred cubic(FCC) crystal structure?

- a) 0.80 b) 0.68 c) 0.52 d) 0.74

Ans: d)

5. Which of these materials is non crystalline?

- a) Table salt b) Window glass c) Ice d) Diamond

Ans: b)

6. Which of these crystal structure is NOT considered a close packed structure?
- a) Body-centred cubic c) Hexagonal close packed
b) Face-centered cubic d) Both FCC and HCP

Ans: a)

REVIEW QUESTIONS:

1. Mention one application in each BCC and FCC structures.
2. Sketch the unit cell of FCC and label the atomic position.
3. Define the following terms a) coordination number b) lattice point c) Packing factor.
4. Write the atomic packing factor for FCC and BCC structures.
5. Sketch the unit cell of BCC and label the atomic position.
6. State the mechanical properties commonly associated with BCC, FCC and HCP crystal structure. Give one example of each metal and its application.
7. Sketch the unit cell of HCP and label the atomic position.
8. Compare BCC, FCC and HCP crystal structure based on atomic arrangement and coordination number.
9. Difference between crystalline and non-crystalline materials.
10. Explain Atomic packing factor for BCC, FCC and HCP with its properties and applications.