

SAMPLE STUDY MATERIAL

Mechanical Engineering

ME



Postal Correspondence Course

Material Science

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CHAPTER-1

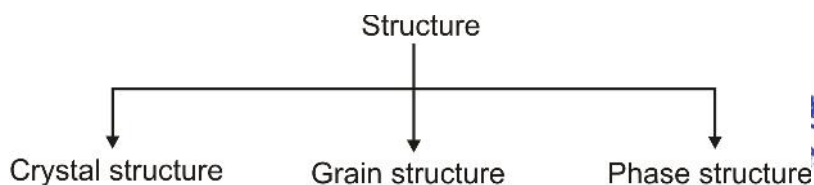
INTRODUCTION

Material Science

- A study of the relation between structure and properties of a material is conducted under material science.
- Material science consist the investigation and relationship that exist between the structure and properties of material.

Structure: Structure is at this point a nebulous term that deserves some explanation.

- Structure of material usually relates to the arrangement of its internal component.



- Due to different structure metal shows different properties.

Characteristics to be crystal:

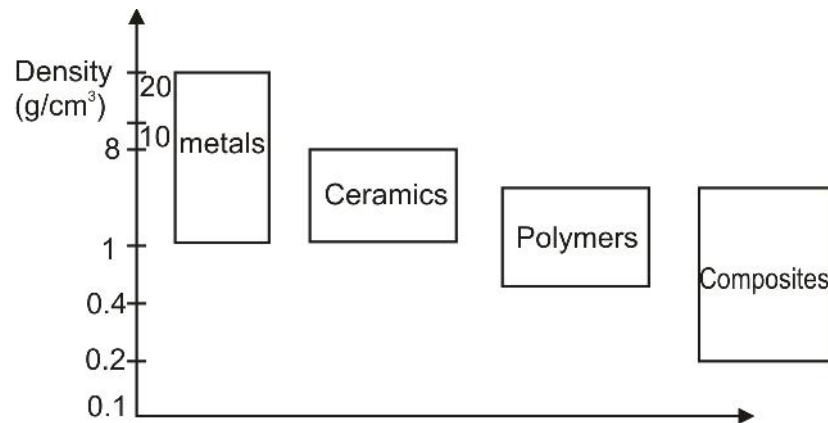
- There should be three condition
 - (a.) 3 – Dimension
 - (b.) Long range
 - (c.) Periodicity
- If all these three condition are satisfied then it is called crystal.

Note:

- (1) All alloy and metals are atomic solid
- (2) All polymers are not crystalline, but some polymer has crystalline (Example = Gear polymer).

Classification of materials:

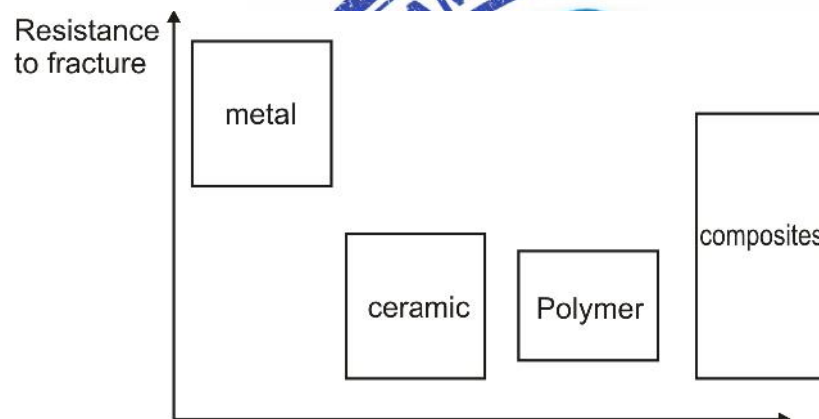
- Solid materials have been conveniently grouped into three basic classification.
 - (a.) Metal
 - (b.) Ceramic
 - (c.) Polymers
- This is based primarily on chemical makeup and atomic structure.
 - (i) Metals: Materials in this group are composed of one or more metallic elements.
 - Example: Copper, titanium, gold etc.
- Atoms in metals and their alloys are arranged in a very orderly manner.
- In comparison to the ceramics and polymers, metal are more dense.



- Metals are good conductors of electricity.
- Metals also exhibit good conductivity to heat.

Ceramics:

- Ceramics are compounds between metallic and non metallic elements.
Example: Al_2O_3 (Alumina), SiO_2 , etc.
- These materials are typically insulative to the passage of heat and electricity.
- They show more resistance to high temperature and harsh environment than metals and polymers.



Polymers:

- Polymers include the familiar plastic and rubber materials many of them are organic compounds that are chemically based on carbon, hydrogen and non-metallic elements.
- One major drawback to the polymers is their tendency to soften and decompose at modest temperature.

Composites:

- A composite is composed of two or more individual materials, which come from the categories discussed above viz, metal, ceramic, polymers.
- Composites are produce to get desired properties that in not displayed by the any single materials.

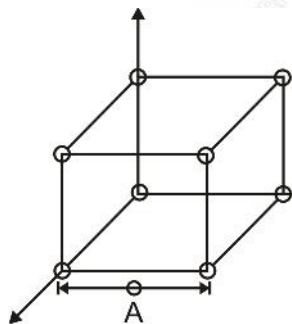
CHAPTER-2

THE STRUCTURE OF CRYSTALLINE SOLIDS

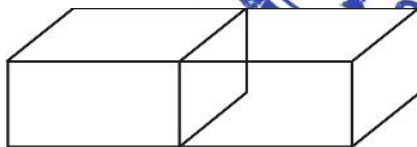
- The properties of some materials are directly related to their crystal structure. For example pure and undeformed magnesium and beryllium, having one crystal structure, are much more brittle than are pure and undeformed metal such as gold and silver that have yet another crystal structure.
- These different properties by the arrangement of molecules so that the structure of crystalline solids plays an important role in accordance to their properties.

Some important Definition:

- (1.) Unit Cell: A unit cell is defined as the smallest representative group of atom, which when repeated in all the crystalline direction for infinity number of time the results in the development of a crystal lattice.

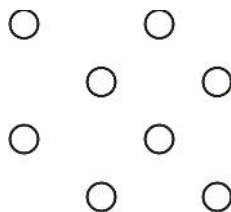


- (2.) Crystal lattice: It is 3 – dimension network of line in space and is also known as a line lattice.



- (3.) Space lattice

- It is a 3 dimensions network of point in space
 → It is also known as a point lattice.



- (4.) Primitive cell: It is a simple cubic unit cell having atoms only at its 8 comers.

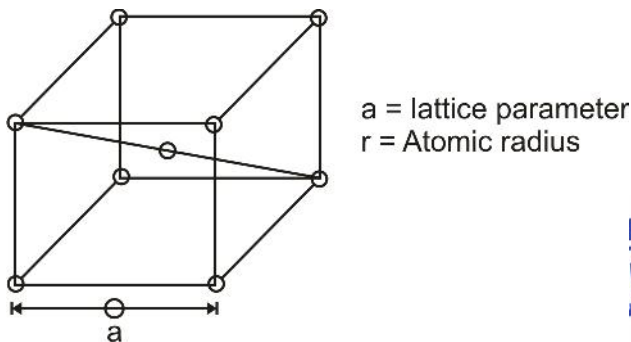
Metallic crystal structures:

→ Three relatively simple crystal structures are found for most of the common metals.

- (a.) Face centered cubic (FCC)
- (b.) Body centered cubic (BCC)
- (c.) Hexagonal close packed (HCP)

(1.) BCC:

→ Metallic crystal structure of cubic unit cell with atoms located at all eight corners and a single atom at the centre of cube, is called BCC crystal structure.



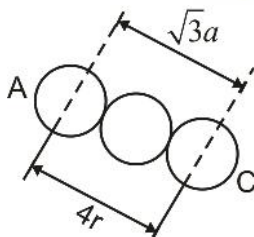
→ Lattice parameter 'a' is defined as the distance between the centers of the neighboring corner atom.

Example of BCC:

1. Tungsten (W)
2. Chromium (ch)

→ BCC are hard and brittle in nature.

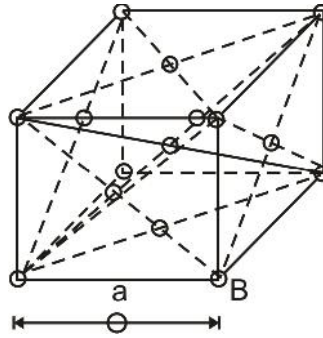
→ Diagonal AC.



→ This is relation between lattice parameter and radius of atom for BCC.

(2.) FCC:

→ The crystal structure has a unit cell of cubic geometry, with atoms located at each of the corners and the centers of all cube face, called face centre cubic structure.

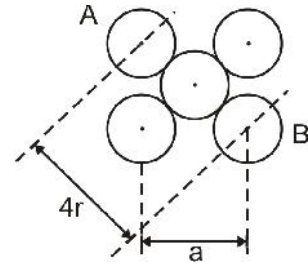


Here

$$u_r = \sqrt{2}a$$

$$a = \frac{u_r}{\sqrt{2}}$$

$$a = 2\sqrt{2}r$$



→ This is the relation between ‘a’ (lattice parameters) and ‘r’ (atom radius).

→ FCC metals generally are more ductile

Example of FCC:

- 1) Iron (Fe) (in the temperature range of 910 – 1400°C)
- 2) Al,
- 3) Cu
- 4) Silver
- 5) Gold etc.

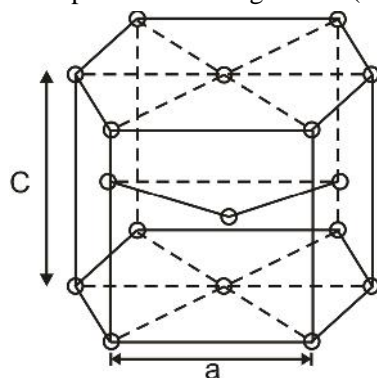


(3.) HCP:

→ HCP structures are called as structure of 4axis symmetry.

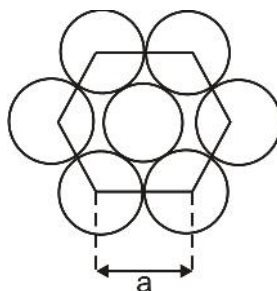
→ The top and bottom face of unit cell consist six atoms that form regular hexagons and surround a single atom in the centre

Example of HCP: Magnesium (Mg).



→ C denotes height of H.C.P structure.

$$\rightarrow \boxed{c/a = 1.632}$$



$$\boxed{a = 2r}$$

→ This is relation between lattice parameters 'a' and atomic radius 'r' for H.C.P

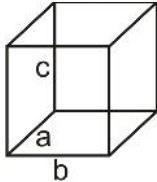
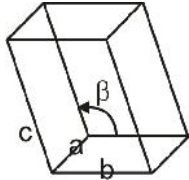
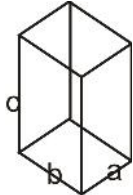
Polymorphism and Allotropy:

- Some metal, as well as non metal may have more than one crystal structure, a phenomenon known as polymorphism.
- When found in element solids, the condition is often termed allotropy.
- The crystal structure depends on both the temperature and the external pressure.

Crystal system:

- The unit cell geometry is completely defined in terms of six parameters (three edge length a, b and c and the three inter axial angle α , β , γ).
- On the basis there are seven different possible combination of a, b and α , β and γ each of which represents a distinct crystal system.

Crystal system	Axial relation	Inter-axial angles	Unit cell geometry
1. Cubic	$a = b = c$	$\alpha = \beta = \gamma = 90^\circ$	
2. Hexagonal	$a = b \neq c$	$\alpha = \beta = 90^\circ \gamma = 120^\circ$	
3. Tetragonal	$a = b \neq c$	$\alpha = \beta = \gamma = 90^\circ$	
4. Rhombohedral	$a = b = c$	$\alpha = \beta = \gamma \neq 90^\circ$	

5. Orthorhombic	$a \neq b \neq c$	$\alpha = \beta = \gamma = 90^\circ$	
6. Monoclinic	$a \neq b \neq c$	$\alpha = \gamma = 90^\circ \neq \beta$	
7. Triclinic	$a \neq b \neq c$	$\alpha \neq \beta \neq \gamma \neq 90^\circ$	

Average No. of atoms:

→ It is defined as the number of atom which originally belongs to a particular unit cell.

$$N_{av} = \frac{N_c}{8} + \frac{N_f}{2} + \frac{N_i}{1} \quad \text{For cubic cell}$$

$$N_{av} = \frac{N_c}{6} + \frac{N_f}{2} + \frac{N_i}{1} \quad \text{For HCP unit cell}$$

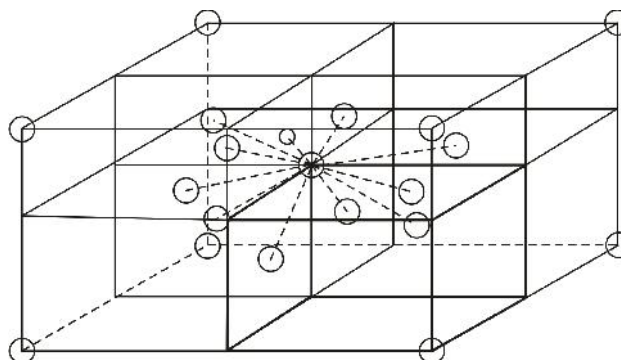
Where N_c = No. of atom at corners

N_f = No. of atom at face center

N_i = No. of atom in body interior.

Co – ordination No:

→ Co – ordination number is defined as the numbers of nearest and equal distance atoms surrounding an atom under consideration.



→ Co – ordination No. is an index of resistance offered by a material to deformation.

→ Co – ordination No. of BCC = 8

→ Co – ordination No. of FCC = 12

→ Co – ordination No. of HCP = 12

Atomic packing factor: (A.P.F)

→ It is defined as the ratio of volume occupied by average number of atom to the volume of unit cell.

$$A.P.F = \frac{\text{Volume occupied by average No. of atom}}{\text{Volume of unit cell}}$$

$$A.P.F = \frac{N_{ax} \times \frac{4}{3} \times f r^3}{\text{Volume of unit cell}}$$

→ A.P.F is an index of density of packing.

→ The structures having the highest value of A.P.F are called as closed pack structure.

→ A.P.F can be improved by allotropic transformation and alloying.

→ A.P.F of BCC = 0.68

→ A.P.F of FCC = 0.74

→ A.P.F of H.C.P = 0.74

Miller Indices of Plane:

→ Miller indices of plane defined as the rationalized reciprocal of fraction intercepts they can along three crystallographic direction and written inside parenthesis without a separating comma between them.

→ It is denoted by (hkl)

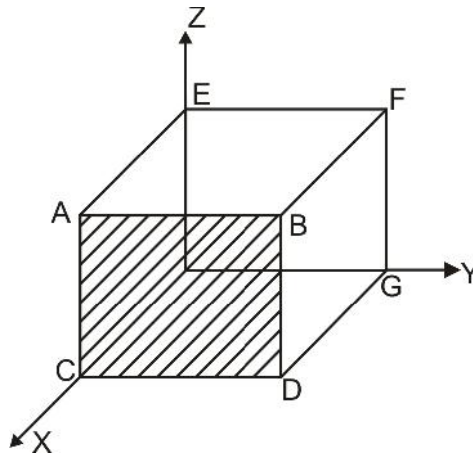
→ Miller indices are always smallest integers.

Procedure to find miller indices:

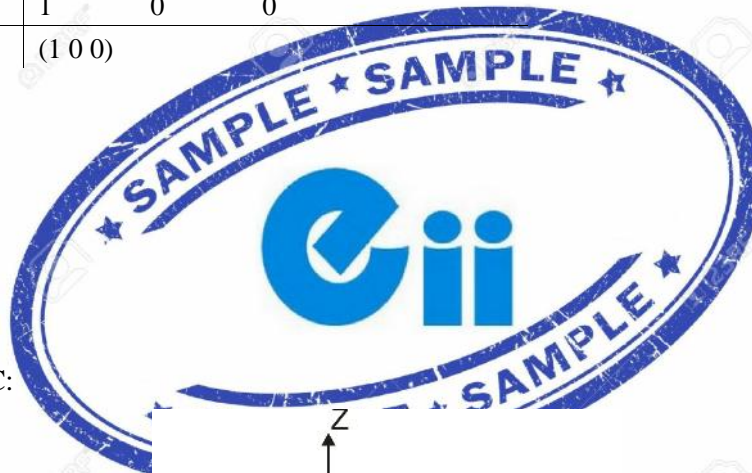
- (1.) If the plane passes through the selected origin, either another parallel plane must be constructed within the unit cell by appropriate translation or a new origin must be established at the corner of another unit cell.
- (2.) At this point the crystallographic plane either intersects or parallel each of three axis; the length of the planar intercept for each axis is determined in term of the lattice parameter a, b and c.
- (3.) The reciprocals of these numbers are taken. A plane that parallels an axis may be considered to have an infinite intercepts and there a zero index.
- (4.) If necessary, these three numbers are changed to the set of smallest integers by multiplication or division by a common factor.
- (5.) Finally, the integers, not separated by commas, are enclosed within parenthesis thus (hkl).

Q. Find miller indices of the planes.

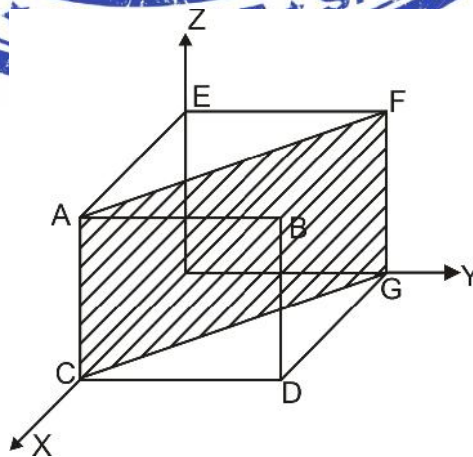
(a.) For plane ABCD:



	X	Y	Z
Intercept	1		
Reciprocal	$\frac{1}{1}$	$\frac{1}{\infty}$	$\frac{1}{\infty}$
Rationalize	1	0	0
Indices	(1 0 0)		

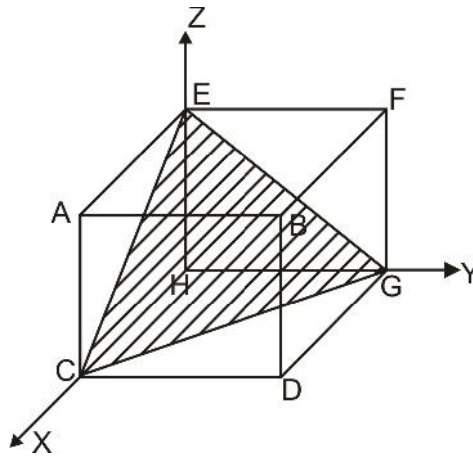


(b.) For plane AFGC:

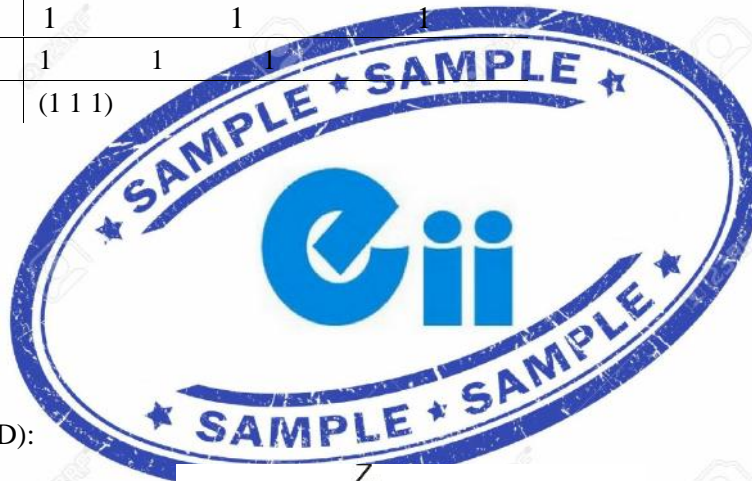


	X	Y	Z
Intercept	1	1	
Reciprocal	$\frac{1}{1}$	$\frac{1}{1}$	$\frac{1}{\infty}$
Rationalize	1	1	0
Indices	(1 1 0)		

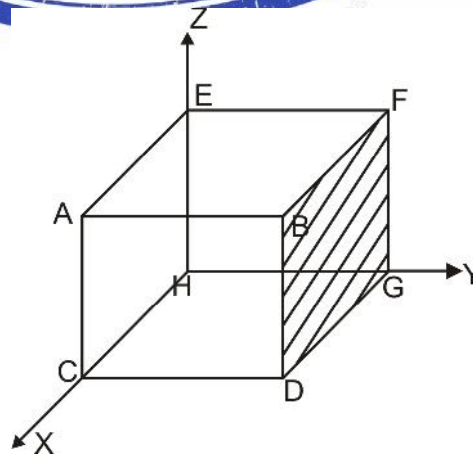
(c.) For plane EGC:



	X	Y	Z
Intercept	1	1	1
Reciprocal	$\frac{1}{1}$	$\frac{1}{1}$	$\frac{1}{1}$
Rationalize	1	1	1
Indices	(1 1 1)		



(d.) For Plane (BFGD):



	X	Y	Z
Intercept		1	
Reciprocal	$\frac{1}{\infty}$	$\frac{1}{1}$	$\frac{1}{\infty}$

Rationalize	0	1	0
Indices	(0 1 0)		

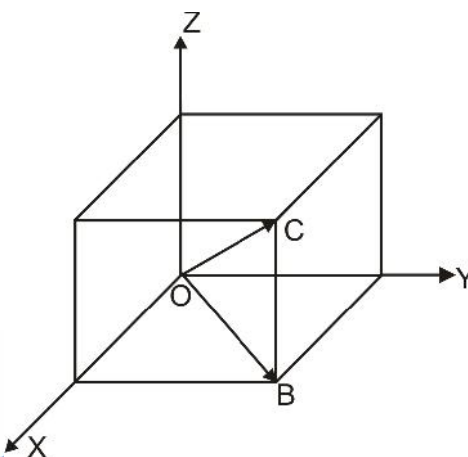
Note:

(1.) Parallel plane have same miller indices expect the sign of non – zero index.

(2.) For mutually perpendicular plane having miller indices $(h_1 k_1 l_1)$ and $(h_2 k_2 l_2)$ the following rule is valid.

$$h_1 h_2 + k_1 k_2 + l_1 l_2 = 0$$

Miller Indices of direction: [h k l]



Example:

(i) Miller indices of $\vec{OA} = [100]$

(ii) Miller indices of $\vec{OB} = [110]$

(iii) Miller indices of $\vec{OC} = [111]$

Note:

Characteristics	BCC	FCC	HCP
'a' to 'r' relation	$a = \frac{4r}{\sqrt{3}}$	$a = 2\sqrt{2}r$	$a = 2r$
Average number of atom	2	4	6
Atomic packing factor	0.68	0.74	0.74
Co – ordination number	8	12	12

Calculation of Density:

(1.) Volume Density (ρ_x):

→ It defined as the ration of weight of average number of atom to the volume of.

$$\text{Volume density} = \frac{\text{weight of } N_{\text{average}}}{\text{Volume of unit cell}}$$

$$\text{Volume density} = \frac{N_{\text{av}} \times \text{Atomic weight}}{A_{\text{vayadro}} \text{ Number} \times \text{Volume of unit cell}}$$

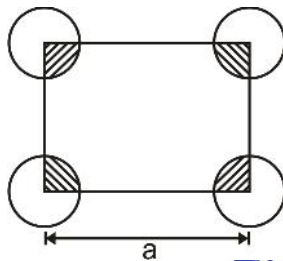
(2.) Planar density: (ρ_{plane})

→ It is defined as the ratio of number of atoms whose centre are intersected by a plane to the area of plane itself.

$$\rho_{\text{plane}} = \frac{\text{Number of atom}}{\text{Area of plane}}$$

Example of BCC, find plane density:

(a.) For plane (100):



$$\left(\rho_{\text{plane}} \right)_{(100)} = \frac{\frac{1}{4} \times 4}{a \times a}$$

$$\left(\left(\rho_{\text{plane}} \right)_{(100)} = \frac{1}{a^2} \right)$$



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