Electrical Engineering material

1 Theory of Metals (3hrs)
2 Free electron theory of conduction in Metals
3 Conduction in liquid and gases (2hrs)
4 Dielectric Materials (4hrs)
5 Magnetic materials (5 hrs)
6 Semiconducting materials (8hrs)
7 Semiconductor Materials Processors (4hrs)

Text book
R.A. Colcaser and Dich. Nagle
McGraw. Hill, New York

References
1. Bhadra Pd Pokhrel (Nirmon publication)
2. Indra Pd Bhandari (K.E.C.)

2. Free electron theory of conduction in metals

Matter

- Gas
- Liquid
- solid
  - Crystalline
    - conductor
    - Semiconductor
    - Insulator
  - Non-crystalline (Amorphous)

Crystalline Solid

A crystalline solid is one in which the atoms or molecules are arranged in regular or orderly (periodic) way in a 3D pattern.

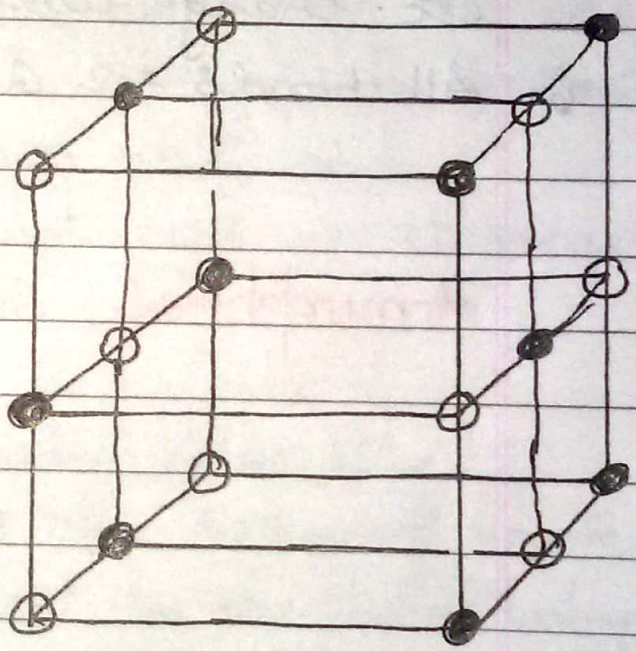


Fig Nacl crystal

In a crystalline solid each atom or molecule is fixed at a definite point in space at definite distance from all other sorrounding atom.

E.g. Nacl crystal, Quartz

An ideal crystal is constructed by the infinite repeatation of identical groups of atoms. A group is called basis.
The set of mathematical points to which the basis is attached is called lattice.

basis + lattice = crystal

The most convenient small cell in the crystal structure that carries the properties of the crystal is called unit cell.
The repeatition of unit cell in 3D generates the whole crystal.

Packing fraction (factor / density):
It is defined as the ratio of volume of atoms per unit cell to the total volume of the unit cell.

$$P.f. = \frac{\text{Volume of atoms in unit cell}}{\text{volume of unit cell}}$$

Characteristic

1. They possess definite geometrical form.
2. They exhibit long range order.
3. They are bound by flat surface.
4. They have sharp m.p. & b.p.
5. They are anisotropic
   i.e. their physical properties like conductivity (electrical & thermal), elasticity etc. change with direction in the crystal
6. All bonds in a crystal are equally strong.

Amorphous Solid

1 Simple Cubic structure

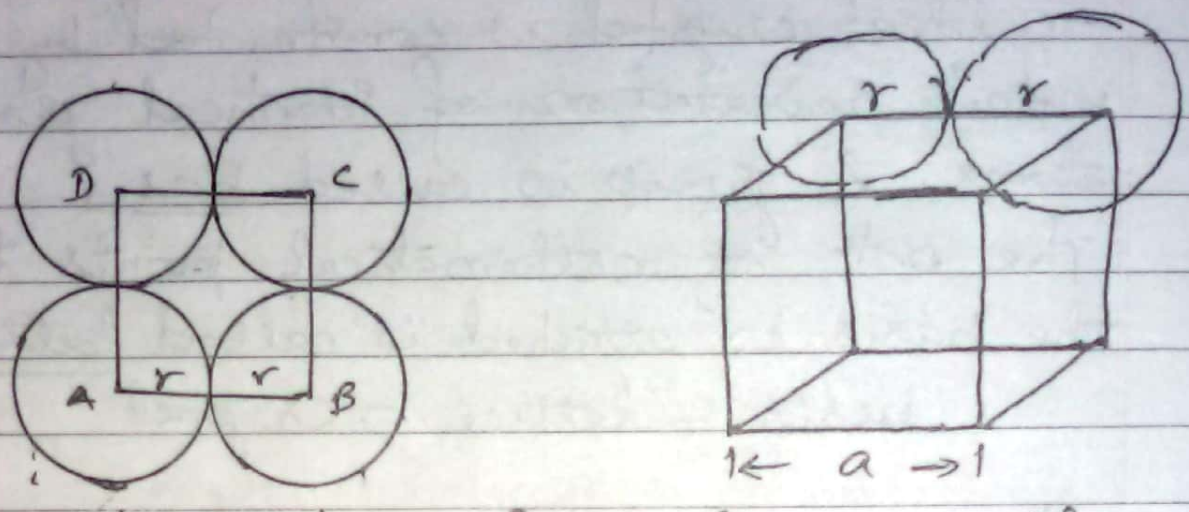


Fig: Simple cubic unit cell

Polonium is the only element which has this structure

There are 8 atoms at 8 corners

Each atom is common for 8 cubes $= \frac{1}{8}$

Thus, the no. of atoms in a unit cell $= 8 \times \frac{1}{8} = 1$

Let a = lattice constant (side of unit cell)

r = radius of the atom

Then $a = 2r$

$\therefore r = \frac{a}{2}$

Volume of one atom $= \frac{4}{3}\pi r^3 = \frac{4}{3}\pi\left(\frac{a}{2}\right)^3$

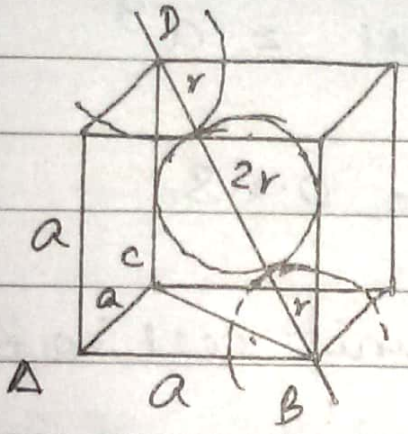
$= \frac{\pi a^3}{6}$

Volume of unit cell $= a^3$

$\therefore$ P.F $= \frac{\pi a^3/6}{a^3} = \frac{\pi}{6} = 0.52$

52% Space of unit cell is occupied by atoms.
Co-ordination number is the no. of atoms in the nearest neighboring atoms which are connected together with the single atom.

2 Body Centered Cubic Structure



There are 8 corner atoms and one atom at the center of the cube.
The center atom is not shared by any unit cell.
But corner atom is shared by 8 unit cells.
Hence, total no. of atoms per unit cell

$$= 1 + (8 \times \tfrac{1}{8}) = 2$$

from figure

$$BD^2 = BC^2 + CD^2 \quad [\because BC^2 = AB^2 + AC^2]$$

$$(r + 2r + r)^2 = AB^2 + AC^2 + CD^2$$

$$(4r)^2 = a^2 + a^2 + a^2$$

$$r = \frac{\sqrt{3}a}{4}$$

Volume of 2 atoms $= 2 \cdot \frac{4}{3}\pi r^3$

$= \frac{8}{3}\pi\left(\frac{\sqrt{3}a}{4}\right)^3$

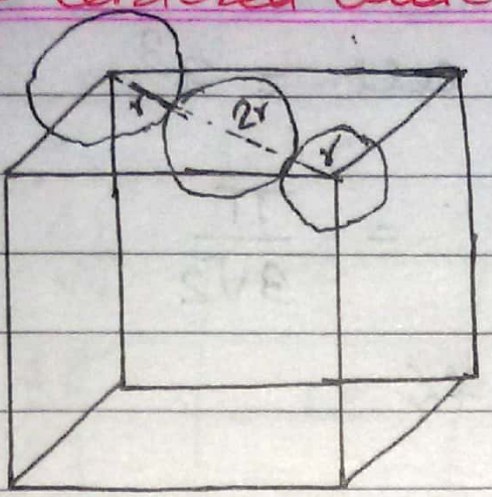
$= \frac{\pi a^3 \sqrt{3}}{8}$

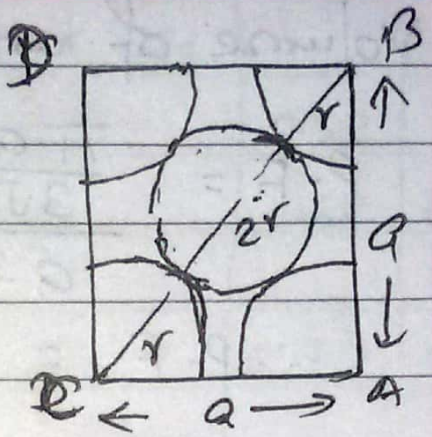
volume of unit cell $= a^3$

P.F. $= \frac{\sqrt{3}\pi}{8} = 0.68$

∴ 68% space of unit cell is occupied by the atoms

3. Face Centered Cubic structure





There are 8 atoms, one at each corner of cube plus 6 face centered atoms at 6 planes of the cube.

Each corner atom is shared by 8 sorrounding cubes $(1/8)$

Each face centered atom is shared by 2 " " $(1/2)$

Hence, total no. of atoms per unit cell

$$= 8 \times \frac{1}{8} + 6 \times \frac{1}{2} = 4$$

From figure $BC^2 = AB^2 + AC^2$

$$(r+2r+r)^2 = a^2 + a^2$$

$$(4r)^2 = 2a^2$$

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

Volume of 4 atoms $= 4 \times \frac{4}{3}\pi r^3$

$$= 4 \times \frac{4}{3}\pi \left(\frac{a}{2\sqrt{2}}\right)^3 = \frac{\pi a^3}{3\sqrt{2}}$$

Volume of unit cell $= a^3$

$$P.F = \frac{\frac{\pi a^3}{3\sqrt{2}}}{a^3} = \frac{\pi}{3\sqrt{2}}$$

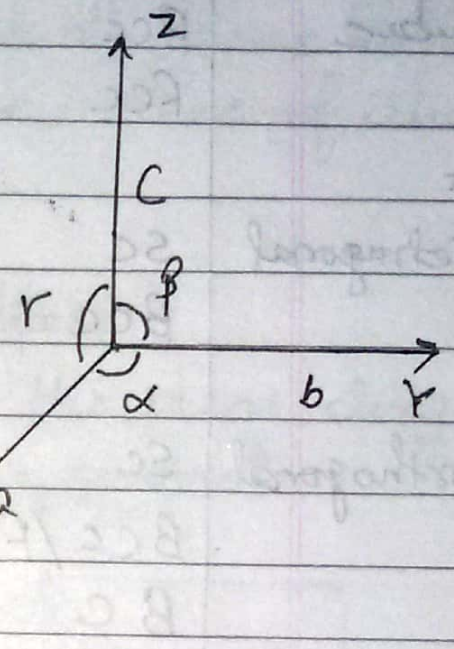
$\therefore P.F. = 0.74$

Crystal structure	Side a & atomic radius	Co-ordination Number	No. of atoms/ unit cell	p.f	Example
S. Cubic	$a = 2r$	6	1	0.52	Po
BCC	$a = \frac{4r}{\sqrt{3}}$	8	2	0.68	Li, Na, Fe
fcc	$a = \frac{4r}{\sqrt{2}}$	12	4	0.74	Ag, Au
HCP	$a = 2r$	12	2	0.74	Zn, Co
Diamond	$a = \frac{8r}{\sqrt{3}}$	4	8	0.34	Si, Ge
CsCl					
Zinc blende					

Ring

Bravais Lattice

There are 14 different distinct lattices that exist in 3D. These 14 distinct lattices are called Bravais lattices.



There can be number of possibilities for choosing a unit cell for given crystal structure. As a convention, the geometry of unit cell is represented by a parallelopiped with sides a, b, c and angles α, β and γ as shown in figure. The sides a, b and c and angles α, β & γ referred to as lattice parameter or primitives.

Different specification for a, b and c as well as α, β and γ generate different crystal systems as listed in table

Crystal	Types of Lattices	No. of Lattice	Length of primitive Edge length	Interfacial angle Angle bet^n axes
Cubic	Sc Bcc Fcc	3	$a=b=c$	$\alpha=\beta=\gamma=90^\circ$
Tetragonal	Sc Bcc	2	$a=b\neq c$	$\alpha=\beta=\gamma=90^\circ$
Orthogonal	Sc Bcc/Fcc Bc	4	$a\neq b\neq c$	$\alpha=\beta=\gamma=90^\circ$
Rhombahedral	R	1	$a=b=c$	$\alpha=\beta=\gamma\neq90^\circ$
Hexagonal	Sc	1	$a=b\neq c$	$\alpha=\beta=90^\circ, \gamma=120^\circ$
Monoclinic	Sc Bc	2	$a\neq b\neq c$	$\alpha=\gamma=90^\circ, \beta\neq90^\circ$
Triclinic	Sc	1	$a\neq b\neq c$	$\alpha\neq\beta\neq\gamma\neq90^\circ$

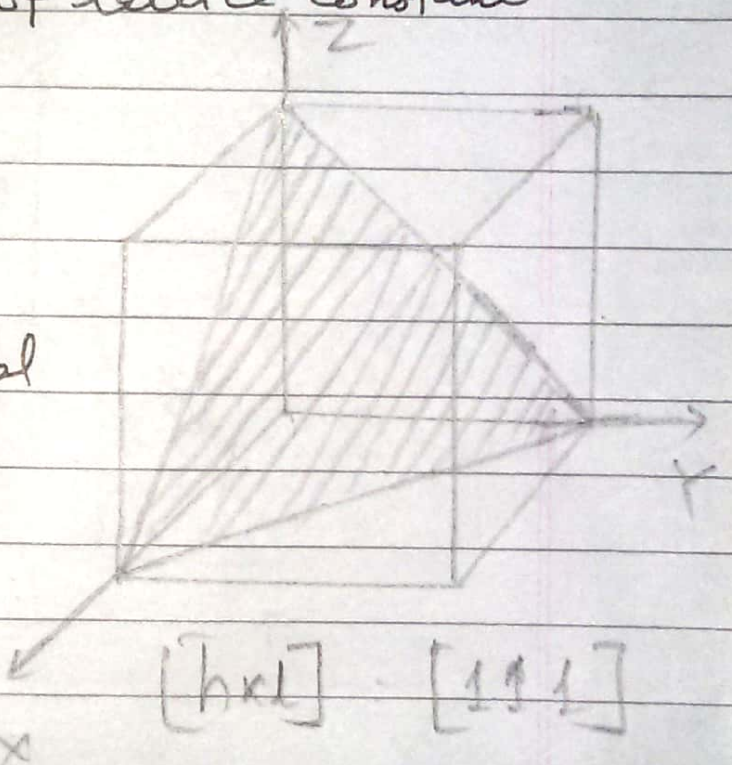
* Miller Indices

Miller introduced a system to designate a plane in a crystal. This set of three numbers is known as Miller indices of the concerned plane.

Procedure to find Miller indices

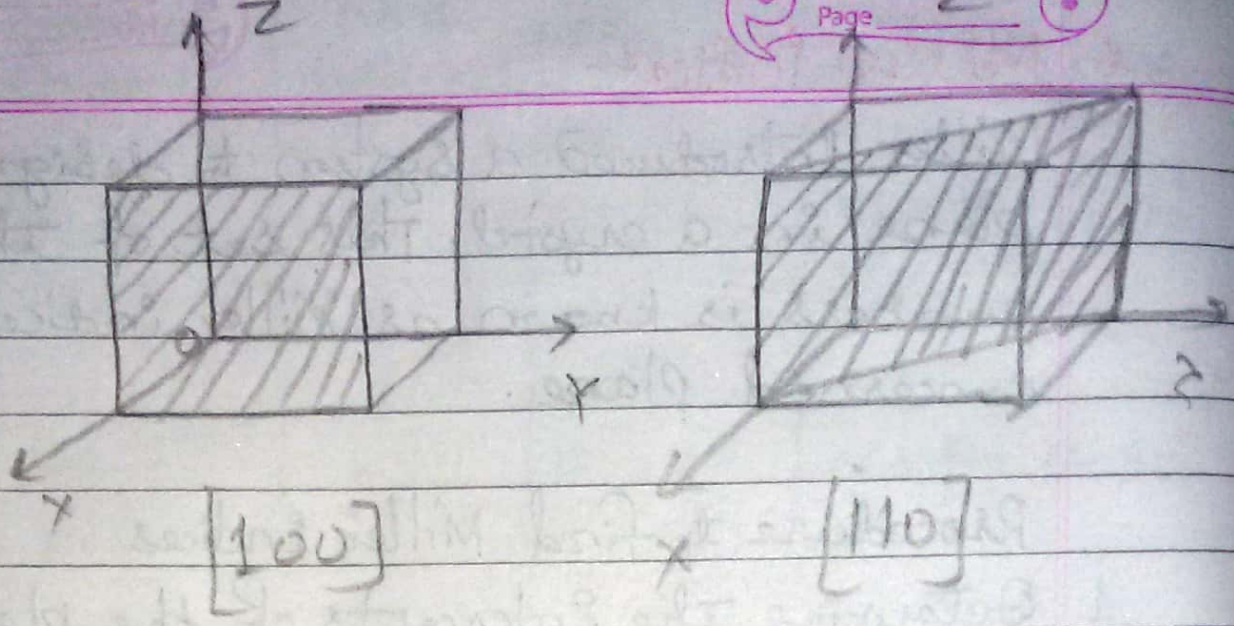
1. Determine the intercepts of the plane along x, y & z in terms of lattice constant

x	y	z
a	b	c

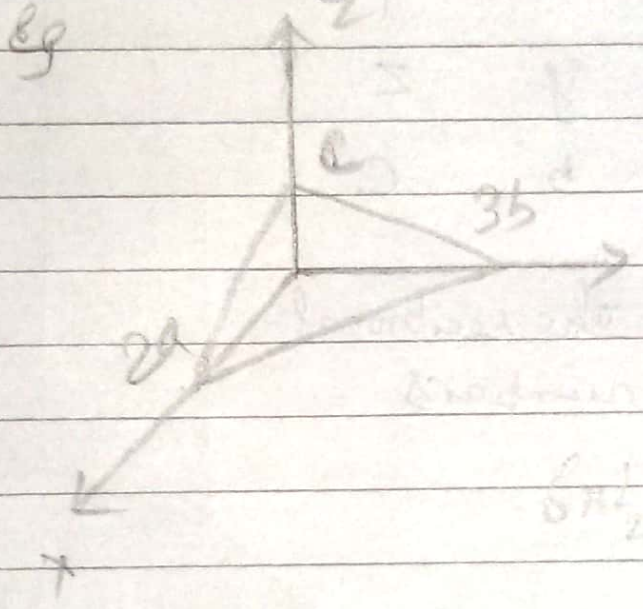


2. Determine the reciprocal of these numbers

3. Find LCD (or CM) and multiply each by this LCD. The result is written in the form (hkl) and is called the Miller indices of the plane.



[100] [110]



(i)	x	y	z	
	2a	3b	c	
(ii)	2	3	1	
(iii)	1/2	1/3	1/1	
(iv)	LCM 6			

(v) [2 3 6]

[hkl] = [3 2 6]