IES/GATE

Electrical Engineering

VOLUME-I

Material Science
Basic Electrical Engineering
Electromagnetic Theory

Contents

Chemical Bond :-

→ Binding forces b/w atoms or molecules in a material are known as chemical bonds

→ There are two types of chemical bonds

(a) Primary bond :-

These bonds are having higher binding energy

eg :- Ionic bond, covalent bond & metallic bond

(b) Secondary bond :-

These bonds are having lesser binding energy as compared to primary bonds

eg :- Vanderwaal forces & hydrogen bond

Ionic Bond :-

→ Ionic bond results from electrostatic interaction b/w oppositevely charged ions by transfer of electrons from one to another

→ Ionic bond formed particularly b/w left hand side and right hand side of periodic table are strongly ionic

eg :- Alkali halides

Covalent Bond :-

→ It is formed due to sharing of electrons

eg :- H_2O, CO_2, Si, Ge

→ Covalent bond formed b/w similar elements is very strong

→ Covalent crystals are also known as valence crystal

Metallic Bond :-

→ Metallic bond is the characteristic of elements having small no. of valence electrons

→ Metals are having large no. of free electrons in their conduction band even at room temperature because they require less amount of energy to be supplied to release their electrons from valence band to the conduction band

→ Metals can be considered as periodic structure of positive ions surrounded by large no. of elect

Vanderwaal's Bond :-

→ Vanderwaal forces are weaker forces which are present in inert gases or materials having dipoles

eg:- $\overset{+}{H} \longrightarrow \overset{-}{F}$

↓

covalent bond
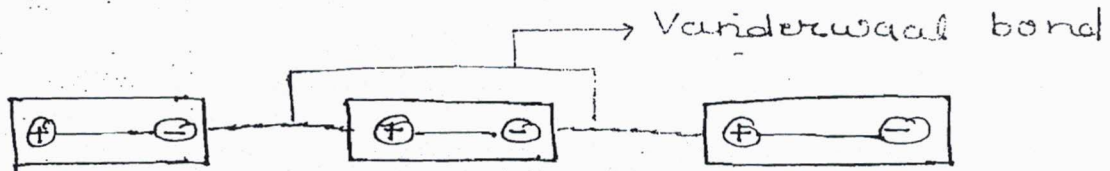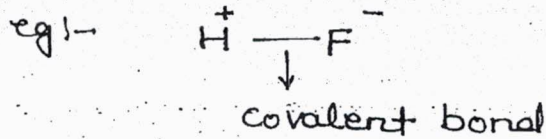
→ Vanderwaal bond

→ Dipole interaction is due to the presence of vanderwaal forces

→ Hydrogen bond is a strong type of vanderwaal's bor

Atomic Arrangement in Solids :-

→ Crystallinity
→ Single crystal material
→ Poly crystalline material
→ Amorphous material.
→ Epitaxial process

(1) Crystallinity :-

The property of solid in which atoms or molecules are arranged in a periodic and regular manner is called crystallinity

(II) Single Crystal Material :-

If material is having only one type of periodic arrangement then material is called single crystal material.

(III) Poly Crystalline Material :-

A polycrystalline material is divided into no. of small regions. These regions are called grains. Each grain is having its own periodic arrangement but their periodic arrangement

varyies from one grain to the other

eg:- polycrystalline silicon

Note :-

Anisotropic Material :-

If properties of material depends on the direction in which they are measured then materi is called anisotropic material

eg:- single crystal materials

Isotropic Material :-

If properties of material are independ of the direction in which they are measured the material is called as isotropic material

)Amorphous Material :-

→ In amorphous material, atoms upto first nearessi neighbours are arranged periodically but the atom which are away from the nearest atoms are found to be arranged randomly

→ When atoms or molecules are not given opportuni to arrange in regular and periodic manner, an amorphous material may be formed

eg:- supercooled state of SiO_2 is known as Glass (Amorphous material), whereas on annealin SiO_2 may crystallise into Quartz (single crystal materi

$$\boxed{SiO_2} \longrightarrow 1000°C$$

Super cooling ↓
Annealing

$-200°C$ $-200°C$
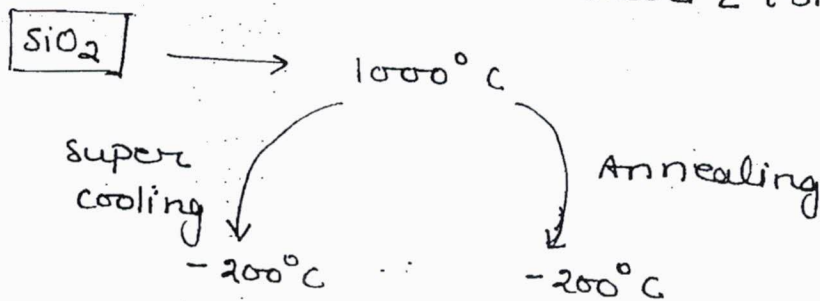
→ In other cases molecules may be extremely long and irregular in shape so that periodic arrangement may not be obtained as in the case of polymers

(v) Epitaxial Process :-

It refers growth of a layer of silicon on a substrate

si layer

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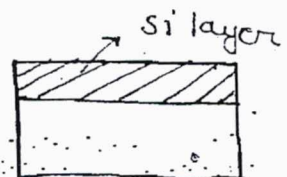
Note :-

Annealing :-

It is a process of heating & slow cooling

Ques :- In a Si Crystal, arrangement of atoms repe periodically. This material can be classified as

(a) Non-crystalline and amorphous

(b) Epitaxial and non-crystalline

(c) Single crystal and epitaxial

(d) Single crystal and amorphous

Ans - (c)

Cubic Crystal Structure :-

Unit Cell :-

It is defined as the minimum area cell in 2-dimension or the minimum volume cell in 3-dimension by repeatition of which a crystal may be formed

Parameters of Unit Cell :-

(I) Unit cell dimension

(II) Angle b/w axis

(III) No. of atoms per unit cell

(IV) Atomic packing factor (APF)

$$APF = \frac{Sum \ of \ atomic \ volume}{Volume \ of \ unit \ cell}$$

$$= \frac{No. \ of \ atoms \ per \ unit \ cell \times Vol. \ of \ an \ atom}{Volume \ of \ unit \ cell}$$

Coordination Number :-

The no. of atoms which are in physical contact with a particular atom in the crystal structure is known as coordination no.

Type of cubic lattices :-

(I) Simple Cubic

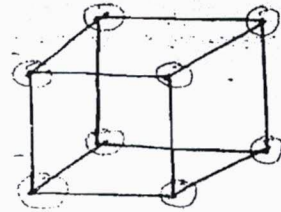(II) Body centred cubic (BCC)

(III) Face centred cubic (FCC)

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Simple Cubic :-

In simple cubic, there are 8 atoms at + 8 corners of the cube

→ Atoms are in physical contact along edge of the cube

→ $r = \dfrac{a}{2}$

→ No. of atoms per unit cell
$$= 8 \times \frac{1}{8} = 1$$

→ $APF = \dfrac{1 \times \frac{4}{3} \pi r^3}{a^3}$

$$= 0.52$$

→ Coordination number : $3 \times 2 = 6$
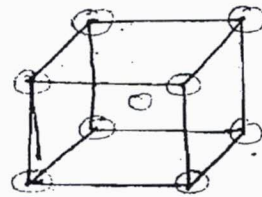
eg :- Mn, Polonium, fluorspar etc

Body Centred Cubic :-

In BCC, there are 8 atoms at 8 corners of the cube and one atom is located at the center of the unit cell

→ Atoms are in physical contact along body diagonal

→ $\sqrt{3}a = 4r \implies r = \dfrac{\sqrt{3}}{4}a$

→ $APF = \dfrac{2 \times \frac{4}{3} \pi r^3}{a^3}$

$$= 0.68$$

→ Coordination No : 8

eg :- Li, Na, K, Cr, Fe (α type), Fe (S-type) etc
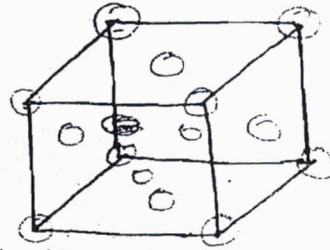
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Face Centred Cubic :-

→ In FCC, there are 8 atoms at 8 corners of the cube and 6 atoms are located at the centre of six faces of the cube

→ Atoms are in physical contact along face diagon

→ $a\sqrt{2} = 4r \implies a = 2\sqrt{2}\,r$

→ $APF = \dfrac{4 \times \frac{4}{3}\pi r^3}{a^3}$

  $= 0.742$

→ Coordination No : 12

→ eg:- Au, Ag, Cu, Pt, Pb, Ni, NaCl, Fe (V-type Note) etc

Note :-

→ FCC is an example of closed packed structure
→ It is also known as cubic closed packed
→ In FCC every third layer is identical
→ If an atom is surrounded by six other atom in the same layer then structure is known as closed packed structure
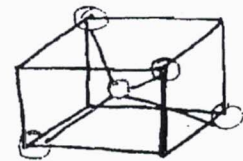
Diamond cubic :-

→ Diamond cubic unit cell is having contributions of 18 atoms (8 corner atoms, 6 face centred atoms & 4 atoms are completely inside)

→ No of atoms per unit cell — $8 \times \frac{1}{8} + 6 \times \frac{1}{2} + 4 = 8$

→ In diamond cubic atoms are connected in tetrahedral form

  smaller cell < Unit cell

→ Coordination No — 4

→ $APF = \dfrac{8 \times \frac{4}{3}\pi r^3}{a^3} = \dfrac{32}{3} \times \dfrac{22}{7} \times \dfrac{a^3\, 3\sqrt{3}}{64 \times 8 \times a^3}$

  $= 0.34$

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→ 7 Diamond cubic structure is also known as Zinc Blende (ZnS)

→ Group - III - V compounds are having zinc blend structure

   eg:- Diamond, C, Si, Ge. & Group III - V compou [GaAs, GaP, AlP etc]

Hexagonal Close Packing (HCP) :-
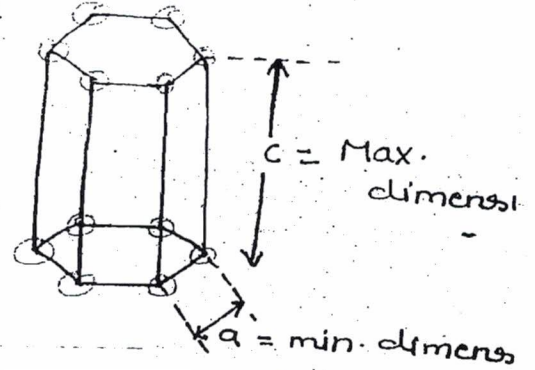
→ HCP unit cell is having

(i) 12 corner atoms

(ii) 2 face centred atoms in top and bottom hexagor

(iii) 3 atoms are completely inside

→ No. of atoms $= 6 \times \dfrac{1}{6} + 6 \times \dfrac{1}{6} + 2 \times \dfrac{1}{2} + 3$

$$= 1 + 1 + 1 + 3$$

$$= 6$$

→ $APF = \dfrac{6 \times \dfrac{4}{3}\pi r^3}{a^3}$

$$= 0.74$$

→ Coordination No : 12

→ $\dfrac{c}{a} = \dfrac{Max. \, dimension}{Min. \, dimension} = 1.63$

→ It is an example of closed pack structure

→ In HCP, every alternate layer is identical
   eg:- Be, Cd, Co, Zn, Mg etc

Graphite :-

→ Structure of graphite is hexagonal but it is not HCP as there is no centre atom in the hexagon

→ Each carbon atom has 4-valence electrons, 3 of these valence electrons are used in forming covalent

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bond with adjacent atoms in the same layer. The 4th electron is free to move over the surface of the layer making graphite an electrical condu

→ Between layers force of attraction is vanderwa because these forces are weak, layers of graphit can slide on each other. Due to sliding propert, of layers, graphite is used as a lubricant

1.

2.

3.

→ Vanderwaal forces of attraction
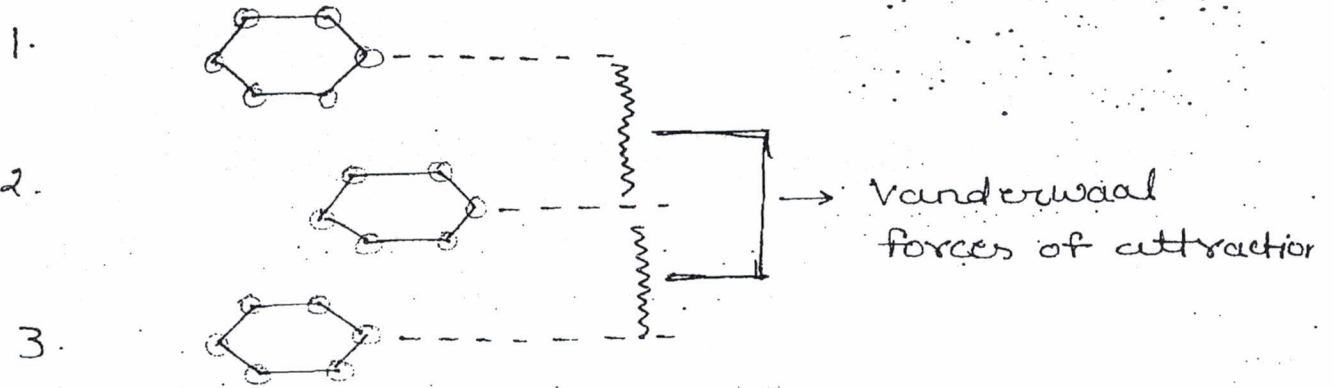
Comparison b/w Diamond and Graphite :-

Property	Diamond	Graphite
Hardness	Extremely hard	Soft
Transparency	Transparent	opaque
3. Electrical conductivity	Insulator	conductor
4. Structure	Tetrahedral	Hexagonal ≠ HCP

Ques!- Consider the statements related to fcc structu

(I) Coordination No. is 12

(II) APF is 0.74

(III) There is an atom at the body centre of the unit cell.

Which of these statements are correc

Ans!- (I) and (II)

Ques :- Which of the following statements are true diamond structure

i) Coordination No. is 4

ii) Packing fraction is 0.34

iii) Cu crystallises into diamond structure

Ans :- (i) and (ii)

Comparison :-

Structure	APF	No. of atoms per unit cell	Coordination No.	Atomic Radius (λ)	Example
Diamond Cubic	0.34	8	4	$\dfrac{a\sqrt{3}}{8}$	Grp (III-. Compour Si, Ge, C Diamond
Simple Cubic	0.52	1	6	$\dfrac{a}{2}$	Mn, Poloniu fluorspa
BCC	0.68	2	8	$\dfrac{a\sqrt{3}}{4}$	Li, Na, K Cr, Fe (α-typ Fe(δ-type
FCC (ABC ABC...)	0.74	4	12	$\dfrac{a\sqrt{2}}{.4}$	Au, Ag, Cu Pt, Al, Pb Ni, NaCl Fe(γ-typ
HCP (ABAB AB)	0.74	6	12	$\dfrac{c}{a}=1.63$	Be, Cd, Co, Zn, Mg

Miller Indices :-

→ Miller indices are used to determine the direction of plane in a crystal structure

Where a, b and c represent unit cell dimension along x, y and z axis respectively

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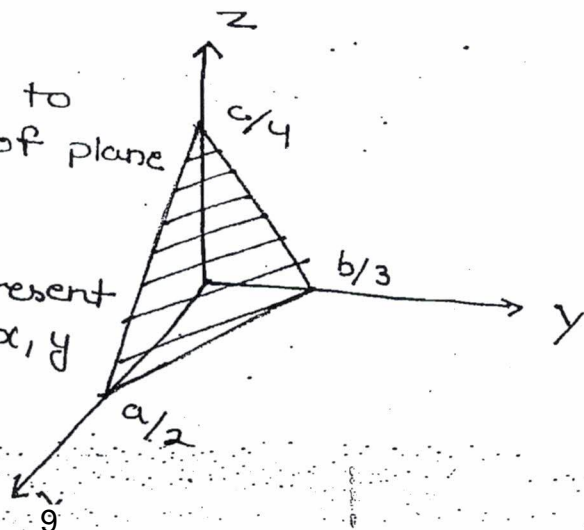
Steps to determine Miller Indices :-

1) Determine intercept made by plane along x, y and z axis respectively

$$\frac{a}{2} , \frac{b}{3} , \frac{c}{4}$$

(II) Express intercepts as multiples of unit cell dimensions

$$\frac{1}{2} , \frac{1}{3} , \frac{1}{4}$$

(III) Get reciprocal of multiples

2, 3, 4

(IV) Reduce reciprocals to the smaller set of integers   [2, 3, 4]

Ques !- Miller indices

Intercepts	$2a , 3b , 4c$
Multiples	2, 3, 4
Reciprocal	$\frac{1}{2} , \frac{1}{3} , \frac{1}{4}$
Integers	[6, 4, 3]

Ques !- Determine miller indices for black shaded portion

Soln :-   Intercept :- ∞ , b , ∞

Multiple :- $\infty , 1 , \infty$
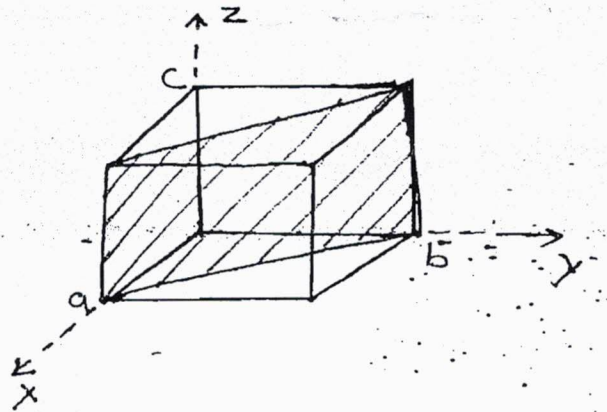
Reciprocal :- 0, 1, 0

Integers :- [0, 1, 0]
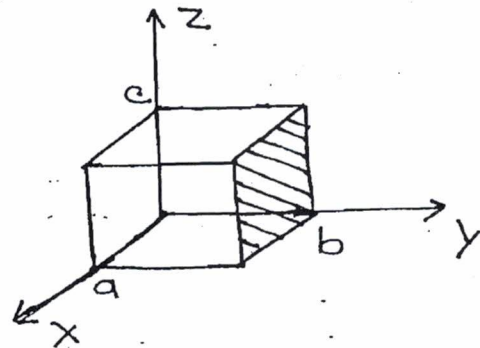
Ques:- Unit cell dimensions are a, b, c. Determine Miller indices for shaded portion

Soln:- Intercept :- a, b, ∞

Multiples :- $1, 1, \infty$

Reciprocal :- $1, 1, 0$
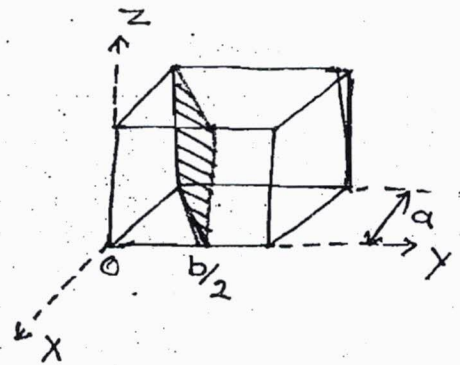
Integers :- $[1, 1, 0]$

Ques:- Unit cell dimensions are a, b & c. Determine Miller indices for black shaded plane

Soln:- Intercepts :- $-a, b/2, \infty$

Multiples :- $-1, \frac{1}{2}, \infty$

Reciprocal :- $[-1, 2, 0]$
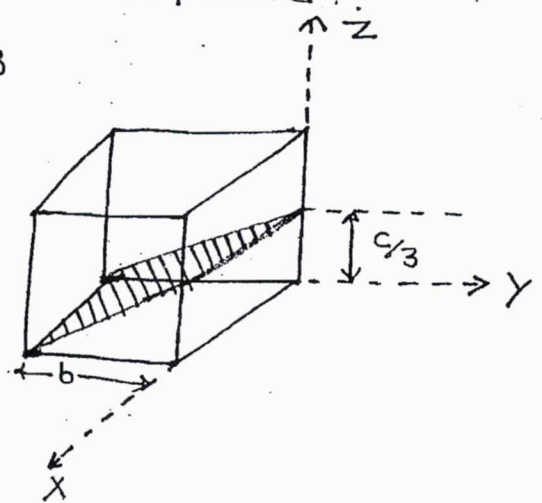
Integers :- $[\bar{1}, 2, 0]$

Ques:- Unit cell dimensions are a, b & c. Determine the Miller indices for black shaded plane

Soln:- Intercepts :- $\infty, -b, c/3$

Multiples :- $\infty, -1, \frac{1}{3}$

Reciprocal :- $0, -1, 3$

Integers :- $[0, \bar{1}, 3]$

Interplanar Separation :-

Distance b/w two parallel adjacent F in a crystal structure is known as interplanar separation

For cubic crystal system, interplanar separation

$$d = \frac{a}{\sqrt{l^2 + m^2 + n^2}}$$

where a = edge length of cube

[l,m,n] = Miller indices for given plane

Ques:- A material has a FCC structure with atom radius 1·06 A°. Calculate the interplanar separation for [1,1,0] planes

Soln:-

→ r = 1·06 A°

→ [l,m,n] = [1,1,0]

→ FCC !

$$r = \frac{a\sqrt{2}}{4} = \frac{a}{2\sqrt{2}} \quad \Rightarrow \quad a = 2\sqrt{2}\, r$$

→ $$d = \frac{a}{\sqrt{l^2 + m^2 + n^2}}$$

$$= \frac{2\sqrt{2}\, r}{\sqrt{2}} = 2r = 2 \times 1·06\, A° = 2·12\, A°$$

Equivalent Planes :-

→ Plane : [1,0,0]

[1,0,0]   [0,1,0]   [0,0,1]

[$\bar{1}$,0,0]   [0,$\bar{1}$,0]   [0,0,$\bar{1}$]
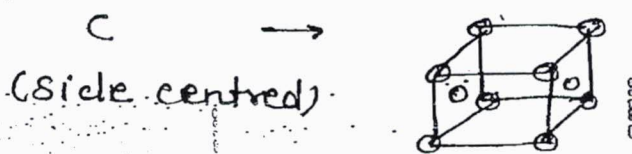
→13 Plane : $[1, 1, 0]$

$[1, 1, 0]$ $[1, 0, 1]$ $[0, 1, 1]$

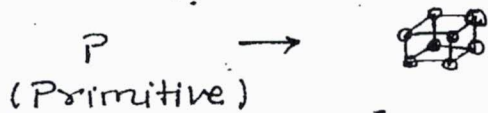$[\bar{1}, 1, 0]$ $[\bar{1}, 0, 1]$ $[0, \bar{1}, 1]$

$[1, \bar{1}, 0]$ $[1, 0, \bar{1}]$ $[0, 1, \bar{1}]$

$[\bar{1}, \bar{1}, 0]$ $[\bar{1}, 0, \bar{1}]$ $[0, \bar{1}, \bar{1}]$

Bravais Crystal System :—
→ 7 Crystal System
→ 14 Bravais lattices

Crystal System	Unit cell Dimension	Angle b/w Axis	Bravais lattices
Orthorhombic	$a \neq b \neq c$	$\alpha = \beta = \gamma = 90°$	P, I, C, F
Monoclinic	$a \neq b \neq c$	$\alpha = \beta = 90° \neq \gamma$	P, C
Triclinic	$a \neq b \neq c$	$\alpha \neq \beta \neq \gamma \neq 90°$	P
Hexagonal	$a = b \neq c$	$\alpha = \beta = 90°, \gamma = 120°$	P
Tetragonal	$a = b \neq c$	$\alpha = \beta = \gamma = 90°$	P, I
Trigonal / Rhombo-hedral	$a = b = c$	$\alpha = \beta = \gamma \neq 90°$	P
Cubic	$a = b = c$	$\alpha = \beta = \gamma = 90°$	P, I, F

P → (Primitive)

F → (Face - centred)

I → (Body centred)

C → (Side centred)
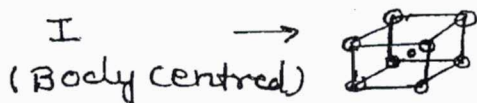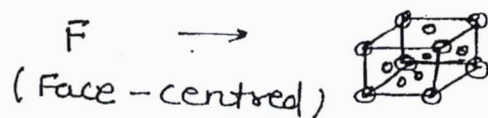
Ques:- Match List I & List -II

List - I

1. Hexagonal

2. Rhombohedral

3. Triclinic

4. Monoclinic

List - II

A. $a = b = c$, $\alpha = \beta = \gamma \neq 90°$

B. $a = b \neq c$, $\alpha = \beta = 90°$ ✓

C. $a \neq b \neq c$, $\alpha = \beta = 90° \neq$ ⌐

D. $a \neq b \neq c$, $\alpha \neq \beta \neq \gamma \neq 90°$

Soln   1   2   3   4

→   B   A   D   C

Structural Imperfections! -

→ Point defect
→ Line defect
→ Surface defect
→ Volume defect
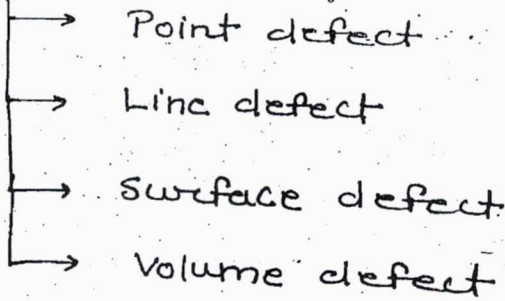
Point Defect !-

Point defect is a localised imperfection which does not spread more than 1 or 2 unit cells
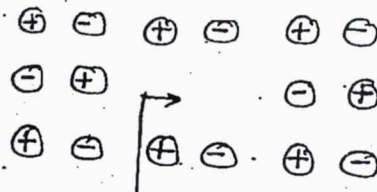
→ There are two types of point defect

(1) Vacancy defect   (11) Impurity defect

1) Vacancy Defect !-

It arises due to absence of atom or molecule in the crystal structure

eg:- schottky defect

Missing atom

$\oplus$ $\ominus$ $\oplus$ $\ominus$ $\oplus$ $\ominus$

$\ominus$ $\oplus$ $\ominus$ $\oplus$

$\oplus$ $\ominus$ $\oplus$ $\ominus$ $\oplus$ $\ominus$
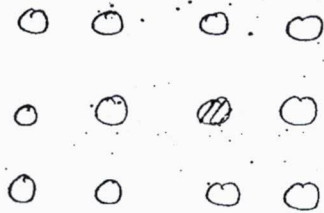
Missing pair of tr ne.

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2. <u>Impurity defect</u> :-

It arises when an impurity atom is introduced in the crystal structure either as an interstitial or substitutional

(a) <u>Substitutional type Impurity defect</u> :-

It arises when impurity atom replaces a parent atom of crystal.

O O O O
O O ⊘ O
O O O O

(b) <u>Interstitial type Impurity defect</u> :-

It arises when an impurity atom occupy free space or void available in the crystal structure

O O O O
O O O⊘ O ⟶ Impurity atom
O O O O
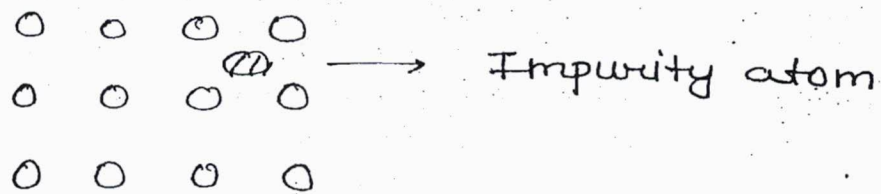
<u>Dielectric Properties of Material</u> :-

⟶ Dielectrics are non-conducting material which can be polarised with an application of electric field

⟶ Non-conducting materials are divided into two categories

(i) Insulator   (ii) Dielectric

(i) <u>Insulator</u> :-

If the main function of non-conducting material is to provide electric insulation then material is called insulator

(II) Dielectric :-

If the main function of non-conducting material is storage of charge, then material is called dielectric

Parameters of dielectric :-

(i) Dielectric constant (E)

(ii) Electric dipole moment (b)

(III) Polarization (P)

(IV) Polarizability (α)

1) Dielectric constant (E) :-

It is defined as the ratio of electric flux density to electric field intensity

i.e.

$$\epsilon = \frac{D}{E}$$

where D = Electric flux density (c/m^2)

E = Electric field intensity (V/m)

Also

$$\epsilon = \epsilon_0 \epsilon_r$$

where ϵ_0 = Permittivity of free space

$= 8.85 \times 10^{-12}$ F/m

ϵ_r = Relative permittivity of material

(Unit less)

(II) Electric dipole Moment (b) :-

(1) Electric dipole :-

Two opposite charges are separated by a finite distance constitute an electric dipole.

→ It is defined as the product of charge and distance of separation

→ It is a vector quatity which is directed from -ve charge to +ve charge.

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