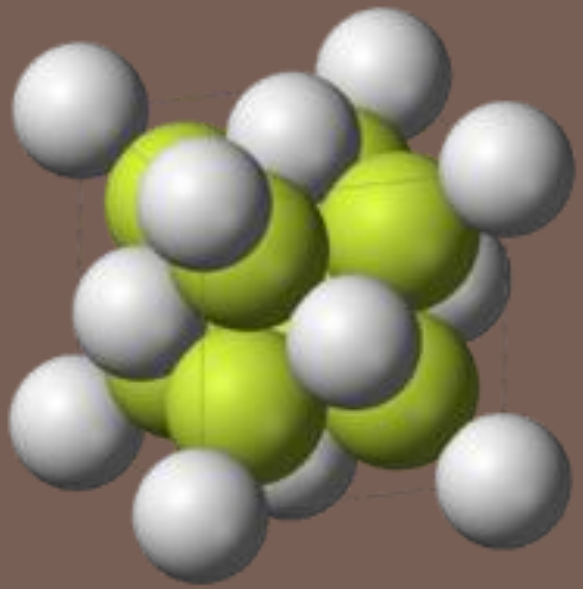
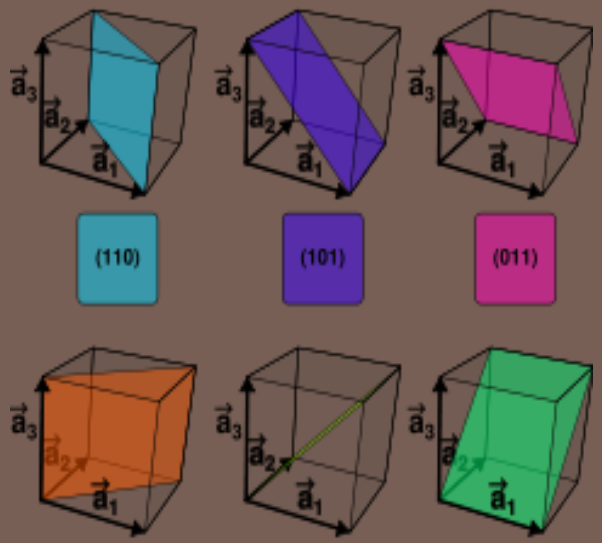
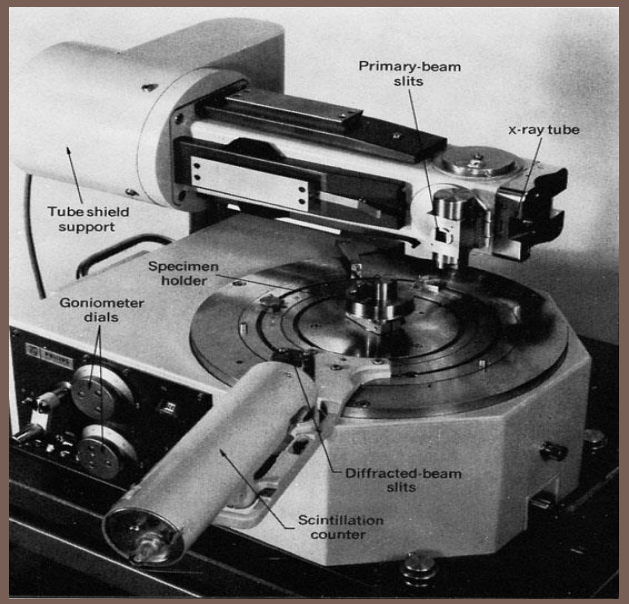
CH. NO. 2

METALLIC MATERIALS & THEIR STRUCTURE





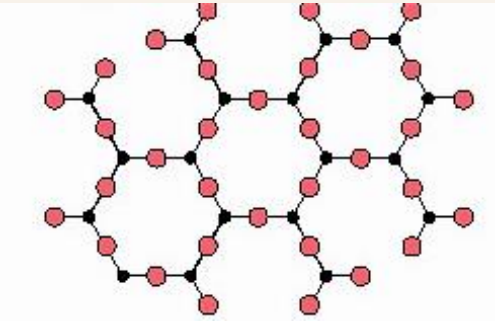


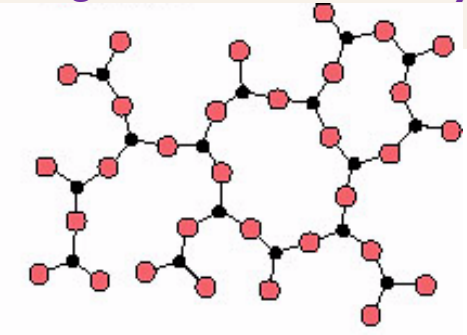
LEARNING OBJECTIVES

1. Structure of Metals
2. Types of fracture in metals –
   (i) Ductile Fracture (ii) Brittle Fracture
3. Macro-examination
4. Microscopic examinations
5. Other tests like – Spark Test, Sulphur Print, Magnetic Testing, Chemical analysis of steel and iron for Carbon, Sulphur & Phosphorous.

2.1 STRUCTURE OF METALS

Crystalline Material		Non-Crystalline Material	
(1)	Atoms or molecules are arranged in a very regular and orderly fashion in three dimensional pattern	(1)	Atoms or molecules are arranged in a random manner
(2)	Strength of these materials are comparatively high	(2)	Strength of these materials are comparatively lower than crystalline material
(3)	Examples are Metals and Alloys	(3)	Examples are Glass, Wood, Plastics, Rubbers, etc.
(4)	Figure below shows highly ordered arrangement of crystalline material	(4)	Figure below shows disordered arrangement of a non-crystalline material

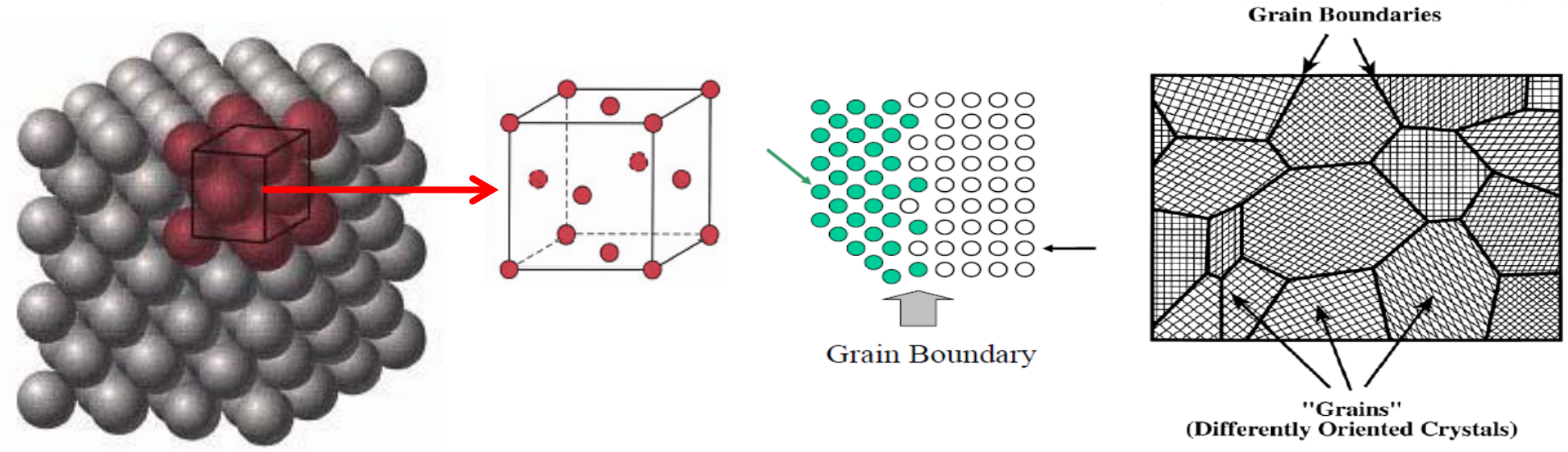




2.1 STRUCTURE OF METALS

Crystal Structure

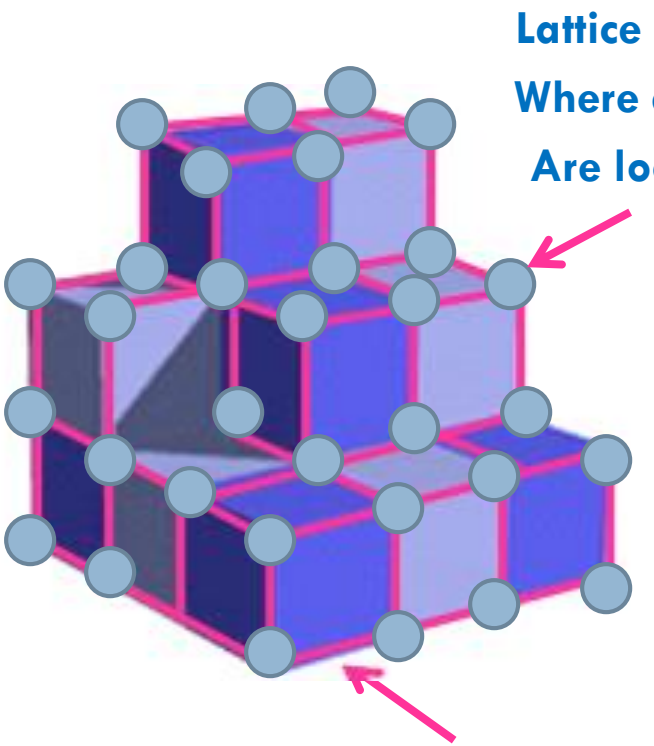
- Crystal structure is defined as regular repetition of three dimensional pattern of atoms in a space.
- A crystalline solid can either be a single crystal or an aggregate of many crystals well separated by well-defined grain boundaries.
- Solids with many crystals are known as **poly-crystalline solids**



2.1 STRUCTURE OF METALS

Space Lattice

- Lattice means an array of points repeating periodically in three dimensions.
- The points of intersection of the lines are called **lattice points**
- **Space lattice** means network of imaginary lines drawn in space such that space is divided into parts of equal size (volume)
- Combing the above two concepts we say that Atoms are located at the lattice points.

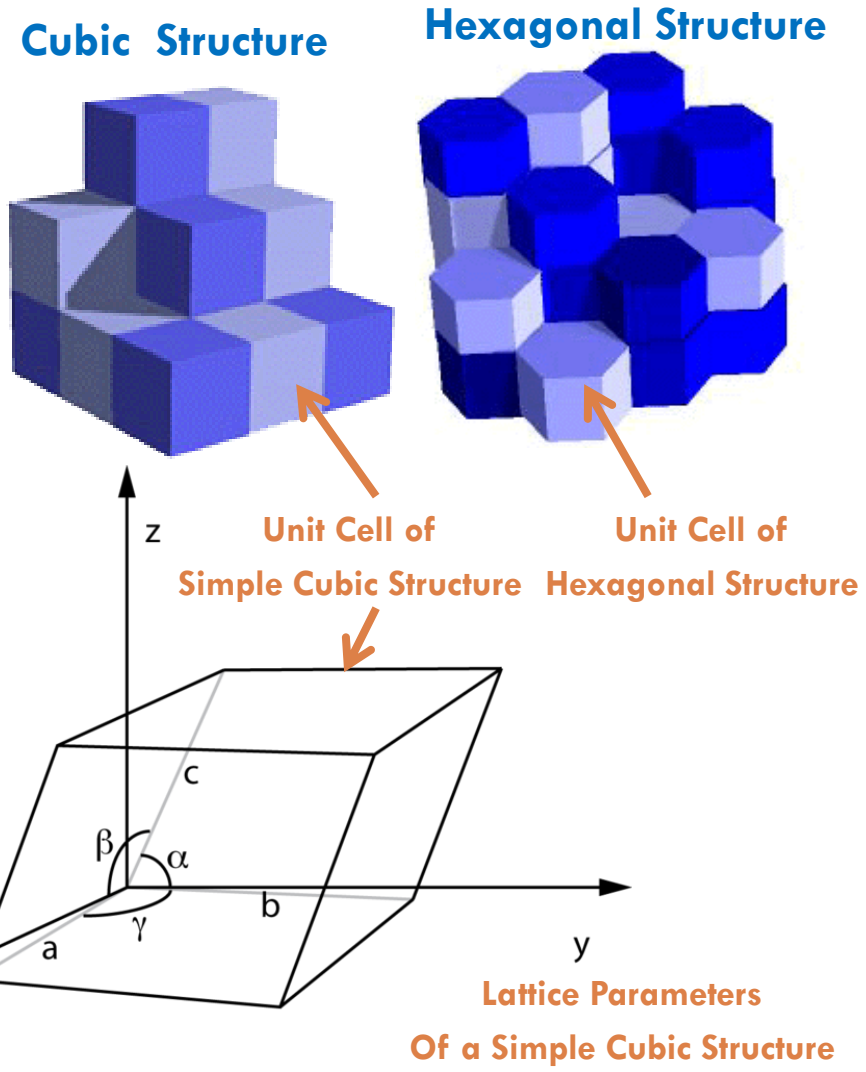


Space Lattice for a Cubic Structure
(Network of imaginary lines)

2.1 STRUCTURE OF METALS

Unit Cell

- Atoms are located upon the points of a lattice.
- The atoms of forming identical tiny boxes, called **unit cells**, that fill the volume of the material.
- The lengths of the edges of a unit cell and the angles between them are called the **lattice parameters**.



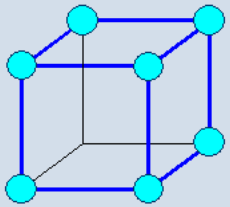
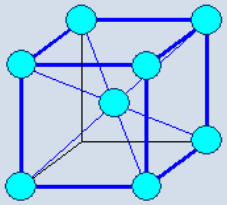
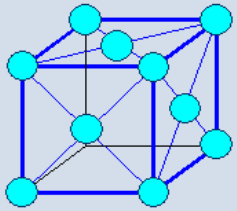
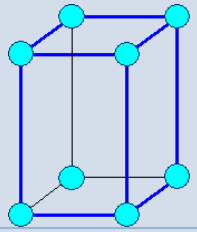
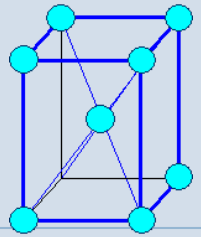
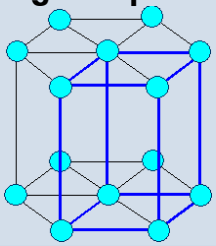
2.1 STRUCTURE OF METALS

Crystal Systems & Bravais Lattices

- The crystals are divided into 7 systems on the basis of
  1. Axial lengths
  2. Interfacial angles
  3. Directions of axis of symmetry
- There are 14 possible ways of arranging points in space lattice so that all the lattice points have exactly same surroundings.

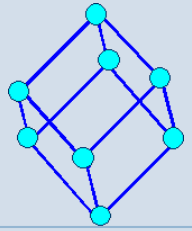
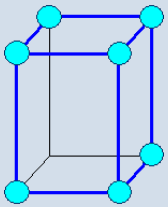
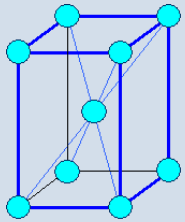
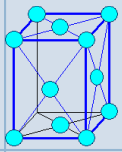
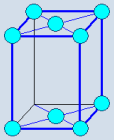
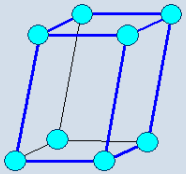
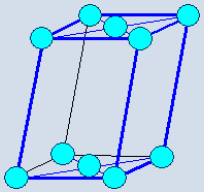
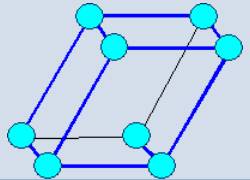
2.1 STRUCTURE OF METALS

7 Crystal Systems & 14 Bravais Lattices

Crystal system Length of Base vectors	Angles between axes	Bravais Lattices		
(1) Cubic a = b = c	α = β = γ = 90⁰	Cubic primitive / Simple Cubic 	Cubic body centered (BCC) 	Cubic face centered (FCC) 
(2) Tetragonal a= b ≠ c	α = β = γ = 90⁰	Tetragonal primitive 	Tetra. body centered 	
(3) Hexagonal a= b ≠ c	α = β = 90⁰, γ = 120⁰	Hexagonal primitive 		

2.1 STRUCTURE OF METALS

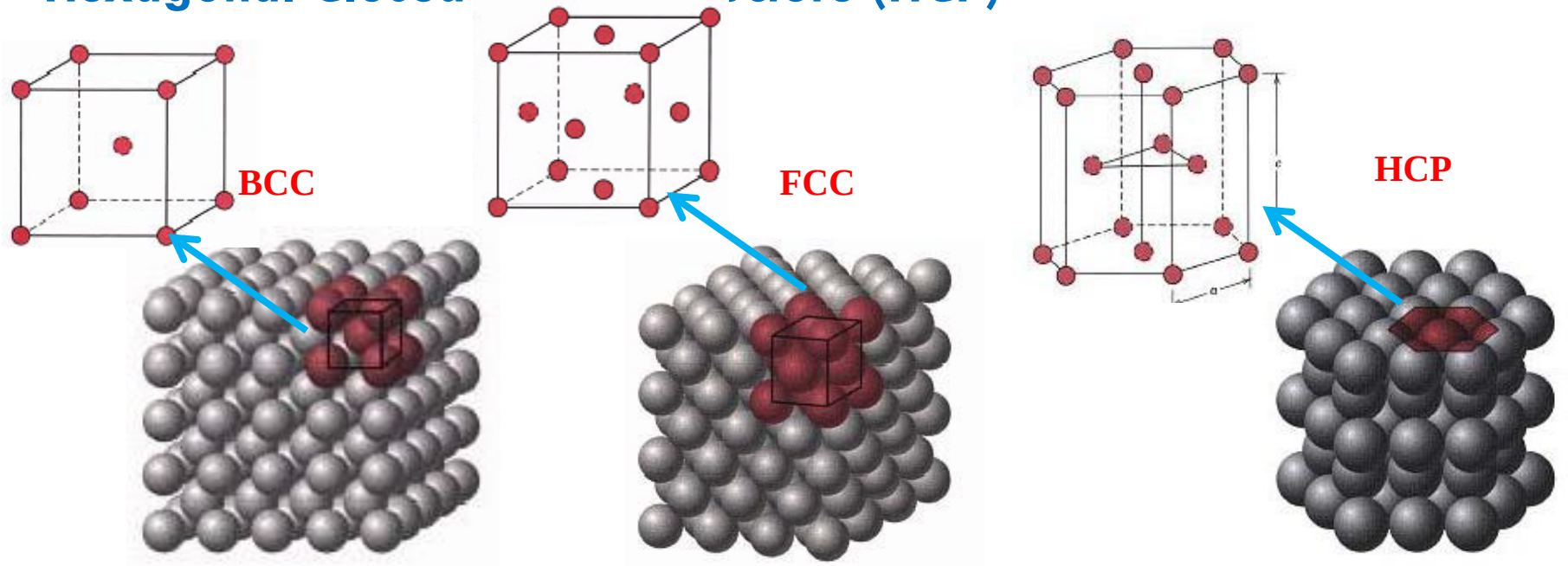
7 Crystal Systems & 14 Bravais Lattices

Crystal system Length of Base vectors	Angles between axes	Bravais Lattices		
(4) Rhombohedral a = b = c	α = β = γ ≠ 90⁰	Rhombohedral 		
(5) Orthorhombic a ≠ b ≠ c	α = β = γ = 90⁰	Orthorhombic primitive 	Ortho. body centered 	Orthorhombic Face Centered  Base Face Centered 
(6) Monoclinic a ≠ b ≠ c	α = β = 90⁰ ≠ γ	Monoclinic primitive 		Mono. face centered 
(7) Triclinic a ≠ b ≠ c	α ≠ β ≠ γ ≠ 90⁰	Triclinic 		

2.1 STRUCTURE OF METALS

Most commonly found crystal structures in pure metals are

1. Simple Cubic Structure
2. Body Centered Cubic Structure (BCC)
3. Face Centered Cubic Structure (FCC)
4. Hexagonal Closed Packed Structure (HCP)

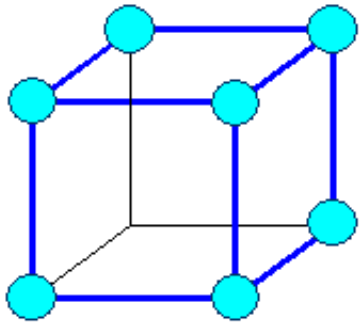


2.1 STRUCTURE OF METALS

Most commonly found crystal structures in pure metals are

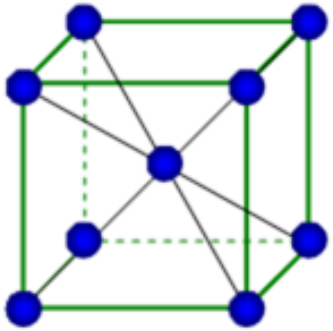
1. **Simple Cubic Structure**
2. **Body Centered Cubic Structure (BCC)**
3. **Face Centered Cubic Structure (FCC)**
4. **Hexagonal Closed Packed Structure (HCP)**

Crystal lattice examples



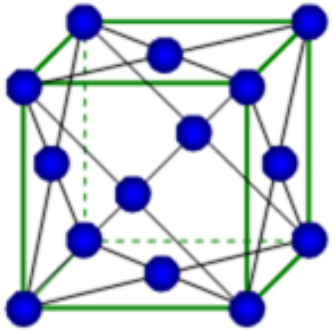
Simple Cubic Structure

Polonium



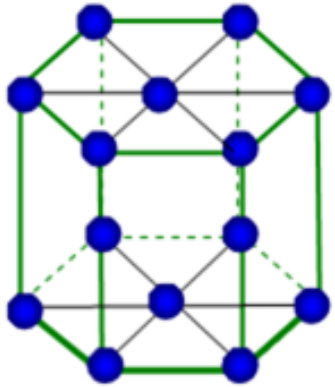
Cubic body centered (bcc)

Fe, V, Nb, Cr



Cubic face centered (fcc)

Al, Ni, Ag, Cu, Au



Hexagonal

Ti, Zn, Mg, Cd

2.1 STRUCTURE OF METALS

Crystal planes and directions (Miller Indices)

- In the analysis of crystal structure, it is necessary to describe the relative orientations of lines & planes. The directions can be described by specifying the coordinates (x, y) of the point through which the line passes (In 2D). In 3D, it is usually denoted by [x ,y ,z].
- The orientations of the planes in a crystal are specified by a system of numbers. It was first used by W. H. Miller in 1839 to describe the faces of a crystal.
- In general, any internal plane is inclined to all the crystallographic axes. The orientation of the plane can be determined by specifying distances from the origin to its point of intersection with the axes.
- The Miller indices is defined as the set of three smallest possible integers which have the same ratio as those of the reciprocals of the intercepts on the three coordinate axes. The Miller indices of the plane are specified as [h, k, l]; this means that the plane has fractional intercepts of 1/h, 1/k, 1/l with the axes and the actual intercepts are a/h, b/k, c/l .

2.1 STRUCTURE OF METALS

Rules for finding Miller Indices

1. Determine the intercepts of plane on the three axes in terms of lattice constants.
2. Take the reciprocals of the intercepts.
3. Reduce the reciprocals to whole no. by multiplying each with LCM which gives the Miller indices of the concerned planes.
4. Enclose the numbers by sq. bracket.

2.1 STRUCTURE OF METALS

An example to find Miller Indices

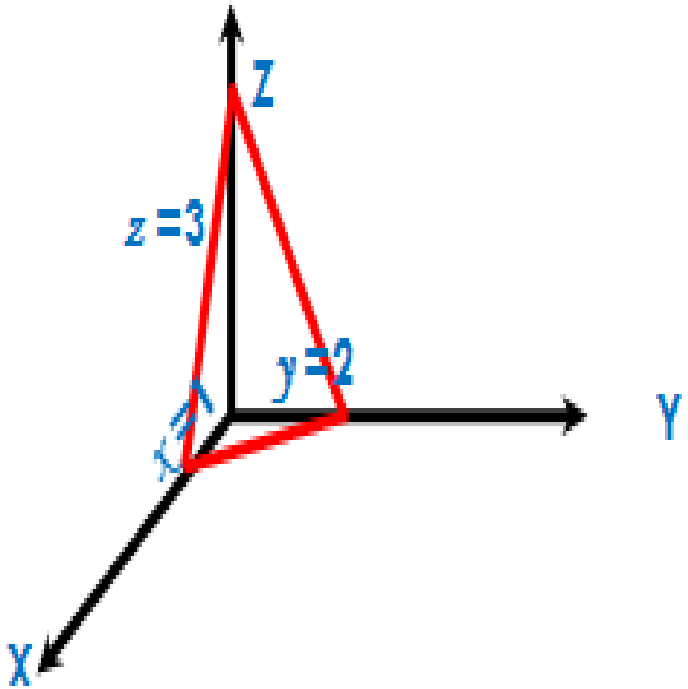
Let the intercepts of a plane on three coordinate axes be x = 1, y = 2, z = 3 ; So …

1. The intercepts are 1, 2, 3
2. The reciprocals are 1/1, 1/2, 1/3
3. The LCM is 6, so, multiplying by 6 in step-2,

   we get 6,3,2

Hence, the Miller Indices is [6,3,2]

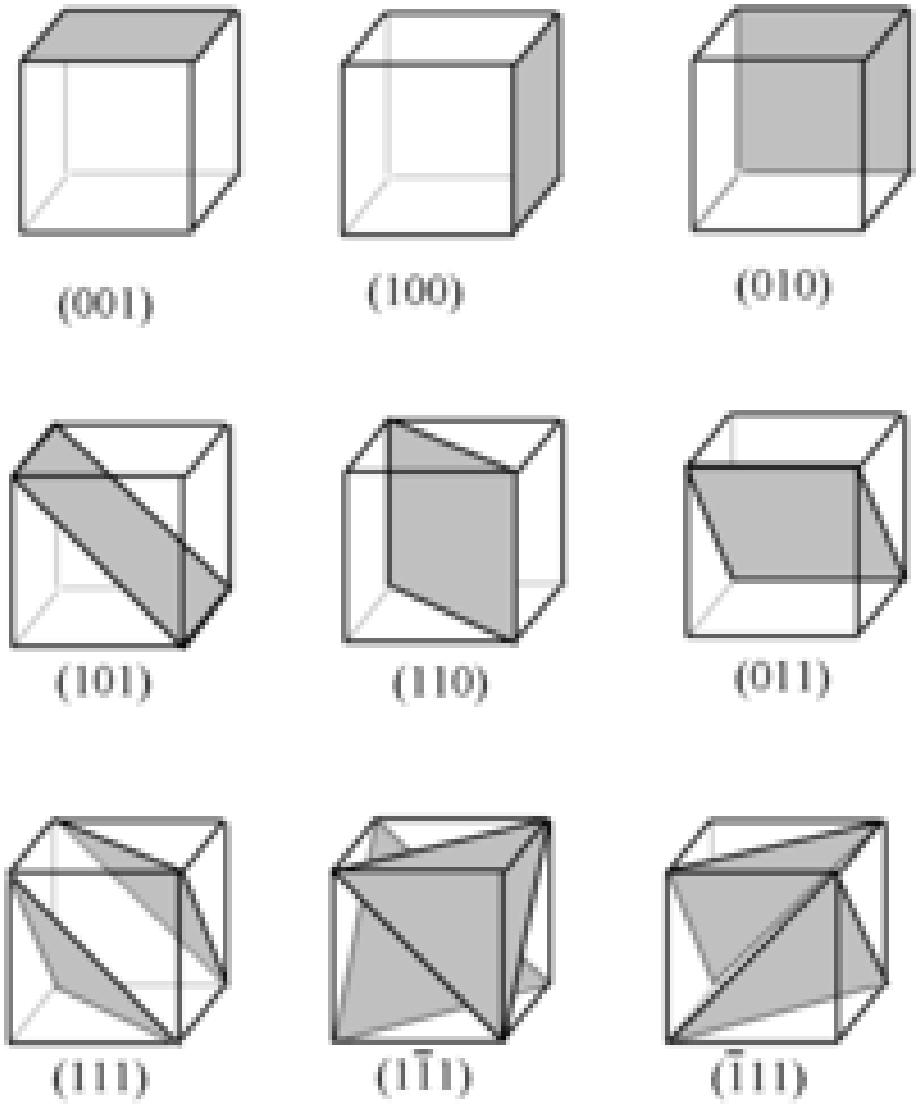
Parameter	X	Y	Z
Intercept	1	2	3
Reciprocal	1/1	1/2	1/3
Miller Indices	6	3	2



2.1 STRUCTURE OF METALS

Miller Indices for a Cubic Crystal

- In a cubic crystal all the three edges of a unit cell are equal and each interfacial angle is 90^0.
- One corner of the unit cell is taken as origin and the intercepts of the plane are measured along the axes of the coordinates in terms of edge length 'a' of a cube.



2.1 STRUCTURE OF METALS

Important features of Miller Indices

- Miller indices describe the angular position of planes with respect to the crystallographic axes but not their actual distances from the origin. All equally spaced II planes have the same Miller indices. So, the Miller indices do not describe the angular position of a single plane but of a set of II planes.
- When the plane is II to one of the coordinate axes it is said to meet that axis at infinity, i.e., length of intercept is infinity. The reciprocal of this numerical parameter is zero. Miller index for that intercept is zero.
- It is the ratio of the indices that is important i$\bar{e}$., [3 3 0] , [2 2 0] , [1 1 0] represents the same set of planes.
- A negative Miller Index shows that the plane [h,k,l] cuts the x-axis on the negative side of the origin.

2.1 STRUCTURE OF METALS

Important features of Miller Indices

- The angle between two crystallographic directions [h k l] and [h' k' l'] can be calculated using the following relation

$$Cos\theta = \frac{hh'+kk'+ll'}{\left(h^2+k^2+l^2\right)\left(h'^2+k'^2+l'^2\right)^{\frac{1}{2}}}$$

- The distance 'd' between the neighboring planes of family [h k l] is given in terms of cube edge 'a' as

$$d = \frac{a}{\left(h^2+k^2+l^2\right)^{\frac{1}{2}}}$$

2.1 STRUCTURE OF METALS

Calculation of lattice constant 'a'

- The no. of lattice points can also be determined if we know the vol density and molecular wt. of the constituent atom of the cell. Let us consider a cubic unit cell of lattice constant **a**. Let **n** be the no. of atoms per unit cell, **ρ** be the density of the crystal material, **M** be the molecular wt. of the material and **$N = 6.023 \times 10^{26}$** be the Avogadro no. As per Avogadro hypothesis, one Kg-mole of a crystalline material contains 6.023×10^{26} atoms or molecules.
- Mass of N atoms or molecules = M Kg
- Mass of unit cell containing n atoms = n. M/N
- Density of unit cell = mass of unit cell/Volm of unit cell

  = n x M/N x 1/V

  = nM/Na3 . Therefore, $a^3 = nM/N\rho$

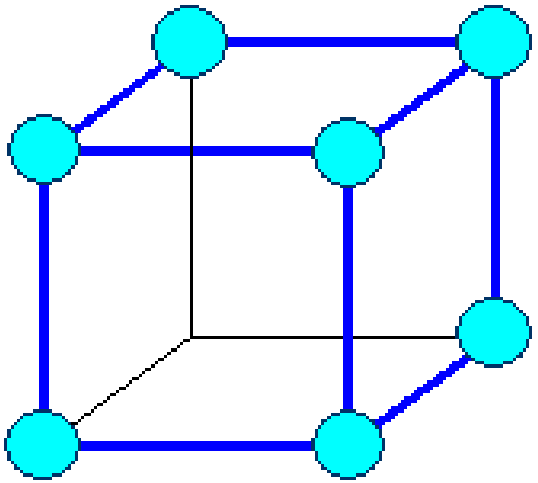
2.1 STRUCTURE OF METALS

No. of Atoms per Unit Cell

It is the effective no. of atoms per unit cell.

1. **Simple Cubic Lattice:**

   An SC lattice has 8 corner atoms. Each corner atom is shared among 8 adjoining cubes. Thus, the share of one corner atom to one unit cell = 1/8 x 8 = 1 Atom



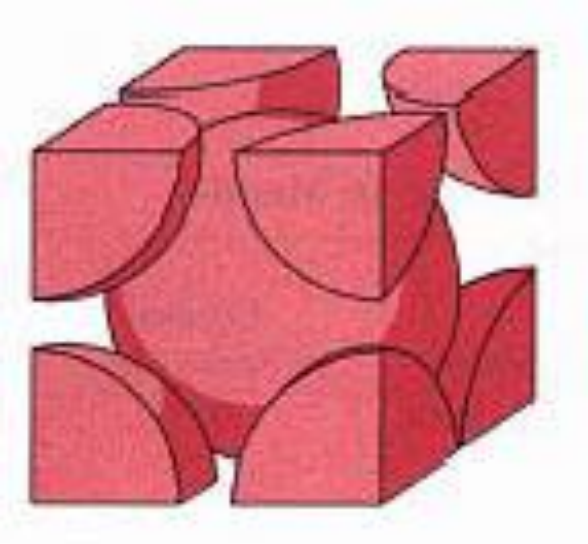
2.1 STRUCTURE OF METALS

No. of Atoms per Unit Cell

It is the effective no. of atoms per unit cell.

2. **BCC Lattice:**

- Contribution from corner atoms to one unit cell= 1/8 x 8 = 1
- Contribution from body centered atom = 1
- Total contribution = 1+1= 2 atoms



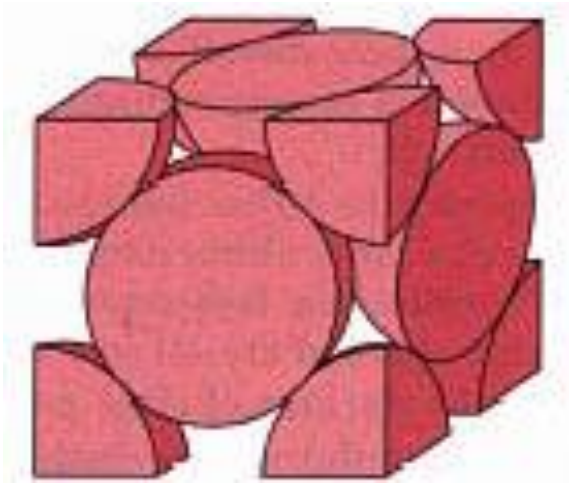
2.1 STRUCTURE OF METALS

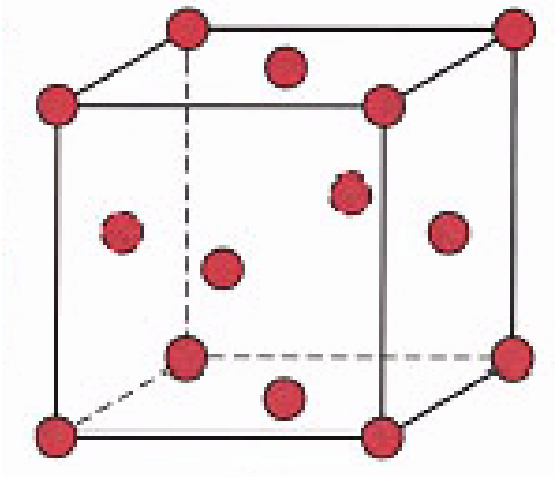
No. of Atoms per Unit Cell

It is the effective no. of atoms per unit cell.

3. FCC Lattice:

- In addition to eight corner atoms, there are six face centered atoms at six planes of the cubes. Each of these six face centered atoms is equally shared by two adjacent cubes. So,
- Contribution from corner atoms to one unit cell= 1/8 x 8 = 1
- Contribution from face centered atoms to one unit cell = 1/2 x 6 = 3
- Total = 1+3 = 4 atoms





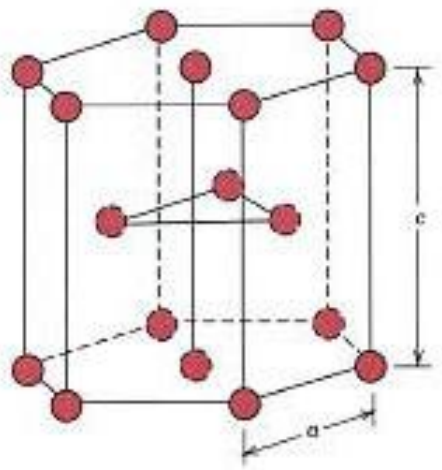
2.1 STRUCTURE OF METALS

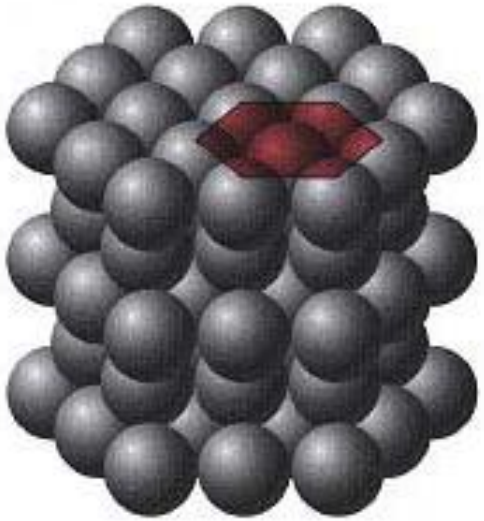
No. of Atoms per Unit Cell

It is the effective no. of atoms per unit cell.

4. HCP Lattice:

- 12 atoms at the corners => 1/6 x 12 = 2
- 02 face Centered atoms => 1/2 x 02 = 1
- 03 middle layer atoms => 1 x 03 = 3
- Total = 6 atoms





2.1 STRUCTURE OF METALS

Atomic Radius

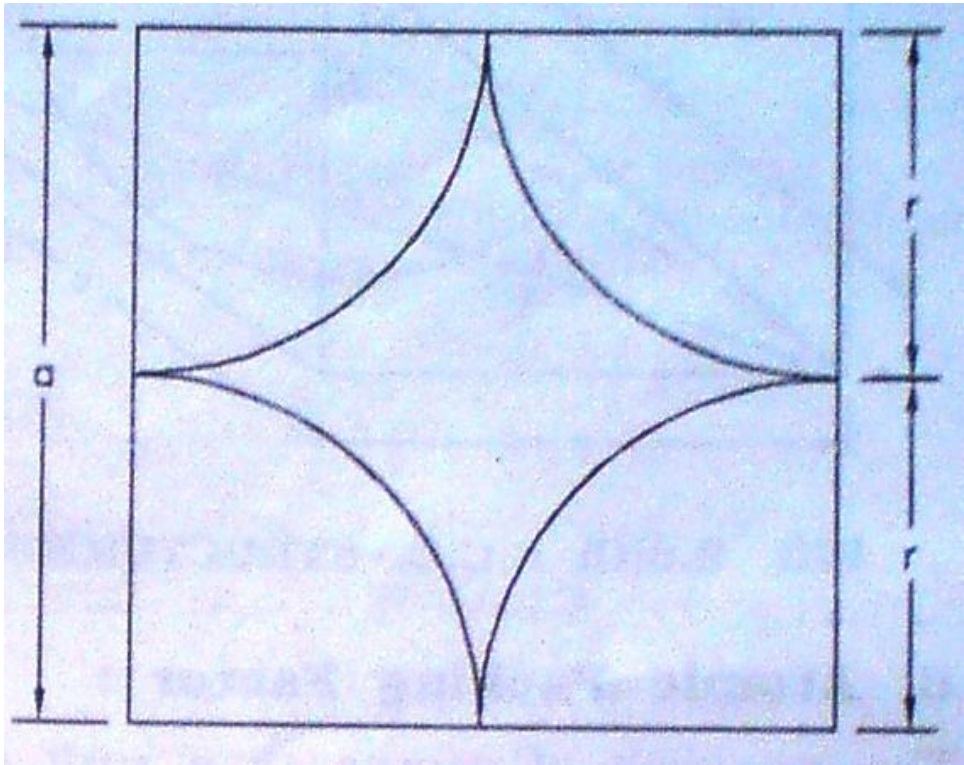
It is possible to evaluate the radii of atoms by assuming that atoms are spheres in contact with each other in a crystal. The atomic radius r is defined as half the distance between the nearest neighbors in a crystal of a pure element.

1. Simple Cubic Lattice:

- One atom is at each of the corners of a cube.
- If 'a' is the lattice parameter i.e. length of the cube edge and 'r' is the atomic radius, then

  $a = 2r$

  So, $r = a/2$



2.1 STRUCTURE OF METALS

Atomic Radius

2. Face Centered Cubic Lattice:

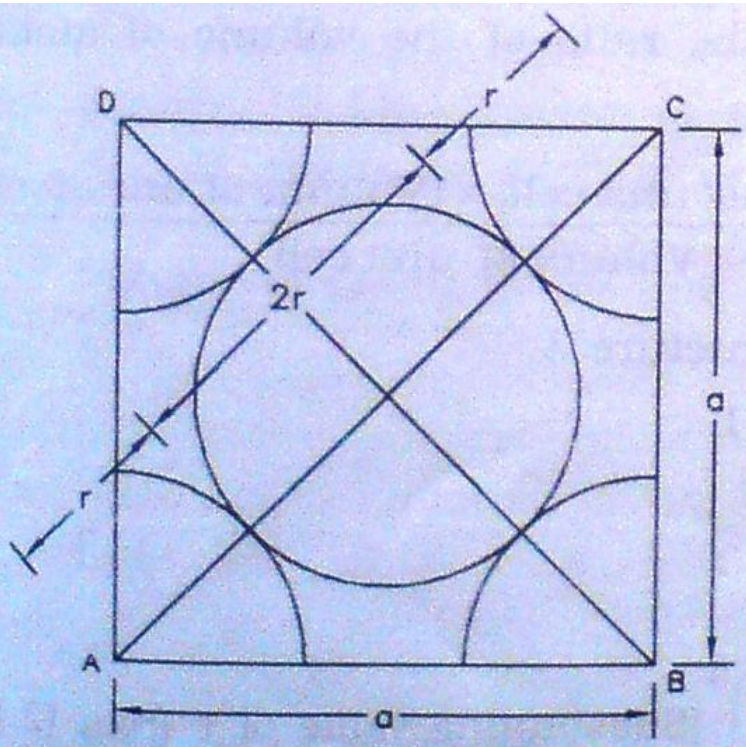


FIG. 2.8(B) FCC STRUCTURE

If 'a' is the lattice parameter and 'r' is the atomic radius, then considering Δ ABC,

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

i.e. $(r + 2r + r)^2 = a^2 + a^2$

$\therefore \quad 16\ r^2 = 2a^2$

$$\therefore \quad r = \sqrt{\frac{2a^2}{16}} = \frac{a\sqrt{2}}{4} \quad \ldots\ \ldots\ \ldots \quad (2.2)$$

2.1 STRUCTURE OF METALS

Atomic Radius

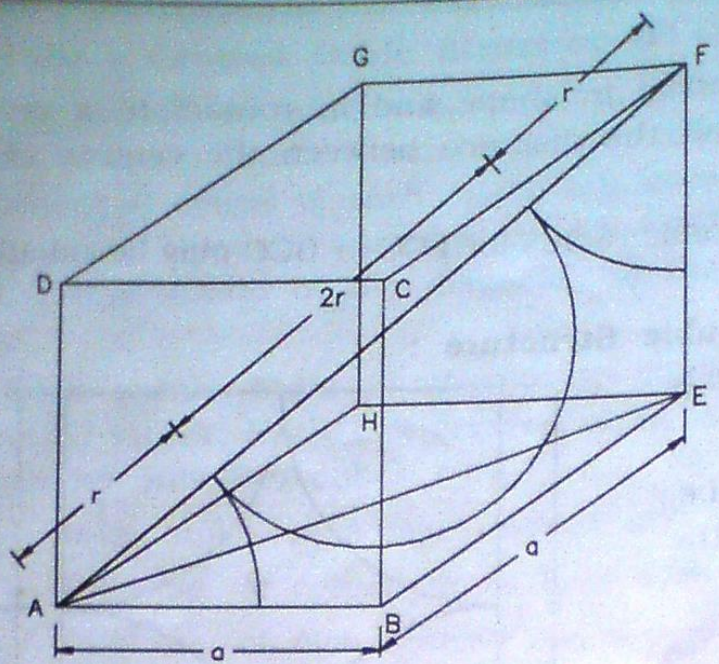
3. BCC Lattice :

Let 'a' be the lattice parameter and 'r' be the atomic radius.

From the figure.

$$(AE)^2 = (AB)^2 + (BE)^2$$

$$\therefore (AE)^2 = a^2 + a^2 = 2a^2$$



and $(AF)^2 = (AE)^2 + (EF)^2$

$$\therefore (AF)^2 = 2a^2 + a^2$$

$$\therefore (AF)^2 = 3a^2$$

$$\therefore AF = a\sqrt{3}$$

Also from the figure.

$$AF = r + 2r + r = 4r.$$

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

$$\therefore r = \frac{a\sqrt{3}}{4} \quad \ldots \ldots \ldots (2.3)$$

2.1 STRUCTURE OF METALS

Atomic Packing Factor

- In crystallography, atomic packing factor (APF) or packing fraction is the fraction of volume in a crystal structure that is occupied by atoms.
- It is dimensionless and always less than unity.
- For practical purposes, the APF of a crystal structure is determined by assuming that atoms are rigid spheres.
- The radius of the atoms (spheres) is taken to be the maximal value such that the atoms do not overlap
- For one-component crystals (those that contain only one type of atom), the APF is represented mathematically by $$\mathrm{APF} = \frac{N_{\mathrm{atoms}} V_{\mathrm{atom}}}{V_{\mathrm{unitcell}}}$$; where

N_{atoms} is the number of atoms in the unit cell

V_{atom} is the volume of an atom

$V_{unit\ cell}$ is the volume occupied by the unit cell.

2.1 STRUCTURE OF METALS

Atomic Packing Factor : Simple Cubic Structure

No. of atoms in simple cubic structure = 1.

$\therefore$ Volume of atoms in the unit cell $= 1 \times \frac{4}{3}\pi r^3$

$= 1 \times \frac{4}{3}\pi\left(\frac{a}{2}\right)^3$ [Substitu

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

Volume of unit cell $= a \times a \times a$ (cubic)

$= a^3$

$\therefore$ APF $= \dfrac{\text{Volume of atoms per unit cell}}{\text{Volume of the unit cell}}$

$= \dfrac{\pi a^3/6}{a^3} = \dfrac{\pi}{6}$

$= 0.52$

2.1 STRUCTURE OF METALS

Atomic Packing Factor : FCC Structure

... ... (2.4)

(b) Atomic Packing Factor of a FCC Structure :

No. of atoms in FCC structure = 4

$\therefore$ Volume of atoms in the unit cell $= 4 \times \frac{4}{3}\pi r^3$

$$= 4 \times \frac{4}{3}\pi \left(\frac{a\sqrt{2}}{4} \right)^3$$ [Substituting value of r from 2.2]

$$= \frac{\pi a^3 \sqrt{2}}{6}$$

Volume of unit cell = $a \times a \times a$ (cubic)

$= a^3$

$$\therefore \text{APF} = \frac{\text{Volume of atoms per unit cell}}{\text{Volume of the unit cell}}$$

$$= \frac{\pi a^3 \sqrt{2}\,/\,6}{a^3} = \frac{\pi\sqrt{2}}{6}$$

$= 0.74$ ... ... (2.5)

2.1 STRUCTURE OF METALS

Atomic Packing Factor : BCC Structure

No. of atoms in BCC structure = 2.

$\therefore$ Volume of atoms in the unit cell $= 2 \times \frac{4}{3}\pi r^3$

$$= 2 \times \frac{4}{3}\pi\left(\frac{a\sqrt{3}}{4}\right)^3$$ [Substituting value of r from 2.3]

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

Volume of unit cell $= a \times a \times a$ (cubic)

$= a^3$

$\therefore$ APF $= \dfrac{\text{Volume of atoms per unit cell}}{\text{Volume of the unit cell}}$

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

$= 0.68$ ... ... (2.6)

2.1 STRUCTURE OF METALS

Atomic Packing Factor :

HCP Structure

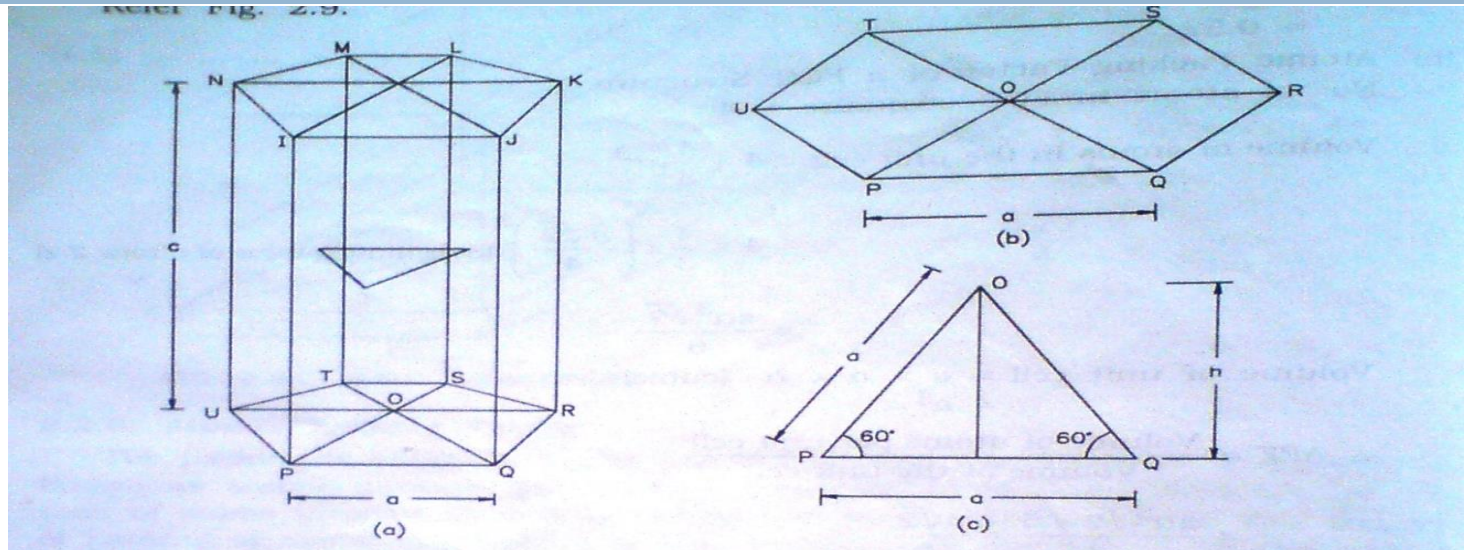


FIG. 2.9 (a) HCP UNIT CELL (b) BASAL PLANE (c) DIAGRAM FOR CALCULATING AREA OF BASAL PLANE TRIANGLE

The volume of the unit cell can be found by calculating area of the basal plane and then multiplying this area by its height.

The area of the basal plane is area PQRSTU. This area is six times the area of equilateral triangle PQO.

From Fig. 2.9 (c)

Area of triangle PQO = 1/2 × (base) × (height).

$= 1/2 \times a \times a \sin 60^\circ$

$= 1/2\ a^2 \sin 60^\circ$

$\therefore$ Total area of the basal plane $= 6 \times 1/2 \times a^2 \sin 60^\circ$

$= 3\ a^2 \sin 60^\circ$

Volume of unit cell = Area of basal plane × height

$= 3\ a^2 \sin 60^\circ \times c.$

For HCP Structures, $a = 2r$

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

... ... (2.7)

2.1 STRUCTURE OF METALS

Co-ordination Number

- This is defined as….

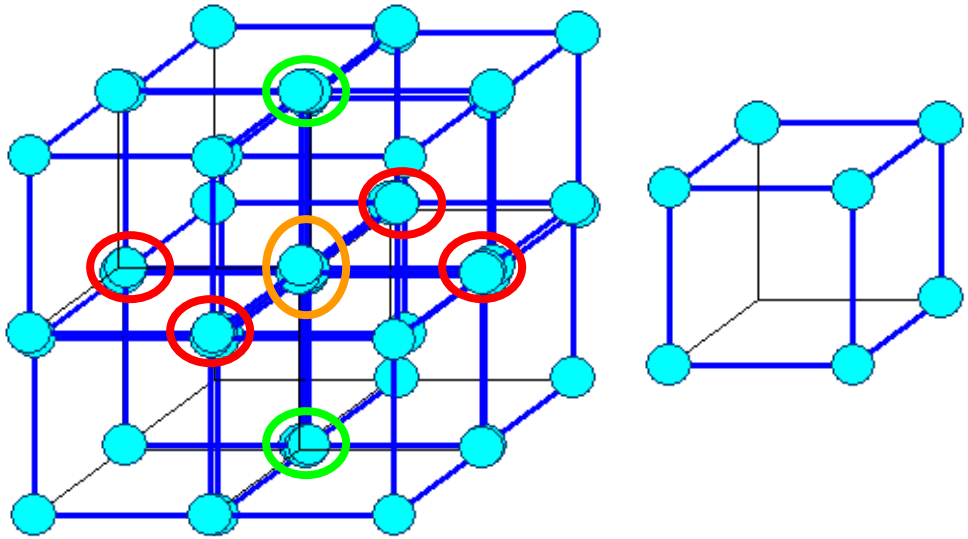
1. *The number of nearest atoms directly surrounding a given atom.*
2. *It can also be defined as the nearest neighbours to an atom in a crystal.*

- Remark : When co-ordination number is larger, the structure is more closely packed.

2.1 STRUCTURE OF METALS

Co-ordination Number : Simple Cubic Structure

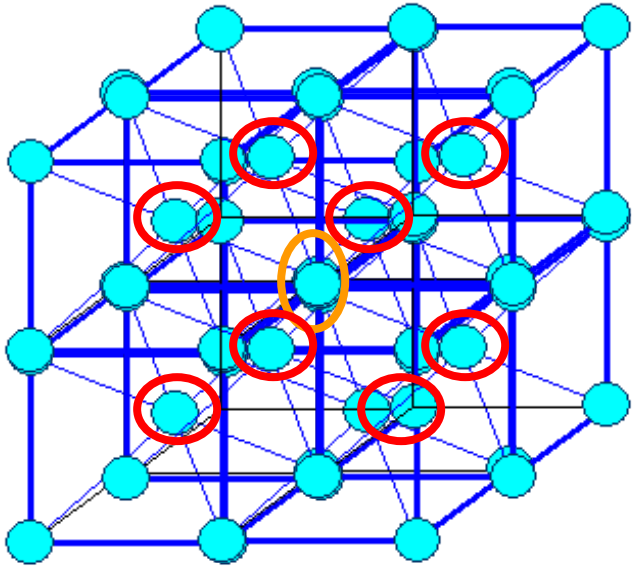
- Consider any atom at a corner of a unit cell.
- Any corner atom atom has four nearest neighbour atoms in the same plane and two nearest neighbours in vertical plane (one exactly above and the other exactly below). So, Co-ordination no. for simple cubic structure is 4+2 = 6
- The distance between the atom and any of the nearest atom will be equal to lattice parameter i.e. a.

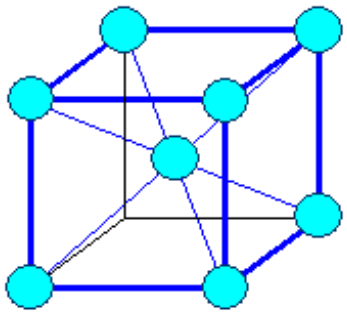


2.1 STRUCTURE OF METALS

Co-ordination Number : BCC structure

- Consider any atom at a corner of a unit cell.
- Any corner atom atom has one body centered atom close to it as shown below. So, Co-ordination no. for BCC structure is 8
- The distance between the atom and any of the nearest atom is $\sqrt{3}a/2$; where a is the lattice parameter.

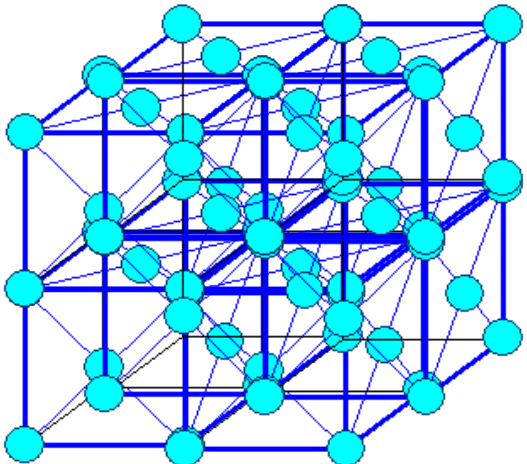


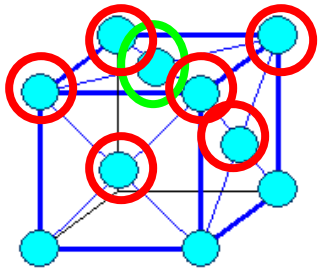


2.1 STRUCTURE OF METALS

Co-ordination Number : FCC structure

- Consider any atom at a corner of a unit cell.
- For any corner atom, there will be 4 face centered atoms of the surrounding unit cells in its own plane, 4 face centered atoms below this plane and 4 face centered atoms above this plane. So, Co-ordination no. for FCC structure is 4+4+4 = 12
- The distance between the atom and any of the nearest atom is $a/\sqrt{2}$; where a is the lattice parameter.

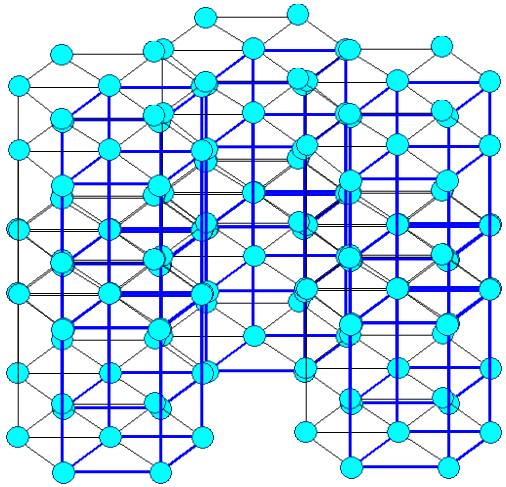


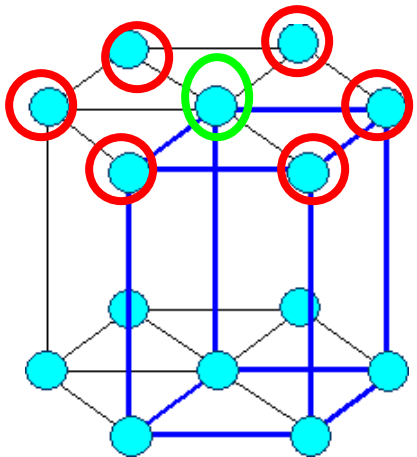


2.1 STRUCTURE OF METALS

Co-ordination Number : HCP structure

- In HCP, each atom in one layer is located directly above or below interstices among three atoms in the adjacent layers. So, each atom touches three atoms in the layer below its plane, six atoms in its own plane, and three atoms in the layer above. So, Co-ordination no. for HCP structure is 3+6+3 = 12





2.1 STRUCTURE OF METALS

APF and CN for Crystal Structure

Sr. No.	Crystal Structure	Atomic Packing Factor (APF)	Co-Ordination No. (CN)
1	Simple Cubic	0.52	6
2	BCC	0.68	8
3	FCC	0.74	12
4	HCP	0.74	12

2.1 STRUCTURE OF METALS

Inter Planar Distance or Spacing

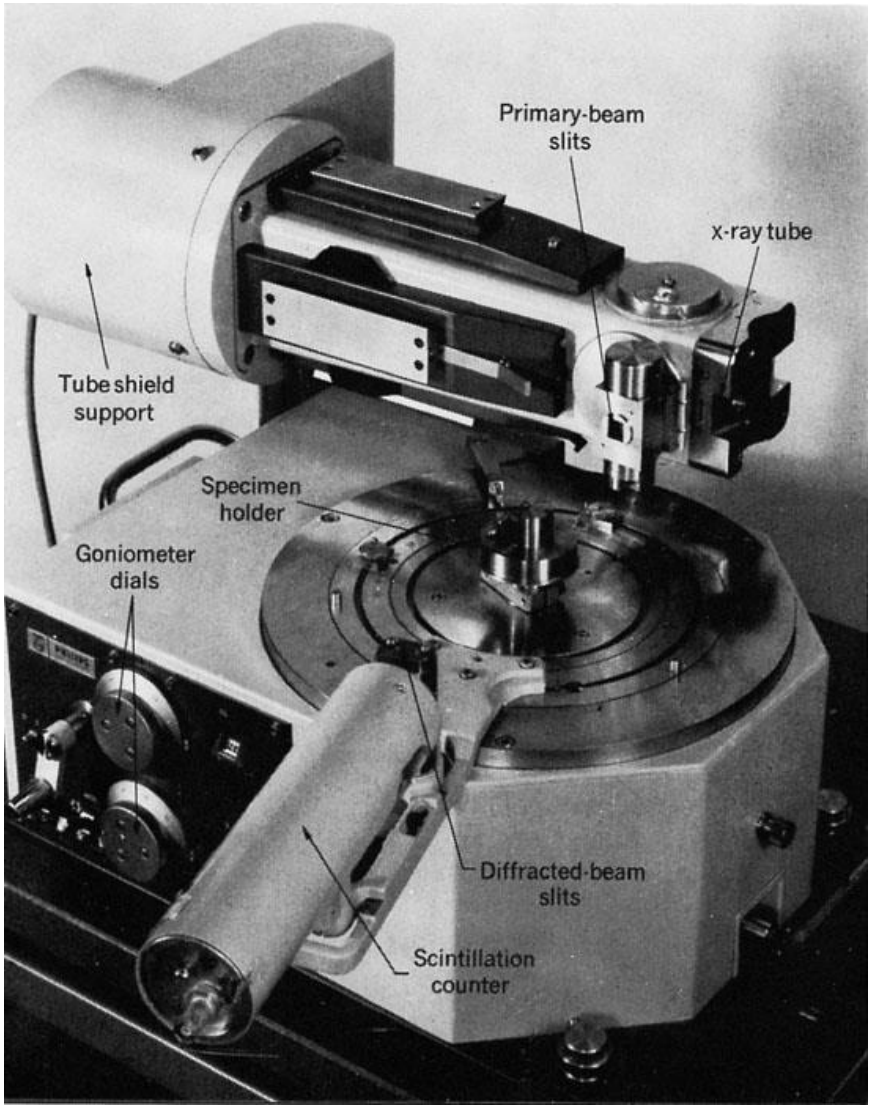
- This is defined as …. The distance between the two atomic planes in a crystal structure measured at right angles to them.
- It is function of…

i. Plane Indices or Miller Indices

ii. Crystal System involved i.e. lattice parameters a, b, c and α, β, γ

2.1 STRUCTURE OF METALS

X-ray Machine for measurement Of Interplanar Distance



2.1 STRUCTURE OF METALS

Inter Planar Distance by Bragg's law

- Bragg's law is based on X-ray diffraction. X-rays are electromagnetic radiations (waves) of very short wavelength varying from 0.2 A^0 to 10A^0.
- These are emitted when fast moving electrons i.e. Cathode rays strike a target of high atomic weight only 2% energy of cathode rays appear as X-rays, the remaining energy appears as heat.
- Wavelength of X-rays is of the same order of magnitude 10^{-10}m (or 1A^0) as that of the inter-atomic spacing in the crystals.
- In engineering, the use of X-rays have provided valuable information on many aspects of structural studies including crystal imperfections, preferable orientation in polycrystalline sheets and the network of atoms in solids.

2.1 STRUCTURE OF METALS

Inter Planar Distance by Bragg's law

- Bragg's law is derived assuming that particular atomic planes within crystalline material act as reflecting planes.
- When X-rays of a certain wavelength fall on atoms, crystal structure behaves as a series of parallel reflecting planes. Hence, the X-rays are reflected according to ordinary laws of reflection.
- The reflected X-rays may due to their relative path differences, either interfere destructively or constructively.
- The beam of reflected X-rays will re-inforce each other if the path difference between the two beams of X-rays from two different parallel planes is equal to some integral multiple of wavelength of X-rays OR
- When reflected X-rays are in phase with each other, constructive interference takes place and when they are out of phase, destructive interference occurs.

2.1 STRUCTURE OF METALS

Inter Planar Distance by Bragg's law

Constructive interference takes place when reflected rays are in phase

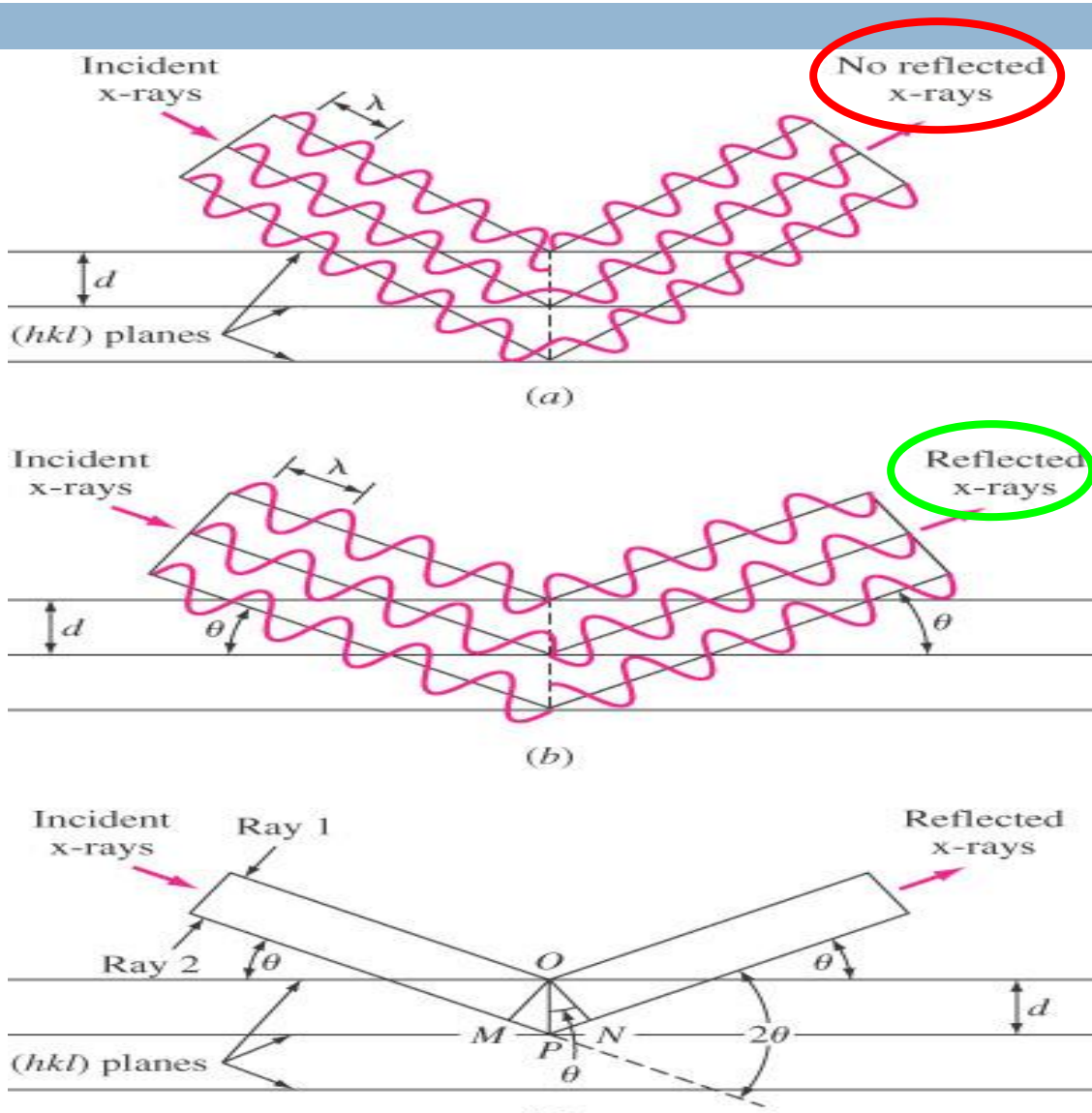
$$n\ \lambda\ =\ 2\ d_{hkl}\ \sin\ \theta$$

n = order of reflection, whole number of reflections

λ = x-ray wavelength

d_{hkl} = spacing between planes with indices (hkl)

θ = angle between incident x-ray beam and crystal planes (hkl)



2.2 TYPES OF FRACTURE IN METALS

- **Why do metals fail in service?**

1. **Excessive Elastic Deformation**
2. **Excessive Plastic Deformation**
3. **Fracture of metals**

2.2 TYPES OF FRACTURE IN METALS

- **Fracture : It can be defined as the separation of a body under stress into two or more parts.**
- **Fracture is considered as end result of plastic deformation processes which results in creation of two or more new surfaces.**
- **Fracture is caused by physical and chemical forces.**
- **It occurs in two stages …**

1. **Crack initiation**
2. **Crack propagation**

- **There are two types of fracture – Brittle Fracture & Ductile Fracture**

2.2 TYPES OF FRACTURE IN METALS

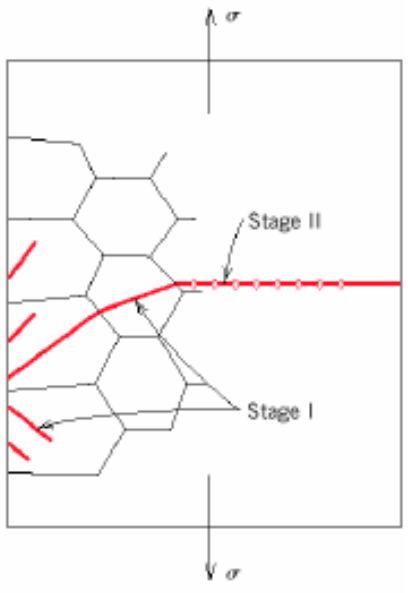
Fatigue: Crack initiation and propagation (II)

- Crack initiation at the sites of stress concentration (microcracks, scratches, indents, interior corners, dislocation slip steps, etc.). Quality of surface is important.

- Crack propagation

  - Stage I: initial slow propagation along crystal planes with high resolved shear stress. Involves just a few grains, and has flat fracture surface

  - Stage II: faster propagation perpendicular to the applied stress. Crack grows by repetitive blunting and sharpening process at crack tip. Rough fracture surface.



- Crack eventually reaches critical dimension and propagates very rapidly

2.2 TYPES OF FRACTURE IN METALS

- **Factors deciding the type of fracture are as follows …**

1. Rate of Impact
2. Temperature
3. Geometry of material

- **Rate of Impact**

- Many materials which fail by non-ductile fracture under a sudden impact fail in a ductile manner when an equal force is applied slowly.
- A sharp impact does not deform such materials plastically and therefore less energy is consumed and the fracture is brittle.
- The materials showing such rate sensitive behaviour are glass and asphalt

2.2 TYPES OF FRACTURE IN METALS

- **Temperature**
- The materials usually have higher toughness at elevated temperatures and more brittleness at reduced temperatures.
- By lowering the temperature, or by increasing the rate of strain, it is possible to increase the strength so that apparently ductile material will fail in a brittle manner.
- **Geometry of material**
- Irregular shapes lead to concentrated stresses and localized cracks. A crack once initiated, served to further concentrate stresses at its root.
- Under similar loading conditions, suppose a small test piece fails in a ductile manner then a large test piece may fail in a brittle manner.

2.2 TYPES OF FRACTURE IN METALS

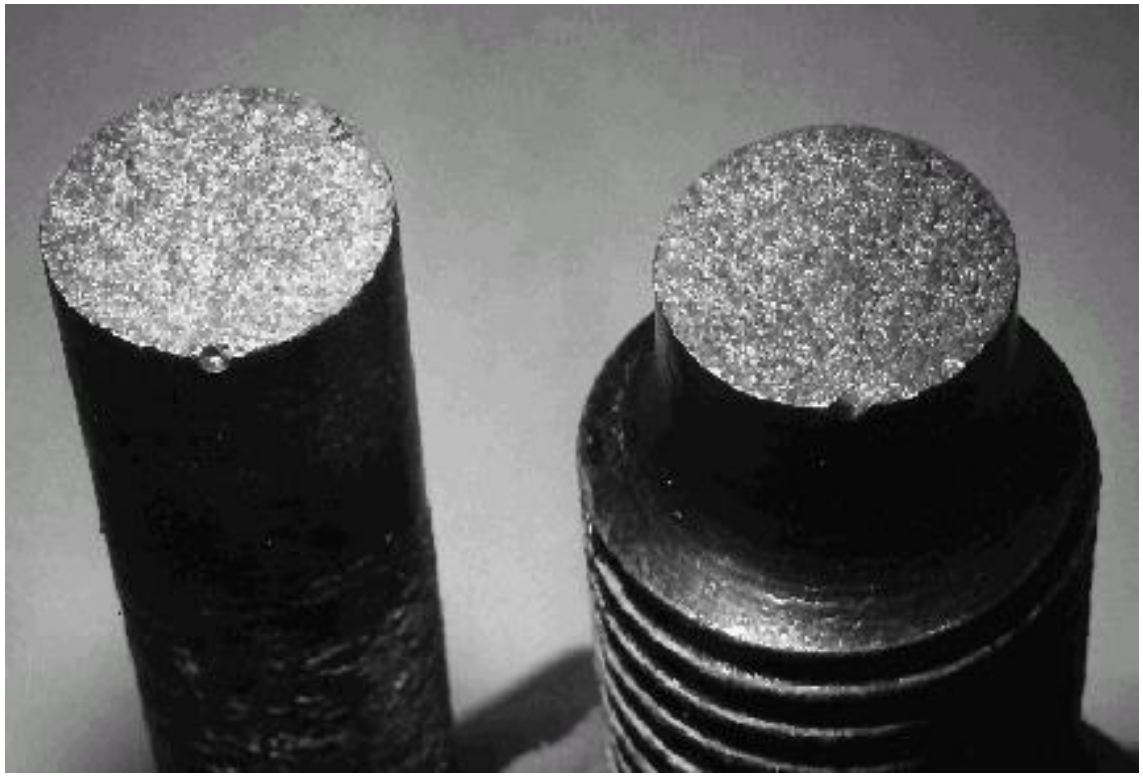
- **Geometry of material (… contd. From previous slide)**
- The ultimate strength will reduce with increase in dimensions of the body because then the probability of presence of weak spots in a material is increased. For e.g. fibres of glass may be as much as 100 times stronger than a piece of glass because number of flaws (defects) in the material are considerably reduced.
- For **brittle materials in compression**, fracture occurs along the direction of the maximum shear stress and is called **shear fracture**.
- For **brittle materials in tension**, fracture occurs across a surface perpendicular to the direction of tension and is called **cleavage fracture**.

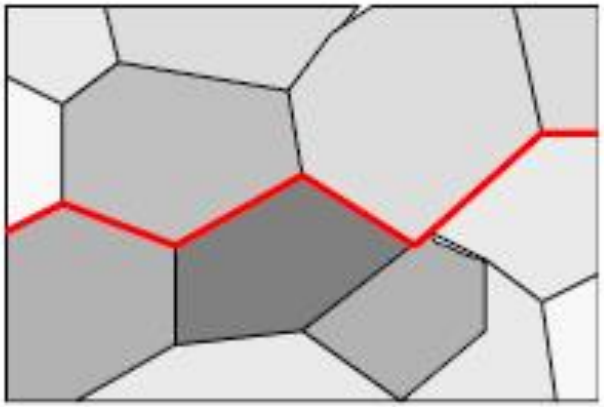
2.2 TYPES OF FRACTURE IN METALS

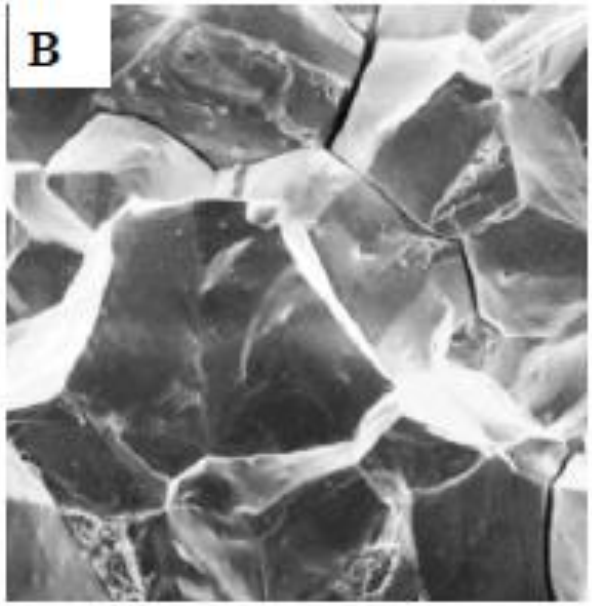
- **Brittle Fracture**
- Brittle fracture is said to occur when there is very little or no plastic deformation in a metal just before failure / fracture.
- A brittle fracture is characterized by…
- rapid rate of crack propagation
- minimum absorption of energy / load applied on the material
- very little or no deformation
- direction of separation / failure is normal to the direction of tensile stress
- crack propagation is along grain boundaries (intergranular)
- it is generally observed in BCC and HCP metals but not FCC
- a completely brittle fracture shows sharp facets which reflect light
- Purely brittle fracture is practically never encountered i.e. there is always a certain plastic deformation in the material before it fails

2.2 TYPES OF FRACTURE IN METALS

- **Brittle Fracture**





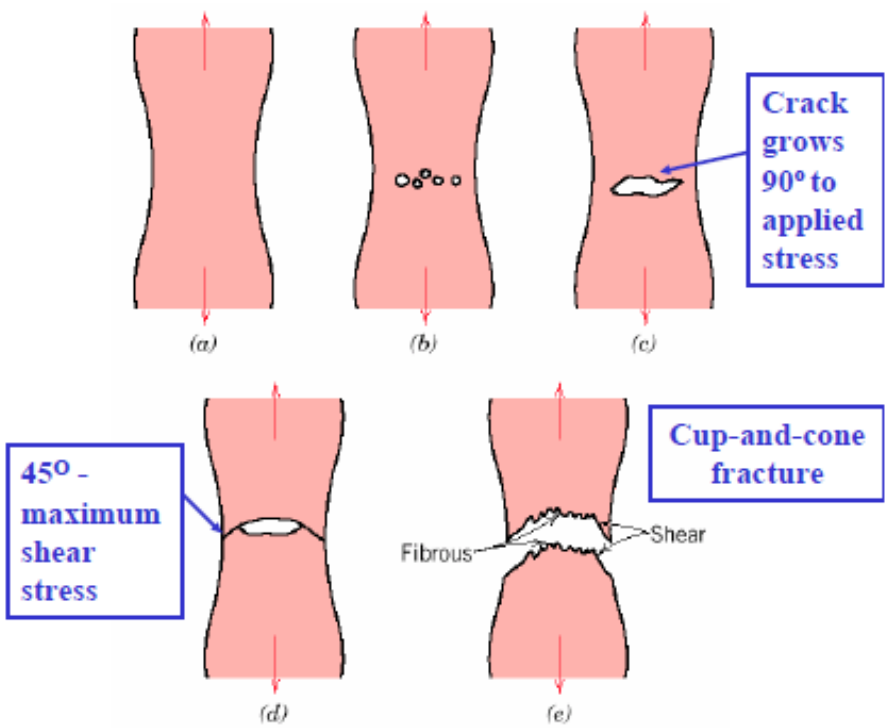


2.2 TYPES OF FRACTURE IN METALS

- **Ductile Fracture**
- Ductile fracture is said to occur when there is appreciable plastic deformation in a metal just before failure / fracture.
- A ductile fracture is characterized by…
- Localized deformation called necking and finally leading to formation of cup-and-cone
- The crack propagation occurs through the grains (transgranular)
- A complete ductile fracture presents a rough and dirty surface
- It occurs normally in FCC metals

2.2 TYPES OF FRACTURE IN METALS

Ductile Fracture (Dislocation Mediated)



(a) Necking

(b) Formation of microvoids

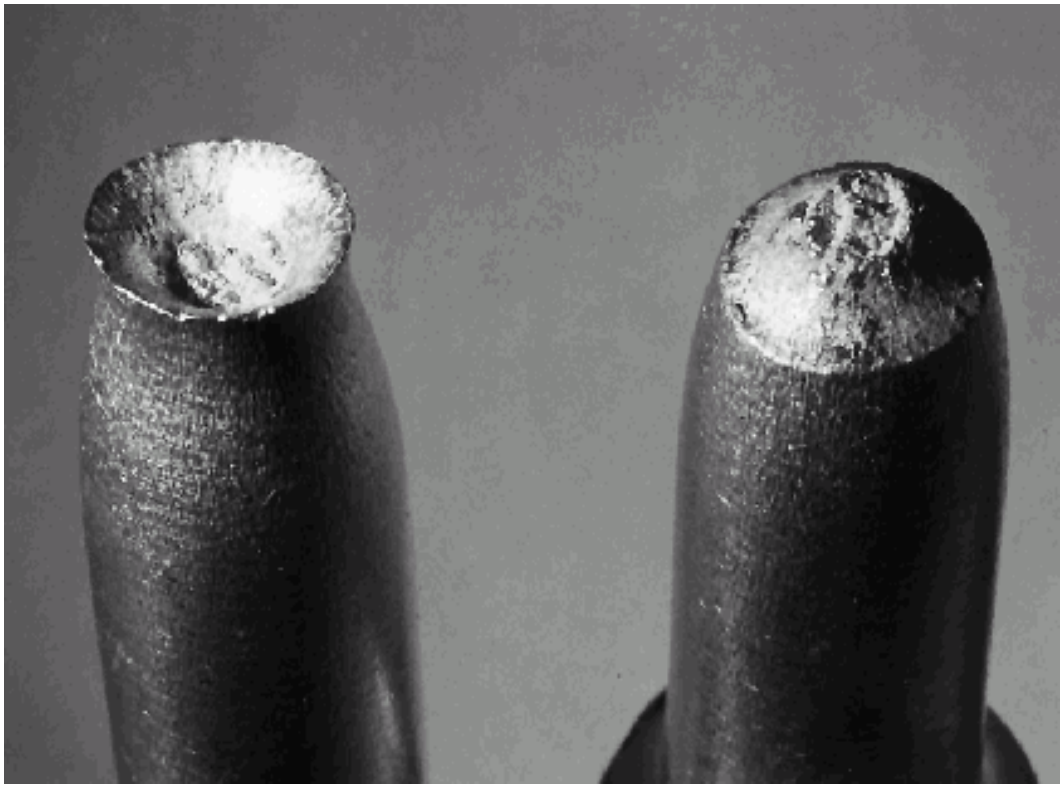
(c) Coalescence of microvoids to form a crack

(d) Crack propagation by shear deformation

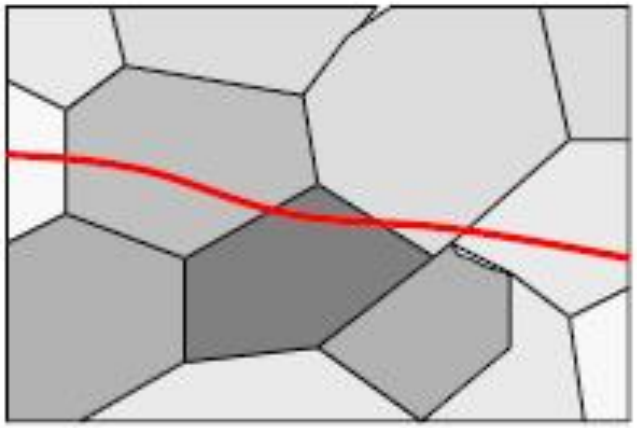
(e) Fracture

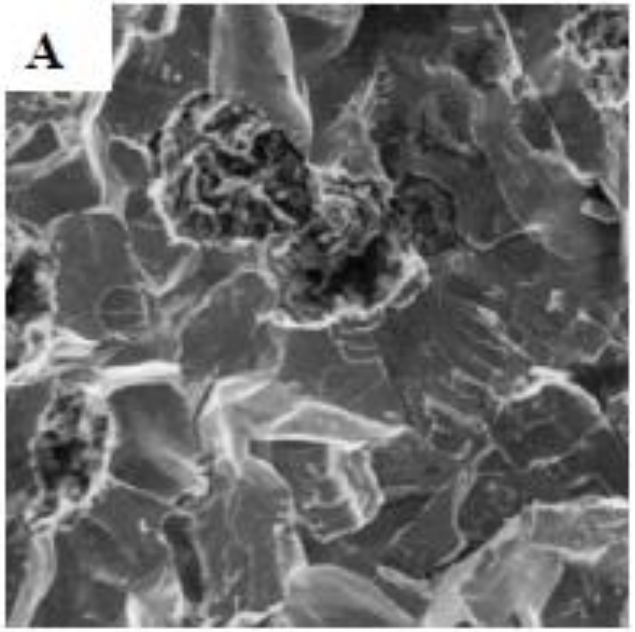
2.2 TYPES OF FRACTURE IN METALS

- **Ductile Fracture**



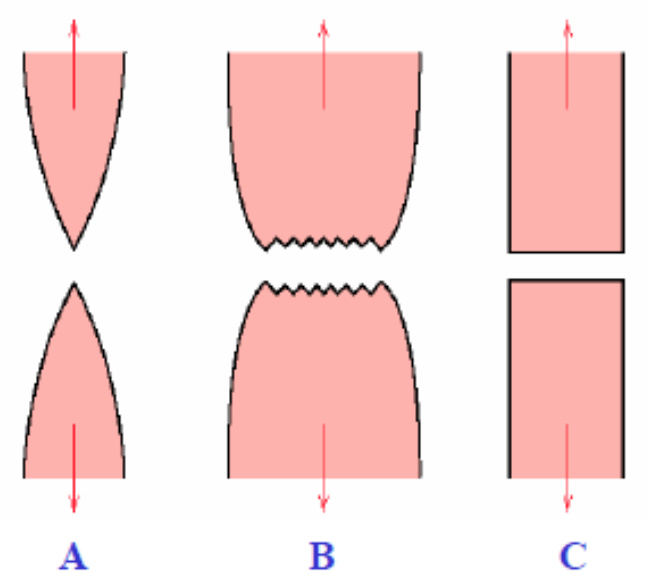
Cup-and-cone fracture in Al

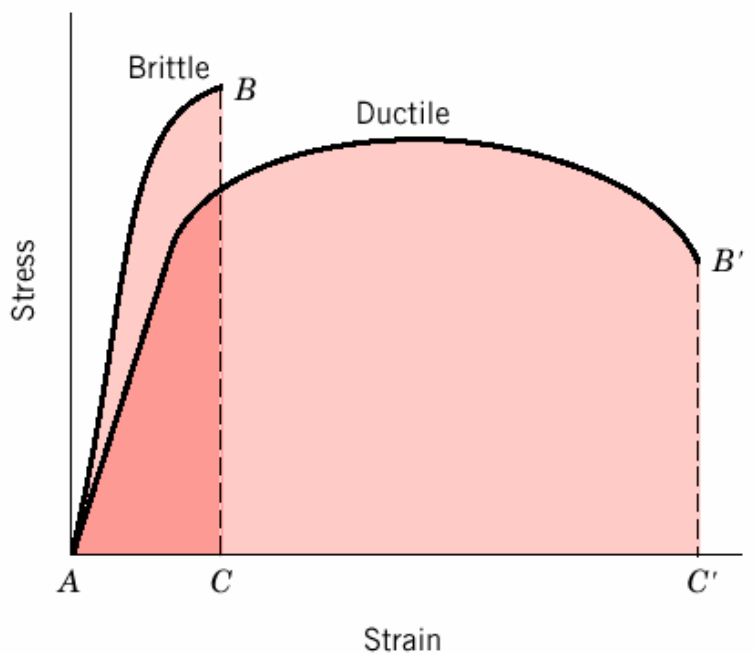




2.2 TYPES OF FRACTURE IN METALS

Brittle vs. Ductile Fracture





A. **Very ductile**, soft metals (e.g. Pb, Au) at room temperature, other metals, polymers, glasses at high temperature.

B. **Moderately ductile fracture**, typical for ductile metals

C. **Brittle fracture**, cold metals, ceramics.

2.3 MACRO-EXAMINATION

- Study of the structure of metals and their alloys with naked eye or using a low power magnification (upto 15x) is known as "macro-examination" and the structure so observed is called "macro-structure".
- Macro-examination is carried out for following purposes …
- To reveal size, form and arrangement of crystallites (dendrites) in cast metals
- To reveal fibres in deformed metals
- To find non-metallic inclusions (sulphides, oxides, slag)
- To find the cause of failure of part
- To check cavities due to gas and porosity during solidification shrinkage
- To find fabrication process generated cracks
- To check manufacturing method (forging, welding, casting, etc.)
- To find chemical non-homogenity during solidification

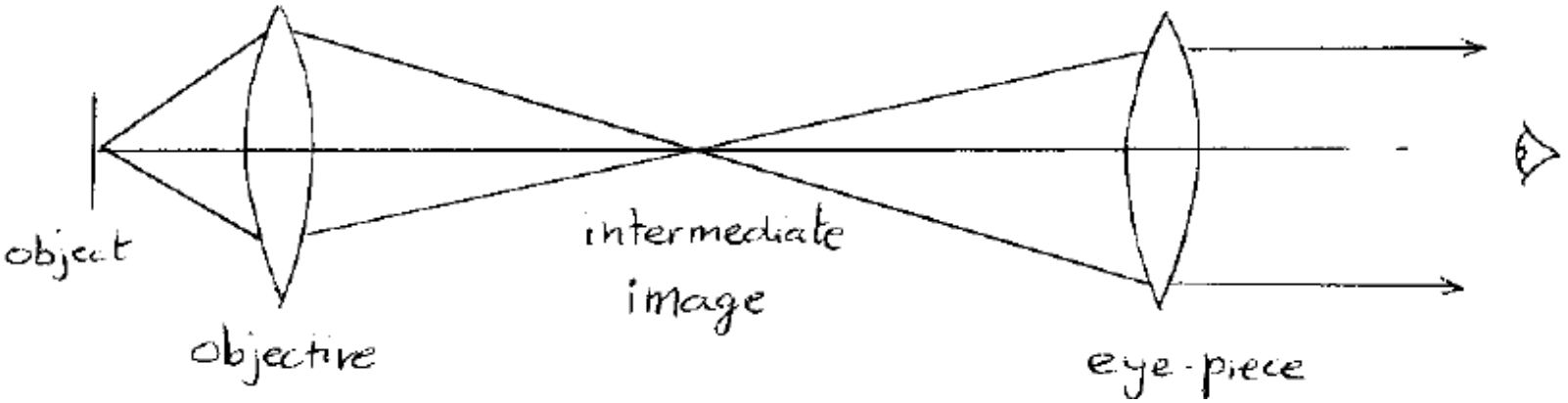
2.4 MICRO-EXAMINATION

- Study of the grain structure of metals and their alloys at high magnification (50x to 1,00,000x) is known as "micro-examination" and the structure so observed is called "micro-structure".
- A photograph of the structure so obtained is termed as photomicrograph or photo of microstructure of metal.
- Micro-examination is carried out for following purpose …
- If the metal is to be identified then one can compare its microstructure with standard photo micrograph.
- If the metal is already known, then from the study of its microstructure, its defects and properties can be judged to some extent.

2.4 MICRO-EXAMINATION

- **Working Principle of a Metallurgical Microscope**

A microscope is in principle nothing else than a simple lens system for magnifying small objects. The first lens, called the objective, has a short focal length (a few mm), and creates an image of the object in the intermediate image plane. This image in turn can be looked at with another lens, the eye-piece, which can provide further magnification.



Note : Shorter the focal length of lens, higher the magnification power

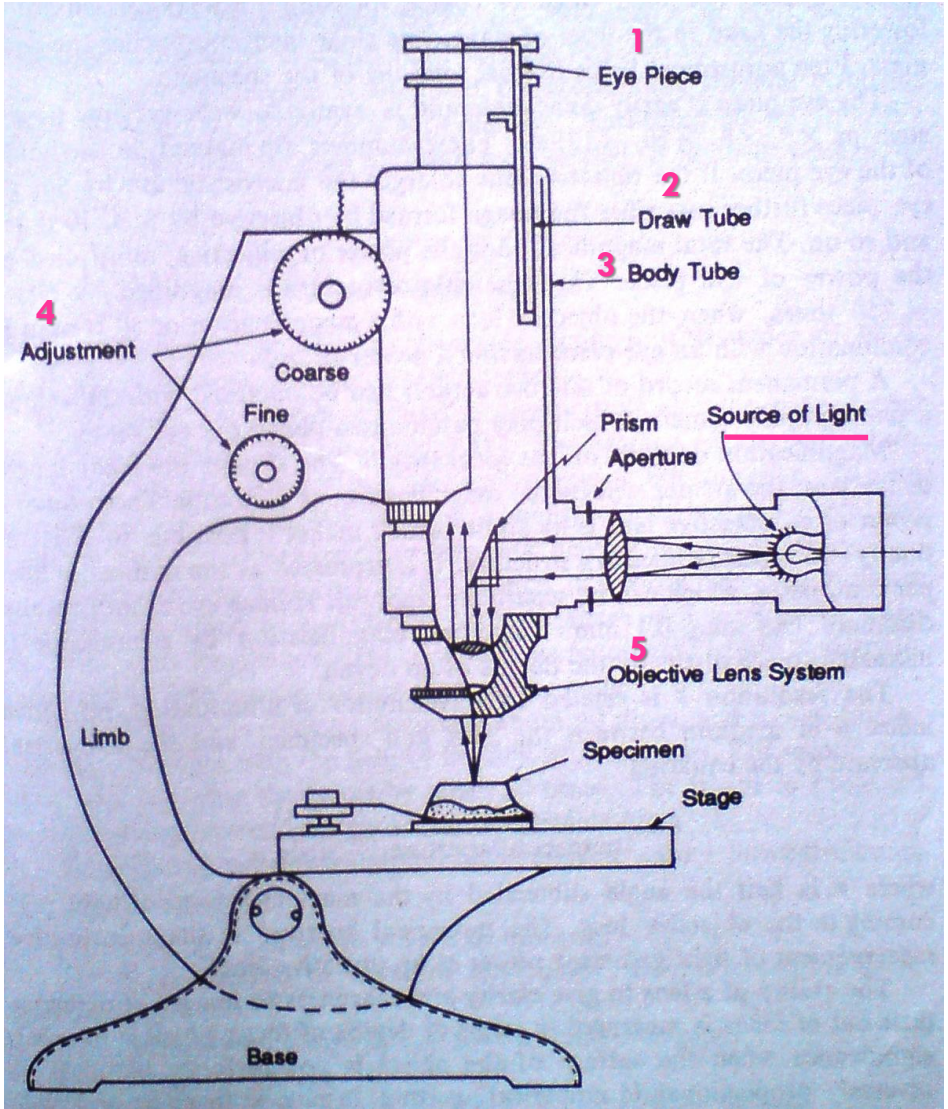
2.4 MICRO-EXAMINATION

- **Magnification of a Metallurgical Microscope**

	Eyepiece	Objective Lens	Magnification
Low Power	10 x	4 x	40 x
Start out	ALWAYS start out with this lens, focus and center before moving on!		
Medium Power	10 x	10 x	100 x
Yellow = Caution	Focus (Fine focus knob only!) and center before moving on!		
High Power	10 x	40 x	400 x
Use Caution	Focus (Fine focus knob only!) and center before moving on! **STOP! Make your diagrams now!**		

2.4 MICRO-EXAMINATION

- A typical Metallurgical Microscope



2.4 MICRO-EXAMINATION

Parts of a Metallurgical Microscope

A microscope typically contains two systems :

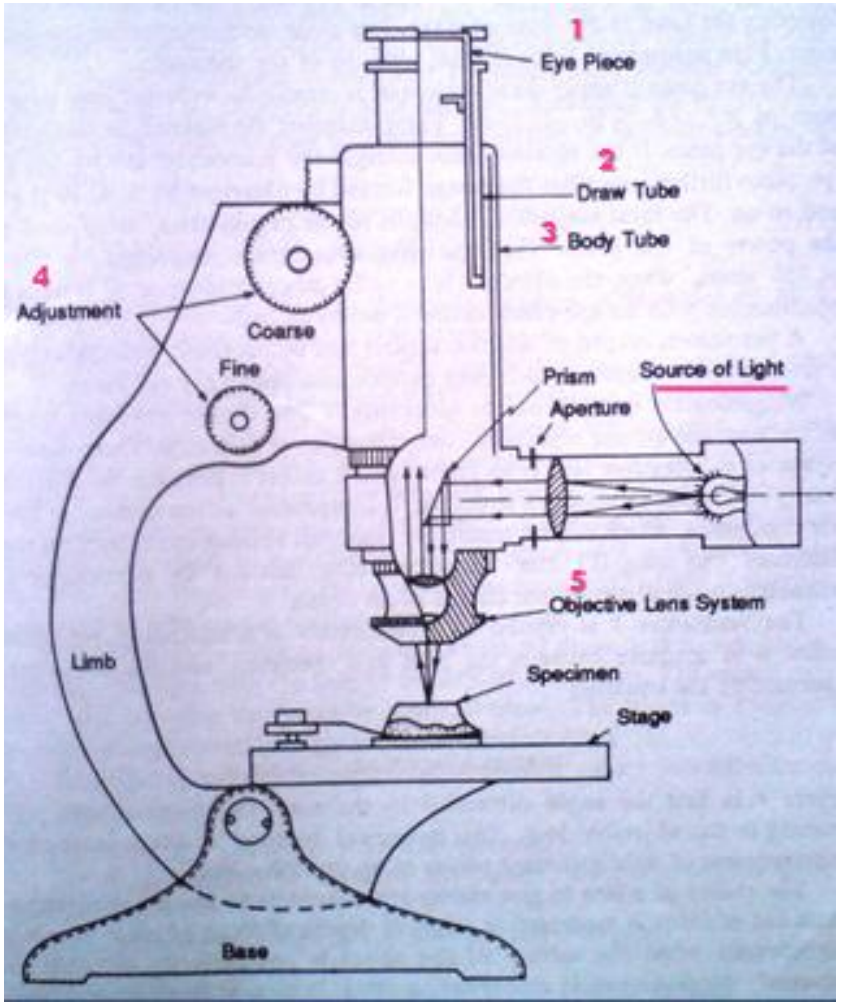
(1) compound microscope system ; and

(2) electrical illuminating system

- Following are the important parts of microscope

1. **Eyepiece :** Eyepiece is a detachable component of microscope. It is carrying a lens for magnification. It is available in varying magnification powers such as 5x, 8x, 10x, 12x,etc.

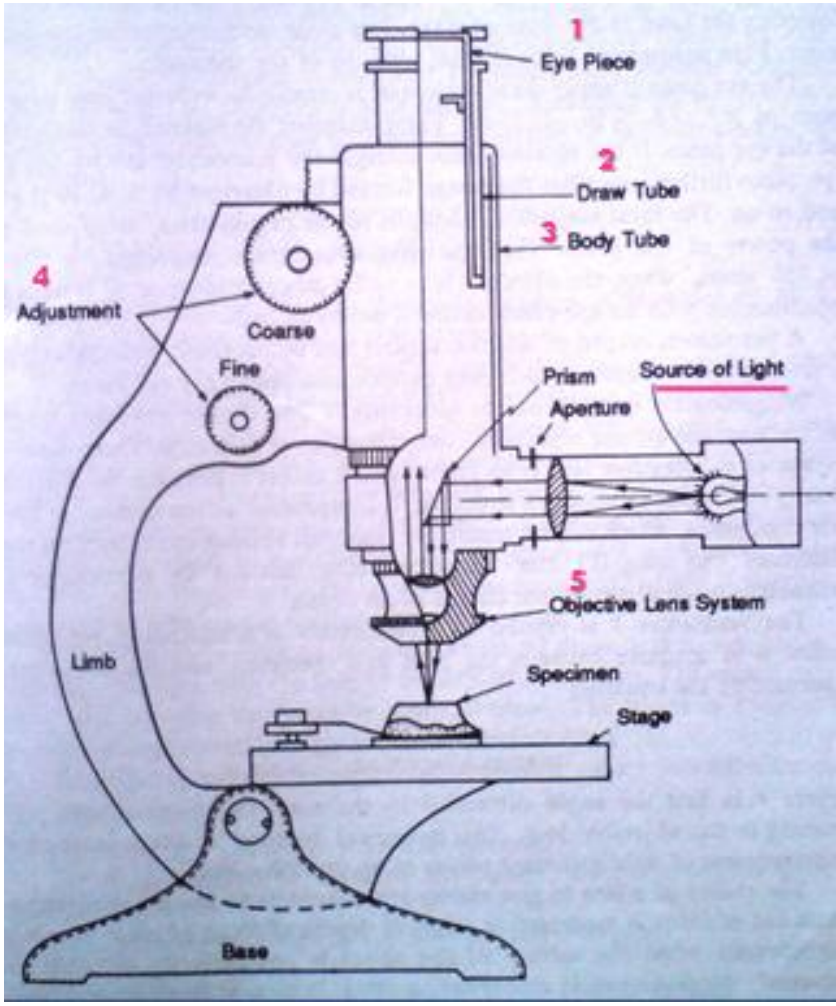
2. **Draw tube :** A draw tube carrying the eyepiece at its top, slides in the upper end of the body tube of the microscope. By sliding the draw tube, the distance between the eyepiece and the objective lens changes. This helps in proper focusing of the specimen.



2.4 MICRO-EXAMINATION

Parts of a Metallurgical Microscope

3. **Body tube :** The body tube is connected to the upper end of the limb with the help of rack and pinion mechanism.
4. **Adjustment Screws :** The body tube is lowered or raised with the help of these screws to get the correct focus (clear image) of the specimen.
5. **Objective lens system :** A beam of light from illuminating source enters into the tube of microscope from the side. The light falls on surface of a prism and is reflected downwards. Reflected light passes from objective lens system and falls on surface of metallic specimen. This surface then reflects the light back to objective lens from where it reaches eyepiece. Magnified virtual image is formed during this process.



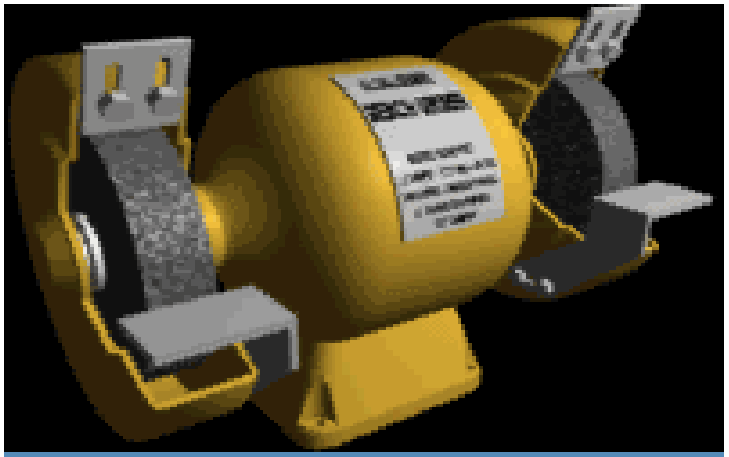
2.4 MICRO-EXAMINATION

- **Steps of Micro-examination**

1. **Cutting & Grinding :**

- In order to present true structures of metals, it is important that the samples be carefully prepared.
- For such examinations, small samples are selected, representing as nearly as possible the entire piece.
- They are cut using a mchine and ground on an emery wheel to have a near flat surface

Hacksaw Machine for cutting specimen



Grinding Machine

2.4 MICRO-EXAMINATION

- **Steps of Micro-examination**

2. **Preliminary polishing :**

- The side which is to be examined is then ground with several emery papers of different coarseness, beginning with coarse and ending with a very fine paper.
- The emery papers generally used are of 220, 320, 400 and 600 grit, water proof type.
- The sample is held so that the scratches made by each emery paper are at right angle to the one made in the preceding operation.

2.4 MICRO-EXAMINATION

- **Steps of Micro-examination**

3. **Final polishing**

- The sample is then polished on a rotating moist cloth using very fine alumina as polishing agent.
- After this preparation, the sample should be nearly flat, free from pitting, and almost free from scratches when views under microscope.

2.4 MICRO-EXAMINATION

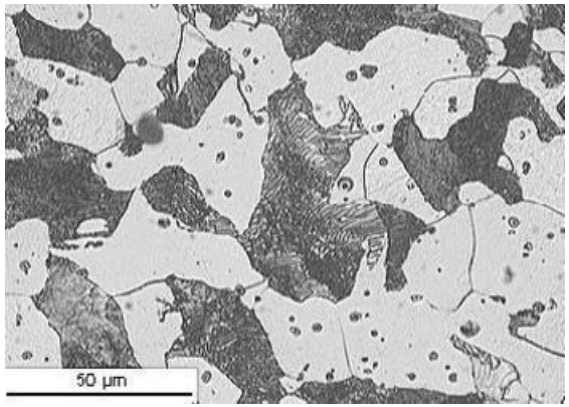
- **Steps of Micro-examination**

4. Etching

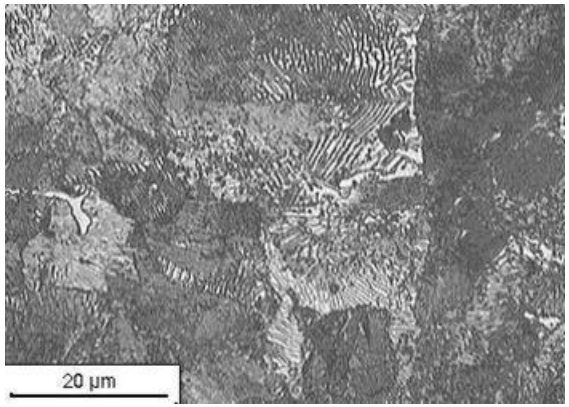
- When a polished but untreated sample is examined under the microscope, a few accidental scratches may be seen, together with some dirt or non-metallic impurities such as slag, manganese sulphide, etc.
- If an alloy is examined under such condition, where some part in the metal is softer and more eroded than rest of the area, then the eroded space will appear black.
- To reveal a clear structure, it is necessary in most cases to etch polished components.
- In etching, the sample is immersed in a dilute acid or other re-agent which will dissolve a portion of the surface (dirt) or tarnish the different constituents selectively (grain boundaries appear darker than grains).

2.4 MICROEXAMINATION

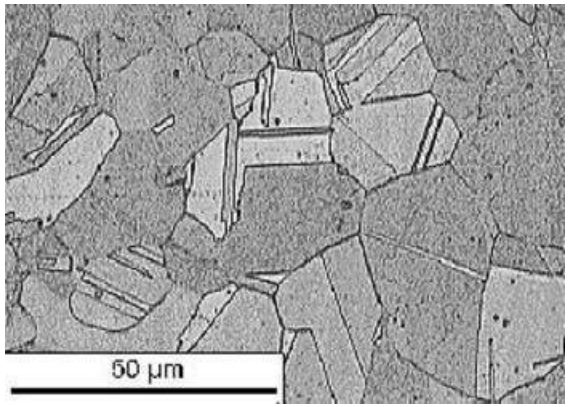
Photographs of Micro-examination



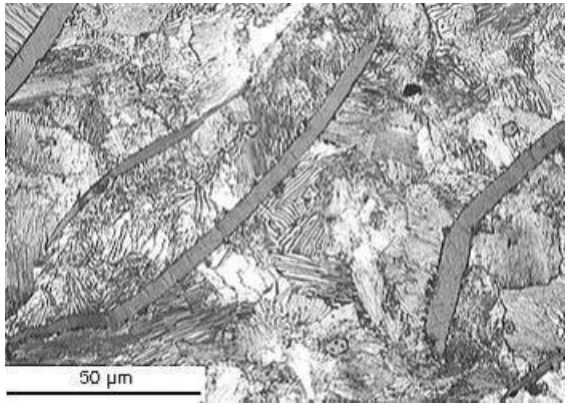
Low Carbon Steel



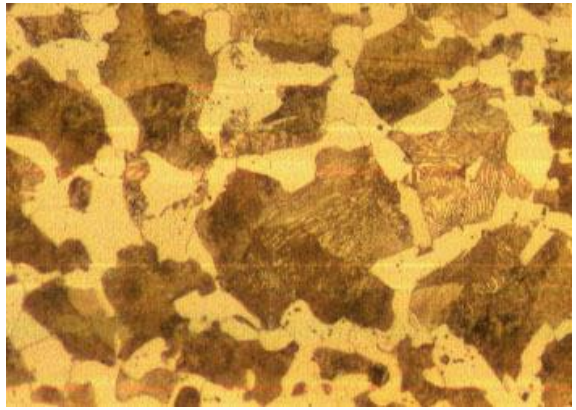
High Carbon Steel



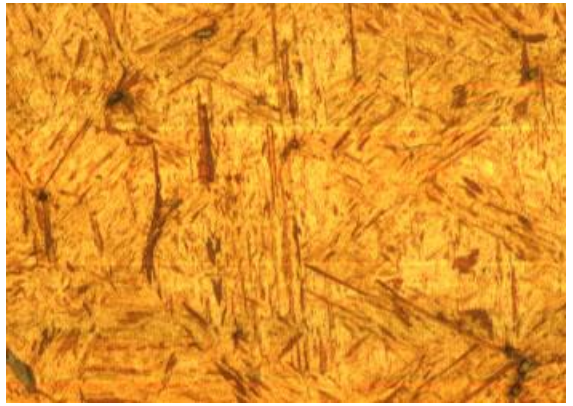
Brass



Cast Iron



Normalized Steel



Quenched Steel

THANKYOU