Basics of Solid-State Physics

Introduction to Solids: Structure and bonding in solids: Overview of crystal lattices and their role in defining material properties. Classification of solids into metals, semiconductors, and insulators based on bonding and electron behavior.

Electronic Properties of Materials: Band theory explaining conduction, valence bands, and energy gaps in different material types. Detailed examination of Fermi level, density of states, and their implications for electronic behavior.

Phonons and Thermal Properties: The role of lattice vibrations (phonons) in thermal and electronic properties. Concepts like specific heat and thermal conductivity in relation to material structure and temperature.

Books:

- Foundations of Materials Science and Engineering – Smith and Hashemi, Ch2: 2.4, 2.5
- Principles of Electronic Materials and Devices – S. O. Kasap, Ch 1, 1.1-1.3

Types of solids

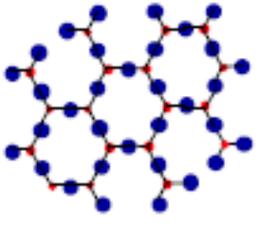
Materials are of two types: Crystalline & Non-crystalline

Non-crystalline solid: Atom are not situated in an orderly, repeating pattern. i.e. glass , rubber, plastic etc.

Crystalline solid: Atoms are spatially arranged in an orderly, repeating pattern extending in all three dimension. i.e. Copper, NaCl

Packing atoms together

Crystalline materials...
- atoms pack in periodic, 3D arrays
- typical of: -metals
  -many ceramics
  -some polymers



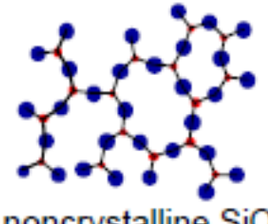
crystalline SiO_2

Adapted from Fig. 3.18(a), *Callister 6e.*

• Si ● Oxygen

Noncrystalline materials...
- atoms have no periodic packing
- occurs for: -complex structures
  -rapid cooling

"Amorphous" = Noncrystalline



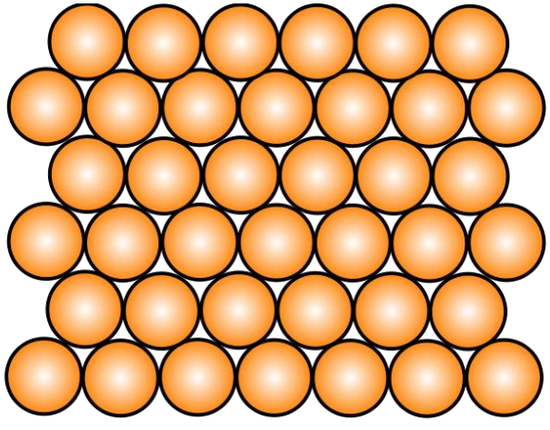
noncrystalline SiO_2

Adapted from Fig. 3.18(b), *Callister 6e.*

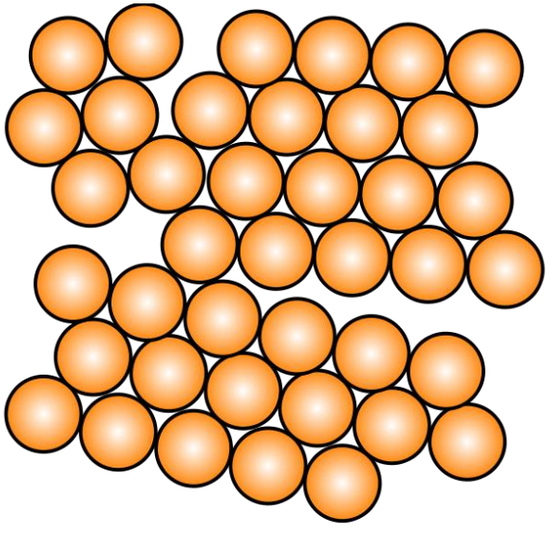
3

Types of solids

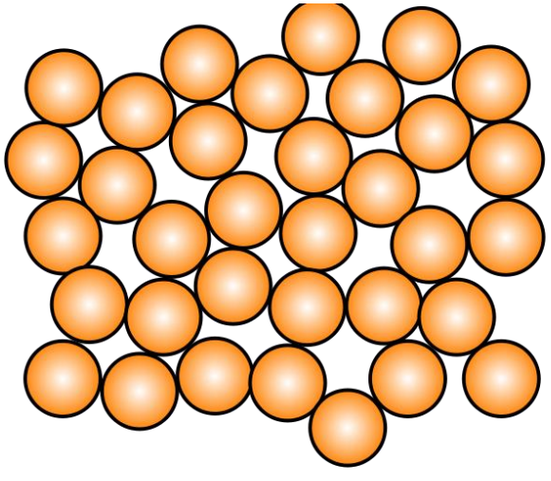
MONOCRYSTALLINE

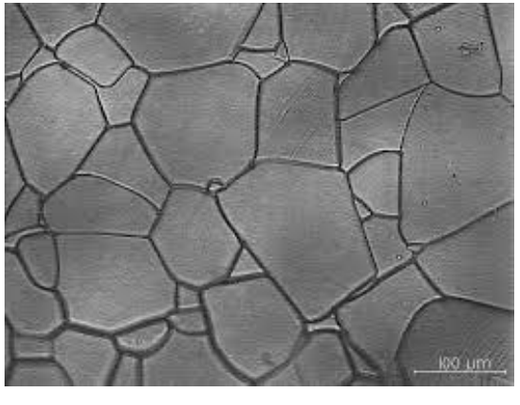


POLYCRYSTALLINE



AMORPHOUS





Crystalline Structures

How to construct the crystal structure?

Lattice : Translationally periodic arrangement of POINTS in space

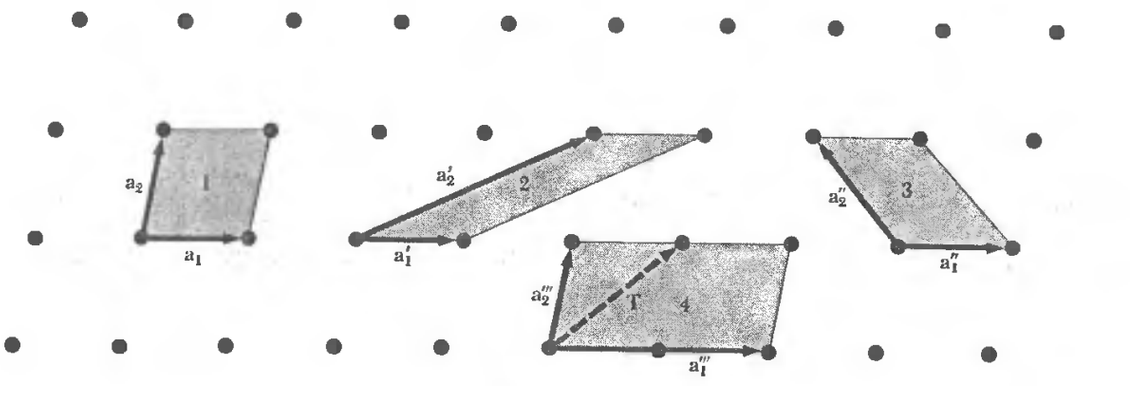
Basis: An atom or a group of atoms associated with each **lattice** point

CRYSTAL = Lattice + Basis

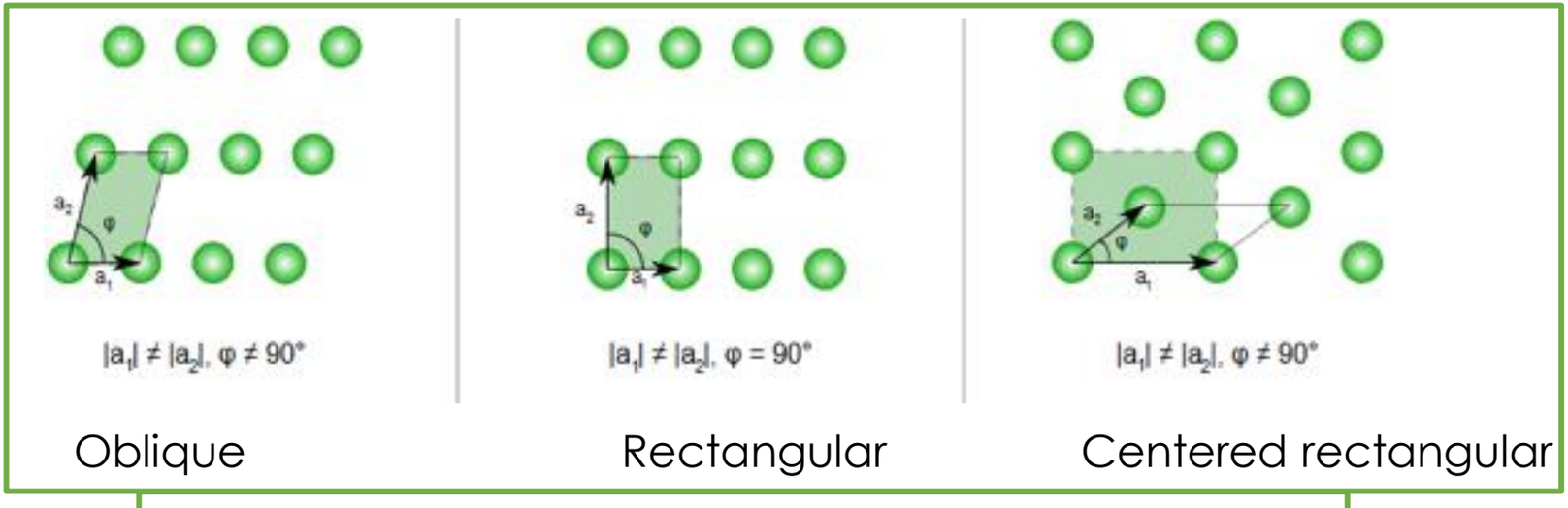
CRYSTAL: Translationally periodic arrangement of ATOMS in space.

A ***space lattice*** is defined as an infinite array of points in three dimensions in which every point has surroundings *identical* to that of every other point in the array.

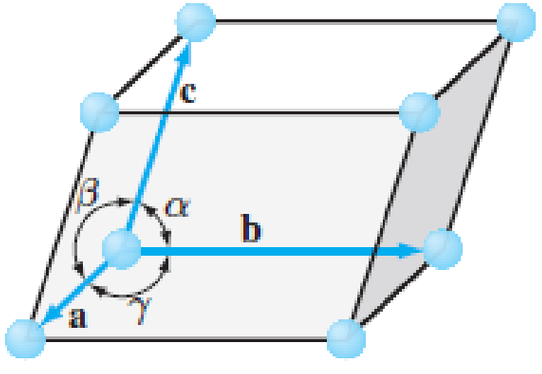
The ***unit cell*** is the smallest unit which, when repeated in space indefinitely, will generate the space lattice.



2-D Bravis Lattice

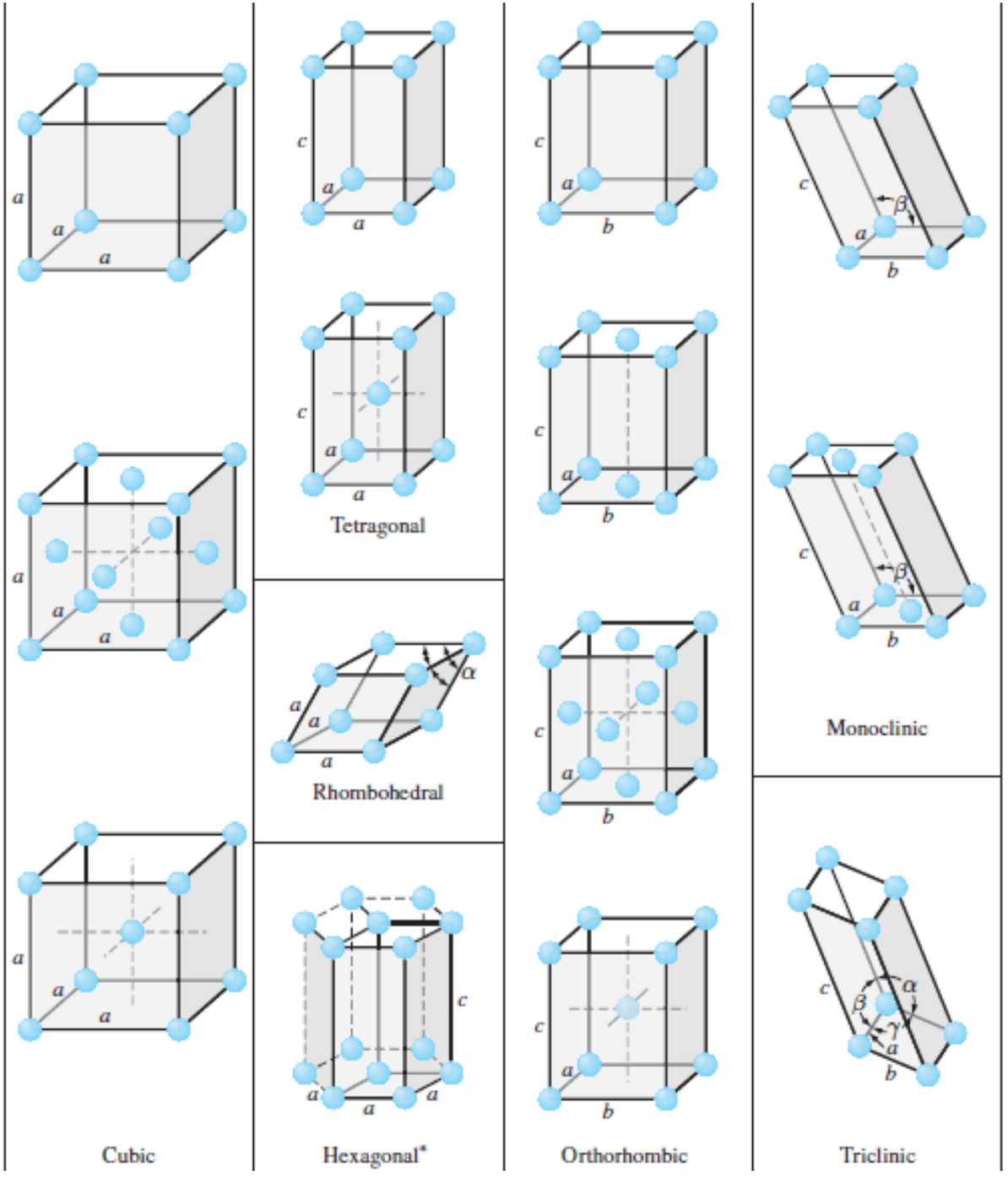


Crystal systems

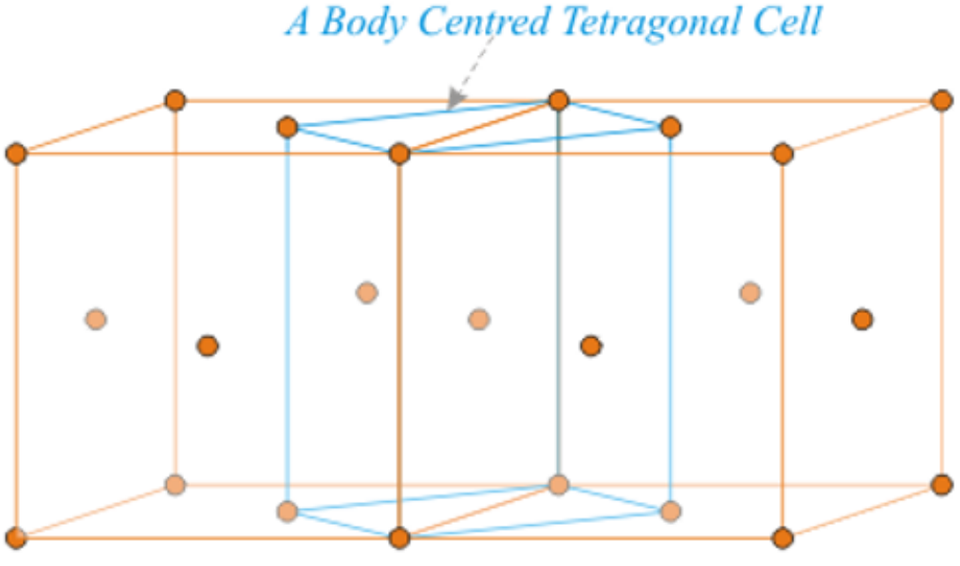


Crystal System	Axial Lengths and Interaxial Angles
Cubic	Three equal axes at right angles $a = b = c, \alpha = \beta = \gamma = 90°$
Tetragonal	Three axes at right angles, two equal $a = b \neq c, \alpha = \beta = \gamma = 90°$
Orthorhombic	Three unequal axes at right angles $a \neq b \neq c, \alpha = \beta = \gamma = 90°$
Rhombohedral	Three equal axes, equally inclined $a = b = c, \alpha = \beta = \gamma \neq 90°$
Hexagonal	Two equal axes at 120°, third axis at right angles $a = b \neq c, \alpha = \beta = 90°, \gamma = 120°$
Monoclinic	Three unequal axes, one pair not at right angles $a \neq b \neq c, \alpha = \gamma = 90° \neq$ b
Triclinic	Three unequal axes, unequally inclined and none at right angles $a \neq b \neq c, \alpha \neq \beta \neq \gamma \neq 90°$

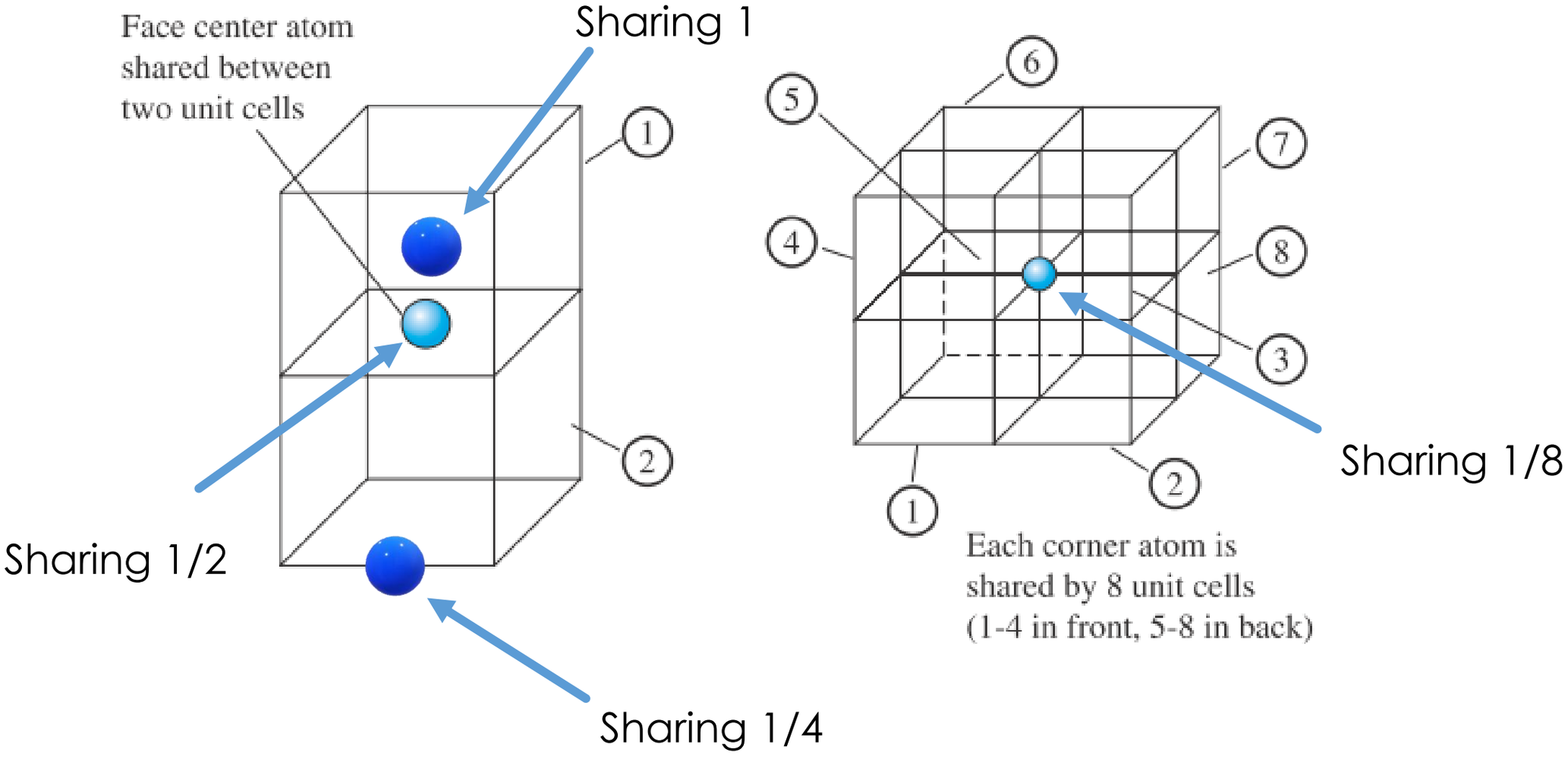
3-D Bravis Lattice



3-D Bravis Lattice

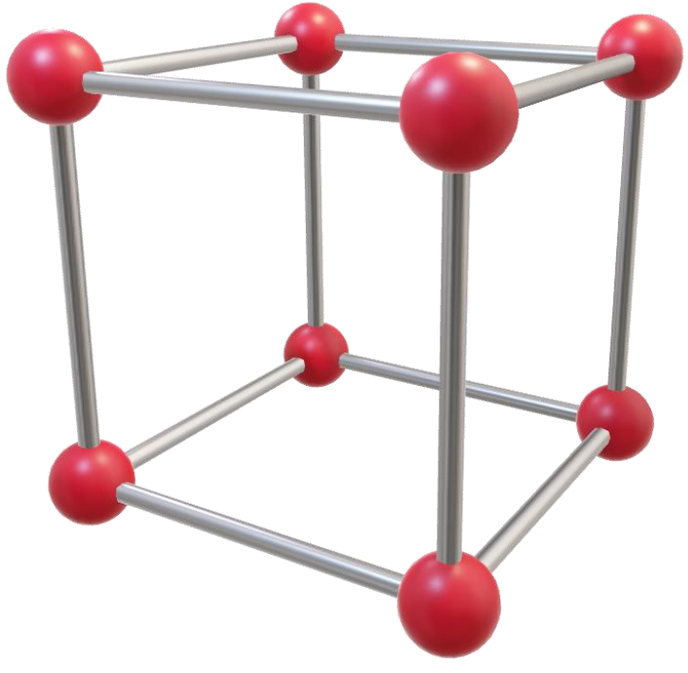


Sharing of lattice points in 3-D



Primitive lattice in 3-D

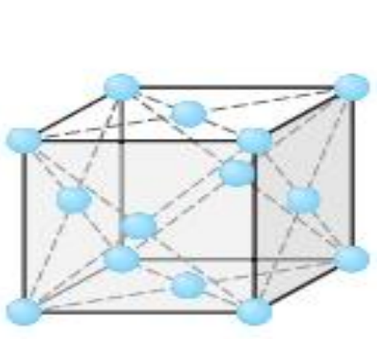
A Lattice with only 1 lattice point

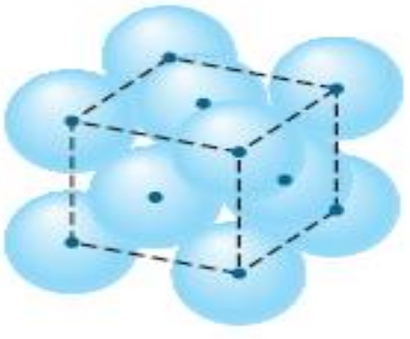


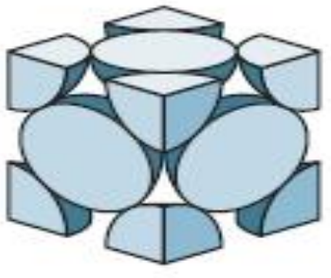
Sharing in a unit cell 1/8 * 8 = 1

Atomic Packing Factor: $\frac{\text{Volume occupied by atoms in a unit cell}}{\text{Volume of the unit cell}}$

FCC:
$APF_{FCC} = 0.74$

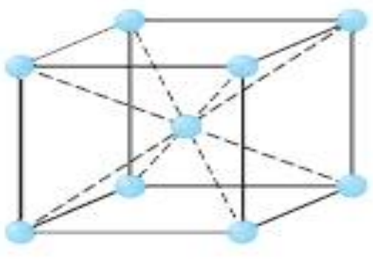


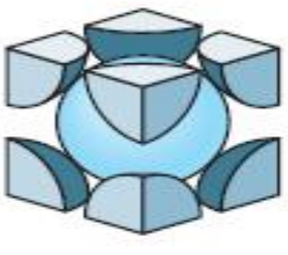


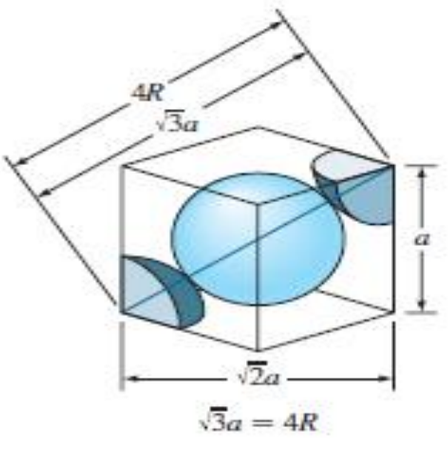


$$\sqrt{2}a = 4R \quad \text{or} \quad a = \frac{4R}{\sqrt{2}}$$

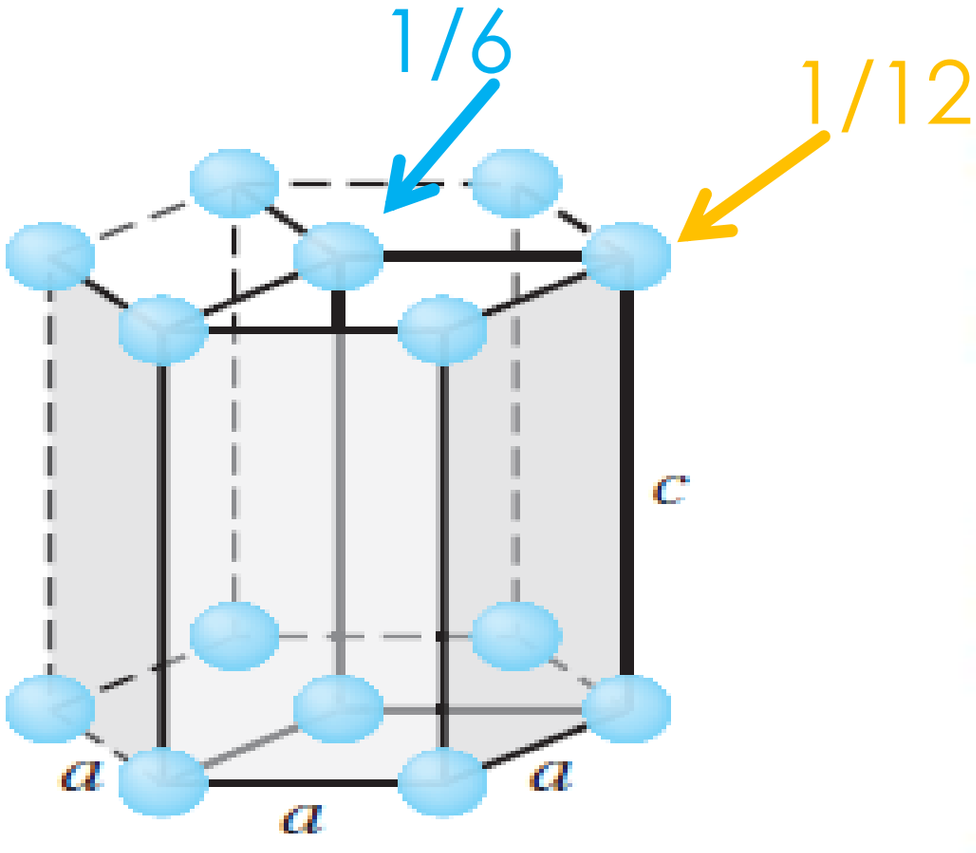
BCC:
$APF_{BCC} = 0.68$



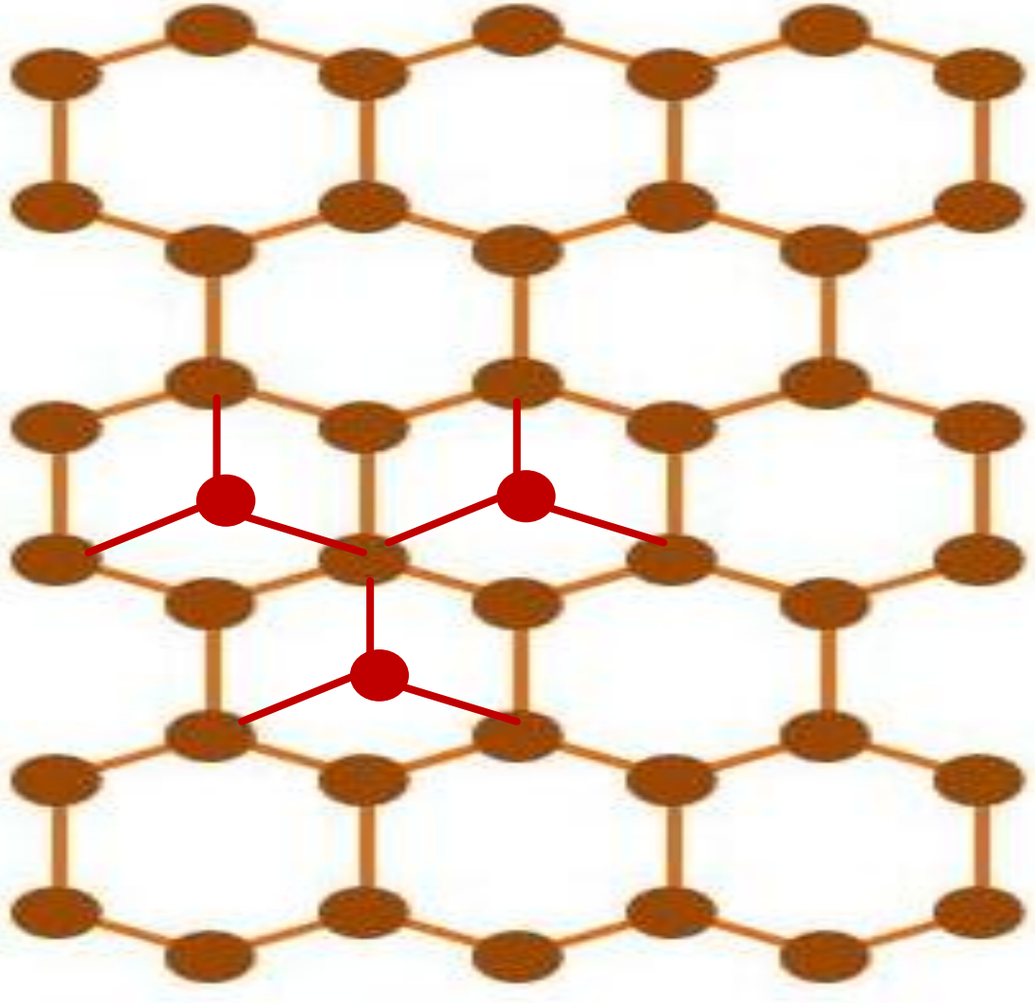




$$\sqrt{3}a = 4R$$



Hexagonal*



Atomic Packing Fraction (APF)

Packing density of the monoatomic unit cell

Atom is assumed as a hard sphere

$$APF = \frac{\text{No of atoms in a unit cell} \times \text{Volume of one atom}}{\text{Volume of the unit cell}}$$

Unit cell is cubic
So a^3

Structure	No. of atoms	APF
SC	1	52%
BCC	2	68%
FCC	4	74%

Density of a Material

Density of a crystalline material can be calculated by