Class: `1st Stage
Subject: Engineering Materials
Asst.Lecturer: Hiba Mohsin AL- bawi
E-mail: hiba.mohsin.abd@uomus.edu.iq

Crystalline and Non-crystalline Materials

Materials may be **crystalline** (where the material's atoms are arranged in a periodic fashion) or they may be **amorphous** (where the material's atoms do not have a long-range order).

Single Crystals

For a crystalline solid, when the periodic and repeated arrangement of atoms is perfect or extends throughout the entirety of the specimen **without interruption**, the result is a single crystal. All unit cells interlock in the same way and have the same orientation. Single crystals found in nature, but they may also be produced artificially. They are ordinarily difficult to grow, because the environment must be carefully controlled.

Polycrystalline Materials

Most crystalline solids are composed of a collection of many small crystals or **grains;** such materials are termed **polycrystalline.** Various stages in the solidification of a polycrystalline specimen are represented schematically in figure 1. Initially, small crystals or nuclei form at various positions. These have random crystallographic orientations, as indicated by the square grids. The small grains grow by the successive addition from the surrounding liquid of atoms to the structure of each. The edges of adjacent grains impact on one another as the solidification process approaches completion. As indicated in figure below, the crystallographic orientation varies from grain to grain. Also, there exists some atomic mismatch within the region where two grains meet; this area, called a **grain boundary.**

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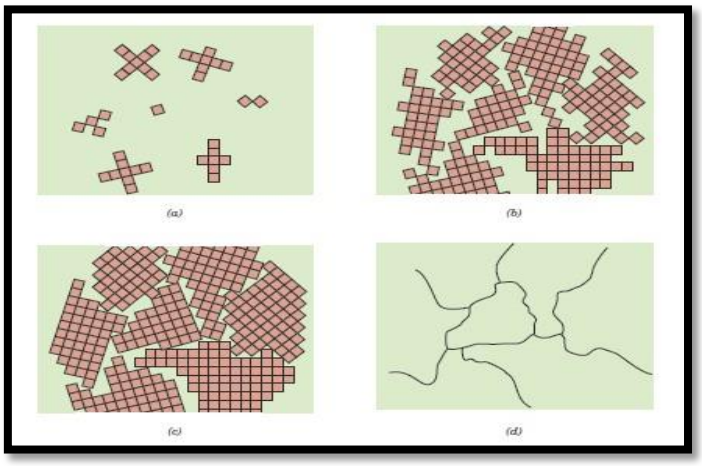

Figure 1. Schematic diagrams of the various stages in the solidification of a polycrystalline material; the square grids depict unit cells. (*a*) Small crystallite nuclei. (*b*) Growth of the crystallites; the obstruction of some grains that are adjacent to one another is also shown. (*c*) Upon completion of solidification, grains having irregular shapes have formed. (*d*) The grain structure as it would appear under the microscope; dark lines are the grain boundaries.

Structure of Metals, Crystal Systems

In materials science and engineering, we use the concept of **lattice** to describe arrangements of atoms or ions. A lattice may be one, two, or three dimensional. One or more atoms associated with each lattice point, is known as the **motif** or **basis**. We obtain a crystal structure by adding the lattice and basis (i.e., crystal structure = lattice + basis).

The **unit cell** is the subdivision of a lattice that still retains the overall characteristics of the entire lattice. Unit cells are shown in figure 1. By stacking identical unit cells, the entire lattice can be constructed. There are seven unique arrangements, known as **crystal systems**, which can be used to fill up a three-dimensional space. These are **cubic**, **tetragonal**, **trigonal**, **hexagonal**, **orthorhombic, monoclinic**, and **triclinic**. Although there are seven crystal systems, we have a total

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of 14 different arrangements of lattice points. These unique arrangements of lattice points are known as the Bravais lattices (Figure 1 and Table 1).

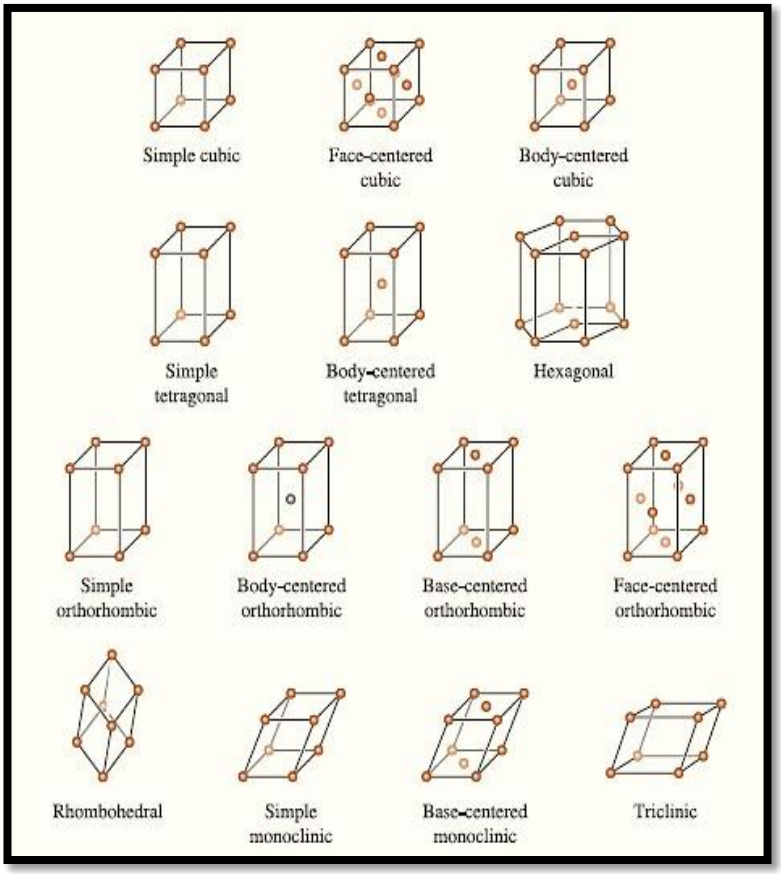

Figure 1. The fourteen types of Bravais lattices grouped in seven crystal systems.

Lattice points are located at the corners of the unit cells and, in some cases, at either faces or at the center of the unit cell. Note that for the cubic crystal system we have simple cubic (SC), face-centered cubic (FCC), and body-centered cubic (BCC) Bravais lattices. Similarly, for the tetragonal crystal system, we have simple tetragonal and body centered tetragonal Bravais lattices. Any other arrangement of atoms can be expressed using these 14 Bravais lattices. For example, if we take the face-centered

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cubic lattice and assume that at each lattice point we have one atom, then we get a face-centered cubic crystal structure.

Structure	Axes	Angles between Axes	Volume of the Unit Cell
Cubic	$a = b = c$	All angles equal 90°	a^3
Tetragonal	$a = b \neq c$	All angles equal 90°	a^2c
Orthorhombic	$a \neq b \neq c$	All angles equal 90°	abc
Hexagonal	$a = b \neq c$	Two angles equal 90°. One angle equals 120°.	$0.866a^2c$
Rhombohedral or trigonal	$a = b = c$	All angles are equal and none equals 90°	$a^3\sqrt{1-3\cos^2\alpha+2\cos^3\alpha}$
Monoclinic	$a \neq b \neq c$	Two angles equal 90°. One angle (β) is not equal to 90°	$abc\sin\beta$
Triclinic	$a \neq b \neq c$	All angles are different and none equals 90°	$abc\sqrt{1-\cos^2\alpha-\cos^2\beta-\cos^2\gamma+2\cos\alpha\cos\beta\cos\gamma}$

Table 1. Characteristics of the seven crystal systems.

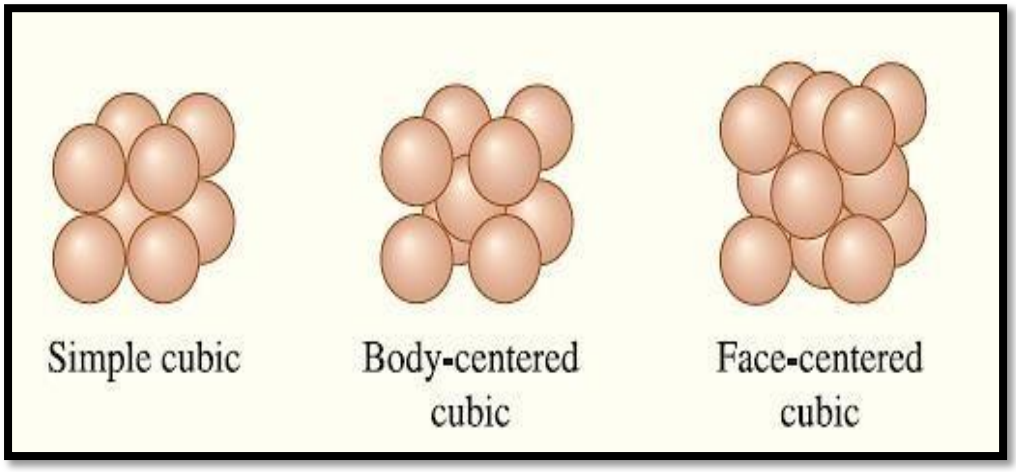

Figure 2. The models for simple cubic (SC), body-centered cubic (BCC), and face-centered cubic (FCC) unit cells, assuming only one atom per lattice point.