Engineering Materials

Teaching / Examination scheme:

Lectures: 3 Hrs. / Week;

Mid-term Exam.

Practical (Metallurgy Laboratory): 0 Hrs. / Week

Final Exam. : 60 Marks

Course Objective

Study of structures, composition, properties, applications, heat treatment and selection of various ferrous and non-ferrous materials

Lecturer: Dr. Kamal Al-Hamdani

(B.Sc., M.Sc. U.o. Baghdad – PhD. U.o. Nottingham-UK)

Recommended text books

1. Materials Science and Engineering, An Introduction (William D. Callister, Jr.)
2. Introduction to MATERIALS SCIENCE FOR ENGINEERS (James F.Shackelford)
3. Engineering Metallurgy by E. C. Rollason, (ELBS)
4. Introduction To Engineering Materials, B.K.Agrawal (TMH)
5. Engineering Metallurgy by Lakhtin, (MIR Publishers)

Subjects:

Introduction to materials engineering

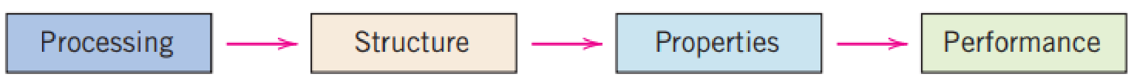
Materials science and materials engineering sub-disciplines.

Strictly speaking, *materials science* involves investigating **the relationships that exist between the structures and properties of materials.** In contrast, materials engineering is, on the basis of these **structure–property correlations**, designing or engineering the structure of a material to produce a predetermined set of properties.2 From a functional perspective, the role of a materials scientist is to develop or synthesize new materials, whereas a materials engineer is called upon to create new products or systems using existing materials, and/or to develop techniques for processing materials. Most graduates in materials programs are trained to be both materials scientists and materials engineers.

Structure is at this point a nebulous term that deserves some explanation. In brief, the structure of a material usually relates to the arrangement of its internal components. **Subatomic structure** involves electrons within the individual atoms and interactions with their nuclei. On an **atomic level**, structure encompasses the organization of atoms or molecules relative to one another. The next larger structural realm, which contains large groups of atoms that are normally agglomerated together, is termed **microscopic**, meaning that which is subject to direct observation using some type of microscope. Finally, structural elements that may be viewed with the naked eye are termed **macroscopic**.

The notion of **property** deserves elaboration. While in service use, all materials are exposed to external action that causes some type of response. For example, a specimen subjected to forces will experience deformation, or a polished metal surface will reflect light. A property is a material feature in terms of **the kind and magnitude of response** to a specific enforced motivation. Generally, definitions of properties are made independent of material shape and size.

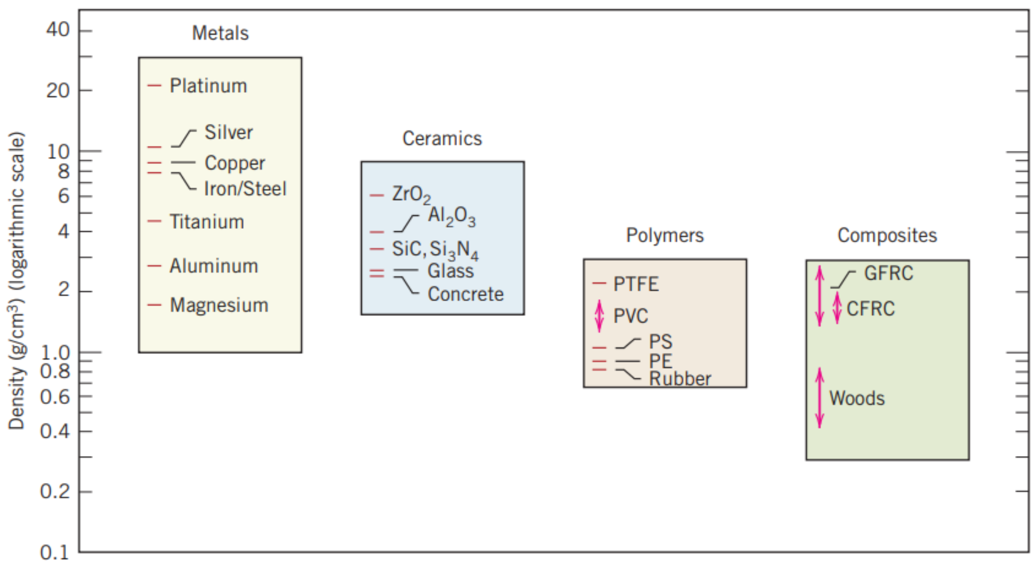
Virtually all important properties of solid materials may be grouped into **six different categories: mechanical, electrical, thermal, magnetic, optical, and deteriorative**. For each there is a characteristic type of **stimulus** capable of **provoking** different responses. **Mechanical properties** relate deformation to an applied load or force; examples include elastic modulus (stiffness), strength, and toughness. For electrical properties, such as electrical conductivity and dielectric constant, the stimulus is an electric field. **The thermal behavior** of solids can be represented in terms of heat capacity and thermal conductivity. **Magnetic properties** demonstrate the response of a material to the application of a magnetic field. For **optical properties**, the stimulus is electromagnetic or light radiation; index of refraction and reflectivity are representative optical properties. Finally, **deteriorative characteristics** relate to the chemical reactivity of materials.



In addition to structure and properties, **two** other important components are involved in the science and engineering of materials namely**, processing and performance**. With regard to the relationships of these four components, the **structure** of a material will depend on how it is **processed**. Furthermore, a material's **performance** will be a function of its **properties**. Thus, the interrelationship between processing, structure, properties, and performance is as described in the schematic illustration shown in Figure. Throughout this text we draw attention to the relationships among these four components in terms of the design, production, and utilization of materials.

Classification of Materials

Solid materials have been grouped into three basic categories: **metals, ceramics, and polymers**. This scheme is based primarily on chemical makeup and atomic structure, and most materials fall into one distinct grouping or another. In addition, there are the composites, which are engineered combinations of two or more different materials. A brief explanation of these material classifications and representative characteristics is offered next. Another category is advanced materials—those used in high-technology applications, such as semiconductors, biomaterials, smart materials, and nano-engineered materials.



Metals

Materials in this group are composed of **one or more metallic elements** (e.g., iron, aluminum, copper, titanium, gold, and nickel), and often also nonmetallic elements (e.g., carbon, nitrogen, and oxygen) in relatively small amounts.3 Atoms in metals and their alloys are arranged in a very orderly manner and in comparison to the ceramics and polymers, are relatively dense regard to mechanical characteristics, these materials are relatively stiff and, yet are ductile (i.e., capable of large amounts of deformation without fracture), and are resistant to fracture, which accounts for their widespread use in structural applications. Metallic materials have large numbers of non-localized electrons; that is, these electrons are not bound to particular atoms. Many properties of metals are directly attributable to these electrons. For example, metals are extremely good conductors of electricity and heat, and are not transparent to visible light; a polished metal surface has a lustrous appearance. In addition, some of the metals (i.e., Fe, Co, and Ni) have desirable magnetic properties.

Ceramics

Ceramics are compounds between metallic and nonmetallic elements; they are most frequently oxides, nitrides, and carbides. For example, common ceramic materials include aluminum oxide (or alumina, Al_2O_3), silicon dioxide (or silica, SiO_2), silicon carbide (SiC), silicon nitride (Si_3N_4), and, in addition, what some refer to as the traditional ceramics—those composed of clay minerals (i.e., porcelain), as well as cement and glass.With regard to mechanical behavior, ceramic materials are relatively stiff and strong—stiffnesses and strengths are comparable to those of the metals . In addition, they are typically very hard. Historically, ceramics have exhibited extreme brittleness (lack of ductility) and are highly susceptible to fracture (Figure 1.6). However, newer ceramics are being engineered to have improved resistance to fracture; these materials are used for cookware, cutlery, and even automobile engine parts. Furthermore, ceramic materials are typically insulative to the passage of heat and electricity (i.e., have low electrical conductivities) and are more resistant to high temperatures and harsh environments than metals and polymers.

Polymers

Polymers include the familiar plastic and rubber materials. Many of them are organic compounds that are chemically based on carbon, hydrogen, and other nonmetallic elements (i.e., O, N, and Si). Furthermore, they have very large molecular structures, often chainlike in nature, that often have a backbone of carbon atoms. Some of the common and familiar polymers are polyethylene (PE), nylon, poly(vinyl chloride)

(PVC), polycarbonate (PC), polystyrene (PS), and silicone rubber. These materials typically have low densities, whereas their mechanical characteristics are generally dissimilar to the metallic and ceramic materials—they are not as stiff nor as strong as these other material types

Composites

A composite is composed of two (or more) individual materials, which come from the categories previously discussed—metals, ceramics, and polymers. The design goal of a composite is to achieve a combination of properties that is not displayed by any single material, and also to incorporate the best characteristics of each of the component materials. A large number of composite types are represented by different combinations of metals, ceramics, and polymers. Furthermore, some naturally occurring materials are composites—for example, wood and bone. However, most of those we consider in our discussions are synthetic (or human-made) composites.

One of the most common and familiar composites is fiberglass, in which small glass fibers are embedded within a polymeric material (normally an epoxy or polyester). The glass fibers are relatively strong and stiff (but also brittle), whereas the polymer is more flexible. Thus, fiberglass is relatively stiff, strong and flexible. In addition, it has a low density. The new Boeing 787 fuselage is primarily made from such CFRP composites.

Advanced Materials:

Materials that are utilized in high-technology (or high-tech) applications are sometimes termed advanced materials. By high technology we mean a device or product that operates or functions using relatively intricate and sophisticated principles; examples include electronic equipment (camcorders, CD/DVD players, etc.), computers, fiber-optic systems, spacecraft, aircraft, and military rocketry. These advanced materials are typically traditional materials whose properties have been enhanced, and also newly developed, high-performance materials. Furthermore, they may be of all material types (e.g., metals, ceramics, polymers), and are normally expensive. Advanced materials include semiconductors, biomaterials, and what we may term “materials of the future” (that is, smart materials and nano-engineered materials), which we discuss next. The properties and applications of a number of these advanced materials, for example, materials that are used for lasers, integrated circuits, magnetic information storage, liquid crystal displays (LCDs), and fiber optics

Semiconductors

Semiconductors have electrical properties that are intermediate between the electrical conductors (i.e., metals and metal alloys) and insulators (i.e., ceramics and polymers). Furthermore, the electrical characteristics of these materials are extremely sensitive to the presence of minute concentrations of impurity atoms, for which the concentrations may be controlled over very small spatial regions. Semiconductors have made possible the advent of integrated circuitry that has totally revolutionized the electronics and computer industries (not to mention our lives) over the past three decades.

Biomaterials

Biomaterials are employed in components implanted into the human body to replace diseased or damaged body parts. These materials must not produce toxic substances and must be compatible with body tissues (i.e., must not cause adverse biological reactions). All of the preceding materials—metals, ceramics, polymers, composites, and semiconductors—may be used as biomaterials. For example, some of the biomaterials that are utilized in artificial hip replacements are discussed in the online Biomaterials Module.

Smart Materials

Smart (or intelligent) materials are a group of new and state-of-the-art materials now being developed that will have a significant influence on many of our technologies. The adjective smart implies that these materials are able to sense changes in their environment and then respond to these changes in predetermined manners—traits that are also found in living organisms. In addition, this "smart" concept is being extended to rather sophisticated systems that consist of both smart and traditional materials.

Nanomaterials

One new material class that has fascinating properties and tremendous technological promise is the nanomaterials. Nanomaterials may be any one of the four basic types—metals, ceramics, polymers, and composites. However, unlike these other materials, they are not distinguished on the basis of their chemistry, but rather, size; the nano-prefix denotes that the dimensions of these structural entities are on the order of a nanometer (10–9 m)—as a rule, less than 100 nanometers (equivalent to approximately 500 atom diameters).

Atomic Structure

In order to understand bonding between atoms, we must specify the structure within the individual atoms. For this purpose, it is sufficient to use a relatively simple planetary model of atomic structure that is, **electrons** (the planets) orbit about a **nucleus** (the sun).

The nucleus consists of number of **protons** and **neutrons** as the basis of the chemical identification of a given atom. Figure 2 is a planetary model of a carbon atom.

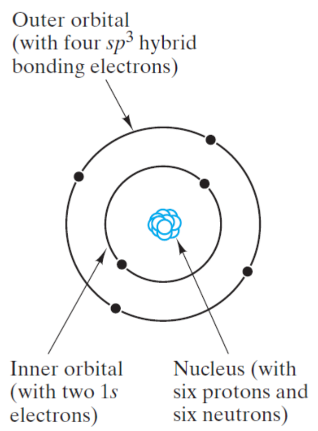
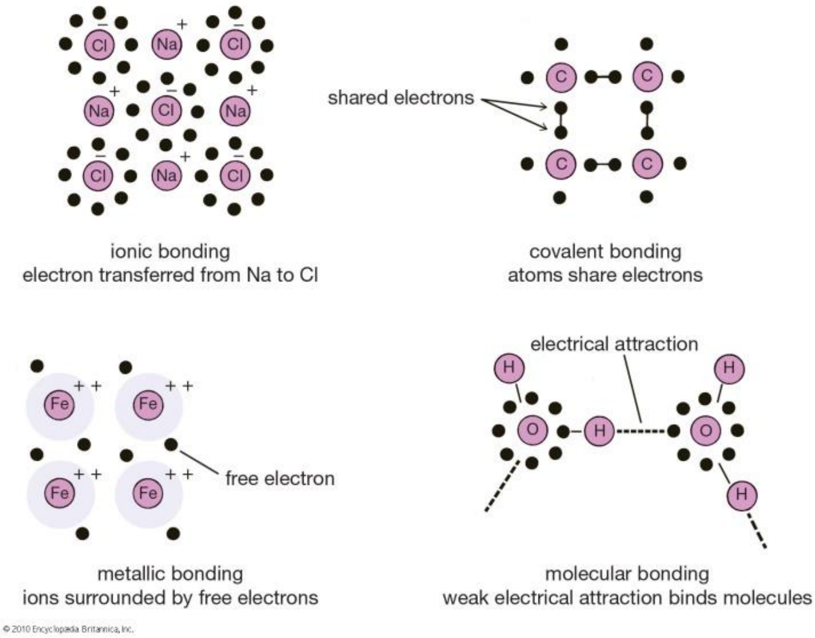


Figure 2 Schematic of the planetary model of a carbon atom

<u>Atomic Bounding</u>

There are four important mechanisms by which atoms are bonded in engineered materials, these are

1. Metallic bonds.
2. Covalent bonds.
3. Ionic bonds.
4. Van der Waals bonds.



The first three types of bonds are relatively strong and are known as **primary bonds** (relatively strong bonds between adjacent atoms resulting from the transfer or sharing of outer orbital electrons). The van der Waals bonds are secondary bonds and originate from a different mechanism and are relatively weaker

a) **Ionic bonding** (found in Ceramics and Glass) this type is always found in compounds that are composed of both metallic and nonmetallic elements. Atoms of a metallic element easily give up their valence electrons to the nonmetallic atoms.

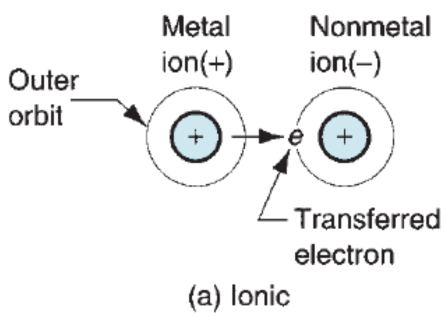


Figure 3 Schematic representation of ionic bonding

b) **Covalent bonding** (found in Polymers) in this type electrons are shared between adjacent atoms, each atoms contribute at least one electron to the bond, and the shared electrons may be considered to belong to both atoms.

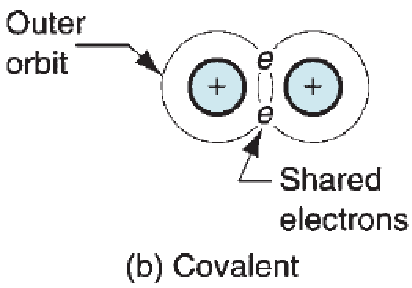


Figure 4 Schematic representation of covalent bonding

c) Metallic Bond (found in metals and their alloys) metallic materials have one, two, or at most, three valence electrons, these valence electrons are free to drift throughout the entire metal forming an electron cloud. The remaining non-valence electrons and atomic nuclei form what are called ***ion cores***, which possess a net positive charge equal in magnitude to the total valence electron charge per atom.

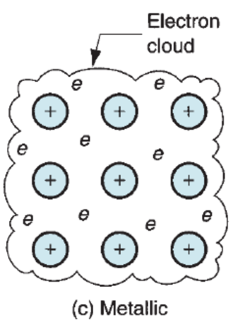


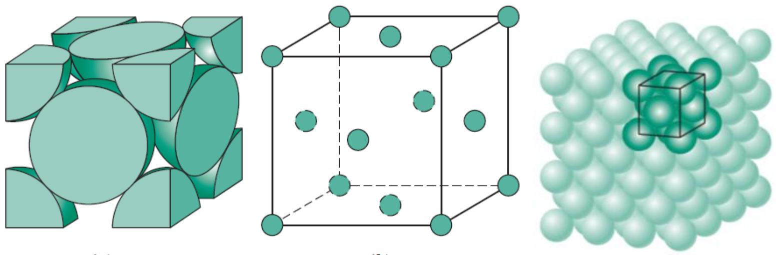
Figure 5 Schematic illustration of metallic bonding

Metallic crystal structures:

<u>Types of crystal structures</u>

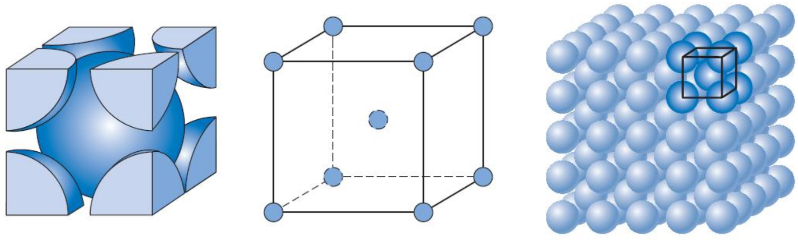
There are three main types of crystal structures of metals as follows:

1- The face-centered cubic crystal structure (FCC): some of the familiar metals having this crystal structure are copper, aluminum, silver, and gold.



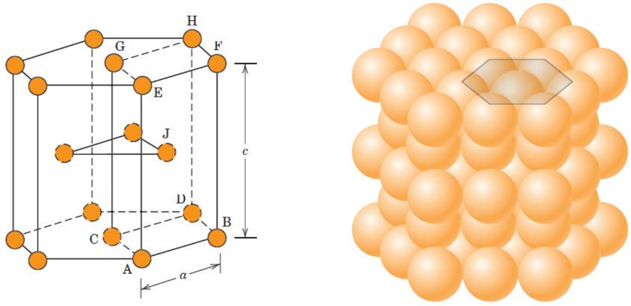
(a) (b) (c)

2- The Body-Centered Cubic Crystal Structure (BCC): Chromium, iron, tungsten exhibits a BCC structure.



(a) (b) (c)

3- The Hexagonal Close-Packed Crystal Structure (HCP):



(a) (b)