Ministry of Higher
Education and Scientific Research
University of Babylon /College of Engineering

LECTURE NOTES OF ENGINEERING METALLURGY

FIRST STAGE -1ST SEMESTER (2026)

PREPARED BY

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Delivery Plan (Weekly Syllabus)	
	Material Covered
Week 1	Introduction To Metallic and Non-Metallic Materials
Week 2	Crystal And Micro-Structure of Metals And Alloys
Week 3	Crystallization And Solidification Process and Cooling Curves
Week 4	Thermal Equilibrium Diagrams
Week 5	Thermal Equilibrium Diagrams of Iron And Carbon
Week 6	Relation Between Micro-Structure And Mechanical Properties
Week 7	Basic Heat Treatments For Iron
Week 9	Basic Heat Treatments For Alloys and Light Metals
Week 10	Copper
Week 11	Zinc
Week 12	Copper And Zinc And Their Alloys
Week 13	Hardening
Week 14	steels
Week 15	**Classification of the steel**

References

1. M. F. Ashby and D. R. H. Jones, Engineering Materials 1, An introduction to Their Properties and Applications, second edition, Butterworth-Heinemann, Woburn, UK, 1996

2. William D. Callister, Jr, Materials Science and Engineering – An introduction, sixth edition, John Wiley & Sons, Inc. 2004.

3. V. Raghavan, Materials Science and Engineering, third edition, Prentice Hall of India Private Limited, New Delhi, 1990.

Chapter 1: Introduction

Materials Science

As engineering materials constitute foundation of technology, it's not only necessary but a must to understand how materials behave like they do and why they differ in properties. This is only possible with the atomistic understanding allowed by quantum mechanics that first explained atoms and then solids starting in the 1930s. The combination of physics, chemistry, and the focus on the relationship between the properties of a material and its microstructure is the domain of Materials Science. The development of this science allowed designing materials and provided a knowledge base for the engineering applications (Materials Engineering).

Important components of the subject Materials Science are structure, properties, processing, and performance. A schematic interrelation between these four components is shown in figure 1.1.

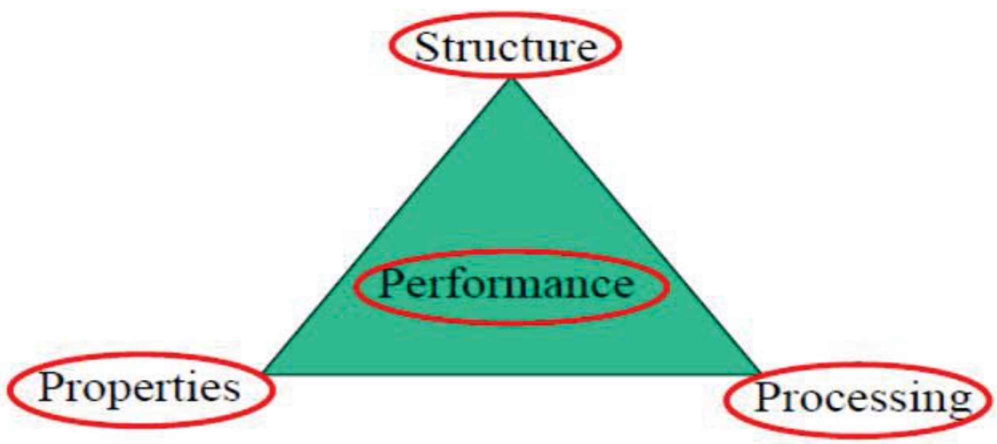


Figure 1.1: *Interrelation between four components of Materials Science.*

1.2 Why Study Materials Science and Engineering? and Classification of Materials?

- To select a material for a given use based on considerations of cost and performance.
- To understand the limits of materials and the change of their properties with use.
- To be able to create a new material that will have some desirable properties.
- To be able to use the material for different application.

1.2.1 Why Study Materials Science and Engineering?

1.2.2 Classification of Materials

Like many other things, materials are classified in groups, so that our brain can handle the complexity. One can classify them based on many criteria, for example crystal structure (arrangement of atoms and bonds between them), or properties, or use. Metals, Ceramics, Polymers, Composites, Semiconductors, and Biomaterials constitute the main classes of present engineering materials.

Metals: These materials are characterized by high thermal and electrical conductivity; strong yet deformable under applied mechanical loads; opaque to light (shiny if polished). These characteristics are due to valence electrons that are detached from atoms, and spread in an *electron sea* that *glues* the ions together, i.e. atoms are bound together by metallic bonds and weaker van der Waalls forces. Pure metals are not good enough for many applications, especially structural applications. Thus metals are used in alloy form i.e. a metal mixed with another metal to improve the desired qualities. E.g.: aluminum, steel, brass, gold.

Ceramics: These are inorganic compounds, and usually made either of oxides, carbides, nitrides, or silicates of metals. Ceramics are typically partly crystalline and partly amorphous. Atoms (ions often) in ceramic materials behave mostly like either positive or negative ions, and are bound by very strong Coulomb forces between them. These materials are characterized by very high strength under compression, low ductility; usually insulators to heat and electricity. Examples: glass, porcelain, many minerals.

Polymers: Polymers in the form of thermo-plastics (nylon, polyethylene, polyvinyl chloride, rubber, etc.) consist of molecules that have covalent bonding within each molecule and van der Waals forces between them. Polymers in the form of thermo-sets (e.g., epoxy, phenolics, etc.) consist of a network of covalent bonds.

Composite materials: Composite materials are multiphase materials obtained by artificial combination of different materials to attain properties that the individual components cannot attain.

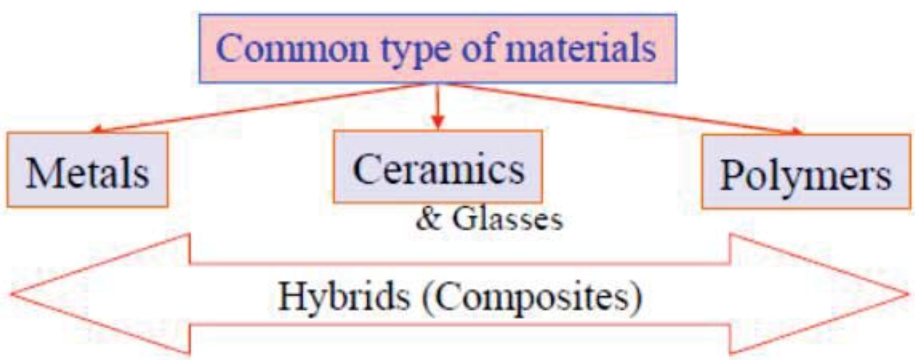
Semiconductors: Semiconductors are covalent in nature. Examples: silicon (Si), germanium (Ge), and gallium arsenide (GaAs, a compound semiconductor).

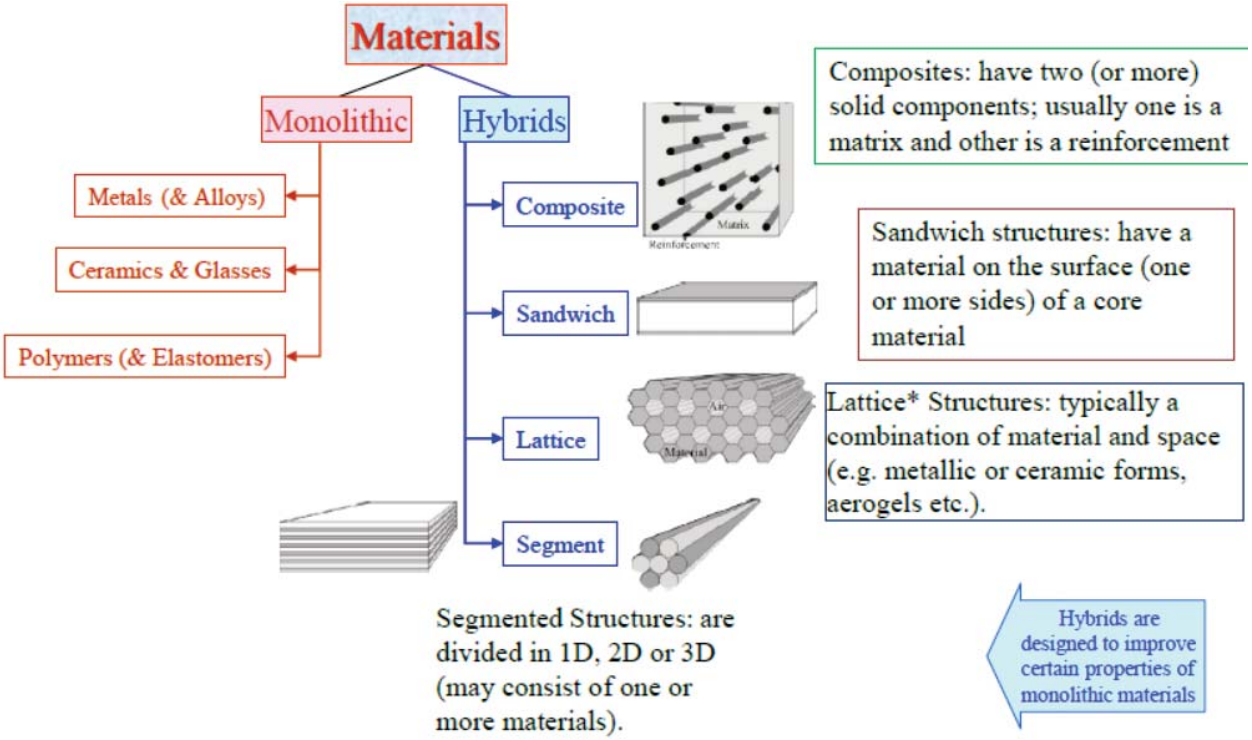
Biomaterials: These are any type material that can be used for replacement of damaged or diseased human body parts. Primary requirement of these materials is that they must be biocompatible with body tissues, and must not produce toxic substances. Other important material factors are: ability to support forces; low friction, wear, density, and cost; reproducibility. Typical applications involve heart valves, hip joints, dental implants, intraocular lenses. Examples: Stainless steel, Co-28Cr-6Mo, Ti-6Al-4V, ultra high molecular weight poly-ethelene, high purity dense Al-oxide, etc.

1.3.1 Advanced Materials

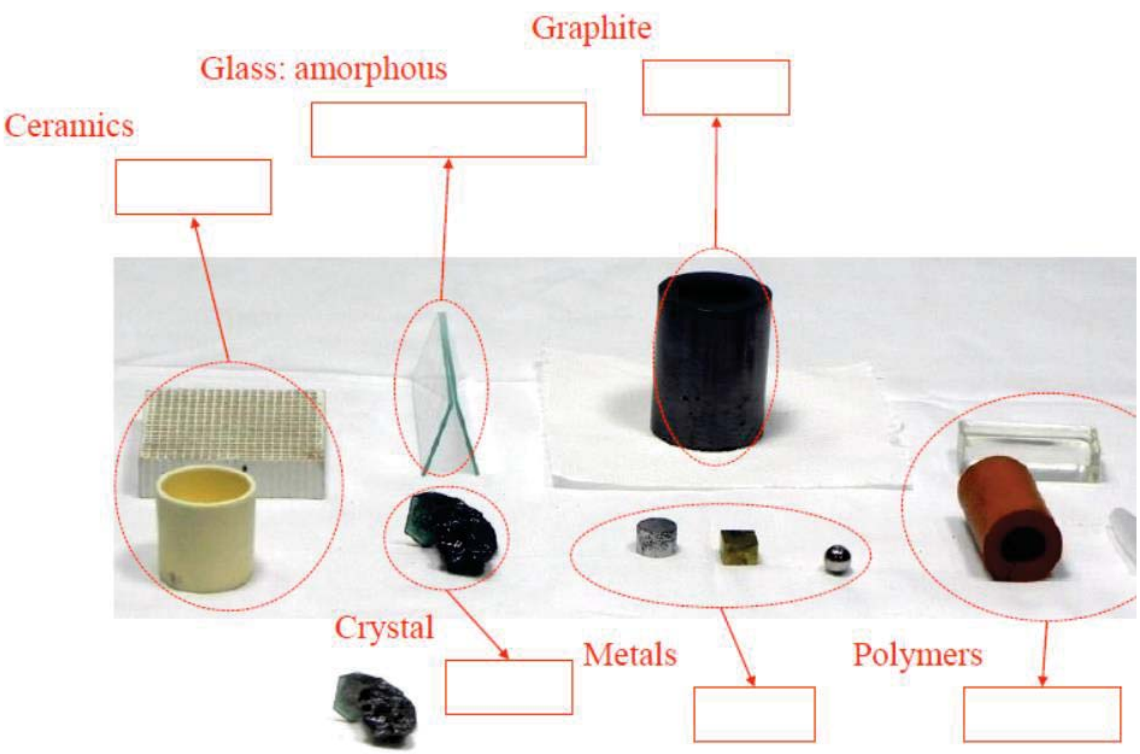
These are materials used in High-Tech devices those operate based on relatively intricate and sophisticated principles (e.g. computers, air/space-crafts, electronic gadgets, etc.). These materials are either traditional materials with enhanced properties or newly developed materials with high-performance capabilities.

Let us consider the common types of Engineering Materials.





Note: this use of the word 'lattice' should not be confused with the use of the word in connection with crystallography.



Engineering metallurgy

Metals and alloys :- Inorganic materials composed of one or more metallic elements .

- They usually have a crystalline structure and are good thermal and electrical conductors .
- Many metal have high strength and high elastic modulus .
- They maintain their good strength at high and low temperature .
- They have sufficient ductility , which is important for many engineering applications.
- They can be strengthened by alloying at heat treatment process.
- They are least resistant to corrosion .

possess many unique fundamental properties that make them an ideal material for use in a diverse range of applications. Properties such as high tensile strength, high fracture toughness, malleability and availability are just some of the many advantages associated with metals.

Metals are generally malleable , they can be hammered or pressed permanently out of shape without breaking or cracking and fusible (able to be fused or melted) and ductile .

Metals in general have high electrical conductivity, high thermal conductivity, and high density .

Metals are generally not used in their pure state but as mixtures of metals or metal and non metal constituents commonly referred to as alloys.

Mechanical properties of metals include ductility, i.e. their capacity for plastic deformation., Reversible elastic deformation in metals can be described by Hooke's Law for restoring forces, where the stress is

linearly proportional to the strain. Forces larger than the elastic limit, or heat, may cause a permanent (irreversible) deformation of the object, known as plastic deformation or plasticity.

Most metals are present in the Earth as compounds of some sort, such as oxides or sulphides. The first metals were discovered accidentally more than 5,000 years ago.

Definition of metal

is a material (an element, compound, or alloy) that is typically hard, opaque, shiny, and has good electrical and thermal conductivity.

Below comparison between metals and non- metals materials:-

Metals	Non-Metals
Good conductors of heat and electricity	Poor conductors of heat & electricity
Malleable: can be beaten into thin sheets	Brittle: if solid
Ductile: can be stretched into wire	Non-ductile
Possess metallic luster	Do not possess metallic luster
Solid at room temperature (except Hg)	Solids, liquids or gases at room temperature

Property	Metals	Non metals
Appearance	Shiny	Dull
Melting and boiling points	High (they are all solid at room temperature, except mercury which is a liquid)	Lower than metals (bromine is a liquid at room temperature, and eleven others are gases).
Density	High (they feel "heavy" for their size)	Low (they feel "light" for their size)
Strength	Strong (they can hold heavy loads without breaking)	Not strong
Malleability	Malleable (they can be hammered into different shapes without breaking).	Brittle (they break or shatter when hammered).
Ductility	Ductile (they can be drawn out to make wires).	Not ductile.
Heat conductivity	Good	Poor
Electrical conductivity	Good	Poor (but graphite, a form of carbon, is an exception).

Types of metals :-

1- noble metals - generally unreactive , e.g. silver, platinum , gold .

2- alkali metals - very reactive with low melting points and soft , e.g. potassium and sodium .

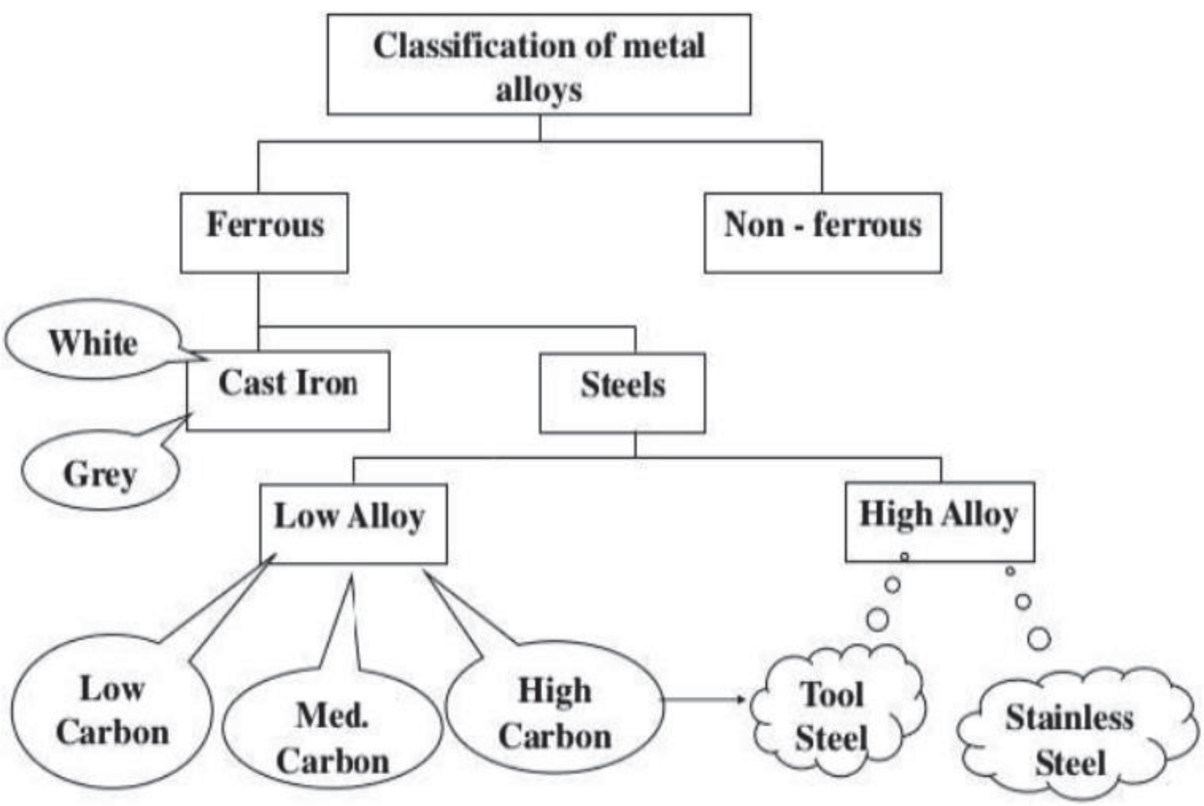
3- alkaline earth metals – less reactive, higher melting points and harder than alkali metals, e.g. calcium, magnesium and barium .

4- transition metals - hard, shiny, strong, and easy to shape, e.g. iron, chromium, nickel, and copper .

5-other metals – diverse properties, e.g. aluminum , gallium indium, tin, thallium, lead and bismuth.

Metals Classification

All metals may be classified as ferrous or nonferrous.



Metallurgy is a domain (field) of materials science and engineering that studies the physical and chemical behavior of metallic elements, their intermetallic compounds, and their mixtures, which are called alloys.

Metallurgy is also the technology of metals: the way in which science is applied to the production of metals, and the engineering of metal components for usage in products for consumers and manufacturers.

The production of metals involves the processing of ores to extract the metal they contain, and the mixture of metals, sometimes with other elements, to produce alloys.

Metallurgy can be separated (classified) into three basic components: *chemical, mechanical, and physical*.

- Chemical metallurgy deals primarily with the making of metals and alloys from their naturally occurring ores.
- Mechanical metallurgy deals with testing mechanical properties, the relationships between properties and engineering design, and the performance of metals in service.
- physical metallurgy.

This aspect deals with the internal world of metals and how internal structure can be designed and produced to give the best properties.

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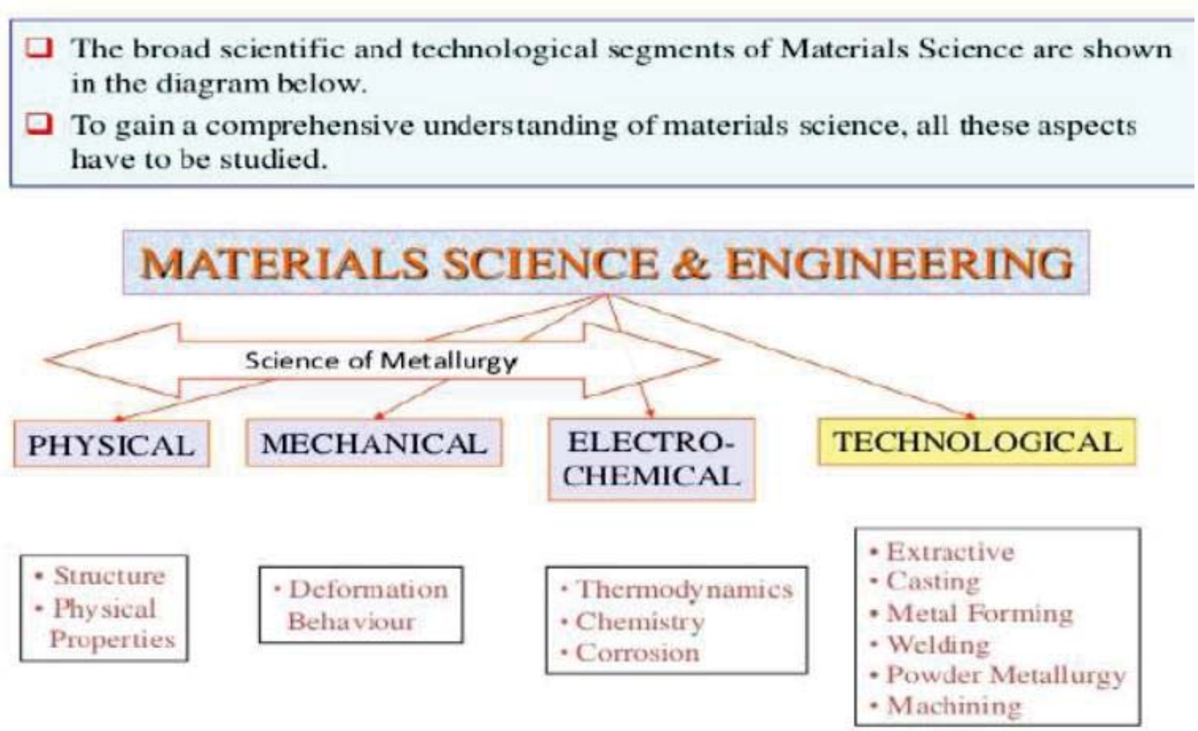


Alloys

Is a homogeneous combination of two or more elements at least one of which is a metal has metallic properties.

Based on iron called (**ferrous alloy).**

Based on other metals (Al, Cu, Mg, Ti, Ni) **called (nonferrous alloy)**

Types and Application of Major metallic alloys:-

all with distinctive properties, include:

1- Steel alloy – low cost , high strength. , Very wide used in ships, buildings, railway lines, reinforced concrete.

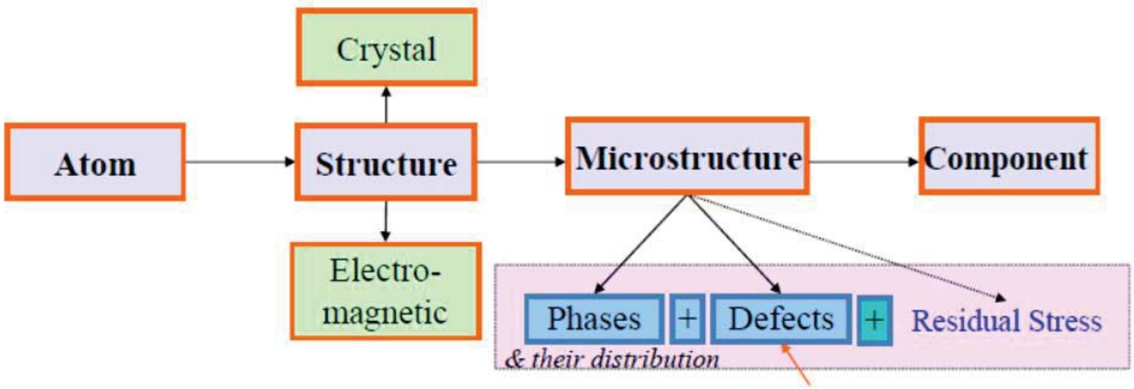
2- aluminum alloys – high specific strength, corrosion resistance, specific conductivity, used in Aerospace, packaging, sports equipment, energy, construction Aircraft, food containers, power cables.

3- titanium alloys – higher specific strength and higher temperature application, used as Biomedical, body implants & medical, aerospace .

4- copper alloy – high electrical & thermal conductivity, easy to form/cost, corrosion resistance, used in electronics, coins, wiring, circuit boards , electronic components.

5- nickel alloy – high temperature strength and creep resistance (super alloys) , used in Aerospace, Aircraft engines .

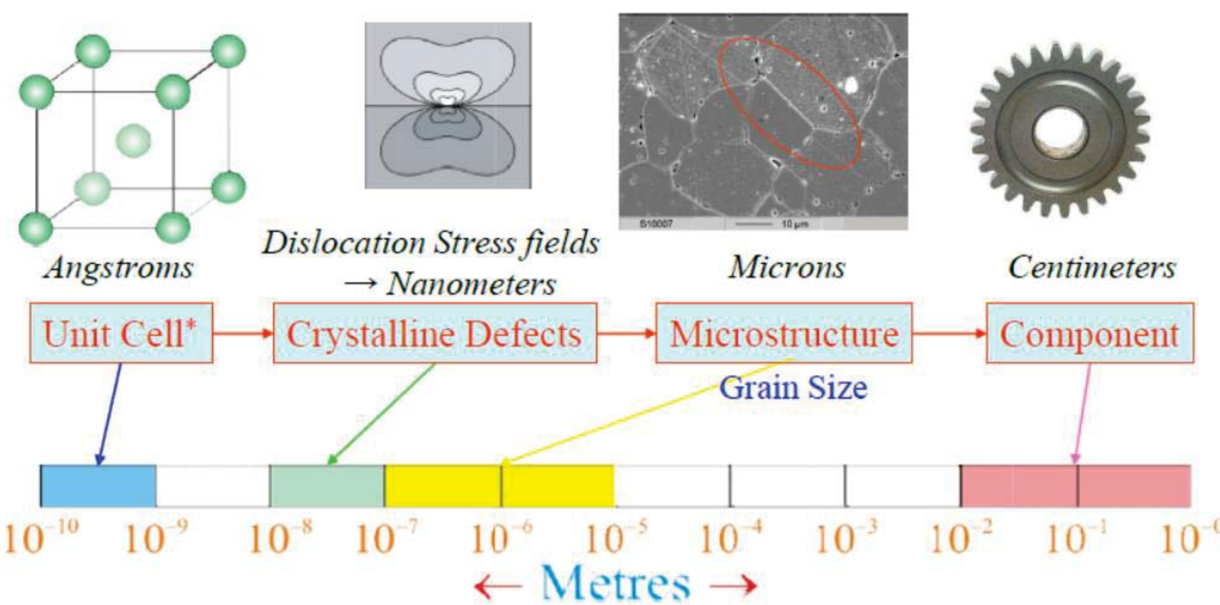
Chapter 2:Crystal And Micro-Structure of Metals And Alloys



- Vacancies
- Dislocations
- Twins
- Stacking Faults
- Grain Boundaries
- Voids
- Cracks

- Structure could imply two types of structure:
  - Crystal structure
  - Electromagnetic structure
- Microstructure can be defined as: (Phases + Defect Structure + Residual Stress) *and their distributions*

Let us start with a cursory look at the lengthscales involved in Materials Science



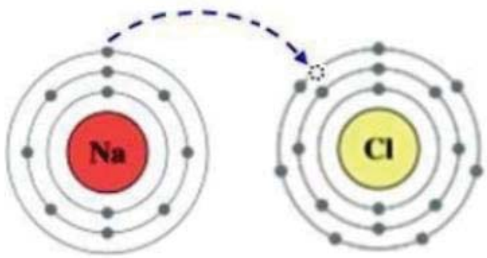
Atomic Bonding

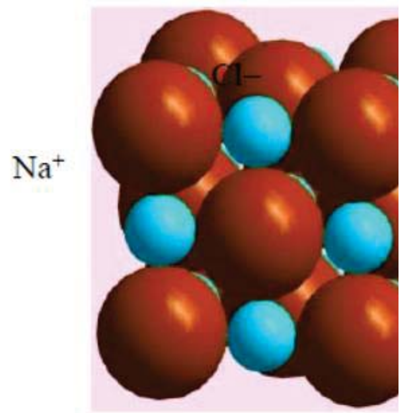
- The mechanisms of bonding between the atoms are based on the foregoing discussion on electrostatic inter- atomic interaction.
- The types of bond and bond strength are determined by the electronic structures of the atoms involved.
- The valence electrons take part in bonding. The atoms involved acquire, loose or share valence electrons to achieve the lowest energy or stable configuration of noble gases.
- Atomic bonding can be broadly classified as i) primary bonding ii) secondary bonding

- Majority of the engineering materials consist of one of these bonds. Many properties of the materials depend on the specific kind of bond and the bond energy.

Ionic Bond

- Ionic bonds are generally found in compounds composed of metal and non-metal and arise out of electrostatic attraction between oppositely charged atoms (ions).
- Number of electron in outer shell is 1 in Na and 7 in Cl . Therefore, Na will tend to reject one electron to get stable configuration of Ne and Cl will accept one electron to obtain Ar configuration.
- The columbic attraction between Na+ and Cl¯ ions thus formed will make an ionic bond to produce NaCl.

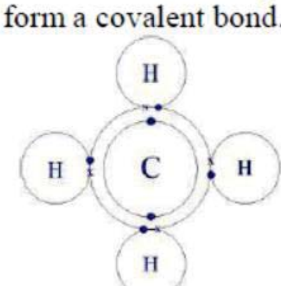


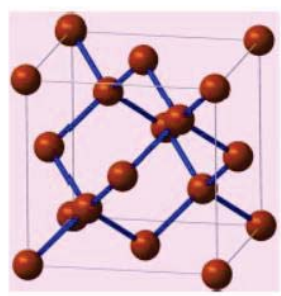


- Some other examples are CaF_2 , CsCl, MgO, Al_2O_3

Covalent Bond

- In this type of bonding, atoms share their valence electrons to get a stable configuration.
- Methane (CH_4): Four hydrogen atoms share their valence electrons with one carbon atom and the carbon atom in turn shares one valence electron with each of the four hydrogen atoms. In the process both H and C atoms get stable configuration and form a covalent bond.

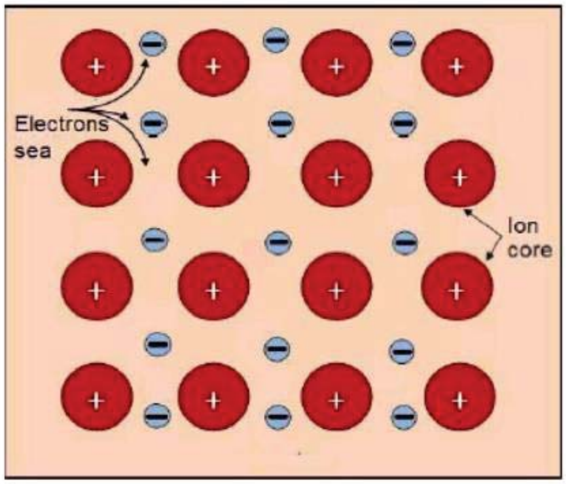




- Covalent bonds are formed between atoms of similar electro negativity.
- C atoms in diamond are covalently bonded to each other.
- Si also has valency of four and forms SiC through covalent bonding with C atoms.

Metallic Bond

- In metals the valence electrons are not really bound to one particular atom, instead they form a sea or cloud of valence electrons which are shared by all the atoms. The remaining electrons and the nuclei form what is called the ion core which is positively charged. The metallic bond arises out of the columbic attraction between these two oppositely charged species – the electron cloud and the ion cores.



Why study crystal structures?

- When we look around much of what we see is non-crystalline (organic things like wood, paper, sand; concrete walls, etc. → some of the things may have some crystalline parts!).
- But, many of the common 'inorganic' materials are *'usually*'* crystalline:
  - Metals: Cu, Zn, Fe, Cu-Zn alloys
  - Semiconductors: Si, Ge, GaAs
  - Ceramics: Alumina (Al_2O_3), Zirconia (Zr_2O_3), SiC, $SrTiO_3$
- Also, the usual form of crystalline materials (say a Cu wire or a piece of alumina) is polycrystalline and special care has to be taken to produce single crystals
- Polymeric materials are *usually* not 'fully' crystalline
- The crystal structure directly influences the properties of the material

Why study crystallography?

- Gives a terse (concise) representation of a large assemblage of species
- Gives the 'first view' towards understanding of the properties of the crystal