Materials are one of the important elements of a manufacturing system. Science the list of materials is large and is constantly increasing with new arrivals, this makes the task of selection of materials very difficult, it requires experience to choose a particular material.

The selected materials should meet the following:

1.The engineering requirements of the designers.

2.The manufacturing requirements of the manufactures.

3.The economics factor of the customer.

Engineering materials differ widely in:

1.Physical properties.

2.Mechanical properties.

3.Machinability characteristics.

4.Manufacturing methods.

All these points must be considered during the selection of a suitable material.

Engineers are involved with materials, having to select and use them and consider their behavior in use.

Engineering Materials aims to provide engineers with a basic knowledge of:

1.The properties which determine the uses that can be made of materials.

2.The structure of the materials.

3.The characteristics of ferrous and non-ferrous metals and of polymeric, ceramic and composite materials in relation to their structure so that an informed choice can be made materials.

4.The <u>methods</u> by which materials can be <u>processed</u>.

5.The <u>ways</u> by which materials can be fail.

6.<u>Criteria of selection</u> (material, process) for types of products.

Materials Classification:

A. To Original nature

1.Ferrous metallic materials ex; iron and its alloy.

2. Non-Ferrous metallic materials ex; Al, Cu, lead, Zinc.

3.Organic materials Ex; natural rubber, wood.

4.Synthetic materials ex; plastic.

B: To Engineering machining

1.Raw materials ex; coal, sand.

2.Semi- Raw materials ex; charcoal, iron ore.

3.Semi-finished materials ex; wire, aluminum plates.

4.Finished materials ex; engine parts, nails of various types.

C. To General classification

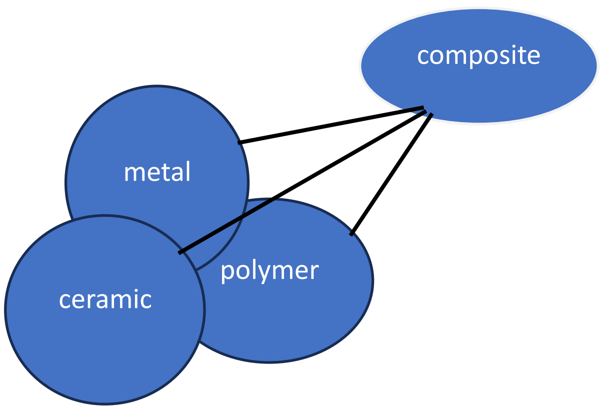
1.Metallic materials.

2.ceramic materials.

3.Polymers materials.

4.Composite materials.

5.Advanced material.



Note: Material that are utilized in high-technology application are sometimes termed Advanced Material. They may be of all materials types (metals, polymers and ceramics), examples; electronic equipment, computer, fiber-optic system, spacecraft, aircraft and military rocketry. The properties of these materials have been enhanced and developed to obtain high performance. They include;

1.Semiconductors: having electrical conductivities intermediate between conductors and insulators.

2.Biomaterials: which sense and respond to changes in their environments in predetermined manners.

3.Smart materials: which sense and respond to changes in their environments in predetermined manners.

4.Nano materials: Have structural features on the order of a nanometer (10^{-9}m) as a rule, less than 100 nanometer, some of which may be designed on the atomic/molecular level.

1.Metalic materials:

-Durable

-Fire proof

-Tough

-Have a relatively high stiffness and strength

-Harder to work

-Can be ductile and thus permit products to be made by being bent into shape, this means can fabricated and shaped by a broad of mechanical process.

-Rusts and corrodes

-Generally, have the highest densities

-Have high electrical conductivities and high thermal conductivities.

Engineering Metals: Are generally alloys being metallic materials formed by mixing two or more elements to improve the properties since pure metals are very weak materials for example;

Mild steel:(is an alloy of iron and carbon)/the carbon improves the strength of iron.

Stainless steel: (is an alloy of iron, chromium, carbon, manganese and possibly other elements)/chromium improves the corrosion resistance.

1.Metallic materials are classified as shown;

A/Ferrous materials;(iron based)

1.Carbon steel (plain carbon steel)

-Low (mild) carbon.

-High and ultrahigh carbon steel.

-Medium carbon steel.

2.Alloy steel (carbon steel alloyed with other elements)

-Nickel steel.

-Chromium steel.

-High speed steel.

3.Cast iron (alloy of iron and carbon 2.1- 4% and other elements:

Silicon, manganese, phosphor.

-White cast iron.

-Grey cast iron.

-Malleable cast iron.

-Ductile cast iron.

B/Non-Ferrous materials ;(not iron based)

1.Light alloys

Aluminum and its alloy (Al silicon alloy and duralumin), Magnesium, Titanium, Zinc.

2.Havey alloys

Copper and its alloy (bronze and brass), Lead, Nickel.

3.Refractory metals

Molybdenum, Tungsten, Chromium, Tantalum

4.Precious metals

Gold, Silver, Platinum

2.Ceramic Materials

-noisy

-good insulators.

-Easy to form while in a plastic state.

-withstand high temperature but difficult to form or modify after they have been fired or set.

-hard and tend to be brittle

-relatively stiff

-stronger in compression than tension

-Chemically inert

-Bad conductors of electricity and heat.

Ceramics are made by heating together materials such as silica, chalk and clays. Other chemicals may be included to act as flux and change color…. etc.

They can be grouped as follows;

1.Glasses: soda line glasses, borosilicate glasses, pyro ceramics.

2.Domestic: porcelain, vitreous China.

3.Engineering ceramics: alumina, carbides and nitrides.

4.Natural ceramics: rocks

5.Electromin materials: ferrites, semiconductors, ferroelectrics, super conducting ceramics.

3.Polymers materials

Have low electrical conductivity and low thermal conductivity.

When they compared with metals:

-have lower densities

-expand more when there is a change in temperature

-are generally more corrosion resistant

-have a lower stiffness

-strength more and are not hard

*Their properties depend very much on the temperature so that a polymer which may be tough and flexible at room temperature may be brittle at 0°c and show considerable creep at 100°c.

*Polymers are made from long chain molecules which may have cross linking bonds affecting flexibility /stiffness.

*There are three groups of polymers:

1.Thermoplastics:

-which may be reformed with heat (soften when heated and become hard again when the heat is removed)

-are generally flexible and relatively soft.

-examples; pvc, Hips, nylon, polycarbonate, PET, acrylic and polyethylene which being widely used as films or sheets for such items as bags, squeezy bottles, and cable insulation.

2.Thermosetting plastics

-which once moulded or formed (cannot be reformed by heat)

-are rigid and hard.

-examples; melamine (MF), epoxy resin, urea formaldehyde (UF) and phenol formaldehyde known as Bakelite is a thermoset widely used for electrical plug castings, door knobs and handles.

3.Elastomers

-rubbers long chain elastic molecules.

-examples; neoprene, natural rubber, used for car types and elastic bands.

4.Composite materials

Are mixtures of materials which give improved properties. One of the materials is called the matrix and the other is the reinforce.

Examples:

-composites involving glass fibers or particles in polymers.

-ceramic particles in meals

-steel rod in concrete (reinforced concrete)

-Wood is a natural composite consisting of tubes of cellulose in a polymer called Lignin.

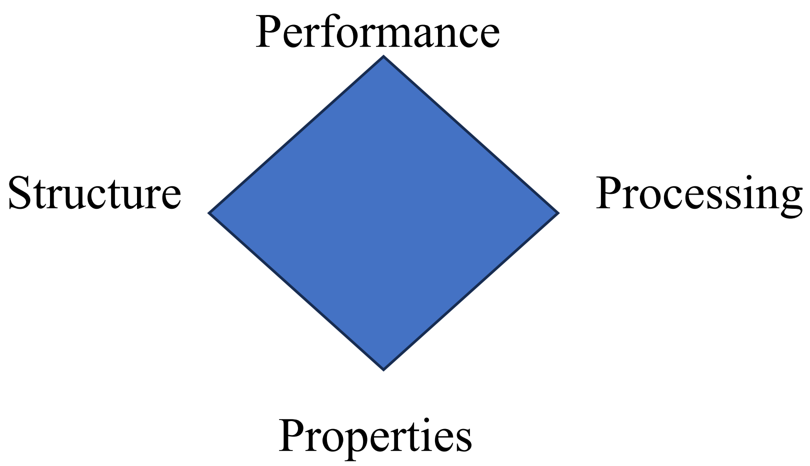
*Composites can be designed to combine the good properties of different types of materials while avoiding some of their draw backs.

Type of Carbon steel	**Carbon content**	**Properties**	**Usage**
Low (mild)Carbon Steel	0.05%-0.29%	-low tensile strength -cheap and malleable -surface hardness can be increased through carburizing	As structural steel
Medium Carbon Steel	0.3%-0.59%	Balances ductility and strength has good wear resistance	Forging and automotive components
High and Ultra -High Carbon Steel	0.6%-0.99% 1.0%-2.0%	-Very strong -Steels that can be tempered to great hardness	-Springs and high-strength wires -special purposes like Knives, axles or punches.

Types of Alloy Steel	Nickel Content	Effect of Alloying Elements	Usage
Nickel Steel	Up to 6%	Usually, to assist hardening during formation	Armor plates
Chromium Steel	A minimum of 11.5 wt. %	To make it resistant to stain, corrosion and rust	Common uses of stainless steel are cutlery and watch straps
High Speed Steel	Alloying composition of high-speed steel grades	To maximize efficiently the hardness and toughness of high speed steels and maintains these properties at the high temperatures generated when cutting metals.	HSS is a material usually used in the manufacture of machine tool bits and other cutters. It is often used in power saw blades and drill bits.

Types of Cast Iron	Properties	Usage
White Cast Iron	Lower silicon content and faster cooling. White iron is too brittle for uses in many structural components, but with good hardness and abrasion resistance and relatively low cost.	Bearing surface
Grey Cast Iron	Grey cast iron has less tensile strength and shock resistance than steel. It is also difficult to weld. Grey cast iron has high thermal conductivity and specific heat capacity.	Engine blocks, fly-wheels, gears, machine -tool bases
Malleable Cast Iron	In general, the properties of malleable cast iron are more like mild steel	Axle bearings, track wheels, automotive crankshafts
Ductile Cast Iron	The properties are similar to malleable iron but parts can be cast with larger sections.	Gears, cams, crankshafts

Material science is the investigation of the relationship among processing, structure, properties and performance of materials.



Processing the structure to achieve specific properties of materials.

Processing (designing or engineering the structure)

Means; changes to structure and desired shape by different ways for shaping materials into useful components (via casting, annealing, joining, sintering, mechanical …)

***Materials Properties**: their behavior as a response to environments and different applied conditions, (Physical, Mechanical, Thermal, Electrical, Magnetic, Optical, Corrosive…).

***Materials Performance**: Strength to weight ratio, Formability, cost.

The success or failure of many engineering activities depends on the selection of engineering materials whose properties match match the specific requirements of the applications.

The engineering properties of a material are a direct result of the structure of that material. Changes in the properties therefore, are the direct result of changes in the structure.

Structure:

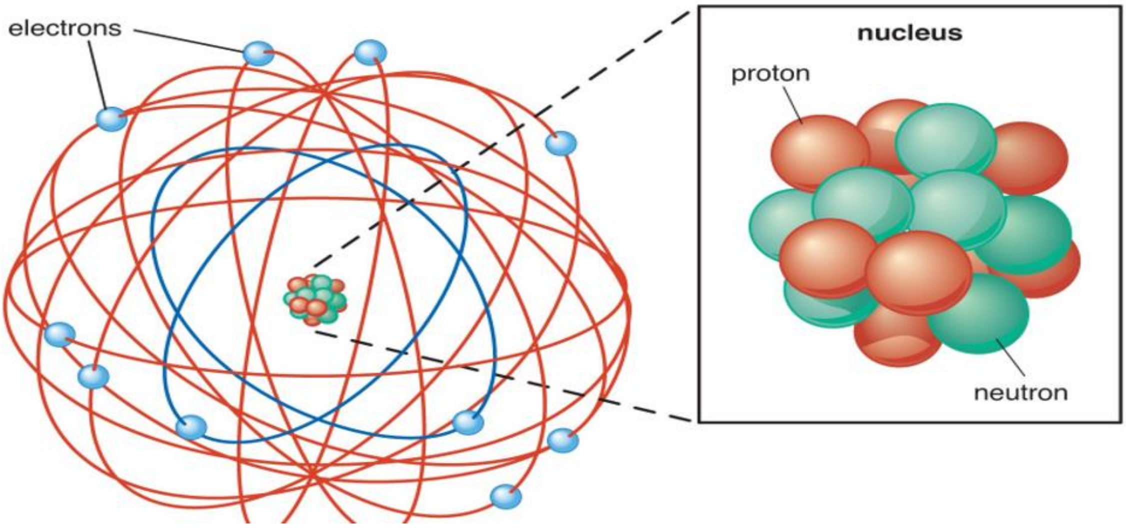
Structure means a description of the arrangements of atoms or ions in a material.

Atomic structure:

Atoms are the building blocks of the matter; they are linked or bonded to other atoms in some manner as a result of interatomic forces. The electron structure of the atoms plays a strong role in determining the nature of the bond.

Atom: is the littlest unit of the matter that is composed of three subatomic particles; the proton, the neutron and therefore the electron.

-Atoms consist of a massive positively charged small central part called nucleus.



-The nucleus contains protons (positively charged) and neutrons (uncharged).

-The electrons revolve around the nucleus in definite circular paths. These circular paths are called shells or orbits.

-Each orbit has fixed energy. Therefore, these orbits are also known as energy shells.

Types of bonding

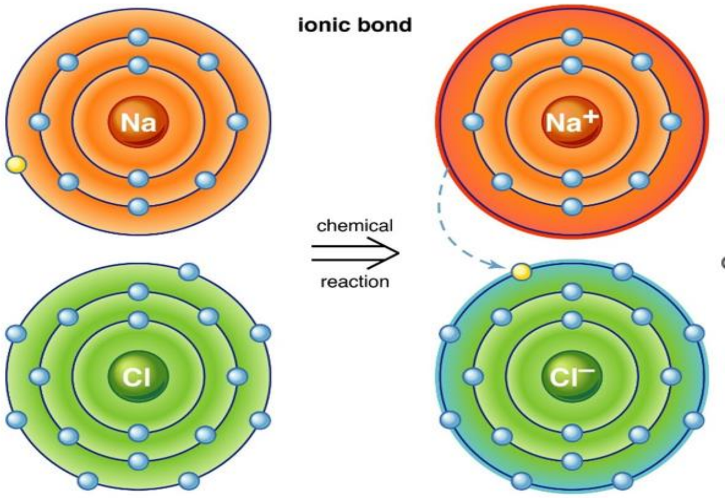
1-Primary bonding: electrons (e-) are transferred or shared, strong (100-1000 KJ/mol)

1.Ionic bond: strong Coulomb interaction among negative atoms (have an extra each) and positive atoms (lost an electron). It is meaning: valence electrons are transferred from one atom to the other to complete the outer electron shell.

-The ionic bond is the electrostatic force of attraction between a positively charged metal ion and a negatively charged non-metal ion.

-The atom that loses the electron becomes a positively charged ion (cation), while the one that gains them becomes a negatively charged ion(anion).

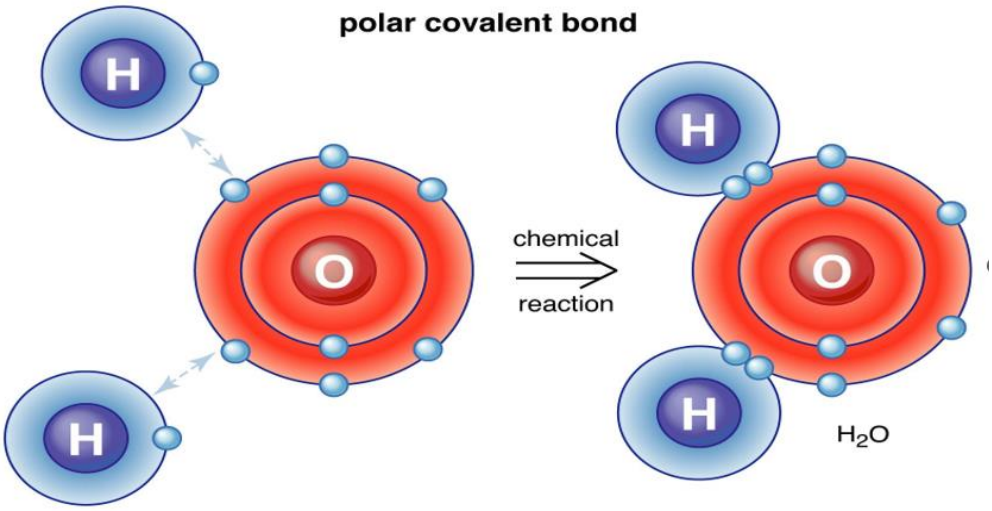
-Ionic bonds are formed between a metal and nonmetal. Example: Na+Cl.



2.Covalent bond: electrons are shared between the molecules, to saturate the valency. Example-H_2O.

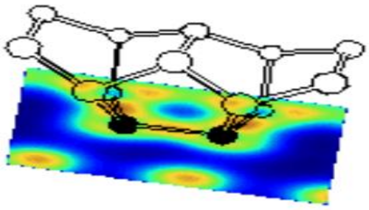
-A covalent bond is formed by equal sharing of electrons from both the participating atom. The pair of electrons participating in this type of bonding is called shared pair or bonding pair.

-The covalent bonds are also termed as molecular bonds. Sharing of bonding pairs will ensure that the atoms achieve stability in their outer shell which is similar to the atoms of noble gases.

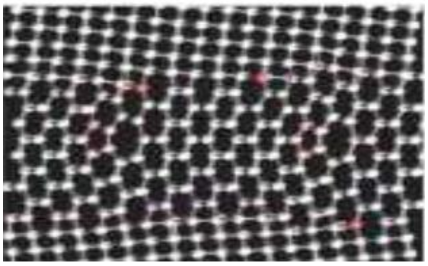


Atomic levels:

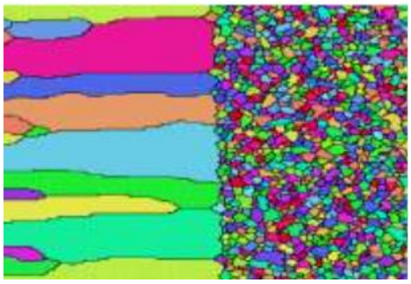
-Subatomic level; (electrons and nuclei (protons and neutrons). Electronic structure of individual atoms that defines interaction among atoms (interatomic bonding) <0.2nm.



-Atomic level;(organization of atoms or molecules) arrangement of atoms in materials (for the same atoms can have different properties, e.g two forms of carbon: graphite and diamond) 0.2 – 10 nm.



-Microscopic structure; (groups of atoms that are normally agglomerated together). Arrangement of small grains of material that can be identified by microscopy 1- 1000 µm.



-Macroscopic structure (Bulk); viewable with the un-aided eye. structural elements that may be viewed with the naked eye >1mm

Length scale

Angstrom=1Ǻ = 1/10.000.000.000 meter =10^{-10} m

Nanometer = 10nm = 1/1.000.000.000 meter = 10^{-9} m

Micrometer = 1μm = 1/1.000.000 meter = 10^{-6} m

Millimeter = 1mm =1/ 1.000 meter = 10^{-3} m

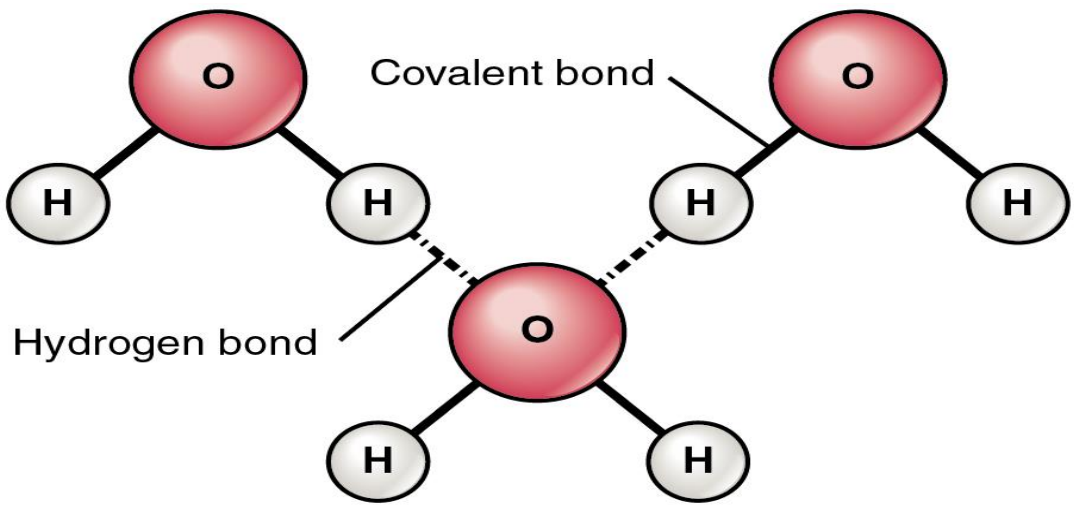
2- Hydrogen bonding

-interaction involving a hydrogen atom located between a pair of other atoms having a high affinity for electrons.

- Such a bond is weaker than an ionic bond or covalent bond but stronger than van der waals forces.

-Hydrogen bonds can exit between atoms in different molecules or in parts of the same molecule. One atom of the pair (the donor), generally a fluorine, nitrogen or oxygen atom, is covalently bonded to a hydrogen atom (-FH, - NH, or -OH), whose electrons it shares unequally: its high electron affinity causes the hydrogen to take on a slight positive charge. The other atom of the pair, also typically F, N, or O, has an unshared electron pair, which gives it a slight negative charge.

-Mainly through electrostatic attraction, the donor atom effectively shares its hydrogen with the acceptor atom, forming a bond.



Amorphous VS Crystal

Amorphous	Crystal
Irregular pattern of ions, molecules or atoms in a solid	Regular and repeating arrangement of components in a solid
Melt over a range of a temperature	Have a sharp melting point
No definite heat fusion	Definite heat fusion
Example; glass	Example; diamond
Called isotropic	Called anisotropic

Materials Class	**Predominant Type of Bonding**	**Microstructure**	**Advantages**
Metals & Alloys	Metallic	Crystalline Amorphous	Strong Ductile Conductive
Polymers	Mixed (covalent &secondary)	Chain molecules Networks Amorphous	Low cost Light weight Resist corrosion
Ceramics & Glasses	Ionic, covalent or Mixed (ionic-covalent)	Crystalline Amorphous	Strong, stiff,hard Resist creep Resist corrosion
Intermetallic	Mixed metallic with some ionic and covalent character	Crystalline Amorphous	Strong,stiff,hard Resist creep Resist corrosion Light weight
Composites	various	Matrix+ fibers Matrix +particles Etc	Strong, stiff Light weight

Crystal Structure of Metals

-Metals are an extremely important class of materials.

-More than 50 of known chemical elements are classified as metals and about 40 have commercial importance.

-Metals are characterized by the metallic bond.

-Metals have distinct properties compared with Non-Metals in terms of ;

Strength, good electrical and thermal conductivity, Luster, Ability to be plastically deformed to a fair degree without fracture(ductile), Have a relatively high specific gravity (high density).

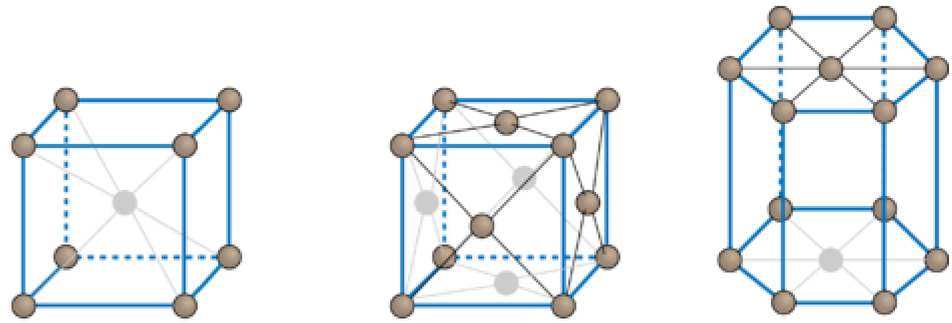
-Above their melting point, metals are liquids and their atoms are randomly arranged and relatively free to move. However, when cooled below their melting point, metals rearrange to form ordered crystalline, three crystal structures favored by metals are;

(a) body – centered cubic (BCC)

(b)face- centered cubic (FCC)

(c) hexagonal close -packed (HCP)

A number of metals are shown below with their room temperature crystal structure indicated structures.



Cubic body centered (bcc) *Fe, V, Nb, Cr*

Cubic face centered (fcc) *Al, Ni, Ag, Cu, Au*

Hexagonal *Ti, Zn, Mg, Cd*

Atom Arrangement in Materials

The particular arrangement of the atoms has a significant effect on the material properties. Depending on the manner of atomic grouping, materials are classified as having;

1.Molecular structures

-Molecule consists of a certain number of atoms, of the same type or of different types, linked to each each other by primary bonds.

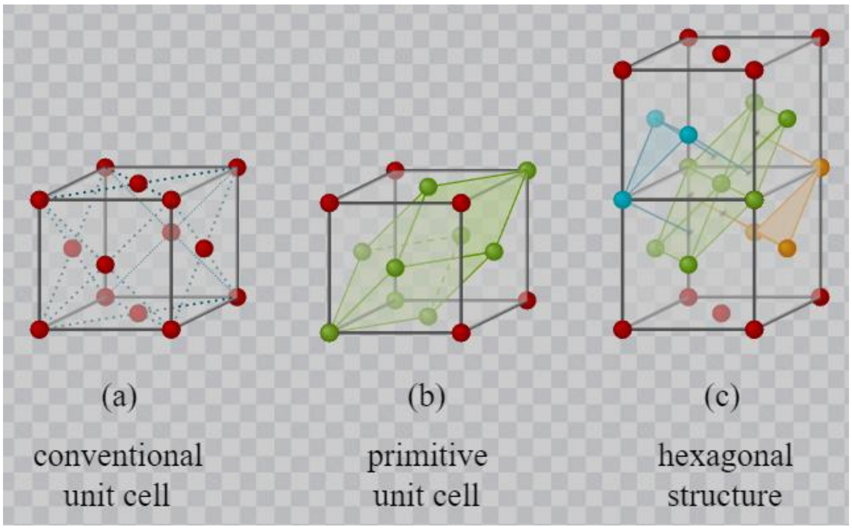
-Molecular materials tend to be weak; they have only weak attraction, however, to other similar groupings and exhibit relatively low melting and boiling points.

-Typical examples of molecules include O_2, H_2O and C_2H_4

2-Crystal structures

-A crystalline material consists of primarily organized crystal structure which is defined as the particular repeating arrangement of atoms (molecules or ions) in a pattern that is repetitive in three dimensions.

-Each crystal structure within a specific crystal system is defined by a unit cell. A unit cell is the smallest repeatable subsection of the crystal.

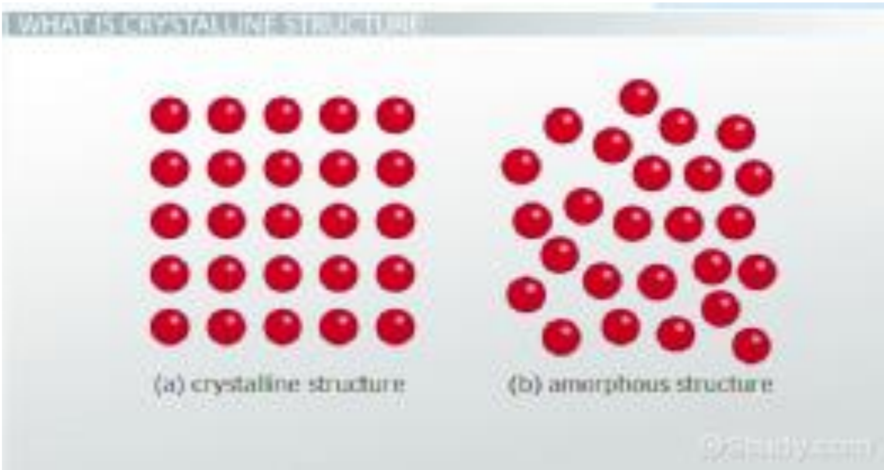


3-Amorphous structures;

-An amorphous structure has no organization (not a crystalline structure)

-Amorphous materials are characterized by atomic or molecular structures that are relatively complex and become ordered only with some difficultly.

-These materials are commonly prepared by rapidly cooling molten material.



2-Secondary Bonding

No electrons (e-)transferred or shared Interaction of atomic/molecular, dipoles weak (<100 KJ/mol)

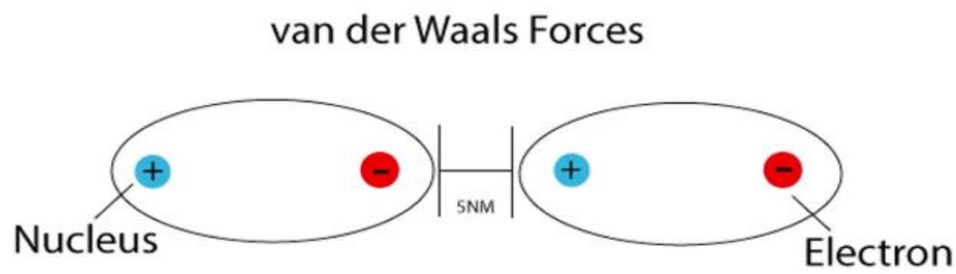
-secondary bonds are weak in comparison to primary bonds.

-They are found in most material, but their effects are often overshadowed by the strength of the primary bonding.

-Secondary bonds are not bonds with a valence electron being shared or donated. They are usually formed when an uneven charge distribution occurs. Creating what is known as a dipole (the total charge is zero, but there is slightly more positive or negative charge on one end of the atom than on the other).

Van Der Waals Bonding

Van der waals forces are weak intermolecular forces that are dependent on the distance between atoms or molecules. These forces arise from the interactions between uncharged atoms/ molecules.



3.Metallic bond: the atoms are ionized, losing some electrons from the valence band. Those electrons from an electron sea, which binds the charged nuclei in place.

*Metallic bond is a term used to describe the collective sharing of a sea of valence electrons between several positively charged metal ions. Metallic bonding is a type of chemical bonding and is responsible for several characteristic properties of metals such as their shiny luster, their malleability, and their conductivities for heat and electricity.