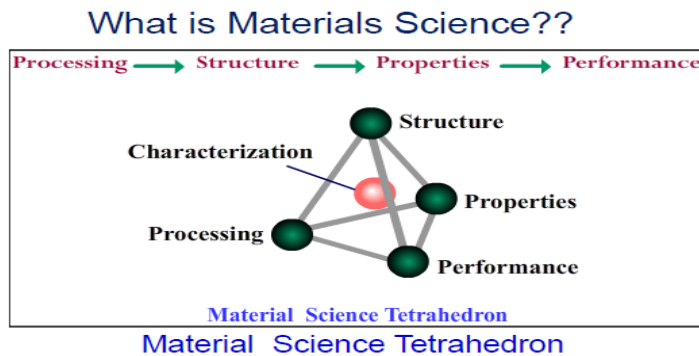
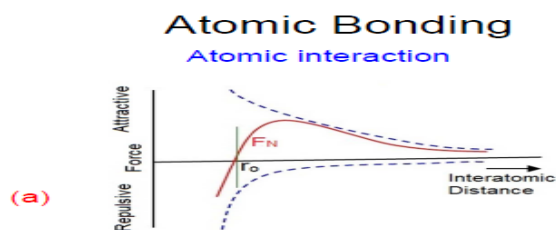


Stream: ECE
Paper Name: Material Science & Engineering
EC605 B

MODULE – I



Material Science can be broadly defined as correlation between microstructure and properties.



- When two neutral atoms are brought close to each other, they experience attractive and or repulsive force
- Attractive force is due to electrostatic attraction between electrons of one atom and the nucleus of the other.

Atomic Bonding

- The mechanisms of bonding between the atoms are based on the foregoing discussion on electrostatic interatomic 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, lose 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

Primary Bonds

Three types primary bonds are found in solids:

- o Ionic
- o Covalent
- o Metallic

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.

Crystalline – periodic arrangement of atoms: definite repetitive pattern Non-crystalline or Amorphous – random arrangement of atoms.

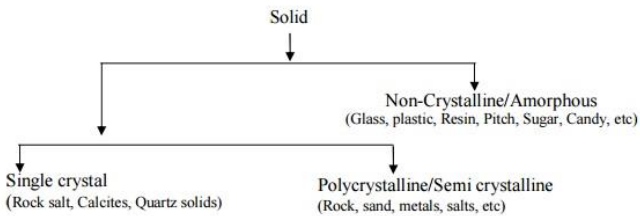
The periodicity of atoms in crystalline solids can be described by a network of points in space called lattice.

Crystalline and Non-crystalline solids:

This can be subdivided into two states-solid and fluid, of which the later is subdivided into liquid and gaseous state. It can also be subdivided into condensed stated and gaseous state where condensed state is subdivided into the solid and liquid state. Although very little of the matter in the universe is in the solid state, solids constitute much of the physical world around us and a large part of the modern technology is based on the special characteristics of the various solid materials.

Crystalline and non-crystalline (Amorphous Solids):

Nature favors the crystalline state of the solids, because the energy of the ordered atomic arrangement is lower than that of an irregular packing of atoms.



Crystalline Solids:

A solid in general is said to be a crystal if the constituent particles (atoms, ions or molecules) are arranged in a three-dimensional periodic manner or simply it has a reticular structure. In crystalline solids the atoms are stacked in a regular manner, forming a 3-D pattern which may be obtained by a 3-D repetition of a certain pattern unit. It has long-range orderings and thus has definite properties such as sharp melting point. Thus, we can say, crystal is a three-dimensional periodic array of atoms. When the crystal grows under constant environment, the external geometrical shape of the crystal often remains unchanged. Thus, the shape is a consequence of the internal arrangement of constituent particles. The ideal crystal has an infinite 3D repetition of identical units, which may be atoms or molecules. All ionic solids and most covalent solids are crystalline. All solid metals, under normal circumstances, are crystalline.

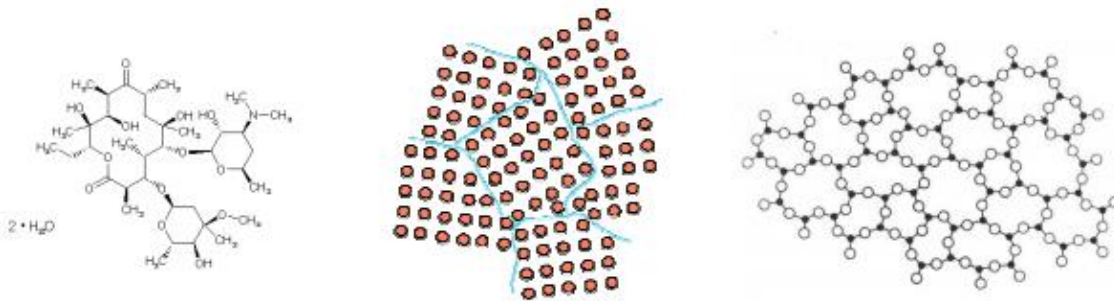
Single crystal:

Solid Non-Crystalline/Amorphous (Glass, plastic, Resin, Pitch, Sugar, Candy, etc) Single crystal (Rock salt, Calcites, Quartz solids) Polycrystalline/Semi crystalline (Rock, sand, metals, salts, etc) Crystalline and Non-crystalline solids 2 When the periodicity in crystal pattern extends throughout a certain piece of materials, one speaks of a single crystal or unit crystal or mono-crystal. Rock salt, calcites, quartz, etc. are examples of common single crystal.

Polycrystalline solids (Polymorphism):

When the periodicity in the crystal structure is interrupted at so-called grain boundaries, the crystal is said to be polycrystalline. In this case the size of the grains or crystallites is smaller than the size of the pattern unit which forms the periodicity. The size of the grain in which the structure is periodic may vary from macroscopic dimensions to several angstroms. In general, the grains in such a solid are not

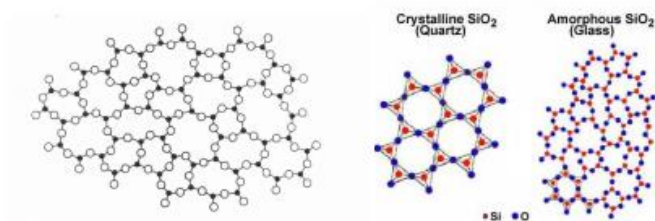
related in shape to the crystal structure, the surface being random in shape rather than well defined crystal planes. Rock, sand, metals, salts, etc. are some examples of polycrystalline solids.



Single crystal, polycrystalline, amorphous [1]

Nanocrystalline solids:

It is the opposite extreme of a single crystal. These types of solids have neither reticular nor granular structure. At most cases exhibit short range orderings in their structure. Glass and plastic are common example of this class. When the size of the grains or crystallites becomes comparable to the size of the pattern unit, we speak of amorphous substances. A typical feature of these substances is that they have no definite melting points. As their temperature is increased, they gradually become soft; their viscosity drops, and begins to behave like ordinary viscous liquids. Amorphous solids have no long-range order. The atoms or molecules in these solids are not periodically located over large distances. An amorphous structure is shown below.



Different crystal structures [1]

Many amorphous materials have internal structures similar to liquids. In fact, the only obvious distinction between amorphous materials, such as glass, and liquids is the high viscosity (resistance to flow) of the amorphous solids. All solids tend to exist in the crystalline state rather than the amorphous state because the crystalline structure always has a larger binding energy. However, in numerous instances amorphous solids are formed when liquids are cooled below the melting temperature.

This occurs for two reasons:

- 1) The structure of the molecules is so complex that they cannot easily rearrange themselves to form a crystalline structure, and/or
- 2) The solid forms so rapidly that the atoms or molecules do not have time enough to rearrange themselves in a crystalline structure.

Generally, amorphous solids have one of two distinct atomic arrangements: either a tangled mass of long-chained molecules or a 3-dimensional network of atoms with no long-range order. Amorphous materials with long-chained molecules (e.g. polymers) have a structure similar to that shown below.



arrangement of molecules for two different materials [1]

Each segment in above figure represents one of the repeating units of the polymer chain. The arrangement of the molecules is fairly random, resulting in a loosely packed structure. Network amorphous solids are usually Oxides, the most common being Silica (SiO_2). The amorphous SiO_2 structure is also shown above. Only oxygen atoms are shown (corners of tetrahedral) in this amorphous SiO_2 structure. There is a Silicon atom at the center of each tetrahedral which is not shown here. This structure has short-range order but none of the long-range order found in crystalline Silica. Thus, in both amorphous and crystalline Silica, each Silicon atom and each Oxygen atom have essentially the same local surroundings, even though there is no long-range periodicity in the amorphous structure.

Solids that do not have long range atomic order are called amorphous solids. They often have subunits that have consistent form, but their long-range order is disturbed because the sub-units pack randomly. Amorphous solids are formed when liquids are cooled too quickly from the molten state to allow the sub-units to arrange themselves in the low energy, crystalline state. Solids with pure ionic bonds do not form amorphous solids but all the other bond types can produce amorphous solids. Silica (SiO_2) can form either covalent amorphous solids, usually called glasses or regular crystal structures (Quartz).

Crystal Planes and Miller Indices:

Index system for crystal directions and planes Crystal directions: The direction is specified by the three integers $[n_1n_2n_3]$. If the numbers $n_1n_2n_3$ have a common factor, this factor is removed. For example, $[111]$ is used rather than $[222]$, or $[100]$, rather than $[400]$. When we speak about directions, we mean a whole set of parallel lines, which are equivalent due to translational symmetry. Opposite orientation is denoted by the negative sign over a number. For example:

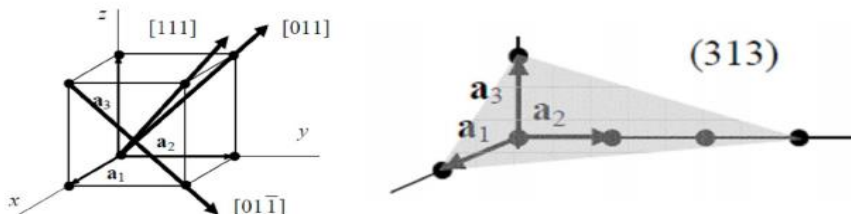


Figure 4: Crystal planes

Crystal planes:

The orientation of a plane in a lattice is specified by Miller indices. They are defined as follows. We find intercept of the plane with the axes along the primitive translation vectors a_1 , a_2 and a_3 . Let's these intercepts be x , y , and z , so that x is fractional multiple of a_1 , y is a fractional multiple of a_2 and z is a fractional multiple of a_3 . Therefore, we can measure x , y , and z in units a_1 , a_2 and a_3 respectively. We have then a triplet of integers $(x\ y\ z)$. Then we invert it $(1/x\ 1/y\ 1/z)$ and reduce this set to a similar one having the smallest integers by multiplying by a common factor. This set is called Miller indices of the plane (hkl) . For example, if the plane intercepts x , y , and z in points 1, 3, and 1, the index of this plane will be (313) . The orientation of a crystal plane is determined by three points in the plane, provided they are not collinear. If each point lay on a different crystal axis, the plane could be specified by giving the coordinates of the points in terms of the lattice constants a , b , c . A notation conventionally used to describe lattice points (sites), directions and planes is known as Miller Indices. A crystal lattice may be considered as an assembly of equidistant parallel planes passing through the lattice points and are called lattice planes. In order to specify the orientation, one employs the so-called Miller indices. For simplicity, let us start with a two-dimensional lattice and then generalized to three-dimensional case. The equation of plane in 2-D and 3D having the intercepts a , b and a , b , c respectively is

$$(x/a) + (y/b) = 1$$

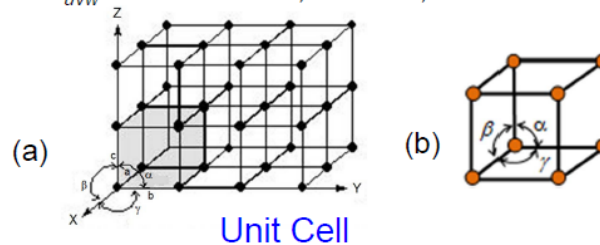
And

$$(x/a) + (y/b) + (z/c) = 1$$

Crystal direction is the direction (line) of axes or line from the origin and denoted as $[111]$, $[100]$, $[010]$ etc.

Crystal Systems

- The space lattice points in a crystal are occupied by atoms.
- The position of any atom in the 3D lattice can be described by a vector $r_{uvw} = ua + vb + wc$, where u , v and w are integers.



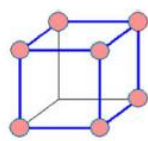
The three unit vectors, a , b , c can define a cell as shown by the shaded region in Fig.(a) This cell is known as unit cell (Fig. b) which when repeated in the three dimensions generates the crystal structure.

Bravais Lattice

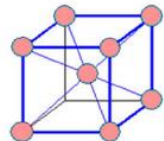
The unit vectors a , b and c are called lattice parameters. Based on their length equality or inequality and their orientation (the angles between them, α , β and γ) a total of 7 crystal systems can be defined. With the centering (face, base and body centering) added to these, 14 kinds of 3D lattices, known as **Bravais lattices**, can be generated.

Crystal Systems

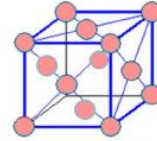
Cubic: $a = b = c, \alpha = \beta = \gamma = 90^\circ$



Simple cubic

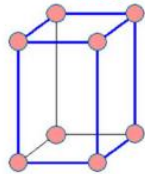


Body-centered cubic (BCC)

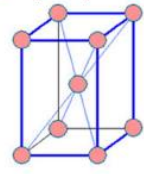


Face-centered cubic (FCC)

Tetragonal: $a = b \neq c, \alpha = \beta = \gamma = 90^\circ$



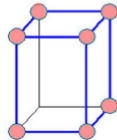
Simple Tetragonal



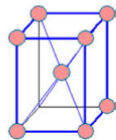
Body-centered Tetragonal (BCT)

Crystal Systems

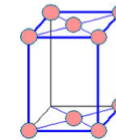
Orthorhombic: $a \neq b \neq c, \alpha = \beta = \gamma = 90^\circ$



Simple



Body-centered

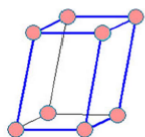


Base-centered

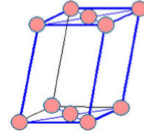


Face-centered

Monoclinic: $a \neq b \neq c, \alpha = \gamma = 90^\circ \neq \beta$

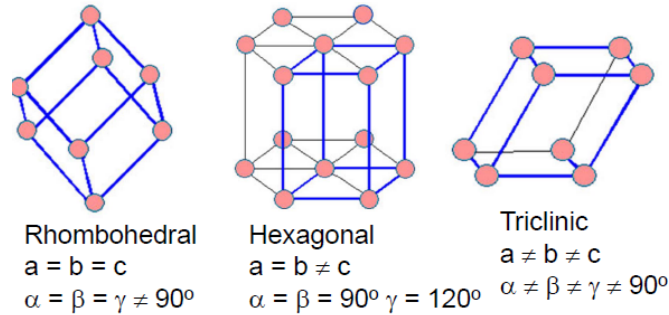


Simple monoclinic

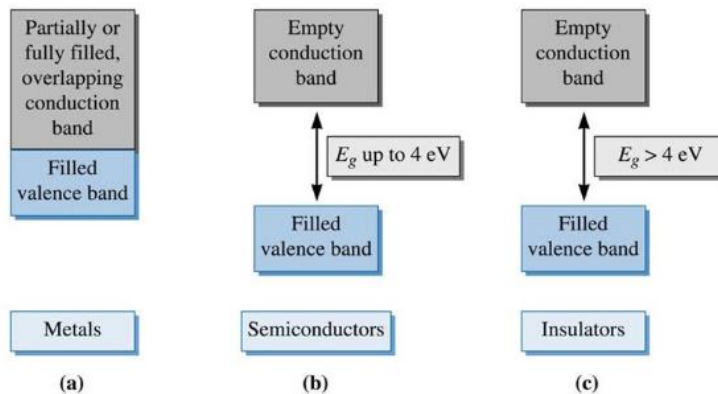


Base-centered monoclinic

Crystal Systems



Crystal system	Example
Triclinic	$K_2S_2O_8, K_2Cr_2O_7$
Monoclinic	$As_4S_4, KNO_3, CaSO_4 \cdot 2H_2O, \beta\text{-S}$
Rhombohedral	Hg, Sb, As, Bi, $CaCO_3$
Hexagonal	Zn, Co, Cd, Mg, Zr, NiAs
Orthorhombic	Ga, $Fe_3C, \alpha\text{-S}$
Tetragonal	In, $TiO_2, \beta\text{-Sn}$
Cubic	Au, Si, Al, Cu, Ag, Fe, NaCl



Engineering Material Selection Parameters for Mechanical Design – Material Selection Parameters for Design Engineers

It is the mechanical design engineer's responsibility to do the material selection right the first time. In fact, the competitiveness of a design depends largely on material selection. Moreover, end users never specify the material of the product. Following are five important parameters that largely influence the engineering material selection process.

Mechanical properties Young's modulus, yield strength, and the Poisson ratio are some of the mechanical properties that lead you to select a suitable material for a particular application. Most of the time you can obtain the required mechanical property values from mechanical design calculations or from the FEA packages.

Physical Properties: The properties like density, boiling point, melting point, and freezing points are called the physical properties of material. But, unlike mechanical properties, the physical properties values of a material are not obtained from the design calculation, but need to be decided based upon atmospheric conditions.

Electrical Properties: For designing electromechanical or electrical systems, various electrical properties like resistivity, permeability, conductivity, etc. will influence your engineering material selection process. For example, for the windings of a motor, copper or aluminum would need to be selected.

Manufacturability: The raw material you have selected for your design needs to shape up as per your design requirements, and here manufacturability comes into picture. Rather than a material selection factor, the manufacturability can be termed a bottleneck. For example, you need a part to be made by casting and you then select stainless steel, which is probably not the best selection.

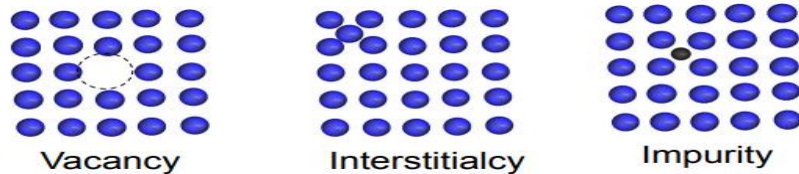
Cost: Cost is the most important factor for every part of any business and nothing different in the case of material selection. For example, you can afford to use costly lightweight composites for aerospace applications, but not for automotive applications.

Engineering material selection process is one of the most important steps for a competitive mechanical design. And much of the selection process involves trade-offs among the different parameters. Various charts are available for comparing different parameters with respect to others. These charts are helpful for doing the trade-off optimally.

Lattice defects-Qualitative ideas of point, line, surface and volume defects.

POINT DEFECTS

A point defect disturbs the crystal pattern at an isolated site. It is useful to distinguish intrinsic defects, which can appear in a pure material, from extrinsic defects, which are caused by solute or impurity atoms.



LINE DEFECTS: DISLOCATIONS:

Dislocations are linear defects; they are lines through the crystal along which crystallographic registry is lost. Their principle role in the microstructure is to control the yield strength and subsequent plastic deformation of crystalline solids at ordinary temperatures. Dislocations also participate in the growth of crystals and in the structures of interfaces between crystals. They act as electrical defects in optical materials and semiconductors, in which they are almost always undesirable.

Point defects



VOLUME DEFECTS

Volume defects in crystals are three-dimensional aggregates of atoms or vacancies. It is common to divide them into four classes in an imprecise classification that is based on a combination of the size and effect of the particle.

The four categories are: precipitates, which are a fraction of a micron in size and decorate the crystal; second phase particles or dispersants, which vary in size from a fraction of a micron to the normal grain size (10-100 μm), but are intentionally introduced into the microstructure; inclusions, which vary in size from a few microns to macroscopic dimensions, and are relatively large, undesirable particles that entered the system as dirt or formed by precipitation; and voids, which are holes in the solid formed by trapped gases or by the accumulation of vacancies.

Bulk defects



Weld defect



Casting defect



Shrinkage cavity

MODULE – II

Electrical conduction

Materials are classified based on their electrical properties as conductors, semiconductors and insulators. Electrical conductivity of a material is defined in terms of ease of charge flow through it. Charge that flows comprised of either electron, ions, charged holes, and their combinations.

Electrical conduction in polymers

Polymers are, in general, insulators. They can be made conductors in two ways: (1) introducing an additive to the polymer to improve conductivity and (2) creating polymers with inherent conductivity.

- (1) Adding ionic compound or Introducing conductive fillers such as carbon black.
- (2) Inherent conductivity by doping.

Ex.: poly para phenylene, poly pyrrole, poly aniline, acetal polymers.

Some other polymers such as poly phthalo cyanine can be cross-linked by special curing processes to raise its conductivity.

Dielectric behavior concept

- Dielectric is a material separating two charged bodies. For a material to be a good dielectric, it must be an electrical insulator. Dielectric materials are used in capacitors, devices used to store the electric energy.
- Energy stored, Q , between two plates having area, A , charged by voltage, V , separated at a distance, l , in vacuum is given by
$$Q = CV \quad C = \epsilon_0 \frac{A}{l}$$
where ϵ_0 – permittivity of vacuum (8.85 X 10⁻¹² F/m)
- For a dielectric material, $\epsilon = \epsilon_r \epsilon_0$
- ϵ_r value is always greater than '1', as a result of polarization.

Polarization

- Four types of polarization: electronic, ionic (atomic), orientation, and space charge (interfacial).
- Electronic polarization arises because the center of the electron cloud around a nucleus is displaced under an applied electric field.
- Ionic polarization occurs in ionic materials because an applied field acts to displace cations in the direction of the applied field while displacing anions in a direction opposite to the applied field.
- Orientation polarization can occur in materials that possess permanent electric dipole moments. These permanent dipoles tend to become aligned with the applied electric field, but entropy and thermal effects tend to counter this alignment, thus it is highly temperature dependent.
- Space charge polarization results from the accumulation of charge at structural interfaces in heterogeneous materials. Such polarization occurs when one of the phases has a much higher resistivity than the other.

Dielectric strength

- At high enough frequencies, the dielectric will experience electrical breakdown initiated by the field-induced excitation of a number of electrons into the conduction band, and the insulator become a conductor. The magnitude of the electric field required to cause dielectric breakdown is called the *dielectric strength* or *breakdown strength*.
- Many ceramics and polymers are utilized as insulators and in capacitors. For example: glass, porcelain, stealite, mica. These have dielectric constants within the range of 6-10. Typical applications: electrical insulation, switch bases, light receptacles.
- Dielectric constant for most polymers lies in the range of 2-5, less than that for ceramics, since the later exhibit greater dipole moments. Typical applications: insulation for wires, cables, motors, generators, some capacitors.

Ferro-electricity

- Ferro-electricity is defined as the spontaneous alignment of electric dipoles by their mutual interaction in the absence of an applied electric field.
- It arises from the fact that the local field increases in proportion to the polarization. Thus, ferro-electric materials must possess permanent dipoles.
Ex.: BaTiO₃, Rochelle salt (NaKC₄H₄O₆·4H₂O), potassium dihydrogen phosphate (KH₂PO₄), potassium niobate (KNbO₃).
- These materials have extremely high dielectric constants at relatively low applied field frequencies. Thus, capacitors made from ferro-electric materials are smaller than capacitors made of other dielectric materials.

Piezo-electricity

- Piezo-electricity, *or* pressure electricity, is defined as polarization induced by the application of external force.
- Thus by reversing the direction of external force, direction of the field can be reversed i.e. the application of an external electric field alters the net dipole length and causes a dimensional change.
- Hence piezo-electric materials are useful as transducers – devices that convert mechanical stress into electrical energy and vice versa.
- Application for these materials includes microphones, ultrasonic generators, sonar detectors, and mechanical strain gauges.
Ex.: Barium titanate, lead titanate, lead zirconate (PbZrO₃), ammonium dihydrogen phosphate (NH₄H₂PO₄), and quartz.

Pyroelectric materials: Pyroelectric materials possess a spontaneous polarization along a unique crystallographic direction which may or may not be reversible by changing the polarity of the applied field. If the latter is true, then a pyroelectric material is also ferroelectric. If it is ferroelectric material too, then the material can either be in a single crystalline state or in a poled state.

Pyroelectricity, in itself, is the ability of materials to generate a voltage when they are heated or cooled. It is temperature dependence of the spontaneous polarization in polar materials due to minute changes in the atomic positions as a result of change in the temperature. If the temperature is constant, then voltage gradually disappears due to leakage of charges through the material or air or the apparatus. Change in the polarization on a sample surface can be measured as an induced current.

MODULE – III

The origin of magnetism lies in the orbital and spin motions of electrons and how the electrons interact with one another. The best way to introduce the different types of magnetism is to describe how materials respond to magnetic fields. This may be surprising to some, but all matter is magnetic. It's just that some materials are much more magnetic than others. The main distinction is that in some materials there is no collective interaction of atomic magnetic moments, whereas in other materials there is a very strong interaction between atomic moments.

The magnetic behavior of materials can be classified into the following five major groups:

1. Diamagnetism
2. Para magnetism
3. Ferromagnetism
4. Ferrimagnetism
5. Anti ferromagnetism

Magnetic Properties of some common minerals

1. Diamagnetism

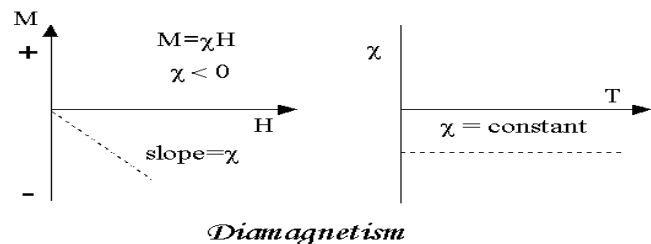
Diamagnetism is a fundamental property of all matter, although it is usually very weak. It is due to the non-cooperative behavior of orbiting electrons when exposed to an applied magnetic field. Diamagnetic substances are composed of atoms which have no net magnetic moments (ie., all the orbital shells are filled and there are no unpaired electrons). However, when exposed to a field, a negative magnetization is produced and thus the susceptibility is negative. If we plot M vs H , we see:

Note that when the field is zero the magnetization is zero. The other characteristic behavior of diamagnetic materials is that the susceptibility is temperature independent. Some well known diamagnetic substances, in units of $10^{-8} \text{ m}^3/\text{kg}$, include:

quartz (SiO_2) -0.62

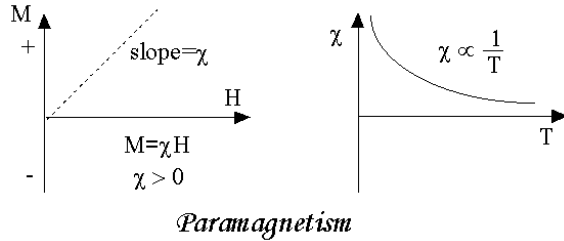
Calcite (CaCO_3) -0.48

water -0.90



Paramagnetism

This class of materials, some of the atoms or ions in the material have a net magnetic moment due to unpaired electrons in partially filled orbitals. One of the most important atoms with unpaired electrons is iron. However, the individual magnetic moments do not interact magnetically, and like diamagnetism, the magnetization is zero when the field is removed. In the presence of a field, there is now a partial alignment of the atomic magnetic moments in the direction of the field, resulting in a net positive magnetization and positive susceptibility.



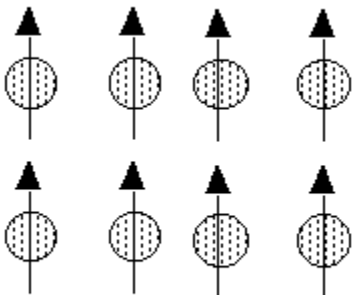
Ferromagnetism

When you think of magnetic materials, you probably think of iron, nickel or magnetite. Unlike paramagnetic materials, the atomic moments in these materials exhibit very strong interactions. These interactions are produced by electronic exchange forces and result in a parallel or antiparallel alignment of atomic moments. Exchange forces are very large, equivalent to a field on the order of 1000 Tesla, or approximately a 100 million times the strength of the earth's field.

The exchange force is a quantum mechanical phenomenon due to the relative orientation of the spins of two electron.

Ferromagnetic materials exhibit parallel alignment of moments resulting in large net magnetization even in the absence of a magnetic field.

parallel alignment



The elements Fe, Ni, and Co and many of their alloys are typical ferromagnetic materials.

Two distinct characteristics of ferromagnetic materials are their

(1) spontaneous magnetization and the existence of

(2) magnetic ordering temperature

Spontaneous Magnetization

Ferromagnetism

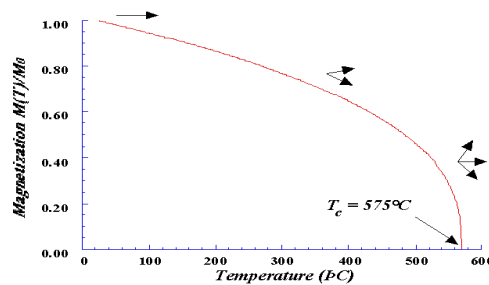
The spontaneous magnetization is the net magnetization that exists inside a uniformly magnetized microscopic volume in the absence of a field. The magnitude of this magnetization, at 0 K, is

dependent on the spin magnetic moments of electrons.

A related term is the saturation magnetization which we can measure in the laboratory. The saturation magnetization is the maximum induced magnetic moment that can be obtained in a magnetic field (H_{sat}); beyond this field no further increase in magnetization occurs.

Curie Temperature

Even though electronic exchange forces in ferromagnets are very large, thermal energy eventually overcomes the exchange and produces a randomizing effect. This occurs at a particular temperature called the Curie temperature (TC). Below the Curie temperature, the ferromagnet is ordered and above it, disordered. The saturation magnetization goes to zero at the Curie temperature. A typical plot of magnetization vs temperature for magnetite is shown below.



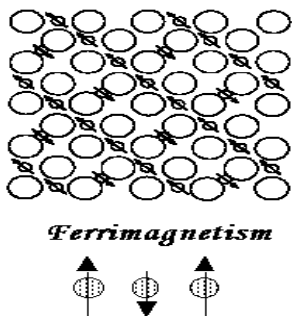
The Curie temperature is also an intrinsic property and is a diagnostic parameter that can be used for mineral identification. However, it is not foolproof because different magnetic minerals, in principle, can have the same Curie temperature.

This occurs at a particular temperature called the Curie temperature (TC). Below the Curie temperature, the ferromagnet is ordered and above it, disordered. The saturation magnetization goes to zero at the Curie temperature. A typical plot of magnetization vs temperature for magnetite is shown below.

Ferrimagnetism

In ionic compounds, such as oxides, more complex forms of magnetic ordering can occur as a result of the crystal structure. One type of magnetic ordering is called ferrimagnetism. A simple representation of the magnetic spins in a ferrimagnetic oxide is shown here.

The magnetic structure is composed of two magnetic sublattices (called A and B) separated by oxygens. The exchange interactions are mediated by the oxygen anions. When this happens, the interactions are called indirect or superexchange interactions. The strongest superexchange interactions result in an antiparallel alignment of spins between the A and B sublattice.



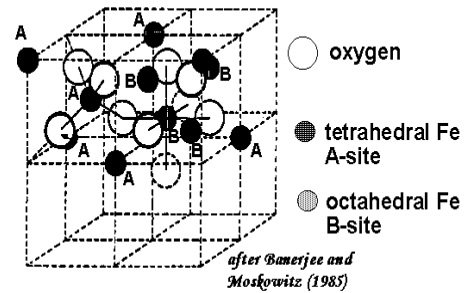
In ferrimagnets, the magnetic moments of the A and B sublattices are not equal and result in a net magnetic moment. Ferrimagnetism is therefore similar to ferromagnetism. It exhibits all the hallmarks of ferromagnetic behavior- spontaneous magnetization, Curie temperatures, hysteresis, and

remanence. However, ferro- and ferrimagnets have very different magnetic ordering.

Magnetite is a well known ferrimagnetic material. Indeed, magnetite was considered a ferromagnet until Néel in the 1940's, provided the theoretical framework for understanding ferrimagnetism.

Crystal Structure of Magnetite

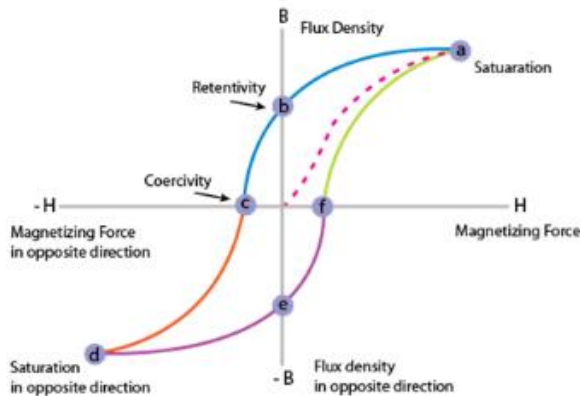
Magnetite, Fe_3O_4 crystallizes with the spinel structure. The large oxygen ions are close packed in a cubic arrangement and the smaller Fe ions fill in the gaps. The gaps come in two flavors: tetrahedral site: Fe ion is surrounded by four oxygens octahedral site: Fe ion is surrounded by six oxygens



The tetrahedral and octahedral sites form the two magnetic sublattices, A and B respectively. The spins on the A sublattice are antiparallel to those on the B sublattice. The two crystal sites are very different and result in complex forms of exchange interactions of the iron ions between and within the two types of sites.

Soft and Hard magnetic materials:

Ferromagnetic materials are basically divided into two broad classes: Soft magnetic materials and hard magnetic materials. Figure 5.1 depicts a typical magnetic hysteresis loop of ferromagnetic materials, when they are placed under an external magnetic field. The area under the hysteresis loops mainly help to quantify them as hard or soft magnetic materials.



Typical magnetic hysteresis loop of a ferromagnetic material

Applications are-

Soft Magnets-

- 1) Power conversion electrical – mechanical.
- 2) Power adaption.
- 3) Signal transfer.
- 4) Magnetic field screening.

Hard Magnets-

- 1) Permanent magnets.
- 2) Data storage analog.
- 3) Data storage digital.
- 4) Quantum devices.

Sr.No.	Soft Magnetic Materials	Hard Magnetic Materials
1	Soft magnetic materials are those materials which have a smaller area enclosed by their Hysteresis loop	Hard magnetic materials are those materials which have a Larger area enclosed by their Hysteresis loop
2	They have low remnant magnetization	They have high remnant magnetization
3	They have low coercivity	They have high coercivity
4	They have high initial permeability	They have low initial permeability
5	Hysteresis loss is less	Hysteresis loss is higher
6	Eddy current loss is less	Eddy current loss is more for metallic types and low for ceramic types.
7	Used in transformer cores, motors, generators, electromagnets, etc.	Used in making permanent magnets, magnetic separators, magnetic detectors, speakers, microphones, etc.

Optical materials

Materials are classified on the basis of their interaction with visible light into three categories.

- Materials that are capable of transmitting light with relatively little absorption and reflection are called transparent materials i.e. we can see through them.
- Translucent materials are those through which light is transmitted diffusely i.e. objects are not clearly distinguishable when viewed through.
- Those materials that are impervious to the transmission of visible light are termed as opaque materials. These materials absorb all the energy from the light photons

Absorption

- When a light beam is impinged on a material surface, portion of the incident beam that is not reflected by the material is either absorbed or transmitted through the material.
- *Bouguer's law*: The fraction of beam that is absorbed is related to the thickness of the materials and the manner in which the photons interact with the material's structure.

$$I = I_0 \exp(-\alpha \cdot x)$$

- Absorption occurs by two mechanisms: Rayleigh scattering and Compton scattering.

Absorption mechanisms

□ Rayleigh scattering: where photon interacts with the electrons, it is deflected without any change in its energy. This is significant for high atomic number atoms and low photon energies. Ex.: Blue color in the sunlight gets scattered more than other colors in the visible spectrum and thus making sky look blue.

□ Tyndall effect is where scattering occurs from particles much larger than the wave length of light. Ex.: Clouds look white.

□ Compton scattering—Interacting photon knocks out an electron losing some of its energy during the process. This is also significant for high atomic number atoms and low photon energies.

□ Photoelectric effect occurs when photon energy is consumed to release an electron from atom nucleus. This effect arises from the fact that the potential energy barrier for electrons is finite at the surface of the metal. Ex.: Solar cells.

Optical applications

□ Light interacts with a material in many ways.

□ Depending on the material, its crystal / micro-structure, and also on the characteristics of incident light, there are many peculiar phenomena occurs, which are known as optical phenomena. These include:

Luminescence

Lasers

Thermal emission
Photo-conductivity
Optical fibers

□ All these find quite many applications in technology for everyday life

Photo-luminescence

□ Based on source for electron excitation, luminescence is three types: photo-luminescence, cathode-luminescence, and electro-luminescence.

□ Photo-luminescence occurs in fluorescent lamps.

□ Here ultra-violet radiation from low-pressure mercury arc is converted to visible light by calcium halo-phosphate phosphor ($\text{Ca}_{10}\text{F}_2\text{P}_6\text{O}_{24}$).

□ In commercial lamps, about 20% of F⁻ ions are replaced with Cl⁻ ions.

□ Antimony, Sb^{3+} , ions provide a blue emission while manganese, Mn^{2+} , ions provide an orange-red emission band.

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Electro-luminescence occurs in devices with p-n rectifying junctions which are stimulated by an externally applied voltage.

□ When a forward biased voltage is applied across the device, electrons and holes recombine at the junction and emit photons in the visible range (mono-chromatic light i.e. single color). These diodes are called light emitting diodes (LEDs).

□ LEDs emit light of many colors, from red to violet, depending on the composition of the semiconductor material used.

Ex.: GaAs, GaP, GaAlAs, and GaAsP are typical materials for LEDs.

Materials for colored LEDs

Wave length (nm)	Color	Material
-	Infra-red	GaAs
660	Red	$\text{GaP}_{0.40}\text{As}_{0.60}$ or $\text{Al}_{0.25}\text{Ga}_{0.75}\text{As}$
635	Orange	$\text{GaP}_{0.65}\text{As}_{0.35}$
578	Yellow	$\text{GaP}_{0.85}\text{As}_{0.15}$
556	Green	GaP ($\text{GaP}_{1.00}\text{As}_{0.00}$)
-	Blue	$\text{Ga}_{0.94}\text{NIn}_{0.06}$

Lasers

- Laser is an acronym for *light amplification by stimulated emission of radiation*. It is in fact special application of luminescence.
- Unlike most radiation processes, such as luminescence, which produce incoherent light, the light produced by laser emission is coherent.
- This is based on the fact that in certain materials, electrons excited by a stimulus produce photons which in turn excite additional photons of identical wavelength.
- Lasers are useful in many applications such as welding, metal cutting, heat treatment, surgery, mapping, reading compact disks, etc. **Ex.:** Ruby, single crystal of Al_2O_3 doped with little amount of Cr_2O_3 ; yttrium aluminium garnet ($\text{Y}_3\text{Al}_5\text{O}_{12}$ – YAG) doped with neodymium, Nd; CO_2 gas; He-Ne gas; some semi-conductors like GaAs and InGaAsP.

Photo-conductivity

Bombardment of semiconductors by photons, with energy equal to greater than the bandgap, may result in creation of electron-hole pairs that can be used to generate current. This process is called photo-conductivity.

□ It is different from photo-electric effect in the sense that an electron-hole pair is generated whose energy is related to the bandgap energy instead of free electron alone whose energy is related to the Fermi level.

□ The current produced in photo-conductivity is directly related to the incident light intensity.

□ This phenomenon is utilized in photographic light meters. Cadmium sulfide (CdS) is commonly used for the detection of visible light, as in light meters.

□ Photo-conductivity is also the underlying principle of the photo-voltaic cell, known to common man as solar cell, used for conversion of solar energy into electricity.

Optical fibers

- Optical fibers have revolutionized the communication industry.
- It primarily consists of core, cladding and coating. The core transmits the signals, while the cladding constrains the light beam to the core; outer coating protects the core and cladding from the external environment.
- Typically both the core and cladding are made of special types of glass with carefully controlled indices of refraction.
- The indices of refraction are selected such that

$$n_{cladding} < n_{core}$$

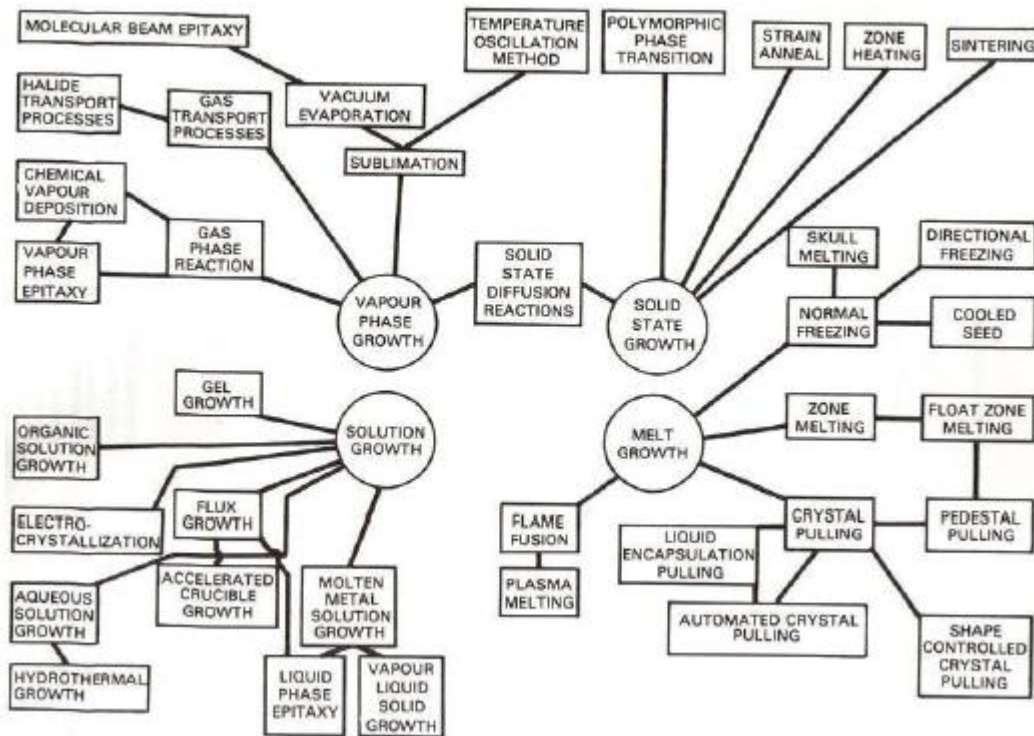
- Once the light enters the core from the source, it is reflected internally and propagates along the length of the fiber.
- Internal reflection is accomplished by varying the index of refraction of the core and cladding glass materials. Usually two designs are employed in this regard.

Types of optical fibers

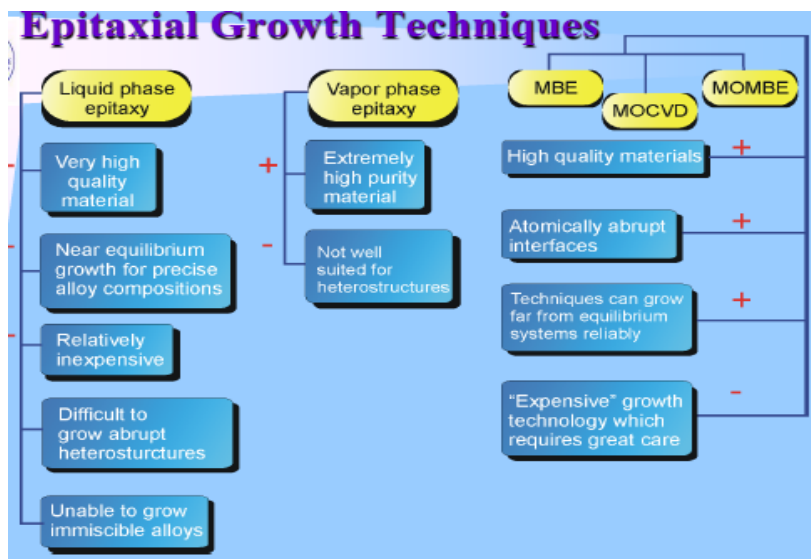
- In step-index optical fiber, there is a sharp change in refractive index between the core and cladding. In this design output pulse will be broader than the input one. It is because light rays traveling in different trajectories have a variety of path lengths.
- It is possible to avoid pulse broadening by using graded-index fiber. This results in a helical path for the light rays, as opposed to zig-zag path in a step-index fiber.
- Here impurities such as boron oxide (B_2O_3) or germanium dioxide (GeO_2) are added to the silica glass such that the index of refraction varied gradually in parabolic manner across the cross section. This enables light to travel faster while close to the periphery than at the center. This avoids pulse broadening.
- Both step- and graded- index fibers are termed as multi-mode fibers. Third type optical fiber is called single-mode fiber in which light travels largely parallel to the fiber axis with little distortion of the digital light pulse. These are used for long transmission lines.

MODULE – V

Crystal growth then is a non-equilibrium process and the importance must be given to the temperature and concentration and other gradients and the fact that, heat of crystallization evolved must be removed to the surroundings. At the same time, the crystal growth process must be kept as near equilibrium to a steady state process as possible. This is why, control of the crystal growth environment and a consideration of growth kinetics both at the macroscopic and the atomic levels are of vital importance to the success of a crystal growth experiment. It is particularly important to avoid constitutional supercooling and the breakdown of the crystal-liquor interface.



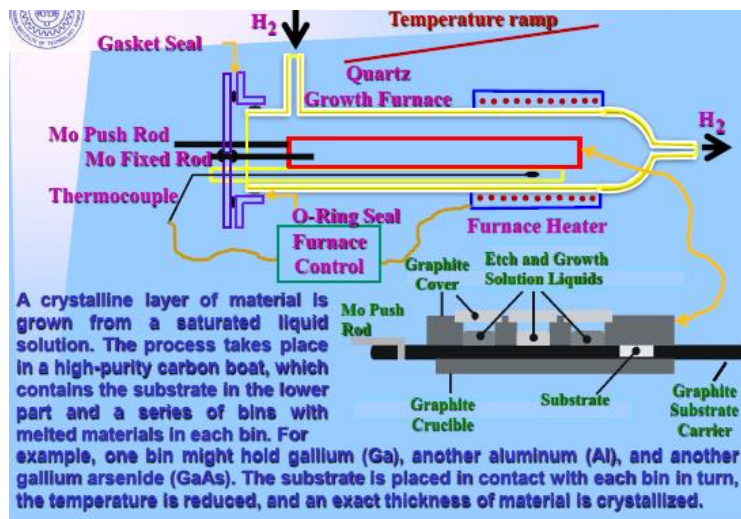
Crystal Growth Techniques (Laudise 1970).



Epitaxial Growth (CBE)

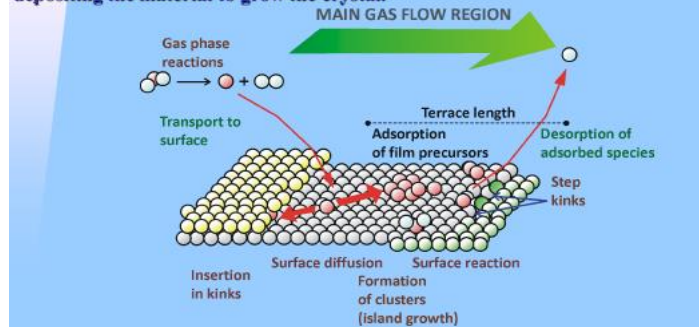
LPE	VPE	MBE	MOCVD	CBE
A)Excellent Quality, Simple Setup.	A)Quality not great but moderate, Rugged	A)Extremely narrow Layers, Quality is good, Characterizing instruments can be mounted on the chamber.	A)Good Quality not as thin a layer as MBE but close, Infinite Source	A)Best compromise between MBE & MOCVD
B)Thin Structure is not possible. Surface uneven.	B)High temperature Growth. Sharp interfaces not possible.	B) Expensive, Limited Source, Not production oriented. P Compounds very difficult.	B) Highly toxic gases, Precautions needed	B) Expensive, Carbon Contamination, Not many Disadvantages.

Liquid-Phase Epitaxy (LPE)



VPE

In vapor-phase epitaxy (VPE), the material to be deposited is transported as part of a gaseous compound, a halogen such as gallium chloride (GaCl_3), or an organometallic compound, such as trimethyl gallium $[(\text{CH}_3)_3\text{Ga}]$. When the vapor touches the substrate, it reacts, depositing the material to grow the crystal. When the vapor touches the substrate, it reacts, depositing the material to grow the crystal.



MODULE – VI

Metallic glasses or amorphous metals are novel engineering alloys in which the structure is not crystalline (as it is in most metals) but rather is disordered, with the atoms occupying more-or-less random positions in the structure. In this sense, metallic glasses are similar to the more familiar oxide glasses such as the soda-lime glasses used for windows and bottles.

From a practical point of view, the amorphous structure of metallic glasses gives them two important properties. First, like other kinds of glasses they experience a glass transition into a supercooled liquid state upon heating. In this state the viscosity of the glass can be controlled over a wide range, creating the possibility for great flexibility in shaping the glass. For example, Liquid metal Technologies produced the golfing putter shown here:



Nanomaterials are materials that have structural components smaller than 1 micrometer in at least one dimension. While the atomic and molecular building blocks (~0.2 nm) of matter are considered nanomaterials, examples such as bulk crystals with lattice spacing of nanometers but macroscopic dimensions overall, are commonly excluded.

Nanoparticles are particles with at least one dimension smaller than 1 micron and potentially as small as atomic and molecular length scales (~0.2 nm). Nanoparticles can have amorphous or crystalline form and their surfaces can act as carriers for liquid droplets or gases. To some degree, nanoparticulate matter should be considered a distinct state of matter, in addition to the solid, liquid, gaseous, and plasma states, due to its distinct properties (large surface area and quantum size effects). Examples of materials in crystalline nanoparticle form are fullerenes and carbon nanotubes, while traditional crystalline solid forms are graphite and diamond.

Advantages at the nano level:

- To enumerate the advantages and disadvantages of nanotechnology, let us first run through the good things this technology brings:
- Nanotechnology can actually revolutionize a lot of electronic products, procedures, and applications. The areas that benefit from the continued development of nanotechnology when it comes to electronic products include nano transistors, nano diodes, OLED, plasma displays, quantum computers, and many more.
- Nanotechnology can also benefit the energy sector. The development of more effective energy-producing, energy-absorbing, and energy storage products in smaller and more efficient devices is possible with this technology. Such items like batteries, fuel cells, and solar cells can be built smaller but can be made to be more effective with this technology.
- Another industry that can benefit from nanotechnology is the manufacturing sector that will need materials like nanotubes, aerogels, nano particles, and other similar items to produce their products with. These materials are often stronger, more durable, and lighter than those that are not produced with the help of nanotechnology.

- In the medical world, nanotechnology is also seen as a boon since these can help with creating what is called smart drugs. These help cure people faster and without the side effects that other traditional drugs have. You will also find that the research of nanotechnology in medicine is now focusing on areas like tissue regeneration, bone repair, immunity and even cures for such ailments like cancer, diabetes, and other life-threatening diseases.

limitations at the nano level:

- Included in the list of disadvantages of this science and its development is the possible loss of jobs in the traditional farming and manufacturing industry.
- You will also find that the development of nanotechnology can also bring about the crash of certain markets due to the lowering of the value of oil and diamonds due to the possibility of developing alternative sources of energy that are more efficient. This can also mean that since people can now develop products at the molecular level, diamonds will also lose its value since it can now be mass produced.
- Atomic weapons can now be more accessible and made to be more powerful and more destructive. These can also become more accessible with nanotechnology.
- Since these particles are very small, problems can actually arise from the inhalation of these minute particles, much like the problems a person gets from inhaling minute asbestos particles.
- Presently, nanotechnology is very expensive and developing it can cost you a lot of money. It is also pretty difficult to manufacture, which is probably why products made with nanotechnology are more expensive.

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