Unit 16

PHYSICS OF SOLIDS

Learning Objectives

After studying this chapter, the students will be able to

- Distinguish between the structure of crystalline, glassy, amorphous and polymeric solids.

- Describe that deformation in solids is caused by a force and that in one dimension, the deformation can be tensile or compressive.

- Describe the behavior of springs in terms of lead-extension, Hooke's law and the spring constant. Define and use the terms Young's modulus, bulk modulus and shear modulus.

- Demonstrate knowledge of the force-extension graphs for typical ductile, brittle and polymeric materials.

- Become familiar of ultimate tensile stress, elastic deformation and plastic deformation of material

- Describe the idea about energy bands in solids.

- Classify insulators, conductors, and semiconductors on the basis of energy bands.

- Become familiar with the behavior of superconductors and their potential uses.

- Distinguish between dia, para and ferro magnetic materials.

- Describe the concepts of magnetic domains in material.

- Classify hard and soft ferromagnetic substances.

- Describe hysteresis loop how magnetic field strength varies with magnetizing current;

Materials have specific uses depending upon their characteristic and properties, such as, hardness, brittleness, ductility, malleability, conductivity etc. The mechanical and magnetic properties depend upon the structure - the particular order and bonding of atoms in a material.

This clue has made it possible to design and creates materials with new and unusual properties for use in modem technology.

A solid consists of atoms or clusters of atoms arranged in close proximity. The physical structure of a solid and its properties are closely related to the scheme of arrangement of atoms within the solid.

In crystals the arrangement of atoms is regular and periodic. The concepts of lattice and unit cell help us in understanding the atomic arrangement in crystals.

The crystal structures are analyzed using x-ray diffraction technique invented by Max von Laue and extensively employed by Bragg. The real crystals have imperfections of different kinds. The study of crystal geometry helps us to understand the diverse behaviour of solids in their mechanical, metallurgical, electrical, magnetic and optical properties. The imperfections in real crystals can be controlled and suitably altered to improve the selected physical properties of the material.

Classification of solids

On the basis of atomic arrangement solids may be classified into three categories, namely crystals, polycrystalline solids and amorphous solids.

Q.1 Distinguish Between the Structure of Crystalline, Glassy, Amorphous and Polymeric Solids?
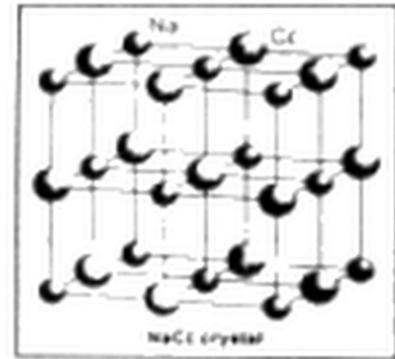
1. Crystals

Crystalline solids are those which have a regular arrangement of atoms and molecules.

The neighbors of every molecule are arranged in regular pattern which is constant throughout the crystal.

Examples

Some examples of crystalline solids are

- In metals copper, iron, zinc etc.

- In ionic compounds-, sodium chloride etc.

- In ceramics: zirconia (zirconium oxide) etc.

- In semiconductors: germanium and silicon.

  ➤ X-ray diffraction studies have shown that in crystals the constituent atoms are arranged in a regular periodic pattern in three dimensions. The arrangement of atoms in specific relation to each other is called order.

In crystals the order exists in the immediate neighborhood of a given atoms as well as over large distance corresponding to several layers of atoms. Therefore, crystals possess both short range order and long-range order.

Quartz, Sucrose (sugar), diamond and rock salt (NaCL) are examples of solids that occur as large size single crystals.

2. Polycrystalline solids

They have intermediate structure in between order and disorder. Polycrystalline is material made up of many small single crystals (also called crystallites or grains).
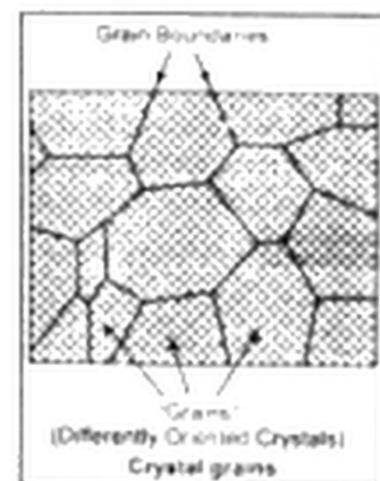
Polymers consist wholly or in part of chemical combination of carbon with oxygen, hydrogen, nitrogen or non- metallic elements. Polythene, polystyrene and nylon are some of the examples of polymers. Natural rubber is composed in the pure state entirely hydrocarbon with the formula $(C_5H_6)_n$.

> These materials have rather low specific gravity compared with even the lightest of metals and even net exhibit good strength to weight ratio.
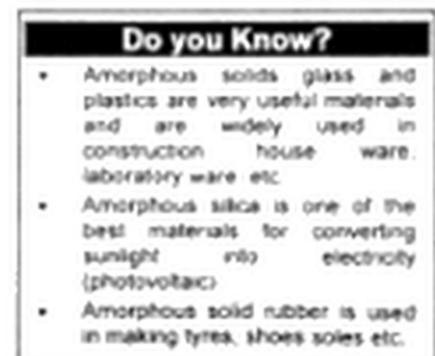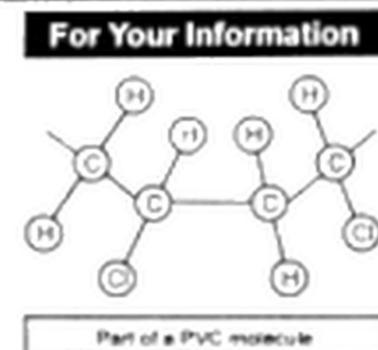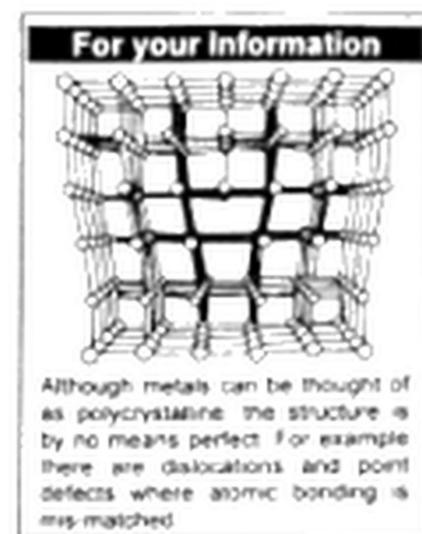

ethene (or ethylene) C_2H_4 polythene (or polyethylene)

Polycrystalline solids consist of fine grins, having a size of 10^3 to 10^4 $\mathring{A}$, separated by well define boundaries and oriented in different directions. Each such grain is a single crystal of an irregular shape. Since the grains are oriented haphazardly, a polycrystalline material is isotropic and exhibits the same properties in all directions. Majority of the natural solids have polycrystalline structure. Metals are examples of polycrystalline solids.

In these solids the ordered regions, vary in size and orientation with respect to one another.

These regions are called as grains (domain) and are separated from one another by grain boundaries. The atomic order can vary from one domain to the next. The grains are usually 100 nm - 100 microns in diameter.

For your Information

Although metals can be thought of as polycrystalline the structure is by no means perfect. For example there are dislocations and point defects where atomic bonding is mis-matched.

For Your Information

Part of a PVC molecule

3. Amorphous Solids

The word amorphous means without form or structure. In amorphous solids, there is no regular arrangement of molecules, so amorphous solids are more like liquids with

Do you Know?

- Amorphous solids glass and plastics are very useful materials and are widely used in construction house ware laboratory ware etc.
- Amorphous silica is one of the best materials for converting sunlight into electricity (photovoltaic)
- Amorphous solid rubber is used in making tyres, shoes soles etc.

disordered structure frozen in it. They are also known as solid liquids (liquids in frozen)

Amorphous (Non-crystalline) solid is composed of randomly orientated atoms, ions, or molecules that do not form defined patterns or lattice structures.

So, in amorphous solids the arrangement of atoms is random. In these solids, the particles are not in regular arrangement and possess only short-range order and have irregular shape.

➢ Some liquids when cooled become more and more viscous and then rigid, retaining random atom characteristic distribution. This state is called undercooled liquid or amorphous solid. Some of the metals may be prepared in amorphous solid form by rapid cooling from molten state. Glass is example of amorphous substances.

➢ The atomic arrangement in two dimensions in cases of the three classes of solids illustrated in fig.

(a) two dimensional lattice points with each having an identical environment
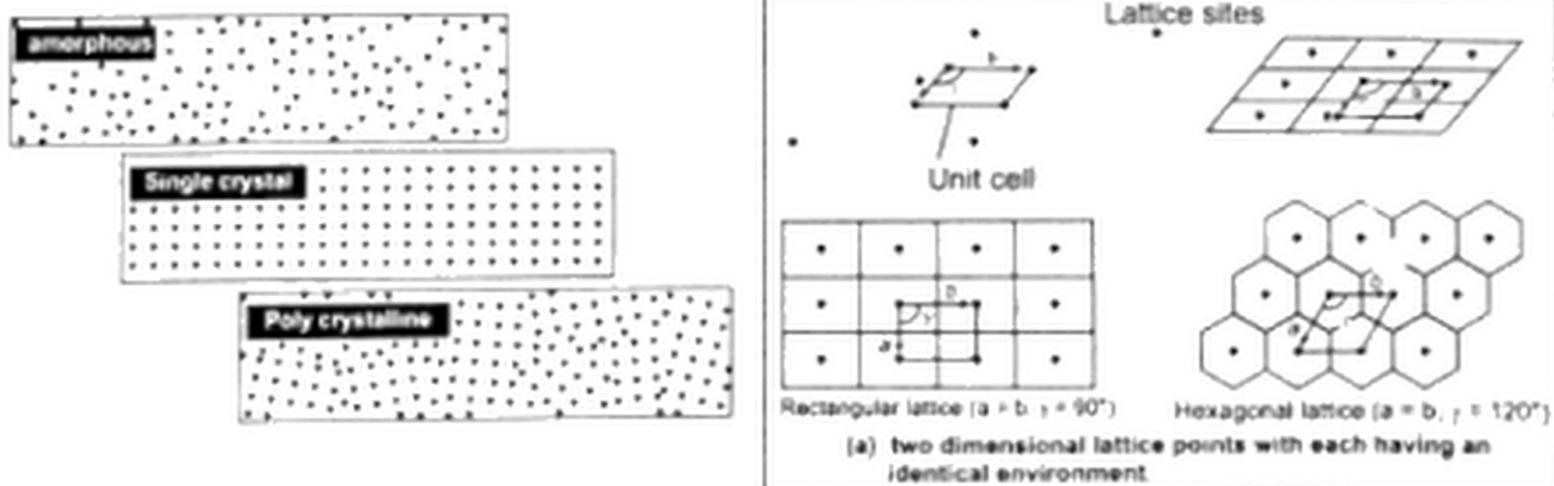
X-ray investigations show that the crystals are composed of atoms (or group of atoms) held in an orderly three-dimensional array. The array may be viewed as produced when the group of atoms, henceforth called a basis or unit, is repeated at regular intervals along all directions in the crystal. The regular and
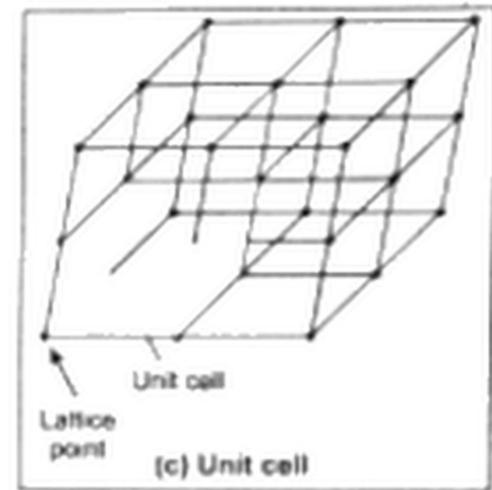

(b) three dimensional lattice
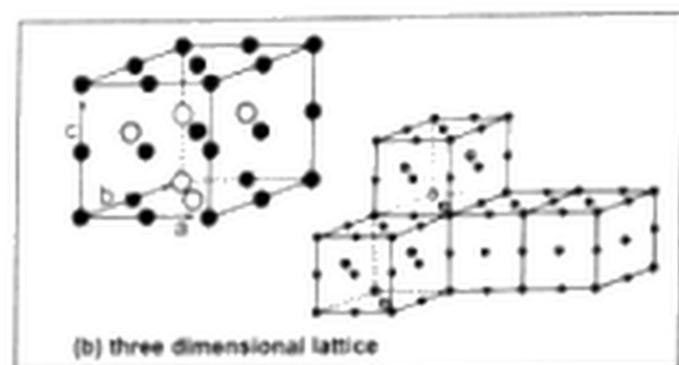
periodic arrangement of the basis is the basic feature of crystals. Geometrical analysis of crystal structure is made by referring to an imaginary array of points in space.

Therefore, the study of crystal structure becomes simpler when it is represented by a space lattice.

> The points which are forming a lattice are called lattice sites.
> The distance between the consecutive neighbors' sites is called lattice constant.
> When we assign direction to these lattice constants, they become lattice translation vectors.

The two-dimensional arrangements of lattice are shown in fig: which shows

that a plane lattice is obtained by translation of $\vec{a}$ and $\vec{b}$ and a space lattice is obtained. by translation of $\vec{a}$, $\vec{b}$ and $\vec{c}$ as shown in fig (a). It is possible to divide the crystal into a (large) number of identical unit cells, each containing one or more atoms.

(c) Unit cell

The smallest geometric figure or unit whose periodic repetition in two or three dimensions form a crystal is called unit cell.

Crystal structure

Crystal structure is obtained when a basis is added at each point in the lattice. The basis must be identical in composition, arrangement and orientation such that the crystal appears exactly the same at one point as it does at other equivalent points. Fig (a) shows the basis consisting of a group of two atoms.

When the basis is associated with each lattice site, the crystal structure is obtained.

Crystal Lattice + Basis Structure = Crystal

(a) Crystal structure

Simple Cubic   Body Centered Cubic   Face Centered Cubic

(b) Some unit cells

Do you Know?

In crystalline solid, the properties like electrical conductance, refractive index, thermal expansion, etc., have different value in different directions as in AB and CD. This type of behaviour is called Anisotropy and the substances with this property are called Anisotropic. A crystalline solid gives a clean surface after cleavage with knife rather than an irregular breakage.

MCQ's from Past Board Papers

1. Which one of the following is crystalline solid:

(A) Zirconia   (B) Glassy solid   (C) Natural rubber   (D) Polystyrene

2. A solid having regular arrangement of molecules throughout its structure is called:

(A) Super solid   (B) Perfect solid   (C) Plasma   (D) Crystalline solid

3. What are the substances called which undergo plastic deformation until they break

(Fed 2011)

(A) Brittle substances   (B) Ductile substances

(C) Amorphous solids   (D) Polymeric solids

4. Which one of the following is polymeric solid:

(A) Glass   (B) Nylon   (C) Copper   (D) Zinc

5. The number of crystalline systems are:

(A) three   (B) five   (C) seven   (D) fifteen

Answer key

1. A	2. D	3. B	4. B	5. C

Q.2 Define Modulus of elasticity. Discuss its different types.

Elastic Moduli

When an external force is applied on the object, it changes its shape or size. Generally, this deformation is small and often temporary.

➢ If an object regains its original shape when external force is removed it is called elastic.

➢ If it remains in deformed state it is called plastic.

➢ There are three types of deformations and corresponding three elastic moduli. The deforming force is expressed in terms of stress and the deformation is expressed in terms of strain. For elastic solids, the ratio of stress to strain is constant and it is called elastic modulus. That is

$$\text{Elastic modulus} = \frac{Stress}{Strain}$$

This is known as Hooke's law. There are three elastic moduli: Young's modulus (Y), rigidity modulus (S) and Bulk modulus (B).

Material	Young's modulus Y(Pa)	Bulk modulus B(Pa)	Shear modulus S(Pa)
Aluminum	7×10^{10}	7.5×10^{10}	2.5×10^{10}
Brass	9×10^{10}	6×10^{10}	3.5×10^{10}
Copper	11×10^{10}	14×10^{10}	4.4×10^{10}
Crown glass	6×10^{10}	5×10^{10}	2.5×10^{10}
Iron	21×10^{10}	16×10^{10}	7.7×10^{10}
Lead	1.6×10^{10}	4.1×10^{10}	0.6×10^{10}
Nickel	21×10^{10}	17×10^{10}	7.8×10^{10}
Steel	20×10^{10}	16×10^{10}	7.5×10^{10}

Young's Modulus

The change in the length due to deforming force is described by Young's modulus. Consider a rod of length L having cross-sectional area A as shown in fig 16.6. If it is clamped at one end and a force is applied perpendicular to the area of cross-section, it changes its length, which is greater than the original length. The internal forces of the rod resist change in length but attain an equilibrium in which the length is (L + ΔL), where, ΔL is the change in length.

Deforming forces on a rod
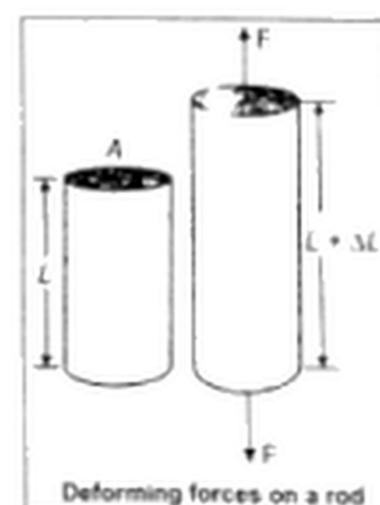
Stress:

The force applied on unit area to produce any change in length, volume or shape of a body is called stress.

$$\text{Stress} = \frac{Force}{Area}$$

$$\sigma = \frac{F}{A}$$

The ratio of the magnitude of external force F to the area of cross-section A is called as tensile stress. Where

$$\text{Tensile stress} = \frac{F}{A} \qquad (1)$$

The ratio of the change in length to the original length is called as tensile strain.

And Tensile strain = $\frac{\Delta L}{L}$ $\qquad (2)$

Young's modulus is defined as the ratio of tensile stress to tensile strain.

$$Y = \frac{Tensile\ stress}{Tensile\ strain} = \frac{F/A}{\Delta L/L} \qquad (3)$$

It SI unit is N/m²

The Hooke's law is valid within the elastic limit and for small strains. When the metal rod is subjected to increasing deforming force, the relation between stress and strain is as shown in fig.
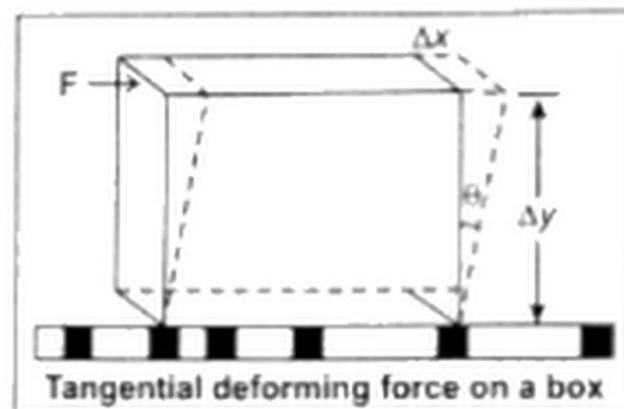
Shear or Rigidity Modulus

When an object is subjected to a force tangential to one of its faces while the opposite face is held fixed there occurs a

Tangential deforming force on a box

deformation. The shear stress is defined as the ratio of tangential deforming force F to the area A of the face being sheared i.e.,

$$\text{Shear stress} = \frac{F}{A} \qquad (1)$$

The shear strain is the ratio of displacement of the sheared face Δx and the fixed face y.

$$\text{Shear strain} = \frac{displacement\ of\ Sheared\ face}{displacement\ of\ fixed\ face}$$

$$= \frac{\Delta x}{y} \qquad (2)$$

It may be described in terms of angle θ, which is called as angle of shear. Hence

$$\tan\theta = = \frac{\Delta x}{y} \qquad (3)$$

When the angle is small,

$$\tan\theta \approx \theta \qquad (4)$$

The shear modulus is defined as the ratio of shear stress to the shear strain.

$$S = \frac{shear\ stress}{shear\ strain} = \frac{F/A}{\Delta x/y} \qquad (5)$$

$$\frac{F/A}{\tan\theta} \approx \frac{F}{A\theta} \qquad (6)$$

Bulk Modulus

When deforming forces, acting on all the surfaces of a body, are at right angles, the body undergoes deformation. The forces are distributed uniformly on all the surfaces as illustrated in figure.

Change in volume V of a box
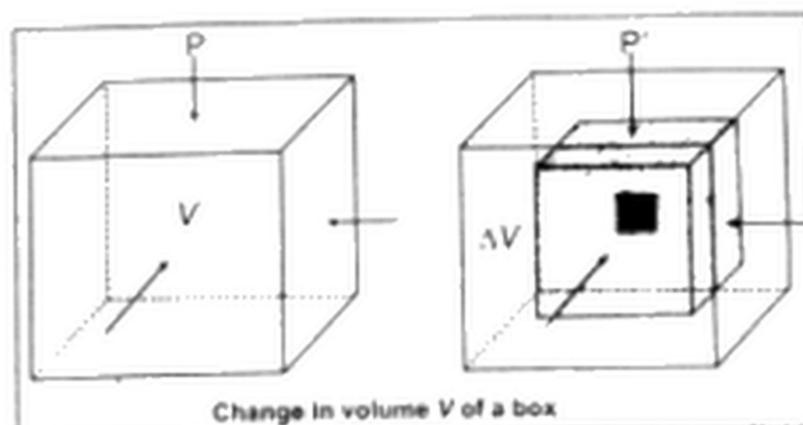
In this case there is a change in the volume and not in the shape. The volume stress is the ratio of magnitude of the normal force F to the area A. Therefore

Bulk or Volume stress = $\frac{F}{A}$

In case of fluids it is called as pressure

$\Delta P = \frac{F}{A}$

The ratio of change in volume ΔV and original volume V is the volume strain. Where,

$$\text{Volume strain} = -\frac{\Delta V}{V} \qquad (7)$$

The bulk modulus is defined as the ratio of volume stress to volume strain.

Therefore,

$$B = \frac{Volume\ stress}{Volume\ Strain} = \frac{F/A}{(-\Delta V/V)}$$

$$= \frac{\Delta P}{(-\Delta V/V)} \qquad (8)$$

The negative sign is inserted because increase in pressure cause decrease in volume. The value of bulk modulus is always taken as positive.

Hooke's law

Stress and strain take different forms in the situations shown in the fig. (16.9). for small deformations the stress and strain are proportional to each other. This is known as Hooke's law.

Thus,

Stress $\propto$ strain

Stress = k x (strain)   (9)

Where, k is the proportionality constant and is known as modulus of elasticity. Hooke's law is an empirical law and is found to be valid for most materials.

However, there are some materials which do not exhibits this linear relationship.

Q.3   Draw a stress-strain curve for a ductile material. Also discuss the terms Elastic Limit, Yield Strength, UTS.

Stress-Strain Curve

Engineering stress and strain are usually measured using a machine that strains the material at a fixed linear rate and records the stress.

The applied stress is gradually increased in steps and the change in length is noted. These values are then plotted on a graph. A typical graph for a metal is shown in figure. The stress-strain curves vary from material to material. These curves help us to understand how a given material deforms with increasing loads.

> From the graph, we can see that in the region between 0 to A, the curve is linear. In this region, Hooke's law is obeyed.

   The body regains its original dimensions when the applied force is removed. In this region, the solid behaves as an elastic body.

> In the region from A to B, stress and strain are not proportional.

   Nevertheless, the body still returns to its original dimension when the load is removed.

   The point B in the curve is known as yield point (also known as elastic limit) and the corresponding stress is known as yield strength (Sy) of the material. If the load is increased further, the stress developed exceeds the yield strength and strain increase rapidly even for a small change in the stress.

> The region of the plasticity is represented by the portion of the curve between B and C.

➢ Where point C in the fig 16.9: shows the ultimate tensile strength (S$_u$) of the material. If the stress is increased beyond point C, the material is said to be permanently changed, and the body does not regain its original dimension.

This type of deformation is called plastic deformation.

➢ At point D the material cannot be stretched further and smallest increase in stress can result in breaking the sample.

Stress strain curve
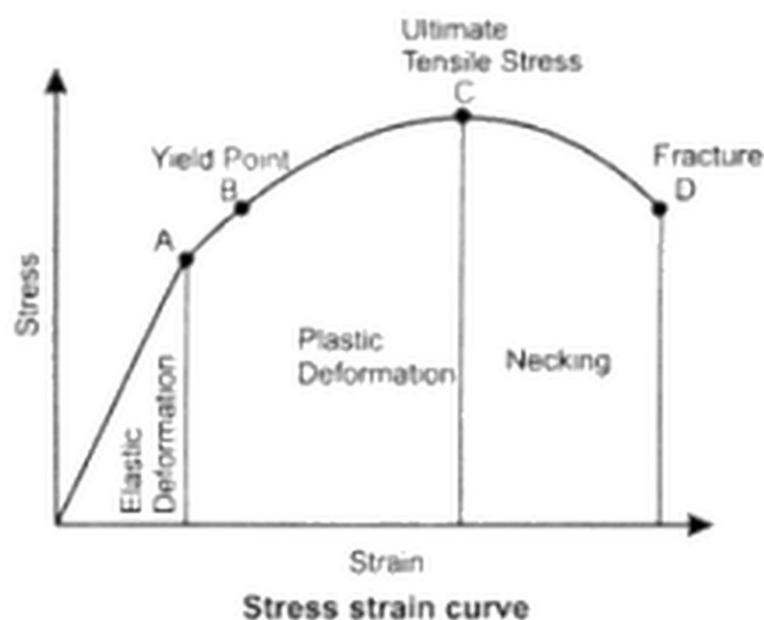
If the ultimate strength and fracture points C and D are close, the material is said to be brittle. If they are far apart, the material is said to be ductile.

Q.4 Discuss Different Mechanical Properties of Solids? and deformation of material.

Mechanical properties of solids

The mechanical properties of a material are those properties that involve a reaction to an applied load.

> ➢ Mechanical properties are also used to help classify and identify material. The most common properties considered are strength, ductility, hardness, impact resistance, and fracture toughness.

1. Strength: The general ability of a material to withstand on applied force.

2. Hardness: hardness is a measure of how easily a material can be scratched or indented. Hard materials are often also very brittle this means they have a low resistance to impact. Well known hard materials include diamond and hardened high carbon steels.

3. Brittleness: A material that has a tendency to break easily or suddenly without any extension first. Good examples are Cast iron, concrete, high carbon steels, ceramics, and some polymers such as urea formaldehyde (UF).

4. Toughness: A material that absorbs impact (sudden forces or shocks such as hammer blows) well is tough — this is the opposite to brittleness. [units for toughness are energy per unit area — J/m^2]

5. Plasticity: the materials which deform permanently when small forces are applied show plasticity. Plasticine and clay are good examples.

Stress-strain curves for brittle and ductile materials. Brittle materials fracture at low strains and absorb little energy. Conversely, ductile materials fail after significant plastic strain (deformation) and absorb more energy.

6. Elasticity: the ability of a material to return to its original form after a load has been applied and removed. Good examples include rubber, mild steel and some plastics such as nylon.

7. Stiffness: the ability to resist bending.

8. Ductility: The ability to be drawn out into a thin wire or threads. It is a measure of how easily a material can be worked.
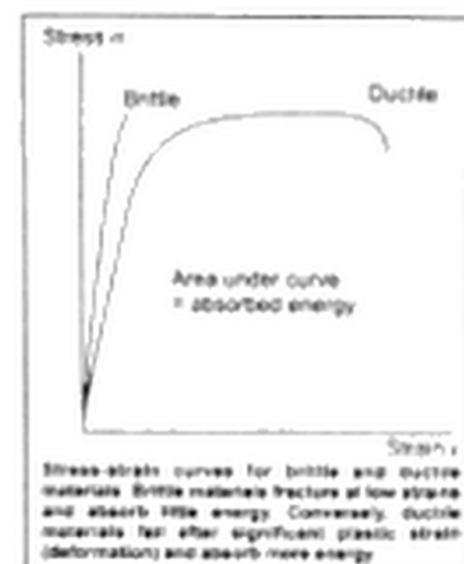
Good examples are gold, copper, titanium, wrought iron, low carbon steels and brass. It also provides an indication of how visible overload damage to a component might become before the component fractures. Ductility is also used a quality control measure to assess the level of impurities and proper processing of a material.

The conventional measures of ductility are the engineering strain at fracture (usually called the elongation) and the reduction of area at fracture. Both of these properties are obtained by fitting the specimen back together after fracture and measuring the change in length and cross-sectional area.

Q.5 What is meant by strain energy? Derive the Relation for Strain Energy from Force Extension Graph?

Strain energy

When a body is loaded without exceeding elastic limit, it changes its dimensions. When the load is removed, it regains its original dimensions. For the period of time it has remained loaded, it stores energy in itself and this energy is called elastic strain energy.

Stretched wire curve
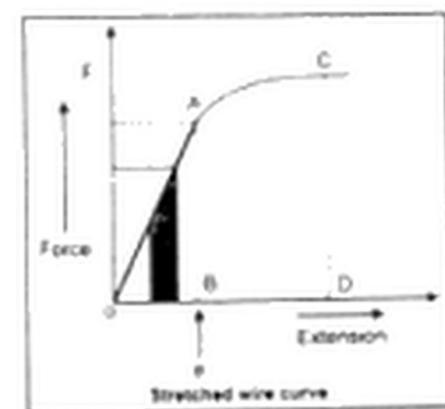
- ➤ The work done when a wire is stretched results in energy being stored in it, called strain energy.
- ➤ The above graph of force- extension has the same shape as the corresponding stress- strain graph.
- ➤ This work is stored in form of P.E in the wire. It is the gain in potential energy of the molecules due to their displacement from their mean positions
- ➤ The force varies from 0 at the start to F at the end when the wire is stretched by an amount e.

Therefore:

➤ Work done on the wire during stretching = (average force) × (extension)

$$= \frac{1}{2} Fe = \text{area of shaded strip} \quad (1)$$

The diagram shows that F is not constant during the extension. However, though the strip has to be drawn quite wide for clarity, we can imagine it to be as thin as we wish, and the thinner it is, the smaller the change in F over the correspondingly small extension.

Total work done while producing extension e in the string = area of triangle OAB

Strain energy $= \frac{1}{2}$ base × height

Strain energy $= \frac{1}{2}$ (OB)(AB) $\quad (2)$

Strain energy $= \frac{1}{2}$ (e)(F)

Strain energy $= \frac{1}{2}$ F e $\quad (3)$

Strain energy per unit volume:

Strain energy per unit volume $= \frac{Strain\ energy}{volume}$

Strain energy per unit volume $= \frac{1}{2}$ F e $\left(\frac{1}{Al}\right)$

Strain energy per unit volume $= \frac{1}{2} \left(\frac{F}{A}\right)\left(\frac{e}{l}\right) \quad (4)$

Strain energy per unit volume $= \frac{1}{2}$ (stress × stain)

This is the area under the stress-strain graph.

MCQ's from Past Board Papers

1. Young's modulus for water is:

(A) Zero   (B) 1   (C) 2   (D) 3

2. The SI unit of stress is same as that of

(A) Pressure   **(B)** Force   **(C)** Momentum   **(D)** Work

3. The atoms, ions and molecules of crystalline materials maintain their long-range order due to:

(A) adhesive force   **(B)** cohesive forces

(C) electrostatic forces   **(D)** Van der Waal's forces

4. Reciprocal of bulk modulus is:

(A) Elasticity   **(B)** Young modulus   **(C)** Compressibility   **(D)** Shear modulus

5. Substances which break just after the elastic limit is reached are called:

(A) Ductile substances   **(B)** Hard substances

(C) Soft substances   **(D)** Brittle substances

6. A wire is stretched by a force F which produces an extension l. The energy stored in the wire is

(A) Fl **(B)** $\frac{1}{2}Fl$ **(C)** $2\,Fl$ **(D)** Fl^2

7. Dimensions of strain are:

(A) L^2 **(B)** L^{-2} **(C)** $ML^{-1}T^{-2}$ **(D)** no dimensions

8. Which of the followings does not undergo plastic deformation?

(A) Copper   **(B)** Wrought iron   **(C)** Lead   **(D)** Glass

9. Substances which undergo plastic deformation until they break are known as:

(A) Brittle Substance   **(B)** Ductile Substance

(C) Non-Magnetic Substance   **(D)** Magnetic Substance

10. The Young's modulus of steel is:

(A) 2×10^{11} Nm^{-2} **(B)** 3.9×10^{-9} Nm^{-2} **(C)** 2×10^{9} Nm^{-2} **(D)** 1.5×10^{9} Nm^{-2}

11. A device used to detect very weak magnetic field produced by brain is named as:

(A) MRI   **(B)** CAT Scans   **(C)** Squid   **(D)** CRO

12. Example of ductile substance is

(A) glass   **(B)** wood   **(C)** lead   **(D)** oxygen

13. Which one is not a Ductile material:

(A) Lead   **(B)** Glass   **(C)** Copper   **(D)** Wrought iron

14.What are substances called which undergo plastic deformation until they break?

(Federal 2017)

(A) Brittle substances   **(B)** Ductile substances

(C) Amorphous solids   **(D)** Polymeric solids

Answer Key

1. A	2. A	3. B	4. C	5. D	6. B	7. D	8.D	9. B	10. A	11. C
12. C	13. B	14. B								

Q.6 What is Energy Band Theory? Distinguish between Conductors, Insulators and Semi- Conductors on the Basis of band Theory?

Energy Band Theory

When atoms bond together to become molecules their energy levels merge and split-this results in the splitting of spectral lines in molecular spectra. In a solid this process takes place between large numbers of atoms and the energy levels divide into bands of closely spaced levels with large energy gaps between the bands. There is a space between these energy bands which cannot be occupied by electrons these are called forbidden energy gap or forbidden energy states. So, electron in an atom can only occupy certain discrete energy states which are called permissible energy states.

Valance band: The electrons in the outer most orbits are called valance electrons. The band occupied by these electrons is called valance band.

> It is highest occupied band.
> It may either be completely filled or partially filled but can never be empty.

Conduction band: The band above the valance band is called conduction band.
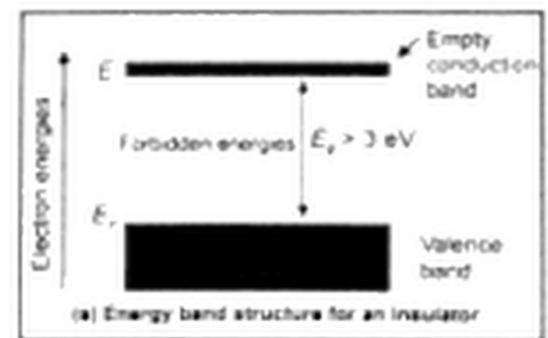
It is may have free electrons.

> Since they play the main role in conduction So they are also called conduction electrons. The conduction band may be either empty or partially filled.

The band below the valance band is called filled band. It plays no part in the conduction. It is due to bounded electrons in an atom.

Insulator

Insulators are those materials in which the valance electrons are bound very tightly to their atoms. They have;

> an empty conduction band.
> a filled valance band.
> a large energy gap of several eV

Thermal vibration might give individual electrons energy boosts, but the energy gap is much greater than the typical size of these thermal excitations so the material is an insulator.

Typical thermal excitation = kT = 0.025eV

In the valence band the electrons are unable to gain energy from an applied electrical field as there are no vacant energy levels for them to jump into.

This explains the extremely high resistivity and low conductivity of many insulators.

Conductors

Conductors are those materials m which we have large number of free electrons, valance band and conduction band overlap

> a partially filled conduction band.
> a partially filled valance band.
> No energy gap.

Semiconductors

Semi-conductors are those materials which have electrical properties lies between those of insulators and conductors. They have; (at room temperature)

> ➢ a partially filled valance band.
> ➢ a partially filled conduction band.
> ➢ a narrow energy gap (1 eV).

In fact, all semiconductors are insulators at very low temperatures. The band gap, however, is much smaller than in materials that are insulators at room temperature.

As a result, some electron will be thermally excited into the conduction band where they can move freely through the material. When this happens, the electrons leave 'holes' in the valence band.

These holes behave just like positive charge carriers and can also move through the material.

When a potential difference is connected across a semiconductor, holes and electrons drift in opposite directions and both contribute to the current that flows.

The concentration of charge carriers in a typical semiconductor at room temperature is about $10^{21}m^{-3}$. The concentration of charge carriers in a metal is about ten million times greater; as their conductivity is in between conductors and insulators so these substances are called semiconductors.


Q.7 Write a Note on Super-Conductors?

Superconductors

The materials whose Resistivity approaches to zero below a certain temperature, are called super-conductors. These materials have zero resistively below a certain temperature to called critical temperature, as shown in graph.

A graph of resistivity versus temperature for a superconductor shows a sharp transition to zero at the critical temperature T_c. High temperature superconductors have verifiable T_c greater than 125 K, well above the easily achieved 77-K temperature of liquid nitrogen.

Low temperature super

This means no heat, sound or any other form of energy would be released from the material when it has reached "critical temperature" (T_c), or the temperature at which the material becomes superconductive.
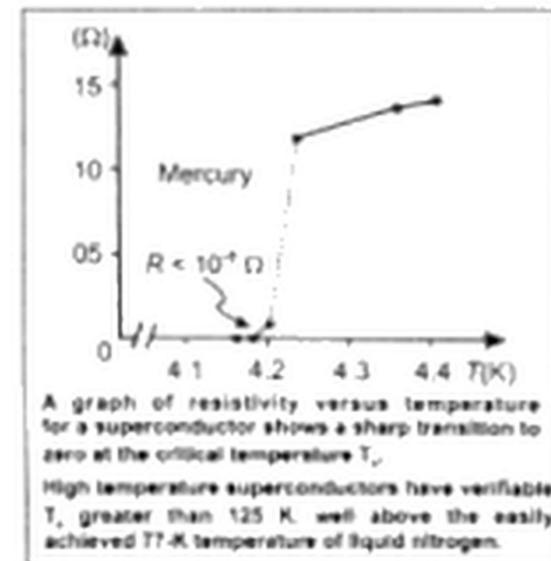
Unfortunately, most materials must be in an extremely low energy state (very cold) in order to become superconductive. The resistance of a superconductor is zero, since there are no heat losses for currents through them; they are used in magnets needing high currents, such as in MRI machines, and it does not offer resistance to transmission line. In the past decade, tremendous advances have been made in producing materials that become superconductors at relatively high temperature. There is hope that room temperature superconductors may someday be manufactured.

Certain other elements were also found to become superconductors, but all had T_c less than 10 K, which are expensive to maintain. In 1986, a ceramic compound was found to have T_c of 35 K. It looked as if much higher critical temperatures could be possible, and by early 1988 another ceramic (thallium, calcium, barium, copper and oxygen) had been found to have T_c = 125 K.

> ➤ The first commercial use of a high temperature superconductor is in an electronic filter for cellular phones.
> ➤ High-temperature superconductors are used in experimental apparatus. The search is on for even higher Tc superconductors, many of complex

and exotic copper oxide Ceramics sometimes including strontium, mercury, or yttrium as well as barium, calcium and other elements.

➢ Room temperature (about 293 K) would be ideal, but any temperature close to room temperature is relatively cheap to produce and maintain.

Applications

i) Magnetic Resonance Imaging (MRI)

ii) Magnetic Levitation trains

iii) Powerful and small motors

iv) Fast computer chips

MCQ's From Past Board Papers

1. The critical temperature of mercury is:

(A) 1 18 K   **(B)** 4.2 K   **(C)** 3.72 K   **(D)** 7.2 K

2. Which one pair belongs to accepter impurity:

(A) Arsenic, phosphorus **(B)** Boron, gallium **(C)** Antimony, indium   **(D)** Arsenic, antimony

3. In an n-type material, the minority charge carriers are:

(A) Free electrons   **(B)** Holes   **(C)** Protons   **(D)** Mesons

4. A p-type material is formed when a semiconductor is doped with:

(A) Trivalent impurity   **(B)** Tetravalent impurity

(C) Pentavalent impurity   **(D)** Divalent impurity

5. Once the resistance of material drops to zero, the

(A) Energy is dissipated

(B) Current is dissipated

(C) Energy and current both are dissipated (D) Energy and current both are not dissipated

6. Ceramic materials exhibit super-conductivity at   .

(A) 0°C   (B) 125 K   (C) 60 K   (D) 30 K

7. N-Type germanium is obtained by doping intrinsic germanium with

(A) Tetravalent impurity atom

(B) Trivalent impurity atom

(C) Pentavalent impurity atom

(D) Hexavalent impurity atom

8. When a silicon crystal is doped with a pentavalent element, it becomes:

(A) p-type semiconductor

(B) n-type semiconductor

(C) intrinsic semiconductor

(D) extrinsic semiconductor

9. The substances with conductivities between 10^{-10} and 10^{-20} $(\Omega m)^{-1}$ are called:

(A) super conductors

(B) Insulators

(C) semi-conductors

(D) conductors

10.   Good conductors have conductivities of the order of:

(A) 10^{-7} $(\Omega m)^{-1}$ (B) 10^{7} $(\Omega m)^{-1}$ (C) 10^{2} $(\Omega m)^{-1}$ (D) 10^{-2} $(\Omega m)^{-1}$

11. Which type of impurity is to be added to a pure semi-conductor crystal to provide holes:

(A) Monovalent   (B) Trivalent   (C) Tetravalent   (D) Pentavalent

12. To get N- type, the Ge is doped with:

(A) Aluminum   (B) Arsenic   (C) Boron   (D) Indium

13. The critical temperature (T$_c$) of lead is

(A) 7.2 k   (B) 3.72 k   (C) 125 k   (D) 77 k

14. Good conductors have conductivities of the order of

(A) $10^3(\Omega m)^{-1}$ (B) $10^6(\Omega m)^{-1}$ (C) $10^7(\Omega m)^{-1}$ (D) $10^9(\Omega m)^{-1}$

15. Which one is pentavalent impurity?

(A) boron   (B) gallium   (C) antimony   (D) indium

16. Minority carriers in p-type substances are:

(A) Holes   (B) Electrons   (C) Protons   (D) Positrons

17. The critical temperature of Aluminum is:

(A) 3.72 K   (B) 1.18 K   (C) 7.2 K   (D) 8.2 K

18. At 0 k semi-conductors are

(A) Conductors   (B) Insulators   (C) Perfect conductors   (D) Perfect insulators

19. The conductivity of semi-conductor is of the order of

(A) 10^7 $(\Omega m)^{-1}$ (B) $10^{-6} - 10^{-4}$ $(\Omega m)^{-1}$ (C) $10^{-20} - 10^{-10}$ $(\Omega m)^{-1}$ (D) $10^6 - 10^4$ $(\Omega m)^{-1}$

20. At 0 K, semiconductors are:

(A) Conductors   (B) Insulators   (C) Perfect conductors   (D) Perfect insulators

21. With the rise in temperature, the conductivity of semi-conductor material:

(A) increases linearly   (B) Decrease linearly

(C) Increases exponentially   (D) Decreases exponentially

22. In extrinsic semiconductors doping is of the order of:

(A) 1 atom to 10^4 (B) 1 atom to 10^8 (C) 1 atom to 10^3 (D) 1 atom to 10^6

Answer Key

| 1. B	2. B	3. B	4. A	5. D	6. B	7. C	8. B	9. B	10. A	11. B
12. B	13. A	14. C	15. B	16. B	17. B	18. D	19. D	20. B	21. A	22. D

Q8. Discuss the magnetic properties of solid? Also classify the materials according, these properties?

Theory of Magnetism

The molecule of a magnetic substance (where magnetized or not) is a complete magnet in itself having a north pole and a south pole of equal strength.

(i) In an un-magnetized substance, the molecular magnets are randomly oriented as shown in Fig. 16.14 (a). The north pole of one molecular magnet cancels the effect of the south pole of the other so that the substance does not show any net magnetism.

(ii) When a magnetizing force is applied to the substance, the molecular magnets are turned and tend to align in the same direction with N-pole of one molecular magnet facing the S-pole of other as shown in fig. 16.14(b). The result is that magnetic field of the molecular magnets aid each other
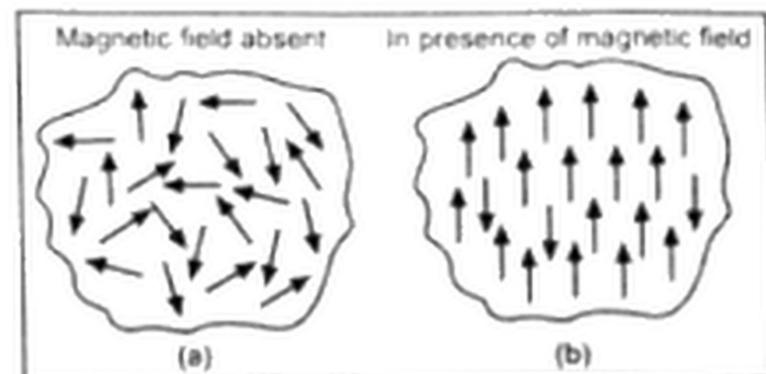
and two definite N and S-pole are developed near the ends of the specimen; the strength of the two poles being equal Hence the substance gets magnetized.

(iii) The extent of magnetization of the substance depends upon the extent of alignment of molecular magnets. When all the molecular magnets are fully aligned, the substance is said to be saturated with magnetism.

(iv) When a magnetized substance (or a magnet) is heated, the molecular magnets acquire kinetic energy and some of them loss their arrangement. For this reason, a magnet loses some magnetism on heating.

Modern View About Magnetism

According to modem view, the magnetic properties of a substance are due to the motions of electrons (orbital and spin) in the atoms. We know that an atom consists of central nucleus with electrons revolving around the nucleus in different orbits. This motion of electrons is called orbital motion, fig 16.15(a). The

electrons also rotate around their own axis. This motion of electrons is called spin motion Fig 16.15(b).

Due to these two motions, each atom is equivalent to a current loop i.e. each atom behaves as a magnetic dipole.

(a) Orbiting electron   (b) Spinning electron
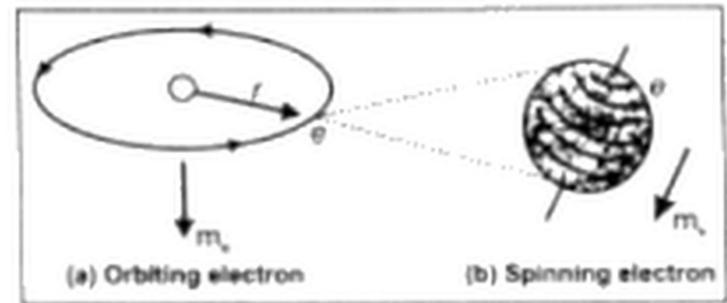
1. In the un-magnetized substances, the magnetic dipoles are randomly oriented so that magnetic fields mutually cancel. When the substance is magnetized, the magnetic dipoles are aligned in the same direction. Hence the substance shows net magnetism.

2. Since the revolving and spinning electrons in each atom cause magnetism, no substance is non-magnetic.

3. It is important to note that spinning motion of electrons in particular is responsible for magnetism of a substance.

Classification of Magnetic Materials

We can classify materials into three categories viz. diamagnetic, paramagnetic and ferromagnetic. The behaviour of these three classes of substances is different in an external magnetic field.

1. Paramagnetic Substances

The substances in which magnetic fields produced by the orbital and spin motion of electrons support each other and the atom behave like a tiny magnet, are called the paramagnetic substances, e. g Aluminum (Al), Platinum manganese etc.

2. Diamagnetic materials

The substances in which magnetic fields produced by the orbital and spin motion of electrons cancel each other so that their resultant field is zero, and

there is no permanent magnetic moment between the atoms, are called diamagnetic substance, e. g Cooper (Cu), Bismuth's (Bi), antimony (Sb) and zinc

Therefore, a diamagnetic substance is weakly repelled by a strong magnet.

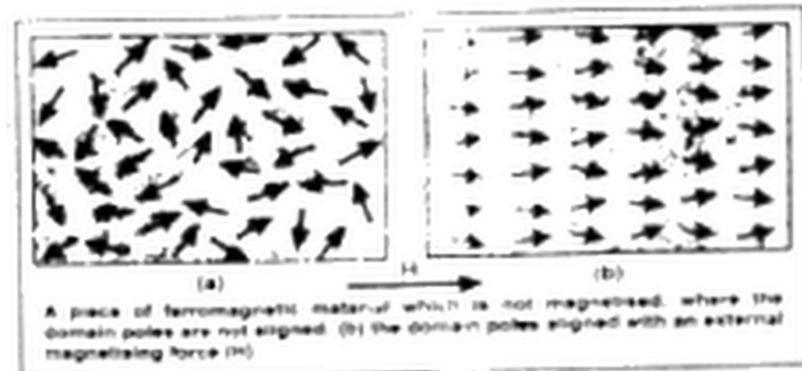## 3. Ferromagnetic materials

(iii) Ferromagnetic Substances

The substances in which the atoms co-operate with each other in such a way so that they exhibit a strong magnetic effect and are strongly attracted by magnetic field, are called ferromagnetic substances, e. g Iron (Fe), Nickle (Ni), cobalt (Co), Chromium dioxide and Alnico (an iron aluminum-nickel-cobalt alloy), etc.

Domain of Ferromagnetic Substances

The small magnetized regions in a ferromagnetic substance are called domains.

The size of these domains is very small of the order of millimeters or less but large

enough to contain atoms from 10^{12} to 10^{16}. Each domain acts like a small magnet with its own north and South Pole. The coupling or interaction between the neighboring tiny magnets is reduced by increasing

A piece of ferromagnetic material which is not magnetised, where the domain poles are not aligned (b) the domain poles aligned with an external magnetising force (H)

the temperature of a substance. The temperature at which a ferromagnetic material becomes paramagnetic is called its curie temperature.

When a ferromagnetic substance (e.g. iron, nickel, cobalt etc.) is placed in a magnetic field, the substance is strongly magnetized in the direction of the applied field.

Therefore, ferromagnetic material is strongly attracted by a magnet.

Domains in Soft Magnetic Material

Iron is a soft magnetic material because its domains can be easily oriented on applying an external magnetic field and also return to original position when field is removed.

Domains in Hard Magnetic Material

Whereas steel is a hard-magnetic substance because its domains cannot be easily oriented on applying the external magnetic field. The domain in steel can be lined up by a very strong external magnetic field, but once oriented, retain their positions.

Effect of Temperature

Thermal vibrations tend to disturb the orderliness of the domains. Ferromagnetic substances preserve the orderliness at ordinary temperature which begins to lose their orderliness due to increase in temperature this process starts at a certain temperature.

Curie Temperature

The temperature above which a ferromagnetic substance becomes paramagnetic, is called curie temperature.

The curie temperature for iron is about 75°C.

Q.9 What is Hysteresis Loop? Discuss it in Detail?

Magnetic Hysteresis

When an electric current is passed through a coil of wire, the coil acts like a bar magnet with a north pole at one end and a south pole at the other. In other words, it acts like an electromagnet. If a bar of soft iron is placed inside the coil, the strength of the electromagnet is much increased. This is because the piece of soft iron is itself converted into a magnet by the effect of the current in the coil. Magnetic field strength (H) is the amount of magnetizing force. The intensity

of the Magnetic Flux Density, (B), is affected by the intensity of the Magnetic Field, (H) the quantities of the substance and the intervening media between the source of the magnetic field and the substance.

The relationship between magnetic field strength and magnetic flux density is:

$$B = H \times \mu_0$$

When a magnetic material is subjected to a cycle of magnetism (i.e., it is magnetized first in one direction and then in the other), it is found that flux density B in the material lags behind the applied magnetizing force H.

This phenomenon is known as hysteresis.

(i) Hysteresis

The phenomenon of lagging of flux density (B) behind the magnetizing force (H) in a magnetic material subjected to cycle of magnetization is known as magnetic hysteresis.

If the magnetization current, I is increased in a positive direction to some value the magnetic field strength H increases linearly with I and the flux density B will also increase as shown by the curve from point O to point a as it heads towards saturation.

Hysteresis loop
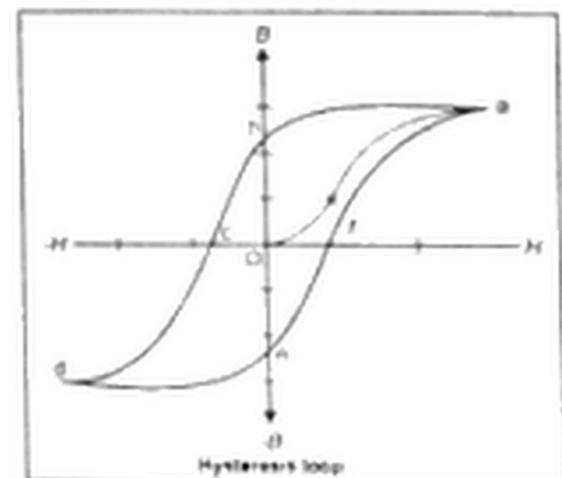
Saturation

The magnetic flux density increases from zero and reaches a maximum value. At this stage the material i said to be magnetically saturated.

Now it the magnetizing current in the coil is reduced to zero the magnetic field around the core reduces to zero hut the magnetic flux docs not reach Zero due to the residual magnetism present within the core and this is shown on the curve from point a to point h.

To reduce the flux density at point b to zero we need to reverse the current flowing through the coil. The magnetizing force which must be applied to null the residual flux density is called a "Coercive Force" This coercive force reverses the magnetic field re-arranging the molecular magnets until the core becomes un-magnetized at point c.

> ➤ **An increase in the reverse current causes the core to be magnetized in the opposite direction and increasing this**

magnetization current will cause the core to reach saturation but in the opposite direction, point d on the curve. If the magnetizing current is reduced again to zero the residual magnetism present in the core will be equal to the previous value but in reverse at point e. Again reversing the magnetizing current flowing through the coil this time into a positive direction will cause the magnetic flux to reach zero, point f on the curve and as before increasing the magnetization current further in a positive direction will cause the core to reach saturation at point a then the B-H curve follows the path of a-b-c-d-e-f-a as the magnetizing current flowing through the coil alternates between a positive and negative value such as the cycle of an AC voltage. This path is called a Magnetic Hysteresis Loop. Thus, when a magnetic material is subjected to one cycle of magnetization, B always lags behind H so that the resultant B-H curve forms a closed loop, called hysteresis loop.

From the hysteresis loop, a number of magnetic properties of a material are

1. Retentivity: It is a material's ability to retain a certain amount of residual magnetic field when the magnetizing force is removed after achieving saturation.

2. Residual Magnetism or Residual Flux: The magnetic lux density that remains in a material when the magnetizing force is zero.

3. Coercive Force: The amount of reverse magnetic field which must be applied to a magnetic material to make the magnetic flux return to zero.

4. Reluctance: Is the opposition that a ferromagnetic material shows to the establishment of a magnetic field.

Reluctance is analogous to the resistance in an electrical circuit.

> **Area of Loop**

The area of the loop is proportional to the energy required to take unit volume of the material round one cycle of magnetization This energy increases the internal energy of the specimen. It is called hysteresis loss and is important when material is subjected to alternating field which take them through many cycles of magnetization per second.
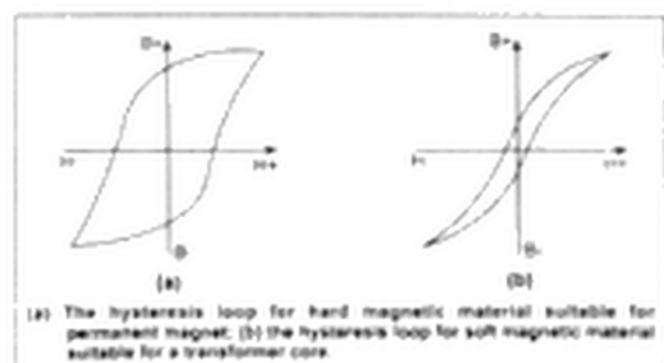
Magnetic Hysteresis Loops for Soft and Hard Materials,

Soft magnetic materials:

Materials with smaller hysteresis loop area are easily magnetized with external magnetic field and easily de-magnetized when external magnetic field is removed are known as soft ferro magnetic materials.

Soft ferromagnetic materials such as iron or silicon steel have very narrow magnetic hysteresis loops resulting in very small amounts of residual magnetism making them ideal for use in relay s, solenoids and transformers as they can be easily magnetized and de-magnetized.

Since a coercive force must be applied to overcome this residual magnetism,

work must be done in closing the hysteresis loop with the energy being used being dissipated as heat in the magnetic material. This heat is known as hysteresis loss. the amount of loss depends on the materials value of coercive force.

(a) The hysteresis loop for hard magnetic material suitable for permanent magnet; (b) the hysteresis loop for soft magnetic material suitable for a transformer core.

By adding silicon, to iron a material with a very small coercive force can be made, such materials typically contain 5 % silicon and have very narrow hysteresis loop (figure 16.18b)

Materials with narrow hysteresis loops are easily magnetized and de-magnetized and known as soft magnetic materials. Magnetic Hysteresis results in the dissipation of wasted energy in the form of heat with the energy wasted being in proportion to the area of the magnetic hysteresis loop. Hysteresis losses will always be a problem in AC transformers where the current is constantly changing direction and thus the magnetic poles in the core will cause losses because they constantly reverse direction.

Hard ferromagnetic materials:

Materials with large hysteresis loops are difficult to de-magnetize and magnetic flux density remains even magnetizing force is removed are known as hard ferromagnetic materials.

In order to create a permanent magnet, a material with a very fat hysteresis loop may be used (figure 16.18a). Such materials, once magnetized, are very difficult to demagnetize and when the magnetizing force is removed a substantial magnetic flux density remains. These materials are known as hard magnetic materials. Its examples are Tungsten steel, Cunife, Cobalt rare earth 1, Sintered ferrite 3, and Sintered alnico 8 etc.,