Unit 16

PHYSICS OF SOLIDS

Major Concepts (13 PERIODS)

- Classification of solids
- Mechanical properties of solids
- Elastic limit and yield strength
- Electrical properties of solids
- Superconductors
- Magnetic properties of solids

Conceptual Linkage

This chapter is built on
Properties of matter Physics IX
Types of Solids Chemistry XI

Students Learning Outcomes

After studying this unit, 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 load-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 a material.
- describe the idea about energy bands in solids.
- classify insulators, conductors, semiconductors on the basis of energy bands.
- become familiar with the behaviour of superconductors and their potential uses.
- distinguish between dia, para and ferro magnetic materials.
- describe the concepts of magnetic domains in a material.
- explain the Curie point.
- classify hard and soft ferromagnetic substances.
- describe hysteresis loss.
- synthesize from hysteresis loop how magnetic field strength varies with magnetizing current.

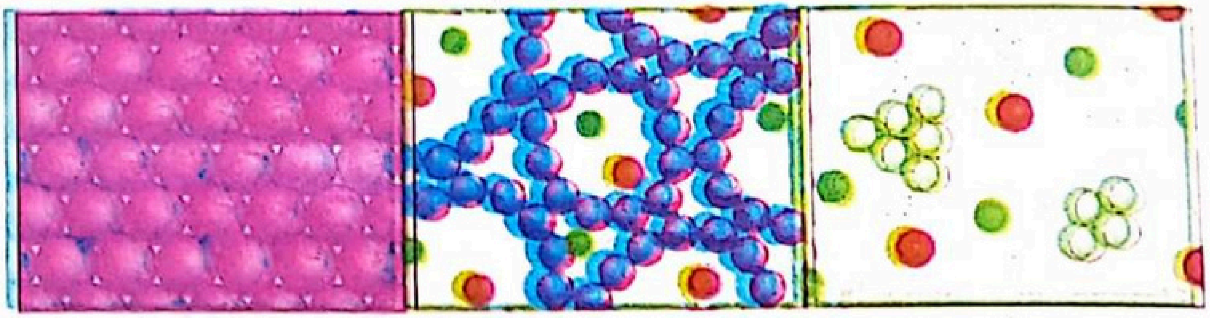
INTRODUCTION

Basically, there are three states of matter solids, liquids and gas. The liquid and gas are compressible and have ability to flow, whereas, solids are incompressible and have definite volume and shapes. These are due to the closeness of their atoms or molecules. Similarly, there are several kinds of solids, among these, each of them has its different characteristics and properties. Some solids are crystalline while others are amorphous or polymer, some are elastic while others are rigid, some are brittle while others are plastic or ductile, some have electrical conductivity while others have magnetic conductivity. For example, diamond is hard, lead is soft, steal is strong, glass is weak, copper has electrical conductivity and iron has magnetic conductivity.

Many solids can be deformed in the form of change in their length, volume or shape by a deforming force. These deformations can be studied in terms of stress and strain.

In this unit we will explain classification of solids. For example, there are three classes of solids with respect to their structure, named as: crystalline, amorphous and polymer. Electrically, there are three classes of solids such as: insulators, conductors and semi-conductors, these can be studied using band theory of solids. Magnetically, the three types of solids are paramagnetic, diamagnetic and ferromagnetic. In addition to the magnetic classes, we will also discuss the phenomenon of hysteresis and hysteresis loop by magnetizing and demagnetizing the magnetic materials.

Arrangement of Molecules in Solid, Liquid and Gas



Solid	Liquid	Gas
Molecules are tightly packed and cannot move freely	Molecules are loosely packed and can move freely	Molecules are very lossely packed and in a continuous random motion.

16.1 CLASSIFICATION OF SOLIDS

We have studied in the previous classes about the three forms of matter such as solids, liquids and gases. Plasma is often termed as the fourth state of the matter. Among all these, solid is the only form of matter which has a definite shape and volume. Normally, the distance between the adjacent atoms of the solid are the same as the diameters of the atoms themselves. Thus, there are strong interactions between the atoms of the solids. On the other hand, the distribution of atoms or molecules of the solids are not alike i.e., the atoms or molecules of some solids are arranged with orderly manner, while, the arrangement of the atoms or molecules of other solids are orderless. On the basis of such distribution of atoms or molecules, solids can be classified into three types.

Crystalline solids

The solid in which their atoms, molecules or ions are arranged in a definite order are called crystalline solids as shown in Fig.16.1. These regular arrangement of atoms, molecules or ions can be studied by using various x-rays techniques. The observations show that the arrangement of atoms, molecules or ions are repeating in a three dimensional pattern with highly ordered throughout the crystal. For example, Sodium Chloride (NaCl) crystal has a cubic structure as shown in Fig.16.2. The red spheres represent the positive sodium ion (Na^+) and blue spheres represent the negative chlorine ion (Cl^-). The distribution of the ions shows that there is regular arrangement of the ions which is repeated in three dimensions. The crystalline solids have a long range order it means that there is a regular pattern of arrangement of particles which repeats itself periodically over the entire crystal. Similarly, crystalline solids have another important property that they have sharp melting point. e.g, aluminum has melting point of 655°C, NaCl has melting point of 800°C and the melting point of copper is 1084°C.

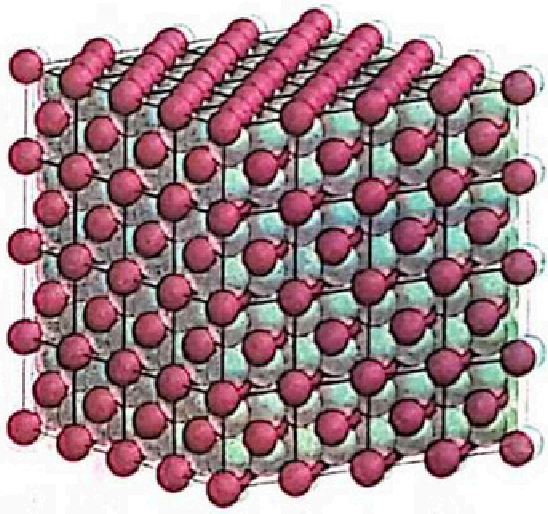


Fig.16.1 Regular arrangement of molecules of a crystalline solid.

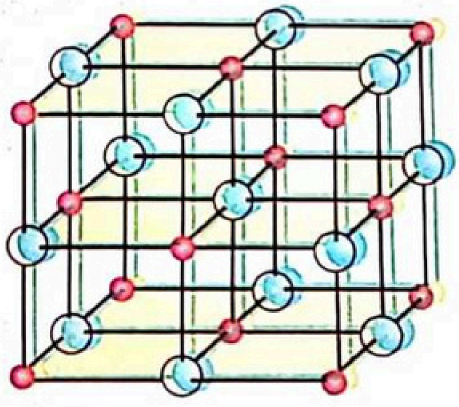
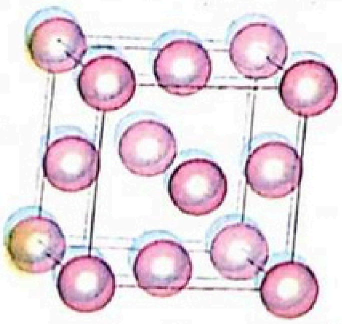
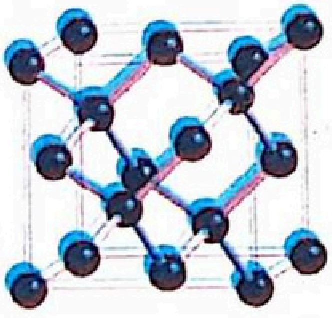


Fig.16.2 A cubic crystal structure of NaCl (Ionic Crystal).

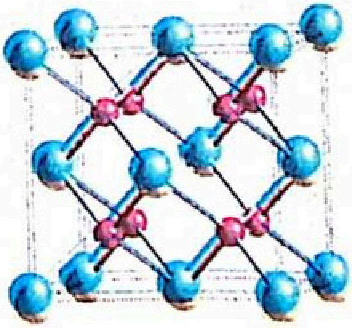
Almost all families of solid fall in the group of crystalline solids including **metals**: such as, copper, zinc and iron, **non-metal** such as, diamond, sulphar and



Crystal structure of copper (metal)



Crystal structure of diamond (non-metal)



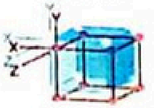
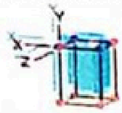
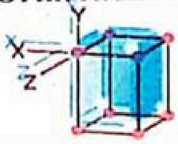
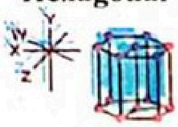
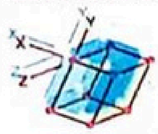
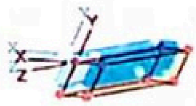
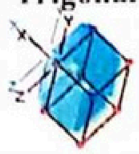
Crystal structure of zirconium (ceramic)

mica, **ionic compound**, such as, sodium chloride and copper sulphate and **ceramic**: such as zirconium.

All these crystalline solids have not only definite volume but also geometrical shapes such as, cubic, trigonal, tetragonal, hexagonal, orthorhombic, monoclinic and triclinic as shown in Table.16.1.

The study shows that the atoms, molecules or ions of the crystalline solids are not stationary, but they vibrate about a fixed point and their amplitude depends upon temperature. i.e., the amplitude of the vibration increases with increasing temperature.

Table.16.1 Different geometrical shapes of crystalline solids.

Cubic  All three axes are equal in length and they are perpendicular to one another.	**Tetragonal**  Two of the three axes are equal in length, and all the three are perpendicular to one another.
Orthorhomibic  All three axes are unequal but perpendicular to one another.	**Hexagonal**  Three axes are of equal length, the fourth axis is perpendicular to the plane of the other three.
Monoclinic  All three axes are unequal and two of them are perpendicular to each other	**Triclinic**  All three axes are unequal and are not perpendicular to another.
Trigonal  All the three axes are equal in length, but none of the axes is perpendicualr to another.	

Amorphous solids

The solids whose constituent particles i.e. atoms, molecules or ions are arranged more-or-less in a random manner are called amorphous solids. Like crystal, the atoms or molecules of the amorphous solids have no order in the long range as shown in Fig.16.3. Although amorphous solids have a definite volume, but they have not definite regular geometrical or crystalline shape. Amorphous solids have some properties as that of the frozen liquid. For example, if we heat a glass rod with a spirit lamp, we will find that the rod begins to flow more and more easily as its temperature rises, this shows that glass has no definite transition from solid to liquid, and no definite melting point. Therefore, one can say that glass at room temperature is an example of amorphous solid, which has no long range order, but only short range order. Thus, amorphous solids are also called glassy solids.

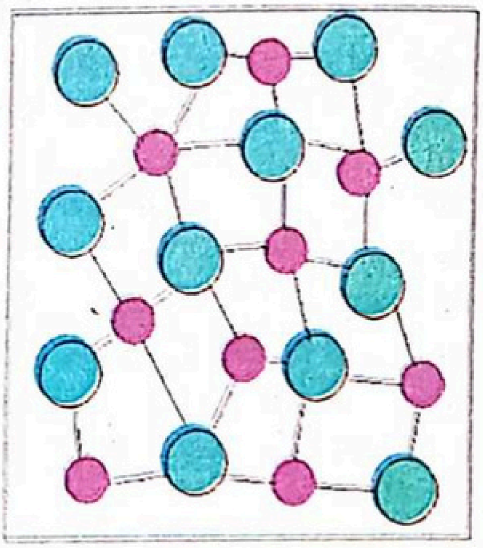


Fig.16.3 Distribution of molecules of amorphous.

Polymeric solids

The solids in which its atoms, molecules or ions are arranged neither periodically like crystalline solids nor random like amorphous solids are called polymeric solids. The distribution of atoms or molecules of polymeric solids is shown in Fig.16.4. The structure of the polymeric solid lies between order and disorder. Thus, polymeric solids may be classified as partially or poorly crystalline solids.

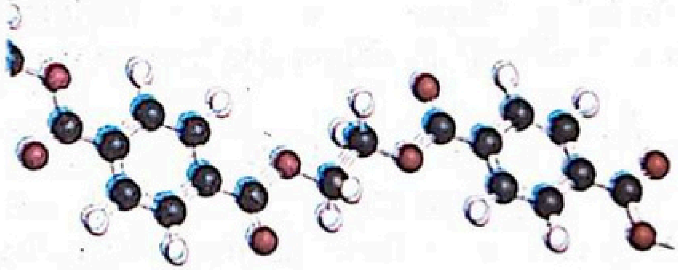


Fig.16.4 Distribution of molecules of polymeric solid.

There are two types of polymeric solids, naturally occurring and synthetic (polymeric by chemical reaction). The polymers that occur naturally are rubber, resin, cotton-wool and wood. Whereas, the synthetic polymers are polythene, polystyrene, polypropylene, polyvinyl chloride etc. Polymers, both natural and synthesized are created under the process of polymerization of many small molecules called monomers. Polymers consists of very long chain of carbon atoms bounded by oxygen, hydrogen, nitrogen and other non-metallic elements as shown in Fig.16.5. For example, plastic and synthetic rubber are formed by polymerization reaction in which relatively simple molecules are chemically combined into massive long chain molecules in the form of three dimensional structure.

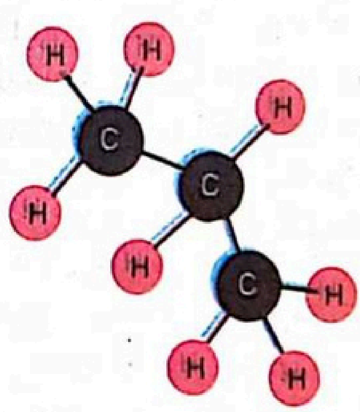


Fig.16.5 A chain of carbons bounded by other elements.

16.2 MECHANICAL PROPERTIES OF SOLIDS

Almost all bodies can be deformed more or less by applying a force called deforming force. The deformation may be in the form of change in its length, volume or shape of a body. All these are explained by some examples;

I. Let the upper end of a wire is fixed and its lower end is pulled down by the weight of the body. A change may produce in the length of the wire called tensile as shown in Fig.16.6(a)

II. Similarly, if a rubber ball is pressed or squeezed from its all sides, its volume decreases, i.e., a change occurs in volume of the ball called volumetric as shown in Fig.16.6(b).

III. When a deforming force is applied on a box, the perpendicular axes of the box are displaced from their fixed position. This causes change in shape of the box called shearing as shown in Fig.16.6(c).

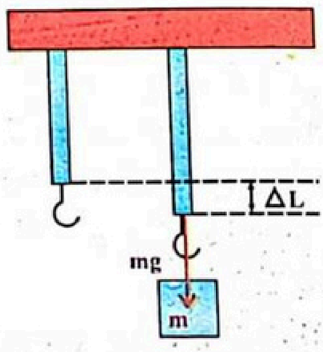


Fig.16.6(a) A change is produced in length of the wire

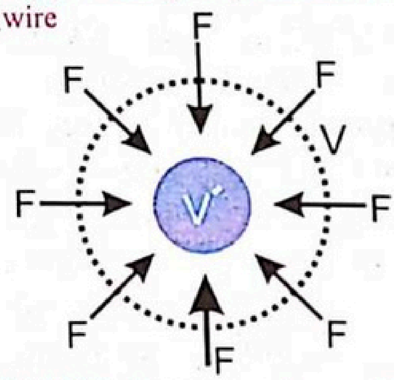


Fig.16.6(b) A change in volume of the ball

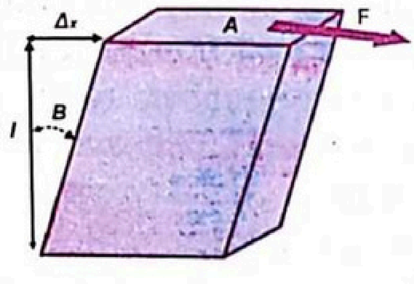


Fig.16.6(c) A change in shape of the box

After deformation, when the deforming forces are removed, and the bodies tend to regain their original conditions, then this property of the bodies is called elasticity. Those bodies which can regain or resume completely their original shape and size, on the removal of deforming forces are called elastic bodies. On the other hand, the bodies which cannot regain their original shape and size, but a permanent change occurs in it after the removal of deforming forces are known as plastic. In practice, there are no perfectly elastic or plastic solids. All the elastic and plastic properties of solids are explained in terms of stress and strain.

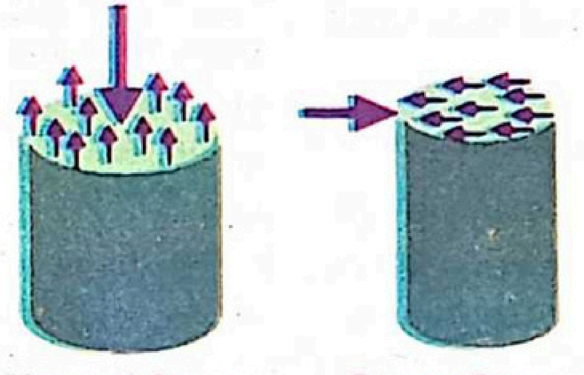
Stress

The deforming force may produce a change in an object's length, volume or shape. The force in terms of its work is stored in the deformed body as elastic potential energy which helps to regain the body to its original position and its corresponding force is called elastic restoring force. Defaming and restoring forces are same in magnitude but in opposite sign. Thus, **the deforming force acting per unit area to produce any change in length, shape or volume in a body is called stress.** i.e.

$$\text{Stress}(\sigma) = \frac{\text{deforming force}}{\text{area}} = \frac{F}{A} \quad ......(16.1)$$

The SI unit of stress is newton per meter square (N m^{-2}) which is termed as Pascal (Pa) and the dimension formula of stress is $[ML^{-1}T^{-2}]$.

If the force is acting normally to the surface, then its corresponding stress is called normal stress. There are two types of normal stress, tensile stress and compressive stress. However, if the force is acting along the surface per unit area then it is called tangential stress or shear stress.



Strain

The change in length, volume or shape of a body due to the deforming force is called strain. It is always measured in terms of the ratio of change in dimension to the original dimension. i.e.,

$$\text{Strain} = \frac{\text{change in dimension}}{\text{original dimension}}$$

As strain is defined in terms of ratio of quantities with same dimensions so it has no unit or dimensions.

If a change occurs in the length of body then the ratio of change in length (ΔL) to the original length (L) is called longitudinal strain, it is caused by longitudinal stress (tensile stress/compressive stress) as shown in Fig.16.7(a), thus

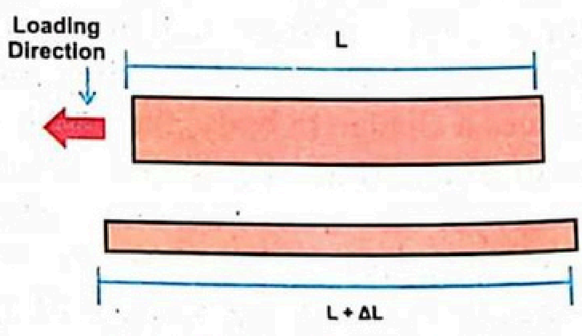


Fig.16.7(a) Longitudinal strain

$$\text{Longitudinal strain} = \frac{\text{change in length}}{\text{original length}}$$

$$\varepsilon = \frac{\Delta L}{L} \quad ......(16.2)$$

Similarly, **the ratio of change of volume of a body to its original volume is called volumetric strain,** as shown in Fig.16.7(b). Mathematically, it is explained as;

$$\text{Volumetric strain} = \frac{\text{change in volume}}{\text{original volume}}$$

$$\text{Volumetric strain} = \frac{\Delta V}{V} \ldots\ldots(16.3)$$

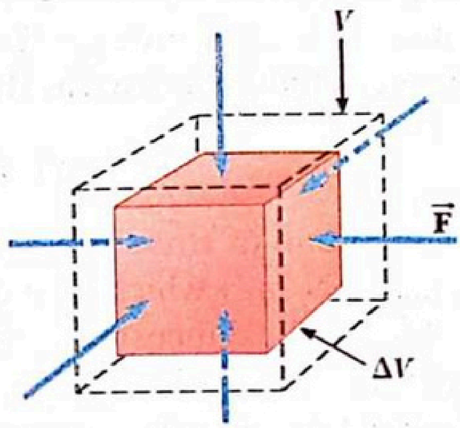


Fig.16.7(b) Volumetric strain

When the deforming force produces a change in the shape of a body (without changing its volume), it is called shear strain. In shear strain, the axes of the body are displaced through an angle 'θ' as shown in Fig.16.7(c). Thus, it is measured in terms of angle 'θ'. i.e.,

$$\text{Shear strain } (\gamma) = \frac{\Delta x}{\ell} = \tan\theta$$

For very small value of angle 'θ' in terms of radian, $\tan\theta = \theta$, so that,

$$\text{Shear strain} = \theta \ldots\ldots(16.4)$$

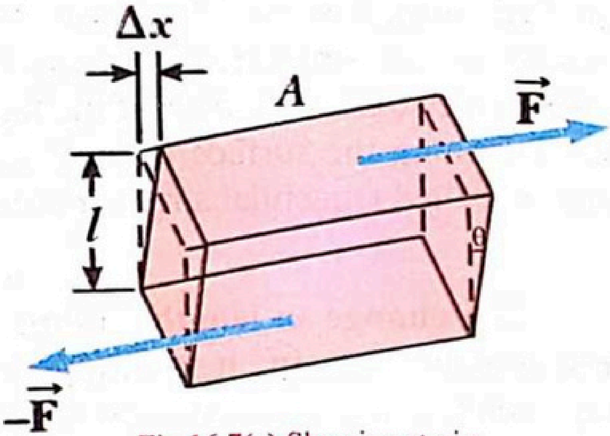


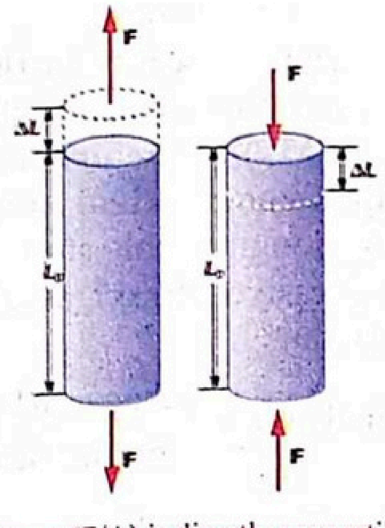
Fig.16.7(c) Shearing strain

16.3 HOOKE'S LAW

Robert Hooke studied the elastic properties of various solids and defined them in terms of stress and strain. It is explained as: when a deforming force produces a change in body, then we have both stress and strain. i.e., stress is a force that acts per unit area of the body, which produce deformation. Whereas, strain is the measurement of the amount of the deformation.

According to Hooke's law, within elastic limit, the strain is directly proportional to the applied stress. i.e.,

$$\text{Stress} \propto \text{Strain}$$



Applied Stress (F/A) is directly proportional to the strain (ΔL).

$$\frac{\text{stress}}{\text{strain}} = E \ldots\ldots (16.5)$$

where 'E' is the constant of proportionality. It is known as coefficient of elasticity or modulus of elasticity. Its value depends upon the nature of the solids. Since strain has no unit, therefore, the unit of modulus of elasticity is same as that of the stress. i.e., N m^{-2}. There are three kinds of modulus of elasticity.

I. Young's Modulus

When the deformation in a body is in the form of change in its length only then there is longitudinal stress and longitudinal strain. The ratio of longitudinal stress to longitudinal strain is called Young's modulus. It is expressed as:

$$\text{Young's Modulus (Y)} = \frac{\text{longitudinal stress}}{\text{longitudinal strain}}$$

$$Y = \frac{F/A}{\Delta L/L}$$

$$Y = \frac{FL}{A\,\Delta L} \ldots\ldots (16.6)$$

> ***POINT TO PONDER***
>
> A wire used to support a weight and is stretched by a millimetre. The wire is replaced by another wire of the same material having twice of cross-section area of the first wire. How much does the new wire stretched when it supports the same weight?

II. Bulk Modulus

When the applied force produces change in the volume of the body, we have the volumetric stress and the volumetric strain. The ratio of volumetric stress to the volumetric strain is called Bulk Modulus. i.e.,

$$\text{Bulk Modulus(K)} = \frac{\text{volumetric stress}}{\text{volumetric strain}}$$

$$K = \frac{F/A}{\Delta V/V}$$

$$K = \frac{FV}{A\,\Delta V} \ldots\ldots (16.7)$$

III. Modulus of Rigidity

In case of shear deformation which causes change in shape of the solid, the ratio of the shear stress to the shear strain is called Modulus of Rigidity. It is expressed as;

$$\text{Modulus of Rigidity } (\eta) = \frac{\text{shear stress}}{\text{shear strain}}$$

$$\eta = \frac{F/A}{\theta}$$

$$\eta = \frac{F}{A\theta} \quad \text{......(16.8)}$$

The typical values of the three elastic constants for some selected materials are given in table 16.2.

Table.16.2 Typical Values of Elastic Moduli

Substance	Young's Modulus (Pa)	Shear Modulus (Pa)	Bulk Modulus (Pa)
Aluminum	7.0×10^{10}	2.5×10^{10}	7.0×10^{10}
Bone	1.8×10^{10}	8.0×10^{10}	-
Brass	9.1×10^{10}	3.5×10^{10}	6.1×10^{10}
Copper	11×10^{10}	4.2×10^{10}	14×10^{10}
Steel	20×10^{10}	8.4×10^{10}	16×10^{10}
Tungsten	35×10^{10}	14×10^{10}	20×10^{10}
Glass	6.5 to 7.8×10^{10}	2.6 to 3.2×10^{10}	5.0 to 5.5×10^{10}
Quartz	5.6×10^{10}	2.6×10^{10}	2.7×10^{10}
Rib Cartilage	1.2×10^{10}	-	-
Rubber	0.1×10^{10}	-	-
Tendon	2×10^{10}	-	-
Water	-	-	0.21×10^{10}
Mercury	-	-	2.8×10^{10}

Example 16.1

A metal wire 80cm long and 15mm in diameter stretches 20mm when a load of 8kg is hung on its end. Find the stress, the strain and Young's modulus for the material of the wire.

Solution:

We have

Length of the wire = L = 80cm = 0.8m

Diameter of the wire = D = 15mm

Radius of the wire = r = 7.5mm = 7.5×10^{-3}m

Change in length = ΔL = 20mm = 2×10^{-2}m

Mass of the load = m = 8kg

Stress = ?

Strain = ?

Young's modulus = ?

$$\text{Stress} = \frac{F}{A} = \frac{W}{\pi r^2} = \frac{mg}{\pi r^2}$$

$$\text{Stress} = \frac{8\text{kg}\left(9.8\text{ms}^{-2}\right)}{3.14\left(7.5\times10^{-3}\text{m}\right)^2}$$

$$= 4.44\times10^{5}\,\text{N m}^{-2}$$

$$\text{Strain} = \frac{\Delta L}{L} = \frac{2\times10^{-2}\text{m}}{0.8\text{m}}$$

$$\text{Strain} = 2.5 \times 10^{-2}$$

$$\text{Young's Modulus(Y)} = \frac{\text{Stress}}{\text{Strain}}$$

$$= \frac{4.44\times10^{5}\,\text{N m}^{-2}}{2.5\times10^{-2}}$$

$$= 1.78 \times 10^{7}\,\text{N m}^{-2} \text{ or Pa}$$

Example 16.2

A box has a top area of 20cm^2 and a height of 4cm. When a shear force of 1.5N is applied to the upper surface, the upper surface is displaced by 5mm relative to the bottom surface. What are the shear stress, shear strain and the modulus of rigidity.

Solution:

We have

$$\text{Top area of the box} = A = 20\text{cm}^2 = 0.002\text{m}^2$$
$$\text{Height of the box} = 4\text{cm} = 0.04\text{m}$$
$$\text{Shearing force} = F = 1.5\text{N}$$
$$\text{Upper surface distance} = 5\text{mm} = 5 \times 10^{-3}\text{m}$$
$$\text{Shearing Stress} = ?$$
$$\text{Shearing Strain} = ?$$
$$\text{Modulus of rigidity} = \eta = ?$$

$$\text{Shearing Stress} = \frac{\text{Force}}{\text{Area}}$$
$$= \frac{1.5\text{N}}{0.002\text{m}} = 750\text{Nm}^{-2}$$

$$\text{shearing Strain} = \frac{\text{distance}}{\text{height}}$$
$$= \frac{5 \times 10^{-3}\,\text{m}}{0.04\text{m}}$$
$$= 0.125$$

$$\text{Modulus of rigidity}(\eta) = \frac{\text{stress}}{\text{strain}}$$
$$= \frac{750\text{Nm}^{-2}}{0.125}$$
$$= 6\text{kPa}$$

16.4 ELASTIC LIMIT AND YIELD STRENGTH

We have studied in the previous section that there is a strong relation between stress and strain, i.e., within elastic limit the applied longitudinal stress is directly proportional to the longitudinal strain. If a graph between stress and strain is plotted, then we have a curved line with different steps. Such curved line is known as stress-strain curve as shown in Fig.16.8. It may be pointed out that this graph represents the tensile stress and the resulting tensile strain. Now we explain the behaviour of solid at various points on the given curved line.

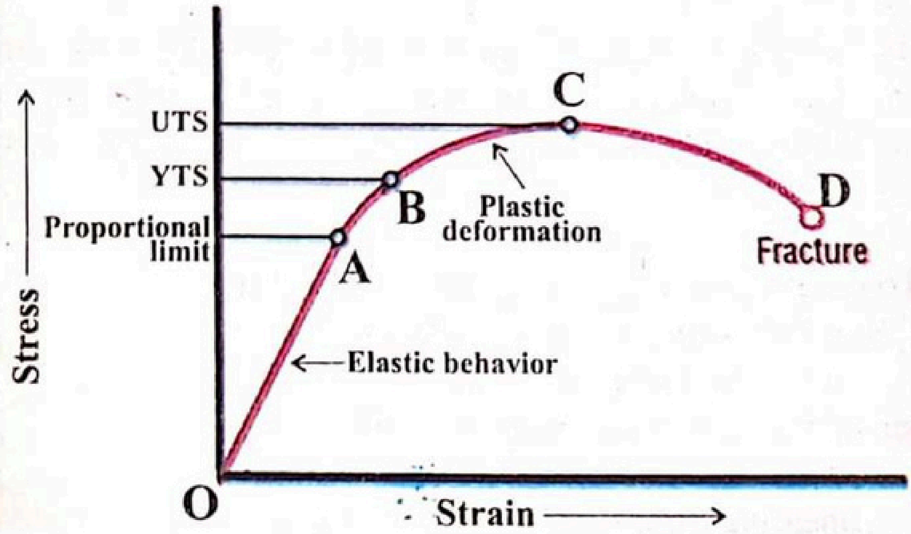


Fig.16.8 Stress vs Strain curved graph for an elastic solid under different stages.

Initially, the graph between stress and strain is a straight line as shown by the section OA of the graph. In this section, stress is directly proportional to the strain and the body obeys Hooke's law. The point 'A' is called the limit of proportionality. If the deforming force is removed at any point within the section OA, the body regains its original position.

If the applied stress exceeds the proportionality limit, the strain is no longer proportional to the stress, but it increases more rapidly. It is represented by the section AB which is a curve and it is called elastic limit. When the stress is removed, the body will return to its original position, because the elastic limit is not crossed.

Similarly, if the stress exceeds the elastic limit, the body deforms permanently. i.e., if the stress is removed the body does not come back to its original position. It is represented by the section BC and it is called plastic limit. The materials become plastic in this region. The point where the stress enters from the elastic region to the plastic region is called yield point and its corresponding stress is known as yield tensile strength (YTS).

If the applied stress is further increased such that it can cross the point 'C', a breaking region starts, i.e., the solids fracture when the stress reaches the breaking point D. On the other hand, the maximum stress that a material can withstands without necking is called the ultimate tensile strength (UTS). The ultimate tensile strength is different for different solids. The materials which continue to stretch beyond its ultimate strength without breaking is called ductile materials, such as gold, silver, copper and lead. These materials can be pulled like a toffee becoming thinner and thinner until finally reaching the breaking point.

The materials whose ultimate tensile strength and breaking point are close together are known as brittle substances e.g., glass, bones cast iron etc. The brighten materials have no plastic deformation. These substances break soon after the elastic limit is reached and they are very strong in compression.

16.4.1 Strain energy in deformed materials

When strain is produced in body by deforming force then there is work done against the elastic restoring force. This work is stored in the body as elastic strain energy and its value can be calculated as; consider a wire of length 'L', cross-section area 'A', whose upper end is fixed while, its lower end is loaded by a weight. So, there is an extension in the length of wire. Within elastic limit, the graph between deforming force and the resulting extension will be a straight line OP as shown in Fig.16.9. Thus within elastic limit, the work done against the elastic restoring force at an extension ΔL under the applied force from 0 to F is equal to area under the straight line OP. i.e.,

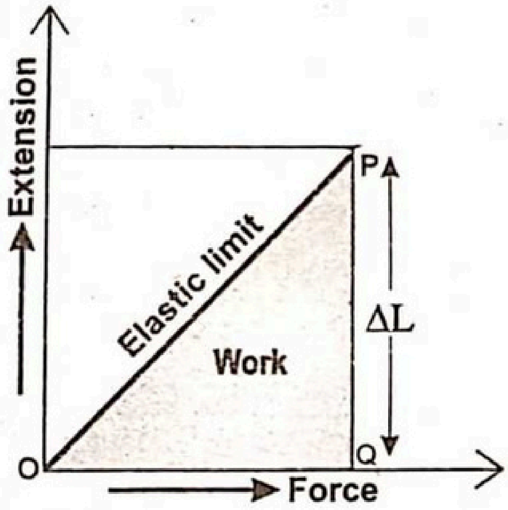


Fig.16.9 Strain energy due to extension of a wire at a distance ΔL.

$$\text{Work} = \text{Area under the straight line OP}$$

$$= \frac{1}{2}(\text{base})(\text{height})$$

$$= \frac{1}{2}F\Delta L$$

$$\text{Work} = \frac{1}{2}F\Delta L$$

> ***POINT TO PONDER***
> If the strain in a wire is doubled, by what factor does the stored energy changed?

But this work is stored in the body in the form of strain energy, therefore,

$$\text{Strain energy} = \frac{1}{2}F\Delta L \quad \text{......(16.9)}$$

Similarly, strain energy per unit volume (AL) called strain energy density of the given wire is given by

$$\text{Strain energy per unit volume } (\mu_0) = \frac{1}{2}\frac{F\Delta L}{AL}$$

$$\mu_0 = \frac{1}{2}\frac{F}{A} \times \frac{\Delta L}{L} \quad ......(16.10)$$

$$\mu_0 = \frac{1}{2}(\text{stress}) \times (\text{strain})$$

According to the definition of Young's modulus

$$Y = \frac{\frac{F}{A}}{\frac{\Delta L}{L}}$$

$$\frac{F}{A} = Y\frac{\Delta L}{L}$$

Eq.16.10 becomes

$$\mu_0 = \frac{1}{2}Y\frac{\Delta L}{L} \times \frac{\Delta L}{L}$$

$$\mu_0 = \frac{1}{2}Y\left(\frac{\Delta L}{L}\right)^2$$

$$\mu_0 = \frac{1}{2}Y(\text{strain})^2$$

This is a mathematical form of strain energy per unit volume.

Example 16.3

Calculate strain energy of a metal wire of length 0.5m and cross-section area $1cm^2$, when the wire is compressed with a force of 60N along its length, the value of Young's modulus for the wire is $1 \times 10^{11} N/m^2$.

Solution:

Strain energy = ?

Length of the wire = L = 0.5m

Cross-section area of the wire = $A = 1cm^2 = 1 \times 10^{-4} m^2$

Deforming force = F = 60N

Young's modulus = $Y = 1 \times 10^{11} Nm^{-2}$

by definition of strain energy

$$\text{strain energy} = \frac{1}{2}F\Delta L$$

but according to Young's modulus

$$Y = \frac{\frac{F}{A}}{\frac{\Delta L}{l}}$$

$$\frac{F}{A} = Y\frac{\Delta L}{L}$$

$$\therefore \quad \Delta L = \frac{LF}{YA}$$

$$\text{Strain energy} = \frac{1}{2}F\Delta L$$

Thus,

$$\text{strain energy} = \frac{1}{2}F\cdot\frac{LF}{YA} = \frac{1}{2}\frac{L}{YA}F^2$$

$$= \frac{1}{2}\frac{(0.5\text{m})(60\text{N})^2}{(1\times10^{11}\text{Nm}^{-2})(1\times10^{-4}\text{m}^2)}$$

$$= 9\times10^{-5}\text{J}$$

16.5 ELECTRICAL PROPERTIES OF SOLIDS

Electrically, the solids can be classified into three classes on the basis of their resistivity and conductivity, these are conductors, insulators and semiconductors.

The solids which have high conductivity or low resistivity are known as conductors. e.g., aluminum, copper, silver, gold, etc. The range of conductivity of the conductor is from $10^2(\Omega\text{m})^{-1}$ to $10^8(\Omega\text{m})^{-1}$ while their resistivity is from $10^{-2}\Omega\text{m}$ to $10^{-8}\Omega\text{m}$.

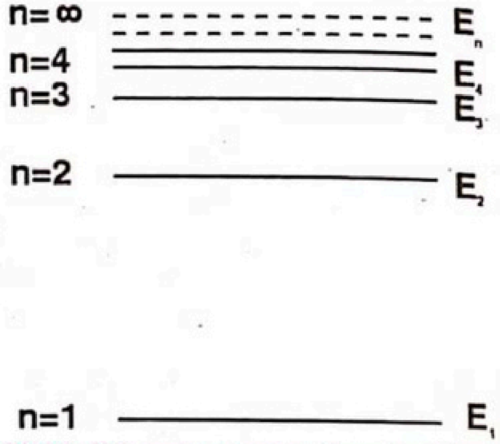
Similarly, those solids which have very small conductivity and very large resistivity are known as insulators, e.g., wood, plastic, rubber, glass, etc. The conductivity of insulators lies between $10^{-11}(\Omega\text{m})^{-1}$ to $10^{-19}(\Omega\text{m})^{-1}$ while their resistivity ranging between $10^{11}\Omega\text{m}$ to $10^{19}\Omega\text{m}$.

On the other hand, those solids which have their conductivity and resistivity in between the conductors and insulators are known as semiconductors. e.g., germanium, silicon etc. The conductivity of the semiconductors is from $10^{-6}(\Omega\text{m})^{-1}$ to $10^4(\Omega\text{m})^{-1}$ and their resistivity is from $10^{-6}\Omega\text{m}$ to $10\Omega\text{m}$.

The free electron theory based on Bohr's atomic model is used to study the electrical properties of solids, but this theory could not explain the conductivity of semiconductors and insulators. Similarly, this theory has also failed to distinguish between metals, semiconductors and insulators. Consequently, we have to use another theory named as band theory. This theory greatly helps us in the understanding of several electrical properties of solids.

Band theory of solid

An isolated atom possesses discrete energy levels such as E_1, E_2, E_3, ... E_n as shown in Fig.16.10. A significant change in the energy levels occurs when a number of identical atoms are brought close together as in solid. For example, if n number of identical atoms are brought close together, the discrete energy levels of individual atoms overlap and form group of energy levels called energy bands. Each band consists of closely spaced energy levels. The individual energies within the band are discrete but so close together, that the energy level may be considered to be a continuous energy band. In the process of formation of bands, there are three bands are formed as shown in Fig.16.11.



16.10 Discrete energy levels of an

The energies of the electrons in the lower states of the atoms are affected very little when the atoms are brought very close together. These electrons remain tightly bound to their nuclei and the band is filled completely by these electrons and plays no part in the electrical conduction.

The outer most electrons of an atom are called valence electrons which are most affected during the formation of bands. The band of energy occupied by these valance electrons is known as valence band. It may be partially or completely filled by the electrons but never empty.

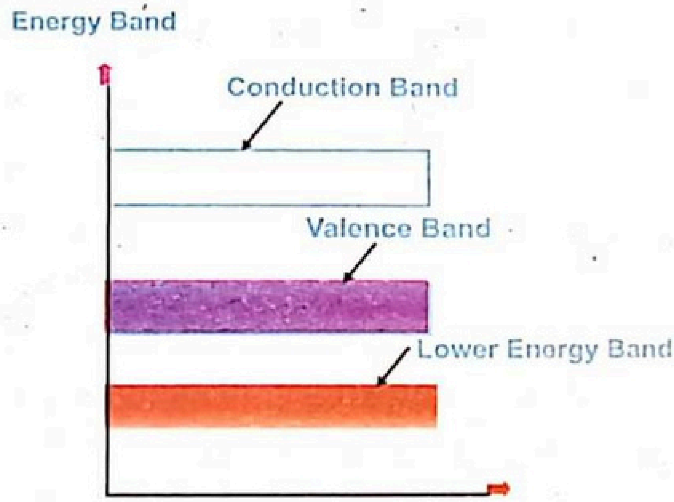


Fig.16.11 Formation of energy bands.

The next higher band above the valence band is called conduction band. It may be empty or partially filled with electrons. In conduction band, electrons can move freely which causes conduction in the solids. This is a reason that why such band is called conduction band.

The gap between valence and conduction bands is known as forbidden gap. It has no allowed energy state. On the basis of the band theory of solids, we can explain insulators, conductors and semiconductors, in terms of conduction and valence bands.

Insulators

Insulators are those materials in which valence electrons are bound very tightly to their atoms and they have no free electrons even at high temperature in conduction band.

In terms of band theory of solids, the valence band is completely filled whereas the conduction band is empty. There is a large forbidden gap between valence and conduction bands as shown in Fig.16.12. The forbidden energy band for an insulator is from 5eV to 10eV. So, the electron cannot jump from valence band to conduction band even at high temperatures or when a high potential difference is applied across it.

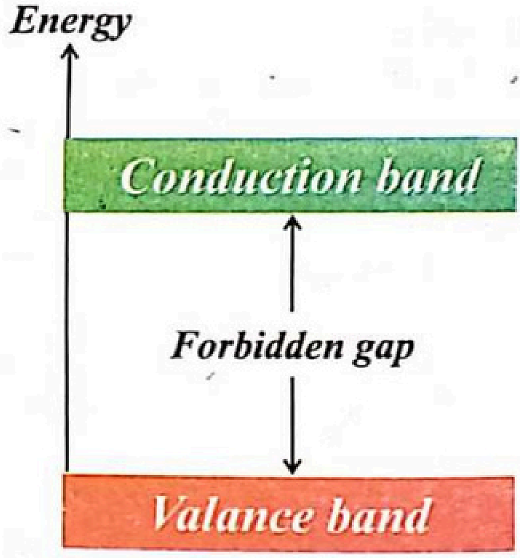


Fig.16.12 In an insulator, a large forbidden gap between filled valence band and empty condition band.

Conductors

Conductors are those substances whose valence electrons are bound loosely with their atoms and they have free electrons available for conduction even at room temperature.

In terms of energy bands of solids, the conduction band of a conductor is partially filled, and its electrons are excited. On the other hand, the valence and conduction band are overlapping. i.e., there is no forbidden energy gap between them as shown in Fig.16.13. Thus, electrons can move easily from valence band to conduction band even when a small potential difference is applied across it or temperature is increased.

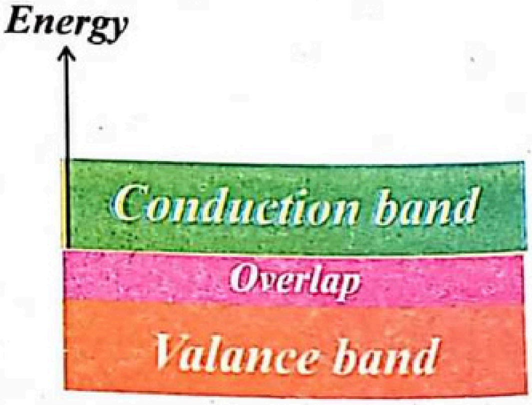


Fig.16.13 In a conductor, partially filled valence band and empty conduction band are overlap to each other.

> **FOR YOUR INFORMATION**
> Certain materials such as mercury, tin, lead, and vanadium become superconductors when cooled by liquid helium to low temperatures.

Semiconductors

Semiconductors are those materials which have both characteristics under different conditions. At absolute zero semiconductor have no free electrons and it behaves like an insulator. However, when the temperature is increased, they have free electrons for conduction and hence they act as conductor. In terms of energy bands, the valence band of semiconductor is filled while its conduction band is empty. On the other hand, there is a small forbidden energy gap approximately 1eV between valence and conduction bands as shown in Fig.16.14. At low temperature, the electrons cannot jump from valence band to conduction band, so semiconductors behave as insulator at this condition. When the temperature of semiconductor is raised then, the electrons gain energy and are enabled to jump from valence band to conduction band. This shows that with the increase in temperature, the semiconductors have more free electrons available for conduction. It means semiconductors are conducting more at higher temperature. Thus, semiconductors typically have negative temperature coefficient of resistance. It may be pointed that the number of temperature dependent electrons available for conduction is not sufficient for making a semiconductor device, we will study it in more detailed form in next unit.

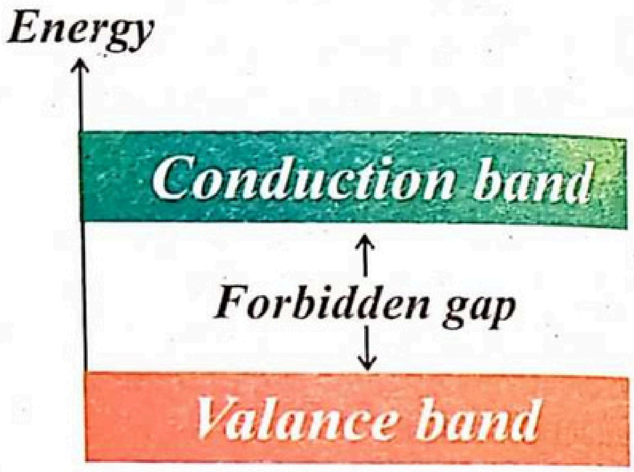


Fig.16.14 An semiconductor there is a small energy gap between filled valence band and empty conduction band.

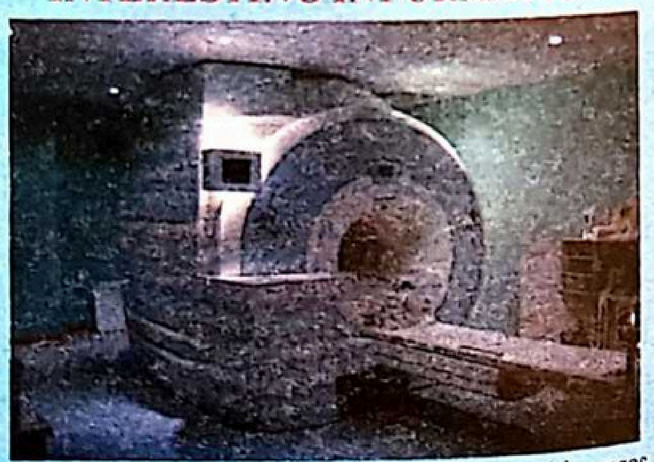
DO YOU KNOW

Superconductors are alloys that it certain temperature conduct electricity with no resistance.

16.6 SUPERCONDUCTORS

We have studied that the resistance of a conductor depends upon temperature i.e., the resistance of the conductors decreases by decreasing the temperature. The experiments show that resistivity of some materials fall to zero

INTERESTING INFORMATION



Magnetic resonance imaging (MRI) machine uses strong magnetic field produced by superconducting material for scanning computer processing produce the image of identifying tumors and inflamed tissues.

at certain temperature called critical temperature T_c. This phenomenon is known as superconductivity and the materials which exhibit superconductivity are known as superconductors. The superconductivity of a superconductor is shown in resistivity-temperature graph. The resistance at first, decreases smoothly with decreasing temperature, and then at its critical temperature its resistance suddenly drops to zero as shown in Fig.16.15. Superconductivity was discovered in 1911 by Kamerlingh Onnes. He observed that, at low temperature below 4.2K, the resistance of mercury suddenly dropped to zero. Later on, a number of other superconductors were also identified, such as aluminum, tin, zinc, lead and indium alloys. All these with their critical temperatures are listed in Table 16.3. It is very interesting to note that copper, silver and gold which are good conductor, but they do not show any superconductivity.

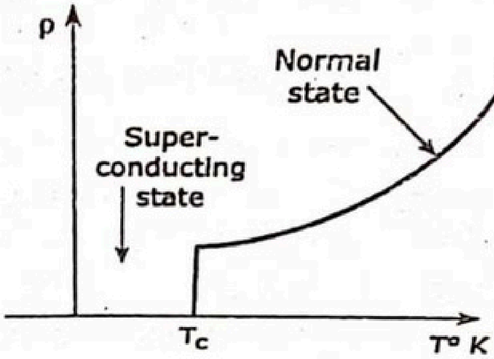
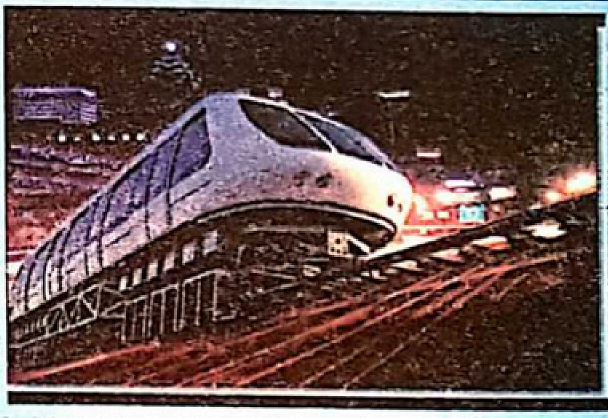


Fig.16.15 At temperature below the critical temperature resistance of the conductor becomes zero.

Table 16.3 Various Superconductors with their critical temperature.

Element	Critical Temperature T_c (K)
Zinc, Zn	0.88
Aluminum, Al	1.14
Tin. Sn	3.69
Mercury, Hg	4.15
Lead, Pb	7.26
Niobium, Nb	9.2

An important development in the field of superconductivity took place in 1986, when new superconductors with higher critical temperature were discovered. For example, the ceramic materials that become superconductor at high temperature of about 125K. Similarly, the most recent identified superconductor is a complex crystalline structure known as Yttrium barium copper oxide whose critical temperature is 163K.

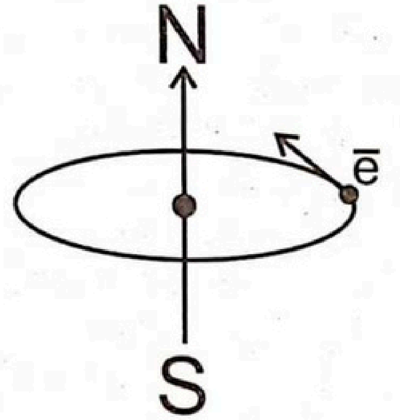


In Magnetic Levitation Train, a (Maglev) is a system of train which consists of a strong magnet that repels and pushes the train up off the track in order to reduce the friction and increase the speed of the train. Such a strong magnetic field is produced on the basis of technology of superconductivity.

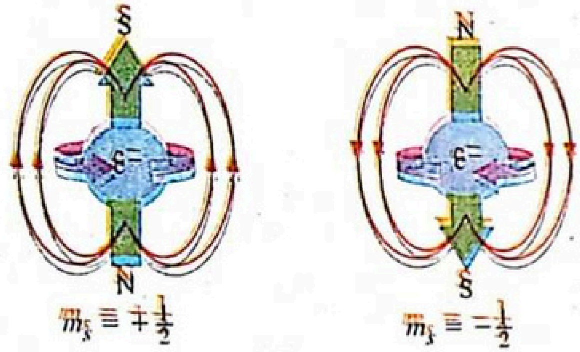
There are number of important and useful applications of superconductor. For example, the development of superconducting magnet which is being used for storage of energy as well as in magnetic resonance imaging (MRI) which is widely used in medical science. Similarly, superconducting technology can also be used for magnetic levitation trains, powerful electric motors, faster computer chips and so many others.

16.7 MAGNETIC PROPERTIES OF SOLIDS

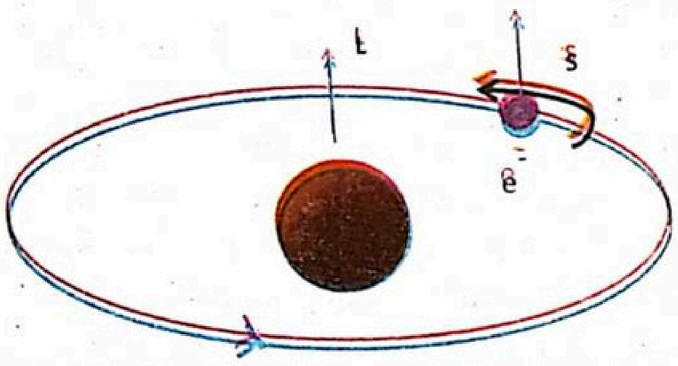
Approximately, all the solids are affected by the applied external magnetic field, i.e., some solids come under the influence of applied magnetic field strongly while the others weakly. We have studied that the electric current through a wire is due to the flow of electrons and hence there is a magnetic field produced around such current carrying the wire. Similarly, in an atom the electrons are revolving around the nucleus in a circular orbits their motion constitute a tiny current which produces small magnetic field. In most solids, the magnetic field of one electron in an atom is cancelled by that of another orbiting electron in the opposite direction. It is therefore, the magnetic field of majority of the solids produced by the orbital motion of the electrons is either zero or very small. That is why most solids do not have magnetic properties.



Orbital magnetic moment of an electron.



Spin magnetic moment of an electron


Combine magnetic moment of an atom.

Besides orbital motion and orbital magnetic field, an electron is also spinning about its own axis. So, there is also a magnetic field associated with the spin motion of electrons. The experiments show that if the spin motion of an electron in an orbit of the atom is clockwise, the motion of the other electron must be anticlockwise. Thus, the atoms which contain pair electrons, the spin magnetic field of one electron is cancelled by the magnetic field of the other electron and the net spin magnetic field of the atom is zero. However, atoms containing odd number of electrons, they have at least one unpaired electron and there is some spin magnetic field.

Thus, the net magnetic field of an atom is equal to the algebraic sum of fields produced by the orbital and spin motions of their electrons such resultant magnetic field is called magnetic dipole. On the basis this magnetic dipole the solids can be classified into three classes.

Diamagnetic materials

Diamagnetic materials are those substances in which atoms have paired electrons and their orbital as well as spin magnetic fields are zero. In other words, diamagnetic materials have no net magnetic moment. e.g., bismuth, copper, zinc, silver, gold, air, water, hydrogen etc.

When a diamagnetic material is brought near to a magnet, it is repelled by the magnet. Similarly, when a diamagnetic material is placed in an applied external magnetic field H, a weak magnetic field B is induced in it. This field inside the diamagnetic material is not only less in magnitude but also in opposite direction to that of the external magnetic field as shown in Fig.16.16. The ratio of magnetic field B inside the diamagnetic material to the external magnetic field H is termed as relative permeability (μ_r). It is expressed as

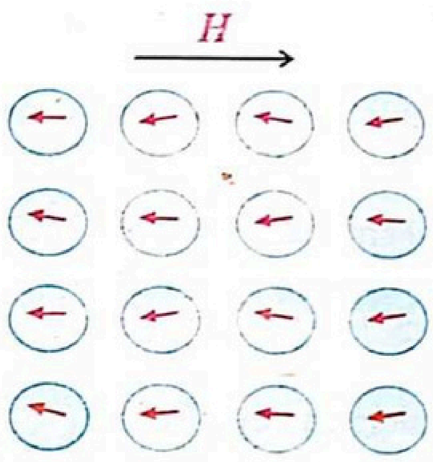


Fig.16.16 The direction of magnetic field inside the diamagnetic material is opposite to the direction of the applied field.

$$\mu_r = \frac{B}{H}$$

This shows that the relative permeability for diamagnetic material is always less than one. i.e., $\mu_r < 1$, because $B < H$. The typical value of μ_r for diamagnetic materials is 0.9998.

Paramagnetic materials

Paramagnetic materials are those in which atoms have one or more unpaired electrons and exhibit a net magnetic moment, e.g., aluminum, antimony, chromium, tungsten, lithium, sodium, oxygen etc.

Each atom of the paramagnetic materials behaves as a tiny magnet. The motions of the atoms in these materials are random as shown in Fig.14.17(a). So, at room temperature they have no net

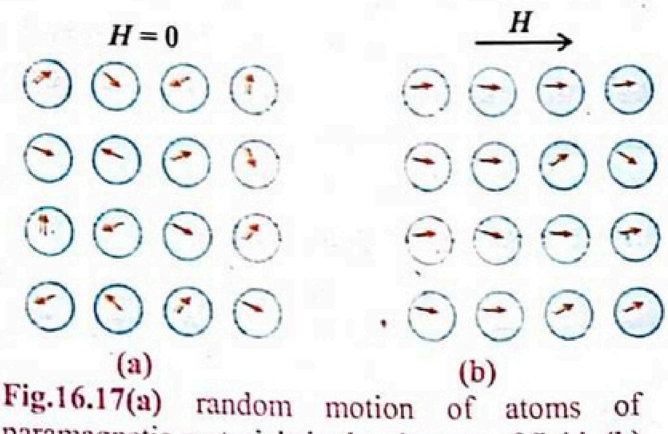


Fig.16.17(a) random motion of atoms of paramagnetic materials in the absence of field. **(b)** alignment of atoms in the presence of field.

magnetic dipole in the absence of an external magnetic field. However, in the presence of magnetic field, the magnetic dipole of the atoms of the paramagnetic materials are aligned as shown in Fig.16.17(b). When a paramagnetic material is brought near to a magnet, it is attracted towards the magnet. Similarly, when a paramagnetic material is placed in an external magnetic field H, the magnetic field B is induced in it, which is slightly greater than the external field H. i.e.,

$$\mu_r = \frac{B}{H}$$

This shows that $\mu_r > 1$, because $B > H$, the typical value of relative permeability for paramagnetic materials is about 1.001.

Ferromagnetic materials

Ferromagnetic materials are those which have one or more unpaired electrons and exhibit a strong magnetic moment. e.g., iron, cobalt, nickel, gadolinium and dysprosium.

Like paramagnetic materials, each atom of a ferromagnetic materials behaves as a tiny magnet. The atoms of ferromagnetic materials cooperate with one another in such a way so as to exhibit a strong magnetic moment. The cooperation of the atoms is in the form of a group in a microscopic region such that all the magnetic dipole are aligned called domain as shown in Fig.16.18. These domains have volumes of about $10^{-12}m^3$ to $10^{-8}m^3$ and contain 10^{17} to 10^{21} atoms.

When a ferromagnetic material is brought near to a magnet, it is strongly attracted towards the magnet. Similarly, when a ferromagnetic material is placed in an applied external magnetic field H, the field B induced inside the ferromagnetic material is stronger than the external field. Thus, the relative permeability for ferromagnetic materials is given by

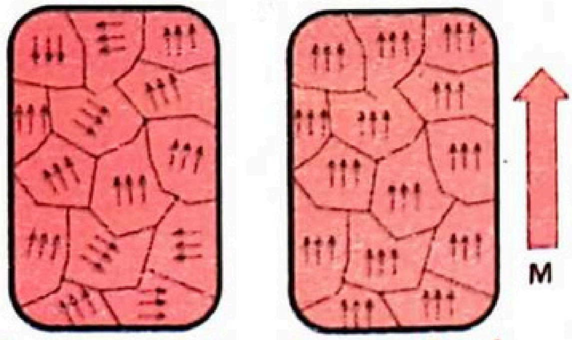
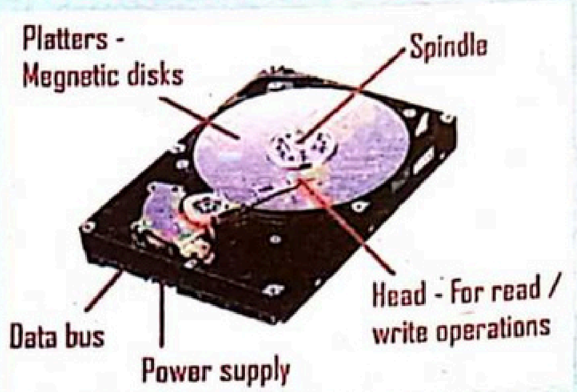


Fig.16.18 Domains of ferromagnetic materials in the presence and the absence of the magnetic field

INTERESTING INFORMATION



A computer hard drive is used to store audio, video or computer data. To record or write, an electro magnet called head is used to magnetize ferromagnetic materials in a coating on the platter of the drive. Ferromagnetic particles retain their magnetization even after the head has removed away.

$$\mu_r = \frac{B}{H}$$

Since B > H, so relative permeability for ferromagnetic material is very large. i.e., its typical value is about 10^4.

Ferromagnetic materials can be classified into two further classes. Hard and soft ferromagnetic materials where hard ferromagnetic materials are made of steel and antimony, they serve as permanent magnet, while, soft ferromagnetic materials are made of soft iron. They are mostly used in motors, fans and other electrical appliances. It has been observed experimentally that ferromagnetism decreases with increase in temperature. When ferromagnetic material is heated it loses its residual magnetism, because random thermal motion tends to destroy the alignment of domains. At certain high temperature where the ferromagnetic property of substance suddenly disappears, and the substance becomes paramagnetic is called Curie temperature. The Curie temperature of various ferromagnetic substance is listed in the table 16.4.

Table 16.4
Curie Temperature of Ferromagnetic Substances

Substances	Curie Temperature
Cobalt	1394K
Iron	1043K
Fe_2O_3	893K
Nickel	631K
Gadolinium	317K

16.8 HYSTERESIS AND HYSTERESIS LOOP

The word hysteresis is derived from Greek word hysterein means lag behind. **Hysteresis is defined as the lagging of induced magnetic flux density B behind the magnetic force 'H' in the process of magnetization or demagnetization of a ferromagnetic substances**. It is explained as;

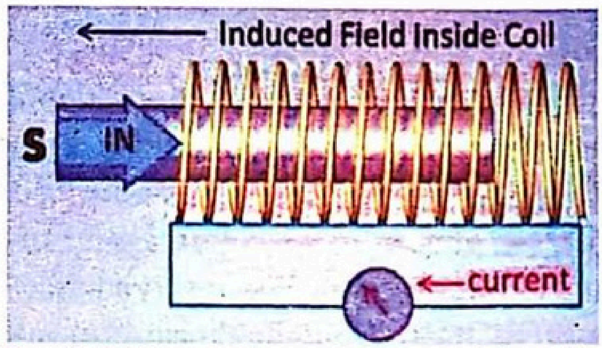


Fig.16.19 Magnetizing and demagnetizing of a ferromagnetic bar inside a solenoid

Consider a bar of ferromagnetic material which is placed inside the solenoid as shown in Fig.16.19. When switch is closed, there is a growth of current in the solenoid. This current produces a magnetic field called magnetizing force 'H' inside the solenoid. The value of 'H' can be increased or decreased by increasing or decreasing the current. On the other hand, the bar also starts magnetizing and its magnetic flux density 'B' increases by increasing the value of 'H'. If the values of 'H' and 'B' is plotted on a graph, a curve line OP is obtained, as shown in Fig.16.20. Where the material becomes magnetically saturated, i.e., it has maximum flux density for H = OM.

Now if 'H' is decreased by decreasing current, magnetic flux density 'B' also starts decreasing but it will not decrease along the line PO, it will decrease slowly, and it is along the line PQ. When H is zero at point Q, but B is not zero. i.e., the bar is not demagnetized. It has some value OQ called remanent or residual flux density B_r. In order to demagnetize the bar, we apply the reverse magnetizing force H. When the reverse value of H is increased, B is reduced to zero at point R where H = OR. This value of magnetizing force H required to wipe off residual magnetism is known as coercive force.

After demagnetization, if the reverse value of 'H' is further increased, the bar again reaches a state of magnetic saturation in opposite direction at point 'S' where H = ON. By repeating the same process, we have another curve line STUP same as that of PQRS but in opposite direction. If we again start the process from point 'U', the same curve UPQRSTU is obtained once again. In the whole process, we have observed that 'H' and 'B' did not attain their zero values simultaneously. Because 'B' always lags behind 'H' and it is named as hysteresis. The closed path PQRSTUP which is obtained during the magnetization and demagnetization of the bar is called hysteresis loop.

The area enclosed by the hysteresis loop represents the energy dissipation. We observe that when H is made zero, the domains of the ferromagnet bar do not become completely unaligned. Thus,

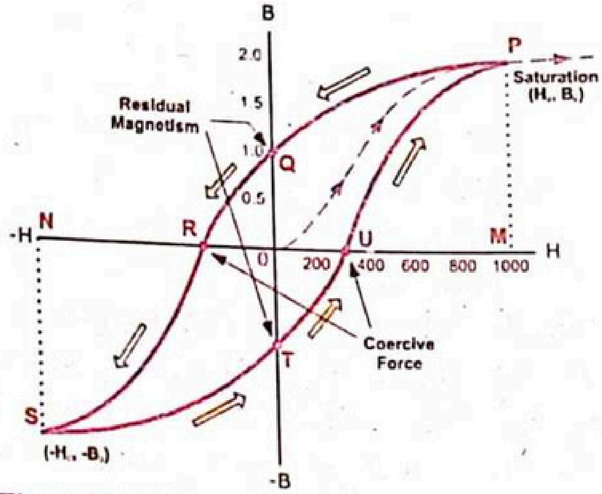


Fig.16.20 A hysteresis loop obtained during the process of magnetization and demagnetization where B is lagging behind H.

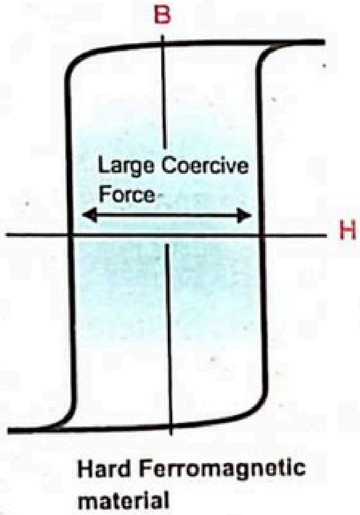


Fig.16.21 Large hysteresis loop area for steel bar.

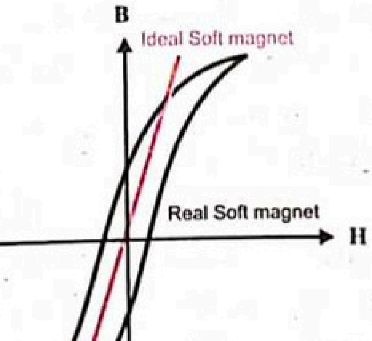


Fig.16.22 Small hysteresis loop area for soft iron.

energy is required against the residual flux density during magnetizing and demagnetizing. This energy is dissipated in form of heat called hysteresis loss.

The shape of the hysteresis loop depends upon the nature of the material. For example, the area of the hysteresis loop for a steel bar is very large due to its high remanent flux density and coercivity as shown in Fig.16.21. Therefore, the hysteresis loss of steel is also large.

On the other hand, the area of the hysteresis loop for soft iron is very small as shown in Fig.16.22. So, the hysteresis loss of soft iron is also small.

SUMMARY

- **Crystalline Solids:** Crystalline solids are those in which atoms, molecules or ions are arranged in regular pattern.
- **Amorphous Solids:** Amorphous solids are those solids which atoms or molecules are arranged in random manner.
- **Polymers:** Polymers solids are those in which atoms, molecules or ions are arranged neither regular like crystalline nor irregular like amorphous. Polymers are also called poor crystalline.
- **Deforming Force:** The applied force which produces a change in length, volume or shape of a body is called deforming force.
- **Stress:** The deforming force acting per unit area of a body is called stress.
- **Strain:** In case of deformation, strain is equal to the ratio of change in dimension to the original dimension.
- **Hooke's Law:** Within elastic limit, the strain is directly proportional to the applied stress.
- **Modulus of Elasticity:** The ratio of stress to strain is called modulus of elasticity.
- **Young's Modulus:** When a change occurs in body's length, then the ratio of longitudinal stress to longitudinal strain is called Young's Modulus.
- **Bulk Modulus:** The ratio of volumetric stress to volumetric strain is called Bulk Modulus.
- **Modulus of Rigidity:** The ratio of shear stress to shear strain is called modulus of rigidity.
- **Elastic Limit:** The limit of deformation where the body comes back to its original position after the removal of the deforming force is called elastic limit.
- **Plastic Limit:** It is the limit of permanent deformation. i.e., the body does not come back to its original position after the removal of the deforming force is called plastic limit.
- **Brittle Substances:** The substances which break down just crossing the elastic limit are called brittle substances.

- **Band Theory:** When a number of identical atoms are combined in a solid substance, than energy levels of individual atoms overlap to form band.
- **Superconductor:** The conductor whose resistance drops to zero by decreasing its temperature is called super conductor.
- **Curie Temperature:** The temperature at which the ferromagnetic materials become paramagnetic materials.
- **Diamagnetic Materials:** The materials whose resultant magnetic moment is zero are called Diamagnetic Materials.
- **Paramagnetic Materials:** The materials which exhibit a weak magnetic moment.
- **Ferromagnetic Materials:** The solids which show a strong magnetic moment.
- **Hysteresis:** The lagging of magnetic flux density 'B' behind the magnetic force H in the process of magnetization or demagnetization is called hysteresis.

EXERCISE

O Select the best option of the following questions:

1. When the temperature increases, the distance between the molecules of a crystal is
(a) Decreased (b) Increased (c) Same (d) Zero

2. Which one of the following has low melting point?
(a) Crystal (b) Amorphous (c) Polymer (d) Glassy Solid

3. Which one of the following is called glassy solid?
(a) Crystal (b) Amorphous (c) Polymer (d) Diamond

4. Which one of the following is a polymeric solid?
(a) Wool (b) Glass (c) Sodium chloride (d) Copper

5. The applied force which produces a change in a body is called
(a) Elastic force (b) Deforming force (c) Electric force (d) Magnetic force

6. The property of a body to attain its original position after the removal of force is called
(a) Plasticity (b) Rigidity (c) Elasticity (d) Resistivity

7. Which one of the following without any dimension and unit?
(a) Stress (b) Strain
(c) Tangential Stress (d) Young Modulus

8. Modulus of elasticity is dimensionally equal to
(a) Strain (b) Shearing Strain (c) Stress (d) Surface tension

9. The Young's modulus 'Y' of an elastic body is due to the applied stress 'S', the energy stored in the body per unit volume is
(a) $\frac{1}{2}\cdot\frac{S}{Y}$ (b) $\frac{1}{2}\cdot\frac{S^2}{Y}$ (c) $\frac{1}{2}\cdot\frac{Y}{S}$ (d) $\frac{1}{2}\cdot\frac{Y^2}{S}$

10. If the applied stress is increased, then according to Hook's law the ratio of stress to strain will be
(a) Increased (b) Decreased (c) Constant (d) Zero

11. A substance which is permanently deformed by the applied stress is called
(a) Elastic (b) Plastic (c) Ductile (d) Brittle

12. A body which breaks down just crossing the elastic limit is known as
(a) Elastic (b) Plastic (c) Ductile (d) Brittle

13. Which one of the following substance is very strong in compression?
(a) Ductile (b) Brittle (c) Monoatomic (d) Diatomic

14. Resistivity range of insulators is between
(a) $10^{2}(\Omega m)^{-1}$ and $10^{8}(\Omega m)^{-1}$ (b) $10^{-2}(\Omega m)^{-1}$ and $10^{-8}(\Omega m)^{-1}$
(c) $10^{-11}(\Omega m)^{-1}$ and $10^{-19}(\Omega m)^{-1}$ (d) $10^{+11}(\Omega m)^{-1}$ and $10^{+19}(\Omega m)^{-1}$

15. The order of the conductivity of the conductor's is
(a) $10^{2}(\Omega m)^{-1}$ to $10^{8}(\Omega m)^{-1}$ (b) $10^{-2}(\Omega m)^{-1}$ to $10^{-8}(\Omega m)^{-1}$
(c) $10^{-11}(\Omega m)^{-1}$ to $10^{-19}(\Omega m)^{-1}$ (d) $10^{+11}(\Omega m)^{-1}$ to $10^{+19}(\Omega m)^{-1}$

16. Which one of the following substance has partially filled valence band?
(a) Insulator (b) Conductor (c) Semiconductor (d) Superconductor

17. The forbidden energy gap between valance and conduction bands in semiconductor is upto
(a) 1eV (b) 2eV (c) 4eV (d) 6eV

18. When the temperature is increased, the conduction in the semiconductor material is
(a) Decrease (b) Increase (c) Same (d) Zero

19. Which one of the following does not exhibit the superconductivity?
(a) Mercury (b) Copper (c) Aluminum (d) Zinc

20. Which one of the following is not a magnetic substance?
(a) Iron (b) Nickel (c) Brass (d) Cobalt

21. Which substance has relative permeability less than 1?
(a) Diamagnetic (b) Paramagnetic (c) Ferromagnetic (d) None of those

22. When a diamagnetic material is placed in an external magnetic field, the direction of field induced in the material is
(a) Along the direction of external field
(b) Opposite to the direction external field
(c) Perpendicular to direction of external field
(d) None of these

23. The relative permeability of an iron is
(a) 0.9999 (b) 1.001 (c) 10^{2} (d) 10^{4}

24. Which substance shows a strong magnetic moment due to the co-operation of its atoms to each other?
(a) Diamagnetic (b) Paramagnetic (c) Ferromagnetic (d) Bismuth

25. The temperature at which the ferromagnetic substance becomes paramagnetic substance is known as
(a) Critical temperature (b) Curie temperature
(c) Absolute temperature (d) Normal temperature

26. When the area of hysteresis loop is small, energy dissipation is
(a) Small (b) Large (c) Uniform (d) Zero

SHORT QUESTIONS

1. Why solids have definite shape and volume?
2. How atoms, molecules or ions are arranged in a crystal?
3. Why frozen amorphous has same property as that of a liquid?
4. Why amorphous is also called glassy solids?
5. Why polymer is also called poor crystalline?
6. Is stress different from pressure?
7. Differentiate among tensile, compressive and shear strains.
8. Define Hooke's law in terms of stress and strain.
9. What do you know about the co-efficient of elasticity?
10. Differentiate between elastic and plastic limits.
11. Differentiate yield and breaking points of a solid.
12. What do you know about the ultimate strength of a solid?
13. Distinguish between brittle and ductile substances.
14. Which is more elastic rubber or iron?
15. Differentiate between valence and conduction bands.
16. What do you know about the forbidden gap?
17. What is critical temperature?
18. How spin and orbital motions of electrons cause of magnetic moment of an atom?
19. Why the magnetic moment of diamagnetic material is zero?
20. Distinguish between paramagnetic and ferromagnetic materials.
21. What is Curie temperature?
22. What do you know about hysteresis and hysteresis loop?
23. What is hysteresis loss?
24. What do you know about domains?
25. What is residual flux density?
26. What do you know about the coercive force?

COMPREHENSIVE QUESTIONS

1. Discuss the three classes of solids: crystal, amorphous and polymeric with examples.
2. What do you know about the mechanical properties of solids? Explain it with examples.
3. State and explain stress, strain and their kinds with suitable examples.
4. Define Hooke's law in terms of stress and strain. Also discuss the three kinds of elastic moduli.
5. Explain graphical representation of Hooke's law and define the terms: Elastic limit, plastic limit, yield strength and ultimate strength.
6. What is meant by the strain energy? Derive the mathematical relation for strain energy.
7. What is band theory of solids? Explain insulator, conductor and semiconductor by using band theory of solid.
8. Define superconductor and explain graphical representation of superconductivity.
9. Discuss magnetic properties of solids and explain the three classes of solids diamagnetic, paramagnetic and ferromagnetic.
10. State and explain hysteresis and hysteresis loop.

NUMERICAL PROBLEMS

1. An iron rod 4m long and $0.5cm^2$ in cross section area stretches by 0.5mm when a mass of 115kg is hung from its lower end. Compute stress, strain and Young's modulus. **(2.254×10^{11}Pa, 1.25×10^{-4}, 1.8×10^{11}Pa)**
2. Calculate change in volume of a copper cube 40mm on each edge, when subjected to a pressure of 2MPa. The bulk modulus for copper is 125GPa. **($1 \times 10^{-9}\ m^3 = 1mm^3$)**
3. A metallic wire of length 15m is stretched 6×10^{-9}m by the applied stress of $5 \times 10^{8}Nm^{-2}$. Calculate the strain energy per unit volume in the wire. **(0.1J)**
4. A solid cylindrical steel column is 6m long and 10cm is diameter. What will be its increase in two length when carrying a load of 2×10^{5}kg(Young Modulus for steel is 1.9×10^{11}Pa) **(7.88mm)**
5. Two parallel and opposite forces, each 4000N are applied tangentially to the upper and lower faces of cubical metal block 25cm on a side. Find the angle of shear. (Shearing modulus is 80GPa) **(8×10^{-5}rad.)**
6. Calculate change in volume of a solid cube 50mm on each edge, when subjected to a stress of 25MPa. (The bulk modulus for copper is 125GPa) **($25mm^3$)**