Introduction

All materials have certain specific uses which depends upon their properties and characteristics like hardness, ductility, melleability, conductivity, resistivity etc. For example, what thing makes steel hard, lead soft, iron magnetic and copper electrically conducting? These things depends upon structure and particular order and bonding of atoms in a material. Such things are used to design and create new materials for use in modern technology.

Physics Of Solids

That branch of physics which

, deals with the nature and properties of solid form of matter, called physics of solids

CLASSIFICATION OF SOLIDS

Solids are classified in three different types.

(i) Crystalline Solids
(ii) Amorphous or Glassy Solids
(iii) Polymeric Solids

CRYSTALLINE SOLIDS

There is regular arrangement of molecules in crystalline solids. The neighbours of every molecule are arranged in a regular pattern which is constant throughout the crystalline solid. Hence in a crystalline solid, there is an ordered structure throughout the crystal.

Crystalline solids exists in majority, e.g, metals such as copper, iron and zinc, ionic compounds such as sodium chloride and ceramics such as zirconia are crystalline. The arrangement

of molecules, atoms or ions in all types of crystalline solids can be studied by using diffraction property of X-rays. For example, each atom in a metal crystal vibrates about a fixed point with an amplitude that increases with rise in temperature. The ordered structure in crystalline solids repeated over large distances.

The cohesive forces between atoms, molecules or ions in crystalline solids maintain the strict long range order inspite of atomic vibrations. For every crystal, there is a temperature at which the vibrations becomes so large that the ordered structure breaks up and the solid melts. Hence every crystalline solid has a definite melting point. This transition from solid to liquid is abrupt or discontinuous.

AMORPHOUS OR GLASSY SOLIDS

Amorphous means without form or structure. Hence in

amorphous solids, there is no regular arrangement of molecules like that in crystalline solids. We can say that amorphous solids are more like liquids with frozen disordered structure.

EXAMPLE

Ordinary glass is a solid at normal temperature has no regular arrangement of molecules. On heating, it gradually soften into a paste and becomes a very viscous liquid at almost 800°C. That's why amorphous solids are also called glassy solids. Such type of solids have no definite melting point.

POLYMERIC SOLIDS

Polymers may be said to be more or less solid materials with a structure that is in between order (solid) and disorder (liquid). So they can be classified

as partially or poorly crystalline solids.

Polymers form a large group of naturally occuring and synthetic materials. Plastics and synthetic rubbers are turned polymers because they are formed by polymerization.

POLYMERIZATION

A process in which relatively simple molecules are chemically combined into massive long chain molecules or three dimensional structures, called polymerization.

Polymeric solids have low specific gravity compared with even the lightest of metals and yet exhibit good strength-to-weight ratio.

EXAMPLE

Polymers consist wholly or partial chemical combinations of carbon with oxygen, hydrogen, nitrogen

and other metallic or non-metallic elements. Polythene, polystrene and nylon etc are examples of polymers. Natural rubber $(C_5H_6)_n$ is composed of hydrocarbons.

CRYSTAL LATTICE

A crystalline solid consists of three dimensional pattern that repeats itself over and over again. This basic structure is called UNIT CELL.

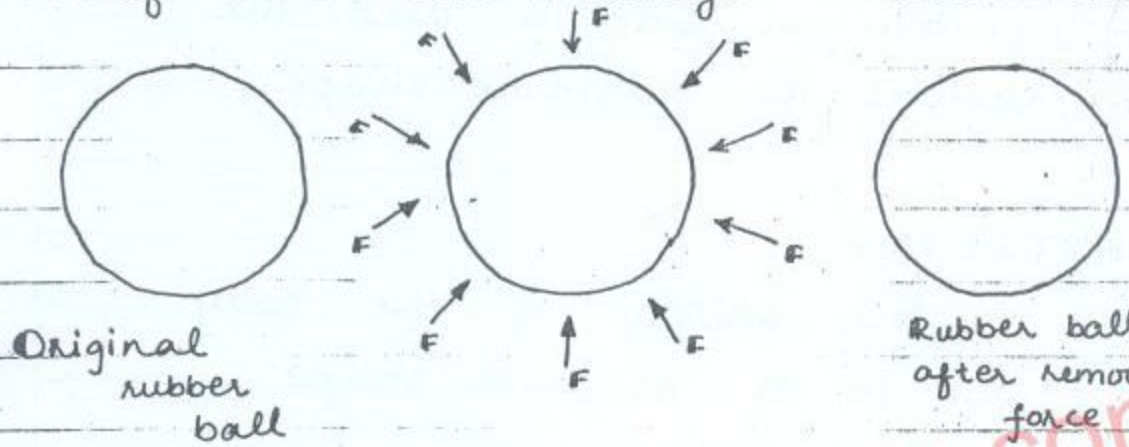
The whole structure obtained by the repetition of unit cell is known as Crystal lattice. For example, the pattern of NaCl particles have a cube shape. In a cubic crystal all the sides meet at right angles.

MECHANICAL PROPERTIES OF SOLIDS

Their are some mechanical properties of solids like deformation, stress, strain, modulus of elasticity given as

DEFORMATION IN SOLIDS

If we hold a soft rubber ball in our hand and then compress it, shape or volume of ball will change.



Now on removing the pressing force, the ball will return to its original shape. The positions of balls are shown in above figure. From this example, it is concluded that deformation (i.e change in shape, length or volume) is produced when an external force is applied. In crystalline solids, atoms are arranged in certain order. These atoms are held about their equilibrium position. When external force is applied on such a body, the interatomic distances between

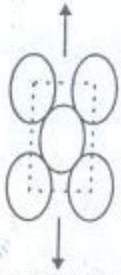
atoms are changed and the body is said to be in state of stress. After the removal of external force, atoms return to their equilibrium position and the body regains its original shape.

ELASTICITY

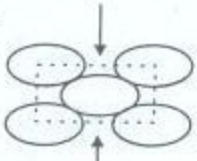
The ability of the body to return to its original shape is called elasticity.

Figure shows the deformation produced in a unit cell of a crystal subjected to an external field

(a) Unstretched unit cell



(b) Unit cell under outward stretching force



(c) Unit cell under inward applied force

(d) Unit cell after removing applied force

RESULTS OF MECHANICAL TESTS

STRESS

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

MATHEMATICALLY,

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

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

UNITS

The S.I unit of stress is newton per square meter ($N.m^{-2}$) which is called pascal (Pa).

TENSILE STRESS

When the stress changes the length of a body, it is called tensile stress.

COMPRESSIONAL STRESS

A stress which changes the volume of a body is called compressional stress.

SHEAR STRESS

When a stress changes the shape of a body is called shear stress.

STRAIN

Strain is a measure of deformation of a solid when stress is applied to it.

LINEAR STRAIN

The ratio between change in length and original length is called linear strain.

If ΔL is the change in length and L is the original length, then

$$\text{Strain} = \frac{\text{Change in length}}{\text{Original length}}$$

$$\varepsilon = \frac{\Delta l}{l}$$

It has no unit and no dimension because the strain is the ratio of lengths.

TENSILE STRAIN

The strain produced due to tensile stress, it is called tensile strain.

COMPRESSIVE STRAIN

The strain produced due to compressive stress, called compressive strain.

VOLUMETRIC STRAIN

When the applied stress changes the volume of body, the change in volume per unit volume is known as volumetric strain.

MATHEMATICALLY,

$$\text{Volumetric strain} = \frac{\text{Change in volume}}{\text{Original volume}}$$

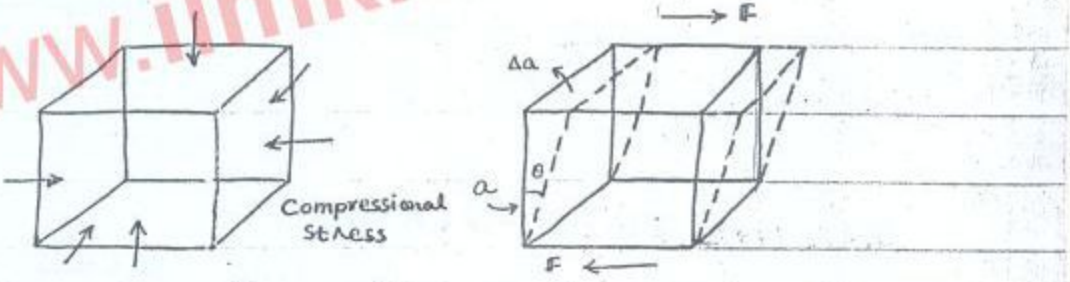
$$\varepsilon = \frac{\Delta V}{V_o}$$

SHEAR STRAIN

The ratio between change in area and original area is called shear strain. It is calso called SUPERFICIAL STRAIN.

Figure shows that a cube is brought under shear stress (i.e force) the shear strain produced is given by

$$\gamma = \frac{\Delta a}{a} = \tan\theta$$



For small value of angle θ (radian)

$$\tan\theta = \theta$$

So that

$$\gamma = \theta$$

MODULUS OF ELASTICITY

The ratio of stress is

constant for a given material, provided the external force is not too great. This is called modulus of elasticity.

MATHEMATICALLY,

$$\text{Modulus of elasticity} = \frac{\text{Stress}}{\text{Strain}}$$

UNITS

The S.I units of modulus of elasticity is $N.m^{-2}$ or Pa

YOUNG'S MODULUS

For linear deformation, the ratio of tensile stress (F/A) to tensile strain ($\Delta l/l$) is called Young's modulus.

MATHEMATICALLY,

$$\text{Young's Modulus} = \frac{\text{Tensile Stress}}{\text{Tensile Strain}}$$

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

Where ΔL is change in original length.

BULK MODULUS

For three dimensional deformation the ratio of applied stress to volumetric strain is called:

Bulk Modulus.

MATHEMATICALLY,

$$\text{Bulk Modulus} = \frac{\text{Applied Stress}}{\text{Volumetric Strain}}$$

$$K = \frac{F/A}{\Delta V/V_0}$$

SHEAR MODULUS

The ratio of applied stress (F/A) to shear strain ($\gamma = \tan\theta$) is called shear modulus.

MATHEMATICALLY,

$$\text{Shear Modulus} = \frac{\text{Applied Stress}}{\text{Shear Strain}}$$

$$G = \frac{F/A}{\tan\theta}$$

ELASTIC LIMIT

It is defined as "The greatest stress that a material can tolerate without any permanent change in shape"

It is the limit up to which

Hook's law holds good.

It is denoted by σ_e.

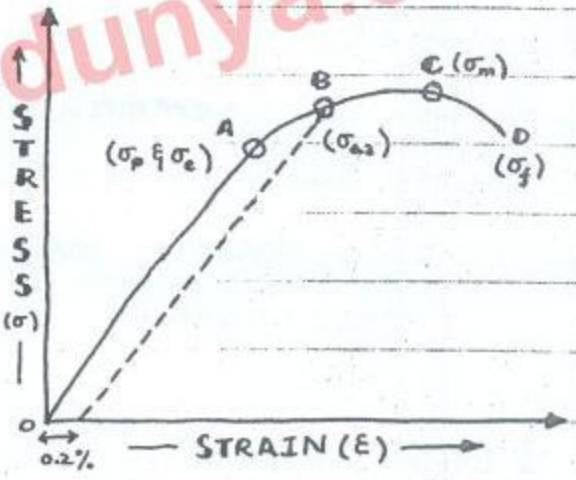
HOOKE'S LAW

It states that the strain is directly propotional to stress.

YIELD POINT

It is limit beyond that Hooke's law does not hold good and the stretched wire never comes to its original length.

A typical stress strain curve for a certain material is shown in figure.



In the initial stage of deformation, stress is increased linearly with the strain till we reach point A on the stress-strain curve. This is called propotional limit

PROPOTIONAL LIMIT

It is defined as "the greatest stress that a material can tolerate without losing straight line propotionality between stress and strain". Therefore, Hooke's law is obeyed in the region OA. It is denoted by σ_p which is similar to σ_e.

In elastic limit, the material can regain its original shape on removing the applied stress. Such a temporary deformation is also known as elastic deformation.

PLASTICITY

If the stress is increased beyond the elastic limit of the material, then the material becomes permanently changed and does not regain its original shape, on removing the applied stress. This property is known as plasticity.

In figure, point C represents

the ultimate tensile strength (UTS) σ_m of the material.

The UTS is defined as "the maximum strength that a material can withstand".

After crossing the point C, the material breaks at point D, this value is known as fracture stress (σ_f).

DUCTILE SUBSTANCES

Substances which undergo plastic deformation until they break, are called ductile substances. Lead, copper are examples of ductile substances.

BRITTLE SUBSTANCES

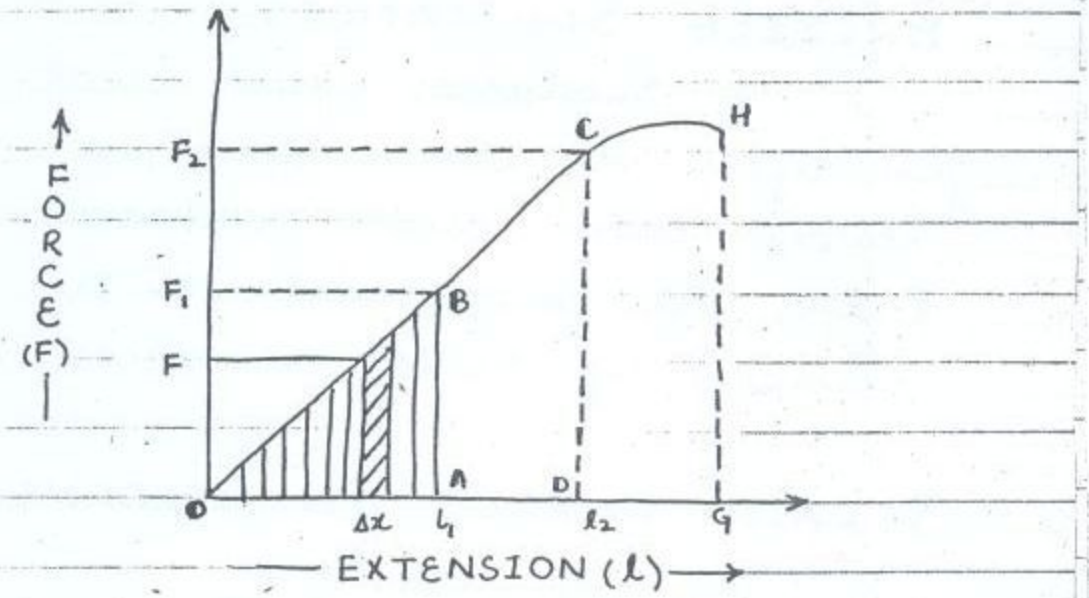
Substances which break just after the elastic limit is reached, called brittle substances. Glass, high carbon steel etc are examples of brittle substances.

STRAIN ENERGY IN DEFORMED

MATERIALS

The strain energy can be obtained by the area of the force - extension graph.

Consider a wire suspended vertically from one end to a support. It is stretched by attaching a weight at the other end. We can increase the stretching force by increasing the weight. By noting the extension l of the wire for different values of stretching force F, a graph is drawn between the force F and extension l as shown in figure.



Let us find the amount of work done on wire when extension is l_1 and force for this extension is F_1.

Figure shows that the force F does not remain constant in producing the extension l_1, it changes 'O' to F_1. Suppose at some stage before attaining the extension l_1, the force in the wire is F and the wire now extends by a very small amount Δx. It is supposed that the force F remains constant for Δx.

$\therefore$ Work done $= F\Delta x \longrightarrow (1)$

We divide the extension l_1 into large number of small parts. Total work done in producing the extension l_1 is equal to the sum of area of these parts i.e it will be equal to the area of the triangle OAB.

$\therefore$ Work done = Area of ΔOAB

$= \frac{1}{2} \times \text{base} \times \text{height}$

$= \frac{1}{2} \times OA \times AB$

$$\text{Work done} = \frac{1}{2} \times l_1 \times F_1 \longrightarrow (2)$$

The work is stored in the wire as potential energy given as

$$P.E = \frac{1}{2} l_1 F_1 \longrightarrow (3)$$

This relation can also be expressed in terms of modulus of elasticity E. If A be the area of cross-section of the wire and L is the total length, then by definition.

$$E = \frac{\text{Stress}}{\text{Strain}}$$

$$\Rightarrow E = \frac{F_1/A}{l_1/L}$$

$$\Rightarrow E = \frac{F_1}{A} \times \frac{L}{l_1}$$

$$\Rightarrow \boxed{F_1 = \frac{EA \times l_1}{L}} \longrightarrow (4)$$

Put this value of F_1 in eq (3)

$$\therefore P.E = \frac{1}{2} l_1 F_1$$

$$\Rightarrow P.E = \frac{1}{2} l_1 \times \frac{EA \times l_1}{L}$$

$$\Rightarrow \boxed{P.E = \frac{1}{2}\left[\frac{EA \times l_1^2}{L}\right]} \longrightarrow (5)$$

This is required result.

P.E BY AREA METHOD

The area method is quite a general one. For example, if the extension is increased from l_1 to l_2, the amount of work done by stretching force would be given by the area of trapezium ABCD. It is also valid for both the linear (elastic) and the non-linear (non-elastic) parts of the force-extension graph. If the extension occurs from O to G, this work done would be the area of OGH

ELECTRICAL PROPERTIES OF SOLIDS

The fundamental electrical property of a solid is its ability to conduct electric current.

Some materials are good conductors e.g metals with conductivity of the order of $10^7 (\Omega.m)^{-1}$. For example iron etc.

Some materials have very

low conductivities of the order of 10^{-10} to 10^{-20} $(\Omega.m)^{-1}$. These are called insulators e.g, wood, diamond etc.

Some materials have intermediate conductivities of the order of 10^{-6} to 10^{-4} $(\Omega.m)^{-1}$. These are called semi-conductors e.g, silicon, germanium.

ENERGY BANDS IN SOLIDS

The concept of energy bands is very useful in differentiating the electrical properties of conductors, insulators and semi-conductors.

Electrons of an isolated system are bound to the nucleus and can only have definite energy levels. When a large number of atoms are brought close to one another to form a solid, each energy level splits into N sub-levels (under the action of forces exerted by other atoms in the solid). which overlap to form band. Each sub-group

of energy levels is called ENERGY BAND.

CONDUCTION BAND

It is occupied by free electrons. It may be either empty or partially filled with electrons. In this band, electrons move freely and conduct electric current through solids. That is why electrons occupying in this band are known as conductive electrons or free electrons. The band above the valence band is called CONDUCTION BAND.

VALENCE BAND

The electrons in the outermost shell of an atom are called valence electrons and the energy band occupying these electrons is known as VALENCE BAND.

It may be either completely filled or partially filled

by electrons and can never be empty. Valence band is below the conduction band.

FORBIDDEN BAND

The energy gap between the valence band and conduction band is called FORBIDDEN BAND. This band does not contain free electrons. The band below the valence band are normally completely filled and play no part in the conduction process.

CLASSIFICATION OF SOLIDS ON THE BASIS OF ELECTRICAL CONDUCTIVITY

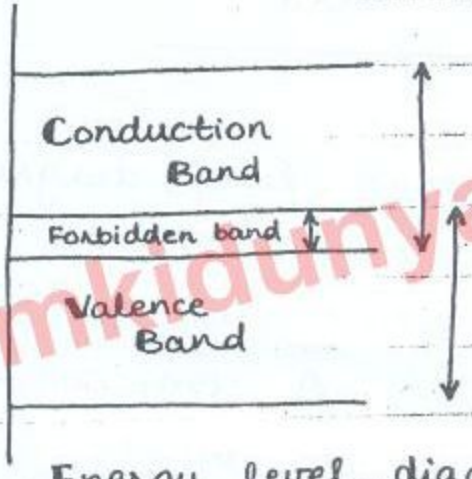
On the basis of electrical conductivity, solids are classified into three types given as

(i) Conductors
(ii) Insulators
(iii) Semi_conductors

CONDUCTORS

Conductors are those materials which have free electrons for electrical conduction.

In conductors, valence band and conduction band overlap each other. Electrons can easily move from valence to conduction band as shown in figure.



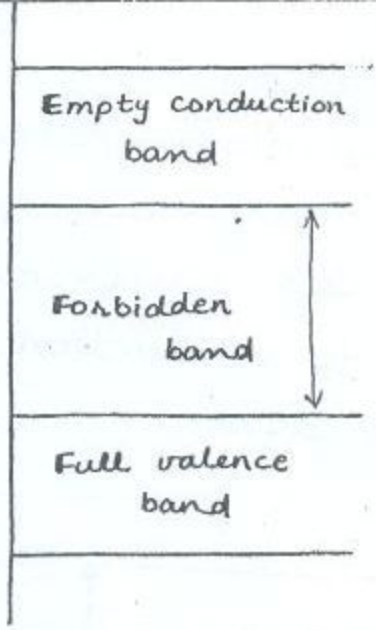
Energy level diagram

INSULATORS

Insulators are those materials in which valence electrons are bound very tightly to their atoms.

An insulator has

a) an empty conduction band (no free electrons)
b) a full valence band
c) a large energy gap between them as shown in figure.



Energy level diagram

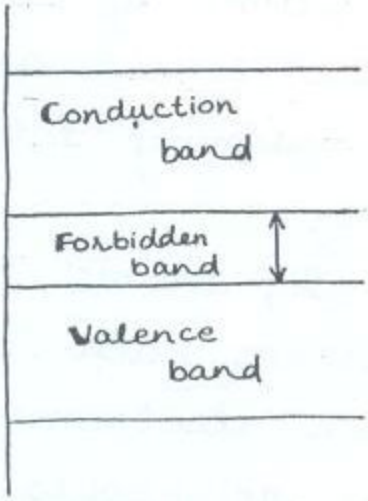
SEMI-CONDUCTORS

A semi-conductor material is one whose electrical properties lie in between those of insulators and conductors

In terms of energy bands, semi-conductors can be defined as those materials which at room temperature have:

(i) partially filled conduction band
(ii) partially filled valence band
(iii) a very narrow forbidden energy gap (of the order of 1eV) between conduction band and valence band

as shown in figure.



Energy level diagram

NOTE

Semi_conductors in pure form are insulators.

INTRINSIC SEMI_CONDUCTOR

A semi_conductor in pure form is called intrinsic semi_conductor. For example, silicon, germanium etc.

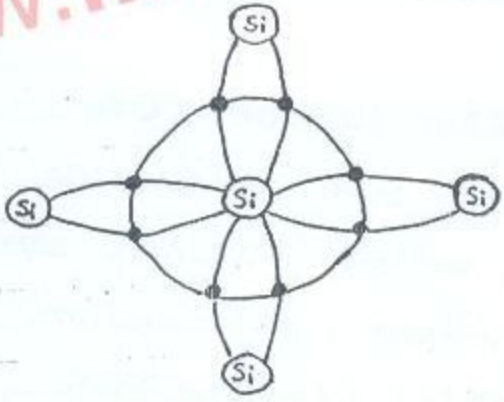
EXTRINSIC SEMI_CONDUCTOR

A semi_conductor in impure i.e un_natural form is called extrinsic semi_conductor. Such type of semi_conductor is obtained by the addition of some impurity.

DOPING

A process in which a small number of atoms of some other element are added as impurity in the ratio of 1 to 10^6 is called doping.

Silicon (Si) atoms has four valence electrons. Each atom shares a valence electron with each of its four neighbours. The sharing of electrons between two atoms gives binding force between them.



Thus the neighbouring atom form covalent bonds by sharing four electrons with each other as shown in figure.

HOLE

When a bond is broken and electron becomes free and vacancy of electrons is produced in the covalent bond. This vacant place is called a hole.

A hole represents the absence of negative charge and has attraction for electron. The hole has positive charge equal to negative charge of electron in magnitude.

TYPES OF EXTRINSIC SEMI_CONDUCTOR

There are two types of extrinsic semi_conductors.

1. n_type semi_conductor
2. p_type semi_conductor

N_TYPE SEMI_CONDUCTOR

When few impurity atoms from one element lies in the fifth group are added in pure semi_conductor materials, then newly

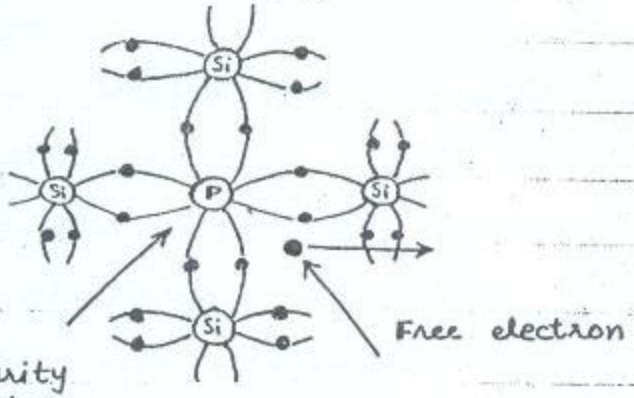
formed substance has excess of free electrons, called N-type semi-conductors.

EXPLANATION

An atom of arsenic (As) or antimony (Sb) contains five valence electrons (i.e pantavelent) and Germenium (Ge) or Silicon (Si) atom contains four electrons in the outer most shell.

If we add an atom of As in a Si as impurity, then n-type crystal is formed.

The four valence electrons of As atom form covalent bonds with the four neighbouring Si atoms. The fifth valence electron of donor As atom is free in the crystal as shown in figure.



P-TYPE SEMI-CONDUCTOR

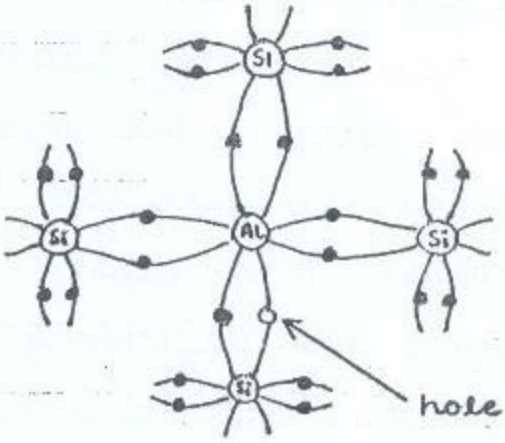
When few impurity atoms from an element lies in the third group are added in pure semi-conductor material, then newly formed substance has deficiency of free electrons, called P-type semi-conductor.

EXPLANATION

An atom of aluminium (Trivalent element) has three valence electrons in the outer most shell

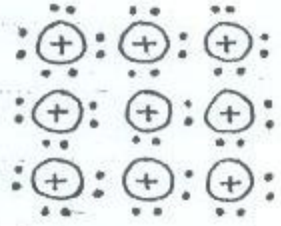
If we add atom of aluminium (AL) in silicon (Si) as impurity, p-type crystal is formed Such type of impurity is called acceptor. The aluminium atom has shortage of one ↑ electron in making the covalent bond with silicon. Three valence electrons of aluminium form covalent bond with three neighbouring atoms of silicon, while one missing electron in the covalent bond with the fourth neighbouring Si atom called a hole

as shown in figure. The aluminium atom is called an accepter atom.



Electrical Conduction By Electrons And Holes In Solids

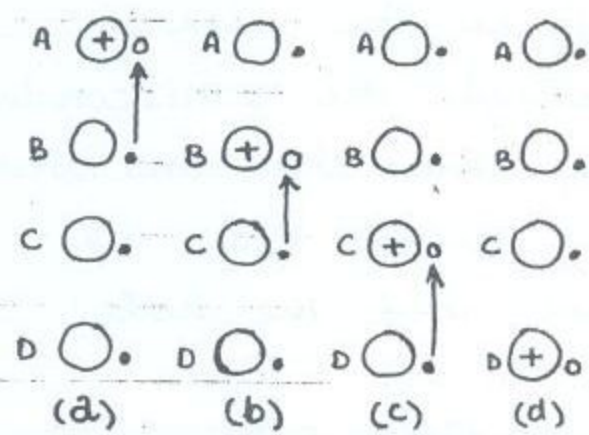
Consider a semi-conductor crystal (Si). The circles represent the positive ions of Si atoms and dots are valence electrons as shown in figure. These electrons are bound by covalent bonds.



Let a covalent bond breaks at room temperature and an electron

hole pair is created. Both the electrons and holes move in the semi-conductor crystal as explained below.

Consider a row of Si atoms in crystal and a hole is present in the valence shell of atom A. As hole is a deficiency of electron. The hole has a positive charge as shown in fig (a). This attracts an electron from a neighbouring atom say B. This creates a hole at B and a hole (positive charge) at B attracts an electron from C as shown in figure (b). This creates a hole at C and a positive charge appears at C which attracts an electron from D as shown in figure (c). This creates a hole at D and a positive charge appears at D as shown in fig (d).



current add up together to give the current I.

SUPER CONDUCTORS

A conductor with almost zero resistance is called super conductor.

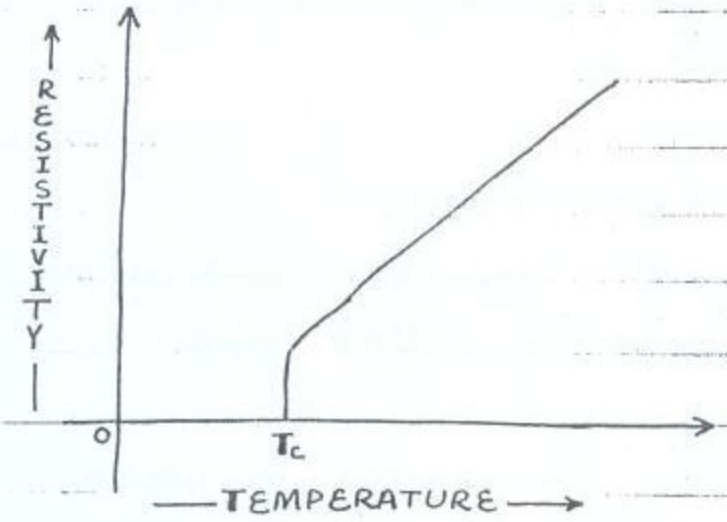
Such phenomenon in which substances are made to form super conductors is called Super conductivity.

A super conductor loses its resistance at very low temperature and no energy is dissipated.

CRITICAL TEMPERATURE

The temperature at which the resistance or resistivity of a conductor becomes zero is called critical temperature. It is denoted by T_c or θ_c.

Figure shows the resistivity-temperature graph. In the figure, at a certain temperature, the value of resistivity ρ falls to zero.



The first super conductor was discovered by Kmaerlingh Ornes in 1911 when it was observed that electrical resistance of mercury disapper suddenly as the temperature is reduced below 4.2 K.

Some other metals such as aluminium ($T_c = 1.18$ K), tin ($T_c = 3.72$ K) and lead ($T_c = 7.2$ K) also become super conductors at very low temperature.

In 1986, some new ceramic substances show super-conductivity even at high temperature at 125 K Prof. Yao Lian's Lee discovered that complex crystalline structure known

as Yyttrium barium copper oxide ($YBa_2Cu_3O_7$) became super conductor at 163 K or −110°C.

HIGH TEMPERATURE SUPER CONDUCTORS

Those substances which show super conductivity at 77 K or above, are called high temperature super conductors.

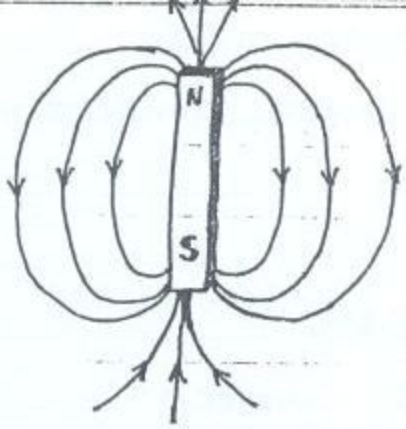
APPLICATIONS

Superconductors have many technological applications. Such as

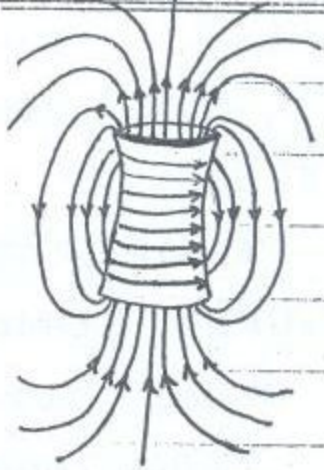
(i) in magnetic resonance imaging (MRI)
(ii) magnetic levitation trains
(iii) small electric motors
(iv) fast computer chips.

MAGNETIC PROPERTIES OF SOLIDS

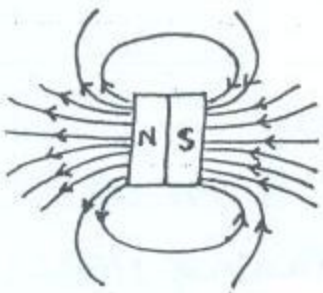
The field of a long bar magnet is like the field produced by a long solenoid carrying current and the field of short bar magnet resemble that of a single loop as shown in figure. The similarity between the fields produced by magnets and currents was



a) Long Bar Magnet



b) Solenoid



C) Short Bar Magnet

d) Magnetic Field Of Current-Loop

proposed by AMPERE.

The magnetism produced by electrons within an atom can arise from two motions. Firstly each electron orbiting the nucleus behaves like an atomic sized loop of current that generates a small magnetic field. This position is similar to the field produced by the current-loop as shown in fig (d)

Each electron possesses a spin that also generates a magnetic field.

The net magnetic field produced by electrons within an atom is due to the combined field created by their orbital and spin motions. Since there are number of electrons in an atom, their currents or spins may be so placed as to cancel the magnetic effects mutually or strengthen the effects of each other. An atom in which there is a resultant magnetic field, behaves like a tiny magnet and is called a MAGNET DIPOLE. Thus the source of magnetism of an atom is the electron.

PARAMAGNETIC SUBSTANCES

The substances in which magnetic fields produced by orbital & spin motions of electrons support each other and the atom behaves like tiny magnet are called PARAMAGNETIC SUBSTANCES. For example, aluminium, platinum etc.

DIAMAGNETIC SUBSTANCES

The substances in which magnetic fields produced by orbital & spin motions of electrons in an atom

add up to zero are called DIAMAGNETIC SUBSTANCES. For example, copper, antimony, bismuth etc.

FERROMAGNETIC SUBSTANCES

The substances in which the atoms co-operate with each other in such a way as to show a strong magnetic effect are called FERROMAGNETIC SUBSTANCES. For example, Fe, Co, Ni, Chromium dioxide and Alcino, steel etc.

DOMAINS

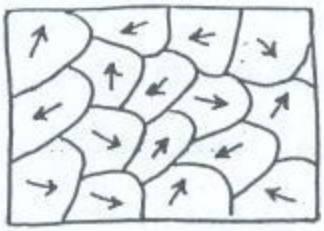
A ferromagnetic substance has small regions called DOMAINS. A domain contains 10^{12} to 10^{16} atoms. Within each domain the magnetic fields of all the spining electrons are parallal to one another. Each domain behaves as a small magnet with its own north and south poles.

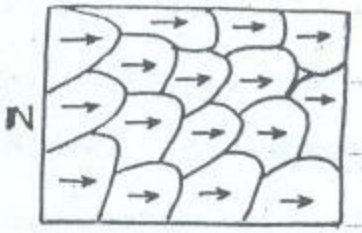
SOFT MAGNETIC MATERIAL

Iron is a soft magnetic material. Its domains are easily oriented on applying an external magnetic field and also return to original position

when the field is removed.

When iron is placed in an external magnetic field as those of a solenoid, the domains line up parallal to external magnetic field and the whole material becomes magnetized.



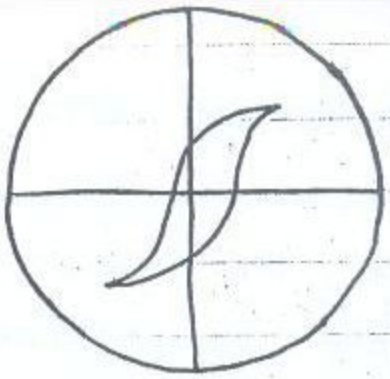


The combination of a solenoid and iron makes a powerful magnet and is called electromagnet. When ferromagnetic materials are heated, they begin to lose their orderliness due to increased thermal motion.

HARD MAGNETIC MATERIAL

Steel is a hard magnetic material. Its domains are not easily oriented on applying external magnetic field. Domains in steel can be lined up by a very strong external field, but once oriented retain the position. Thus steel makes a good parmanent magnet.

The flux density versus the different values of magnetizing current of the solenoid is plotted by a CRO as shown in figure

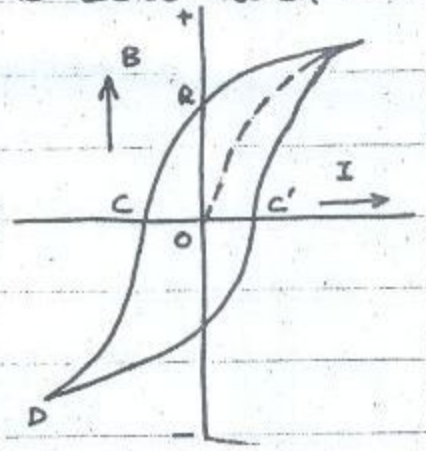


MAIN PARTS OF HYSTERISIS CYCLE

1. HYSTERESIS

The magnetism lags behind the magnetising current. This phenomenon is known as hysterisis.

Consider a ferromagnetic substance (iron) is placed in an alternating current solenoid. Initially when current is zero and iron is un-magnetized. The portion OA of the curve is obtained when the magnetizing current I is increased and AR is the portion when current is decreased.



a) Hysteresis loop of steel

2. SATUREATION

The magnetic flux density B increases from zero and reaches a maximum value. At this stage, the material

is said to be magnetically saturated.

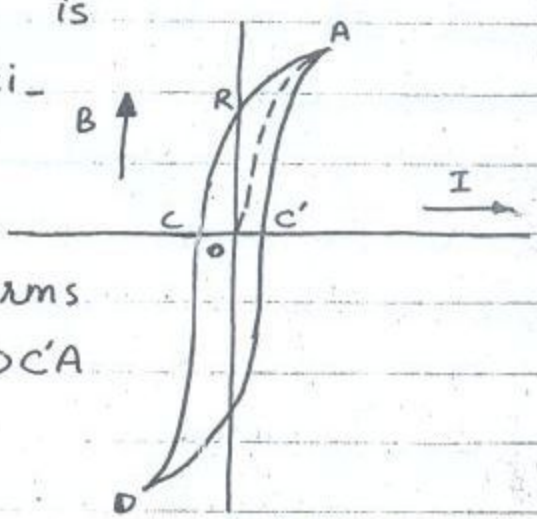
3. REMANENCE OR RETANTIVITY

When the current is reduced to zero, the material still remains strongly magnetized represented by point R on the curve.

4. COERCIVITY

To magnetising the material, the magnetising current is reversed and increased to reduce the magnetization to zero. This is known as coercive current represented by C on the curve. The coercivity of steel is more than that of iron as more current is needed to demagnetise it. as shown in figure.

Once the material is magnetized, its magnetization curve never passes through the origin. Instead, it forms the closed loop ABCDC'A which is called hysteresis loop.



5. AREA OF THE LOOP

Area of the loop is the measure of the energy needed to magnetize and demagnetize each cycle. This is the energy required to do work against internal friction of the domains. The work appears as a heat dissipated. It is called hysteresis loss.

Hard magnetic materials like steel can not be easily magnetized or de-magnetized, so they have large loop area as compared to soft magnetic materials such as iron which can easily be magnetized. Hence, energy dissipated per cycle for iron is less than for steel.

USE ⇨ Use of magnetic materials for different purposes can be studied by taking the specimen through a complete cycle and drawing the hysteresis loop. A material with high retentivity and large coercive force would be most suitable to make a permanent magnet.

QUESTIONS

17.1. Distinguish between crystalline, amorphous and polymeric solids?

Ans. Crystalline solids are those which have periodic arrangement of molecules / atoms or ions, in three dimensions, called lattice. The amorphous solids are those, which do not have particular structure of molecules atoms or ions. Or there is no regular arrangement of atoms/molecules in these substances.

17.2. Define stress and strain. What are their SI units? Differentiate between tensile, compressive and shear modes of stress and strain?

Ans. Stress is defined by the following relation

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

Its units are Nm^{-2} or Pa. The strain is fractional change in the length, area or volume of a substance due to stress applied on it. It is a number with out any units. Tensile strain $= \frac{\Delta l}{l}$ change in length per unit length.

Compressive strain $= \frac{\Delta V}{V}$, change in volume per unit value.

shearing strain = $\tan \theta$

17.3. Define modulus of elasticity. Show that the units of modulus of elasticity and stress are the same. Also discuss its three kinds?

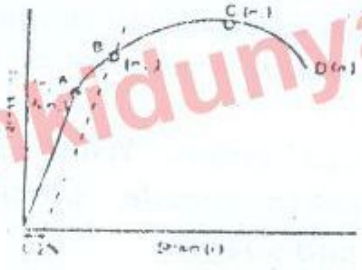
Ans. The ratio of stress over strain is called "modulus of elasticity" Its units are Nm^{-2}

As strain has no units so E = modulus of elasticity $= \frac{\text{Stress}}{\text{Strain}}$.

The E. has same units (Nm^{-2}) as those of stress.

17.4. Draw a stress-strain curve for a ductile material, and then define the terms: Elastic limit, Yield point and Ultimate tensile stress?

Ans. The curve stress and strain for a ductile material is shown below.



The ductile materials are those, which undergo plastic deformation unit these break, for example, lead, copper.

Elastic limit:

The maximum stress up to which the body comes back to its original shape, when stress is removed from it is called its elastic limit (point A in the above shown curve)