Chapter = 17

Physics of Solids

17-1 Classification of solids:

(with respect to the arrangments of Molecules.)

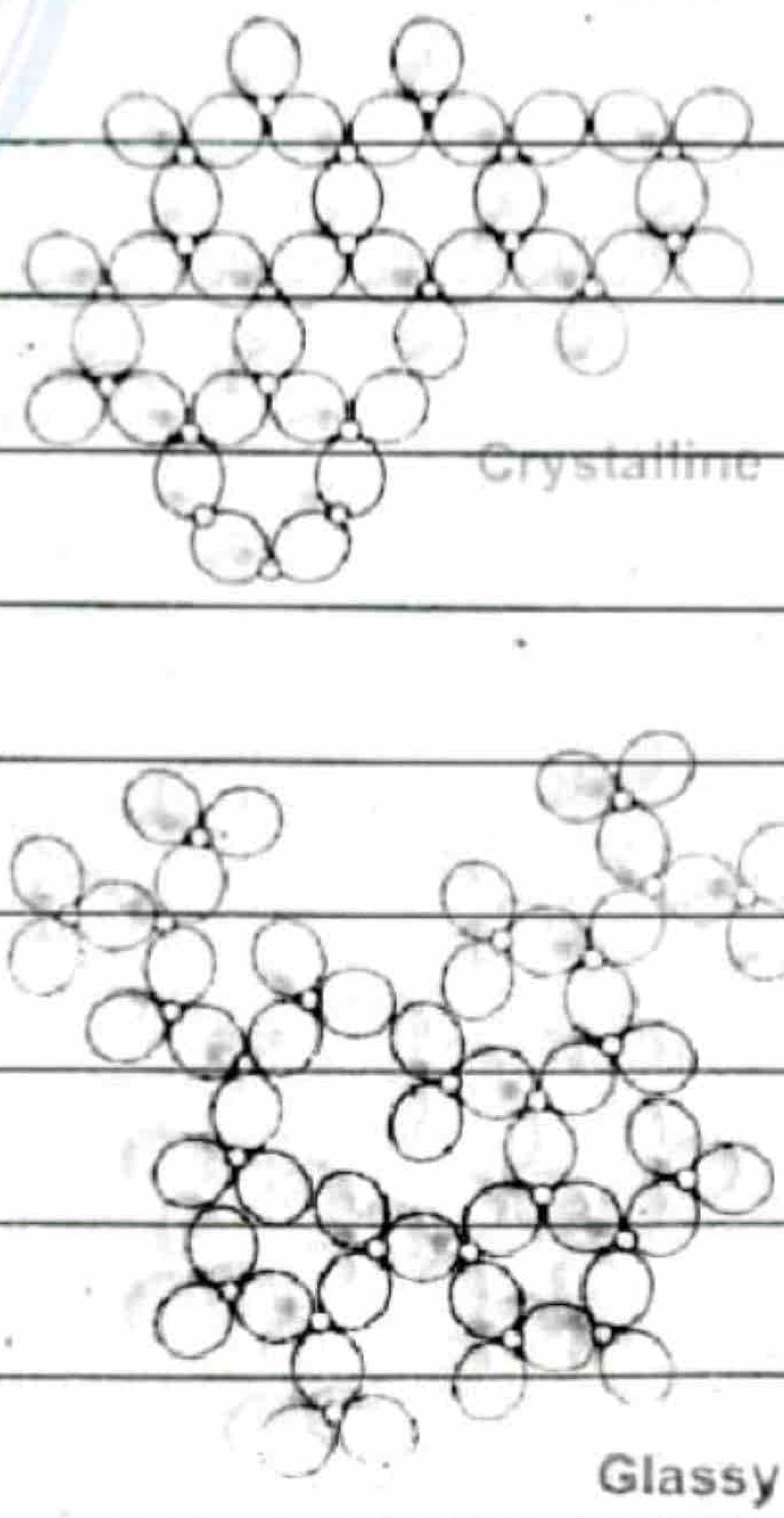
1- Crystalline Solids:

Regular arrangement of molecules:

In crystalline solids there is a ragular arrangement of molecules. They are arranged in a regular pattern that is constant through out the crystal.

The arrangement of molecules, atoms or ions, with in all types of crystolline solids can be studied by using various X-ray techniques.

For Your Information



Glassy and crystalline solids-short- and long-range order.

Vibrating particles:

Atoms, ions or molecules in a crystalline solids are not static. Each atom in a metal crystal vibrates about a fixed point with an amplitude that increases with the rise of temperature.

Cohesive forces:

The cohesive forces between atoms, molecules or ions in crystalline solids maintain the long-range order inspite of atomic vibrations.

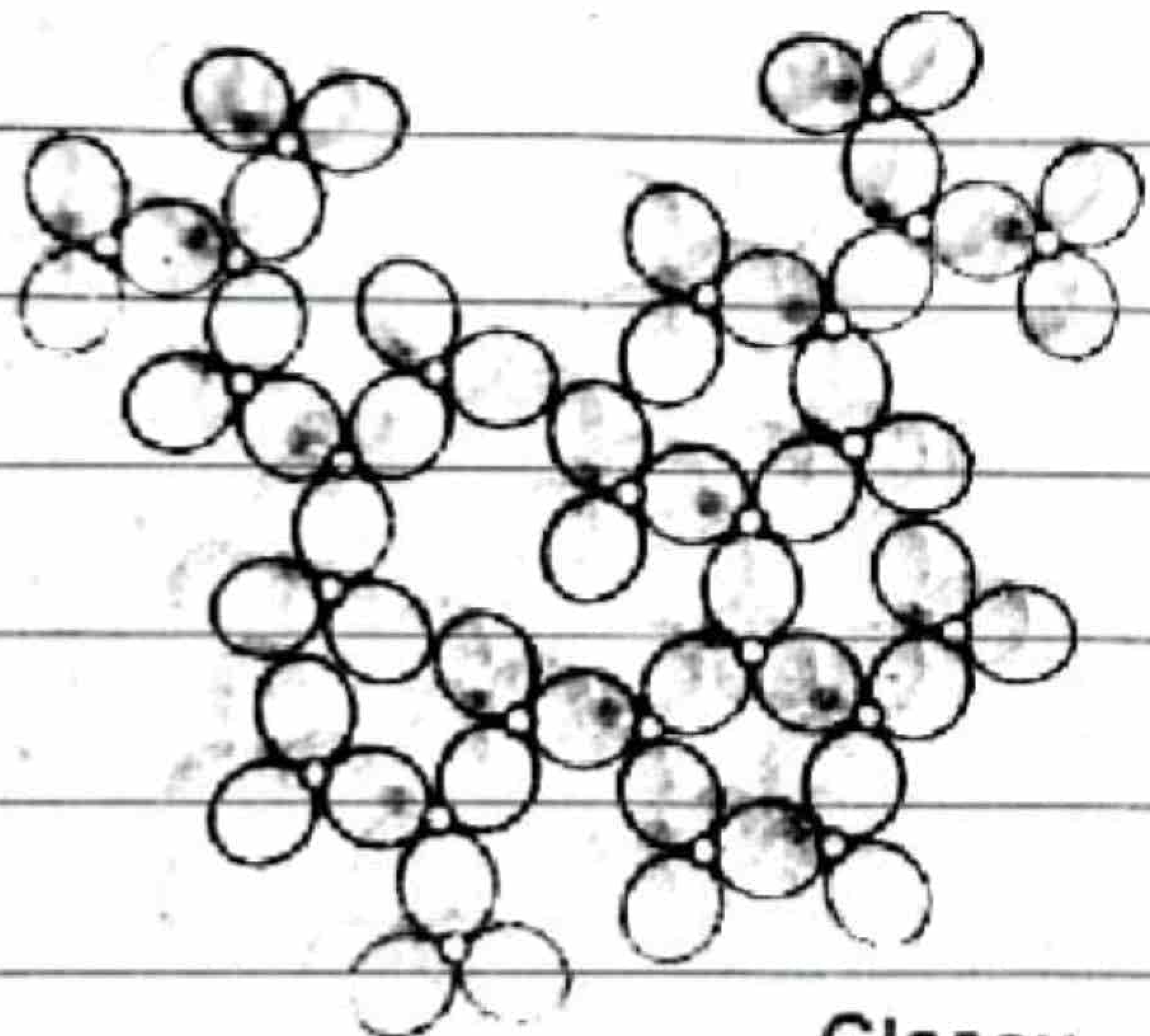
Definite melting point:

In crystalline solids, there is a temperature at which the atomic vibrations become so great that structure suddenly breaks up and the solid melts. So, every crystalline solid has a definite melting point.

2: Amorphous or Glassy solids

Irregular arrangement of molecules:

The word "amorphous" means without form or structure. So, in amorphous solids there is no regular arrangement of molecules like that in crystalline solids. Honce amorphous solids are more like liquids and the disordered structure is frozen in.



Glassy

Example:

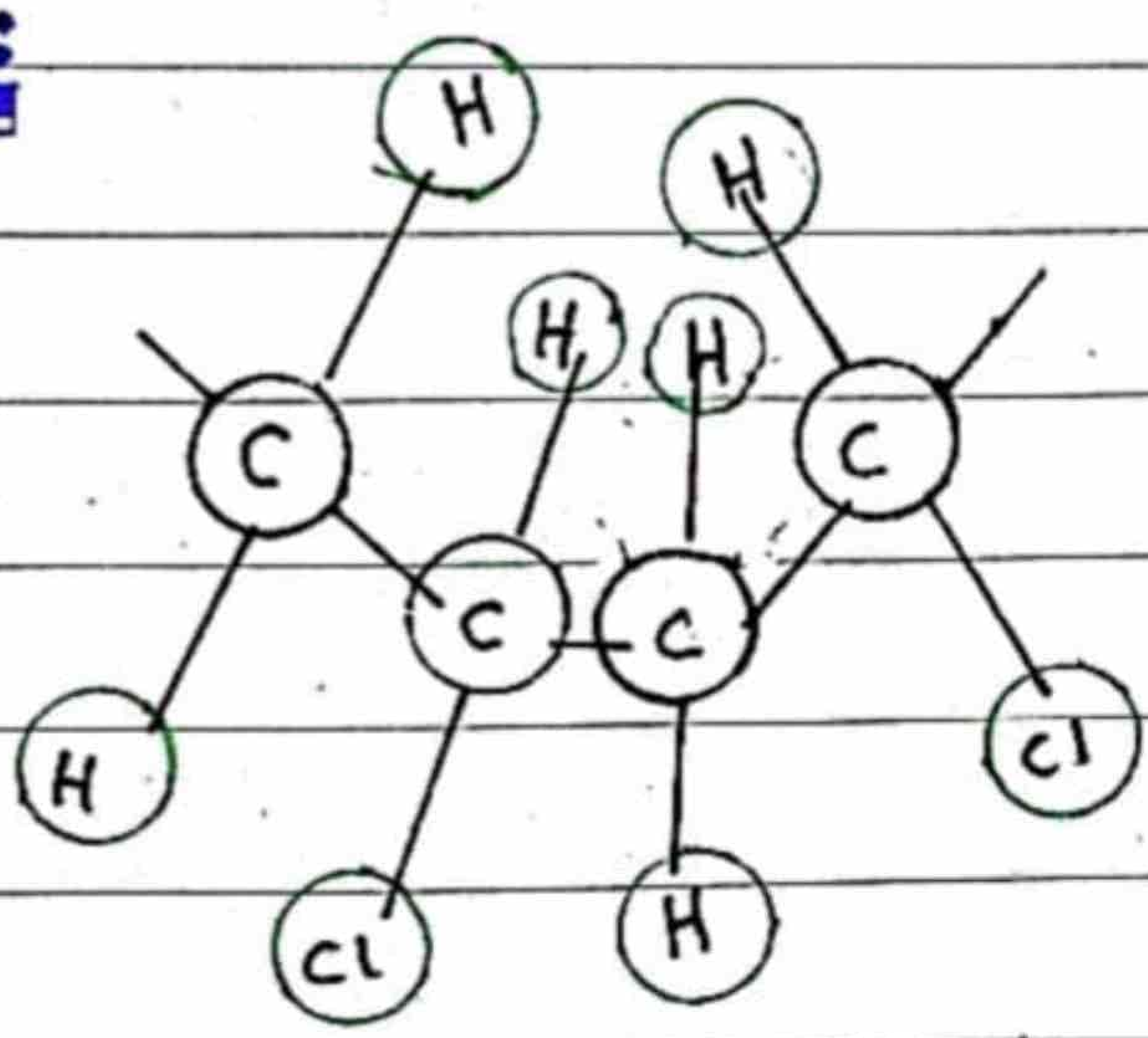
Ordinarg glass is an amorphous solid. It is a solid at ordinary temperature and has no regular arrangement of molecules. On heating it gradually softnes in to a paste like state before it becomes a very viscous liquid at about 800°C.

Amorphous solids have no definite melting point.

3 : Polymeric solids:

Partially crystalline solids:

Polymers or polymeric solids have a structure that is intermediate between order and disorder. So, they are also called



Part of PVC molecules

partially or poorly crysto-lline solids.

Partially crystalline solids are two types.

i) : Natural polymers e.g rubber.

ii) : Synthetic polymers e.g plastic.

Polymerization:

Polymeric solids are obtained by polymerization reactions in which relatively simple molecules are chemically combined in-to massive long chain molecules or "three dimensional structures."

Specific gravity and strength to weight ratio:

$$\text{Specific gravity} = \frac{\text{Density of medium}}{\text{Density of water}}$$

These materials have low specific gravity as compared with even the lightest metals, yet they have good (large) strength to weight ratio.

Composition:

Polymers consist of chemical combination of carbon with oxygen hydrog-en, nitrogen and other metallic or non-metallic elements.

Examples:

Polythene, polystrene and nylon etc. Natural rubber is composed in pure state entirely of hydrocarbon with formula $(C_5 H_6)_n$.

Unit cell:

"A crystalline solid consists of three dimensional pattern that repeats itself over and over again. This smallest three dimensional basic structure is called a unit cell."

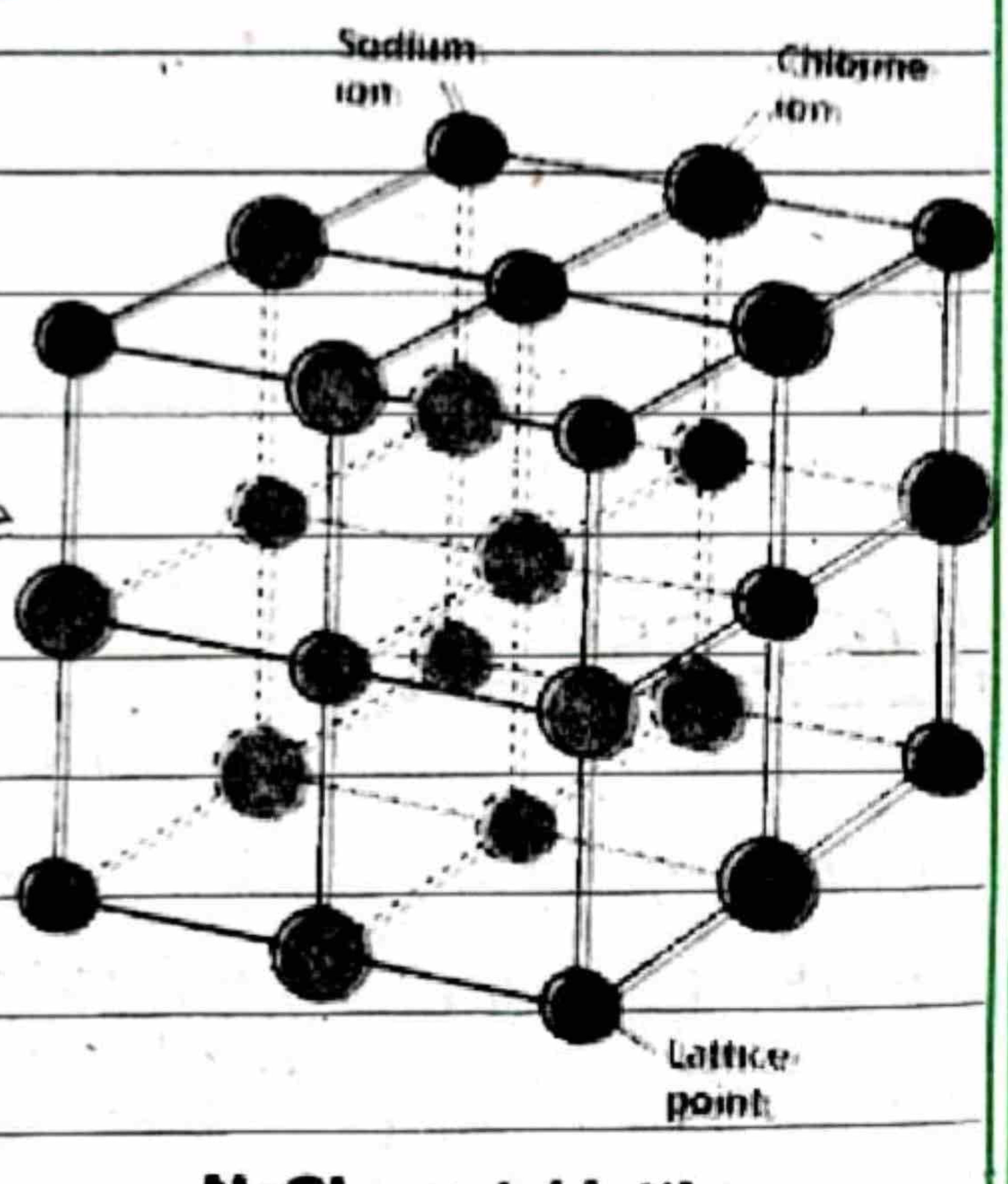
Crystal Lattice:

"The whole structure of crystalline solid obtained by the repetition of unit cell is known as crystal lattice."

Example:

The pattern of Nacl particles have a cube shape. The cube shape of sodium chloride is just one of several crystal shape.

In a cubic crystal all the sides meet at



NaCl crystal lattice

right angles. In other crystals all angles are not "90°."

17.2 Mechanical Properties of Solids

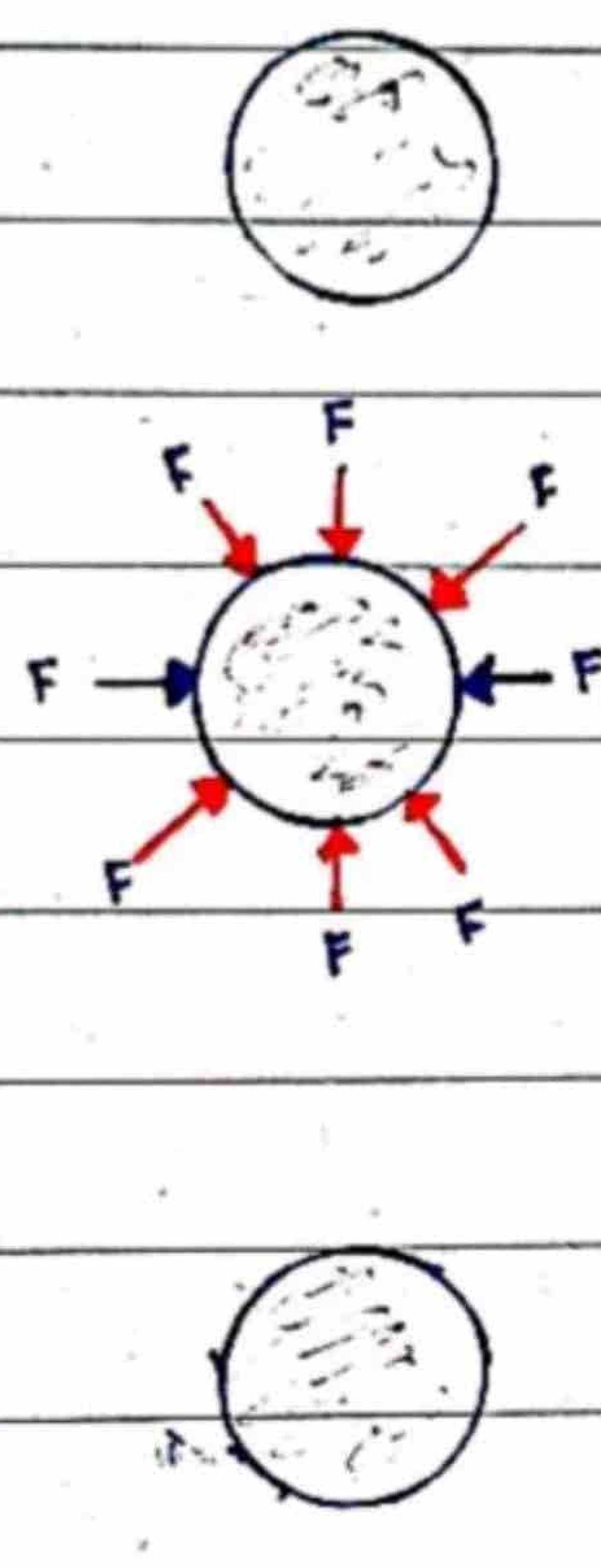
Deformation in Solids:

Definition:

"Deformation is the process in which the length, volume or shape of a body changes due to an external force."

Explanation with examples:

i) : If we hold a soft rubber ball in our hand and then squeeze it the volume or shape of the ball will change. However if we stop squeezing the ball and open our hand then the ball will return to its orignal spherical shape.



(a) (b) (c)

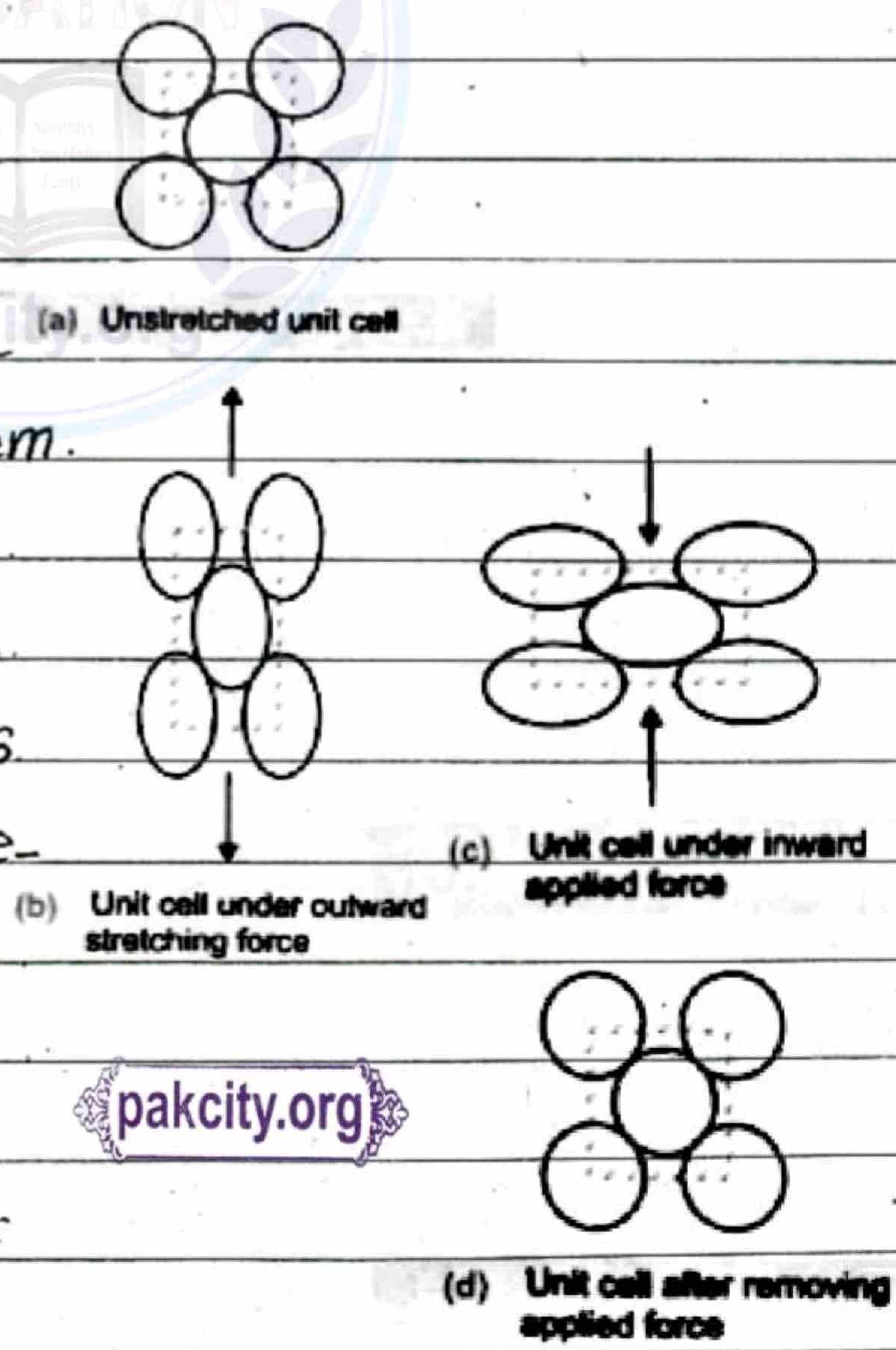
ii) : Similarly if a string is elongated by an external force, then on removing the applied force, the string will return to its orignal length.

Conclusion:

From these examples, it is concluded that deformation i.e change in length or change in shape or change in volume is produced when a body experiences some external force.

Deformation in crystalline solids:

In crystalline solids, atoms are usually arranged in a certain order. These atoms are held about their equilibrium position due to interatomic cohesive forces between them. When external force is applied on such a body, a distortion results because of the displacement of atoms from their equilibrium position and the body is said to be in the state of stress.



(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

After the removol of external force, the atoms return to their equilibrium position, and the body regains its orignal shape, provided that external force is not too large. The fig. shows the deformation produced in a unit cell of a crystal due to external applied force.

Stress and Strain

Elasticity:

"It is the property of a body due to which it returns to its orignal length volume or shape after remolval of the applied force."

Stress:

"It is defined as the force applied per unit area to produce any change in length, volume or shape of a body."

Symbol:

Sigma (σ) is the symbol of stress.

$$\text{Stres } (\sigma) = \frac{\text{Force 'F'}}{\text{Area 'A'}}$$

Unit of stress σ are Nm^{-2} or Pa (Pascal).

Types of stress:

Stress may change length, volume or shape of a body.

1): Tensile stress:

"When a stress changes length it is called tensile stree"

2): Compressional or Volumetric stress:

"When a stress changes volume, it is called compressional stress."

Shear stress:

"When a stress changes shape of a body, it is called shear stress."

Strain:

"Strain is the measure of deformation of a solid, when stress is appied to it."

Types of strain:

1): Tensile strain:

"It is defined as change in length per unit orignal length" or "it is fractional change in length."

Tensile strain $(\varepsilon) = \frac{\text{change in length } (\Delta l)}{\text{orignal length } (l)}$

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

Tensile strain is due to tensile stress.

2): Volumetric strain:

"It is defined as change in volume per unit volume" or "It is fractional change in volume." Its denoted by β

Volumetric strain $(\beta) = \frac{\text{change in volum } (\Delta V)}{\text{orignal volume } (V_o)}$

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

Compressional strain is due to compressional stress.

3): Shear strain:

"It is angular deformation in a body." Its denoted by "γ."

$$\gamma = \frac{\Delta a}{a} \quad \tan(\theta)$$

When θ is small $\tan\theta \simeq \theta$

$$\gamma = \theta$$

Elastic constants

Modulus of elasticity:

The ratio of stress to strain is a constant for a given material, provided the external force is not too large. "This constant is called modulus of elasticity." Its denoted by "E".

$$E = \frac{\text{stress}}{\text{strain}}$$

1): Young's Modulus:

"In case of linear deformation the ratio of tensile or compressive stress to tensile strain is called Young's Modulus."

$$\text{Young's modulus } Y = \frac{F/A}{\Delta l/l}$$

2): Bulk modulus:

"In case of three dimensional deformation when volume is involved, the ratio of applied stress to volumetric strain is called bulk modulus."

$$\text{Bulk modules } k = \frac{F/A}{\Delta V/V}$$

3): Shear modulus:

"It is the ratio of shear stress to shear strain."

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

i): strain has no units.

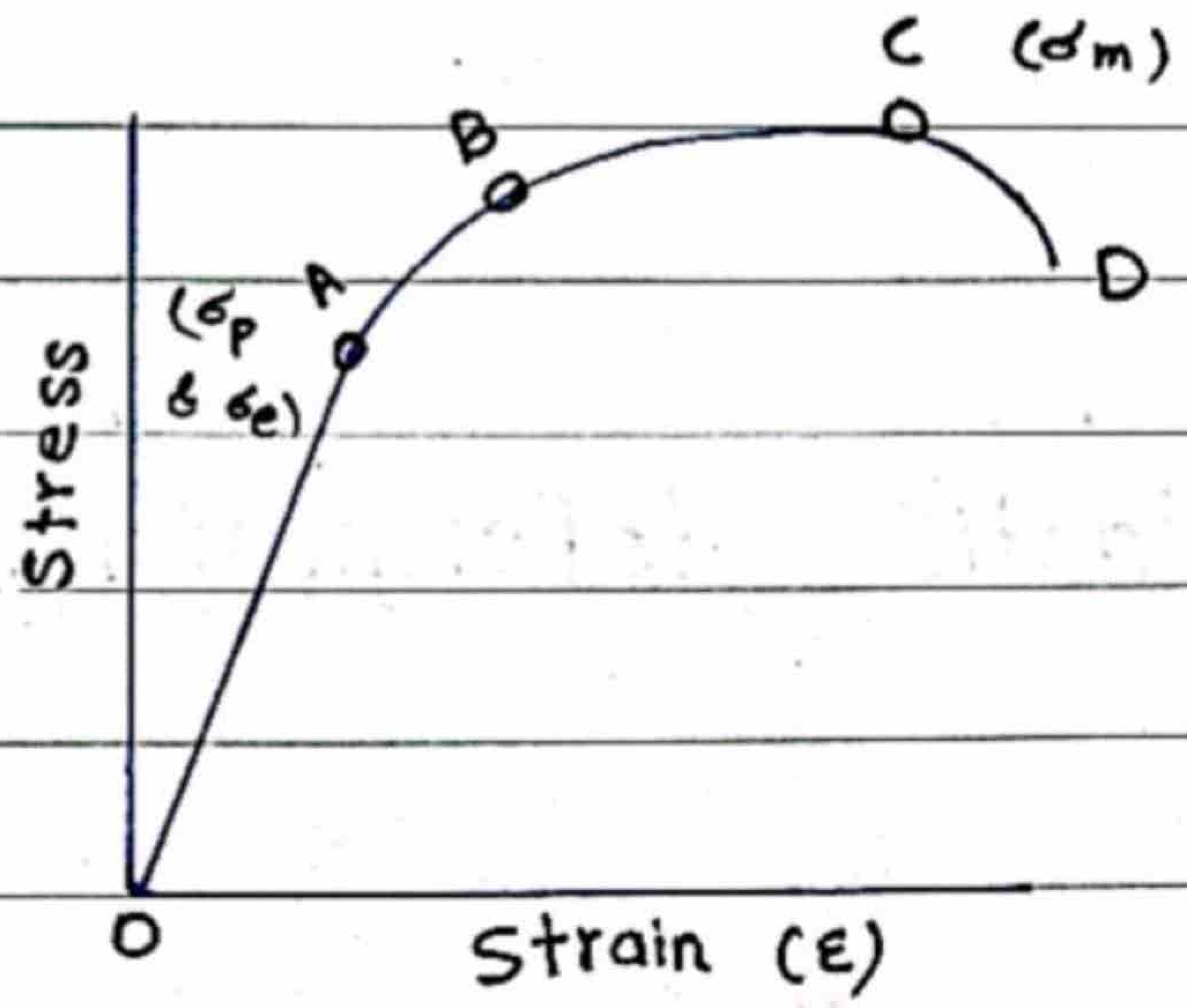
ii): Young modulus, Bulk modulus and shear modulus all have the same units as that of stress i.e. Nm^{-2} or Pascal

Elastic limit and Yield strength

Stress strain curve:

"Stress strain curve explains different mechanical properties of solids when they are deformed."

Stress strain curve is plotted automatically on XY chart recorder. Stress strain curve of a typical material is shown in fig.



Elastic limit (σ_e):

In the initial stage of deformation i.e., from O to A stress is directly proportional to strain and hence OA is a straight line. The stress (δ_p) and (δ_e) at point A are called proportional limit or elastic limit.

Definition:

"The proportional limit (δ_p) is defined as the greatest stress that a material can tolerate without losing straight line proportionality between stress and strain."

The proportional limit (δ_p) is identical with the elastic limit (δ_e) which is defined as the greatest stress that a material can tolerate without any permanent change in shape or dimensions.

Hook's Law:

Hook's law which states that strain is directly proportional to the stress is therfore obeyed in the region "OA"

Elastic deformation:

Deformation produced with in "OA" region is temporary because the material can return to its orignal shape or dimensions on removing the applied stress. "Such a temporary deformation is also known as elastic deformation and this proces is called Elasticity."

Yield point:

The point "A" on the stress-strain curve is called the yield point.

Plasticity:

"Plasticity is defined as the property of material due to which it does not regain its original shape after the stress is removed"

Ultimate Tensile Stress (UTS):

Point "C" on the stress strain curve represents the ultimate tensile stress (UTS σ_m) of material "UTS is defined as the maximum stress that a material can bear."

Fracture stress (σ_F):

After crossing point "C" the material breaks at point "D." The value of stress at this point where material break, is called fracture stress (σ_F).

Ductile substance:

"Substances that undergo plastic (permanant) deformation until they break are known as ductile substances". e.g Lead, copper.

Brittle substance:

"Substances which break just after the elastic limit is reached are called brittle substances." e.g Glass, High carbon steel.

Strain energy in deformed materials:

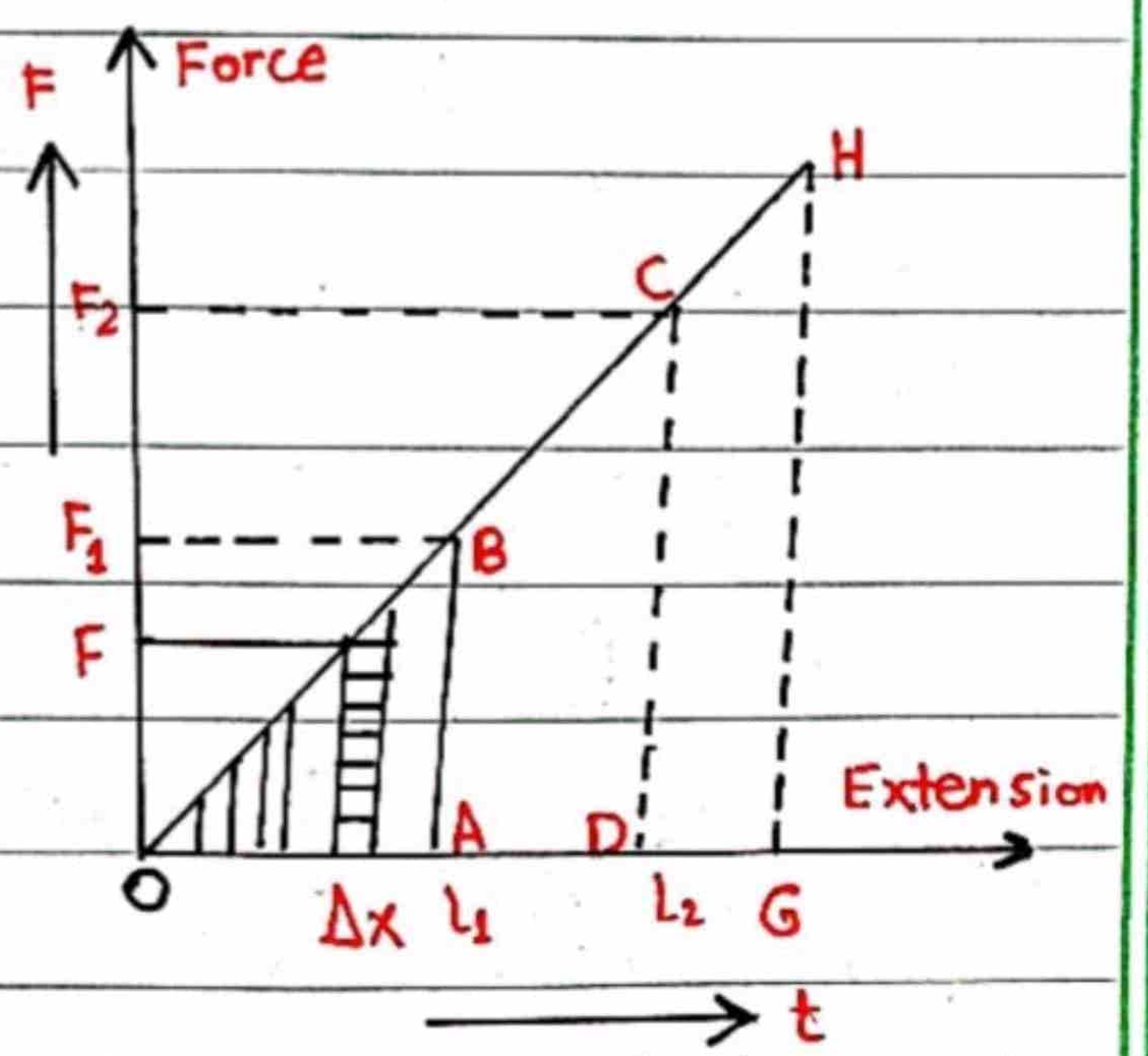
Definition:

"It is the potential energy stored in the molecules of a deformed material and is equal to the work done by the deforming force."

Explanation:

Consider a wire is suspended vertically from one end. It is stretched by attaching a weight at the lower end.

A graph is drawn between force and extension of the wire. If the



Energy in stretched wire

elastic limit is not crossed the graph is a straight line.

When a force "F" stretches the wire by some length "I", then work done is

$$Work = Force \times Extension$$

$$Work = F \times I$$

As the force increases from zero 0 to "F_1" the extension increases from zero 0 to "I_1". Suppose at some stage before "I_1" the force is "F" and "Δx" is the small extension. "Δx" is so small that "F" may be assumed to be constant.

Work done = $F\Delta x$ is equal to the shaded area. The total extension "I_1" is divided into small elements and work for each small extension is calculated which is equal to the area of "ΔOAB"

$$\text{work done} = \text{Area of } \Delta AOB$$

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

$$\text{work done} = \frac{1}{2} F_1 \times I_1 \longrightarrow (1)$$

This work is stored in the wire as P.E. of molecules.

Work done in terms of modulus of

Elasticity:

Let.

A = Area of crossection of wire.

L = Total length of wire.

I_1 = Extension in the wire.

$$E = \frac{F_1/A}{I_1/L} = \frac{F_1 \times L}{I_1 \times A}$$

$$F_1 = \frac{EAI_1}{L} \longrightarrow (2)$$

Eq.(2) put in eq.(1)

$$W = \frac{1}{2} \cdot \frac{EAI_1}{L} \times I_1$$

$$W = \frac{1}{2}\left[\frac{EAI_1^2}{L}\right]$$

$$\text{Strain energy} = \frac{1}{2}\left[\frac{EAI_1^2}{L}\right]$$

In general. If extension $= I_1 = \Delta I$

Results:

★; Graphical method for finding out the work done is a general method. If extension increases from I_1 to I_2 then work done is equal to the area of trapezium "ABCD"

★; This method is also valid for both linear and non-linear.

17.3 Electrical Properties of Solids

1): Conductors:

These solids have high conductivities of the order of $10^7 (\Omega m)^{-1}$.

Examples:

Copper, Gold, Aluminium.

2): Insulators:

These solids have very low conductivities ranging between 10^{-10} to $10^{-20} (\Omega m)^{-1}$.

Examples:

Wood, diamond.

3): Semiconductors:

These solids have intermediate conductivities, generally from 10^{-6} to $10^{-4} (\Omega m)^{-1}$.

Examples:

Silicon, Germanium etc.

Free electron theory based on the Bohr model failed to explain the electrical behaviour of solids.

Energy band Theory based on wave mechanical model successfully explained all the features.

Energy band theory of solids

Formation of energy bands:

Electrons of an isolated atom are bound to the nucleus and can only have distinct energy levels. However when a large number of atoms say "N" are brought closer to one another to from a solid, then each energy level splits into "N" sub_levels, These sub_levels are called Permissible energy states.

These are so closely spaced that they appear to form a continuous energy band called Permissible energy bands.

Types of energy Band

1): Forbidden energy band or band gap:

In between two consecutive permissible energy band, there is an energy gap which cannot be occupied by electrons. This is called Forbidden energy band.

2): Valance Band:

It is the band which is occupied by the valance electrons. Valance electrons are those electrons which are present in the outermost shell of the atom. It may be partially filled or completel filled with valance electrons but never empty.

3): Conduction Band:

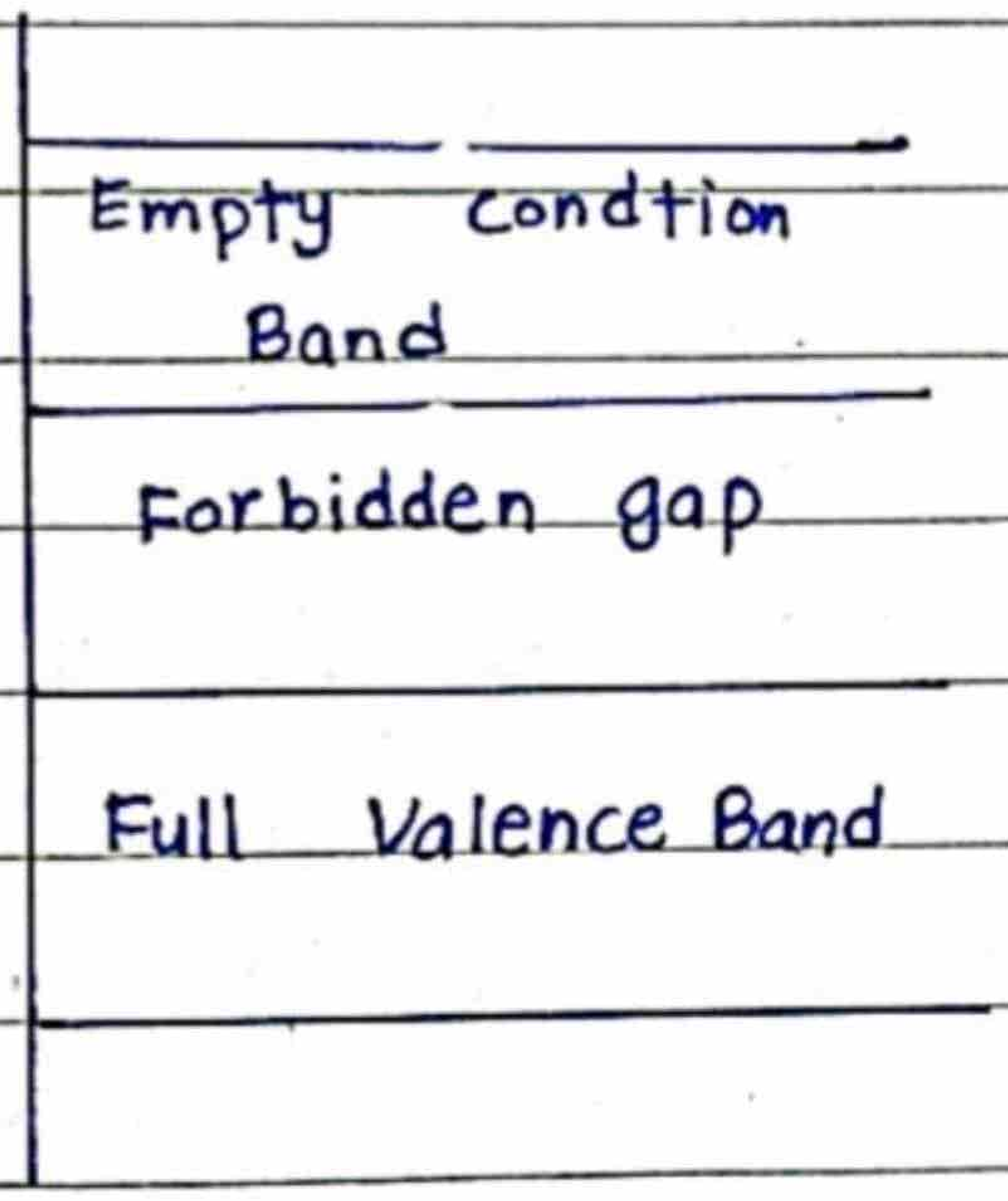
The band above the valance band is called conduction band. It may be empty or partially filled with conduction electrons.

Difference between Insulators, conductors and semiconductors on the basis of band theory:

1): Insulators:

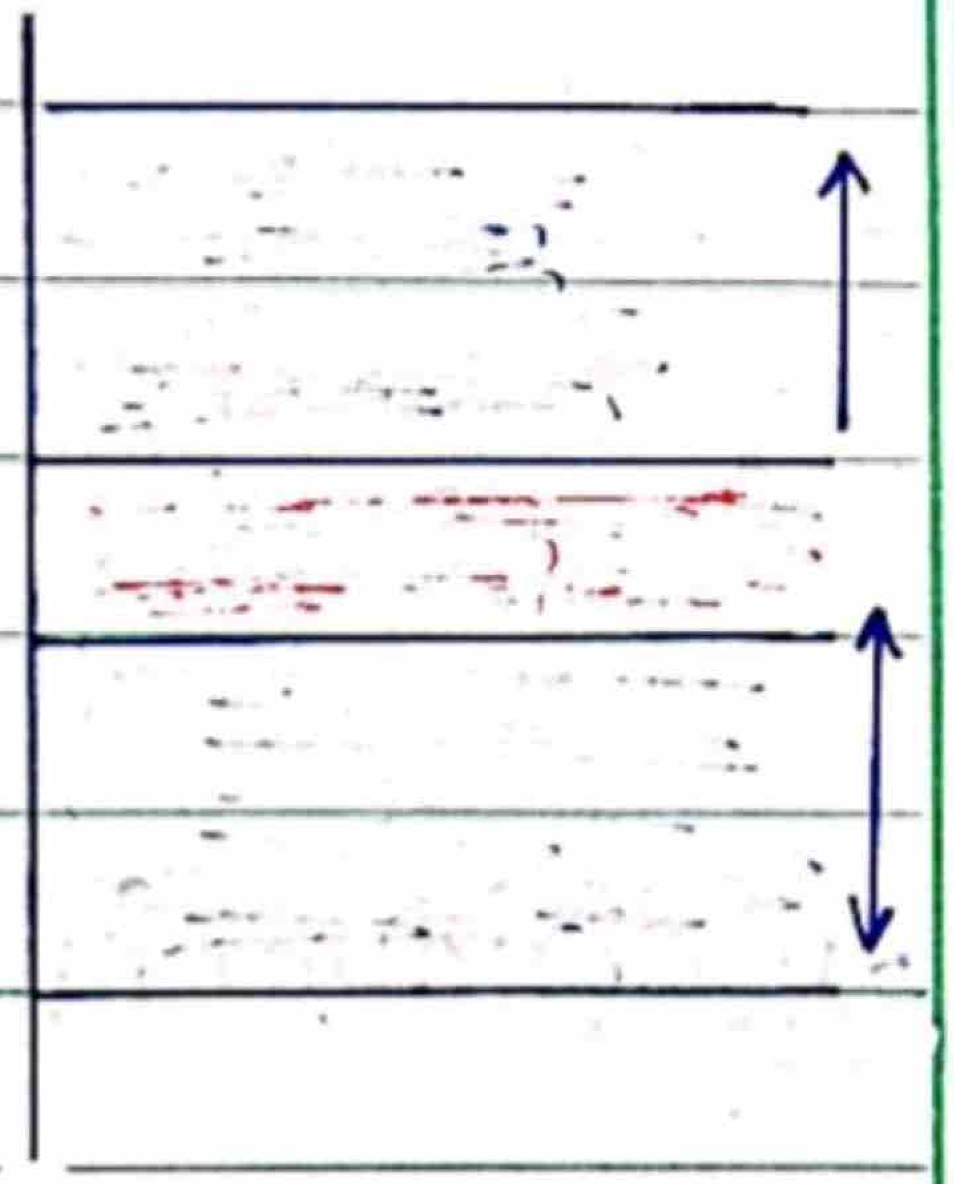
In insulators valance electrons are very tightly bound to their atoms and are not free.

In insulators valence band is full, and empty



conduction band, A large forbidden energy gap between conduction band and valance band.

2): Conductors:

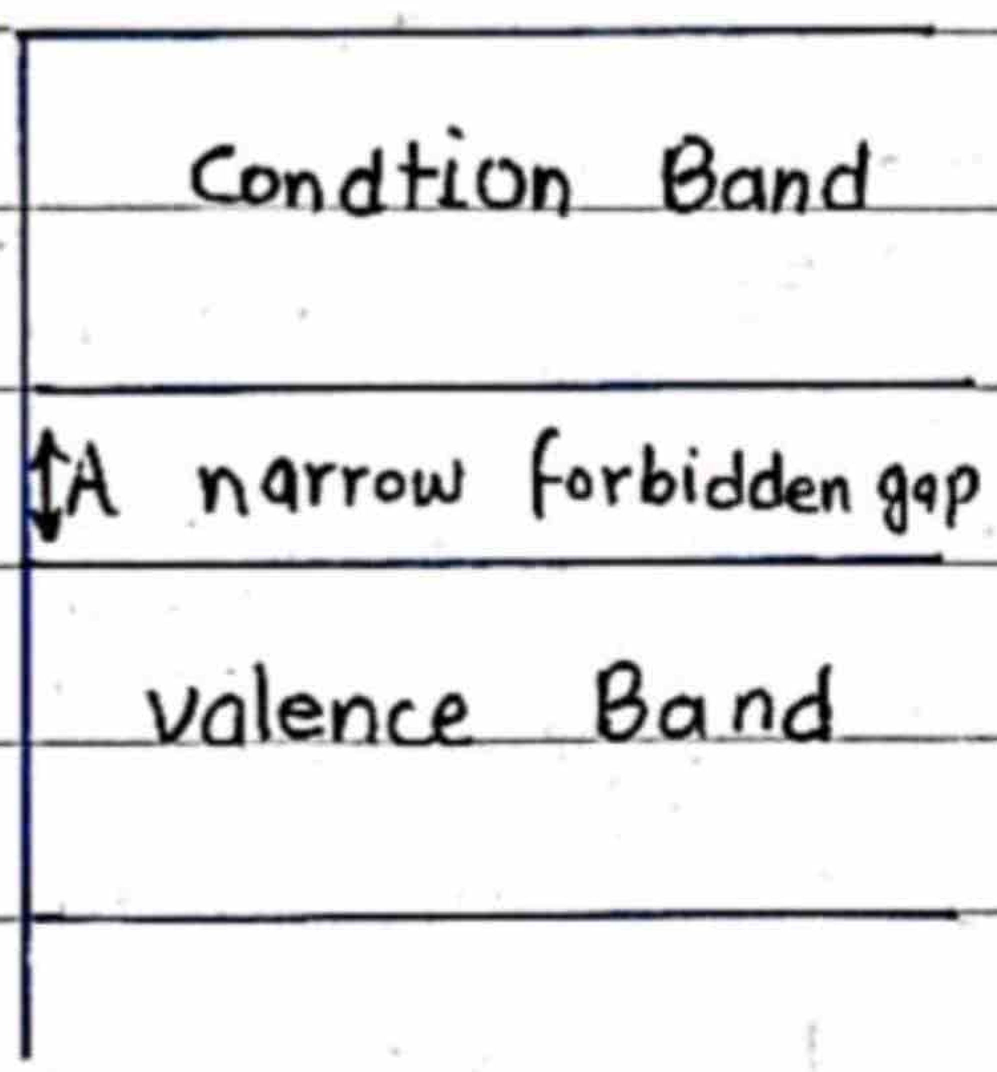


In case of conductors the forbidden energy gap does not exist and there is overlaping of valance and conduction bands. There are large number of free electrons and easy flow of current.

In conductors conduction band is partially filled, and valance band is partially filled.

3): Semiconductors:

In semiconductors there is a narrow forbidden energy gap between the conduction band and valance band. At room temperature some electrons may jump from the valance band to the conduction band.



Semiconductors such as Ge, si are insulators at 0 K and the conduction band is empty, valance band is completely filled. In semiconductors, conduction bond is partially filled, valance bond is partially filled and narrow forbidden energy gap between valance and conduction band.

Intrinsic and Extrinsic semiconductors

There are two types of semiconductors.

1): Intrinsic Semiconductors:

A semiconductor in its pure form is called intrinsic semiconductors.

Composition and structure:

Pure elemental silicon "Si" and Germonium "Ge" are intrinsic semiconductors. Each atom has four valance electrons. In solid crystalline form, the atoms of these elements arrange themselves in such a pattern that each atom has four equidistant neighbour.

Each atom with its four valance electrons share an electron from its 4-neighbouring atoms. So each atom has 8 electrons in

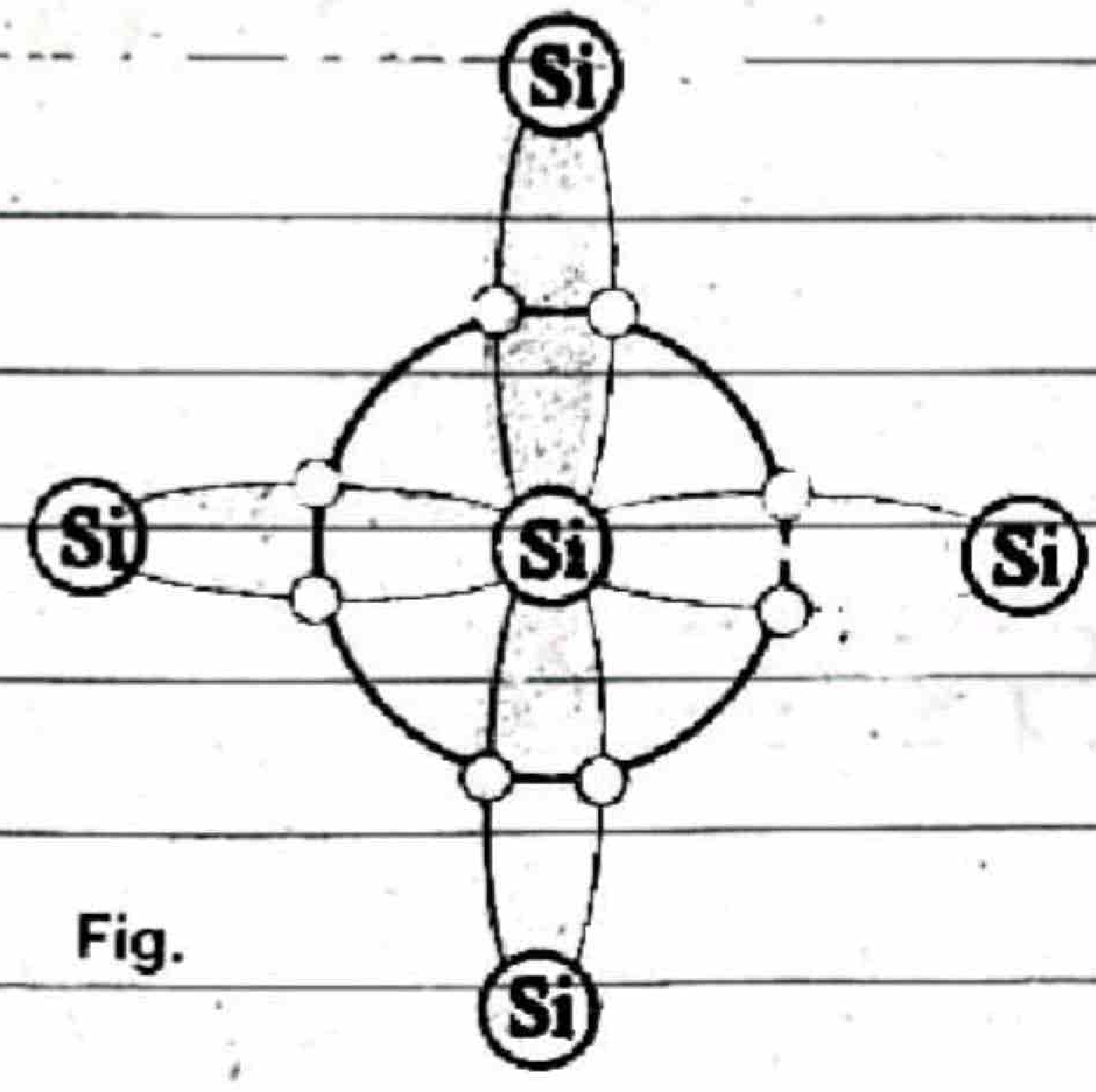


Fig.

the outermost shell, which is a stable state. This sharing of electrons between two atoms covalent bonds. Due to these covalent bonds, electrons are bound in their respective shells.

2): Extrinsic Semiconductors:

"These semiconductors are obtained by adding impurities to pure semiconductors."

Doping:

"It is the process in which a small amount of impurity is added to an intrinsic semiconductor and its electrical behaviour is changed."

Atoms are added in the ratio of $1:10^6$.

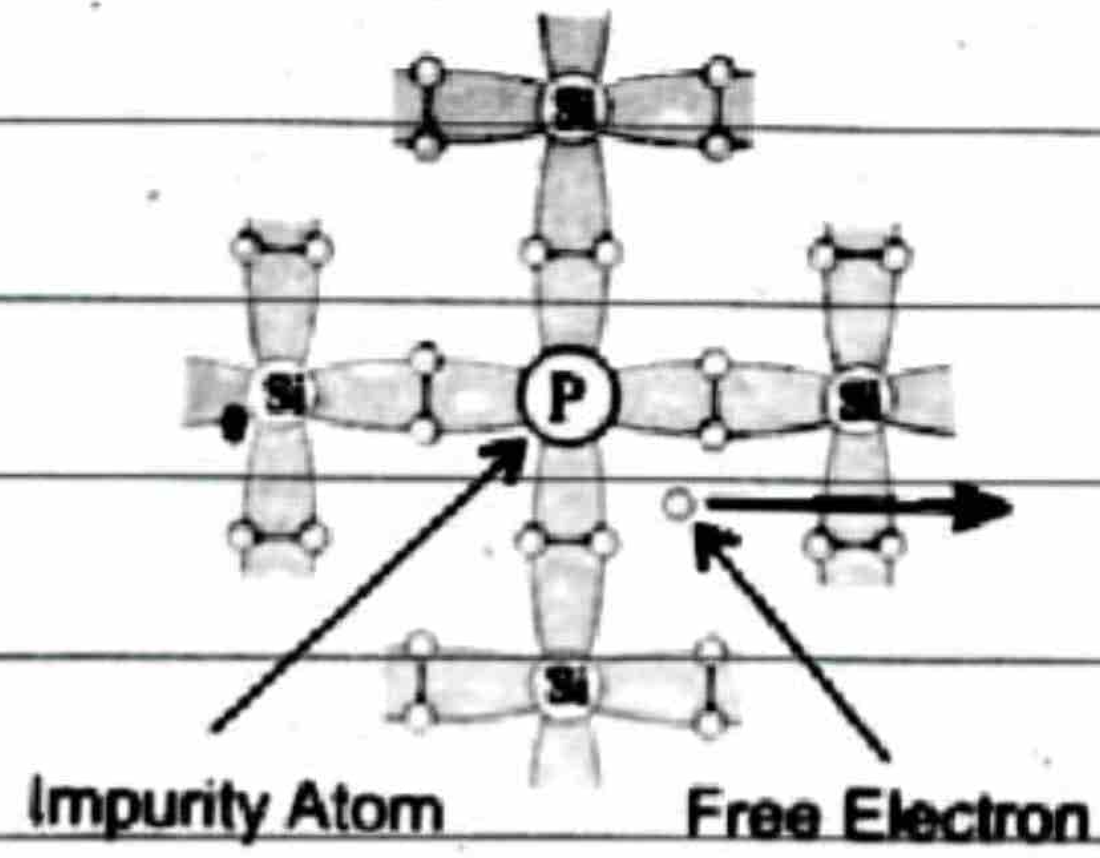
Types of Extrinsic semiconductors:

1): N-Type semiconductor:

"N-type semiconductor is obtained by doping pure Si or Ge with a pentavalent element."

Explanation:

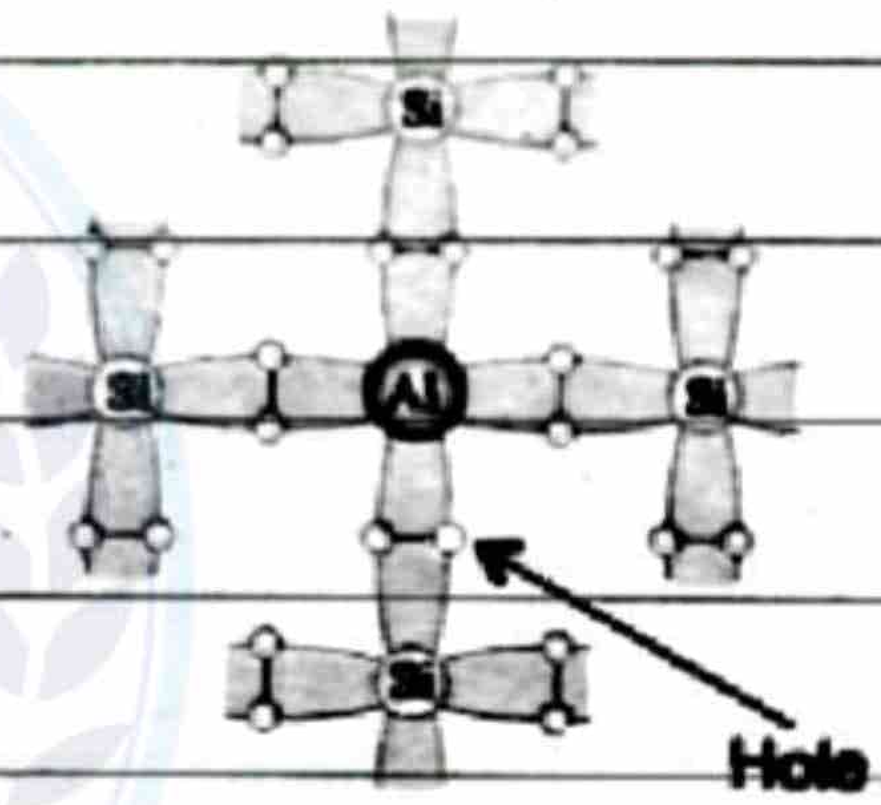
When a silicon Si crystal is doped with a pentavalent element four arsenic, antimony, phosphorous). Valonce electrons of the impurity atom form covalent bonds with four neighbouring Si atoms, while the fifth valance electron provides a free electron in the crystal.



(a)

Figure shows silicon crystal lattice doped with a pentavalent impurity such as phosphorous.

The phosphorous atom is called a donor atom because it donates a free electron which is thermally excited into the conduction band.



(b)

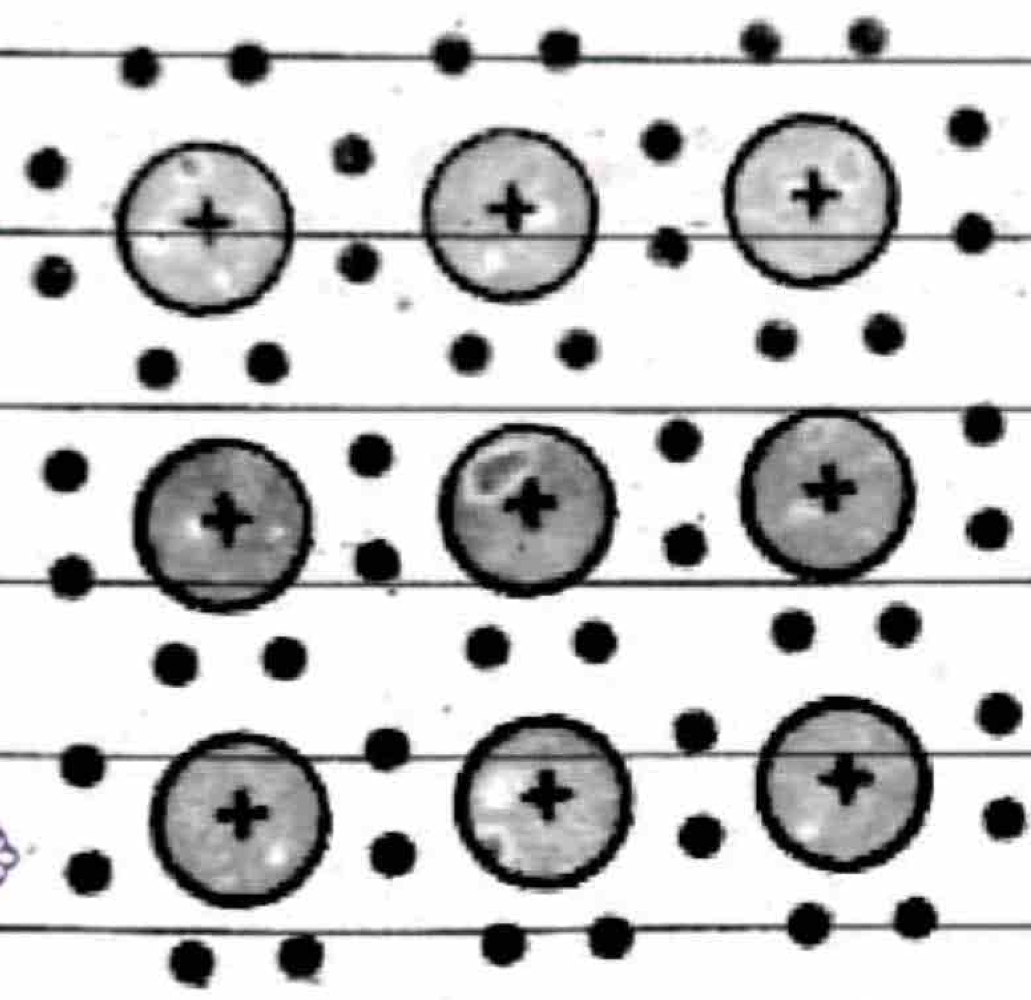
"Here phosphorous atom is called a Dopant."

2) P-type semiconductor:

"It is obtained by doping pure Si or Ge with a trivalent element."

Explanation:

When a silicon crystal is doped with a trivalent element (boron,



aluminium, gallium, indium etc). There valance electrons of the impurity atom from covalent bonds with the three neighbouring Si atoms, then in the fourth covalent bond, there is a vacancy of an electron.

This vacancy of an electron is called a Hole.

Figure shows silicon crystal lattice doped with aluminium Al. "The aluminum atom is called an Acceptor" atom because it is easy for an Aluminium ion core to accept a valance electron from a silicon atom producing a hole in valance bond.

Hole:

A vacancy of an electron in a bond is called a Hole. When an electron breaks away from a covalent bond, it leaves behind a vacant state which serves as a positive charge carrier. So "hole is a positive charge carrier."

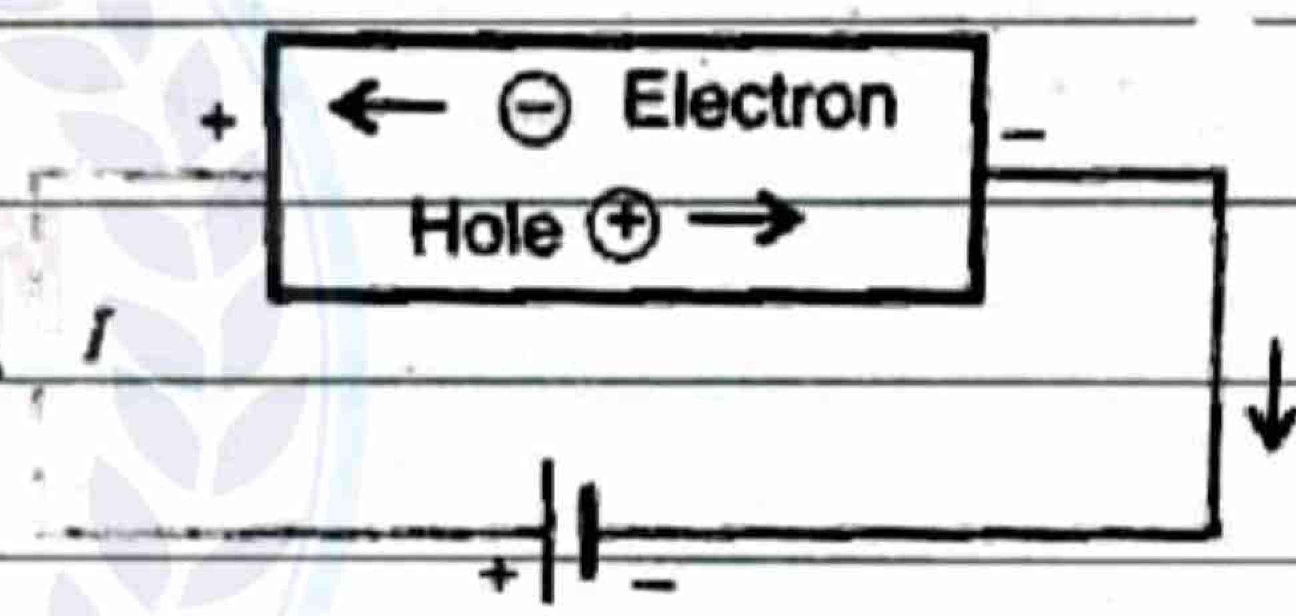
17.4 Superconductors

"The materials whose resistivity becomes zero below a certain temperature."

"Superconductors are alloys that at a certain temperature conduct electricity with no resistance." This is why they are called perfect conductors.

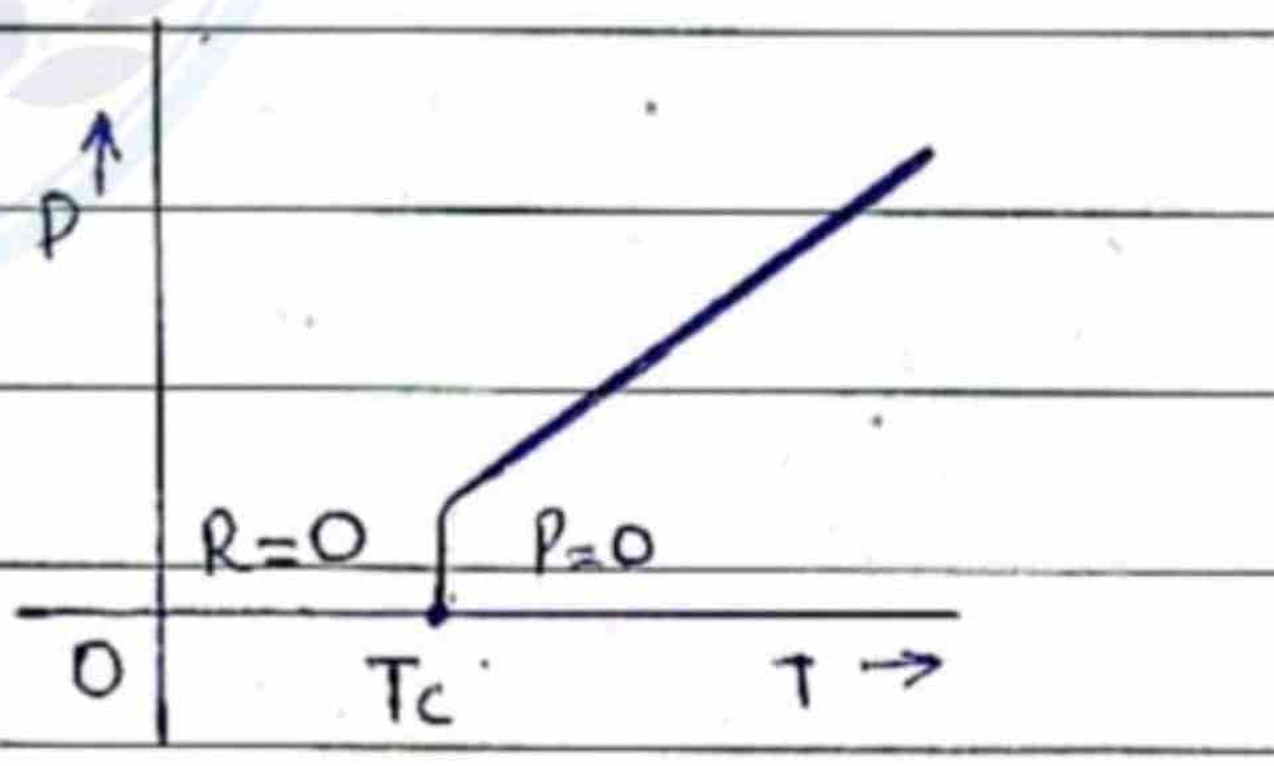
No energy dissipation in Superconductors:

In superconductors no energy is dissipated and hence once current is supplied by a source of "emf", then current continues to exist indefinitely with out source of emf (i.e. battery).



Critical temperature T_c:

"Certain temperature below which a material becomes superconductor is called critical temperature." It is shown fig.



Types of superconductors:

These are two types of superconductors

i): Low temperature superconductor.

ii): High temperature superconductor.

i): Low temperature superconductor:

The first superconductor was discovered in 1911 by Kmaerlingh Ornes when it was observed that electrical resistance of mercury disappears suddenly as the temperature is reduced below 4.2 K. Some other materials such as aluminium $T_c = 1.18\,K$, tin $T_c = 3.72\,K$ and lead $T_c = 7.2\,K$ also become superconductors at very low temperatures.

ii): High temperature superconductor:

"Any superconductor with a critical temperature above 77K is called a High temperature superconductor."

In 1986, a new class of ceramic materials was discovered that becomes superconductor even at high temperature 125K recently Prof. Yao Lian's Lee at Cambridge university discovered that complex crystalline structure known as Yttrium barium copper oxide ($YBa_2cu_3O_7$) become superconductor at 163 K or 110°C.

Perhaps one day room temperature superconductor will be developed and that day will be a new revolution in electrical technologies.

Applications:

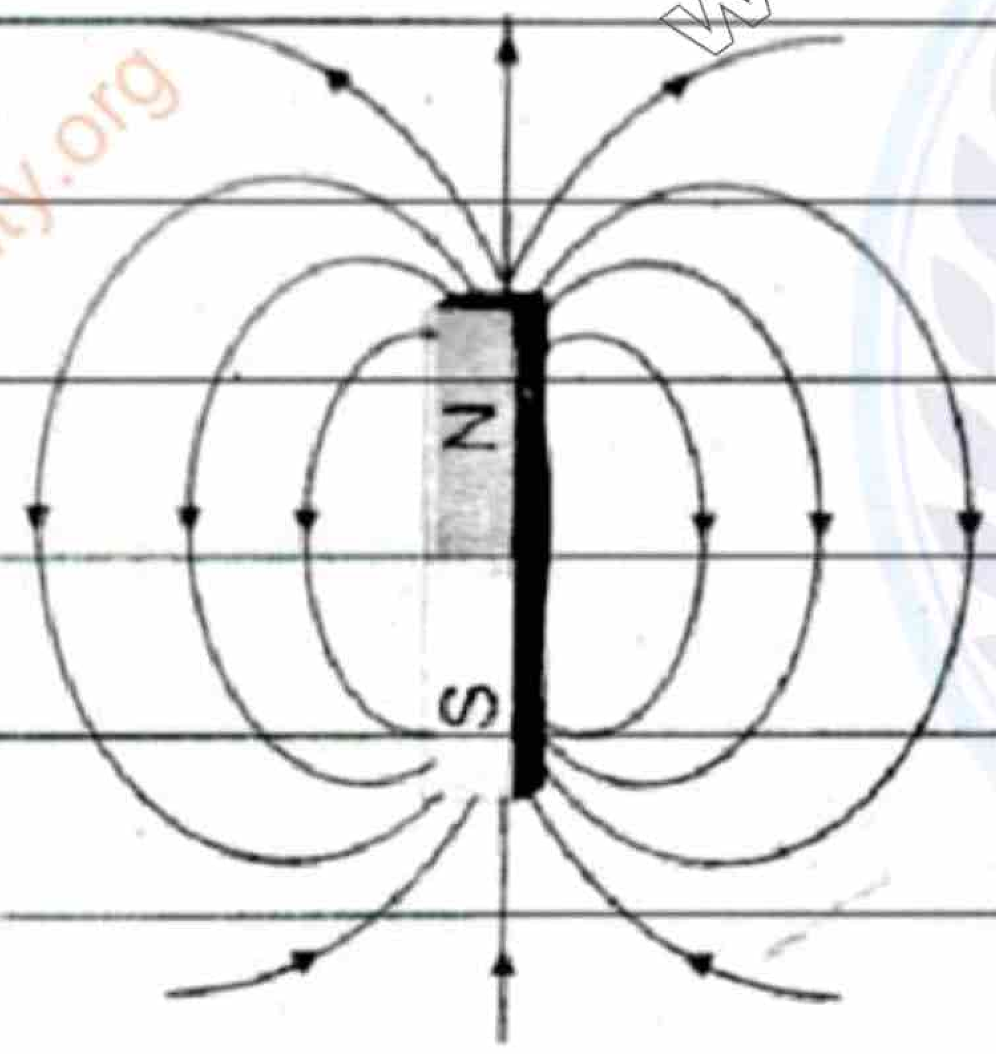
Superconductors have many technological applications such as in.

1): Magnetic resonance imaging (MRI)
2): Powerful and small electric motors.
3): Fast computer chips.
4): Magnetic lavitation trains.

17.5 Magnetic Properties of Solids

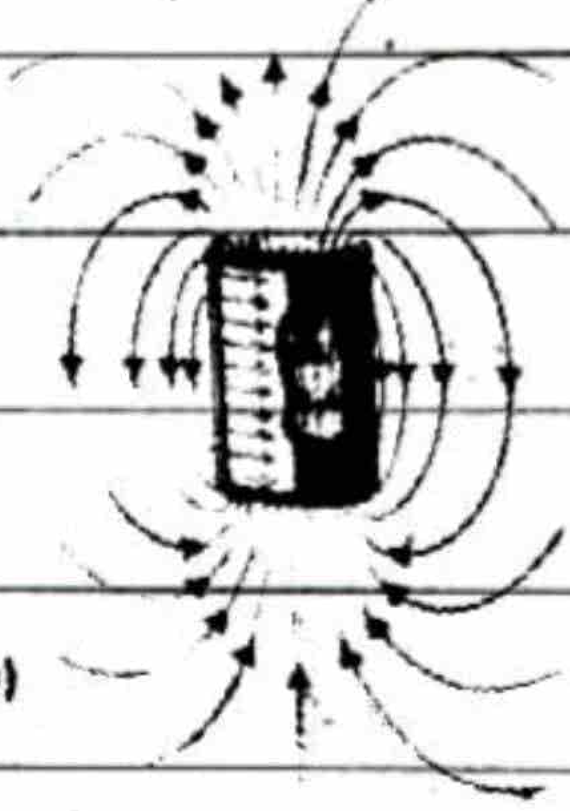
Origin of Magnetism

The field of a long bar magnet is same as that of produced by a long current corring solenoid Fig (a) and Fig (b)



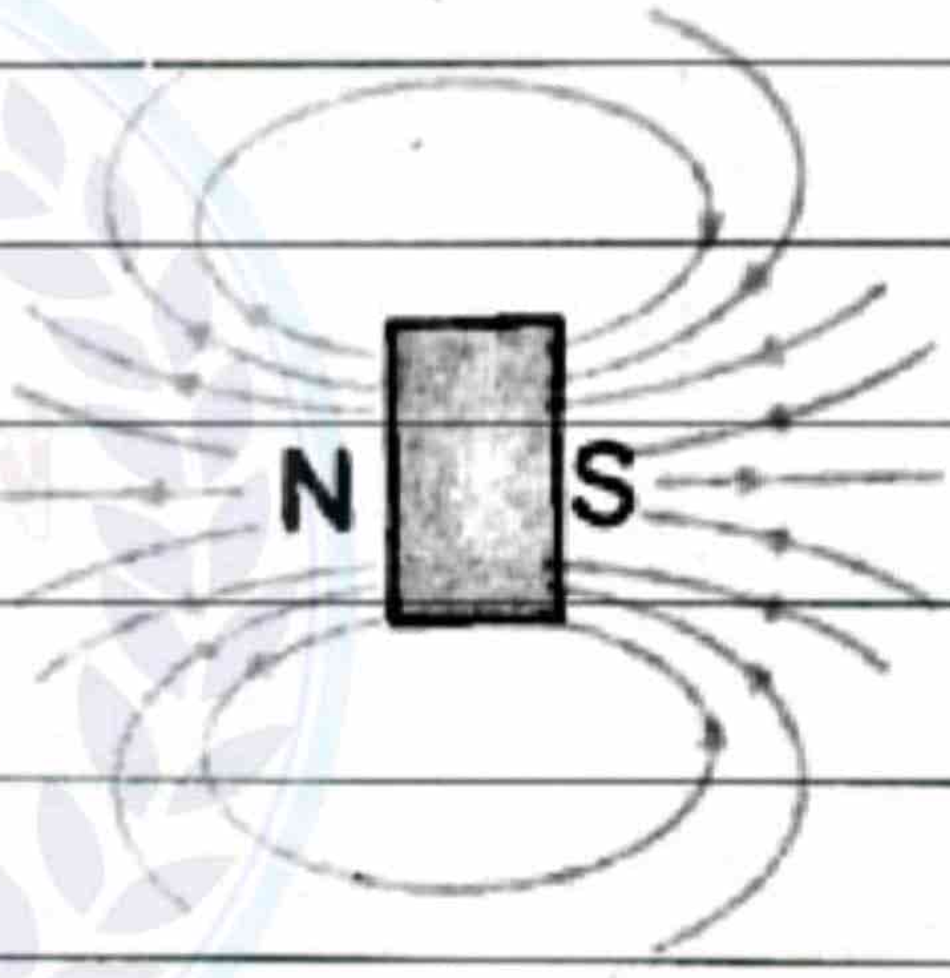
Long Bar magnet

(a)



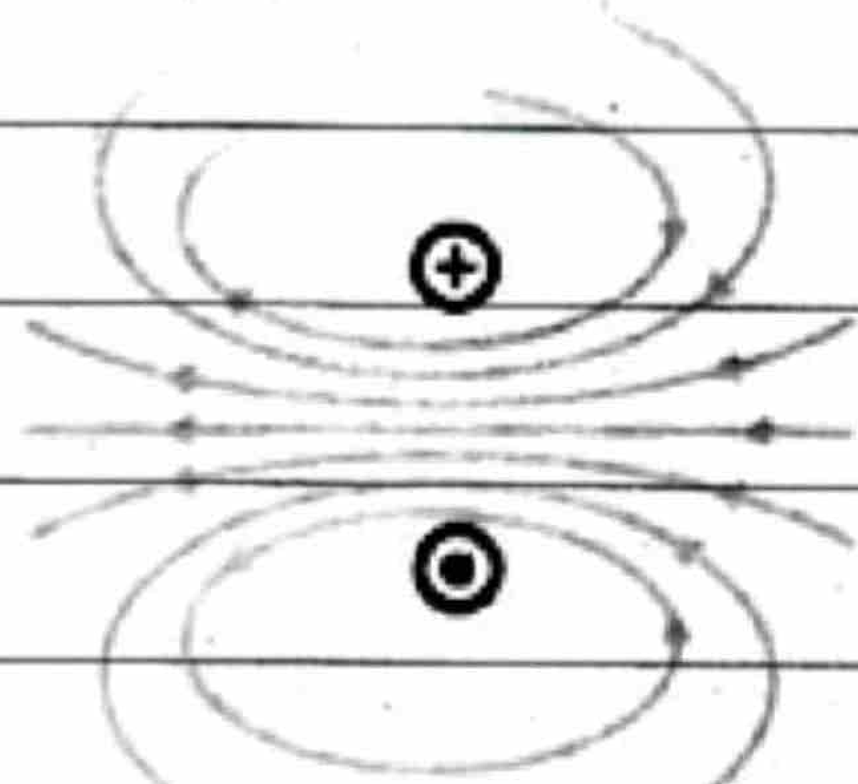
(b)

Solenoid



Bar magnet

(c)



(d)

Magnet field of a current loop

The field of a short barmagnet is like that of a signal current corring loop. Fig (c) and (d)

This similarity between the fields produced by magnets and currents gives the idea that all the magnetic effects may be due to moving charges.

This view was first given by Ampere. The idea was not given due importance at that time because the structure of atom was not known at that time.

Amperes view appears to be basically correct after the discovery of structure of atom.

Magnetism by Electrons:

The magnetism produced by electrons within an atom may be due to two motions

(i) Orbital Motion (ii) Spin Motion

i) Orbital Motion of Electrons:

Each Electrons orbiting the nucleus behaves Like an atomic sized loop of current that produces a small magnetic field. This situation is similar to the field created by the current loop in fig (d)

ii) Spin Motion of Electrons:

Each electron posses a spin that also produces magnetic field.

Thus magnetism is due to spin and orbital motion of electrons surrounding the nucleus and is a property of all substances.

Explanation:

The net magnetic field produced by the electrons within the atom is due to the combined field produced by their orbital and spin motions.

Since there are a number of electrons in an atom, there current or spins may be so oriented as to cancel the magnetic effects or support the effect of each other.

Magnetic Dipole:

"An atom in which there is a resultant magnetic field due to strengthening of magnetic fields, behaves like a tiny magnet and is called a Magnetic dipole."

Magnetic fields of

the atoms are responsible for the magnetic behaviour of the substances made up of these atoms.

Charged nucleus:

The magnetic field produced by the positively charged nucleus is negligible as compared to the fields of electrons orbiting around the nucleus.

Source of Magnetism of an atom is electrons.

Isolated North Pole:

Isolated North Pole cannot be obtained.

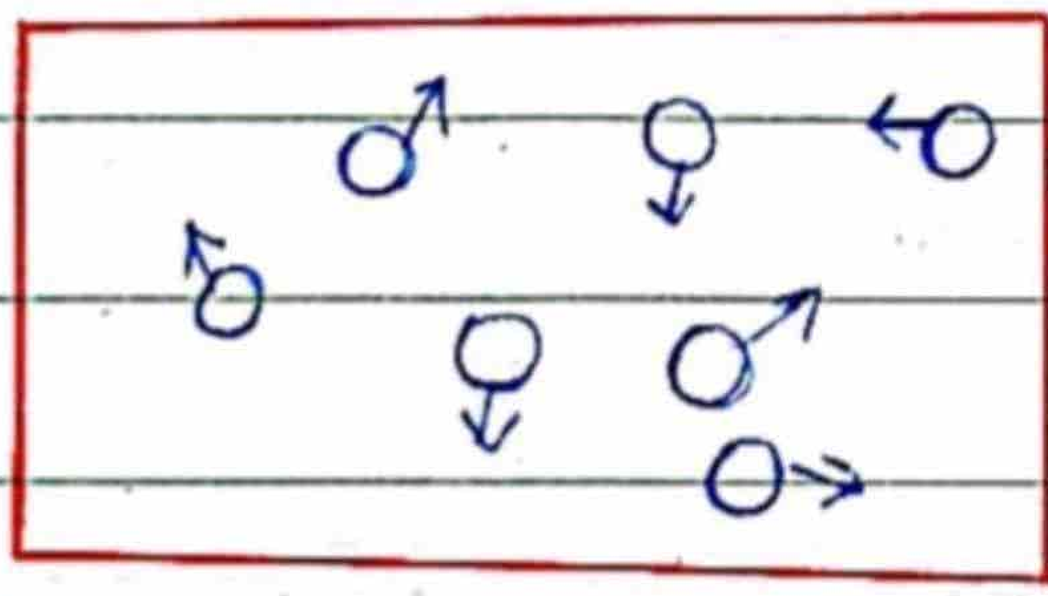
As the magnetic field is considered to be produced by current Loops and the 'North Pole' is merely one side of a current Loop, so the other side will always be present as a 'South Pole'. Hence the two poles of a magnet cannot be seperated.

Magnetic Classification of Solids

Paramagnetic Substances:

In these substances the orbits and spin axis of the electrons in an atom are so oriented that their fields support each other. Hence an atom behave like a tiny magnet. However the magnetic fields of different atoms do not support each other.

Example's:



Platinum, Ozone.

2. Dimagnetic Substances:

In these substances magnetic fields due to spin and orbital motion of electrons add up to zero and the individual atoms do not behave as magnets.

Examples:

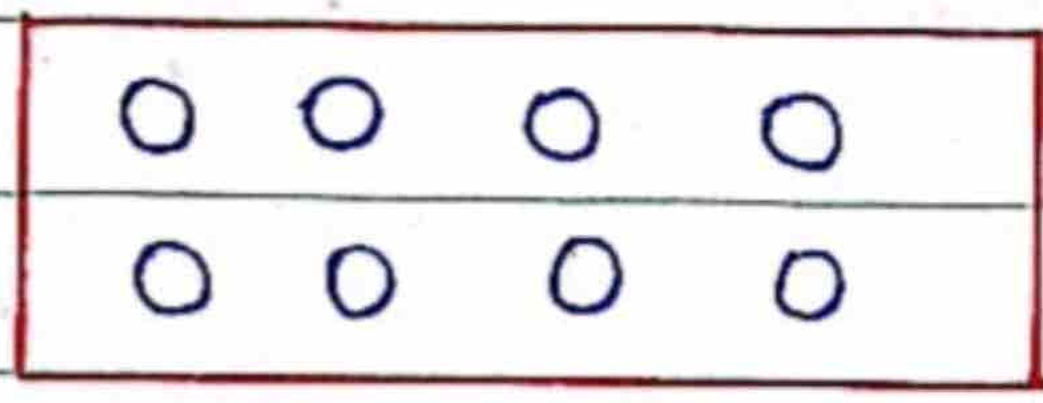
Water, copper, Bismuth, antimony.

3. Ferromagnetic Substances:

In these Substances atoms cooperate with each other in such a way so as to exhibit a strong magnetic effect.

Examples:

Water, copper, Bismuth, antmony.



3. Ferromagnetic Substances:

In these substances atoms cooperate with each other in such a way so as to exhibit a strong magnetic effect.

Examples:

Iron, Nickle, Cobalt, (Fe, Ni, Co) Chromium Oxide and AlNiCo (An iron, aluminium, nickle, Cobaltally)

Ferromagnetic Materials are of great interest for electrical Engineers.

Domain Theory for Ferromagnetic Substance:

Small regions in which atoms cooperate with each other in such a way to give a strong magnetic effect in ferromagnetic substances are called magnetic domains.

Magnetic domains are of

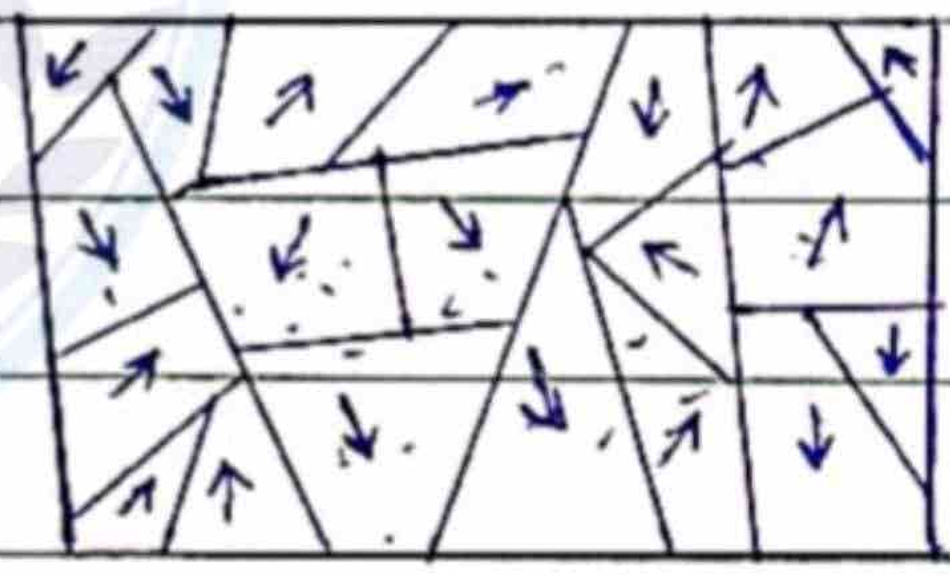
macroscopic size of the order of millimeters or less but Large enough to contain.

10^{12} to 10^{16} atoms:

Within each domain the magnetic fields of all the spining electrons are parallel to one another. Each domain behaves as a small magnet with its own north and south poles.

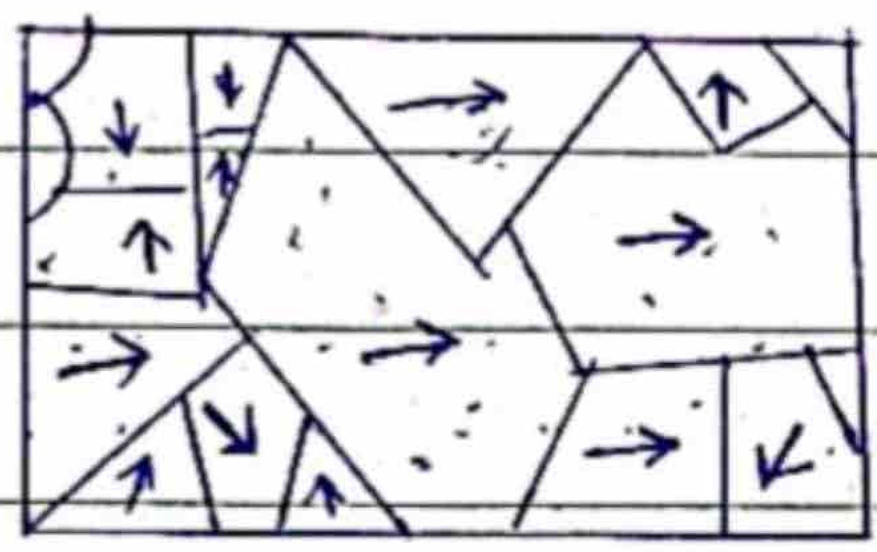
Electromagnet:

In an unmagnetised iron the doimans are in random directions, Fig(a) and the net magnetic field is zero.



Magnetic domains Within an unmagnetized Ferromagnet

When the iron piece is placed in an external magnetic field as that of a solenoid, the domains Line up parallel to the magnetic lines of external magnetic Fig (b)



field and the specimen get saturated. The combination of a solenoid and a specimen of iron inside it makes a powerful magnet called an electromagnet.

Classification of Ferromagnetic Material

1- Soft Magnetic Materials:

"Domains can easily ordered and disordered are called Soft Magnetic Materials."

Example:

Iron is a Soft Magnetic Material.

Use:

It is used in electromagnets and also in transformer cores.

2. Hard Magnetic Materials:

"Domains cannot easily ordered and disordered are called Hard Magnetic Materials."

Example:

Steel, Alnico V alloy.

Use:

These materials are used for making Permanenet Magnets.

Effect of Temperature on Ferromagnetic Materials:

Thermal vibrations tend to disturb the orderliness of the domains in ferromagnetic substances. Ferromagnetic materials preserve the orderliness at ordinary temperatures.

When heated they begin in to lose their orderliness due to increased thermal motion. This process begin to occur at a particular temperature (different for different materials) called Curi temperature.

Curi Temperature:

At this temperature ferromagnetism disappears and the Substance becomes paramagnetic.

For iron:

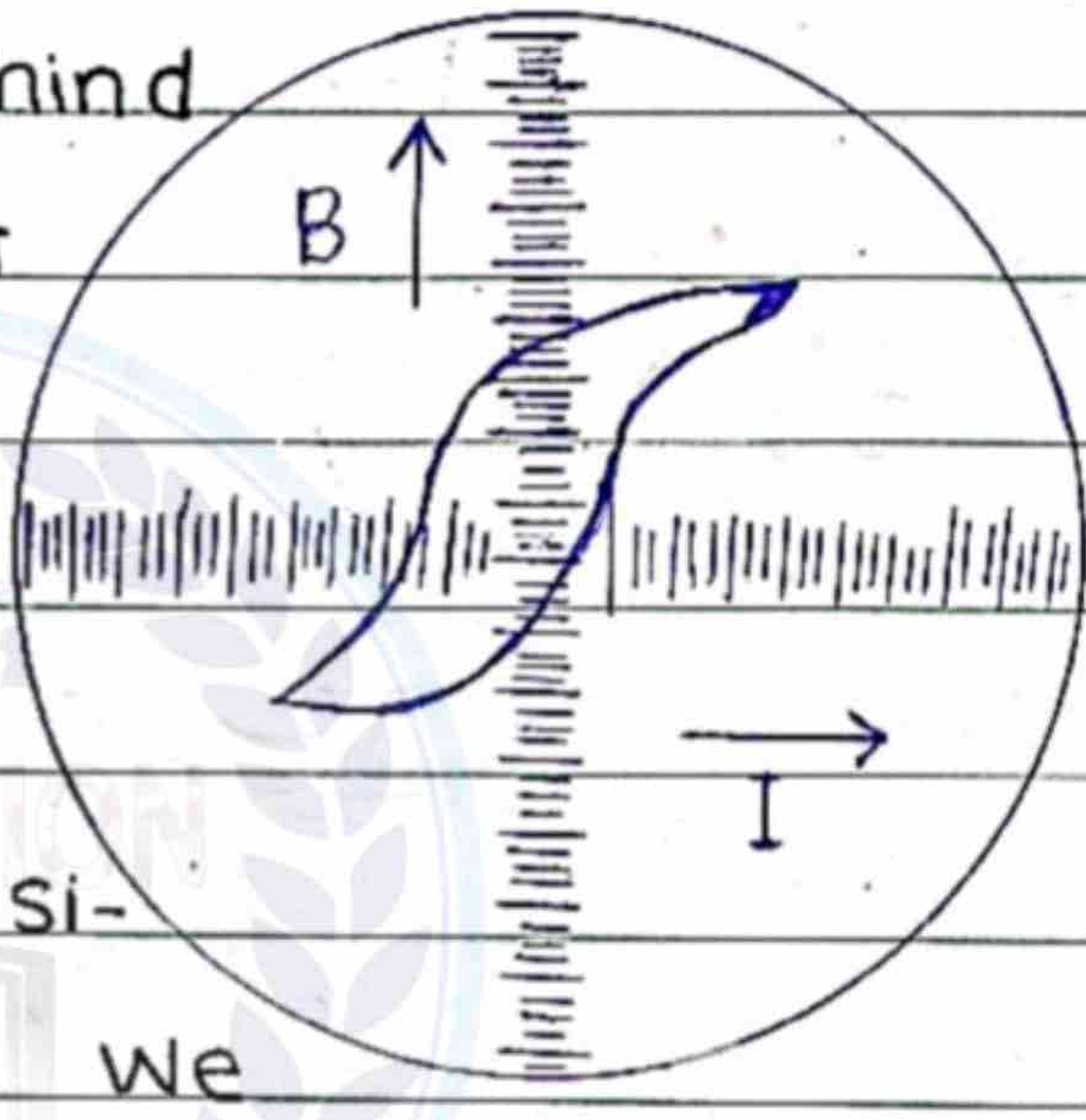
Curi Temperature = 750°C

" Above curi temperature iron is a paramagnetic but not Ferromagnetic."

Hysteresis Loop

Hysteresis:

The phenomenon in which magnetism Lags behind the magnetizing current is called Hysteresis.



Hysteresis Loop:

Hysteresis Loop is formed when we plote a graph between "magnetic flux density B" and the 'magnetizing current I.'

Use:

It object is to give us information about the different magnetic properties of ferromagnetic materials.

Explanation:

A bar of iron is placed inside alterternating current is flowing. When the alternating current at its positive peak value, it fully magnetises the iron core in one direction. When the current is at its negative peak it fully magnetises the it in opposite direction.

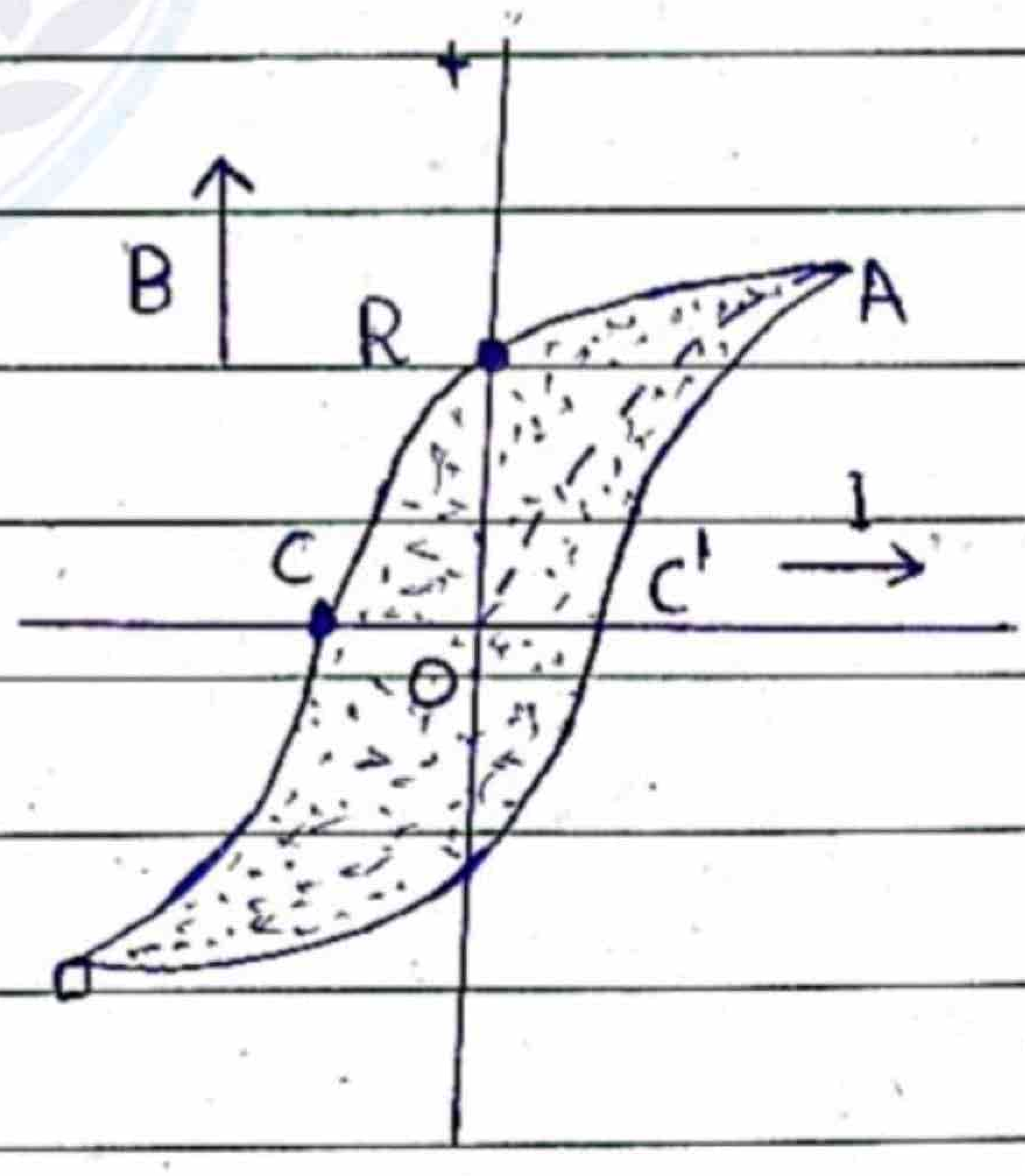
Thus as one cycle of AC is completed, then at the same time specimen (iron core) completes one cycle of magnetization.

The graph between magnetic flux density B and the magnetizing current I is plotted by CRO.

Main Features

1. Hysteresis:

The portion OA on the graph is obtained when the current I is increased. AR is the portion when I is decreased.

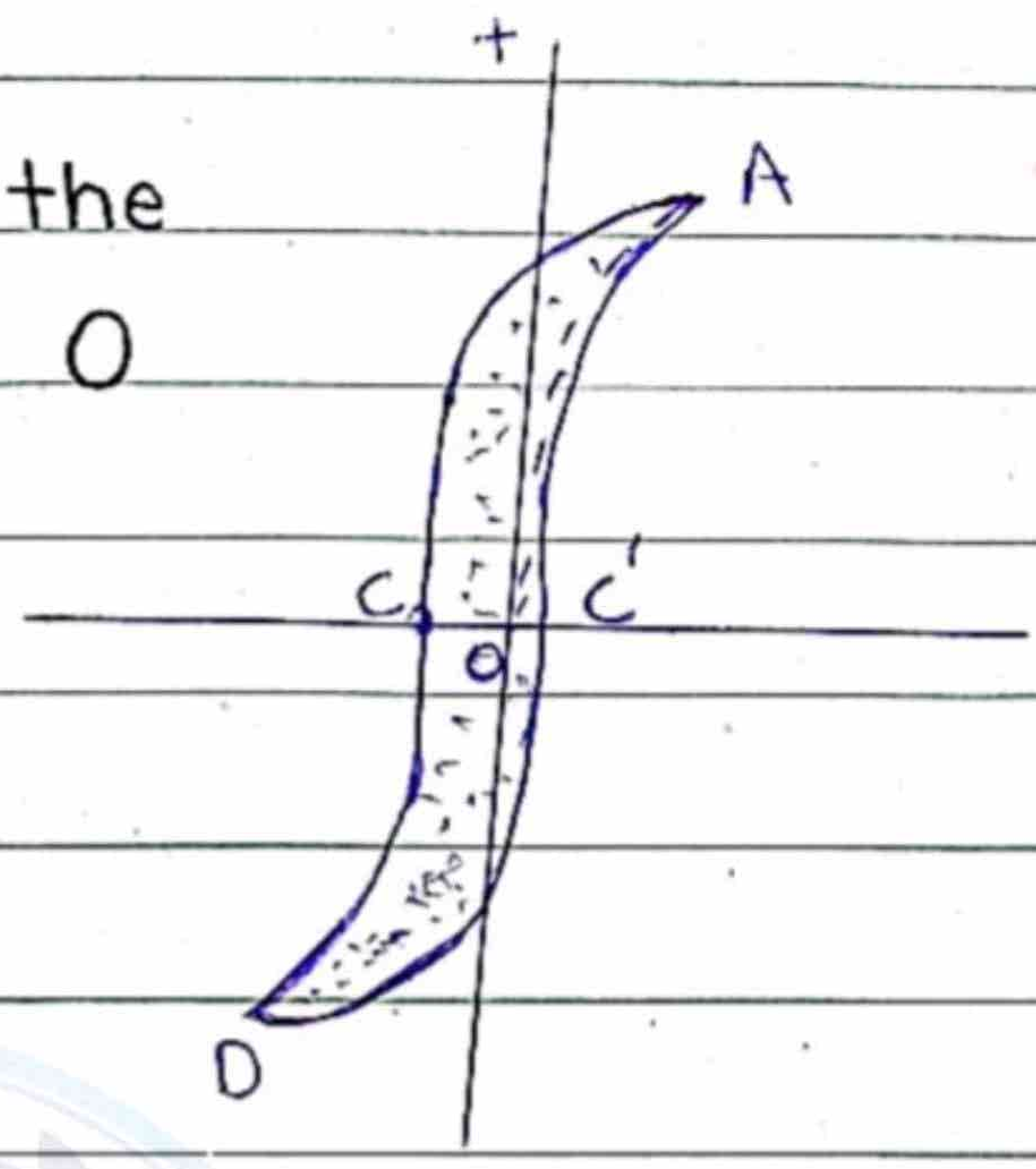


It is observed from the graph that (a) Hysteresis loop value of magnetic flux of steel density B for any value of current I is always greater when current is decreasing.

Hence B lags behind I

2. Saturation:

A. When the current is increased from O to maximum value, the magnetic flux density B reaches the maximum value. The material is said to be magnetically saturated. It is point A on the curve.



(b) Hysteresis loop of soft iron

OR = Retentivity

OC = Coercivity

3. Permanance OR Retantivity 'R':

When the current reduces to zero, the material still remain strongly magnetized. B is not zero. This is represented by the point R on the curve. It is due to the tendency of domains to stay partly in line once they have been aligned.

4. Coercivity 'c':

To demagnetize the

material, reversed and increased to make the magnetize to zero.

The reverse current at which the magnetization becomes equal to zero (B = 0) is called coercive current.

It is represented by point C on the curve. This property is called coercivity and is represented by OC on the graph.

The coercivity of steel is more than that of iron as more current is needed to demagnetize it.

Note that when the material is once magnetised, its magnetization curve never passes through the origin. Instead it forms a closed loop ACDC'A which is called Hysteresis Loop.

5- Area of the Hysteresis loop:

The area of the loop is a measure of the energy needed to magnetize and demagnetize a specimen during each AC cycle. This energy is used to do work against internal friction, of the domains. This work is dissipated as heat. It is called Hysteresis loss.

i Hard magnetic materials like steel cannot be easily magnetized or demagnetized. So they have large loop area.

ii Soft magnetic materials like soft iron have smaller loop area.

Hence energy dissipated per cycle for iron is less than for steel.

Suitability of magnetic Materials can be stuided by taking the specimen through a complete cycle and drawing the Hystresis loop.

Permanent Magnet:

A meterial with high retentivity and large coercivity is most suitable for making a permanent Magnet. It has a large loop area.

Cores of Electromagnets used for alternating currents should have narrows Hyteresis curve of small area, to minimize the waste of energy.

Chapter = 17

Example

Example 17.1

Solution:

(a) As tensile stress $\sigma = \frac{F}{A}$

$$\frac{F}{A} = \frac{10{,}000\,N}{3.14 \times (6 \times 10^{-3}\,m)^2}$$

$$= 88.46 \times 10^{6}\,Nm^{-2}$$

$$\frac{F}{A} = 88.46\,MPa$$

(b) The tensil strain $\varepsilon = \frac{\Delta L}{L}$

also $E = \frac{\text{stress}}{\text{Strain}}$

$$= \frac{88.46 \times 10^{6}\,Nm^{-2}}{\text{Strain}}$$

$$= 200 \times 10^{9}\,Nm^{-2}$$

$$\text{Strain} = \frac{88.46 \times 10^{6}\ Nm^{-2}}{200 \times 10^{9}\ Nm^{-2}}$$

$$\text{Strain} = 4.4 \times 10^{-4}$$

(c) Now using the relation strain $= \frac{\Delta L}{L}$

We get

$$\Delta l = 4.4 \times 10^{-4} \times 11\,m$$

$$\Delta L = 4.84 \times 10^{-3}\,m$$

$$\Delta L = 4.84\,mm$$

Chapter = 17

Problems

Problem 17.1

Solution:

$d = 1.25\ cm$

$d = 1.25 \times 10^{-2} m$

$r = \frac{d}{2}$

$r = \frac{1.25 \times 10^{-2}}{2}$

$r = 6.25 \times 10^{-3} m$

$m = 2500 kg$

Strees $\sigma = ?$

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

$= \frac{\omega}{\pi r^2}$

$$\sigma = \frac{mg}{\pi r^2}$$

$$\sigma = \frac{2500 \times 9.8}{3.14 \times (6.25 \times 10^{-3})^2}$$

$$\sigma = 1.997 \times 10^{8} \text{ pa}$$

$$\sigma = 199.7 \times 10^{6} \text{ P}$$

$$\sigma = 200 \times 10^{6} \text{ pa}$$

Strees = 200 MPa

Problem 17.2

Solution:

$$L = 1.0 \text{m}$$

$$\Delta L = 20 \text{cm}$$

$$\Delta L = \frac{20}{100} \text{ m}$$

$$\Delta L = 0.20 \text{m}$$

Tensile strain ε = ?

Percentage elongation = ?

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

$$= \frac{0.2}{1}$$

$$= 0.2$$

$$\text{Percentage elongation} = \frac{\Delta L}{L} \times 100\%$$

$$= \frac{0.2}{1} \times 100\%$$

Percentage ..... = 20%

Problem 17.3

Solution:

$L = 2.5\ m$

$A = 10^{-5}\ m^2$

$\Delta L = 1.5\ mm$

$\Delta L = 1.5 \times 10^{-3}\ m$

$F = 100N$

i Tensile strain $\varepsilon = ?$

ii Youngs modulus $= Y = ?$

iii Energy stored $= ?$

i
$$\varepsilon = \frac{\Delta L}{L}$$

$$\varepsilon = \frac{1.5 \times 10^{-3}}{2.5}$$

$$\varepsilon = 6 \times 10^{-4}$$

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

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

$$Y = \frac{100 \times 2.5}{1 \times 10^{-5} \times 1.5 \times 10^{-3}}$$

$$Y = 1.66 \times 10^{10}\ Pa$$

iii
Energy stored $= \frac{1}{2} F \times \Delta L$

$$\text{Energy Stored} = \frac{1}{2} \times 100 \times 1.5 \times 10^{-3}$$

$$= 7.5 \times 10^{-2}\ J$$

$$\boxed{\text{Energy Stored} = 7.5 \times 10^{-2}\ J}$$

Problem 17.4

Solution:

$$\text{Stress } \sigma = ?$$

$$\% \frac{\Delta L}{L} = 0.01\%$$

$$\% \frac{\Delta L}{L} = \frac{0.01}{100}$$

$$\text{Strain} = 1.0 \times 10^{-4}$$

$$Y = 12 \times 10^{10}\ Pa$$

$$F = ?$$

$$d = 0.56\ mm$$

$$d = 0.56 \times 10^{-3}\ m$$

$$r = \frac{d}{2}$$

$$r = \frac{0.56 \times 10^{-3}}{2}$$

$$r = 2.8 \times 10^{-4}\ m$$

$$Y = \frac{Stress}{Strain}$$

$$Stress = Y \times strain$$

$$= 12 \times 10^{10} \times 1.0 \times 10^{-4}$$

$$= 12 \times 10^{6}\ Pa$$

$$Stress = 12\ MPa$$

$$Stress = \frac{F}{N}$$

$$F = Stress \times A$$

$$F = Stress \times \pi r^2$$

$$F = 12 \times 10^{6} \times 3.14 \times (2.8 \times 10^{-4})^2$$

$$F = 2.96 N$$

Problem 17.5

Solution:

$L = 1.0\,m$

$A = 0.03 \times 10^{-4}\ m^2$

$F = 100N$

$Y = 3.0 \times 10^{11}\ Nm^{-2}$

Work $W = ?$

$W = \frac{1}{2} F \times \Delta L \longrightarrow (1)$

$\Delta L = ?$

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

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

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

$\Delta L = \frac{100}{0.03 \times 10^{-4}} \times \frac{1}{3 \times 10^{11}}$

$\Delta L = 1.1 \times 10^{-4}$ m Put in eq (1)

$W = \frac{1}{2} \times 100 \times 1.11 \times 10^{-4}$

$W = 5.55 \times 10^{-3}$ J

$$W = 5.6 \times 10^{-3} \text{ J}$$

Problem 17.6

Solution:

For Copper wire:

$L_1 = 1.5$ m

$d_1 = 2$mm

$r_1 = \frac{d_1}{2}$

$= \frac{2\text{mm}}{2}$

$= 1$mm

$= 1 \times 10^{-3}$ m

strain $\varepsilon_1 = ?$

Young's Modulus $Y_1 = 1.2 \times 10^{11}$ Pa

For steel wire:

$L_1 = 1.5\,m$

$d_2 = 2\,mm$

$r^2 = \frac{d_2}{2}$

$r_2 = \frac{2\,mm}{2}$

$r_2 = 1\,mm$

$r_2 = 1 \times 10^{-3}\,m$

Youngs Modulus $Y_2 = 2.0 \times 10^{11}\,Pa$

Change in Length of steel wire $= \Delta L_2$

Final length of composite Wire $= 3.003\,m$

Total change in Length

$\Delta L = 3.003 - 3.0$

$= 0.003\,m$

Total change in Length =

$\Delta L = \Delta L_1 + \Delta L_2$

$\Delta L_2 = \Delta L - \Delta L_1$

$$\Delta L_2 = 0.003 - \Delta L_1$$

$$\varepsilon_1 = \frac{\Delta L_1}{L_1}$$

$$= \frac{\Delta L_1}{1.5}$$

$$\varepsilon_2 = \frac{\Delta L_2}{L_2}$$

$$\varepsilon_2 = \left[\frac{0.003 - \Delta L_1}{1.5}\right]$$

$$Y_1 = \frac{\sigma_1}{\varepsilon_1} \qquad \therefore \sigma_1 = Y_1 \varepsilon_1$$

$$Y_2 = \frac{\sigma_2}{\varepsilon_2} \qquad \therefore \sigma_2 = Y_2 \varepsilon_2$$

As stress is equal on both the wires, So

$$\sigma_1 = \sigma_2$$

$$Y_1 \times \varepsilon_1 = Y_2 \times \varepsilon_2$$

$$1.2 \times 10^{11} \times \frac{\Delta L_1}{1.5} = 2.0 \times 10^{11} \times \left[\frac{0.003 - \Delta L_1}{1.5}\right]$$

$$1.2 \times \Delta L_1 = 2\left[0.003 - \Delta L_1\right]$$

$$1.2 \times \Delta L_1 = 0.006 - 2\Delta L_1$$

$$1.2 \times L_1 + 2\Delta L_1 = 0.006$$

$$3.2\Delta L_1 = 0.006$$

$$\Delta L_1 = \frac{0.006}{3.2}$$

$$\Delta L_1 = 1.875 \times 10^{-3}\ m$$

$$\Delta L_2 = 0.003 - \Delta L_1$$

$$\Delta L_2 = 0.003 - 1.875 \times 10^{-3}$$

$$\Delta L_2 = 1.125 \times 10^{-3}\ m$$

$$\varepsilon_1 = \frac{\Delta L_1}{L_1}$$

$$\varepsilon_1 = \frac{1.875 \times 10^{-3}}{1.5}$$

$$\varepsilon_1 = 1.25 \times 10^{-3}$$

$$\varepsilon_2 = \left[\frac{0.003 - \Delta L_1}{1.5}\right]$$

$$\varepsilon_2 = \left[\frac{0.003 - 1.875 \times 10^{-3}}{1.5}\right]$$

$$\varepsilon_2 = 7.5 \times 10^{-4}$$

Force = F = ?

$$Y_1 = \frac{\text{stress}}{\text{Strain}}$$

$$Y_1 = \frac{F/A_1}{\frac{\Delta L_1}{L_1}}$$

$$Y_1 = \frac{F}{A_1} \times \frac{L_1}{\Delta L_1}$$

$$F = \frac{Y_1 \times A_1 \times \Delta L_1}{L_1}$$

$$F = \frac{Y_1 \pi r_1^2 \Delta L_1}{L_1}$$

$$F = \frac{1.2 \times 10^{11} \times 3.14 \times (1.0 \times 10^{-3})^2 \times 1.875 \times 10^{-3}}{1.5}$$

$$F = 471\,N$$