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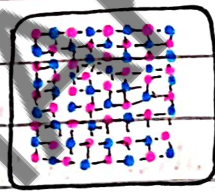
PHYSICS of SOLIDS

→ Classification of solids:
Solids are classified on the basis of atomic arrangement.

Diagrams

→ **Crystalline solids:** "Particles are arranged in a definite geometric pattern in three dimensional network. Such solids cleave along preferred directions."

Example: NaCl, sucrose, Quartz, diamond.

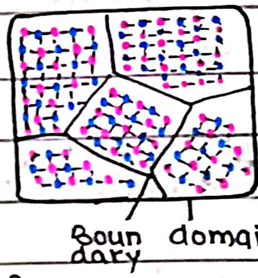


▲ Crystalline

→ **Polycrystalline solids:** "Single crystals or crystallites separated by boundaries constitute the whole solid. Crystallites are irregular in shape. Polycrystalline solids are isotropic."

Domains: These solids have ordered regions called domains / crystallites / grains.

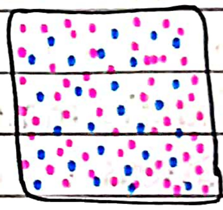
Example: ice.



▲ Polycrystalline

→ **Amorphous solids:** "Solid is composed of randomly oriented atoms, ions, or molecules that do not form defined patterns or lattice structures."

Example: supercooled liquids; glass. Rubber, glue.



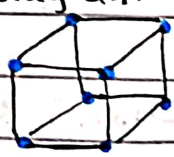
▲ Amorphous

→ Crystal:
"Crystals are composed of atoms held in ordely three-dimensional array."

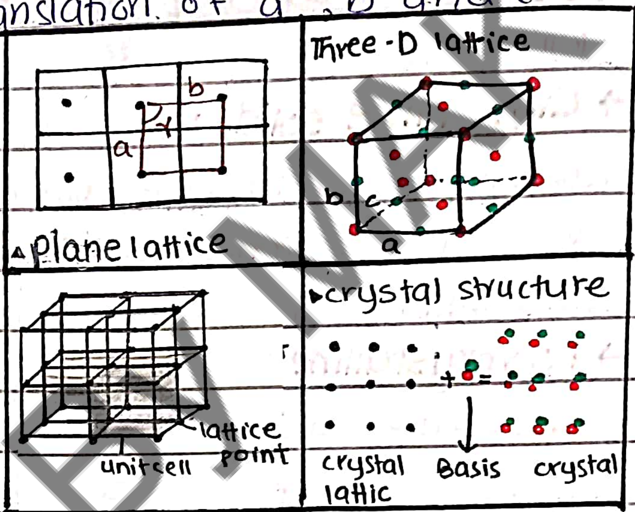
→ **Basis or unit:** Group of atoms which repeat at regular intervals along all directions in the crystal. Regular arrangement of 'basis' is the basic feature of crystals.

→ **Lattice:** Collection of infinite number of points in a periodic manner is called lattice. Lattice is a skeleton upon which crystal structure is built.

Diagram



- lattice sites: Points forming a lattice are called lattice sites.
- lattice constant: Distance between consecutive sites is lattice constant.
- plane lattice: Two dimensional lattice obtained by translation of $\vec{a}$ and $\vec{b}$
- Space lattice: 3-D lattice obtained by translation of $\vec{a}$, $\vec{b}$ and $\vec{c}$



→ **Unit cell:** The smallest geometric figure or unit whose periodic repitition forms a crystal is called unit cell.

→ **Crystal Structure:** Crystal structure is obtained when a basis is added at each point in lattice.

crystal lattice + Basis = crystal

→ Elastic Moduli: "For elastic solids, ratio of stress to strain is constant and it is called elastic modulus or Hookes law".

→ **Mathematically:** Elastic modulus = stress : strain.

→ **Elastic material:** If an object regains its original shape after external force is removed it is called elastic

→ **Plastic material:** If the object remains in deformed state it is called plastic

→ **Stress:** The force applied on unit area to produce any change in length, volume or shape of a body is called stress. stress = $\frac{Force}{Area}$

→ **Strain:** Strain is measurement of deformation of solid when stress is applied on it.

types: There are three types of elastic moduli:

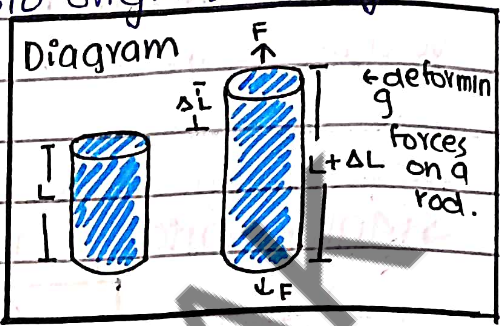
1. YOUNG'S MODULUS: "Ratio between tensile stress and tensile strain is called young's modulus".

→ **Tensile stress:** Ratio of magnitude of external force to the area of cross-section A is called tensile strain.

Tensile stress = F/A

→ **Tensile Strain:** The ratio of change in length to original length.

Tensile strain = $\frac{\Delta L}{L}$

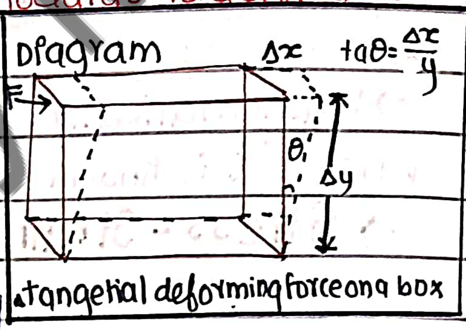


→ **Mathematically:** Young's modulus = $\frac{\text{T. stress}}{\text{T. strain}}$

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

SI unit: N/m^2

2. SHEAR OR RIGIDITY MODULUS: "Shear modulus is defined as the ratio of shear stress to shear strain."



→ **Shear stress:** Shear stress is defined as ratio of tangential deforming force F to the area A of the face being sheared.

• tangential deforming force: Deforming force acting at tangent to face of object being deformed.

Shear stress = $\frac{F}{A}$

→ **Shear strain:** Shear strain is ratio of displacement of the (deformed) sheared face Δx and the fixed face y. Shear strain = $\Delta x / y$

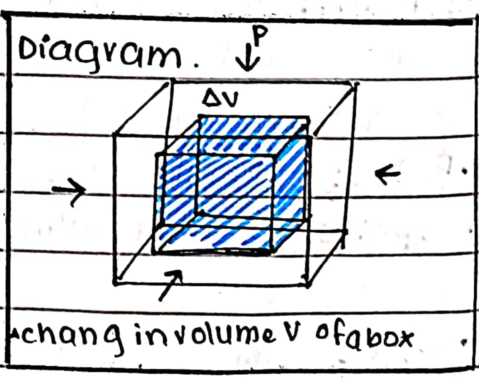
• angle of shear: $\tan\theta = \frac{\Delta x}{y}$ when angle is small $\tan\theta \approx \theta$ thus $\theta = \frac{\Delta x}{Y}$.

→ **Mathematically:**

shear modulus = $\frac{\text{shear stress}}{\text{shear strain}} = \frac{F/A}{\Delta x/y}$, $S = \frac{F/A}{\tan\theta} \simeq \frac{F}{A\theta}$

$\boxed{S = F/A\theta}$

3. BULK MODULUS: "It's defined as ratio of volume stress to volume strain."



→ **Volume stress:** Volume stress is ratio of magnitude of the normal force to area.

Volume stress = F/A

→ **Volume strain:** Ratio of change in volume ΔV and original volume is the volume strain.

$$\text{volume strain} = \frac{-\Delta V}{V}$$

-negative sign shows volume always decreases upon pressure exertion.

→ **Mathematically:** Bulk modulus $B = \frac{\text{volume stress}}{\text{volume strain}}$

$$B = \frac{F/A}{-\Delta V/V}$$

$$\boxed{B = \frac{\Delta P}{(-\Delta V/V)}}$$

→ Hooke's law:

Hooke's law states that for small deformations the stress and strain are proportional to each other.

→ **Mathematically:** Stress ∝ strain   stress = k strain.

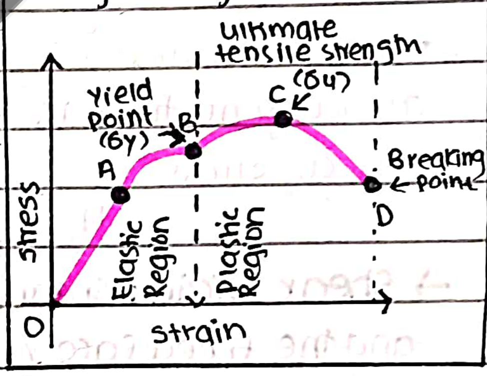
where 'k' is known as modulus of elasticity.

→ Stress - Strain Curve:

Stress-strain curves vary from material to material. These curves help us to understand how a given material deforms with increasing load.

consider the graph (a).

Diagram/graph



- **O → A:** Hooke's law is obeyed. Solid behaves like a perfectly elastic body. If deforming force is removed, body regains its original shape.
- **A → B:** Stress and strain aren't proportional. Exact original shape can't be attained but deformation isn't ~~sis~~ notable.
- **B point:** It's called yield point or elastic limit point. corresponding stress (σ_y) is called yield stress. If load exceeds yield point, strain will increase rapidly on even small change in stress.
- **B → C:** Material enters state of plasticity. Deformed face remains if force is removed.
- **C point:** It's called ultimate tensile strength (σ_u) If stress increases beyound this point, material is permanently deformed. In this case if stress is zero, strain isn't.
- **C → D:** Maximum a body can be streched / deformed is limited upto D.
- **D point:** Beyond this point, stress will break the material.

→ What does C and D being close or far mean? If C and D points are close for a material, body is brittle meaning it can break easily. (It will break producing a 'tucc' sound). If C and D points are far away, body is ductile meaning it can not be broken easily.

→ Energy Band Theory:

A theory based on quantum mechanics which explain electrical properties of solids in terms of energy bands is called energy band theory.

→ Formation of energy bands: Electrons revolve in fixed energy levels around nucleus. When two atoms come together, the apply electrostatic forces on eachother, due to it energy levels further split into sub energy levels. As there are large number of atoms interacting with eachother, so each energy levels splits up into very close large number of states (sub-levels) for electrons and hence form energy bands.

→ Forbidden energy gap: space between energy bands which electrons can not occupy are called forbidden energy gaps.

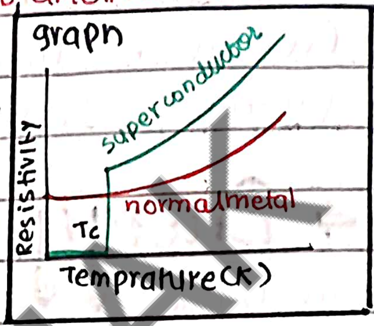
→ Valence band: Highest occupied band containing outermost electrons.

→ Conduction band: above valence band where free ēs are present.

conduction band can be empty but valence band can never be empty.

CONDUCTORS (copper, silver, iron)	INSULATORS (glass, rubber, plastic)	SEMICONDUCTORS
→ Partially filled conduction band.	→ An empty conduction band.	→ Conduction band empty at low T and partially filled at room temprature
→ Partially filled valence band	→ filled valence band.	→ Partially filled valence band at room temprature.
→ No energy gap valence and conduction band overlap.	→ Large forbidden E-gap greater than 5eV.	→ Small energy gap of the order 1.1eV.
→ Thermal energy causes more ē to enter conduction band	→ Thermal energy can't cause ē to enter conduction band.	→ Thermal energy causes ē to enter conduction band.
Ec conduction.b Ev valence band	Ec conduction.b forbidden energies Ev valence band	Ec conduction.b small e.gap Ev valence band

→ **Super Conductors:** "A superconductor is a material that can conduct electricity or transport electrons from one atom to another with no resistance."



→ **Under what condition a material becomes superconductive?** Most materials must be in an extremely low energy state (very cold).

→ **Resistance of a superconductor:** A superconductor offers zero resistance which means maximum current flows through it with no heat or power loss.

→ **At what temprature a material becomes super conductive?** The temprature at which and below which a material becomes a superconductor is said to be its critical temprature denoted by Tc. (Tc varies from material to material).

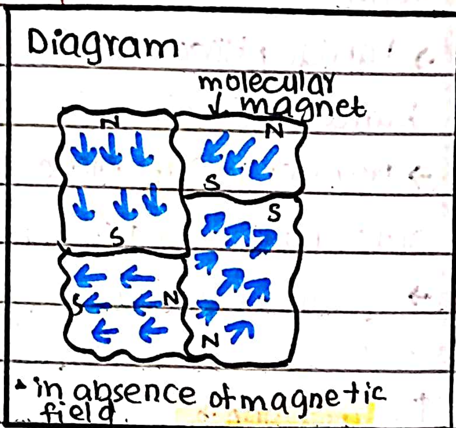
→ **Applications:** used in MRIs, maglev trains, particle accelerators,

magnetic levitation is a very famous application. Transport vehicles such as trains can be made to float on superconducting magnets.

levitation of magnetic cube; The field of the magnet induces currents in super conductor upon which cube is placed. current induced in super conductor generates an equal but opposite field which repels the cube causing it to levitate.

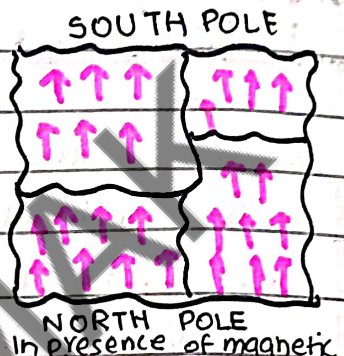
→ **Theory of Magnetism:** "The molecule of a magnetic substance (wether magnetized or not) is a complete magnet in itself having a north pole and a south pole of equal strength"

→ **In absence of magnetizing force:** The entire substance contains molecular magnets which individually have north and south poles. But the molecular magnets are arranged in such a way that they cancel each others magnetic effect.



→ **In presence of magnetic force:** When magnetic force is applied, molecular magnets allign in a way that North pole of of one molecular magnet faces the South pole of other. The whole substance becomes such that its one end becomes North pole and other becomes South.

Diagram



▲ In presence of magnetic field

→ **Extent of magnetization:** depends upon the extent of alignment of molecular magnets. When all molecular magnets are fully aligned, the substance is said to be saturated with magnetism.

→ **Loss of magnetism:** When magnetized material is subjected to high temprature, molecular magnets lose their arrangement. same is the case when magnets are thrown again and again.

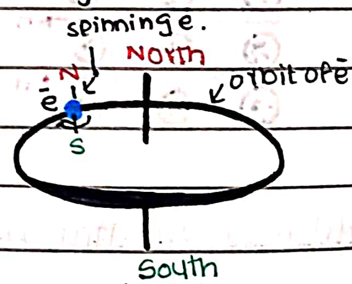
→ **Modern View About Magnetism:** "Magnetism is the propert of substance due to the orbital spin motion of its electrons".

→ **Magnetic Dipole:** Due to spinning and revolving motion of electrons, an atom is converted into a tiny magnet having north and south pole this is termed as magnetic dipole. A substance constitutes millions of magnetic dipoles.

→ **In Absence of magnetizing force:** Magnetic dipoles are randomly arranged thus magnetic fields mutually cancel.

→ **In presence of magnetic force:** Magnetic dipoles are alligned in the same direction thus substance shows net magnetism.

Diagram:

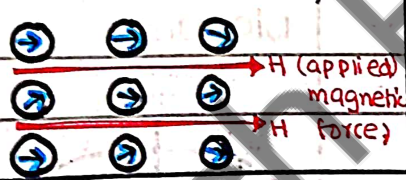
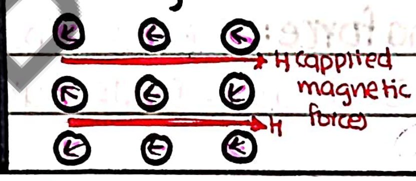
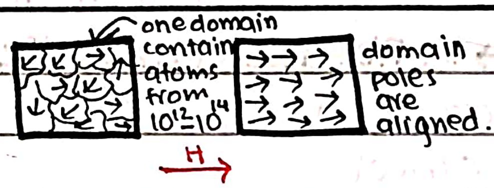


▲ magnetic Dipole

→ **Key factor responsible for magnetism:** The spinning motion of electrons in particular is responsible for magnetism.

→ **Conclusion:** Since revolving and spinning electrons in each atoms cause magnetism, no substance is non-magnetic.

→ Classification of Magnetic Materials:

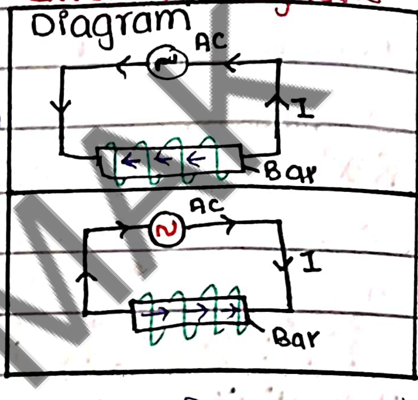
PARAMAGNETIC	DIAMAGNETIC	FERROMAGNETIC
	(i) Description	
→ Orbital, spin axis of ês is so oriented that their field supports each other and atom behaves like a tiny magnet.	→ Orbits and spin axis of electrons are so oriented that their field cancel the effect of each other	→ Individual atoms act like tiny magnets called magnetic domains. Interaction b/w them is so strong that they line up parallel even in absence of external magnetic field.
	(ii) Behaviour in response to applied field	
→ Substance is weakly magnetized in direction of applied field	→ Substance is weakly magnetized opposite to applied field	→ Domain poles align entirely with an external applied field.
	(iii) Response to permanent magnet	
→ Weakly attracted by permanent magnet.	→ weakly repelled by permanent magnet.	→ Strongly attracted by magnet.
	(iv) Diagram	
		
	Example:	
→ Aluminium, Antimony, Li	→ Cu, Bi, Zn, H, Be	→ Fe, Ni, Co

→ **Curie Temprature:** "The temprature at which ferromagnetic material becomes paramagnetic is called its curie temprature or curie point."

→ Magnetic Hysteresis:

HYSTERESIS LOOP: "A close curve showing the variation of the magnetic flux density "B" of ferromagnetic material with external magnetic field strength "H" producing it, is called hysteresis loop."

Diagram



→ Introduction: Suppose a soft iron bar placed inside a coil. When current passes through coil, one end becomes north and other becomes south and the soft bar placed inside also turns into a magnet. (soft bar is used so that it can be easily magnetized and demagnetized).

→ Magnetic field strength 'H': is the amount of magnetizing force applied by external magnetic field of electromagnet (coil).

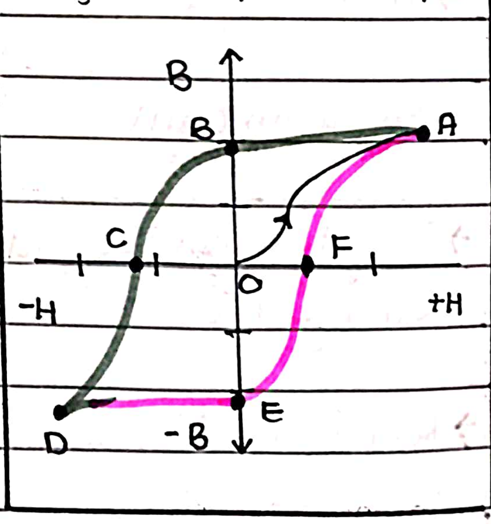
→ Effect of 'H' on 'B': B is magnetic flux Density (number of magnetic field lines passing through area of bar) as H increases, B also increases.

→ Mathematically: $B \propto H$ $\boxed{B = H \times \mu_0}$ where μ_0 is permeability

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

→ Explanation: Increasing magnetizing current I will cause 'H' to increase and 'B' will also increase linearly.

Diagram: Hysteresis Loop.



O→A: H and B increase linearly, saturation is obtained at point 'a'. Magnetization of soft bar takes place.

A→B: As 'I' reverses its direction 'H' also reverses and becomes zero but 'B' doesn't become zero. This is because some magnetism persists in the bar.

B→C: 'H' becomes negative, the extra reversal which 'H' has to make in order to turn 'B' zero is called coercive force. Bar is now demagnetized.

C→D: 'I' reaches its max negative value and bar is magnetized once again. C→D is just like O→A but in opposite direction.

D→E: 'I' is now declining from -ve extreme. H is becoming positive and bar is demagnetizing. D→E is just like A→B but in opposite direction. at E point 'H' becomes zero but 'B' doesn't.

E→F: I is increasing towards positive side, H is also increasing. coercive force comes in action and 'B' becomes zero at F point. Bar is finally demagnetized again

F→A: As 'I' completes one cycle, the loop becomes complete i.e, o-a-b-c-d-e-f-a. Bar has once again reached saturation (maximum magnetized) and 'H' has reached its positive extreme.

MAGNETIC PROPERTIES OF A MATERIAL:

→ **Retentivity:** Material's ability to retain a certain amount of residual magnetic field when magnetic force is removed after achieving saturation

→ **Residual flux:** Flux density that remains in a material when 'H' is zero

→ **Coercive Force:** Reverse magnetic field that must be applied to make the magnetic flux to become zero

→ **Reluctance:** Opposition a ferromagnetic material shows to establishment of magnetic field.

→ Soft magnetic materials	→ Hard magnetic materials
(i) Hysteresis loop	
→ Narrow loop	→ fat loop
(ii) Residual Magnetism	
→ Small amount	→ large amount
(iii) Magnetizing and demagnetizing	
→ Easy to magnetize and demagnetize	→ Difficult to magnetize and demagnetize
(iv) Hysteresis loss and coercive force	
→ Relatively less	→ Relatively great
(v) Example	
Silicon, Iron	Tungsten, cunife, cobalt