Engineering Physics

Theory Notes

Unit No. 5 Ch-1

PHYSICS OF NANOPARTICLES

By

Prof. S. J. Gadakh

Nanotechnology
Unit NO- 6 CH-2

① Prof. S. J. Gadakh

|IMP|

Q What is nanotechnology?

→ Nanotechnology is manipulation of matter on an atomic, molecular and supermolecular scale.

OR

The research and application of nano-structures into nanoscale devices is called nanotechnology.

|IMP|

Q Define nanostructures and nanoparticles.

→ 1] Nanostructures -

The molecules and structures with at least one dimension is in size range of 1 to 100 nm.

2] Nanoparticles -

Nanoparticles are the particles between one to 100 nm in size with surrounding interfecial layer.

|VIMP|

Q Explain Quantum confinement

and

How this affects the properties of nano-particles?

→ Quantum Confinement:

- Quantum confinement is a change of electronic and optical properties when the material sampled is of sufficiently small size - typically 10 nm or less.

- The band gap increases as the size of the nanostructure decreases.

- The band gap of ZnS nanoparticles was found to be 4.03 eV which is higher than that of bulk ZnS which is 3.7 eV is due to quantum Confinement

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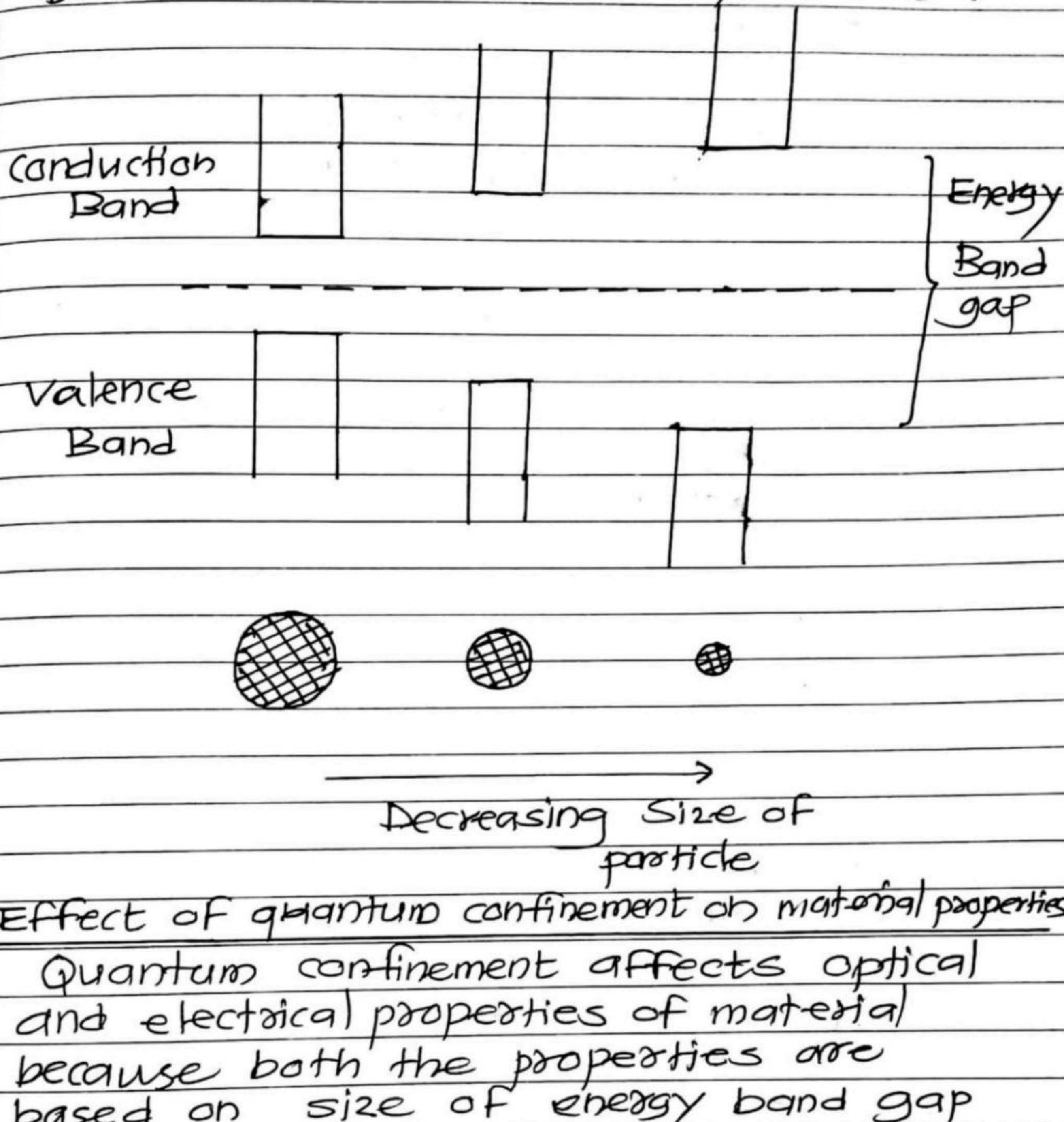
- Quantum confinement effects describe electron in terms of energy levels, potential well, valence bands, conduction bands and electron energy band gap.



Effect of quantum confinement on material properties

- Quantum confinement affects optical and electrical properties of material because both the properties are based on size of energy band gap
- As the band gap increases material will become transparent to light.
- Resistivity of material increases with increasing band gap size.

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Properties

Q Explain any two properties of nanoparticles.

Q Explain the following properties of nanoparticles
1] Electrical
2] Mechanical
3] Optical

⟹

1] Electrical property

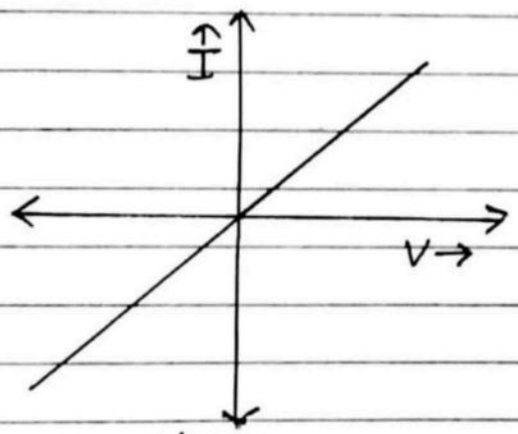

fig-① V vs I For typical metal resistor in bulk size

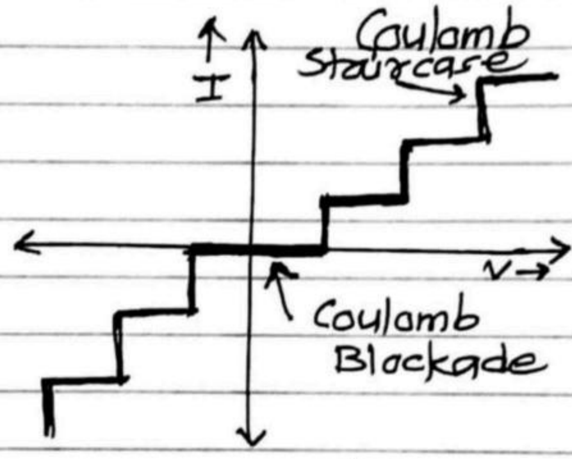

fig-② V vs I For Quantum dot.

- When a voltage V is applied across the conductor, current flowing through it is given by Ohm's law and gives a linear graph as shown in fig-①

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- If the dimensions of metal piece is reduced to 100 nm or less, there appears a region around zero voltage for which there is no current.

- The electrons are transferred when the voltage is $\pm e/2C$.

- A single electron is transferred by tunneling when the voltage is less than this, the electron can not be transferred.

- This gives the region of zero current at low bias voltage and is known as 'Coulomb Blockade region'.

- The repeated tunneling of single electron produces 'Coulomb Staircase'

- In genral, electrical resistivity of materials having nanosized grain is larger than the polycrystalline materials.

- When electrons are moving, they get scattered at grain boundaries. This results in higher resistivity.

2] Mechanical Property:

- The mechanical property of material depends upon the composition and bonds between the atoms.

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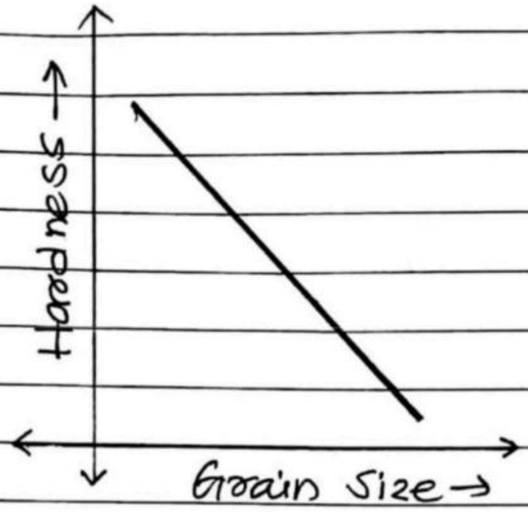
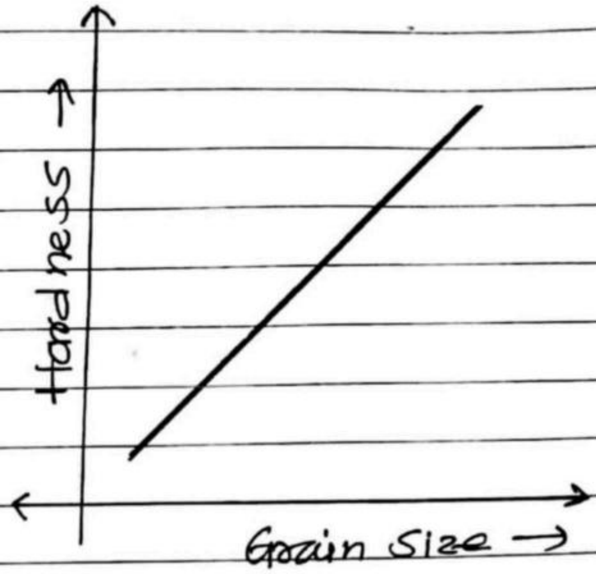


a) Material in nano-size



b) Material in Bulk size.

- For bulk material, the hardness increases linearly with the grain size.
- But in nanomaterials, the hardness increases linearly with decreases of the particle size as shown in fig.

- For nanoscale material, the material tends to form a single crystal. The nano crystals are highly pure and free of imperfections.

- It has been observed that in metallic nanocrystals, Young's modulus reduces drammatically.
- For example, magnesium nanocrystal has Young's modulus 3900 N/mm² but for polycrystalline form it is 4100 N/mm².

Magnetic properties of Nanoparticles.

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Q. Explain the magnetic properties of Nanoparticles

⟹

Properties

- When material is converted from bulk to nanoparticles, its magnetic properties undergo significant changes.
- Magnetic properties of nanoparticles are changed because of change in surface to to volume ration
- Nanoparticles below a critical size can exhibit superparamagnetism. They behave like single magnetic domain.
- Nanoparticles show higher magnetic anisotropy than bulk materials due to surface effect.

	Property	Bulk material	Nanoparticles
1)	Magnetic moment	Lower	Higher
2)	Super magnetism	Not observed	observed below critical size
3)	Magnetic Anisotropy	lower	Higher
4)	coercivity	lower	Higher

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3] Optical Property -

- The colour of nanoparticles are different from the colour of bulk material.

- The gold nanoparticles have bright red colour instead of yellow as it appears in bulk form.

- In case of stained glasses the colour appearing on the glass is due to mixing of small amount of metal nanoparticles like gold, cobalt, nickel etc. are mixed with glass at the time of making.

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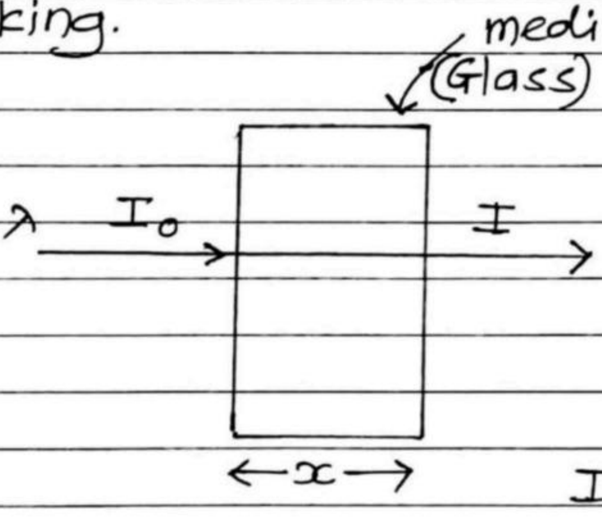

Where,
I = intensity of transmitted light
I_0 = Intensity of incident light
x = Thickness
λ = wavelength of incident light

- G. Mie explained that, when a beam of light of intensity I_0 and wave length λ passes through a medium, the transmitted intensity I is given by

$$I = I_0 e^{-\mu x}$$ ← G. Mie equation

Where 'μ' is 'extinction coefficient' and depends on the number particles in the medium, Volume of colloidal particles and extinction cross section of medium particle. Extinction cross section is sum of absorption extinction and scattered extinction.

Applications

VIMP)

Q Explain the following applications of nanoparticles.
1] Targeted drug delivery (Medical)

→

1] Targeted Drug delivery.

- The nanoparticles can be used for drug delivery in the body.

- As nanoparticles are very small in size, they can be injected easily and can be guided

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towards specific part in the body.

- Recently, gold nanorods which have strong scattering and absorption property in the infrared are used to detect and destroy cancer cells in rats.

- Drugs can be encapsulated in nano capsules and can be guided towards desired parts of the body.

- Then drug can be delivered in controlled manner, fastly and slowly by opening the capsule in desired way.

- The opening of capsule can be controlled externally by magnetic field, infrared light or physiologically.

- this will help in treating cancer, diabetic or HIV affected patients.

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Q. # Applications

⇒ 1] Automobile Application :

- By using nanoparticles light weight and less rubber consuming, thiner tyres can be made.

- This will reduce the weight and price of the car and will increase the mileage as a result of reduced weight.

- Nanoparticles can be used as a catalysts to convert harmful emissions into less harmful gases.

- With the help of nanocarbon tubes, hydrogen fuel can be stored safely and can be used for running a car.

- Nanoparticle's paints provide smooth, thin and attractive coating.

- Research is going on to change the colour of car by applying small voltage.

- The body of car is made up of steel and some alloys. To make body of car nanotube composite can be used because they have better mechanical strength than steel.

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- Self-Cleaning glass can be made by mixing small amount of (TiO_2) nanoparticles while manufacturing it. The TiO_2 is capable to dissociating organic dust in presence of UV light. Because of this the glass will be remained clean all the time.

Applications of Nanotechnology in the field of environmental & Energy sectors.

IMP Give/

Q. Explain the applications of Nanotechnology in environmental sector.

→ 1) Nanotechnology improves water quality through advance filtration, contaminant removal and desalination techniques.

2) Nanoparticles help reduce air pollution by capturing and neutralizing harmful gases and particulates.

3) Nanoparticles can detoxify polluted soils by breaking down organic pollutants.

4) Nanobased sensors detect and monitor pollutants in real time with high sensitivity and accuracy.

5) Nano-catalysts convert toxic gases into less Harmful substances.

IMP Give/

Q Explain the applications of Nanotechnology in Energy sector.

⟹ 1) Nanotechnology enhances the efficiency and performance of renewable energy systems.

2) Quantum dots and perovskite nanoparticles improve light absorption and conversion efficiency of in photovoltaic cells/solar cells.

3) Nanostructured silicon increases the efficiency of traditional silicon-based solar cells.

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4) In case of wind turbines, nanocomposite materials reduce the weight and increase the strength of turbine blades.
5) In Lithium - ion batteries nanostructured anodes enhance the energy ~~of~~ density and charge discharge rates.

Applications of Nanotechnology in Electronics

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Q. What are the applications of nanotechnology in electronics. Explain GMR effect and its application in read-write the head of the HDD.

→ Applications in electronics

1) Nanotechnology is utilized in advanced semiconductor technologies like 5 nm & 3 nm nodes.
2) Nanotechnology is utilized in manufacturing of memory storage devices to increase storage density and speed in devices such as
   1) Flash memory
   2) NRAM and ReRAM
3) Nanotechnology is used in manufacturing displays to improve brighness and colour accuracy in QLED displays.
4) Graphene and silver nanowires enable flexible displays, electronic skin and smart textiles.
5) Carbon nanotubes and graphene increase energy storage capacity and discharge rates.

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GMR Effect and its application in read-write the head of HDD.

- Nanotechnology plays a crucial role in the development of the Giant Magneto-Resistance (GMR) effect by enabling precise control over the material properties and structure at the nanoscale.
- GMR effect is the quantum phenomenon observed in thin film composed of alternating Ferromagnetic & Non magnetic layers.
- Nanotechnology helps optimize the interface between Ferromagnetic and nonmagnetic layers to enhance electron scattering and maximize the GMR effect.
- GMR effect is extensively used in the read-write heads of hard disk drives (HDD)
- IN HDD data is stored as tiny magnetic domains on the disk.
- The read head based on the GMR sensors detech changes in the magnetic field as the disk spins.

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Q Why properties of nanomaterials are different from bulk?

→ - One reason for this is surface area to volume ratio. In case of nanoparticles this is very large than bulk.

- Because of higher surface area to volume ratio maximum number of atoms are on surface of particle than the atoms present inside.
- These atoms which are on the surface of particle plays very crucial role in every property of the material.
- Atoms on the surface of material are more reactive than those in the center, so, large surface area of material means material is more reactive.

- For nanomaterials, not only their chemical composition but also their morphological properties and surface properties determine their characteristics.
- These properties do not only differ in comparison to the corresponding bulk material but also between different

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Synthesis Methods.

Q. Explain Ball milling method of synthesis of nano particles

Ans ① Ball Milling

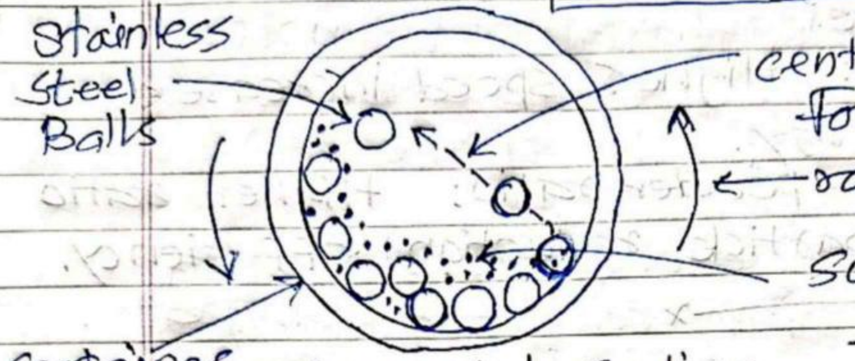

fig- Ball milling Method

Principle -
The method is based on mechanical force, where powder particles subjected to severe plastic deformation, cold welding and fracturing, leading to the formation of nanoparticles.

Process:-

1) Raw materials -
- A powder mixture (e.g. metals, ceramics, polymers) is placed in a ball milling along with balls made of stainless steel, tungsten carbide or zirconia.

2) Milling -
- The ball mill is rotated at high speeds.
- The balls impact the powder particles, causing repeated fracturing, cold welding and re-fracturing.
- The size of the nanoparticles is reduced

by shear, impact and collision forces.

3) control parameters –

a) Milling time: Longer time reduces particle size.

b) speed: Higher speed increases impact energy.

c) Ball-to-powder ratio: Higher ratio increases particle reduction efficiency.

——x——x——x

Advantages:

1. simple and cost-effective.
2. Scalable for industrial applications.
3. Can synthesize nano particles of various materials.

Applications:

1. Synthesis of metal oxides, carbon nanotubes and ceramic nanoparticles.
2. Used in industries like pharmaceuticals, electronics and energy storage devices.

Limitations:

- High energy consumption.
- Potential contamination from the milling media
- Requires optimization of parameters to control particle size and shapes.

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Synthesis method

② Physical Vapour Deposition (PVD)

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Q. Explain physical vapour Deposition (PVD) method for synthesis of Nanoparticles.

⟹

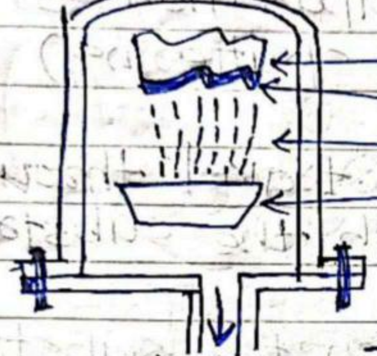

fig - Evaporation method of PVD

Principle -
- PVD involves converting a solid material into its vapor phase and then condensing it back into a solid form as nanoparticles on a substrate.

Types of PVD processes -

1) Evaporation -
- The source material is heated in a vacuum chamber until it evaporates and condenses as nanoparticles on a cooler substrate.
- Techniques - Thermal evaporation, Electron beam evaporation.

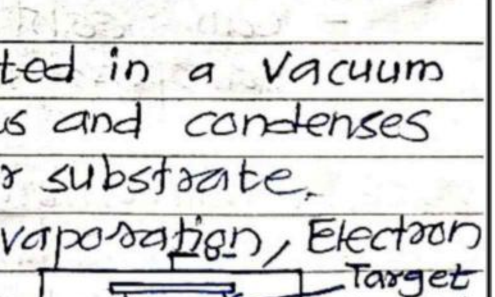

fig - Sputtering

2) Sputtering -
- High energy ions (typically Argon) bombard the target material, ejecting atoms that deposite on the substrate forming nanoparticles.
- Techniques : DC/PF magnetron Sputtering, Ion beam sputtering.

D.

Process -

- The substrate and source material are placed inside a vacuum chember.

- The source material is vaporized by applying heat (in evaporation) or by ion bombardment (in sputtering)

- The vaporized atoms travel through the vacuum and reach the substrate.

- The atoms condense on the substrate, forming a thin film or nanoparticles.

—x— —x—

Advantages -
- produce high-purity nanoparticles.
- Suitable for a wide range of materials.
- Can control film thickness and nanoparticles size precisely.

Applications -
- Thin film coatings for semiconductors, solars cells and optical devices.
- Synthesis of metal and oxide nanoparticles for catalysis and sensors.

Limitation -
- Expensive equipment and high operational cost.
- Limited to material that can vaporized.
- Requires vaccum conditions, which increases complexity.

Engineering Physics

Theory Notes

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Unit-5 Ch-2
Superconductivity

Superconductivity: Temperature dependence of resistivity, critical magnetic field, critical current, Meissner effect and perfect diamagnetism; Type I and Type II Superconductors, Numerical problems on critical magnetic field; Formation of Cooper pairs, DC and AC Josephson effect, SQUID: working principle and applications; Engineering applications: electronics, principle of Maglev train.

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Unit No. 5
CH-1: Superconductivity

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Superconductivity & Critical Temperature

Q Explain the phenomenon of superconductivity. Dec-12, Dec-16

Q Define the term superconductivity.

⟹ Superconductivity - (Definition)

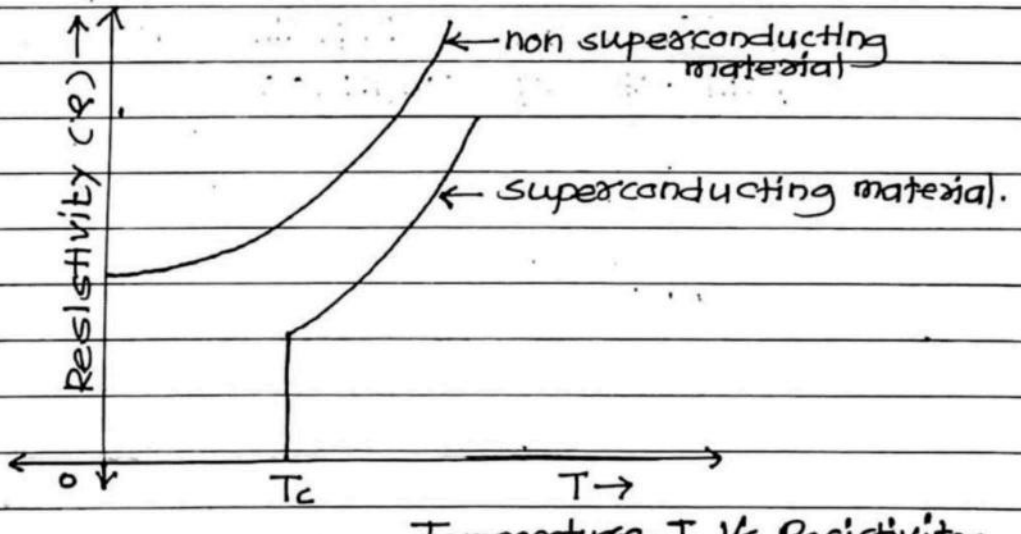
The below particular temperature, the resistance of a particular material becomes zero and conductivity becomes infinity. This phenomenon is known as superconductivity.

T_c Critical temperature - (Definition) or Transition Temperature

The temperature at which conductivity becomes infinite is known as critical temperature.

OR

In the phenomenon of superconductivity, the temperature at which resistance of the material becomes zero is known as critical temperature.



Temperature T Vs Resistivity

Fig - Graph of Temperature dependence of Resistivity

For certain materials, like mercury, the resistance suddenly drops to zero at very low temperature typically near the boiling point of liquid helium. This phenomenon is known as superconductivity.

Some metals, doped semiconductors, alloys and ceramics show superconductivity. Some of the best conductors like gold, silver and copper do not show superconductivity at any temperature, where as some ceramics which are insulators at room temperature show superconductivity.

In metals, both thermal vibrations of atoms and presence of impurities or imperfection scatter the moving conduction electrons. This gives rise to electrical resistivity.

In superconductivity

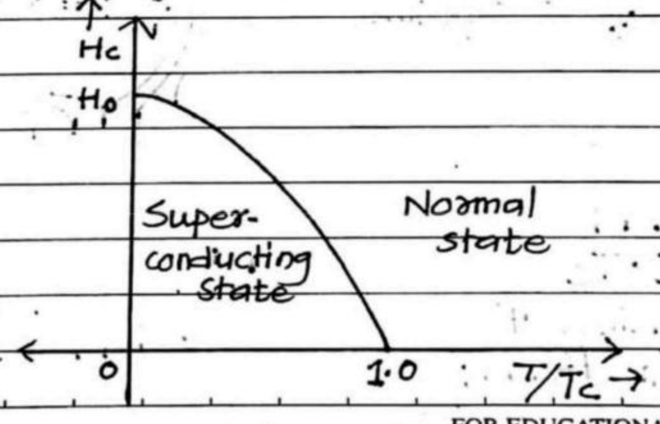
1) The electrical resistance drops to zero below critical temperature.
2) The magnetic flux lines are excluded from the bulk of superconductor.

c. CRITICAL MAGNETIC FIELD

IMP Q Explain the effect of external magnetic field on Superconductor.

Q Explain the term critical magnetic field. H_c.

⟹



T/T_c Vs H

$$H_c = H_0\left[1 - \left(\frac{T}{T_c}\right)^2\right]$$

T_c = Critical Temperature

T = Temperature of material

H_0 = Critical Magnetic Field at $T = 0K$

SC ④

Critical Magnetic field (Hc) -

- The minimum applied magnetic field neccessary to destroy superconductivity and further restore the normal resistivity is called critical field Hc.

- Hc depends on the temperature.
- The curve shown in above diagram is nearly parabolic and can be reasonably well represented by the relation

$$H_c = H_0\left[1 - \left(\frac{T}{T_c}\right)^2\right]$$

Where, Ho is the critical field at absolute zero. Hc is critical magnetic field, T is temperature of specimen and Tc is critical temperature.

MEISNER EFFECT

IMP Q State and explain Meisner effect. Hence show that susceptibility is negative is superconducting State. (Dec-12,14,15,16, May-14,15,17)

⟹ Meisner Effect:-

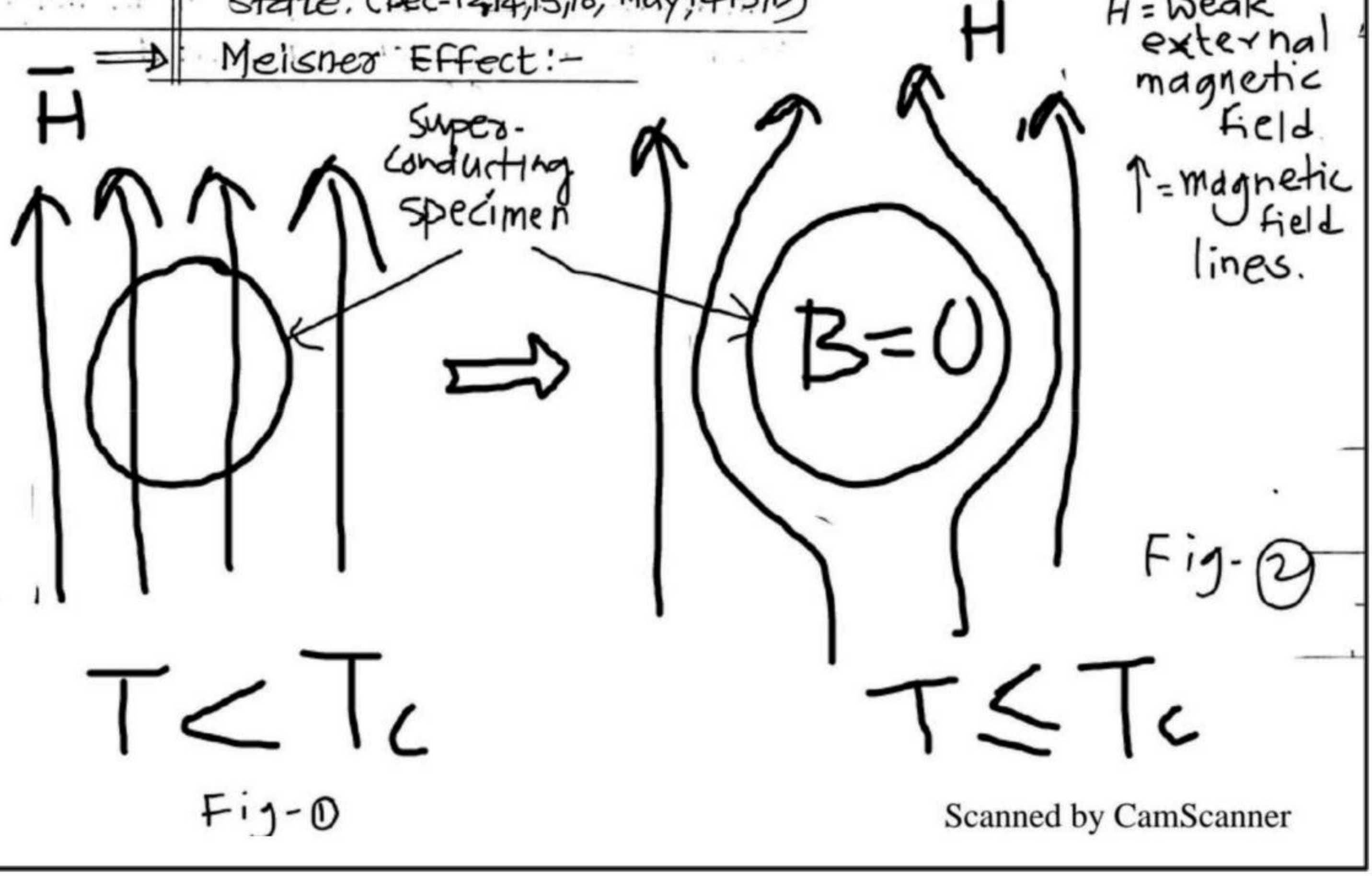


Fig-①

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statement :- Meisner Effect

When superconducting specimen is placed in a weak magnetic field and cooled below the critical temperature T_c, the magnetic flux originally present in the specimen is ejected from the specimen as shown in above fig. this effect is known as Meissner's effect.

Perfect Diamagnetism :-

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- Thus superconductors acts as a perfect diamagnets with zero magnetic induction in the interior when placed in weak magnetic field.
- The magnetic induction inside the specimen in the normal state is given by

$$B = \mu_0 (H + M)$$

Where, B = magnetic induction in side the specimen
μ_0 = magnetic permiability of space.
H = external magnetic field strength
M = magnetization inside the specimen.

- When temperature 'T' of the specimen is lowered below its critical temperature T_c.

then , $B = 0$

$\therefore \quad 0 = \mu_0 (H + M)$

$$H = -M$$

The susceptibility χ is given by

$$\chi = \frac{M}{H}$$

In this case $\frac{M}{H} = -1$ $\therefore$ i.e. Susceptibility is negative

$$\boxed{\chi = -1}$$

This indicates in superconducting state material becomes perfect diama

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SC 10-1

Q Show that, Meissner effect can not be explained by assuming that the superconductor is perfect conductor.

⟹ Meissner can not be explained by assuming that the superconductor is a perfect conductor with zero electrical resistivity.

The electric field is given by

$$E = \frac{V}{l} = \frac{IR}{l}$$

$$= \frac{IR}{l} \times \frac{A}{A}$$

$$= \frac{RA}{l} \times \frac{I}{A}$$

$$E = \rho \times J$$

Where ρ is resistivity and J is current density

If ρ becomes zero for a finite current density J, then $E=0$.

From Maxwell's equation

$$\bar{\nabla} \times \bar{E} = -\frac{d\bar{B}}{dt} \quad \text{As } E=0, \ \frac{d\bar{B}}{dt} = 0$$

it means $B = \text{constant}$

∴ In a conductor the flux can not change an cooling below critical temperature.

This contradicts Meissner effect according to which the flux must be reduce to zero.

Hence, superconductor is not just a perfect conductor.

IMP What is Meissner effect? Show that Superconductors are perfect diamagets

(This question is on Meissner effect

Ref. page NO. 4 & 5.)

[IMP]

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SC (15)

TYPES OF SUPERCONDUCTORS

Q Explain type 1 & type 2 superconductors (S-16, Dec-12)

Q Explain Soft & Hard superconductors.

Q Explain the types of superconductors.

→ There are two types:

1) Type 1 Superconductors
   (Soft Superconductors)

2) Type 2 Superconductors
   (Hard Superconductors)

- Both have similar thermal properties at the transition temperature in absence of magnetic field.
- The difference lies in their behaviour in a magnetic field, particularly in Meissner effect.

A] Type 1 Superconductor :-

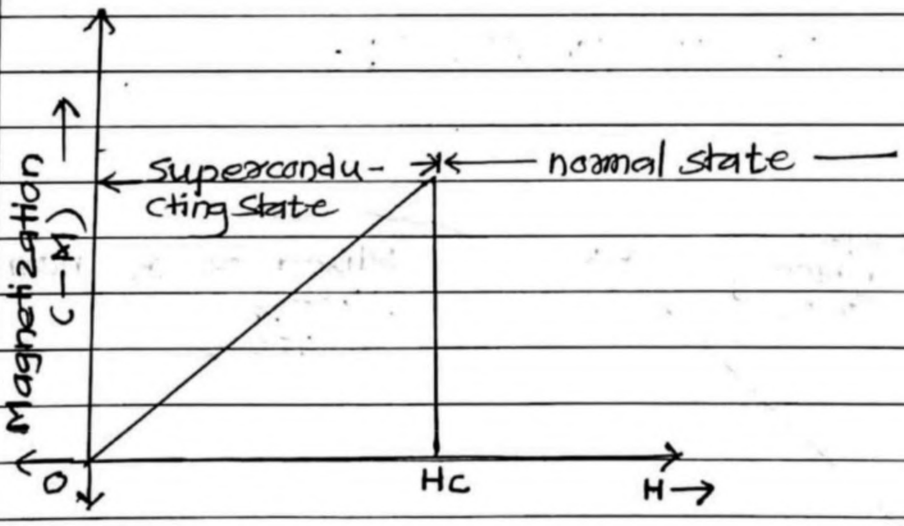


Fig- Magnetization curve for type-1

- Type-1 superconductors are also called soft superconductors.
- In this type, the transition from a superconducting state to normal state, in the presence of external magnetic field, occurs sharply at critical value Hc.
- These are completely diamagnetic.
- They completely expel the magnetic field from the interior of the specimen up to the critical value Hc.
- Magnetization of the material grows in proportion to the external field, at Hc it suddenly drops to zero.
- Superconductivity of such types of superconductors suddenly drops to normal conducting state at low values of critical magnetic field. Therefore type 1 superconductors can not be used in solenoids for producing large magnetic fields.
- Examples: Aluminium, Lead.

A] Type 2 Superconductors :-

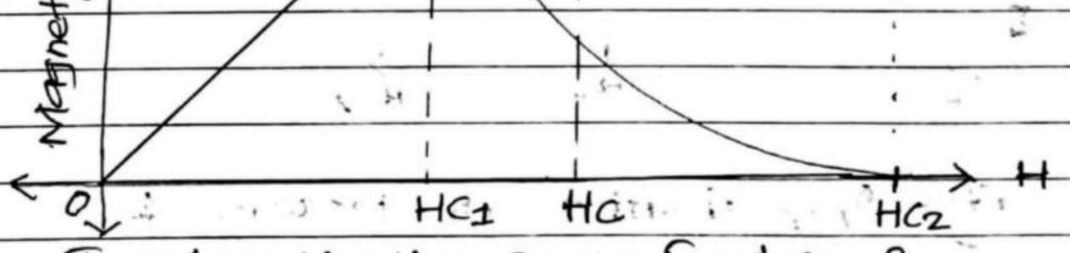


fig- Magnetization curve for type-2.

- Type 2 superconductors are also known as 'Hard superconductors' is characterized by two critical fields H_{C1} and H_{C2}. ($H_{C1} < H_C < H_{C2}$)

- It exists in three states:
1) Superconducting
2) Mixed (Vortex)
3) Normal

1] Superconducting state :-
- This occurs upto a critical field H_{C1}. The magnetization increases with applied magnetic field and external magnetic flux is completely expelled from the interior of the material.

2] Mixed state (Vortex state) :-
- This region extends from H_{C1} to H_{C2}.
- At H_{C1}, the magnetic field penetrates the material.
- Between H_{C1} & H_{C2} the material is in a mixed state magnetically but electrically it is a superconductor.
- Meisner effect is incomplete.
- This region is also called vortex state.
- The value of H_{C2} is hundred times higher than H_C (~ 20 to 50 Wb/m^2)

3) Normal state :-
- When magnetic field exceeds critical field strength H_{C2}, magnetization vanishes completely.

- The material is penetrated by the external field and superconductivity is completely destroyed.

- The specimen reverts from superconducting state to normal state.

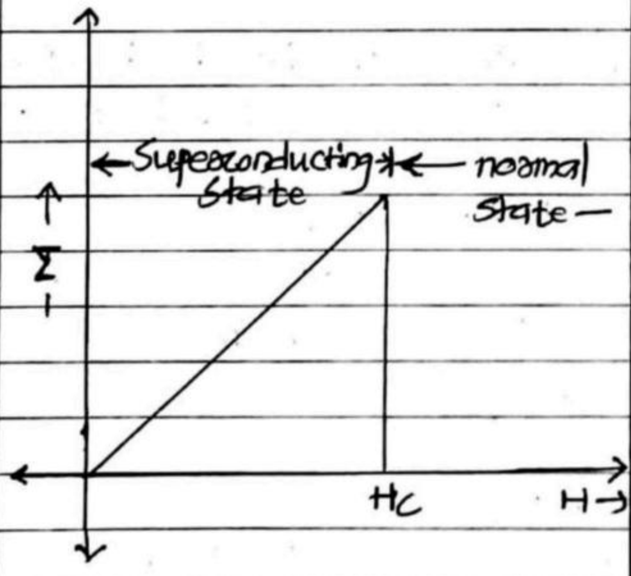
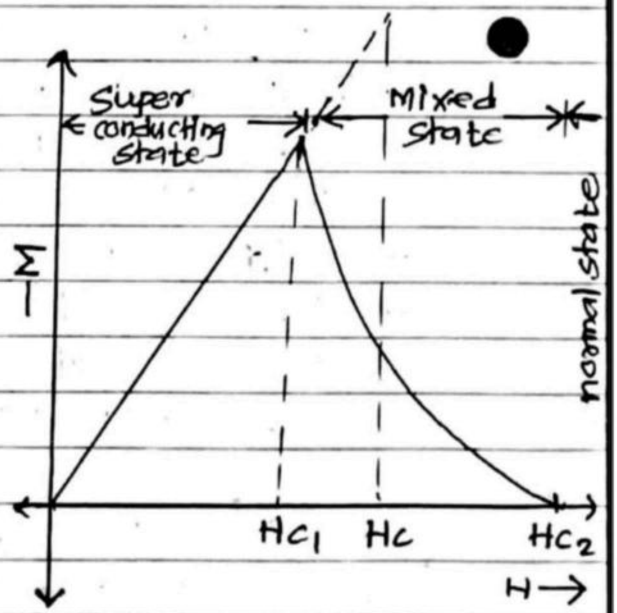
- Type 2 superconductors are found useful in application where high magnetic fields are required.

Very IMP

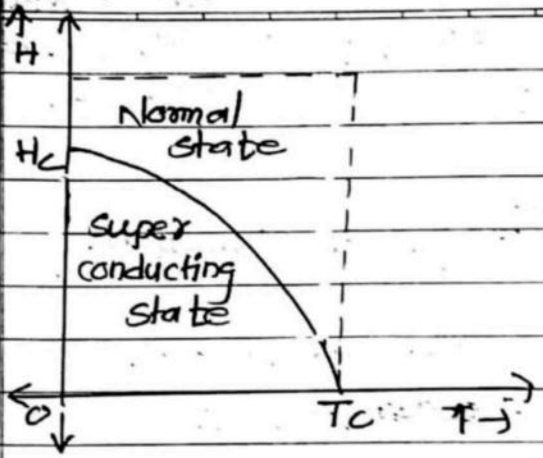
Difference between type 1 and type 2 superconductors.

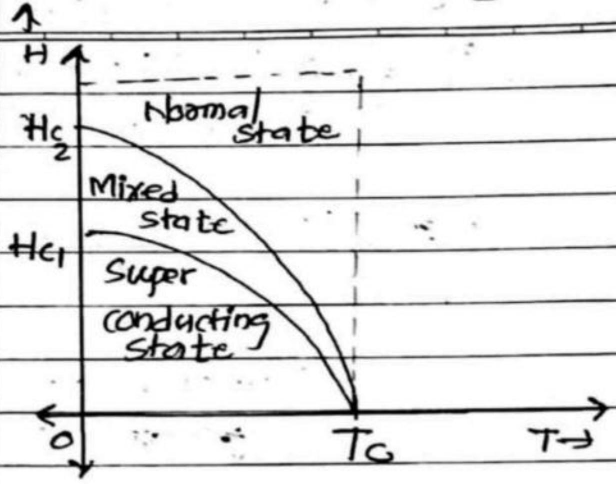
Q Distinguish between Type one and Type two superconductors (May-12,13,15,17 Dec-13,14)

4 Marks

Type - I	Type - II
1)  fig - Magnetization curve	 fig - Magnetization curve.

2]





3	It is known as soft superconductor	It is known as hard superconductor.
4	Less industrial applications	More industrial applications
5	Has one critical magnetic field	Has two critical magnetic field.
6	It has less current carrying capacity than type-2.	It has more current carrying capacity than type-1
7	They are perfectly dimagnetic below Hc and completely expel magnetic field from interior of the superconducting phase	For $H_{c_1} < H_c < H_{c2}$ they exist in magnetically mixed and electrically superconducting state.
8	Examples:- Pure element like Al, In, Zn, Mo, Sn	Alloy like Nbn, Nb_3Sn, $BaBi_3$ $CoSi_2$, HTS
9	The material loses magnetization abruptly.	The material loses magnetization gradually.

Josephson Effect

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Josephson Effect

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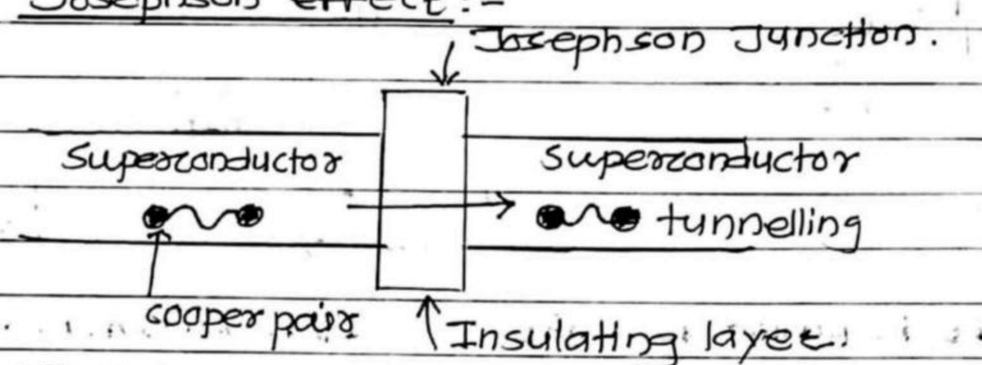
Q What is Josephson effect? Explain DC & AC Josephson effect? (Dec - 13)

⇒ <u>Josephson effect:-</u>



<u>Statement:</u>

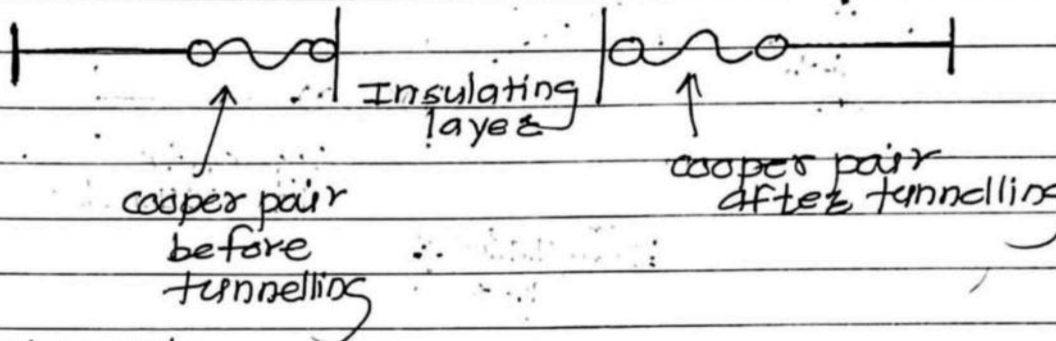
- Brain D. Josephson, of Cambridge University, in 1962, Predicted that electrical current would be flow between two superconducting materials even though they are seperated by a non superconductor or insulator. This tunnelling phenomenon is called as Josephson effect.

- As shown in above fig., two superconductors connected by a thin layer of insulating material (∼ 2 - 3 nm) is called a 'Josephson Junction'.
- Remarcable effects are associated with the tunneling of superconducting electron pairs from a superconductors, through thin layer of an insulator into another superconductor.
- The Junction is called as weak link.

- There are two types of Josephson effect.

a) D.C. Josephson
b) A.C. Josephson effect.

9) D.C. Josephson effect.



Statement

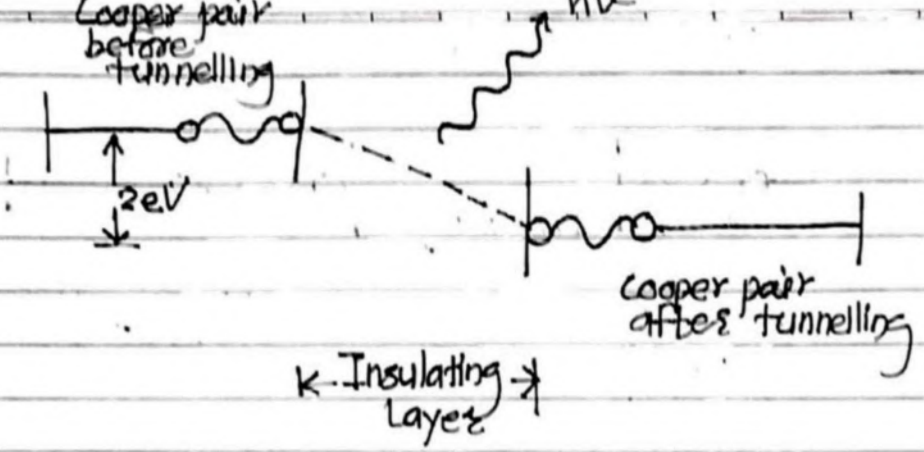
- When two superconductors are seperated by a thin insulating layer, cooper pairs tunnel through the junction and current flows across the junction without any external applied voltage.

- If this current does not exceed critical current I_c, the voltage accross the junction is zero.
- This complete effect is known as D.C. Josephson effect.

- The D.C. current is given by $I_J = I_c \sin\phi$ where ϕ is the phase difference between wave functions of cooper pairs on either side. I_J is Josephson current & I_c is critical current.

2] A.C. Josephson Effect :-

→ When the D.C. voltage is applied to the Josephson junction and the current I through the junction exceeds a critical current value I_c, a potential difference V appears across the Josephson junction. Current I, varies sinusoidally with time. This effect is known as ac Josephso effect.



- In such case, the energies of cooper pair on both the sides of the barrier differ by 2eV.
- The alternating supercurrent is accompanied by the emission or absorption of electromagnetic radiation.

Applications of Superconductivity

(Maglev Trains)

IMP.

1) Magnetic Levitation :-

- The zero magnetic induction in a superconductor is responsible for levitation effect.
- This phenomenon has led to one of the most spectacular applications, Maglev Trains.
- Superconducting magnetic coil produces the magnetic repulsion require to levitate the train.
- Maglev trains will not slide over the rails but will float on an air cushion over a magnetised track.
- There is no mechanical friction therefore speed up to 500 km/hr can be achieved easily.

[IMP] **CRITICAL CURRENT (I_c)**

Q Explain the team. Critical current Density.

→ If superconducting material carries a current and if the magnetic field produced by this current is equal to Hc, Then the superconductivity disappear. This maximum current at which superconductivity vanishes is called the critical current **Ic.**

$$I_c = 2\pi r H_c$$

$$I_c = \pi D H_c$$

r = radius D - Diameter

Important Formulas -

4] $$H_c = H_0\left[1-\left(\frac{T}{T_c}\right)^2\right]$$

where, H_c = Critical field
H_0 = Critical field at $0^{\circ}K$.
T = Temperature of specimen

5] $$T = T_c\left[1-\frac{H_c}{H_0}\right]^{1/2}$$

6] $I_c = 2\pi r H_c = \pi d H_c$ $\qquad$ I_c = Critical current

Problems:-

1) In a superconducting material isotopic mass is 199.5 amu and critical temperature is 5K. Calculate isotopic mass at 5.1 K.

→ Given:- $m_1 = 199.5$ amu, $T_{c1} = 5K$, $T_{c2} = 5.1K$
$m_2 = ?$

Formula: $T_c \propto m^{-1/2}$

There fore $T_{c1}\, m^{1/2} = T_{c2}\, m_2^{1/2}$

OR $$m_2 = m_1\left(\frac{T_1}{T_2}\right)^2$$

$$= 199.5 \text{ amu}\left[\frac{5k}{5.1k}\right]^2$$

$$\boxed{m_2 = 191.68 \text{ amu}}$$

2] Calculate the critical current for a wire of lead having a diameter of 1 mm at 4.2 K. The critical temperature for lead is 7.18 K and $H_o = 6.5\times10^4$ A/m.

→ Given,

$H_o = 6.5\times10^4$ A/m , $T = 4.2$ K , $T_c = 7.18$ K

Solution:-

$$H_c = H_o\left[1-\left(\frac{T}{T_c}\right)^2\right]$$

$$= 6.5\times10^4 \text{ A/m}\left[1-\left(\frac{4.2\text{K}}{7.18\text{K}}\right)^2\right]$$

$$\boxed{H_c = 4.28\times10^4 \text{ A/m}}$$

The critical current $I_c = 2\pi r H_c = \pi d H_c$

$$I_c = 1\times3.14\times10^{-3}\text{ m}\times4.28\times10^4 \text{ A/m}$$

$$\boxed{I_c = 134.5 \text{ A}}$$

3] The transition temperature for lead is 7.26 K. The maximum critical field for the material is 8×10^5 A/m. Lead has to be used as a super conductor subjected to a magnetic field of 4×10^4 A/m. What precaution will have to be taken?

→ Sol^n:

Data :- $T_c = 7.26$ K

$H_o = 8\times10^5$ A/m , $H_c = 4\times10^4$ A/m

Formula: $T = T_c\left[1-\frac{H_c}{H_o}\right]^{1/2}$

$$T = T_c\left[1-\frac{H_c}{H_o}\right]^{1/2} = 7.26\left[1-\frac{4\times10^4}{8\times10^5}\right]^{1/2} = 7.08\text{K}$$

Precaution: Temperature of the metal should be held below 7.08 K.

Prof. S. J. Gadakh

SQUID

Superconductor Quantum Interference Device

IMP

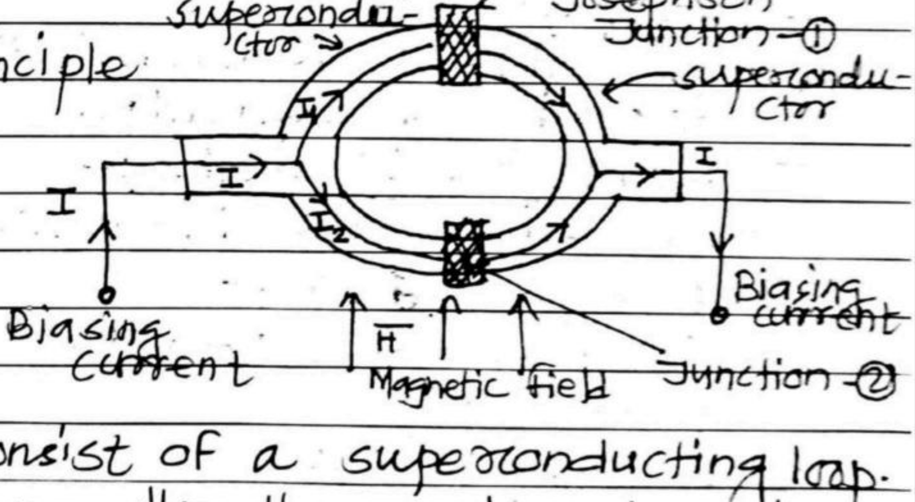
Q. What is SQUD.
Explain the working principle of SQUID.

⟹

Full form of SQUID -
Superconducting Quantum Interference Device.

SQUID is an extremely sensitive magnetometer used measure very small magnetic fields, based on the principles of superconductivity and quantum interference.

Working principle



A SQUID consist of a superconducting loop. These junctions allow the quantum tunneling of cooper pairs (paired electrons in a superconductors.)

In superconducting loop, the magnetic flux is quatized.

When a small magnetic field is applied to the loop, it induces a circulating current that modifies the phase difference across the Josephson Junction. This change in phase difference causes interference in the tunneling cooper pairs, affecting the current flowing through the device. Prof. S. J. Gadakh

- The quantum interference of the superconducting wavefunctions across the junctions causes the total current to oscillate as function of the applied magnetic field.
- By applying a bias current through the SQUID, the device generates a voltage that varies periodically with the applied magnetic flux.

IMP Q. ~~Explain~~ What are the applications of SQUID.

→ **Applications**

1] Medical Imaging:
- Magnetoencephalography (MEG) to map brain activity.
- Magnetic resonance imaging (MRI) enhancement.

2] Geophysics:-
- Detecting weak Magnetic fields from the earth for mineral exploration.

3] Nondestructive testing:-
- Detecting flaws in materials and structures.

4] Physics Research -
Studying superconductivity and quatum phenomenon.

5] Biomagnetism.
- Measuring weak magnetic fields generated by the heart or other organs.

classmate

Date ____
Page ____

Applications of superconductivity in Electronics

IMP

Q What are the applications of superconductivity in Electronics.

→ Applications:

1] Particle Detectors:
- Superconducting sensors with high sensitivity to detect subatomic particles.

2] Superconducting Filters:
- Provide high selectivity and low signal loss for RF and microwave frequencies.
- Used in telecommunications, satellite communications and mobile networks.

3] Superconducting power cables:
- Transmit electricity with negligible energy loss, increasing efficiency in power grids.
- Used in power transmission in urban areas and highcapacity energy network.

4] Superconducting Qubits :-
- Form the basis of quantum computers, providing stable coherent qubits for quantum computations.
- Used in quantum computing research.

5] Superconducting ditital circuits:
- ~~Ea~~ Enable Ultra-fast switching and low power consumption.
- Used in High - performance computing and advanced communication systems.