Unit-5

Superconductivity

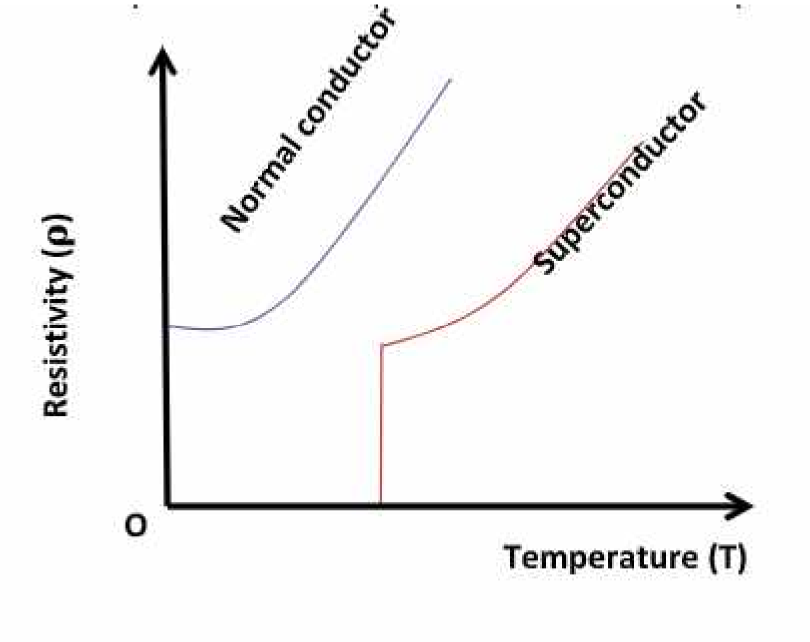
Lecture-37

Outlines

- Introduction to superconductivity
- Dependency of resistant on temperature in superconductors
- Transition temperature values for some superconductors
- Meissner effect

Introduction

- Heike kammerlingh Onnes discovered the superconducting phenomenon in 1911, while measuring the resistance of mercury metal.
- When any material (which have potential to show superconductivity) cooled below its transition temperature, its resistant drops suddenly to zero.



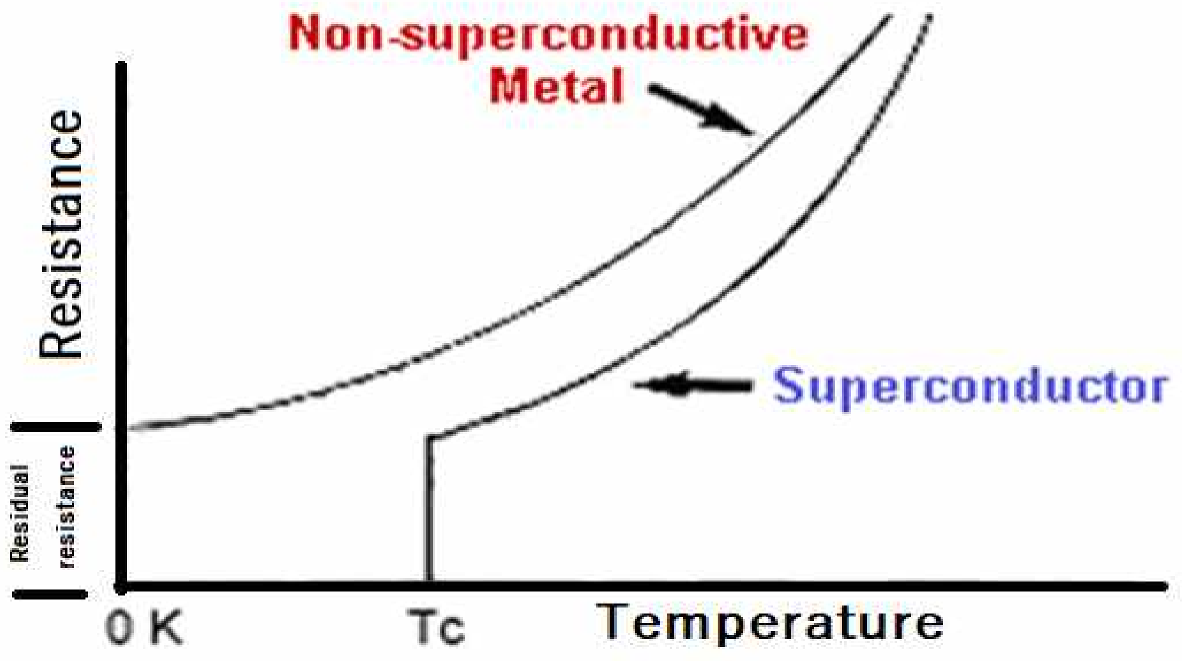
- This phenomenon is called superconductivity. Substance showing this property are called superconductors.

- Superconductivity is the property of certain materials to conduct direct current (DC) electricity without energy loss when they are cooled below a critical temperature (T_c).

- For example silver, lead, gallium, iridium etc.

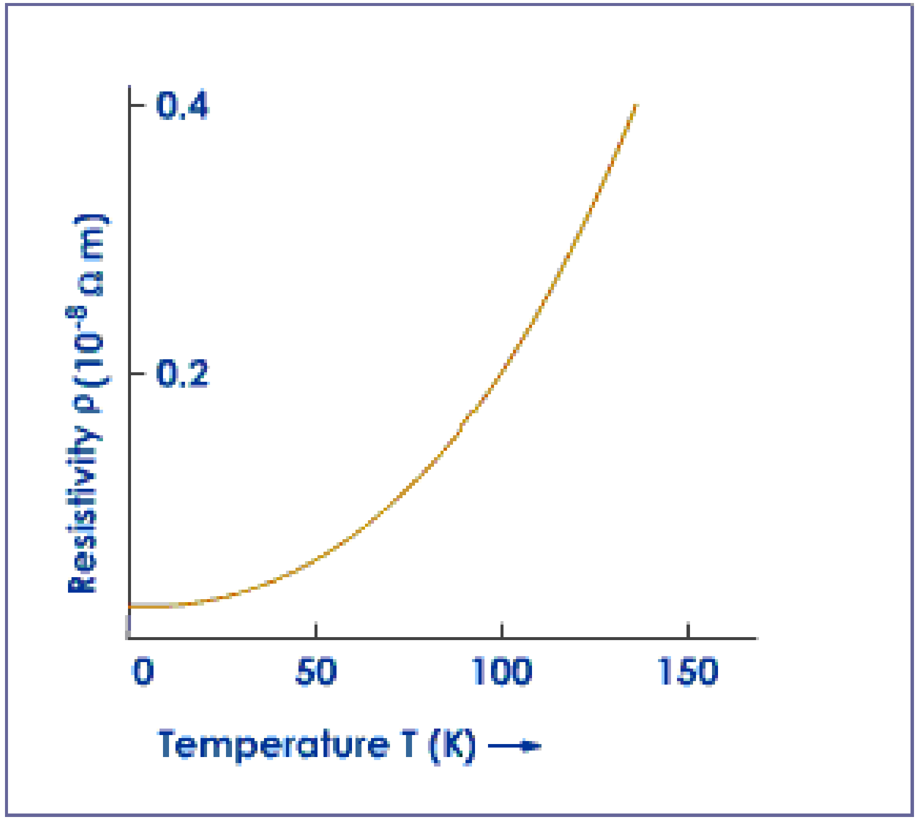
Temperature dependency resistivity in Metals

- Metals are good conductors of electricity as they have plenty of free electrons. However they offer resistance to the flow of charges.
- Even at 0K, the metals have some resistance called residual resistance.

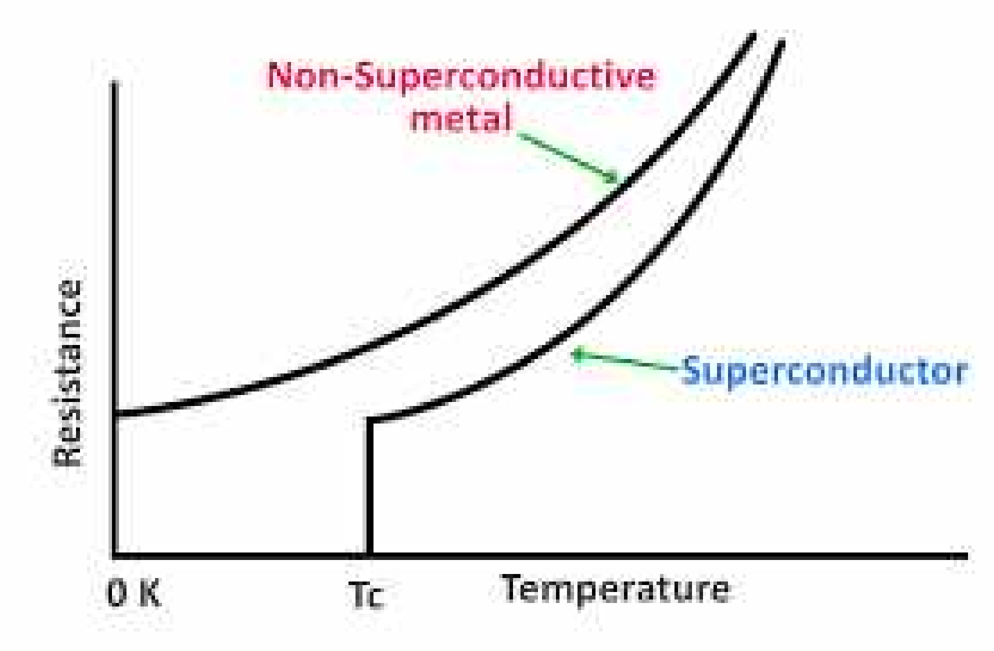


Temperature dependency resistivity in Metals

- Variation of resistivity of metal with variation in temperature are given below.



Temperature dependency resistivity in Superconductors



Temperature dependency of resistivity in superconductors

Transition temperature for superconductors

- The temperature at which normal metal turns into superconductor is called transition temperature.

- Examples are given in below table.

Element	T_C (K)	Compound	T_C (K)
Tungsten	0.01	$ZrAl_2$	0.30
Cadmium	0.56	AuBe	2.60
Aluminium	1.19	NiBi	4.25
Mercury	4.15	Nb_3Al	17.5

Important points

- In metal, there exist a small resistant value at lower temperature, this exist due to the impurity present in metal and called residual resistivity.

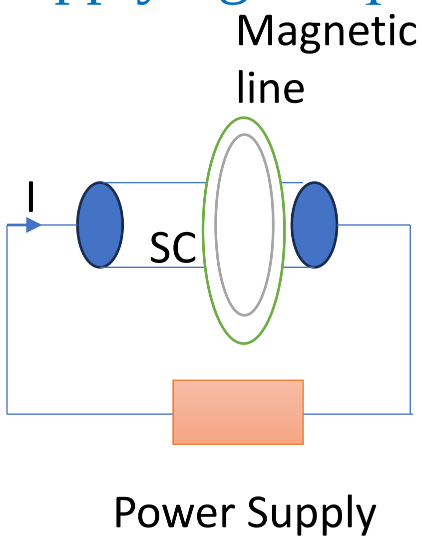
- On the other hand, transformation to superconducting state is independent to the impurity.

- The critical temperature is characteristic of superconducting material.

- If the temperature of superconducting material is increased, the material transformed to normal metal above the critical temperature.

Critical current

The maximum current that can be passed in a superconductor without destroying its superconductivity is called critical current. It is denoted by I_C.
Consider a superconducting wire of radius(r) and carrying a current I, Applying Ampere's law



$$\oint H.dl = I$$

$$H(2\pi r) = I$$

At $H = H_C$, Let $I = I_C$ then

$$I_C = 2\pi r H_C \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

If I become I_C, Superconductivity will be destroyed.

If external transverse magnetic field H is applied then total magnetic strength should be less than the critical magnetic field. Therefore

$$H_c = H_I + 2H$$

$$H_I = H_C - 2H$$

$$\frac{I_C}{2\pi r} = H_C - 2H$$

$$I_C = 2\pi r(H_C - 2H) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

This is called Silsbee's rule

Critical current

From equation (2) we conclude that critical current I_C decrease with applied field H. It becomes zero for $H = \frac{H_c}{2}$. If applied field is zero than

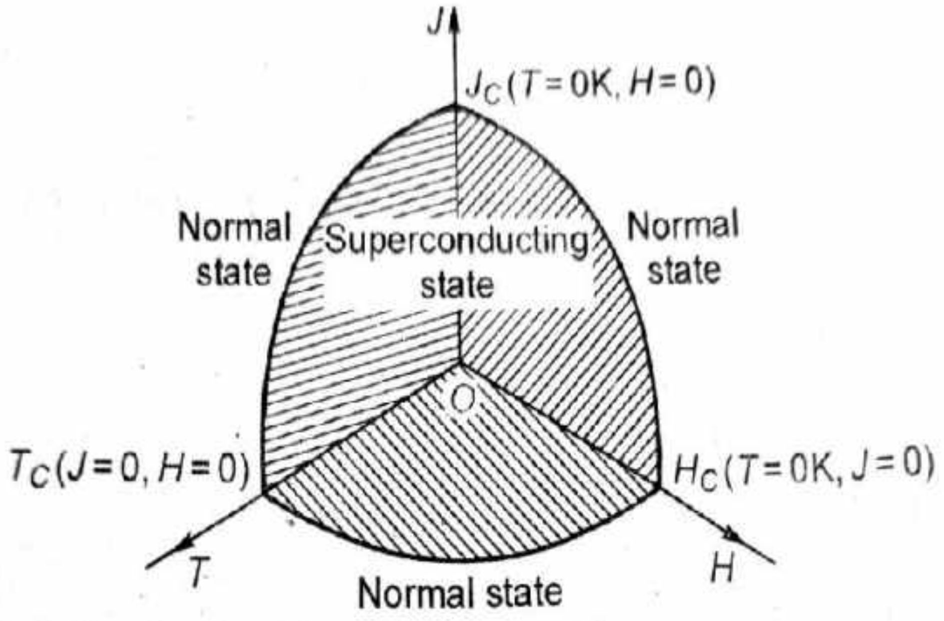
$$I_C = 2\pi r H_C \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Means superconducting state not only depends on temperature and magnetic field but also depends on current or current density.

These exists a critical surface in T, H and J for a particular superconductor as shown in figure in next slide.

Critical current

Therefore, within the boundary of phase diagram, the material is a superconductor and beyond it, the material exists in a normal state.



Phase diagram showing the effect of temperature, current density and magnetic field.

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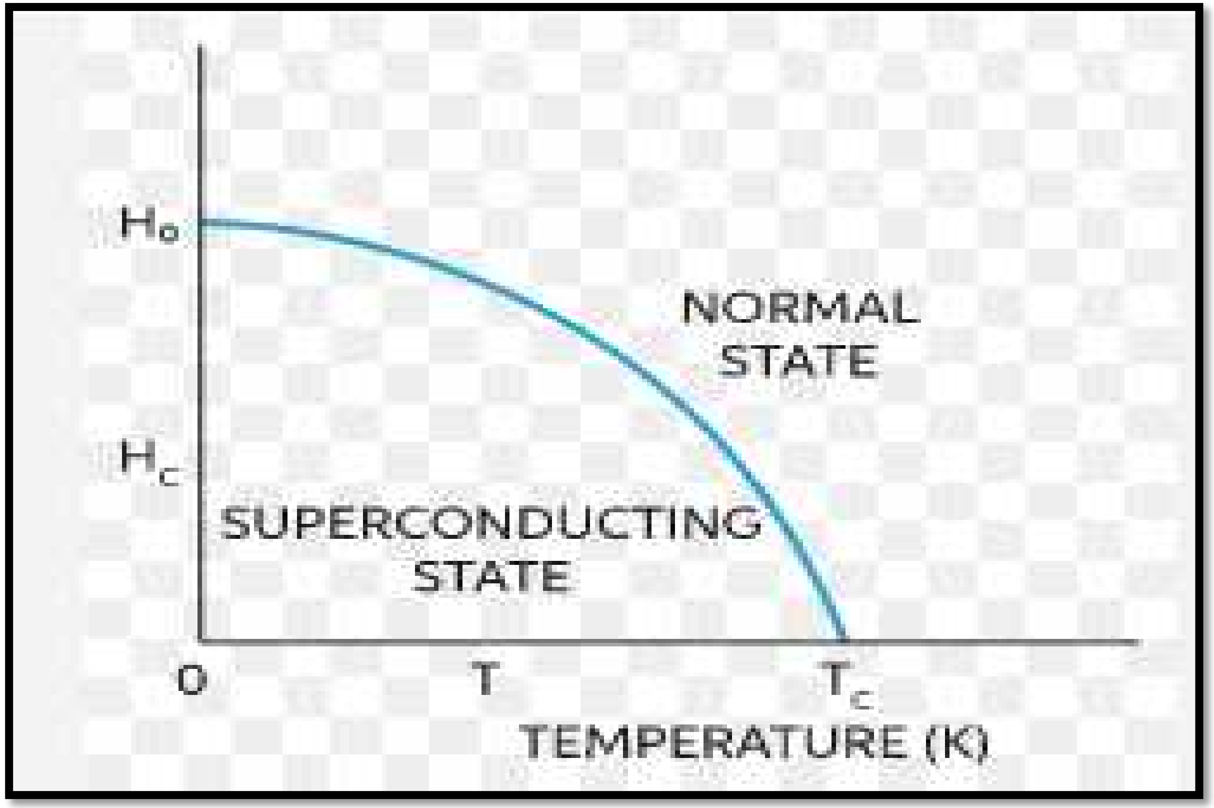
Outlines

- Temperature dependency on magnetic field in superconductors
- Meissner effect
- Transition temperature values for some superconductors

Effect of magnetic field (Temperature dependence of critical field)

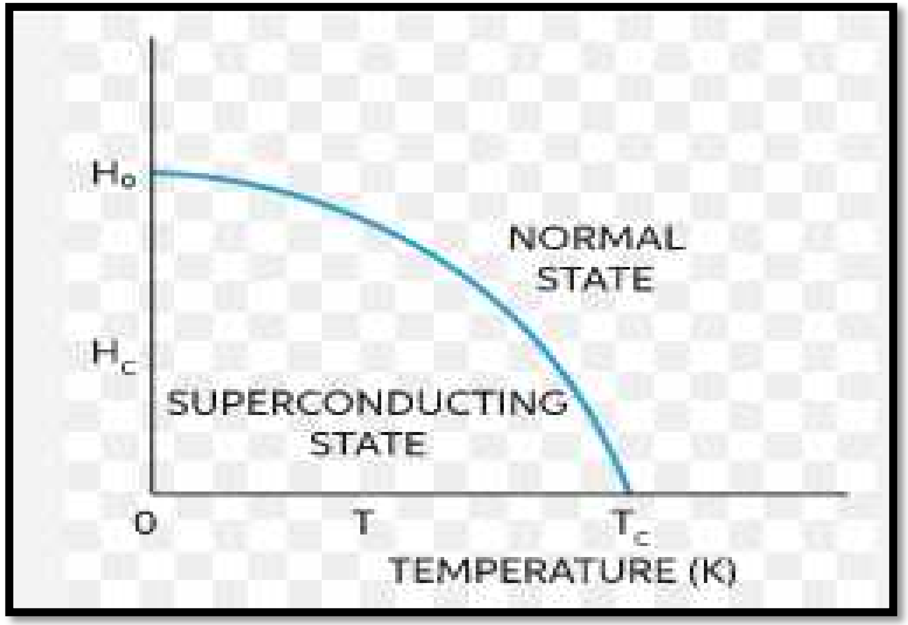
- Superconducting material restores its normal resistance when a strong magnetic field is applied. The minimum value of applied magnetic field when the superconductor loses its superconductivity is called the **critical magnetic field**.
- If the applied magnetic field exceeds the critical value H_C (0), the superconducting state is destroyed.



Normal conducting state of the material is restored if magnetic field is greater than the critical value or the temperature of specimen is raised above critical temperature $T_{C.}$

$$H_C(T) = H_C(0)\left[1 - \frac{T^2}{T_c^2}\right]$$

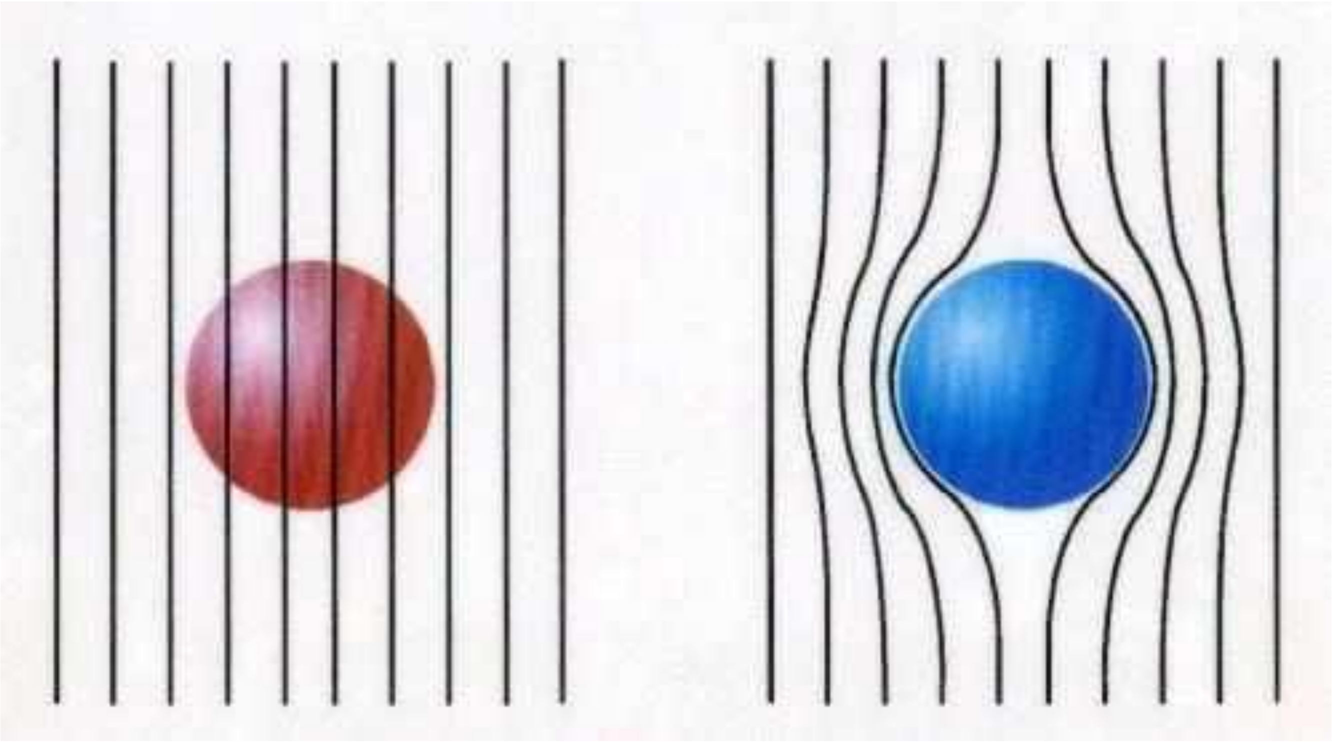
Where H_C (T) is the maximum critical field strength at temperature T, H_C (0) is the maximum critical field strength at absolute zero and T_C is the critical temperature.



Meissner effect

- Meissner and Ochsenfeld observed that if a superconductor cooled in a magnetic field, below the critical temperature corresponding to that field, magnetic field expelled out from material, and this effect is called Meissner effect.

- In normal state of material, magnetic field penetrate the material.



T > Tc

T < Tc

(1) Meissner effect is reversible, when temperature is increased below Tc, the flux suddenly penetrate through the specimen and substance comes to its normal state.

(2) A superconductor is a perfect diamagnetic.

Therefore, for superconductors

$$B = \mu_0(H+M) = 0$$

$$\text{or} \quad M = - H \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The magnetic susceptibility (χ) is given by –

$$\chi = \frac{M}{H} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

From (1) & (2)

$$\chi = \frac{-H}{H} = -1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

This is the maximum value for the susceptibility of a diamagnetic material.

(3) Maxwell's third equation is given by-

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \quad \text{-------} \ (4)$$

According to ohm's law

V =I R   and E = V/d

$$E = \frac{IR}{d} = \frac{(JA)R}{d}$$

$$E = J\rho$$

Where $\rho = AR/d$ ………… (5)

We know that for finite current density (J) resistivity(ρ) of a superconductor is zero. Therefore, E should be zero in equation (5)

From equation (4) $\frac{\partial \vec{B}}{\partial t} = 0$ or $\vec{B}$= constant

This shows that magnetic flux should not change when specimen is cooled. This condition shows contradiction to Meissner effect.

Therefore, superconductor should be judged by both the condition independently

- *Zero resistance below critical temperature.*
- *Meissner effect below critical temperature.*

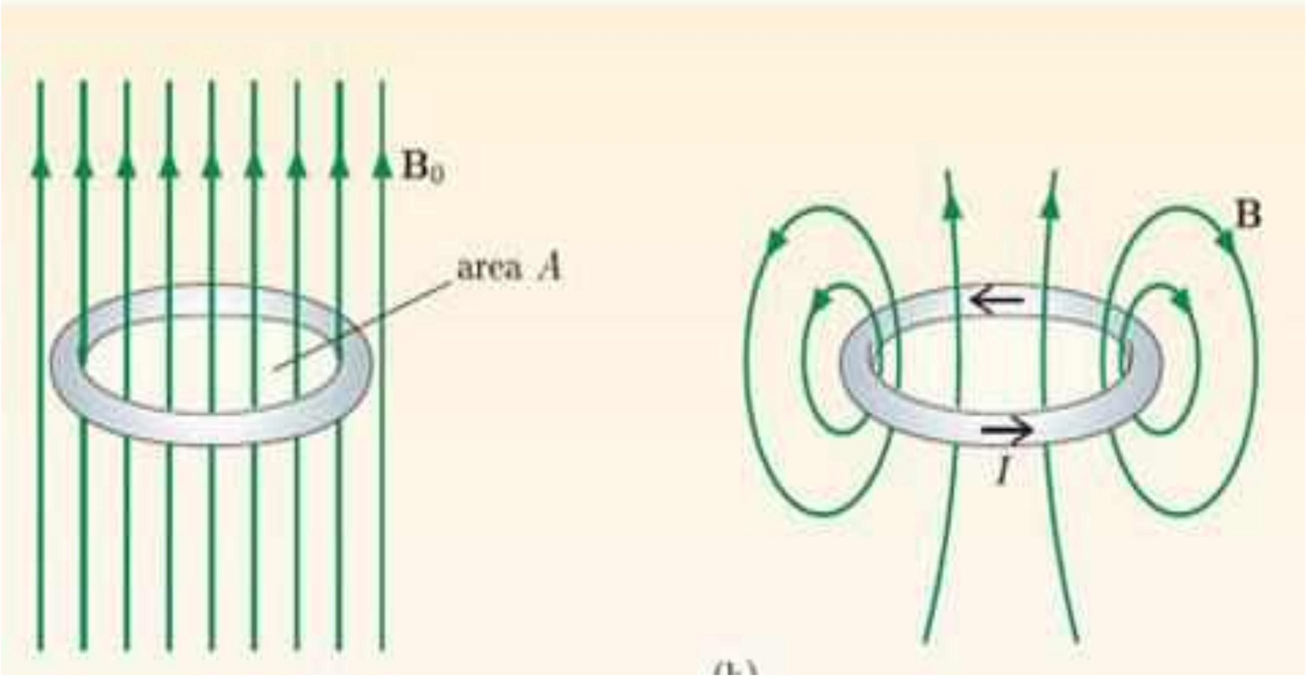
Persistent current in superconductor

- Persistent current refers to a perpetual electrical current, not requiring external power source. Such a current is impossible in normal electrical devices since all commonly used conductors have a non-zero resistance and this resistance would rapidly dissipate any such current as heat.

- Persist current will continue indefinitely as long as the medium is superconducting. The magnetic field inside the open area of the cylinder will also persist.

- Persistent current is one which flows in superconductors without any loss in its value for long time. Since in superconductor as the resistance is zero, the amount of current flowing remains same.

- Persist current carry in superconductor have to carry very high current, normally in the range of few thousand Amperes, compared to less than 1000 Amperes in conventional termination leads.



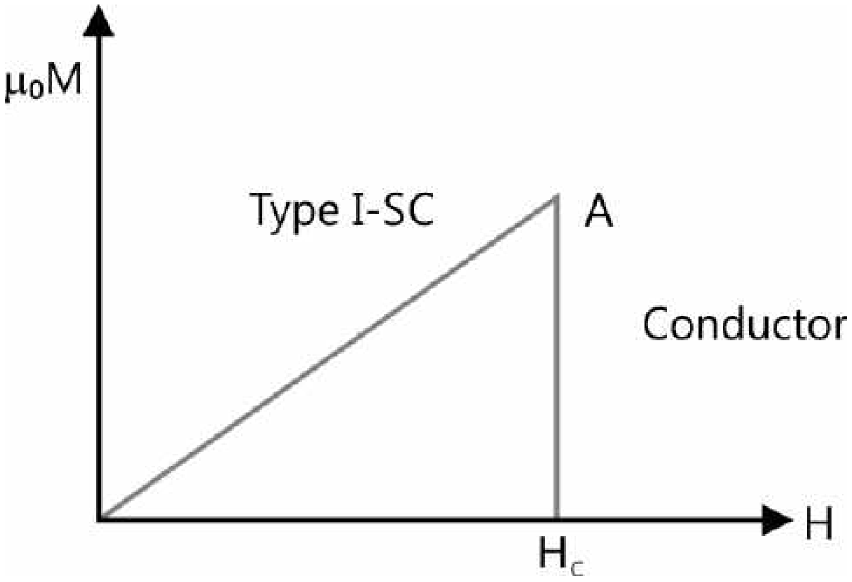
Types of Superconductor

Based on magnetic behavior, the superconductors are classified into following two categories:

1) Type –I superconductors or soft superconductors
2) Type- II superconductors or hard superconductors

Type –I Superconductors

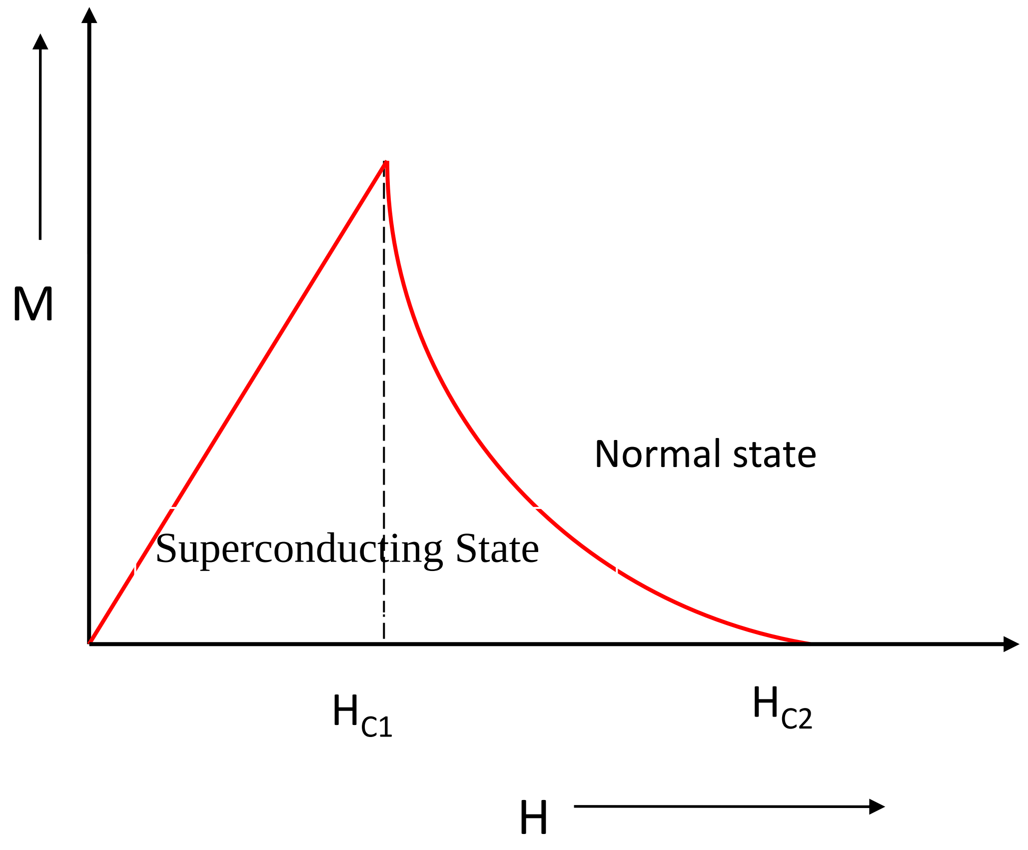
The dependence of magnetization of superconductor of type-I as a function of external field H. Up to the critical field strength (H_C), the magnetization of superconductor grows in proportional to the external field. As soon as the applied field H exceeds H_C, the magnetization abruptly drops to zero, as shown in figure



It loses its diamagnetic property completely, when H exceed H_C. In this state, magnetic flux penetrates throughout the superconductor. So type-I superconductor is one in which the transition from superconducting state to normal state in presence of magnetic field occurs sharply at the critical H_C. The critical field value H_C for type-I superconductors is found to be very low. *Aluminum, lead and indium* are example of type –I superconductors.

Type II Superconductors

- The magnetization of type –II superconductor is shown in above figure. The type –II superconductor is characterized by **two critical magnetic fields H_{C1} and H_{C2}.**



- For the field strength below $H_{C1,}$ the superconductors expel the magnetic field from its body completely and behave as a perfect diamagnetic. H_{C1} is called the lower critical field.

- As the magnetic field increases from H_{C1}, the magnetic field lines begin to penetrate the material. The penetration increases until H_{C1} is reached. H_{C2} is called the upper critical field. At H_{C2}, the magnetization vanished completely; i.e the external field has completely penetrated into superconductor and destroyed the superconductivity.

- In region from H_{C1} to H_{C2}, the specimen assumes a complicated **mixed structure** of normal and superconducting states. The superconductor is said to be in a mixed state which is commonly known as **vortex state.**

- After H_{C2}, the material turns to normal state so, type –II superconductor is one which is characterized by two critical fields H_{C1} and H_{C2}. Transition to normal state take place gradually as magnetic field is increased from H_{C1} to H_{C2}.

Difference between type –I and type –II superconductors

Type-I Superconductors	Type-II Superconductors
Type-I superconductors exhibit complete Meissner effect.	Type-II superconductors show complete Meissner effect below $H_{C1,}$ and allow penetrating the superconductor between H_{C1} and $H_{C2.}$ Between H_{C1} and $H_{C2,}$ the material shows a region of mixed state.
Above critical field $H_{C,}$ the superconductors become normal conductor.	Between H_{C1} and $H_{C2,}$ superconductor exits in a mixed state called as vertex state and above $H_{C2,}$ they comes in normal state
Type-I superconductors are known as Soft superconductors	Type-II superconductors are known as Hard superconductors
The critical field H_C is relatively low. They can generate field about 100 to 1000 gauss.	The value of H_{C2} is very large. They are able to produce very high magnetic field. They can carry large current when magnetic field is between H_{C1} and H_{C2}
Type-I superconductors are materials such as Al, Zn, Ga etc.	Type-II Superconductors alloys like lead-indium alloy etc.

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Superconductivity

Lecture-39

Outlines

- Introduction to High Temperature Superconductors
- Property of superconductors
- Application of superconductors

High Temperature Superconductors

- The high temperature superconductors are also called as high T_C material.
- All high temperature superconductors are different type of oxides of copper. High temperature superconductors showed promise in pre-commercial applications, as in thin film device& wires being fabricated. Few examples are-

$BaPb_{0.75}Bi_{0.25}O_3$	**T_{C} = 12K**	**(BPBO)**
$La_{1.85}Ba_{0.15}CuO_4$	T_{C} = 36K	(LBCO)
$YBa_2Cu_3O_7$	T_{C} = 90K	(YBCO)
$Tl_2Ba_2Ca_2Cu_3O_{10}$	T_{C} = 120K	(TBCCO)

Important observations

1. All high temperature superconductors bear a particular type of crystal structure called the Perovskite structure.

2. The addition of extra copper oxygen layer into the structure unit of superconducting copper oxide complexes pushes the critical temperature to high values.

3. The addition of any atom into copper oxide layer either being down or destroy the effect of superconductivity.

4. The important observation is that the formation of super-currents in high T_C superconductors is direction dependent. The superconductors are strong in Copper-Oxygen planes and weak in direction perpendicular to the plane.

Properties of superconductors

1. It is a low temperature phenomenon.
2. Superconductors are perfect diamagnetic materials, have magnetic susceptibility -1.
3. Superconductors loses their superconductivity above critical temperature values.
4. They show Meissner effect below critical temperature.
5. They have infinite conductivity or zero resistivity ideally.
6. The transition temperature is different for different substances.
7. Ferro and anti-ferromagnetic materials are not superconductors.

Application of superconductors

1. Power transition

Electrical power transition through any conductor is always accompanied by energy lossI^2R, where I is current & R is resistant of the conductor. If superconductors are used, the losses will be eliminated & power transition can be done at a lower voltage level.

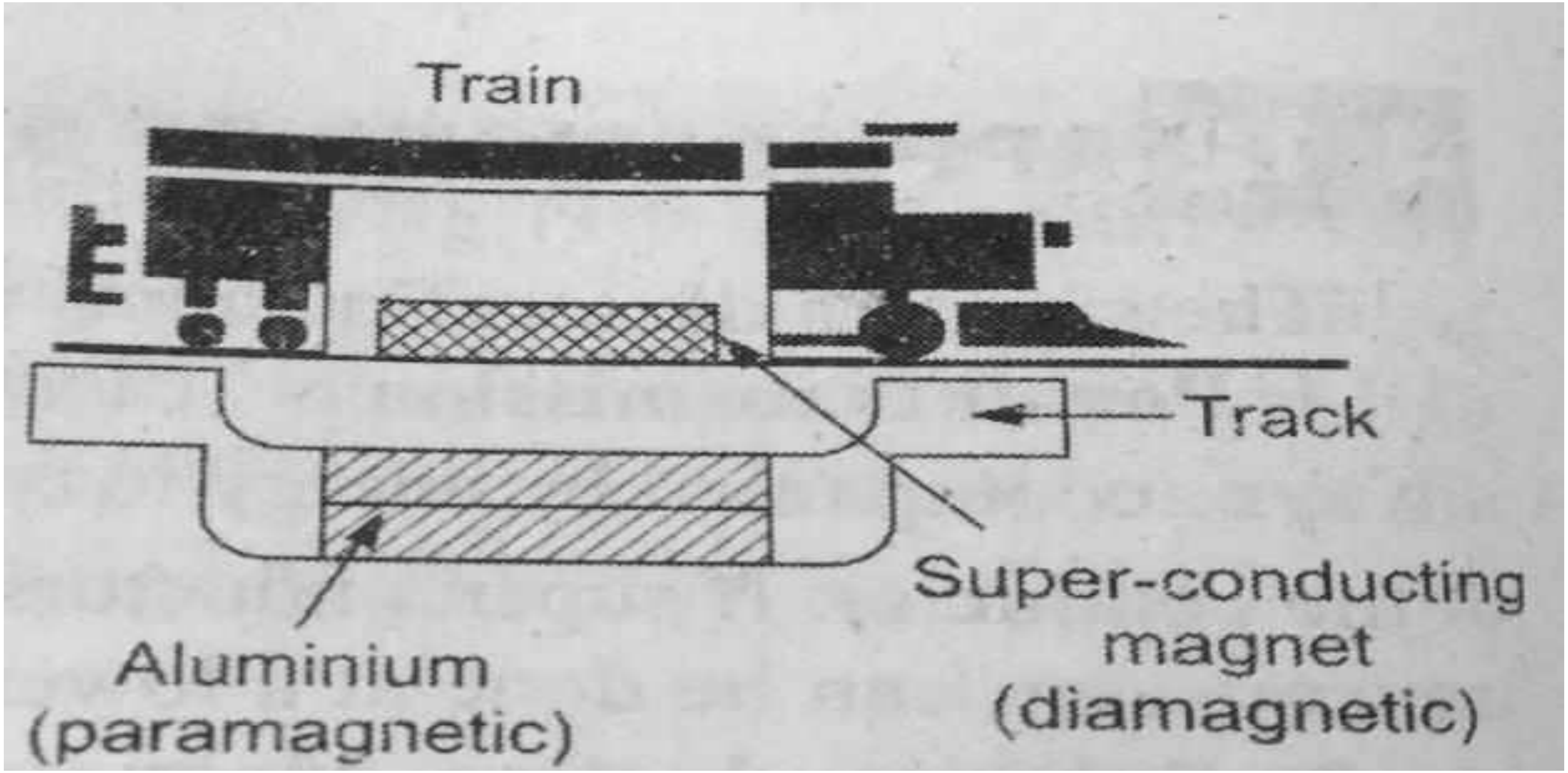
2. Superconducting Magnets

An electromagnet made by using coils of superconducting material (wire & cables) is called superconducting magnets. The main advantage is that once the current is set-up, the coil requires no source of e.m.f. to drive the current.

3. Maglev Vehicles

- In a superconductor, the magnetization is in the direction opposite to that of external magnetic field. This is known as diamagnetism. When a superconductor magnet is brought near a permanent magnet, there is a strong repulsive force between them. This force causes the lighter one to float over the other. This is known as Magnetic Levitation

- The Maglev vehicle (say a train) consisting of superconducting magnets build into its base. Say the vehicle runs over an aluminum track in which a current is flowing. The train is set afloat by magnetic levitation as shown in fig. This is due to enormous repulsion between two highly powerful magnetic fieldstone produce by the superconducting magnet inside the train & other due to electric currents in the aluminum track. As in the fig. the train floats without touching the track as repulsion between superconducting magnets & the magnetic field induced in the track.


Train
Track
Super-conducting
magnet
(diamagnetic)
Aluminium
(paramagnetic)

4. Very strong magnetic field

Very strong magnetic field (of order of 50 Tesla by consuming only 10KV) can be generated with coil made superconducting materials. High magnetic fields are required in many areas of research and diagnostic equipment's in medicine.

5. SQUIDS (Superconducting quantum interference devices)

SQUIDS are fundamentally superconducting ring that act as stronger devices of magnetic flux. They are used to detect very minute changes in magnetic field of human brain and body.

6. For progress of computer technology

At present, due to heat generated through I^2R , there is limit to which the components can be crowded on a chip of give size. The use of superconductors will make it possible to cram more circuits in given area.

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Superconductivity

Lecture-40

Outlines

- Numerical regarding Superconductors

The transition temperature for Pb is 7.2K. However at 5K it lose the superconductivity property if subjected to a magnetic field of 3.3×10^4 A/m. Find the value of H_c (0) which will allow the metal to retain its superconductivity at 0K.

Sol.

$$H_c(T) = H_c(0)\left[1 - \frac{T^2}{T_C{}^2}\right]$$

$$H_c(0) = \frac{H_c(T)}{\left[1-\frac{T^2}{T_C{}^2}\right]}$$

$$H_c(0) = \frac{3.3\times10^4}{\left[1-\frac{5^2}{(7.2)^2}\right]} = \frac{3.3\times10^4}{[1-0.4875]}$$

$$H_c(0) = 6.37$$

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

Sol.

$$T = T_c\left[1 - \frac{H_c(T)}{H_c(0)}\right]^{1/2}$$

$$= 7.26\left[1 - \frac{4\times10^4}{8\times10^5}\right]^{1/2}$$

$$= 7.08\ \mathrm{K}$$

At what temperature is $H_c(T) = 0.1\ H_c(0)$ for lead having T_c 7.2K.

Sol-

$$H_c(T)=H_c(0)\left[1-\frac{T^2}{T_C{}^2}\right]$$

$$0.1H_c\,(0) = H_c\,(0)\left[1-\frac{T^2}{(7.2)^2}\right]$$

$$0.1 = 1-\frac{T^2}{(7.2)^2}$$

$$T^2 = (7.2)^2\,[1\text{-}0.1] = 6.83\ K$$

A superconducting material has a critical temperature of 3.7K in zero magnetic field of 0.0306 Tesla at 0K. Find the critical field at 2K.

Sol.:-

$$H_c(T) = H_c(0)\left[1 - \frac{T^2}{T_C{}^2}\right]$$

$$H_c(T) = 0.0306\left[1 - \frac{2^2}{(3.7)^2}\right] = 0.0306(1\text{-}0.29002)$$

$$H_c(T) = 0.0217 \text{ Tesla}$$

The critical field for Niobium is 1×10^4 A/m at 8K & 2×10^5 A/m at 0K. Calculate the transition temperature of the element.

Sol.:-

$$T = T_c\left[1 - \frac{H_c(T)}{H_c(0)}\right]^{1/2}$$

$$T_c = \frac{T}{\left[1-\frac{H_c(T)}{H_c(0)}\right]^{1/2}}$$

$$= \frac{8}{\left[1-\frac{1\times10^4}{2\times10^5}\right]^{1/2}}$$

$$= \frac{8}{\left[1-\frac{1}{20}\right]^{1/2}} = 7.08\ \text{K}$$

The magnetic field intensity in the material is zero at 3.69K and ($\frac{3\times10^5}{4\pi}$) at 0K. Calculate the temperature of the superconductors if the field intensity is measured as ($\frac{2\times10^5}{4\pi}$).

Sol.:-

$$H_c(T) = H_c(0)\left[1 - \frac{T^2}{T_C{}^2}\right]$$

$$B_c(T) = B_c(0)\left[1 - \frac{T^2}{T_C{}^2}\right]$$

$$\frac{\mathbf{2\times10^5}}{\mathbf{4\pi}} = \frac{\mathbf{3\times10^5}}{\mathbf{4\pi}}\left[1 - \frac{T^2}{3.69^2}\right]$$

$$\frac{T^2}{(3.69)^2} = 1 - \frac{2}{3}$$

$$T = 2.13K$$

For a specimen of superconductor, the critical fields are 1.4×10^5 and 4.2×10^5 A/m for temperature 14 and 13K. Calculate the transition temperature and critical field at 0K and 4.2 K.

Sol.:- $(H_c)_1 = H_0\left[1 - \frac{(14)^2}{T_C{}^2}\right] = 1.4\times10^5$ ....(i)

$(H_c)_2 = H_0\left[1 - \frac{(13)^2}{T_C{}^2}\right] = 4.2\times10$ .... (ii)

Dividing eq. (ii) by eq. (i), we get

$$\frac{(H_{C1})}{(H_{C2})} = \frac{T_C{}^2-(13)^2}{T_C{}^2-(14)^2} = \frac{4.2}{1.4}$$ .... (iii)

Solving equation (3) for T_c, we get

$T_c = 14.5K$

Put $T_{c\ in}$ eq. (i)

$$H_0\left[1 - \frac{(14)^2}{(14.5)^2}\right] = 1.40 \times 10^5$$

$$H_0 = \frac{1.40\times10^5}{1-\frac{(14)^2}{(14.5)^2}} = 20.67 \times 10^5 \text{ A/m}$$

Now

$$(H_c)_{4.2} = H_0\left[\frac{1-(4.2)^2}{(14.5)^2}\right]$$

$$= (20.67\times 10^5) \times (0.916)$$

$$= 18.9 \times 10^5 \text{ A/m}$$

Calculate the critical current which can flow through a long thin superconducting wire of diameter 10^{-3},given H_c=7.9$\times$ 10^{3}amp/m

Sol:-

$$I_c = 2\pi r H_c$$

$$= 2 \times 3.14 \times \frac{10^{-3}}{2} \times (7.9 \times 10^{-3})$$

$$= 24.81\ A$$

Determine the critical current and critical current density for a superconducting ring of diameter 10^{-3}m at temperature of 4.2K. Given the critical temperature for the sample is 7.18K and critical magnetic field is 6.5×10^{4}A/m.

Sol:-

$$H_c(T) = H_c(0)\left[1 - \left(\frac{T}{Tc}\right)^2\right]$$

$H_c(0) = 6.5\times10^4$ A/M, Tc= 7.18 K, T= 4.2 K

Putting the value of parameters in above equation

$H_c(0)= 4.276\times10^4$ A/M

Critical Current;

$I_c = 2\pi r H_c$

$I_c= 2\times3.14\times(10^{-3})\times(1/2)\times4.276\times10^4$

I_c=134.3 Amp

Current density:

$$J_c = I_c/\text{Area}$$

$$Jc = 1.71 \times 10^8\ \text{A/m}^2$$

Calculate the temperature at which the critical magnetic field is two third of the value at 0K for a tin superconductor with T_c = 4 K (2018,19)

Sol:- Given ; $H_c(T) = 2/3\ H_c(0)$, $T_c = 4K$

We know that,

$$\left(H_c(T) = H_c(0)\left[1 - \left(\frac{T}{Tc}\right)^2\right]\right)$$

$$2/3\ H_c(0) = H_c(0)\left[1 - \left(\frac{T}{Tc}\right)^2\right]$$

$$\left(\frac{T}{4}\right)^2 = 1/3$$

$$T = 2.31\ K.$$

Unit-5

Nanomaterials

Lecture-41

Outlines

- Introduction of nano world

Nanomaterials

1. Nanomaterials have a relatively larger surface to volume ratio than their bulk counterpart. This makes them more chemically reactive and affect their strength or electrical properties.
2. Quantum effects dominating in the atomic ranges affecting various behaviour of materials.

- For example: Opaque substances can become transparent(copper)

- Stable materials can become combustible(aluminium)

- Inert materials can become catalyst(platinum)

- Solids can change into liquid at room temperature(gold)

Nanotechnology

- Nanotechnology is that technology of design, synthesis, characterization and application of materials on nanoscale.

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Nanomaterials

Lecture-42

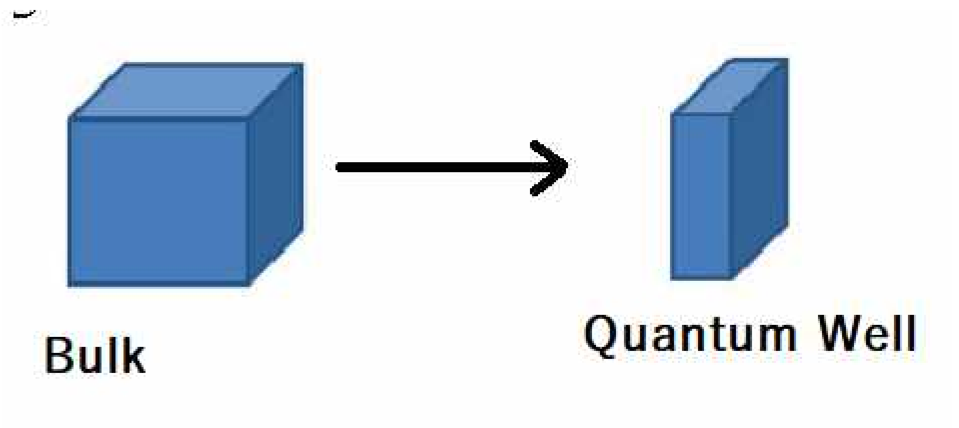
Outlines

- Quantum Well
- Quantum Wire
- Quantum Dots

Quantum well

A quantum well is a nanometer thin layer which can confine particles in the dimension perpendicular to the layer surface, whereas the movement in the other dimension is not restricted.

If one dimension is reduced to the nanometer range while the other dimensions remain unchanged then the structure formed is called quantum well.



- These are made by epitaxial crystal growth techniques.

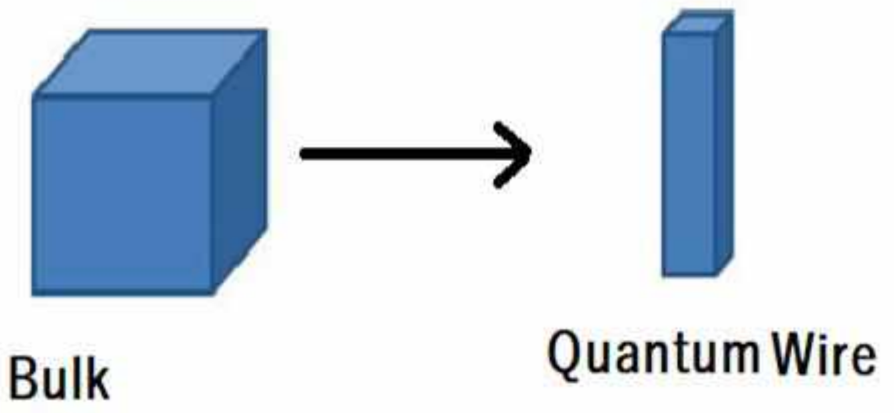
- These are used widely in diode lasers, including red lasers for DVDs, lasers printers and also for HEMTs (High Electron Mobility Transistors) which are used in low-noise electronics.

Quantum wire

If two dimensions are reduced to nano-range while the third remains the same, then the structure so formed is called quantum wire.

A quantum wire is a cable or a wire, often similar in function to copper wire, but made with usually carbon Nano-tubes Quantum wires are usually conductors, but may be made as insulators or semiconductors.

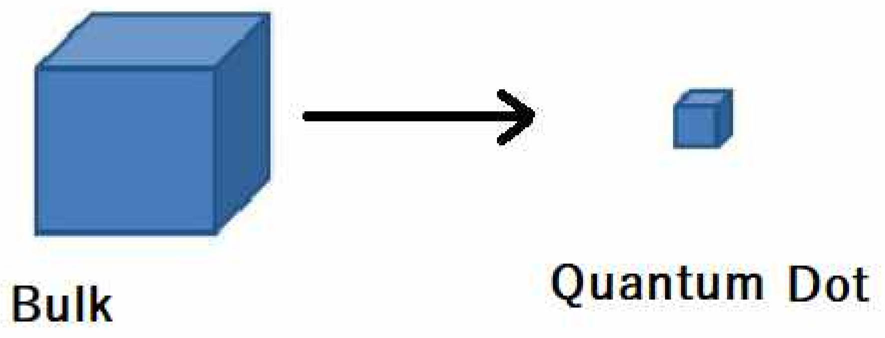
Nano-wires have two quantum-confined directions but one unconfined direction available for electrical conduction.



Quantum Dots

When all the three dimensions of the material are reduced to nano range, then it is called as quantum dots.

Quantum dots have properties intermediate between bulk semiconductors and discrete atoms or molecules. These are zero-dimensional nanostructures.



These are semiconductor particles a few nanometers in size having optical and electrical properties.

eg. Larger QDs (5-6 nm) emits longer wavelength while smaller ODs (2-3 nm) emits shorter wavelength.

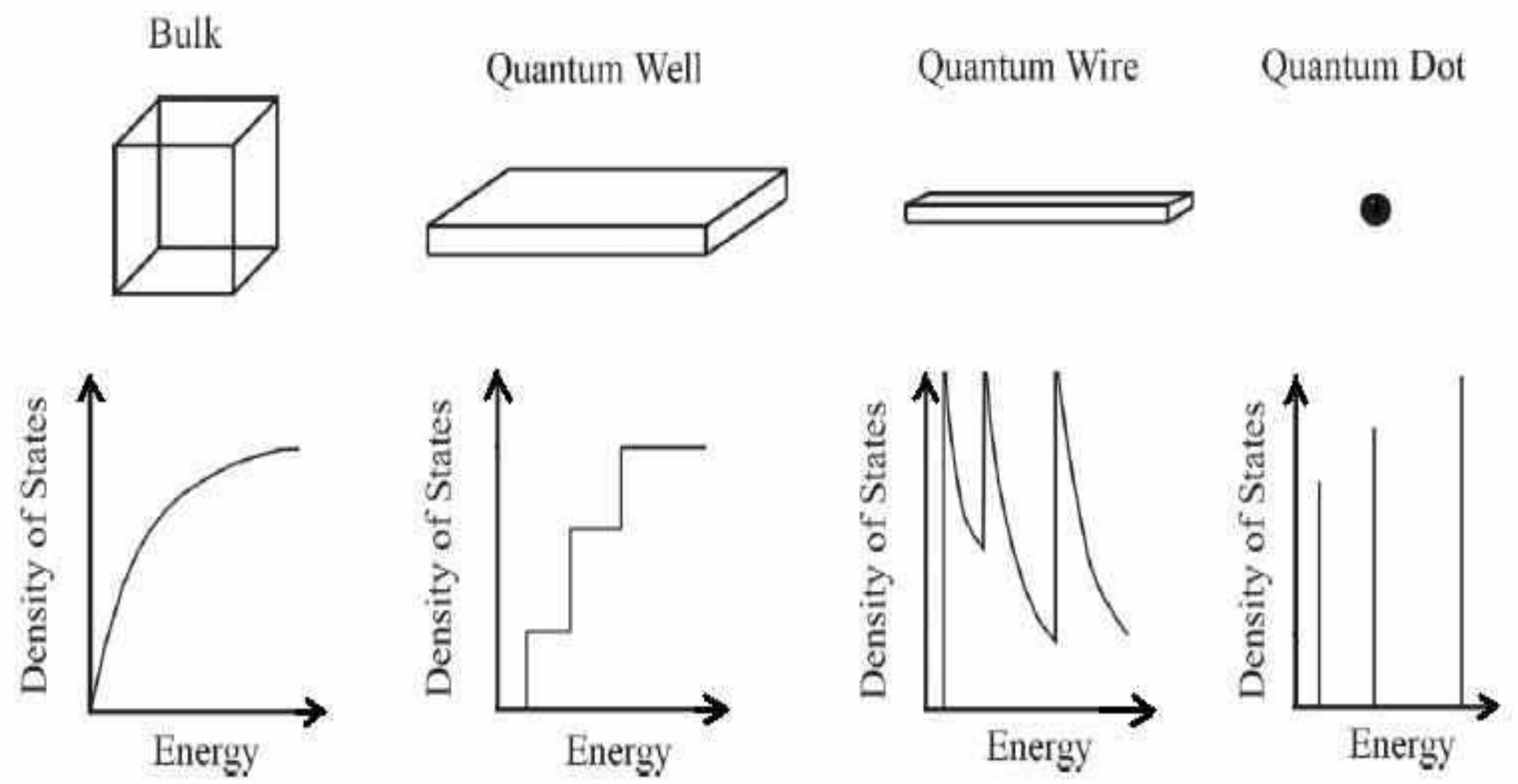
Examples of Quantum dots are:

Cadmium selenide (CaSe), cadmium telluride (CdTe)

Zinc selenide (ZnSe), Indium Phosphide (InP)

Density of states

It is defined as number of states per unit energy per unit volume that electrons are allowed to occupy. It is denoted by g(E)



Unit-5

Nanomaterials

Lecture-43

Outlines

- ➢ Synthesis of Nanomaterials

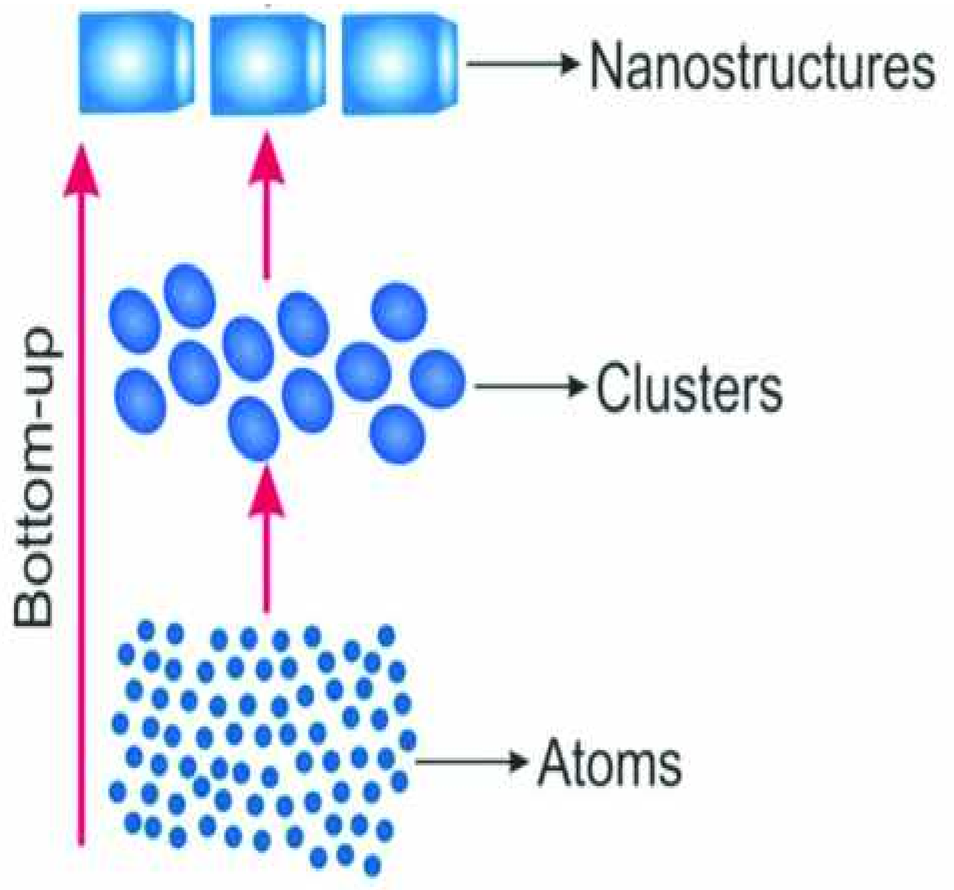
1. Bottom up Technique
2. Top- down Technique

- ➢ Chemical Vapour Deposition
- ➢ Sol gel Method
- ➢ Advantage of CVD method
- ➢ Advantage of Sol gel method

Synthesis of nanomaterials

Bottom -up Technique

This is a technique in which materials and devices are build up atom by atom i.e, a technique to collect, consolidate and fashion individual atoms and molecule into the structure. This is carried out by a sequence of chemical reactions controlled by series of catalysts.



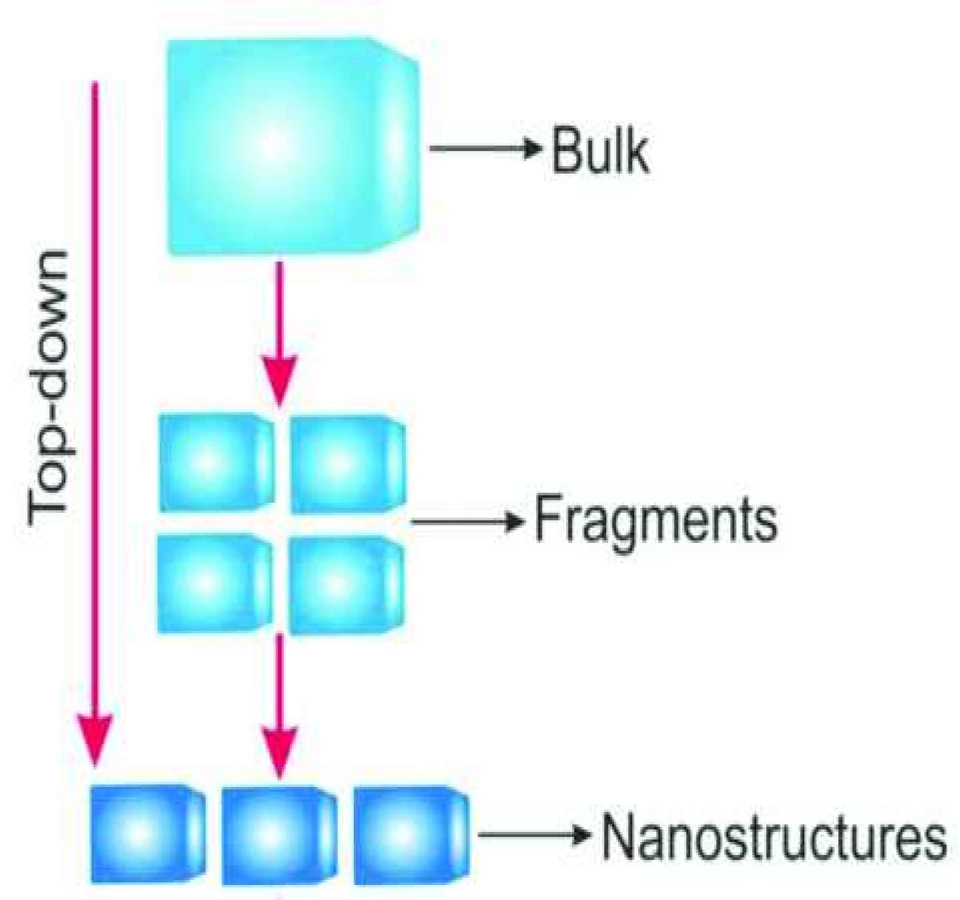
Synthesis of nanomaterials

Top-Down Technique

This is a technique in which materials and devices are synthesized or constructed by removing existing material from larger entities.

Therefore, in this technique a large-scale object or pattern is gradually reduced in dimension to nanoscale pattern.

This can be accomplished by a technique called lithography.



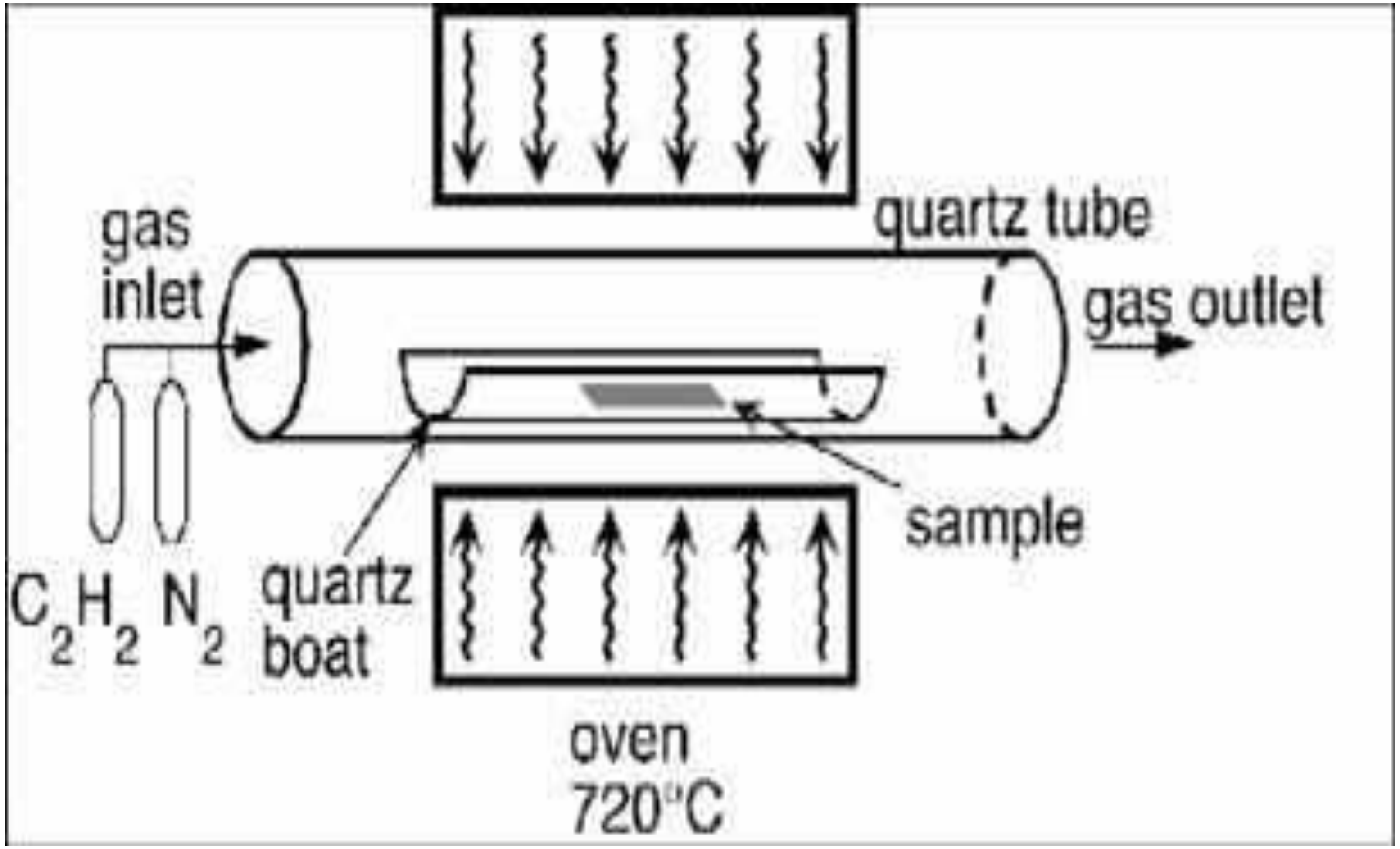
Chemical Vapour Deposition (CVD)

In this method a substrate is prepared with a layer of metal catalyst particle such as nickel, cobalt or iron.The substrate is heated to approximately 700^0C in a chamber. To initiate the growth of nanotubes, two gases are blown into the chamber (precursors) which are methane (carbon containing gas) and other is a process gas ammonia, nitrogen or hydrogen.

The high temperature breaks the bonds between the carbon atoms and hydrogen atoms in the methane molecules. This results in carbon atoms with no hydrogen atoms attached. These carbon atoms attach to the catalyst particles where they bond to other carbon atoms. This results in the formation of nanotube.

Nanotubes formed can be:

a) SWNT (single walled nanotubes)
b) MWNT (Multi walled nanotubes)



Chemical Vapour Deposition Process

Sol-Gel method

It is bottom-up approach and chemical-based method to synthesize nanomaterials. This method is used to synthesize metal oxide nanoparticles. A sol is a colloidal (the dispersed phase in which size of particles is so small that gravitational forces do not exist.)

A gel is a semi-rigid mass that forms when the solvent from the sol begins to evaporate and the particles left behind begin to join together in a continuous network. This is accomplished by sedimentation on centrifugation.

The remaining liquid is removed using the crying process accomplished by thermal treatment and remaining left as dried gel. This further enhanced the mechanical stability The dried gel is grinded to get the material into powdered form.

The powder then is sifted (process of removing lumps) to get the final product. This final product can be deposited on a substrate to get a thin film or we can cast it into desired shapes.

Sol-Gel method

Advantages of a CVD

- It is used to produce high purity, high performance solid materials.
- By-products are removed by carrier gas flow through the reaction chamber.
- Substrate is exposed to one or more volatile precursors which reacts or decompose on substrate surface to produce desired compound.

This is widely applied to produce coatings, powders, fibres and monolithic components.

Advantages of Sol-Gel method

- It is a cheap and low-temperature technique.
- It gives us fine control of product's chemical composition.
- Rate of reaction can be easily controlled.
- Even small quantities of dopants can be uniformly dispersed in the final product.

Unit-5

Nanomaterials

Lecture-44

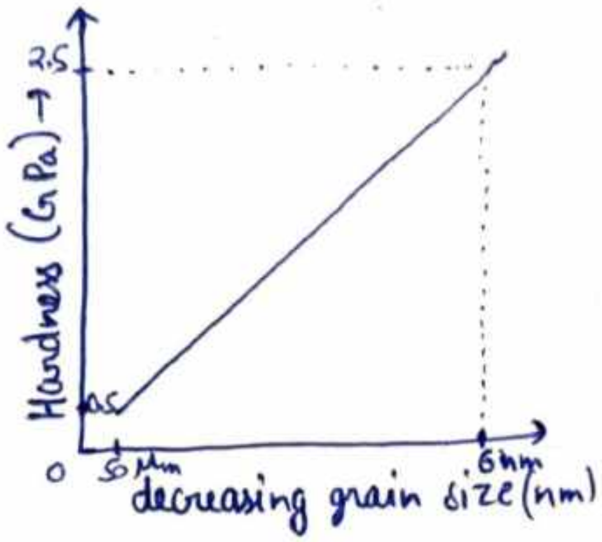
Outlines

- Properties of Nanomaterials
- Mechanical property
- Optical Property
- Magnetic property
- Electronic property
- Application of nanomaterials
- Numerical

Properties of Nanomaterials

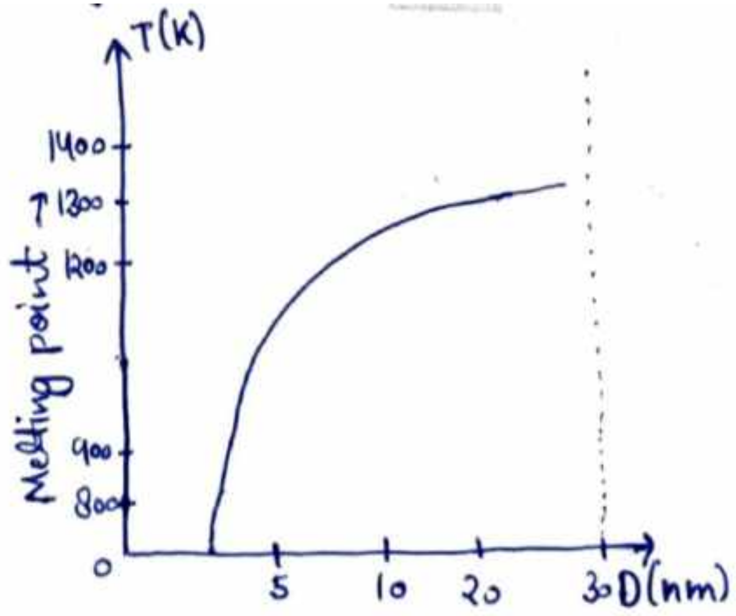
1. Mechanical Properties

Very small nanoparticles have almost all their atoms on the surface which give them more. go larger from their equilibrium positions. freedom to Nanophase metals with their exceptionally small grain size are found to be exceptionally strong.



The variation of hardness with diameter of copper nanocrystal is shown.

The melting point of the cluster depends on the number of atoms/ in the crystal. It increases with increase in number of atoms & attains the value of bulk material when cluster contains > 1000 atoms.



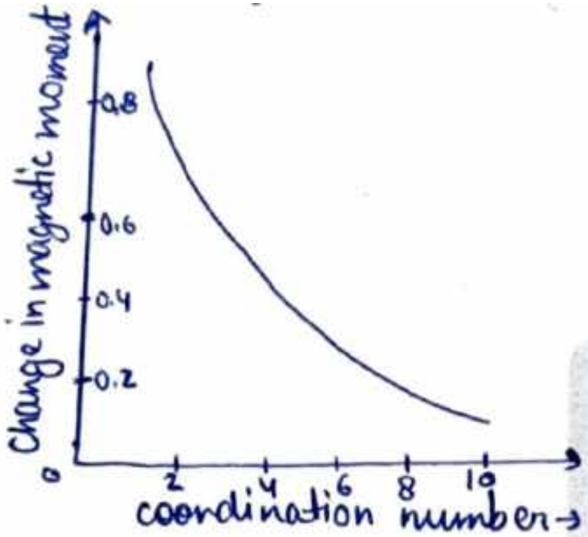
Melting point of gold as a function of grain size.

2. Optical Properties

The absorption of photons occurs because electrons from lower energy state to higher energy states. It is observed that clusters of different sizes have different energy level separations. So, their absorption is different for different clusters hence the different colours.

3. Magnetic Properties

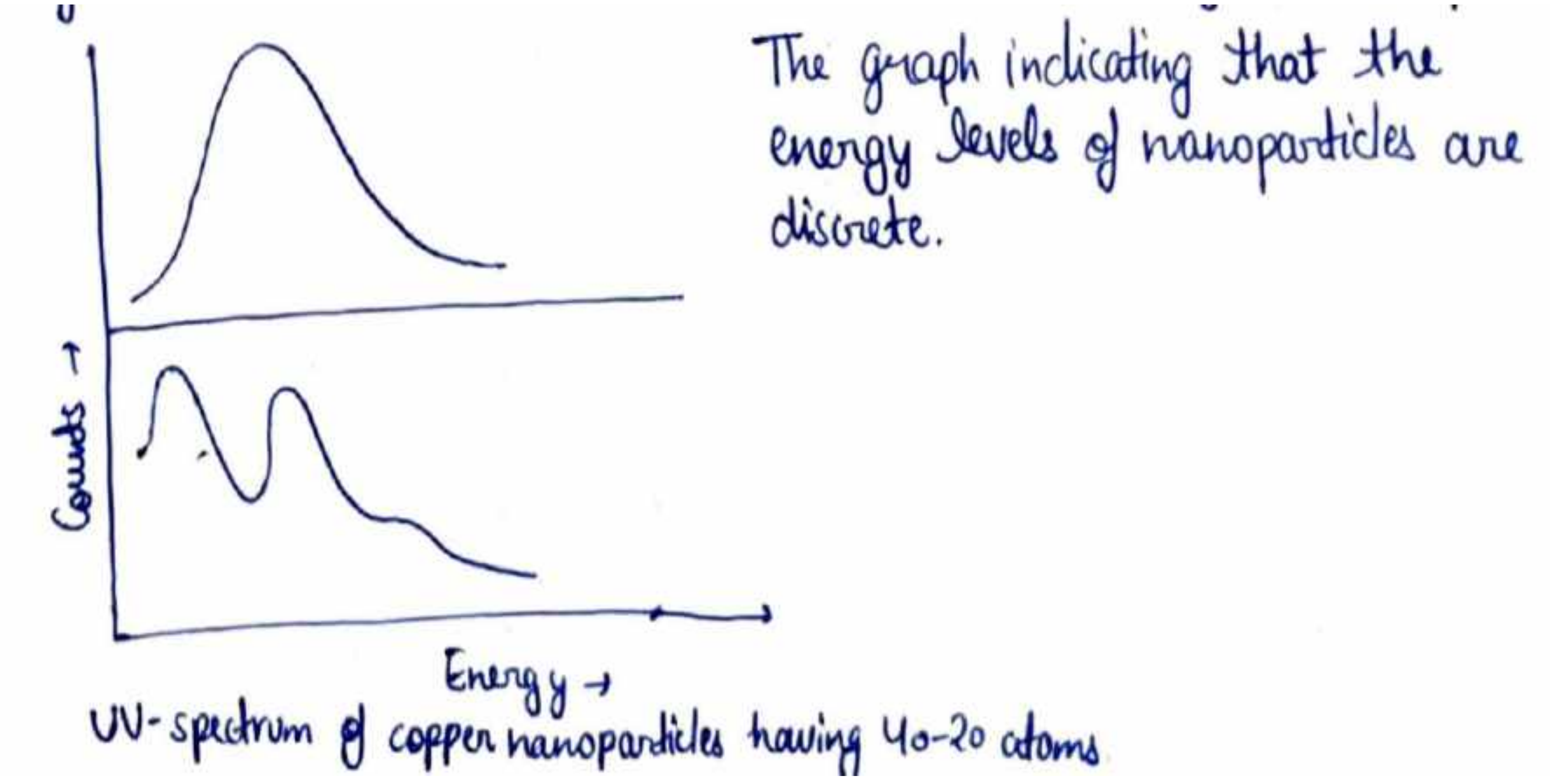
The nanoparticles of magnetic solid. new class of magnetic properties. The smaller particles a more magnetic than bulk material.



Metal	Bulk	Cluster
Na, K	Paramagnetic	Ferromagnetic
Fe, Co, Ni	Ferromagnetic	Super paramagnetic
Gd, Tb	Ferromagnetic	Super paramagnetic
Rh	Paramagnetic	Ferromagnetic

4.Electronic Properties

The electronic structure of nanoparticles can be studied by UV-photoelectron spectroscopy. When UV photon strikes an electron in the valance band of atom, the e- is ejected from the atom. The emitted e^-'s are counted by spectroscope. The energy levels of nanoparticles are discrete



Applications of Nanomaterials

1. Electronics

Electronics is currently the workhorse technology for computing and communications. The electronics devices" with typical dimensions of nanometers in other the three directions, display many unique properties. Single electron transistor (SET), spin values and magnetic tunnel junctions (MTJ) are conceptually nanotechnology. new devices based on the

2.Optics

Nanoscience has entered in the field of light emission by the use of light emitting diode (LED). The phenomena of luminescence is also of substantial interest in a number of applications e.g luminescent bar code structures Photovoltaics, is one of the most immediately attractive applications of nanostructures.

3. Diagnostics

Nanotechnology is helpful in medical diagnostics by providing faster, cheaper & portable diagnostic equipment's.

4. Sensors

Sense based on nanotechnology are more sensitive hence more effective.

5. Superior, light-weight materials

The strength & light weight of nano materials make them widely used in tear resistant cloths, spout materials, bullet proof clothing, carbon fibre, etc.

What are the risk of using nanomaterials to human body?

Sol: The use of nanomaterials does pose potential risks to the human body when includes

(1) Toxicity: materials may become toxic in their nano state that could harm to cells, tissues, or organ upon exposure.

(2) Bioaccumulation: Nanomaterials might accumulate in the body over time, leading to long term negative health impacts.

(3) Inhalation Hazards: they can be inhaled easily, potentially reaching sensitive areas of the respiratory systems.

(4) Skin Penetration: They have the ability to penetrate the skin, raising concerns about direct contact and possible skin reactions.

Numericals

A copper ball of radius 2cm is converted into copper nano-powder in which the copper clusters are spherical in shape and having radius 56mm. Calculate the surface to volume ratio in two cases.

Sol. $$Surface\ to\ volume\ ratio = \frac{Surface\ area\ of\ sphere}{Volume\ of\ sphere}$$

$$\frac{S}{V} = \frac{4\pi R^2}{\frac{4}{3}\pi R^3} = \frac{3}{R}$$

<u>Case (i)</u> For Copper sphere R= 2cm

$$\frac{S}{V} = \frac{3}{R} = \frac{3}{2cm}$$

$$\frac{S}{V} = 150m^{-1}$$

Case (ii) For copper nano-powder cluster R = 56nm

$$\frac{S}{V} = \frac{3}{R} = \frac{3}{56nm}$$

$$\frac{S}{V} = 5.36 \times 10^7 m^{-1}$$

Thank you