Unit V

Magnetism and superconductivity

Course objective:- To teach students basic concepts and principles of physics, relate them to laboratory experiments and their applications

Course outcome:- Summarize basics of magnetism and superconductivity. Explore few of their technological applications.

Topic - Magnetism

Magnetism:- Magnetism is defined as property by virtue of which a magnetic material is able to create an attraction or repulsion

Magnetism is behaviour of material in magnetic field.

The first magnet was discovered from a naturally occuring minerals called magnetite. The britisher William Gilbert was the first to investigate the magnetism as well as earth magnetism.

Magnetic poles exist in pairs called magnetic dipoles.

Properties of Magnet

1) It attracts iron, nickel, cobalt, steel etc
2) It always rest in N-S direction if

suspended freely.
3) like poles repel & unlike poles attract
4) Poles exist in pair (dipole), if bar is broken each piece has N-S poles.
5) Magnet can magnetize another materi like Iron.

N	S

Classification of magnetic materials on the basis of material

Magnetic Material
- soft magnetic material
- Hard magnetic ma

soft magnetic material
- soft material
- susceptibility & permeability is high
- Temparary magnetism
- used in current applications
- in switching ckt

Hard magnetic ma
- Hard material
- susceptibility & permeability is l
- Retain magneti
- used in produc permanent magne
- in storage devi

Basic definations:-

Magnetic field:- Magnetic field is the region surrounding the magnet where its magnetic effect / influence is detect

Magnetic lines of force :-
Imaginary lines representing magnetic field called magnetic lines of force.

Magnetic flux :-
Total number of magnetic lines of force in the field is called magnetic flux.

Magnetic Induction :-
Magnetic flux per unit area in the magnetic field is called magnetic induction or magnetic flux density

OR

Total number of lines of force through a unit area of cross section perpendicularly.

Unit of magnetic induction - weber / m^2

$$\text{Magnetic induction} = \frac{\text{magnetic flux}}{\text{Area}}$$

$$= Wb/m^2$$

Magnetic field strength (H)
It is force which a unit North pole experiences when placed within the magnetic field.

It is also called magnetizing force
S.I unit Tesla or Ampere/meter

Magnetization :-
It is the magnetic moment per unit volume.
S.I unit ampere per meter

As magnetization is induced by magnet field.

M is proportional to H

Thus
$$M \propto x$$
$$\therefore \quad M = x H$$

$H \rightarrow$ magnetic field strength
$x \rightarrow$ susceptibility of material

Magnetic Susceptibility :-

Magnetic susceptibility of a materia is a measure of the ease with which the material can be magneti

susceptibility is defined as magneti (M) produced in the material per ~~unit~~.

applied magnetic field (H)

$\chi = \frac{M}{H}$ ... It is dimensionless quantity.

High susceptibility → easily magnetized

Magnetic dipole moment :-
The strength of a magnetic dipole is represented by magnetic dipole moment.
It is a measure of a dipole's ability to align itself according to direction of external magnetic field

Magnetic dipole moment is defined as the maximum amount of torque caused by magnetic force on a dipole that arises per unit value of surrounding magnetic field in vacuum.

$$\tau = \mu \times B$$

τ → maximum torque

μ → Permeability of the material

B → Magnetic induction.

Absolute permeability (μ) :-
Absolute permeability of the material is a measure of the degree of which the field lines penetrate the material.

It is defined as the ratio of magnetic induction B in the medium to the magnetizing field strength H

Thus,

$$\mu = \frac{B}{H}$$

& $\mu = \mu_0 \mu_r$

$\mu_0 \rightarrow$ permeability of free space

$\mu_0 = 4\pi \times 10^{-7}$ (H/m) (Henry/meter)

$\mu_r \rightarrow$ Relative permeability

Relative permeability of a material is a measure of the degree to which the material can be magnetized.

Relative permeability (μ_r) of any med is defined as the ratio of permeabilit of medium (μ) to the permeability of free space (μ_0)

$$\mu_r = \frac{\mu}{\mu_0}$$

$\mu_r \rightarrow$ only number, no unit

$\mu_r = 1$, for air.

Relation between B, M and H :- When a material is kept in a magnetic field, two induction arises

(1) When magnetic field H is applied in vacuum, the flux density at any point is, $\mu_0 H$ i.e. induction due to magnetizing field H.

(2) If solid medium is placed in the field, there will be induced dipole moments giving rise to an additional flux density of $\mu_0 M$ i.e. induction due to magnetization M of material itself.

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

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

Relation between μ_r and χ

As,

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

and magnetic induction by defination

$$B = \mu H$$

$$B = \mu_r \mu_0 H$$

$$\therefore \mu_r \mu_0 H = \mu_0 (H + M)$$

$$\mu_r H = H + M$$

$$\mu_r = \frac{H}{H} + \frac{M}{H}$$

$$\mu_r = 1 + \frac{M}{H}$$

but

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

$$\boxed{\mu_r = 1 + \chi}$$

Bohr Magneton (μ_B)

Bohr magneton is the elementary electro[n] magnetic moment and no electron can ha[ve] a magnetic moment below it.

It is the natural unit for the measur[ement] of atomic magnetic moments.

$$\mu_B = \frac{eh}{4\pi m_e} = 9.28 \times 10^{-24} \ A \cdot m^2$$

It represents the minimum non-zero value of the projection of magnetic moment of the electron in an arbitary direction.

Origin of magnetization :-

Magnetic properties of solids arises due to electrons undergoing different motions in atom

these motions give rise to magnetic dipole moments.

Magnetic dipole moment of the atom arises because of three sources

(1) Orbital motion of electrons

Electrons move around a nucleus in a specific orbits.
Each ~~loop~~ orbit is equivalent to current loop.
It behaves as an elementary magnet having a magnetic dipole moment.

The sum of orbital magnetic moments of individual electrons generates the total orbital magnetic moment of an atom.

$$\mu_B = \frac{eh}{4\pi m} = 9.28 \times 10^{-24} \ A \cdot m^2$$

(2) The electron spin

Each electron is spinning about itself and this gives rise to a magnetic dipole moment.

$$\mu_S = s \cdot \left(\frac{eh}{2\pi m}\right)$$

$S \rightarrow$ spin quantum number $= \pm \frac{1}{2}$

3) The Nuclear spin:-

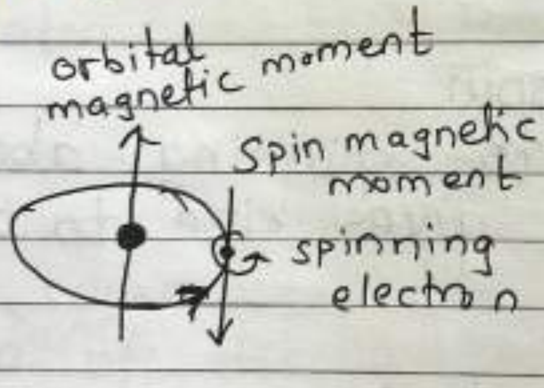
Nucleus spins around itself and it also contributes to magnetic moment of atoms due to magnetic field produced by protons.

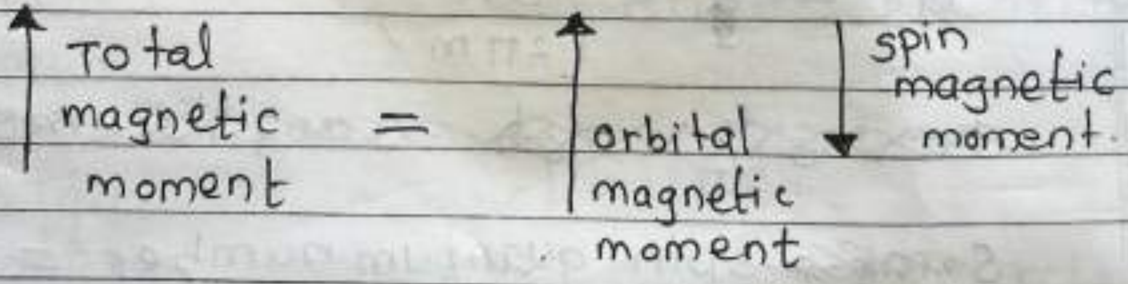
Nuclear magnetic moment is,

$$\mu_N = \frac{eh}{4\pi m_p} = 5.05\times10^{-27}\ A\cdot m^2$$

Magnetic moment of the nucleus is about $\frac{1}{1837}$ of the magnetic moment of the electron.

$\therefore$ Therefore, in studying magnetic properties of solids, the magneti moment due to nuclear spin is neglected.

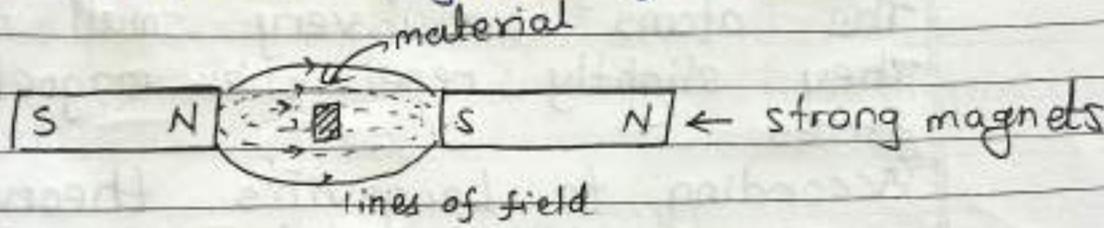




Magnetization of atoms and materials

For a solid, the resultant magnetic moment of an atom is sum of the orbital and spin magnetic moments of its electrons. & contribution is mainly from the spin of unpaired valence electrons. Number of such magnetic moments aligns in different directions.

When a material is placed in a magnetic field, the atomic dipoles respond to the external magnetic field.



(1) Diamagnetic

1) ~~In~~ some material like Bismuth, Atomic moments are weakly aligned along opposite direction of external magnetic field. is diamagnetic material, repelled from magnetic field

2) Materials like aluminium, atomic moments are weakly aligned along same direction of ext. field. weakly attracted towards field, is paramagnetic material

3) Materials like iron, strongly aligned along same direction of ext. field, strongly attracted towards magnetic field is ferromagnetic material.

classification of magnetism
OR
classification of magnetic material on th basis of permeability.

⟨1⟩ Diamagnetism ⟨2⟩ Paramagnetism ⟨3⟩ Ferroma

Diamagnetism :-
Relative permeability is less than 1; μ
If diamagnetic material is placed in a external magnetic field, develop a w magnetism in opposite direction of the external magnetic field.
The atoms have very small magnetic m
They slightly repel the magnetic lines forces.
According to Langevin's theory of Diamagnetism, Orbital motion of elect gives rise to diamagnetic properties

susceptibility of diamagnetic material

$$\chi = -\frac{N Z e^2 \mu_0}{6m} \langle r^2 \rangle$$

∴ susceptibility of diamagnetic materi is very small and negative.

$$\boxed{\chi < 0}$$

χ is indpt. of strength of appl

It is due to repulsion experienced by diamagnetic materials when place

e.g. Bismuth ($\mu_r = 0.00083$)
Copper ($\mu_r = 0.000005$)
wood ($\mu_r = 0.999$)

⟨2⟩ Paramagnetism :-

Relative permeability is slightly greater than 1, $\mu_r > 1$

If paramagnetic material is placed in an external magnetic field, it acquires small magnetism in the direction of the magnetic field.

The atoms are slightly oriented along the direction of the external magnetic field.

They attract the lines of force slightly

According to Langevin theory of paramagnetism, the random thermal motion tends to disturb this alignment making this effect temp. dependent.

Paramagnetic susceptibility,

$$\chi = \frac{\mu_0 \mu_m^2 N}{3KT} = \frac{C}{T} \quad \text{.... Curie law}$$

$C \rightarrow$ curie constant

χ is small & positive value.

$\boxed{\chi > 1}$ Here χ is inversely propo. to temp.

It is due to slight attraction of field.

According to Weiss, in addition to externally applied field, the internal molecular field produced by ~~mote~~ neighbouring molecules also acts on magnetic dipole moment.

$$\chi = \frac{C}{T - \theta_c} \quad \ldots\ldots \text{ curie - Weiss law}$$

$\theta_c \rightarrow$ paramagnetic curie point

$C \rightarrow$ curie const.

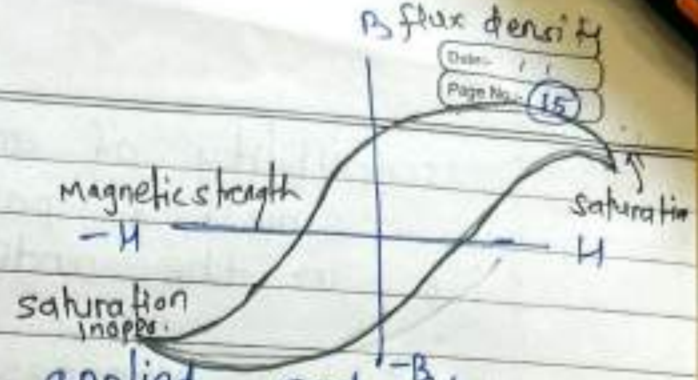
$T \rightarrow$ Temp.

e.g. Aluminium ($\mu_r = 1.00000065$)
Tungsten ($\mu_r = 1.000068$)

Ferromagnetism :-
Relative permeability is much greater than
$\mu_r > 1$
If ferromagnetic material is placed in ext. magnetic field, becomes strongly magnetized in the direction of field. these materials are strongly attracted by field.
They attract the lines of force str
On removing the external magnetic field, the material retains magnetic properties and the material shows ~~perp~~ permanent magnetism.
The material loses it magnetic propert on increasing the temp upto curie t
Above curie temp T_c, ferromagnetic materials behave as paramagnetic materials.

$$x = \frac{c}{T - T_c}$$

T_c - critica temp.



When a field is applied and then removed, the magnetization does not return to its original value.
This phenomenon referred to as hysteresis.

Above the curie temperature, spontaneous magnetization of the ferromagnetic material vanishes and it becomes paramagnetic
Iron ($T_c = 1043K$), Cobalt ($T_c = 1394K$), Nickel ($T_c = 631K$)
ferromagnetic susceptibility is greater than one and positive $x >> 1$
due to large attraction of field.
E.g. Iron ($\mu_r = 100000$)
Cobalt ($\mu_r = 18000$)

Antiferromagnetism:-
Antiferromagnetism is the presence of magnetic field, the magnetic moments of atoms are aligned in opposite directions and equal magnitude
It cancels magnetic effect.
∴ When unmagnetized, their net magnetization is zero. Above temp. (T_N) i.e. ~~above~~ perticular temp. such materials act as paramagnetic material & such temp is called as Neel temperature (T_N).
& Below T_N it shows antiferromagnetism.

susceptibility of antiferromagnetic materia
is small & positive.
i.e. in the order of 10^{-3} and 10^{-5}.

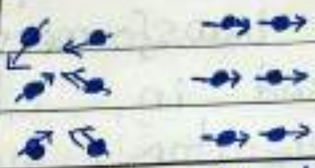
Example :- Maganese, MnO, FeO, NiO

$\uparrow\downarrow\uparrow\downarrow\uparrow\downarrow$

Ferrites and Ferrimagnetism:-
Some ceramic materials exhibit net magnetization.
Ferrimagnetic material is also having antipa alignment of magnetic moments of atoms. Here direction is opposite but magnitud is not small.
Because ~~same~~ dipoles of some cations a aligned & while other may not.
So it is not equal & opposite dipol It has only opposite moment but no equal.
Thus dipole moment cannot cancel to each other. so net spin moment exists.
Below Neel temp. (T_N) ferrima -gnetic materials behave very like ferro magnetic materials & above Neel temp. behaves as paramagnetic materials.
Susceptibility is of ferrimagnetic mate is large but field dependent. They als weiss curie behaviour. e.g. Fe_3O_4, $NiFe_2O_4$

$\uparrow\downarrow\uparrow\downarrow\uparrow\downarrow\uparrow\downarrow$

Distinguish or Comparision of types of Magnetism

No	Diamagnetics	Paramagnetics	Ferromagnetics
1)	Develop a weak magnetism in oppo. direction	Develop a weak magnetism in same direction	Develop a strong magnetism in same direction
2)	Alignment is opposite and weak $H=0$ $H \rightarrow$ 	Alignment is weak & same $H=0$ $H \rightarrow$ 	Alignment is same & strong $H=0$ $H \rightarrow$ 
3)	Slightly repelled by ext. magne. field.	slightly attracted by ext. magne. field	strongly attracted by ext. magne. field
4)	Relative permeability $\mu_r < 1$ $Bi = 0.00083$	Relative permeability $\mu_r > 1$ $Al = 1.00000065$	Relative permeability $\mu_r >> 1$ $Fe = 1000000$
5)	susceptibility is small & negative $\chi < 0$	susceptibility is small but positive $\chi < 1$	susceptibility is very high $\chi >> 1$
6)	χ is indpt. of temp.	$\chi \propto 1/T$	χ is also dept. on temp. in complex way
7)	No hysteresis	No hysteresis	hysteresis exhibited
8)	e.g. Bismuth Copper wood	e.g. Aluminium tungsten	e.g. iron cobalt Nickel

Application of Magnetic materials

1) Transformer cores
2) Magnetic storage
3) Magneto optical recording

Transformer cores / Magnetic core

The magnetic core is a material with magn permeability, which helps confine magnetic fields in transformers.
It is used in electromagnets, transfor motors, generators, inductors, magnetic recording heads.
It is made up from ferromagnet materials.
A coil without magnetic core is cal an 'air - core' coil.
The amount of magnetic field is incr by the core depends on the magnetic permeability of the core material.

Materials used for magnetic core

1) soft iron / solid iron cores
   - magnetic assembly, direct curre electromagnets, in electric moto
   - magnetic field 2-16 Tesla wit saturating
   - low coercitivity
   - Because of resistance of the it get heated and power los
   - not used in transformers.

<2> Laminated magnetic cores.
- losses observed in solid iron core can be minimised here
- made up stacks of thin iron sheet coated with insulation.
- because of insulation barrier to eddy current avoids power losses. uses in transformers

<3> Carbonyl iron
- powdered cores made of carbonyl iron
- high stability
- ~~Re~~duces eddy current at high freq. (50 kHz - 200 MHz)
- used in high freq. and broadband inductors and transformer.
- called "RF cores"

<4> Amorphous metal
- noncrystalline or glassy
- material is highly responsive to magnetic field, low hysteresis loss.
- reduces eddy current.
- High mechanical strength
- used in high efficienciency transformore
- corrosion free

⟨2⟩ Magnetic storage:-

Data storage devices are the essential requirements of entertainment electronic and computer system.

- semiconductor memories (volatile) (RAM)
- ~~Also~~ magnetic memories (permanent and nonvolatile) (ROM)

several types of media are used to store data

⟨a⟩ magnetic tape

⟨b⟩ Floppy disk

⟨c⟩ Hard disk

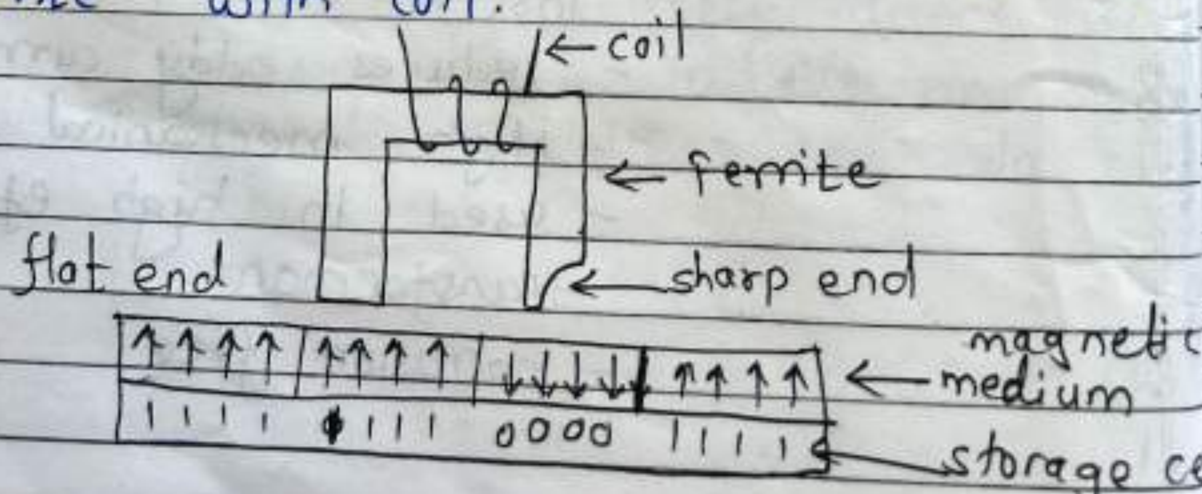
For magnetic storage, ferromagnetic material is used. By using polarity in terms of 0 & 1, data is stored in digital format.

⟨a⟩ Magnetic tape:-

- made up of plastic strip with thin layer of ferric oxide
- rolled into large reels or small cassettes.

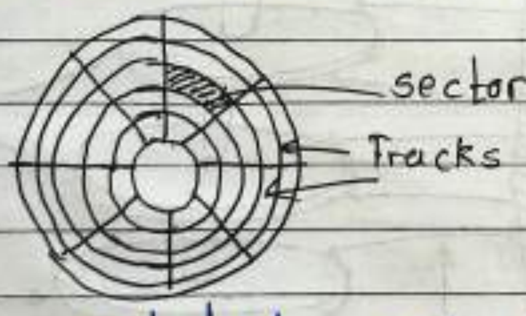
Here ~~recordi~~ magnetic moments are aligned in a vertical direction perpendicular to the plane of the tap.

Recording head is made up of of ferrite with coil.



The tape is moved from flat end towards the sharp end so that magnetic flux will be utilized to align the magnetic moments. The data is stored in multiple tracks, in the form of 0 & 1.
we can say upward direction 1 & downward 0.
It is low cost, easy to handle, high storage capacity.
Disadvantage is access to data is sequential. To access particular data in the tape required longer time.

(b) Floppy disk
Floppy disks are made of thin plastic disk with a coating of magnetic material on it.
Disk is divided into sectors



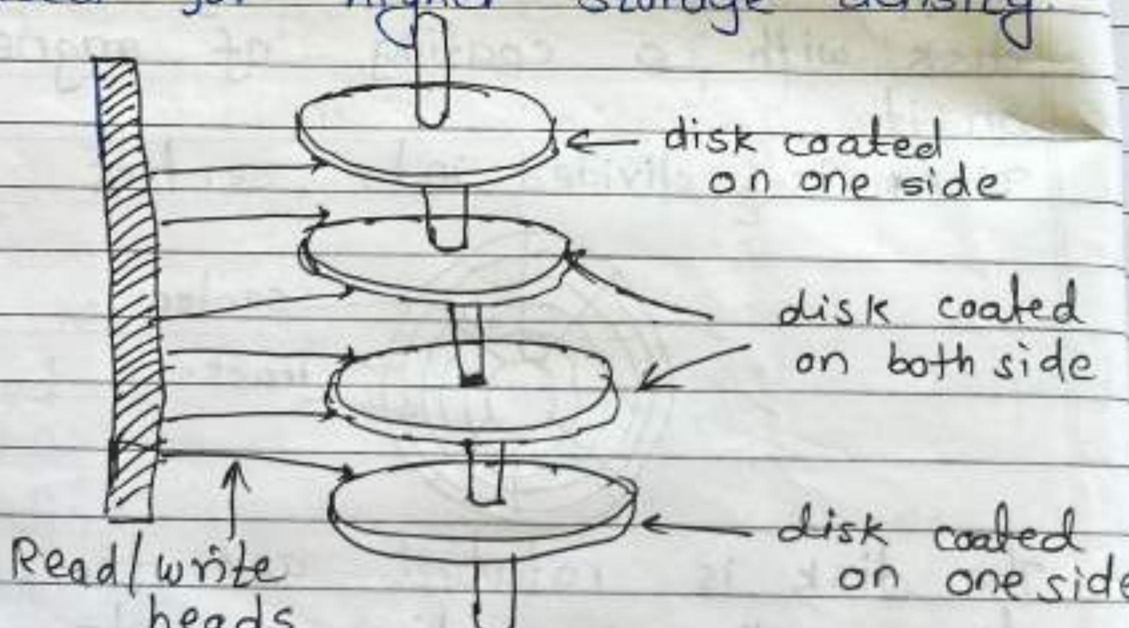
The disk is rotated and the write head aligns the magnetic moments on the tracks as it passes over them.
Floppy disks have small storage capacity 1.44 MB
Now they are replaced by compact disk and DVD.

(c) Hard disks.

It is magnetic disk similar to floppy di[sk] but with larger number of disks.
Many disks mounted on a common central shaft coated with magnetic material, on both side. outermost disk are coated on inner side only.
one read/write head is provided per surface.

- Each disk have tracks and sectors.

The write head aligns the magnetic moments on the tracks as it passes over the track.
Vertical alignment of magnetic moments is used for higher storage density.



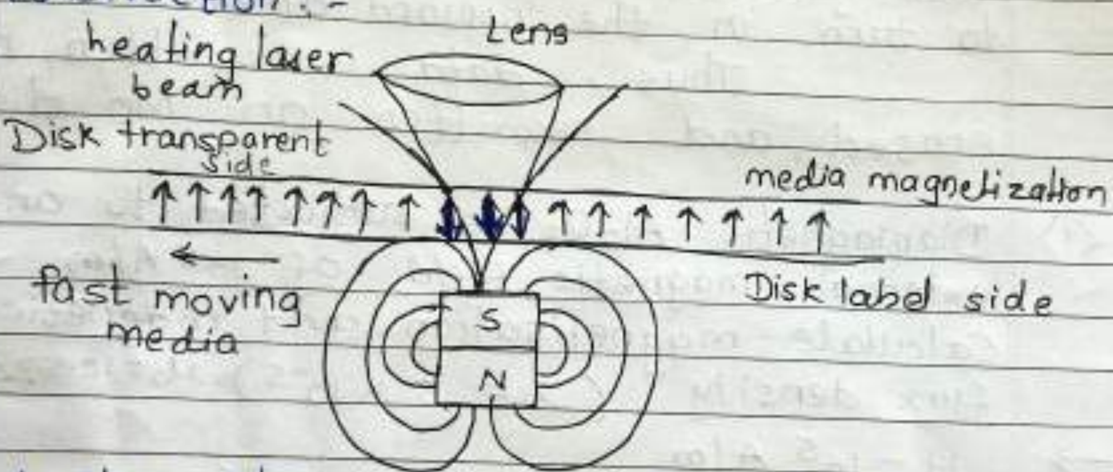
Data can be stored on both sides of disks. Hence has large storage capaci[ty] upto 5 terabytes (5 TB)
Available as both internal hard disk (in and as external hard disk.

Magneto optical Recording

MO recording is a method of storing and retrieving data using a laser and magnet. Magneto optical means write magnetically and read optically.

Principle :- LASER beam is used for recording, reading and erasing data on a MO medium.

construction :-



A thin film of magnetic material is coated on the substrate over which the data is written.

Recording :- when the disk is inserted into drive, the label side face the magnet. the transparent side will face the laser. Atomic magnetic moments are oriented in the upword direction perpendicular to the film. When focused pulsed laser falls on the film, heating occurs. At the high temp. domain reverses and turn downword. Some are in upword dir and some in downword. In this way data is stored.

Reading:- MO system can be read with p
light only. upword & downword dir
of moment gives change in polarized light
The change in magnetization is associa
with 0 & 1, which stores data In
binary system. This data can be read

Erasing:- To erase the data, magnetic
field is applied in the upward direct

The focused laser pulse causes local
heating which assists the atomic ma
to turn in the upward direction.

Thus, data is written, read
erased, and rewritten on MO disc.

<1> Diamagnetic Al_2O_3 is subjected to an external magnetic field of 10^5 A/m. Calculate magnetisation and magnetic flux density ($\chi = 5 \times 10^{-5}$). $\mu_0 = 12.57 \times 10^{-7}$

→ $H = 10^5$ A/m

$\chi = -5 \times 10^{-5}$

$M = \chi H = -5 \times 10^{-5} \times 10^{-5}$

$M = -5$ A/m

$B = \mu_0 (H + M)$

$\therefore B = \mu_0 (10^5 - 5)$

$B = 12.57 \times 10^{-7} (10^5 - 5)$

$\boxed{B = 0.126 \text{ W/m}^2}$

Superconductivity

Superconductivity is a state of matter exhibited usually at very low temperature where the resistivity of the material drops to zero.
The superconducting state is a state in which quantum mechanics operates on a macroscopic scale.
The superconducting state is influenced by temperature, current and magnetic field.

Conductivity :- Ability to conduct the electricity (σ)
Resistivity :- Reciprocal of conductivity
:- Ability to oppose the current.

Electrical resistivity of metal increases with increasing temp.
When current is flowing through the conductor, it has free electrons. When temp. increases lattice vibration increases and cause more scattering of electrons leading to more resistance
Even at 0 K, metals offer finite resistance, called residual resistance.
In 1911, H. K. Onnes first time verified behaviour of metals at very low temperatures. He discovered that the electrical resistance of mercury dropped to zero at a temperature of 4.15 K. Here 4.15 K is called transition temp.
This is entirely new phenomenon

Onnes also found that at the transition temperature (above 4.15K) regained its resistivity.

Superconductivity:- is the phenomenon in which electrical resistance of materials suddenly disappear below a certain temperature.

The material which ~~sh~~ are in supercon state are called superconductors.

Critical temp / Transition temp:- the tem at which a normal material abrupt changes into a superconductors is called transition temp. or critical temp. (Tc.)

B.C.S Theory:-

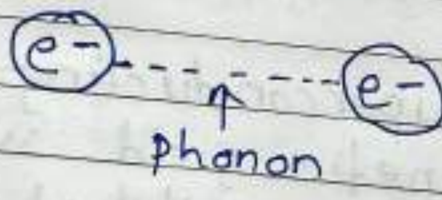
American scientists John Bardeen, Leon Cooper and John Schrieffer join developed the theory to explain supercon uctivity which is known as B.C.S. Theor When free electron passes near an ion in a lattice, there is coulomb attraction bet them. This causes deformation of the lattice. If second free electron passing nearby, takes advantage of the deform to lower its energy. Thus second elect is also attracted towards ~~phonc~~ lattice. This interaction is called

electron - lattice - electron interaction through phonon.

Phonon is quantum of lattice vibrationa energy.

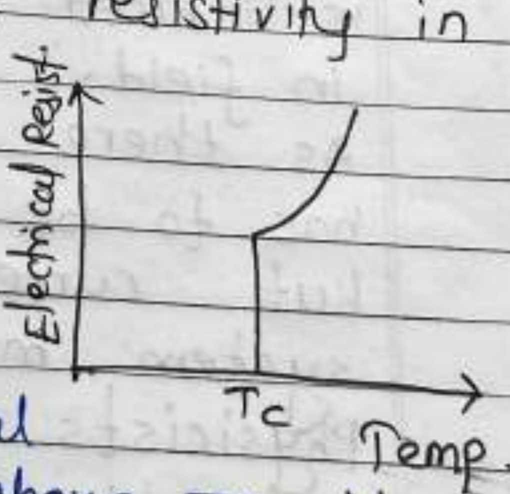
Simply first electron emits a phonon which is absorbed by the second electron. Such pairs of electrons coupled together through a phonon are called cooper pairs. Cooper pairs are very weak, they can easily seperated as temperature increases. (thermal vibrations)

At low temp. density of cooper pairs is large and they move collectively through the lattice, which minimizes collision, which avoids resistance and we get larger current, eventhough they have small velocity.
We get superconductors at lower temp.



Temperature Dependence of resistivity in superconducting material

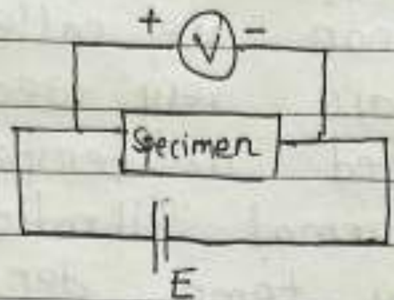
At critical temp. resistivity suddenly drops to zero



Below critical temp. material is superconductor. whereas above Tc it behaves like normal conductor.

Properties of superconductors :-

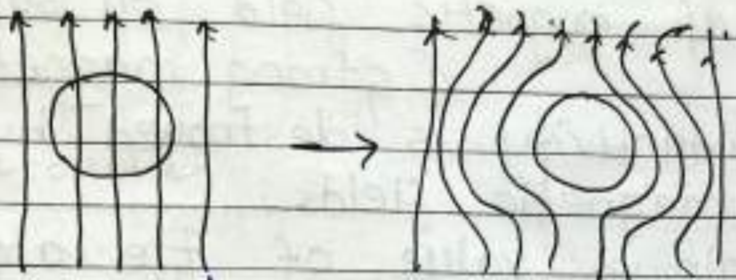
<1> zero Electrical Resistance



The electrical resistivity is zero.
The experimental testing of zero resista
can be done with above diagram.
The temperature of the specimen is lowered. It is observed that below critical temperature, the potential differen across the specimen suddenly dropped to zero.

~~Sameway~~ If superconducting ring was kept in a magnetic field. When the magnetic field was switched off, current is induced in the ring due to change in field.
As there is no voltage source, current has to be ~~dec~~ reduce, because of resist but current is remains same in the system means no resistance is ther
Physicists File and Mills concluded that ~~time~~ decay ~~fo~~ time for curren in superconducting solenoids is more 105 years.

2) Meissner effect :- (weak magnetic field)
When a specimen is placed in a weak magnetic field and cooled below the critical temp. the magnetic flux present in the specimen is ejected from the specimen. This effect is known meissner effect.



This effect is reversible and the specimen returns to its normal state when it ~~is~~ temp is raised above critical temp.

Superconductor act as perfect diamagnets with zero magnetic induction $B = 0$

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

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

$$H = -M$$

Susceptibility is,

$$\chi = \frac{M}{H} = -1$$

Relative permeability, $\mu_r = 1 + \chi$

$$= 1 - 1$$

$$\boxed{\mu_r = 0}$$

shows perfect diamagnetism.

Meissner effect can not explained by assuming that the superconductor is perfect conductor.

Due to meissner effect, superconductors strongly repel external magnets which leads to magnetic levitatio

3) Effect of magnetic field on supercondu (strong magnetic field)

Superconductivity is destroyed by sufficie strong magnetic fields.

The minimum value of the applied ma field required to destroy supercondu is called the critical field H_c.

H_c is function of temperature.

Above critical temp, $H_c = 0$

Below critical temp, H_c depends on T

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

$H_0 \rightarrow$ critical field at absolute

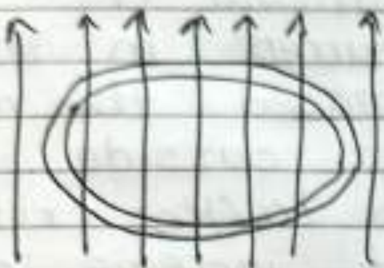
4) Persistent currents :-

When superconducting ring is placed in a magnetic field and the fiel is switched off, a current is induce in the ring

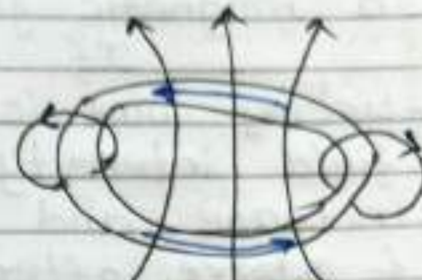
Current remains same eventhough there is no source of emf.

5)

zero resistance in superconductors gives steady currents even after years and years, called persistent currents.



superconducting ring in field B



persistent current associated with magnetic field B is switched off.

Thus superconducting rings can be used to produce magnetic fields which do not require any power supply to maintain a constant field.

5) Isotope effect:-
The critical temperature of superconductors varies with isotopic mass.
For larger isotopic mass, critical temperat is smaller. This is isotope effect.

$$T_C M^{\alpha} = \text{constant}$$

$\alpha = \frac{1}{2}$ for many materials

$$T_C M^{1/2} = \text{const.}$$

$T_c \propto M^{-1/2}$

6) Critical current

Every current carrying conductor produc[es] a magnetic field around it.

If the current in the superc[ond]-ucting wire is increased, the magnetic field intensity just outside it will increase and reach to (H_c) critical fie[ld] & ~~above~~ after that increase in current increases field H_c & which destroys to superconducting state.

The maximum current that superconductor can carry without reverting back to its normal state i[s] known as critical current.

A superconducting ring or radius R ceases to be a superconductor if t[he] critical current exceeds,

$$I_c = 2\pi R H_c$$

current density is defined as current per unit area

critical current density :- The maximum current density at which the superconductivity disappears.

1) Superconducting tin (Sn) has a critical temperature of 3.7K at zero magnetic field and a critical field of 0.0306 T at 0K. Find the critical field 2K.

→ Given,

$T_c = 3.7\ K$

$T = 2\ K$

$B = 0.0306\ T$ & $H = \frac{B}{\mu_0}$

$H_c = \frac{B_c}{\mu_0}$ and $H_0 = \frac{B_0}{\mu_0}$

$\therefore B_c = B_0\left[1 - \left(\frac{T}{T_c}\right)^2\right]$

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

$\boxed{B_c = 0.02166\ T}$

2) Calculate the critical magnetic field for lead at 4.2K. The critical temperature for lead is 7.18 K and $H_c = 6.5 \times 10^4$ A/m at 0K

→ $T = 4.2\ K$ $\quad$ H_c at 0 K $= H_0$

$T_c = 7.18\ K$

$H_0 = 6.5 \times 10^4\ A/m$

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

$H_c = 6.5 \times 10^4\left[1 - \left(\frac{4.2}{7.18}\right)^2\right]$

$\boxed{H_c = 4.28 \times 10^4\ A/m}$

3) In a superconductor ring of radius 0... the critical magnetic field is 2×10^3 A/... at 5K. Find the value of critical current.

→ $R = 0.02\,m$

$H_c = 2 \times 10^3\ A/m$

$$I_c = 2\pi R H_c$$

$$= 2 \times 3.14 \times 0.02 \times 2 \times 10^3$$

$$\boxed{I_c = 251.4\ A}$$

4) The critical temp. for a metal with isotopic mass 199.5 is 4.185 K. Calculate the isotopic mass if the critical temp. falls to 4.133 K. Assu... $\alpha = 0.5$. Given - $T_{c_1} = 4.185\ K$, $M_1 = 199.5$, $T_{c_2} = 4.133\ K$

→ $T_c M^{\alpha} = \text{constant}$

$$\alpha = 0.5$$

$$T_c M^{0.5} = \text{constant}$$

$$T_{c_1} M_1^{0.5} = T_{c_2} M_2^{0.5}$$

$$M_2^{0.5} = \frac{4.185 \times 199.5^{0.5}}{4.133} =$$

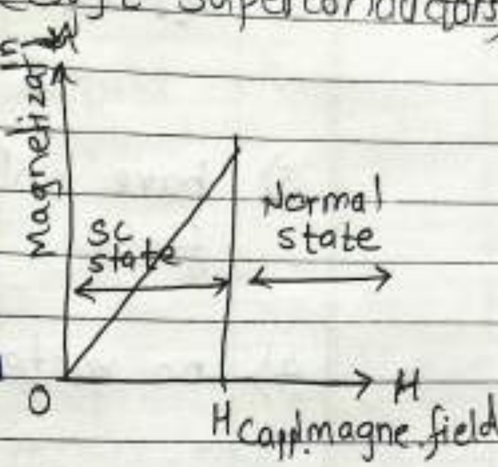
$$\cancel{M_2^{0.5} =} \quad \boxed{M_2 = 204.55}$$

Types of superconductors :-

(1) Types I superconductors (soft superconductors)
(2) Type II superconductors (Hard superconductors)

1) Type I superconductors (soft superconductors)

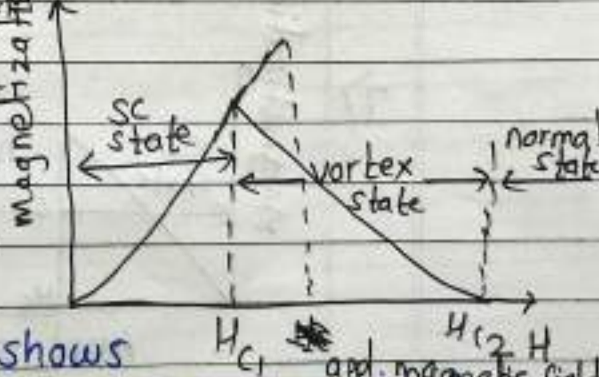
Type I superconductors shows meissner effect when the applied magnetic field H is less than H_c
For above H_c, it becomes normal conductor



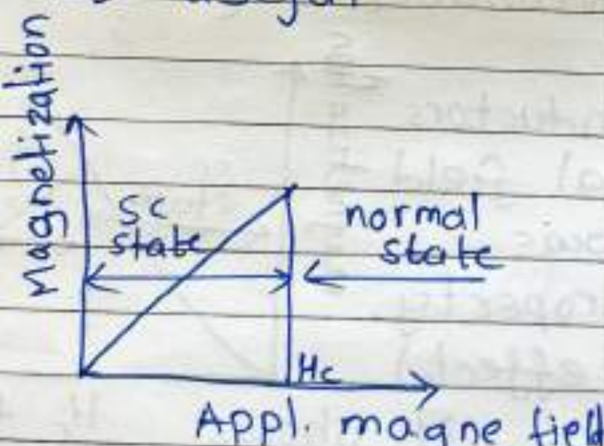
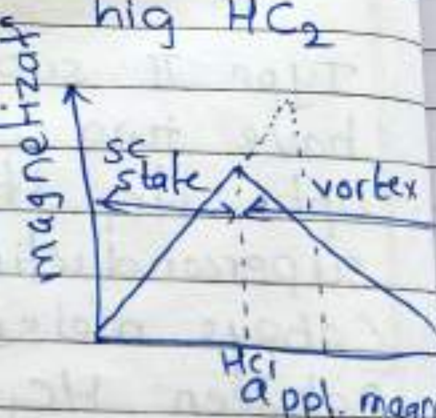
Highest value of $H_c \approx 0.01$ to $0.2\ Wb/m^2$
e.g. Aluminium, lead, mercury

2) Type II superconductors (Hard superconductors)

Type II superconductors have two critical field
Upto H_{c_1} it shows superconducting property. (obeys meissner effect)



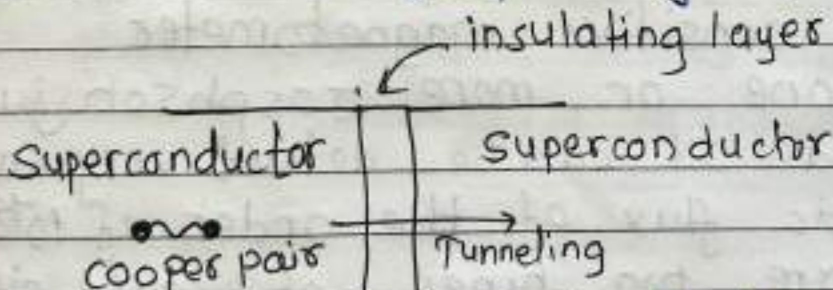
Between H_{c_1} & H_{c_2}, it shows zero resistance but not meissner effect
∴ it is said to be intermediate or vortex state. (mixed state)
Above H_{c_2} it is normal conductor.
Highest value of $H_c \sim 30\ wb/m^2$
e.g. Nb-Sn, Nb-Ti
(Niobium tin, Niobium titanium)

Type I superconductors	Type II supercond
1) soft superconductors	1) Hard supercondu
2) They shows meissner effect below Hc	2) They show meiss effect below Hc but it is incomp
3) have only one critical field	3) have two magne critical field
4) no vortex state	4) Between H_{C_1} & H_{C_2} vortex sta
5) Highest value of $H_C = 0.2$ Wb/m2	5) Highest value $H_{C_2} = 30$ Wb/m^2
6) not useful	6) useful due to hig H_{C_2}
7)  $H < H_c \rightarrow$ superconductor $H > H_c \rightarrow$ conductor	7)  $H < H_{C_1}$ supercon $H_{C_1} > H < H_{C_2}$ - vor $H > H_{C_2}$ - conduc

On the basis of critical temp.
Low & High temperature superconductors

	Low temp. Superconductor		High temp. superconductor
(1)	$T_c \approx$ below 24 K	(1)	$T_c \approx$ 27K to 138 K
(2)	Liquid Helium coolant is used	(2)	Liquid nitrogen coolant is used
(3)	They are elements	(3)	They are alloys
(4)	not useful for commercial appli.	(4)	useful in generators, motors, MRI, NMR etc

Josephson Effect :-
Two superconductors connected by a thin layer of insulating material (~1-2 nm) is called a Josephson junction.



Tunnelling of superconducting electron pairs i.e cooper pairs from one superconductor to another through insulating layer.
Junction is called "weak link"
Effect is called Josphson effect.

Josphson effect

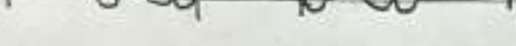
DC Josephson effect

→ cooper pair tunnel through the junction without ext. applied voltage

→ DC current is obtained

→ $I = I_c \sin\phi$

insulating layer

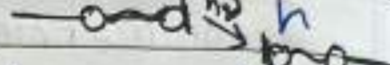


AC Josephson e

→ After applying d. voltage cooper pa tunnel through junction

→ AC current is obt i.e. Radio freq. current oscillatio are produced

$\nu = \frac{2eV}{h}$



On the basis of Josphson effect sensitive magnetometer is form. i.e. squid.

SQUID (superconducting quantum interfer.ence device)

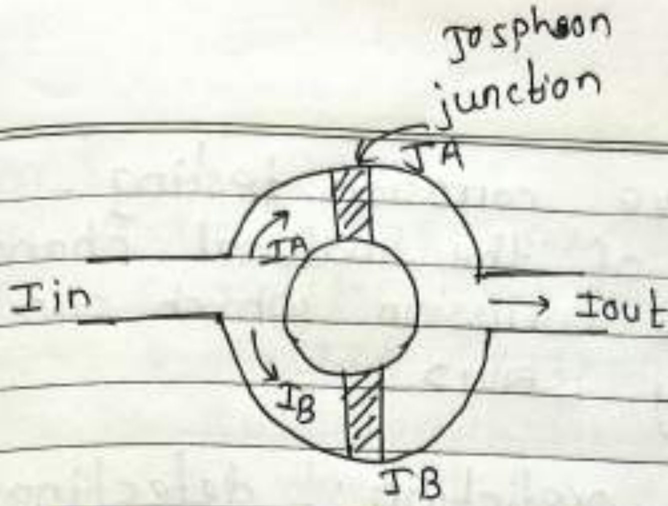
It is sensitive magnetometer

Here one or more Josphson juncti are used. It can be detect very small magnetic flux of the order of 10^{-14} T.

There are two types of squid circui

(1) dc squid (2 junction) (2) ac squid (1 junction)

superconducting ring is used which consist of Josephson junction.



J_A & J_B → Two Josphson junctions

If an ext. magnetic field is applied, Iin ~~It~~ modifies the phase of the two currents I_A & I_B which finally modifies output current Iout.
The output current varies periodically with applied magnetic flux.
Thus if a magnetic field is applied to a squid, its output current changes.
This change in current is used to find the magnetic flux.
It can detect very small magnetic fields like 10^{-14} T.
∴ they are used as diagnostic tools in detecting brain signal.

Applications of squid
1) MRI scan
For scanning of human body, strong magnetic field and radio waves are used.
Water molecules in body contain Hydrogen nuclei. (proton). Because of strong magnetic field proton spins in alignment. This spin is detected by SQUID.

2> Non-destructive corrosion testing:-
Magnetism of the material changes due to the corrosion, which can be detected by SQUID.

3> Earthquake prediction:- detecting change in magnetism of earth by SQUID

4> Mineral exploration:- by detecting magnetic field changes inside the earth crust. can find materials in the earth's crust by SQUID.

Applications of superconductors.

1> Superconducting magnets:-
Solenoid made of superconducting wires produces large magnetic field without consuming large power. these magnets will be light weight and compact.

2> Magnetic levitation:-
When a magnet is brought near a superconducting ~~wires~~ coil, current is induced in the superconductor which in turn produces a magnetic field which repels the magnet.
Thus magnet is floating in air (i.e. levitate) on the superconducting coil

3) SQUID :-
Two superconductors seperated by a thin layer of insulator gives Josephson junction, effect is called Josephson effect.
SQUID is superconducting quantum interference devices.
In SQUID Josphson junctions are used.
MRI, nondestructive corrosion testing, earth quake ~~predict~~ prediction and mineral exploration are the appl. of squid.

4) Cryotron :-
Cryotron works on the principle that superconductivity is destroyed when magnetic field in which it is placed exceeds the critical field.
Tantalum wire is wounded by niobium wire.
Niobium has larger critical field than tantalum.
This arrangement is used in switches.

5) Superconducting magnets :- solenoids made of superconducting wires can generate strong magnetic fields without consuming large amount of power.

6) Superconducting transition cables
It avoids transmission losses. Also power can be transmitted at low voltage levels.

Bearings:- superconducting bearings can oper without frictional losses.

8) IC fabrication:- Heat losses are minimized hence density of components can be increased. It uses in digital integrated circuit

9) Superconducting transistors:- It is based on Josephson effect. It increases speed of microprocessors.

10) Supercomputers:
Semiconductor logic elements is having speed limit, they operate at a speed of few nanoseconds. Logic elements based on Josephson junction can operate at the speed of few picoseconds, which increases speed of computers.

Important Questions of unit 5

<1> Define a) magnetic induction (b) magnetization
b) magnetic field strength (d) Absolute permeability
e) Relative permeability (f) magnetic flux [6]

<2> Explain origin of magnetic properties. What is Bohr magneton. [6]

<3> State and explain relation between B, M, H and Relation between χ & μ_r [4]

<4> Differentiate between diamagnetism, paramagnetism and ferromagnetism. [6]

<5> Classify magnetic materials on the basis of their permeability. [6]

<6> Explain various storage devices [6]

7> State and explain the applications of magnetic ~~field~~ materials. [6]

8> Explain how information is recorded and retriered in magneto-optical recording [6]

9> What is superconductivity? Explain zero electrical resistance and peristent current [6]

10> Explain formation of cooper pair in superconductors (B.C.S. theory) with the help of electron phonon interaction [6]

<11> State and explain Meissner effect [4]

<12> What is critical temperature, critical magne. field and critical current density? [4]

<13> Differentiate between type I & type II supercondu.

<14> Explain DC and AC Josephson effect with diagram. [6]

<15> What is SQUID? Explain the basics and give two applications of SQUID [6]

<16> State and explain applications of superconductors [6]