

3. Magnetic field strength (H)

- The strength (or intensity) of magnetic field at any point in magnetic field is force experienced by a unit north pole placed at that point. It is denoted by **H**.
- The unit of **H** is ampere-turns per meter (A/m) in SI system.

4. Magnetization (M)

- Magnetization (or intensity of magnetization) is the measure of magnetism of magnetic materials. It is defined as magnetic moment per unit volume and denoted by **M**.
- The unit of magnetization in SI system is amperes per meter (A/m).
- As magnetization is induced by magnetic field, M is proportional to H.
Thus, $M \propto H$ or $M = \chi H$
Where, χ is called as magnetic susceptibility.

5. Magnetic Susceptibility (χ)

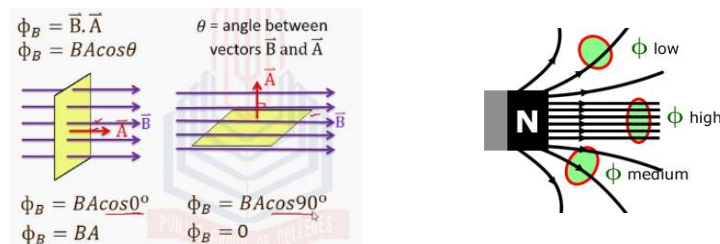
- The magnetic susceptibility of a material is a measure of the ease with which the material can be magnetized. It is defined as magnetization (M) produced in the material per unit applied magnetic field (H).
- Hence, $\chi = M/H$
- Materials having high susceptibility are easily magnetized.

6. Magnetic flux (ϕ)

- Magnetic flux is a measurement of the total magnetic field which passes through a given area. The lines of induction are collectively called as flux.
- The SI unit of magnetic flux is the Weber (Wb).

7. Magnetic Induction or magnetic flux density (B)

- A magnetic field is schematically represented by lines of magnetic induction or magnetic flux density).
- The magnetic flux per unit area is defined as magnetic flux density.
- Magnetic induction is the number of lines of force through a unit area of cross section perpendicular to it.
- Thus, $B = \phi/A$.
- The SI unit of B is Weber per square meter (Wb/m^2) and CGS unit is Tesla (T)
- $1 \text{ Gauss} = 10^{-4} \text{ Tesla}$



8. Relation between B and H

When a material is kept in a magnetic field, two types of induction arise – one due to magnetizing field **H** and other due to magnetization **M** of the material itself. The magnetic induction **B** produced inside the material is given by

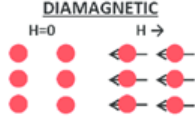
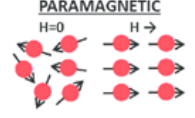
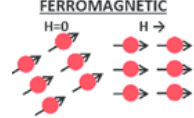
$$B = \mu_0(H + M)$$

Where, μ_0 is known as permeability of the free space. It is equal to $4\pi \times 10^{-7}$ henry per meter (H/m)

$$B = \mu_0 \left(1 + \frac{M}{H}\right) H$$

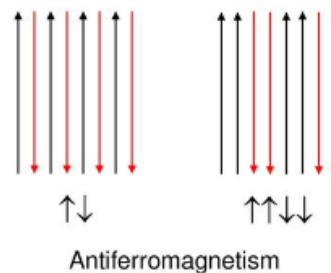
Or $B = \mu_0(1 + \chi)H$

Or $B = \mu H$

Sr.	Property	Diamagnetics	Paramagnetics	Ferromagnetics
1	Behavior in external magnetic field	Develop a weak magnetism in opposite direction	Develop a weak magnetism in the same direction	Develop a strong magnetism in the same direction
2	Alignment of magnetic dipoles in external magnetic field	Opposite and weak 	Same direction and weak 	Same direction and strong 
3	Response to external magnetic field	Slightly repelled by external magnetic field	Slightly attracted by external magnetic field	Strongly attracted by external magnetic field
4	Relative permeability (μ_r)	$\mu_r < 1$ (Bi: 0.00083)	$\mu_r > 1$ (Al: 1.00000065)	$\mu_r \gg 1$ (Fe: 1,00,000 or more)
5	Susceptibility (χ)	Very small and negative i.e. $\chi < 0$	Less than one but positive i.e. $\chi < 1$	Very high $\chi \gg 1$
6	Effect of temperature on susceptibility	χ is independent of temperature	Obeys Curie law $\chi \propto \frac{1}{T}$	Susceptibility χ decrease with temperature in complex way
7	Curie Point (above which become paramagnetic)	No Curie point	No Curie point	Have definite Curie point
8	Hysteresis (Lag in change on magnetization)	Not exhibited	Not exhibited	Exhibited
9	Retentivity (Residual magnetism)	Not exhibited	Not exhibited	Exhibited
10	Examples	Bismuth, silver, copper, hydrogen, etc	Aluminum, tin, magnesium etc	Iron, steel, nickel, cobalt etc

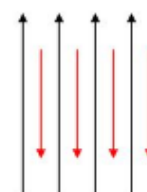
4. Antiferromagnetism [for reference]

- Antiferromagnetic materials are crystalline materials.
- In the presence of the strong magnetic field, antiferromagnetic materials are weakly magnetized in the direction the field. This property of the materials is called antiferromagnetism.
- The magnetic moments of atoms are aligned in opposite directions and are equal in magnitude. Thus, when unmagnetized, their net magnetisation is zero.
- Examples of antiferromagnetic substances: MnO, FeO, CoO, NiO, Cr, Mn
- This is the case below a particular temperature, called as Néel temperature (T_N) above which the material behaves as a paramagnet.
- Antiferromagnetic materials exhibit a small positive susceptibility χ of order of 10^{-3} and 10^{-5} from 0 K to T_N and show antiferromagnetic behavior. Above T_N , the susceptibility show paramagnetic behavior.



5. Ferrites and Ferrimagnetism [for reference]

- Some ceramic materials exhibit net magnetization.
- For example: Fe_3O_4 , NiFe_2O_4 ,
- In a magnetic field, the dipoles of some cation may line up with the field, while dipoles of other cation may not. These ceramics are called ferrites, and the effect is known as ferri-magnetism.



$$I = I_c \sin \left(\phi + 2\pi t \left(\frac{2eV}{h} \right) \right)$$

This current can be represented by an alternating current of frequency $\nu = \frac{2eV}{h}$. This frequency only depends on the applied voltage. This effect is known as **ac Josephson effect**.

- The frequency of alternating currents does not depend on the dimensions of the superconductors. Also this frequency does not depend on properties of superconductors such as critical temperature, chemical composition.
- At $V=1 \mu\text{V}$, ac current of frequency 483.6 MHz is produced.

5.2.7 Superconducting Quantum Interference Devices (SQUID)

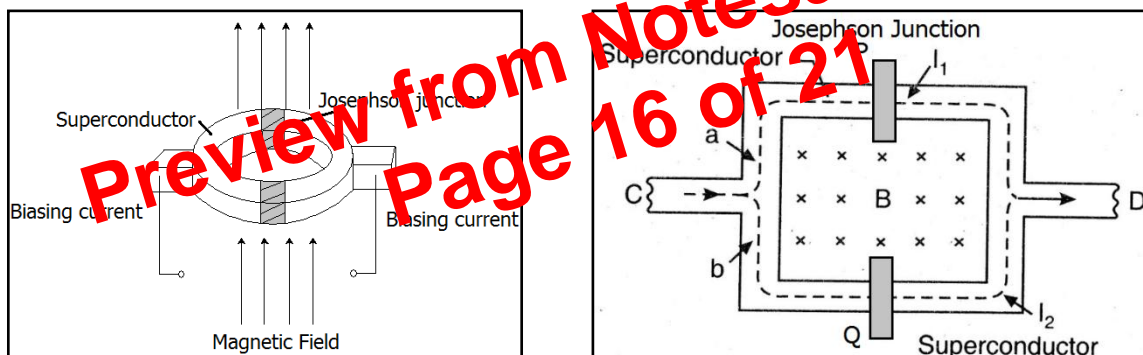
A SQUID (Superconducting Quantum Interference Device) is a very sensitive magnetometer used to measure extremely subtle (small) magnetic flux of the order of 10^{-18} Tesla. Their working is based on superconducting loops containing Josephson junctions.

Construction of SQUID

There are two main types of SQUID: direct current (DC) and radio frequency (RF). A radio frequency (RF) SQUID is made up of one Josephson junction, which is mounted on a superconducting ring. A direct current (DC) SQUID consists of two Josephson junctions in parallel, which is more sensitive.

Construction

SQUIDs are usually fabricated from lead or pure niobium. The tunnel barrier is oxidized onto lead or niobium surface. The entire device is cooled to within a few degrees of absolute zero with liquid helium. A schematic of a two-junction dc SQUID is shown in figure. It consists of two Josephson junctions arranged in parallel.



Working

A constant dc supercurrent is applied to the SQUID. This current is known as bias current which enters into the SQUID through arm C. It is divided along the paths a and b and again merge into one and leaves through the arm D. I_1 and I_2 are currents tunneling through Josephson junctions.

In absence of magnetic field

- In a superconductor, a single wave function describes all the Cooper pairs. The wave function experiences a phase shift at the Josephson junctions P and Q.
- In absence of magnetic field, Phase difference across P and Q = 0

In presence of magnetic field

- When a magnetic field is applied, it changes the quantum mechanical phase difference across each of the two junctions. This phase difference between reuniting currents (δ_0) is directly proportional to the magnetic flux Φ through the ring.