3. Magnetic Properties of Materials

3.1. Introduction

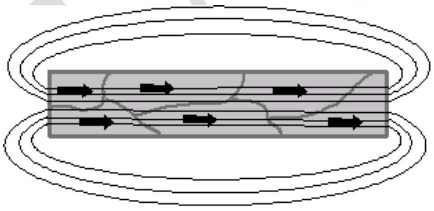
A very large number of modern devices depend upon magnetic properties of materials for their working. For example, the speakers, electrical power generators, electrical machines, transformers, television, data storage devices like magnetic tapes and disks, magnetic compass, etc., Now a days Magnetic Resonance Scanning is an important non-invasive diagnostic tool in medical field.

Understanding the origin of magnetism and the behaviour of magnetic materials will be helpful not only in the selection of suitable materials for a particular application but also in proper utilization of such devices.

3.2. Magnetism in materials

It arises from the magnetic moment or magnetic dipole of the magnetic materials. When an electron revolves around the positive nucleus, orbital magnetic moment arises. Similarly when the electron spins, spin magnetic moment arises.

Materials which can be magnetised by an external magnetic field are called magnetic materials. The space around the magnet or the current carrying conductor where the magnetic effect is felt is called magnetic field.



The magnetic lines of force is a continuous curve in a magnetic field. The tangent at any point of this curve gives the direction of resultant intensity at that point. All the molecules of a material contain electrons rotating around the nucleus. These orbits are equivalent to circulating currents. So they produce a magnetic motive force (MMF). MMF is a force which produces the magnetic effect.

In most of the molecules, each MMF due to an individual orbit is neutralized by an opposite one. But, in the magnetic materials like iron and steel, there are number of unneutralized orbits. Then, the resultant axis of MMF produces a magnetic dipole.

In unmagnetized specimens, the molecular MMF axes lie along continuous closed paths. Therefore, no external magnetic effect can be found.

In magnetic specimens, the magnetic dipoles may remain aligned in the direction of the external field, thus it produces permanent magnetism.

3.3. Basic definition

- ***Magnetic dipole***

Any two equal and opposite magnetic poles separated by a small distance 'l' constitute a magnetic dipole.

- ***Magnetic dipole moment (M)***

If 'm' is the magnetic pole strength and 'l' is the length of the magnet, its dipole moment is given by the product 'ml'.

$M = m\, l$

It is expressed in Am^2. It is a vector quantity.

- ***Magnetic flux density (or) Magnetic induction (B)***

The magnetic flux density is defined as the number of magnetic lines of forces passing perpendicular through a unit area of cross section and is given by $B = \Phi/A$. Where, Φ is the number of magnetic lines of forces, A is the area of cross section

It is expressed in Wbm^2 (or) Tesla.

- ***Magnetic field strength (or) Magnetic field intensity (H)***

It is the force expressed by unit North Pole placed at a given point in a magnetic field. It is also defined as the ratio between the magnetic induction and the permeability of the medium in which the magnetic field exists. $H = B/\mu$

Where μ is permeability. It is expressed in Am^{-1}.

- ***Magnetic permeability (μ)***

The magnetic permeability is a measure of the amount of magnetic lines of forces penetrating through a material. It is defined as the ratio of the magnetic flux density (B) in the sample to the applied magnetic field intensity (H).

$\mu = B/H$

It is expressed in Henry m^{-1}.

- ***Magnetization (or) Intensity of Magnetization (I)***

It is defined as the magnetic moment per unit volume. $I = M / V$

It is expressed in Am^{-1}.

- ***Magnetic Susceptibility (χ)***

It is defined as the ratio of magnetization (I) produced in the sample to the magnetic field strength (H).

$\chi = I/ H$. It has no unit.

- ***Relation Between 'χ ' and 'μ'***

We know, $\mu = B/H$

This equation can be written in other way as,

$B = \mu_0 (M+H)$

Where, μ_0 is the permeability of free space.

The relative permeability $\mu_r = \mu / \mu_0$

$$= \frac{B/H}{B/(H+M)}$$

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

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

$$= 1 + \chi$$

Where, χ is the susceptibility of the medium. The relative permeability (μ_r) has no unit.

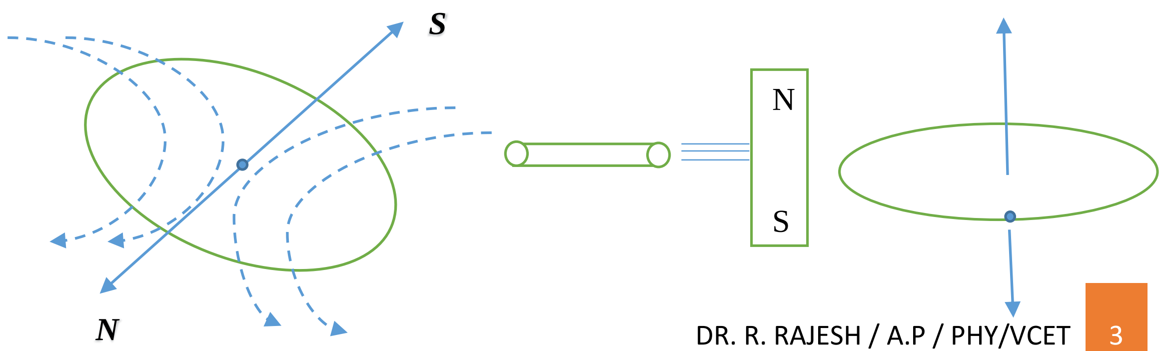
3.4. Atomic magnetic moments

The fundamental reason for the response of a material to an external magnetic field is that the atoms possess magnetic moments. That is, each atom acts like a tiny magnet. There are two source that contribute to atomic magnetic moment.

- Magnetic moment due to the movement of electrons in orbits around the nucleus, i.e., due to orbital angular momentum. This is called the orbital magnetic moment.
- Magnetic moment due to the spin of the electron i.e., due to spin angular momentum. This is called *spin magnetic moment.*

3.5. Magnetic moment due to orbital angular momentum of electrons

The orbital motion of electron revolving about a nucleus is equivalent to a tiny current loop. This produces a magnetic moment perpendicular to the plane of the orbit as shown in figure.



(a) An electron revolving around a nucleus produces a magnetic field

(b) An electron orbit is equivalent to a tiny bar magnet

(c) Magnetic dipole moment μ is opposite (electron has negative charge) to orbital angular momentum L direction.

The magnetic moment originates from the orbit motion and spinning motion of electrons in an atom. In general, there are three contributions to the angular momentum of an atom.

(i) Orbital angular momentum of the electrons:- $\mu_\circ$

Consider an electron revolving in an orbit with radius 'r' moving with linear velocity 'v' and produces a constant angular velocity 'w'. Any electron revolving around orbit produces magnetic field perpendicular to its plane which produces an orbital magnetic moment given by μ_0 = IA

$$= \left(\frac{ew}{2\pi}\right)\pi r^2$$

But v = rω and $\omega = \frac{v}{r}$

$$\therefore \mu_0 = \left(\frac{evr}{2}\right)$$

$$= -e\left(\frac{mvr}{2m}\right) \qquad \mu_\circ = \left(\frac{-el}{2m}\right)$$

By quantum theory, this orbital magnetic moment of an atom can be expressed in Bohr magnetron given by μ_B = 9.27 x 10^{-24} Am^2

(ii) Electron spin magnetic moment (μ_S)

In an atom, every two electrons will form a pair with opposite spins. Thus the resultant spin magnetic moment is zero. But in magnetic materials, the unpaired electrons spin magnetic moments interacts with the adjacent atom's to form unpaired electron spin magnetic moment which is responsible for ferro and paramagnetic behaviour of materials. Accordingly to Quantum theory, spin magnetic moment $\mu_S = \frac{e}{2m} S$

Where μ_S = ±1 Bohr Magnetron.

(iii) Nuclear spin magnetic moment (μ_N)

The mass of the nucleus is larger than that of electron by a factor of the order of 10^3. Hence, nuclear spin magnetic moment is of the order of 10^{-3} Bohr magnetron.

Since μ_S and μ_N are very small, then the practical purpose, the total magnetic moment arises due to spin magnetic moment.

3.6. Classification of magnetic materials

Magnetic materials are classified into two categories based on the existence of dipole moment and the response of material to external magnetic field namely,

Diamagnetic materials – no permanent magnetic moment

Paramagnetic, Ferromagnetic, Antiferromagnetic and Ferrimagnetic materials – having permanent magnetic moment.

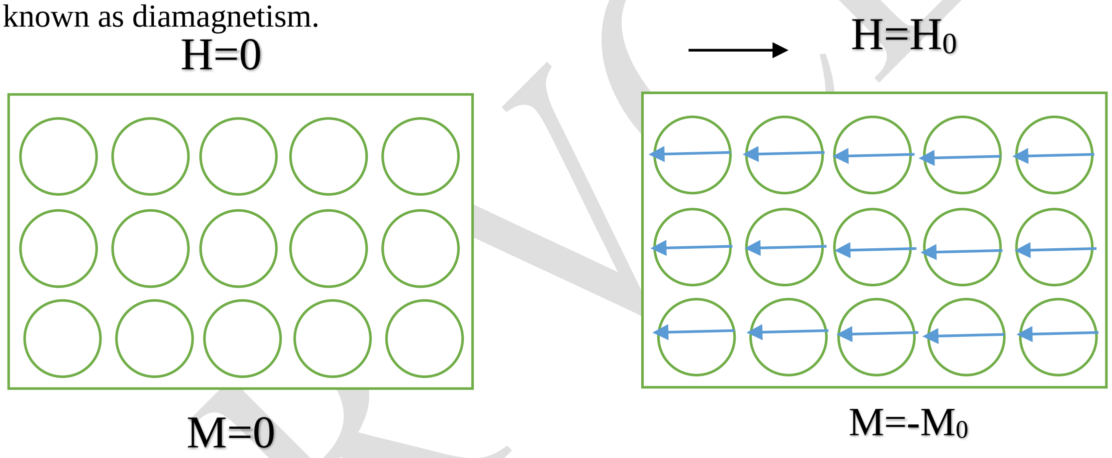
Generally diamagnetic and paramagnetic materials are known as non-magnetic materials due to poor response to an external magnetic field. Whereas the ferromagnetic, antiferromagnetic and ferrimagnetic materials are known as magnetic materials. These materials strongly respond to an external magnetic field.

Diamagnetism

The atoms in diamagnetic materials do not possess permanent magnetic moments. However, when the diamagnetic material is placed in an external magnetic field, the electrons in the atomic orbits tend to counteract the external magnetic field. Hence, the atoms acquire an induced magnetic moment.

As a result, the material becomes magnetised. The direction of the induced dipole moment is opposite to that of the externally applied magnetic field.

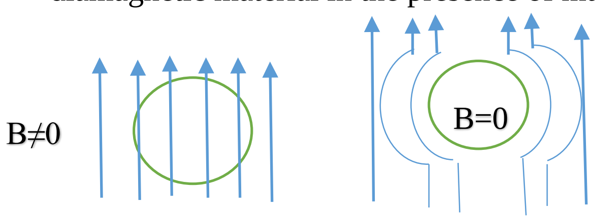
Due to this effect, the material is very weakly repelled in magnetic field. This phenomenon is known as diamagnetism.



When the magnetic field H is zero, the atoms possess zero magnetic moment. When a magnetic field H_0 is applied in the direction shown, the atom acquire an induced magnetic moment in the direction opposite to that of the magnetic field. The strength of the induced magnetic moment is proportional to the applied field and hence the magnetization of the material varies directly with the strength of the magnetic field. The induced dipoles and magnetization vanish as soon as the applied magnetic field is removed. The susceptibility of the diamagnetic material is negative. Due to this, the material is weakly repelled in the magnetic field.

Properties

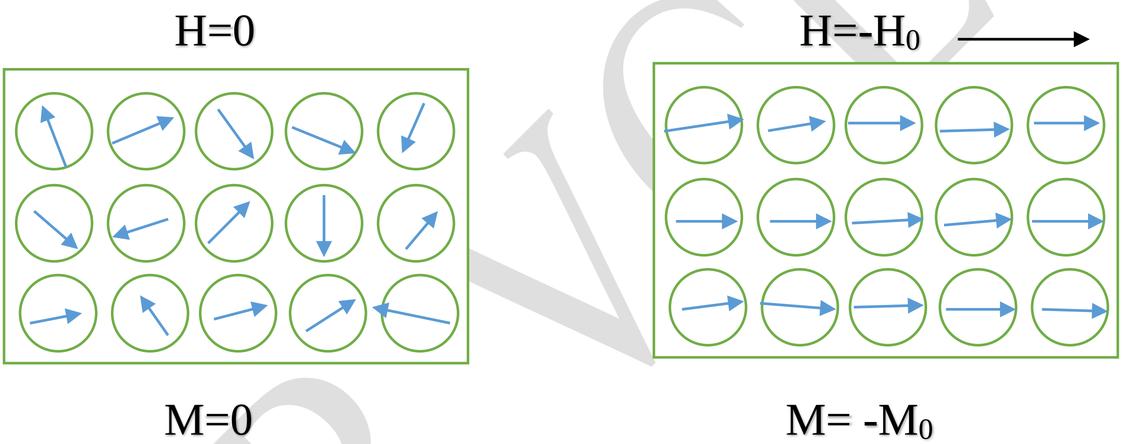
1. The diamagnetic materials repel the magnetic lines of force. The behaviour of a perfect diamagnetic material in the presence of magnetic field is shown in figure.



2. There is no permanent dipole moment. Therefore, the magnetic effects are very small in these materials.
3. The magnetic susceptibility is negative and it does not depend on temperature and applied magnetic field strength.
   Eg: Gold, germanium and silicon.

Paramagnetism

In certain materials, each atom or molecule possesses a net permanent magnetic moment (due to orbital and spin magnetic moments) even in the absence of an external magnetic field. The magnetic moments are randomly oriented in the absence of an external magnetic field. The magnetic moments are randomly oriented in the absence of an external magnetic field as shown in figure. This makes the net magnetic moment zero and hence the magnetisation of the material is zero. But, when an external magnetic field is applied the magnetic dipoles tend to align themselves in the direction of the magnetic field as shown in figure and the material becomes magnetised. This effect is known as Paramagnetism.



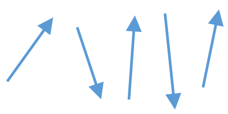
With an increase in temperature, increase in thermal agitation disturbs the alignment of the magnetic moments. It tends to randomize the dipole direction thus leading to decrease in magnetization. This indicates that the paramagnetic susceptibility decreases with increase in temperature. It is noted that the paramagnetic susceptibility varies inversely with temperature.

$$\chi \infty \frac{1}{T} \text{ (or) } \chi = \frac{C}{T}$$

This is known as the Curie's law of Paramagnetism. C is a constant which is called Curie's constant.

Properties

1. The paramagnetic materials attract the magnetic lines of force
2. They possess permanent dipole moment.
3. The value of susceptibility is positive and it depends on temperature. It is given by
   $$\chi = \frac{C}{T-\theta}$$
4. The spin alignment is shown in figure



Example: Magnesium sulphate, ferric oxide, ferrous sulphate and nickel sulphate

Ferromagnetism

Certain metals like iron (Fe), cobalt (Co), nickel (Ni) and certain alloys exhibit high degree of magnetism. These materials show the spontaneous magnetization. i.e., they have magnetisation even in the absence of an external magnetic field. This indicates that there is a strong internal field within the material which makes the atomic magnetic moments align with each other. This phenomenon is known as ferromagnetism

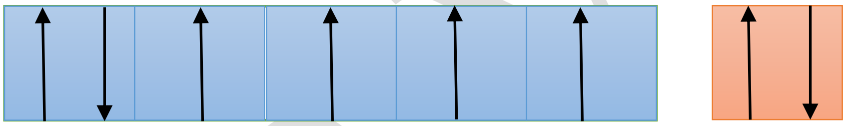
3.7. Origin of ferromagnetism and exchange interaction

The ferromagnetic property is exhibited by transition elements such as iron, cobalt and nickel at room temperature and rare earth elements like gadolinium and dysprosium.

The ferromagnetic materials possess parallel alignment of dipoles. This parallel alignment of dipoles is not due to the magnetic force existing between any two dipoles. The reason is that the magnetic potential energy is very small and it is smaller than thermal energy.

The electronic configuration of iron is $1s^2$, $2s^2$, $2p^6$, $3s^2$, $3p^6$, $3d^6$, $4s^2$. For iron , the 3*d* sub shell is an unfilled one. This 3*d* subshell have five orbitals. For iron, the six electron present in the 3*d* subshell occupy the orbitals such that there are four unpaired electrons and two paired electrons as shown in figure.

3d orbital *4s* orbital

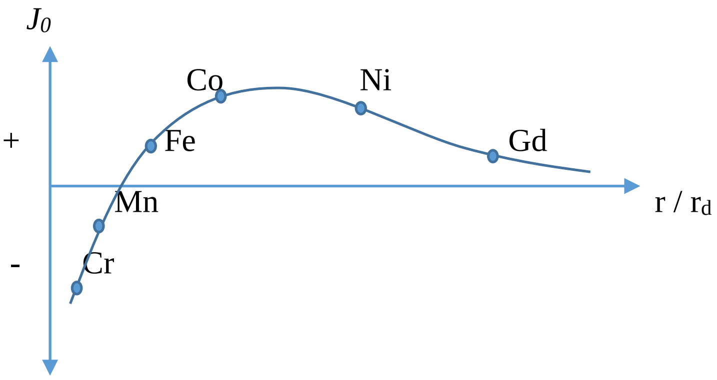


These four unpaired electrons contribute a magnetic moment of $4\mu B$. This arrangement shows the parallel alignment of four unpaired electrons. The parallel alignment of dipoles in iron is not due to the magnetic interaction. It is due to the Pauli's exclusion principle and electrostatic interaction energy. **The Pauli's exclusion principle and electrostatic interaction energy are combined together and constitute a new kind of interaction known as exchange interaction. The exchange interaction is a quantum mechanical concept.** The exchange interaction between any two atoms depends upon the interatomic separation between the two interacting atoms and the relative spins of the two outer electrons. The exchange interaction between any atoms is given by $E_{ex} = -J_e S_1 S_2$

Where J_e is the numerical value of the exchange integral, S_1 *and* S_2 are the spin angular momenta of the first and second electrons. The exchange integral value is negative for the number of elements. Therefore, the exchange energy value is negative when the spin angular momentum S_1 *and* S_2 are opposite direction. Hence antiparallel alignment of diploe is favoured. This explains the antiparallel alignment of dipoles in antiferromagnetic materials.

In some materials like iron, cobalt and nickel the exchange integral value is positive. The exchange energy is negative when the spin angular momentum is in the same direction.

This will produce a parallel alignment of dipoles. A plot between the exchange integral and the ratio of the interatomic separation of the radius of 3*d* orbital (r/r_d) is shown in figure.



For the transition metals like iron, cobalt, nickel and gadolinium the exchange integral is positive, whereas for magnese and chromium the exchange integral is negative. The positive value of the exchange integral represents the material is ferromagnetic and the negative exchange integral value represents the material us antiferromagnetic. In general, if the ratio, $r/r_d > 3$, the material is ferromagnetic, otherwise it is antiferromagnetic.

3.8. Weiss molecular Theory of ferromagnetism - Curie temperature

The metals like Fe, Co, Ni etc., exhibit magnetisation even in the absence of external field. Therefore Weiss gave a molecular field theory and postulated the existence of an internal molecular field (H_i). *This internal field is responsible for spontaneous magnetization of a ferromagnetic material, so that only the material possess magnetization even in the absence of an external field.*

The net or effective magnetic moment $H_c = H + H_i$ (1)

Where H is external field, H_i is the internal molecular field and is proportional to the intensity of magnetization

1.e., $H_i \propto I$ (2)

$H_i = \lambda I$ (3)

Where λ is Weiss constant

Substituting equation (3) in (1), we get

$$H_e = H + \lambda I$$

From Langevin theory, the intensity of magnetization of the ferromagnetic material is given by

$$I = \frac{N\mu^2}{3K_BT}\left(H + \lambda I\right) \quad (4)$$

Where N is the number of atoms

$$I = \frac{HN\mu^2}{3K_BT}\left(1 + \lambda\frac{I}{H}\right)$$

(or) $\frac{I}{H} = \frac{N\mu^2}{3K_BT}\left(1+\lambda\frac{I}{H}\right)$

$$\chi_m = \frac{C}{T}\left[1+\lambda\chi_m\right] \qquad \left[\because \frac{I}{H} = \chi_m\right] \qquad (5)$$

Where $C = \frac{N\mu^2}{3K_B}$

Equation (5) can be rewritten as

$$\chi_m = \frac{C}{T} + \frac{C}{T}\lambda\chi_m$$

(or) $\chi_m = \frac{C}{T-\lambda C}$

(or) $\chi_m = \frac{C}{T-\theta}$ (6)

This is known as Curie – Weiss law and θ is known as curie temperature.

Equation (6) has three special cases

Case 1: when $T = \theta$, $\chi_m \rightarrow$ α

The material is ready to attain external magnetization

Case 2: when $T > \theta$, $\chi_m = 1/+ve$ i.e., χ_m is positive

In this case, the thermal agitation opposes the tendency of Weiss molecular field to align the molecular magnets. So it becomes paramagnetic above Curie temperature.

Case 3: when $T < \theta$, *the material behaves as ferromagnetic material* because at lower temperature Weiss molecular field energy is high and sufficient to overcome the thermal agitation.

Curie temperature

Ferromagnetic material have a critical temperature below which they behave as ferromagnetic and above which they behave as paramagnetic. This critical temperature is known as ferromagnetic curie temperature.

3.9. Spontaneous and Saturation magnetization

The molecular magnets in the ferromagnetic material is aligned in such a way that, they exhibit a magnetization even in the absence of an external magnetic field. This is called spontaneous magnetization.

We know that, $H_c = H + H_i$

Here $H = 0$, therefore $H_e = H_i$

(or) $H_e = \lambda I$

Where I is spontaneous magnetization.

Temperature dependence of spontaneous magnetization

When the external field is zero, $H_e = \lambda I$ (1)

From the Langevin theory, we can write intensity of magnetization I as

$I = I_s L(\alpha)$ (2)

Where I_s *is the* saturation magnetization

For Ferro magnets $\alpha = \frac{\mu H_e}{K_B T}$ [since $H = 0$]

(or) $H_e = \frac{\mu\alpha}{K_B T}$ (3)

Comparing equation (1) and (3), we get

$$\lambda I = \frac{\alpha K_B T}{\mu} (or) I = \frac{\alpha K_B T}{\mu\lambda} \quad (4)$$

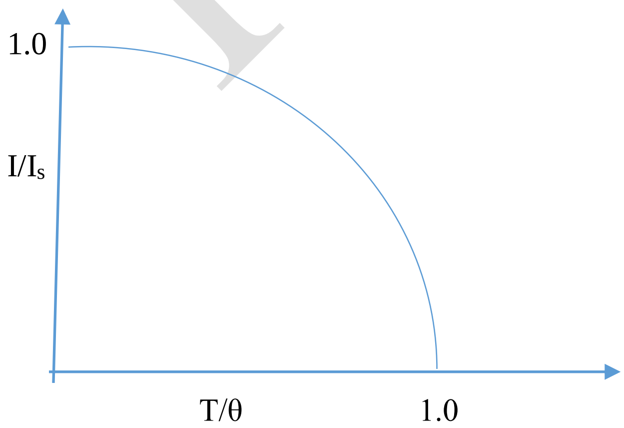
We know $I_s = N\mu$ (5)

Dividing equation (4) by (5), we have

$$\frac{I}{I_s} = \frac{\alpha K_B T}{N\mu^2\lambda} = \frac{\alpha}{3}\left(\frac{T}{\theta}\right) \qquad \left[\because \theta = \frac{N\mu^2\lambda}{3K_B}\right]$$

(or) $\frac{I}{I_s} = f\left(\frac{T}{\theta}\right)$ [where $f = \alpha/3$]

A graph is plotted between I/I_s as a function of T/θ as shown in figure. From the graph, we infer that



(i)**when the temperature is low,** Weiss field overpowers the thermal energy and it gives rise to maximum magnetization

i.e., $I/I_s = 1$

(ii) **when the temperature is increased** thermal energy increases which randomises more and more of the parallel spins and at curie temperature (T = θ), all the parallel alignment of spin vanishes give rise to zero value of spontaneous magnetization and the Material is to highly susceptible to get the external field. Thus, the substance become paramagnetic.

3.10. Domain theory of ferromagnetism

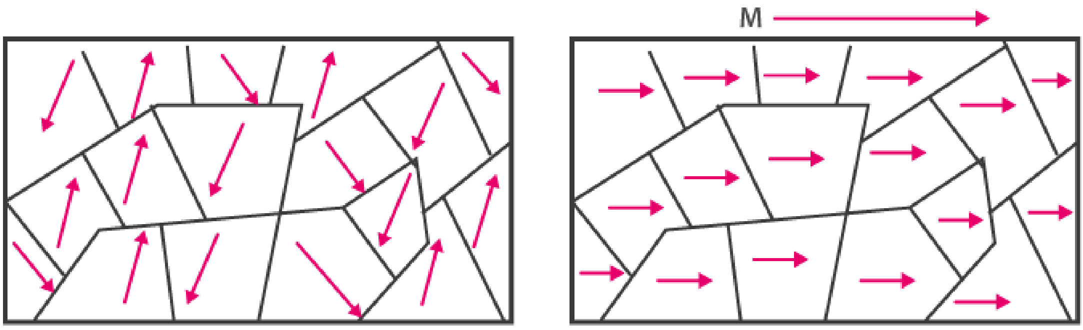
Weiss proposed the concept of domains in order to explain the properties of ferromagnetic materials.

Principle

The group of atomic dipoles organised in tiny bounded regions in the ferromagnetic materials are called magnetic dipoles.

Explanation

Ferromagnetic material contains a large number of domains. In each domain the magnetic moments of the atoms are aligned in the same direction. Thus, the domain is a region of ferromagnetic material in which all the magnetic moments are aligned to produce a net magnetic moment in one direction only. Thus, it behaves like a magnet with its own magnetic moment and axis.



A. Random domain orientation B. After magnetization

In a demagnetized ferromagnetic material, the domains are randomly oriented as shown in figure. So that the magnetization of the material as a whole is zero. The boundaries separating the domains are called *domain walls.* These domain walls are analogous to the grain boundaries in a polycrystalline material. However, the domain walls are thicker than the grain boundaries. Like grain growth, the domain size can also grow due to the movement of domain walls. When a magnetic field is applied externally to a ferromagnetic material, the domains align themselves with field as shown in figure. When a magnetic field is applied externally to a ferromagnetic material, the domain align themselves with the field as shown in figure. This results in a large net magnetization of the material.

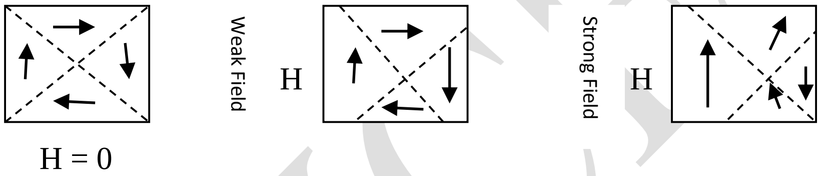
According to Weiss, *Ferro magnetic materials consists of large number of small regions called domain. Each domain varies from 10^{-6} to entire size of the crystal*. In each domain the spontaneous magnetization is due to parallel alignment of all magnetic domains. The direction of spontaneous magnetization varies from domain to domain. Hence the resultant magnetization may be zero or nearly zero, when the external field is applied. There are two ways of alignment of a random domain:

(i) **By the motion of domain walls**:-

The volume of the domains that are favorably oriented with respect to the magnetizing field increases at the cost of those that are unfavorably oriented as shown in figure

(ii) By the rotation of domains:-

When the applied magnetic field is strong, rotation of the direction of magnetization occurs in the direction of the field as shown in figure



By bitter powder pattern, when a drop of colloidal suspension of finely divided ferromagnetic material has strong magnetic field near boundaries when external magnetic field is applied domain walls are move. The domain walls & their movements can be observed from microscope.

In the process of domain growth, four types of energies are involved:

(i) <u>Exchange energy (or) Magnetic field energy (or) Magneto-static energy:-</u>

"The interaction energy makes the adjacent dipoles align themselves. It arises from the interaction of electron spins".

This exchange energy is the energy required in assembling the atomic magnets in single domain and this work done is stored as potential energy, the size of domain may be obtained from the principal of minimum energy volume of domain = 15^2 to 10^{-6} cm^3.

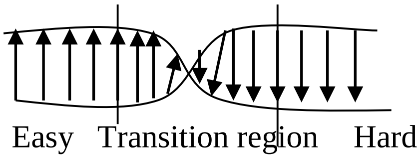
(ii) <u>Anisotropy energy</u>:-

In ferromagnetic crystals, energy of magnetization is found to be a function of crystals orientation i.e., crystal have easy and hard direction of magnetization.

Example: In BCC iron, easy direction is [100], the medium direction is [110] and the hard direction is [111]. "The excess energy required to magnetize a specimen in a particular direction over that required to magnetize it along the easy direction" is called crystalline anisotropy energy.

(iii) <u>Domain wall energy (or) Bloch wall energy:-</u>

The thin region that separates adjacent domains magnetized in different direction is called "Domain wall energy". Bloch walls are 200 to 300 lattice constant thicknesses. It changes the spin when transfer from one domain to other. The exchange energy is lower when the change is gradual but the anisotropy energy is less when spin change abruptly. Hence the Bloch wall compromise between two.



(iv) Magnetostrictive energy:-

When the domains are magnetized in different directions, they will either expand (or) shrink. Therefore there exists a deformation (i.e., change in dimension of a material) when it is magnetized this phenomenon is known as Magnetostriction and the energy produced is Magnetostrictive energy.

3.11. Hysteresis M vs H behaviour

When a Ferromagnetic is subjected to external field, there is an increase in the value of the resultant magnetic moment due to

(i) The movement of domain walls

(ii) The rotation of domains

When a weak external field is applied, the domain walls are displaced slightly in the soft direction of magnetization. This gives rise to small magnetization corresponding to the initial portion of the hysteresis curve (OA) as shown in figure .Now, if applied field is removed, then the domains return to its original state and it is known as "**Reversible Domains**".

When a strong external field is applied, large number of domains contributes to the magnetization and thus the magnetization increases rapidly with "H"↑

Here, even when the field is removed, because of the displacement of domain wall to a very large distance. The domain boundaries do not come back to their original position. This process is indicated as (AB) in Figure and this domains are called **"Irreversible Domains".**

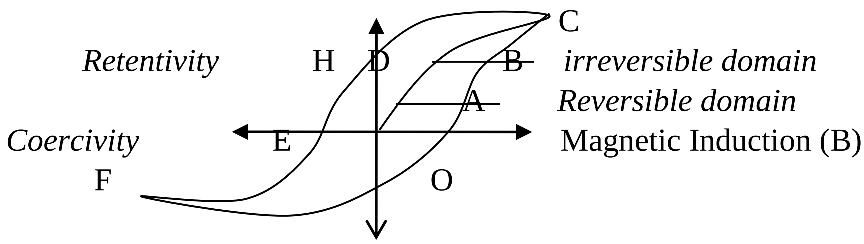
At point "B" all the domains have got magnetized along the soft direction. Now, when the field is further increased, the domains start rotating along with the field direction and the anisotropic energy is stored in the "*Hard Direction*" represented as "BC" in figure

Thus the specimen is said to attain the maximum magnetization. At this position, even after the removal of external field the material possess maximum magnetization called **"Retentivity"** represented by "OD" in figure

Actually after the removal of the external field, the specimen will try to attain the original configuration by the movement of Bloch wall. But this movement is stopped due to the presence of impurities, lattice imperfections, etc., therefore to overcome this, a large amount of reverse magnetic field is applied to the specimen. The amount of energy spend to reduce the magnetization of Zero is called **"Coercivity"** represented by "OE" in figure

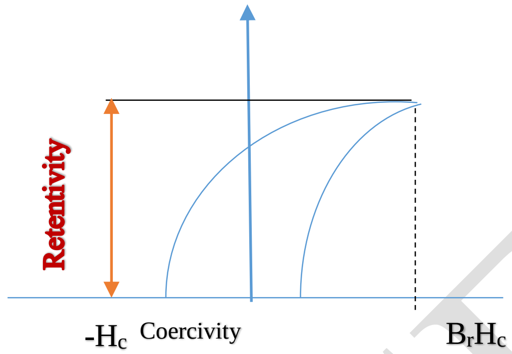
Hysteresis Loss:

It is the loss of energy in taking a ferromagnetic specimen through a complete cycle of magnetization and the area enclosed is called "Hysteresis Loop". Based on this area of hysteresis, the magnetic are classified as soft and hard magnetic materials.



3.12. Energy Product

The product of retentivity (B_r) and coercivity (H_c) is known as energy product. It represents the maximum amount of energy stored in the specimen. Therefore for permanent magnets the value of energy product should be high as shown in figure

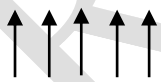


Ferromagnetic materials

The materials which possessing permanent magnetic moments even in the absence of the external magnetic field is called ferromagnetism. The materials which exhibiting ferromagnetism are called ferromagnetic materials.

Properties

- All the dipoles are aligned parallel to each other due to the magnetic interaction between the dipoles.
- They have permanent dipole moment. They are strongly attracted by the magnetic field.
- They exhibit magnetization even in the absence of magnetic field. This property of ferromagnetic materials is called as *spontaneous magnetisation*.
- They exhibit hysteresis (lagging of magnetisation with applied magnetic field).
- On heating, they lose their magnetisation slowly.
- The dipole alignment is as follows:



- The magnetic susceptibility is very high and it depends on temperature. It is given by

  $\chi = \frac{C}{T-\theta}$ (for T > θ, paramagnetic behaviour; for T < θ, ferromagnetic behaviour)

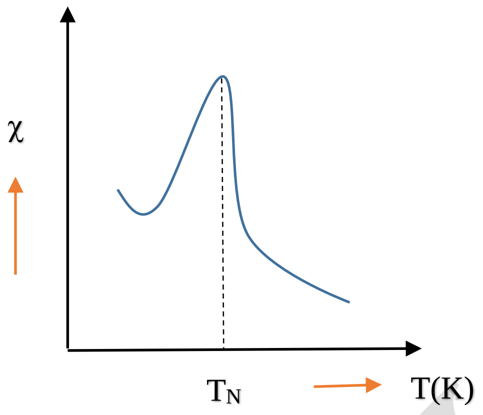
  Here C – Curie constant and θ - ferromagnetic Curie temperature.

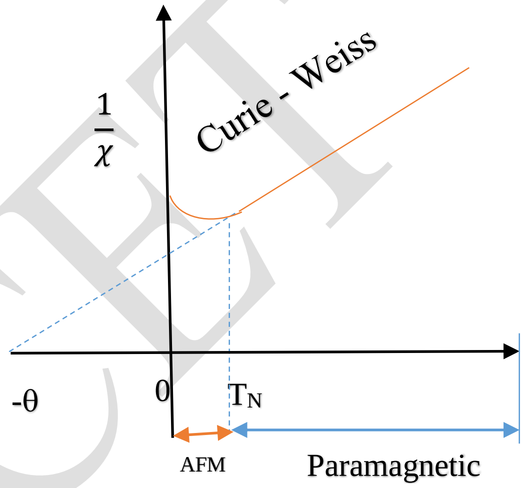
3.13 Antiferromagnetism

Antiferromagnetic materials are magnetic materials which exhibit a small positive susceptibility of the order of 10^{-3} to 10^{-5}.The variation of susceptibility with temperature shows a peculiar pattern in these materials. The susceptibility increases with increasing temperature and it reaches a maximum at a certain temperature called Neel temperature **T_N.** With further increase in temperature, the material reaches paramagnetic state. The material is antiferromagnetic below T_N. The transition temperature T_N lies far below the room temperature for most of the materials. In the paramagnetic state, the variation of inverse susceptibility ($1/\chi$) with temperature is linear, as shown in figure. The extrapolation of the paramagnetic line to $1/\chi = 0$ yields a negative θ. Therefore, the variation of susceptibility with temperature obeys modified Curie – Weiss law.

$$\chi_{a.f} = \frac{C}{T-(-\theta)} \text{ (or) } \chi = \frac{C}{T+\theta} \text{ when } T>T_N$$

θ - paramagnetic curie temperature, C – Curie constant



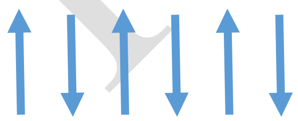


In antiferromagnetism, the magnetic moments of sub lattices in crystal cell are equal in magnitude but opposite in direction so they cancel out each other. This gives net zero magnetization.

The materials exhibits antiferromagnetism are called as antiferromagnetic materials. The elements manganese and chromium exhibit antiferromagnetism at room temperature. Most of the antiferromagnetic materials are ionic compounds. MnO, MnS, Cr_2O_3, NiCr are some of the compounds which exhibit antiferromagnetism.

Properties

- The adjacent magnetic dipoles are aligned antiparallel



- Antiferromagnetic susceptibility mainly depends on temperature
- The magnetic susceptibility of the antiferromagnetic materials is small and positive. It is given by
- $\chi_{a.f} = \frac{C}{T+\theta}$ when $T>T_N$; where T_N is the Neel temperature; $\chi \propto T$ when $T<T_N$
- The magnetic susceptibility initially increases slightly with temperature and beyond Neel temperature, it decreases with temperature.

Ferrimagnetism

There are some magnetic materials in which the magnetic moments of two sub lattices are opposite in direction but not exactly equal in magnitude (because of two different types of ions in the lattices).Such crystals possess spontaneous magnetization and exhibit most of the properties of ferromagnetic materials. This uncompensated antiferromagnetism is known as ferrimagnetism.

3.14. Ferrimagnetic materials or ferrites

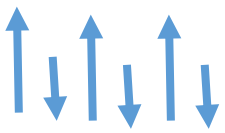
Materials exhibit ferrimagnetism are called ferrimagnetic materials

Properties

- Ferrites have net magnetic moment
- Above Curie temperature it becomes paramagnetic an it behaves as ferrimagnetic material below Curie temperature.
- The susceptibility of ferrite is very large and positive. It depends on temperature. It is given by

$$\chi = \frac{C}{T \pm \theta} \text{ for } T > T_N$$

- Spin alignment is antiparallel of different magnitude as shown in figure



- Mechanically, it has pure iron character
- They have high permeability and resistivity
- They have low eddy current and hysteresis losses.

Applications

- Hard magnetic ferrites are used in the manufacture of permanent magnets.
- Such magnets are used in super high frequency technology.
- Soft magnetic ferrites are used in the production of cores for inductor coils used in telecommunication and low power transformers.
- Ferrites are used in magnetic films in which demagnetization process occurs at the speed exceeding million times/second. This technology is important for electronics, automobiles and computer hardware engineering.
- Ferrites are used in information storage devices such as magnetic discs and tapes.
- Ferrite rods are used to produce ultrasonics by magnetostriction principle.
- Ferrite rods are used in radio receiver to increase sensitivity and selectivity.
- Since the ferrite has low hysteresis loss and eddy current loss, it is used in two port microwave devices such as gyrator, circulator and isolator.

3.15 Type of Magnetic material

Magnetic materials are classified into two types

(i) soft magnetic materials

(ii) Hard magnetic materials

(i) Soft magnetic materials

Soft magnetic materials are the materials which are easily magnetized and demagnetized. In soft magnetic materials, for the small changes in the magnetic field, the magnetization changes by large amounts. This is because of easy movement o domain walls and movement is also reversible. The soft magnetic materials are prepared by heating the pure material to a particular temperature at which the sufficient movement of the atoms is possible and also to settle into an ordered lattice, followed by slow cooling.

Properties

The properties of soft magnetic materials are listed as follows:

1. In soft magnetic materials, the hysteresis loop is very sharp as shown in fig
2. The hysteresis area is very small and hence, the hysteresis loss is also small.
3. These materials are free from irregularities like impurities
4. Their magnetostatic energy is very small.
5. These materials have large values of susceptibility and permeability.
6. The resistivity of these materials are very high and hence they have low eddy current loss.
7. The coercivity and retentivity values are small.

Eg: Iron-silicon alloys, Ni-Fe alloys, and Fe-Cobalt alloys.

Applications

1. Si steel is used in large alternators and high frequency rotating materials.
2. Iron- silicon alloys are used in electrical equipment and magnetic cores of transformers.
3. Ni alloys are used to manufacture transformers, insulators, relays and small motors.

(ii) Hard magnetic materials

Hard magnetic materials are the materials which are very difficult to magnetize and demagnetize. The hard magnetic materials are prepared by the heating the magnetic materials to a particular temperature and then suddenly cooling them by dipping in a cold liquid. This type of magnetic materials become hard by introducing impurities.

Properties

The properties of hard magnetic materials are as follows:

1. The hysteresis curve is broad and has a large area as shown in Fig
2. Since the area of the hysteresis curve is large, the hysteresis loss is also large.
3. The coercivity and retentivity values are large.
4. These materials have large amount of impurities and lattice defects.
5. The magnetostatic energy is large.
6. The eddy current loss is very high.

7. These materials have low value of susceptibility and permeability.

Egs: Tungsten steel, Carbon steel, chromium steel atc.

Applications

1. Magnets made by carbon steel are used for manufacturing the toys, compass needle and some types of meters.
2. Tungsten steel is used in dc meter magnets.
3. Chromium steel is used as the permanent magnet.

3.16. Magnetic principle in computer data storage

Magnetic recording involves the storage of data in the form of magnetization pattern as a sequence of binary magnetization states in the magnetic medium.

Reading Process:

An audio tape is simply a polymer packing tape coating with magnetic oxide. The audio signal to be recorded is converted in to current signal & it is passed through electromagnet made up of ferrite which has small air gap of about 0.3m wide

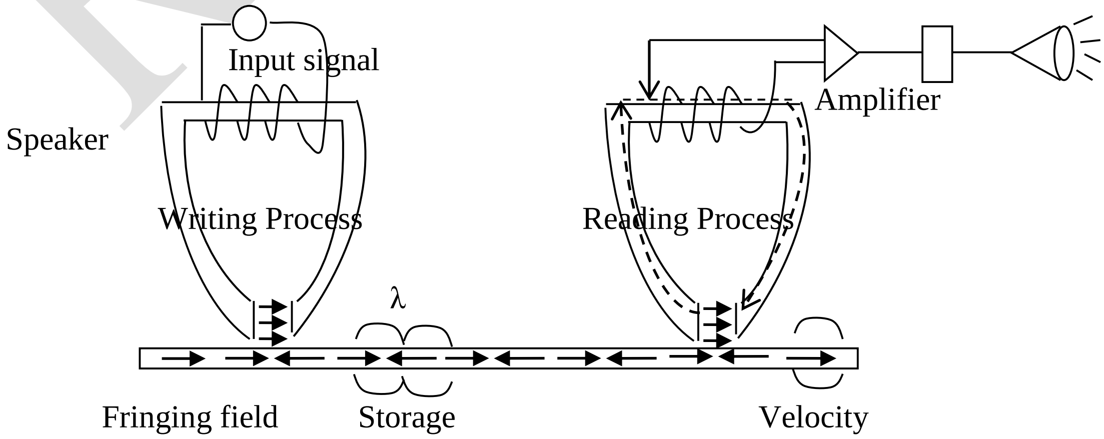
Whenever the current signal passes through the electromagnet, it produces a magnetic field in the material which produces a magnetic field in the recording head (air gap)

When the tape touches the head, the magnetic field present in the head magnetize the magnetic material present in the tape. The recording on the tape is done by fringing magnetic field around the air gap region. This fringing magnetic field magnetizes the audio tape passing under the head at constant speed. Th intensity of the fringing magnetic field varies with the intensity of the current signal. Thus the electrical signal is stored by means of spatial magnetic pattern on the tape. This type of magnetic recording is called *longitudinal recording*

Writing Process:-

The reading process is based on the principle of Faraday's law of electromagnetic induction. A portion of magnetic field present in the tape penetrates through the recording head.

This magnetic field loops around the core of the head. As the tape is moving with a constant velocity, the magnetic field present in the tape while flowing through the core gets converted in to the corresponding voltage signal & the voltage signal is converted into an audio signal by a amplifier & loud speaker.



Storage of Magnetic data

In general memory units are the devices used to store the information in the form of bits. [8 bit =1 byte]. The memory units are classified as

1. Main memory (or) Internal memory
2. Auxiliary memory (or) External memory

Main Memory:

The memory unit of CPU is called main memory. Thus data's are write and finally be erased if necessary.

Eg: EPROM, ROM, RAM etc.,

Auxiliary Memory:

This type of memory is also referred to as back-up storages because; it is used to store large volume of data on permanent basis. This date can be accessed or recopied if necessary.

Eg: Magnetic tapes, Magnetic disk, Ferrite core memories and Bubble memories.

1. Magnetic Tape:

The tape is a plastic ribbon with metal oxide material coated on one side which can be magnetized, in this information can be written and also can be read by write/read heads.

Information recorded in the tape is in the form of tiny magnetized and non-magnetized spots on the metal oxide coating. The magnetized spot represents '1' sun magnetized spot represent '0' in binary code. The information can be accessed, processed, erased and can be stored again in same area.

Advantages:-

(i) Storage capacity is large
(ii) Easy to handle
(iii) Loss expensive
(iv) Erased and reused.

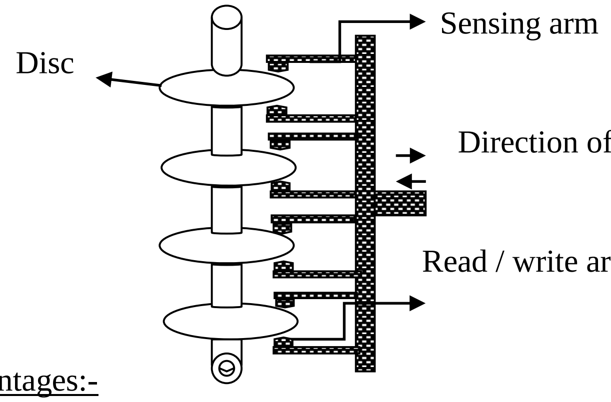
Disadvantages:-

(i) It consumes lot of time.

2. Magnetic Disc Devices:

(A) Hard disk drives:

It is the direct access storage device made up of hard aluminum platters. This platter surface is carefully machined for flat. This surface is coated with magnetic oxides and built in to a bar. Similar such disks are mounted on a vertical shaft, forming a disk pack as shown in figure. The drive mechanism drives the disc pack with the spindle. The data is written can read by the R/W heads in the horizontal sensing arms by moving in and out between the platters with the precaution that the R/W head doesn't touches the surface instead, it fly over the disk surface by a fraction of a mm.



Advantages:-

1. It has large storage capacity.
2. Thousand of files can be permanently stored.
3. Very high speed in reading and writing the information
4. This is prevented from dust, since they are sealed.

Disadvantages:-

1. It is very costly
2. If data is completed, there is a heavy loss.

(*B*) *Floppy disc drives*:

Floppy is made of a very thin and flexible plastic materials coated with magnetic materials. This disc is inserted in floppy disc drive for read/write operation by the read/write head in the disc. Size: 5.25" called mini floppy, 3.25" called micro floppy.

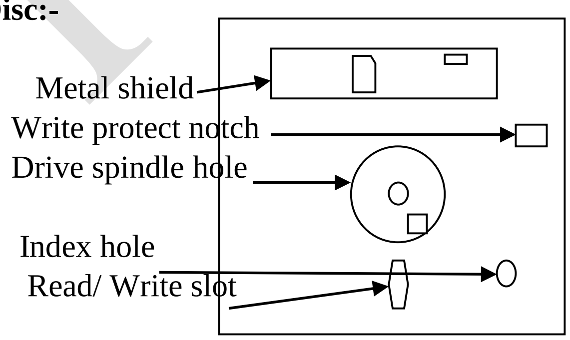
Organization:-

Surface of the floppy disc is divided into a number of concentric circles known as tracks where the information is recorded. The tiny magnetic spots are used to record the logic 1 (or) 0 state. The spot magnetized in one direction are '1' state and in other direction are called '0' state. Each track has number of sectors

Operation;-

When the floppy is put in drive unit. When drive is operated. The floppy disc is rotated which makes physical contact with read/write head. This magnetic material movement is controlled by serve mechanism.

Floppy Disc:-



Advantages:-

(i) Storing and transporting of data is easier.
(ii) Cost is less
(iii) It can reused many times

Disadvantages:-

(i) Storage capacity is less
(ii) Care to be taken for handling.

3. Ferrite Core Memory:

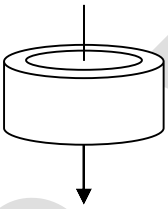
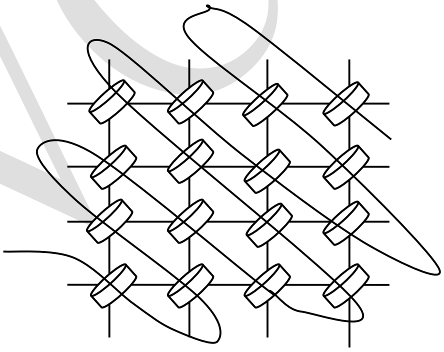


Figure (3)



Here the magnetic core consists of a ferrite core in the shape of a torrid ring as shown in figure.

We know that the ferrites have square hysteresis loop and low coercivity as shown in figure. Such hysteresis is used for making core memory as a different form of magnetic recording.

The magnetic cones of the memory are arranged in a matrix interlaced thought fine metal wires both horizontally and vertically as shown in figure (3)

A change in the state only occurs during reinforced magnetization i.e. both the horizontal current and vertical current pass through the core in same direction. The current passing through one of the wires will not induce a change in the magnetization of the cores reading of the magnetic cores is achieved using a third sense wire threaded through the core. It will pick up an induced voltage, if the core changes state. To facilitate a fast response for a high speed memory, soft magnets are always used in the core.

4. Magnetic Bubbles Memories:

Magnetic bubbles are soft magnetic materials with magnetic domains of a few micrometers in diameter.

Construction:-

Bubble memory consists of magnetic garnets deposited on a non-magnetic substrate made up of Gadolinium Gallium Garnet (GGG)

When a magnetic field is applied by placing in between two permanent magnets, the magnetic domains contracts and finally forms a small cylindrical domain area which is called magnetic bubble.

These bubbles constitute a magnetic region of one polarity surrounded by magnetic region of opposite polarity.

The information is represented as the presence (or) absence of a bubble at specified location. The bubble position remains unchanged even in the absence of electric power. These bubbles can be moved electronically through the access lines at very high speed and hence its access and storage time is less.

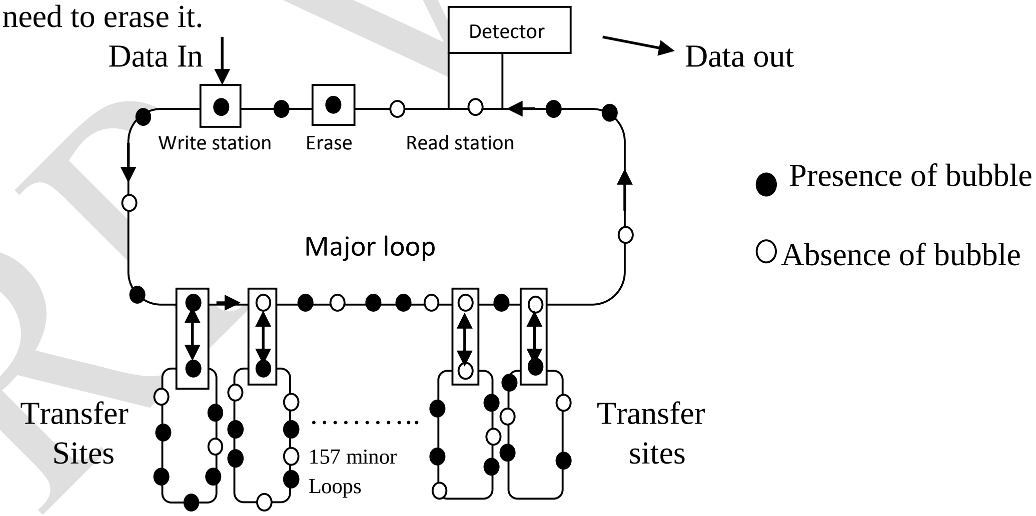
Here presence of bubble is logic '1' state and absence is logic '0' state. The schematic diagram show in fig. It consists of '1' major loop and '15' minor loops which are arranged from right to left. Each minor loops has 641 bubble sites, thousands of coded characters may be stored in a single chip.

Writing Operation:-

When a data has to be stored, the bubbles from the minor loops are transferred to major loop and it goes to write station. In write station the message is entered and the bubble site again comes to minor loop.

Reading Operation:-

To read the data from the storage, the bubble from minor loops are transferred to major loops and it goes to read station, then it comes to minor loop. The data can be altered by the erase station, if we need to erase it.



Advantages:-

(i) Large amount of data stored permanently
(ii) Data is not lost while power is off
(iii) It is a non-volatile memory
(iv) Bubble sites are moved electronically

Disadvantages:-

(i) It requires a high recording time for storing and retrieving the data.

3.17. Giant Magnetoresistance

Principle

In hard disk drives, the binary data in terms of zero's (0) an one's (1) are stored by inducing magnetic moment in a thin magnetic layer and GMR effect is used as the principle to read the data in HDD. Here zero (0) represents missing transition and one (1) represents transition in the medium.

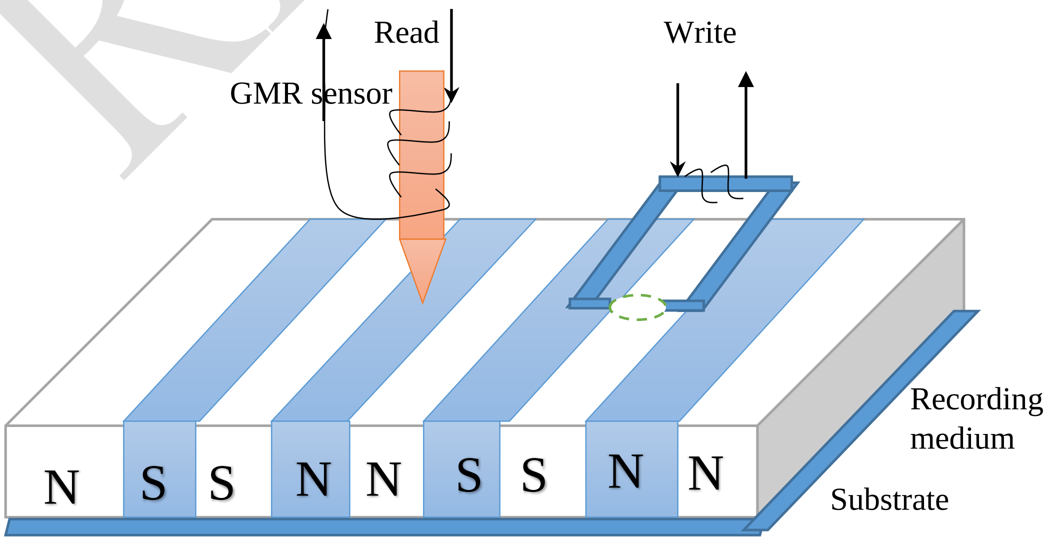
Construction

The HD consists of recording medium madeup of thin layer of magnetic garnets grown over the substrate. The GMR sensor, which is made up of ferrites and antiferromagnetic materials is used as reading element. The writing element is madeup of inductive magnetic transducer. The writing element and the GMR sensor shall be made to slide over the recording media in the longitudinal direction as shown in figure. Hence this method is also called as longitudinal recording. The flow of current through the GMR sensor and writing element shall be adjusted and inturn the magnetization is sensed (or) controlled in the recording media.

Working

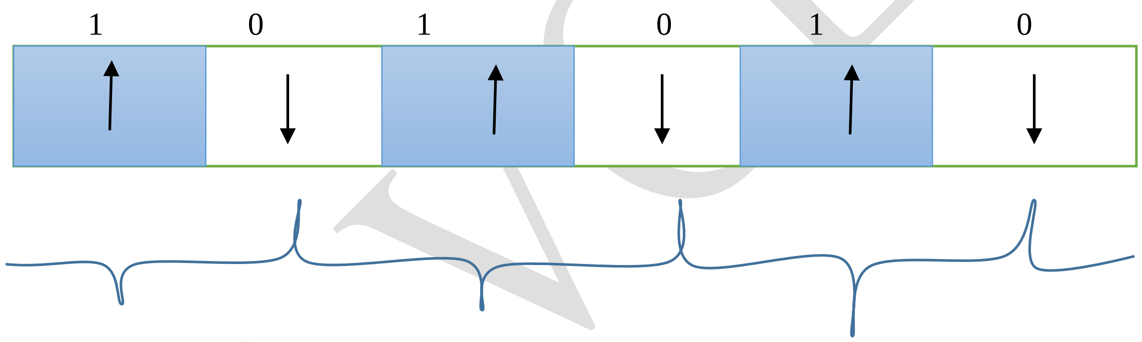
Writing / Storing

1. Initially the current is passed through the writing element and a magnetic field is induced in between the gap of the inductive magnetic transducer.
2. During writing, the amplitude of current is kept constant, and the direction of current is reversed.
3. Due to reversal of current, the magnetization orientation is reversed in the recording medium i.e., from south → North as shown in figure
4. When the induced magnetic field is greater than the coercivity of the recording media, then data is recorded in the form of 1.
5. Thus one (1) is stored as data in the recording medium as a magnetic transition.
6. When there is no magnetic transition, then it is referred as zero (0).
7. In this way the zero's (0's) and one's (1's) are stored in the recording medium.



Reading / Retrieving

8. Giant Magnetoresistive (GMR) effect is the principle used to read / retrieve the data from the recording medium.
9. When the GMR sensor is made to move near the recorded medium, then the resistance of the GMR sensor varies with respect to the orientation of the magnetic moments as follows.
10. When the layers are magnetised in parallel manner, then the resistance in the GMR sensor is minimum and therefore maximum current flows through the sensor, which represents the data as one (1)
11. When the layers are magnetised in antiparallel manner, then the resistance in the GMR sensor is maximum and therefore minimum(or) almost no current flows through the sensor, which represents the data as zero (0)
12. Therefore with the help of the reading current, the zero's (0's) and one's (1's) can be retrieved from the magnetic hard disk drive.



Advantages

- HDD can store the data in terabytes
- It has very large storage capacity
- It is compact in size and can be easily transferred from one place to another.
- The size of recording medium is reduce up to few nano meter range using nanotechnology
- GMR sensor are non-diffusive and are very sensitive in reading

Disadvantages

- HDD is slower than soli state drives
- Consume large power
- Data may be corrupted due to thermal radiation
- HDD has bulkier form factor
- GMR noise ratio is high for nano size recording media

Applications

- Used as storage devices in cloud applications

- Used in coding and signal processing units
- Used in control systems, Nano electronics, etc.,