MAGNETIC MATERIALS

1) What is magnetic dipole and magnetic field? (Short answer question)

Magnetic dipole:

The magnetic effects are greatly exhibited at the two ends of a bar magnet. These ends are called magnetic poles, the north and south poles. It is found that magnetic poles always occur in pairs and cannot be isolated. A system consisting of two equal and opposite magnetic poles separated by a small fixed distance is called magnetic dipole.

Magnetic field:

The space around a magnet where its influence is experienced is known as the magnetic field. The Danish physicist, Oersted discovered in 1819, that a current carrying conductor also produces a magnetic field.

2) Define magnetic dipole moment and Magnetic flux? (Short answer question)

Magnetic dipole moment (M):

The product of the pole strength (*m)* and the length of the magnet (*2l*) is called magnetic diploe moment, $M = 2l\,m$. It is a vector quantity. Its direction is from south pole to the north pole. Its unit is ampere– metre^2.

Magnetic flux (φ) *:*

The magnetic field can be visualized in the form of magnetic flux lines which are also called the lines of induction. A line of magnetic flux is the line that would be traced out by a free hypothetical north pole under the influence of the field. The total number of magnetic lines of force passing normally through a surface is called magnetic flux.

The flux is denoted by φ . The SI unit of flux is Weber. In a strong field, there will be crowding of the flux lines and in weak field the flux lines fall apart.

3) Define Magnetic flux density, Magnetic field strength? (Short answer question)

MAGNETIC FLUX DENSITY OR MAGNETIC INDUCTION (B) *:*

The concentration of magnetic flux is called magnetic flux density**.** It is defined as the number of flux lines passing through unit area of a surface held normally to the flux. It is denoted by *B*. The unit of *B* in SI system is Tesla (T) or Wb/m^2. The CGS unit for B is gauss (G). $(1G = 10^{-4}\ T)$. It is a vector quantity.

$$B = \varphi/A$$

MAGNETIC FIELD STRENGTH (H) *:*

The magnetic field strength is defined as the force experienced by a unit north pole placed at a point in the field. It is denoted by *H*. The units of *H* are Ampere per meter in SI system and Oersted in Gaussian system. It is a vector quantity. It is a measure of magnetizing field.

$$H = F/m$$

4) Define intensity of magnetization and magnetic susceptibility? (Short answer question)

INTENSITY OF MAGNETIZATION (I) *:*

The process of converting a non-magnetic specimen into a magnetic specimen is referred to as magnetization. The magnetic moment per unit volume of the material is called intensity of magnetization. If M is the magnetic moment and V is the volume of the magnet, then the intensity of magnetization is

$$I = M/V$$

If *m* be the pole strength, *2l* is the length of the magnet and *A* is the area of the magnet then,

$I = {m \times 2l}/{A \times 2l} = m/A$. The intensity of magnetization may also be defined as the pole strength per unit area. It is a vector quantity. Its direction is along the direction of the magnetic moment. Its SI unit is Ampere per meter.

MAGNETIC SUSCEPTIBILITY:

When two different materials of identical shape and size are brought under the influence of magnetic fields of same strength, the one which develops higher degree of magnetization is more susceptible to get magnetized. Thus, the term magnetic susceptibility is defined.

The ratio of magnetization to the strength of the magnetic field is called the magnetic susceptibility χ of the material. It has no units.

$$I \,\alpha\, H \;\Rightarrow I = \chi H \;\Rightarrow \chi = {}^{I}/_{H}$$

5) What is Magnetic permeability? (Short answer question)

The magnetic flux has the ability to pass through matter. But the freeness with which the flux can penetrate through a given material depends on the material. The materials which allow the flux to penetrate easily are said to have higher permeability.

The magnetic flux density (B) is directly proportional to the magnetic field strength (H).

$B \,\alpha\, H \;\Rightarrow B = \mu H$, where μ is a constant of proportionality and is known as permeability of the medium. The permeability is defined as the ratio of the magnetic flux density (*B*) in the medium to the magnetizing field (*H*). The magnetic flux density in air or vacuum is $B_0 = \mu_0 H$, where B_0 is the magnetic flux density of air or vacuum and μ_0 is the permeability of air or vacuum. The value of $\mu_0 = 4\pi \times 10^{-7}$ henry per metre.

The ratio of permeability of medium to the permeability of air or vacuum is called relative permeability and is denoted by μ_r . It has no units.

$$\mu_r = {}^{\mu}/_{\mu_0}$$

6) Show that $\boldsymbol{B = \mu_0 (H + I)}$. (Short answer question)

When a magnetic material of cross-sectional area *A* and relative permeability μ_r is placed in a uniform magnetic field strength *H*, two types of magnetic lines of induction can pass through it. One is due to the magnetic field strength *H* and the other is due to the material itself being magnetized by induction. Thus the total flux density *B* will be given by

$$B = B_0 + B_I = \mu_0 H + \mu_0 I = \mu_0 (H + I)$$

$B_0 = \mu_0 H$ is the magnetic flux density due to the magnetizing field and $B_I = \mu_0 I$ is the magnetic flux density due to the magnetization of the material.

7) What is the relation between Relative permeability and Magnetic susceptibility? (Short answer question)

We know that, $B = \mu_0 \, \mu_r \, H \; and \; B = \mu_0 \, (H + I)$

$$\mu_0 \, \mu_r \, H = \mu_0 \, (H + I)$$

$$\mu_r = {}^{(H+I)}/_{H} = 1 + {}^{I}/_{H}$$

$$\mu_r = 1 + \chi$$

8) Explain the origin of magnetic moment at the atomic level. (Short answer question)

We know that electric current through a conductor develops magnetic field around it or current through a coil of wire will act as a magnet. This informs that there is an intimate relation between electric current and magnetic field. Flow of electrons along a path constitute electric current. In all atoms, electrons are revolving around the nucleus in different orbits. These revolving electrons constitute an electric current in the orbits. These currents form magnetic dipoles. Therefore, the magnetic dipole moment of an atom is due to the orbital motion of electrons, spin of electrons and spin of nucleus.

9) Explain the origin of magnetic moment at the atomic level.

ORIGIN OF MAGNETIC MOMENT:

We know that electric current through a conductor develops magnetic field around it or current through a coil of wire will act as a magnet. This informs that there is an intimate relation between electric current and magnetic field. Flow of electrons along a path constitute electric current. In all atoms, electrons are revolving around the nucleus in different orbits. These revolving electrons constitute an electric current in the orbits. These currents form magnetic dipoles. As electrons in an atom are revolving in different orbits that are randomly oriented, so the magnetic dipoles due to orbital motion of electrons are randomly oriented, results in zero magnetic dipole moment. The spin of orbital electrons and the spin of nucleus also contribute to the magnetic effects of an atom. Under an external applied magnetic field, these dipoles experience torque in the direction of the applied field and the atom acquires certain magnetism. Therefore, the magnetic dipole moment of an atom is due to the orbital motion of electrons, spin of electrons and spin of nucleus.

MAGNETIC MOMENT DUE TO ORBITAL MOTION OF ELECTRONS:

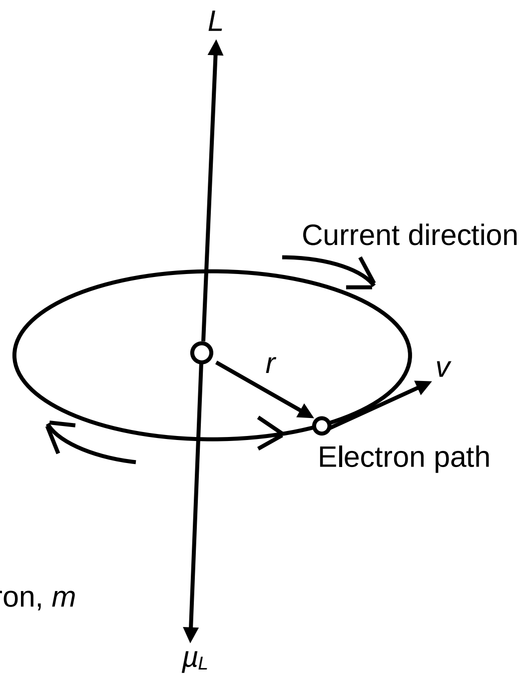
Consider an electron of mass *m* and charge –*e* is revolving round the nucleus in a circular orbit of radius *r*. Let *v* be its velocity, ω be its angular velocity and *T* be the period of revolution.

The charge that crosses any reference point in the orbit in unit time is $^{-e}/_{T}$ and this is equal to current in the orbit. So, current in the orbit is

$i = \frac{-e}{T}$ ---------- (1)

The magnetic moment (μ_L) associated with the orbit due to orbital motion of electron is

$\mu_L = i\,A$ ----------- (2)



Where *A* = area of the orbit = $\pi\,r^2$.

Equation (2) becomes $\mu_L = \frac{-e\,\pi\,r^2}{T}$ -------- (3)

The angular velocity, $\omega = \frac{2\,\pi}{T}$ or $T = \frac{2\,\pi}{\omega}$ -------- (4)

Substituting equation (4) in equation (3), we have

$\mu_L = \frac{-e\,\pi\,r^2\,\omega}{2\,\pi} = \frac{-e\,r\,(r\,\omega)}{2} = \frac{-e\,r\,v}{2}$ --------- (5)

Since linear velocity $v = r\,\omega$.

Multiplying and dividing equation (5) with mass of electron, *m*

$\mu_L = \frac{-e\,m\,v\,r}{2\,m} = \frac{-e\,L}{2\,m}$ ----------- (6)

Where $L = m\,v\,r$ = orbital angular momentum of the electron. The negative sign in equation (6) indicates that the angular momentum vector and magnetic moment vector are in opposite direction.

Magnetic moment = $\frac{-e}{2\,m}$ $\times$ angular momentum

In quantum theory, the angular momentum is expressed as

$L = l\,\hbar$ ------------ (7) where

l is the azimuthal quantum number and takes the values $l = 0, 1,2, 3 \ldots \ldots. (n-1)$, for *s, p, d..*etc. electrons, n is the principal quantum number and takes the values $n = 1, 2, 3 \ldots$ corresponds to *K, L, M*……. shells respectively and $\hbar = \frac{h}{2\,\pi}$.

Substituting equation (7) in (6), we get

$$\mu_L = \frac{-\,e\,l\,\hbar}{2\,m}$$

In the above equation, the quantity $\frac{e\,\hbar}{2\,m}$ is an atomic unit called Bohr magneton represented as μ_B and its value is equal to $9.27\times 10^{-24}\,A - m^2$. Bohr magneton is the elementary electron magnetic moment. No electron can have a magnetic moment below μ_B. It represents the minimum non zero value of the projection of the magnetic moment of the electron in an arbitrary direction. In general the component of the electron orbital magnetic moment along an external field is equal to 1 Bohr magneton.

$$\therefore\ \mu_L = -l\,\mu_B.$$

In many substances, the orbital magnetic moment of one electron in an atom gets cancelled by the orbital magnetic moment of other electron revolving in opposite direction in the same orbit. Thus, the resultant magnetic dipole moment of an atom and in turn the substance is zero or very small.

MAGNETIC MOMENT DUE TO SPIN OF ELECTRONS:

The electron possesses angular momentum due to their spinning motion. The magnetic spin quantum number m_s gives the direction of spin vectors of an electron. There are two possible directions for spin vectors namely upward and downward spins. Therefore the quantum number takes only two values namely $\pm\frac{1}{2}$.

The relation between magnetic moment and spin angular momentum is

$$\mu_{m\,spin} = -\frac{e}{m}\mu_s$$

Where μ_s is the angular momentum contributed by spinning motion of an electron.

The possible values of μ_s are

$$\mu_s = \frac{1}{2}\frac{h}{2\pi} \quad \text{and} \quad -\frac{1}{2}\frac{h}{2\pi} \qquad \text{or } \mu_s = \frac{1}{2}\hbar \ \text{ and } \ -\frac{1}{2}\hbar$$

Therefore, the magnetic moment contributed by the spinning motion is

$$\mu_{m\,spin} = \frac{e}{2m}\,\hbar \text{ and } \mu_{m\,spin} = -\frac{e}{2m}\,\hbar$$

$\mu_{m\,spin} = \pm\mu_B$ where μ_B is the Bohr magneton.

Each orbital in an atom accommodates two electrons which orient themselves in opposite directions and revolve in opposite directions. Because of this the spin and orbital magnetic moments of the pair cancel each other. Consequently, an atom having completely filled electron subshells or shells does not possess permanent magnetic moment. Hence, the magnetic moment of an atom is determined only by the electrons which occupy partially filled shells. In majority of cases, the partially filled shells happen to be the outer valence shells. Therefore, the magnetic moment of a free atom is mainly determined by uncompensated spins of the outer electrons.

MAGNETIC MOMENT DUE TO NUCLEAR SPIN:

The magnetic moment is also produced by the spin of the nucleus and is known as nuclear magnetic moment and is given by

$\mu_{p\,s} = \left(\frac{e}{2\,m_p}\right)\hbar$ where m_p represents the mass of the proton. Substituting the constants in the expression we get, $\mu_{p\,s} = 5.05 \times 10^{-27}\, A - m^2$. Therefore, the nuclear magnetic moment is smaller than those associated with electrons by a factor 1000 and it can be neglected.

10) What is Bohr magneton? (Short answer question)

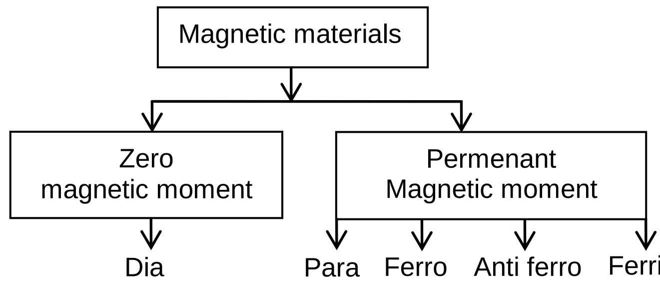
When the atom is placed in a magnetic field, the orbital magnetic moment of the electrons is quantized. A quantum of magnetic moment of an atomic system is known as Bohr magneton.

$$\mu_B = \frac{e\,\hbar}{2m}$$

Its value is equal to $9.27 \times 10^{-24}\, A - m^2$. Bohr magneton is the elementary electron magnetic moment. No electron can have a magnetic moment below μ_B. It represents the minimum non zero value of the projection of the magnetic moment of the electron in an arbitrary direction.

11) Explain the classification of magnetic materials.

Any substance when placed in a magnetic field, behaves in a particular way, which is not the same for all the substances. This behavior depends on the magnetic dipoles associated with an atom in that particular substance. Based on the permanent magnetic dipole moments, magnetic materials are classified into two broad groups.



Materials composed of atoms having zero magnetic moment, called diamagnetic, and materials composed of atoms having permanent magnetic moment. This class of materials is further classified into four types based on the interaction between the adjacent atoms. They are paramagnetic, ferromagnetic, anti-ferromagnetic and ferrimagnetic.

DIAMAGNETIC MATERIALS:

If in a material, the arrangement of the orbits and orientation is such that the vector sum of magnetic moment is zero, then the material is said to be a diamagnetic.

The atoms in these materials do not possess permanent magnetic moment. When the material is placed in a magnetic field, the orbits of the electrons undergo a processional motion. This is called Larmor's precession. This processional motion of charge produces a current, which induces a magnetic field inside the atom. This intrinsic magnetic field is opposite in direction to the external field. Thus, a diamagnetic material repels the external field.

PROPERTIES

(a) The magnetic susceptibility χ is negative and small. Temperature has no effect on the susceptibility of diamagnetic materials.

(b) The relative permeability μ_r is less than 1, but positive. This means lines of magnetic field become less dense in the material than in the air.

(c) In general, the substances whose atoms possess paired electrons exhibit diamagnetism. There are some exceptions like Cu to this behavior.

Examples of diamagnetic substance are, bismuth (Bi), zinc (Zn), copper (Cu), silver (Ag), gold (Au), diamond, NaCl, water, nitrogen, hydrogen.

PARAMAGNETIC MATERIALS:

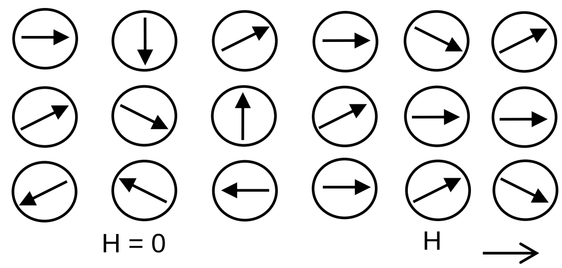


Fig. 1 Fig. 2

If in a material, the arrangement of orbits and the orientation is such that the vector sum of magnetic moments is non-zero, but small, then such substance is called a paramagnetic substance.

Paramagnetic materials are substances whose molecules possess a net permanent magnetic moment even in the absence of the field. These magnetic moments are randomly oriented in the absence of the external field. Hence, the net magnetization of the material is zero.

When the material is subjected to the influence of the magnetic field, the magnetic dipoles tend to align in the direction of the field, and the material becomes feebly magnetized.

PROPERTIES

(a) The magnetic susceptibility is small and positive (10^{-3} to 10^{-5})

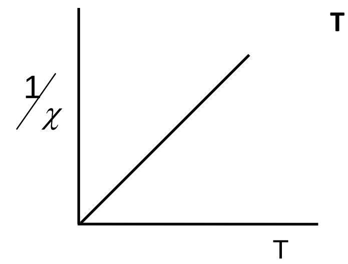
(b) The relative permeability μ_r is greater than 1 but small. This indicates that when a paramagnetic substance is placed in a uniform magnetic field, the field in the material will be more than the applied field.

(c)These substances have unpaired electrons in their valence orbit.

(d) Temperature Dependence

The thermal agitation tends to counteract the orientation of the dipoles. With an increase in the temperature, the increase in the thermal agitation tends to randomize the dipole directions thus decreasing the magnetization. Thus, the magnetic susceptibility decreases with magnetization.

$\chi \;\alpha\; \frac{1}{T} \Rightarrow \chi = \frac{C}{T}$. This law is called Curie's law, and C is called the Curie's constant.



Examples of paramagnetic substance are, aluminum, magnesium, tungsten, platinum, oxides like Co O, Fe O, chlorides like Fe Cl_2. and gases like oxygen, nitrogen.

FERROMAGNETIC MATERIALS:

If in a material the orbits are so oriented that the atom as a whole possesses a large magnetic moment, then the material is called a ferromagnetic material.

The spin magnetic moments are greatly responsible for ferromagnetism. In definite conditions, the spin moments of electrons become aligned parallel to one another even in the absence of external magnetic field. Thus, ferromagnetic materials are those which possess a magnetization even in the absence of magnetic field. This is called the spontaneous magnetization. When placed in an external field, these substances get easily magnetized to a large value.

PROPERTIES

(a) The susceptibility is very high and positive. (10^2 to 10^6)

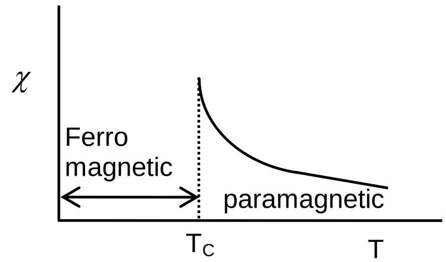
(b) The relative permeability is also very high. Lines of force are very dense in ferromagnetic substances

(c) Ferromagnetic substances exhibit hysteresis.

(d) Temperature Dependence

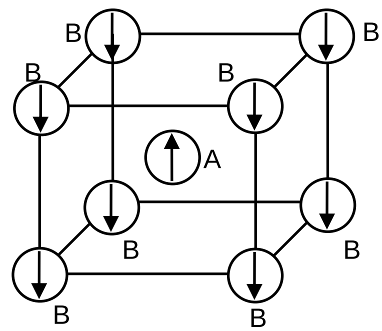
The susceptibility is fairly high and constant up to certain temperature according to the equation,

$$\chi = \frac{C}{T - T_C}$$



This law is called Curie-Weiss law. T_C is called the Curie temperature. When the temperature of the ferromagnetic substance is increased above a temperature called Curie temperature, thermal agitations dominate the existing interaction between the electron spins leading to randomization of the dipoles. Thus, the spontaneous magnetization is lost above T_C and the substance behaves as a paramagnetic material. Few examples of ferromagnetic materials are, iron (Fe), nickel (Ni), cobalt (Co), Gadolinium (Gd).

ANTIFERROMAGNETIC MATERIALS:



This is the property of the substances whose spin moments of neighboring atoms are oriented in an anti-parallel order. i.e., the alternate atoms have spin moments parallel to each other but, the adjacent atoms have not.

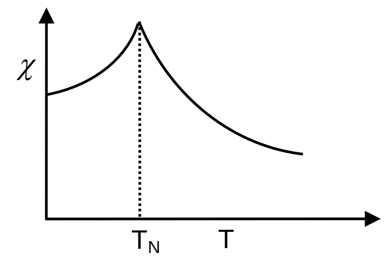
These crystals are composed of two interpenetrating sub-lattices A & B, one lattice consisting of atoms with moments in one direction and the other lattice consisting of atoms with moments in opposite direction. If no external field is applied, the net magnetization of an antiferro magnetic substance will be zero because; the moments exactly cancel when summed up over the entire crystal. If the field is applied, the absolute value of one of the sublattice magnetizations differing from that of the other sublattice, resulting in a nonzero net magnetization, a small magnetization in the direction of the field results.

PROPERTIES

(a) The susceptibility of an antiferro magnetic substance is small and positive, since the magnetization is small.

(b) Temperature Dependence

The magnetization increases as the temperature increases. Above a particular temperature called Neel's temperature, thermal agitations dominate the orientation of the dipoles in the field direction. The temperature dependence of the susceptibility for an antiferro magnetic material is given by the relation,

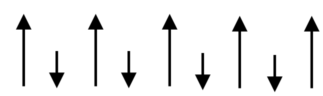


$$\chi = \frac{C}{T + T_N}$$

This is called Curie-Weiss law for antiferro magnetic materials where T_N is the Neel's temperature. Hence, above Neel's temperature, the magnetization decreases with increase in temperature and the specimen turns out to be a paramagnetic material.

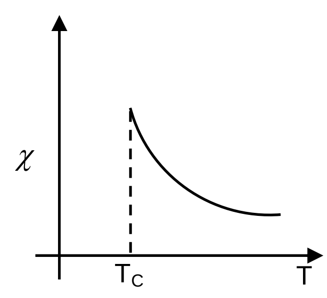
Few examples of antiferro magnetic materials are salts of transition elements, MnO, MnS, MnTe, MnF_2, $FeCl_2$ etc.

FERRIMAGNETIC MATERIALS:



This kind of materials is much similar to ferromagnetic materials in their macroscopic magnetic characteristics. The magnetic moments of the sub-lattices in this material are unequal spins and opposite in direction.

The adjacent atoms in ferrimagnetic materials differ in the magnitude of the magnetic moments and their directions also. Thus, the net magnetization of a ferrimagnetic material has a non-zero value. i.e., they possess a small value of magnetization.

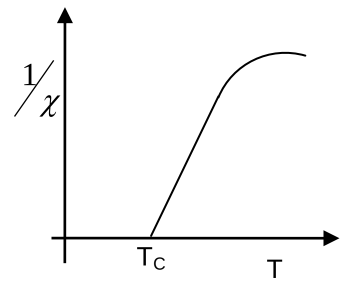


Thus, ferrimagnetism can also be referred to as uncompensated anti ferromagnetism. When placed in external magnetic field, they orient in the direction of the field. Due to the prevalence of spontaneous magnetization, they get easily magnetized.

PROPERTIES

(a) The value of susceptibility, χ is large and positive.

(b) Temperature Dependence



The spontaneous magnetization decreases with the increase in temperature above a temperature called Curie temperature. i.e., above T_C it converts itself into a paramagnetic material. But in paramagnetic state, the linear relation between χ & T is not maintained. The curvature in the plot of $1/\chi$ vs. T is a characteristic feature of a ferri magnetic substance.

Ferrites like $CuFe_2O_4$, $MnFe_2O_4$, $ZnFe_2O_4$, $FeFe_2O_4$, are examples of this kind.

12) What are diamagnetic materials and state their properties? (Short answer question)

If in a material, the arrangement of the orbits and orientation is such that the vector sum of magnetic moment is zero, then the material is said to be a diamagnetic.

The atoms in these materials do not possess permanent magnetic moment. When the material is placed in a magnetic field, the orbits of the electrons undergo a processional motion. This is called Larmor's precession. This processional motion of charge produces a current, which induces a magnetic field inside the atom. This intrinsic magnetic field is opposite in direction to the external field. Thus, a diamagnetic material repels the external field.

PROPERTIES:

(a) The magnetic susceptibility χ is negative and small. Temperature has no effect on the susceptibility of diamagnetic materials.

(b) The relative permeability μ_r is less than 1, but positive.

(c) In general, the substances whose atoms possess paired electrons exhibit diamagnetism.

13) What are paramagnetic materials and state their properties? (Short answer question)

If in a material, the arrangement of orbits and the orientation is such that the vector sum of magnetic moments is non-zero, but small, then such substance is called a paramagnetic substance. Paramagnetic materials are substances whose molecules possess a net permanent magnetic moment even in the absence of the field. These magnetic moments are randomly oriented in the absence of the external field. Hence, the net magnetization of the material is zero.

When the material is subjected to the influence of the magnetic field, the magnetic dipoles tend to align in the direction of the field, and the material becomes feebly magnetized.

PROPERTIES:

(a) The magnetic susceptibility is small and positive.

(b) The relative permeability μ_r is greater than 1 but small.

(c)These substances have unpaired electrons in their valence orbit.

(d) The magnetic susceptibility depends on temperature.

14) What are ferromagnetic materials and state their properties? (Short answer question)

If in a material the orbits are so oriented that the atom as a whole possesses a large magnetic moment, then the material is called a ferromagnetic material.

The spin magnetic moments are greatly responsible for ferromagnetism. In definite conditions, the spin moments of electrons become aligned parallel to one another even in the absence of external magnetic field. Thus, ferromagnetic materials are those which possess a magnetization even in the absence of magnetic field. This is called the spontaneous magnetization. When placed in an external field, these substances get easily magnetized to a large value.

PROPERTIES:

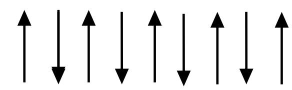
(a) The susceptibility is very high and positive.

(b) The relative permeability is also very high.

(c) Ferromagnetic substances exhibit hysteresis.

(d) The susceptibility depends on temperature. When the temperature of the ferromagnetic substance is increased above a temperature called Curie temperature T_c, the spontaneous magnetization is lost and above T_C and the substance behaves as a paramagnetic material.

15) What are antiferromagnetic materials and state their properties? (Short answer question)



These crystals are composed of two interpenetrating sub-lattices A & B, one lattice consisting of atoms with moments in one direction and the other lattice consisting of atoms with moments in opposite direction. If no external field is applied, the net magnetization of an antiferro magnetic substance will be zero because; the moments exactly cancel when summed up over the entire crystal. If the field is applied, the absolute value of one of the sub-lattice magnetizations differing from that of the other sub-lattice, resulting in a nonzero net magnetization, a small magnetization in the direction of the field results.

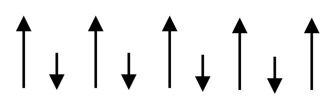
PROPERTIES:

(a) The susceptibility of an antiferro magnetic substance is small and positive.

(b) The susceptibility depends on temperature. Above a particular temperature called Neel's temperature, thermal agitations dominate the orientation of the dipoles in the field direction. Above Neel's temperature, the magnetization decreases with increase in temperature and the specimen turns out to be a paramagnetic material.

16) What are ferrimagnetic materials and state their properties? (Short answer question)

This kind of materials is much similar to ferromagnetic materials in their macroscopic magnetic characteristics. The adjacent atoms in ferrimagnetic materials differ in the magnitude of the magnetic moments and their directions also. Thus, the net magnetization of a ferrimagnetic material has a non-zero value. i.e., they possess a small value of magnetization.



Thus, ferrimagnetism can also be referred to as uncompensated anti ferromagnetism. When placed in external magnetic field, they orient in the direction of the field. Due to the prevalence of spontaneous magnetization, they get easily magnetized.

PROPERTIES:

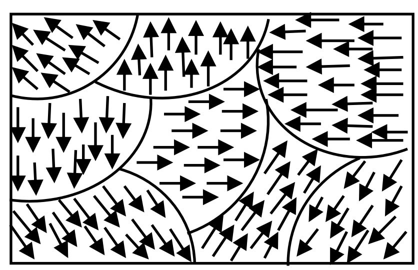
(a) The value of susceptibility, χ is large and positive.

(b) The spontaneous magnetization decreases with the increase in temperature above a temperature called Curie temperature. i.e., above T_C it converts itself into a paramagnetic material. But in paramagnetic state, the linear relation between χ & T is not maintained.

17) What are Domains in ferromagnetic materials?

In order to explain the theory of ferromagnetism, Weiss introduced the new concept of magnetic domains. The atoms of ferromagnetic materials have a permanent magnetic moment like paramagnetic materials. But in ferromagnetic materials, internal molecular field sets up spontaneous magnetization and that a macroscopic ferromagnetic specimen is divided up into small regions called domains. The internal molecular field is due to quantum exchange interactions between electrons. Each domain has a size varying from 10^{-9} to 10^{-5} m^3 and contains about 10^{17} to 10^{21} atoms whose magnetic axes are aligned in the same direction even in the absence of any external field. Each domain is in the state of magnetic saturation i.e., it is a strong magnet. However, in the normal state of the material, the different domains are randomly distributed. Hence their resultant magnetic moment in any direction is zero.

18) Give an account of domain theory of ferromagnetism.

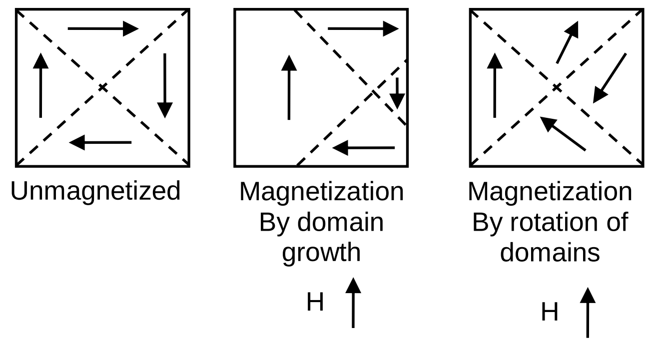


WEISS' DOMAIN THEORY OF FERROMAGNETISM:

In order to explain the theory of ferromagnetism, Weiss introduced the new concept of magnetic domains. The atoms of ferromagnetic materials have a permanent magnetic moment like paramagnetic materials. But in ferromagnetic materials, internal molecular field sets up spontaneous magnetization and that a macroscopic ferromagnetic specimen is divided up into small regions called domains as shown in the figure. The internal molecular field is due to quantum exchange interactions between electrons. Each domain has a size varying from 10^{-9} to 10^{-5} m^3 and contains about 10^{17} to 10^{21} atoms whose magnetic axes are aligned in the same direction even in the absence of any external field. Each domain is in the state of magnetic saturation i.e., it is a strong magnet. However, in the normal state of the material, the different domains are randomly distributed. Hence their resultant magnetic moment in any direction is zero.

When such a substance is placed in external magnetic field, there are two possible processes which contribute to the total magnetization of the specimen. The first one is,

With small or weak applied fields, the domains pointing approximately in the field direction grow in size at the expense of the other domains. This phenomenon is also referred to as boundary displacement. This gives rise to small magnetization of the specimen.



The second kind of effect is, with the application of strong fields, all the domains orient in the field direction by rotation of their dipoles, resulting in a large magnetization. If the strength of the field is increased, all the domains point fully in the field direction, thereby magnetizing the specimen completely.

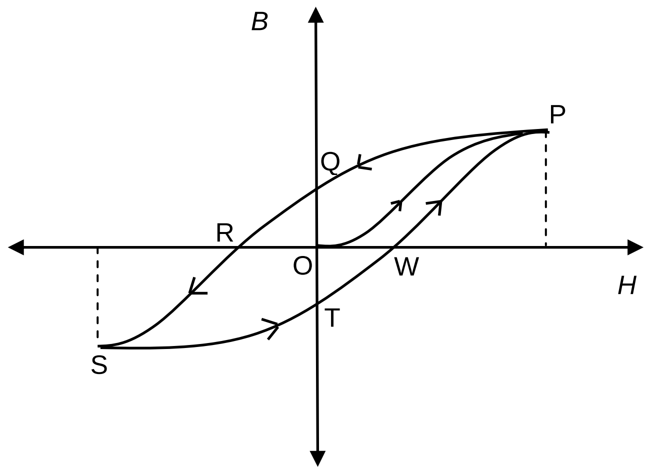
On the removal of external field, the boundaries do not move completely back to their original position and hence the specimen is not completely demagnetized, i.e., there still remains some residual magnetism. At high temperature, the domains are broken up and the ferromagnetic material becomes paramagnetic.

19) What is hysteresis in ferromagnetic materials? (Short answer question)

Hysteresis means lagging of an effect behind the cause of the effect. When a ferromagnetic substance is placed in an external magnetic field, it is magnetized. However, the magnetization of the specimen does not vary linearly with the applied field. The magnetization which is realized in terms of the magnetic induction B lags behind the applied field H. This lagging of magnetization behind magnetic field is known as hysteresis.

20) Explain hysteresis loop observed in ferromagnetic materials.

Hysteresis means lagging of an effect behind the cause of the effect. When a ferromagnetic substance is placed in an external magnetic field, it is magnetized. However, the magnetization of the specimen does not vary linearly with the applied field. The magnetization which is realized in terms of the magnetic induction B lags behind the applied field H. This lagging of magnetization behind magnetic field is known as hysteresis. The above process is explained in the following steps.



(a) The external magnetic field H is gradually increased, the value of B also increases along OP.

(b) After the point P, B remains constant in spite of continued increase in H. This value of B at P is called the saturation value and the state of specimen is referred to as saturation magnetization.

(c) Saturation magnetization is defined as the maximum extent up to which a ferromagnetic substance can be magnetized.

(d) The value of H is then decreased. B also starts decreasing, but the curve will be along PQ instead of PO. This indicates hysteresis is an irreversible process.

(e) When the field H is reduced to zero, B will have a value equal to OQ. This value of B is called residual magnetization or retentivity, or remanance. Retentivity is the property of magnetic material in which the magnetic flux density remaining, when the applied field is reduced from saturation to zero. The magnetic flux density remaining when the applied field is reduced from saturation to zero is called residual flux density.

(f) In order to demagnetize the specimen completely, we need to apply a magnetic field in the reverse direction. When a reverse field is applied, the magnetic induction B gradually reduces and become zero at a value $H = -$ OR. The reverse field where the magnetization reduces to zero is called the coercive field or coercivity. Coercivity is the property of magnetic material in which the residual magnetic flux density becomes zero at certain value of reverse magnetic field applied to the material. The amount of reverse magnetic field applied to the magnetic material in which the residual magnetic flux density becomes zero is called coercive field.

(g) Further increase of the reverse field *H* results in process similar to that in the positive field and reaches saturation at the point S.

(h) If the field is decreased to zero, for which the curve traces the path ST. This doesn't retrace old path SR.

(i) The direction of H is now reversed and increased. The specimen gets completely demagnetized once again for H = OW. As H is increased further, the curve traces the path WP.

(j) The closed loop PQRSTWP is known as hysteresis loop.

IMPORTANCE OF HYSTERISIS LOOP:

Study of hysteresis loop in ferromagnetic materials is important because, it allows estimation of many magnetic properties and based on that we can judge whether a material is useful or not for a specified application.

The significance of hysteresis loop is

(a) Area of the loop gives the energy loss per cycle per m^3

(b) Steepness of the curve indicates whether the magnetization is quick or not

(c) The product of retentivity and coercivity is called the energy product of the specimen. Materials that are used as permanent magnets should have high energy product value.

EXPLANATION OF HYSTERISIS LOOP ON THE BASIS OF DOMAIN THEORY:

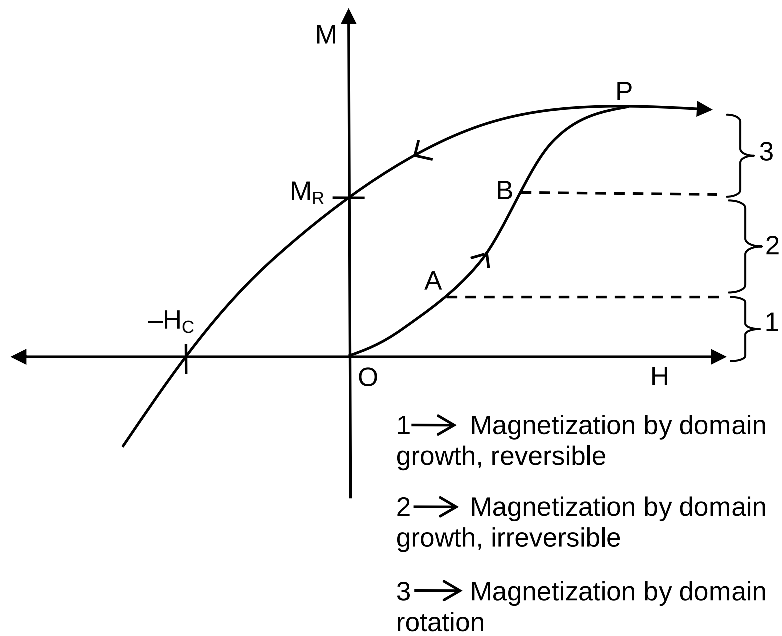
The hysteresis of a ferromagnetic substance can be explained based on domain theory. It is as follows:

When a small magnetic field is applied across the specimen, the domains that are pointing nearly in the direction of the external field grow in size at the expense of other domains. This gives rise to small magnetization corresponding to the portion OA. The displacement of boundaries is reversible within this region.

As the external field increases, a large number of domains grow favorably in the direction of the field resulting in the increase of magnetization (AB). But, the boundary displacements are irreversible.

Application of still higher fields rotates the dipole moments of other domains in the field direction. During this stage (BP), the increase in magnetization is slow and at a particular field, all the domains are oriented in the direction of the applied field.

The specimen at this moment is completely magnetized and reaches a stage where its magnetization attains a maximum value called saturation magnetization denoted by P in the figure.



If the field is now decreased, the magnetization begins to decrease. But, this decrease does not occur along PBAO because, domains do not return to their original random arrangement. The presence of imperfections and impurities hampers the restoration of original arrangement. This is why even when the field is removed completely, the magnetization does not reach zero and a field of $-H_C$, called coercive field is required to completely demagnetize the specimen. If the negative field is increased, the above process repeats in the reverse direction.

21) Discuss the importance or significance of Hysteresis loop. (Short answer question)

Study of hysteresis loop in ferromagnetic materials is important because, it allows estimation of many magnetic properties and based on that we can judge whether a material is useful or not for a specified application.

The significance of hysteresis loop is

(a) Area of the loop gives the energy loss per cycle per m^3

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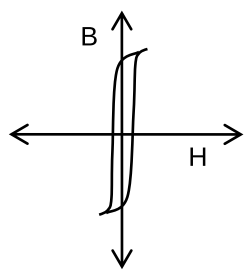
(c) The product of retentivity and coercivity is called the energy product of the specimen. Materials that are used as permanent magnets should have high energy product value.

22) What are soft magnetic materials? Explain their properties.

Basing upon the ease of magnetization, the magnetic materials are classified as, Soft magnetic materials & Hard magnetic materials.

SOFT MAGNETIC MATERIALS

If the material is easy to magnetize and demagnetize, then such magnetic material is called a soft magnetic material. Soft magnetic materials reach its saturation magnetization with a relatively low applied field and exhibits low hysteresis energy losses. A low value of coercivity corresponds to the easy movement of domain walls as the applied magnetic field changes in magnitude and direction. Structural defects impede the domain wall motion and increase coercivity. Therefore, a soft magnetic material must be free of such structural defects.



The following characterize soft magnetic materials:

(a)The area of the hysteresis curve in soft materials is less. Hence, they exhibit small hysteresis loss.

(b) Coercivity and retentivity are small

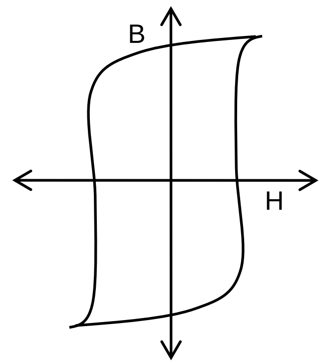
(c)These possess large values of permeability and susceptibility

(d) Eddy current loss is small due to its higher resistivity

(e) Used in applications which require frequent reversal of direction of the magnetization such as cores of transformers, motors, inductors and generators

(f) Examples of soft magnetic materials are Permallo (alloy of Fe & Ni), Silicon-Iron alloy, Pure iron, Mumetal (alloy of Ni, Cu, Cr and Fe) and Amorphous ferrous alloys (alloys of Fe, Si & B).

23) What are hard magnetic materials? Explain their properties.



If the material cannot be easily magnetized and demagnetized then such kind of magnetic material is called hard magnetic material. Here a large amount of reverse field is required to demagnetize the specimen. The following are the features of a hard magnetic material:

(a) The area of the hysteresis in hard materials is very large. Hence, they exhibit large hysteresis loss.

(b) Coercivity and retentivity are large

(c) These possess small values of permeability and susceptibility

(d) Eddy current loss is more due to its small resistivity

(e) Used to produce permanent magnets

(f) Permanent magnets used in magnetic detectors, microphones, flux meters, voltage regulators.

(g) Examples of hard magnetic materials are Alnico alloy (alloy of Al, Ni, Co, Cu & Fe), Samarium-Cobalt alloy, Tungsten steel alloy, Platinum Cobalt alloy and Invar.