Nishant Jindal

MAGNETIC PROPERTIES OF MATERIALS

MAGNETIC PROPERTIES OF MATERIALS

Curie and Faraday observed that almost all substances have certain magnetic properties. On the basis of magnetic behavior of different materials, they divided them into three categories:

(i) Diamagnetism

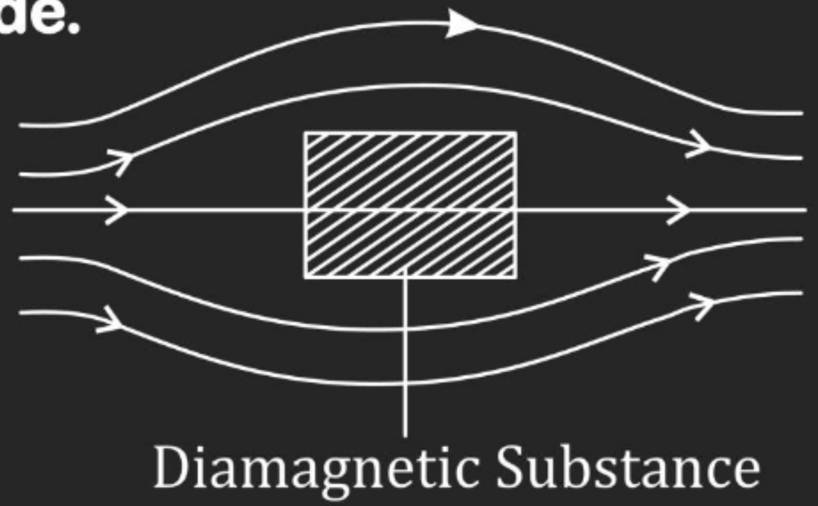
(ii) Paramagnetism

(iii) Ferromagnetism

MAGNETIC PROPERTIES OF MATERIALS

Diamagnetism

1. The substances which have tendency to move from stronger to weaker part of external magnetic fieid. They develop this tendency because they are feebly magnetized in a direction opposite to that of external magnetising field.
2. Some of diamagnetic substances are as follows bismuth, copper, lead, silicon, nitrogen (at STP), water and sodium chloride.



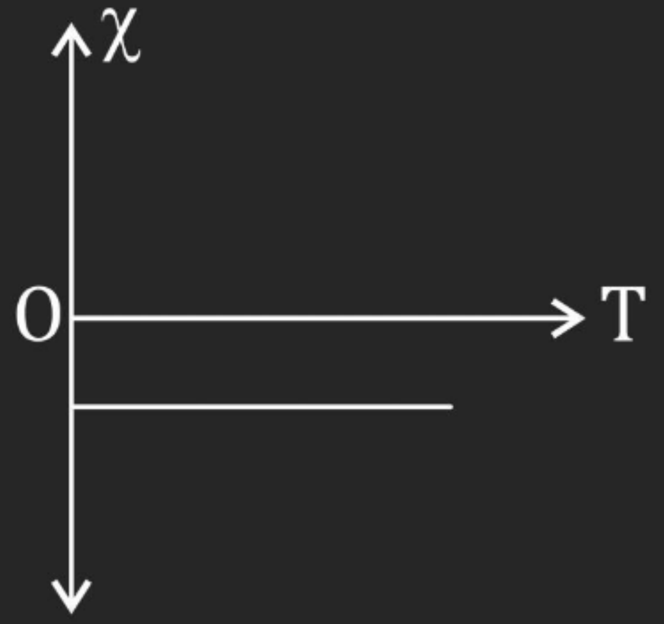
3. The magnetic field lines are expelled by these substances
4. Magnetic field inside diamagnetic substance (B) is less than in free space B_0, therefore,

$$\frac{B}{B_0} < 1, \frac{\mu}{\mu_0} < 1, \mu_r < 1. \mu_r < 1$$

Nishant Jindal

MAGNETIC PROPERTIES OF MATERIALS

5. Relative permeability of diamagnetic substance is less than one.
6. As $\mu_r = (1 + \chi_m)$, $\mu_r < 1$, therefore, χ_m is negative for diamagnetic material.
7. Magnetic susceptibility χ_m of diamagnetic substance is independent of temperature.



8. Diamagnetism is a universal property i.e. it is present in all substances. However, the effect is so weak in most cases that it gets shifted by other effects like paramagnetism, ferromagnetism etc.

Nishant Jindal

MAGNETIC PROPERTIES OF MATERIALS

Explanation of Diamagnetism

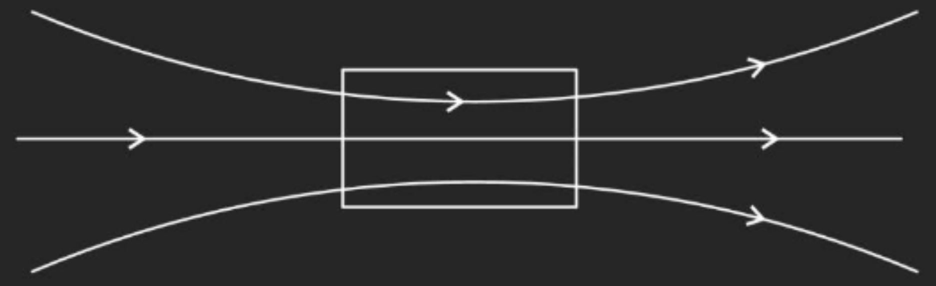
Electron in an atom orbiting around nucleus possess orbital angular momentum. These orbiting electrons are equivalent to current carrying loop and thus possess orbital magnetic moment. Diamagnetic substances are those in which net magnetic dipole moment of an atom is zero. When magnetic field is applied, those electrons having orbital magnetic moment in the same direction slow down and those in opposite direction speed up. This is due to induced current in accordance with Lenz's law. Thus, the substance develops a net magnetic moment opposite to applied field hence it is repelled from stronger field to weaker field.

Nishant Jindal

MAGNETIC PROPERTIES OF MATERIALS

Paramagnetism

1. These are the substances which get feebly magnetised in the direction of applied external magnetic field. Therefore, they have tendency to move from region of weak magnetic field to strong magnetic field i.e. they get weakly attracted to a magnet.
2. Some paramagnetic substances are as follows : aluminum, sodium, calcium, oxygen (at STP) and copper chloride.
3. Magnetic field lines tend to pass through these substances therefore, magnetic field inside substance is more than the outside.



4. $B > B_0, \frac{B}{B_0} > 1, \mu > \mu_0, \frac{\mu}{\mu_0} > 1, \mu_r > 1$
5. The relative permeability of paramagnetic substances is greater than one.
6. As $\mu_r = 1 + \chi_m, \chi_m$ is positive. (The magnetic susceptibility of paramagnetic substance is small and positive).

MAGNETIC PROPERTIES OF MATERIALS

Curie's Law

This law states that the magnetisation of a paramagnetic material is inversely proportional to the absolute temperature T.

$$I \propto \frac{B_0}{T}$$

$$I = c\frac{B_0}{T}$$

Or

Magnetic susceptibility of paramagnetic substance is inversely proportional to absolute temperature T.

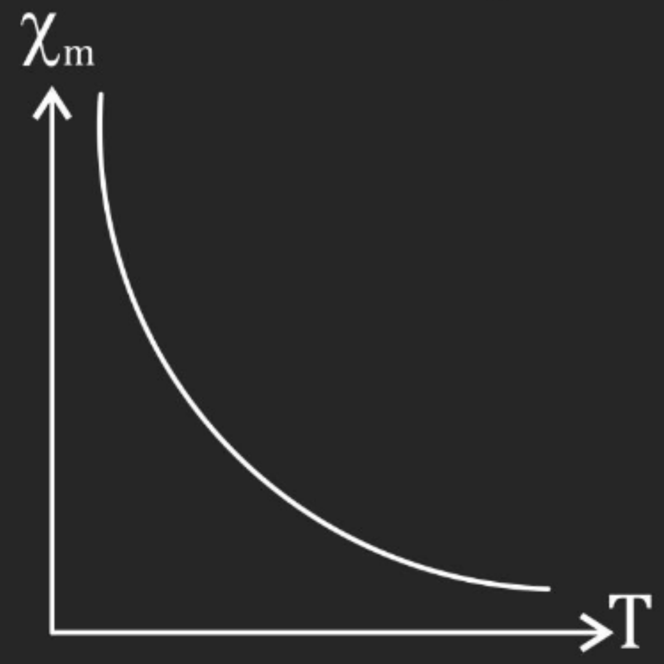
$$\chi_m \propto \frac{\mu_0}{T}$$

$$\chi_m = c\frac{\mu_0}{T}$$

MAGNETIC PROPERTIES OF MATERIALS

The constant c is called Curie's constant.

For a paramagnetic substance both χ_m and μ_r depend not only on the material but also on the temperature. As the field is increased or the temperature is lowered, the magnetisation increases until it reaches the saturation value (m_s) [At this point all atomic dipoles are aligned with applied field. Beyond this Curie's law is not valid].

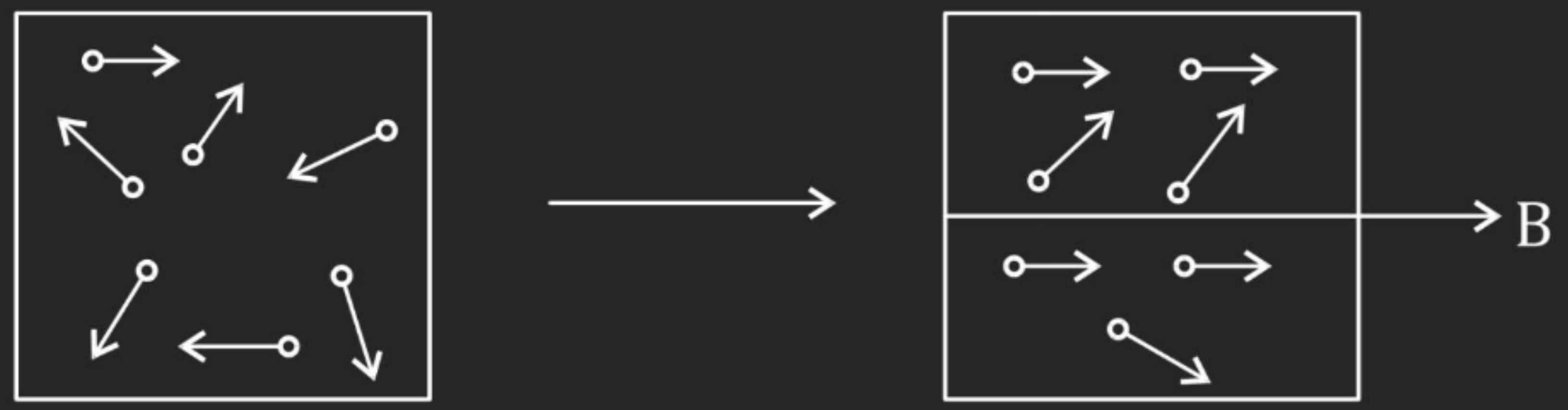


MAGNETIC PROPERTIES OF MATERIALS

Explanation of Paramagnetism

In paramagnetic substances, vector sum of orbital magnetic moment of electrons is not zero, therefore, each atom behaves like tiny magnetic dipole and has some finite dipole moment. Due to thermal agitations the atomic dipoles in substance are randomly oriented hence total net dipole moment becomes zero.

When this substance is kept in an external field, these atomic dipoles get align which results into net dipole moment.



MAGNETIC PROPERTIES OF MATERIALS

Note : The magnetic susceptibility of paramagnetic substances is around hundred times higher than that of diamagnetic substances.

Nishant Jindal

MAGNETIC PROPERTIES OF MATERIALS

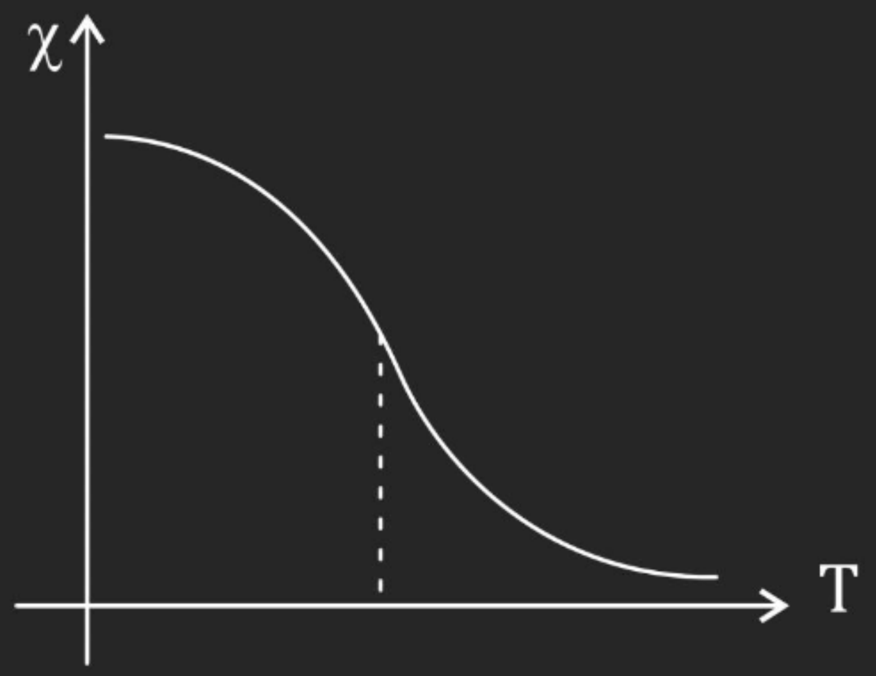
Ferromagnetism

1. These are the substances which get strongly magnetised when placed in an external magnetic field, so they have strong tendency to move from a region of weak magnetic field to strong magnetic field. They get strongly attracted to the magnet.
2. Some of the ferromagnetic substances are as follows : iron, cobalt, nickel, alloys like alnico etc.
3. Magnetic field lines tend to crowd into ferromagnetic material.
4. Permeability of ferromagnetic materials is very large, of the order of hundreds and thousands.
5. Magnetic susceptibility χ_m of ferromagnetic substance is very high, therefore, they can be magnetised easily and strongly.
6. With rise in temperature, susceptibility of ferromagnetic materials decreases. At a certain temperature ferromagnetic substance is converted into paramagnetic substance. This transition temperature is called Curie temperature or Curie point T_C.

MAGNETIC PROPERTIES OF MATERIALS

7. Curie-Weiss law : At temperature above the Curie temperature, a ferromagnetic substance becomes an ordinary paramagnetic substance whose magnetic susceptibility obeys the Curie-Weiss law according to which

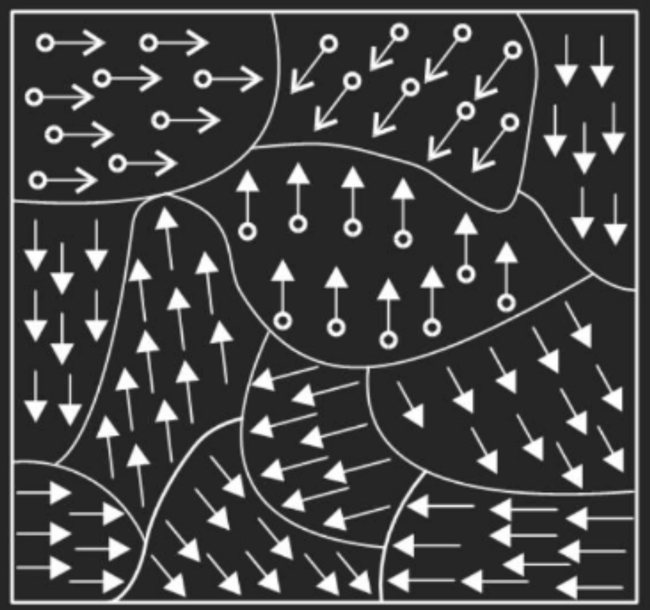
$$\boxed{\chi_m = \frac{C}{T - T_C}}$$



MAGNETIC PROPERTIES OF MATERIALS

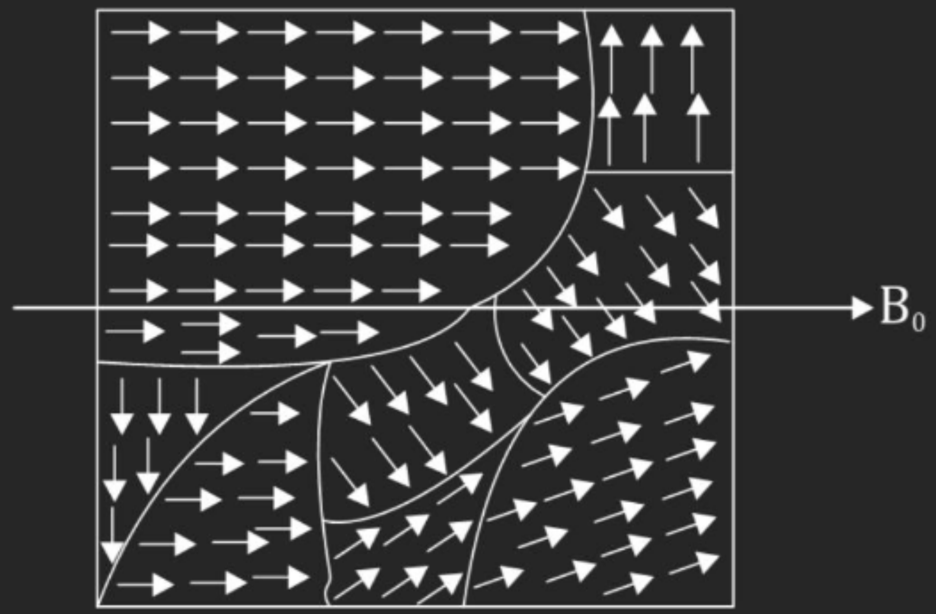
Explanation of Ferromagnetism

The individual atom in a ferromagnetic substance has net dipole moment. However, they interact with one another in such a way that they spontaneously align themself in a common direction over a macroscopic volume called domain. Each domain has net magnetisation. The typical size of a domain is $1\ \mathrm{mm}$ and contains about 10^{11} atoms. These domains are randomly oriented so net magnetisation of whole substance is zero. When external field B_0 is applied, the domains orient themself in the direction of B_0 and simultaneously the domains oriented in direction of B_0 grow in size.



Randomly oriented domains

Size of domain increases



MAGNETIC PROPERTIES OF MATERIALS

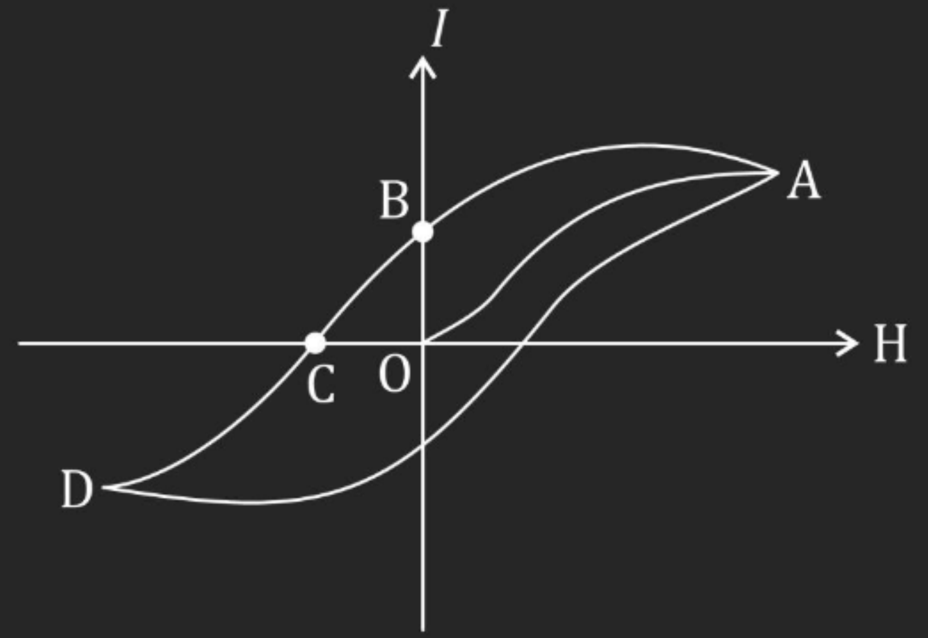
Materials and their cure temperature

Material	$T_c(K)$
Cobalt	1394
Iron	1043
Fe_2O_3	893
Nickel	631
Gadolinium	317

MAGNETIC PROPERTIES OF MATERIALS

HYSTERESIS

1. When intensity of magnetisation I of ferromagnetic substances is plotted against magnetic intensity for a complete cycle of magnetisation and demagnetisation the resulting loop is called hysteresis loop.



2. When intensity of magnetising field (H) is increased, the intensity of magnetisation increases, because more and more domains are aligned in the direction of applied field.
3. When all domains are aligned, material is magnetically saturated. Beyond this if intensity of magnetising field (H) is increased, intensity of magnetisation (I) does not increase.

MAGNETIC PROPERTIES OF MATERIALS

4. Now if intensity of magnetising field (H) is decreased intensity of magnetisation also decreases but it lags behind H. Therefore, when H becomes zero / does not reduce to zero, i.e. the curve does not retrace itself.
5. The value of intensity of magnetisation (I) left in the material at $\mathrm{H}=0$, is called retentivity or remanence. It is due to the fact that all domains do not dealing even if $\mathrm{H}=0$.
6. Now if magnetising field is applied in reverse direction and its intensity H is increased,material starts de-magnetising. The value of magnetising field needed to reduce magnetisation to zero is called coercivity (OC).
7. As reverse magnetising field is increased further, the material again becomes saturated. Now, if the magnetising field is reduced after attaining the reverse saturation, the cycle repeats itself.
8. The area enclosed by the loop represents loss of energy per unit volume during a cycle of magnetisation and demagnetisation.

MAGNETIC PROPERTIES OF MATERIALS

Retentivity of a specimen is a measure of the magnetic flux remaining in the specimen when the magnetizing force is removed.

Coercivity is a measure of the magnetic intensity required to destroy the residual magnetism of the specimen.

TYPE OF MAGNET

Hard and Soft Magnets

1. The ferromagnetic material which retain magnetisation for a long period of time are called hard magnetic material or hard ferromagnets. Some hard magnetic materials are Alnico (an alloy of iron, aluminum, nickel, cobalt and copper) and naturally occurring lodestone. They are used for permanent magnets. For permanent magnet material should have high retentivity and high coercivity.
2. The ferromagnetic material which retain magnetisation as long as the external field persists are called soft magnetic materials or soft ferromagnets. Soft ferromagnets is soft iron. Such material is used for making electromagnets. For electromagnets material should have low retentivity and low coercivity. Electromagnets are used in electric bells, loudspeakers and telephone diaphragms.

TYPE OF MAGNET

Soft and Hard Magnetic Materials : The magnetic properties of a ferromagnetic substance can be obtained from the size and shape of the hysteresis loop.

The susceptibility is greater for soft materials than for hard materials.

Permeability is greater for soft materials than for hard materials.

Retentivity is greater for soft materials than for hard materials. Higher the retentivity, stronger the magnet.

Coercivity is less for soft materials than for hard materials. Higher the coercivity more permanent is the magnet.

The area of hysteresis loop and hence hysteresis loss per unit volume per cycle is less for soft materials than for hard materials.

TYPE OF MAGNET

Permanent Magnets and Electromagnets

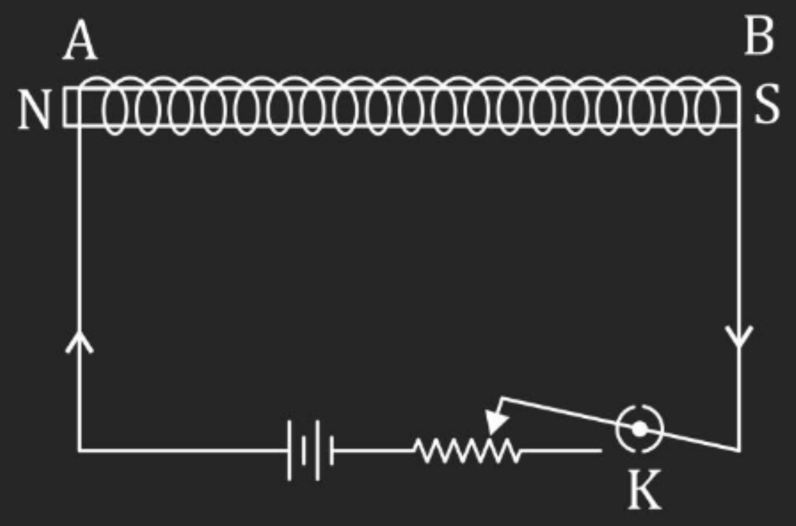
(i) Permanent Magnets

The substances which at room temperature retain their magnetisation for long period of time are called Permanent magnets. Permanent magnets should have (a) high retentivity (so that the magnet is strong) and (b) high coercivity (so that the magnetizing is not wiped out by stray magnetic fields, mechanical ill- treatment or by temperature change). As the material in this case is never put to cyclic changes of magnetization, hence hysteresis is immaterial. From the view point of these facts, steel is more suitable for the construction of permanent magnets than soft iron. The fact that the retentivity of iron is little greater than that of steel is outweighed by the much smaller value of its coercivity. Recently a number of alloys, having large values of coercivity have been developed for the purpose of construction of permanent magnets. The very suitable alloy of highest coercivity is named as vicalloy (vanadium, iron and cobalt).

TYPE OF MAGNET

(ii) Electromagnets

An electromagnet is a temporary strong magnet and is just a solenoid with its winding on a soft iron core which has high permeability and low retentivity.



Uses:

1. Used in electrical devices such as an electric bell, an electric fan, telegraph, and electric train, an electric motor generator etc.
2. In medical practices for removing pieces or iron from wounds.

TYPE OF MAGNET

Electromagnets should have (a) high initial permeability (b) low hysteresis loss and (c) maximum magnetic induction B with comparatively small value of magnetizing field. From the view point of these facts the soft-iron is an ideal material for this purpose.

Cores of transformers and chokes, Armatures of Dynamos and Motors, and for Telephone Diaphragms : As the magnetic material used in these cases is subjected to cyclic changes, the essential requirements for the selection of material are (a) high initial permeability to obtain large flux density B for low values of magnetizing field H (b) low hysteresis loss to prevent the breakdown of insulation of the windings as less dissipation of energy produces a small heating effect and (c) high specific resistance to reduce eddy current losses. Soft iron is better than steel for these purposes. Soft iron has initial permeability about 250 . The permeability is greatly increased by alloying it with 4% silicon. It is very useful and is known as transformer steel. There are some other alloys and nickel, known as permalloys.

Nishant Jindal

TYPE OF MAGNET

	Symbol	Nature	Dimensions	Units	Remarks
Permeability of free space	μ_0	Scalar	$[MLT^{-2}A^{-2}]$	TmA^{-1}	$\mu_0/4\pi = 10^{-7}$
Magnetic field, Magnetic induction, Magnetic flux density	B	Vector	$[MT^{-2}\ A^{-1}]$	T (tesla)	10^4G (gauss) $= 1$ T
Magnetic moment	M	Vector	$[L^{-2}\ A]$	Am^2	
Magnetic flux	ϕ_B	Scalar	$[ML^2\ T^{-2}\ A^{-1}]$	W (weber)	$W = Tm^2$
Magnetisation	I	Vector	$[L^{-1}\ A]$	Am^{-1}	$\frac{\text{Magnetic moment}}{\text{Volume}}$
Magnetic intensity, Magnetic field strength	H	Vector	$[L^{-1}A]$	Am^{-1}	$B = \mu_0(H + I)$
Magnetic susceptibility	χ	Scalar	-	-	$I = \chi H$
Relative magnetic permeability	μ_r	Scalar	-	-	$B = \mu_0\ \mu_r H$
Magnetic permeability	μ	Scalar	$[MLT^{-2}A^{-2}]$	TmA^{-1} NA^{-2}	$\mu = \mu_0\ \mu_r$ $B = \mu H$