Classification of Materials and Magnets

Objectives

After going through this module, the learners will be able to:

- Categorize materials on the basis of magnetic properties.
- Distinguish between diamagnetic, paramagnetic and ferromagnetic substance
- Understand that magnetic properties of materials change with temperature
- Select materials for making permanent and temporary magnets

Content Outline

- Unit Syllabus
- Module wise distribution of unit syllabus
- Words you must know
- Introduction
- Classification of materials
- Diamagnetic substances
- Paramagnetic substances
- Ferromagnetic substances
- Magnetic Hysteresis
- Permanent magnets and electromagnets
- Summary

Unit Syllabus

Unit –III: Magnetic Effects of Current and Magnetism 10 Modules

Chapter-4: Moving Charges and Magnetism

Concept of magnetic field, Oersted's experiment.

Biot - Savart law and its application to the current carrying circular loop.

Ampere's law and its applications to infinitely long straight wire. Straight and toroidal solenoids, Force on a moving charge in uniform magnetic and electric fields. Cyclotron.

Force on a current-carrying conductor in a uniform magnetic field. Force between two parallel current-carrying conductors-definition of ampere. Torque experienced by a current loop in uniform magnetic field; moving coil galvanometer-its current sensitivity and conversion to ammeter and voltmeter.

Chapter-5: Magnetism and Matter

Current loop as a magnetic dipole and its magnetic dipole moment.Magnetic dipole moment of a revolving electron. Magnetic field intensity due to a magnetic dipole (bar magnet) along its axis and perpendicular to its axis. Torque on a magnetic dipole (bar magnet) in a uniform magnetic field; bar magnet as an equivalent solenoid, magnetic field lines; Earth's magnetic field and magnetic elements.

Para-, dia - and ferro - magnetic substances, with examples .Electromagnets and factors affecting their strengths. Permanent magnets.

Module Wise Distribution of Unit syllabus

Module 1	• Introducing moving charges and magnetism • Direction of magnetic field produced by a moving charge • Concept of Magnetic field • Oersted's Experiment • Strength of the magnetic field at a point due to current carrying conductor • Biot-Savart Law • Comparison of coulomb's law and Biot Savart's law
Module 2	• Applications of Biot- Savart Law to current carrying circular loop, straight wire • Magnetic field due to a straight conductor of finite size • Examples
Module 3	• Ampere's Law and its proof • Application of ampere's circuital law: straight wire,straight and toroidal solenoids. • Force on a moving charge in a magnetic field • Unit of magnetic field • Examples
Module 4	• Force on moving charges in uniform magnetic field and uniform electric field. • Lorentz force • Cyclotron

Module 5	● Force on a current carrying conductor in uniform magnetic field ● Force between two parallel current carrying conductors ● Definition of ampere
Module 6	● Torque experienced by a current rectangular loop in uniform magnetic field ● Direction of torque acting on current carrying rectangular loop in uniform magnetic field ● Orientation of a rectangular current carrying loop in a uniform magnetic field for maximum and minimum potential energy
Module 7	● Moving coil Galvanometer- ● Need for radial pole pieces to create a uniform magnetic field ● Establish a relation between deflection in the galvanometer and the current its current sensitivity ● Voltage sensitivity ● Conversion to ammeter and voltmeter ● Examples
Module 8	● Magnetic field intensity due to a magnetic dipole (bar magnet) along its axis and perpendicular to its axis. ● Torque on a magnetic dipole in a uniform magnetic field. ● Explanation of magnetic property of materials
Module 9	● Dia, Para and ferro-magnetic substances with examples. Electromagnets and factors affecting their strengths, permanent magnets
Module 10	● Earth's magnetic field and magnetic elements.

Module 9

Words You Must Know

Let us remember the words we have been using in our study of this physics course

- **Magnetic field:** The magnetic field at a point may be defined as the force acting on a unit charge moving with a unit velocity at right angle to the direction of the field.

- **S I unit of Magnetic field:** SI unit of magnetic field is tesla (T). The magnetic field is said to be one tesla if a charge of one coulomb moving with a speed of 1 m/s at right angles to the field experiences a force of one newton.
- **C G S unit of magnetic field:** Cgs unit of magnetic field is gauss (G). $1T = 10^{-4}G$
- **Lorentz magnetic force:** The force acting on moving charge in a magnetic field is called Lorentz magnetic force. This force is maximum when the direction of motion of a charged particle is perpendicular to the direction of magnetic field.
- **Direction of force on current carrying conductor:** Direction of force acting on a current carrying conductor in magnetic field is given by the right hand thumb rule. The force is perpendicular to both the direction of magnetic field and the direction of current.
- **Maximum Force:** The force acting on the current carrying conductor in a magnetic field is maximum when the conductor is placed perpendicular to the direction of magnetic field.
- **Torque:** It is defined as the moment of force. It is given by cross product of distance of force from axis of rotation and the force.
- **Magnetic Moment:** M = NIA.
- **Torque on coil:** The torque acting on current carrying coil in magnetic field is maximum when the plane of coil is parallel to magnetic field. The coil does not experience torque when the plane of the coil becomes perpendicular to the magnetic field.
- **Relative permeability:** The ratio of permeability of the medium to the permeability of free space is called relative permeability. It has no unit.
- **Intensity of magnetization:** When a substance is placed in a magnetic field the net magnetic moment developed per unit volume is defined as the intensity of magnetisation (M).

  $M = m_{net}/V$, M is a vector quantity with dimensions of M is $[L^{-1} A]$ and is measured in units of $A\ m^{-1}$.
- **Magnetizing field:** The magnetic field that exists in vacuum and induces magnetization is called magnetizing field. Consider a long solenoid of n turns per unit length and carrying a current I. The magnetic field induced inside the solenoid is given by $B_0 = \mu_0 nI$. This field is called a magnetizing field.
- **Magnetizing field intensity:** The ability of a magnetizing field to magnetize a material is expressed by H called Magnetizing field intensity. Its magnitude is defined

as the number of ampere turns flowing round per unit length of the solenoid required to produce the given magnetizing field. Thus

$B_0 = \mu_0 nI = = \mu_0 H$

So H= nI, dimension of H is $[L^{-1} A]$ and is measured in units of $A\ m^{-1}$.

- **Magnetic susceptibility:** It measures the ability of a substance to get magnetized when placed in a magnetic field. It is defined as the ratio of the intensity of magnetization M to the magnetizing field intensity H. it is represented by the symbol χ_m

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

  It has no unit.

- **Relation between relative permeability and magnetic susceptibility:**

  If the interior of the solenoid is filled with a material with non-zero magnetization, the field inside the solenoid will be greater than B_0. The net B field in the interior of the solenoid may be expressed as:

  $B = B_0 + B_m$ (where B_m is the field contributed by the material core)

  $B_m \propto M$

  $B_m = \mu_0 M$ (where μ_0 is the permeability of vacuum)

  Thus, the total magnetic field B is written as:

  $B = \mu_0 (H + M)$

  And $B = \mu H$

  Therefore $\mu H = \mu_0 (H + M)$

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

  $\mu_r = (1 + \chi_m)$

Introduction

The earth consists of a bewildering variety of elements and compounds. In addition, we have been synthesizing new alloys, compounds and even elements. One would like to classify the magnetic properties of these substances.

All materials are magnetic, in the sense that they are magnetic properties. The fact that atoms consist of moving electrons, which make up a current loop. every atomic electron thus has a dipole moment. The magnitude of dipole moment would be given by

I A . Here we must keep in mind that the electronic orbital radius as well as the speed of electrons in each orbit differs. This results in a range of magnetic dipole moments.

The net effect or the collective effect determines the gross magnetic property of the material.

In this module, we define and explain certain terms which will help us to classify materials on the basis of magnetic properties. This new classification is in addition to those we have considered on the basis of say mass density, elastic property or optical density etc.

Classification of Materials

The discussion in the previous modules helps us to classify materials on the basis of their behaviour in a magnetic field.

They are divided into **three** categories

- Diamagnetic materials
- Paramagnetic materials
- Ferromagnetic materials

Diamagnetic Substances

Diamagnetic substances are those substances which get feebly magnetized in the opposite direction of the magnetizing field. Such substances are feebly repelled by magnets and tend to move from stronger to weaker parts of the magnetic field. Examples of diamagnetic substances are **Bismuth, copper, lead, zinc, tin, gold, silicon, nitrogen and silver.**

Cause of Diamagnetism

The simplest explanation for diamagnetism is as follows.

Electrons in an atom orbiting around a nucleus possess orbital angular momentum. These orbiting electrons are equivalent to current-carrying loop and thus possess orbital magnetic moment. **Diamagnetic substances are the ones in which the resultant magnetic moment in an atom is zero.**

All substances are diamagnetic: the strong external magnetic field speeds up or slows down the electrons orbiting in atoms in such a way as to oppose the action of the external field.

When an external magnetic field is applied, across a diamagnetic material, those electrons having orbital magnetic moment in the same direction slow down and those in the opposite direction speed up. This happens due to induced current in accordance with Lenz's law.

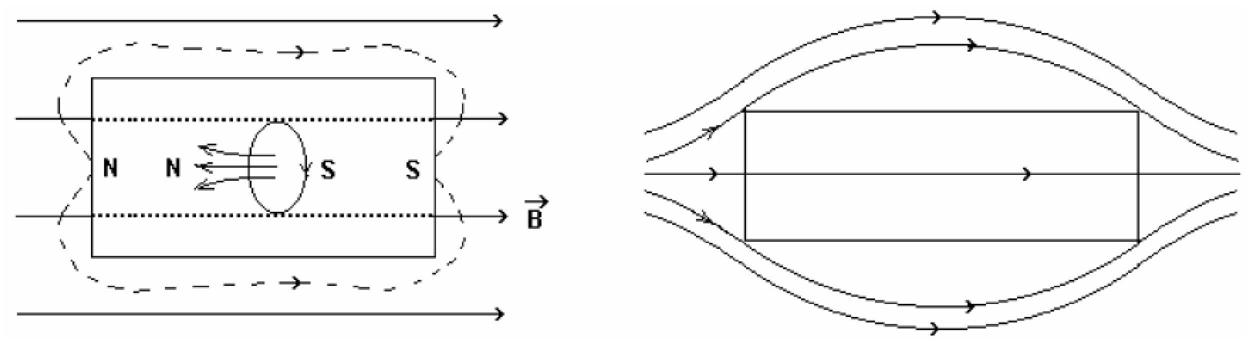
The diamagnetism of some materials, Diamagnetism is *observable* in substances with symmetric electronic structure (as ionic crystals and rare gases) and no permanent magnetic moment.

As above, diamagnetism is scarcely affected by changes in temperature.

For diamagnetic materials the value of the susceptibility (a measure of the relative amount of induced magnetism) is always negative

Thus, **the substance develops a net magnetic moment in direction opposite to that of the applied field and hence repulsion.**

Some diamagnetic materials are bismuth, copper, lead, silicon, nitrogen (at STP), water and sodium chloride.



Diamagnetic material in external magnetic field

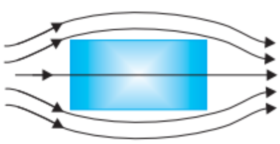
Field lines in diamagnetic material

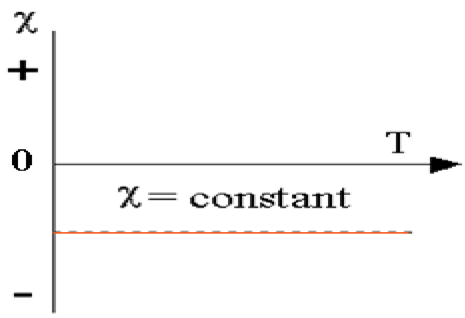
Diamagnetism is present in all the substances.

However, the effect is so weak in most cases that it gets shifted by other effects like paramagnetism, ferromagnetism etc.

Properties of Diamagnetic Substances

- **Diamagnetic substances are feebly magnetized in the opposite direction of the magnetizing field.**
- **They are feebly repelled by magnets.**
- **They tend to move from stronger to weaker parts of the magnetic field.**
- **The field lines are repelled or expelled and the field inside the material is reduced.**





- **When a thin and long rod of a diamagnetic substance is suspended freely in a uniform magnetic field, it aligns itself perpendicular to the magnetizing field.**
- **Their magnetic susceptibility is negative and small.**

- **The relative permeability is positive but less than one**
- **The magnetic susceptibility is independent of temperature.**
- **The magnetization of a diamagnetic substance lasts so long as the magnetizing field is applied.**

Example: Why is diamagnetism almost independent of temperature?

Answer

In a sample of **diamagnetic substance**, each molecule is **not** a magnetic dipole itself, even though each electron does So, the random thermal motion of the molecules does **not affect** the magnetism of the sample. Thus, the **diamagnetism** is almost independent of **temperature**.

Paramagnetic Substances

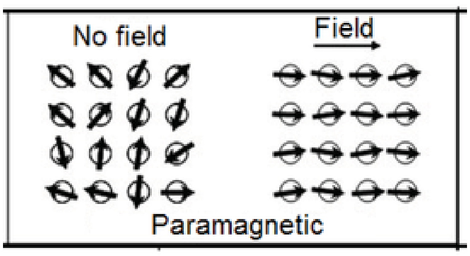
Paramagnetic substances are those which get weakly magnetized when placed in an external magnetic field. They have a tendency to move from a region of weak magnetic field to strong magnetic field. They get weakly attracted to a magnet.

Some examples of paramagnetic substances are manganese aluminium, chromium, platinum, sodium, copper chloride and oxygen at STP.

Cause of Paramagnetism

The individual atoms (or ions or molecules) of a paramagnetic material possess a permanent magnetic dipole moment of their own. On account of the ceaseless random thermal motion of the atoms, no net magnetization is seen.

In the presence of an external field, which is strong enough, and at low temperatures, the individual atomic dipole moment can be made to align and point in the same direction as the applied field.



Some paramagnetic materials are aluminium, sodium, calcium, oxygen (at STP) and copper chloride.

Curie's Law

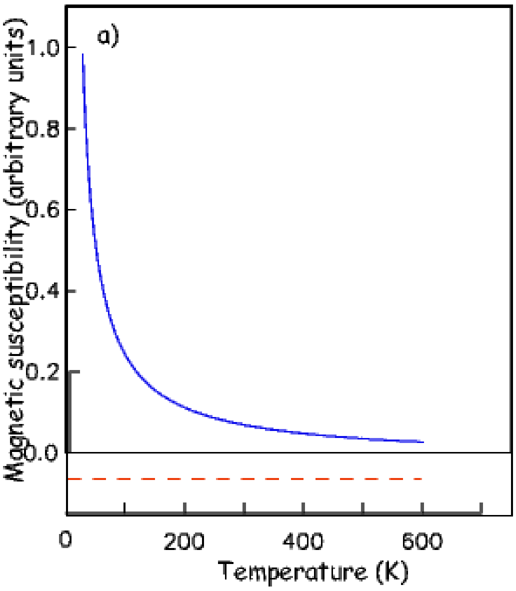
Experimentally, it was found that t**he magnetisation of a paramagnetic material is inversely proportional to the absolute temperature T**,

$$M = C\,B_0 / T$$

equivalently, $\boldsymbol{\chi_m = C\,\mu_0 / T}$

This is known as Curie's law, after its discoverer Pierre Curie (1859- 1906).

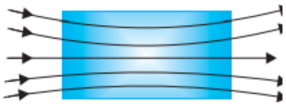
The constant C is called Curie's constant. Thus, for a paramagnetic material both χ and μr depend not only on the material, but also (in a simple way) on the sample temperature.



As the field is increased or the temperature is lowered, the magnetisation increases until it reaches the saturation value, at which point all the dipoles are perfectly aligned with the field. Beyond this, Curie's law is no longer valid.

Properties of Paramagnetic Substances

- Paramagnetic substances are feebly magnetized in the direction of the magnetizing field.
- They are feebly attracted by magnets.
- They tend to move from weaker to stronger parts of the magnetic field.
- The field lines get concentrated inside the material, and the field inside is enhanced.



- When a thin and long rod of a diamagnetic substance is suspended freely in a uniform magnetic field, it aligns itself parallel to the magnetizing field.
- Their magnetic susceptibility is positive and small.
- The relative permeability is positive but slightly more than one.
- The magnetic susceptibility is inversely proportional to the absolute temperature.
- The intensity of magnetization is directly proportional to the strength of the magnetizing field.
- The magnetization of a paramagnetic substance lasts so long as the magnetizing field is applied.

Note

A miniscule difference in the value of χ the magnetic susceptibility, yields radically different behavior: diamagnetic versus paramagnetic.

For diamagnetic materials $\chi = -10^{-5}$

whereas $\chi = +10^{-5}$ for paramagnetic materials.

Example

Why does a paramagnetic substance show greater magnetization for the same magnetizing field at low temperatures?

Answer

The tendency to disrupt the alignment of dipoles with the magnetizing field arising from random thermal motion decreases with decrease in temperature.

Example

How does the magnetic field due to a current in a toroid change if the core is a bismuth rod?

Answer

As bismuth is diamagnetic and it gets magnetized in a direction opposite to the magnetizing field, so the field in the toroid will be slightly less than when the core is empty.

Ferromagnetic Substances

Ferromagnetic substances are those which get strongly magnetized when placed in an external magnetic field. They have a tendency to move from a region of weak magnetic field to strong magnetic field. They get strongly attracted to a magnet.

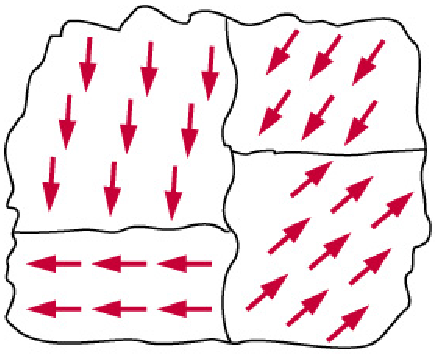
Some examples of ferromagnetic substances are iron, cobalt, nickel and alloys like alnico

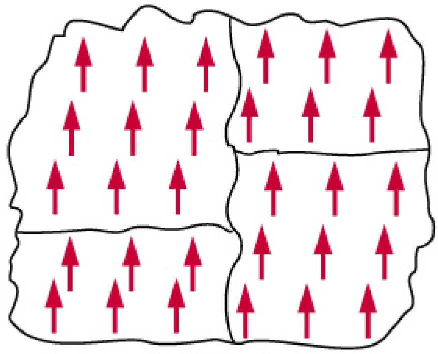
Cause of Ferromagnetism

The individual atoms (or ions or molecules) in a ferromagnetic material possess a dipole moment as in a paramagnetic material.

However, they interact with one another in such a way that they spontaneously align themselves in a common direction over a macroscopic volume called domain. The explanation of this cooperative effect requires quantum mechanics and is beyond the scope of this textbook.

Magnetic Field Absent   Magnetic Field Present





Each domain has a net magnetisation. Typical domain size is 1mm and the domain contains about 10^{11} atoms. In the first instant, the magnetisation varies randomly from domain to domain and there is no bulk magnetisation. This is shown in Fig. . When we apply an external magnetic field B_0, the domains orient themselves in the direction of B_0 and simultaneously the domain oriented in the direction of B_0 grows in size.

Temperature Dependence of Ferromagnetism

The ferromagnetic property depends on temperature. At high enough temperature, a ferrimagnet becomes a paramagnet. The domain structure disintegrates with temperature. This disappearance of magnetisation with temperature is gradual. It is a phase transition reminding us of the melting of a solid crystal. The temperature of transition from ferromagnetic to paramagnetic is called the Curie Temperature T_c. The susceptibility above the Curie temperature, i.e., in the paramagnetic phase is described by,

$\chi = \frac{C}{T-T_c}$ $(t > t_c)$

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

Curie temperature for some ferromagnetic materials

Properties of Ferromagnetic Substances

- Ferromagnetic substances are strongly magnetized in the direction of the magnetizing field.
- They Are strongly attracted to magnets.
- They tend to move from weaker to stronger parts of the magnetic field.
- The field lines get strongly concentrated inside the material, and the field inside is greatly enhanced.
- When a thin and long rod of a ferromagnetic substance is suspended freely in a uniform magnetic field, it quickly aligns itself parallel to the magnetizing field.
- Their magnetic susceptibility is positive and large. It is of the order of several thousand.
- The relative permeability is positive and large.
- The magnetic susceptibility of a ferromagnetic substance decreases with temperature according to Curie-Weiss law, $\chi_m = C/(T-T_c)$ where $T_c$is Curie temperature.
- At a certain temperature called Curie point the susceptibility suddenly decreases and the substance becomes paramagnetic.
- The intensity of magnetization depends on the strength of the magnetizing field and also on the past magnetic and mechanical history of the material.
- A ferromagnetic substance retains magnetism even after the magnetizing field is removed.

Example

A domain in ferromagnetic iron is in the form of a cube of side length 1μm. Estimate the number of iron atoms in the domain and the maximum possible dipole moment and magnetisation of the domain. The molecular mass of iron is 55 g/mole and its density is 7.9 g/cm3. Assume that each iron atom has a dipole moment
of 9.27×10-24 A m2.

Solution

The volume of the cubic domain is

$V = (10^{-6}\text{ m})^3 = 10^{-18}\text{ m}^3 = 10^{-12}\text{ cm}^3$

Its mass is volume × density = $7.9\text{ g cm}^{-3} \times 10^{-12}\text{ cm}^3 = 7.9 \times 10^{-12}\text{g}$

It is given that Avogadro number (6.023×10^{23}) of iron atoms have amass of 55 g. Hence, the number of atoms in the domain is

$N = 7.9 \times 10^{-12\times}\ 6.023\times 10^{23}/55$

$= 8.65 \times 10^{10}$ atoms

The maximum possible dipole moment m_{max} is achieved for the (unrealistic) case when all the atomic moments are perfectly aligned.

Thus,

$m_{max} = (8.65 \times 10^{10}) \times (9.27 \times 10^{-24})$

$= 8.0 \times 10^{-13}$ A m^2

The consequent magnetisation is

$M_{max} = m_{max}/Domain\ volume$

$= 8.0 \times 10^{-13}$ Am^2/10^{-18} m^3

$= 8.0 \times 10^5$ Am^{-1}

Example

Is the permeability of a ferromagnetic substance independent of temperature?

Answer: No

Example

Would the maximum possible magnetization of a paramagnetic substance be of the same order as magnetization of a ferromagnetic substance?

Answer

Yes, the individual atomic dipole of two different materials, a paramagnetic with saturated magnetization will have the same order of magnetization, but the saturation requires an impractically high magnetizing field.

Example

A certain region of space is to be shielded from magnetic fields, suggest a method.

Answer

Surround the region with soft iron rings. Magnetic field lines will be drawn into the rings and the enclosed space will be free of magnetic field.

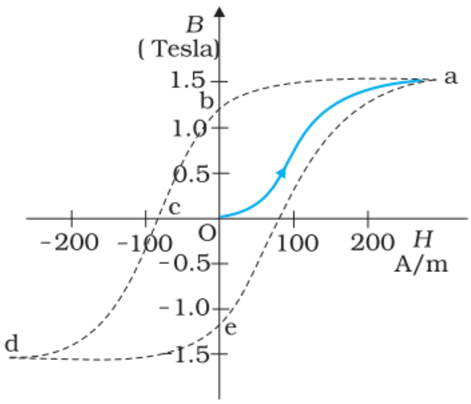
This shielding is not perfect shielding like the one in electrostatics.

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

Magnetic physical quantities their symbols, nature dimensions units and inter relation

Magnetic Hysteresis

The relation between B and H in ferromagnetic materials is complex. It is often not linear and it depends on the magnetic history of the sample. Figure below depicts the behaviour of the material as we take it through one cycle of magnetisation.



Let the material be unmagnetised initially.We place it in a solenoid and increase the current through the solenoid. The magnetic field B in the material rises and saturates as depicted in the curve Oa. This behaviour represents the alignment and merger of domains until no further enhancement is possible. It is pointless to increase the current (and hence the magnetic intensity H) beyond this.

Next, we decrease H and reduce it to zero. At H = 0, B ≠ 0. This is represented by the curve ab. The value of B at H = 0 is called **retentivity or remanence**. The domains are not completely randomized even though the external driving field has been removed. Next, the current in the solenoid is reversed and slowly increased. Certain domains are flipped until the net field inside stands nullified. This is represented by the curve bc. The value of H at c is called **coercivity.**

As the reversed current is increased in magnitude, we once again obtain saturation. The curve cd depicts this. Next, the current is reduced (curve de) and reversed (curve ea). The cycle repeats itself. Note that the curve Oa does not retrace itself as H is reduced. For a given value of H, B is not unique but depends on the previous history of the sample. This phenomenon is called hysteresis. The word hysteresis means lagging behind (and not ‘history the hysteresis curve allows us to select suitable materials for permanent magnets.

Permanent Magnets and Electromagnets Permanent Magnets

Substances which at room temperature retain their ferromagnetic property for a long period of time are called permanent magnets.

One can also hold a steel rod and stroke it with one end of a bar magnet a large number of times, always in the same sense to make a permanent magnet. An efficient way to make a permanent magnet is to place a ferromagnetic rod in a solenoid and pass a current. The magnetic field of the solenoid magnetises the rod. The hysteresis curve allows us to select suitable materials for permanent magnets. **The material should have:**

- **High retentivity so that the magnet is strong.**
- **High coercivity so that the magnetisation is not erased by stray magnetic fields, temperature fluctuations or minor mechanical damage.**
- **Further, the material should have a high permeability.**

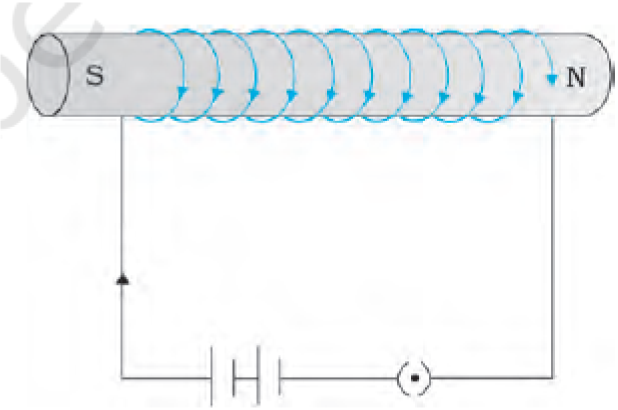
Steel is a one-favoured choice. It has a slightly smaller retentivity than soft iron but this is outweighed by the much smaller coercivity of soft iron. Other suitable materials for permanent magnets are alnico, cobalt steel and ticonal.

Electromagnets

Core of electromagnets are made of ferromagnetic materials which have

- **high permeability**
- **low retentivity**
- **Less B-H area curve**

Soft iron is a suitable material for electromagnets.



A soft iron core in solenoid acts as an electromagnet

A soft iron core in solenoid acts as an electromagnet. In certain applications, the material goes through an ac cycle of magnetization for a long period. This is the case in transformer cores and telephone diaphragms. The hysteresis curve of such materials must be narrow. The energy dissipated and the heating will consequently be small. Electromagnets are used in electric bells, loudspeakers and telephone diaphragms.

Summary

- Consider a material placed in an external magnetic field B_0. The magnetic intensity is defined as, $\mu_0 = B_0 /H$.
- The magnetization M of the material is its dipole moment per unit volume.
- The magnetic field B in the material is, $B = \mu_0 (H + M)$. For a linear material $M = \chi H$. So that $B = \mu H$ and χ is called the magnetic susceptibility of the material.
- The three quantities, χ, the relative magnetic permeability μ_r , and the magnetic permeability μ are related as follows: $\mu = \mu_0 \mu_r$ and $\mu_r = 1+ \chi$
- Magnetic materials are broadly classified as: diamagnetic, paramagnetic, and ferromagnetic.
- For diamagnetic materials χ is negative and small and for paramagnetic materials it is positive and small.

- Ferromagnetic materials have large χ and are characterized by non-linear relations between B and H. They show the property of hysteresis.
- Substances, which at room temperature retain their ferromagnetic property for a long period of time are called permanent magnets.

Comparison between diamagnetic, para magnetic and ferromagnetic materials

Diamagnetic	**Paramagnetic**	**Ferromagnetic**
Weakly repelled by a magnet	Weakly attracted by a magnet	Strongly attracted by a magnet
Feebly magnetized in opposite direction of the magnetizing field.	Feebly magnetized in the direction of the magnetizing field.	Strongly magnetized in the direction of the magnetizing field.
Move slowly from the weaker to stronger part of the magnetic field.	Move slowly from the stronger to weaker part of the magnetic field.	Move quickly from the stronger to weaker part of the magnetic field.
A thin and long rod aligns slowly its longer side perpendicular to the magnetizing field.	A thin and long rod aligns slowly its longer side parallel to the magnetizing field.	A thin and long rod aligns quickly, its longer side parallel to the magnetizing field.
χ is small and negative	χ susceptibility is positive and small	χ susceptibility is positive and large
μ_r is positive,but less than 1	μ_r is positive , slightly more than 1	μ_r is positive , very large
susceptibility is independent of temperature	Susceptibility varies inversely with temperature and follow Curie's law	Susceptibility varies inversely with temperature and follow Curie-Weiss law up to Curie point and thereafter behaves like a paramagnetic substance