MODULE 4

MAGNETIC MATERIALS

MAGNETIC MATERIALS - TERMS

- Magnetic Susceptibility: Ratio of intensity of magnetisation produced in the sample to the magnetic field intensity which produces magnetization. It has no units.

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

- Magnetization: The process of converting a non magnetic material to a magnetic material.

- Intensity of magnetization: It is magnetic moment per unit volume.

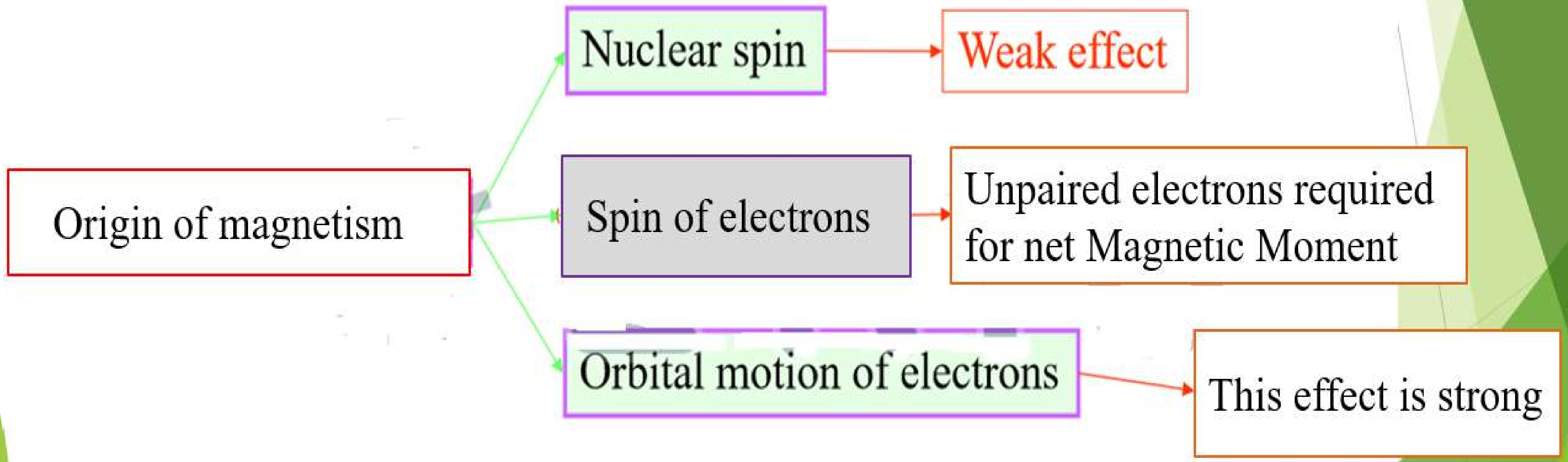
- Relative permeability: The ratio of flux density produced in a material to the flux density produced in vacuum by the same magnetising force.

MAGNETIC MATERIALS - TERMS

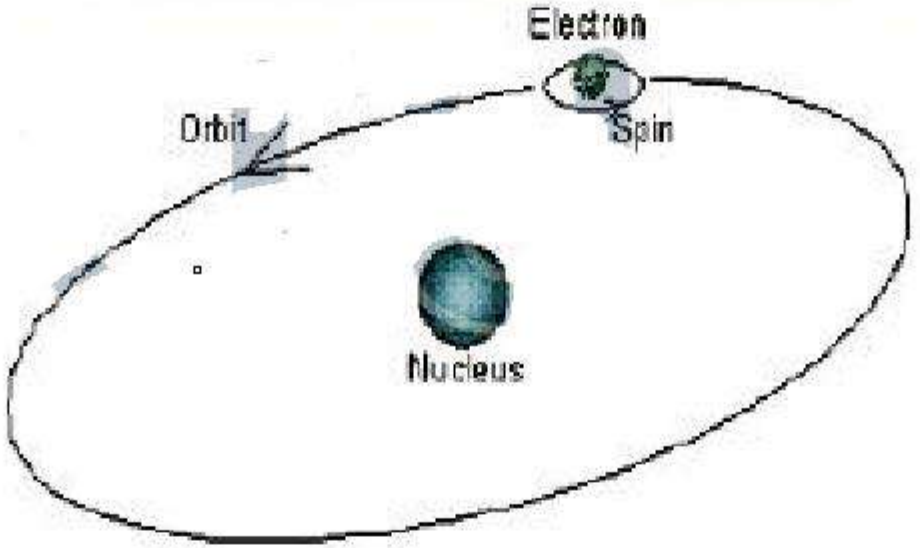
- Magnetic flux (Φ): The total no: of magnetic lines of force in a magnetic field (unit- Weber)
- Magnetic flux density (B): Magnetic flux per unit area at right angles to the direction of flux. (Wb/m^2)
- Magnetic field intensity (H): Magneto motive force per unit length of the magnetic circuit. It is also called magnetic field strength or magnetizing force. (A-turns/m)
- Permeability (μ): The ability of a material to conduct magnetic flux through it. (H/m)

ORIGIN OF PERMENANT MAGNETIC DIPOLES

- A moving electric charge is responsible for Magnetism.

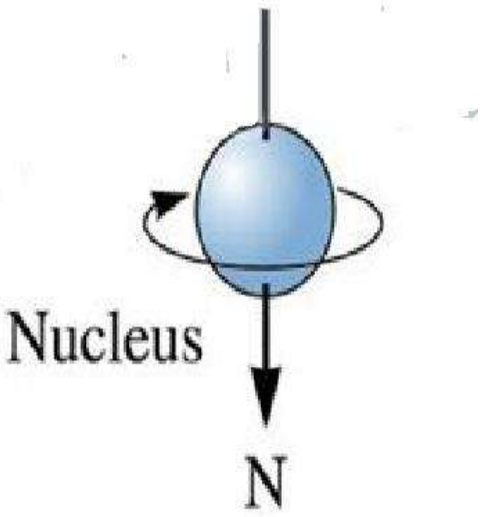


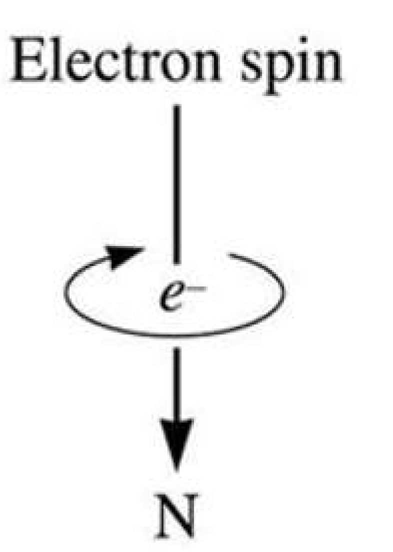
ORIGIN OF PERMENANT MAGNETIC DIPOLES



ORBITAL SPIN

ORBITAL MOMENTUM





CLASSIFICATION OF MAGNETIC MATERIALS

- Diamagnetic – materials which lack permanent dipoles are called diamagnetic
- Paramagnetic – if the permanent dipoles do not interact among themselves, the material is paramagnetic
- Ferromagnetic – if the interaction among permanent dipoles is strong such that all the dipoles line up in parallel, the material is ferromagnetic
- Antiferromagnetic – if the permanent dipoles line up in antiparallel direction, the material is antiferromagnetic
- Ferrimagnetic – antiparallel with unequal magnitude

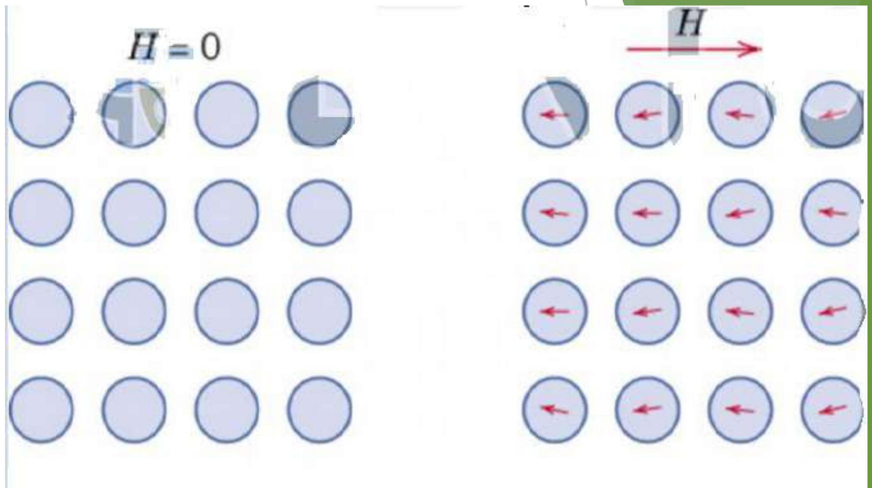
CLASSIFICATION OF MAGNETIC MATERIALS

DIAMAGNETIC MATERIALS

- No permanent dipoles are present so net magnetic moment is zero.
- Dipoles are induced in the material in presence of external magnetic field.
- The magnetization becomes zero on removal of the external field.
- Magnetic dipoles in these substances tend to align in opposition to the applied field.
- Hence, they produce an internal magnetic field that opposes the applied field and the substance tends to repel the external field around it.
- This reduces the magnetic induction in the specimen.

CLASSIFICATION OF MAGNETIC MATERIALS

DIAMAGNETIC MATERIALS

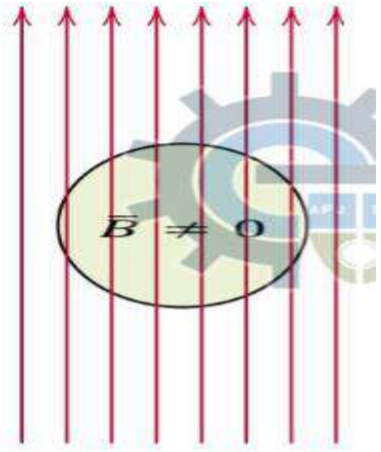


- Magnetic susceptibility is small and negative.
- Relative permeability is less than one.
- It is present in all materials, but since it is so weak it can be observed only when other types of magnetism are totally absent.
- Ex: Gold, water, mercury, B, Si, P, S, ions like Na+, Cl- and their salts, diatoms like H2, N2,..

CLASSIFICATION OF MAGNETIC MATERIALS

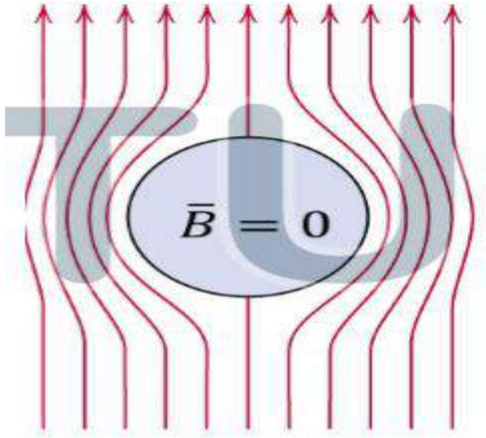
DIAMAGNETIC MATERIALS

They repel the magnetic lines of force. The existence of this behavior in a diamagnetic material is shown



← Normal conductors

Diamagnetic materials →



CLASSIFICATION OF MAGNETIC MATERIALS

PARAMAGNETIC MATERIALS

- If the orbital's are not completely filled or spins are not balanced, an overall small magnetic moment may exist
- The magnetic dipoles tend to align along the applied magnetic field and thus reinforce the applied magnetic field.
- Such materials get feebly magnetized in the presence of a magnetic field i.e. the material allows few magnetic lines of force to pass through it.
- The magnetization disappears as soon as the external field is removed.

CLASSIFICATION OF MAGNETIC MATERIALS

PARAMAGNETIC MATERIALS

- The magnetization (M) of such materials was discovered by Madam Curie and is dependent on the external magnetic field (B) and temperature T as:

  $$\chi = \frac{C}{T} \quad \text{where, C= Curie Constant}$$

- The orientation of magnetic dipoles depends on temperature and applied field.

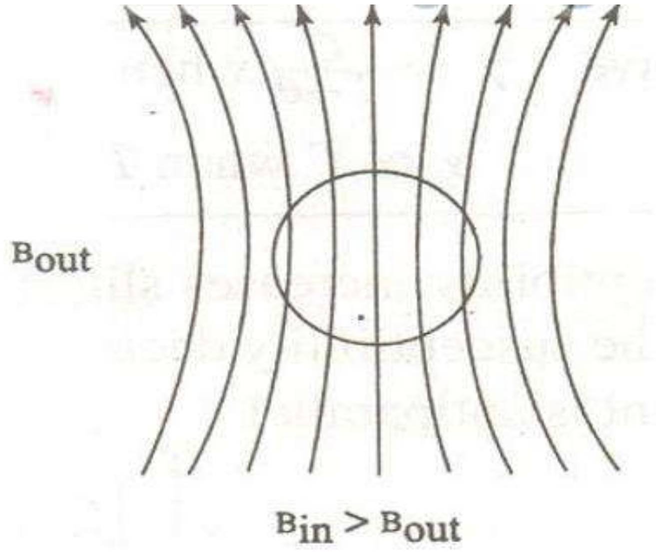
- Relative permeability $\mu_r > 1$

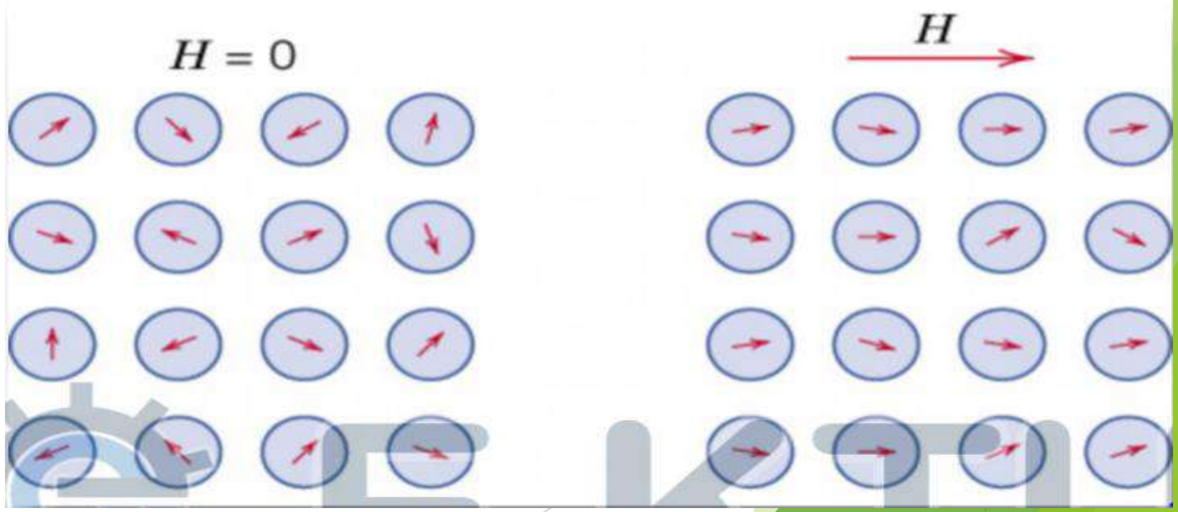
- Susceptibility is independent of applied magnetic field and depends on temperature

CLASSIFICATION OF MAGNETIC MATERIALS

PARAMAGNETIC MATERIALS

- Susceptibility is small and positive
- These materials are used in lasers.
- Ex: Liquid oxygen, sodium, platinum, salts of iron and nickel, rare earth oxides





CLASSIFICATION OF MAGNETIC MATERIALS

FERROMAGNETIC MATERIALS

- They exhibit strongest magnetic behavior.
- Permanent dipoles are present which contributes a net magnetic moment.
- Possess spontaneous magnetization because of interaction between dipoles
- Origin for magnetism in Ferro magnetic materials are due to Spin magnetic moment. All spins are aligned parallel & in same direction
- When placed in external magnetic field it strongly attracts magnetic lines of force.
- The domains reorient themselves to reinforce the external field and produce a strong internal magnetic field that is along the external field.

CLASSIFICATION OF MAGNETIC MATERIALS

FERROMAGNETIC MATERIALS

- Most of the domains continues to be aligned in the direction of the magnetic field even after removal of external field.
- Thus, the magnetic field of these magnetic materials persists even when the external field disappears.
- This property is used to produce Permanent magnets.
- Transition metals, iron, cobalt, nickel, neodymium and their alloys are usually highly ferromagnetic and are used to make permanent magnets.

CLASSIFICATION OF MAGNETIC MATERIALS

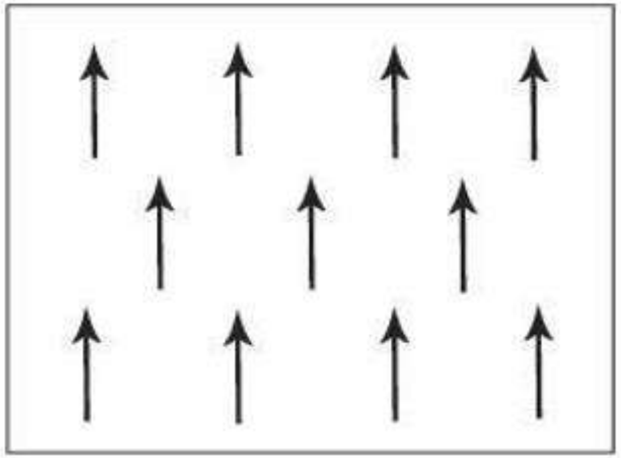
FERROMAGNETIC MATERIALS

- Susceptibility is large and positive, it is given by Curie Weiss Law;

$$\chi = \frac{C}{T - \theta}$$ where, C is Curie constant & θ is Curie temperature.

- When temperature is greater than Curie temperature then the material gets converted in to paramagnetic.

- They possess the property of Hysteresis.



CLASSIFICATION OF MAGNETIC MATERIALS

FERROMAGNETIC MATERIALS

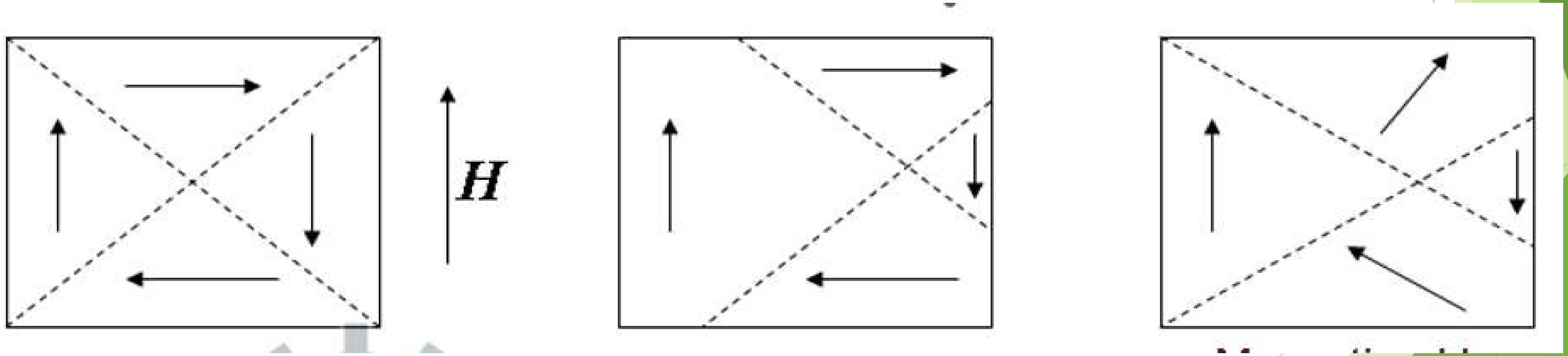
Domain theory of ferromagnetic materials:

- A magnetic domain is a region within a magnetic material in which the magnetization is in a uniform direction.
- Ferromagnetic materials tend to form magnetic domains.
- Each domain is magnetized in a different direction.
- Applying a field changes domain structure. Domains with magnetization in direction of field grow. (Domain growth)
- Domain structure minimizes energy due to stray fields.

CLASSIFICATION OF MAGNETIC MATERIALS

Domain theory of ferromagnetic materials:

- Domains with magnetization in the direction of field grow while other domains shrink.
- Applying very strong fields can saturate magnetization by creating single domain. (Domain rotation)



Un-magnetized | Magnetized by domain growth | Magnetized by domain rotation

CLASSIFICATION OF MAGNETIC MATERIALS

FERROMAGNETIC MATERIALS

Hysteresis:

- The property of Ferro Magnetic materials which gives the relation between Magnetization and the strength of Magnetic field is called Hysteresis.

- The magnetization of the specimen increases from zero to higher values and attains its maximum value at a point referred to as Saturation Magnetization.

- When we further increase Magnetic field H there is no further increment in Magnetic moment.

CLASSIFICATION OF MAGNETIC MATERIALS

FERROMAGNETIC MATERIALS

Hysteresis:

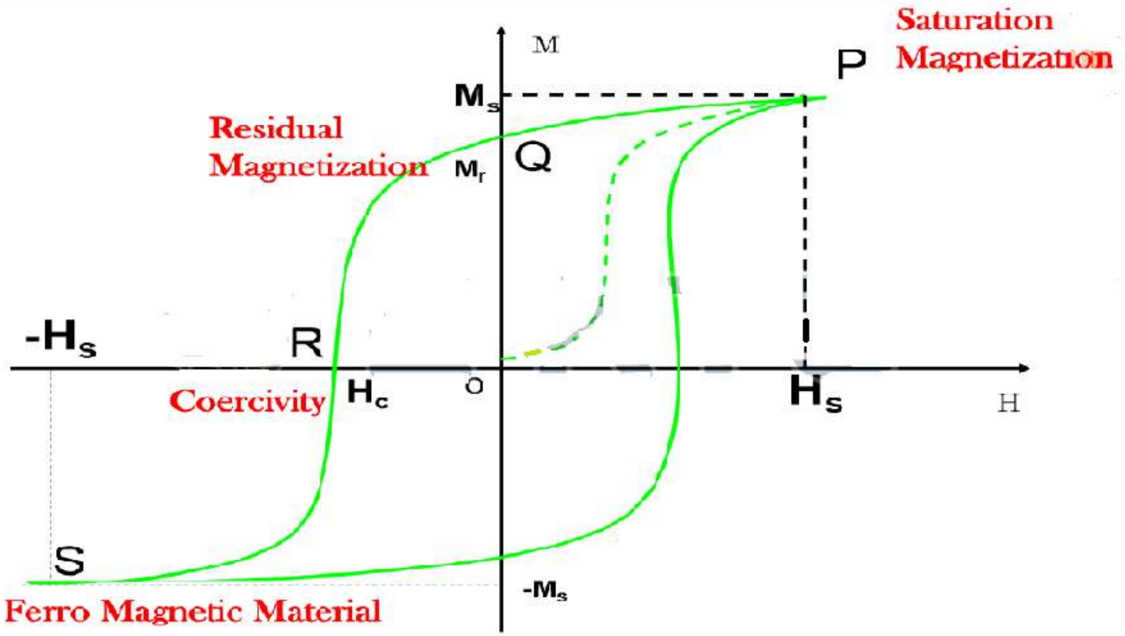
- When we decrease Magnetic field H to Zero, the Magnetization M attains point Q referred to as Residual Magnetization, Mr.
- Further if we change the Magnetic field from zero to negative values, the Magnetization of material becomes zero at a point R, where magnetic field Hc is referred as Coercivity of the specimen.
- If we increase Magnetic field H in reverse direction Magnetization of material reaches its peak value at a points S.
- The area of loop indicates the amount of energy wasted in one cycle of operation

CLASSIFICATION OF MAGNETIC MATERIALS

FERROMAGNETIC MATERIALS

Hysteresis:

- Hysteresis loop - The loop traced out by magnetization in a ferromagnetic or ferrimagnetic material as the magnetic field is cycled



CLASSIFICATION OF MAGNETIC MATERIALS

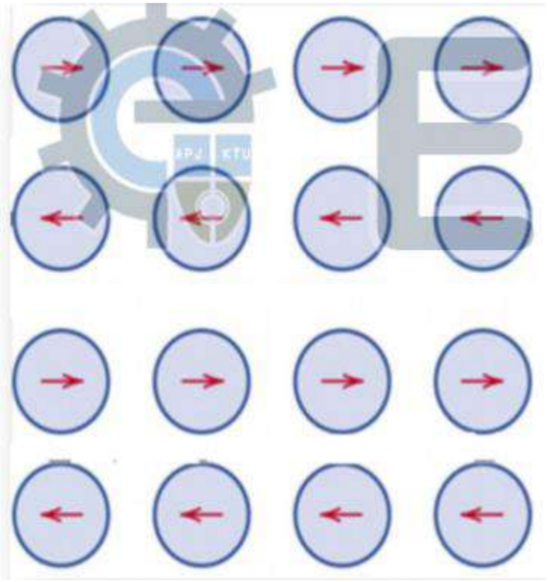
ANTIFERROMAGNETIC MATERIALS

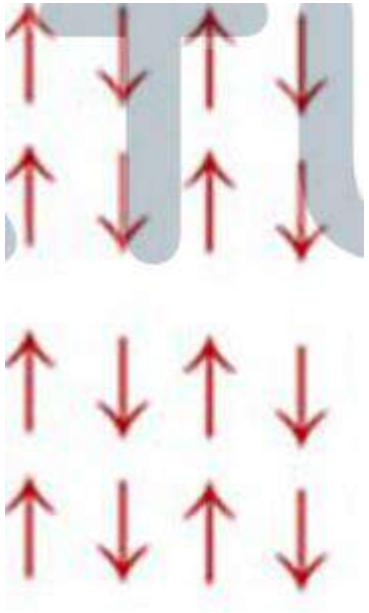
- The spin alignment is in antiparallel manner.
- Susceptibility is small and positive and it depends on temperature.
- Initially susceptibility increases with increase in temperature and beyond Neel temperature the susceptibility decreases with temperature.
- The antiparallel alignment exists in material below a critical temperature known as Neel temperature
- At Neel temperature susceptibility is maximum.

CLASSIFICATION OF MAGNETIC MATERIALS

ANTIFERROMAGNETIC MATERIALS

- Susceptibility, $\chi = \frac{C}{T+\theta}$
- Examples: Mn, Cr, FeO, MnO, Cr2O3 and salts of transition elements.

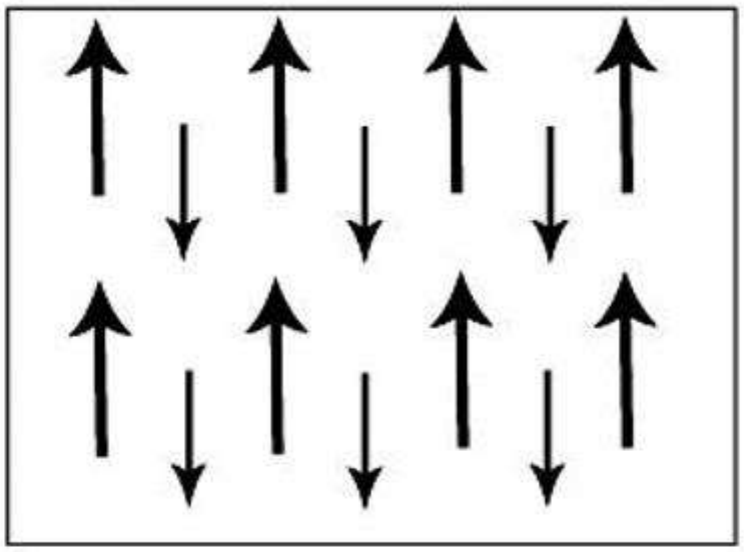




CLASSIFICATION OF MAGNETIC MATERIALS

FERRI MAGNETIC MATERIALS

- The spin alignment is antiparallel but have different magnitude.
- So they possess net magnetic moment which produce a large magnetization even for a small applied external field.
- It is also called ferrites.
- Susceptibility is very large and positive.
- Examples: ferrous ferrite, nickel ferrite



CLASSIFICATION OF MAGNETIC MATERIALS

Comparison:

S.no.	Property	Diamagnetic materials	Paramagnetic materials	Ferromagnetic materials
1.	Cause of magnetism	Orbital motion of electrons	Spin motion of electrons	Formation of domains
2.	State of magnetization	Weakly magnetized in direction opposite to that external magnetic field	Weakly magnetized in the direction of the external magnetic field	Strongly magnetized in the direction of the
3.	Magnetic susceptibility χ	Low and negative	Low but positive	High and positive
4.	Temperature dependence of χ	Independent	$\chi = C/T$	$\chi = C/(T - T_C)$
5.	Magnetic moment	Low and is in direction opposite to that of the external magnetic field	Low but in the direction of external magnetic field	High and in the direction of external magnetic field
6.	Relative permeability μ_r	$\mu_r < 1$	$\mu_r > 1$	$\mu_r >> 1$
7.	Examples	Cu, Ag, Au, Zn, Bi, Sb, etc.	Al, Pt, Na, Mn, etc.	Fe, Ni, Co, etc.

CURIE – WEISS LAW

- The Curie–Weiss law describes the magnetic susceptibility χ of ferromagnetic materials at temperatures above the Curie point:

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

where, C = Material specific Curie constant, T = Absolute temperature, Tc = Curie temperature in Kelvin

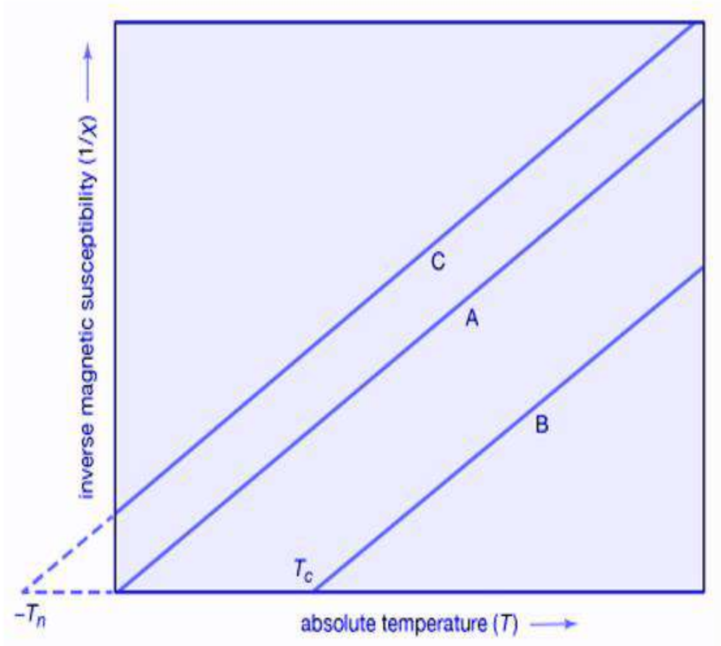
- As temperature increases the magnetism of a ferromagnetic material decreases.

- The random thermal motion destroys the ordering of spins.

- For temperatures above the Curie temperature, the long range order of spin is lost and only a short range order exists.

CURIE – WEISS LAW

- Curie-Weiss Law Limitation;
  - The Curie-Weiss law holds false in many materials.
  - Instead, there is a critical behavior of the form. $\chi \sim \frac{1}{(T-T_c)\gamma}$
  - At temperature T≫Tc, the expression of the law still holds true. But, Tc will be replaced by temperature (θ) higher than the Curie temperature.



PROPERTIES AND APPLICATIONS OF IRON

PROPERTIES

- Pure iron is soft, malleable, and ductile

- It rusts in damp air, but not in dry air.

- It dissolves readily in dilute acids.

- It melts at 1536°C and boils at 2861°C.

- Being a metal it is magnetic in nature.

- Iron is a lustrous, ductile, malleable, silver-gray metal (group VIII of the periodic table).

PROPERTIES AND APPLICATIONS OF IRON

PROPERTIES

- It is known to exist in four distinct crystalline forms;
  - Ordinary or α-iron (alpha-iron) at lower temperature
  - γ -iron (gamma-iron) is soft in nature
  - δ-iron (delta-iron)
  - At very high pressure, epsilon-iron exists (€-iron)
- At room temperature, this metal is in the form of ferrite (α-iron)
- The internal arrangement of the atoms in the crystal lattice changes in the transition from one form to another.
- The transition from α-iron to γ-iron occurs at about 910°C, and the transition from γ-iron to δ-iron occurs at about 1400°C

PROPERTIES AND APPLICATIONS OF IRON

APPLICATIONS

- Iron is used in numerous sectors such as electronics, manufacturing, automotive, and construction and building.

- It is used as the primary constituent of ferrous metals/alloys and steels

- It is alloyed with carbon, nickel, chromium and various other elements to form cast iron or steel which is used;
  - In fabricated metal products
  - In industrial machinery
  - In transportation equipment
  - In instruments
  - In magnets

PROPERTIES AND APPLICATIONS OF IRON

APPLICATIONS

- Iron is used to make alloy steels like carbon steels with additives such as nickel, chromium, vanadium, tungsten and manganese.
- These are used to make bridges, electricity pylons, bicycle chains, cutting tools and rifle barrels.
- Cast iron contains 3–5% carbon. It is used for pipes, valves and pumps and in the manufacturing of ‘resistance grids’ to be used in the starting of large dc motors
- Iron catalysts are used in the Haber process for producing ammonia.
- Galvanized steel and iron wires which are generally used for earth conductor in low voltage distribution systems may also be used for the phase conductor in rural areas

ALLOYS OF IRON

- Alloy is the substance, which is composed of two or more metals.
- The properties of alloys are different from those of their constituent elements. Properties such as strength and corrosion resistance may be considerably greater for an alloy than for any of the separate metals. Hence, alloys are more generally used than pure metals.
- Pure iron has low resistivity, which results in higher eddy current losses. These losses can be minimized by increasing the resistivity of the material, which is achieved by adding 1-4% of silicon to iron.
- The most important alloy of iron is steel. Steel is stronger and harder than wrought iron (pure iron)
- The mixtures (alloys) of steel with metals like chromium, manganese, molybdenum, nickel, tungsten, and vanadium, are stronger and harder than steel itself, and many of them are also more corrosion-resistant than iron or steel.

ALLOYS OF IRON

- **Carbon steels**
  - Steels in which the main alloying additive is carbon.
  - Mild steel is the most common due to its low cost.
  - It is neither brittle nor ductile, has relatively low tensile strength, and is malleable.
  - Surface hardness can be increased through carburizing.
  - High carbon steels have a higher carbon content which provides a much higher strength at the cost of ductility.

- **Alloy steels**
  - Steels (iron and carbon) alloyed with other metals to improve properties.
  - The most common metals in low alloyed steels are molybdenum, chromium, and nickel to improve weldability, formability, wear resistance, and corrosion resistance.

ALLOYS OF IRON

- **Stainless steels**

  - Steels that contain a minimum of 10% chromium.
  - There are many grades of stainless steel, but the most common grade used for typical corrosion resistant applications is type 304, also known as 18-8.
  - The term 18-8 refers to the amount of chromium (18%) and nickel (8%) combined with iron and other elements in smaller quantities.
  - The metal’s finish is depicted by a number, 3 to 8, with 3 being the roughest and 8 being a mirror-like finish.
  - Other specifications considered include textures and coatings.

ALLOYS OF IRON

- **Tool steels**

  - Steels designed for being made into tools.
  - They are known for toughness, resistance to abrasion, ability to hold a cutting edge, and/or their resistance to deformation at high temperatures.
  - The three types of tool steel available are;
    - cold work steels used in lower operating temperature environments,
    - hot work steels used at elevated temperatures, and
    - high speed steels able to withstand even higher temperatures giving them the ability to cut at higher speeds.

ALLOYS OF IRON

- **Cast iron**

  - Iron alloy derived from pig iron, alloyed with carbon and silicon.
  - Carbon is added to the base melt in amounts that exceed the solubility limits in iron and precipitates out as graphite particles.
  - Silicon is added to the melt to nucleate the graphite which optimizes the properties of cast iron.
  - It is referred to as cheap, dirty, brittle metal
  - Cast iron is getting much more attention and use today because of its machinability, light weight, strength, wear resistance, and damping properties.

ALLOYS OF IRON

- **Maraging steels**

  - Carbon free iron-nickel alloys with additions of cobalt, molybdenum, titanium, and aluminum.
  - The term maraging is derived from the strengthening mechanism, which is transforming the alloy to martensite with subsequent age hardening.
  - With yield strengths between 1400 and 2400 MPa, maraging steels belong to the category of ultra-high-strength materials.
  - The high strength is combined with excellent toughness properties and weldability.

ALLOYS OF IRON

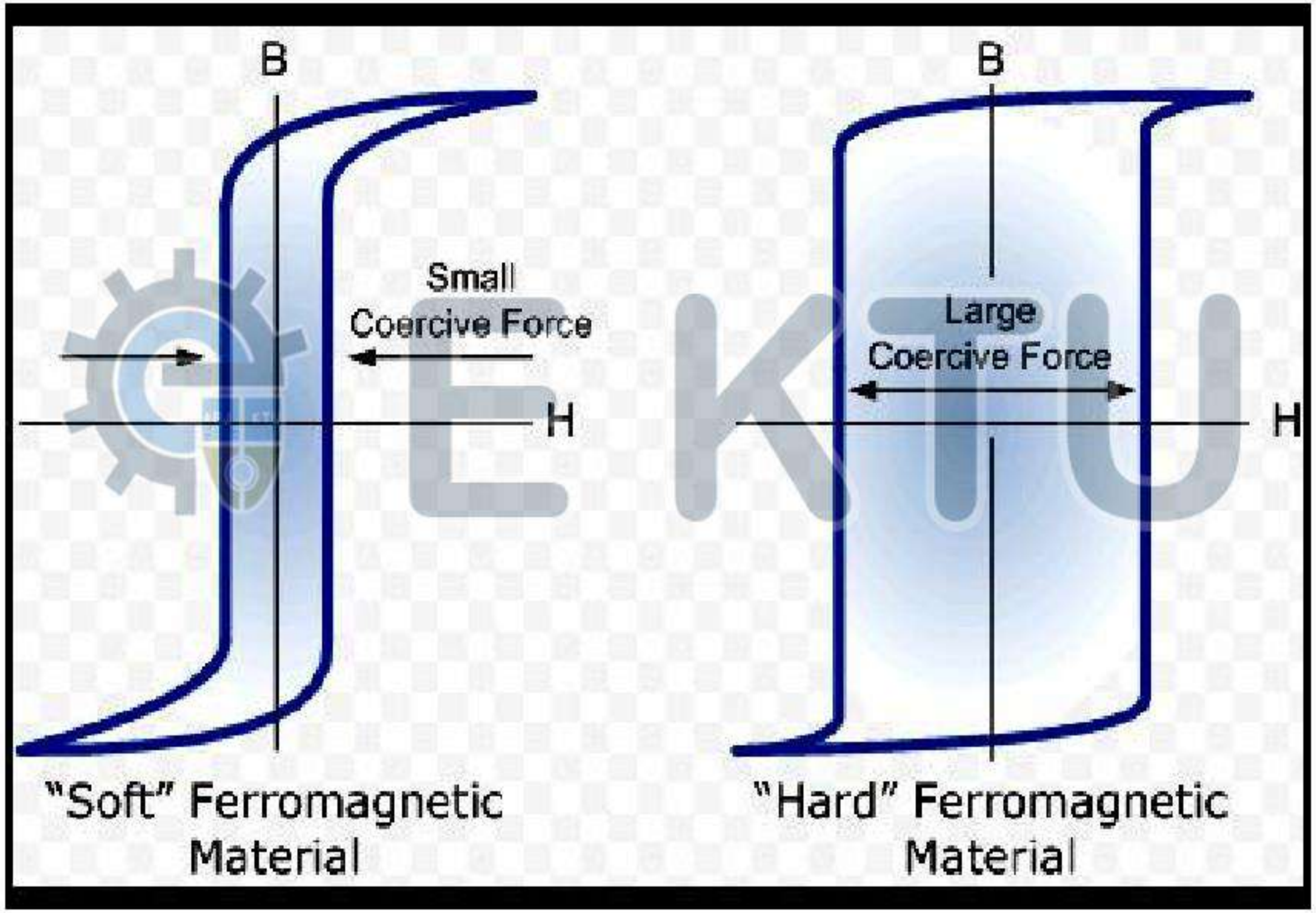
- **Mu- metal**
  - It consists of iron, nickel, copper and chromium.
  - It is a soft magnetic material used in miniature transformers for circuit applications

- **Nickel iron alloys**
  - Good choice for devices like audio transformer and recording head.
  - These alloys have high higher initial permeability, low hysteresis and low eddy current losses.
  - Commercial name of Nickel iron alloy is “hypenik”.
  - Two important compositions are the following
    1) 50 Permalloy – 50% Ni 50% Fe
    2) 78 Permalloy – 78% Ni 22% Fe
    3) Supermalloy - 78% Ni 17% Fe and 5% Mo

ALLOYS OF IRON

- **Silicon iron alloy**:
  - Silicon increases the electrical resistivity of iron.
  - It reduces hysteresis loss.
  - The magnetostriction effect is also reduced.
  - It increases the permeability
  - Silicon iron alloy is used in the form of thin sheets called laminations. These laminations are used in transformers, small machines and large turbo generators.
  - Silicon iron alloy with 2% silicon has large magnetic saturation. Hence, it is employed in the cores of electrical rotating machines.
  - Silicon – iron alloy with 4% silicon is used in the magnetic circuits of power transformers which operate under very high flux density.
  - Permeability of silicon iron alloy is relatively low under weak fields. Therefore it is not suitable for high sensitivity applications such as in communication equipment.

HARD AND SOFT MAGNETIC MATERIALS



HARD AND SOFT MAGNETIC MATERIALS

SOFT MAGNETIC MATERIALS

Properties:

- These magnetic materials can be easily magnetized and demagnetized, but they cannot be permanently magnetized
- Less energy is required to magnetize and demagnetize a soft magnetic material.
- These are used to make electromagnets.
- Eg: Iron silicon alloys, Ferrous nickel alloy, Iron-cobalt alloys, Ferrite and garnets
- Low Hysteresis loss and low coercivity.
- These materials have large values of permeability and susceptibility

HARD AND SOFT MAGNETIC MATERIALS

SOFT MAGNETIC MATERIALS

Applications:

- Soft magnetic materials have relatively small and narrow hysteresis loop and hence small energy loss per cycle of magnetization. They are widely used for the construction of cores of electrical rotating machines, transformers, and for making electro-magnets, reactors, relays

- Soft magnetic materials are mostly used where changing magnetic flux is associated, such as magnetic core of electric motors, alternators, DC generators, electrical transformers, protective relays, inductors.
- Used for making a path for flux in permanent magnetic motors

- Used for magnetic shielding, electromagnetic pole-pieces, to activate the solenoid switch
- Permanent magnet uses soft magnetic material to make a path for flux lines

HARD AND SOFT MAGNETIC MATERIALS

SOFT MAGNETIC MATERIALS

Examples:

- Nickel Iron Alloys - It is used in communication equipment such as audio transformer, recording heads and magnetic modulators. Since it has high initial permeability in feeble fields, low hysteresis and low eddy current losses.
- Grain oriented sheet steel: used to make transformer cores.
- Mu-metal: used in miniature transformers meant for circuit applications.
- Ceramic magnets: used for making memory devices for microwave devices and computer

HARD AND SOFT MAGNETIC MATERIALS

HARD MAGNETIC MATERIALS

Properties:

- These magnetic materials cannot be easily magnetized and demagnetized, but they can be permanently magnetized.
- The reason is that the domain walls are motionless owing to crystal defects and imperfections.
- Hard magnetic materials have large hysteresis loss due to large hysteresis loop area
- These are used to make permanent magnets.
- High remnant magnetization

HARD AND SOFT MAGNETIC MATERIALS

HARD MAGNETIC MATERIALS

Properties:

- The shape of BH loop is nearly rectangle.
- Small initial permeability.
- Relatively low permeability and susceptibility
- These materials have high Coercivity and retentivity. Hence, cannot be easily magnetized and demagnetized.
- High magnetizing force is required to attain magnetic saturation.
- Eg: Alnico alloy, Copper nickel iron alloy, Copper nickel cobalt alloy

HARD AND SOFT MAGNETIC MATERIALS

HARD MAGNETIC MATERIALS

Applications:

- Hard magnetic materials (such as carbon steel, tungsten steel, cobalt steel and hard ferrites) have large hysteresis loop area and consequently large energy loss per cycle of magnetization and are used in making all kinds of instruments and devices requiring permanent magnets.

Various other applications are;

- Automotive: motor drives for fans, wipers, injection pumps, starter motors, Control for seats, windows etc.
- Telecommunication: Microphones, Loud Speakers, Telephone Ringers etc.
- Data processing: Printers, Stepping Motors, Disc Drives and Actuators.

HARD AND SOFT MAGNETIC MATERIALS

HARD MAGNETIC MATERIALS

Applications:

- Consumer electronics: Home computers, Clocks, DC Motors for showers etc.
- Electronic and instrumentation: Energy Meter Disc, Sensors, Dampers etc.
- Industrial: Lifting apparatus, Robotics, Meters etc.
- Astro and aerospace: Auto-compass, Couplings, Instrumentation etc.
- Biosurgical: NMR/MRI body scanner, Wound Closures etc.

HARD AND SOFT MAGNETIC MATERIALS

HARD MAGNETIC MATERIALS

Examples:

- Steel:
  - Carbon steel have large hysteresis loop. It is used in making magnets for toys and in certain types of measuring meters. Due to any shock or vibration, they lose their magnetic properties rapidly.
  - Tungsten steel, chromium steel and cobalt steel have high energy product.

- Alnico: It is made up of aluminium, nickel and cobalt. Alnico 5 is the most important material used to create permanent magnet. It is used in high temperature operation

HARD AND SOFT MAGNETIC MATERIALS

HARD MAGNETIC MATERIALS

Examples:

- Rare-Earth Alloys: $SmCo_5$, Sm_2Co_{17}, NdFeB etc.
- Hard Ferrites or Ceramic magnets (like Barium Ferrites): These materials can be powdered and used as a binder in plastics. The plastics made by this method are called plastic magnet.
- Bonded Magnets: It is used in DC motors, Stepper motors etc.
- Nano crystalline hard magnet (Nd-Fe-B Alloys): The small size and weight of these material make it suitable for use in medical devices, thin motors etc.

HARD AND SOFT MAGNETIC MATERIALS

COMPARISON

Hard Magnetic Material	Soft Magnetic Material
Have **large hysteresis** loss.	Have **low hysteresis** loss.
Coercivity & Retentivity are **large.**	Coercivity & Retentivity are **small**.
Cannot be easily magnetized & demagnetized	**Can be easily** magnetized & demagnetized.
Magneto static energy is **large**.	Magneto static energy is **small**.
Have **small values** of permeability and susceptibility	Have **large values** of susceptibility and permeability.
Used to make **permanent magnets.**	Used to make **electromagnets**.
Eg: Iron-nickel-aluminum alloys, copper-nickle-iron alloys, copper–nickel– cobalt alloys	Eg: Iron- silicon alloys, ferrous-nickel alloys, ferrites, garnets.
Which **retain their magnetism** even after the removal of the field	These materials **lost their magnetism** after the removal of the load
Domain wall movement is difficult due to the presence of impurities and crystal imperfections	Domain wall movement is easy

FERRITES

- Ferrites are compounds of iron oxides with oxides of other metal.
- A ferrite is a type of ceramic compound composed of iron(III) oxide (Fe_2O_3) combined chemically with one or more additional metallic elements.
- They are both electrically nonconductive and ferrimagnetic, meaning they can be magnetized or attracted to a magnet.
- Based on their magnetic coercivity and resistance to being demagnetized, ferrites are of two types; soft and hard ferrites
- Hard ferrites have high coercivity, hence they are difficult to demagnetize. They are used to make permanent magnets, for devices such as refrigerator magnets, loudspeakers and small electric motors.

FERRITES

- Soft ferrites have low coercivity. They are used in the electronics industry to make ferrite cores for inductors and transformers, and in various microwave components.

- Ferrite compounds have extremely low cost, being made of iron oxide (i.e. rusted iron), and also have excellent corrosion resistance.

- They are very stable and difficult to demagnetize, and can be made with both high and low coercive forces.

- It is used for high frequency applications.

FERRITES

- Mechanically, they have pure iron character.
- They have low tensile strength and are brittle.
- Ferrites can also be used in the design of ferromagnetic amplifiers of microwave signals.

FERRITES

Properties

- Hard
- Brittle
- Iron-containing
- Polycrystalline
- High electrical resistivity
- Low electrical losses
- Significant saturation magnetization
- Very good chemical stability
- Generally grey or black

FERRITES

CLASSIFICATION:

❑ **Soft ferrites**

- Soft ferrite does not retain significant magnetization.
- They have a low coercivity
- Used in transformers or electromagnetic cores and contain nickel, zinc, or manganese compounds.
- Manganese-zinc ferrites (MnZn) have higher permeability and saturation.
- Nickel-zinc ferrites (NiZn) exhibit higher resistivity than MnZn, and are therefore more suitable for frequencies above 1 MHz.

FERRITES

CLASSIFICATION:

- **Hard ferrites**

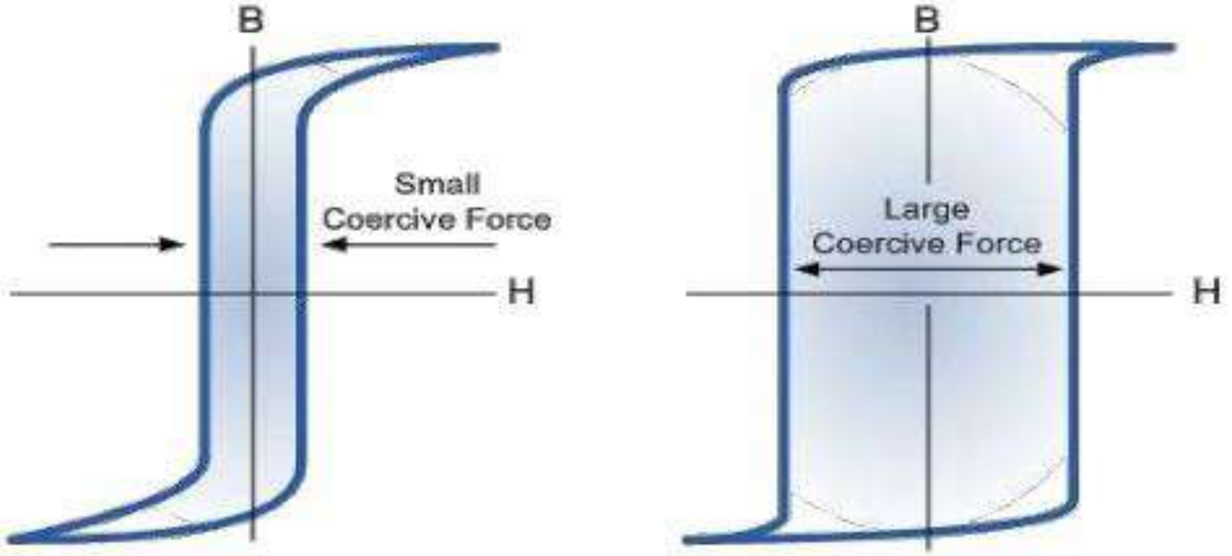
- In hard ferrites, magnetization is considered permanent.
- Have high coercivity.
- Iron oxide and barium or strontium carbonate are used in manufacturing of hard ferrite magnets
- Strontium ferrite, $SrFe_{12}O_{19}$ ($SrO \cdot 6Fe_2O_3$), used in small electric motors, micro-wave devices, recording media, magneto-optic media, telecommunication and electronic industry.
- Barium ferrites, $BaFe_{12}O_{19}$ ($BaO \cdot 6Fe_2O_3$), are robust ceramics that are generally stable to moisture and corrosion-resistant. They are used in loudspeaker magnets and as a medium for magnetic recording, e.g. on magnetic stripe cards.
- Cobalt ferrite, $CoFe_2O_4$ ($CoO \cdot Fe_2O_3$), used in some media for magnetic recording

FERRITES

CHARACTERISTICS:

Soft ferrites Low Coercivity means the material's magnetization can easily reverse direction without dissipating much energy (hysteresis losses), while high resistivity prevents eddy currents in the core.

Hard ferrites High Coercivity means the materials are very resistant to becoming demagnetized, as in Permanent Magnet. Due to high magnetic permeability , these are called ***Ceramic magnets*** .



"Soft" Ferromagnetic Material

"Hard" Ferromagnetic Material

FERRITES

APPLICATIONS

- Ferrites have importance in engineering and technology since they possess spontaneous magnetic moment below the Curie temperature just as iron, cobalt, nickel.
- Due to vey low eddy current losses, ferrites are used as a core of coils in microwave frequency(high frequency) devices and computer memory core elements.
- Due to relatively low permeability and flux density compared to iron, ferrites are not suitable for the use in high field and high power applications, such as motors, generators and power transformers, but they can be used in low field and low power applications.

FERRITES

APPLICATIONS

- Ferrites are used as ferromagnetic insulators in electrical circuits.

- Ferrites like ZnO find low frequency applications in timers. They are also used as switches in refrigerators, air conditioners, etc.

- Ferrites are used as magnetic head transducer in recording.

- Power transformer and chokes: HF Power supplies and lighting ballasts

- Inductors and tuned transformers: Frequency selective circuits

- Pulse and wideband transformers: Matching devices

- Magnetic deflection structures: TV sets and monitors

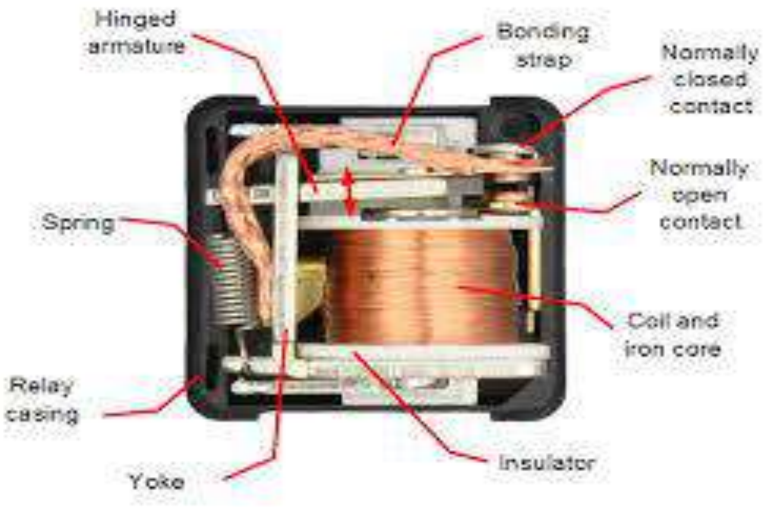
FERRITES

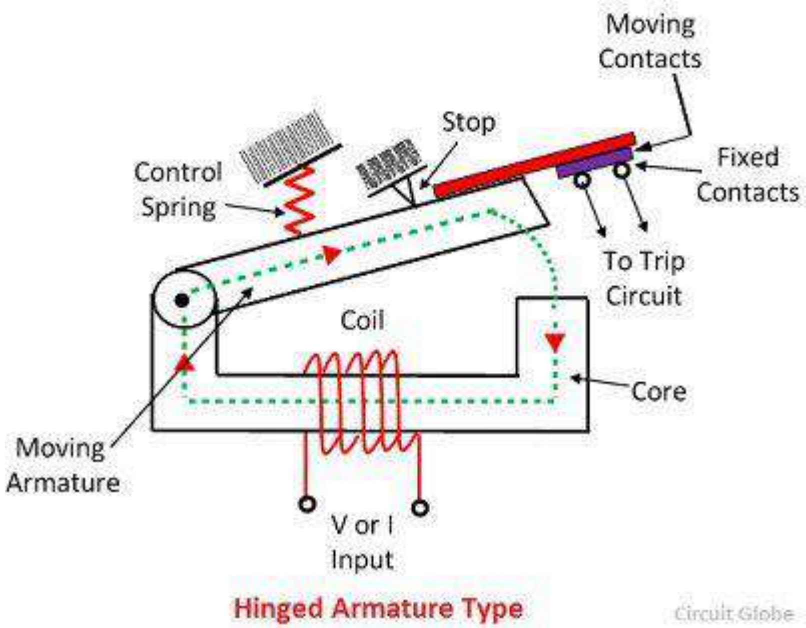
APPLICATIONS

- Recording heads: Storage devices
- Rotating transformers: VCR’s
- Shield beads and chokes: Interference suppression
- Transducers: Vending machines and ultrasonic cleaners
- Catalysis: high surface area, controlled crystal surfaces
- Optical properties: sun screen, hyper thermic cancer treatment, Fluorescent tags
- Light scattering: smoke/fog screens

MAGNETIC MATERIALS USED IN RELAYS

- A relay is an electrically operated switch.
- A simple electromagnetic relay consists of a coil of wire surrounding a soft iron core, an iron yoke which provides a low reluctance path for magnetic flux, a movable iron armature and one or more set of contacts.
- When an electric current is passed through the coil, it generates a magnetic field, that attracts the armature and movement of the movable contact either makes or breaks a connection.





MAGNETIC MATERIALS USED IN RELAYS

The magnetic materials used in relays are:

- **Ceramic Magnets**:
  - Ceramic magnets are composed of Strontium or Barium Ferrite and a ceramic base material.
  - Ceramic magnets are hard and brittle.
  - Advantages; 1) They are the least expensive magnets. 2) They are very resistant to corrosion. 3) They are stable up to approximately 300°C.

- **Alnico Types:**
  - Alnico magnets are made of alloys of Aluminum, Nickel and Cobalt.
  - Inexpensive.
  - They are stable up to very high temperatures (550°C).
  - They are very resistant to corrosion.

MAGNETIC MATERIALS USED IN RELAYS

- **Samarium - Cobalt family**
  - There are two compositions of Samarium - Cobalt magnets. They are Sm_1Co_5 and Sm_2Co_{17}.
  - The excellent temperature stability can be increased by doping Gadolinium.
  - These are stable at high temperatures
  - But they are expensive

MAGNETIC MATERIALS USED ELECTRICAL MACHINES

- **Iron-silicon alloy** material called **silicon steel** developed for relatively strong alternating magnetic fields are generally used in transformers, electrical rotating machines, reactors, electromagnets and relays.
- Silicon sharply increases the electrical resistivity of iron, thus decreasing the iron losses due to eddy currents.
- It increases the permeability at low and moderate flux densities but decreases it at high densities.
- Addition of silicon to iron reduces the hysteresis loss.
- The magnetostriction effect is also reduced

MAGNETIC MATERIALS USED ELECTRICAL MACHINES

- In the past, **iron** used as the core material in the form of sheets caused gradual deterioration of the material due to repeated heating and cooling. This difficulty was overcome by using silicon sheet steel as core material.

- High frequency power transformers operating at 10 to 100 kHz, pulse transformers up to 100' MHz, recording heads, etc.. make use of cores made of soft ferrites.

- **Alnico** magnets find applications in microwave devices, motors, generators, vending machines and communication devices