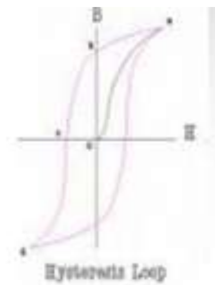
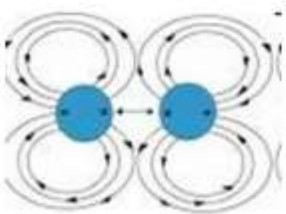
CHAPTER-6



MAGNETIC MATERIALS



TOPICS TO BE COVERED

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- 6.1 Introduction - ferromagnetic materials, permeability, B-H curve, magnetic saturation, hysteresis loop including coercive force and residual magnetism, concept of eddy current and hysteresis loss, Curie temperature, magnetostriction effect.
- 6.2 Soft Magnetic Materials:
- 6.2.1 Alloyed steels with silicon: High silicon, alloy steel for transformers, low silicon alloy steel for electric rotating machines
- 6.2.2 Cold rolled grain oriented steels for transformer, Non-oriented steels for rotating machine
- 6.2.3 Nickel-iron alloys
- 6.2.4 Soft Ferrites

TOPICS TO BE COVERED

- 6.3 Hard magnetic materials
- Tungsten steel, chrome steel, hard ferrites and cobalt steel, their applications

Magnetic material

- Which can be magnetized easily
- Which are attracted by a magnet
- Which respond to the external magnetic field
- Ex- Iron, cobalt, nickel, aluminium
- Such materials when magnetized create a magnetic field in the surrounding space.
- Used in making magnetic circuits of electrical machines, relays and other instruments

MAGNET: A DEVICE THAT ATTRACTS IRON AND PRODUCES A MAGNETIC FIELD

MANY OF OUR MODERN TECHNOLOGICAL DEVICES RELAY ON MAGNETISM AND MAGNETIC MATERIALS

POWER GENERATORS, TRANSFORMERS, ELECTRIC MOTORS, RADIO, TELEVISION, TELEPHONES, COMPUTERS & COMPONENTS OF SOUND & VIDEO REPRODUCTION SYSTEMS.

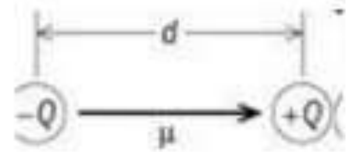
Concept

- Materials-made up of atoms-nucleus and extra nucleus-nucleus-protons and neutrons-electrons revolve around the nucleus in orbits-current flow in electrons-rotation of electrons constitute circulating current-this circulating current constitute emf and mmf in the coil-magnetic property depends upon the spin movements of electrons-if more electrons spin in one direction they exhibit some magnetic property

- Terms connected with magnetic materials :

  - Magnetic force
  - Magnetic flux density
  - Magnetic field strength
  - Relative permeability
  - Absolute permeability
  - Remanance
  - Retentivity
  - Curie temperature (T_c)
  - Hysteresis loop & losses

Magnetic dipole: The two equal and opposite magnetic poles are separated by a small distance.



Magnetic dipole moment: Product of pole strength and length of the magnet.

$$\boxed{\mu_m = ml}$$

Magnetic Induction (or) magnetic flux density (B): It represents the magnitude of the internal field strength within a substance that is subjected to an H field.

Magnetic field Intensity (H):

Ratio between the magnetic induction and the permeability of the medium *i.e.*

$$H = \frac{B}{\mu} \text{ ampere } m^{-1}$$

Magnetic Permeability (μ):

Ratio of the magnetic induction to the applied magnetic field intensity

$$\mu = \frac{B}{H} \textit{henry } m^{-1}$$

Magnetic Susceptibility (χ): Ratio between the ntensity of magnetization to the applied nagnetic field intensity

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

Intensity of Magnetization*(I or M)* :

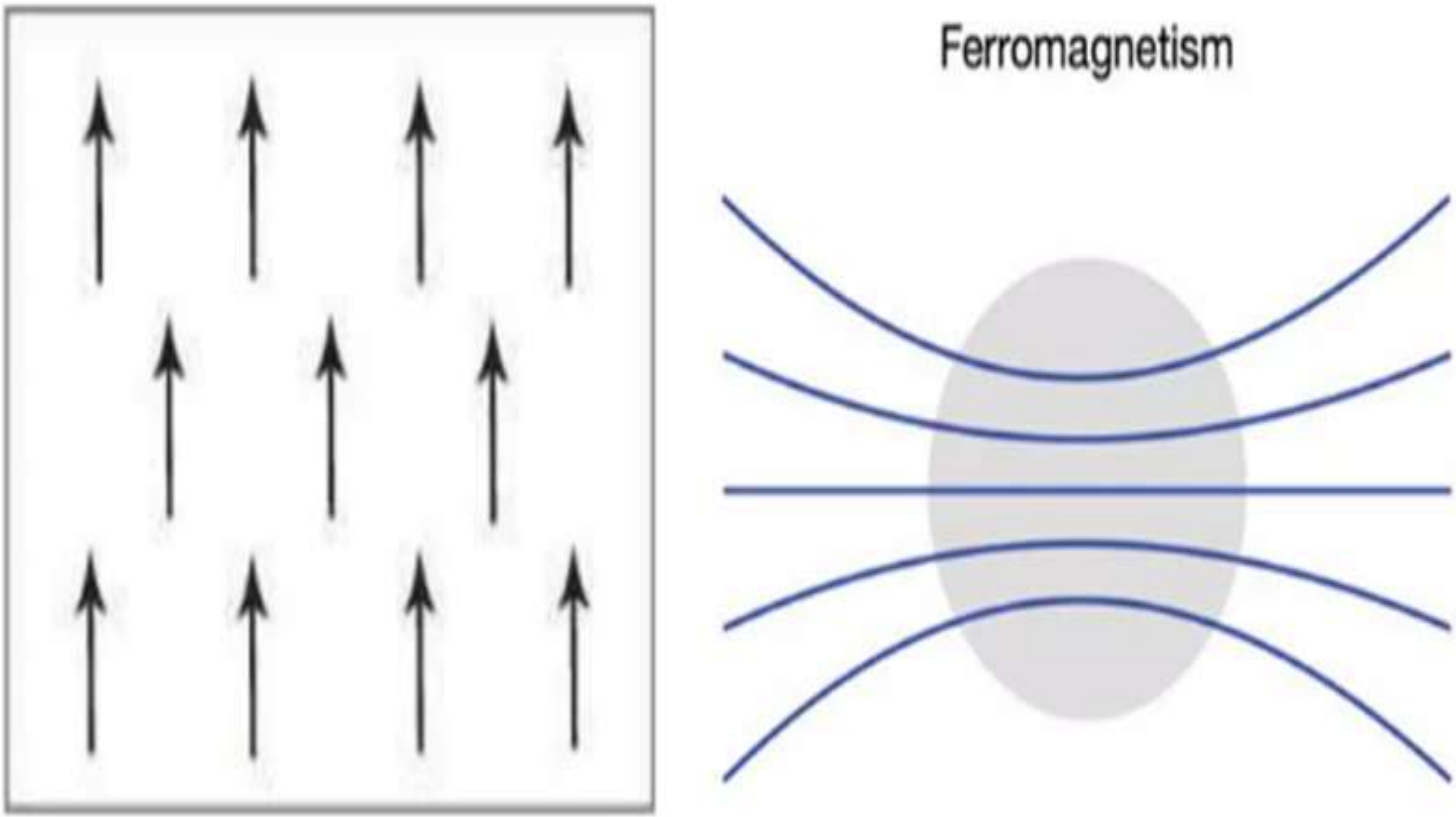
- The process of converting a non magnetic material into a magnetic material.

- Magnetic moment per unit volume.. Unit- A/m

- Classification :
  - Ferromagnetic
  - Paramagnetic
  - Diamagnetic
  - Magnetically Soft material
  - Magnetically Hard material

Ferromagnetic materials

- Those materials which when placed in magnetic field become strongly magnetised in the direction and of applied field.
- They attract the lines of force strongly.
- The relative permeability (μ_r) is much greater than unity and dependent on field strength.
- These materials are attracted by a magnet.
- Have high Susceptibility
- Ex-iron, nickel, steel, cobalt etc

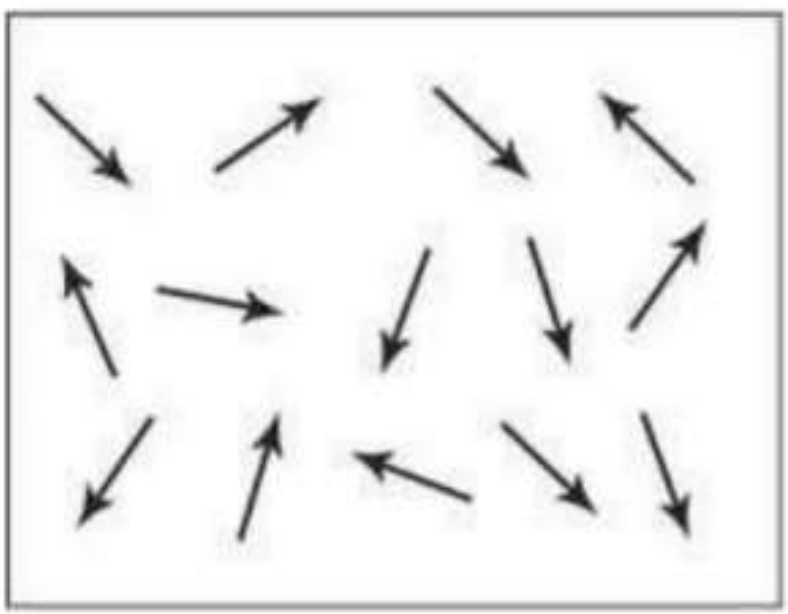

Ferromagnetism

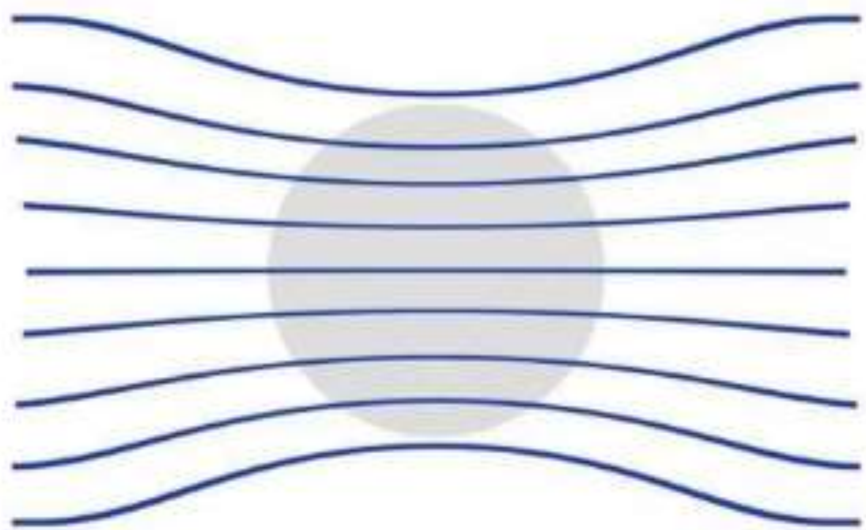
Paramagnetic material

- Those materials which when placed in magnetic field become slightly magnetised in the direction of applied field.
- They attract the lines of force weakly.
- The relative permeability (μ_r) is slightly greater than unity and are magnetized slightly.
- Ex- Aluminium, platinum , oxygen etc

- Al, Pt, Ca, O_2 are such materials.

Paramagnetism



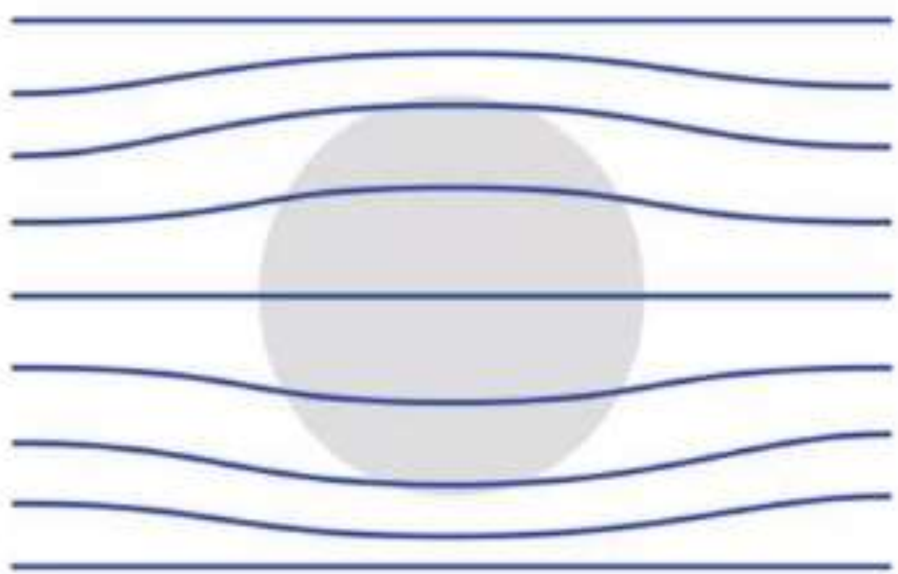


Diamagnetic material

- Those materials which when placed in magnetic field slightly repelled in the magnetic field.
- They repel the lines of force slightly.
- The relative permeability (μ_r) is slightly less than unity and are magnetized slightly.
- Susceptibility is negative
- Ex- Bismuth, Gold,silver, copper,mercury hydrogen etc

- The examples are bismuth silver, copper and hydrogen.

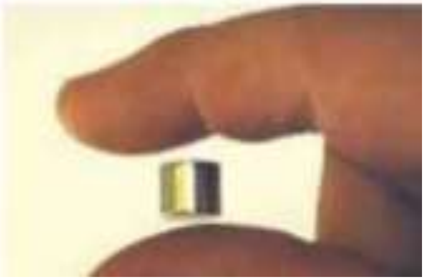
Diamagnetism



• Applications :

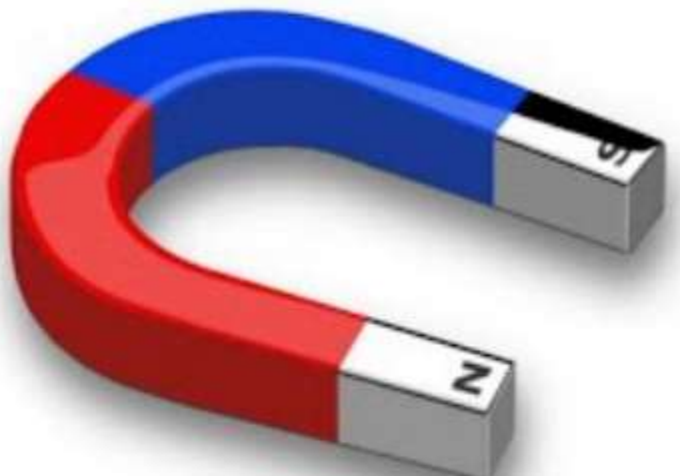
- **Ferromagnetic** materials are used in magnetic recording devices, such as for cassette tapes, floppy discs for computers, and the magnetic stripe on the back of credit cards.

- **Diamagnetic materials** are used for magnetic levitation, where an object will be made to float in are above a strong magnet.



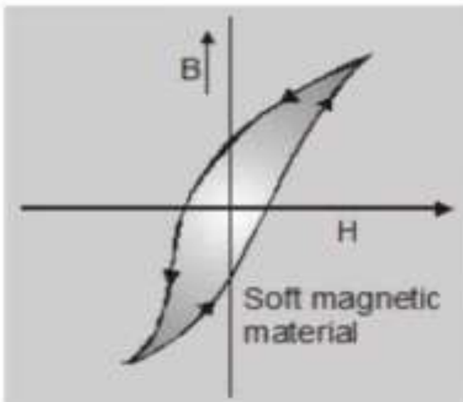
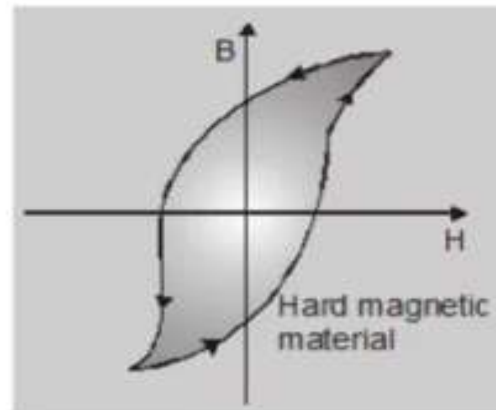
MAGNETIC MATERIAL

HARD



SOFT

Soft Magnetic Material	Hard Magnetic Material
Materials which can be magnetised and demagnetised easily	High magnetizing force is required to magnetise and demagnetise
Have high permeability (μ)	Have low permeability (μ)
Small area of Hysteresis loop and low hysteresis loss, Low coercive force, Low retentivity	Large area of Hysteresis loop and more hysteresis loss, High coercive force (coercivity), High retentivity
Ex- wrought iron, silicon steel, nickel iron alloys and soft ferrites	Ex- chrome steel, tungsten steel, cobalt steel, alnico, hard ferrites
They operate at high frequency	They operate at low frequency

SOFT AND HARD MAGNETIC MATERIALS	
Soft Magnetic Material	**Hard Magnetic Material**
(1) These materials have low retentivity, low coercivity, small hysteresis loss and high saturation magnetisation	These materials have high retentivity, high coercivity, large hystersis loss and high saturation magnetisation
	
(2) These are suitable for temporary magnetism. e.g. Soft iron for making electromagnets, cores of transformers, motors, generators mu-metal for audio coils, magnetic shielding Stalloy for pulse transformers, magnetic amplifiers.	These are suitable for permanent magnetism. eg. Steel, Alnico, Alcomax and Ticonal are used in making different types of permanent magnets, electric meters and loudspeakers

- **Magnetic soft materials** are used in making electromagnets and these electromagnets are used in telephone receiver, bells, loud speakers etc.

- **Magnetic hard materials** are used in making permanent magnets.

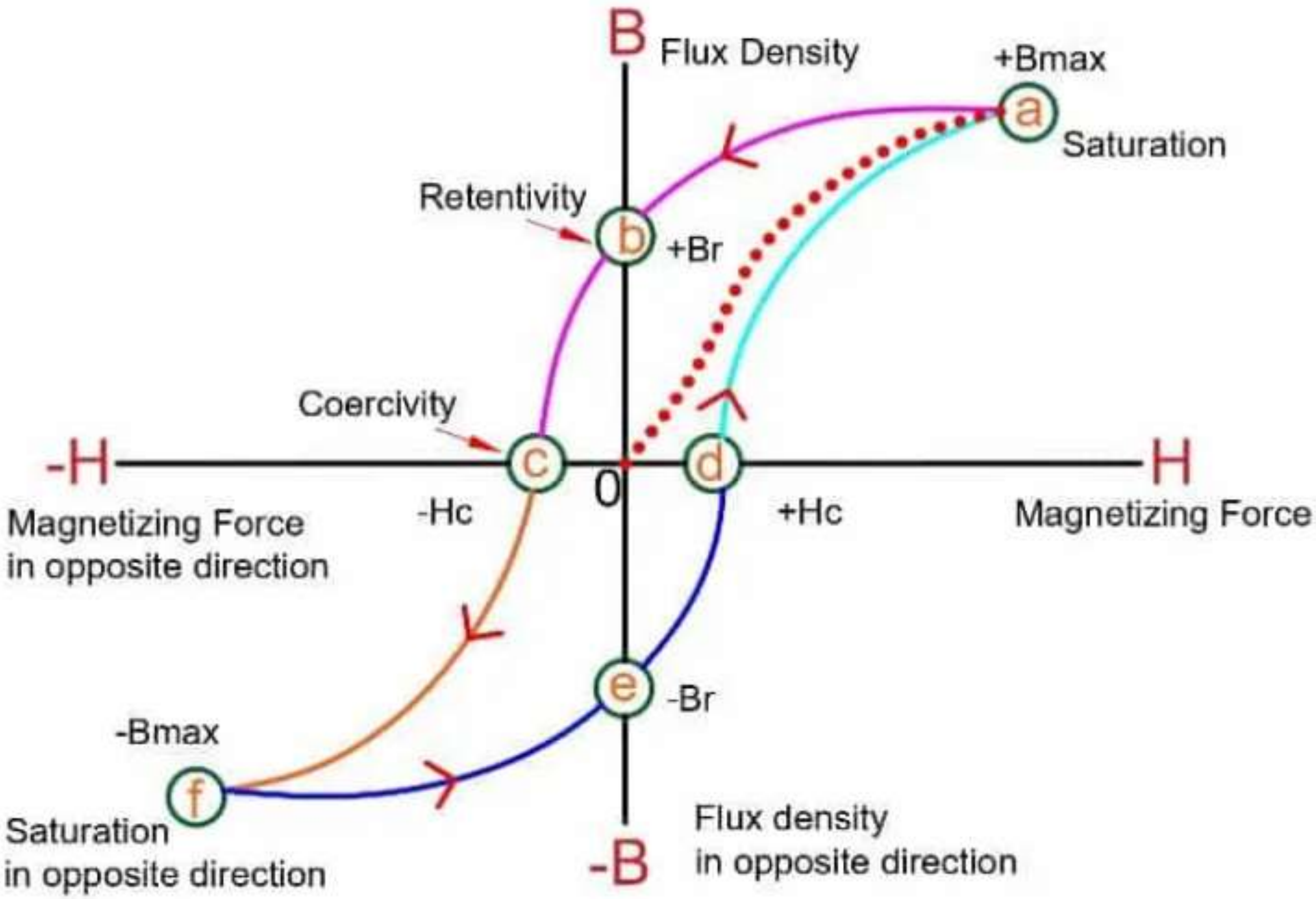
Hysteresis loop

- It is the graph between magnetic flux density (B) and Intensity of Magnetisation (H)
- When a magnetic material is subjected to a complete cycle of magnetisation and demagnetisation , flux density B is plotted against magnetising force (H) which results in hysteresis loop

Hysteresis loop

- The energy required in taking the material through one complete cycle of magnetisation and demagnetisation is proportional of the area enclosed by the hysteresis loop or magnetisation curve

Hysteresis loop



Magnetic saturation

- It starts from 0 ,
- When the field strength or magnetising force (H) ↑ flux density B ↑ (0 to a)
- At ‘a’ saturation of magnetic materials takes place, curve becomes horizontal, no further increase in B with further increase in H
- This is magnetic saturation

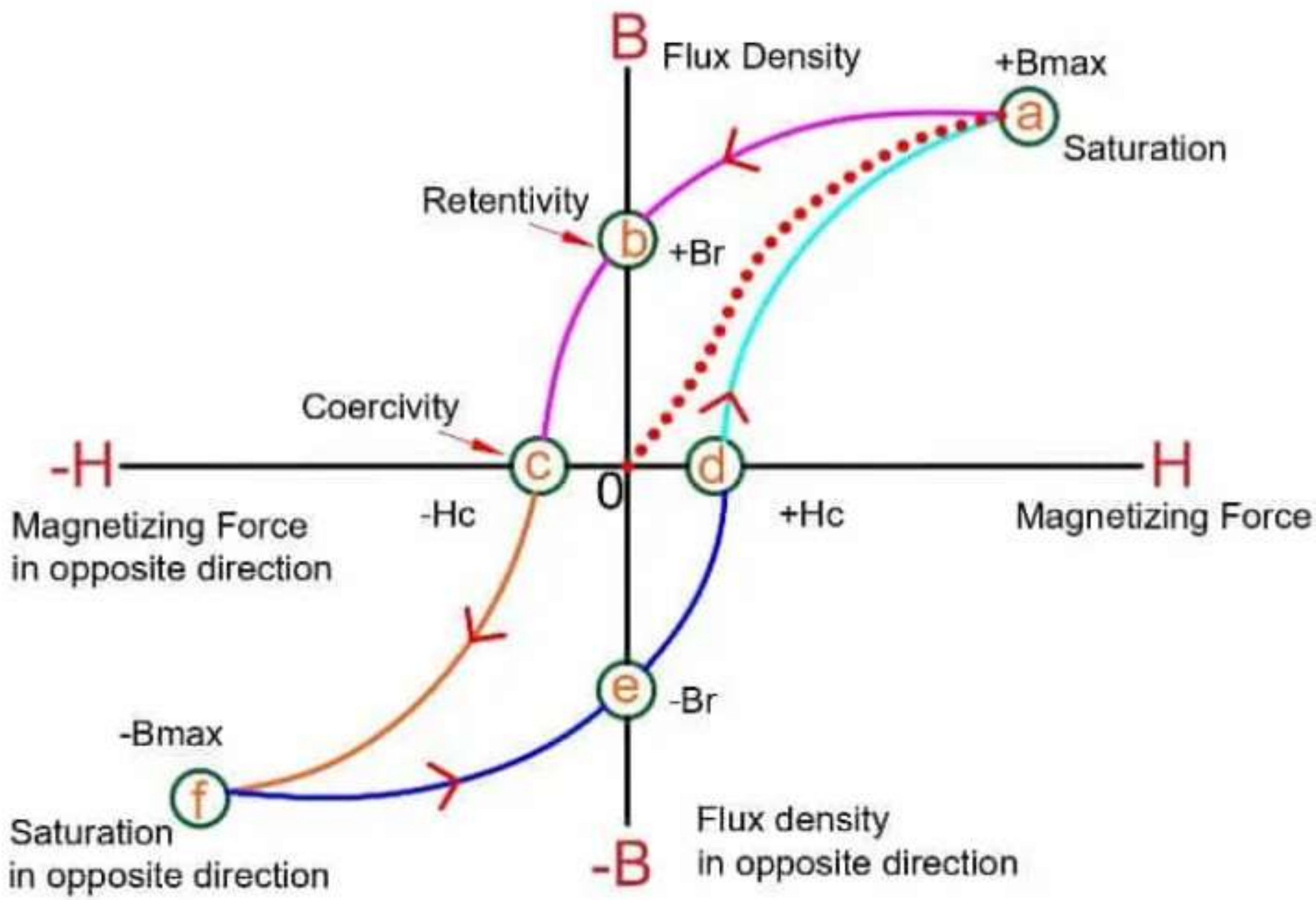
Residual magnetism

- It starts from a
- When the field strength or magnetising force (H) ↓ same path ‘0a’ is not retraced but curve takes new path ‘ab’
- At ‘b’ H is 0, but still B is present in the material , this Br is called residual magnetism

Coercive force

- To make this Br to 0, magnetic field is applied in reverse direction i.e 0 to c
- At ‘c’ , Br becomes 0
- This field which is applied in reverse direction to make residual magnetism zero is called coercive force (Hc)

Hysteresis loop



Hysteresis loop

- After ‘c’ , it is increased in reverse direction then B also increases negatively
- ‘f’ is obtained when B is max in opp direction
- In this way curve is completed through ‘feda’ and cycle is completed
- Loop abcfeda is called hysteresis loop
- It represents energy loss during the complete cycle called hysteresis loss

Hysteresis loss

- When magnetic material is subjected to alternating field, energy is spent in its magnetisation and demagnetisation
- If the magnetisation is carried through a complete cycle, energy loss is proportional to the area of the hysteresis loop
- Shape of hysteresis loop depends upon the nature of the magnetic material i.e. iron or steel
- It is proportional to

1. area enclosed in hysteresis loop
2. Frequency of alternating current
3. On the material

Magnetostriction effect

- The small change in the dimension of ferromagnetic material takes place on the application of magnetic field . This is called Magnetostriction
- The change is due to rapid and continuous expansion and contraction of materials leading to changes in interatomic distances
- This process is not reversible
- This is the major cause of hum in transformers and chokes

Eddy current loss

- When ac is applied to a circuit having magnetic core, due to change in magnetic flux linkage , emf is induced in it, which causes eddy currents to circulate in the core material.
- These eddy currents are undesirable and so referred as eddy current loss (produce heating effect)
- In AC circuits the eddy currents will be flowing continuously in alternate directions

How to reduce eddy current loss

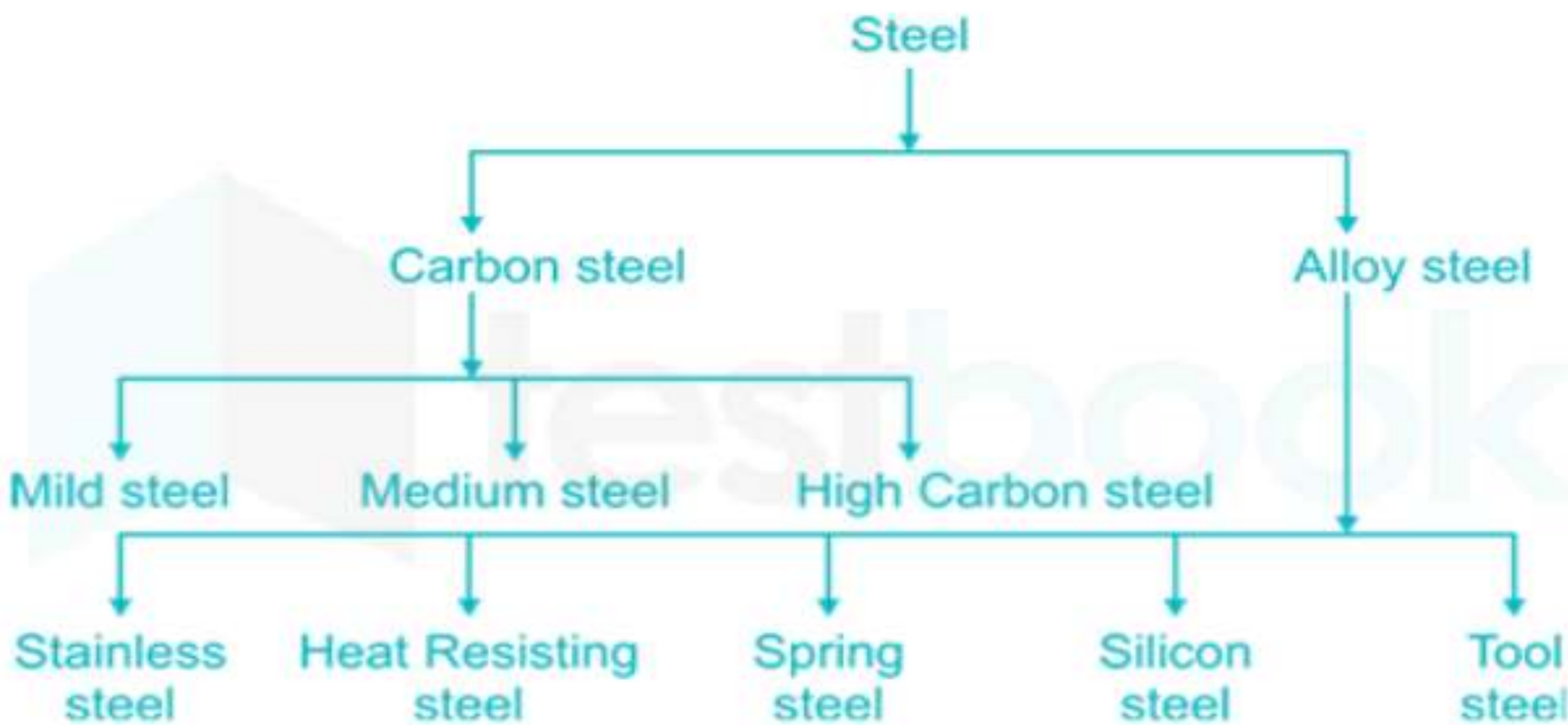
1. Using thin sheets of laminations of steel instead of single solid core
2. eddy current is proportional to f^2 so if f is low then losses will be less

Soft magnetic materials

Alloyed steel with carbon

Steel is basically an alloy of iron and carbon in which the carbon content can be less than 1.7 % and carbon is present in the form of iron carbide to impart hardness and strength.

Two main categories of steel are (a) Plain carbon steel and (b) alloy steel.



Steels in which carbon is the prime alloying element are termed plain carbon steels, whereas alloy steels contain appreciable concentrations of other elements. Alloying materials like chromium, nickel, molybdenum, copper, aluminium, sulphur etc. are added to improve the properties of steel.

Silicon steel

- **Si-steel/ Soft iron/ Fe-Si alloy**
- Iron -95% , silicon =5%
- When 5% Si is added, permeability increases and reduces the area of hysteresis loop (low hysteresis losses), decreases eddy current losses, increases hardness
- It is used for making cores of transformers, poles of motors and generators

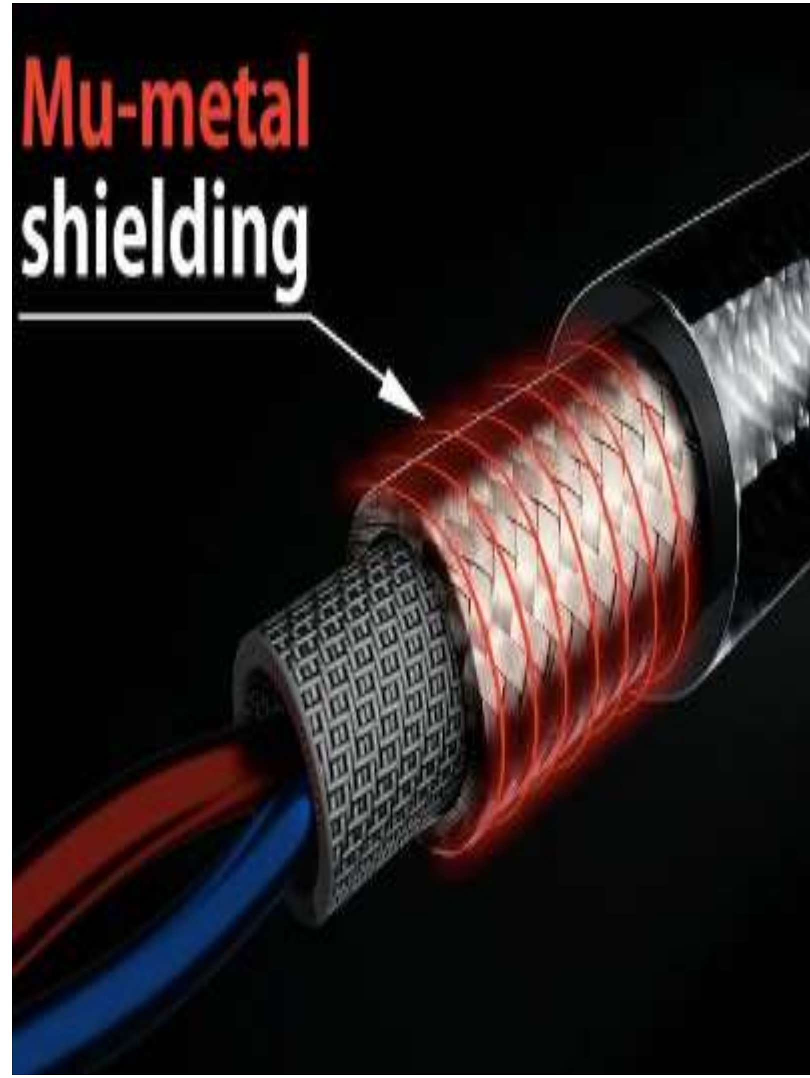
Ni-iron alloys

- Iron allys containing nickel between 30-80% with addition of molybdenum and chromium
- High permeability
- Ex- Mu-metal , permalloy, supermalloy

Mu-metal

- Composition- Fe-17%, Ni-75%,Cu-5%, Cr-3%
- It is annealed in pure hydrogen at 110ºC and then is slowly cooled
- High magnetic permeability
- Negligible hysteresis losses
- Low coercivity
- Used for making transformer core
- For making instrument transformers (CT/PT)
- Used as a magnetic shield in electronic equipments

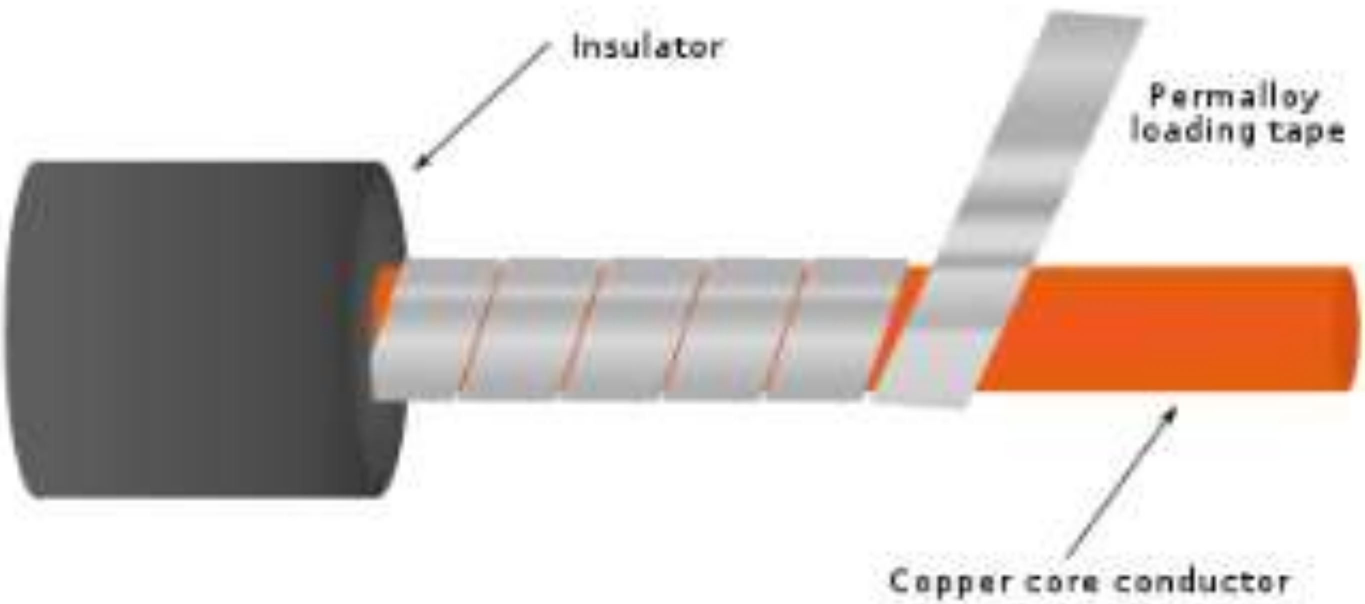
- Cu or silver meshed shield, not enough protection from magnetic noise.
- Copper or silver protect well against electric noise, but very poorly against magnetic one,
- Only Mu-metal protect audio signal from both electro-magnetic noise.



Permalloy

- Composition- Fe-52%, Ni-45%,with small quantities of Cu, Cr, Co , Mn
- low coercivity, near zero magnetostriction
- very high magnetic permeability, which makes it useful as a magnetic core material in electrical and electronic equipment
- Used in loading coils of transmission cables
- Used in submarine cables
- used in transformer laminations and magnetic recording heads.

Permalloy



Submarine telegraph cable wrapped with permalloy tape.

Supermalloy

- Composition- Fe-20%, Ni-75%, Mb and Cu-5%
- extremely high relative magnetic permeability
- low coercivity.
- Used in manufacturing components for radio engineering, telephony, and telemechanics instruments.
- Used in magnetic cores and magnetic shielding in electrical components
- Used in pulse transformers and ultra-sensitive magnetic amplifiers

Magnetic Iron

•Fe-99.9 % , rest is carbon
•Pure iron undergoes pacification after melting and then it is solidified.
•Excellent magnetic properties
•low retentivity and coercivity.
•well suited for welding.
Gaskets in the chemical and petrochemical industries
Magnetic shielding
Welding rods and fuse wire
Relays, solenoids core , magnetic pole pieces for scientific instruments and electronic apparatus

Cast Iron

•Composition-Fe, carbon content is 2-4 %
•Cast iron is made by reducing Iron Ore in a Blast Furnace.
•Cheaper than steel
•Brittle , good ductility, excellent machinability
•Poor magnetic properties
•It is used in frames of DC m/cs
•It is used for electrical fittings and equipment, hand tools, pipe fittings, washers, brackets, farm equipment, mining hardware, and machine parts.

Carbon steel

- Composition -steel with carbon content 0.05 - to 2 % by weight
- As the carbon percentage content rises, steel has the ability to become harder and stronger
- less ductile, less weldability
- Low carbon steel is usually made into flat-rolled sheets and strips, used for shipbuilding, wire, vehicle bodies and domestic appliances.

Sand dust

- Composition- Fe-85%, Ni-10%, Al=5%
- Also known as magnetic sand
- High magnetic permeability
- low coercivity.

Soft Ferrites

- Composition-Basically iron oxides (Fe2o3) form with small percentage of divalent oxides(like Mno2)
- Made by mixing powdered oxides , compacting and then sintering at high temperature.
- Also known as ceramic magnets

Properties of Soft Ferrites

- High permeability
- Low coercive force
- Much higher high resistivity of the order of 10^9 Ω-cm
- Reduced eddy current losses at HF
- Narrow hysteresis loop
- Less hysteresis losses
- Hard and brittle materials
- Poor machinability which cant be shaped by ordinary machining process

Applications of Soft Ferrites

- Used in high frequency equipments such as computer, microwaves etc
- Used in HF transformer of TV & FM receivers
- Used in electromechanical transducers when these are present with large magnetostrictive effects

Grain Orientation

- A magnetic material is composed of magnetic dipoles oriented in random direction such that total magnetisation in any direction is zero
- When a magnetic material is magnetised by applying an external magnetic field ,dipoles start orienting themselves in the direction of applied magnetic field
- Now the material will require less magnetising force
- This process is called <u>GRAIN ORIENTATION</u>
- Adv- require less Im,permeability↑, hysteresis loss ↓

CRGO SILICON STEEL

- COLD ROLLED GRAIN ORIENTED SILICON STEEL
- Made by grain orientation of silicon steel
- Silicon steel is widely used material for making t/f core
- Silicon steel sheet is grain oriented by special method "cold rolling "during the manufacturing process
- Adv- require less Im,permeability↑, hysteresis loss ↓

Applications of CRGO SILICON STEEL

- Used in magnetic cores of large size transformers
- For making Core of transformer either E-I or L type laminations

What will happen if we will use non grain oriented silicon steel??

- Large amount of magnetising force is needed to establish flux in the core
- Core will offer high reluctance that means low permeability

Point to be noted

- CRGO Silicon steel is never used for rotating machines
- Non oriented Silicon steel is used for rotating machines

Hard magnetic materials

TUNGSTEN STEEL

- It is an alloy of iron and tungsten
- Composition- Tungsten 6%, C=0.6% and rest is iron
- High hysteresis loss
- High residual magnetism
- Used for making permanent magnets

CHROME STEEL

- It is an alloy of iron, Mn and chromium
- Composition- chromium=3.5 %, Mn=0.3% and rest is iron
- Very hard & tough
- High electrical resistivity due to which eddy current losses at high frequences reduced
- High hysteresis loss
- Used for making permanent magnets

COBALT STEEL

- It is an alloy of iron, cobalt, Mn and Cr
- Composition- cobalt= 38%,Cr=3 %, Mn=0.3% and rest is iron
- High tensile strength, sufficiently hard and strong
- It is expensive due to greater content of cobalt
- High hysteresis loss
- Used for making permanent magnets
- Used to make meter used in motor applications
- For making hysteresis motor

Hard Ferrites

- Composition-Basically iron oxides (Fe2o3) form with either Barium carbnonates or strontium carbonates
- Made by calcining iron oxides and carbonates and then mixture is ball milledwhich is further formed into suitable shape magnets
- Magnets made are hard and brittle

Properties of Hard Ferrites

- hard and brittle magnets
- High coercive force
- high resistivity
- Low density
- Operate at low frequency

Applications of Hard Ferrites

- Light weight permanent magnets
- In hearing aids and electric clocks
- Used in loudspeakers,
- Microwave ovens
- dc motors
- relays
- Magnetic separator units
- Magnetson tubes
- Holding magnets
- Chip collectors
- Magnets of toys

Soft Ferrites	Hard Ferrites
Composition-Basically iron oxides (Fe2o3) form with small percentage of divalent oxides(like Mno2)	Composition-Basically iron oxides (Fe2o3) form with either Barium carbonates or strontium carbonates
Made by mixing powdered oxides , compacting and then sintering at high temperature.	iron oxides and carbonates are calcined then mixture is ball milled which is further formed into suitable shape magnets

Soft Ferrites	Hard Ferrites
Hard and brittle materials but Poor machinability, low coercive force, high permeability	Hard and brittle materials , low density, high coercive force
Used in high frequency equipments such as computer, microwaves , HF transformer of TV & FM receivers, in electromechanical transducers	Light weight permanent magnets In hearing aids and electric clocks, loudspeakers, Microwave ovens , dc motors, relays Magnetic separator units, Magnetson tubes, Holding magnets, Chip collectors Magnets of toys
They operate at high frequency	They operate at low frequency