Electrical Machines

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Magnetic circuits

DC motor

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Transformers

Synchronous Machines

Servomotors

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AC Machinery

Brushless DC motor

Galina Demidova

DC motor hometask

Dmitry Lukichev

AC hometask

Transformer hometask

Alexander Mamatov

SM hometask

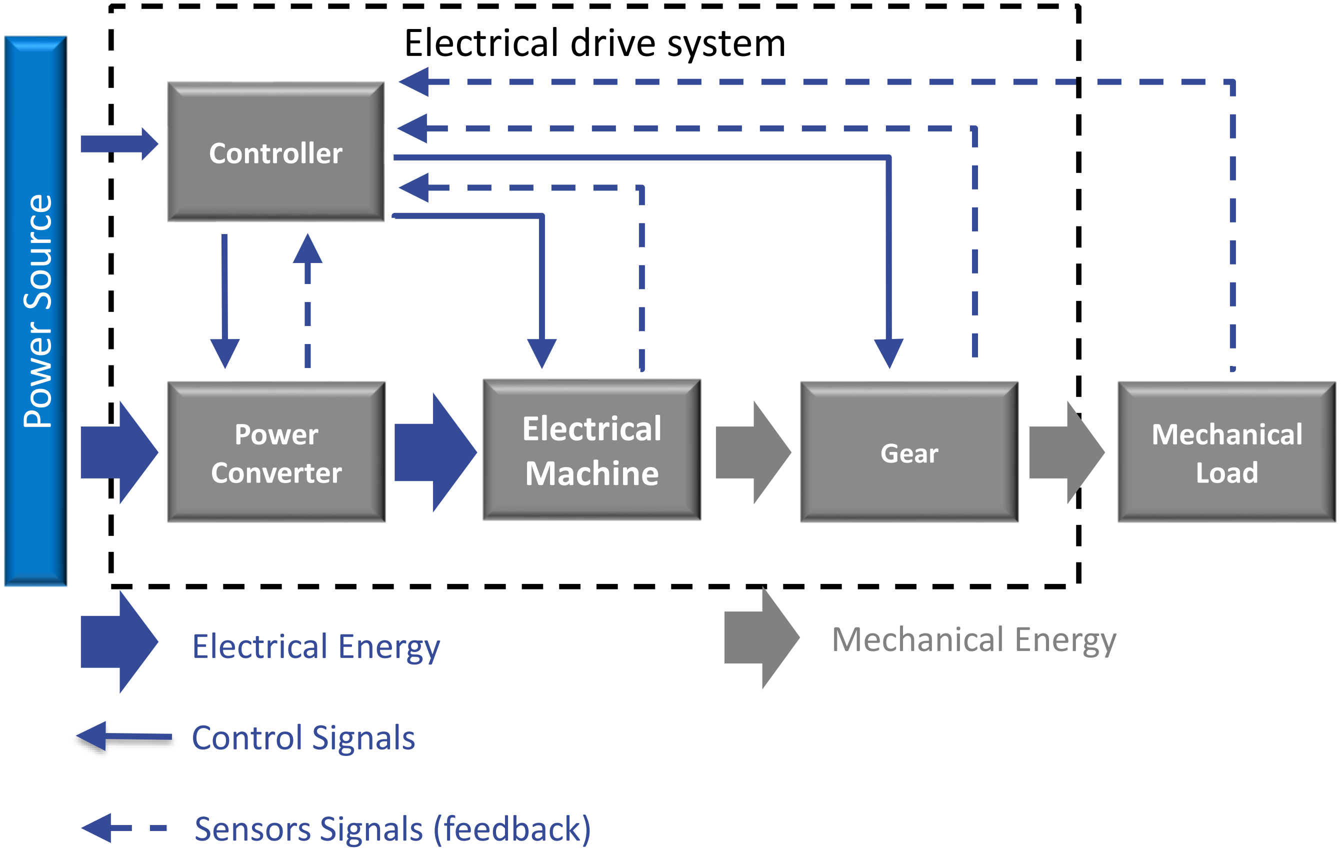
An introduction to electric machines.
Simple magnetic circuits.

COURSE AIMS

- To give an overview about Electrical Machines and their applications in industry, service and everyday life.
- To give basic knowledge in the basic composition of Electrical Machines, components used in these systems and application principles of these systems.
- To give basic knowledge for designing and exploitation of Electrical Machines in the respective field.

LEARNING OUTCOMES

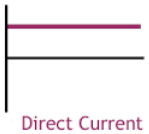
- Knows and orients in main structures of electrical machines and knows respective application areas.
- Knows the main type of electrical machines, their components and orients in respective basic applications.
- Knows and is able to evaluate the characteristics of electrical machines and the role of different knowledge in the design and integration of the components into a whole operational system.


Electrical drive system
Power Source
Controller
Power Converter
Electrical Machine
Gear
Mechanical Load
Electrical Energy
Mechanical Energy
Control Signals
Sensors Signals (feedback)

Electrical Machines

Power type

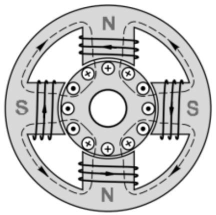
D.C. (direct current)



A.C. (Alternating current)

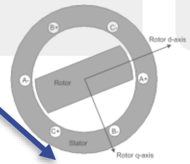
Electric machine type

Direct Current Commutator Machine

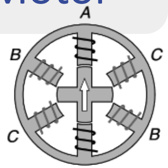


BLDC (Brushless DC motor)

Synchronous Machine

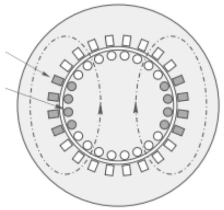


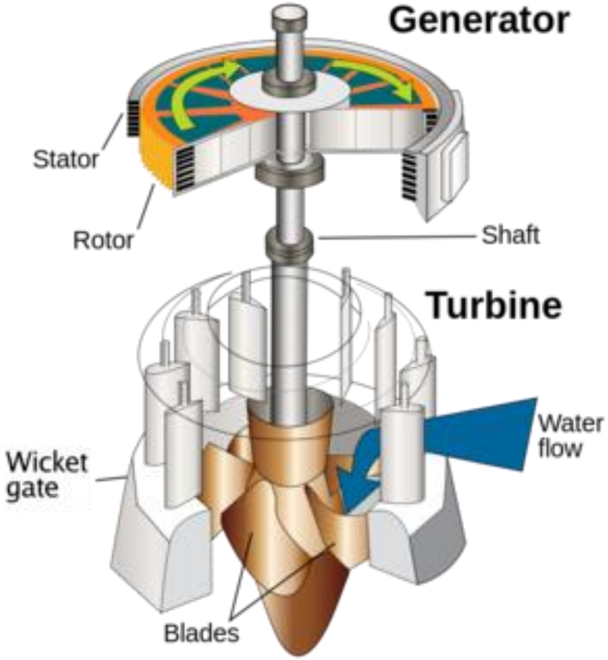
Stepper Motor



PMSM (Permanent Magnet Synchronous Motor)

Induction Machine

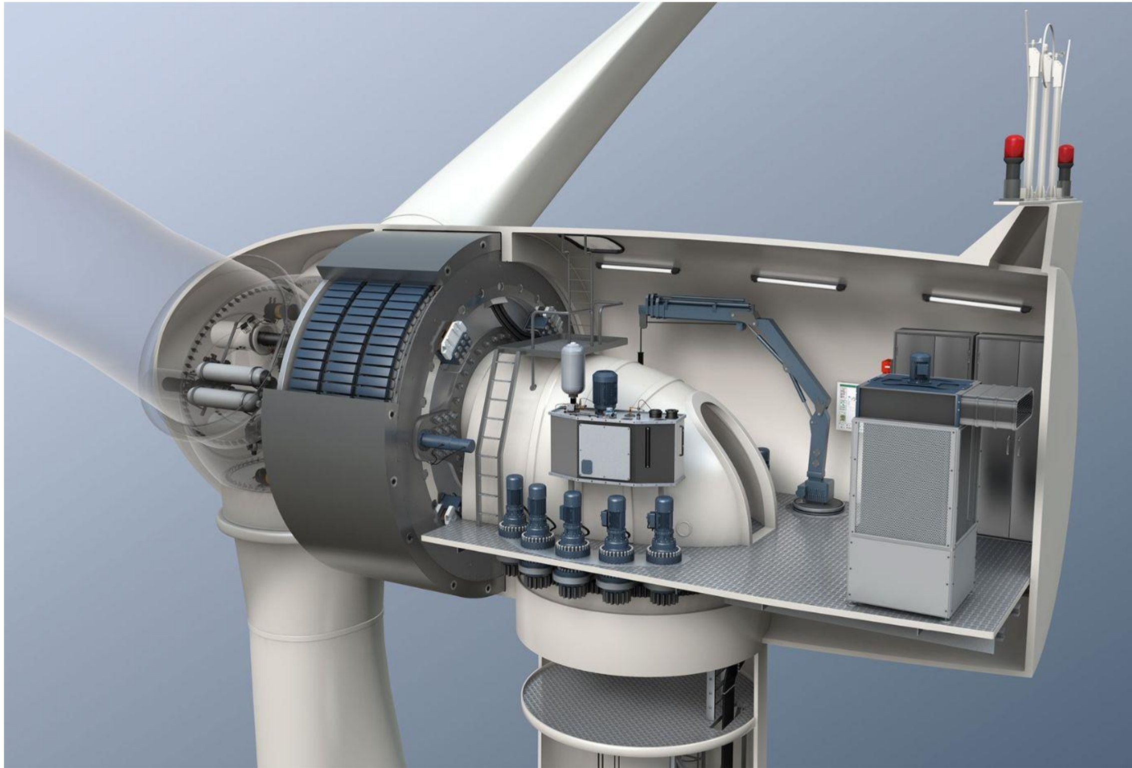



Generator
Stator
Rotor
Shaft
Turbine
Wicket
gate
Water
flow
Blades

AC Electrical Machines

Generators

- ❑ Utility generators
- ❑ Backup generators
- ❑ Wind turbines



AC Electrical Machines

Motors

- ❑ Single phase induction
  - Washing machines
  - Compressor
  - Dryers

  Household use

- ❑ 3-phase induction
  - Cranes
  - Elevators
  - Fire pumps

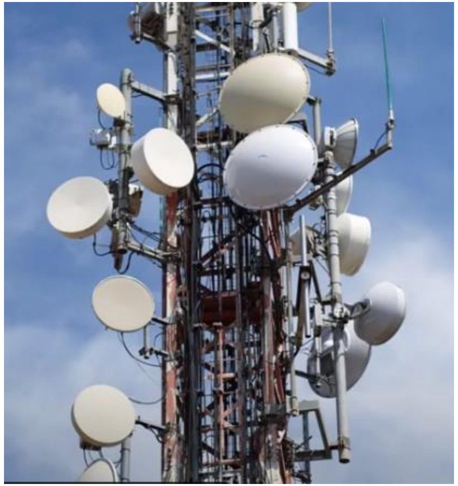
  Industry use

- ❑ Synchronous Motors
  - Servomotors
  - Clocks
  - Synchronous condenser

DC Electrical Machines

Generators

- ❑ Early power systems
- ❑ Standalone systems (cellphone towels)
- ❑ Lift, cranes, trains



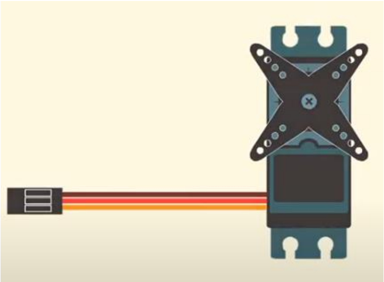
DC Electrical Machines

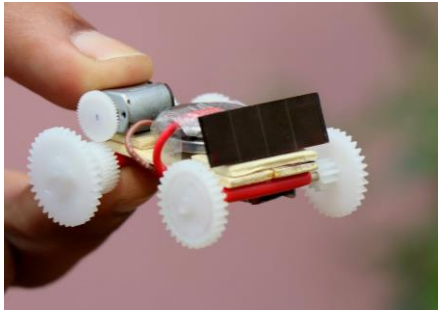
Motors

Toys

Medical equipment

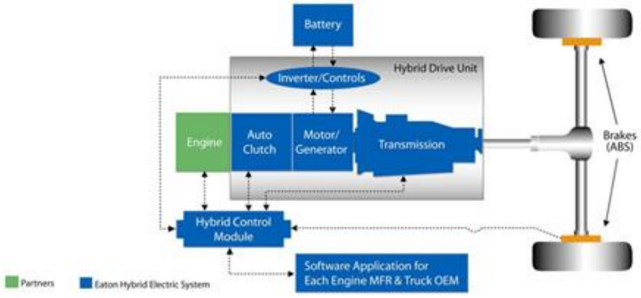
Electric vehicles



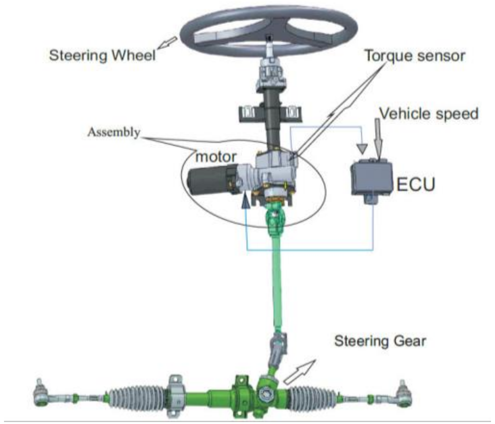


Electric vehicles

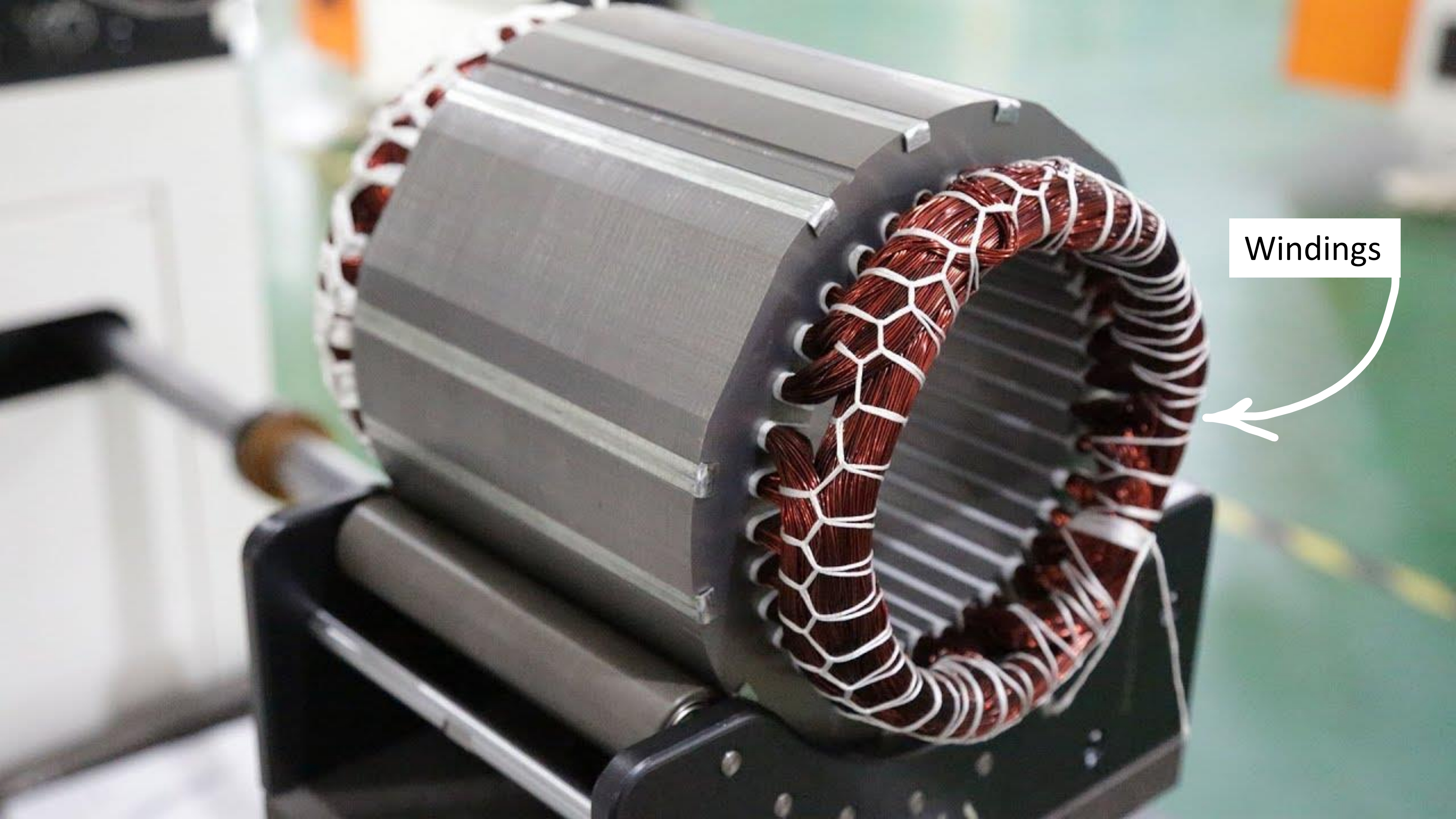
Hybrid electric vehicle drivetrain



Electronic power steering systems



HVAC (Heating, Ventilation And Air conditioning) system


Windings

Windings

copper

aluminum

copper

Advantages

- Stronger than aluminum
- Higher Current carrying capacity
- Transformer with copper winding less expensive
- No Galvanic corrosion
- Smaller winding size
- Easy to repair broken wire connection

Disadvantages

- Expensive
- Less Flexible
- Lesser resources available

Advantages

- Less Cost
- Corrosion resistive
- Conductivity
- More Flexible
- Lower eddy losses

aluminum

Disadvantages

- Susceptible to oxidation at Joints
- Higher Resistivity

Resistivity of Copper is 1.68×10^{-8} Ohm

Resistivity of Aluminum 2.65×10^{-8} Ohm

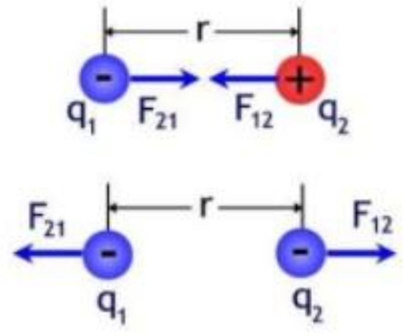
Aluminum/Copper $= (2.65 \times 10^{-8}) / (1.68 \times 10^{-8}) = \mathbf{1.6}$

- Conductivity

- Magnetic materials are those materials in which a state of magnetization can be induced.
- Such materials when magnetized create a magnetic field in the surrounding space.
  - Magnetic materials include the elements
    iron
    nickel
    cobalt

alloys containing some of these such as **steel** and some of their compounds.

Magnetic Field



The force of attraction / repulsion between two magnetic poles is directly proportional to the strength of the poles and inversely proportional to the square of the distance between them

$$F_E = \frac{kq_1q_2}{r^2}$$

Electric field:

1) A distribution of electric charge at rest creates an electric field E in the surrounding space.
2) The electric field exerts a force $\bar{F}_E = q\bar{E}$ on any other charges in presence of that field.

Magnetic field:

1) A moving charge or current creates a magnetic field in the surrounding space (in addition to $\bar{E}$).
2) The magnetic field exerts a force $\bar{F}_m$ on any other moving charge or current present in that field.

The magnetic field is a vector field vector quantity associated with each point in space.

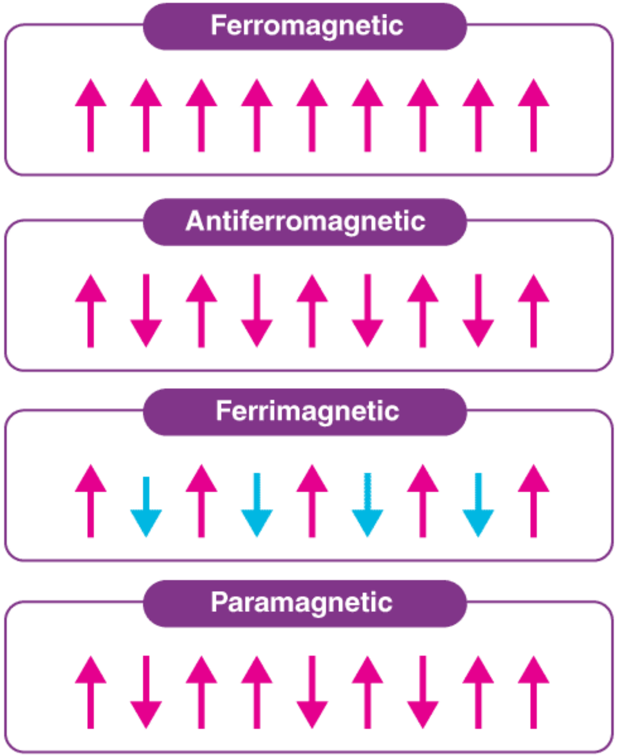
$$\bar{F}_m = |q| v_\perp B = |q| vB \sin\varphi$$

$$\boxed{\bar{F}_m = q\bar{v} \times \bar{B}}$$

$\bar{F}_m$ is always perpendicular to $\bar{B}$ and $\bar{v}$

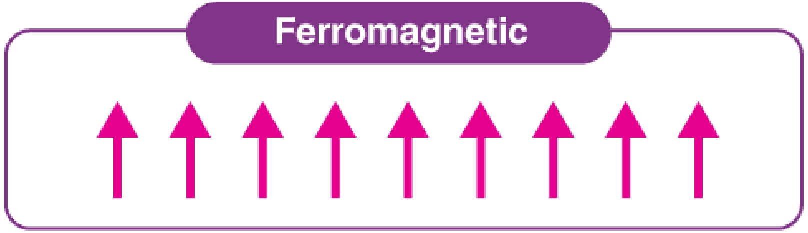
Classification

- ❑ Ferromagnetic
- ❑ Paramagnetic
- ❑ Diamagnetic
- ❑ Magnetically Soft Material
- ❑ Magnetically Hard Material

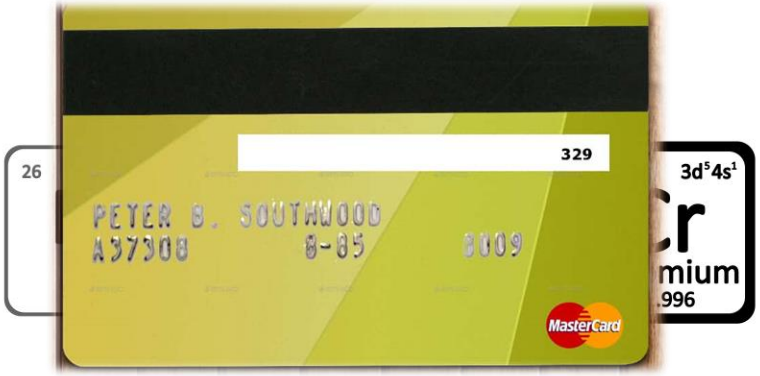


Ferromagnetic

- A type of material that is highly attracted to magnets and can become permanently magnetized is called a ferromagnetic.
- The relative permeability is much greater than unity and are dependent on the field strength
- These have hight susceptibility

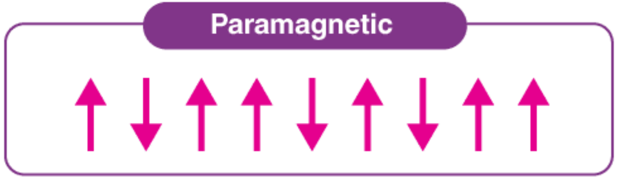


Spins are aligned parallel in magnetic domains

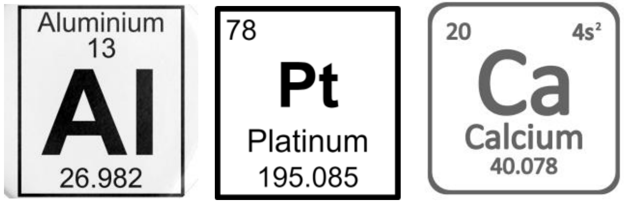


Paramagnetic

- It is a substance or body which very weakly attracted by the poles of a magnet, but not retaining any permanent magnetism.
- These have relative permeability slightly greather than unity and are magnetized slightly.
- They attract the lines of forces weakly.



Spins are randomly oriented



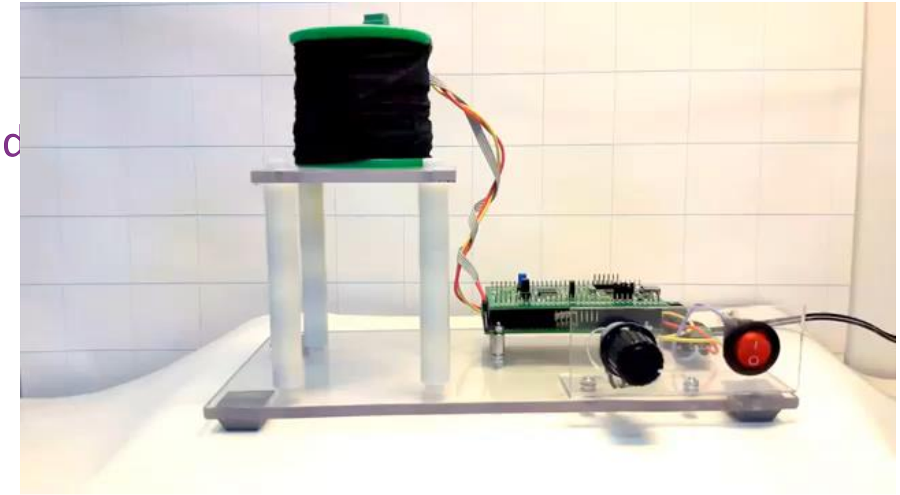
Diamagnetic

- It is substance which create a magnetic field in opposite to an externally applied field.

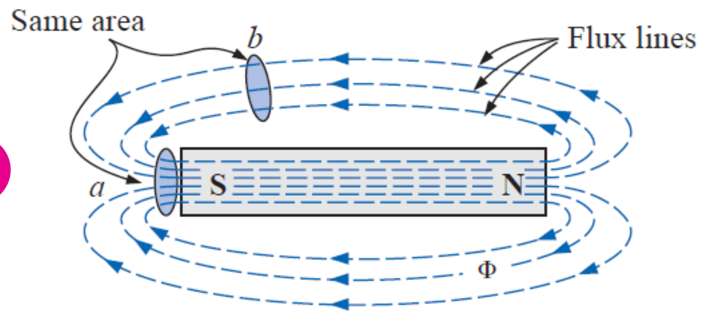
- Susceptibility is negative.

- These have relative permeability slightly less than unity.

- They reppel the lines of force slightly.

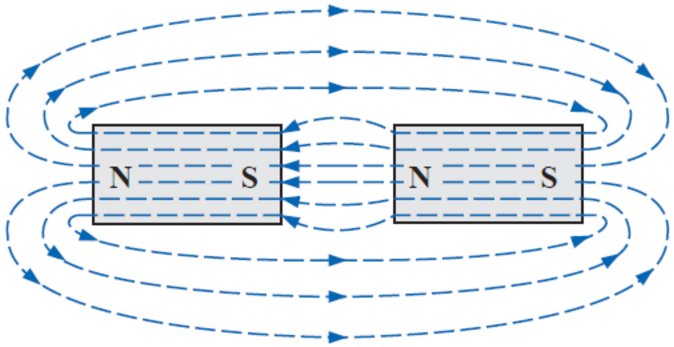


1



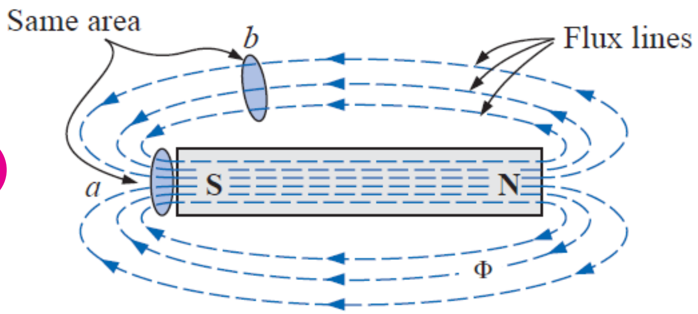
Flux distribution for a permanent magnet

2



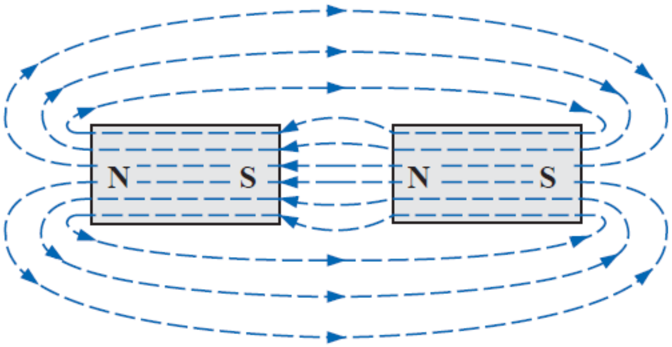
Flux distribution for two adjacent, opposite poles

1



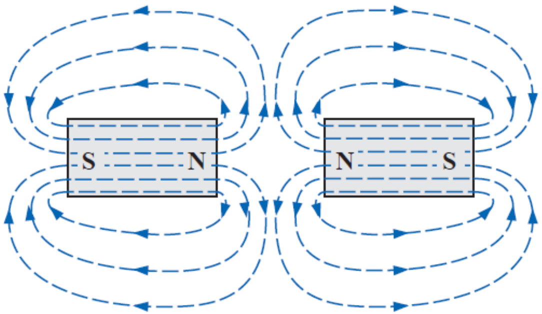
Flux distribution for a permanent magnet

2



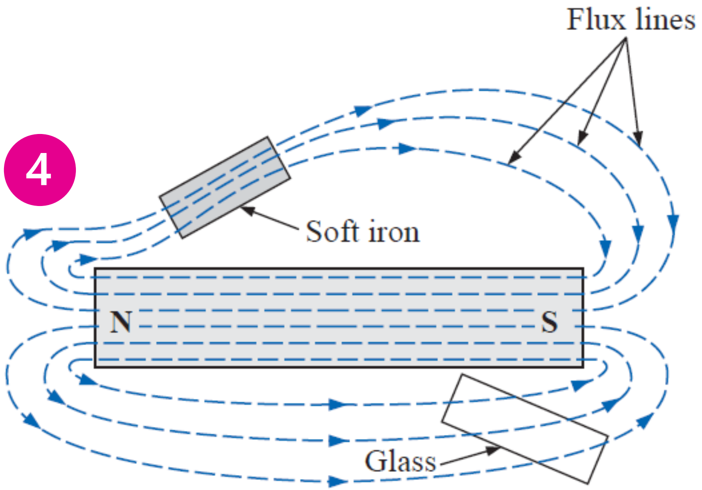
Flux distribution for two adjacent, opposite poles

3



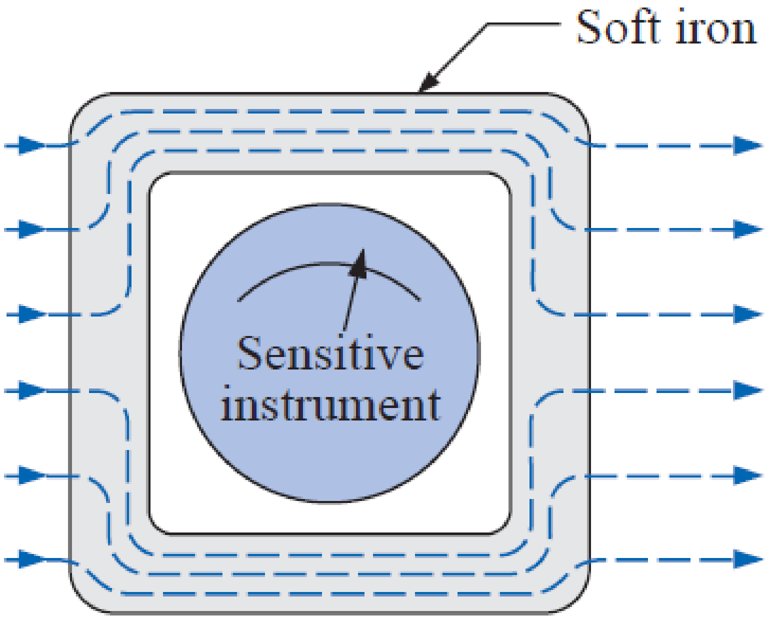
Flux distribution for two adjacent, like poles

4



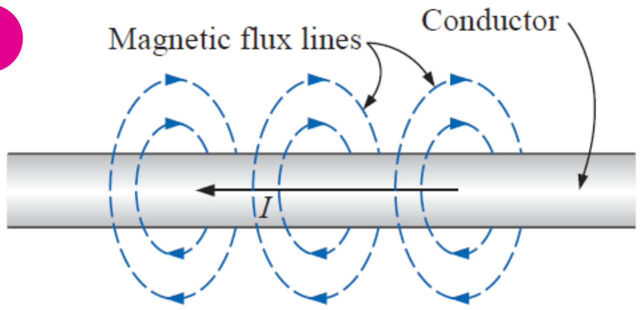
Effect of a ferromagnetic sample on the flux distribution of a permanent magnet

5



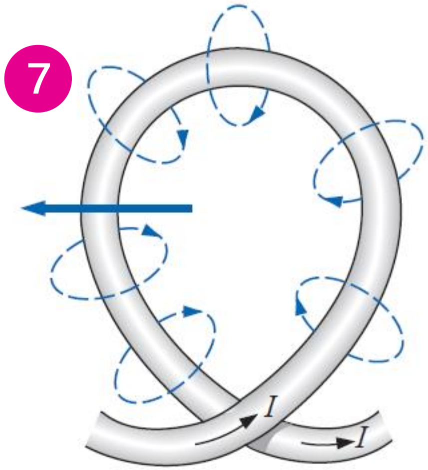
Effect of a magnetic shield on the flux distribution

6



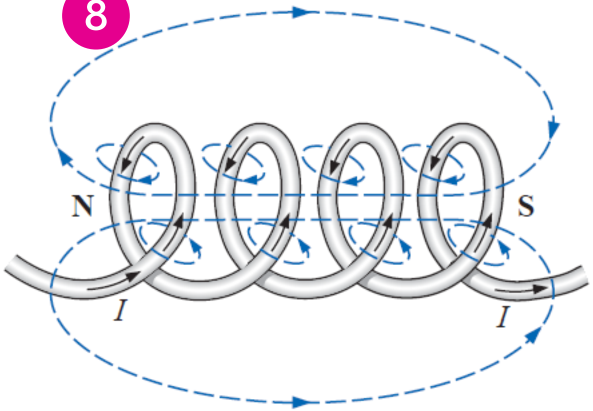
Magnetic flux lines around a current-carrying conductor

7



Flux distribution of a single-turn coil

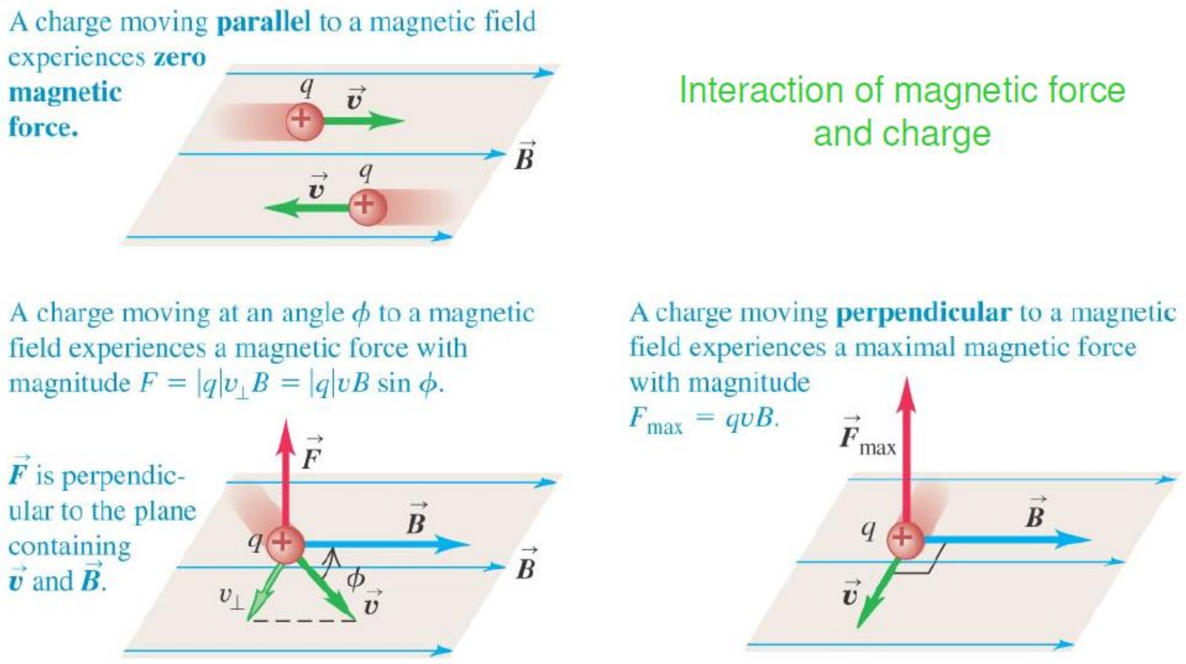
8



Flux distribution of a current-carrying coil

Magnetic Field

The moving charge interacts with the fixed magnet. The force between them is at a maximum when the velocity of the charge is perpendicular to the magnetic field.



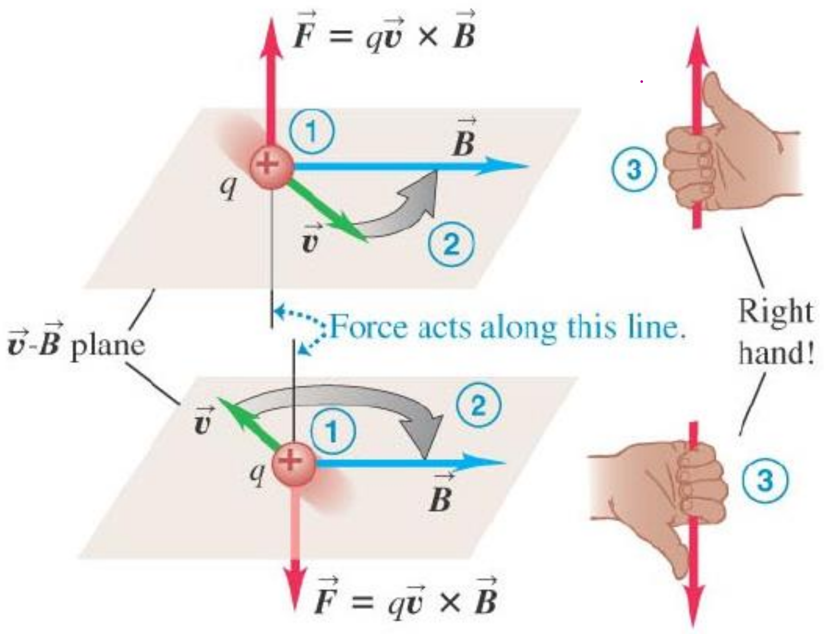
Interaction of magnetic force and charge

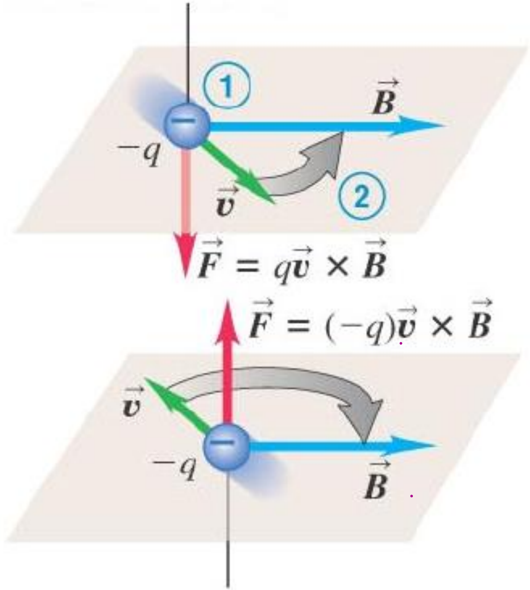
Magnetic Field

Right Hand Rule

Positive charge moving in magnetic field direction of force follows right hand rule

Negative charge F direction contrary to right hand rule.





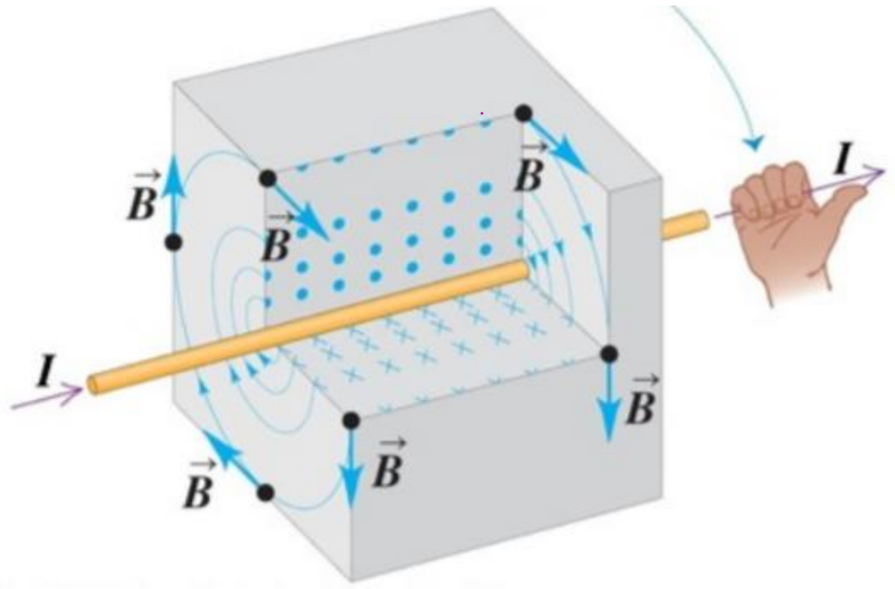
$$\bar{F}_m = |q| vB_{\perp}$$

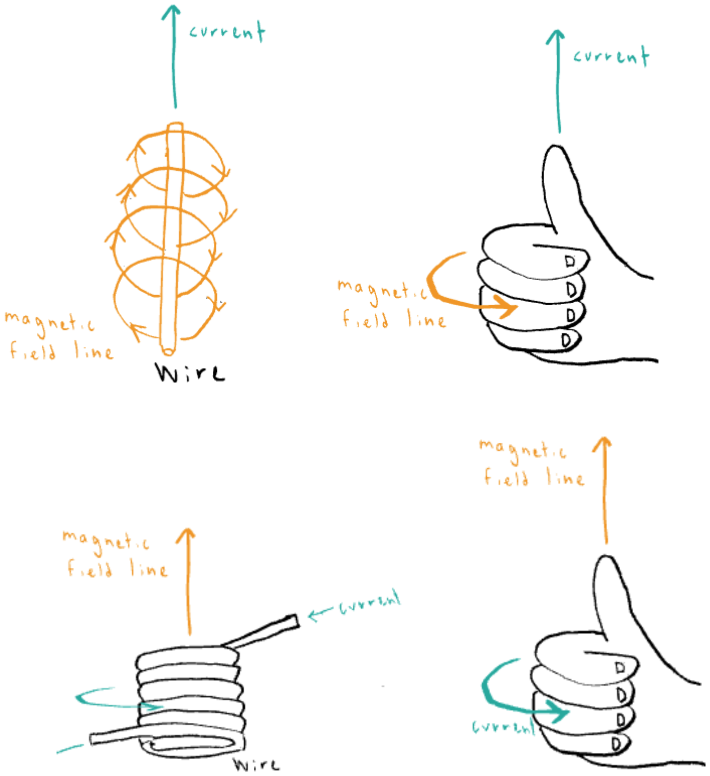
Units:

1 Tesla = 1 N s / C m = 1 N/A m

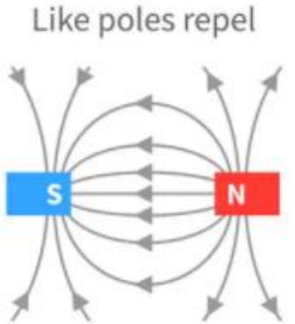
1 Gauss = 10-4 T

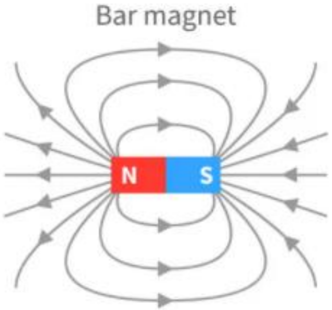
Right Hand Rule

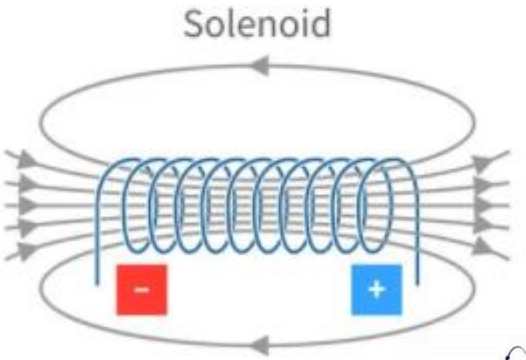


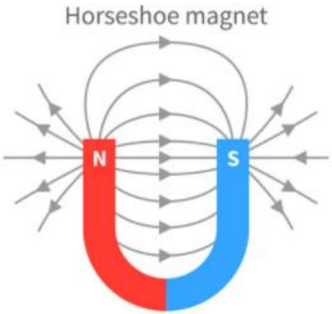


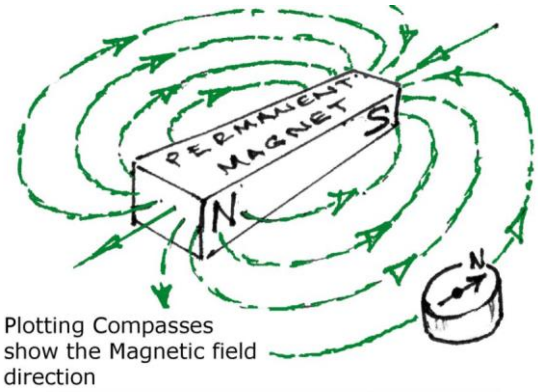
Magnetic field

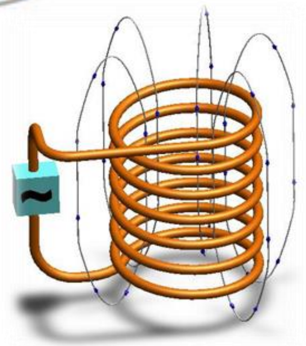


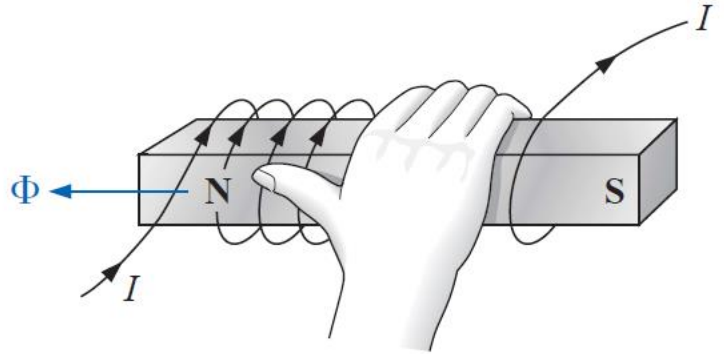








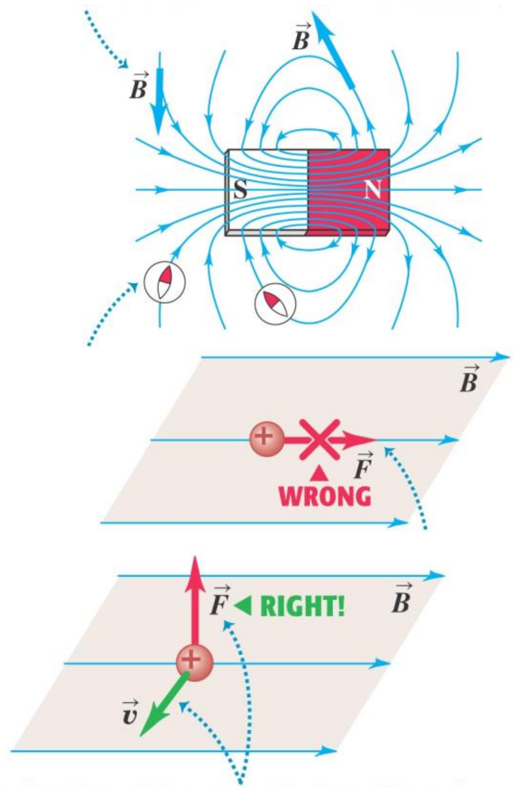




Determining the direction of flux for an electromagnet

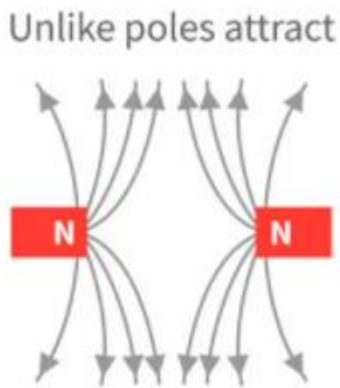
Magnetic Field Lines and Magnetic Flux

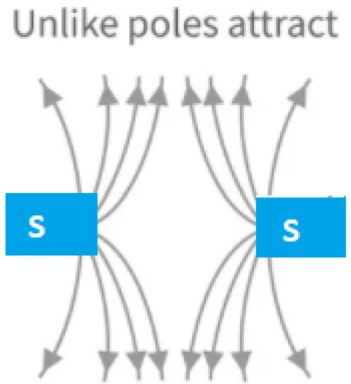
- Magnetic field lines may be traced from N toward S (analogous to the electric field lines).
  - At each point they are tangent to magnetic field vector.
- The more densely packed the field lines, the stronger the field at a point.
  - Field lines never intersect.
- The field lines point in the same direction as a compass (from N toward S).
  - Magnetic field lines are not “lines of force”.



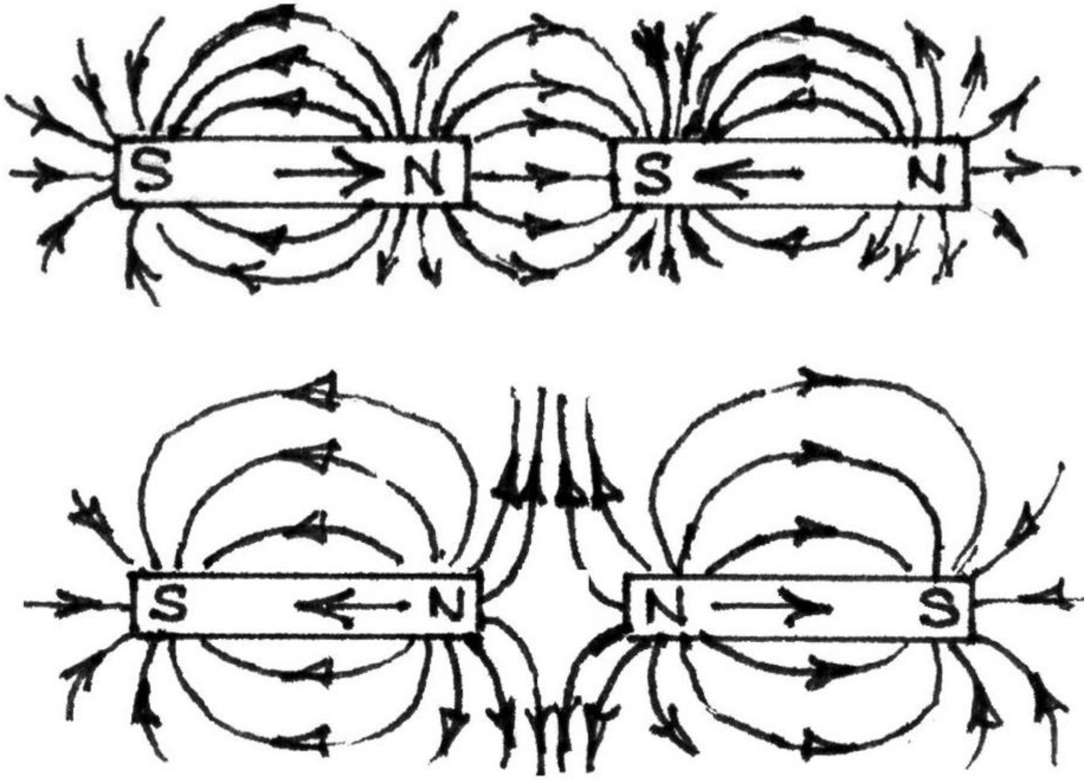
The direction of the magnetic force depends on the velocity $\vec{v}$, as expressed by the magnetic force law $\vec{F} = q\vec{v} \times \vec{B}$.

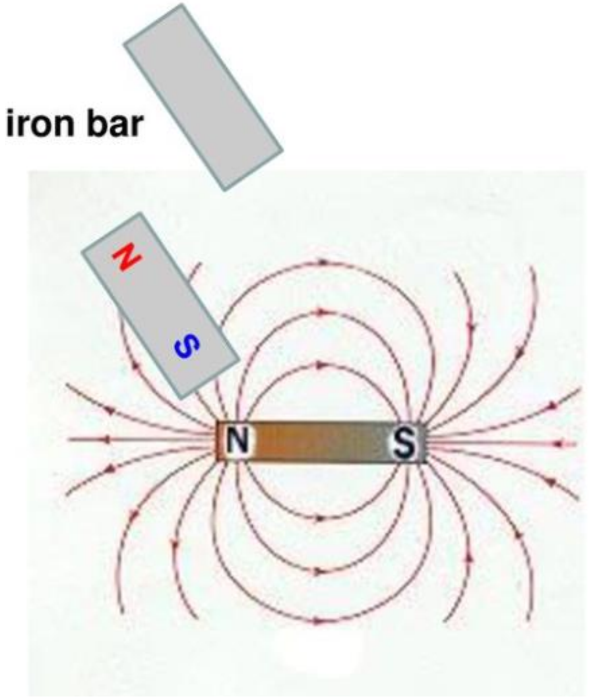
Magnetic fields between two bar magnets





Practical part





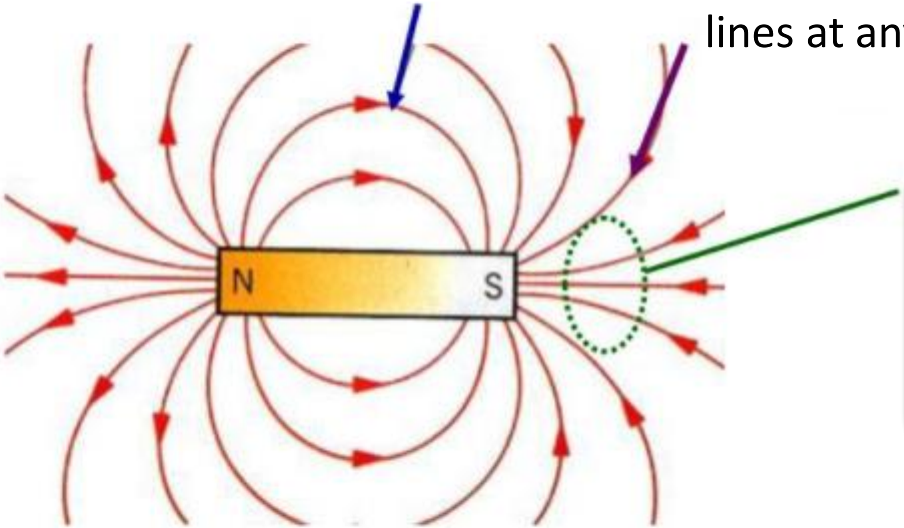
If the material is magnetically hard it will retain its magnetism once removed from the field.

Magnetic Field

B - SI unit
T - tesla

Magnetic field lines

B is tanget to the field lines at any point

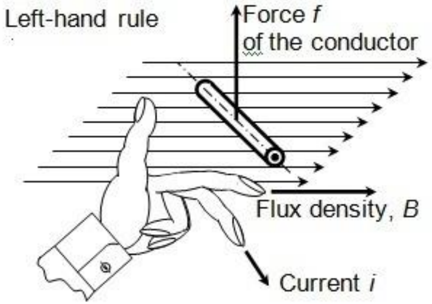


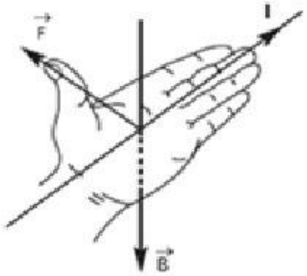
The stronger the magnetic field the denser the magnetic field lines

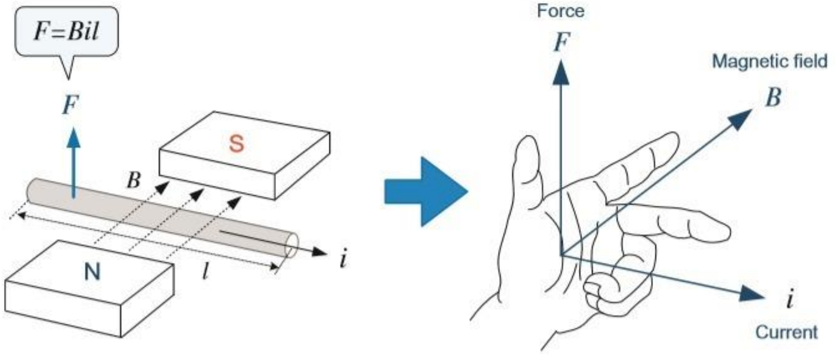
Magnetic Field

Fleming's left-hand rule
(for electric motors)

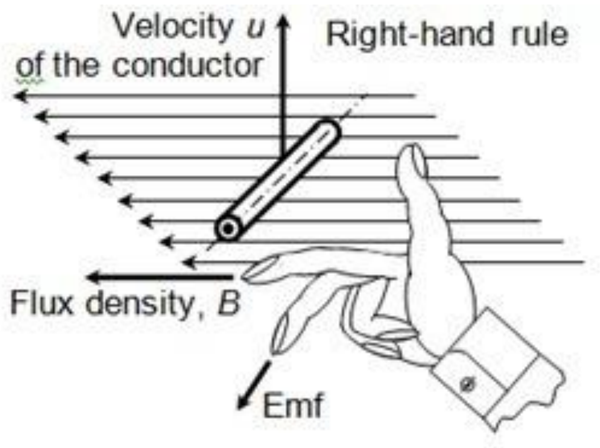
Direction of the force: (Fleming's Left-hand rule)



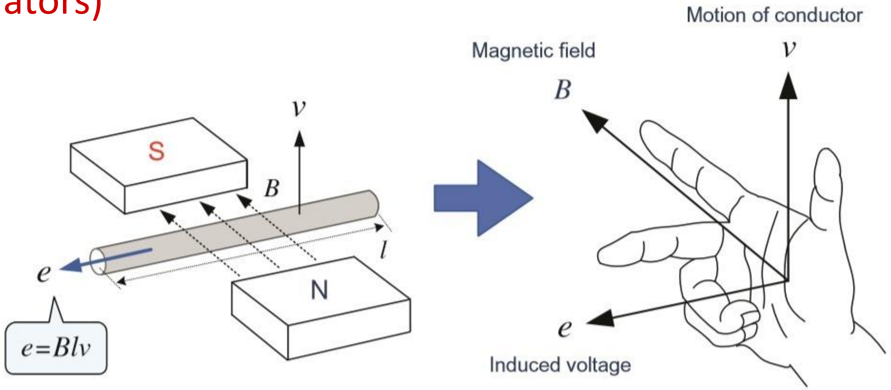




Magnetic Field



Fleming's right-hand rule
(for generators)

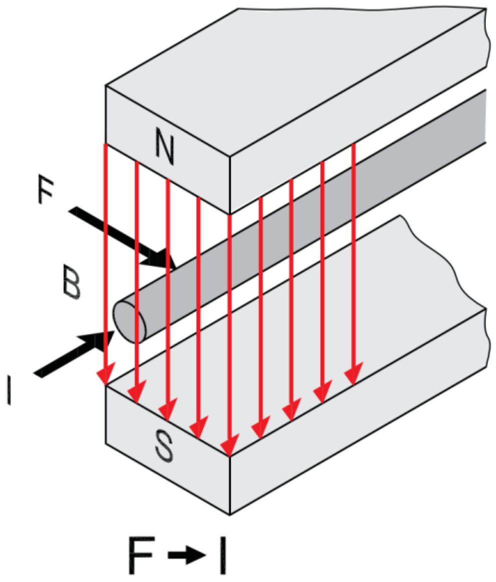


If charged particle moves in region where both, E and B are present:

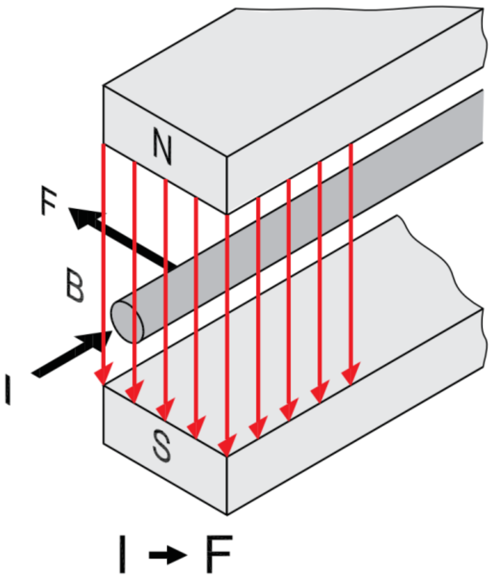
$$\bar{F}_m = |q|\left(\bar{E} + \bar{v} \times \bar{B}\right)$$

Principle for electromagnetic induction

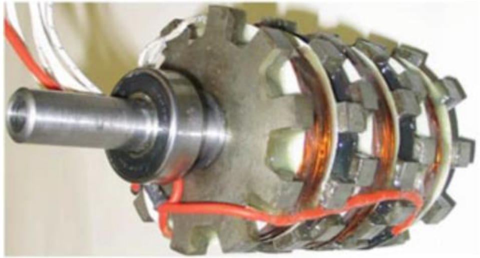
Fleming's Right-hand Rule

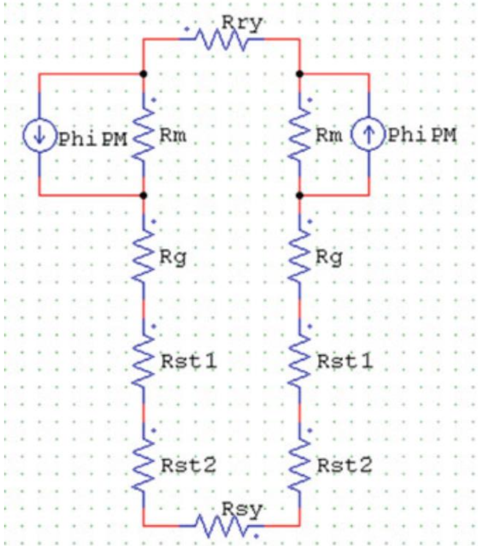


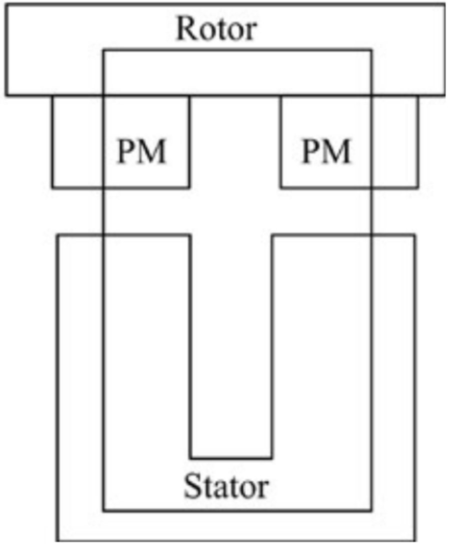
Fleming’s Left-hand Rule



- The **magnetic circuit model** acts as a uniform principle in descriptive magnetostatics, and as an approximate computational aid in electrical machine design.
- The model uses the conception of magnetic reluctance to establish an equivalent circuit for approximate analysis of static magnetic field in electrical machines.





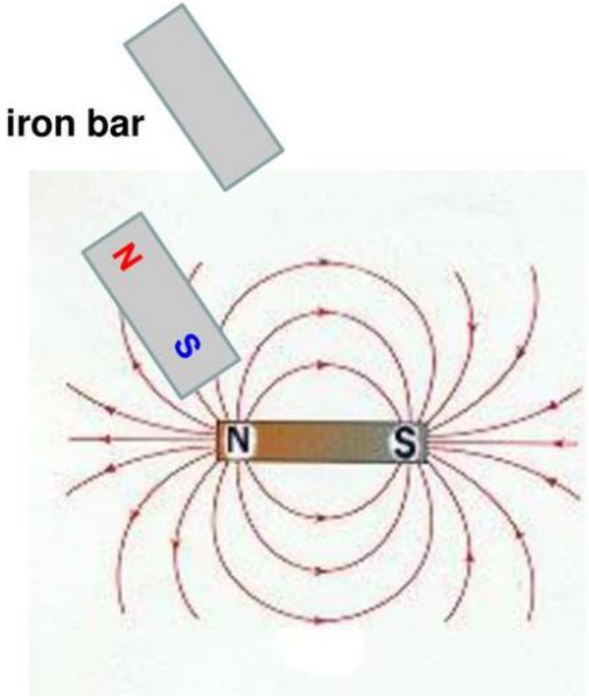


Comparison of Electric and Magnetic Force

- ❑ Electric force vector along direction of electric field
- ❑ Electric force acts on charged particle regardless of whether particle is moving
- ❑ Electric force does work in displacing a charged particle

- ❑ Magnetic force vector perpendicular to magnetic field
- ❑ Magnetic force acts on charged particle only when particle is in motion
- ❑ Magnetic force associated with steady magnetic field does no work when a particle is displaced → force perpendicular to displacement of its point of application

B(H) Characteristics



$$B_{ind} = \mu_0 M$$

$$\mu_0 = 4\pi \cdot 10^{-7} [Wb / Am]$$

$$B = \mu_0 M + \mu_0 H$$

$$M = \chi H$$

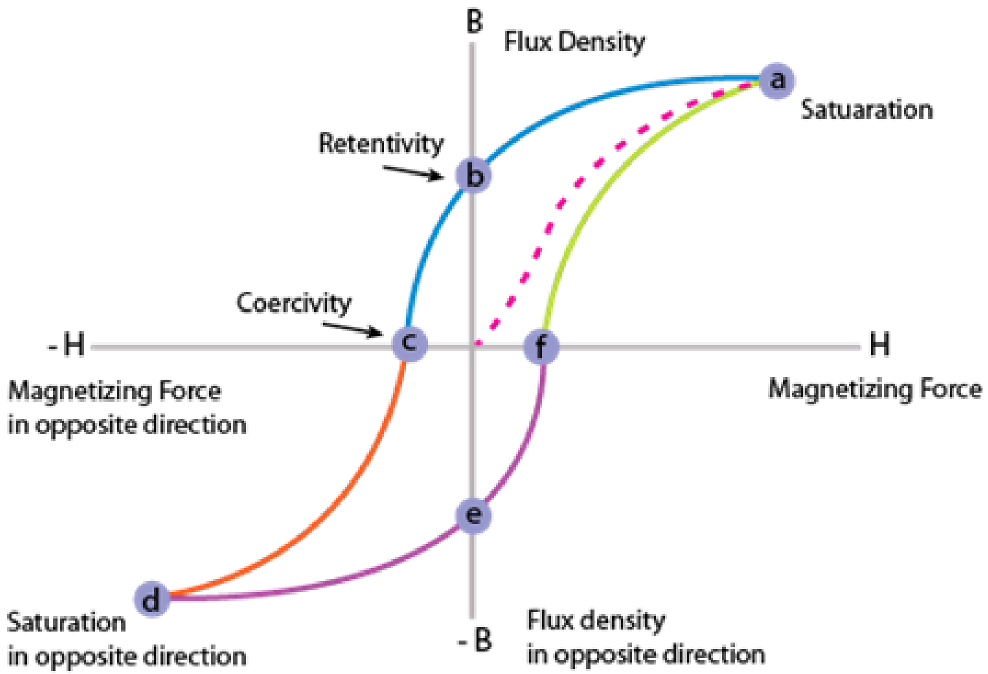
magnetic susceptibility of the material

$$B = \mu_0 \underbrace{(\chi + 1)}_{\mu_r} H = \mu H$$

μ_r relative permeability

Simple magnetic circuits

B(H) Characteristics

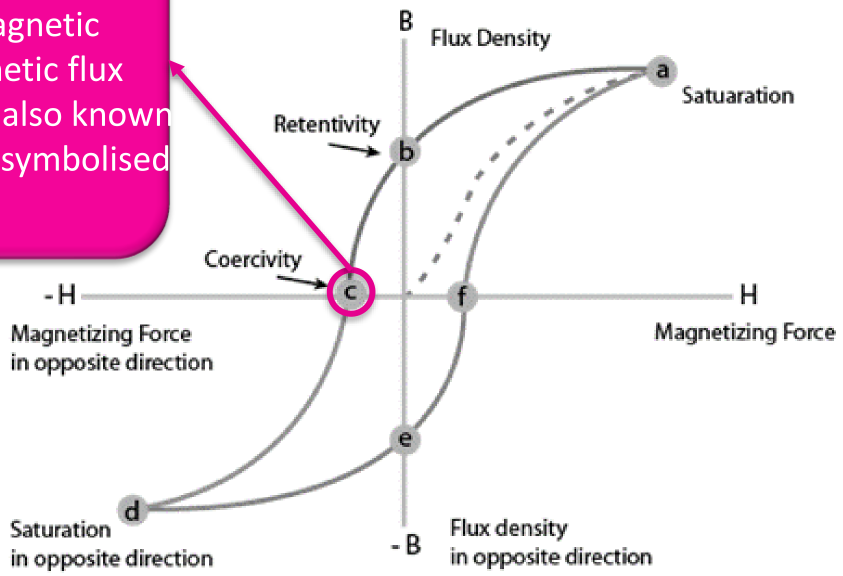


Typical B-H loop of a ferromagnetic material

Chukwuchekwa, Nkwachukwu 2011. *Investigation of magnetic properties and Barkhausen noise of electrical steel.* PhD Thesis, Cardiff University.

B(H) Characteristics

This is the amount of reverse magneti
field that is applied to a magnetic material to make the magnetic flux density return to zero. It is also known as the coercive field and is symbolised as H_C.



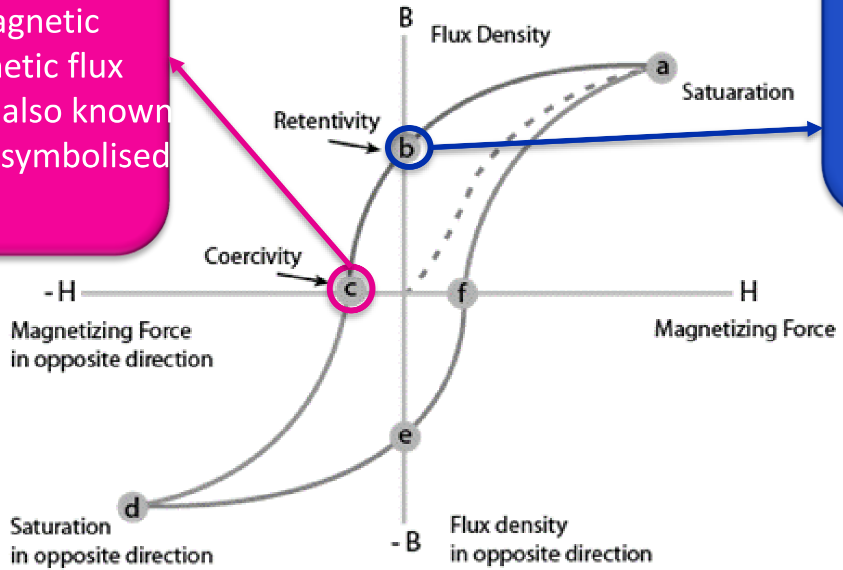
Typical B-H loop of a ferromagnetic material

Chukwuchekwa, Nkwachukwu 2011. *Investigation of magnetic properties and Barkhausen noise of electrical steel.* PhD Thesis, Cardiff University.

B(H) Characteristics

This is the amount of reverse magnetic field that is applied to a magnetic material to make the magnetic flux density return to zero. It is also known as the coercive field and is symbolised as H_C.

This is the magnetic flux density that remains in a material when the magnetic field is zero. It can be represented with the symbol BR.



Typical B-H loop of a ferromagnetic material

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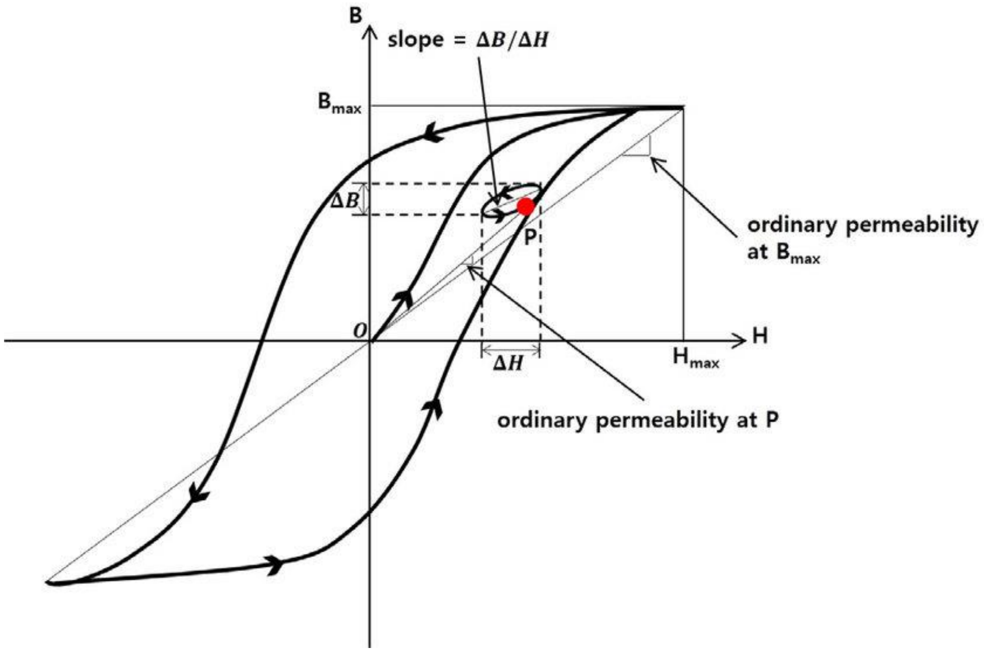


B-H Curve of a typical ferromagnetic material

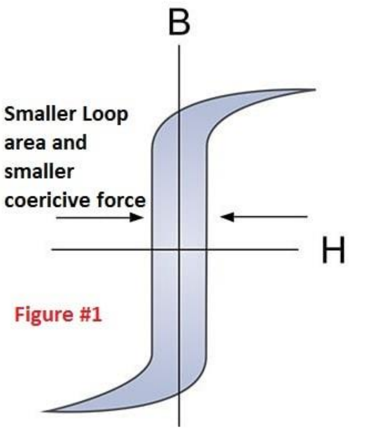
Total loss = Static hysteresis Loss + Classical eddy current loss + Excess (anomalous) loss

Park, Jooyoung;Kim, Junkyeong;Zhang, Aoqi;Lee, Hwanwoo;Park, Seunghee "Embedded EM Sensor for Tensile Force Estimation of PS tendon of PSC Girder" Journal of the Computational Structural Engineering Institute of Korea. 2015. Dec, 28(6): 691-697

Magnetically Soft material

Characteristics:

- They have hight permeability
- The magnetic energy stored is not high
- They have negligible coercive force
- They have low remanence
- Hysteresis loop is narrow



Soft Magnetic Material

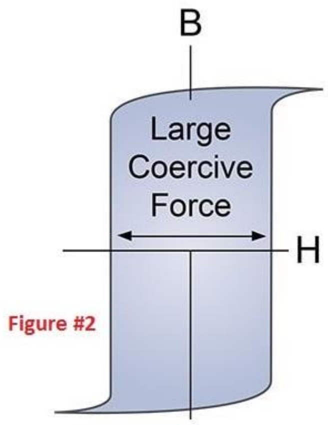
Examples:

pure or ingot iron
cast iron
carbon steel
manganese and nickel steel

Magnetically Hard Material

Characteristics:

- ❑ They posses hight value of BH product
- ❑ High retentivity
- ❑ High coercitivity
- ❑ Strong magnetic reluctance
- ❑ Hysteresis loop is more rectangular in shape



Hard Magnetic Material

Examples:

Tungsten steel
Cobalt steel
Chromium steel

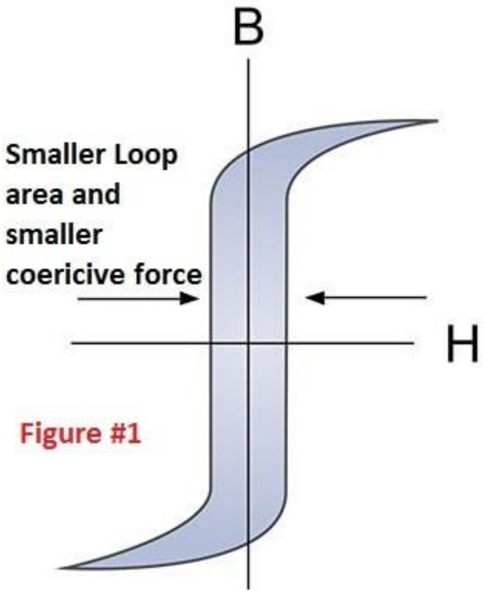


Figure #1

Soft Magnetic Material

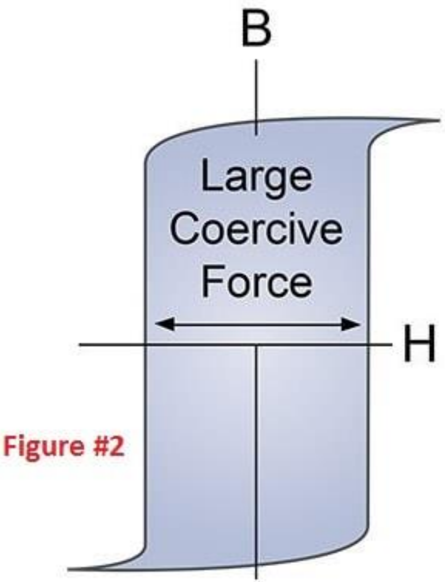


Figure #2

Hard Magnetic Material