Basic Electrical Technology

2. Magnetic Circuits & Electromagnetism

LECTURE 13 – 08 DEC 2021

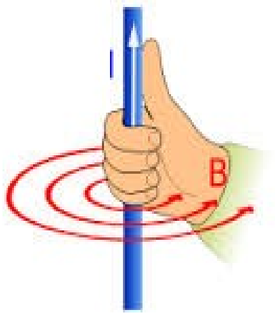
Introduction to Magnetism (Contd…)
Series Magnetic Circuits

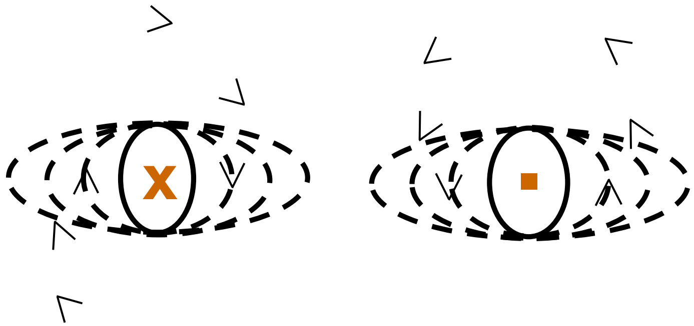
Magnetic Field (in a Current-Carrying Conductor)

- An electric current flowing in a conductor creates a magnetic field around it

- **Direction of magnetic field**
  - **By Maxwell's Right Hand Grip Rule:**

    Assume that the current carrying conductor is held in right hand so that the fingers wrap around the conductor and the thumb is stretched along the direction of current. Wrapped fingers will show the direction of circular magnetic field lines.





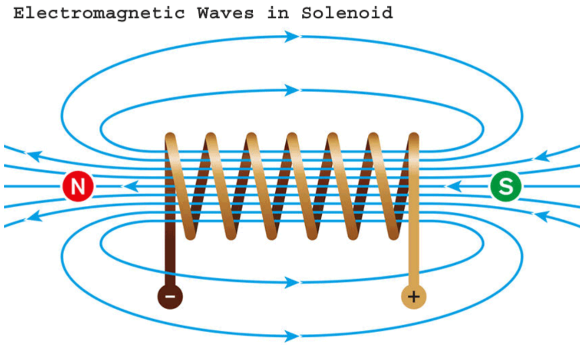
Current inwards

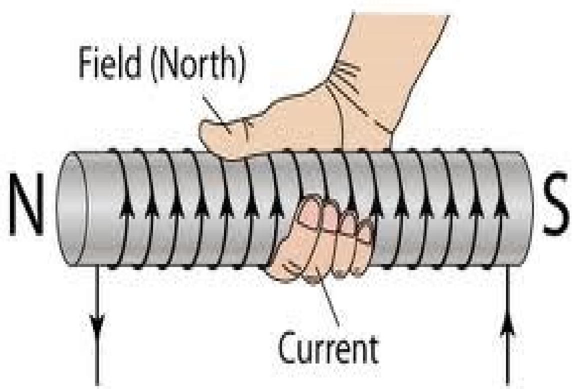
Current outwards

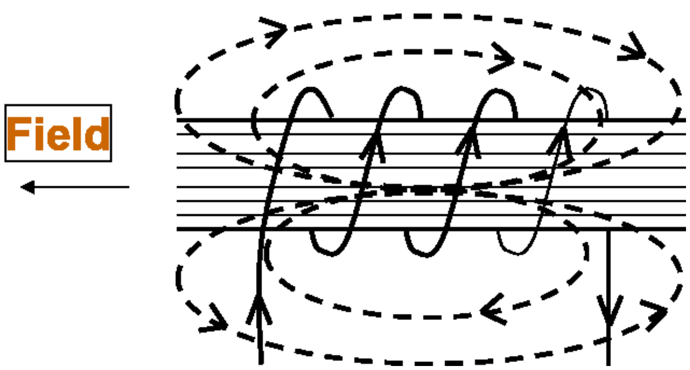
Magnetic Field (in a Solenoid)

- **Direction of magnetic field**
  - **By Right Hand Grip Rule:**

    If the coil is gripped with the right hand, with the fingers pointing in the direction of the current, then the thumb, outstretched parallel to the axis of the solenoid, points in the direction of the magnetic field inside the solenoid

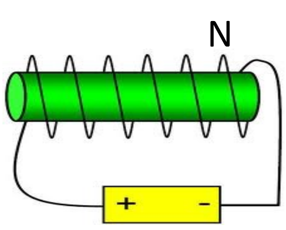


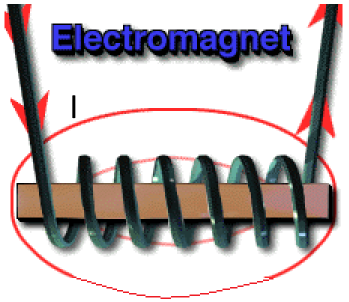




Electromagnets

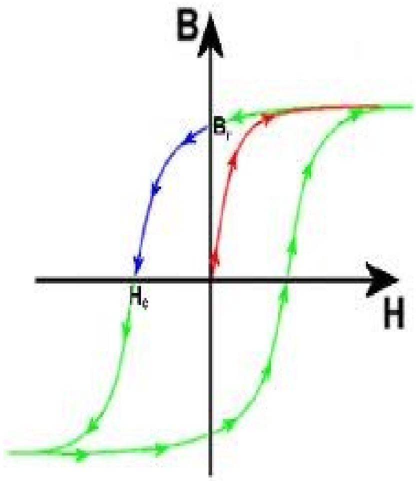
- **Principle:** An electric current flowing in a conductor creates a magnetic field around it
- Strength of the field is proportional to the amount of current in the coil
- The field disappears when the current is turned off
- A simple electromagnet consists of a coil of insulated wire wrapped around an iron core
- Widely used as components of motors, generators, relays etc.



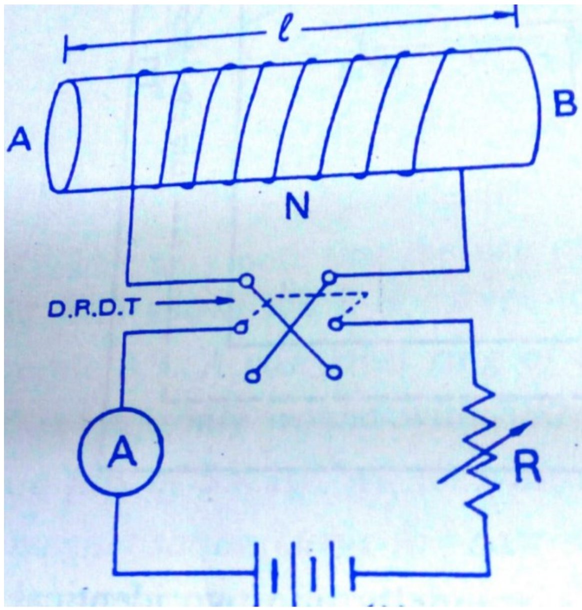


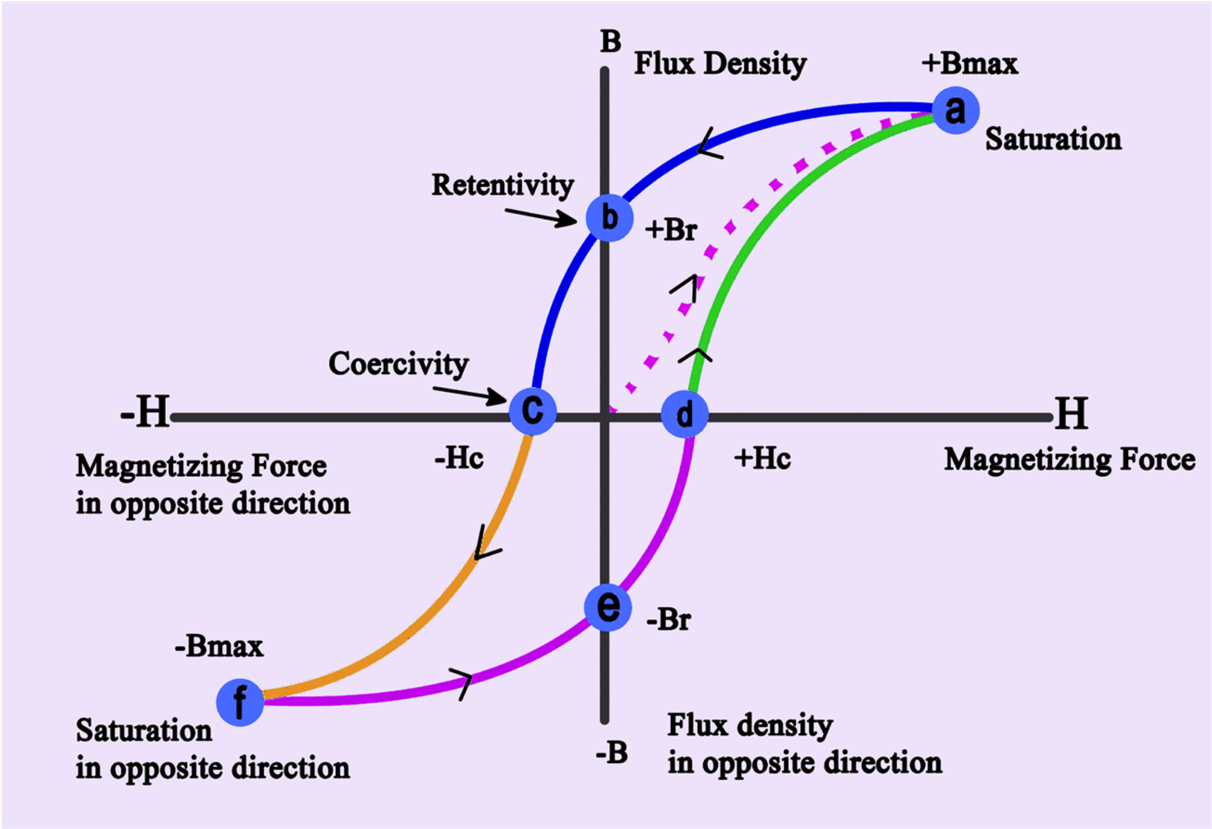
Losses in Magnetic Circuit

- **Hysteresis Loss**
  - Lagging of magnetization or flux density behind the magnetizing force is called **Magnetic Hysteresis**
  - The energy dissipated as heat in the process of magnetization and demagnetization which is proportional to the area of hysteresis loop is the **Hysteresis Loss**



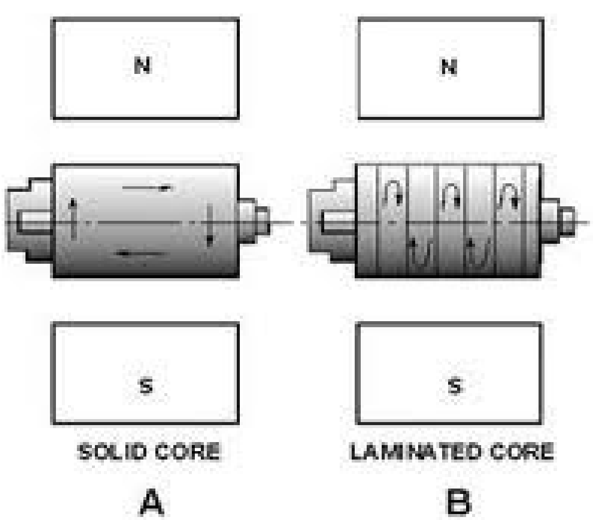
Hysteresis loop

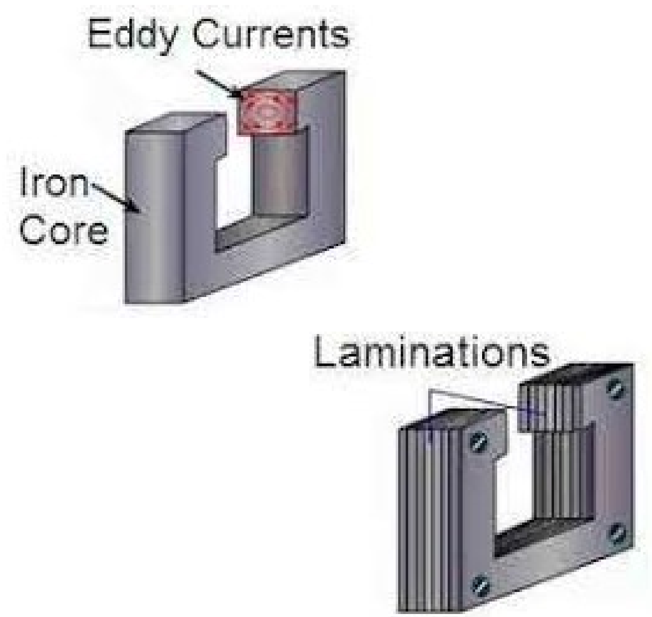

l
A
B
N
D.R.D.T
A
R


B
Flux Density
+Bmax
a
Saturation
Retentivity
b
+Br
Coercivity
-H
c
d
H
Magnetizing Force
in opposite direction
-Hc
+Hc
Magnetizing Force
e
-Br
-Bmax
f
Saturation
in opposite direction
-B
Flux density
in opposite direction

Losses in Magnetic Circuit

- **Eddy Current Loss**
  - The varying flux in the magnetic core induces emf and hence eddy current within the material
  - Flow in closed loops in planes perpendicular to the magnetic field
  - Results in loss of power and heating of the material
  - Cores of electric machines are laminated to reduce eddy current loss





Comparison of Electric and Magnetic Circuits

Analogy:

Electric Circuits	Magnetic Circuits
Current	Flux
Current Density	Flux Density
EMF	MMF
Conductivity	Permeability
Resistance	Reluctance

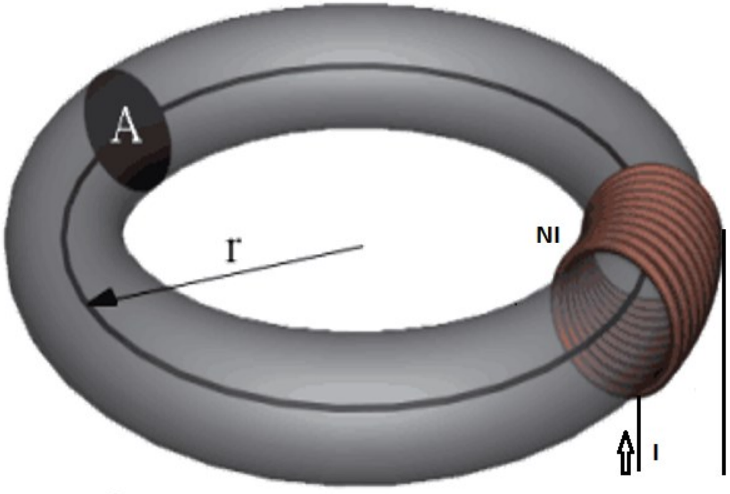
Electric Circuits	Magnetic Circuits
Conductance	Permeance
Electric Field Intensity	Magnetic Field Intensity
Voltage Drop	mmf Drop

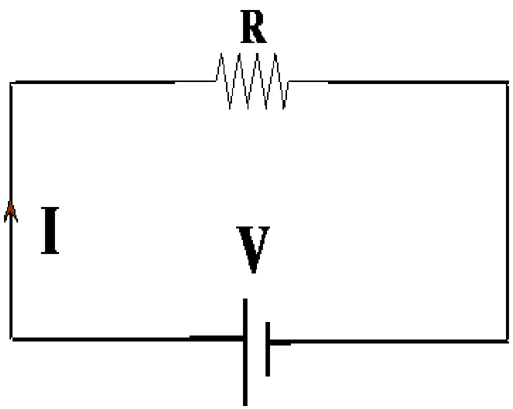
Differences:

Electric Circuits	Magnetic Circuits
Current actually flows	Flux does not flow, it seems to flow
Current can not flow in air / vacuum	Flux can be created in air / vacuum
Resistivity (P) varies very slightly with temperature	μ_r is not constant for a given magnetic material
Energy is expended and dissipated as heat as long as the current flows	No energy is expended in a magnetic circuit (practically)

Magnetic Circuits

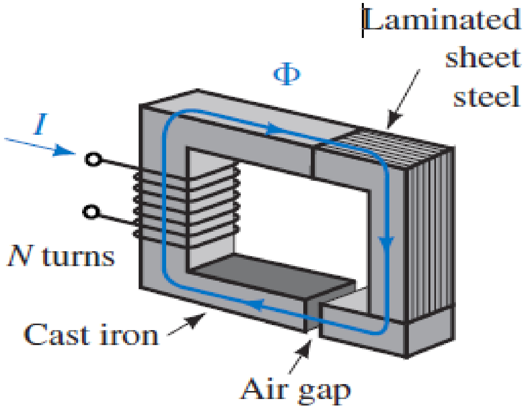
The complete closed path followed by any group of magnetic lines of flux





Series Magnetic Circuit

- Flux ϕ is the same in all sections if leakage flux is neglected.
- Flux density and reluctance in each section may vary, depending on its effective cross-sectional area and material.
- Equivalent reluctance is the sum of reluctance of different parts/elements.
- The resultant MMF is the sum of MMFs in each individual parts/elements



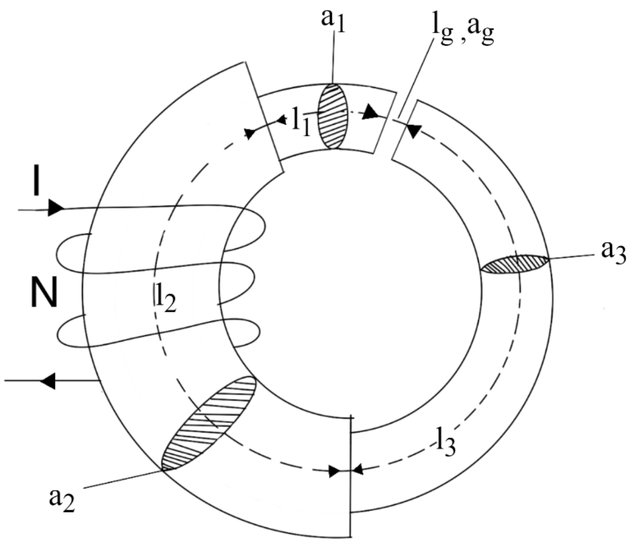
Rectangular shaped series magnetic circuit with air gap.

Series Magnetic Circuit

$$\boldsymbol{S_1 = \frac{l_1}{\mu_0\, \mu_{r1}\, a_1},\ S_2 = \frac{l_2}{\mu_0\, \mu_{r2}\, a_2}}$$

$$\boldsymbol{S_3 = \frac{l_3}{\mu_0\, \mu_{r3}\, a_3},\ S_g = \frac{l_g}{\mu_0\, a_g}}$$

$$\boldsymbol{S_T = S_1 + S_2 + S_3 + S_g}$$



$$Total\ mmf = \phi_1 S_1 + \phi_2 S_2 + \phi_3 S_3 + \phi_g S_g$$

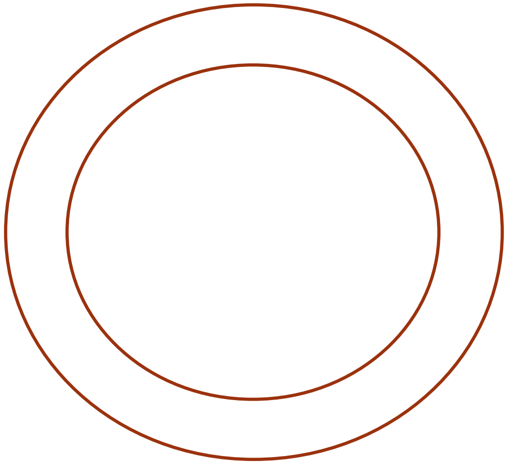
$$= H_1 l_1 + H_2 l_2 + H_3 l_3 + H_g l_g$$

$$= \left(\frac{B_1 l_1}{\mu_0 \mu_{r1}} + \frac{B_2 l_2}{\mu_0 \mu_{r2}} + \frac{B_3 l_3}{\mu_0 \mu_{r3}} + \frac{B_g l_g}{\mu_0}\right)$$

Illustration 2

An iron ring has a circular cross- sectional area of 5 cm^2 and a mean circumference of 100 cm. The ring is uniformly wound with a coil of 1000 turns. Relative permeability of iron is 800.

a) Find the current required to produce a flux of 1 mWb in the ring.
b) If a saw cut of 2 mm wide is made in the ring, find the flux produced, if the current is same as that found in **part a**.
c) Find the current required to produce the same flux as in **part a** for the cut made in the ring in **part b**.



Ans:
a) 1.99 A
b) 0.385 mWb
c) 5.17 A