SYLLABUS(EE-205-F)

SECTION-A

MAGNETIC CIRCUITS AND INDUCTION:

Magnetic Circuits, Magnetic Materials and their properties, static and dynamic emfs and force on current carrying conductor, AC operation of Magnetic Circuits, Hysteresis and Eddy current losses.

SECTION-B

DC MACHINES :

Basic theory of DC generator, brief idea of construction, emf equation, load characteristics, basic theory of DC motor, concept of back emf, torque and power equations, load characteristics, starting and speed control of DC motors, applications.

SECTION -C

Synchronous Machine

Constructional features, Armature winding, EMF Equation, Winding coefficients, equivalent circuit and phasor diagram, Armature reaction, O. C. & S. C. tests, Voltage Regulation

- **Synchronous Motor:** Starting methods, Effect of varying field current at different loads, V- Curves.

SECTION-D

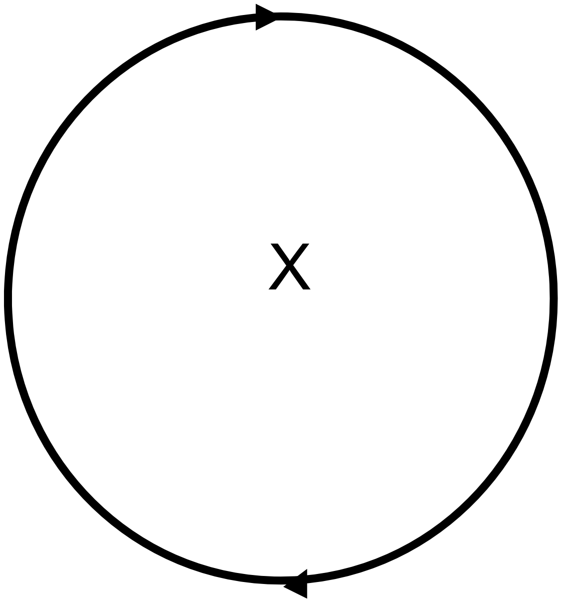
Three phase Transformer & Induction Machine

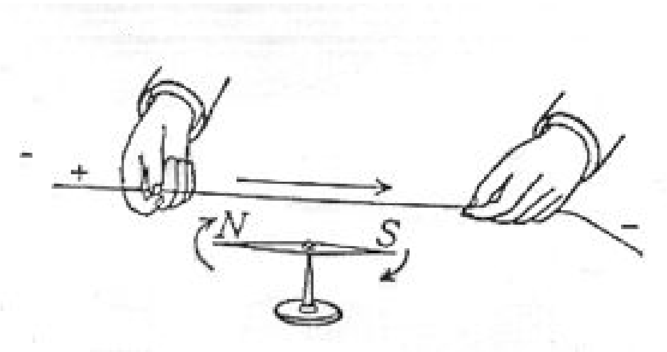
Three Phase Transformer: Review of Single phase transformer. Three Phase transformer: Basics & operation

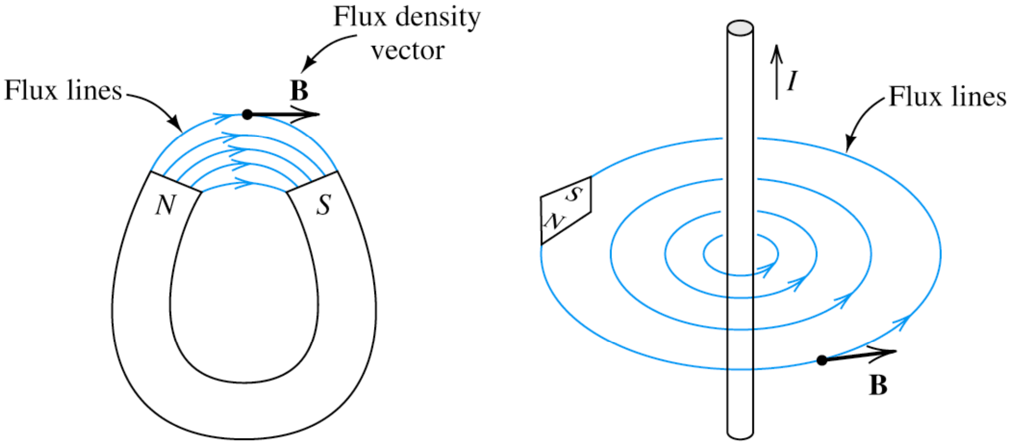
Induction Machine: Constructional features, Rotating magnetic field, Principle of operation Phasor diagram, equivalent circuit, torque and power equations, Torque- slip characteristics, no load & blocked rotor tests, efficiency, Induction generator & its applications. Introduction of S**ingle phase Induction Motor, R**epulsion motor. **AC Commutator Motors:**Universal motor, Single phase a.c. series compensated motor, stepper motors

Hans Christian Oersted (1777 – 1851)

In 1820 he showed that a current produces a magnetic field.

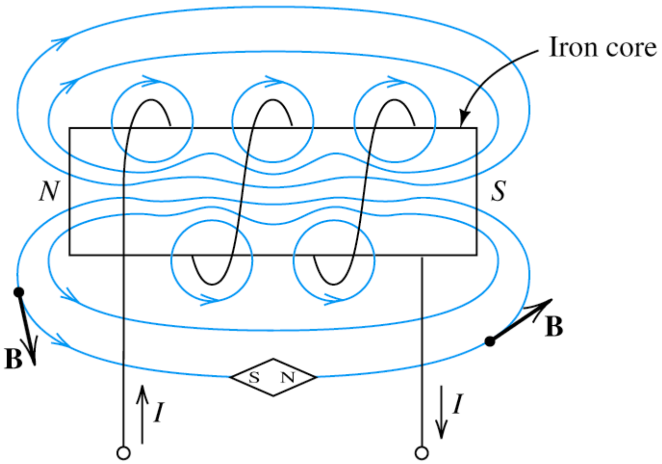






(a) Permanent magnet

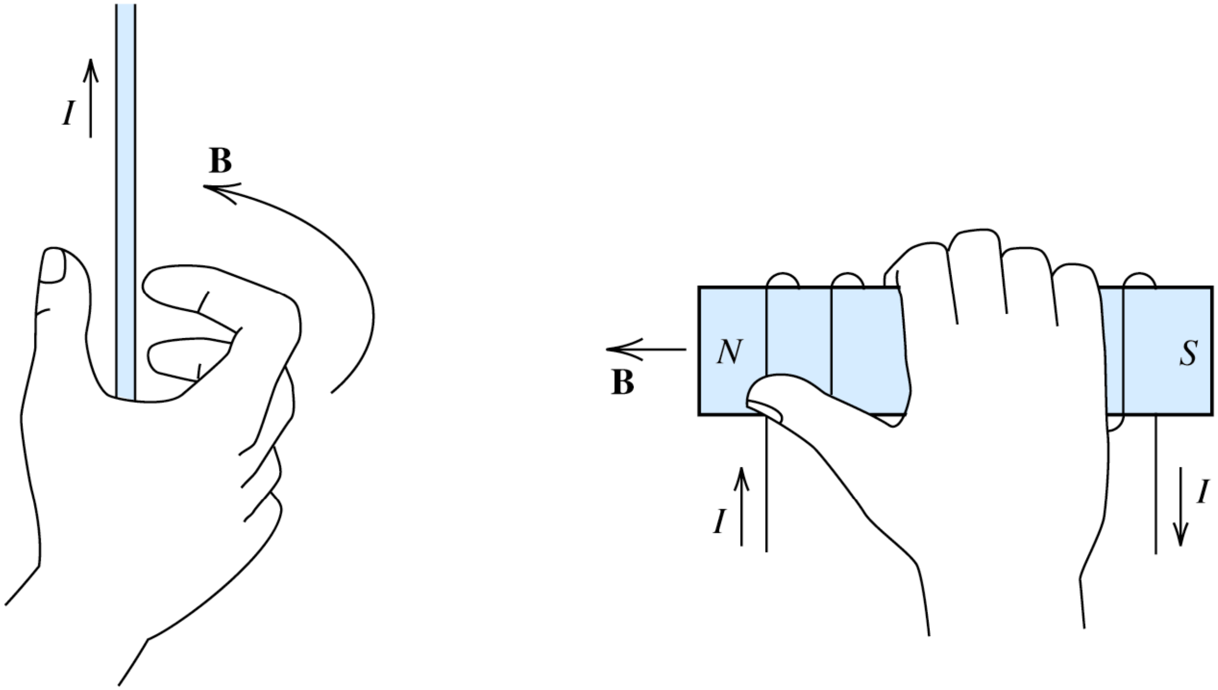
(b) Field around a straight wire carrying current I



(c) Field for a coil of wire

Figure 15.1 Magnetic fields can be visualized as lines of flux that form closed paths. Using a compass, we can determine the direction of the flux lines at any point. Note that the flux density vector **B** is tangent to the lines of flux.

Electric Current and Magnetic Field



(a) If a wire is grasped with the thumb pointing in the current direction, the fingers encircle the wire in the direction of the magnetic field

(b) If a coil is grasped with the fingers pointing in the current direction, the thumb points in the direction of the magnetic field inside the coil

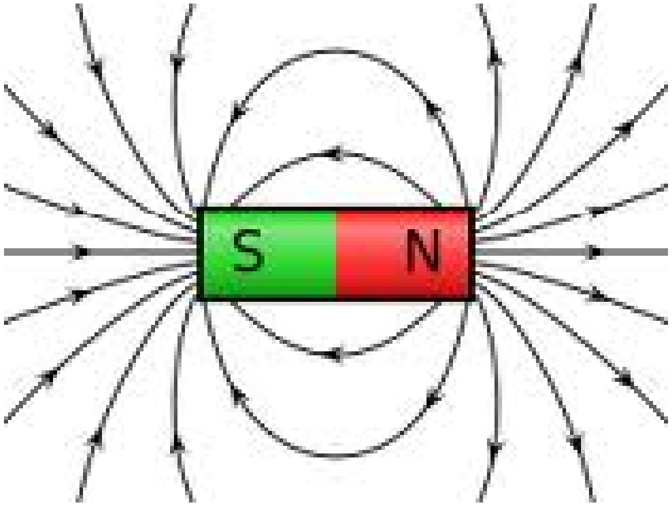
Figure 15.2 Illustrations of the right-hand rule.

Terminology

1. Flux density (Φ)
2. Magnetic flux Density (B)
3. Magnetic field Intensity (H)
4. MMF (Magneto Motive Force)
5. Reluctance ($S=L/\mu a$)
6. Permeability ($B/H=\mu$)
7. Relative permeability ($B_i/B_a=\mu_r$)

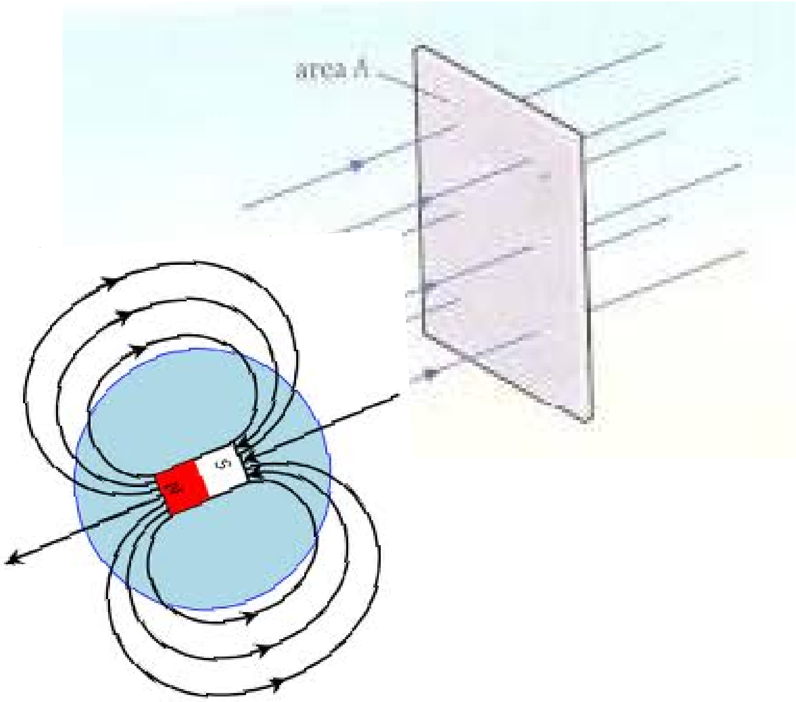
Magnetic Flux (Φ)

- Total number of line of force in a magnetic field
- Unit is Weber (Wb)
- 1 weber = 10^8 line of force

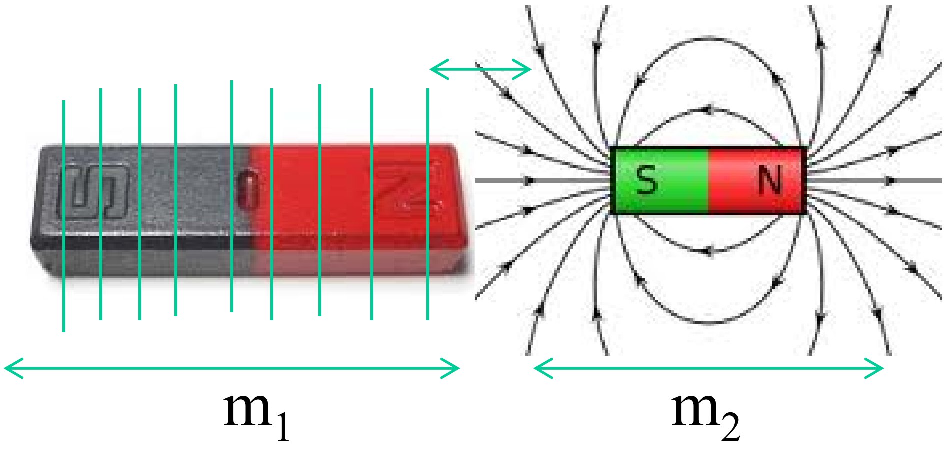


Magnetic flux density (B)

- Flux per unit area
- $B = \Phi/A$
- Unit is Tesla



Magnetic field Intensity/strength (H)

- Force experience by a unit North pole placed in a magnetic field of another magnet (m_2).
- 

  $F_1 = F_2 = Km_1m_2/r^2$
- Unit N-pole is the N-pole with the pole strength of 1 Wb
- $H = F/m_1 = Km_1m_2/r^2 / m_1 = Km_2/r^2$

Reluctance and Permeability

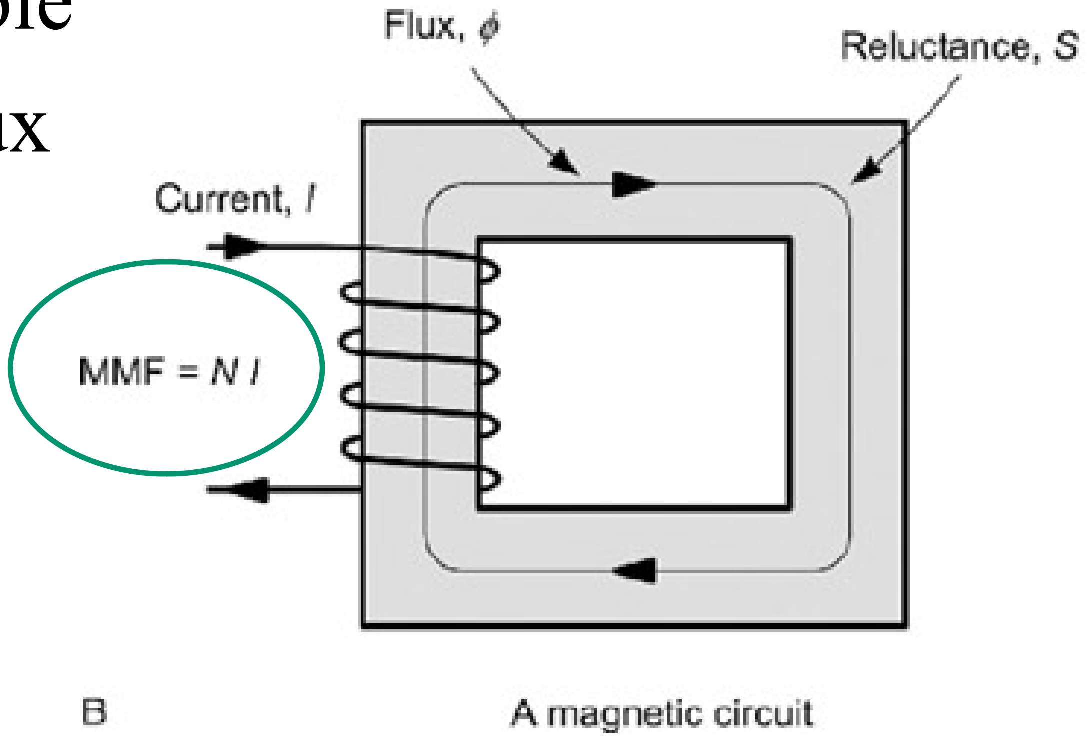
- Reluctance $S = K\ell/a$ (like resistance($R=\rho\ell/a$))
- Permanence = $1/S$ (like conductance(G)
  = 1/resistance(R))
- $K = 1/\mu$ (like resistivity($\rho = 1/\sigma$))
- K = constant
- μ = permeability (like conductivity(σ))
- $\mu = B/H = \Phi/a \big/ F/m_1 = \Phi r^2 \big/ aKm_2$
- Means $S = \ell/\mu a$ and $S = mmf/\Phi = N \times I/\Phi$

- $S = N \times I/\Phi \quad \Rightarrow \quad \Phi = N \times I/S$
- But $B = \Phi/a$
- Therefore, $B = N \times I/Sa$
- $H = B/\mu \quad \Rightarrow \quad N \times I/\mu Sa$
- But $S = \ell/\mu a$
- $\Rightarrow H = N \times I/\ell$
- This is the magnetic field intensity inside the solenoid.

MMF

- Magneto motive force
- Force responsible

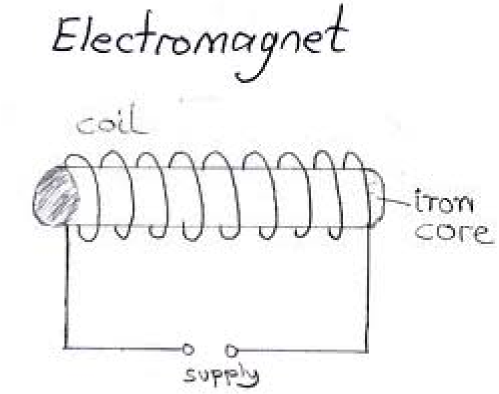
for the flow of flux



A magnetic circuit

Electromagnets

- Whenever current passes through a conductor or a coil, magnetic field gets developed across it.
- The magnetic material piece in between the piece will start acting as a magnet

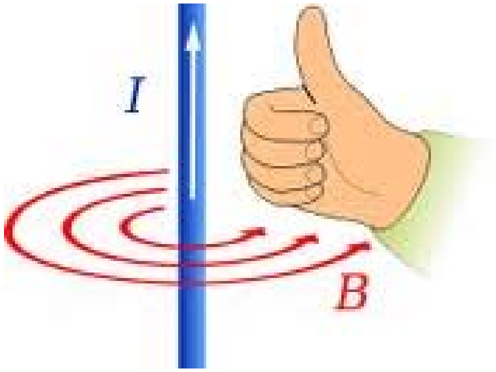


- IMP: when the current stop passing through, the electromagnetic stop loses its magnetic property.

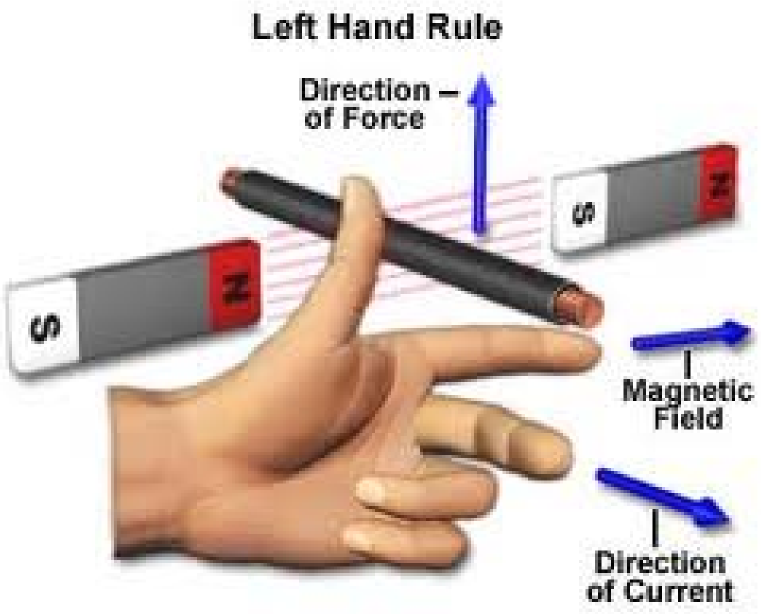
Right hand rule

- An electric current passes through a straight wire. Here, the thumb points in the direction of the conventional current

(from positive to negative), and the fingers point in the direction of the magnetic lines of flux.

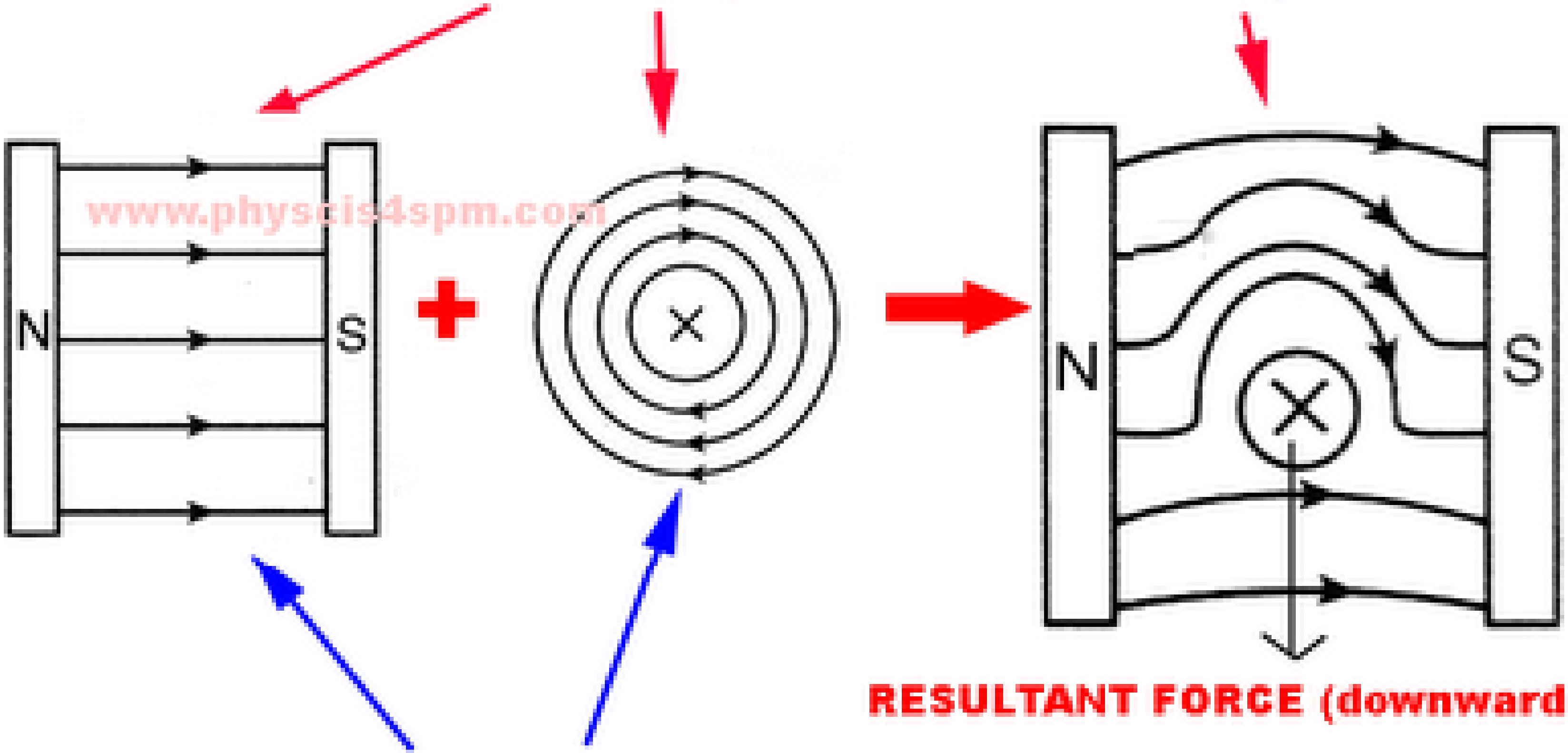


Flemings left hand rule



- When an electric current flows in a wire, and an external magnetic field is applied across that flow, the wire experiences a force perpendicular both to that field and to the direction of the current flow.
- Used in Motors
- Fleming right hand rule used in generators
- $F = B I \ell$

Why force produce?



combined line of fields at the top are in same direction = stronger force

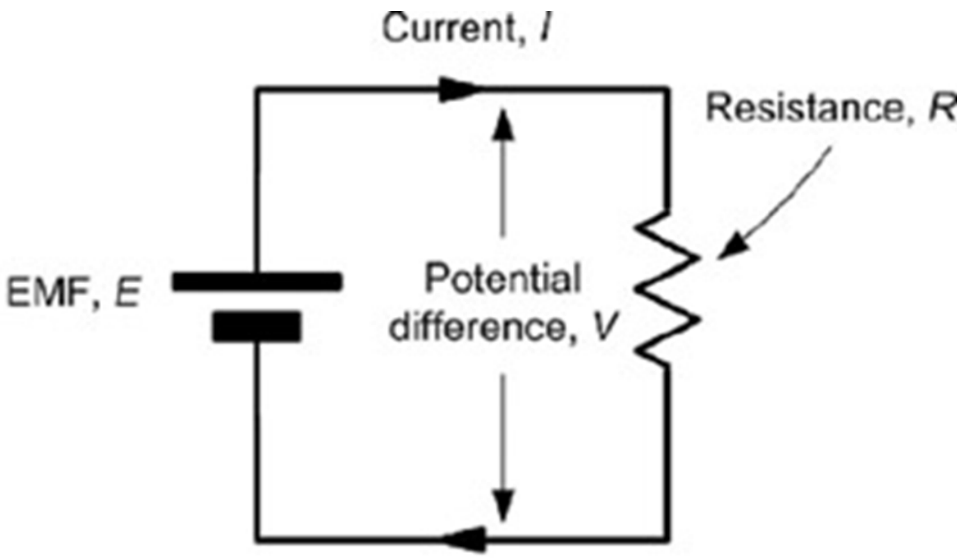
RESULTANT FORCE (downward)

combined line of fields at the bottom are
in different direction,
weaker force

Properties of lines of force

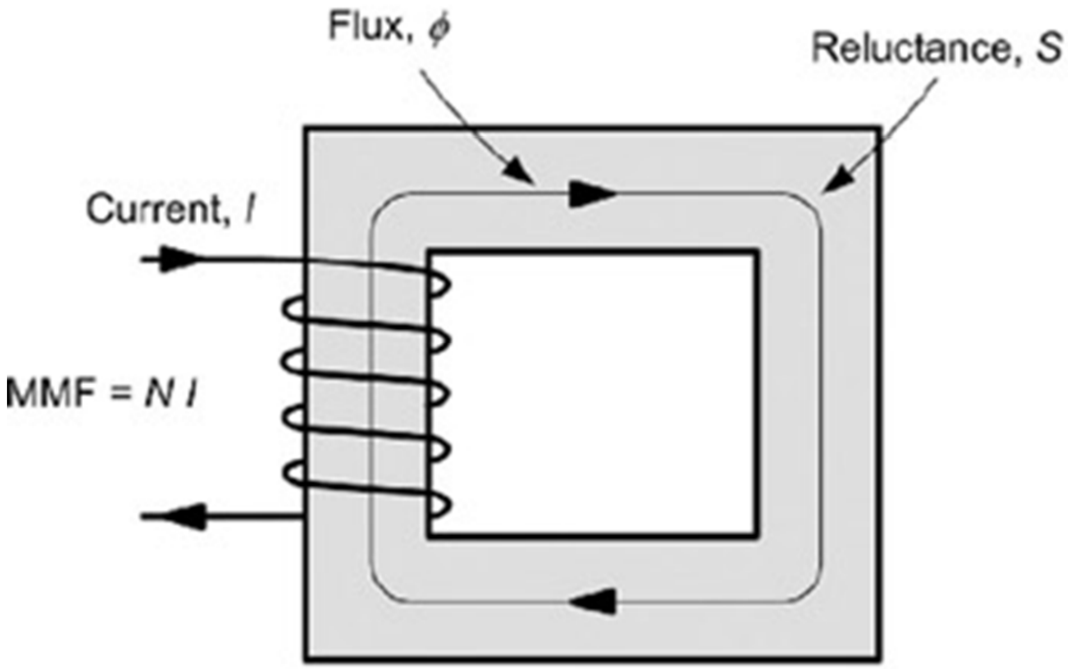
- They all have the same strength.
- The lines never cross one another.
- They form closed curve which outside the magnet is directed from north pole to south pole & inside the magnet from south pole to north pole.
- Always try to contract its length.
- **So, exert a force on a conductor downwards.**

Electric Circuit



A An electric circuit

Magnetic Circuit



B A magnetic circuit

A Few Definitions Related to Electromagnetic Field

Φ (Unit is Weber (Wb)) = No. of lines of force in the magnetic field

B (Unit is Tesla (T)) = Magnetic Flux Density = $\Phi/A = wb/m^2$

H (Unit is Amp/m) = Magnetic Field Intensity=NI/l

μ = permeability = $\mu_o \mu_r = B/H$

$\mu_o = 4\pi * 10^{-7}$ H/m (H ⇒Henry) = Permeability of free space (air)

μ_r = Relative Permeability

$\mu_r >> 1$ for Magnetic Material

Magnetic Circuits (2)

F =NI= Magneto Motive Force or MMF = # of turns * Current passing through it

$$F = NI = H\ell \text{ (why!)}$$

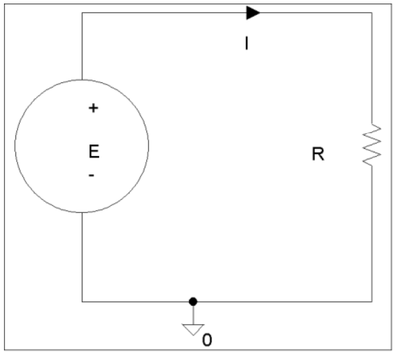
or $$\frac{B}{\mu}\ell = NI$$ or $$\frac{\Phi}{\mu A}\ell = NI$$

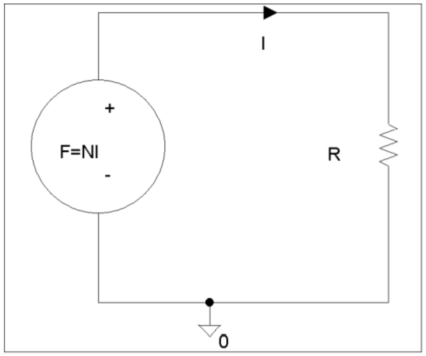
or $$\Phi = \frac{NI}{\ell/(\mu A)}$$

or $$\Phi = \frac{NI}{\Re}$$

$\Re$ = ***Reluctance*** of magnetic path

Analogy Between Magnetic and Electric Circuits





F =MMF is analogous to Electromotive force (EMF) =E

Φ = Flux is analogous to I = Current

$\Re$ = Reluctance is analogous to R = Resistance

P = Permeance $= \frac{1}{\Re}$ = Analogous to conductance $G = \frac{1}{R}$

Analogy between 'magnetic circuits' and electrical circuits

	Magnetic ckt.	Electric ckt
1.Driving force	mmf	emf
2.Response	flux	current
3.Field intensity	Magnetic field int.	Electric field int.
4.Density	Flux density	Current density
6.Impedance	Reluctance	Resistance
	(i)Series	(i)Series
	(ii) Parallel	(ii) parallel

Magnetic materials

- Diamagnetic materials $=\mu_r < 1$

  e.g. Zinc, Mercury, lead, silver, copper (orbital and axial rotation are opposite to each other)

- Paramagnetic materials $= \mu_r > 1$

  e.g. Aluminium(1.00000065), tin, platinum, magnesium, manganese

- Ferromagnetic materials $=\mu_r >>> 1$ (they are in same direction)varying from hundreds to thousands.

  e.g. iron, steel, nickel, cobalt and some other alloys

Ferromagnetic materials

1. Soft Ferromagnetic material

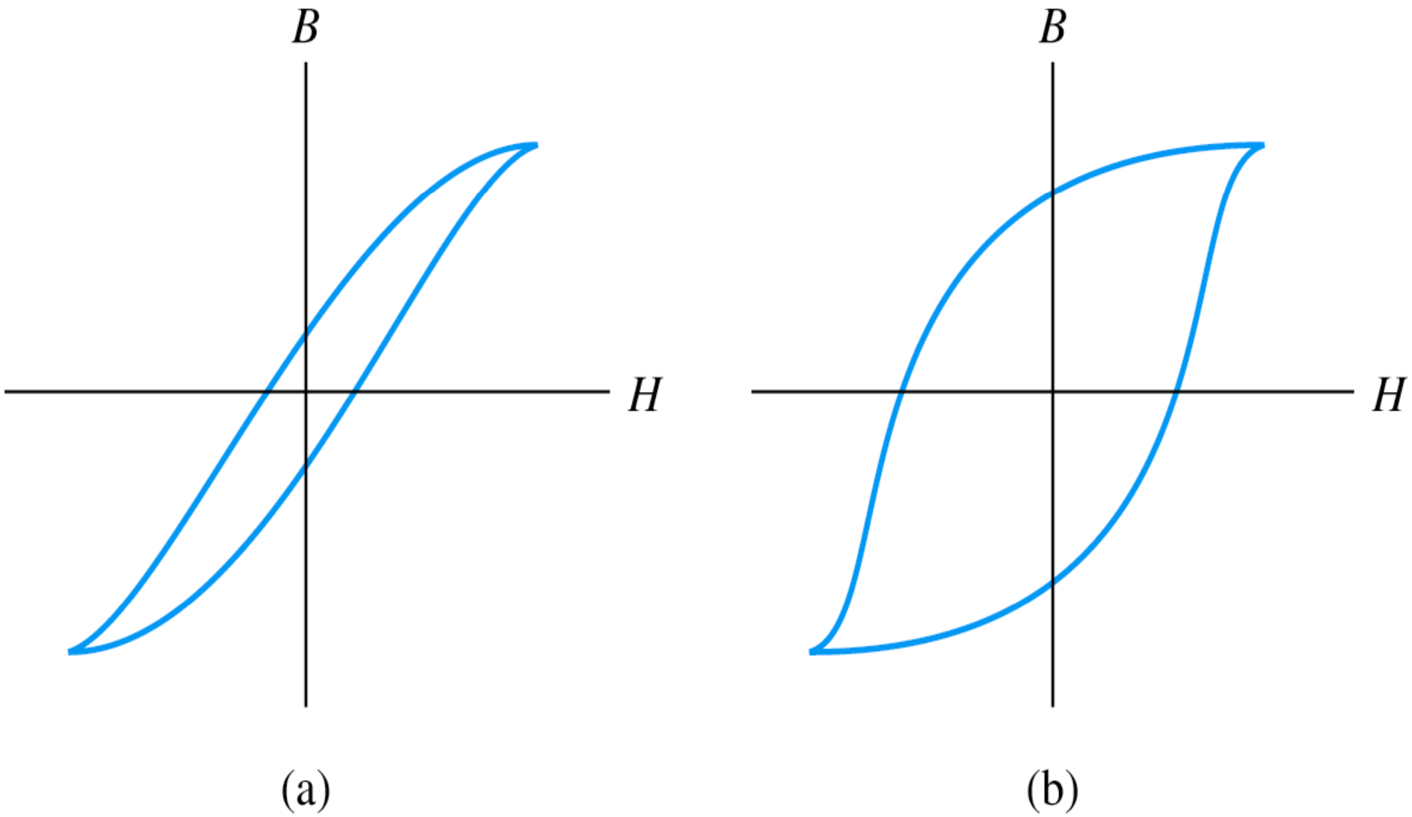
   High permeability, easily magnetized and demagnetized, extremely small hysteresis, iron and its alloys with nickel, cobalt tungsten and aluminium

   suitable for transformers, inductors, generators telephone

   recievers.

2. Hard Ferromagnetic material relatively low permeability, difficult to magnetize and demagnetize, relatively high hysteresis loss, high coercive force, cobalt steel and various alloys of nickel, aluminium and cobalt.(cobalt steel)

   Permanent magnets in loud speakers



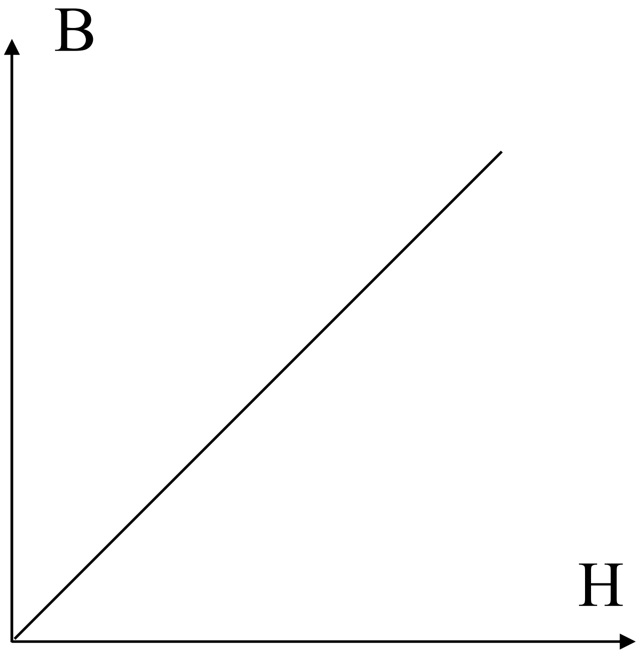
(a) (b)

Figure 15.21 When we want to minimize core loss (as in a transformer or motor), we choose a material having a thin hysteresis loop. On the other hand, for a permanent magnet, we should choose a material with a wide loop.

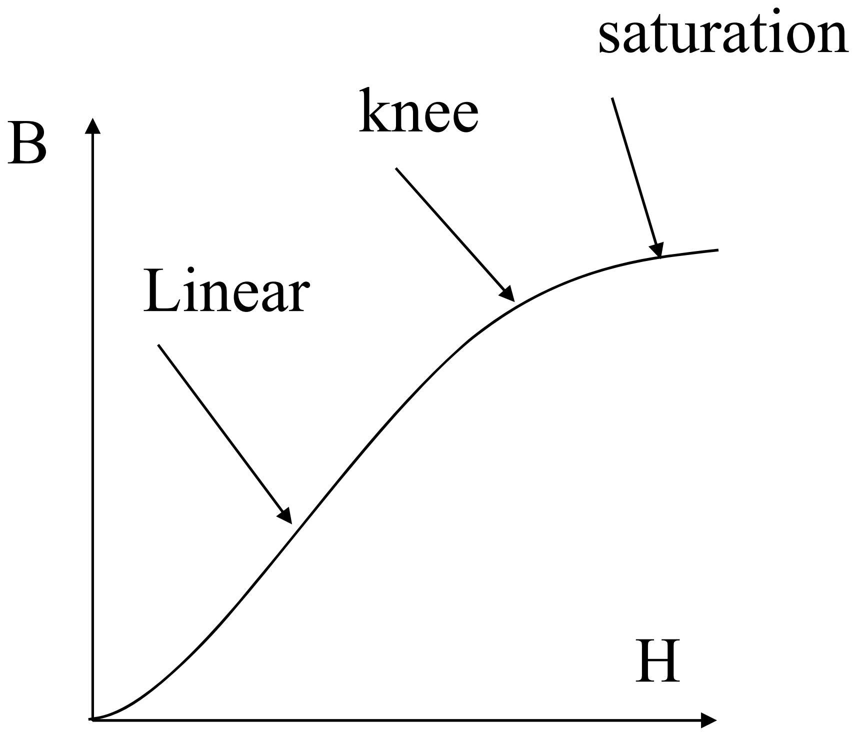
Permanent Magnets

- Alloys of Iron, Cobalt and Nickle
- Have large B-H loops, with large B_r and $-H_c$
- Due to heat treatment becomes mechanically hard and are thus called HARD IRON
- Field intensity is determined by the coercive field required to demagnetize it

Magnetization Curves

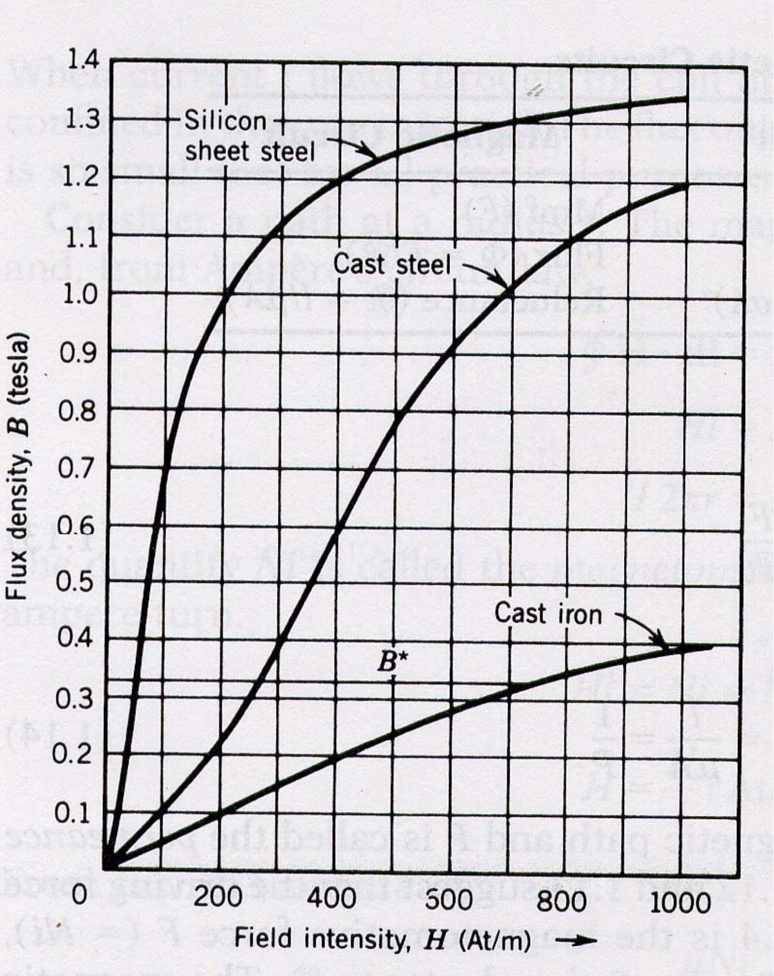


Magnetization curve
(linear) (Ideal) Air



Magnetization curve
(non-linear) iron,etc.

Magnetization Curves (for examples)



Magnetization Curves(2)

•One can linearize magnetic circuits by including air-gaps

•However that would cause a large increase in ampere-turn requirements.

Ex: Transformers don’t have air-gaps. They have very little magnetizing current (5% of full load)

Induction motors have air-gaps. They have large magnetizing current (30-50%)

Question: why induction motors have air –gap and transformers don’t?

Iron Losses in Magnetic Circuit

There are two types of iron losses

a) Hysteresis losses

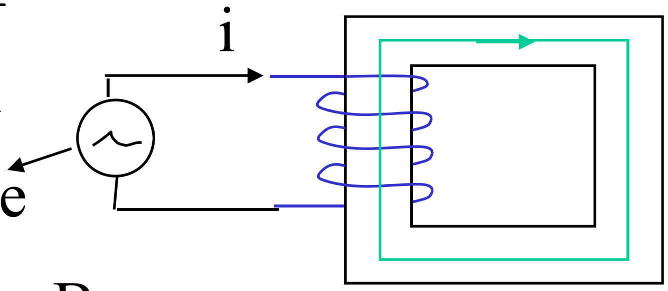
b) Eddy Current Losses

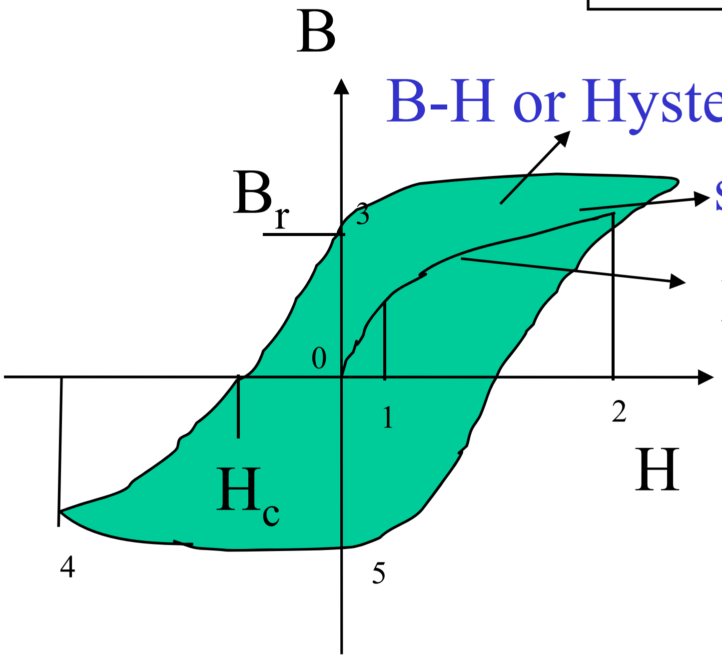
Total iron loss is the sum of these two losses

Hysteresis losses

$$f = \frac{1}{T}$$

f =frequency of sine source

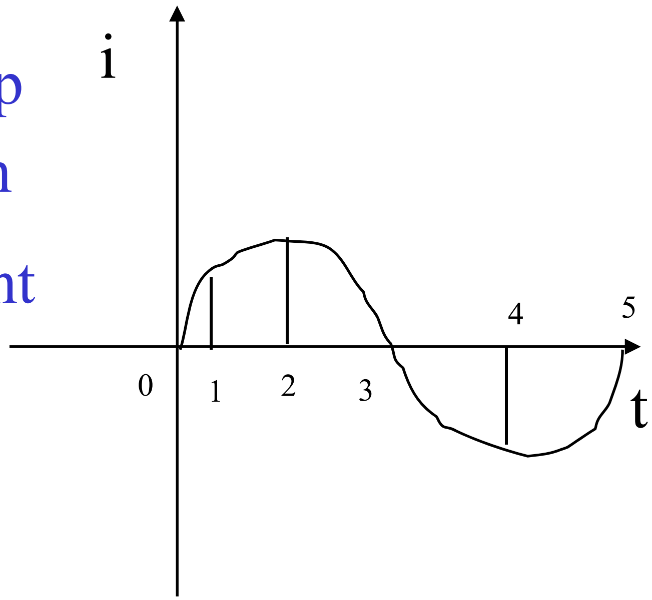




B-H or Hysteresis loop

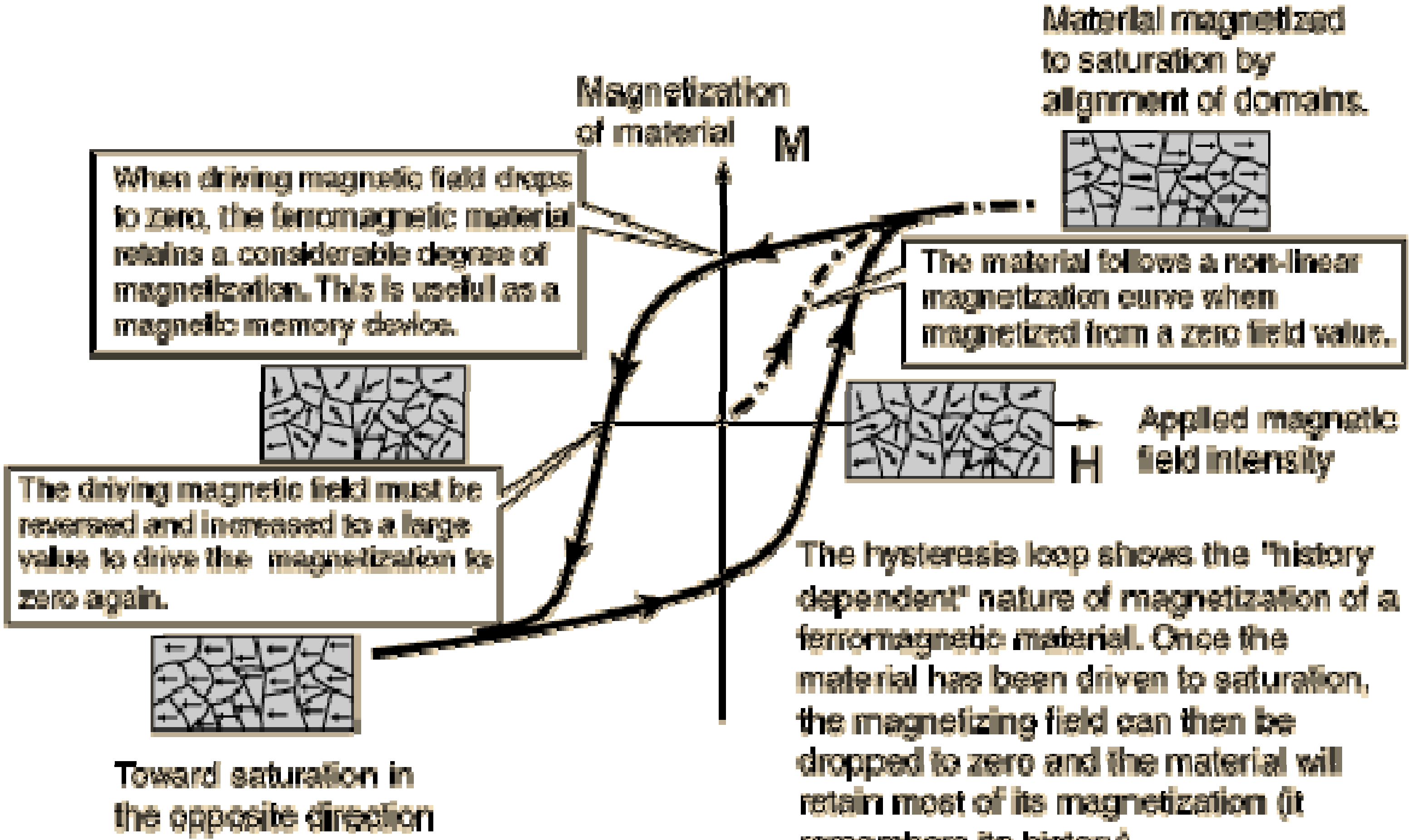
saturation

knee point



B_r = Retentive flux density (due to property of retentivity)

H_c= Coercive field intensity (due to property of coercivity)



Material magnetized to saturation by alignment of domains.

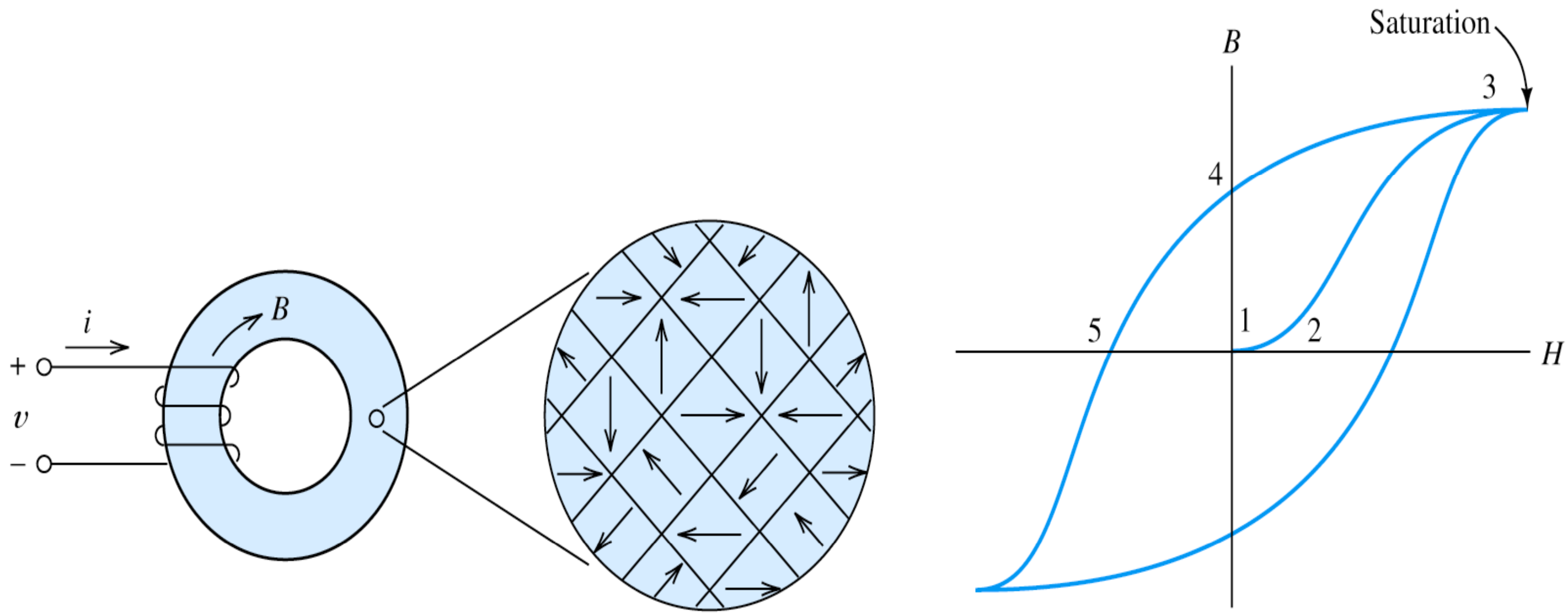
When driving magnetic field drops to zero, the ferromagnetic material retains a considerable degree of magnetization. This is useful as a magnetic memory device.

The material follows a non-linear magnetization curve when magnetized from a zero field value.

The driving magnetic field must be reversed and increased to a large value to drive the magnetization to zero again.

Toward saturation in the opposite direction

The hysteresis loop shows the "history dependent" nature of magnetization of a ferromagnetic material. Once the material has been driven to saturation, the magnetizing field can then be dropped to zero and the material will retain most of its magnetization (it remembers its history).



(a) Sample and coil for applying H (b) Magnetic domains (c) Hysteresis loop in the $B-H$ plane

Figure 15.18 Materials such as iron display a $B–H$ relationship with hysteresis and saturation.

Hysteresis losses (2)

- The lagging phenomenon of B behind H is called hysteresis

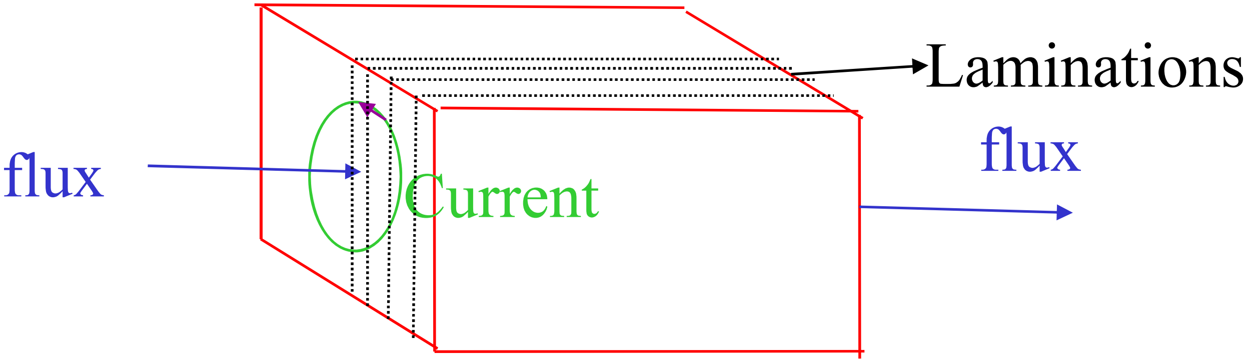
- In each of the current cycle the energy lost in the core is proportional to the area of the B-H loop

- Energy lost/cycle = $V_{core} \oint HdB$

- P_h = Hysteresis loss = $f V_{core} \oint HdB = k_h B^n_{max} f$

k_h = Constant, n = 1.5-2.5, B_{max} = Peak flux density

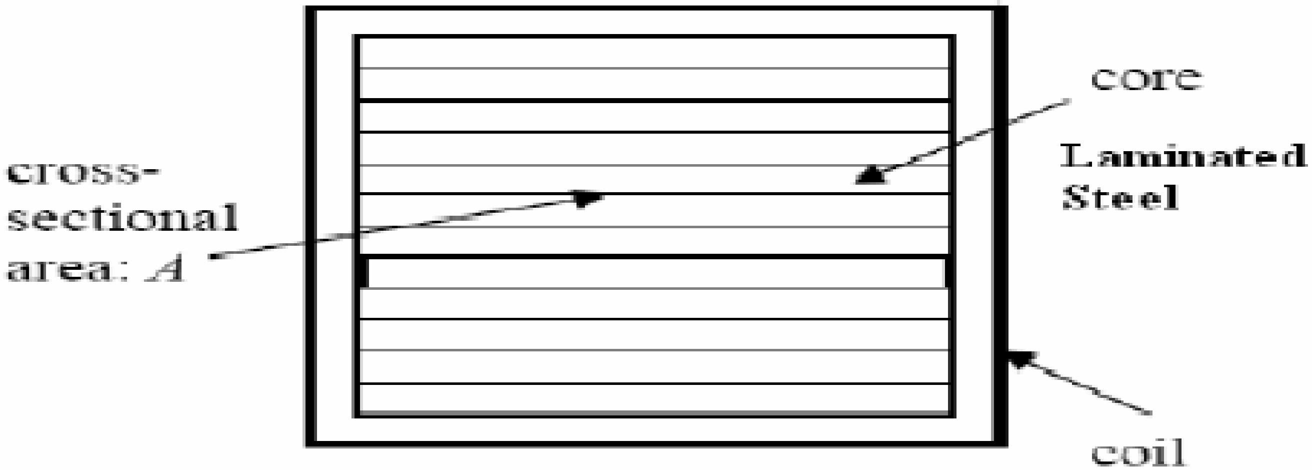
Eddy current loss



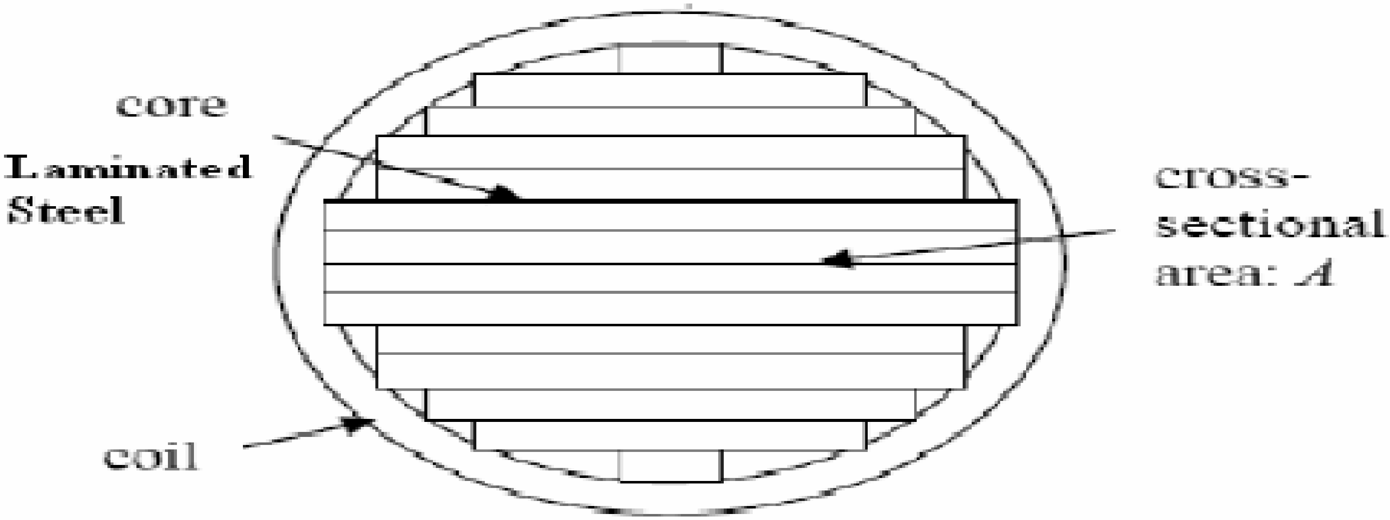
Because of time variation of flux flowing through the magnetic material as shown, current is induced in the magnetic material, following Faraday’s law. This current is called eddy current.
The direction of the current is determined by Lenz’s law. This current can be reduced by using laminated (thin sheet) iron structure, with Insulation between the laminations.

- P_e = Eddy current loss $= k_e B^2_{max} f$

k_e = Constant , B_{max} = Peak flux density

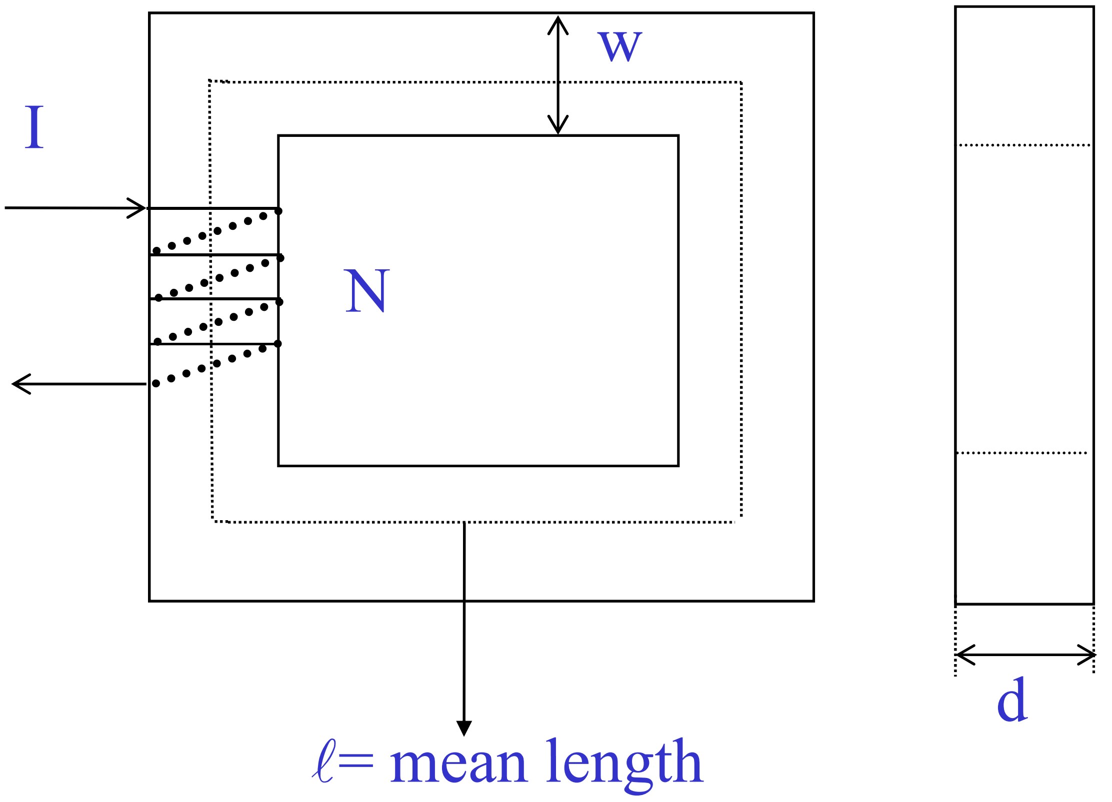


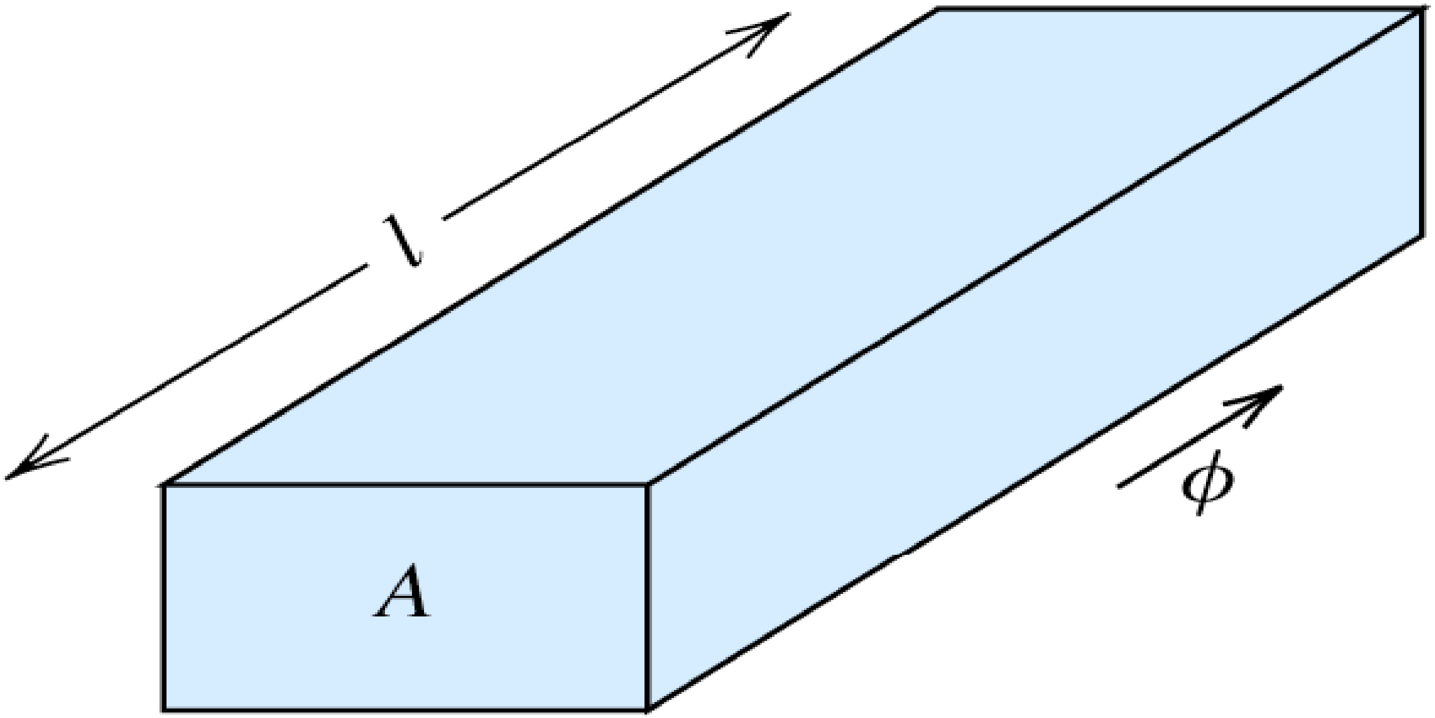
(a) Square core



(b) Stepped core

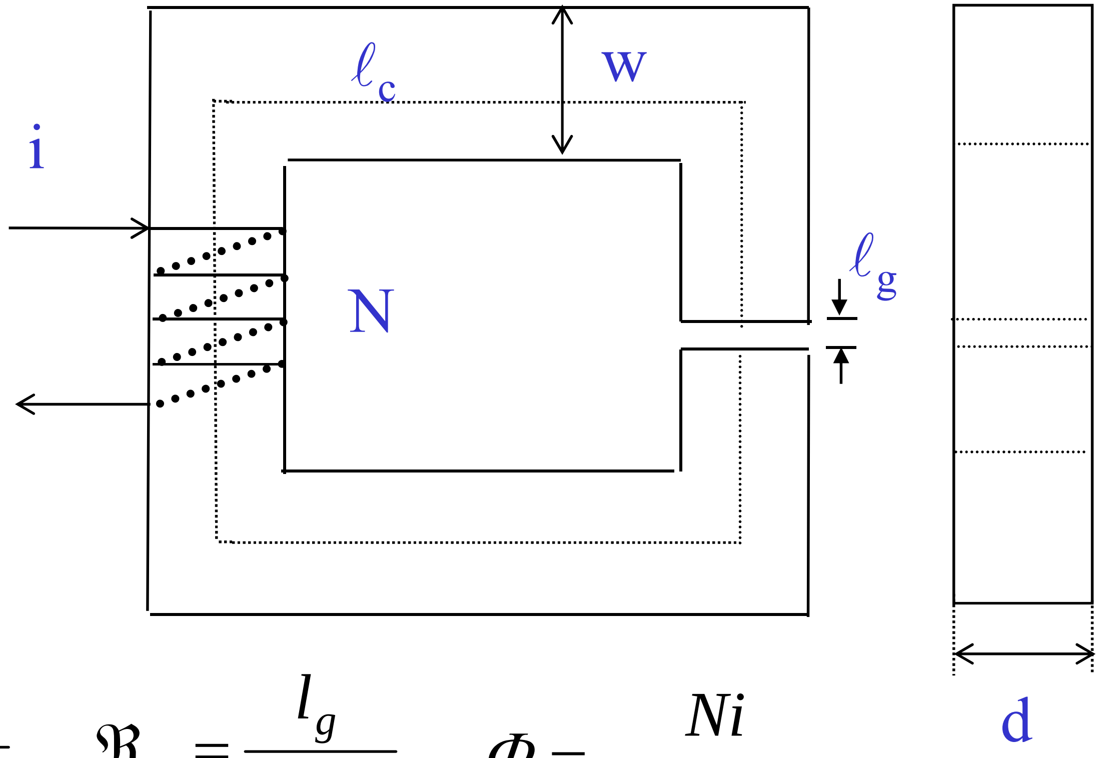
Magnetic Circuits (1)





$$\mathcal{R} = \frac{l}{\mu A}$$

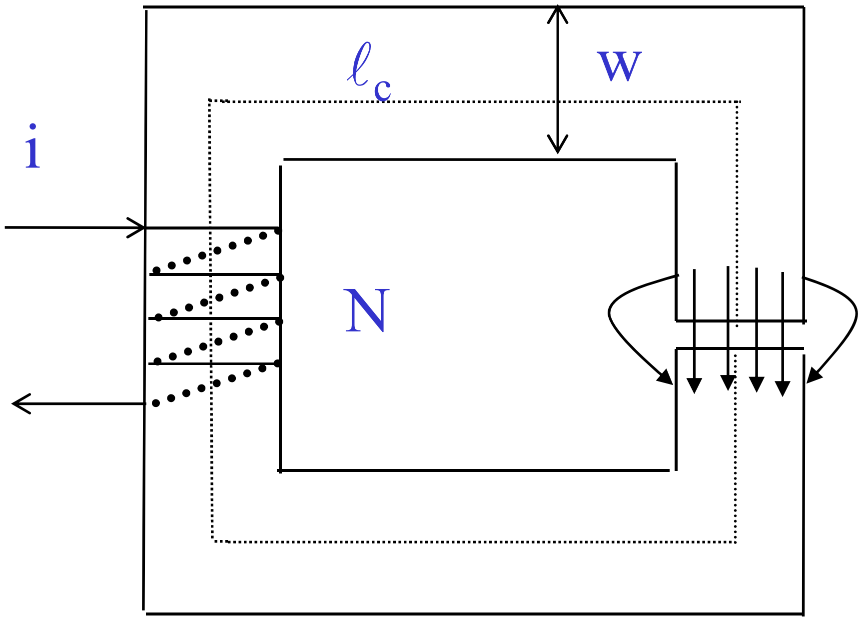
Magnetization Circuits with Air-gap



$$\Re_c = \frac{l_c}{\mu_c A_c} \qquad \Re_g = \frac{l_g}{\mu_g A_g} \qquad \Phi = \frac{Ni}{\Re_c + \Re_g}$$

$$Ni = H_c l_c + H_g l_g \qquad A_c = A_g = wd\,(Neglecting\ fringing)$$

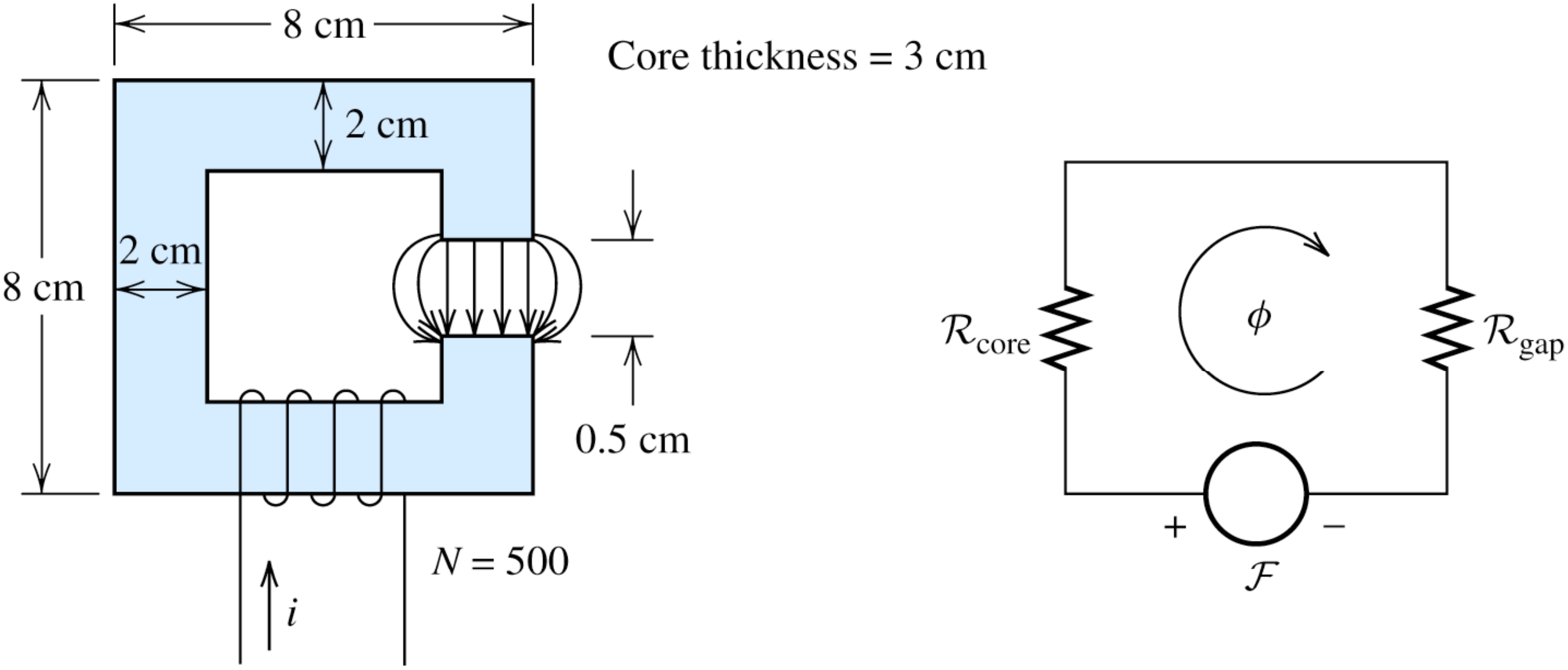
Fringing



With large air-gaps, flux tends to leak outside the air –gap. This is called fringing which increases the effective flux area. One way to approximate this increase is:

$$w_n = w + l_g ; d_n = d + l_g ; A_{gn} = w_n d_n$$

Find Exciting current if B=1.2T and μ_r=6000 with and without fringing

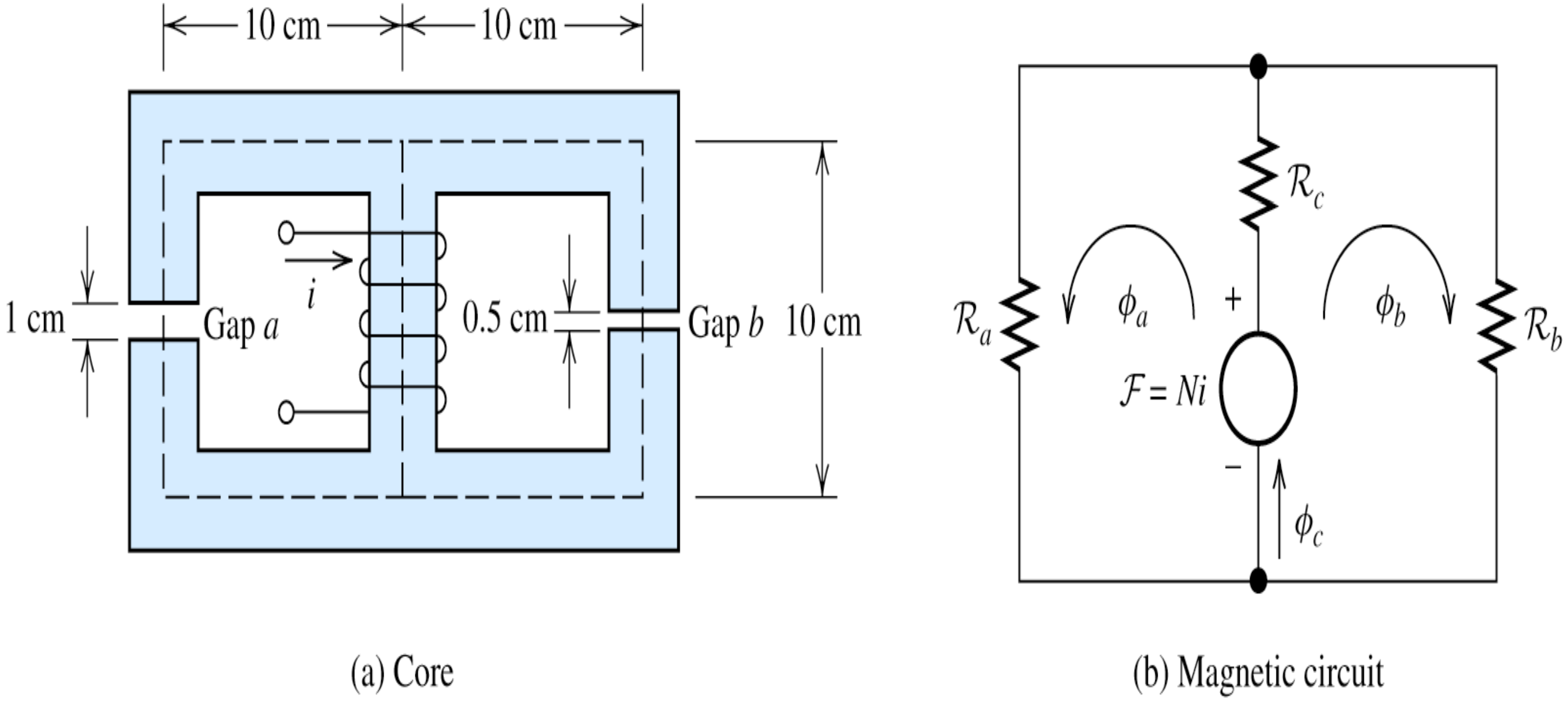


(a) Iron core with an air gap

(b) Magnetic circuit

Figure 15.12 Magnetic circuit of Example 15.5.

A Magnetic Circuit with Reluctances in Series and Parallel (Find I)



(a) Core

(b) Magnetic circuit

Figure 15.13 Magnetic circuit of Example 15.6.

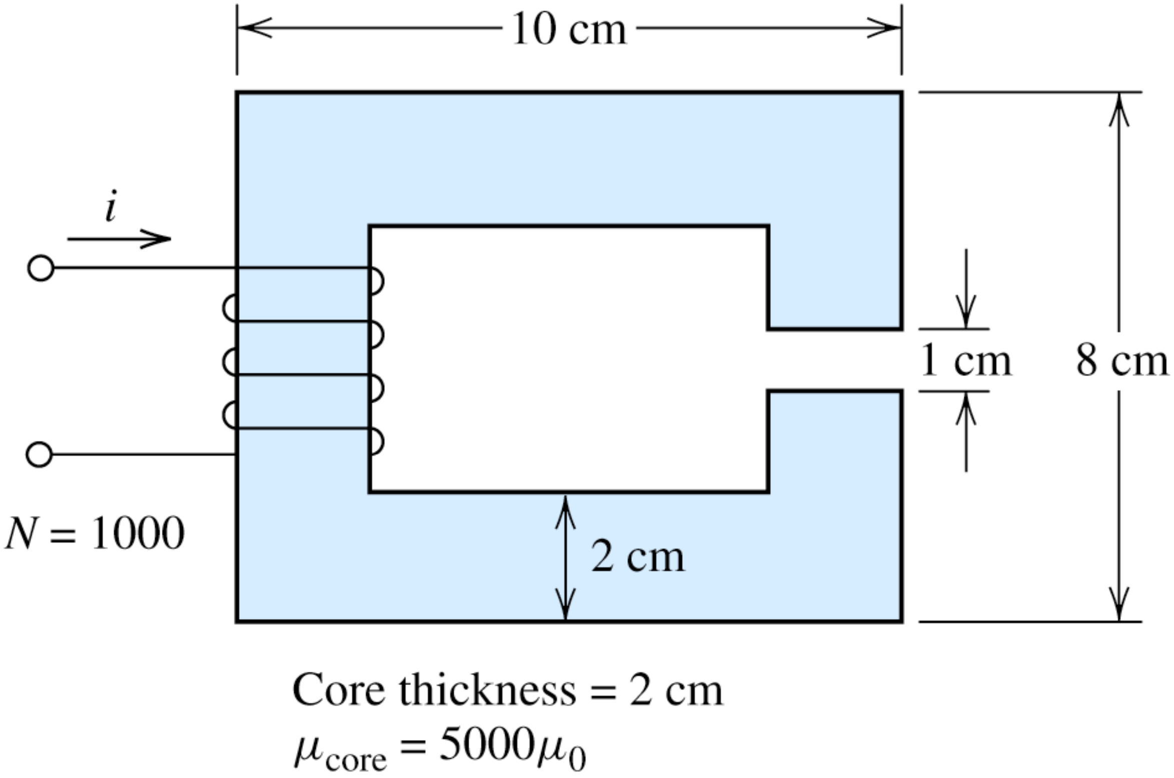


Figure 15.14 Magnetic circuit of Exercise 15.9.

Static emf Dynamic emf

When the conductor in which the emf is induced is stationary then the emf is called static emf .

- Eg . Transformer
- When the conductor in which the emf is induced is moving one then the emf is called dynamic emf.

- eg. D.C. generator

Faraday’s law of Electromagnetic Induction

The EMF (Electromotive Force) induced in a magnetic circuit is Equal to the rate of change of flux linked with the circuit and is opposite to the cause which produces it.

$$e = -\frac{d\lambda}{dt} = -\frac{d(N\Phi)}{dt} = -N\frac{d\Phi}{dt} \qquad \phi = \frac{Ni}{l/\mu A}$$

$$e = -N\frac{d}{dt}\left[\frac{Ni}{l/\mu A}\right] \qquad e = -\frac{N^2\mu A}{l}\frac{di}{dt}$$

$$L = \frac{N^2\mu A}{l} \qquad \therefore e = \frac{dLi}{dt} = L\frac{di}{dt}$$

Dynamically induced emf

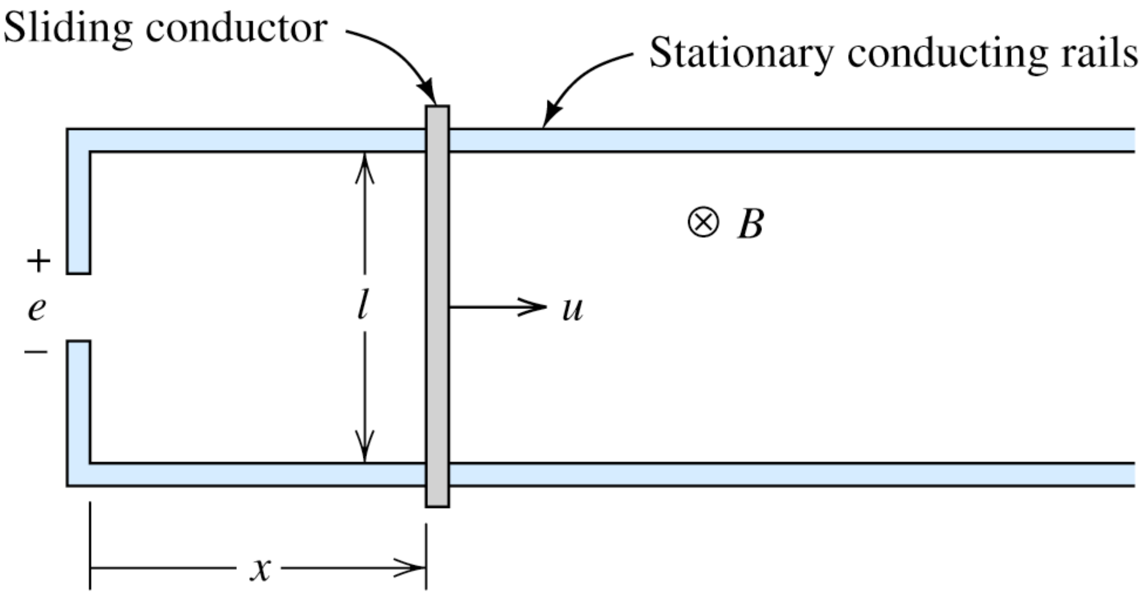
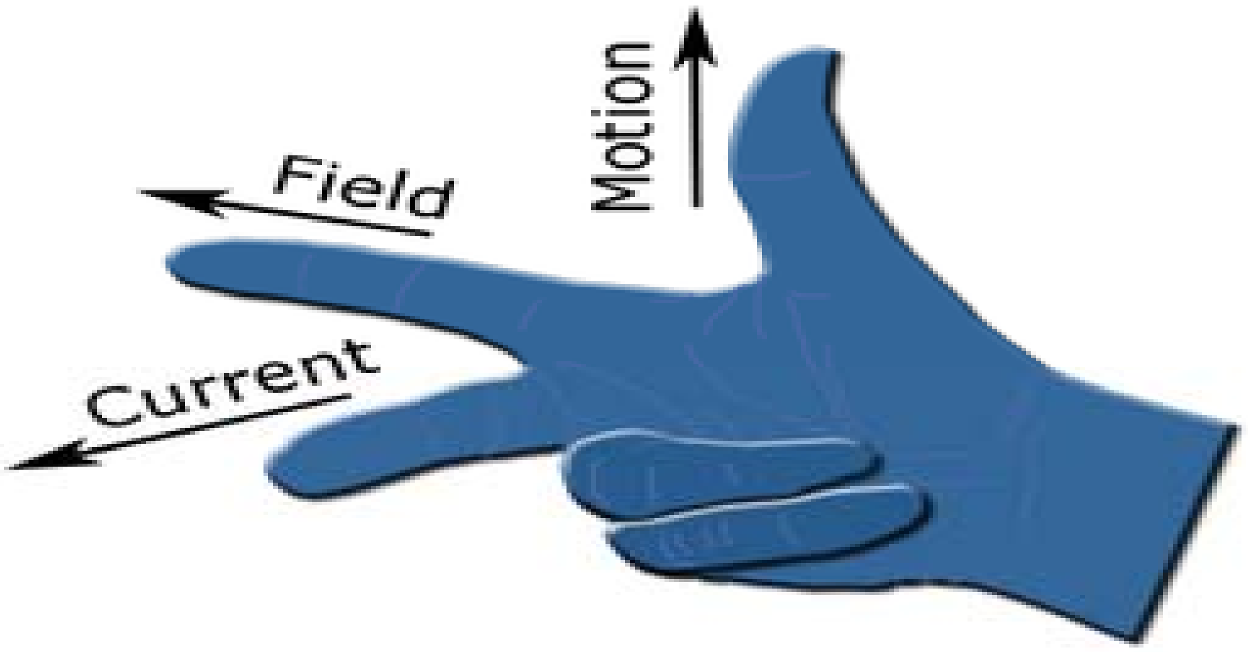
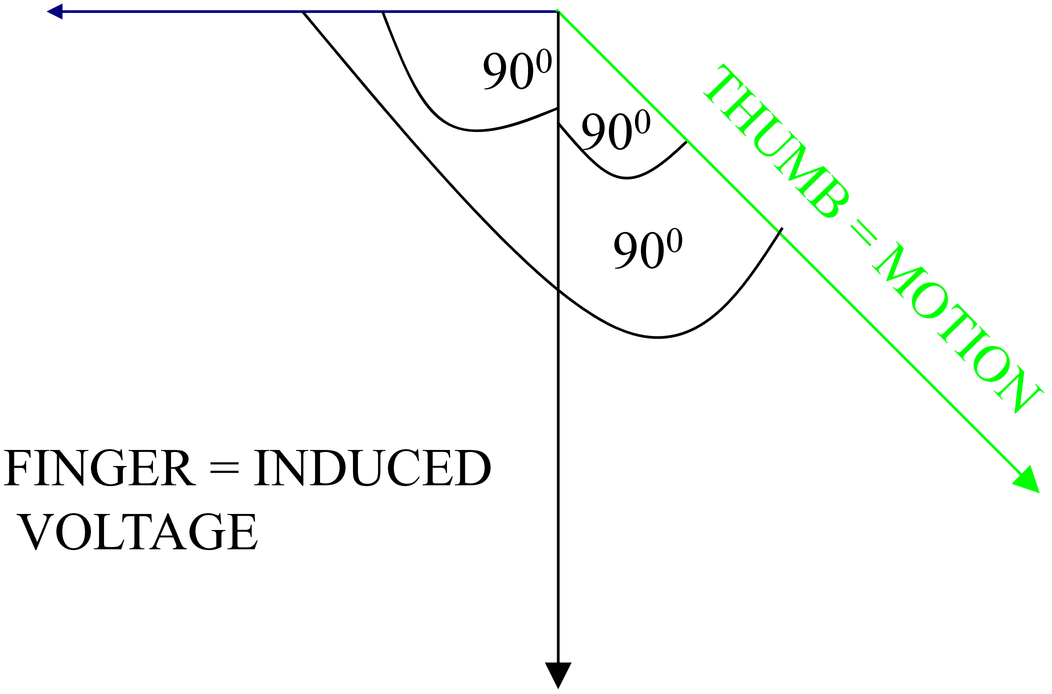


Figure 15.5 A voltage is induced in a conductor moving so as to cut through magnetic flux lines.

Flemings right hand rule



Fleming's Right Hand Rule Or Generator Rule

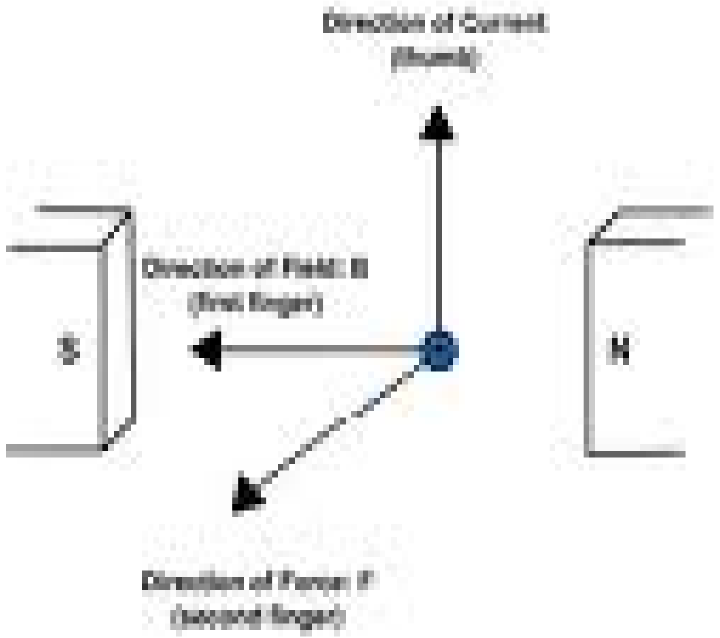


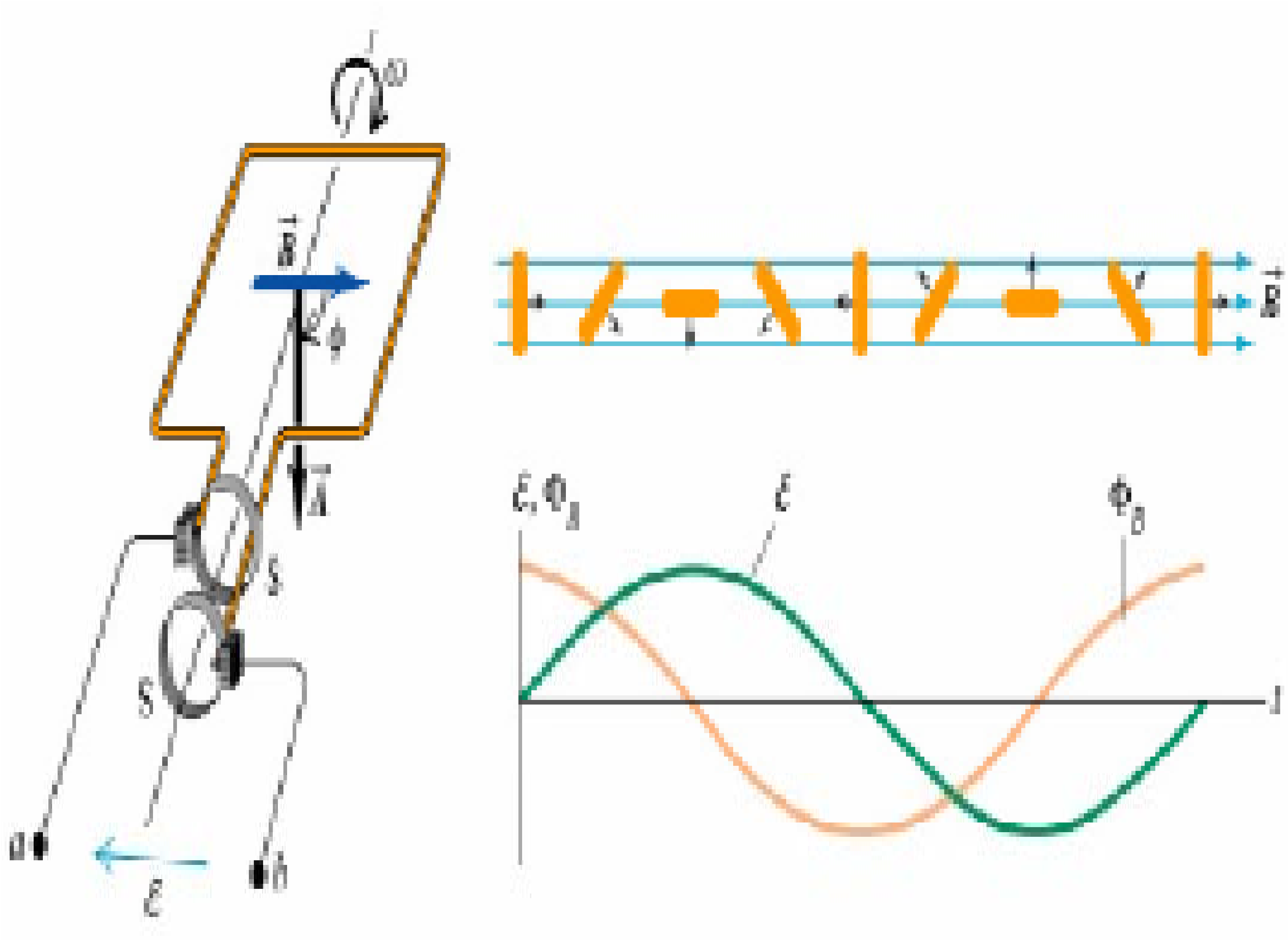
FORE FINGER = MAGNETIC FIELD

THUMB = MOTION

MIDDLE FINGER = INDUCED VOLTAGE

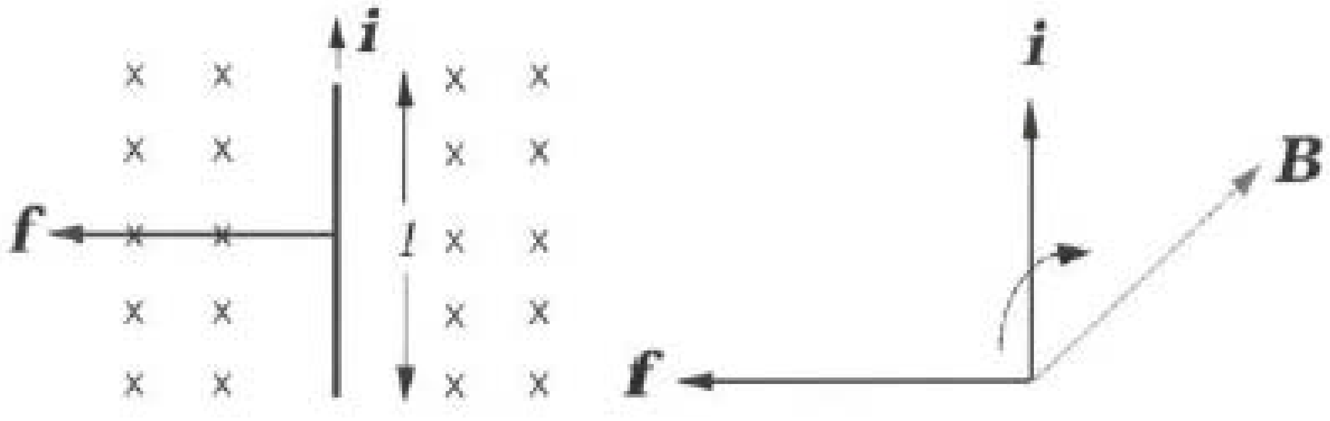
VOLTAGE = B *l u*


Direction of Current
(thumb)
Direction of Field: B
(first finger)
S
N
Direction of Force: F
(second finger)



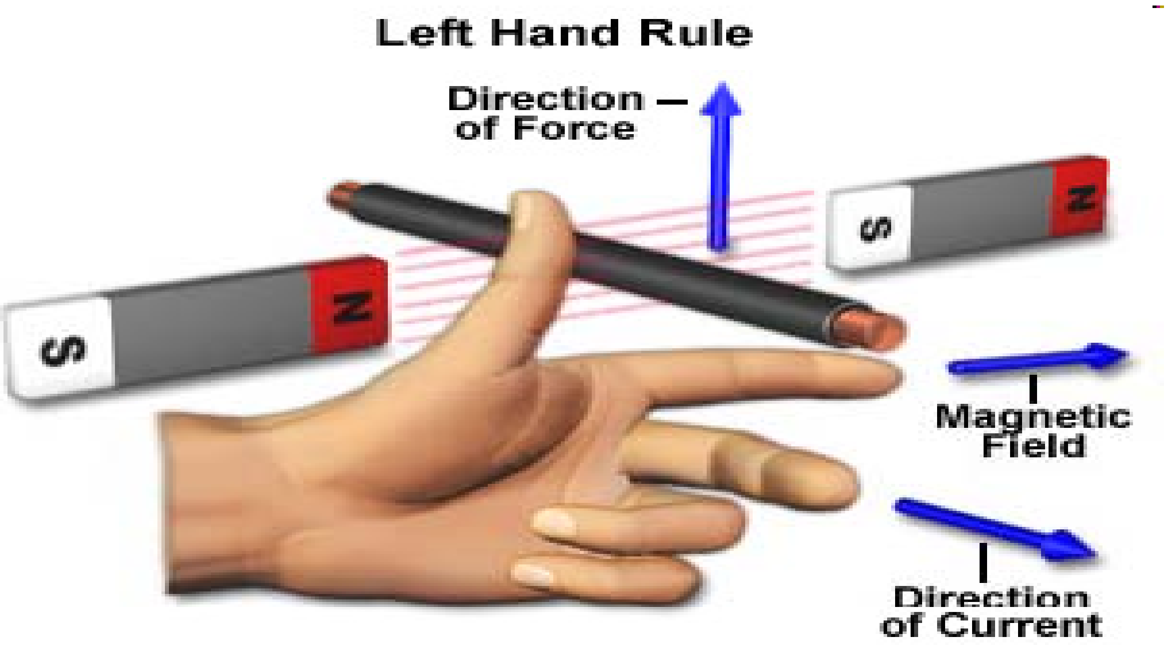
ω
$\vec{B}$
ϕ
$\vec{A}$
S
S
a
b
ℰ
$\vec{B}$
ℰ, Φ_B
ℰ
Φ_B
t

Electromagnetic Force, *f*



f=Bli, where B, f and i are mutually perpendicular. Turn the current vector i towards the flux vector B. If a right hand screw is turned in the same way, the direction in which the screw will move represents the direction of the force f.

Flemings left hand rule



EMEC TEST

Q.1 Explain the Magnemotive force,reluctance,magnetic flux density (6)

Q.2 Differentiate between magnetic and electric circuits (4)

Q.3A wrought iron bar 30 cm long and 2 cm in diameter is bent into a circular shape .It is then wound with 600 turns of wire . Calculate the current required to produce a flux of .5 mWb in magnetic circuit in the following cases:

i) no air-gap

ii) With an air gap of 1mm and μ=4000 and (10) iii)With an air gap of 1mm ; assume the following data for the magnetization of iron:

H	2500	3000	3500	4000
B	1.55	1.59	1.6	1.615

ANSWERS

- I =0.158 (with no air gap)
- I=2.258 (with air gap)
- ATg = Hglg =1260
- Hc = 3000AT/m
- AT =2160
- I=2160/600 =3.6 A

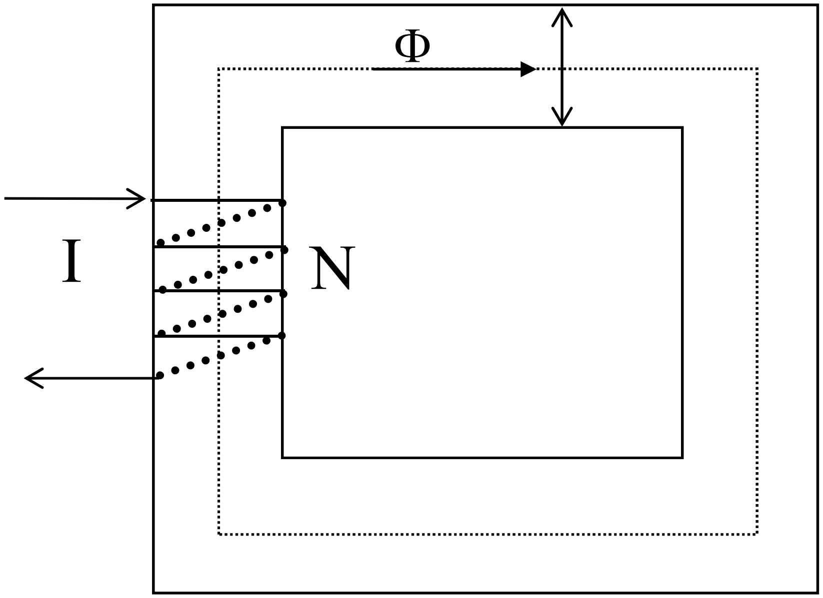
Inductance(L)

Definition: Flux Linkage(λ) per unit of current(I) in a magnetic circuit

$$L = \frac{\lambda}{I} = \frac{N\Phi}{I}$$

$$\Phi = \frac{NI}{\Re}$$

$$\therefore L = \frac{N^2}{\Re}$$



Thus inductance depends on the geometry of construction