Unit-4
Magnetic Circuits

- The branch of engineering which deals with the magnetic effect of electric current is called electro magnetism

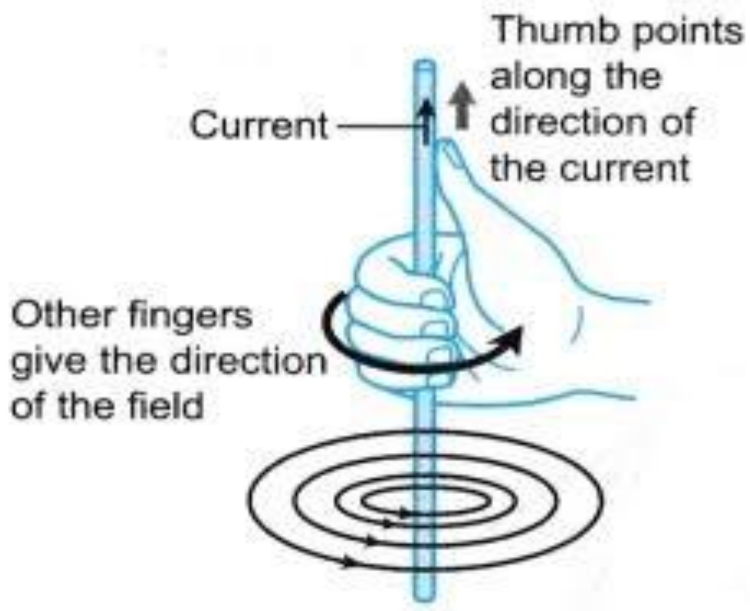


Figure (a)

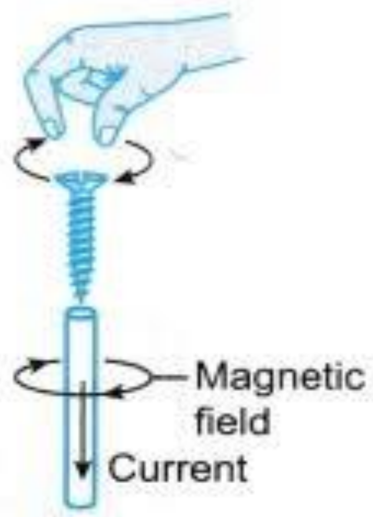
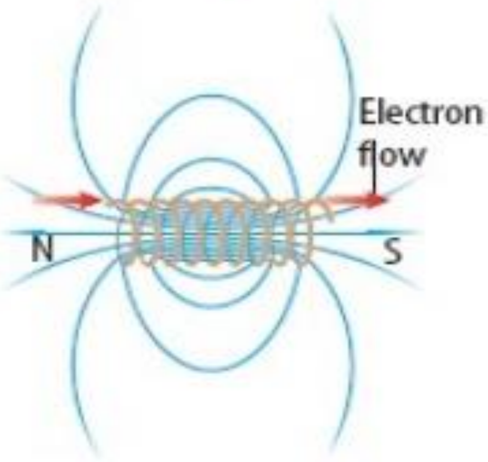
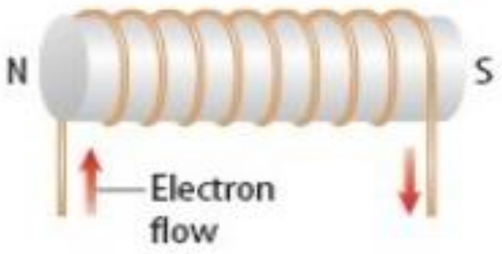


Figure (b)

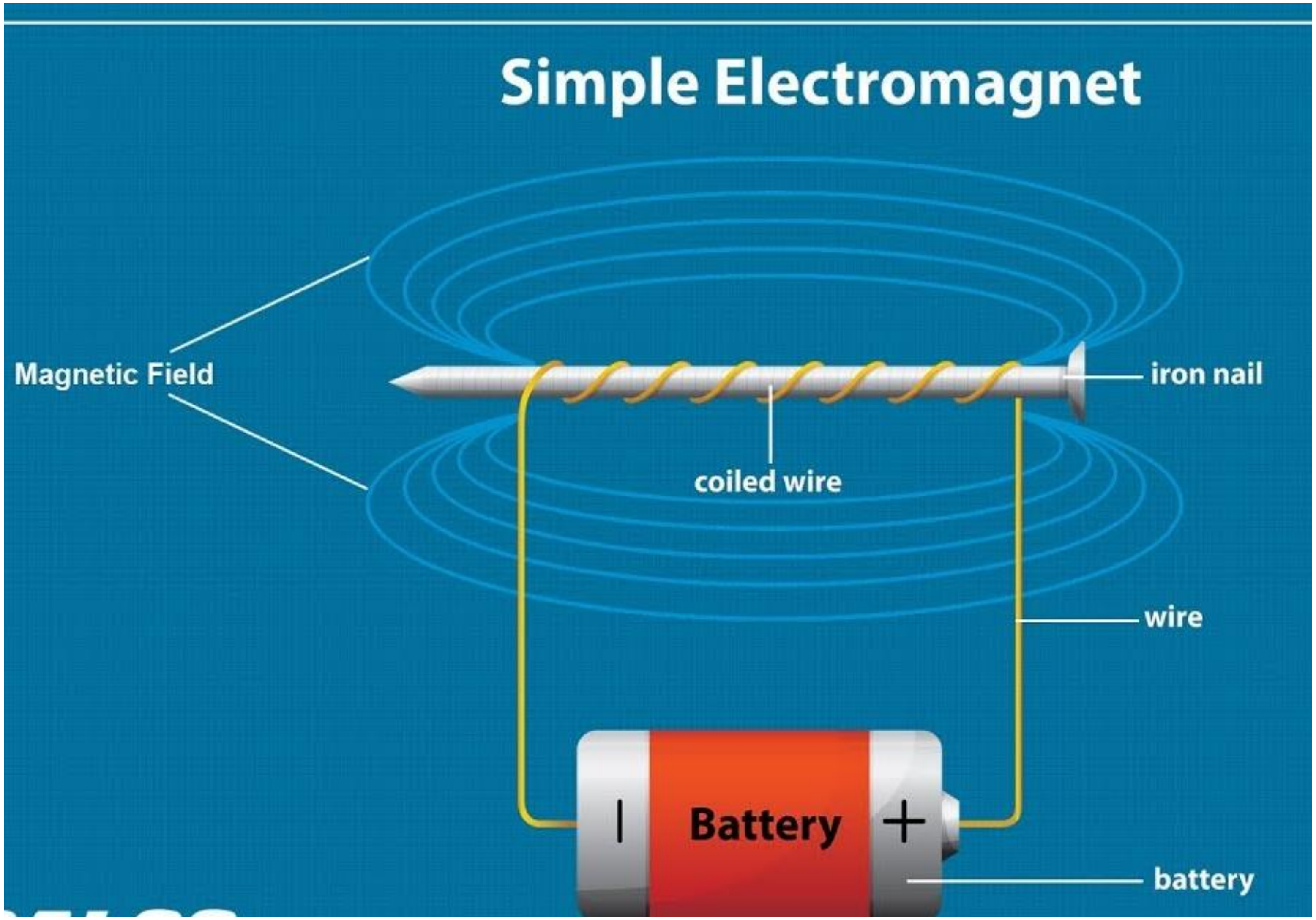
Electro magnet Vs Permanent magnet

- Electro magnet: When an electric current is passed through a coil of wire wrapped around a metal core, a very strong magnetic field is produced. This is called an electromagnet.





An iron core inserted into the coil becomes a magnet.

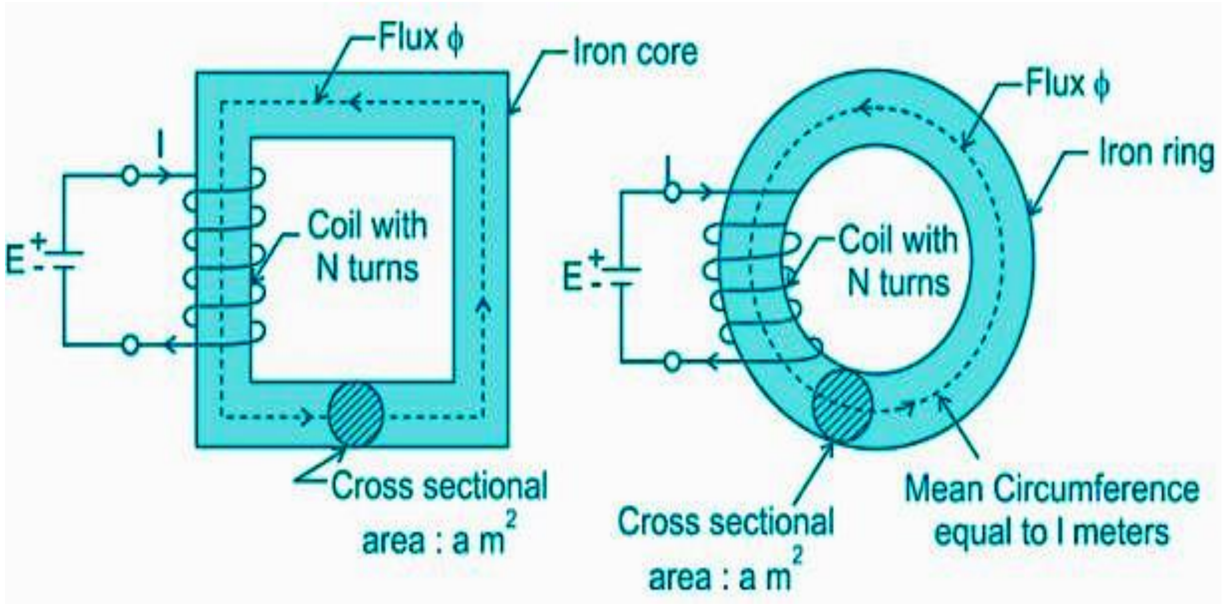


Simple Electromagnet
Magnetic Field
iron nail
coiled wire
wire
Battery
+
battery

Permanent Magnet

- A **magnet** is a material or object that produces a magnetic field. This magnetic field is invisible but is responsible for the most notable property of a magnet: a force that pulls on other ferromagnetic materials such as iron, steel, nickel, cobalt etc. and attracts or repels other magnets.

Concept of Magnetic circuit



As shown in Fig a conducting material coil is wound on various shapes of the core of same or different materials. When current is passed through these coils, this current will set up flux lines. These lines will follow a closed path as shown in Fig. This closed path, followed by magnetic flux is called as magnetic circuit.

Terms related to Magnetic Circuits

- The magnetic flux setup in the magnetic circuit depends upon the various factors, such as

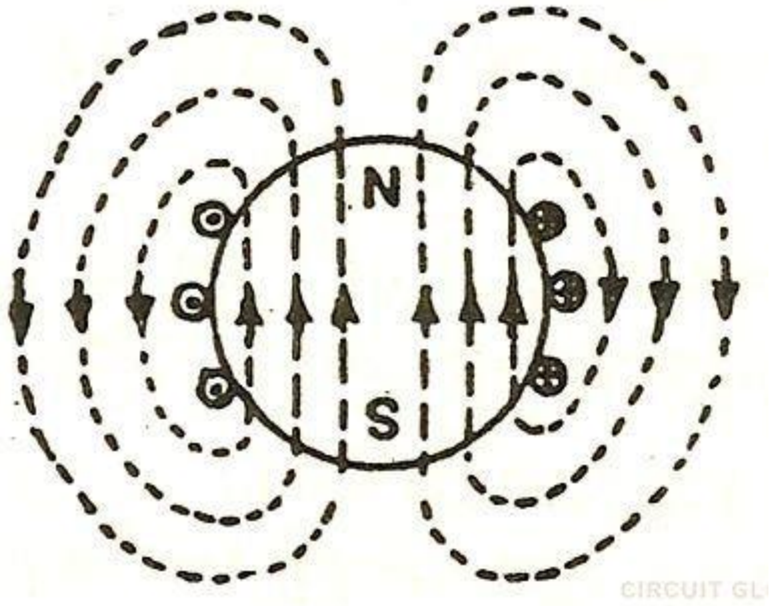
1. Number of turns of the coil
2. Magnitude of the current in the coil
3. Length of the magnetic path i.e Magnetic circuit
4. Core material
5. Cross-Section of the core

Important Terms regarding to Magnetic circuit

- Magnetic flux
- Magnetic flux density
- Reluctance
- Magneto motive force (m.m.f)
- Magnetic field intensity
- Magnetic permeability
- Magnetic susceptibility

Magnetic flux

- The number of magnetic lines of forces set up in a magnetic circuit is called **Magnetic Flux**. It is analogous to electric current, I in an electric circuit. Its SI unit is Weber (Wb) and its CGS unit is Maxwell. It is denoted by ϕ.



Magnetic flux density

- Surface magnetic flux density at any point is the magnetic flux passing or linking per unit area of a surface at right angles to the magnetic flux lines direction. Flux density is denoted by a letter 'B'

If Φ is the flux in webers, A is the area of cross section, then

$B=\frac{\emptyset}{A}$ weber/meter2 or it may also be expressed in Tesla.

Magneto motive force

- As in electric circuit current flows due to the existence of electro-motive force (i.e emf) across the circuit, similarly to drive magnetic flux through a magnetic circuit a magneto motive force(i.e mmf) is required

- **Hence MMF of magnetic circuit is analogous to emf in the electric circuit.**

- If number of turns of the coil are N and I amperes current is flowing through it, then, mmf=NI
- Since N is in turns, current in amperes, so the mmf is measured in ampere-turns, which is generally written as AT

Magnetic Field Strength (H)

A magnetic field strength is defined as the mmf required to circulate the flux through unit (1 m) length of the magnetic circuit. It is also called as **Magnetic Field Intensity or Magnetizing Force.**

$$\therefore H = \frac{mmf}{Length} = \frac{IN}{\ell} \text{......Amperes / metre}$$

Absolute Permeability (μ)

An absolute permeability μ is defined as the ratio of the magnetic flux density 'B' to the magnetic field strength 'H'. It can also be defined as the magnetic flux density produced by an unit (1 A/m) field strength.

i.e. $\mu = \frac{B}{H}$ ....Henrys / metre or (H / m)

Absolute Permeability (μ)

In SI it is measured in henry/metre (H/m). One henry/metre is defined as the absolute permeability of the magnetic core material or medium which produces the magnetic flux density of one tesla (1 Wb/m^2) for the magnetic field strength of one ampere per metre.

$$\therefore 1 \text{ henrey / metre} = \frac{1\,T}{1\,A/m} = \frac{1\,Wb/m^2}{1\,A/m} = 1\ Wb/Am$$

Permeability of Free Space (μ_0)

It is found that the ratio of B to H i.e. the permeability m is constant for the free space, vacuum, air or non-magnetic materials such as wood, glass, rubber, brass etc.

This constant permeability is termed as the permeability of free space and is denoted by μ_0. It is also called the **magnetic constant.**

μ_0 is also measured in henry/metre just similar to the absolute permeability μ.

The constant value of μ_0 is $4\pi \times 10^{-7}$ H/m.

Relative Permeability (μ_r)

A relative permeability is defined as the ratio of absolute permeability μ to the permeability of free space μ_0.

i.e. $\mu_r = \dfrac{\mu}{\mu_0}$

Thus the absolute permeability μ may be expressed as

$\mu = \mu_0 \mu_r$ ....H/m

Where the term μ_r denotes the relative permeability of the medium material w.r.t. the free space.

As μ and μ_0 are measured in (H/m) and $\mu_r = \dfrac{\mu}{\mu_0}$, μ_r is a pure number. It has no unit.

Properties of μ_r

1) As $\mu = \mu_0$ for free space, vacuum, air and non-magnetic materials such as wood, glass rubber, paper, brass etc.

   $\mu_r = 1$ for free space, vacuum, air and non-magnetic materials.

2) μ_r has different values for different magnetic materials such as hard steel, wrought iron, sheet steel etc.

3) Even for a particular magnetic material, μ_r is not constant. Its value varies with the values of H or B.

Reluctance (S) and Permeance

1) Reluctance (S)

A reluctance is defined as the opposition of the magnetic circuit to the passage of the magnetic flux through it.

The reluctance of the magnetic circuit is,

i) directly proportional to the length 'ℓ' of the magnetic circuit (path). i.e. $S \propto \ell$

ii) inversely proportional to the cross-sectional area 'a' of the circuit. i.e. $S \propto \frac{1}{a}$

Thus $S \propto \frac{\ell}{a}$

$$\therefore S = \frac{\ell}{\mu a} = \frac{\ell}{\mu_r \mu_0 a}$$

Where $\mu = \mu_0 \mu_r$ is the constant of proportionality for the magnetic material which is known as the absolute permeability of the material as seen earlier.

Thus the reluctance is inversely proportional to the absolute permeability of the medium through which the flux is set up.

i.e. $S \propto \frac{1}{\mu} \propto \frac{1}{\mu_0 \mu_r}$

As reluctance and $S = \frac{\ell}{\mu a}$ and SI units of 'ℓ', 'μ' and 'a' are metre, Wb/A.m and m^2, the SI unit of 'S' comes out to be $\frac{m}{(Wb/Am)m^2} = \frac{A}{Wb}$ i.e. Ampere per Weber.

Thus the reluctance is measured in ampere/weber (A/Wb).

Permeance

The permeance of the magnetic circuit is defined as the property of the magnetic circuit due to which it permits the passage of magnetic flux through it. This term is inverse or reciprocal of the reluctance.

$$\text{i.e.}\quad \text{Permeance} = \frac{1}{\text{Reluctance}} = \frac{1}{S} \quad \text{.......Wb / A}$$

The permeance is measured in webers per ampere (Wb/A).

OHMS LAW FOR MAGNETIC CIRCUIT

This law relates flowing quantity to the forcing quantity with due consideration of the opposing quantity in the magnetic circuit.

The Ohm's law for the magnetic circuit states that the flux (ϕ) passing through the magnetic circuit is directly proportional to the magnetomotive fore (mmf) and inversely proportional to the reluctance (S) of the magnetic circuit.

i.e. $$\phi = \frac{\text{mmf}}{S}$$

∴ The reluctance is given by,

$$S = \frac{mmf}{\phi} \text{ .... ampere - turns / weber}$$

Considering the SI units of mmf and 'ϕ' the reluctance 'S' is measured in amperes/weber (A/wb).

One ampere-turn/weber is defined as that reluctance of the magnetic circuit which passes a flux of one weber when the mmf is one ampere or one ampere-turn.

$$\text{i.e. } 1(A/Wb) \text{ Reluctance} = \frac{1\ (A)\ mmf}{1\ (Wb)\ flux}$$

Thus by Ohm's law for magnetic circuit,

$$S = \frac{\text{mmf}}{\phi}$$

But $\quad \text{mmf} = H \cdot \ell \qquad \left(\because H = \frac{\text{mmf}}{\ell} \text{ by definition} \right)$

and $\quad \phi = B \cdot a \qquad \left(\because B = \frac{\phi}{a} \text{ by definition} \right)$

Also $B = \mu H = \mu_0 \mu_r H$

$\therefore \phi = Ba = \mu Ha = \mu_0 \mu_r Ha$

and hence reluctance S is given by,

$$S = \frac{H \cdot \ell}{\mu Ha} = \frac{\ell}{\mu a} = \frac{\ell}{\mu_0 \mu_r a}$$

POINTS TO REMEMBER ABOUT RELUCTANCE

- The opposition offered to the magnetic flux in a magnetic circuit is called as Reluctance of the circuit.
- Reluctance of the magnetic circuit depends upon

1. Length of the magnetic path
2. Area of cross- section through which flux is passing
3. Nature of the magnetic material

- Reluctance of any magnetic circuit is

1. Directly proportional to the length of the magnetic path
2. Inversely proportional to the cross-sectional area of the material through which flux is passing
3. Inversely proportional to the permeability of the magnetic material or medium

Reluctance is denoted by letter '*S*' and its unit in SI units is AT/Wb

$$S = \frac{l}{\mu_0 \mu_r A} AT/Wb$$

THANK YOU