Magnetic Circuit

Introduction-

- Magnetic Circuit-

  The closed path followed by magnetic flux is called a magnetic circuit.

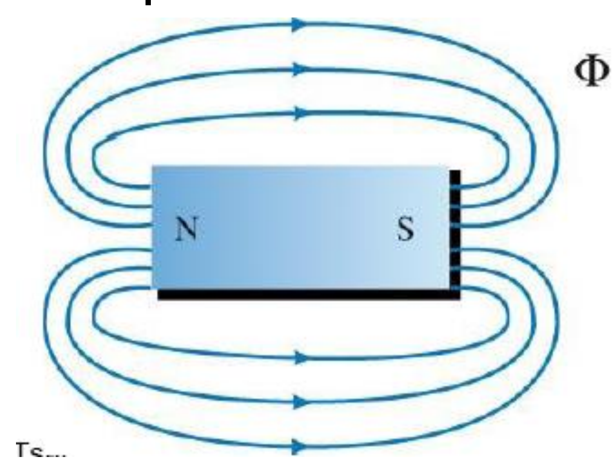
- Magnetism-

  Force of attraction or repulsion that acts between magnets and other magnetic materials.

- Flux lines-

  Show direction and intensity of this field at all points

- Field is strongest at poles and direction is from N to S



- Ferromagnetic materials are attracted by magnet because they provide an easy path for magnetic flux.

  e.g. Iron, nickel, cobalt, and their alloys

- Nonmagnetic materials such as plastic, wood, and glass have no effect on the field.

Magnetic Flux and Flux Density

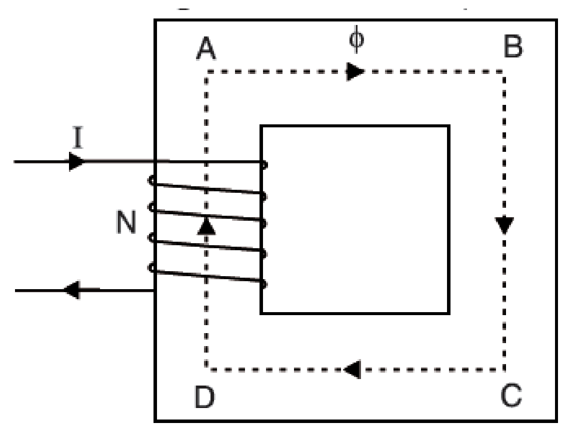
- Magnetic Flux(Φ) : Total number of magnetic lines of force passing through a given medium. It is measured in Webers (Wb)

- Flux density(B): It is defined as the number of magnetic lines of force per unit area of the magnetic circuit.

  $B = \Phi / A$

  Units for flux density- Wb/m2 or teslas (T)

Consider a coil of N turns wound on an iron core as shown in Fig. When current I is passed through the coil, magnetic flux ϕ is set up in the core. The flux follows the closed path ABCDA and hence ABCDA is the magnetic circuit.



- Magnetomotive force (m.m.f.)- It is a magnetic pressure which sets up or tends to set up flux in a magnetic circuit.

The product N* I is called the magnetomotive force (m.m.f.) and determines the amount of flux set up in the magnetic circuit.

$$\text{m.m.f.} = N\,I \quad \text{(ampere-turns)}$$

- Reluctance- The opposition that the magnetic circuit offers to magnetic flux is called reluctance. Its unit is AT/Wb.

The reluctance of a magnetic circuit depends upon its length, area of X-section and permeability of the material that makes up the magnetic circuit.

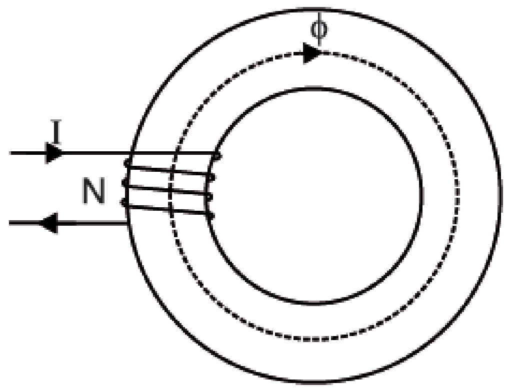
Reluctance,

$$S = \frac{l}{a\,\mu_0\,\mu_r}$$

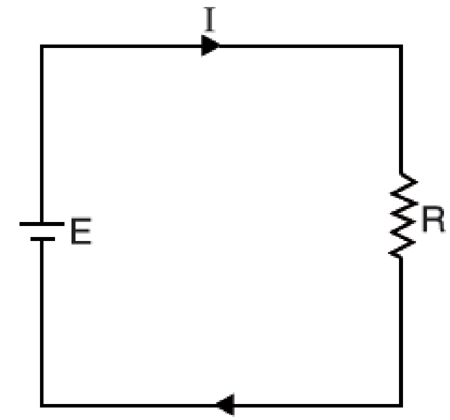
- Permeance- It is the reciprocal of reluctance and is a measure of the ease with which flux can pass through the material. Its unit is Wb/AT.
- Magnetic field strength- It is defined as the m.m.f. required to circulate the flux through unit length of the circuit. Its unit is AT/m.

$$\mathrm{H} = \frac{m.m.f.}{length} = \frac{NI}{l}$$

Magnetic Circuit



Electric Circuit



Similarities

1. The closed path for magnetic flux is called a magnetic circuit.	1. The closed path for electric current is called an electric circuit.
2. Flux, $\phi = \dfrac{\text{m.m.f.}}{\text{reluctance}}$	2. Current, $I = \dfrac{\text{e.m.f.}}{\text{resistance}}$
3. m.m.f. (ampere-turns)	3. e.m.f. (volts)
4. Reluctance, $S = \dfrac{l}{a\mu_0\mu_r}$	4. Resistance, $R = \rho \dfrac{l}{a}$
5. Flux density, $B = \dfrac{\phi}{a}\,\text{Wb/m}^2$	5. Current density, $J = \dfrac{I}{a}\,\text{A/m}^2$
6. m.m.f. drop $= \phi\, S$	6. Voltage drop $= I\, R$
7. Magnetic intensity, $H = N\,I/l$	7. Electric intensity, $E = V/d$
8. Permeance	8. Conductance.
9. Permeability	9. Conductivity

Dissimilarities

1. Truly speaking, magnetic flux does not flow.	**1.** The electric current acutally flows in an electric circuit.
2. There is no magnetic insulator. For example, flux can be set up even in air (the best known magnetic insulator) with reasonable m.m.f.	**2.** There are a number of electric insulators. For instance, air is a very good insulator and current cannot pass through it.
3. The value of μ_r is not constant for a given magnetic material. It varies considerably with flux density (B) in the material. This implies that reluctance of a magnetic circuit is not constant rather it depends upon B.	**3.** The value of resistivity (ρ) varies very slightly with temperature. Therefore, the resistance of an electric circuit is practically constant. This salient feature calls for different approach to the solution of magnetic and electric circuits.
4. No energy is expended in a magnetic circuit. In other words, energy is required in creating the flux, and not in maintaining it.	**4.** When current flows through an electric circuit, energy is expended so long as the current flows. The expended energy is dissipated in the form of heat.

Calculation of Ampere-Turns

$$\text{Flux, } \phi = \frac{\text{m.m.f.}}{\text{reluctance}} = \frac{AT}{(l/a\mu_0\mu_r)}$$

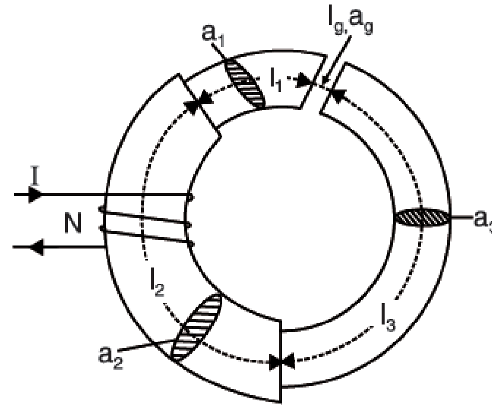
$$AT \text{ required} = \phi \times \frac{l}{a\mu_0\mu_r} = \frac{\phi}{a} \times \frac{l}{\mu_0\mu_r}$$

$$= \frac{B}{\mu_0\mu_r} \times l \qquad \left(\because \; B = \frac{\phi}{a}\right)$$

$$= H \times l \qquad (\because \; H = B/\mu_0\,\mu_r)$$

Series Magnetic Circuits

In a series magnetic circuit, the same flux ϕ flows through each part of the circuit.



$$\text{Total reluctance} = \frac{l_1}{a_1 \mu_0 \mu_{r1}} + \frac{l_2}{a_2 \mu_0 \mu_{r2}} + \frac{l_3}{a_3 \mu_0 \mu_{r3}} + \frac{l_g}{a_g \mu_0}^{**}$$

$$\text{Total m.m.f.} = \text{Flux} \times \text{Total reluctance}$$

$$= \phi \left[\frac{l_1}{a_1 \mu_0 \mu_{r1}} + \frac{l_2}{a_2 \mu_0 \mu_{r2}} + \frac{l_3}{a_3 \mu_0 \mu_{r3}} + \frac{l_g}{a_g \mu_0} \right]$$

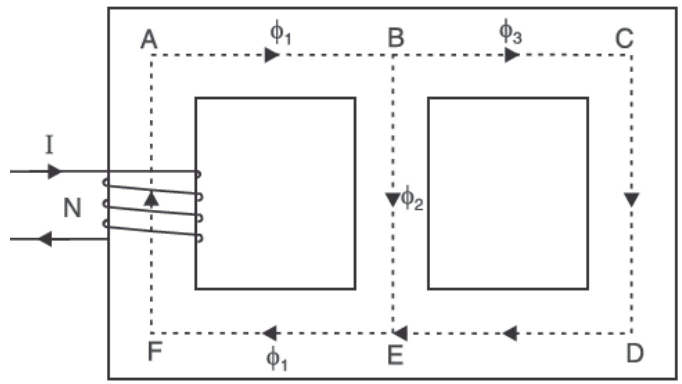
$$= \frac{\phi}{a_1 \mu_0 \mu_{r1}} \times l_1 + \frac{\phi}{a_2 \mu_0 \mu_{r2}} \times l_2 + \frac{\phi}{a_3 \mu_0 \mu_{r3}} \times l_3 + \frac{\phi}{a_g \mu_0} \times l_g$$

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

$$= H_1 l_1 + H_2 l_2 + H_3 l_3 + H_g l_g \qquad (\because \quad H = B/\mu_0 \mu_r)$$

Parallel Magnetic Circuits

A magnetic circuit which has more than one path for flux is called a parallel magnetic circuit.



$$\text{Clearly, } \phi_1 = \phi_2 + \phi_3$$

The magnetic paths *BE* and *BCDE* are in parallel and form a parallel magnetic circuit. The *AT* required for this parallel circuit is equal to *AT* required for any *one of the paths.

Let S_1 = reluctance of path *EFAB*

S_2 = reluctance of path *BE*

S_3 = reluctance of path *BCDE*

$\therefore$ Total m.m.f. required = m.m.f. for path *EFAB* + m.m.f. for path *BE* or path *BCDE*

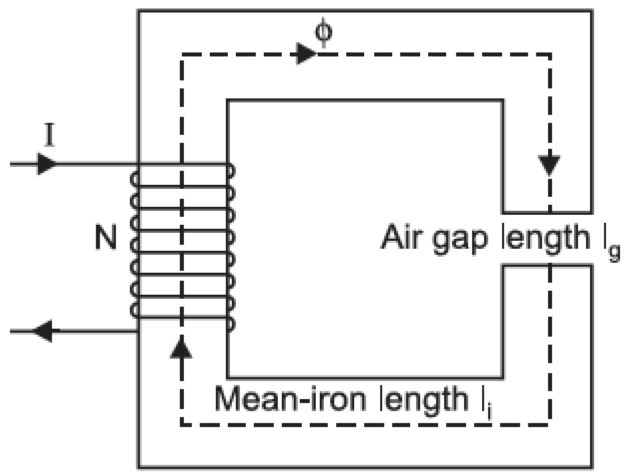
or

$$NI = \phi_1 S_1 + \phi_2 S_2$$

$$= \phi_1 S_1 + \phi_3 S_3$$

Air Gaps in Magnetic Circuits

The magnitude of AT required for air gap is much greater than that required for iron part of the magnetic circuit. It is because reluctance of air is very large compared to that offered by iron.



$$\text{Reluctance of air gap} = \frac{l_g}{a\mu_0}$$

$$\text{Reluctance of iron part} = \frac{l_i}{a\mu_0\mu_r}$$

Magnetizing curves

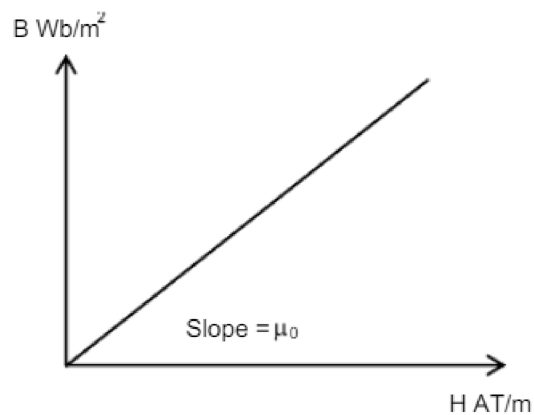
For free space or a non-magnetic material the ratio of magnetic flux density B to magnetic filed strength H is a constant. This constant is known as the permeability for free space and has the symbol μ_0

$$\mu_0 = \frac{B}{H} = 4\pi \times 10^{-7} \qquad \left(\frac{Wb/m^2}{AT/m} \Rightarrow \frac{Wb}{mAT} \right)$$

Note that this constant has a numerical value of $4\pi * 10^{-7}$ Wb/(mAT). Another unit for this constant is henrys/m.

All non-magnetic materials are considered to have the same permeability μ_0 as free space.

B-H curve-



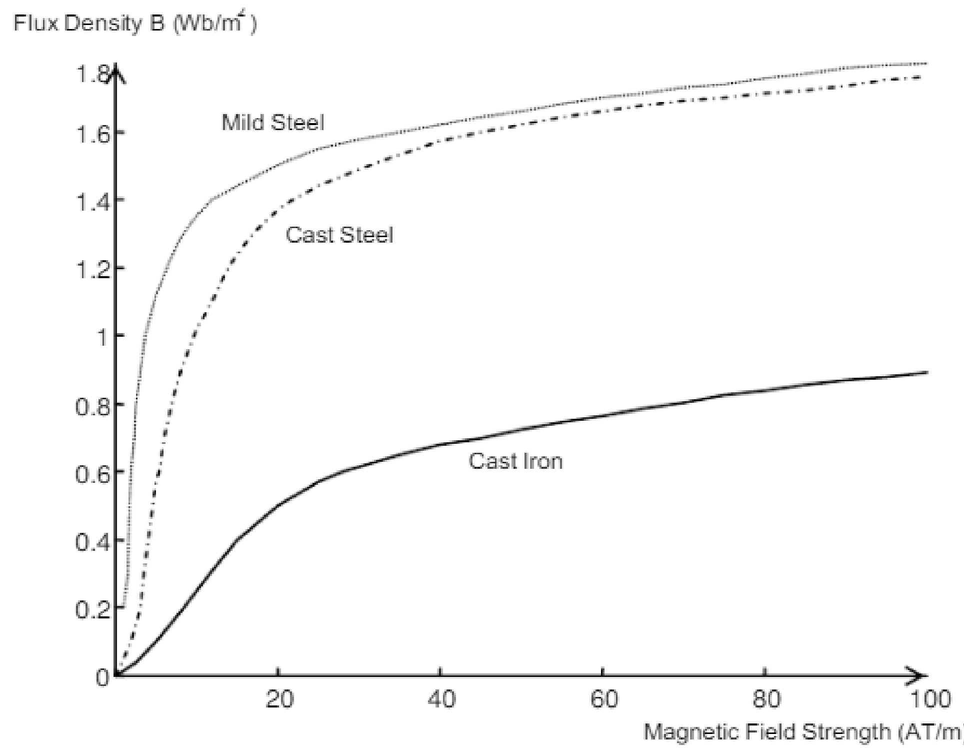
The absolute permeability of a ferromagnetic material is expressed in relation to the permeability of free space and is given as

$$\mu = \mu_0 \mu_r = \frac{B}{H} \qquad Wb/(mAT)$$

Where μ_r is the relative permeability of the ferromagnetic material which has no units. The relative permeability of free space is 1.

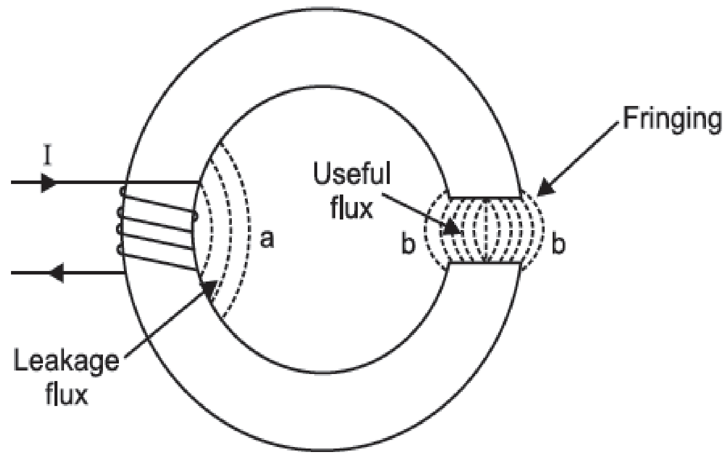
B-H curve for different magnetic materials-

The B-H Curve is a plot of the **Magnetic Flux Density** (B) versus the Magnetic Field Strength (H). This is an important curve in selecting materials for electric machines. The curve tells us about the change in the Flux density of a material as the magnetic field strength is increased.



Magnetic Leakage and Fringing

The flux that does not follow the desired path in a magnetic circuit is called a leakage flux.



Let,

$$\phi_i = \text{total flux produced } i.e., \text{ flux in the ***iron ring}$$

$$\phi_g = \text{useful flux across the air gap}$$

$$\text{Leakage flux,} \quad \phi_{leak} = \phi_i - \phi_g$$

$$\text{Leakage coefficient, } \lambda = \frac{\text{Total flux}}{\text{Useful flux}} = \frac{\phi_i}{\phi_g}$$

The value of leakage coefficients for electrical machines is usually about 1.15 to 1.25.

Magnetic leakage is undesirable in electrical machines because it increases the weight as well as cost of the machine. Magnetic leakage can be greatly reduced by placing source of m.m.f. close to the air gap.

Fringing-

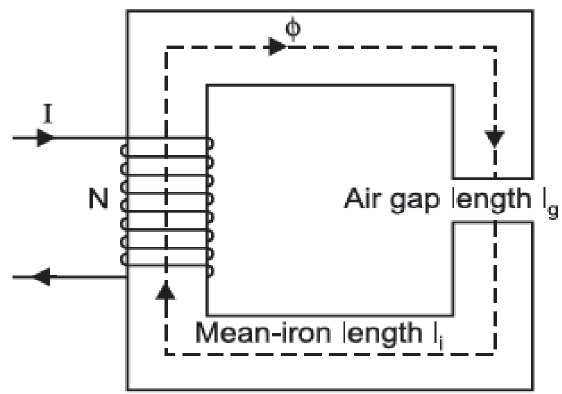
When crossing an air gap, magnetic lines of force tend to bulge out such as lines of force at bb in Figure. It is because lines of force repel each other when passing through non-magnetic material such as air. This effect is known as fringing.

The result of bulging or fringing is to increase the effective area of air gap and thus decrease the flux density in the gap. The longer the air gap, the greater is the fringing and vice-versa.

Numericals

1. A cast steel electromagnet has an air gap length of 3mm and an iron path length of 40cm.Find the number of ampere turns necessary to produce a flux density of $0.7 Wb/m^2$ in the gap. Neglect leakage and fringing.(Corresponding to flux density of $0.7 Wb/m^2$ AT/m of flux path length for cast steel material obtained from B-H curve is 660AT/m).

Solution-



Total AT = AT iron portion + AT of air gap

AT of air gap= $0.796 B_g \, l_g * 10^6$

AT iron portion= $660 AT/m * l_i$

2. A steel ring of 25cm mean diameter and of circular section 3cm in diameter has an air gap of 1.5mm length. It is wound uniformly with 700 turns of wire carrying a current of 2A. Calculate i) magnetomotive force ii)Flux density iii)magnetic flux iv)Reluctance v)relative permeability of steel ring

Neglect magnetic leakage and assume that iron path takes about 35% of total mmf.

Solution-

i) Total mmf= N*I

ii) Mmf of iron portion= 0.35* Total mmf

Mmf for air gap= Total mmf - Mmf of iron portion

AT of air gap= $0.796B_g l_g * 10^6$ Flux Density=?

iii) Cross Sectional area=pi*d^2/4

Magnetic flux=flux density *Cross Sectional area

iv) Reluctance=Total mmf /magnetic flux

v) Length of mean flux path=pi*d_{mean}

$H_i=(NI)_i$ / Length of mean flux path

$$\mu_0\mu_r = \frac{B}{H} \qquad Wb/(mAT)$$

3.Iron ring of mean circumference equal to 80cm is uniformly wound with 500turns.Current passing through coil is 1A and flux density is 1.1Tesla is produced in iron ring. Calculate relative permeability.

Solution-

Mmf= N*I= Flux*Reluctance

$$= \phi * \frac{l_i}{a\mu_0\mu_r}$$

4.Calculate mmf required to produce a flux of 0.02Wb across an air gap 2mm long having an effective area of $100cm^2$

Solution- Mmf= N*I= Flux*Reluctance

$$= \phi * \frac{l_i}{a\mu_0\mu_r}$$

THANK YOU