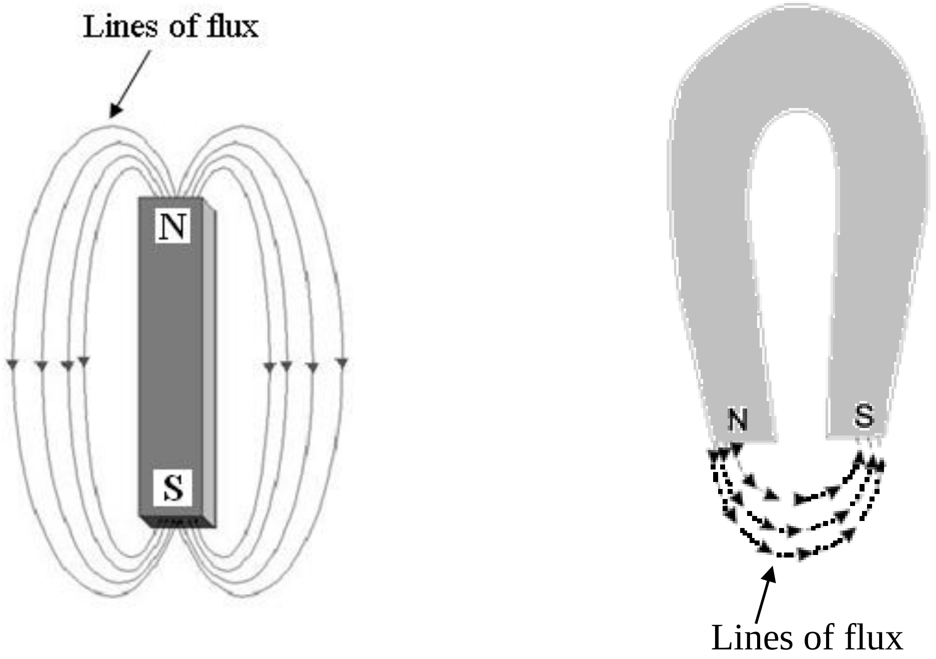
Chapter one

Manetization and magnetic circuits

We all know that a permanent magnet will attract and hold metal objects when the object is near or in contact with the magnet.
The magnetic field of two permanent magnets is represented by "Lines of flux".
The numbers of lines of flux vary from one magnetic field to another. The stronger the magnetic field, the greater the number of lines of flux which are drawn to represent the magnetic field



Bar Magnet   Horseshoe Magnet

Figure 1

The lines of flux of a magnetic field travel from the N-pole to the S-pole.
Another but similar type of magnetic field is produced around an electrical conductor when an electric current is passed through the conductor as shown in Figure 2-a. These lines of flux define the magnetic field and are in the form of concentric circles around the wir*e*

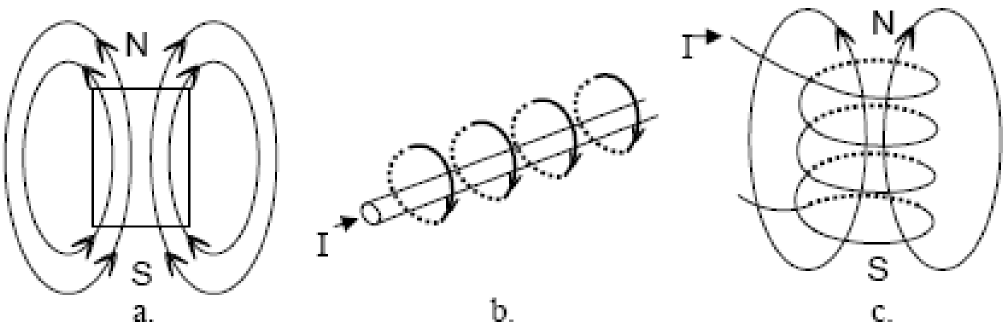


Figure2: Lines of Magnetic Flux (Φ) for (a) A Permanent Magnet; (b) Current-Carrying Conductor; (c) Current-Carry Coil

"Right hand Rule"
The rule states that if you point the thumb of your Right hand in the direction of the current, your fingers will point in the direction of the magnetic field.

When the wire is shaped into a coil as shown in Figure 3, all the individual flux lines produced by each section of wire join together to form one large magnetic field around the total coil.
As with the permanent magnet, these flux lines leave the north of the coil and re-enter the coil at its south pole.

The magnetic lines around a current carrying conductor leave from the N-pole and re-enter at the S-pole.

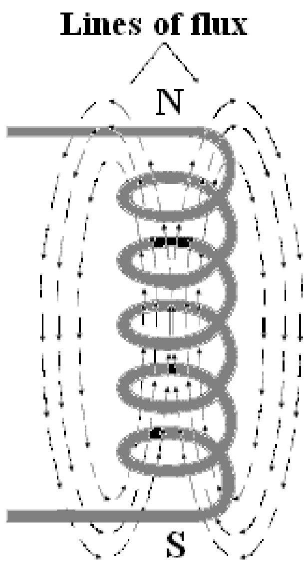


Figure 3

1- Law of magnetism

When such two magnets are brought near each other, their behaviour is governed by some laws called law of magnetism.

Law 1: it states that ‘like’ magnetic pole repels and ‘unlike’ poles attracts each other.

Law 2: the force (F) exerted by one pole on the other pole is,

1-directly proportional to the product of the pole strengths.

2- inversely proportional to the square of the distance between them.

3- dependent on the nature of medium surrounding the poles.

Mathematically this law can be expressed as

$$F = \frac{KM_1M_2}{d^2}$$

Where M1 and M2 are the pole strengths of the poles while ‘d’ is the distance between the two poles.
Where K is constant which depends on the nature of the surrounding.

Magnetic field and flux

Magnetic field: the region around a magnet within which the influence of magnet can be experienced is called its magnetic field.
The magnetic field is represented by imaginary lines around a magnet
These are called magnetic lines of force.

Magnetic flux: the total number of lines of force existing in a particular field is called magnetic flux, denoted a symbol (Φ)
It measured in a unit weber.

1 weber = 10^8 lines of force.

Magnetic flux density: is defined as the ratio of the magnetic flux divided by the area perpendicular to flux. In mathematical symbols

B=Φ / A Tesla

2-Magnetization curve

To explain the response of the ferromagnetic materials to the applied field, Let us consider the circuit shown in fig.(4) with switch ***S*** opened.

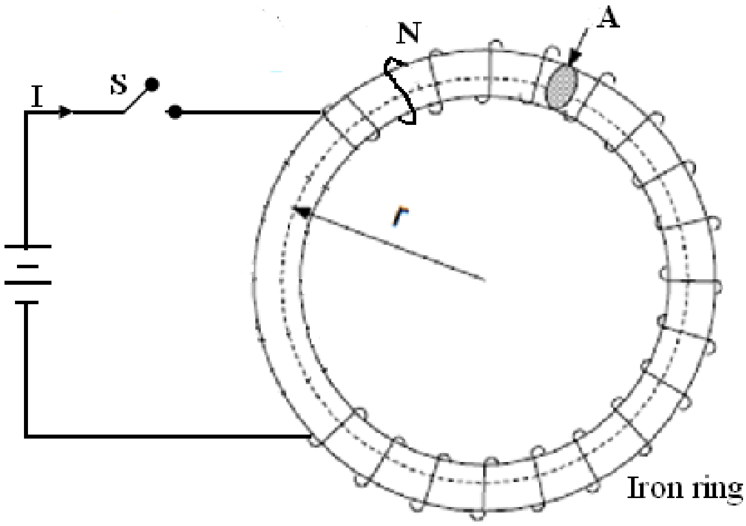
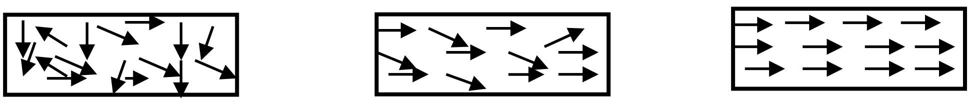


Fig.(4)

In un magnetized iron crystal the domains directed as shown in fig(5a) If the switch S is closed and the voltage increased gradually , the core will be affected by a magnetizing force (***H***) and the domains become unstable and a few of them may rotate so that they have the same direction as the field, fig. (5b). with further increase of field more domains change over each as an individual unit , until all the domains are in the same direction, the magnetic saturation is reached, as illustrated in fig. (5c).



a b c

Fig.(5)

Then the magnetic field (***B***) increases gradually as (***H***) increases. The relation between ***B*** and ***H*** is shown in fig.(6) curve 1. ***B*** is directly proportional to ***H*** , and the relation starts approximately liner up to a certain point then the saturation starts until the curve being parallel to that of the vacuum(curve 2). This relation in the linear region

$$B \alpha H$$

$$\therefore \quad B = \mu H$$

$\mu = B/H$ is the permeability of the material

and $\mu = \mu_r \mu_o$

where:

μ_r is the relative permeability of the material ,and

μ_o is the permeability of vacuum

$$\mu_o = 4\pi \cdot 10^{-7}$$

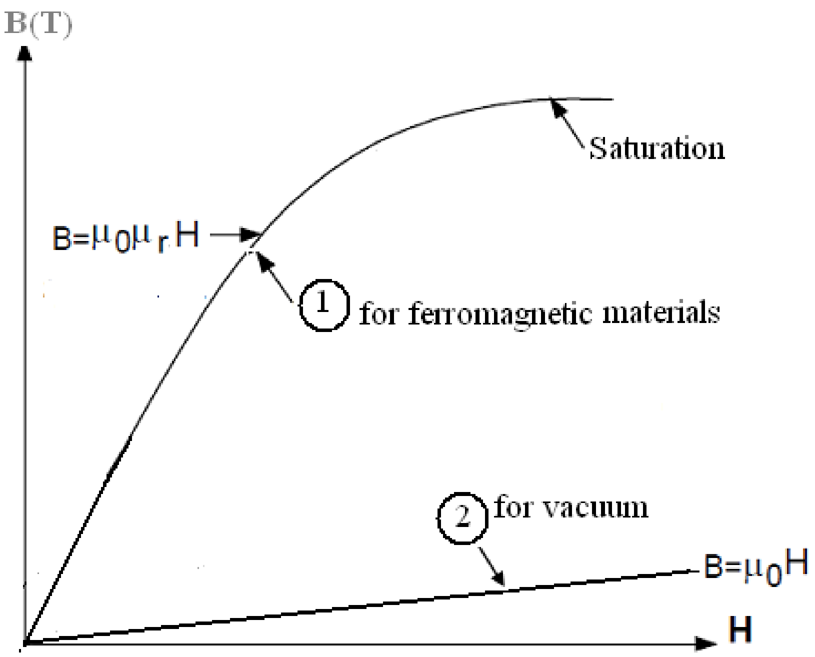


Fig.(6) B-H Curve

3-<u>Ferromagnetic materials in a.c circuits</u>

The relation between ***B*** and ***H*** in a.c circuits gives a very interested c/c's of the materials as shown in fig. (7,8,9). When the current varies from ***a*** to ***b*** the relation follows the ordinary B-H curve . When the current decreases to zero (b$\longrightarrow$**c**) the core is still magnetized and this is called the residual magnetization (Br). Then the current increases in reverse direction ***c*** to ***d*** at which the flux density B equals zero this part called coercive force(H_C).this value of H required to wipe off residual magnetism is known coercive force. Then the current increases in reverse direction ***d*** to ***e***. the value of H is further increased in the negative i.e reversed direction, the iron again reaches a stat of magnetic saturation represented by point e. periodically in closed loop (bcdefgb) which called the hysteresis loop. The area of this loop gives an idea about the losses of the material and c/c's.

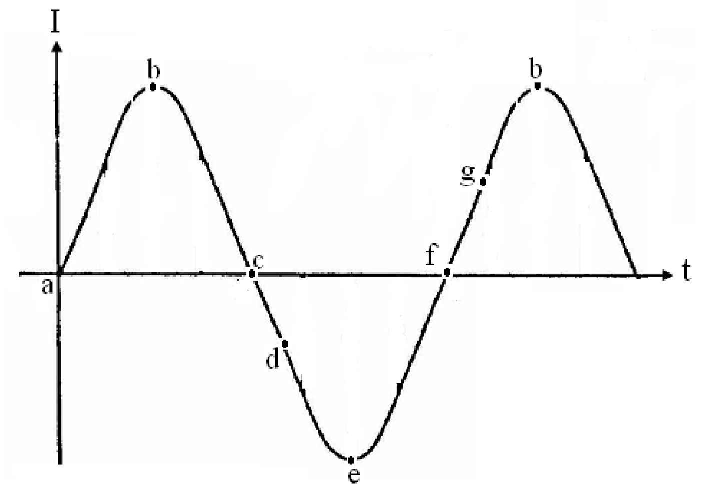


Fig.(7)

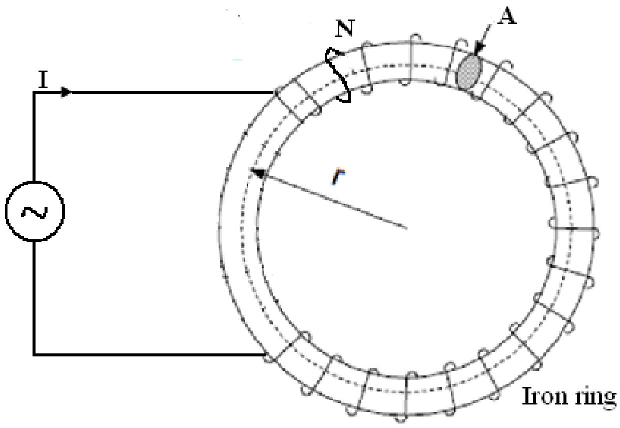


Fig.(8)

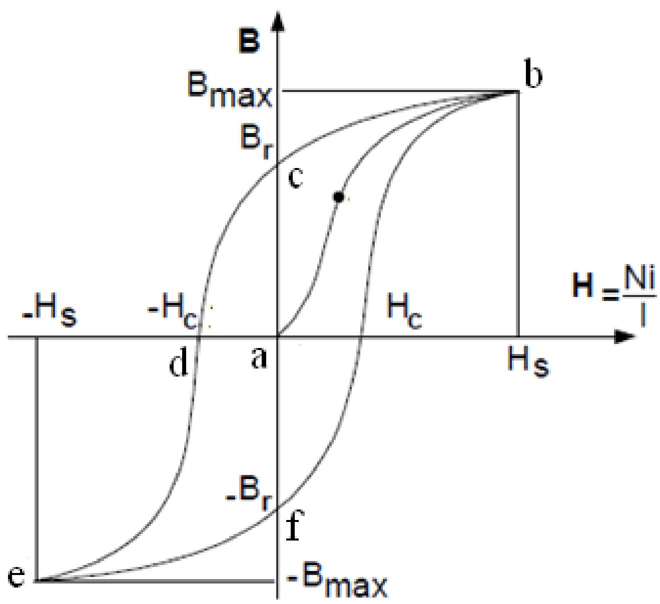
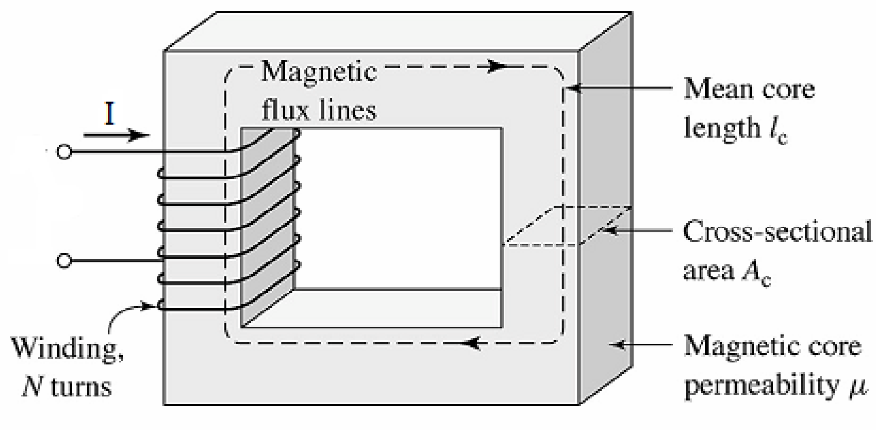


Fig.(9)

Simple magnetic circuit
It is defined as the path followed by the magnetic flux for
For the circuit shown in fig. below



$B=\mu H$ ----------- 1

As $\mu / \mu_\circ = \mu_r$ $\quad$ $\therefore \mu = \mu_\circ \mu_r$

so $B = \mu_\circ \mu_r H$

where μ_r is the relative permeability of the material

μ_o is the permeability of the vacuun $\mu_0 = 4\Pi x 10^{-7}\ H/m$

But $B = \frac{\Phi}{A}$

And $H = \frac{NI}{l}$

$\therefore$ Eqn 1 becomes

$$\frac{\Phi}{A} = \mu_\circ \mu_r \frac{NI}{l}$$

Then $\Phi = \frac{NI}{1/\mu_\circ \mu_r A}$

If $S = 1/\mu_\circ \mu_r A$ $\quad$ Then $\Phi = \frac{NI}{S}$ -------- 2

Equation 2 is analogous to ohms law , so it can be written as follws

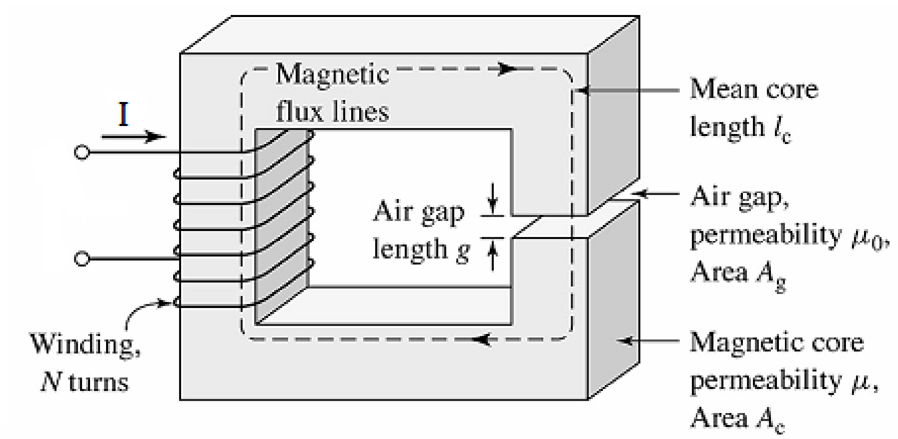
$$\text{Flux} = \frac{\text{Magnetomotive force}}{\text{Reluctance}}$$

The magnetomotive force (mmf) = NI (AT)

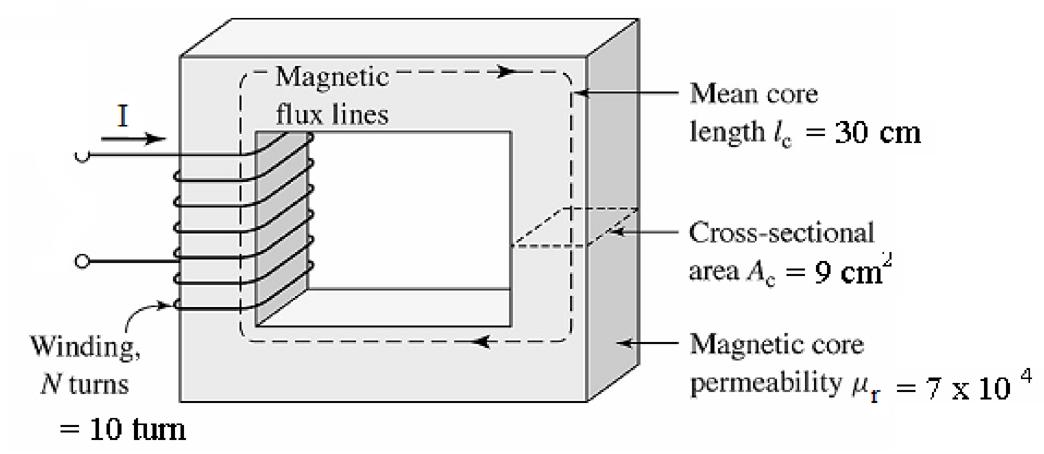
The reluctance (S) = $1/\mu_\circ \mu_r A \quad \frac{A.t}{Wb}$

The reluctance is defined as "the property of a medium which opposes the creation of magnetic flux in it"

<u>Magnetic circuit with air gap</u>



Example:1 For the circuit show in fig. below . Find current (I) to achieve $B_C = 1\ T$.



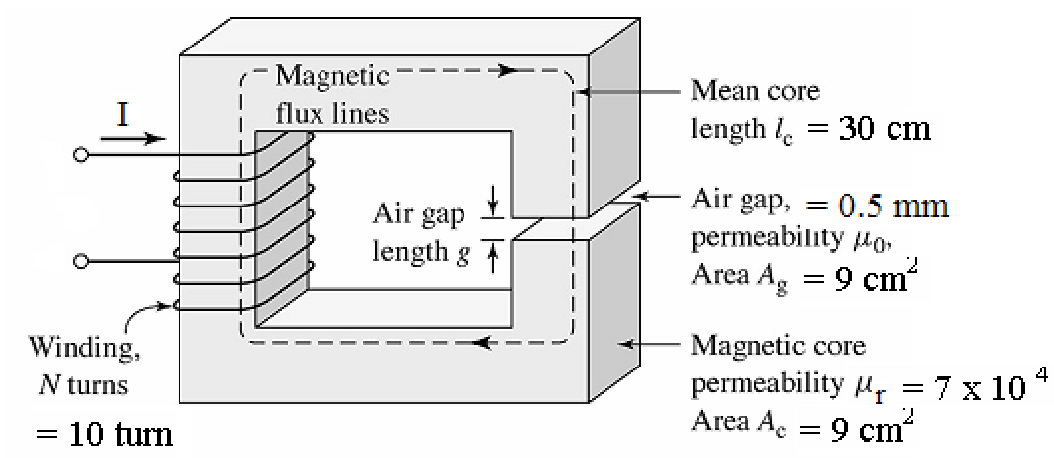
Solution

$$\Phi = \frac{NI}{S} \qquad\qquad I = \frac{S\Phi}{N} = \frac{\ell_C \Phi}{\mu_o \mu_r A_C N}$$

$$\Phi = B_C A_C$$

$$I = \frac{\ell_C B_C A_C}{\mu_o \mu_r A_C N} = \frac{\ell_C B_C}{\mu_o \mu_r N} = \frac{30\times10^{-2}\times1}{4\pi\times10^{-7}\times7\times10^{4}\times10} = 0.341 \quad \text{Amper}$$

Example:2 For the circuit show in fig. above let us make an air-gap of 0.5 mm length. Calculate the mmf required to achive $B_C = 1\ T$.



Solution

The *mmf* in Ex.1 *NI=10 x 0.341=3.41 Amper Turn (A.T)*
To find *mmf* in the case of Ex. 2 proceed as follows

$$\Phi = \frac{NI}{S_i + S_g}$$

Where S_i, S_g are the reluctances of iron and air-gap respectively

$$NI = \Phi(S_i + S_g) = A_C B_C \left(\frac{\ell_i}{\mu_0 \mu_r A_C} + \frac{\ell_g}{\mu_0 A_g}\right)$$

$$NI = \frac{A_C B_C}{\mu_0 A_C}\left(\frac{\ell_i}{\mu_r} + \ell_g\right) = \frac{B_C}{\mu_0}\left(\frac{\ell_i}{\mu_r} + \ell_g\right) = \frac{1}{4\pi\times10^{-7}}\left(\frac{30\times10^{-2}}{7\times10^4} + 0.5\times10^{-3}\right. = 400\ AT$$

Discussion

The difference between the two magnetic circuits in both examples is an air-gap of 0.5 mm.
This small air-gap requires an *mmf =400-3.41=396.59 AT*
In order to achive the same flux density inside the air-gap

$$\frac{NI_2}{NI_1} = \frac{400}{3.41} = 117.3$$

This means that we have to increase I or N of the air-gap circuit *117.3* times to achive $B_c = 1\ T$.
If *NI* remains unchanged, so the new flux density will be

$$\Phi = \frac{NI}{S_i + S_g} = \frac{NI}{\dfrac{\ell_C}{\mu_0 \mu_r A_C} + \dfrac{\ell_g}{\mu_0 A_g}} = \frac{NI\mu_0 A_C}{\dfrac{\ell_C}{\mu_r} + \ell_g}$$

$$\Phi = \frac{3.41 \times 10 \times 4\pi \times 10^{-7} \times 9 \times 10^{-4}}{\dfrac{30 \times 10^{-2}}{7 \times 10^{4}} + 0.5 \times 10^{-3}} = 7 \times 10^{-12} \quad wb$$

$$B_C = \frac{7 \times 10^{-12}}{9 \times 10^{-4}} = 0.777 \times 10^{-8} \quad T$$