ELEMENTS OF ELECTRICAL ENGINEERING
(22215)

CHAPTER-1 MAGNETIC CIRCUITS - 10 M

CO1: Use principles of magnetic circuits.

By SAROJ DESAI

CHAPTER-1 MAGNETIC CIRCUITS - 10 M

1.1 Magnetic Flux,flux density.MMF,Magnetic field strength,permeability,reluctance

1.2 Electric and magnetic circuits

1.3 Series and Parallel magnetic circuits

1.4 Faraday's Law of Electromagnetic induction, fleming’s right and left hand rule

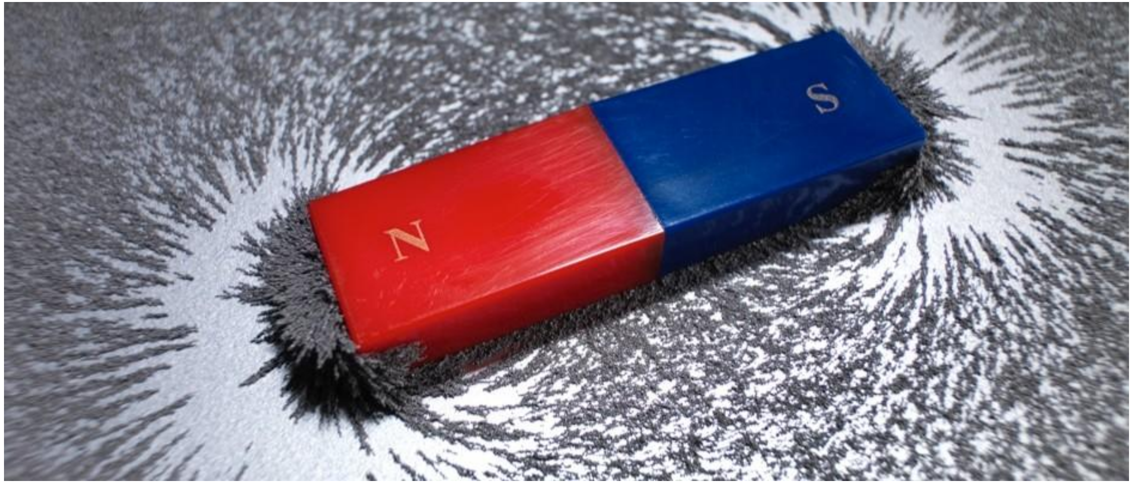
1.5 statistically and dynamically induced emf, self and mutual inductance

1.6 B-H curve and hysteresis

MAGNETIC CIRCUITS

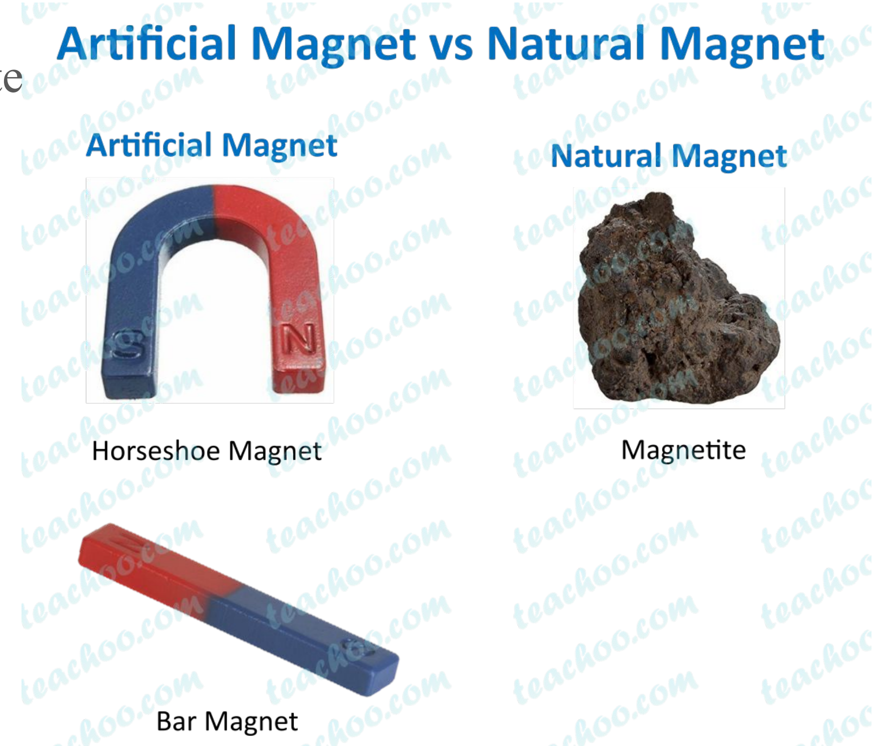
Magnet A substance that attracts piece of iron and steel is called magnet.

ThE property of the material is called **magnetism.**



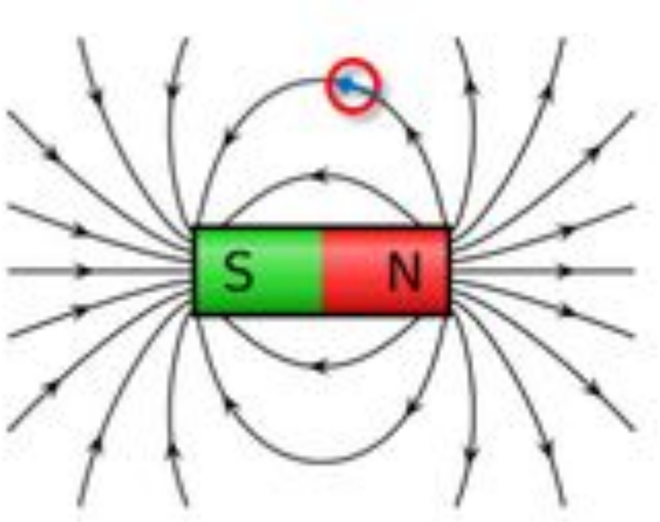
TYPES OF MAGNET

- Natural magnets- Iodestone, magnetite
- Artificial magnets
  - Temporary magnet
  - Permanent magnet



1.1. Terminology

Magnetic field: The space (or field) in which a magnetic pole experiences a force is called a magnetic **field**.



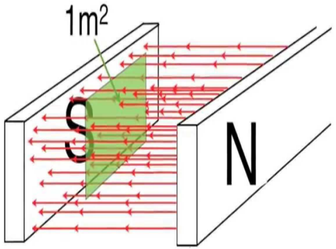
Continue...

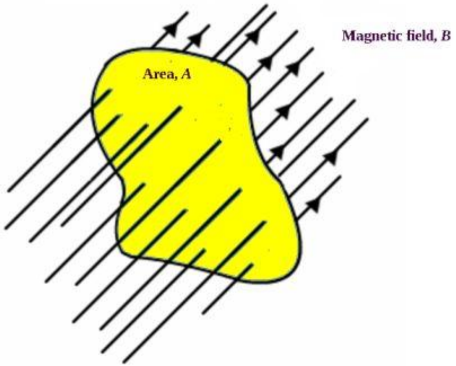
Magnetic Line of force: he magnetic field around a magnet is represented by imaginary lines called **magnetic lines of force.**

Magnetic Flux: A magnetic line of force can be drawn so that the field lines emanate from the North pole and go toward the South pole of the magnet.It is defined as the amount of magnetic field produced by a magnetic source. In other words it is the number of lines of force produced by Magnetic source. The symbol for magnetic flux is Φ.

The unit of magnetic flux is **weber (Wb)**

Properties of Magnetic Flux





1. **Magnetic flux** of a field is considered as the total number of magnetic lines of force in the field. These are also called magnetic flux lines.
2. Each magnetic flux line is closed loop.
3. Each magnetic flux line starts from north pole of a magnet and comes to the south pole through the field and continues from south pole to north pole in the body of the magnet.
4. No two flux lines cross each other.
5. Two similar lines of force travel side by side but repeal each other.
6. The lines of force are stretched like elastic cord.

Terminology

Magnetic flux density: It is the amount of flux passing through a defined area that is perpendicular to the direction of the flux.

Magnetic flux density = (magnetic flux) / (area) = $B = \Phi / A$--- (1)

The symbol for magnetic flux density is B.

The unit of magnetic flux density is the Tesla (T)

$1\ T = 1 Wb/m^2$

Terminology

Permeability: (μ) Permeability of a material means its conductivity for magnetic flux. The greater is the Permeability of a material, greater is its conductivity for magnetic flux and vice versa.

$\mu 0$ = absolute permeability of air or vaccum = $4\pi \times 10^{-7}$ H/m

μr = Relative permeability of a material.

$$\mathbf{\mu 0.\mu r = \mu ----(2)}$$

reluctance: It is the magnetic resistance of a magnetic circuit to the presence of magnetic flux(Φ).

The unit of reluctance is **AT/Wb** .

Magnetic field strength (H): The definition of H is $H = B/\mu$, where B is the magnetic flux density, a measure of the actual magnetic field within a material considered as a concentration of magnetic field lines, or flux, per unit cross-sectional area; μ is the magnetic permeability.

$$\mathbf{B = \mu 0.\mu r\ H----(3)}$$

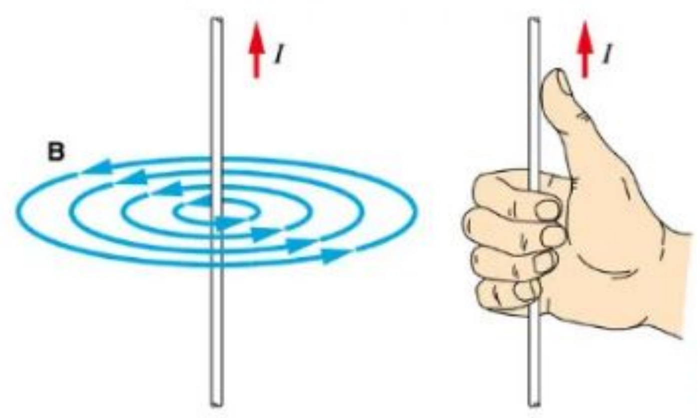
Terminology

Electromagnetism: The branch of engg. Which deals with the magnetic effect electric current is called electromagnetism.
Electromagnetism is produced when an electrical current flows through a simple conductor such as a piece of wire or cable. A small magnetic field is created around the conductor with the direction of this magnetic field with regards to its “North” and “South” poles being determined by the direction of the current flowing through the conductor.

MagnetoMotive Force (m.m.f.): It is the cause of the presence of a magnetic flux in a magnetic circuit.It is produced when current flows in a coil of one or more turns.The magnitude of mmf is directly proportional to the current I and the number of turns of the coil N.
mmf= NI----(4)

Magnetic field due to current carrying conductor

Suppose a conductor carries current I and it is with the length (l). As it is carrying current (DC), some flux lines will be generated around the conductor and they are concentric with the central axis of the conductor. So an electromagnetic field is established due to this current through this conductor. (By Scientist Oersted.1820)



Following right hand thumb rule the magnetic flux lines get the direction along the bent fingers when thumb denotes the direction of the current flow, i.e. shown in the figure below

Terminology

Reluctance S (or R_M) : It is the magnetic resistance of a magnetic circuit to the presence of magnetic flux(Φ).

The unit of reluctance is **AT/Wb (ampere-turns / Weber).**

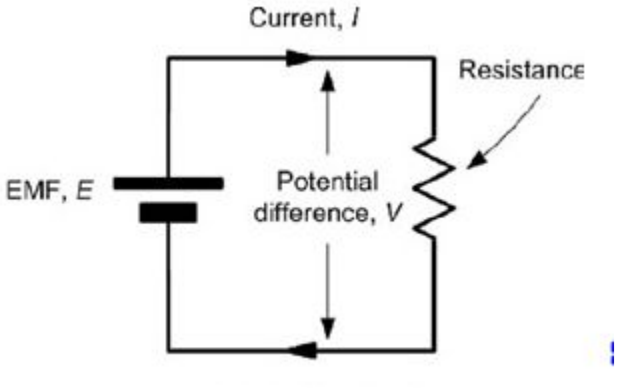
$$Reluctance\ (S) = \frac{m.m.f}{flux} = \frac{F}{\emptyset}$$

Where, S – reluctance in ampere-turns per weber.

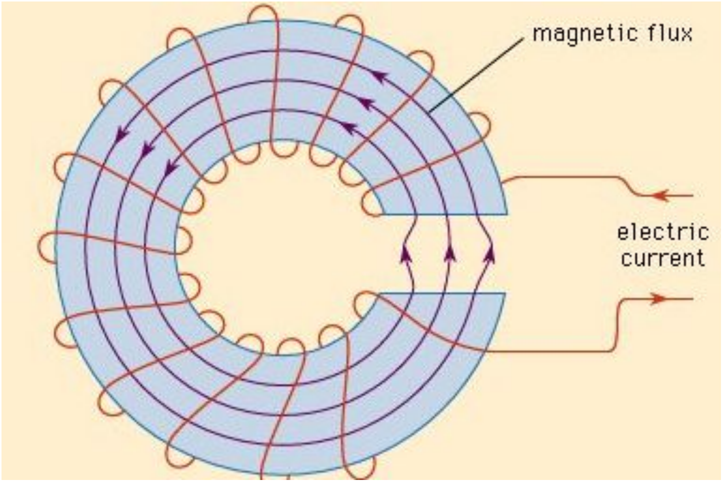
F – magnetic motive force

Φ – magnetic flux

1.2 Compare Magnetic Circuits and Electric Circuits



Electric Circuit



Magnetic Circuit

Compare Magnetic Circuits and Electric Circuits.

Electric Circuit	Magnetic Circuit
In the electric circuit, the current is actually flows. ie there is movement of electrons.	Due to mmf flux gets established and does not flow in the sense in which current flows.
There are many materials which can be used as insulators (air, PVC, synthetic resins etc) which current can not pass	There is no magnetic insulator as flux can pass through all the materials, even through the air as well.
Energy must be supplied to the electric circuit to maintain the flow of current.	Energy is required to create the magnetic flux, but is not required to maintain it.
The resistance and conductivity are independent of current density under constant temperature. But may change due to the temperature.	The reluctance, permanence and permeability are dependent on the flux density.
Electric lines of flux are not closed. They start from positive charge and end on negative charge.	Magnetic lines of flux are closed lines. They flow from N pole to S pole externally while S pole to N pole internally.
There is continuous consumption of electrical energy.	Energy is required to create the magnetic flux and not to maintain it.

Compare Magnetic Circuits and Electric Circuits.

Electric Circuit	Magnetic Circuit
e.m.f. E (V)	m.m.f. F_m (A)
current I (A)	flux Φ (Wb).
resistance R (Ω)	reluctance S (H^{-1})
$R = (\rho l) / A$	**$S = l / \mu_0 \mu_r A$**
$I = E / R$	**$\Phi = mmf / S$**

Compare Magnetic Circuits and Electric Circuits.

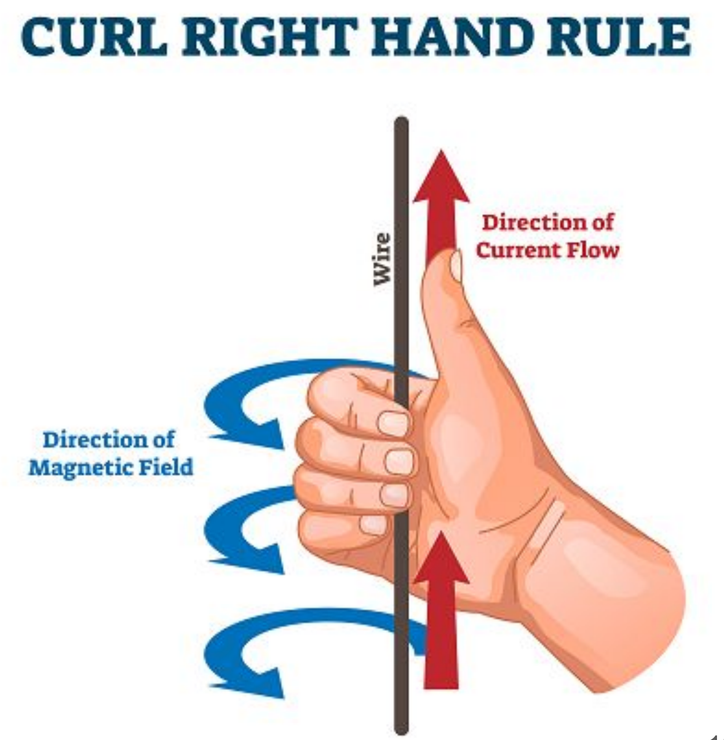
Electric Circuit	**Magnetic Circuit**
Path traced by the current is known as electric current.	Path traced by the magnetic flux is called as magnetic circuit.
EMF is the driving force in the electric circuit. The unit is Volts.	MMF is the driving force in the magnetic circuit. The unit is ampere turns.
There is a current I in the electric circuit which is measured in amperes.	There is flux φ in the magnetic circuit which is measured in the weber.
The flow of electrons decides the current in conductor.	The number of magnetic lines of force decides the flux.
Resistance (R) oppose the flow of the current. The unit is Ohm	Reluctance (S) is opposed by magnetic path to the flux. The Unit is ampere turn/weber.
$R = \rho.\ l/a$. Directly proportional to l. Inversely proportional to a. Depends on nature of material.	$S = l/\ (\mu_0\mu_r a)$. Directly proportional to l. Inversely proportional to $\mu = \mu_0\mu_r$. Inversely proportional to a
The current I = EMF/ Resistance	The Flux = MMF/ Reluctance
The current density	The flux density
Kirchhoff current law and voltage law is applicable to the electric circuit.	Kirchhoff mmf law and flux law is applicable to the magnetic flux.

1.4 Faraday's Law of Electromagnetic induction, fleming’s right and left hand rule

To understand the direction of magnetic field following rules are defined.

Right Hand Rule # 1

Current running through a wire creates a magnetic field. This version of the "right hand rule" shows the thumb running in the direction of the current, and the magnetic field curves around the wire in the direction that the fingers curl.



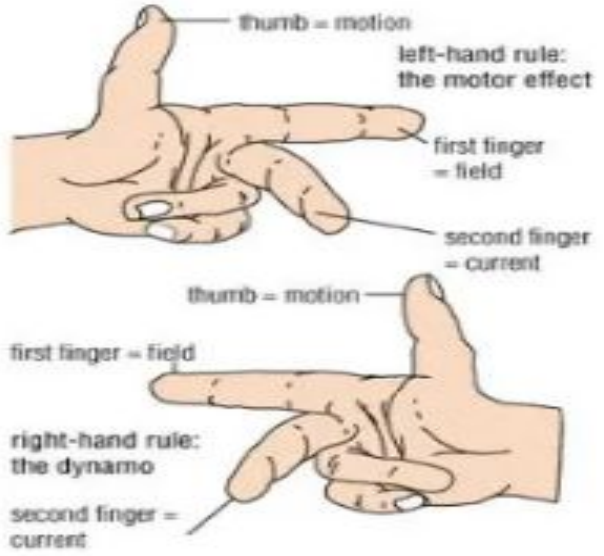
To understand the direction of magnetic field following rules are defined.

#Fleming's Rule # 1

Whenever a current carrying conductor comes under a magnetic field, there will be a force acting on the conductor. The direction of this force can be found using Fleming's Left Hand Rule (also known as 'Fleming's left-hand rule for motors').

Similarly if a conductor is forcefully brought under a magnetic field, there will be an induced current in that conductor. The direction of this force can be found using Fleming's Right Hand Rule.

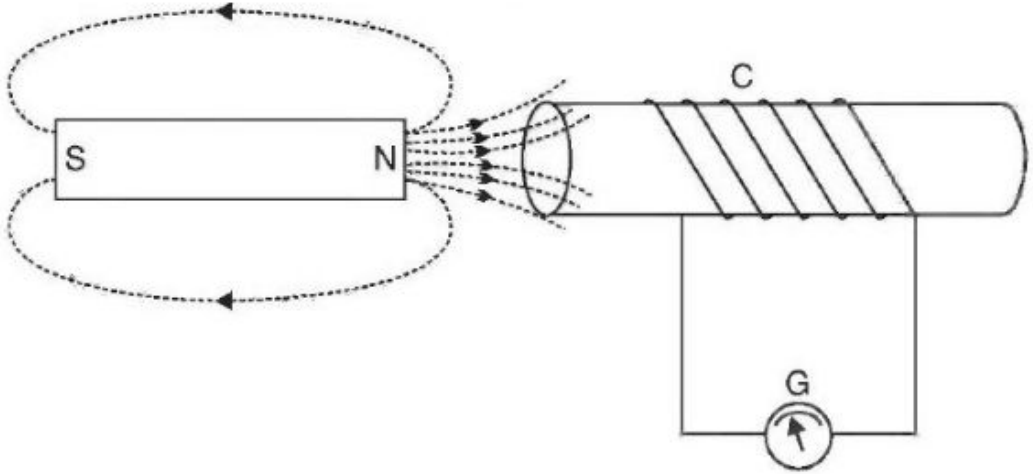
Fleming's Left-Hand rule is mainly applicable to electric motors and **Fleming's Right-Hand rule** is mainly applicable to **electric generators.**



Faraday’s Law of Electromagnetic induction.

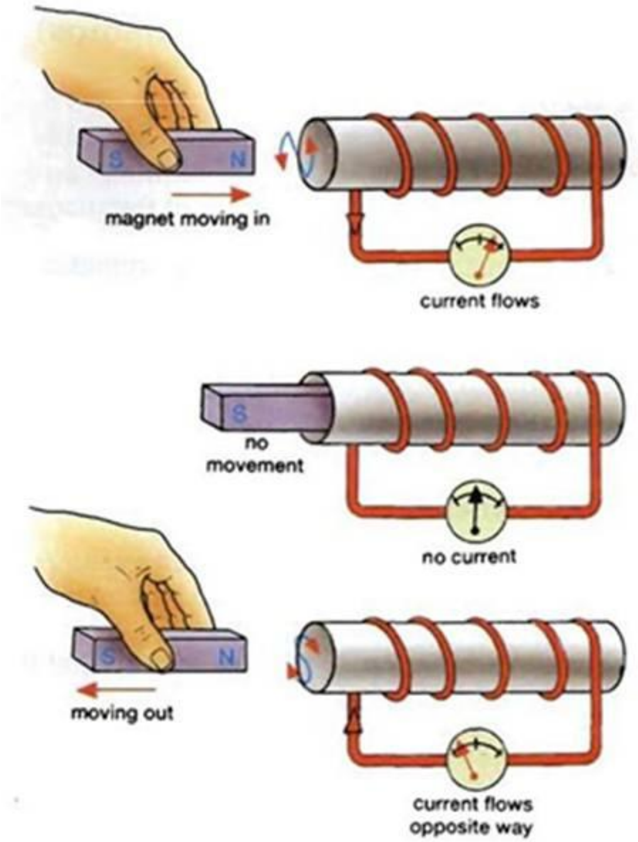
First law: It states that,When the magnetic flux linking a conductor or coil changes, an e.m. f. is induced in it.

Second Law: It states that….The magnitude of induced e. m.f. in a coil is equal to the rate of change of magnetic flux linkages.



https://youtu.be/Z0R4TwF2kHo https://youtu.be/zRmfNvTzIhk

Faraday's Law of Electromagnetic induction.



https://youtu.be/tC6E9J925pY

Faraday's Law of Electromagnetic induction.

First law: It states that,When the magnetic flux linking a conductor or coil changes, an e.m. f. is induced in it.

Second Law: It states that….The magnitude of induced e. m.f. in a coil is equal to the rate of change of magnetic flux linkages.

Suppose a coil has N turns and magnetic flux linking the coil increases from $\Phi1$*Wb to $\Phi2$*Wb in t seconds. Now magnetic flux linkages means the product of magnetic flux and no. of turns.

Initial magnetic flux linkage = $N*\Phi1$

final magnetic flux linkage = $N* \Phi2$

e = rate of change of magnetic flux linkages

$= N. \Phi2 - N. \Phi1 / t$

$= N (\Phi2- \Phi1) / t$

In differential form, we have, **$e = N d \Phi / dt$ volts**

Faraday’s Law of Electromagnetic induction.

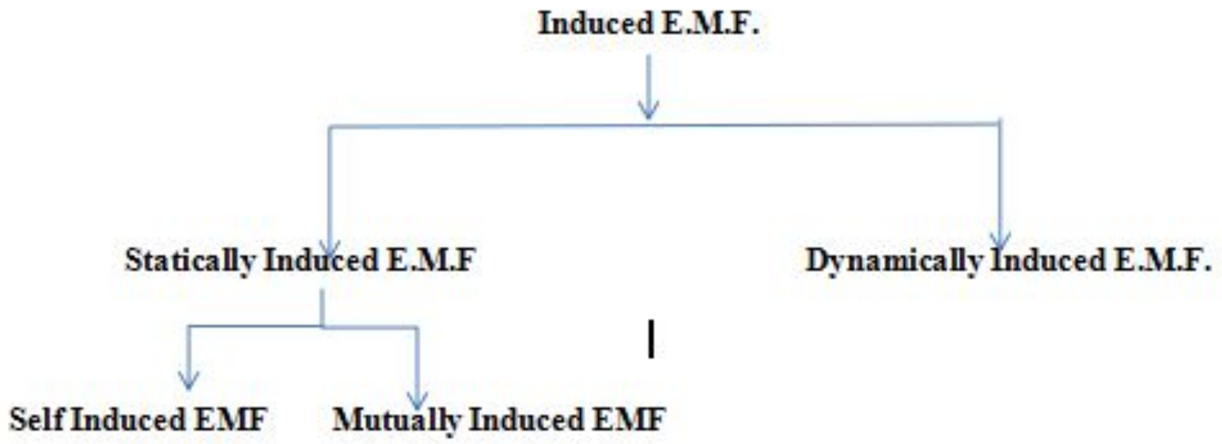
It is a usual practice to give a minus sign to right hand side expression. The minus sign comes from **Lenz’s law** and indicates that the voltage is induced in a direction opposite to the change in flux that produced it.

$$e = - N\, d\Phi / dt \quad \text{volts}$$

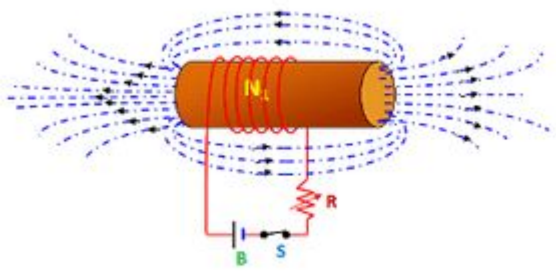
So how much voltage (emf) can be induced into the coil using just magnetism. Well this is determined by the following 3 different factors.

- 1). Increasing the number of turns of wire in the coil.
- 2). Increasing the speed of the relative motion between the coil and the magnet.
- 3). Increasing the strength of the magnetic field.

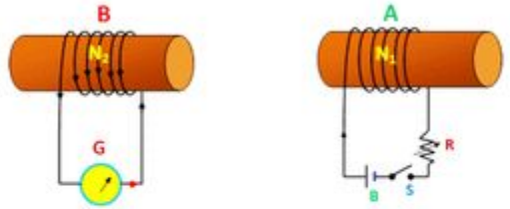
1.5 Different types of Induced EMF



Statically Induced EMF

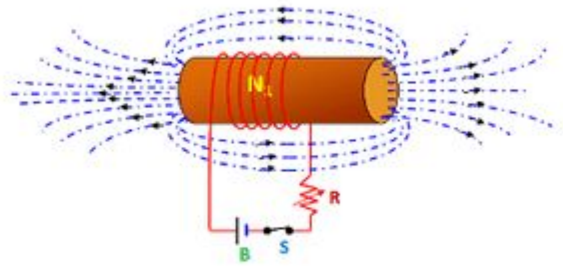


Self induced EMF



Mutually induced EMF

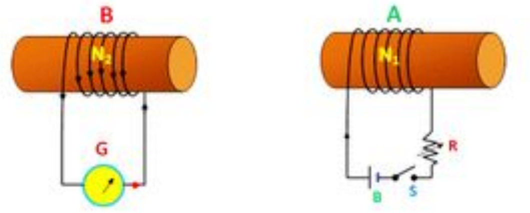
Statically Induced EMF



Self induced EMF

- Self induction is that phenomenon where by a change in the current in a conductor induces an emf in the conductor itself.
- That means when a conductor is given current, flux will be produced, and if the current is changed the flux also changes, as per Faraday's law when there is a change of flux, an emf will be induced. This is called self induction.
- The induced emf will be always opposite in direction to the applied emf.
- The opposing emf thus produced is called the counter emf of self induction.

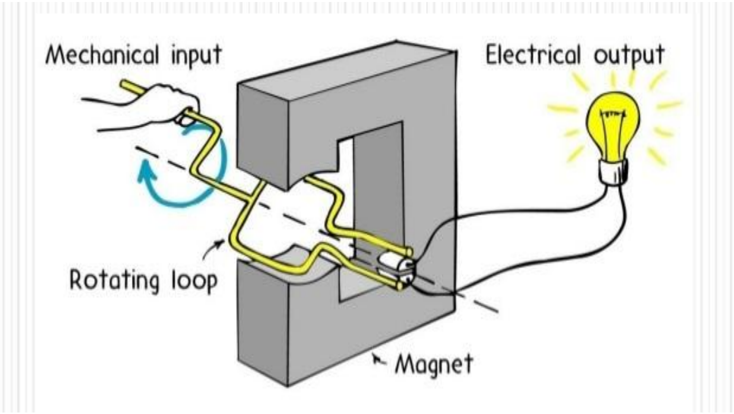
Mutually Induced EMF

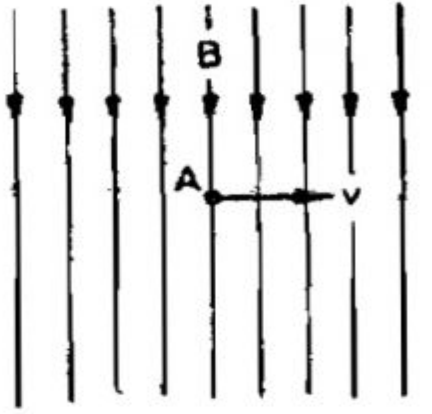


Mutually induced EMF

- It is the electromagnetic induction produced by one circuit in the nearby second circuits due to the variable flux of the first circuit cutting the conductor of the second circuit
- That means when two coils or circuits are kept near to each other and if current is given to one circuit and it is changed, the flux produced due to that current which is linking both the coils or circuits cuts both the coils, an emf will be produced in both the circuits.
- The production of emf in second coil is due to the variation of current in first coil known as mutual induction.

Dynamically Induced EMF





- Dynamically induced **emf** means an emf induced in a conductor when the conductor moves across a magnetic field. The Figure shows when a conductor "A"with the length "L" moves across a "B" wb/m2.
- Flux density with "V" velocity, then the dynamically induced emf is induced in the conductor. This induced emf is utilized in the generator. The quantity of the emf can be calculated using the equation
- **emf= Blv** volt

Dynamically Induced EMF

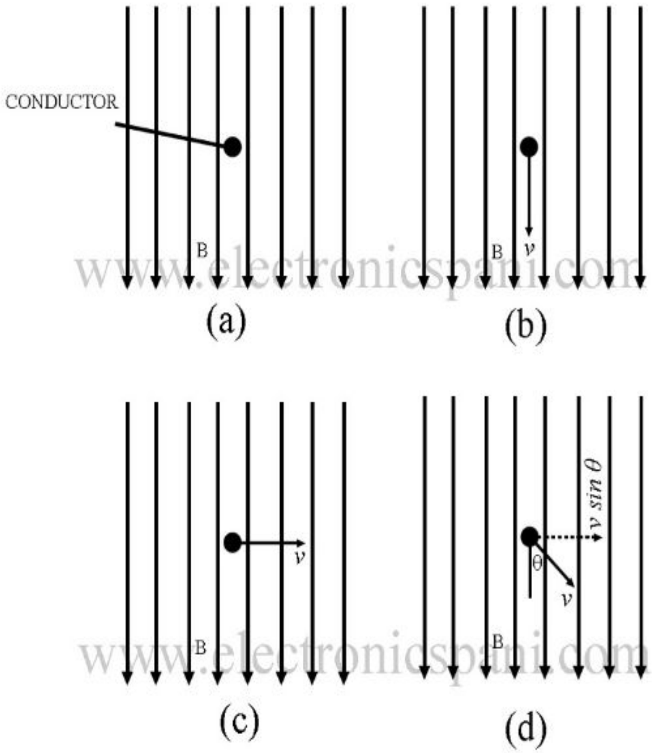


Figure : Conductor in uniform magnetic field

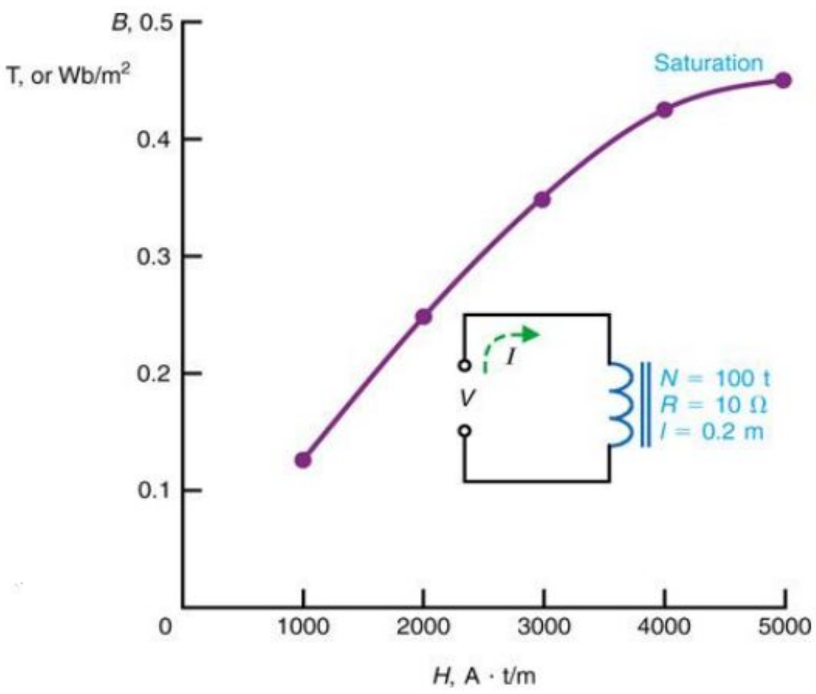
- **Consider a conductor of length *l* meters placed in a uniform magnetic field of density , as shown in Fig.(a).In this case no flux is cut by the conductor, therefore, no emf is induced in it.**
- **if this conductor is moved with Velocity *v* m/s in a direction perpendicular to its own length and perpendicular to the direction of the magnetic field, as shown in Fig.(c) flux is cut by the conductor, therefore, an emf is induced in the conductor.**
- **Area swept per second by the conductor = (l * v)m2/s**
- **Flux cut per second= Flux density * area swept per second**
  = Blv
- **EMF induced = Flux cut per second = Blv**
- **If the conductor moves with velocity as shown in Fig.(d), with the angle ϴ**
- **The magnitude of emf induced. is proportional to the component of the velocity in a direction perpendicular to the direction of the magnetic field and induced emf is given by**

  e= Blvsinϴ volts

1.6 B-H curve and hysteresis

The B-H magnetization curve shows how much flux density B results from increasing field intensity H.

Saturation is the effect of little change in flux density when the field intensity increases.

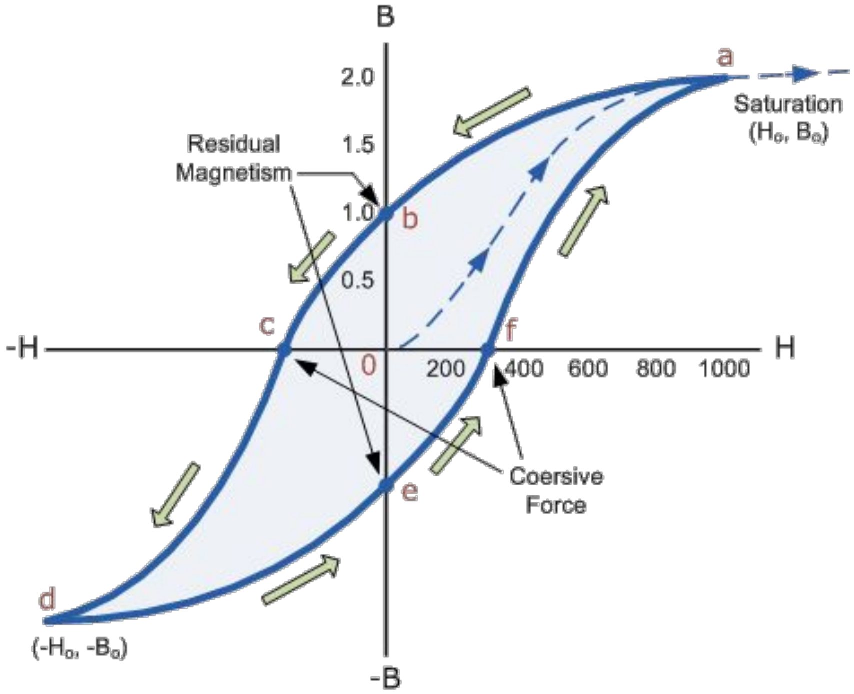


1.6 B-H curve and hysteresis

– Hysteresis refers to a situation where the magnetic flux lags the increases or decreases in magnetizing force.

– Hysteresis loss is energy wasted in the form of heat when alternating current reverses rapidly and molecular dipoles lag the magnetizing force.

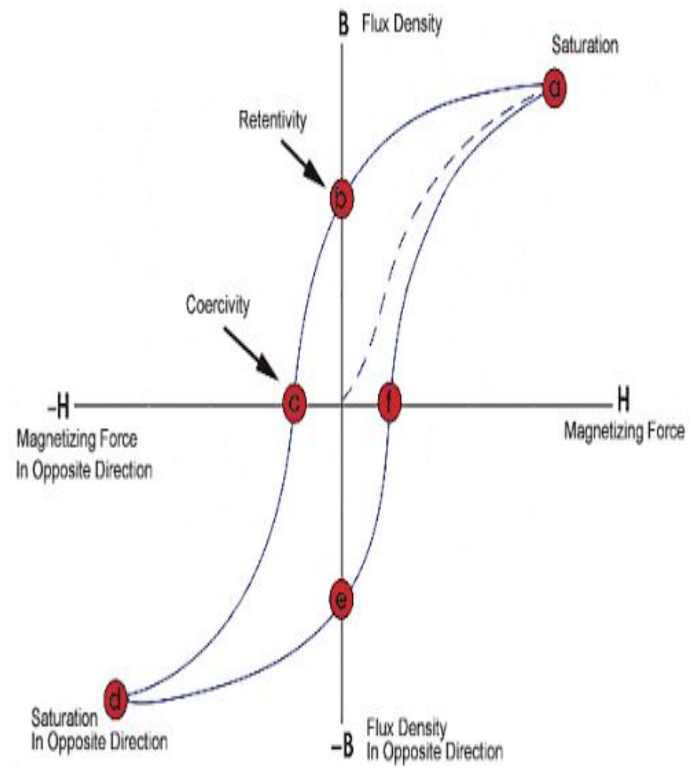
– For steel and other hard magnetic materials, hysteresis losses are much higher than in soft magnetic materials like iron



1.6 B-H curve and hysteresis

– The loop is formed while measuring B for multiple H values and if these values are outlined as a graphical form, then it forms a loop. Here,

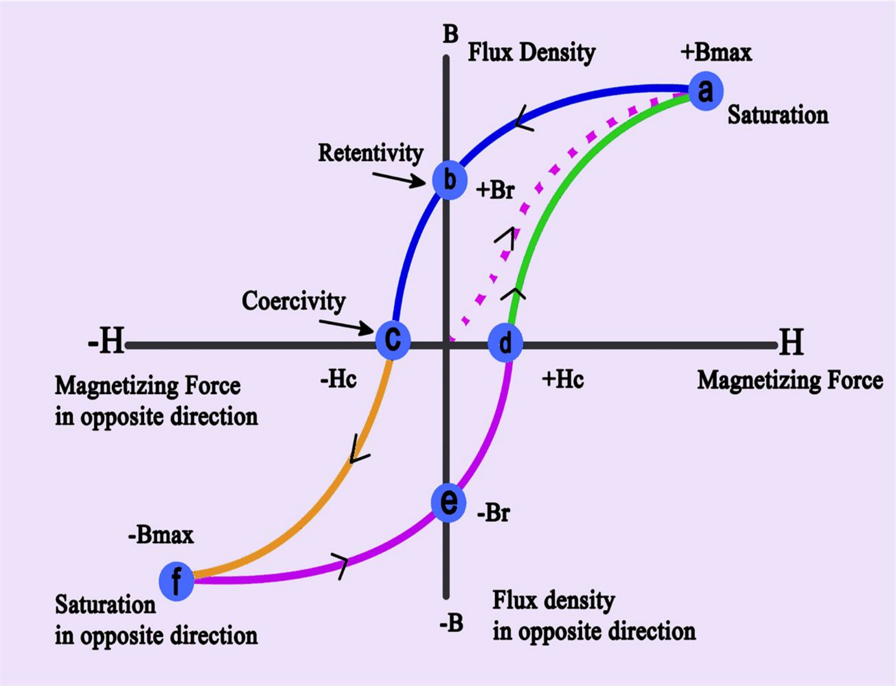
- The value of ‘B’ gets increased when ‘H’ value is simultaneously increased.
- Increasing the magnetic field impact enhances the magnetism value and at the end, it gets to the point ‘A’, which is termed as a saturation point where ‘B’ stays at constant.



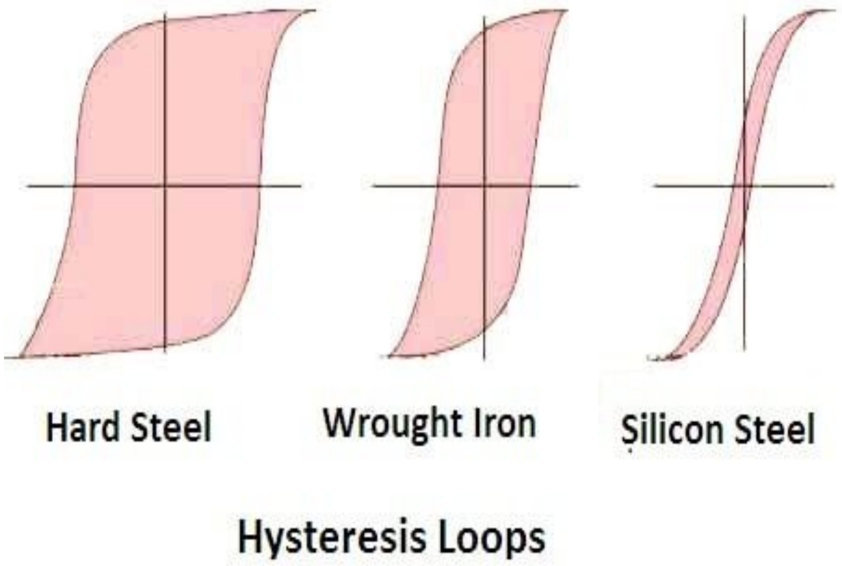
1.6 B-H curve and hysteresis

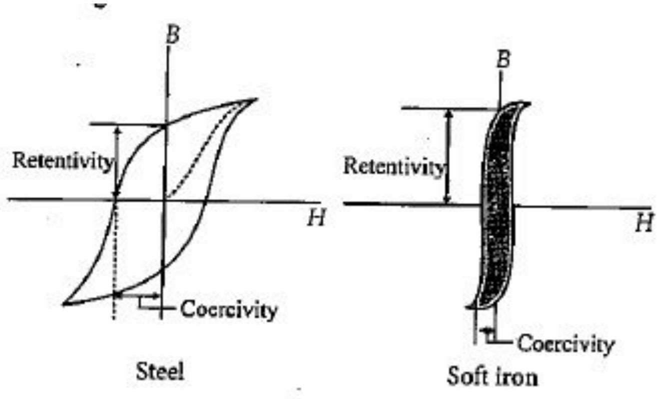
– By decreasing the magnetic field amount, the magnetism impact also gets decreased. But 'B' and 'H' values are similar which is '0', the magnetic substance holds few magnetism properties and this is defined as either residual magnetism or as retentivity.

- **And when there is a decline in the effect of a magnetic field, magnetism property will also get decrease. And at 'C', the material gets entirely demagnetized and has zero magnetic properties.**
- **Both these forward and reverse direction procedures complete one entire cycle and form a loop that is termed as a hysteresis loop.**



hysteresis loop for various materials





FIND THE ATTACHED LINK TO SOLVE THE EXAM ON MULTIPLE CHOICE QUESTION. THE TIME LIMIT IS 1 HOUR.
SUBMIT IT BEFORE 12:00PM OTHERWISE RESPONSE WILL NOT BE RECORED.