UNIT-4

MAGNETISM, ELECTRO MAGNETISM & ELECTROMAGNETIC INDUCTION

INTRODUCTION TO MAGNETISM

Magnet is the substance which attracts magnetic material such as iron, nickel, cobalt steel, manganese etc. The magnetic properties of materials were known from ancient times. A mineral discovered around 800 B.C. in the town of Magnesia was found to have a wondrous property. It could attract pieces of iron towards it. This mineral is called Magnetite after the place where it was discovered. Further, it was found that thin strips of magnetite always align themselves in particular direction when suspended freely in air. For this property, it was given the name 'Leading Stone' or 'Lead stone'. Later, it was found that magnetite is mainly composed of oxides of iron (Fe_3O_4). These are now known as magnets and the study of their property is called **MAGNETISM.**

William Gilbert did the first detailed study of magnets and their properties in 1600. Magnets are now widely used for variety of purposes. Magnets form an essential component of all generators used for the production of electricity, transmission and utilization of electric power. They are also used in electric motors that are an essential component of many machines and gadgets that operate on electricity. Modern electronic gadgets, like television, radio, tape recorder. Electric door bells also make use of magnets. Working of many of these devices also depends on the magnetic effect of electric current.

MAGNETIC FIELD

A magnetic field is the region around the magnet where force of attraction and repulsion takes place. The magnetic field is filled with the magnetic lines of force. Magnetic lines of force is nothing but the path along which iron fillings will re-adjust ina magneticfield.

MAGNETIC AXIS

An imaginary line passing through magnetic north and South Pole of a bar magnet is called **Magnetic axis.** Between the two poles there is a region showing no attraction. This region is called **Magnetic equator**. This is also called Neutral Line. Magnetic axis and the neutral line will be mutually at 90 and the neutral line bisects the magnetic axis.

MAGNETIC POLES

1. **Magnetic pole:** This is a region where the external magnetic effects of a magnet are concentrated or it is the point where the strength of magnet is maximum.
2. **Unit magnetic pole:** One unit pole defined as the strength of the magnet is that it exerts a force of a dyne when placed at a distance of one cm from another unit pole in a medium of unit permeability.
3. **Forces between poles:** The forces between two magnetic poles are directly proportional to the strength of the poles and inversely proportional to the square of the distance between poles.

$$F \propto m_1 m_2$$

$$F \propto d^2$$

$$F \propto \frac{m_1 m_2}{d^2}$$

$$F = \frac{m_1 m_2}{\mu d^2}$$

Where m_1 and m_2 = pole strength

μ= permeability of the medium

d = distance between poles

One unit magnetic pole may be defined as the strength of the magnet that it exerts a force of a dyne when placed at a distance of one cm from another unit pole in a medium of unit permeability.

MAGNETIC LINES OF FORCE

It is a line drawn in a magnetic field such that its direction at every point gives the direction of the force exerted on a magnet poles placed at that point, Or those imaginary lines which start from North pole and pass through air or magnetic medium end at south pole.

MAGNETIC FIELDSTRENGTH

With in the magnetic field, the field strength at any point will be measured by the source felt by the North pole of one Weber placed at that point. Denoted by H. Hence unit of H is Nm/wb.

Also if a pole of M Weber's is placed in uniform field of strength H. Nm/wb the force, if felt by the pole is MH Newton's.

Where F = mH Newton's

m = Pole strength in Weber's

H = field strength in Nm/wb

F = force in Newton's

MAGNETIC FLUX

A group of lines of force crossing the space occupied by a magnetic field. It is denoted by ø=BxA. where A is area of magnetic core and B is flux density.

Unit of Magnetic flux = Maxwell is C.G.S. system;
Weber is M.K.S. system
1 Weber = 10^8 lines.

FLUX DENSITY

The number of lines of magnetic flux per. Unit area, represented by letter 'B'.

$$\text{Flux density } B = \frac{\text{Flux}(\phi)}{\text{Area}(A)}$$

Unit of flux density is Gauss. It is the Maxwell per square centimeter.
Weber/meter^2 in M.K.S. system.

MAGNETO MOTIVE FORCE

M.M.F. is the difference of magnetic potential which maintains a magnetic flux in a magneticcircuit. It is just like e.m.f. in electric circuit.

The unit of Magneto Motive Force (m.m.f.) is Gilbert in M.K.S. system it is Ampere turns(AT).

MAGNETIC RELUCTANCE:

It is the opposition offered by a magnetic path to the establishment ofa magnetic flux, just like resistance in electrical circuit. Its unit is At/wb.

MAGNETIC FIELD AROUND A STRAIGHT CONDUCTOR

Take a flat cardboard and over it fix a white sheet of tape. In the middle of the card board make a hole and through it pass a thick wire as shown in fig. Connect the ends of a wire to abattery through a connecting wire.

Plot the magnetic lines of force around the conductor with the help of plotting compass. It is observed that the lines of force are in the form of concentric circles. The direction of lines offorce will be clock wise.

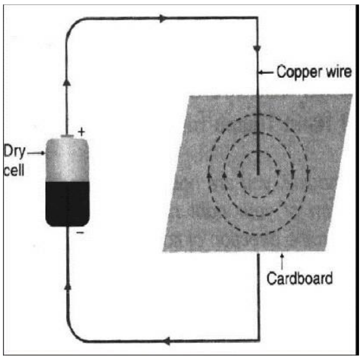


Fig.4.1: Magnetic field around a straight conductor

If the experiment is repeated but the current is passed in opposite direction, the lines of forcewill be in anti-clock wise direction. Furthermore, it is found that on increasing the strength ofcurrent, the number of magnetic lines of force around conductor increases. This in turn, increases the magnetic strength of conductor.

PROPERTIES OF MAGNETIC LINES OF FORCE AROUND STRAIGHT CONDUCTOR

(1) The magnetic lines of force are in the form of concentric circles.
(2) The plane of magnetic lines of force and hence, magnetic field is at right angle to the plane of conductor carrying current.
(3) The direction of magnetic lines of force reverses with the changes in the direction of flow of current.
(4) On increasing the magnitude of current in conductor, the number of magnetic lines of force increases.
(5) Magnetising force at 'p' due to a long straight current carrying conductor at a distance of 'R' meters is H= (I / 2rrR) AT / m

RULE FOR DETERMINING THE DIRECTION OF MAGNETIC LINES OF FORCE AROUND STRAIGHT CONDUCTOR

1. RIGHT HAND THUMB RULE

Imagine you are holding the conductor with the palm of your right hand, such that thumb points in the direction of flow of current. Then the direction in which fingers curl aroundconductor gives the direction of magnetic lines of force.
In. fig fingers are curling in anti - clock wise direction when thumb is pointing in the direction of current. Therefore the direction of magnetic lines of force is anti - clock wise.

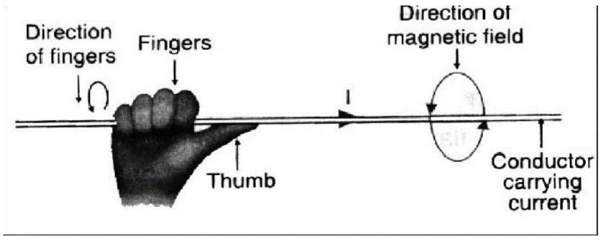


Fig.4.2: Finding the direction of magnetic lines of force

2. AMPERE RULE

Imagine a man swimming in the circuit in the direction of the current with his face to the bar, his left hand points towards north pole of the bar. It is used for finding the direction of lines of force around a wire carrying current. Ampere rule can also be used for finding direction ofmagnetic needle.

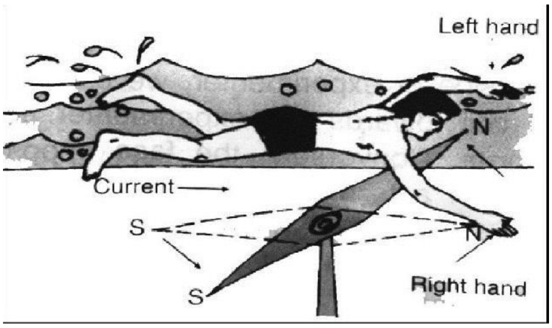


Fig.4.3: Ampere's swimming rule

From Figure, the swimmer is swimming in the direction of current and looking at needle. His left hand is pointing towards west. Hence, the north pole of magnetic needle will deflect towards west. If a current carrying conductor is placed at right angles to the lines of force of a magnetic field a mechanical force will be exerted on the conductor. The magnitude of the mechanical force can be calculated by using Ampere's law.

MAGNETIC FIELD DUE TO CURRENT IN A CIRCULAR COIL

Take a drawing board and fix over it a white sheet of paper. Make two holes A and B in drawing board and pass through it a thick copper coil. Connect the ends of copper coil to a dry cell through a Switch and variable resistance close the circuit and plot magnetic lines offorce with the help of plotting needle.

It is seen that magnetic lines of force around A are in anti - clock wise direction, Whereas that around B are in clock wise direction. However the magnetic lines of force near the centre of coil become almost parallel. As these lines of force seem to enter the coil from the side of the experiment, we can say that face of coil towards the experiment acts as south pole. Conversely, the face opposite to experiment acts as north pole.

If we relate the above observation to the flow of current in the coil, then we can say that if the current flows in the coil in clock wise direction facing the experimenter, then that face of the coil will act as South Pole. In the same way, if the current in coil facing experimenter is in anti - clock wise direction, then that face of the coil will behave like north pole.

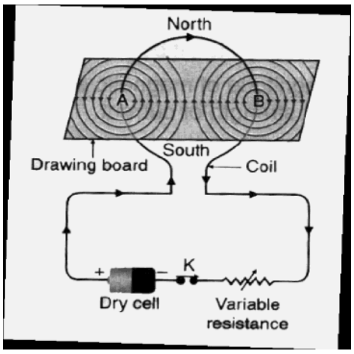
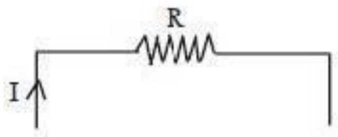
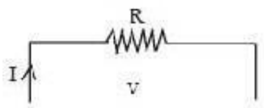
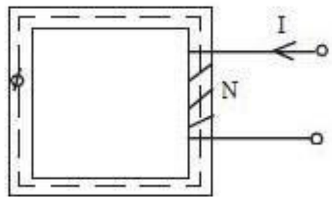
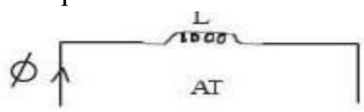


Fig.4.4: Magnetic Field around a circular coil

COMPARISON BETWEEN ELECTRIC CIRCUIT AND MAGNETIC CIRCUIT

Electric Circuit	Magnetic Circuit
 2. E.M.F is the source to pass current 3. Current in amperes; current density in A/m2 4. Current = EMF / Resistance 5. Resistance = R = ρL /a and is constant 6. Conductance = 1/Resistance 7. Energy is wasted as long as the current lasts. 8. No leakage of current 9. Current can be insulated i.e. it cannot pass through all the mediums. 10. Current flow is true flow. 11. Equivalent circuit. 	 2. MMF is the source to pass flux (ø) MMF is caused by flow of current. 3. Flux(ø) is in Weber's; Flux density in wb/m^2 4. Flux = MMF / Reluctance 5. Reluctance = $L/\mu_0\mu_r A$ It varies as $\mu_r$variable. 6. Permanence = 1/ Reluctance 7. Energy is required to establish the flux only and not for maintain it. 8. There is leakage of flux. 9. There is no magnetic insulator. The flux passes through all the mediums. 10. There is no actual flow of flux. 11. Equivalent circuit. 

CONCEPT OF ELECTRO MAGNETIC INDUCTION

The transfer of electric energy form one circuit to another without the aid of the electric connections is called induction. When electric energy is transferred by means of a magnetic field, it is called electro-magnetic induction. This type of induction is universally employed in the generation of electric power. Electromagnetic induction is also the principlewhich makes possible the operation of electric transformers.

Electromagnetic induction occurs whenever there is a relative movement between a conductor and a magnetic field, provided that the conductor is cutting across (linking with) magnetic lines of force and is not moving parallel to them.

The relative movement may be caused by a stationary conductor and a moving field or by a moving conductor with a stationary field. A moving field may be provided by a moving magnet or by changing the value of the current in an electromagnet.

The phenomenon of electromagnetic induction was discovered by Michael Faraday (1791 - 1867) an English physicist in 1831. He formulated the basic laws underlying the phenomenon of electromagnetic induction and known after his name.

FARADAY'S LAWS OF ELECTRO MAGNETIC INDUCTION

1ST LAW :

It states that " whenever the magnetic flux links with a coil or circuit changes, an e.m.f. is induced in it" or "Whenever a conductor cuts the magnetic flux, an e.m.f. is induced in theconductor".

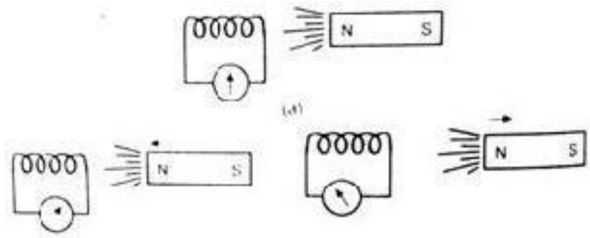


Fig.4.5: Production of Electricity from magnetism

Fig. shows an arrangement used by Faraday to study the production of electricity from magnetism. A bar magnet is placed close to a coil whose terminals are connected to asensitive galvanometer G as shown in Fig. (a). As it is, some flux is linking the coil butthere is no deflection of the galvanometer. Now, suppose the magnet is suddenly brought closer to the coil (or the coil is moved closer to the magnet) as shown in Fig.(b), there is a momentary deflection in the galvanometer. If the magnet is suddenly moved away from thecoil (or the Coil is moved away from the magnet), as shown in Fig.(c) there is a momentary deflection in the galvanometer (but the deflection is in the opposite direction to the earlier).

The deflection of the galvanometer indicates the production of e.m.f. in the coil. The only cause of the production can be the sudden movement of the magnet form the coil or vice-versa. It is important to note that the actual cause for the production of e.m.f. is the change of the flux linking with the coil. Stationary flux, however strong it may be, will never induce any e.m.f. in a stationary conductor / coil.

2ND LAW:

It states that “The magnitude of the induced e.m.f. is equal to the rate of change of flux linkages”.

Let e = induced e.m.f. (V)

N= number of turns in a coil

$ø_1$ = initial flux linkages (wb)

$ø_2$ = final flux linkages (wb)

t = time taken to change the flux from ø1 to ø2 (or ø2 to ø1) (second)

Initial flux linkages = N $ø_1$

Final flux linkages = N $ø_2$

Change of flux linkages = $Nø_2$ - $Nø_1$ = N ($ø_2$ - $ø_1$) wb -turns

According to Faraday’s second law

$$Induced\ e.m.f., e = \frac{\text{Change of flux linkages}}{Time} = \frac{N(\Phi_2 - \Phi_1}{t}$$

Putting the above equation in differential form, we get $e = \frac{d(N\Phi)}{dt} = N\frac{d\Phi}{dt}$

$$e = -\mathrm{N}\frac{d\Phi}{dt}$$

Usually, a minus sign is given to signify that the direction of the induced e.m.f. opposes the very cause producing it.

LENZ’S LAW

The direction e.m.f. and hence current in a conductor can be determined by

1. Lenz’s law or
2. Flemings right hand rule.

Lenz’s law states that ‘An induced current is always flows in such direction that its field opposes any change in the existing field.

or

‘An induced current is always flows in such a direction, that it opposes the very cause of its production”

FLEMINGS RIGHT HAND RULE

Flemings Right hand rule can be used to find out the direction of induced e.m.f. in a conductor cutting magnetic flux. Hold the thumb and the first two fingers of the right hand mutually at right angles. Place the fore finger in the direction of the flux and turn the hand so that the thumb points in the direction of motion. The second finger will point in the direction of the induced e.m.f.

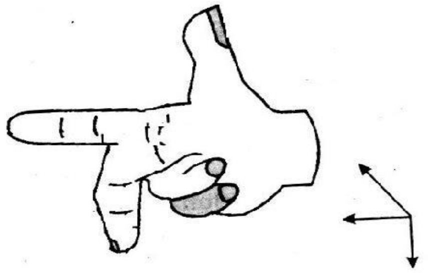


Fig.4.6: Fleming's Right hand rule

The direction of the induced e.m.f. is such that it tends to oppose the change in flux which induces it.

Magnitude of induced e.m.f. : e = Blv Volts B =

Uniform magnetic field in Weber's

L = Length of conductor in mts.

V = Velocity of the conductor in mts / sec

Direction of induced e.m.f.:

Direction of induced e.m.f. depends upon Fleming Right hand rule:

Force on a current carrying conductor is

F = BIL Newton's.

B = Field Intensity in wb / m2

I = Current in Amps

L = Length of conduct in mts.

Field intensity inside a solenoid H =NI/L ampere turns / mts

TYPES OF INDUCED E.M.F'S

The e.m.f. produced by electromagnetic induction can be divided into two types.

(1) Dynamically induced e.m.f. (motionally)

(2) Statically induced e.m.f.(Nomotion)

The magnetic flux through a circuit or coil or conductor may be changed by various means, and by that change of flux linkages causing the production of induced e.m.f.

a. The e.m.f. produced by the generator or Dynamo means magnetic line of forces cut by the conductors generate the e.m.f. called "Dynamically Induced e.m.f."

Ex. Generators.

b. When we cut the magnetic fixed flux conductor produced by the Alternating current (A.C) which generate EMF is called"Statistically induced e.m.f."

Ex. Transformer.

Induced EMF

Dynamically induced e.m.f. | Statistically induced e.m.f.

Conductor rotates induced | Flux rotates | Self induced | Mutually

DYNAMICALLY INDUCED E.M.F.

The e.m.f. induced in a conductor due to motion (either conductor electromagnet) is calleddynamically induced e.m.f.

Consider a single conductor of length ’I’ meter moving at right angles to a uniform magnetic field of B wb/m^2 with a velocity of Vm/s. Suppose the conductor moves through a small distance of ’dx’ in ’dt’ seconds.The area swept by the conductor dA =ldx
Flux cut, dø= flux density x area swept = B 1 dx.

STATICALLY INDUCED E.M.F.

The e.m.f. induced by variation of flux in a stationary conductor and magnet is known asstatically induced e.m.f. It can further divided into
(1) Self induced e.m.f. (Current changes in the coil itself)
(2) Mutually induced e.m.f. (Action of neighbouring coil)

1. SELF INDUCED E.M.F.

It is defined as the e.m.f. induced in the coil due to increase or decrease of the current in thesame coil. If the current is constant no e.m.f. is induced When a current is passed to a circuitdue to self induced e.m.f. the flow of current in the circuit is opposed.

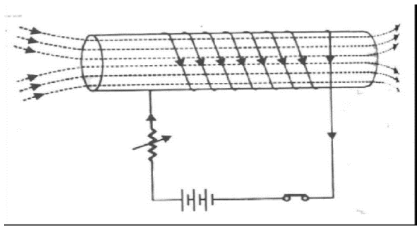


Fig.4.7: Self Induced EMF

2. MUTUALLY INDUCED E.M.F.

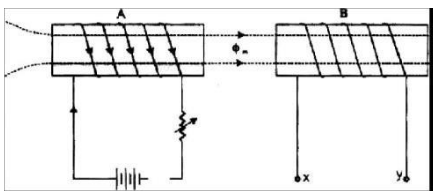


Fig.4.8 Mutually Induced EMF

Coil ‘B’ is connected to galvanometer. Coil ‘A’ is connected to a cell. The two coils are placed close together. The coil connected to a supply is called primary coil A. The other coil ‘B’ is called secondary coil. The coil in which e.m.f. is induced by mutual induction is called secondary coil.

When current through coil ‘A’ is established by closing switch ‘S’ then its magnetic field is setup which partly links with or threads through the coil ‘B’. As current through ‘A’ is changed the flux linked with ‘B’ is also changed. Hence mutually induced e.m.f. is produced in ‘B’ whose magnitude is given by faraday’slaw and direction by Lenz’s law.

The property of inducing e.m.f. in one coil due to change of current in other coil placed near the former is called mutual induction and this property is used in Transformers and Inductioncoils.

INDUCTANCE

Inductance is defined as the property of the coil due to which it opposes the change of currentin the coil. This is due to Lenz’s law.

SELF INDUCTANCE

Self inductance is defined as the Weber turns / ampere of the coil and is denoted by the letter‘L’ and its units as Henry (H).

The expression of self Induction by definition is $L = \frac{N\phi}{I}$ web-turns/Amp

N = No. of turns of a coil.
I = Current in Amps
L = Self Inductance
Ø = Flux in Weber’s

USES OF SELF-INDUCTANCE

1. In the Fluorescent tubes for starting purpose and to reduce the voltage (choke).
2. In regulators, to give reduced voltage to the fans.
3. In lightning arrester.
4. In auto-transformer.
5. In smooth chock which is used in welding plant.
6. In rectifiers to keep arc stationary.

MUTUALINDUCTANCE

When current in coil ‘A’ changes, the changing flux linking coil ‘B’. Induces e.m.f. in coil ‘B’ and is known as mutually induced e.m.f. Mutual inductance between two coils ‘A’ and ‘B’ is the flux linkages of one coil B due to one ampere of outset in the other coil ‘A’

Let N1 = No. of turns of coil ‘A’

N2 = No. of turns of coil 'B' I_1 = Current in coil A

I_2 = Current in coil B.

A = Area of cross section of coil.

$Ø_2$,$Ø_1$= Flux linking with coil A and B.

Hence by definition of expression of mutual inductance (m) = N2 Ø2Henry and

USES OF MUTUAL INDUCTANCE

1. It is used in ignition coil which is used in motor car.
2. It is also used in inductance furnace.
3. It is the principle of transformer.

SELF INDUCTION

Self Induction is the phenomenon by which an alternating e.m.f. is induced in a coil when an alternating current flows, through that coil.

MUTUAL INDUCTION

The process of production of an e.m.f. in one circuit when the current changes in another circuit (kept close to first circuit) is called " Mutual Induction".

Short Answer Questions

1. Define magnetic field.
2. Define magnetic flux.
3. Explain the term flux density.
4. Explain magneto motive force.
5. Explain Lenz's law.
6. Explain Faraday's laws.

Long Answer Questions

1. Write the comparison between electric circuit and magnetic circuit.
2. Explain types of induced E.M.F.
3. Explain a) Ampere rule b) Self-inductance c) Mutual induction