LESSON 3

Electro Magnetism

ALG89

LEARNING OBJECTIVES

To know the classification and properties of magnetic materials, concepts of magnet, types of electromagnetic induction, Hysteresis and its laws related to magnetism.

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3.1 MAGNETISM - INTRODUCTION

Magnetism is a force field that acts on some materials. A physical device which possess this force is called a magnet.

The force to attract iron particle is known as magnetism. The properties which possess magnetism are called magnet. The materials attracted by magnets are known as magnetic materials.

Magnetism plays an important role in electricity. Without the aid of magnet, it is impossible to operate devices like generator, electric motors, transformers, electrical instruments, etc. Magnets are also used in the functioning of radio, television, phones and ignition system of auto mobiles.

3.2 PROPERTIES OF MAGNET

- Magnet attracts magnetic substances such as iron, nickel, cobalt and its alloy.
- If a magnet is freely suspended, the pole will always tend to set themselves in the direction of north and south.
- Like poles repels and unlike poles attracts each other.

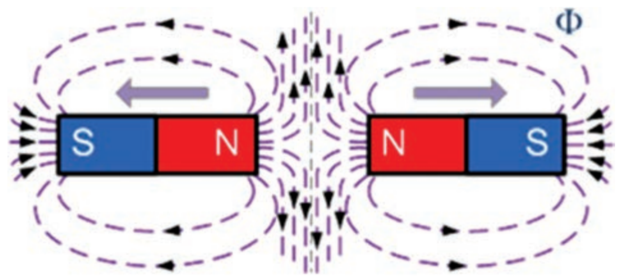


Fig 3.1 *Like poles*

- If a magnet is broken into number of pieces, each piece becomes an independent magnet which has North and South.

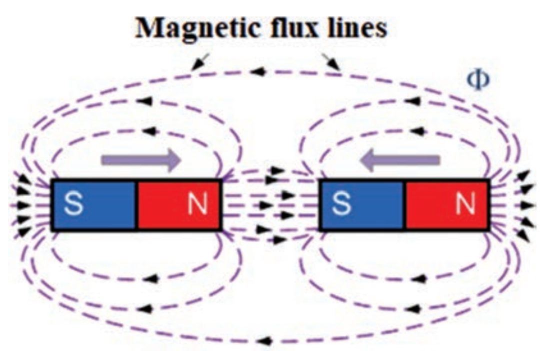


Fig 3.2 *Unlike poles*

- A magnet loses its properties when it is heated, hammered or dropped from height.

3.2.1 Classification of magnets

1. Natural magnet

The magnet found in nature is known as lodestone. The natural magnet is one of the iron ore magnetite with chemical composition Fe_3O_4

2. Artificial magnet

The magnets prepared by artificial method are called artificial magnets. It can be made in different shape, size and strength only in certain metals. There are two types of artificial magnet.

a) Permanent magnet

In a permanent magnet, the magnetic materials can retain magnetic property permanently for a long time. Bar magnet, Horse shoe magnet, Ring magnet, Cylindrical magnet are some types based on shapes.

Fig 3.3 *Permanent magnets*

ALNICO (Aluminium-Nickel-Cobalt) is an alloy metal specifically used as permanent magnet because it can be lifted up to 50 times weight load compared to its own weight. Permanent magnets can be formed by touch method, electric current method and induction method.

b) Temporary magnet (or) Electro magnet

When an electric current is passed through a coil of wire wound around a soft laminated silicon steel core, a very strong magnetic field is produced. This is called as electro magnet. If the current is cut off, the core will be demagnetized, and hence itis also known as temporary magnet.

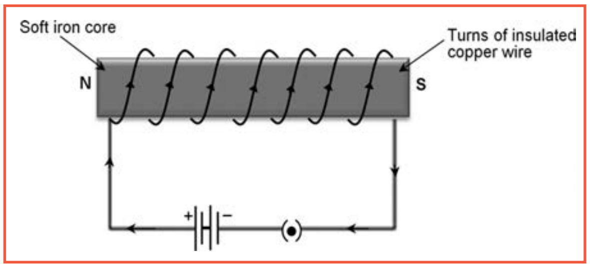


Fig 3.4 *Electro magnet*

3.2.2 Comparison of Electro magnet & Permanent magnet

Electro magnet	Permanent magnet
1. Polarity can be changed easily.	Polarity cannot be changed easily.
2. Strength can be varied.	strength cannot be varied.
3. More cost.	Less cost
4. Suitable for large size motorand and generator.	Not suitable for large size.
5. Used in electric bells, signals, escalators, cranes.	Not used in any of these.
6. Cannot be used for navigation	Mostly used for navigation as magnetic needle
7. Cannot be used in cycle and motor cycle dynamo.	Used in cycle and motor cycle dynamo.

3.3 MAGNETIC MATRIALS

Magnetic materials are classified based on permeability property by three types.

a) Dia–magnetic materials

- The materials which are repelled by a magnet are known as diamagnetic materials. Ex: zinc, mercury, lead, sulphur, copper, silver, bismuth, wood, etc.
- The permeability value of these materials is less than one.

b) Para magnetic materials

- The materials which are not strongly attracted by a magnet are known as paramagnetic materials. Ex: (aluminium, tin, platinum, magnesium etc.).
- The permeability value of these materials is just greater than one.

c) Ferro -magnetic materials

- The materials which are strongly attracted by a magnet are known as ferromagnetic materials. Ex: (iron, nickel, cobalt, etc.)
- The permeability value of these materials is very high (varies from several hundreds to thousands).
- Materials which are easily magnetized with a high relative permeability, low coercive force (small hysteresis) are called soft ferromagnetic materials.
- Materials which are difficult to magnetize, but retain magnetism with great tenacity, with low relative permeability, high coercive force are called hard ferromagnetic materials.

3.3.1 Magnetic terms and properties

a) Magnetic field:

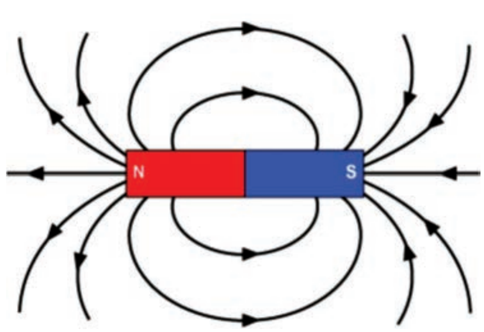


Fig 3.5 *Magnetic field lines*

- The magnetic field around a magnet is represented by imaginary lines called magnetic line of force.
- The magnetic line of force emerges from north pole to south pole and it continues through the body of magnet to form a closed loop.
- Two magnetic lines of force will not intersect each other.
- If magnetic lines of force are rows together, the field is strong. If they are spaced out the magnetic field is weak.

b) Magnetic flux

- The amount of magnetic field produced by a magnetic source is called magnetic flux.
- It is denoted by Greek Letter ϕ and its unit is weber.

c) Magnetic flux density

- The magnetic flux density is the flux per unit area at right angles to the flux.

Magnetic flux density, $B = \phi/A$ wb/m^2

d) Permeability

- Permeability of a material means, the conductivity for magnetic flux. The greater the permeability of material, the greater is its conductivity of magnetic flux and vice-versa. Air or Vacuum is the poorest conductor of magnetic flux. The absolute (actual) permeability μ_0 (Greek Letter 'mu') of air is $4\pi \times 10^{-7}$ Henry/metre. The absolute (actual) permeability of magnetic material(μ) is much greater than μ_0.

The ratio between permeability of material and permeability of air (μ_0) is called relative permeability(μ_r)

$$\mu_r = \mu/\mu_0$$

The relative permeability for air is 1 ($\mu_r = \mu_0/\mu_0$)

The value of μ_r for all non- magnetic material is also 1.

The relative permeability of magnetic materials is very high. For example, soft iron (i.e pure iron) has a relative permeability of 8000, whereas its value for perm alloy (22% Iron, +78% nickel) is as high as 50,000.

e) Magneto Motive Force (MMF)

It is a magnetic pressure which tends to set up magnetic flux in a Magnetic circuit.

The work done in moving a unit magnetic pole once round the magnetic circuit is called MMF. It is equal to the product of current and number of turns of the coil.

MMF = Number of turns × current.
Its unit is Ampere-turns (AT)

f) Reluctance

The opposition that the magnetic circuit offers to magnetic flux is called reluctance. Magnetic materials (eg iron, steel) have low reluctance, on the other hand non-magnetic materials have a high reluctance.

$$\text{Reluctance } S = l/ \mu_0 \mu_r A$$

g) Magnetic Neutral Axis (MNA)

The imaginary line which is perpendicular to the magnetic axis and passes through the centre of the magnet is called magnetic neutral axis. There is no magnetic influence along this line.

Magnetic Axis (MA) is the imaginary straight line joining North to South pole. There is maximum magnetic influence along this line.

i) Magnetic saturation

The limit beyond which the strength of magnet cannot be increased is called magnetic saturation.

ii) Residual magnetism

It is the magnetism which remains in a material when the effective magnetizing force has been reduced to zero.

iii) Magnetic retentivity

The property of retaining magnetism by a magnetic material is called magnetic retentivity.

iv) Hysteresis

The energy required to demagnetize the residual magnetism of material is known as hysteresis.

v) Leakage flux

Leakage flux is defined as the magnetic flux which does not follow the particularly intended path in a magnetic circuit.

vi) Coercivity

Coercivity is a measure of the ability of a ferro magnetic materials to withstand an external magnetic field without becoming demagnetized.

3.4 ELECTRO MAGNETISM

When current is passed through a coil of wire, a magnetic field is set up around the coil. If soft iron bar is placed inside the coil of wire carrying current, the iron bar becomes magnetized. This process is known as electro magnetism.

The iron remains as a magnet as long as the current is flowing in the circuit. It looses its magnetism when current is switched off.

The polarity of an electromagnet depends upon the direction of the current flowing through it.

If the direction of current is altered, the polarity of the magnetic field will also be changed.

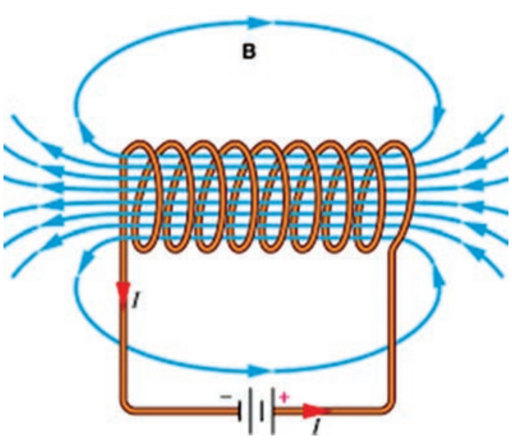


Fig 3.6 *Magnetic field lines*

3.4.1 Lenz law

A change in current produces an emf, whose direction is in such a way that it opposes the change of current.

3.4.2 Lorent'z law

Lorentz law states that the Lorentz force (or electromagnetic force) is the combination of electric and magnetic force on a point charge due to electromagnetic fields as shown in the figure

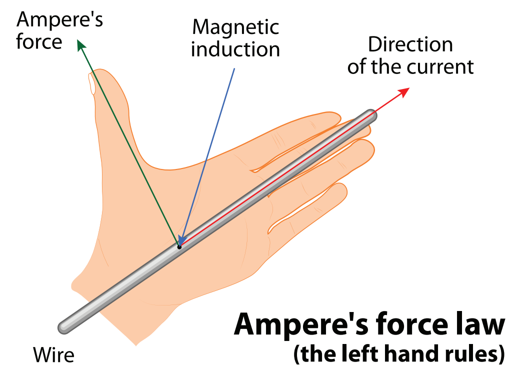


Fig 3.7 *Indication of Lorent'z law*

3.4.3 Electric field

It is a medium around a charge (or) region in which the electric force act is called electric field.

Electric field is the physical field that surrounds electrically charged particles and exerts force on all other charged particles in the field.

Electric field strength is measured in SI unit volt per meter (V/M) The direction of this field is taken as the direction of the force which is exerted on the positive charges.

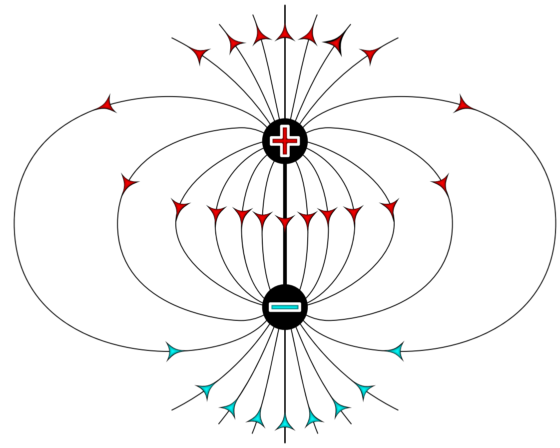


Fig 3.8 *Electric field*

E = F/Q

E – Electric field

F – Force

Q – Charge

The electric field is radially outwards from positive charge and radially in towards negative point charge.

3.4.4 Electro magnetism in a current carrying conductor

A magnetic field is formed around a conductor carrying current. The direction of the magnetic field depends on the direction of the current flow.

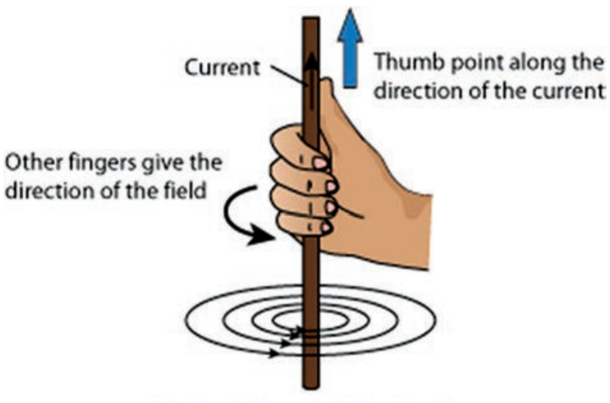


Fig 3.9 *Right hand grip rule*

Right hand grip rule

- It is used to determine the direction of the magnetic field in a current carrying conductor.
- If you wrap your fingers around the wire with your thumb pointing direction of current flow, your index finger will point the direction of magnetic field.

Maxwell's cork screw rule

- Assume a right handed cork screw to be along the wire to advance in the direction of current.
- The motion of handle gives the direction of magnetic lines around the conductor.

Force between parallel conductors

When two current carrying conductors are parallel to each other, a mechanical force act on each conductor. This force is due to magnetic field produced in the two conductors. If the currents are in the same direction, the forces are attractive. If the currents are in the opposite direction, the forces are repulsive.

i) Current in the same direction

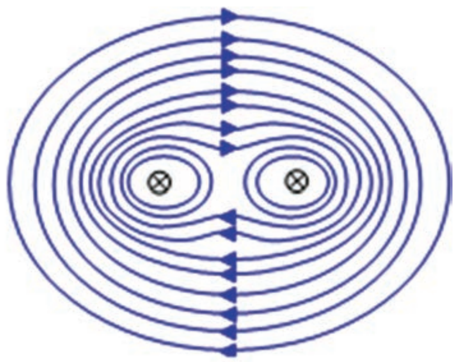


Fig 3.10 *Current in same direction*

- If two wires (A & B) carrying current in same direction are brought together, their magnetic fields will aid one another and attracts.
- Since the flux lines around two conductors are going in the same direction, the flux lines join and the field brings the wire together.

ii) Current in the opposite direction

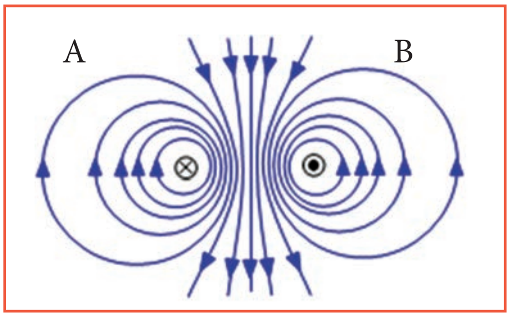


Fig 3.11 *Currents in opposite direction*

- If two wires (A & B) carrying current in opposite directions are brought together their magnetic field will oppose one another.
- Since the flux lines around two conductors are going in the opposite direction, the flux lines cannot cross and the field moves the wires apart.

3.4.5 Solenoid

A current carrying wire is made to form a loop and a number of loops are wound in the same direction to form a coil. More magnetic fields will add to make the flux lines through the coil stronger and dense.

A helically wound coil that is made to produce a strong magnetic field is called a solenoid.

The flux lines in a solenoid act in the same way as in a magnet. They leave the north pole and go around to the south pole.

The directions of the magnetic field in a solenoid is known by the following rules.

End rule

Look at the end of the solenoid of the electromagnet. If the current in the coil is clock wise the end is south pole . If the current in the coil is counter-clockwise the end is north pole.

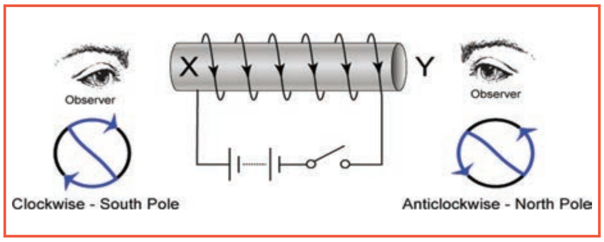


Fig 3.12 *End rule*

Helix rule

Hold the right hand palm over the solenoid in such a way the fingers point in the direction of current in the solenoid conductors. Then the thumb indicates the direction of magnetic field (North) of the solenoid.

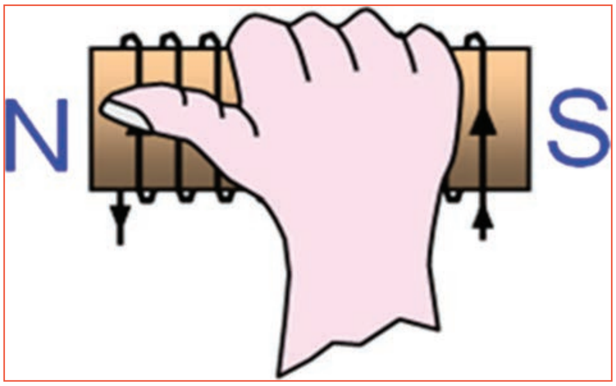


Fig 3.13 *Helix rule*

Uses of solenoid

- Used for circuit breaking.
- Voltage regulating device.
- Automatic motor starter.
- Contactor, elevator, crane.

Toroid

A helix bent into a circular form is known as Toroid (i.e coiled coil)

Fig 3.14 *Toroid*

3.4.6 Comparision between magnetic and electric circuits

S.No	Properties	Magnetic circuit	Electric circuit
1	Definition	The closed path followed by magnetic flux is called magnetic circuit.	The closed circuit followed by electric current is called electric circuit.
2	Driving Force	MMF is the pressure required to set up the magnetic flux in magnetic circuit (Ampere-Turn)	EMF is the pressure required to set up the current in an electric circuit (Volt).
3	Response	Flux $(\varnothing) = \frac{MMF}{Reluctance}(weber)$	$Current(I) = \frac{EMF}{Resistance}(Ampere)$
4	Impendance	Reluctance$(S)=l/(\mu_0\mu_r A)$ [AT/Weber]	Resistance $(R)=\rho l/A$(ohms)
5	Admittance	$Permeance = \frac{1}{Reluctance}[wb/AT]$	$Conductance = \frac{1}{Resistance}(Siemens)$
6	Proportionality	$Reluctivity = \frac{1}{Permeability}(M/H)$	$Resistivity = \frac{1}{Conductivity}(ohm\text{-}meter)$
7	Density	Flux density $B = \mu H(wb/m^2)$	Current density $J=I/A(Amp/m^2)$
8	Field Intensity	Magnetic field intensity$(H)=NI/l$(AT/m)	Electric field intensity$=E/l$(volt/m)

3.5 ELECTRO MAGNETIC INDUCTION

Electricity induced by the magnetic field is known as electro magnetic induction.

Whenever a conductor or coil is moved or rotated in a magnetic field and cut the magnetic line of force (flux), an EMF will be induced in that conductor or coil.

3.5.1 Faraday's law of electromagnetic induction

First law: Whenever a conductor cuts magnetic flux, an EMF is induced in that conductor.
Second law: The magnitude of the induced EMF is directly proportional to the rate of change of flux linked with the conductor.

Types of EMF induced are:

i) Dynamically induced EMF.

ii) Statically induced EMF.

3.5.2 Dynamically induced EMF

Moving a coil/conductor in a uniform magnetic field will induce an EMF which is known as dynamically induced EMF. DC Generator works on this principle.

Consider a conductor of length l (meters) placed in a uniform magnetic field of density $B(wb/m^2)$, moved with a velocity V(m/s) perpendicular to the direction of the magnetic field. Then the flux is cut by the conductor and an EMF is induced.

The magnitude of EMF induced is $e = BlV \sin\theta$

3.5.3 Statically induced emf

By keeping a conductor or coil in statically and varying the magnetic field will induce an electro motive force in the conductor or coil which is statically induced electro motive force.

Statically induced electro motive force can be classified as self inductance and mutual inductance.

(a) Self induction

- This is the EMF induced in a coil due to the change of its own flux linked with it.
- If current through the coil is changed, then the flux linked with its own turns will also change, which will produce self induced EMF.
- The induced EMF is always opposite in direction to the applied EMF.

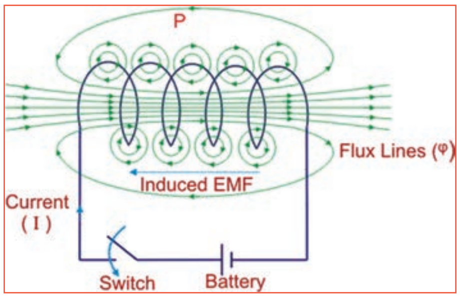


Fig 3.15 *Self induction*

(b) Mutual induction

It is the ability of one coil to produce an EMF by induction. When the current in the second coil changes, both coils are placed nearer.

- When two coils are placed nearer and current is passed through one of the coil, magnetic flux will be produced which is common to both coils.
- When current through first coil is varied, the magnetic flux will vary, which will induce an emf in second coil.

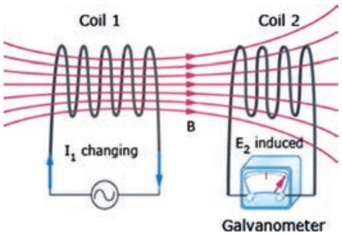


Fig3.16 *Mutual induction*

Fleming's right hand rule

The direction of induced EMF in generators and alternators (Dynamically induced emf) is given by Fleming's Right hand rule.

Stretch the thumb, forefinger and middle finger Right hand mutually at right angles [90°] to each other.

If the thumb indicates the direction of motion of the conductor, the forefinger indicates direction of the magnetic flux, then the middle finger indicates the direction of the induced EMF.

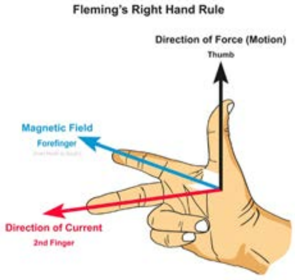


Fig 3.17 *Right hand rule*

Fleming's left hand rule

Stretch thumb, forefinger and middle finger of the left hand mutually at right angles (90°) to each other .

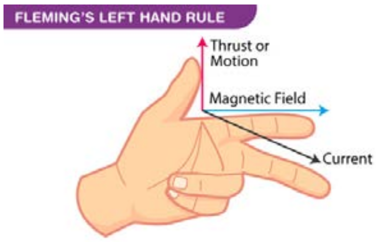


Fig 3.18(a) *Left hand rule*

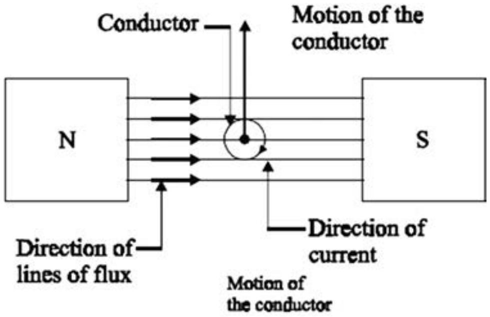


Fig 3.18(b)

If the forefinger indicates the direction of the magnetic field (B), the middle finger indicates the direction of current (I) in the conductor and the thumb point to the direction of motion (F) of the conductor.

3.6 HYSTERESIS LOOP

Take a piece of iron bar AB and magnetise the same by placing it within the field of solenoid. The field H produced by the solenoid is called the magnetising field. The field (H) can be increased (or) decreased by increasing (or) decreasing the current through it. Let 'H' be increased slowly from zero to a maximum value and the corresponding value of flux density (B) be noted. If we plot the relation between H and B, OA is obtained. The material becomes magnetically saturated at point A and has the maximum flux density induced in it.

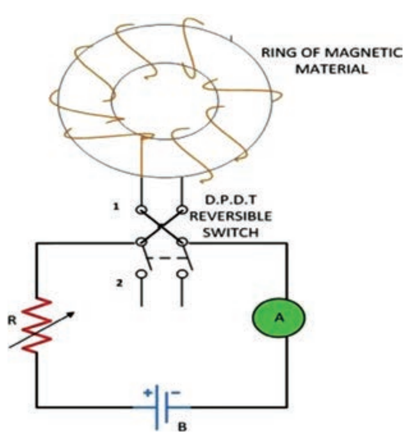


Fig 3.19 *Hysteresis loop circuit*

If 'H' is decreased slowly by decreasing the current in the solenoid, the flux density(B) will not decrease along AO but will decrease less rapidly along AR_1. When H is made to be zero, at that time, B will not be zero but will have the value OR_1. It means that on removing the magnetising force, H the iron bar is not completely demagnetized. This value ($B = OR_1$) is the retentivity of the material (Residual magnetism).

To demagnetise the bar, we have to supply the force H in the opposite direction.

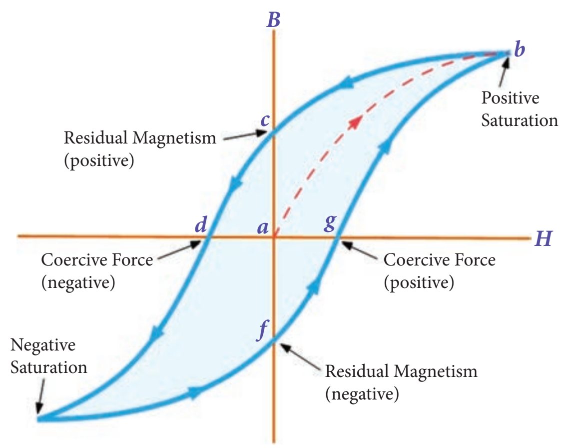


Fig 3.20 *Hysteresis loop*

When H is reversed by reversing the current through the solenoid, then B is reduced to zero at point C. This value is required to clear off the residual magnetism. This is known as the coercive force and is a measure of the coercivity of the material.

After reducing the magnetism to zero, if the value of H is further increased in the negative direction (i.e reversed direction), the iron bar reaches a state of magnetic saturation at point A_1, which is negative saturation. By taking H back from its value corresponding to negative saturation to its value for positive saturation, the closed loop which is obtained when iron bar is taken through one complete cycle of magnetism. This loop is called hysteresis loop .

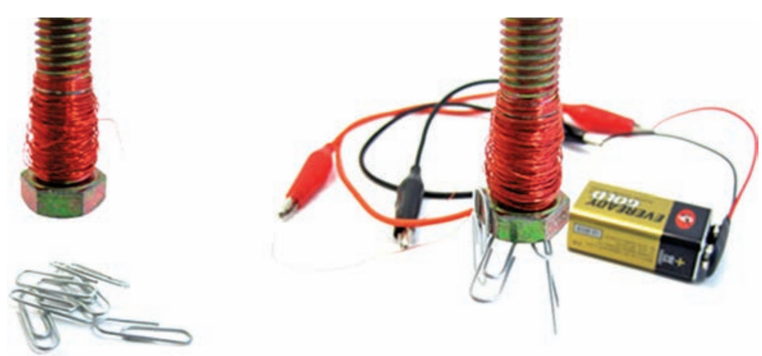
In this BH curve, it is seen that B always lag behind H. The two never attain zero value simultaneously. Hysteresis literally means to lag behind. The closed loop which is obtained when iron bar is taken through one complete cycle of reversal of magnetisation is known as hysteresis loop.

3.7 RULES/LAWS RELATED TO MAGNETISM

Rule or Law	Uses
Maxwell cork screw rule	To find out the direction of line of force (magnetic field) around a straight current carrying conductor.
Right and grip rule	Wrap your fingers around the wire with your thumb pointing direction of current flow, your index finger will point the direction of magnetic field.
Helix rule	To find out polarity of the poles of an electromagnet (solenoid)
End rule	To find out polarity of the poles of an electromagnet (solenoid)
Fleming's right hand rule	To find out the direction of current in the conductor of a generator.
Fleming's left hand rule	To find out the direction of rotation of the armature of DC motor.
Lenz's law	To find out the direction of the counter current produced in the armature.
Lorentz law	To find out the direction of line of the electrification at a point.

Activities

1. Apply the magnetic rule by using two magnets.
2. How can the induced current be known by mutual induction method.
3. Do the practice observed from the diagram.



GLOSSARY

Permanent magnet	—	நிலைக் காந்தம்
Artificial magnet	—	செயற்கைக் காந்தம்
Electro magnet	—	மின்காந்தம்
MMF (Magneto Motive Force)	—	காந்த இயக்கு விசை
Magnetic flux	—	காந்தப் புலம்
Magnetic saturation	—	காந்தப் பூரிதம்
Residual magnetism	—	தங்கிக் கொண்ட காந்த சக்தி
Hysteresis loop	—	காந்தத் தயக்க வளையம்

Q A PART Mark 1

Choose the correct answer:

1. Magnetic field lines
   a) intersect each other
   b) cannot intersect.
   c) are crowded near poles
   d) are crowded near north poles

2. In an electro magnet, when current is switched off, the iron bar
   a) holds its magnetism
   b) gains voltage
   c) losses its magnetism
   d) gains current

3. The direction of magnetic lines of force is
   a) from south pole to north pole
   b) from north pole to south pole
   c) from one end of the magnet to other
   d) direction of current

IF8K2

4. Fleming's left hand rule is applicable for ___________
   a) Motor
   b) Generator
   c) Inverter
   d) Computer

5. In Fleming's left hand rule, middle finger represents ___________
   a) direction of generated current
   b) direction of magnetic field
   c) direction of motion of the conductor
   d) direction of generated voltage

6. In Fleming's left hand rule, thumb represents ___________
   a) direction of motion of the conductor
   b) direction of magnetic field
   c) direction of generated current
   d) direction of generated voltage

7. The permanent magnet is used in
   a) Dynamo
   b) Energy meters
   c) Transformers
   d) Loud Speaker

8. Magnetic properties in a magnet can be destroyed by
   a) heating
   b) hammering
   c) by inductive action of another magnet
   d) by all above methods.

9. A material which is slightly repelled by magnetic field is known as
   a) Ferro magnetic material
   b) Para magnetic material
   c) Dia magnetic material
   d) Conducting material.

10. Total number of magnetic field lines passing through an area is called
    a) Magnetic flux density
    b) EMF
    c) Magnetic flux
    d) Voltage.

11. The unit of magnetic flux density is
    a) weber/m^2
    b) lumens
    c) tesla
    d) weber

12. Which of the following circuit element stores energy in an electromagnetic field?
    a) Capacitor
    b) Inductance
    c) Resistance
    d) Variable resistance

13. EMF induced by motion of conductor across magnetic field is called
    a) emf
    b) dynamic emf
    c) static emf
    d) rotational emf

14. The magnitude of the induced emf in a conductor depends on the
    a) flux density of the magnetic field
    b) amount of flux cut
    c) amount of flux linkages
    d) rate of change of flux linklages

QA

PART B

Mark 3

Answer the questions in briefly

1. What is called an electro magnet?
2. Why ALNICO is used in permanent magnet?
3. State any three uses of permanent magnets.
4. State Maxwell cork's screw rule.
5. What is Solenoid and Toroid?
6. What are the uses of solenoid?
7. Define End rule.
8. Define Faraday's laws of electromagnetic induction.
9. State Flemings right hand rule.
10. Explain Fleming's left hand rule.
11. Define Lenz's law.
12. Define Lorentz's law.
13. Define Electric field.

QA

PART C

Mark 5

Answer the questions not exceeding one page

1. Compare electro magnet and permanent magnet.
2. Explain magnetic materials?
3. Define Flux, MMF and Reluctance.
4. Define Magnetic saturation, Retentivity and Residual magnetism.
5. How to do you increase the magnitude of induced emf.

QA

PART D

Mark 10

Answer the questions not exceeding two page

1. Explain the types of electro magnetic induction with neat diagram.
2. Explain hysteresis loop with a neat diagram.

Reference book

1. 'A text book of Electrical Technology' B.L. Theraja and A.K. Theraja, S. Chand & Company Ltd.

Internet resource

1. www.sciencebuddies.org