TOPIC: **MAGNETISM III**
General Objective: The learner should be able to explain the relationship between electricity and magnetism
SUB-TOPIC: **The principle of the electric motor.**
SPECIFIC OBJECTIVES: The learner should be able to;

- Demonstrate the existence of a force on a current carrying conductor in a magnetic field.
- Use Fleming's left hand rule to predict the direction of force.
- Investigate the factors affecting the size of the force.
- Explain the operation of moving coil instruments.

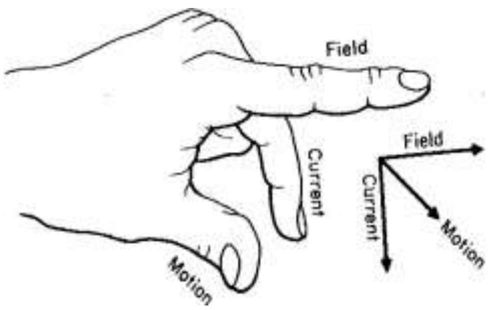
THE MOTOR EFFECT:

FORCE ON CURRENT CARRYING CONDUCTOR IN THE MAGNETIC FIELD.

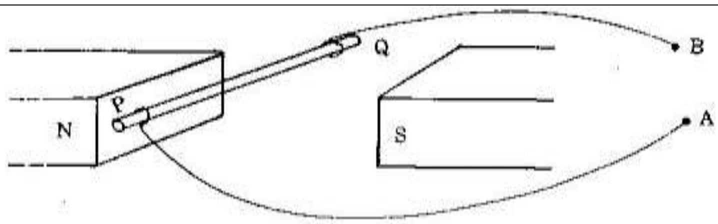
When a conductor carrying current is placed in a magnetic field, it experiences a mechanical force.
The direction of the force (or thrust) on the conductor is predicted using

Fleming's Left hand rule,
STATEMENT OF FLEMING'S LEFT HAND RULE:

If the first, the second and the thumb of the left hand are placed at right angles to each other, with the **F**irst finger pointing in the direction of the **F**ield, the se**C**ond finger in the direction of the **C**urrent, then the thu**M**b points in the direction of the **M**otion,



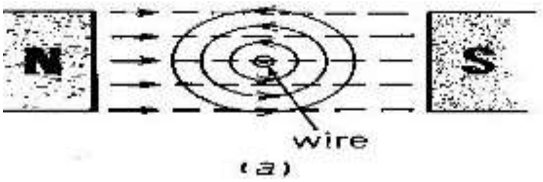
- The **F**irst finger points in the direction of the field.
- The Se**C**ond figure points in the direction of current.
- the thu**M**b will point in the direction of the force or Motion.



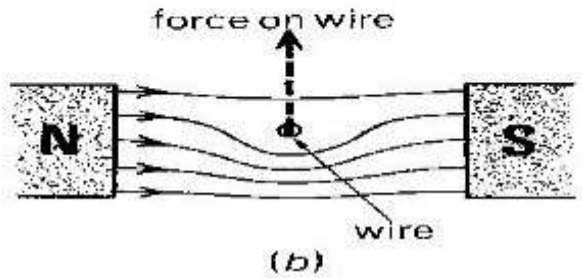
When the switch is on, current flows through the wire from B to A.
The wire jumps upwards.
If either the direction of current or magnetic field is reversed, the wire moves down wards.

EXPLANATION

The magnetic fields due to the magnet and current carrying wire are shown below.



The field due to current carrying wire is indicted by the circles while the dotted lines are field lines of magnet.
The resultant field obtained by combining both fields is as shown below.



There are more field lines below the wire since both fields act in the same direction, but fewer above it because they are in opposition.
If we suppose field lines to be a stretched elastic material, those below will try to straighten out and in so doing, they will exert an upward force on the wire.

FACTORS AFFECTING THE MAGNITUDE OF FORCE ON A CURRENT CARRYING CONDUCTOR.

Magnitude of force exerted on a current carrying conductor is directly proportional to:
- The magnitude of current flowing through the conductor.
- Field strength of the magnet.
- The length of the conductor exposed to the magnetic field.
- The angle of inclination of the current carrying conductor to the magnetic flux. (the force is a maximum when the direction of the current is perpendicular to the magnetic field lines).

N.B – The effect of the magnetic field on a current carrying conductor is referred to as the **motor effect**.

STATEMENT OF THE MOTOR EFFECT.

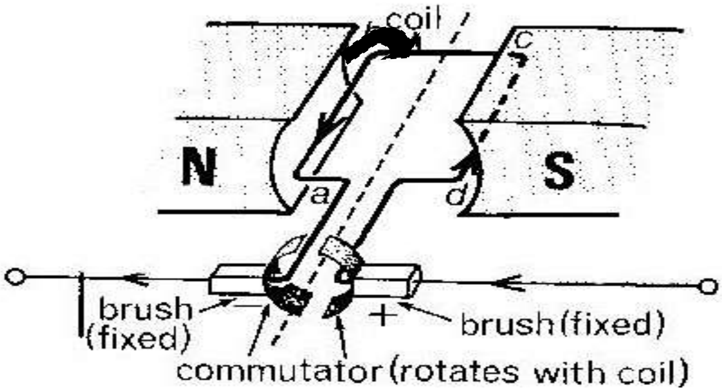
A current carrying conductor placed in a magnetic field experiences a force.

APPLICATION OF THE MOTOR EFFECT

- Moving coil loud speaker
- Simple d.c motor
- Moving coil galvanometer

SIMPLE D.C MOTOR

A **simple d.c motor** is a device that converts **electrical energy** to **mechanical energy**.
STRUCTURE



The Simple d.c motor consists of a rectangular coil of wire placed between pieces of a strong magnet, and its ends are connected to half – split commutators. The commutators are each in contact with a carbon brush which are in turn connected to a d.c supply. The coil is free to rotate in the uniform magnetic field.

MODE OF OPERATION:

- When current is passed through the coil, equal opposite forces are exerted on the wire sections ab and cd of the coil causing it to rotate.
- When the coil reaches the vertical position, the brushes B_1 and B_2 lose contact with the commutators C_1 and C_2, hence the current is cut off.
- The momentum of the coil however carries it beyond the vertical position and the commutator halves reverse contact and the coil continues to rotate in the same direction.

NOTE: After the vertical position: The e.m.f in the coil reverses so that the direction of current in the coil and the external circuit remains the same.

PRACTICAL MOTORS

In Practical motors

- A coil of many turns is wound on soft-iron core. Both the coil and core form the armature.
  The soft-iron core is easily magnetized by the field, hence increasing the magnetic flux in which the coil rotates.
- There are several coils each in a slot in the core and each having a pair of commutator segments. This results into more power and smoother running.
- An electromagnet instead of permanent magnet. The magnetic field due to an electro magnet can be varied according to the demand.
- The current in the coil is increased.
- The area of the coil in the magnetic field is increased.

This causes the motor to run faster, hence, increasing the resultant mechanical energy.

FACTORS THAT CAUSE ENERGY LOSSES IN AN ELECTRIC MOTOR AND HOW THEY CAN BE MINIMISED.

	FACTORS CAUSING ENERGY LOSS AND REDUCTION OF EFFICIENCY OF THE ELCTRIC MOTOR.	**METHOD OF OVERCOMING THE EFFECT**
1.	**Resistance in the coils** leading to the heating up of the motor coils.	Thick copper coils of low resistance are used to reduce heating.
2	**Eddy currents** in the core: Magnetic flux changing in the soft iron core cuts the core, thus inducing e.m.f. in it, which in turn sets up eddy currents to flow in the core. These currents oppose the magnetic flux change in the coils	The core is laminated to reduce the eddy currents.
3	**Magnetic reversals (Hysteresis losses) in** the iron core. Energy is lost in the form of magnetizing and demagnetizing the core when the current reverses.	Using a soft iron core that easily magnetizes and demagnetizes.
4	**Friction** in the moving parts of the coil.	Lubrication of the spaces between the commutators and the carbon brushes.

Increasing the Power of an Electric motor:

The power of an electric motor can be increased by:

1. Increasing the current flowing through the coils.
2. Increasing the strength of the magnetic field.

3. Increasing the area of the coil.
4. Increasing the number of turns of the coil.
5. Winding the coil on a soft magnetic material (i.e. soft – iron core) that is easily magnetized and demagnetized. (Do not use hard magnetic materials like steel)

Back e.m.f in an electric motor.

When an electric motor is running, it also acts as a dynamo and sets up a back e.m.f. The back e.m.f acts in the opposite direction and opposes the e.m.f, E applied to the motor to drive it.

The resulting current, **I,** flowing in the coil is given by the formula:

$$\mathbf{I = \frac{E - E_b}{R}}$$

Where $E = \text{e.m.f. applied to motor}, \; E_b = \text{back e.m.f},$

$R = \text{resisitance of the coil},$

Therefore, the p.d across the armature coils is given by the equation:

$$\mathbf{IR = E - E_b}$$

From Ohm's law: $\mathbf{IR = E_a = E - E_b}$

The p.d , E_a, produces a current,$\mathbf{I}$ to flow through the armature coils and this in turn causes the coils to heat up.

 The power wasted as heat in the coils is given by = $\mathbf{E_a I = (IR)I = I^2R}$.

Therefore;

Power output = power input   power wasted in heating the coils

$$\mathbf{power\ output = IE - IE_a = I(E - E_a) = IE_b}$$

EFFICIENCY OF AN ELECTRIC MOTOR:

Efficiency of the motor,

$$\eta = \frac{\text{Power output}}{\text{Power input}} \times 100 = \frac{IE_b}{IE} \times 100 = \frac{E_b}{E} \times 100$$

Where E = e.m.f of the supply, E_b = back e.m.f.

N.B. The greater the back e.m.f. E_b, the greater the efficiency of an electric motor.

APPLICATIONS OF THE ELECTRIC MOTOR:

Electric motors are applied in electrical appliances like:

Fans, Refrigerators, washing machines, hair dryers, drilling machines, radio cassettes or DVD players, vehicle wipers, etc.

Example:

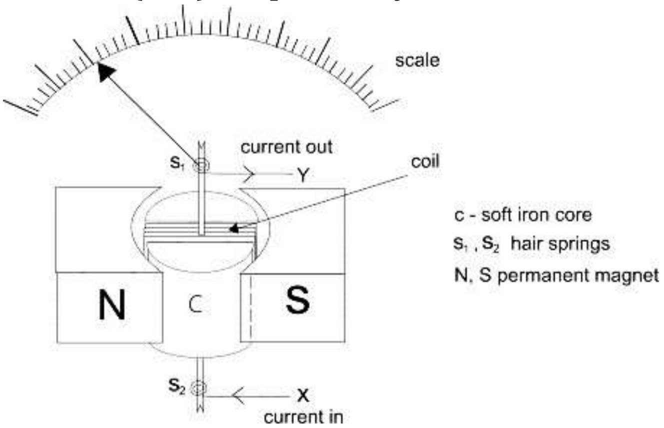
1. An electric motor 90% efficient operates a water pump. If it raises 0.9 kg of water through 20 m every second, calculate the electric power supplied to the motor.
   ANSWER:
   Work done by the motor = $F \times d = mgh$
   $= 0.9 \times 10 \times 20 = 180\ J$

   $$\text{Power output} = \frac{W}{t} = \frac{180}{1}\ Js^{-1} = 180\ W$$
   $$\text{Efficiency,} \quad \eta = \frac{\text{power output}}{\text{power input}} \times 100\%$$
   $$\text{power input, } P = \frac{\text{power output}}{\eta} \times 100\% = \frac{180}{90} \times 100 = 200\ W$$

2. A 240 V vacuum cleaner motor takes a current of 0.6 A.
   Find the efficiency of the motor if the useful mechanical power output is 72 W. State how the rest of the energy is being wasted.
   ANSWER:
   $$\text{Efficiency,} \quad \eta = \frac{\text{power output}}{\text{power input}} \times 100\%$$
   $$\text{Efficiency, } \eta = \frac{72}{EI} \times 100\% = \frac{72}{240 \times 0.6} 100\% = 50\%$$

MOVING COIL GALVANOMETER.

A galvanometer is a device used to detect small current or small p.d usually in miiliamperes (mA) or millivolts (mV) respectively.



STRUCTURE

- It consists of a fine insulated copper coil of several turns wound on a soft iron or light aluminium frame that rotates in a radial magnetic field provided by the semi – circular pole pieces of a permanent magnet.
- The frame is pivoted on jeweled bearings.

- The coil is connected to the pointer which moves over the scale when it turns.

MODE OF OPERATION

- A current to be measured is let in and out through the hair springs S1 and S2.
- The vertical sides of the coil experience equal and opposite forces which constitute a couple.
- The couple then turns the coil until the torsional couple in the hair springs (of S1 and S2) balances with the torque due to the magnetic field.
- The position of the pointer is then the measure of current.

NB : 1. The coil is put in a **soft iron cylinder** which concentrates the magnetic flux radially in the annular space.

2. The **radial magnetic field** ensures that the coil is always at right angles to the magnetic field lines so as to experience a uniform (constant) torque throughout its rotation.

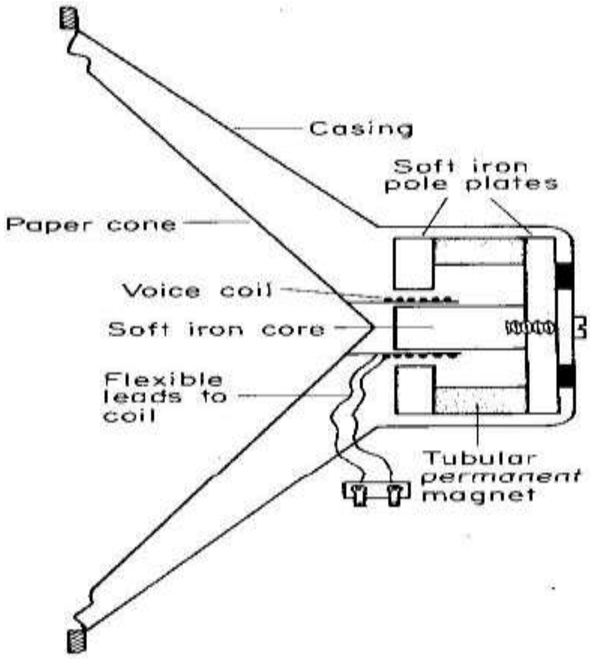
SENSITIVITY OF THE GALVANOMETER:

The sensitivity of the galvanometer is increased by:

- Increasing the number of turns in the coil.
- Using a stronger magnet with a high magnetic flux.
- Using a coil of large area.
- Using weak hair springs to give a small control couple.

MOVING COIL LOUD SPEAKER.

A loud speaker converts electrical energy to sound energy.



STRUCTURE.

It consists of a cylindrical voice coil placed inside a soft iron core which is attached to a permanent magnet.

ACTION

Varying current flows through the terminal into the coil which is in a magnetic field. The coil experiences a varying force which causes it and the paper cone attached to it to move to and fro. This sets the air in contact with paper cone into vibrations, hence setting up a sound wave which follows the same pattern as the original electrical signal.

SUB-TOPIC: ELECTROMAGNETIC INDUCTION.

SPECIFIC OBJECTIVES: The learner should be able to;

- Practically demonstrate the generation of electricity from magnetism.
- State Faraday's and Lenz's laws and demonstrate them.
- Use Fleming's right hand rule o predict the direction of the induced current.

ELECTROMAGNETIC INDUCTION

Electromagnetic induction is the reverse process of the motor effect.

It deals with generation of an electric current by means of a **changing magnetic field.**

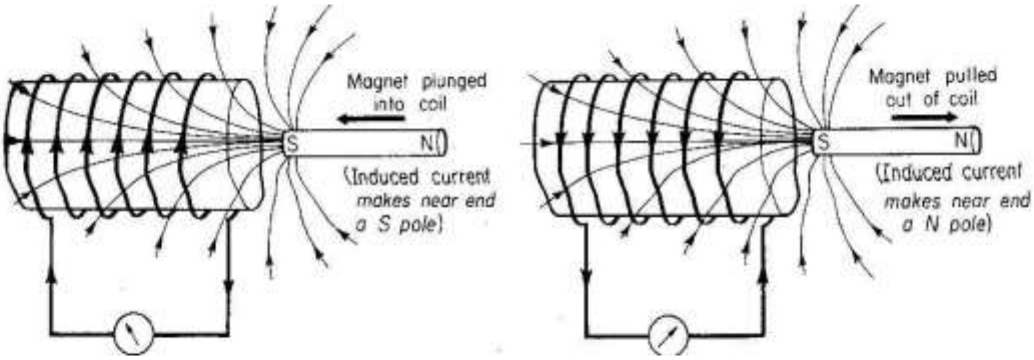
- Whenever there is a change in the magnetic flux in which a conductor is situated, an e.m.f is induced in the conductor which lasts **for as long as the change is taking place.**
- If the conductor forms part of a closed circuit, the induced e.m.f causes a current to flow in the circuit, and the effect is called **electromagnetic induction**.

FACTORS THAT DETERMINE THE MAGNITUDE OF THE INDUCED EM.F.

The magnitude of the induced e.m.f depends on:

- The rate (speed) at which the magnetic flux through the coil changes.
- The number of turns in the coil.
- The strength of the magnetic field.
- The area of the coil.
- The resistance of the coil wire.

FARADAY'S EXPERIMENT: TO VERIFY ELECTROMAGNETIC INDUCTION



- The ends of the coil are connected to a sensitive galvanometer.
- When a magnet is moved towards the coil, the galvanometer deflects in one direction, showing that current had been induced in the coil.
- When the magnet is moved away from the coil, the galvanometer deflects in the opposite direction.
- When the bar magnet is stationary, the galvanometer does not indicate any deflection.

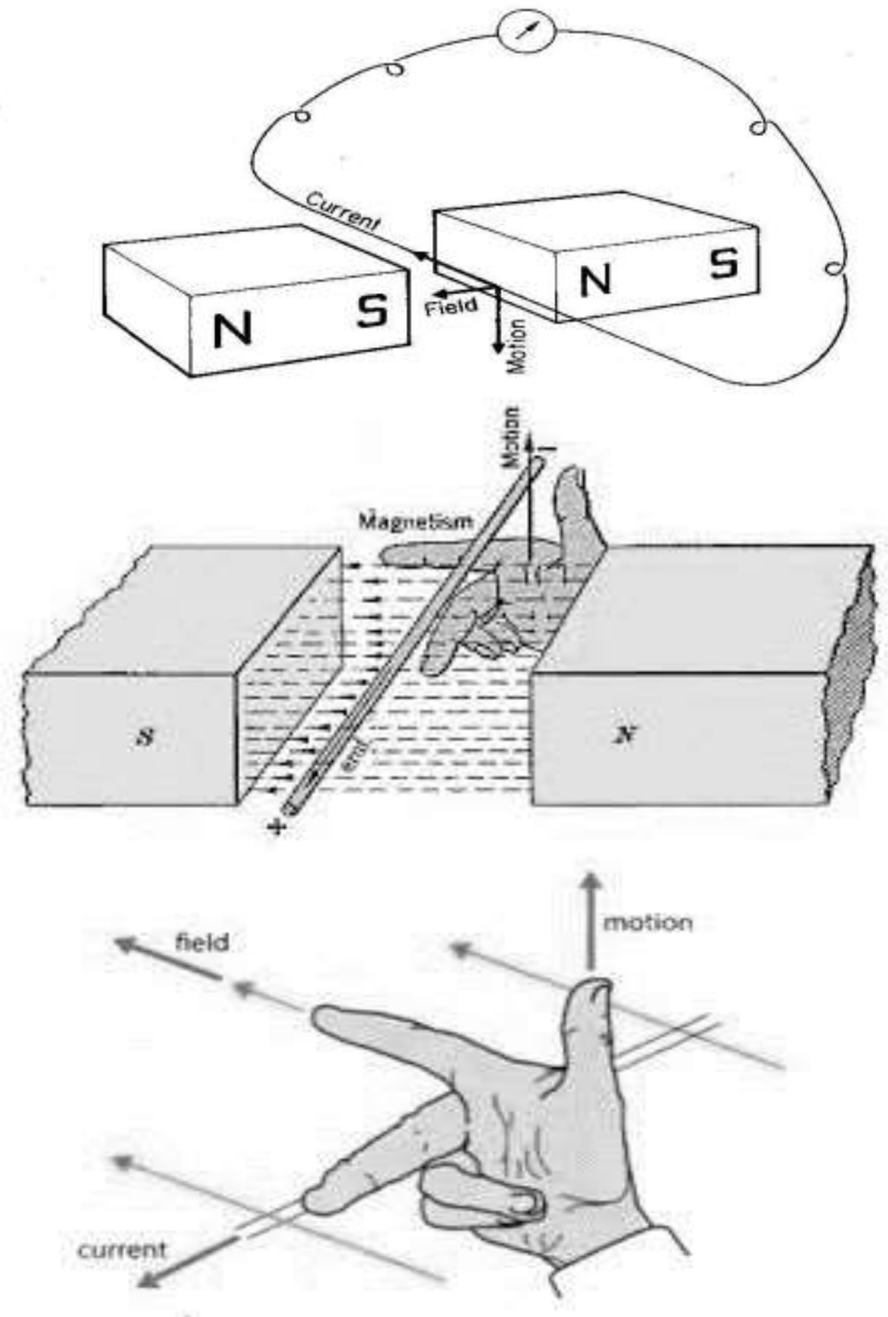
CONCLUSION.

- The direction of induced e.m.f depends on the direction of motion of the magnet.
- The magnitude of induced e.m.f depends on the speed of motion of the magnet and the number of turns of the coil.

NB. The direction of induced e.m.f. is showed by Fleming's right hand rule.

FLEMINGS RIGHT HAND RULE.

If the thumb, the first figure and the second figure of the right hand are held mutually perpendicular to each other so that the first figure points in the direction of the field, the thumb points in the direction of the motion of the conductor, then, the second figure points in the direction of the induced current.



LAWS OF ELECTROMAGNETIC INDUCTION

1. Faraday's law

It states that:

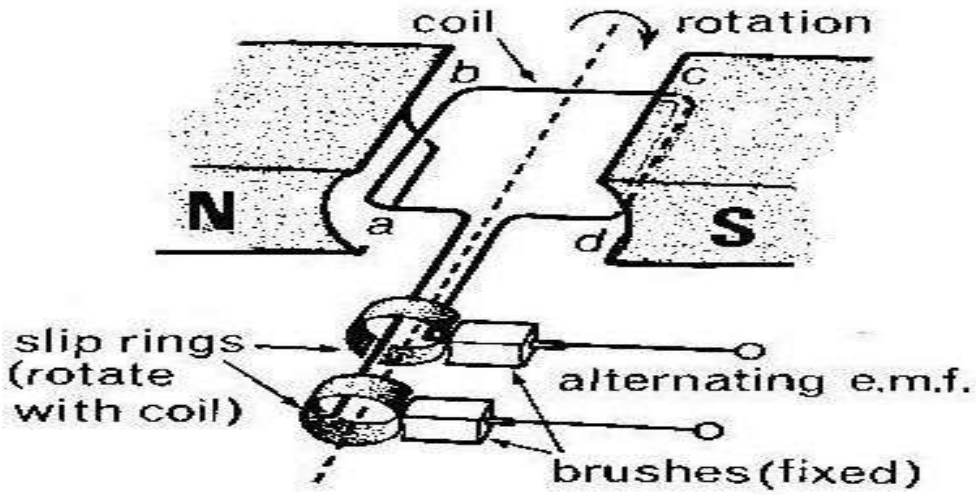
whenever there is a change in magnetic flux, linked with a circuit, an e.m.f is induced, the strength of which is directly proportional to the rate of change of flux linked with the circuit or coil.

2. **Lenz's law** It states that:

the direction of induced e.m.f is always such as to oppose the change producing it.

APPLICATION OF ELECTROMAGNETIC INDUCTION

1. The a.c Generator:

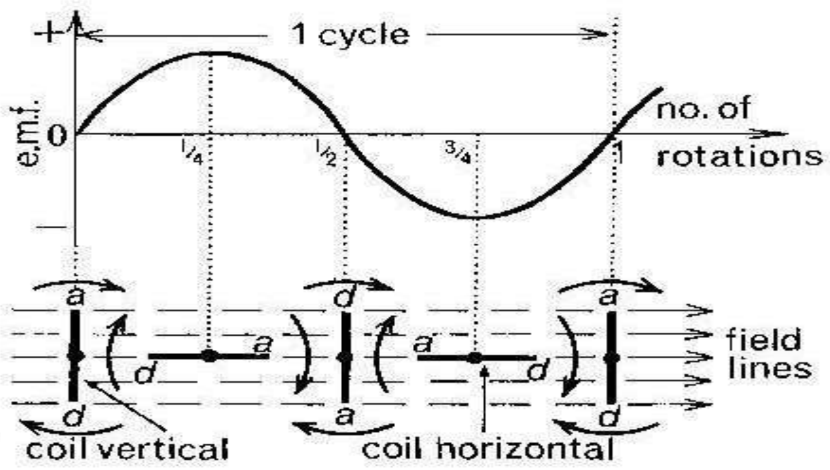


STRUCTURE

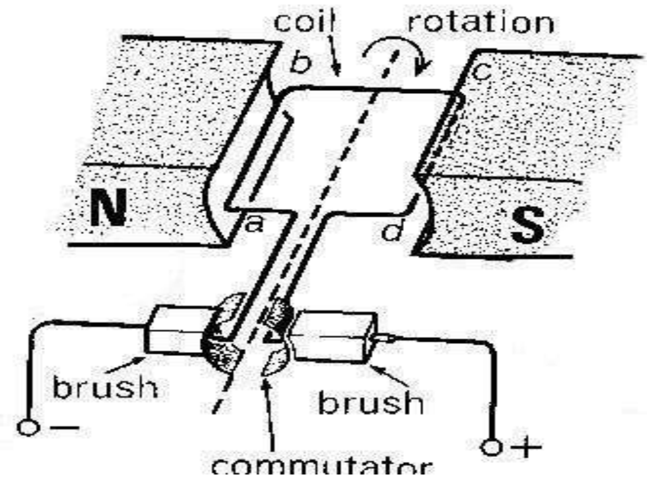
A simple a.c. generator consists of a rectangular coil mounted between pieces of a strong magnet and free to rotate with a uniform speed. The ends of the coil are connected to copper slip rings S_1 and S_2 which press against the carbon brushes $B_1$and B_2.

MODE OF OPERATION

- When the coil is rotated in the magnetic field, the field linking it changes and an induced current flows in the coil.
- The induced current is led away by means of slip rings.
- When side AB of the coil is moving upwards and side CD downwards, induced current flows from A to B and from C to D in accordance to Flemings R.H. rule respectively.
- When the coil reaches the **vertical position**, no current is induced in it. The coil rolls over due to its **inertia**.
- After the half revolution AB is moving downwards while CD is moving upwards and the induced current reverses.
- Since sides AB and CD are connected to specific rings, the polarity of the carbon brushes keeps changing every after half-cycle resulting into an alternating e.m.f. that causes an alternating current to flow in the external circuit.



2. **The d.c. GENERATOR (DYNAMO)**



STRUCTURE.

It consists of a rectangular coil which is rotated between the pole pieces of a strong magnet.

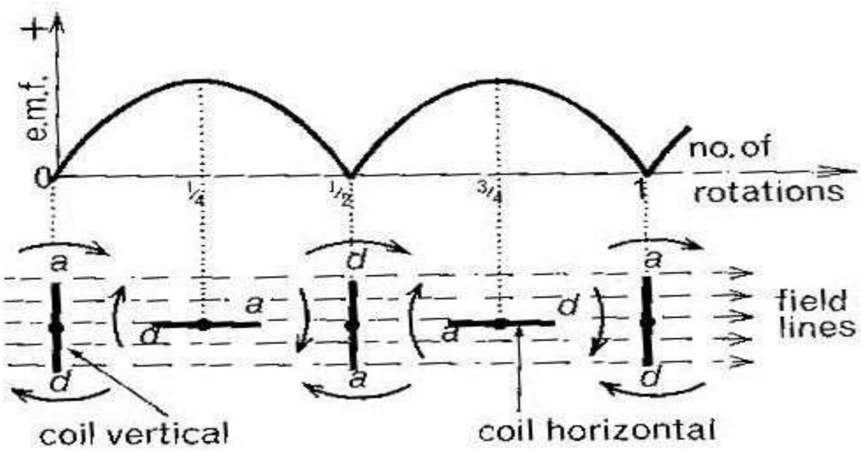
The ends of the coil are connected to separate halves of a single split-ring or commutator. Each half of the split-ring makes contact with carbon brushes that connect them to an external circuit.

MODE OF OPERATION

When the coil rotates, the magnetic field linking with it changes and a current is induced to flow in it and its direction is determined by Fleming's right hand rule.

During the vertical position, no e.m.f is induced in the coil and the half-split rings do not make contact with the carbon brushes. The coil rolls through the vertical position by reason of its inertia.

As the coil is rotated from the vertical position, it starts to cut across the magnetic field and an e.m.f is induced in it, increasing from zero to a maximum when the coil is in a horizontal position and back to zero whenever the coil reaches the vertical position. The half-split rings change contact with the carbon brushes whenever the coil rolls through the vertical position. This ensures that one brush is always positive and other negative, and a direct current flows through the external circuit.



MODIFICATION OF a.c GENEATOR TO d.c GENERATOR

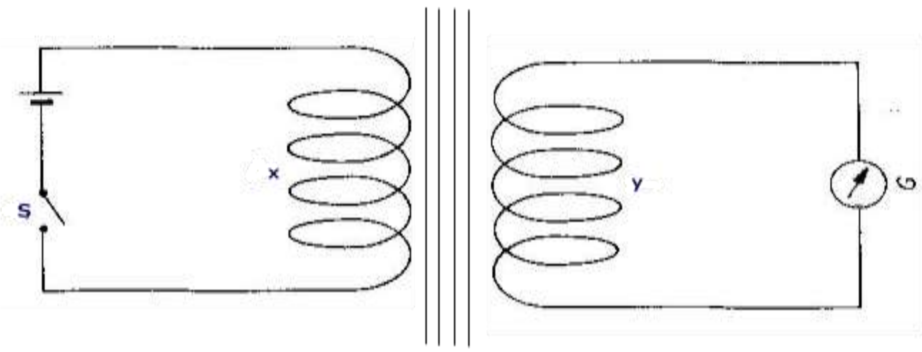
In order to convert an a.c to a d.c generator, the ends of the coil are connected to halfsplit rings or commutators instead of slip - rings.

ADVANTAGES OF a.c OVER d.c

1. There is little or no power losses.
2. a.c. can easily and cheaply be stepped up or stepped down.
3. Frequency of the supply can be precisely controlled.
4. Thinner cables can be used since voltage can be stepped up and down.

MUTUAL INDUCTION

This is the generation of an e.m.f in one coil due to change in current in a nearby coil.



When the switch is closed, electric current flows through the primary coil.
As the current builds up in the coil from zero to its maximum value, it sets up a varying magnetic field around it that induces an e.m.f. in the neighboring coil.

The induced e.m.f. is detected by the deflection of the galvanometer connected in the circuit of the secondary coil.
The circuit that induces the electromotive force is called the primary circuit, while the circuit where the electromotive force is induced is called the secondary circuit. The galvanometer will deflect again but in the opposite direction when the switch is being opened (i.e. the current is changing from maximum to zero).

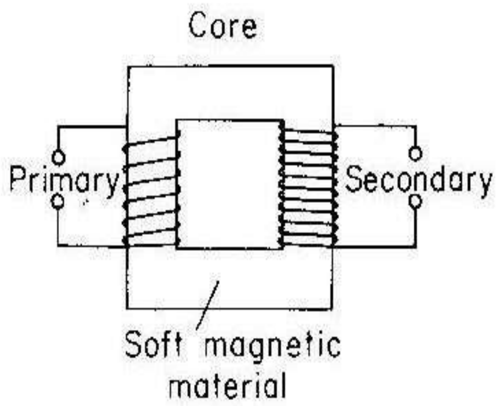
Mutual induction is the effect of inducing an electromotive force in secondary circuit due to change in current in the neighbouring primary coil.

Mutual induction occurs only when switching **on** or **off** the current in the primary circuit. The switching on and off of the current can also be achieved by replacing the battery and switch with an a.c power supply.
The principal of mutual induction is employed in transformers.

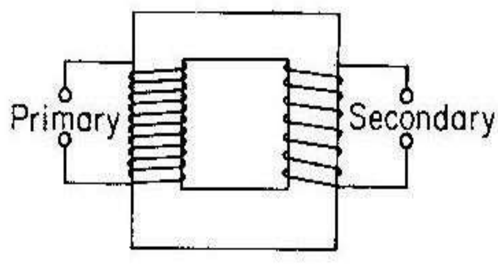
TRANSFORMERS

A transformer is a device which transfers electrical energy from one circuit to another by electromagnetic induction.

A transformer either alters a.c voltage from high to low or from low to high voltage. It consists of two coils (primary and secondary coils) wound on a soft iron core made of insulated sheets of iron.



Step – up



Step-down

When an alternating p.d is applied to the primary coil, the resultant current produces a large alternating magnetic flux which links with the secondary coil and induces an e.m.f in it.
The value of the induced e.m.f depends on the number of turns on the secondary coil.
There are two types of transformers, namely;

1. Step – up transformers.
2. Step – down transformers.

1. A **step – up transformer** has more turns in the secondary coil than in the primary coil. This enables it to produce an output e.m.f. that is larger than the source e.m.f connected to the primary coil.

2. A **step – down transformer** has fewer turns in the secondary coil than in the primary coil. This enables it to produce an output e.m.f that is smaller than the source e.m.f connected to the primary coil.

Experiments show that

$$\frac{\text{e. m. f induced in the secondary coil}, V_s}{\text{e. m. f connected to the primary coil}, V_p} = \frac{\text{Number of turns in the secondary coil}, N_s}{\text{Number of turns in the primary coil}, N_p}$$

Therefore:

$$\mathbf{\frac{V_s}{V_p} = \frac{N_s}{N_p}}$$

Efficiency of a transformer:

In a transformer, the energy supplied per second to the primary coil is called the power input, while the energy obtained per second from the secondary coil is called the power output.

In an ideal transformer, the power input is equal to the power output. Such a transformer is said to be 100% efficient.

The efficiency of a transformer is the ratio of the power output to power input expressed as a percentage.

$$\text{efficiency} = \frac{\text{power output}}{\text{power input}} \times 100\%$$

The condition for an ideal transformer (i.e. A transformer that is 100% efficient) is that:

$$\text{power input} = \text{power output}$$

$$\text{power input} = V_pI_{p,}, \quad \text{power output} = V_sI_s$$

$$\therefore \quad V_pI_{p,} = V_sI_s$$

$$\therefore \quad \frac{V_s}{V_p} = \frac{I_p}{I_2}$$

EXAMPLE

1. A transformer steps down a voltage from 240 V to12 V for a radio. if the primary windings are 300 turns, how many turns are in the secondary windings?
SOLUTION:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$\frac{12}{240} = \frac{N_s}{300}$$

$$N_s = \frac{12 \times 300}{240} = 15 \text{ turns}$$

2. An alternating electromotive force of 240 V is applied to a step – up transformer having 200 turns on the primary coil and 4,000 turns on the secondary coil. The secondary current is 0.2 A. Calculate the;
(i) Secondary electromotive force
(ii) Primary current (iii) Power input, (iv) Efficiency.

ENERGY LOSSES IN TRANSFORMERS

CAUSES	**WAYS OF MINIMISING POWER LOSSES**
Heat loss due to **resistance** in the windings	Using thick copper wire of low resistance
Heat energy lost in the iron core due **eddy current.**	Laminating the iron core reduces the effect of eddy currents
Hysteresis loss (magnetic reversal) This is due to repeated magnetization and demagnetization of the core i.e. when the alignment of the magnetic domains reverse.	Using a magnetically soft material.
Flux leakage Caused by some of the magnetic flux lines associated with the primary coil fail to link with the secondary coil.	The is minimized by improving the design of the transformer. The secondary coil can be wound on top of the primary coil or adjacent to it.

QUESTIONS:

1. A transformer connected to a 240 V a.c mains is used to light a 12V/36W lamp. (i) What current does the lamp need to light normally?

(ii) If the efficiency of the transformer is 75%, what current is drawn from the mains?

(iii) Calculate the magnitude of the resistance of a resistor that should be connected in series with the lamp in the lamp were connected directly to the mains.

2. The primary coil of a transformer draws a current of 50 mA when connected to a 240 V a.c supply. The secondary coil is connected to a 5 Ω resistor in which a current of 1.5 A flows. Calculate:

(i) The power supplied in the transformer.

(ii) The power dissipated in the 5 Ω resistor.

(iii) The efficiency of the transformer.

(iv) The current that would flow in the 5 Ω resistor if the transformer was 100% efficient.

3. A transformer with 1200 turns in the primary coil and 400 turns in the secondary coil has a current of 0.8 A fed into its input by a 192W supply.

(a) Identify the type of transformer. Give a reason for your answer.

(b) Calculate

(i) the voltage of its output.

(ii) The current at the output.

4. An electric power generator produces 24kW at 240V a.c mains. The voltage is stepped up to 4000V for transmission to a factory where its stepped down to 240V.The total resistance of the transmission wires is 0.5 ohms.

(i) What is the ratio of the number of turns in the primary to the number of turns in secondary in the step down transformer?

(ii) Find the power lost in transmission lines assuming both transformers are 100% efficient.

(iii) What power would have been lost in the transmission lines if the same electric power had been transmitted directly to the factory without use of the transformers.

THE END.