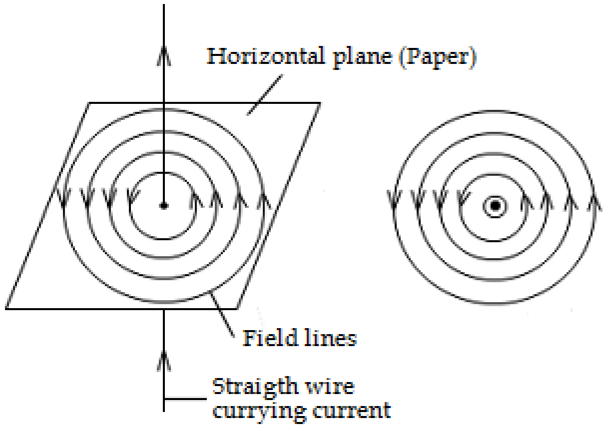
S4 PHYSICS CONTINUATION

ELECTROMAGNETISM

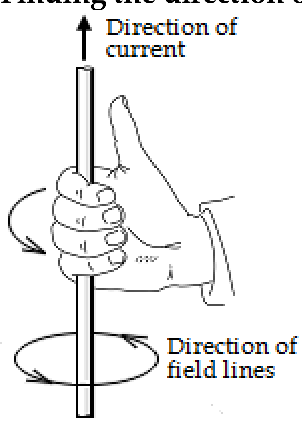
When a current flows through a conductor, a magnetic field is created around it.
The magnetic effect due to an electric current is called electromagnetism.

(a) Magnetic field pattern due to current flowing through a straight conductor.

The magnetic field pattern is obtained by connecting a current source to a straight wire passing through a card-board sprinkled with iron filings.
When the current is switched on and the board tapped slightly, the iron fillings arrange themselves in concentric circles with the wire as the centre.
The field pattern can also be obtained using a compass needle. When the direction of current is reversed the direction of the field is also reversed.



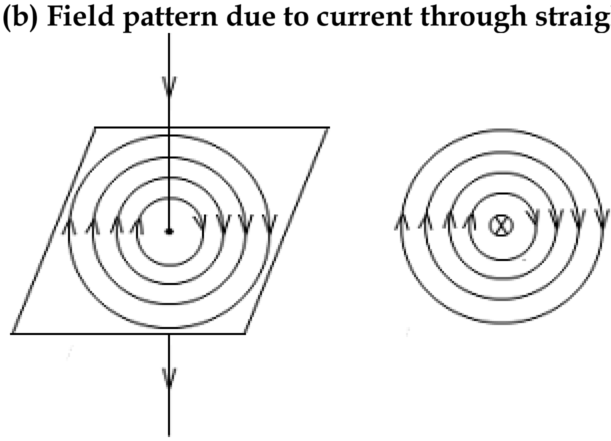
Finding the direction of the field due to current in a straight conductor



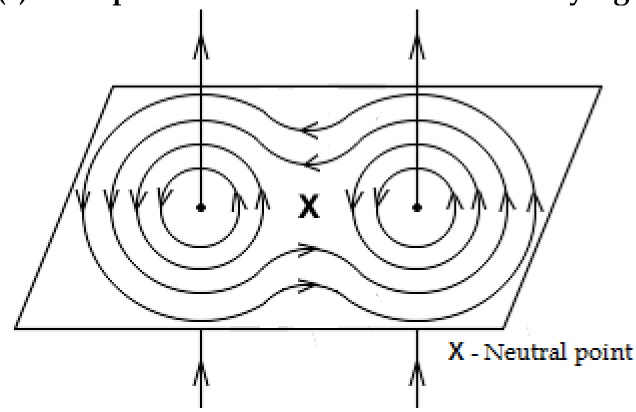
The direction of the field is determined by the Right Hand Grip Rule which states that; when the right hand grips the conductor with the thumb pointing in the direction of current, the fingers point in the direction of the magnetic field.

Note: The direction of the field depends on the direction of the current flowing in the conductor.

(b) Field pattern due to current through straight conductor down-wards (into the paper)

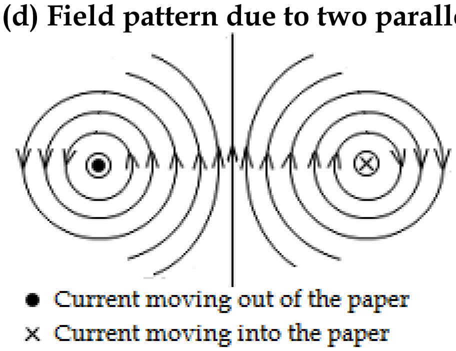


(c) Field pattern due to two conductors carrying current in the same direction (down wards)



When current is flowing in the same direction in the two conductors, they experience an attractive force between them.

(d) Field pattern due to two parallel conductors carrying current in opposite directions



When current is flowing in opposite directions in the two conductors, they repel each other.

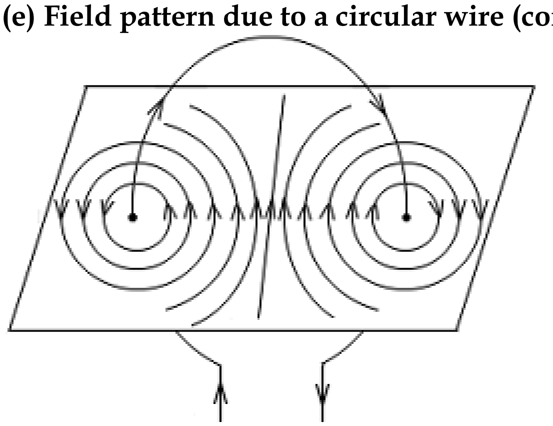
Question

Explain with aid of a diagram what happens when two vertical, parallel conductors are placed near one another and carry current in

(i) The same direction

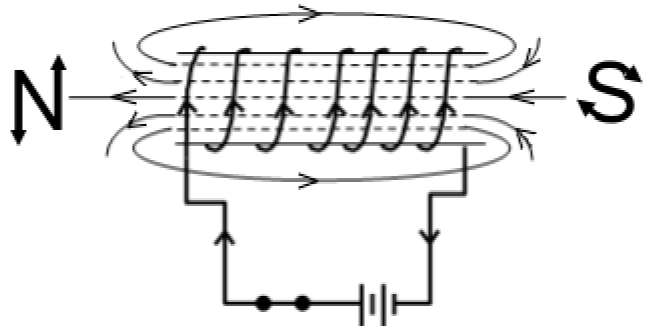
(ii) Opposite direction

(e) Field pattern due to a circular wire (coil) carrying current



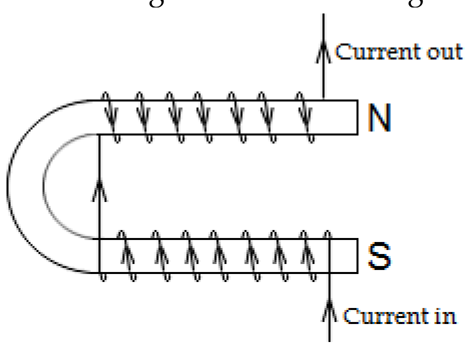
(f) Field pattern due to solenoid

A solenoid is a copper wire wound on a soft cylindrical iron core a number of times. The field due to a solenoid is similar to that of a bar magnet as shown below



Determining the polarity of the magnetic field
Method I
If on looking at the end of the solenoid, the current is flowing in the clock wi**S**e direction, that end will be a south pole.
If current is flowing in the a**N**ti-clock wise direction that end will be a North Pole.
Method II
The polarity can be given by the right hand grip rule. It states that if the fingers of the right hand grip the solenoid in the direction of the current; the thumb points to the North Pole.
Note: The strength of the magnetic field inside the solenoid can be increased by:-
(i) Having a large number of turns wound on the core
(ii) Increasing the current flowing through the coil

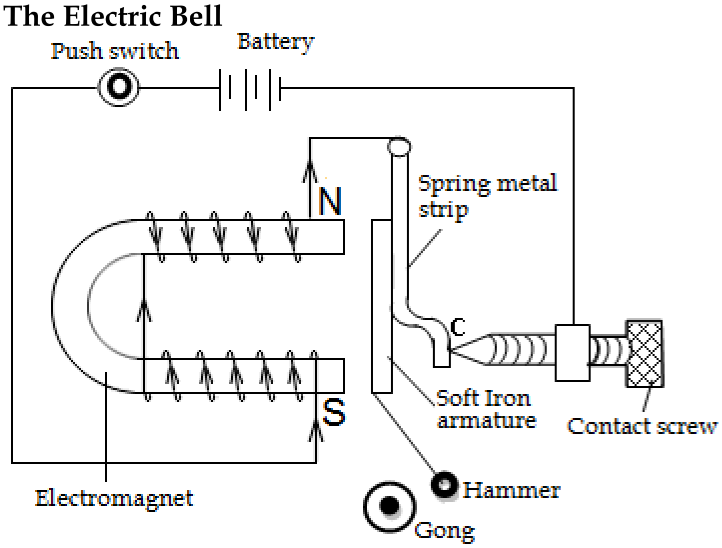
ELECTROMAGNET
An electromagnet is made by winding a copper wire oppositely on a U – shaped soft iron core to form two solenoids as shown below. The soft iron core is magnetised only when current flows through the surrounding coil. An electromagnet is a temporary magnet which can be switched on and off.



Soft iron core is used in making electromagnets because;
(i) It can easily be magnetized and demagnetized
(ii) It is strongly magnetized.
The strength of an electromagnet can be increased by:-
(i) Increasing the current flowing through the coils.
(ii) Increasing the number of turns on the coil.
(iii) Making the poles close to each other.

Practical applications of electromagnets
Electromagnets have a number of practical applications among which includes;-
(i) Electric bell
(ii) Telephone receiver
(iii) Magnetic relay
(iv) Lifting magnets used in scrap yards and steel industries

The Electric Bell



How an Electric Bell Works

▬ When the switch is pushed, current flows through the coils magnetizing the iron core which attracts the soft iron armature.

▬ The soft iron armature moves along with the hammer which hits the gong producing sound.

▬ The attraction of the armature breaks the contact at C opening the circuit. The magnetism in the soft iron core is lost and the armature is returned to its position by the spring metal strip.

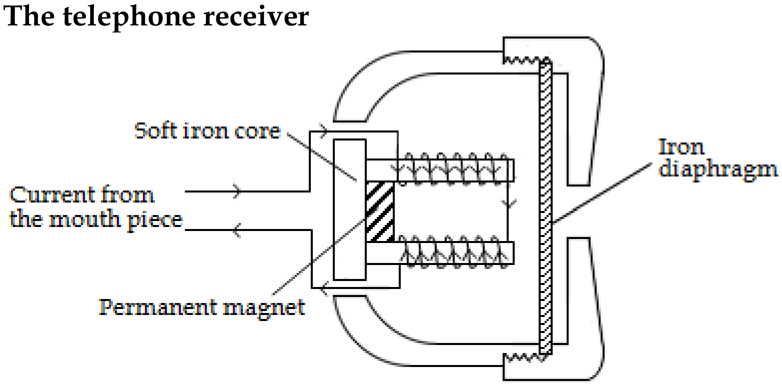
▬ When the armature is in its original position, contact at C is remade and the cycle is repeated producing continuous sound.

Note:

(i) An electric bell is a device which converts electrical energy to sound

(ii)The energy changes that take place in an electric bell: electrical energy to magnetic energy to kinetic energy and to sound energy

The telephone receiver



How a Telephone Receiver Works

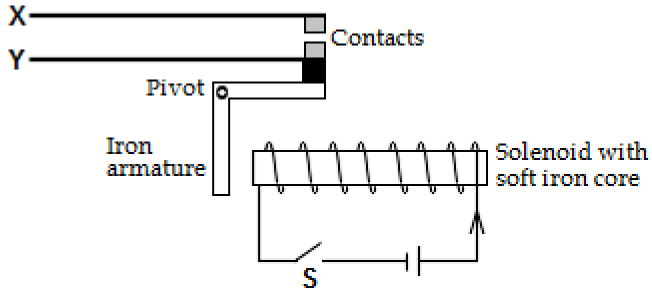
▬When a person speaks into a microphone at the other end of the line, a varying electric current is setup having the same frequency as the sound waves.

▬The varying electric current passes through the coils in the receiver (earpiece), and magnetises the electromagnet.

▬The varying electromagnetic strength makes the diaphragm to vibrate at the frequency of the original sound and the sound is reproduced.

Note: A telephone receiver changes electrical energy to sound energy.

Magnetic relay

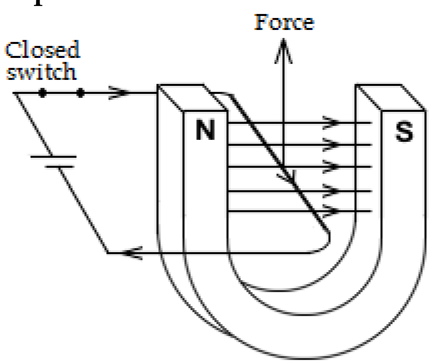


A Relay is an electrical device in which large current circuit can be operated by a low current dc circuit. From the diagram, when the switch S is closed, the iron core inside the solenoid becomes magnetised. It attracts the iron armature, which is pivoted. The upper limb of the armature causes the contacts in the secondary circuit XY to close, thus activating the large circuit.

Force on a Current Carrying Conductor Placed in a Magnetic Field

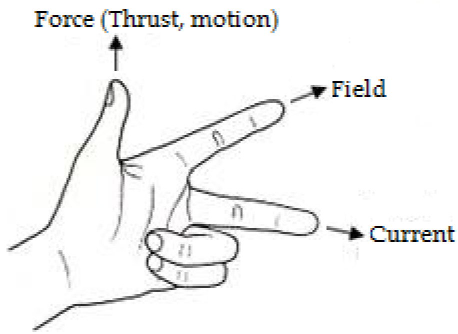
When a current carrying conductor is placed at right angles to the magnetic field produced by a permanent magnet, it experiences a force which pushes it in a direction which is perpendicular to that of both the field and current.

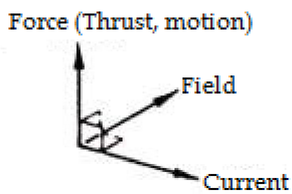
Experiment to demonstrate the Force on a Current Carrying Conductor placed in a magnetic field



- A strip of copper connected to a battery is placed at right angles to the magnetic field of a U–shaped magnet as shown above.
- When the switch is closed the copper strip is seen to move upwards. This is because of the upward force that acts on it.
- If either the direction of the current or that of the magnetic field is reversed, the copper strip moves downwards.

Note: The direction of the force on a current carrying conductor is given by **Flemings Left Hand Rule. It states;** that when the thumb, the first finger and the second finger of the left hand are held at right angles to each other with the first finger pointing in the direction of the field and the second finger pointing in the direction of the current, then the thumb points in the direction force (thrust).ie the direction in which the conductor moves.

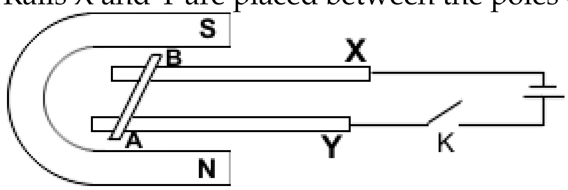




The magnitude of the force on the current carrying conductor placed in a magnetic field is increased by;
(i) Increasing the current flowing in the conductor.
(ii) Using a stronger magnetic field
(iii) Increasing the length of the conductor lying in the magnetic field.

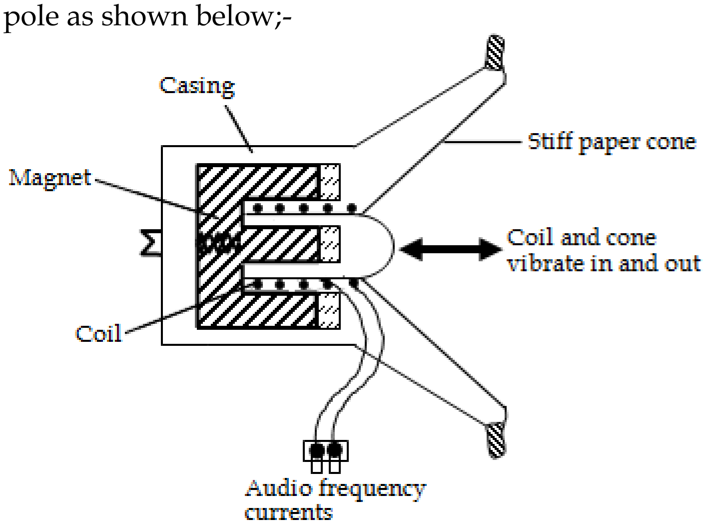
Applications of Force on a Current Carrying Conductor in Magnetic Field
(i) Moving coil loud speaker
(ii) Direct current motor (D.C motor)
(iii) Moving coil galvanometer

Question
A bare copper wire AB lies horizontally over fixed rails X and Y connected to a battery as shown in the diagram.
Rails X and Y are placed between the poles of a U-shaped magnet.



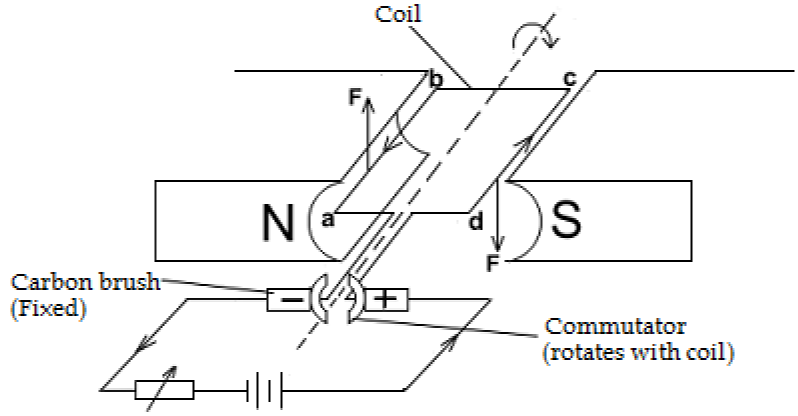
(a) Explain what happens to AB,
(i) When switch K is closed.
(ii) if two cells are used instead of one.
(b) Name the instruments which use the effect above.

The Moving Coil Loud Speaker
This is a device which changes electrical energy into sound energy. It consists of a short coil whose turns are at right angles to the magnetic field of a magnet with a central pole and a surrounding ring pole as shown below;-



How a Loud Speaker Works (action)
- When a varying audio frequency current enters the coil placed in a radial magnetic field, a force acts on the coil which according to Fleming's left hand rule makes it move in and out (vibrate).
- A paper cone attached to the coil vibrates along with it and sets up sound waves in the surrounding air with the same frequency as the original sound that entered the amplifier.

The Direct Current Motor (D.C motor)
This is a device which converts electrical energy to mechanical energy (kinetic energy). It consists of a rectangular coil **abcd** of insulated copper wire which can rotate in a uniform magnetic field. The two ends of the coil are connected to a split ring commutator. It has two carbon brushes which press lightly on the commutator.



Mode of action (How it works)

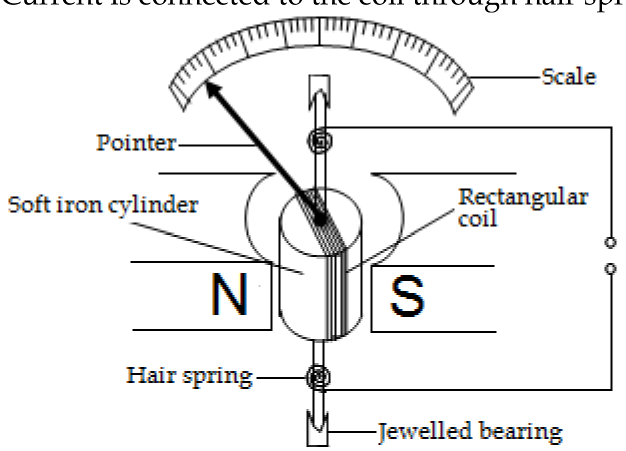
▬ When current flows in the coil, according to Fleming's left hand rule side **ab** experiences an upward force while side **cd** experiences a downward force.

▬ The two equal but opposite forces on the sides make up a couple, which rotates the coil in the clockwise direction.

▬When the coil reaches the vertical position, the carbon brushes loose contact with the commutator and current is cut off but the coil continues to rotate by its own inertia.

▬Beyond the vertical position, the commutator exchanges contact with the carbon brushes and the direction of current in the coil is reversed. Therefore side **ab** now **downwards** while side **cd** moves **upwards**. Hence the coil continues to rotate in the clockwise direction

The Moving Coil Galvanometer
A moving coil galvanometer is an instrument which is used to detect and measure small currents or small p.ds in order of milliamperes (mA) millivolts (mV). It consists of rectangular coil of fine insulated copper wire pivoted on jewelled bearings between two concave poles of a permanent magnet.
Current is connected to the coil through hair springs wound oppositely to provide a control couple.



Mode of action (How it Works)

▬When current to be measured is passed through the coil, equal but opposite forces act on the vertical sides of the coil.

▬ These forces form a couple which rotates the coil until it is stopped by the control couple in the hairy springs.
▬ The angle of deflection is proportional to the current passing through the coil. The current is read from the position of the pointer on the scale.

Sensitivity of the Galvanometer

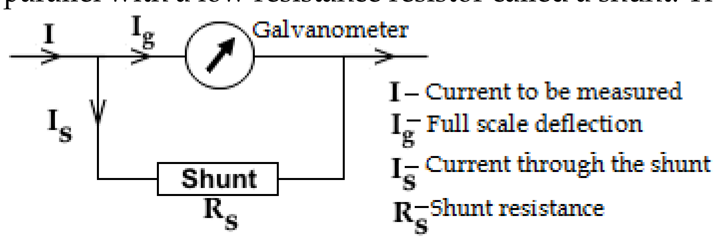
The sensitivity of the galvanometer is the ability of a galvanometer to detect very small current of the order of micro-amperes (μA).
The sensitivity of the galvanometer is increased by having
(i) A large number of turns on the coil.
(ii) A stronger permanent magnet.
(iii) Weak hair springs to give a small control couple.

Full Scale Deflection of a Galvanometer

This is the maximum current a galvanometer can measure.
It is the current needed to move the galvanometer pointer up to the end of the scale.
The galvanometer can be modified to measure higher current or voltage than its full scale deflection value.

How to Convert a Galvanometer to an Ammeter

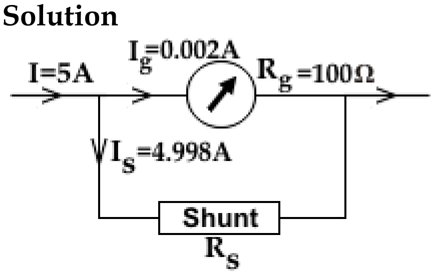
A galvanometer can be converted into an ammeter to measure higher current by connecting it in parallel with a low resistance resistor called a shunt. This is called **Shunting** the instrument.



Examples

1. A galvanometer has a resistance of 100Ω and gives a full scale deflection of 2mA. What is the resistance of the shunt required to make the meter suitable to measure current up to 5A.

Solution



$I = 5A$

$I_g = \frac{2}{1000} = 0.002A$

$I = I_g + I_s$

$I_s = I - I_g$

$I_s = 5 - 0.002$

$I_s = 4.998A$

Since the galvanometer and the Shunt are in parallel, then
P.d across the galvanometer = P.d across the shunt

From $V = I \times R$

$I_s \times R_s = I_g \times R_g$

$4.998 \times R_s = 0.002 \times 100$

$$R_s = \frac{0.002 \times 100}{4.998}$$

$\mathbf{R_s = 0.04\Omega}$

A shunt of resistance 0.04Ω must be connected across the galvanometer for it to measure up to 5A.

2. A galvanometer of resistance 50Ω with full scale deflection of 15mA is to be used to measure current up to 2.5A. Describe briefly how this can be done.
(Calculate the value of Rs before describing how it is connected)

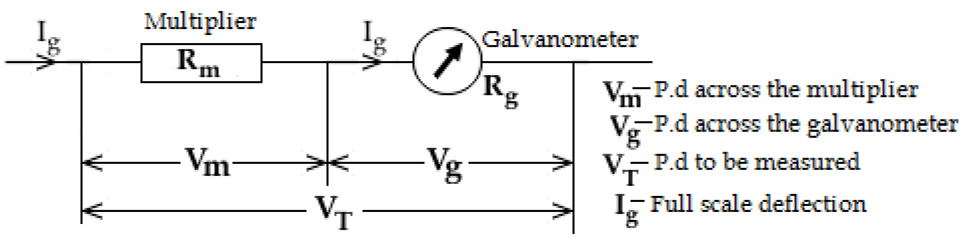
3. A galvanometer has a resistance of 20 Ω and a current range of 40mA. If this instrument is to be used to measure maximum current of 10A, describe how this can be done.

4. A milliammeter has an internal resistance of 24Ω and full scale deflection of 0.015A. Calculate the value of the resistor that must be connected across the milliammeter so that a maximum current of 5A can be measured.

5. A galvanometer of resistance 5Ω and full scale deflection of 10mA is to be adapted to measure current up to 1.0A. Explain how this is done.

How to Convert a Galvanometer to a Voltmeter

This is done by connecting a galvanometer in series with a resistor of high resistance called a **multiplier.**



Note

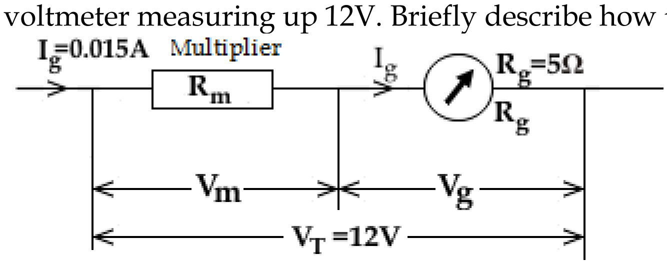
(i) The full scale deflection current passes through both the multiplier and the galvanometer

(ii) The p.d to be measured is the sum of the p.d across the multiplier and that across the galvanometer.

$V_T = V_m + V_g$

Examples

1. A galvanometer of internal resistance 5Ω and full scale deflection of 15mA is to be converted to a voltmeter measuring up 12V. Briefly describe how this is done.

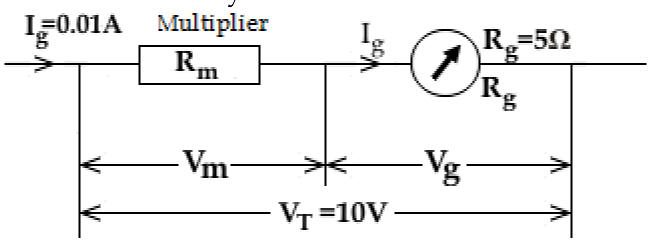


$$I_g = \frac{15}{1000} = 0.015A$$

$R_g = 5\Omega, V_T = 12V$

$V_T = V_m + V_g$

From $V = I \times R$

$V_T = I_g \times R_m + I_g \times R_g$
$12 = 0.015 \times R_m + 0.015 \times 5$
$0.015R_m = 12 - 0.075$
$0.015R_m = 11.925$
$R_m = \frac{11.925}{0.075}$
$\mathbf{R_m = 795\Omega}$
The galvanometer must be connected in series with a multiplier of resistance 795Ω in order to measure voltage up to 12V.
2. A galvanometer has a resistance of 5Ωand a full scale deflection of 10mA. The instrument is to be adapted to measure voltage up to 10V. Calculate the resistance of the multiplier required for the meter to work effectively.


$I_g = \frac{10}{1000} = 0.01A$
$R_g = 5\Omega, V_T = 10V$
$V_T = V_m + V_g$
From $V = I \times R$
$V_T = I_g \times R_m + I_g \times R_g$
$10 = 0.01 \times R_m + 0.01 \times 5$
$0.01R_m = 10 - 0.05$
$0.01R_m = 9.95$
$R_m = \frac{9.95}{0.01}$
$\mathbf{R_m = 995\Omega}$
The galvanometer must be connected in series with a multiplier of resistance 995Ω in order to measure voltage up to 10V.

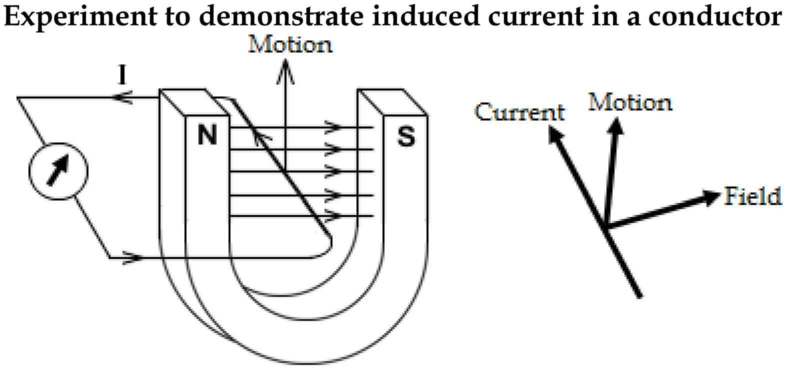
Exercise
1. A galvanometer has internal resistance of 10Ω and a full scale deflection current of 10mA.
(a)Show on a diagram how a resistor must be connected to the meter above to convert it to a voltmeter.
(b) What resistance is needed to allow the galvanometer to measure voltages up to 15V?
2. A galvanometer of resistance of 0.5Ω gives full scale deflection for current of 10mA. Explain how you would adopt it;
(a) To measure current up to 5A
(b) For use as a voltmeter which reads up to 20V
3. A galvanometer of internal resistance of 20Ω gives a full scale deflection with a current of 50mA. How should the galvanometer be modified for use as;-
(a) An ammeter which reads up to 1.0A?
(b) A voltmeter that read 100V?

4. The resistance of a milliammeter is 6Ω. If the instrument is to be used to measure potential difference up to 20V, briefly explain how this is done given that the full scale deflection of the milliammeter is 10mA.
5. A moving coil meter which gives a full scale deflection with 5mA is converted to a voltmeter reading up to 5V using an external resistor of resistance 975Ω. What is the internal resistance of the meter?
6. An ammeter gives a full scale reading for a current of 0.1A and its resistance is 0.5Ω. explain how you would adapt it;-
(a) To give a full scale reading of 2A
(b) For use as a voltmeter to read up to 100V
7. A moving coil galvanometer has a resistance of 5Ω and will give a full scale deflection when a current of 0.015A flows through it. Calculate;-
(a) The p.d across the meter when a current of 0.015A flows through it
(b) The value of the resistance which would convert the meter into an ammeter reading up to 3A.
(c) The value of the resistance which would convert the meter to a voltmeter reading up to 10V.
8. A moving coil milliammeter gives a full scale deflection for a current of 1mA. The p.d between its terminals is then 100mV. What resistor placed in series with the meter will limit the current flow to 1mA when 10V is applied across the combination?

Leave four (4) pages for discussion of the solutions

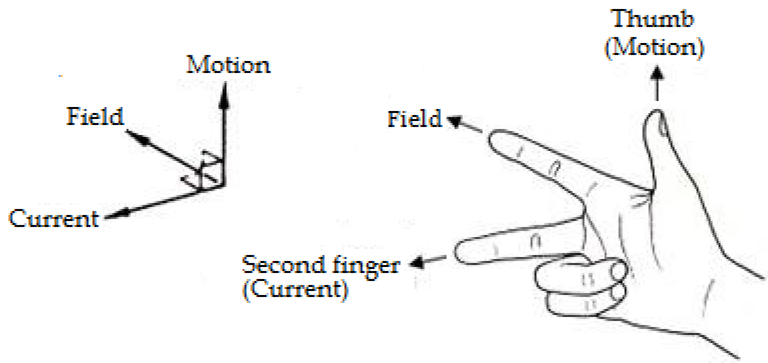
ELECTROMAGNETIC INDUCTION
When a conductor is moved in a magnetic field an electric current is induced in it. This process is called electromagnetic induction.

Experiment to demonstrate induced current in a conductor moved in a magnetic field



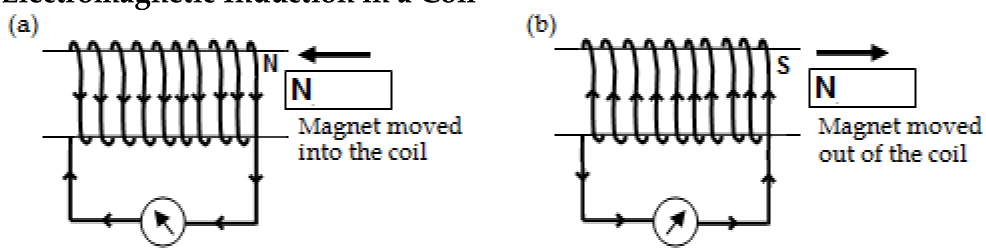
- A highly sensitive galvanometer is connected to the ends of a straight conductor placed at right angles to the magnetic field of a U – shaped magnet.
- When the conductor is moved up wards, the galvanometer shows a deflection indicating that current is flowing in the anti-clockwise direction.
- If the conductor is moved down wards, the direction of deflection of the galvanometer changes to the opposite meaning that current now flows in the clockwise direction.
- If the conductor is held stationary or moved parallel to the magnetic field, the galvanometer shows no deflection, indicating that no current is induced in the conductor.

The direction of the induced current is determined by **Fleming's Right Hand Rule which states that;** when the thumb, the first finger and the second finger of the right hand are held at right angles to each other with the first finger pointing in the direction of the field and the thumb pointing in the direction of motion of the conductor, then the second finger points in the direction of induced current.



The magnitude of the induced current (emf) can be increased by;-
(i) Moving the conductor at a high speed within the magnetic field
(ii) Using a stronger magnet which can provide a strong magnetic flux
(iii) Increasing the length of the conductor lying within the magnetic field

Electromagnetic Induction in a Coil

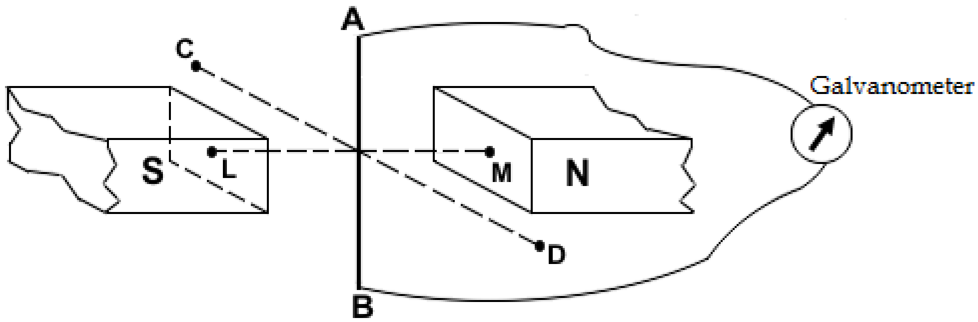


- When a North Pole of a bar magnet is moved into the coil which is connected to a highly sensitive galvanometer, it shows a deflection which indicates that current is induced in the coil. The induced current flows such that the end of the coil next to the magnet becomes a North Pole.
- When the North Pole is moved out of the coil, the galvanometer shows a deflection in the opposite direction. Here the induced current flows such that the end of the coil next to the magnet becomes a South Pole.

Note:
(i) The same results are obtained when the bar magnet is held stationary and the coil is moved towards or away the magnet.
(ii) When the South Pole of the bar magnet is used in figures (a) and (b) above, the direction of the induced current is reversed.
(iii) There is no deflection of the galvanometer if both the magnet and the coil are held stationary or both moved at the same speed in the same direction.
This means that for current (emf) to be induced in the circuit, there should be a change of the magnetic flux linking up the circuit.

The magnitude of the induced current in the coil can be increased by;
(i) Using a stronger magnet.
(ii) Increasing the speed at which the magnet or coil is moved
(iii) Increasing the number of turns on the coil

Question
A stiff wire AB is held between opposite poles of two bar magnets and connected to a center-zero galvanometer as shown in the diagram.



The wire AB is kept vertical and moved horizontally along the line CD
(i) Explain what is observed on the galvanometer as the wire AB moves towards C and towards D
(ii) Explain what would be observed if the wire were moved along LM

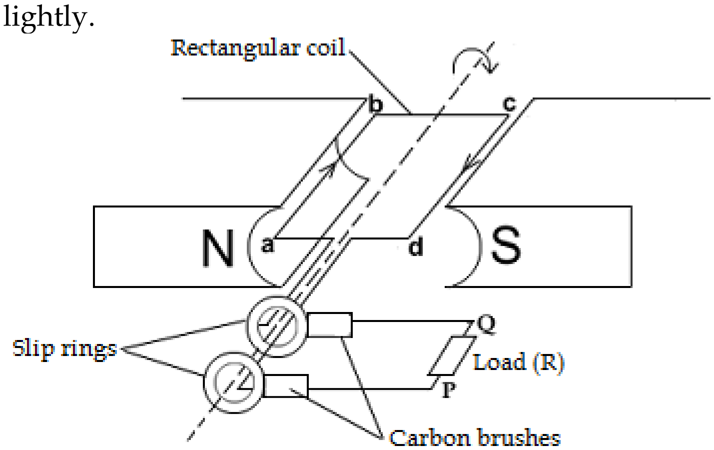
Faraday's Law of Electromagnetic Induction
It states that; the magnitude of the induced emf is directly proportional to the rate at which the conductor cuts the magnetic field lines.

Lenz's Law of Electromagnetic Induction
It states that; the induced current flows in a direction such that it opposes the change producing it. Alternatively, the direction of the induced current is such as to oppose the change causing it.

Applications of Electromagnetic Induction include;-
(i) Simple A.C generator (Alternator)
(ii) Simple D.C generator (D.C dynamo)
(iii) Moving coil microphone
(iv) Transformer

The Simple A.C Generator (Alternator)
The a.c generator produces current that changes direction as the coil rotates, i.e current flows in one direction during the first half cycle and in the opposite direction during the second half cycle.

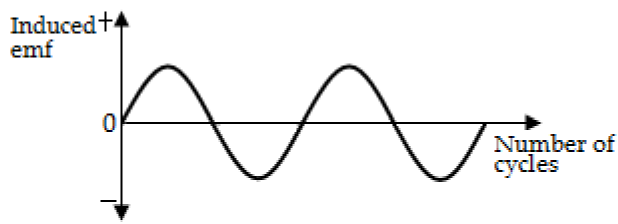
Structure
It consists of a rectangular coil abcd which is rotated in a magnetic field provided by a permanent magnet. The two ends of the coil are connected to two slip rings on which two carbon brushes press lightly.



How it works (Mode of action)

- When the coil **abcd** is rotated in the magnetic field in the clockwise direction i.e with **side ab** moving upwards and **side cd** moving down wards, the sides cut through the magnetic flux and an emf is induced in them.
- By Fleming's right hand rule, the induced current through **side ab** flows from **a** to **b** while that through **side cd** is from **c** to **d**. the induced current is tapped from the coil through two carbon brushes which press lightly on the slip rings.
- When the coil reaches the vertical position, no current is induced in it because the sides' ab and cd of the coil are moving parallel to the field.
- After turning through 180^0, **side ab** now moves down wards while **side cd** moves upwards. This means that by Fleming's right hand rule the direction of flow of the induced current through **side ab** is from **b** to **a** while that through **side cd** is from **d** to **c**. i.e the current is reversed.

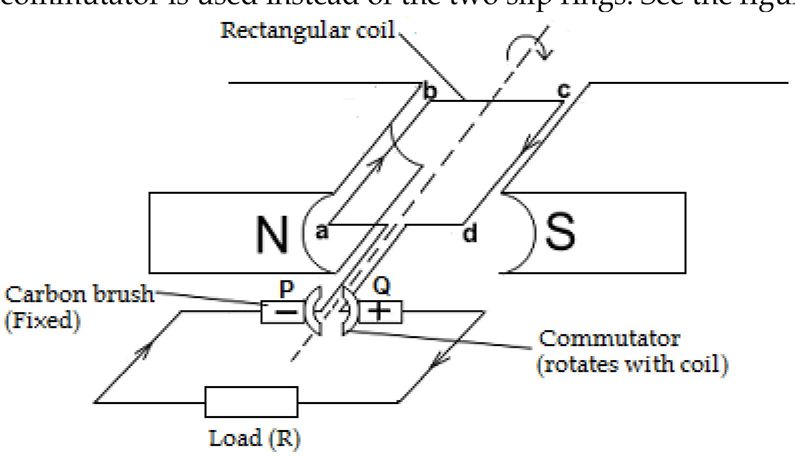
The graph below shows how the induced emf in the coil varies over two cycles.



Note: The induced emf is greatest, when the coil is passing through the horizontal plane and zero when the coil is in the vertical plane.

The Simple D.C Generator (D.C Dynamo)

The direct current (d.c) generator differs from an alternator (a.c generator) in that a split ring commutator is used instead of the two slip rings. See the figure below;-

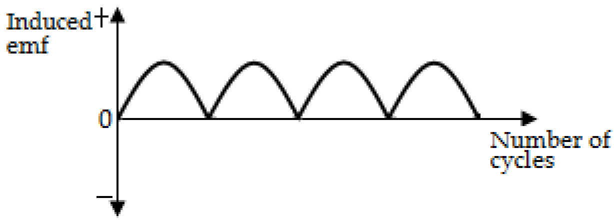


Mode of action (How it works)

- When the coil **abcd** is rotated in the magnetic field with side ab moving upwards while side cd moves down wards, the sides cut through the magnetic flux and an emf is induced in them.
- According to Fleming's right hand rule, the induced current through **side ab** is from **a** to **b,** while that through **side cd** is from **c** to **d.** the induced current is tapped through the two carbon brushes P and Q.
- When the coil reaches the vertical position, no current is induced in the coil because the sides **ab** and **cd** of the coil are moving parallel to the field and also the commutator is not in touch with the carbon brushes.

▬ After turning through 180^0, the commutator exchanges contact with the carbon brushes i.e side ab now moving down wards is in contact with carbon brush Q while side cd now moving upwards is in contact with carbon brush P.
▬ The induced current through the load R will continue to flow in the same direction even though current in the coil is reversed. This one directional current is called d.c current.

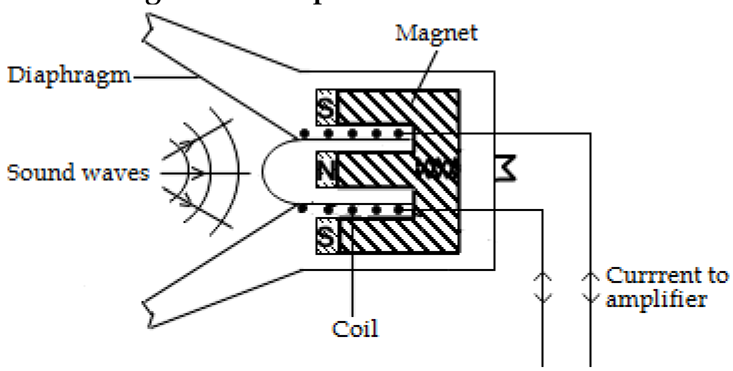
The graph below shows the variation of the induced emf with number of oscillations.



Note:
1. The ac and dc generators described above are used to convert mechanical energy (K.E) of the rotating coil into electrical energy induced in the coil.
2. The magnitude of the induced e.m.f. can be increased by;
(i) Increasing the speed of rotation of the coil
(ii) Increasing the number of turns of the coil
(iii) Using a stronger magnet
(iv) Winding the coil on a soft iron material.

Question
(a) Describe with aid of a diagram, how a direct current generator works
(b) State three ways of increasing the e.m.f. produced by the generator.

The Moving Coil Microphone



Action (How it Works)
▬ When one speaks into a moving coil microphone, the sound waves produced cause the diaphragm and coil to vibrate in and out.
▬ As the coil vibrates, it cuts the radial magnetic flux provided by a magnet and a small alternating current is induced in the coil.
▬ This small induced current is amplified before it is fed into a loud speaker to reproduce the original sound.

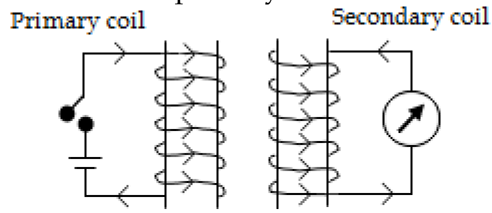
Self Induction
When a changing current flows through a coil / circuit, an emf is induced in it. This is because of the changing magnetic flux in the same circuit. This process where an emf is induced in a circuit because

of the varying current through itself is called **Self Induction** and the induced current is called **back emf.**

Mutual Induction

This is the process by which an emf is induced in one circuit because of a changing current in another nearby circuit. The circuit through which a changing current flows is called **a primary circuit** while that within which an emf is induced is called **a secondary circuit**.

Consider the primary coil and secondary coil arranged as shown below



- When the switch in the primary coil is closed, the galvanometer connected to the secondary coil shows a momentary deflection which indicates that current is induced in the secondary coil.
- When the switch is opened, the galvanometer shows a momentary deflection in the opposite direction. This indicates that the direction of the induced current has been reversed.
- When the current flowing through the primary coil is not changing, the galvanometer shows no deflection indicating that no current is induced in the secondary coil.

The magnitude of the induced emf can be increased by;-

(i) Winding the coils on soft iron cores

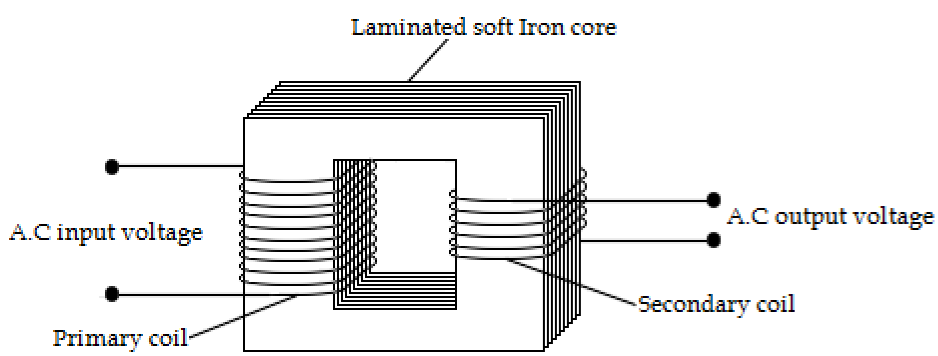
(ii) Winding more turns of wire in the secondary coil

(iii) Increasing on the rate of changing of the magnetic flux in the primary coil

Note: The major application of mutual Induction is the operation of a transformer

The Transformer

A transformer is a device used to change alternating current (ac) from one voltage value to another voltage value by mutual induction.



A transformer consists of two coils of insulated copper wire wound on a laminated soft iron core. The coil connected to the a.c input is called the primary coil while that connected to the a.c output is called the secondary coil.

Being laminated, it means that the core is made up of thin sheets of iron insulated from each other by layers of varnish

Note:
1. A transformer can only operate on alternating voltage (a.c voltage)
2. Copper wires are used because copper has a low resistance.
3. Soft iron is used in order to increase on the strength of the magnetic flux between the two coils.
4. The core is laminated in order to reduce eddy currents.

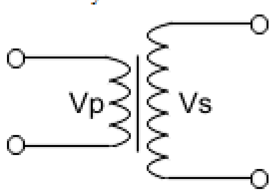
Working

- If an alternating current is passed through the primary coil, a changing magnetic flux is generated in the iron core which concentrates it and links it to the secondary coil.
- Since the flux linking up the secondary coil is changing, an alternating emf is induced in the secondary coil.
- The size of the induced emf (output voltage) depends on the emf applied to the primary coil and relative number of turns on the two coils.
- If V_p and V_s are the primary and secondary voltages while N_p and N_s are the primary number of turns and secondary number of turns respectively, then the transformer ratio is given by;

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

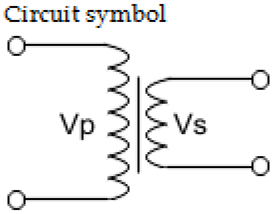
Note:
1. In a **step–up transformer**, the secondary coil has more turns than the primary coil($N_s > N_p$). The voltage is increased($V_s > V_p$).

Circuit symbol



2. In a **step–down transformer**, the primary coil has more turns than the secondary coil($N_p > N_s$). The voltage is reduced($V_p > V_s$).

Circuit symbol



3. If the transformer is 100% efficient, then the input power is equal to the output power.
Ie, The input power = output power

$$V_p I_p = V_s I_s$$

$$\frac{V_p}{V_s} = \frac{I_s}{I_p}$$

4. However, transformer cannot be 100% efficient; therefore the output power is less than the input power.

$$\text{Efficiency} = \frac{\text{Power output}}{\text{Power input}} \times 100$$

$$\text{Efficiency} = \frac{V_s \times I_s}{V_p \times I_p} \times 100\%$$

Energy Losses in a Transformer
A transformer is designed in such a way to minimise energy losses. This is to ensure that its efficiency is as high as possible. There are four causes of energy losses in a transformer.

1. Resistance of windings
The resistance of copper wires used for the windings contributes to heat loss (I^2R_{copper}).
➡ This energy loss is reduced by using thick copper wires which have very low resistance.

2. Eddy currents
The changing magnetic field also induces eddy currents in the soft iron core itself. The eddy currents cause heat loss within the soft iron core.
➡ This energy loss is reduced by using a laminated core, i.e a core made of thin sheets of soft iron insulated from one another.

3. Hysteresis
This is the repeated magnetisation and demagnetisation of the soft iron core by the alternating magnetic field. This process causes energy loss in form of heat.
➡ This energy loss is reduced by using a core made of a magnetic material which is easy to magnetise and demagnetise like soft iron.

4. Flux leakage
This occurs when some of the magnetic flux produced by the primary coil is not linked to the secondary coil due to the design of the core.
➡ This is reduced by winding the secondary coil on top of the primary coil on an E–shaped soft iron core.

Examples
1. A 240V mains transformer has 1000 turns in the primary. Find the number of turns in the secondary if it is used to supply a 12V, 24W lamp.

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

$$\frac{240}{12} = \frac{1000}{N_s}$$

$$N_s = \frac{1000 \times 12}{240}$$

$$\mathbf{N_s = 50\ Turns}$$

2. A transformer has 10,000turns in the secondary coil and 100turns in the primary coil. An alternating current of 5.0A flows in the primary coil when connected across a 12V a.c supply.
(i) What is the type of transformer above?
(ii) Calculate the voltage across the secondary coil
(iii) If this transformer is 90% efficient, calculate the current in the secondary coil.

Solution
(i) This is a step–up transformer because the number of turns in the secondary coil is greater than the number of turns in the primary coil.
(ii)

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

$$\frac{12}{V_s} = \frac{100}{10000}$$

$V_s = \frac{10000}{100} \times 12$

$\mathbf{V_s = 1200V}$

(iii) Output power = 90% the input power

$V_s \times I_s = \frac{90}{100} V_p \times I_p$

$1200 \times I_s = \frac{90}{100} \times 12 \times 5.0$

$I_s = \frac{0.9 \times 12 \times 5.0}{1200}$

$\mathbf{I_s = 0.045A}$

3. A transformer with 4,000 turns in the primary coil is designed to operate at a 240V mains and to run a door bell at a voltage of 6V a.c.
(i) What is this type of transformer?
(ii) If the door bell is working at full voltage, how many turns are in the secondary coil?
(iii) What is the primary current if a current of 2.4A flows through the bell and the transformer is 95% efficient?

Solution

(i) This is **a step–down transformer** because the output voltage is less than the input voltage.

(ii) $\frac{V_p}{V_s} = \frac{N_p}{N_s}$

$\frac{240}{6} = \frac{4000}{N_s}$

$N_s = \frac{4000 \times 6}{240}$

$\mathbf{N_s = 100\ Turms}$

(iii) Also, 95% of input power = output power

$\frac{95}{100} V_p \times I_p = V_s \times I_s$

$\frac{95}{100} \times 240 \times I_p = 2.4 \times 6$

$I_p = \frac{2.4 \times 6 \times 100}{95 \times 240}$

$\mathbf{I_s = 0.063A}$

Exercise

1. A transformer is designed to operator at a 240V mains supply and delivers 10V. The current from the mains supply is 1.5A. If the efficiency of the transformer is 96%, calculate the
(i) Maximum output current
(ii) Power loss in the transformer
2. Calculate the voltage obtained from the secondary coil of a 240V mains transformer which has 11500 turns on its primary and 600 turns on its secondary?
5. A 230Vmains transformer takes a current of 2.5 A. It delivers a power of 460 W to a load. Calculate the percentage efficiency of this transformer.

3. A step–up transformer is designed to operate at 20V a.c supply and delivers energy at 250V. if the transformer is 80% efficient, and the output terminals are connected to a 250V, 100W lamp; determine
(i) The current in the secondary coil
(ii) The current in the primary coil
(iii) The power loss in the transformer.
4. A transformer is used on the 250V a.c supply to deliver 9.0A at 80V to a heating coil. If 10% of the energy taken from the supply is dissipated in the transformer itself; what is the current in the primary winding?
5. A 240V step down mains transformer is designed to light 10 ray box lamps rated 12V, 20W and it draws a current of 1A in the primary coil.
(i) Calculate the efficiency of the transformer
(ii) State the causes of power losses in a transformer
6. A transformer is designed to operate at 240V mains supply to deliver 9V. The current drawn from the power source is 1.0A. If the efficiency of the transformer is 90%, calculate;
(i) The maximum output current
(ii) The power loss
7. An A.C transformer operates on a 240V mains. The voltage across the secondary, which has 960 turns, is 20V. If the efficiency of the transformer is 80%, calculate the current in the primary coil when a resistor of 40 is connected across the secondary.
8. A transformer supplies a current of 13.5A at a voltage of 48V to a device from an A.C mains supply of 240V. Given the transformer is 85% efficient, calculate the;
(i) Power wasted
(ii) Current in the primary coil