Chapter 10 Electro-magnetism

SYLLABUS

Magnetic effect of current (principles only, laws not required); Electromagnetic induction (elementary); transformer.

Scope of syllabus : Oersted's experiment on the magnetic effect of electric current; magnetic field (B) and field lines due to current in a straight wire (qualitative only), right hand rule; magnetic field due to a current in a loop; electromagnets, their uses; comparison with a permanent magnet; Fleming's left hand rule, the dc electric motor — simple sketch of main parts (coil, magnet, split ring commutator and brushes); brief description and type of energy transfer (working not required); simple introduction to electromagnetic induction, frequency of a.c. in household supplies, ac generator — simple sketch of main parts, brief description and type of energy transfer (working not required); advantage of a.c. over d.c.; transformer — its types, charactertics of primary and secondary coils in each type (simple labelled diagram and its uses).

(A) MAGNETIC EFFECT OF ELECTRIC CURRENT

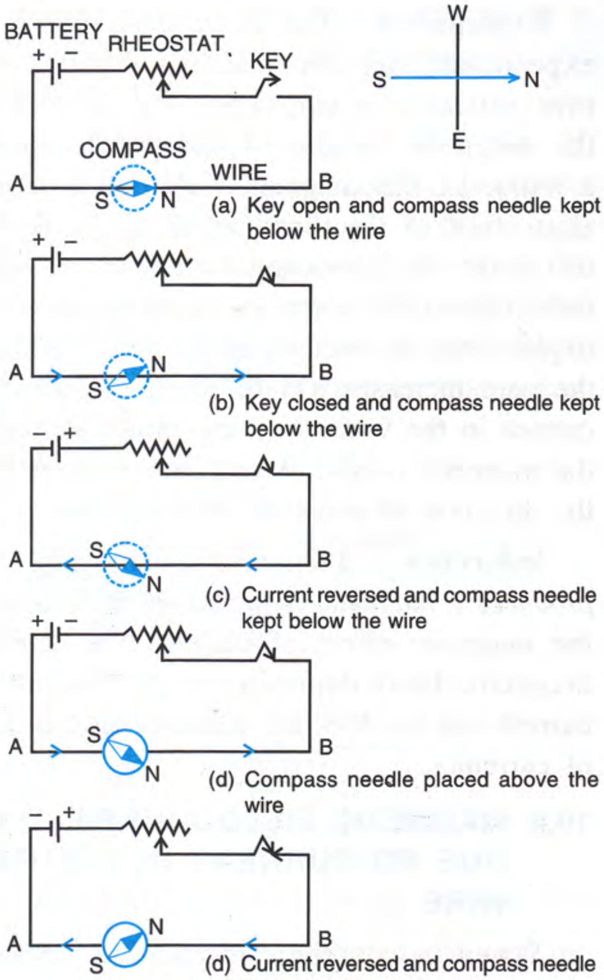
10.1 OERSTED'S EXPERIMENT ON THE MAGNETIC EFFECT OF ELECTRIC CURRENT

Hans Oersted, in 1820, in his experiments observed that *when an electric current is passed through a conducting wire, a magnetic field is produced around it*. The presence of magnetic field at any point around the current carrying wire can be detected with the help of a campass needle.

In absence of any magnetic field, the needle of compass can rest in any direction. But in presence of a magnetic field, the needle of compass rests only along the direction of the magnetic field. In the earth's magnetic field alone, the needle rests only along the north-south direction.

Experiment : In Fig. 10.1, AB is a wire lying in the north-south direction and connected to a battery through a rheostat and a tapping key. A compass needle is placed just below the wire.

Observations : (1) When the key is open *i.e.*, no current passes through the wire, the needle points in the N-S direction (*i.e.,*along the earth's magnetic field) with the north pole of needle pointing towards the north direction. In this



(a) Key open and compass needle kept below the wire

(b) Key closed and compass needle kept below the wire

(c) Current reversed and compass needle kept below the wire

(d) Compass needle placed above the wire

(d) Current reversed and compass needle kept above the wire

Fig. 10.1 Oersted experiment on the magnetic effect of current position, the needle is parallel to the wire as shown in Fig. 10.1 (a).

(2) When the key is pressed, a current passes in the wire in the direction from A to B (*i.e.*, from south to north) and the north pole (N) of the needle deflects towards the west [Fig. 10.1 (b)]. If current in the wire is increased, the deflection of the needle also increases.

(3) When the direction of current in the wire is reversed by reversing the connections at the terminals of the battery, the north pole (N) of the needle deflects towards the east [Fig. 10.1 (c)].

(4) If the compass needle is placed just above the wire, the north pole (N) deflects towards east when the direction of current in wire is from A to B [Fig. 10.1(d)], but the needle deflects towards west as shown in Fig. 10.1 (e) if the direction of current in wire is from B to A.

Explanation : The above observations of the experiment suggest that *a current carrying wire produces a magnetic field around it* and the magnetic needle of compass experiences a torque in this magnetic field, so it deflects to align itself in the direction of magnetic field at that point. On increasing current in the wire, the deflection of the compass needle increases which implies that the strength of magnetic field around the wire increases. On reversing the direction of current in the wire, the direction of deflection of the magnetic needle of compass reverses because the direction of magnetic field reverses.

Inference : *A current (or moving charge) produces a magnetic field around it.* This is called the magnetic effect of current. The strength of magnetic field depends on the magnitude of current and its direction depends on the direction of current.

10.2 MAGNETIC FIELD AND FIELD LINES DUE TO CURRENT IN A STRAIGHT WIRE

When a current is passed through a conducting wire, a magnetic field is produced around it. At a point, the direction of magnetic field will be along the tangent drawn on the magnetic field line at that point. The magnetic field lines can be drawn by means of iron filings as follows.

Experiment : Take a sheet of smooth cardboard with a hole at its centre. Place it horizontal and pass a thick copper wire XY vertically through the hole. Connect an ammeter A, battery B, rheostat Rh and a key K between the ends X and Y of the wire as shown in Fig. 10.2. Sprinkle some iron filings on the cardboard and pass an electric current through the wire by inserting the plug in the key K. Gently tap the cardboard.

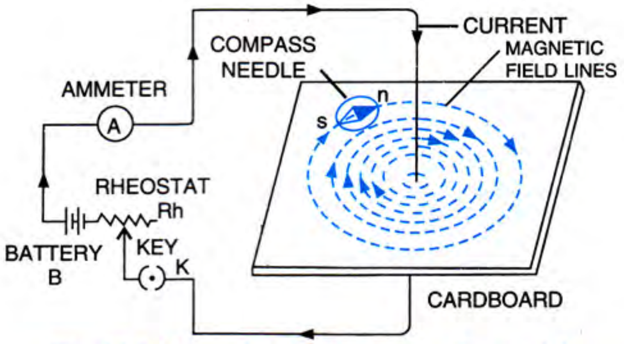


Fig. 10.2 Magnetic field lines around a straight current carrying wire

It is observed that the iron filings get arranged along the concentric circles around the wire as shown by the dotted lines in Fig. 10.2.

If a small compass needle is placed anywhere on the board near the wire, the direction in which the north pole of needle points, gives the direction of magnetic field at that point which is marked by an arrow on the field line.

From the magnetic field lines patterns, we note that

(1) The magnetic field lines form the concentric circles around the wire, with their plane perpendicular to the straight wire and with their centres lying on the wire.

(2) When the direction of current in the wire is reversed, the pattern of iron filings does not change, but the direction of deflection of the compass needle gets reversed. The

north pole of the compass needle now points in a direction *opposite* to the previous direction showing that the direction of magnetic field has reversed.

(3) On increasing current in the wire, the magnetic field lines become *denser* and the iron filings get arranged in circles up to a larger distance from the wire, showing that the magnetic field strength has *increased* and it is effective up to a larger distance.

Note : The magnetic field at any point is the *combined effect* of the magnetic field due to current in the wire and the magnetic field of the earth*. At points near the wire, the magnetic field due to current in the wire predominates due to which iron filings arrange themselves in circles, while at points far away from the wire, the magnetic field due to earth becomes more pronounced as compared to the magnetic field due to current in the wire, as a result filings tend to arrange themselves in straight lines. The point where the two fields are equal and opposite, is called a *neutral point*. At the neutral point, the resultant magnetic field is zero and the compass needle at this point rests in any direction.

10.3 RULE TO FIND THE DIRECTION OF MAGNETIC FIELD

Experimentally the direction of magnetic field at a point is determined with the help of compass needle. But theoretically the direction of magnetic field (or magnetic field lines) produced due to flow of current in a conductor can be determined by various rules. One such rule is the *right hand thumb rule*.

Right hand thumb rule

If we hold the current carrying conductor in our right hand such that the thumb points in the direction of flow of current, then the fingers encircle the wire in the direction of the magnetic field lines (Fig. 10.3).

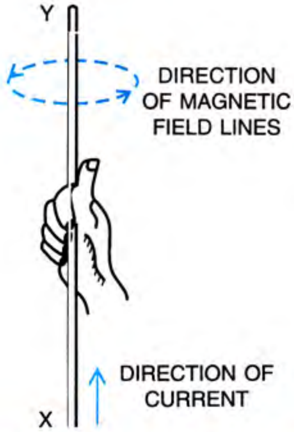


Fig. 10.3 Right hand thumb rule

In Fig. 10.3, the direction of current in the conductor XY is upwards (*i.e.*, X to Y). The magnetic field lines are anticlockwise around the conductor.

10.4 MAGNETIC FIELD DUE TO CURRENT IN A LOOP (OR CIRCULAR COIL)

The magnetic field lines due to current in a loop (or circular coil) can be obtained by the following experiment.

Experiment : Take a piece of thick wire A bent in the form of a loop (or coil). It is passed at two points P and Q through a horizontal cardboard C such that the points P and Q lie in a plane through the diameter of the coil. Then sprinkle some iron filings on the cardboard. Connect a battery through a rheostat and a key between the ends X and Y of the loop as shown in Fig. 10.4.

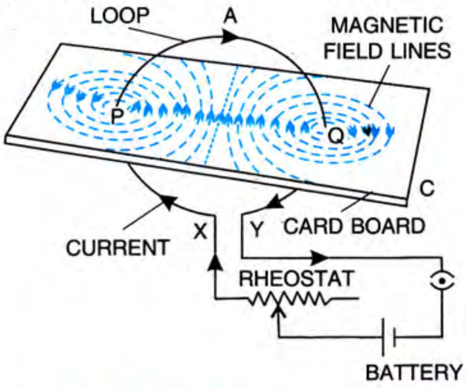


Fig. 10.4 Magnetic field due to current in a loop

When current is passed through the coil by closing the key and the cardboard is gently tapped, we find that the iron filings get arranged

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* The magnetic field of earth in a limited space in a horizontal plane is uniform. It is directed from the geographic south to geographic north.

in a definite pattern representing the magnetic field lines of the current carrying loop (Fig. 10.4). To find the direction of magnetic field lines, a compass needle is used. The direction of magnetic field at a point is along the needle in direction in which its north pole points. An arrow is marked on each magnetic field line to indicate the direction of magnetic field.

From the pattern of magnetic field lines, it is noted that

(1) In the vicinity of wire at P and Q, the magnetic field lines are nearly circular.

(2) Within the space enclosed by the wire (*i.e.*, between P and Q), the magnetic field lines are in the same direction.

(3) Near the centre of loop, the magnetic field lines are nearly parallel to each other, so the magnetic field may be assumed to be nearly *uniform* in a small space near the centre.

(4) At the centre, the magnetic field lines are along the axis of loop and normal to its plane.

(5) The magnetic field lines become denser (*i.e.*, the magnetic field strength is increased) if

   (i) the strength of current in loop is increased, and

   (ii) the number of turns in the loop are increased.

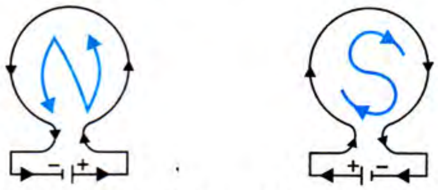
(6) The magnetic field lines pass through the loop in same direction. They appear to come out from the face of loop on other side, so that face behaves as a *north pole*, while the magnetic field lines appear to enter in at the front face of loop, so it behaves as a *south pole*. Thus the loop acts like a *dipole* and it has a magnetic field similar to that of a magnetised disc of radius same as that of the loop.

The polarity at the two faces of loop depends on the direction of current in the loop. On reversing the direction of current in loop, the polarity at the faces of loop gets reversed. The polarity at the faces of the loop is determined by the *clock rule*.

Clock rule (clockwise current–south pole and anticlockwise current–north pole)

> *Looking at the face of loop, if the current around that face is in anticlockwise direction, the face has the north polarity, while if the current at that face is in clockwise direction, the face has the south polarity.*

This can be tested by using a compass needle. In Fig. 10.5 (a), current at the face of loop is anticlockwise, so it behaves as north pole, while in Fig. 10.5(b), current at the face of loop is clockwise so it behaves as south pole.



ANTICLOCKWISE CURRENT
(a)

CLOCKWISE CURRENT
(b)

Fig. 10.5 Polarities at the faces of a loop carrying current

10.5 MAGNETIC FIELD DUE TO A CURRENT CARYING CYLINDRICAL COIL (OR SOLENOID)

If a conducting wire is wound in form of a cylindrical coil whose diameter is less in comparison to its length, the coil is called a ***solenoid***. It looks like a helical spring. To obtain the magnetic field lines due to a current carrying solenoid, the following experiment is performed.

Experiment : Take a cardboard having two slits PQ and P′Q′ parallel to each other, at a small separation and parallel to its length. Wind a uniform spiral of an insulated thick copper wire through the two slits such that the axis of spiral is in the plane of the cardboard. Connect a battery through a rheostat and a key between the ends X and Y of the solenoid. Sprinkle some iron filings on the cardboard and pass current through the solenoid by closing the key. Gently tap the cardboard.

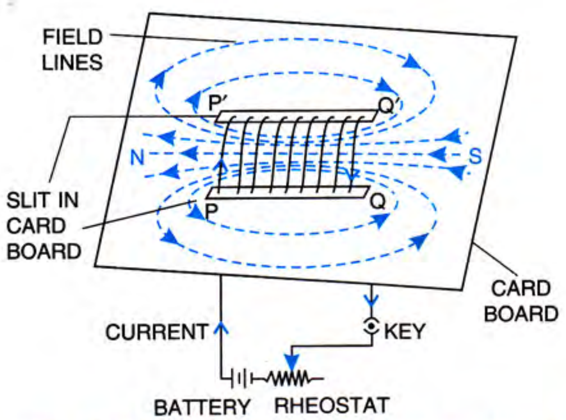


Fig. 10.6 Magnetic field lines due to a solenoid carrying current

It is found that the iron filings on the cardboard get arranged in a definite pattern as shown by the dotted lines in Fig. 10.6, representing the pattern of magnetic field lines due to the current carrying solenoid. The direction of magnetic field at a point is determined by using a compass needle and arrows are marked on these lines in the direction in which the north pole of the compass needle points.

From the pattern of magentic field lines, it is found that

(1) The magnetic field lines inside the solenoid are nearly straight and parallel to the axis of solenoid *i.e.*, the magnetic field is *uniform* inside the solenoid.

(2) The magnetic field lines become denser (*i.e.*, a strong magnetic field is obtained) on increasing current in the solenoid.

(3) The magnetic field is increased, if the number of turns in the solenoid of given length is increased.

(4) The magnetic field is also increased, if a soft iron rod (core) is placed along the axis of solenoid. The soft iron increases the strength of magnetic field of the solenoid since soft iron has a high magnetic permeability.

(5) In Fig. 10.6, the end P at which the direction of current is *anticlockwise* behaves as a *north pole* (N), while the end Q at which the direction of current is *clockwise* behaves as a *south pole* (S). On reversing the direction of current in the solenoid, the polarities at the ends of solenoid are reversed because the direction of magnetic field has reversed.

Similarities between a current carrying solenoid and a bar magnet

(1) The magnetic field lines of a current carrying solenoid are similar to the magnetic field lines of a bar magnet*. Thus *a current carrying solenoid behaves just like a bar magnet.*

(2) A current carrying solenoid when suspended freely sets itself in the north-south direction exactly in the same manner as a bar magnet does.

(3) A current carrying solenoid also acquires the attractive property of a magnet. If iron filings are brought near the current carrying solenoid, it attracts them.

Dissimilarities between a current carrying solenoid and a bar magnet

(1) The strength of magnetic field due to a solenoid can be changed by changing the current in it, while the strength of magnetic field due to a bar magnet cannot be changed.

(2) The direction of magnetic field due to a solenoid can be reversed by reversing the direction of current in it, but the direction of magnetic field due to a bar magnet cannot be reversed.

10.6 ELECTROMAGNET

An electromagnet is a temporary strong magnet made by passing current in a coil wound around a piece of soft iron. It is an artificial magnet.

An electromagnet can be made in any shape, but usually the following *two* shapes of electromagnet are in use :

(1) *I–shape* (or *bar) magnet,* and

(2) *U-shape* (or *horse-shoe) magnet.*

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* Refer Vol. I, Chapter X.

(1) Construction of I-shaped (or bar) electromagnet

To construct an I-shaped electromagnet, a thin insulated copper wire XY is wound in form of a solenoid around a straight soft iron bar PQ. A battery B through an ammeter A, a rheostat Rh and a key K, is connected between the ends X and Y of the wire as shown in Fig 10.7.

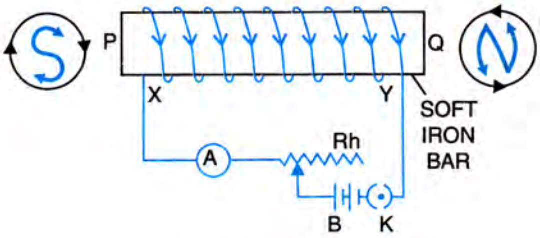

Fig. 10.7 I-shaped electromagnet

When current is passed through the winding of solenoid by closing the key K, the end P of the bar becomes the *south pole* (S) since current at this face is clockwise, while the end Q at which the current is anticlockwise, becomes the *north pole* (N). Thus the bar PQ becomes a magnet. The bar remains magnetised so long the electric current flows through the solenoid, but it gets demagnetised as soon as the current is switched off (since soft iron has a low retentivity), thus it is a temporary magnet.

Use : A bar shaped electromagnet is commonly used in relay.*

(2) Construction of U-shaped (or horse-shoe) electromagnet

To construct a horse-shoe electromagnet, a thin insulated copper wire XY is spirally wound on the two arms of a U-shaped soft iron core, such that the winding as seen from the ends, is in *opposite sense* on the two arms. In Fig. 10.8, winding on the arm P starts from the front and it is in the clockwise direction (when viewed from the bottom). On reaching the upper end of the arm P, winding starts from the back at the top of the arm Q and it is in anticlockwise direction. Between the ends X and Y of the wire, a battery through an ammeter, rheostat and a key, is connected.

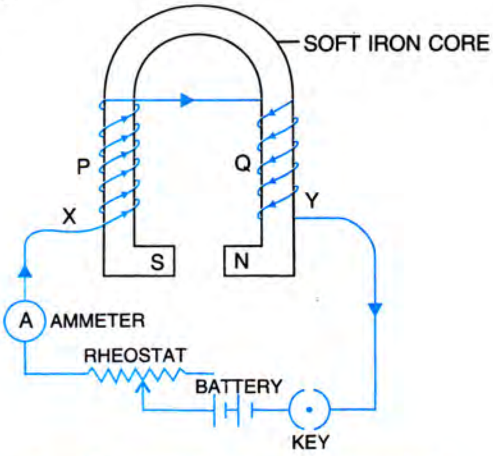

Fig. 10.8 Horse-shoe electro-magnet

When current is passed through the winding by closing the key, the end of the arm P becomes the *south pole* S (current at this face is clockwise) and the end of the arm Q becomes the *north pole* N (current at this face is anti-clockwise). Thus we get a very strong magnetic field in gap between the two poles. The magnetic field in gap vanishes as soon as current in the circuit is switched off. Thus it is a temporary magnet.

Use : Horse shoe magnets are used in gadgets like d.c. motor, a.c. generator, electric bell, etc.

> ***Note :*** For sending current in the coil, the source must be the d.c. source (*i.e.*, battery). With an a.c. source of frequency 50 Hz, although the soft iron core gets magnetised as long the current is passed, but its polarity at the ends changes 50 times in each second.

Ways of increasing the magnetic field of an electromagnet

The magnetic field of an electromagnet (I or U-shaped) can be increased by the following *two* ways :

(1) *by increasing the number of turns of winding in the solenoid, and*

(2) *by increasing the current through the solenoid.*

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* A relay is a switching device.

10.7 PERMANENT MAGNET

A permanent magnet is a naturally occuring magnet. Since it is not strong enough and of required shape for many purposes, so a strong permanent magnet is made like an electromagnet using the piece of steel, instead of soft iron. A coil of insulated copper wire is wound around the steel piece and then current is passed in the coil. Once magnetised, it does not lose its magnetism easily (since steel has more retentivity than the soft iron) so it becomes a permanent magnet.

Use : The permanent magnets are used in electric meters (*e.g.*, galvanometer, ammeter, voltmeter) and in magnetic compass, etc.

10.8 COMPARISON OF AN ELECTRO MAGNET WITH A PERMANENT MAGNET

Electromagnet	Permanent magnet
1. It is made of soft iron.	1. It is made of steel.
2. It produces the magnetic field so long as current flows in its coil. *i.e.*, it produces the temporary magnetic field.	2. It produces a permanent magnetic field.
3. The magnetic field strength can be changed.	3. The magnetic field strength cannot be changed.
4. The magnetic field of an electromagnet can be very strong.	4. The magnetic field of a permanent magnet is not so strong.
5. The polarity of an electromagnet can be reversed.	5. The polarity of a permanent magnet can not be reversed.
6. It can easily be demagnetised by switching off the current.	6. It can not be easily demagnetised.

10.9 ADVANTAGES OF AN ELECTRO-MAGNET OVER A PERMANENT MAGNET

An electromagnet has the following advantages over a permanent magnet :

(1) An electromagnet can produce a strong magnetic field.

(2) The strength of the magnetic field of an electromagnet can easily be changed by changing the current (or the number of turns) in its solenoid.

(3) The polarity of the electromagnet can be reversed by reversing the direction of current in its solenoid.

10.10 USES OF ELECTROMAGNET

Electromagnets are mainly used for the following purposes :

(1) For lifting and transporting heavy iron scrap, girders, plates, etc. particularly when it is not convenient to take the help of human labour. Electromagnets are used to lift as much as 20,000 kg of iron in a single lift. To unload the iron objects at the desired place, the current in the electromagnet is switched off so that the electromagnet gets demagnetised and the iron objects get detached.

(2) For loading the furnaces with iron.

(3) For separating the iron pieces from debris and ores, where iron exists as impurities (e.g., for separating iron from the crushed copper ore in copper mines).

(4) For removing the pieces of iron from wounds.

(5) In scientific research, to study the magnetic properties of a substance in a magnetic field.

(6) In several electrical devices such as electric bell, telegraph, electric tram, electric motor, relay, microphone, loud speaker, etc.

Use of electromagnet in an electric bell

An electric bell is one of the most commonly used application of an electromagnet.

Construction and wiring : An electric bell is shown in Fig. 10.9.

The main parts of the bell are :

(i) a horse-shoe electromagnet M, having a soft iron core,

(ii) a soft iron armature A,

(iii) a hammer H,

(iv) a gong G,

(v) a metallic spring strip SS,

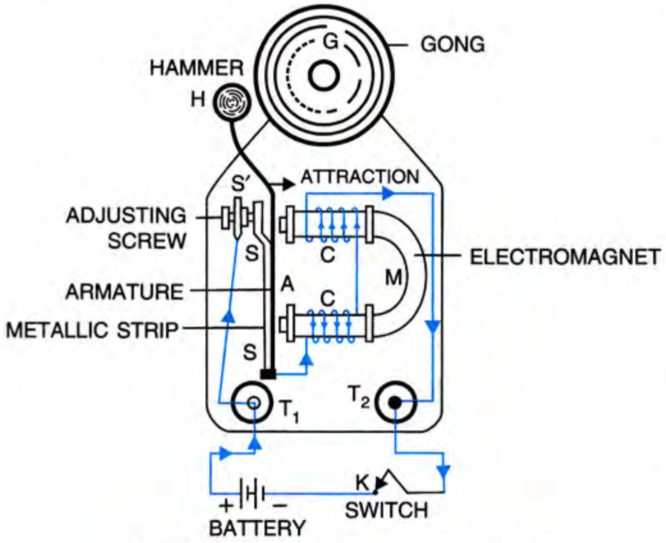


Fig. 10.9 Electric bell and its wiring

(vi) an adjusting screw S′,

(vii) a switch (or bell-push) K, and

(viii) a battery.

The armature A is fixed to the spring strip SS. The hammer H is attached at the upper end of the armature A. When the switch K is not pressed, the strip SS makes contact with the adjusting screw S′ and there is a gap between the armature A and the poles of the electromagnet.

The coil CC is wound on the two arms of the electromagnet in the *opposite direction* as shown in the diagram. One end of the coil is connected to the terminal T_1 through the strip SS and the screw S′, while the other end is connected to the terminal T_2. A battery is provided in series with the switch K across the terminals T_1 and T_2.

Working and function of each part : The working of an electric bell is based on the magnetic effect of current. As the electric circuit is closed by pressing the switch K, the current flows through the coil CC and the core of the electromagnet gets magnetised and therefore it attracts the armature A as shown by the arrow in Fig. 10.9. Due to movement of the armature A, the hammer H strikes the gong G and the bell rings.

At the moment, when the armature A moves towards the electromagnet due to magnetic attraction, the connection between the strip SS and the screw S′ breaks due to which the flow of current in the coil stops. Consequently, the electromagnet gets demagnetised and the armature A flies back to its original position due to the spring effect of the strip SS. Now the armature again touches the screw S′, which results in the flow of current in the coil. The electromagnet regains its magnetism and the armature A is again attracted, so the hammer H again strikes the gong G. This process continues.

The process of make and break of the circuit goes on and the hammer strikes the gong repeatedly so the bell rings as long the switch K is kept pressed.

Note : If an a.c. source is used in place of the battery, the core of electromagnet will get magnetised, but the polarity at its ends will change. Since attraction of armature does not depend on the polarity of the electromagnet, so the bell will still ring on pressing the switch K.

EXAMPLES

1. Why does a magnetic needle show a deflection when brought close to a current carrying conductor ?

A current carrying conductor produces a magnetic field around it and the magnetic needle in this magnetic field experiences a torque due to which it deflects to align itself in the direction of magnetic field.

2. A straight conductor passes vertically through a cardboard having some iron filings sprinkled on it.

(a) A current is passed in the conductor in downward direction and the cardboard is gently tapped. Show the setting of iron filings on the card board and draw arrows to represent the direction of magnetic field lines.

(b) What changes occur in the arrangement of iron filings in part (a) if

(i) the strength of current is increased ?

(ii) the single conductor is replaced by several parallel conductors each carrying the same

current flowing in the same direction ? Give reason in each case (i) and (ii).

(c) Name the law used by you to find the direction of magnetic field lines.

(a) Fig. 10.10 shows the pattern in which the iron filings will set themselves. The arrows show the direction of the magnetic field lines.

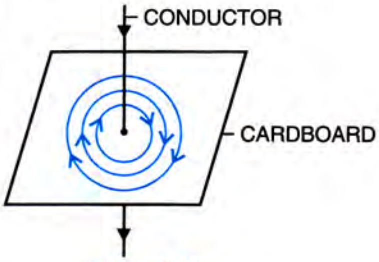


Fig. 10.10

(b) (i) The arrangement of iron filings remains unchanged, but they **become denser** and get arranged **up to a larger distance** from the conductor when the strength of current is increased. This is because on increasing the strength of current, the strength of magnetic field is increased and it is effective up to a larger distance from the conductor.

(ii) The magnetic field at a point due to each conductor will be in same direction, so they will be added up. Thus the magnetic field strength is increased and it is effective up to a large distance so the magnetic field lines **come closer** and iron filings get **arranged up to a larger distance**.

(c) **Right hand thumb rule.**

3. In Fig. 10.11, A and B represent two straight wires carrying equal currents in a direction normal to the plane of paper inwards.

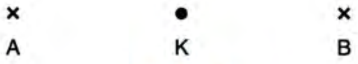


Fig. 10.11

(a) Sketch separately the magnetic field lines produced by each current.

(b) What will be the magnetic field at mid point K of the line joining A and B. Give reason.

(c) How will the magnetic needle of compass rest if it is placed at the point K ?

(d) What will be the effect on the magnetic field at the point K if the current in wire B is reversed ?

(a) Fig 10.12 shows the sketch of magnetic field lines produced by the current in wires A and B.

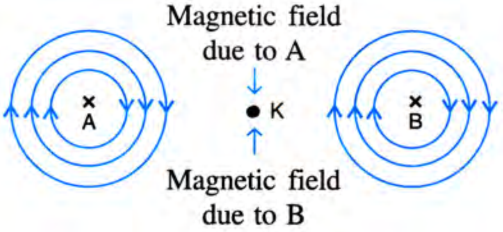


Fig. 10.12

(b) The net magnetic field at the point K is **zero**.

Reason : The point K is equidistant from the wires A and B, and the wires A and B carry equal currents, so the magnetic fields at the point K due to current in the wires A and B are equal in magnitude, but opposite in direction. Due to current in the wire A, it is downwards in the plane of paper, while due to current in the wire B, it is upwards in the plane of paper. The two fields cancel each other.

(c) The magnetic needle of compass at the point K will rest in geographic north-south direction due to the earth's magnetic field.

(d) On reversing the direction of current in the wire B, the direction of magnetic field due to current in it is reversed at the point K *i.e.*, it becomes downwards in the plane of paper. Then both the magnetic fields due to currents in wires A and B at the point K get added, so the net magnetic field at the point K is **downwards in the plane of paper**.

4. The diagram in Fig. 10.13 shows a current carrying loop passing through a sheet of stiff cardboard at the points P and Q.

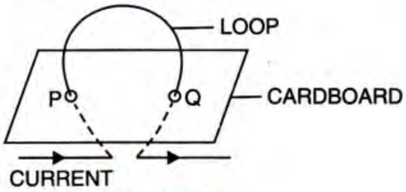


Fig. 10.13

(a) Draw *three* magnetic field lines on the cardboard, one each at points P and Q, and one at the centre of loop. Draw arrows to show the direction of magnetic field lines.

(b) State *two* factors on which the magnitude of magnetic field at the centre of loop depends.

(a) Fig. 10.14 represents *three* magnetic field lines due to the current carrying loop. Two magnetic field lines are shown, one each at points P and Q where the loop passes through the card board, and one magnetic field line is shown at the centre of loop. At P, current is upwards, so magnetic field line is

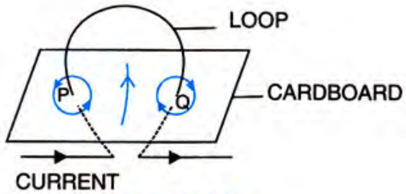


Fig. 10.14

anticlockwise. At Q, current is downwards, so magnetic field line is **clockwise**. Since current in loop is clockwise, magnetic field line at the centre is **along the axis of loop inwards**.

(b) The magnitude of the magnetic field at the centre of loop depends on (i) the strength of current in the loop, and (ii) the radius of loop.

5. Draw a labelled diagram to make an electromagnet from a soft iron bar AB. Mark the polarity at its ends A and B. State *one* precaution which you will observe.

The labelled diagram is shown in Fig. 10.15. The polarity at the **end A** where the current is clockwise, is **south (S)**, while at the **end B** where the current is anticlockwise, is **north (N)**.

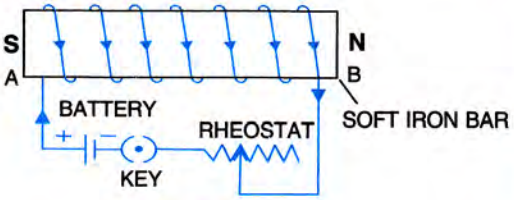


Fig. 10.15

Precaution : The source of current must be the d.c. source.

6. (a) Draw a diagram representing the magnetic field lines inside and outside a solenoid through which a current is flowing and mark the direction of current in the solenoid and the direction of magnetic field lines. Also mark the polarity at the faces of solenoid.

(b) A bar of soft iron is placed inside the solenoid parallel to its length in part (a). Describe what happens.

(a) Fig. 10.16 shows the magnetic field lines inside and outside, due to a current carrying solenoid. The direction of current in the solenoid at the face A is **clockwise**, so it will have the **south polarity (S)** and the face B of solenoid at which the current is **anticlockwise** will have the **north polarity (N)**. Inside the solenoid, the magnetic field lines are closer, while they become farther outside the solenoid.

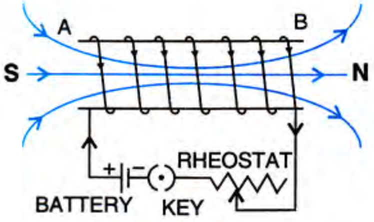


Fig. 10.16

(b) If a bar of soft iron is placed inside the solenoid parallel to its length, the magnetic field lines inside the solenoid **become still closer** *i.e.*, the magnetic field inside the solenoid is **increased**.

EXERCISE–10(A)

1. By using a compass needle describe how can you demonstrate that there is a magnetic field around a current carrying conductor.
2. Draw a diagram showing the direction of *three* magnetic field lines due to a straight wire carrying a current. Also show the direction of current in the wire.
3. How is the magnetic field due to a straight current carrying wire affected if current in the wire is (a) decreased, (b) reversed ?
4. State a law which determines the direction of magnetic field around a current carrying wire.
5. A straight wire lying in a horizontal plane carries a current from north to south. (a) What will be the direction of magnetic field at a point just underneath it ? (b) Name the law used to arrive at the answer in part (a).

   Ans. (a) towards east (b) right hand thumb rule
6. What will happen to a compass needle when the compass is placed below a wire with needle parallel to it and a current is made to flow through the wire ? Give a reason to justify your answer.
7. Draw a labelled diagram showing *three* magnetic field lines of a loop carrying current. Mark the direction of current and the direction of magnetic field by arrows in your diagram.

8. A wire, bent into a circle, carries a current in an anticlockwise direction. What polarity does this face of the coil exhibit ? **Ans.** north

9. What is the direction of magnetic field at the centre of a coil carrying current in (i) the clockwise, (ii) the anticlockwise direction ?

Ans. (i) along the axis of coil inwards
(ii) along the axis of coil outwards.

10. Draw a diagram to represent the magnetic field lines along the axis of a current carrying solenoid. Mark arrows to show the direction of current in the solenoid and the direction of magnetic field lines.

11. Name and state the rule by which the polarity at the ends of a current carrying solenoid is determined.

12. The diagram in Fig. 10.17 shows a small magnet placed near a solenoid AB with its north pole N near the end A. Current is switched on in the solenoid by pressing the key K.

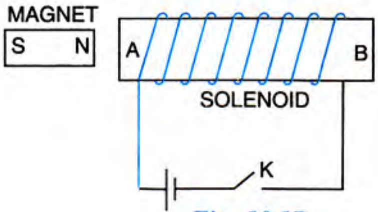


Fig. 10.17

(a) State the polarity at the ends A and B. (b) Will the magnet be attracted or repelled ? Give a reason for your answer.

Ans. (a) A —north pole, B—south pole

(b) repelled because the end A of the solenoid becomes the north pole as current at this face is anti-clockwise and it repels the north pole of the magnet.

13. The diagram in Fig. 10.18 shows a spiral coil wound on a hollow cardboard tube AB. A magnetic compass is placed close to it. Current is switched on by closing the key. (a) What will be the polarity at the ends A and B ? (b) How will the compass needle be affected ? Give reason.

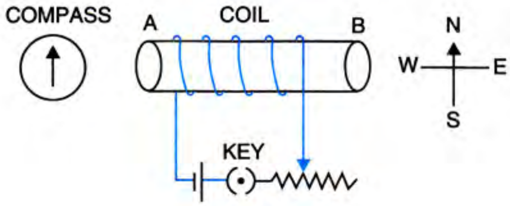


Fig. 10.18

Ans. (a) A—north pole, B—south pole (b) the north pole of compass needle will deflect towards west.

Reason : End A of the coil behaves like north pole which repels the north pole of the compass needle towards west.

14. State *two* ways by which the magnetic field due to a current carrying solenoid can be made stronger.

15. Why does a current carrying freely suspended solenoid rest along a particular direction ? State the direction in which it rests.

Ans. a current carrying solenoid behaves like a bar magnet. It rest in geographic north-south direction.

16. What effect will there be on a magnetic compass when it is brought near a current carrying solenoid ?

Ans. the needle of the compass will rest in the direction of magnetic field due to the solenoid at that point.

17. How is the magnetic field due to a solenoid carrying current affected if a soft iron bar is introduced inside the solenoid ?

Ans. the strength of magnetic field increases

18. Complete the following sentences :

(a) When current flows in a wire, it creates ....

(b) On reversing the direction of current in a wire, the magnetic field produced by it gets ....

(c) A current carrying solenoid behaves like a........

(d) A current carrying solenoid when freely suspended, it always rests in .... direction.

Ans. (a) a magnetic field around it (b) reversed (c) bar magnet (d) north-south

19. You are required to make an electromagnet from a soft iron bar by using a cell, an insulated coil of copper wire and a switch. (a) Draw a circuit diagram to represent the process. (b) Label the poles of the electromagnet.

20. The diagram in Fig. 10.19 shows a coil wound around a soft iron bar XY. (a) State the polarity at the ends X and Y as the switch is pressed. (b) Suggest *one* way of increasing the strength of electromagnet so formed.

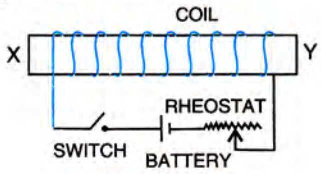


Fig. 10.19

Ans. (a) X-north pole, Y-south pole.

(b) by reducing the resistance of circuit by means of rheostat to increase current in the coil.

21. (a) What name is given to a cylindrical coil of diameter less than its length ?

(b) If a piece of soft iron is placed inside the coil mentioned in part (a) and current is passed in the coil from a battery, what name is then given to the device so obtained ?

(c) Give *one* use of the device mentioned in part (b).

Ans. (a) solenoid, (b) electromagnet, (c) electric relay.

22. Show with the aid of a diagram how a wire is wound on a U-shaped piece of soft iron in order to make it an electromagnet. Complete the circuit diagram and label the poles of the electromagnet.

23. What is an electromagnet ? Name *two* factors on which the strength of magnetic field of an electromagnet depends and state how does it depend on the factors stated by you.

24. Fig. 10.20 shows the current flowing in the coil of wire wound around the soft iron horse shoe core. State the polarities developed at the ends A and B.

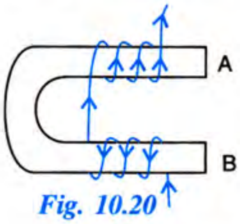


Fig. 10.20

Ans. at A—south and at B—north

25. State *two* ways by which the strength of an electromagnet can be increased.

26. Name *one* device that uses an electromagnet.

Ans. electric bell.

27. State *two* advantages of an electromagnet over a permanent magnet.

28. State *two* differences between an electromagnet and a permanent magnet.

29. Why is soft iron used as the core of the electromagnet in an electric bell ?

30. How is the working of an electric bell affected, if alternating current be used instead of direct current ?

31. The incomplete diagram of an electric bell is given in Fig 10.21. Draw winding of coil on the core and complete the electric circuit in the diagram

G–Gong
H–Hammer
A–Armature
C–Core
B–Battery

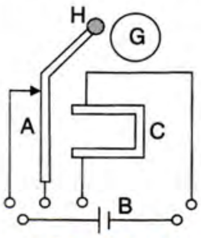


Fig. 10.21

32. Name the material used for making the armature of an electric bell. Give a reason for your answer.

MULTIPLE CHOICE TYPE

1. The presence of magnetic field at a point can be detected by means of :

(a) a strong magnet (b) a solenoid
(c) a compass needle (d) a current carrying wire.

Ans. (c) a compass needle.

2. On reversing the direction of current in a wire, the magnetic field produced by it :

(a) gets reversed in direction
(b) increases in strength
(c) decreases in strength
(d) remains unchanged in strength and direction.

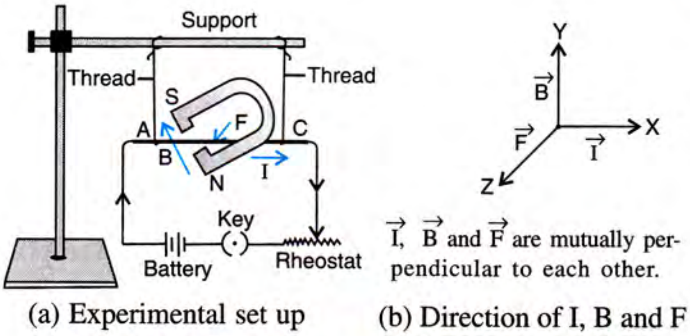
Ans. (a) gets reversed in direction.

(B) FORCE ON A CURRENT CARRYING CONDUCTOR IN A MAGNETIC FIELD AND ITS APPLICATION IN D.C. MOTOR

10.11 FORCE ON A CURRENT CARRYING CONDUCTOR IN A MAGNETIC FIELD

Lorentz found that a charge moving in a magnetic field, in a direction other than the direction of magnetic field, experiences a force. It is called the *Lorentz force*. Since charge in motion constitutes a current, therefore a conductor carrying moving charges (or current) placed in a magnetic field, in direction other than the direction of magnetic field, will also experience a force and can produce motion in the conductor. This can be demonstrated by the following experiment.

Experiment : Fig. 10.22(a) shows a thick copper wire AC suspended at its ends A and C from a support by means of threads. A magnetic field B is applied by keeping the wire AC in between the poles N and S of a horse shoe magnet, with length AC of wire normal to the magnetic field lines of the magnet. Between the ends A and C of the wire, a rheostat, key and battery are connected. In Fig. 10.22, the magnetic field B is in the plane of paper in upward direction (*i.e.*, in Y direction) and the wire also lies in the plane of paper with its length AC in X direction.



$\vec{I}$, $\vec{B}$ and $\vec{F}$ are mutually perpendicular to each other.

(a) Experimental set up (b) Direction of I, B and F

Fig. 10.22 Force on a current carrying conductor

Experimentally, it is observed that

(1) When *no* current flows in the wire, *no* force acts on the wire and the wire does not move.

(2) When current I is passed in the wire in direction from A to C (*i.e.*, in X direction), a force F acts on the wire in a direction perpendicular to both the direction of current I and the direction of magnetic field B, as shown in Fig. 10.22 (b). Due to the force F, the conductor begins to move normal to the plane of paper in outward direction (*i.e.*, in Z direction).

(3) If the direction of current through the wire is reversed by interchanging the terminals of the battery, the direction of force (*i.e.*, the direction of movement of the wire) is also reversed *i.e.*, now it moves normal to the plane of paper in inward direction (or in – Z direction).

(4) On reversing the direction of magnetic field (*i.e.*, on reversing the polarities N and S of the horse shoe magnet), the direction of force (*i.e.*, the direction of movement of wire) is reversed *i.e.*, now it moves in – Z direction.

Note : If wire is short enough and is placed between the poles of magnet with its length AC in Y direction such that the current in it is in the direction parallel to the direction of magnetic field, *no* force acts on the wire and it does not move.

Magnitude of force : Experimentally it is found that the magnitude of force acting on a current carrying wire placed in a magnetic field in the direction perpendicular to its length, depends on the following *three* factors :

(a) The force F is directly proportional to the current I flowing in the wire, *i.e.*,

$$F \propto I \qquad ....(i)$$

(b) The force F is directly proportional to the strength of magnetic field B, *i.e.*,

$$F \propto B \qquad ....(ii)$$

(c) The force F is directly proportional to the length l of the wire (within the magnetic field), *i.e.*,

$$F \propto l \qquad ....(iii)$$

Combining the eqns. (i), (ii) and (iii),

$$F \propto IBl$$

or $$F = KIBl$$

where K is a constant whose value depends on the choice of the unit. In S.I. units, the unit of B is such that $K = 1$. Then

$$\boxed{F = IBl} \qquad ...(10.1)$$

Unit of magnetic field : From eqn. (10.1), $B = \frac{F}{I \times l}$, so the S.I. unit of magnetic field is $\frac{\text{newton}}{\text{ampere} \times \text{metre}}$ or N A^{-1} m^{-1}. It is also named as tesla (symbol T) or weber/metre^2 (symbol Wb m^{-2}).

Fleming's left hand rule for the direction of force

The direction of force on a current carrying conductor placed in a magnetic field is obtained by the *Fleming's left hand rule.*

Fleming's left hand rule : *Stretch the forefinger, central finger and the thumb of your left hand mutually perpendicular to each other as shown in Fig. 10.23. If the forefinger indicates the direction of magnetic field and the central finger indicates the direction of current, then the thumb will indicate the direction of motion of conductor (i.e., force on conductor).*

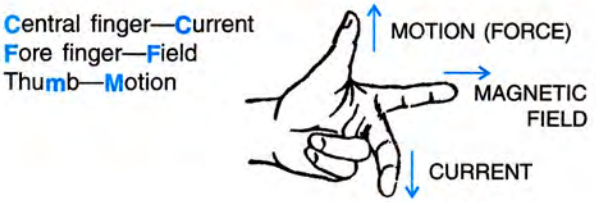


Fig. 10.23 Fleming's left hand rule

10.12 SIMPLE D.C. MOTOR

We know that in electric gadgets such as fan, washing machine, juicer, mixer, grinder, etc., an electric motor is used to produce rotational motion by the use of electricity. Thus

An electric motor is a device which converts the electrical energy into the mechanical energy.

Principle : A d.c. motor works on the principle that when an electric current is passed through a conductor placed normally in a magnetic field, a force acts on the conductor as a result of which the conductor begins to move and thus mechanical energy (or work) is obtained. The direction of force on the conductor is obtained with the help of Fleming's left hand rule.

Construction and its main parts : The basic construction of an electric motor is shown in Fig. 10.24. The main parts of an electric motor are :

(1) the *armature coil* ABCD mounted on an axle,

(2) the *split parts* S_1 and S_2 *of a ring* (*i.e.*, a copper slip ring being divided in two parts S_1 and S_2) *which is known as split ring commutator*,

(3) a pair of carbon (or copper) *brushes* B_1 and B_2,

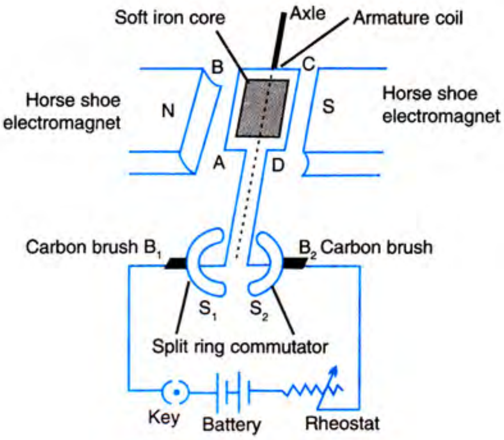


Fig. 10.24 A d.c. motor

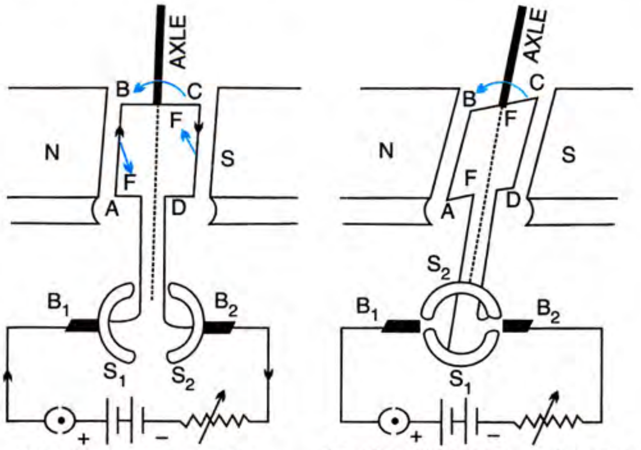
(4) a *horse-shoe electromagnet* NS, and

(5) a d.c. source (*i.e.*, battery).

The armature coil ABCD is wound around a soft iron core and it is placed in between the pole pieces of a strong horse-shoe electromagnet NS. The coil is free to rotate about its axis. The ends A and D of the coil are connected respectively to the split parts S_1 and S_2 of a ring. The brush B_1 presses gently against the split ring S_1 and the brush B_2 presses gently against the split ring S_2. A d.c. source (*i.e.*, battery) is connected across the brushes B_1 and B_2 through a key and rheostat. *When the coil rotates, the split parts of ring rotate with it, while the brushes which are fixed, remain at their position so as to remain in contact with the split ring.*

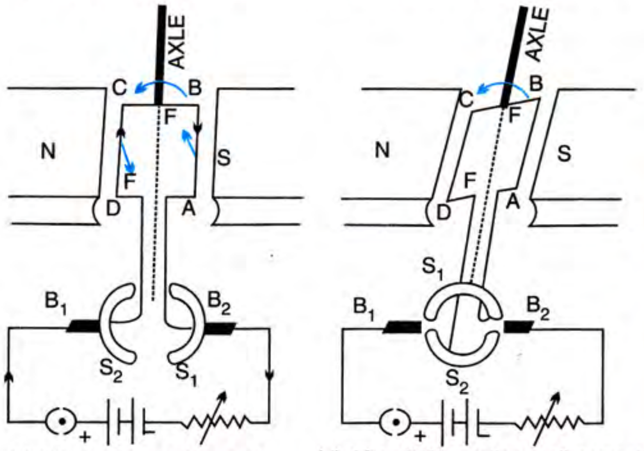
A wheel can be mounted on the axle attached to the armature coil along its axis so as to rotate the desired part of the machine where the motor is used.

Working : In Fig. 10.25 (a), the plane of the coil is horizontal and the split ring S_1 touches the brush B_1, while the split ring S_2 touches the brush B_2. The brush B_1 is connected to the + ve terminal of d.c. battery, while the brush B_2 is connected to its – ve terminal. When key is closed, the current flows in the coil in direction ABCD. The current in arms BC and DA is parallel to the magnetic field, so these arms experience no force. The current in arms AB and CD is perpendicular to the magnetic field, so each arm experiences a force F (= IBl). Here I is the current in the coil, B is the magnetic field strength and l is the length AB or CD. According to Fleming's left hand rule, the force F on the arm AB is in *inward* direction perpendicular to the plane of paper and the force F on the arm CD is in *outward* direction perpendicular to the plane of paper. The forces on the arms AB and CD being equal and opposite, form an anti-clockwise couple due to which the coil begins to rotate such that the arm AB *goes in* and the arm CD *comes out*.



(a) Initial position, coil in plane of magnetic field

(b) After 90° rotation, coil normal to the plane of magnetic field.



(c) After 180° rotation, coil in plane of magnetic field

(d) After 270° rotation, coil normal to the plane of magnetic field.

Fig. 10.25 Working of a d.c. motor

When the coil reaches the vertical position after 90° rotation (*i.e.,* perpendicular to the plane of paper with the arm CD out and the arm AB in) as shown in Fig. 10.25 (b), momentarily there is no contact between the brush B_1 and split ring S_1 or between the brush B_2 and split ring S_2. So at this moment, *no* current flows through the coil and thus *no* force acts on the coil. Due to the inertia of rotational motion, the coil does not stop in this position, but it continues to rotate.

As the coil passes from its vertical position, the split ring S_1 comes in contact with the brush B_2, while the split ring S_2 comes in contact with the brush B_1 [Fig. 10.25 (c)]. Now the current flows through the coil in direction DCBA. The arms CB and AD being parallel to the magnetic field, experience no force. On the arm DC, a force acts in *inward* direction perpendicular to the plane of paper and on the arm BA, an equal force acts in *outward* direction perpendicular to the plane of paper. The force is maximum (*i.e.* $F = IBl$) when the coil turns by 180° from the initial position. The forces acting on the arms DC and BA of the coil *again form an anticlockwise couple due to which the coil remains rotating in the same direction.*

After rotation by 270°, the coil reaches to the vertical position as shown in Fig. 10.25(d). Again for a moment, there is no contact between the brush B_1 and split ring S_2 or between the brush B_2 and split ring S_1, hence *no* current flows in the coil. But due to inertia of motion, the coil continues to rotate and again it reaches back to its initial position.

Note : **(1)** The deflecting couple on the coil of the motor is maximum when the plane of coil is parallel to the direction of magnetic field, while the deflecting couple is zero (or minimum) when the plane of the coil is perpendicular to the magnetic field.

(2) The speed of rotation of coil, obviously, depends on the magnitude of deflecting couple formed by the forces acting on the arms AB and CD of the coil. Deflecting couple is $BAnI$ where B = strength of magnetic field, A = area of coil, n = number of turns in coil, and I = current in coil. Hence the speed of rotation of coil is directly proportional to these factors.

Ways of increasing the speed of rotation of coil

The speed of rotation of coil can be increased by the following *four* ways :

(1) *by increasing the strength of current in the coil,*

(2) *by increasing the number of turns in the coil,*

(3) *by increasing the area of the coil, and*

(4) *by increasing the strength of magnetic field.*

To increase the strength of magnetic field, a soft iron core is inserted within the coil. The insertion of core makes the magnetic field strong and radial. Due to radial field, the couple acting on the coil remains almost constant during the rotation of coil, except in the vertical position of coil when the couple is zero.

Function of split ring commutator : Whenever the coil passes from the vertical position, the direction of *current through the coil has to be reversed,* so that the coil continues to rotate in the same direction. This is achieved by the two split parts S_1 and S_2 of a conducting ring which reverses the direction of current in the coil. They are called the **split ring commutator.**

Transformation of energy in a d.c. motor : In a d.c. motor, the electrical energy supplied by the battery to the coil is transferred to the mechanical energy which rotates the coil.

EXAMPLES

1. A rectangular coil ABCD having a battery connected between its ends A and D is placed in between the pole pieces of a horseshoe magnet as shown in Fig. 10.26.

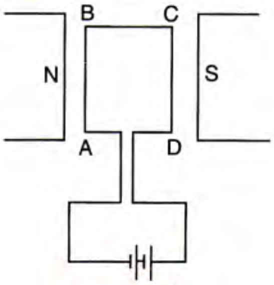


Fig. 10.26

(i) What is the direction of current in the coil ?

(ii) What is the direction of force on each arm ?

(iii) What is the effect of the forces on coil ?

(iv) How is the effect of forces on coil changed if the connections at the terminals of battery are interchanged ?

(i) In Fig. 10.26, the current in coil is in direction DCBA.

(ii) By Fleming's left hand rule, on the arm **AB**, the force is **outwards** normal to the plane of coil. On the arm **BC, no force** acts. On the arm **CD**, the force is **inwards** perpendicular to the plane of coil. On the arm **DA, no force** acts.

(iii) The forces on the arms AB and CD are equal in magnitude, but opposite in direction. They form a **clockwise couple**. So the coil rotates clockwise with the arm AB coming out and the arm CD going in.

(iv) On interchanging the connections at the terminals of battery, the direction of current in the coil is reversed, so the forces on the arms AB and CD of the coil also get reversed and the coil rotates **anticlockwise**.

2. Fig. 10.27 shows a rectangular coil ABCD placed in between the pole pieces of a horse-shoe magnet with its plane perpendicular to the magnetic field. A battery is connected between the ends A and D of the coil.

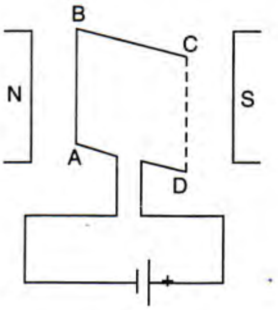


Fig. 10.27

(i) What is the direction of current in the coil ?

(ii) What is the direction of force on each arm of the coil ?

(iii) Will the coil rotate due to the forces on its arms ?

(i) In Fig. 10.27, the current in coil is in direction DCBA.

(ii) On the arm **AB**, the force is **outwards in the plane of coil** *i.e.*, away from the arm CD. On the arm **BC**, the force is **outwards in the plane of coil** *i.e.*, away from the arm AD. On the arm **CD**, the force is **outwards in the plane of coil** *i.e.*, away from the arm AB. On arm **DA**, the force is **outwards in the plane of coil** *i.e.*, away from the arm BC.

(iii) The coil will **not rotate** (because all the arms experience an outward pull) and no couple is formed.

3. State the function of split ring in a d.c. motor.

The split ring act as a **commutator** in a d.c. motor. With the split ring, the direction of current through the coil is reversed after each half rotation of coil and thus the direction of couple rotating the coil remains unchanged and the coil continues to rotate in the same direction.

4. A d.c. motor is rotating in a clockwise direction. How can its direction of rotation be reversed ?

The direction of rotation of motor can be reversed by **reversing the direction of current** in the coil *i.e.*, by interchanging the connections at the terminals of the battery joined to the brushes of the motor.

5. State with reason in a d.c. motor, the effect of (i) inserting a soft iron core within the coil, (ii) increasing the area of the coil, and (iii) increasing the strength of current in the coil.

(i) On inserting a soft iron core within the coil of a d.c. motor, the **speed of rotation of coil increases**. The reason is that on inserting the soft iron core in the coil, the strength of magnetic field between the pole pieces of magnet increases due to which the deflecting couple on the coil increases.

(ii) On increasing the area of coil, the deflecting couple on the coil increases, so the **speed of rotation of coil increases**.

(iii) By increasing the strength of current in the coil, the deflecting couple on the coil increases, so the **speed of rotation of the coil increases**.

EXERCISE–10(B)

1. Name *three* factors on which the magnitude of force on a current carrying conductor placed in a magnetic field depends and state how does the force depend on the factors stated by you.

Ans. (i) on strength of magnetic field B ($F \propto B$)
(ii) on current I in the conductor ($F \propto I$) and
(iii) on length l of conductor ($F \propto l$)

2. State condition in each case for the magnitude of force on a current carrying conductor placed in a magnetic field to be (a) zero, and (b) maximum.

Ans. (a) when current in conductor is in the direction of magnetic field.
(b) when current in conductor is normal to the magnetic field.

3. How will the direction of force be changed, if the current is reversed in the conductor placed in a magnetic field ? **Ans.** direction of force is reversed.

4. Name and state the law which is used to determine the direction of force on a current carrying conductor placed in a magnetic field.

5. State Fleming's left hand rule.

6. State the unit of magnetic field in terms of the force experienced by a current carrying conductor placed in a magnetic field.

Ans. newton / ampere × metre (or N A^{-1} m^{-1})

7. A flat coil ABCD is freely suspended between the poles of a U-shaped permanent magnet with the plane of coil parallel to the magnetic field.
(a) What happens when a current is passed in the coil ?
(b) When will the coil come to rest ?
(c) When will the couple acting on the coil be (i) maximum, and (ii) minimum ?
(d) Name an instrument which makes use of the principle stated above.

Ans. (a) the coil experiences a torque due to which it rotates.
(b) the coil will come to rest when its plane becomes normal to the magnetic field.
(c) (i) when the plane of coil is parallel to the magnetic field, (ii) when the plane of coil is normal to the magnetic field.
(d) d.c. motor.

8. A coil ABCD mounted on an axle is placed between the poles N and S of a permanent magnet as shown in Fig. 10.28.

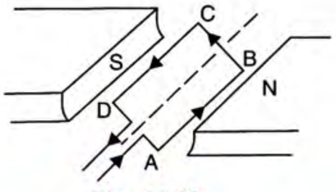


Fig. 10.28

(a) In which direction will the coil begin to rotate when current is passed through the coil in direction ABCD by connecting a battery between the ends A and D of the coil ?

(b) Why is a commutator necessary for the continuous rotation of coil ?

(c) Complete the diagram with commutator, etc. for the flow of current in the coil.

Ans. (a) anticolckwise (b) after half rotation, the arms AB and CD get interchanged, so the direction of torque on coil reverses. To keep the coil rotating in the same direction, a commutator is needed to reverse the direction of current in the coil after each half rotation of coil.

9. What is an electric motor ? State its principle.

10. Draw a labelled diagram of a d.c. motor showing its main parts.

11. What energy conversion does take place during the working of a d.c. motor ?

12. State *two* ways by which the speed of rotation of an electric motor can be increased.

13. Name *two* appliances in which an electric motor is used.

MULTIPLE CHOICE TYPE

1. In an electric motor, the energy transformation is :

(a) from electrical to chemical

(b) from chemical to light

(c) from mechanical to electrical

(d) from electrical to mechanical.

Ans. (d) from electrical to mechanical.

(C) ELECTROMAGNETIC INDUCTION AND ITS APPLICATIONS TO A.C. GENERATOR AND TRANSFORMER

10.13 ELECTROMAGNETIC INDUCTION

We have read that when an electric current is passed through a conductor, a magnetic field is produced around the conductor. Faraday thought since a magnetic field is produced by an electric current, it should be possible to produce an electric current by the magnetic field. He performed a number of experiments and observed that *whenever there is a change in the number of magnetic field lines linked with a conductor**, *an electromotive force (e.m.f.) is developed between the ends of the conductor which lasts as long as there is a change in the number of magnetic field lines*. This phenomenon is called the *electromagnetic induction*.

Demonstration of the phenomenon of electromagnetic induction

Experiment : Wind an insulated copper wire in form of a spiral on a paper (or wooden) cylinder so as to form a coil in the form of a solenoid. Connect a centre zero galvanometer G between the two ends of the solenoid. Then place a magnet NS at some distance, along the axis of solenoid as shown in Fig. 10.29.

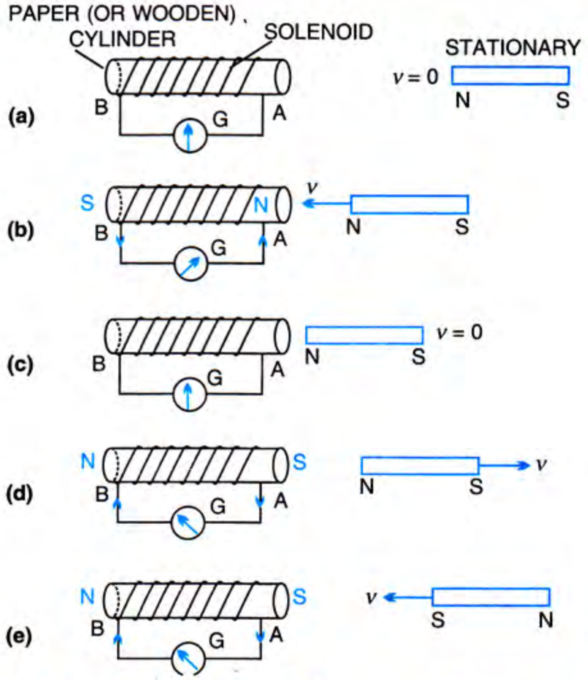


Fig. 10.29 Demonstration of electromagnetic induction

Observations : It is observed that

(1) When the magnet is stationary ($v = 0$), there is no deflection in galvanometer and its pointer reads zero [Fig. 10.29 (a)].

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* The number of magnetic field lines linked with a conductor is called the magnetic flux linked with it.

(2) When the magnet with its north pole facing the solenoid is moved towards it, the galvanometer shows a *deflection towards right* showing that a current flows in solenoid in the direction B to A as shown in Fig. 10.29 (b).

(3) As the motion of magnet is stopped, the pointer of galvanometer comes to zero position [Fig. 10.29 (c)]. This shows that *the current in solenoid flows as long as the magnet remains moving.*

(4) If the magnet is moved away from the solenoid, the pointer of galvanometer *deflects towards left* [Fig. 10.29 (d)] showing that the current in solenoid flows again, but now in direction A to B which is opposite to that shown in Fig. 10.29 (b).

(5) If the magnet is moved away rapidly, the deflection in the galvanometer increases although the direction of deflection remains same. It shows that now more current flows.

(6) If the magnet is brought towards the solenoid by keeping its south pole towards it, the pointer of galvanometer deflects towards left [Fig. 10.29 (e)] showing that the current in solenoid flows in direction A to B which is opposite to that shown in Fig. 10.29 (b).

Exactly similar observations are made in galvanometer if magnet is kept stationary and the solenoid is moved. It implies that *it is the relative motion between the solenoid and magnet which produces a current, irrespecitive of whether the magnet moves* or *the solenoid moves.*

Conclusions : From the above observations Faraday made the following *three* conclusions :

(1) *A current flows in the coil only when there is a relative motion between the coil and magnet.*

(2) *The direction of current is reversed if the direction of motion (or polarity of the magnet) is reversed.*

(3) *The current in the coil is increased*

  (i) *by the rapid motion of magnet (or coil),*

  (ii) *by the use of a strong magnet, and*

  (iii) *by increasing the area of cross section of coil and by increasing the number of turns in the coil.*

Faraday's explanation

When there is no relative motion between the magnet and coil, total number of magnetic field lines of the magnet passing through the coil (*i.e.*, the magnetic flux linked with the coil) remains constant, therefore no e.m.f. is induced in the coil and no current flows in it.

When there is a relative motion between the coil and magnet, magnetic flux linked with the coil changes. For example in Fig. 10.30, the coil is moved towards the north pole of magnet, so the magnetic flux through the coil increases. similarly if the coil is moved away from the north pole of magnet, the magnetic flux through the coil decreases. *Due to change in the magnetic flux linked with the coil, an e.m.f. is induced in the coil.* The induced e.m.f. causes a current to flow in the coil *if the circuit of coil is closed.* Thus,

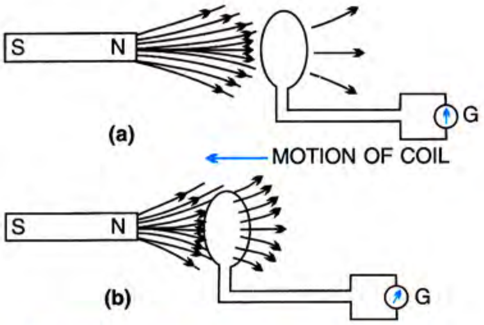


Fig. 10.30 Change of magnetic flux through a coil

> *Electromagnetic induction is the phenomenon in which an e.m.f. is induced in the coil if there is a change in the magnetic flux linked with the coil.*

In electromagnetic induction, the mechanical energy spent (i.e., the work done) in moving the coil or *the magnet, to change the magnetic flux* *is transformed into the electrical energy in the form of current in the coil.*

10.14 FARADAY'S LAWS OF ELECTRO-MAGNETIC INDUCTION

On the basis of the above experimental observations, Faraday formulated the following *two* laws of electromagnetic induction :

(1) *Whenever there is a change in magnetic flux linked with a coil, an e.m.f. is induced.* The e.m.f. induced lasts so long there is a change in magnetic flux linked with the coil.

(2) *The magnitude of e.m.f. induced is directly proportional to the rate of change of magnetic flux linked with the coil.* If magnetic flux changes at a constant rate, a steady e.m.f. is produced.

If the circuit of coil is closed, a current flows in it due to the e.m.f. induced across its ends.

Factors affecting the magnitude of induced e.m.f.

The magnitude of e.m.f. induced in a coil is equal to the product of rate of change of magnetic flux linked with each turn of the coil and the number of turns in the coil. *i.e.*,

$$\text{Induced e.m.f.} = \frac{\text{change in magnetic flux of each turn} \times \text{number of turns in the coil}}{\text{time in which the magnetic flux changes}} \quad ...(10.2)$$

Thus, for a given coil and magnet, it depends on the following *two* factors :

(1) on the rate of change of magnetic flux with each turn, and

(2) on the number of turns in the coil.

Direction of induced e.m.f.

The direction of induced e.m.f. (and hence the direction of induced current) depends on whether there is an increase or decrease in magnetic flux. It can be obtained by any of the following *two* rules : (1) *Fleming's right hand rule,* and (2) *Lenz's law.*

(1) Fleming's right hand rule

Stretch the thumb, central finger and forefinger of your right hand mutually perpendicular to each other as shown in Fig. 10.31. If the forefinger indicates the direction of magnetic field and the thumb indicates the direction of motion of the conductor, then the central finger will indicate the direction of induced current.

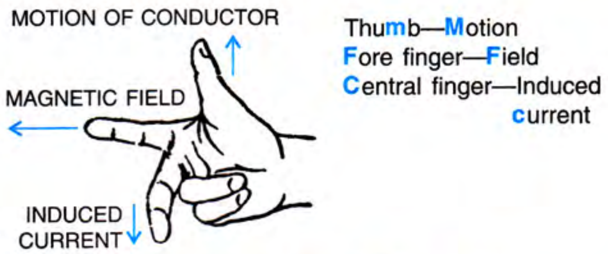


Fig. 10.31 Fleming's right hand rule

(2) Lenz's law

According to Lenz's law, *the direction of induced e.m.f. (or induced current) is such that it opposes the cause which produces it.*

In Fig. 10.29 (b), when north pole of the magnet is brought towards the end A of solenoid, the induced current flows in solenoid in direction B to A *i.e.*, at the end A, the current is anticlockwise, so the end A of solenoid becomes a north pole to repel the magnet. Thus it opposes the motion of north pole of magnet towards the solenoid which is the cause of producing it.

Similarly, in Fig. 10.29 (d), when north pole of magnet recedes from end A of the solenoid, the direction of induced current in the solenoid is from B to A *i.e.*, it is clockwise at the end A, and it becomes the south pole so as to oppose the motion of north pole of the magnet away from the solenoid which is the cause of producing it.

Lenz's law is based on the *law of conservation of energy.* It shows that the mechanical energy spent in doing work against the opposing force experienced by the moving magnet, is transformed into the electrical energy due to which current flows in the solenoid.

10.15 A.C. GENERATOR

We know the use of an a.c. generator in our house (or factory) as an alternative source of electricity when electric supply from mains is not available.

> *An a.c. generator is a device which converts the mechanical energy into the electrical energy using the principle of electromagnetic induction.*

Principle : In a generator, a coil is rotated in a magnetic field. Due to rotation, the magnetic flux linked with the coil changes and therefore an e.m.f. is induced between the ends of the coil. Thus a generator acts as a source of current in an external circuit containing load when it is joined between the ends of its coil.

Construction and its main parts : The basic construction of an a.c. generator is shown in Fig. 10.32.

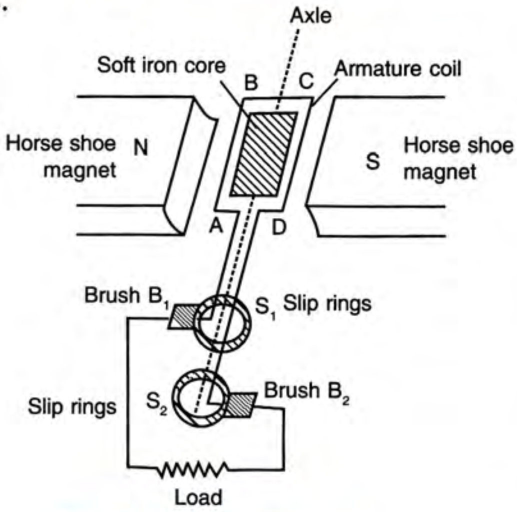


Fig. 10.32 A.C. generator

The main parts of an a.c. generator are :

(1) A horse shoe electromagnet NS,

(2) the armature coil ABCD,

(3) the slip rings S_1, S_2, and

(4) the brushes B_1, B_2.

(1) ***A horse shoe electromagnet NS :*** It is a strong magnet with poles N and S.

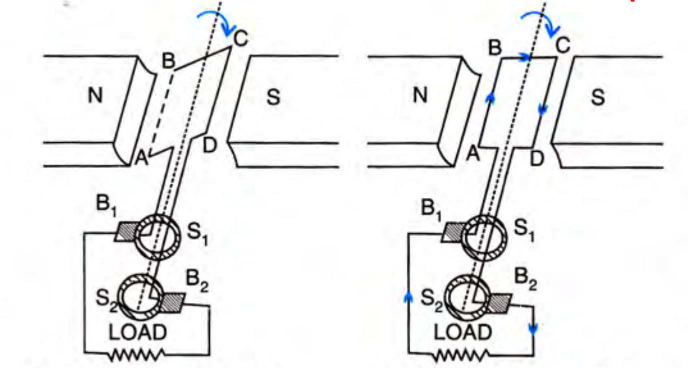
(2) ***Armature coil ABCD :*** There is a soft iron core on which a coil ABCD having a large number of turns of *insulated copper wire* is wound. The coil is rotated rapidly in the magnetic field between the poles of the field magnet, by an axle fixed to it.

(3) ***Slip rings S_1 and S_2 :*** There are *two* coaxial metallic rings S_1 and S_2 which rotate along with the coil. One end of the coil is connected to the slip ring S_1 and the other end of the coil is connected to the slip ring S_2. Each ring slips against a brush which is stationary

(4) ***Brushes B_1 and B_2 :*** There are *two* brushes B_1 and B_2 made of carbon, which press gently against the slip rings S_1 and S_2 respectively. The other ends of brushes act as terminals of the generator across which the external circuit containing load is connected. *The brushes* B_1 *and* B_2 *do not rotate along with the coil and the slip rings.*

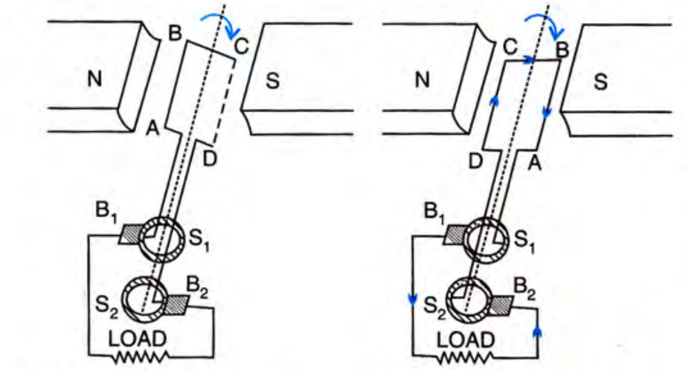
Working : The working of an a.c. generator is shown in Fig. 10.33. Let the magnetic field be in the plane of paper from north pole N to the south pole S. Initially let the plane of coil be perpendicular to the magnetic field (*i.e.*, $\theta = 0°$) so maximum magnetic field lines pass through the coil. In this position, the arm AB of coil is below the plane of paper, while the arm CD of coil is above the plane of paper as shown in Fig. 10.33(a). The end A of coil is connected to the slip ring S_1 and the end D to the slip ring S_2. The brush B_1 touches the slip ring S_1 and the brush B_2 touches the slip ring S_2. No e.m.f. is induced in the coil when it is at rest.

Let the coil be rotated clockwise by the handle attached to the axle. As the coil starts rotating, the magnetic flux through the coil decreases and therefore an e.m.f. is induced between the ends of coil due to which an induced current flows in the coil. By Fleming's right hand rule, the direction of induced current in coil is along ABCD. This is because when the coil rotates clockwise, the arm AB moves upwards (*i.e.*, from below to the plane of paper) so the induced current in the arm AB is from



(a) Plane of coil normal to magnetic field (initial position)

(b) Plane of coil parallel to magnetic field (after 90° rotation)



(c) Plane of coil normal to magnetic field (after 180° rotation)

(d) Plane of coil parallel to magnetic field (after 270° rotation)

Fig. 10.33 Working of a.c. generator

A to B, while in the arm CD which moves inwards (or from above into the plane of paper), the induced current is from C to D. Therefore in the external circuit, the current flows from the brush B_2 to the brush B_1 through the load. When the coil gets rotated by 90° (*i.e.*, the plane of coil becomes parallel to the magnetic field or $\theta = 90°$) as shown in Fig. 10.33(b), no magnetic field line passes through the coil, so the magnetic flux linked with coil becomes zero. At this instant, the e.m.f. induced in coil is *maximum* because the rate of change of magnetic flux is maximum at this instant.

On rotation of coil by 180°, the plane of coil again becomes normal to the magnetic field as shown in Fig. 10.33(c). Now the magnetic field lines passing through the coil becomes maximum. At this position of coil, the rate of change of magnetic flux is zero, therefore no e.m.f. is induced in the coil.

When the coil gets rotated further, the magnetic flux linked with the coil decreases and the e.m.f. again increases to the same maximum value, but in opposite direction. When the coil gets turned by 270° from its initial position as shown in Fig. 10.33(d), the e.m.f. induced in the coil is *maximum* because the rate of change of magnetic flux is again maximum at this instant. Now the arms of coil AB and CD have interchanged their position. As a result, an induced current flows in the coil in direction DCBA (*i.e.* in the external circuit from the brush B_1 to the brush B_2).

On further rotation of the coil, the induced e.m.f. reduces to zero and the magnetic flux linked with coil becomes maximum when the plane of coil gets rotated by 360° and becomes normal to the magnetic field as shown in Fig. 10.33(a).

Thus as the coil rotates in the magnetic field between the poles of field magnet, an induced e.m.f. is produced between the ends of the coil. The e.m.f. so produced between the ends of the coil changes its polarity as well as magnitude in each rotation of the coil, so it is called an *alternating e.m.f.* Due to this induced e.m.f., an alternating current flows in the external circuit connected between the brushes B_1 and B_2. The direction of current reverses after each half rotation of the coil.

Fig. 10.34 represents the variation in e.m.f. induced between the ends of coil with angle θ which the normal to the plane of coil makes with the magnetic field.

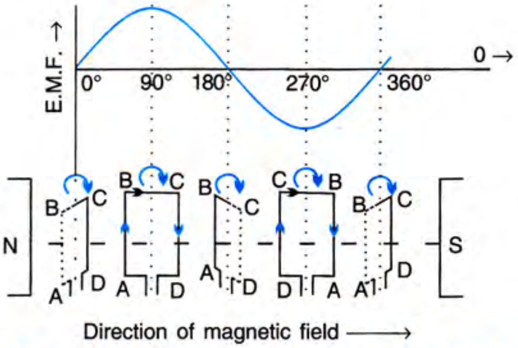


Fig. 10.34 Generation of e.m.f. in the coil

Note : **(1)** *The magnitude of induced e.m.f. becomes maximum when the magnetic flux linked with coil reduces to zero from its maximum value. This happens when the plane of coil lies in direction of the magnetic field.*

(2) *The induced e.m.f. becomes zero when the magnetic flux linked with coil is maximum. This happens when the plane of coil is normal to the magnetic field.*

Frequency of alternating current

In one complete rotation of coil, we get one cycle of alternating current in the external circuit. Thus *the alternating current has the frequency equal to the frequency of rotation of coil.*

If the coil makes n rotations per second, the magnitude of induced e.m.f. at any instant t is given as

$$\boxed{e = e_0 \sin 2\pi nt} \qquad ...(10.3)$$

and the current is expressed as

$$\boxed{i = i_0 \sin 2\pi nt} \qquad ...(10.4)$$

where e_0 and i_0 represent the maximum values of e.m.f. and current respectively*. The *alternating current* is abbraviated as a.c.

The maximum value e_0 of e.m.f. induced can be increased (1) by increasing the number of turns in coil, (2) by increasing the area of cross section of coil, and (3) by increasing the speed of rotation of coil.

Note : **(1)** By increasing the speed of rotation of coil, the frequency of a.c. generated will also increase, along with the increase in the maximum value e_0 of the induced e.m.f.

(2) The magnitude of alternating current changes continuously with time in a periodic manner.

10.16 FREQUENCY OF a.c. IN HOUCEHOLD SUPPLIES

In our houses, we have electric supply of frequency 50 Hz (n = 50 Hz) *i.e.*, the polarity at the supply terminal changes 100 times a second (50 times + and 50 times –).

Difference between the d.c. and a.c.

If a resistor is connected across the terminals of a battery, a current flows in the circuit, the magnitude of which remains constant and it always flows in a direction from positive terminal of the battery to its negative terminal. But if a resistor is connected at the output terminals of an a.c. generator (or mains in our house), the magnitude of current in resistor changes periodically (the current repeats its value after each time interval equal to $\frac{1}{50}$ s) and its direction also changes (it is in one direction for $\frac{1}{100}$ s and then in reverse direction for the next $\frac{1}{100}$ s).

A current of constant magnitude and unique direction, is called d.c., while a current changing its magnitude as well as direction periodically, is called a.c. A battery is a d.c. source, while the a.c. generator and mains are the a.c. sources.

DISTINCTION BETWEEN D.C. AND A.C.

Direct current (d.c.)	Alternating current (a.c.)
1. It is the current of constant magnitude.	1. It is the current of magnitude varying perodically with time.
2. It flows in one direction in the circuit.	2. It reverses its direction periodically while flowing in a circuit.
3. It is obtained from a cell (or battery).	3. It is obtained from an a.c. generator and mains.

Advantage of a.c. over d.c.

In India, we use 220 volt a.c. in our houses and factories. The use of a.c. is advantageous over d.c. because only the voltage of a.c. can be increased by the use of step up transformer at the power generating station and then can be decreased by the use of step down transformer for transmission in the city. It reduces the loss of

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* $e_0 = 2\pi nBAN$ where B = strength of magnetic field, A = area of cross section of coil, N = number of turns in coil, and n = number of rotations of coil per second. $i_0 = e_0/R$ if R is the resistance of load connected in the external circuit.

electrical energy as heat in the transmission line wires. If d.c. is generated at the power generating station, its voltage cannot be increased for transmission, and so due to passage of high current in the transmission line wires, there will be a huge loss of electrical energy as heat in the line wires.

10.17 DISTINCTION BETWEEN AN A.C. GENERATOR AND D.C. MOTOR

A.C. generator	D.C. motor
1. A generator is a device which converts the mechanical energy into the electrical energy.	1. A d.c. motor is a device which converts the electrical energy into the mechanical energy.
2. A generator works on the principle of electro-magnetic induction.	2. A d.c. motor works on the principle of force acting on a current carrying conductor placed in a magnetic field.
3. In a generator, the coil is rotated in a magnetic field so as to produce an electric current.	3. In a d.c. motor, the current from a d.c. source flows in the coil placed in a magnetic field due to which the coil rotates.
4. A generator makes use of two separate coaxial slip rings.	4. A d.c. motor makes use of two parts of a slip ring (*i.e.*, split ring) which acts as a commutator.

Similarities between an A.C. generator and a D.C. motor

(1) Both in an a.c. generator and d.c. motor, a coil rotates in a magnetic field between the pole pieces of a powerful electromagnet.

(2) Both in an a.c. generator and d.c. motor, there is a transformation of energy from one form to the other form.

10.18 TRANSFORMER

In our daily life, we use various electrical appliances which require working voltage different from the voltage of mains (*i.e.*, 220 V) *e.g.* a door bell needs 6 V, while the cathode ray tube in a television needs nearly 10,000 V. To provide suitable voltage to different appliances from the mains, we use transformers with them. Thus,

> *Transformer is a device by which the magnitude of an alternating e.m.f. can be increased or decreased.*

A transformer does not affect the frequency of the alternating voltage. The frequency remains unchanged (= 50 Hz).

Principle : *A transformer works on the principle of electromagnetic induction* and makes use of *two* coils having different number of turns. The two coils are : (1) the primary coil, and (2) the secondary coil. The given alternating e.m.f., of which magnitude is to be changed, is applied across the *primary coil* and the appliance in which output is to be obtained is connected across the secondary coil. When there is a change in the magnetic field lines due to varying current in the primary coil, the number of magnetic field lines linked with the secondary coil changes and so an induced varying current of same frequency, but of different magnitude flows in the *secondary coil.*

A transformer cannot be used with the direct current (d.c.) source because if current in primary coil is constant (*i.e.*, d.c.), then there will be no change in the number of magnetic field lines linked with the secondary coil and hence no e.m.f. will be induced in the secondary coil.

Construction : A transformer consists of a rectangular soft iron core made up from the thin laminated sheets of soft iron of T and U shape, placed alternately one above the other and insulated from each other by a paint (or varnish) coating over them as shown in Fig. 10.35. This forms a simple rectangular core.

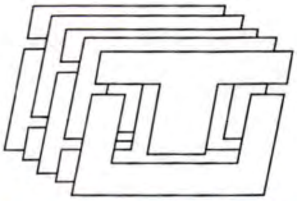

Fig. 10.35 Laminated iron core

On one arm of the core, the *primary coil* P of insulated copper wire is wound. This coil is connected with the source of alternating e.m.f. (*i.e.,* at the ends of this coil, the *input* is given). On the other arm of the core, secondary coil S of insulated copper wire is wound. The induced alternating e.m.f. is obtained across the terminals of this coil (*i.e., output* is obtained at the ends of this coil). The ratio of number of turns N_s in secondary coil to the number of turns N_p in primary coil (*i.e.,* N_s / N_p) is called the *turns ratio. i.e.,*

$$\text{Turns ratio } n = \frac{\text{number of turns in secondary coil } N_s}{\text{number of turns in primary coil } N_p} \qquad \text{....(10.5)}$$

Note : **(1)** *The laminated core prevents the loss of energy due to induced (or eddy) currents in the core.* **(2)** The advantage of using a closed core is that it gives a closed path for the magnetic field lines and therefore almost all the magnetic field lines, caused due to current in the primary coil, remain linked with the secondary coil (*i.e.,* the flux linkage is nearly perfect) and loss of energy is avoided. **(3)** *The core is made of soft iron (or hysteresis) so that the loss of energy in the core gets minimised.*

Working : When the terminals of primary coil are connected to the source of alternating e.m.f., a varying current flows through the primary coil. This varying current produces a varying magnetic field in the core of transformer. Thus the number of magnetic field lines linked with the secondary coil vary due to which an e.m.f. induces in it. The induced e.m.f. varies in the same manner as the applied e.m.f. in the primary coil varies and thus has the same frequency as that of the applied e.m.f.

For a transformer,

$$\frac{\text{e.m.f. across the secondary coil } (E_S)}{\text{e.m.f. across the primary coil } (E_P)} = \frac{\text{number of turns in the secondary coil } (N_S)}{\text{number of turns in the primary coil } (N_P)}$$

or

$$\frac{E_s}{E_p} = \frac{N_s}{N_p} = \text{turns ratio } n \qquad \text{...(10.6)}$$

$$\text{i.e., } E_s = E_p \times \text{turns ratio } n$$

Thus the magnitude of e.m.f. induced in the secondary coil depends on the following *two* factors :

(1) *the ratio of the number of turns in the secondary coil to the number of turns in the primary coil (i.e., turns ratio), and*

(2) *the magnitude of e.m.f. applied in the primary coil.*

For *an ideal transformer*, when there is no energy loss, the output power will be equal to the input power. *i.e.,*

power in secondary coil = power in primary coil

or

$$E_s I_s = E_p I_p \qquad \text{...(10.7)}$$

But $\frac{E_S}{E_P} = \frac{N_S}{N_P}$

$$\therefore \frac{I_P}{I_S} = \frac{E_S}{E_P} = \frac{N_S}{N_P} \qquad \text{...(10.8)}$$

Types of transformers : There are *two* types of transformers : (1) step up transformer, and (2) step down transformer.

(1) Step up transformer : The transformer used to change a low alternating voltage to a high alternating voltage (of same frequency) is called a step up transformer (*i.e.,* $E_S > E_P$). *In a step up transformer, the number of turns in the secondary coil is more than the number of turns in the primary coil* ($N_s > N_p$) *i.e., turns ratio n* > 1 as shown in Fig. 10.36. Since current in primary coil is

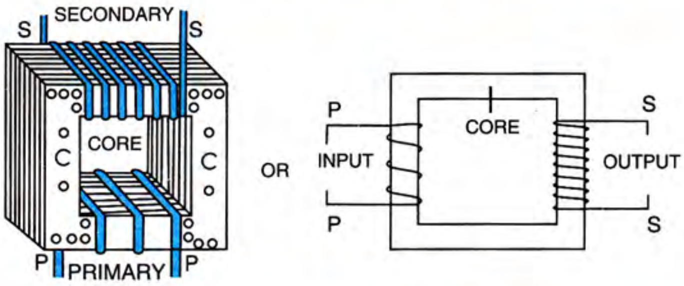

Fig. 10.36 Step up and step down transformers

more than in secondary coil (or $I_P > I_S$), so the wire in the primary coil is thicker than in the secondary coil.

(2) **Step down transformer :** The transformer used to change a high alternating voltage to a low alternating voltage (of same frequency) is called a step down transformer ($E_S < E_P$). *In a step down transformer, the number of turns in the secondary coil are less than the number of turns in the primary coil* ($N_s < N_p$) *i.e.*, turns ratio $n < 1$ as shown in Fig. 10.37. Since current in secondary coil is more than in the primary coil (*i.e.*, $I_S > I_P$) so *the wire in secondary coil is thicker than in the primary coil.*

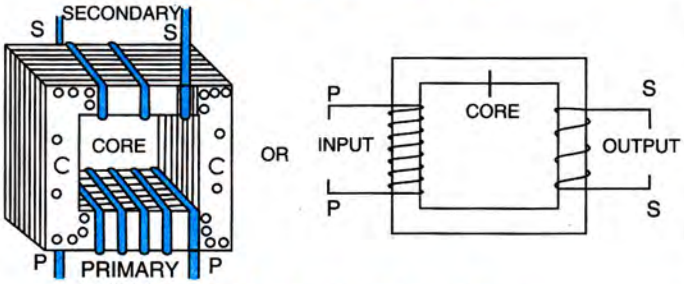

Fig. 10.37 Step down transformer

> ***Note :*** The use of thicker wire in a coil reduces its resistance and therefore reduces the loss of energy as heat in that coil (This energy loss due to heat is known as *copper loss*).

Examples : **(1)** If we want to transmit 1·1 kW, 220 V electric power at 11 kV, we use a step up transformer which will step up E_p = 220 V to E_s = 11 kV (= 11000 V). The turns ratio for this transformer will be

$$n = \frac{N_S}{N_P} = \frac{E_S}{E_P} = \frac{11000}{220} = \frac{50}{1}$$

i.e., the number of turns in the secondary coil will be 50 times that of the primary coil. The current in primary coil will be $I_p = \frac{P}{V} = \frac{1{\cdot}1 \times 1000\,\text{W}}{220\,\text{V}} = 5$ A while for the same output power (= 1·1 kW), current in secondary coil will be $I_s = \frac{1{\cdot}1 \times 1000\,\text{W}}{11 \times 1000\,\text{V}} = 0{\cdot}1$ A. Hence the primary winding has to be of a thicker wire as compared to that of the secondary winding to reduce the heat (or copper) loss.

(2) If we want to run a 6 W, 12 V bulb with our mains supply of 240 V, we use a step down transformer which will step down E_p = 240 V to E_s = 12 V. The turns ratio for this transformer will be

$$n = \frac{N_S}{N_P} = \frac{E_S}{E_P} = \frac{12}{240} = \frac{1}{20}$$

i.e., the number of turns in the secondary coil will be one-twentieth of that in the primary coil. Further as the output power is 6 W, the input power will also be 6 W. Therefore current in primary coil is $I_p = \frac{6\,\text{W}}{240\,\text{V}} = 0{\cdot}025$ A = 25 mA, while current in secondary coil will be $I_s = \frac{6\,\text{W}}{12\,\text{V}} = 0{\cdot}5$ A. Hence the secondary winding has to be of a thicker wire as compared to that of the primary winding to reduce the heat (or copper) loss.

Uses of transformers : In our houses, both type of transformers are used with electrical appliances which operate at a voltage other than the voltage supplied by the mains (e.g., a door bell needs 6 V, while a T.V. requires nearly 10,000 V).

(A) *Uses of step up transformers* :

(1) In transmission of electric power at the power generating station to step up the voltage.

(2) With television.

(3) With wireless sets.

(4) With X-ray tubes to provide a high accelerating voltage.

(B) *Uses of step down transformers* :

(1) With electric bells, night electric bulbs, mobile phones, computers, etc.

(2) At the power sub-stations to step down the voltage before its distribution to the consumers.

Distinction between the step up and step down transformers

Step up transformer	Step down transformer
1. It increases the a.c. voltage and decreases the current. *i.e.*, $E_s > E_p$ and $I_s < I_p$.	1. It decreases the a.c. voltage and increases the current. *i.e.*, $E_s < E_p$ and $I_s > I_p$.
2. The turns ratio $N_s/N_p > 1$ *i.e.*, it has more number of turns in the secondary coil than in the primary coil.	2. Its turns ratio $N_s/N_p < 1$ *i.e.*, it has less number of turns in the secondary coil than in the primary coil.
3. The wire of primary coil is thicker than that of the secondary coil.	3. The wire of the secondary coil is thicker than that of the primary coil.
Uses : At power generating station, with X-ray tubes, television, etc.	**Uses :** At power substations, with night electric bulbs, computers, electric bells, etc.

EXAMPLES

1. Fig. 10.38 shows a coil AB connected to a centre zero galvanometer G and a magnet NS.

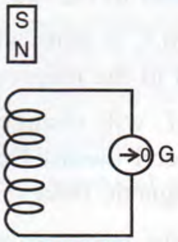

Fig. 10.38

(i) What will you observe when : (a) the magnet is inserted into the coil, (b) the magnet is taken out of the coil ?

(ii) How will your observation in part (i) change if the number of turns in the coil is increased ?

(iii) State the direction of current in the coil in part (i) (a).

(iv) State the law by which you arrived to the answer in part (iii).

(i) (a) As the magnet enters the coil, a **momentary deflection** is observed in the galvanometer so long the magnetic field lines linked with the coil increases. As the magnet completely enters inside the coil, the deflection becomes zero.

(b) On taking the magnet out of the coil, again a **momentary deflection** is observed in the galvanometer in a direction opposite to that in part (a) above. The deflection lasts so long as the magnetic field lines linked with the coil decreases.

(ii) On increasing the number of turns in the coil, the deflection observed in part (i) will **increase**.

(iii) In part (i) (a), the current in coil will be from A to B (*i.e.* **anticlockwise** as seen from above, so that the end of the coil near the N pole of the magnet becomes the north pole).

(iv) According to **Lenz's law**, the current induced in the coil is such that it opposes the cause of its origin.

2. Two coils P and Q are placed as shown in Fig. 10.39. The coil A is connected to a battery B and a key K, while the coil Q is connected to a centre zero galvanometer G.

What will you observe in the galvanometer G when

(i) the key K is closed ?

(ii) the key K is opened ?

(iii) with the key K closed, the coil P is moved rapidly towards the coil Q ?

(iv) with the key K closed, the coil Q is moved rapidly towards the coil P ?

(v) with the key K closed, the coils P and Q are moved away from each other ?

(vi) with the key K closed, the coils P and Q are moved with the same speed in same direction ?

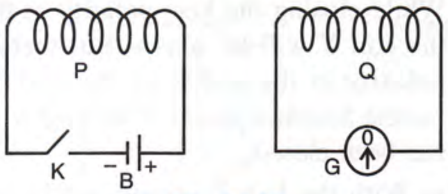

Fig. 10.39

(i) As the key K is closed, the galvanometer needle **deflects for a moment** and then returns to zero.

(ii) As the key K is opened, again a **momentary deflection (but more)** is observed in the galvanometer in the opposite direction.

(iii) With the key K closed, if the coil P is moved rapidly towards the coil Q, a **deflection** is obtained in the galvanometer in the direction same as in case (i). But the deflection lasts so long as the coil P moves.

(iv) With the key K closed, if the coil Q is moved rapidly towards the coil P, again a deflection is observed in the galvanometer in direction **same** as in case (i). The deflection lasts so long as the coil Q moves.

(v) With the key K closed, if the coils P and Q are moved away from each other, a **deflection** is obtained in the galvanometer in direction same as in case (ii). The deflection lasts so long as there is relative motion between the coils.

(vi) With the key K closed, if the coils P and Q are moved with the same speed in the same direction, there is **no deflection** in the galvanometer.

3. The diagram in Fig. 10.40 shows two coils X and Y. The coil X is connected to a battery B and a key K. The coil Y is connected to a galvanometer G.

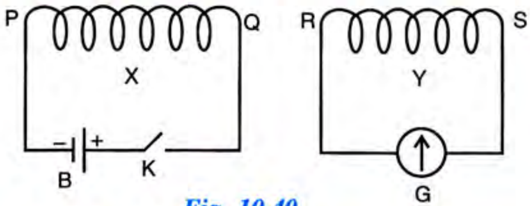

Fig. 10.40

When the key K is closed, state the polarity

(i) at the end Q of the coil X,

(ii) at the end R of the coil Y,

(iii) at the end R of the coil Y if the coil Y is (a) moved towards the coil X, (b) moved away from the coil X.

(i) On closing the key K, the current at the end Q of the coil X is anticlockwise, therefore at this end there is a **north pole**.

(ii) While closing the key, polarity at the end R of the coil Y will be **north**. But there will be no polarity at the end R of the coil Y when the current becomes steady in the coil X after the key has been closed.

(iii)(a) With the key K closed, while the coil Y is moved towards the coil X, the polarity at the end R of the coil Y is **north**.

(b) With the key K closed, while the coil Y is moved away from the coil X, the polarity at the end R of the coil Y is **south**.

4. A coil has 50 turns and the magnetic flux linked with the coil increases by 0·5 weber in 10·0 s. Calcualte the e.m.f. induced in the coil.

Given : increase in magnetic flux = 0·5 weber, time $t = 10{\cdot}0$ s, $N = 50$.

e.m.f. induced e

$$= N \times \text{rate of increase of magnetic flux}$$

$$= 50 \times \frac{0{\cdot}5}{10{\cdot}0} = \mathbf{0{\cdot}25\ V}$$

5. A flat rectangular coil is rotated between the pole pieces of a horse-shoe magnet. (a) In which position of coil with respect to the magnetic field, will the e.m.f. be (i) maximum, and (ii) zero. (b) When does the e.m.f. change its direction ?

(a) (i) The e.m.f. is maximum when the plane of coil is **parallel** to the magnetic field.

(ii) The e.m.f. is zero when the plane of coil is **normal** to the magnetic field.

(b) The e.m.f. will change its direction when the plane of coil **passes from the position normal** to the magnetic field.

6. (i) Name the principle on which a transformer works.

(ii) What is the function of a step up transformer ?

(iii) Draw a simple labelled diagram of a step down transformer.

(iv) Can a transformer work when it is connected to a d.c. source ? Give a reason.

(v) Draw a simple labelled diagram of a step up transformer.

(i) A transformer works on the principle of **electromagnetic induction**.

(ii) The function of a step up transformer is to convert a **low a.c. voltage to a high a.c. voltage**.

(iii) Fig 10.41 shows a simple labelled diagram of a step down transformer.

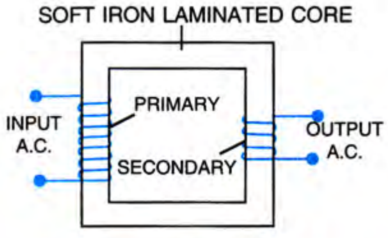

Fig. 10.41 Step down transformer

(iv) No. A transformer **cannot work** when it is connected to a d.c. source because there will then be no change in the magnetic flux linked with the secondary coil.

(v) Fig 10.42 shows a simple labelled diagram of a step up transformer.

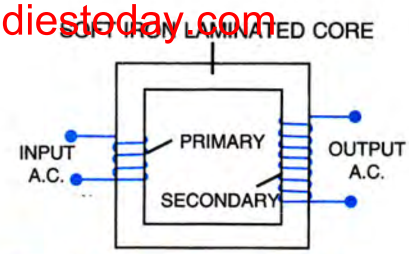

Fig. 10.42 Step up transformer

EXERCISE–10(C)

1. (a) What is electromagnetic induction ?

(b) Describe *one* experiment to demonstrate the phenomenon of electromagnetic induction.

2. State Faraday's laws of electromagnetic induction.

3. State *two* factors on which the magnitude of induced e.m.f. in a coil depend.

Ans. (i) rate of change in magnetic flux with each turn of coil, (ii) the number of turns in the coil.

4. (a) What kind of energy change takes place when a magnet is moved towards a coil having a galvanometer between its ends ?

(b) Name the phenomenon.

Ans. (a) mechanical energy changes to the electrical energy.
(b) electromagnetic induction.

5. (a) How would you demonstrate that a momentary current can be obtained by the suitable use of a magnet, a coil of wire and a galvanometer ?

(b) What is the source of energy associated with the current obtained in part (a) ?

Ans. (a) by moving the magnet towards the coil connected to the galvanometer (b) mechanical energy spent in moving the magnet towards the coil.

6. (a) Describe briefly *one* way of producing an induced e.m.f.

(b) State *one* factor that determines the magnitude of induced e.m.f. in part (a) above.

(c) What factor determines the direction of induced e.m.f. in part (a) above ?

7. Complete the following sentence :
The current is induced in a closed circuit only if there is ....

Ans. change in number of magnetic field lines linked with the circuit.

8. In which of the following cases e.m.f. is induced ?

(i) A current is started in a wire held near a loop of wire.

(ii) The current is switched off in a wire held near a loop of wire.

(iii) A magnet is moved through a loop of wire.

(iv) A loop of wire is held near a magnet.

Ans. In cases (i), (ii) and (iii)

9. A conductor is moved in a varying magnetic field. Name the law which determines the direction of current induced in the conductor.

Ans. Fleming's right hand rule

10. State Fleming's right hand rule.

11. What is Lenz's law ?

12. Why does it beocme more difficult to move a magnet towards a coil when the number of turns in a coil have been increased ?

(**Hint :** e.m.f. induced in the coil becomes more when the number of turns in the coil are increased. The e.m.f. induced opposes the motion of the magnet towards the coil).

13. Explain why an induced current must flow in such a direction so as to oppose the change producing it.

Ans. so that some mechanical energy is spent in producing the change, which changes into the electrical energy in form of the induced current.

14. Explain how does the Lenz's law show the conservation of energy in the phenomenon of electromagnetic induction.

15. The diagram in Fig.10.43 shows a coil of several turns of copper wire near a magnet NS. The coil is moved in the direction of arrow shown in the diagram.

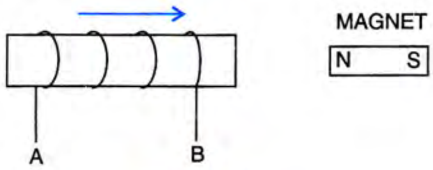

Fig. 10.43

(i) In what direction does the induced current flow in the coil ?

(ii) Name the law used to arrive at the conclusion in part (i).

(iii) How would the current in coil be altered if (a) the coil has twice the number of turns, (b) the coil was made to move *three* times fast ?

Ans. (i) A to B, (ii) Lenz's law (iii) (a) current becomes twice (b) current becomes thrice.

16. The diagram in Fig. 10.44 shows a fixed coil of several turns connected to a centre zero galvanometer G and a magnet NS which can move in the direction shown in the diagram.

(a) Describe the observation in the galvanometer if (i) the magnet is moved rapidly, (ii) the magnet is kept stationary after it has moved into the coil, (iii) the magnet is then rapidly pulled out of the coil.

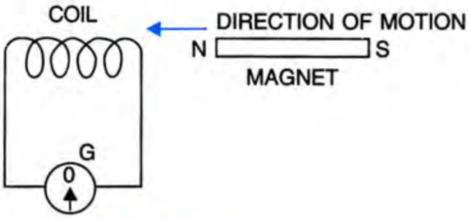

Fig. 10.44

(b) How would the observation in (i) of part (a) change if a more powerful magnet is used ?

Ans. (a) (i) a deflection is observed in the galvanometer towards the right, (ii) the deflection becomes zero, (iii) the deflection again occurs in opposite direction. (b) the deflection is increased.

17. The diagram in Fig. 10.45 shows a coil X connected to a sensitive centre-zero galvanometer G and a coil Y connected to a battery through a switch S.

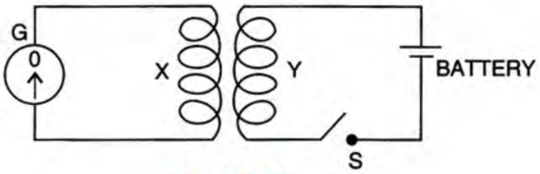

Fig. 10.45

(a) Describe the observation when the switch S is (i) closed suddenly, (ii) then kept closed, and (iii) finally opened.

(b) Name and state the law which explains the above observations.

18. Name and state the principle of a simple a.c. generator. What is its use ?

19. What determines the frequency of a.c. produced in a generator ?

Ans. the number of rotations of the coil in one second (or the speed of rotation of the coil).

20. Draw a labelled diagram of a simple a.c. generator.

21. In an a.c. generator, the speed at which the coil rotates is doubled. How would this affect (a) the frequency of the output voltage, (b) the maximum output voltage.

Ans. (a) frequency is doubled (b) maximum output voltage is doubled.

22. State *two* ways to produce a higher e.m.f. in an a.c. generator.

Ans. (i) by increasing the speed of rotation of coil, (ii) by increasing the number of turns in the coil.

23. What energy conversion does take place in a generator when it is in use ?

Ans. the mechanical energy changes into the electrical energy.

24. State (i) *two* dis-similarities, and (ii) *two* similarities between a d.c. motor and an a.c. generator.

25. State *one* advantage of using an a.c. over the d.c..

26. For what purpose are the transformers used ? Can they be used with a direct current source ?

Ans. to step up or step down the a.c. voltage. No, a transformer cannot be used with a d.c. source.

27. State *two* factors on which the magnitude of an induced e.m.f. in the secondary coil of a transformer depends.

Ans. (i) turns ratio, and (ii) the input voltage

28. How are the e.m.f. in the primary and secondary coils of a transformer related with the number of turns in these coils ?

Ans. (b) $E_s / E_p = N_s / N_p$

29. Draw a labelled diagram to show the various components of a step up transformer.

30. Name the device used to transform 12 V a.c. to 200 V a.c. Name the principle on which it works.

Ans. step up transformer, electromagnetic induction

31. Draw a labelled diagram of a step up transformer and explain how does it work. State *two* characteristics of the primary coil as compared to its secondary coil.

32. Draw a labelled diagram of a device you would use to transform 200 V a.c. to 15 V a.c. Name the device and explain how does it work. Give its *two* uses.

33. Name the coil of which the wire is thicker in a (i) step up, (ii) step down transformer. Give reason to your answer.

34. (a) Complete the following diagram in Fig. 10.46 of a transformer and name the parts labelled A and B.

(b) Name the part you have drawn to complete the diagram in part (a).

(c) What is the material of the part named above ?

(d) Is this transformer a step-up or stepdown ? Give reason.

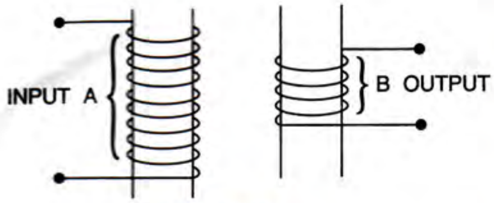

Fig. 10.46

35. The diagram in Fig. 10.47 shows the core of a transformer and its input and output connections.

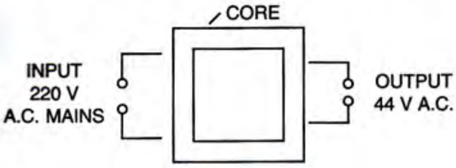

Fig. 10.47

(a) State the material used for the core and describe its structure.

(b) Complete the diagram of the transformer and connections by labelling all parts joined by you.

(c) Name the transformer : step up or step down ?

36. The out put current of a transformer in which the voltage is *stepped down* is usually higher than the input current. Explain why.

37. Why is the iron core of a transformer made *laminated* (thin sheets) instead of being in one solid piece ?

Ans. to reduce the energy losses due to eddy currents.

38. Complete the following sentences :

(i) In a step up transformer, the number of turns in the primary are .... than the number of turns in the secondary.

(ii) The transformer is used in .... current circuits.

(iii) In a tranformer, the frequency of a.c. voltage .... (increase/decreases/remains same)

Ans. (i) less (ii) alternating (iii) remains same

39. How do the input and output powers in a transformer compare ? State the assumption made.

40. Name *one* kind of energy loss in a transformer. How is it minimised ?

41. Give *two* points of difference between a step up and a step down transformer.

42. Name the material of the core in (a) an electric bell, (b) electromagnet, (c) a d.c. motor, (d) an a.c. generator, and (e) a transformer.

Ans. soft iron in each

43. Name the tranformer used in the (i) power generating station, (ii) power sub-station.

State the function of each transfomer.

MULTIPLE CHOICE TYPE

1. The direction of induced current is obtained by :

(a) Fleming's left hand rule

(b) Clock rule

(c) Right hand thumb rule

(d) Fleming's right hand rule.

Ans. (d) Fleming's right hand rule.

2. In a step up transformer :

(a) $N_s = N_p$ (b) $N_s < N_p$

(c) $N_s > N_p$ (d) nothing can be said.

Ans. (c) $N_s > N_p$

NUMERICALS

1. The magnetic flux through a coil having 100 turns decreases from 5 milli weber to zero in 5 second. Calculate the e.m.f. induced in the coil.

Ans. 100 mV

2. The primary coil of a transformer has 800 turns and the secondary coil has 8 turns. It is connected to a 220 V a.c. supply. What will be the output voltage ? **Ans.** 2·2 volt

3. A transformer is designed to give a supply of 8 V to ring a house-bell from the 240 V a.c. mains. The primary coil has 4800 turns. How many turns will be in the secondary coil ?

Ans. 160

4. The input and output voltages of a transformer are 220 V and 44 V respectively. Find : (a) the turns ratio, (b) the current in input circuit if the output current is 2 A. **Ans.** (a) 1 : 5 (b) 0·4 A