



We are familiar with bar magnet and magnetic compass. Any magnet has two poles at its ends. They are north pole and south pole, irrespective of shape. A magnetic compass needle is a very light needle-shaped magnet being pivoted at its centre and free to rotate about the pivot in a horizontal plane. The needle is enclosed in a small case with a fixed glass cover. When no magnet is around the magnetic needle it sets parallel to the south-north direction of the earth. When two magnets are kept close to each other they exert forces on each other, due to the magnetic field created around. Such magnetic field can also be produced by a current carrying conductor. In this chapter you shall study about the fields due to bar magnet and current carrying conductor along with the principle of an electric motor.

9.1 Magnetic Field and Lines of Force

When there is no magnet or magnetic material in the vicinity of a magnetic compass needle, the needle stays parallel to the south-north direction of the earth. If a magnet is brought close to the needle, it deflects in general. This is because the magnet produces a magnetic field and this field exerts a deflecting force on the needle. The direction of the needle from its south pole to the north pole gives the direction of the magnetic field produced by the magnet.

In order to study the above phenomenon you can take up the following Activity.

Activity 9.1

Take a bar magnet, a magnetic compass needle, a white sheet of paper, a wooden board and some drawing pins. Place the magnetic compass on the sheet of paper fixed on the board with the help of drawing pins. Remove any magnet or magnetic material far away from the board. Now, note the position of the magnetic needle as shown in Figure 9.1. Again, suspend the bar magnet from an unspun cotton thread to its middle. The other end of the thread is tied to a stand as shown in Figure 9.2.

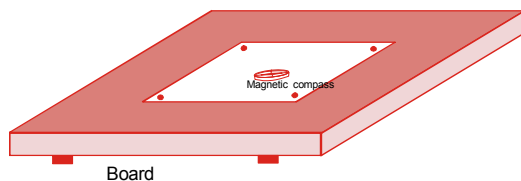


Figure 9.1 *A compass needle on the board*

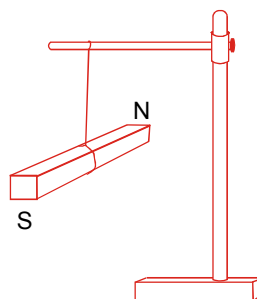


Figure 9.2 *A suspended bar magnet*

Mark the direction in which it comes to rest. Turn the magnet gently by your hand to point it in another direction and leave it. Notice, the direction in which it finally settles. The tip of the bar magnet which points towards the north is its north pole while the tip that points towards south is its south pole.

1. A freely suspended magnet always points in the south-north direction, (directive property).
2. A magnet always attracts substances like iron, steel, cobalt, nickel, (attractive property).
3. Like magnetic poles repel each other but unlike magnetic poles attract each other.
4. Magnetic poles always exist in pairs (magnetic monopole does not exist).
5. The region surrounding a magnet in which the magnetic force can be detected is called its magnetic field.

Activity 9.2

Place a compass needle close to the north pole. Mark the position of the north pole of the needle. Shift the compass needle so that its south pole falls at the same point where its north-pole was situated in the previous positions, as shown in Figure 9.3. Again, mark the position of the north pole of the needle.

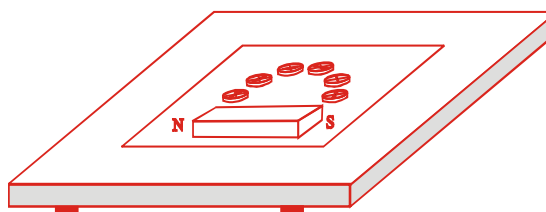


Figure 9.3

Repeat the procedure till the needle reaches near the south pole of the bar magnet. You will see that the deflection of the needle increases as the needle is nearer to the poles.

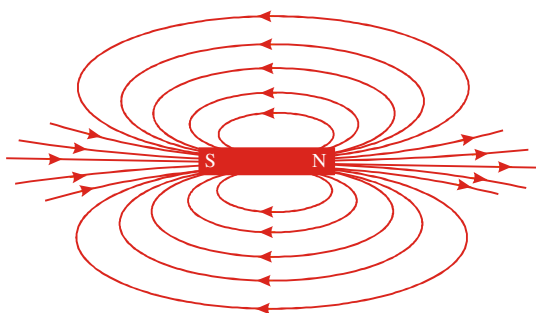


Figure 9.4

Now connect the marked points using a pencil. A closed curve is obtained [It represents a magnetic line of force]. A number of lines of force due to the bar magnet shown in Figure 9.4. No two field-lines are found to cross each other. If they cross, the compass needle would point towards two directions at the point of crossing each other – which is not possible.

A magnetic line of force is used to indicate the direction of the magnetic field. The field at any point is along the tangent to the line of force at that point.

The magnetic lines of force can also be obtained without using a compass needle. Take a glass plate with a bar magnet as shown in Figure 9.5

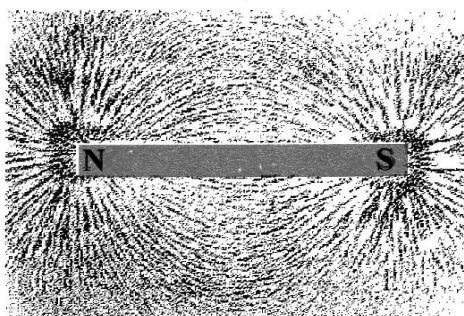


Figure 9.5

Sprinkle iron filings on the glass plate and then gently tap the plate with your finger. You will observe the iron filings arranging themselves in a regular pattern, as shown in the same figure. This regular pattern shows the magnetic lines of force due to the magnet. The relative strength of the magnetic field is shown by the degree of closeness of the field lines, being closer in the stronger regions near the poles.

9.2 Magnetic Field produced by Current Carrying Wire

Does an electric current carrying wire behave like a magnet or produce a magnetic field? Let us perform the following Activity to answer the above questions.

Activity 9.3

Take a straight copper wire XY in an electric circuit as shown in Figure 9.6. The position of the wire XY is set parallel to the needle of the magnetic compass.

Now, pass the electric current through the circuit by inserting key into the plug key. Observe the change in the position of the needle of the magnetic compass. Also observe the position of the needle in the compass after removing the key from the plug.

We see that the needle is deflected when the current is made to pass through the circuit and it returns to the earlier position when the current is cut off. What does it mean? It means that the electric current through the copper wire produces a magnetic field. In other words a current carrying conductor behaves as a magnet. This is called magnetic effect of electric current or electromagnetism. Here we shall study about electromagnetism and electric motors which involves the magnetic effect of electric current.

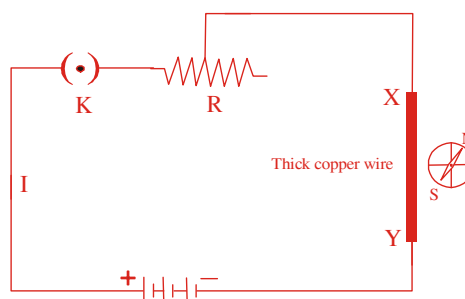


Figure 9.6 Compass needle is deflected on passing current through a metallic conductor

*Hans Christian Oersted, Danish Physicist, in 1820 accidentally discovered that a compass needle placed in parallel and close to a metallic wire carrying electric current got deflected. Through this observation Oersted showed that electricity and magnetism are related phenomena. His research work later created technologies such as electric motor, radio, television etc. The unit of magnetic field strength is named **oersted** in honour of him.*

Repeat the Activity 9.3, by varying the amount of electric current with the help of rheostat 'R'. You will observe that the amount of deflection of needle also changes; being larger with the increase of current through the circuit and vice-versa.

9.3 Magnetic Field due to a Straight Conductor Carrying Current

In order to find the direction of the magnetic field produced by a straight conductor carrying current, let us take up the following Activity.

Activity 9.4

Take a long copper wire, a battery of two or three cells of 1.5 V each and a plug key. Connect accordingly as shown in the Figure 9.7(a).

Adjust the position of the copper wire parallel to and above the needle of the magnetic compass.

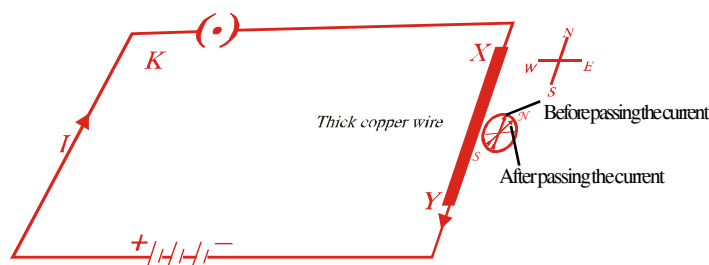


Figure 9.7(a) An electric circuit to observe magnetic effect of current

Insert the key in the plug key and observe the direction of deflection of the north pole of the needle. If the current flows from north to south, the north pole of the compass needle would move towards the east as shown in Figure 9.7(a).

Reverse the cell connection in the circuit as shown in the next Figure 9.7(b). You will observe the change in the direction of deflection of the needle because the direction of current flow is from south to north. That is the needle moves towards west. It means that the direction of magnetic field produced by the current is also reversed.

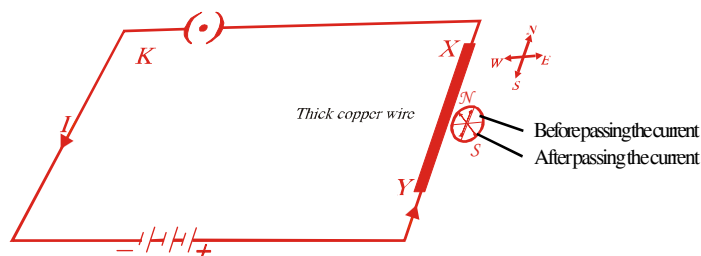


Figure 9.7(b) The deflection of the needle becomes opposite when the direction of current is reversed

9.2.1 Magnetic Field due to a Straight Conductor Carrying Current

From the above section you have learnt that the direction of the magnetic field generated depends on the direction of current flow. You must have an eagerness to know further dependence such as – “Does the pattern depend on the shape or configuration of conductor carrying current”?

To understand that we shall first consider the pattern of the magnetic field around a straight conductor carrying current through the following Activity.

Activity 9.5

Use a battery of 12 V, a variable resistance, an ammeter, a plug key and a long straight thick copper wire of length about 30cm and a rectangular cardboard with a circular hole at the centre.

Insert the copper wire XY through the hole in the card board so that it is normal to the plane of the board. Care must be taken so that the card board does not slide up and down freely.

Then connect the copper wire vertically between X and Y as shown in Figure 9.8,. Sprinkle some iron filings uniformly on the cardboard.

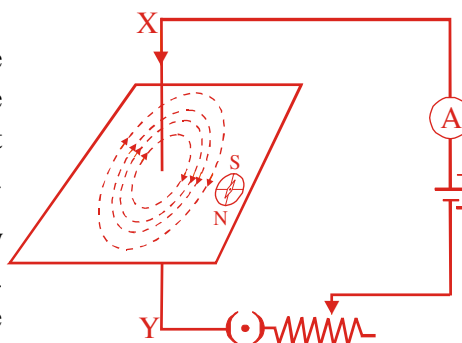


Figure 9.8

Close the key and note the current in the ammeter. The value of the current can be fixed to a desired value by adjusting the position of the variable of the rheostat at a fixed position.

Now, gently tap the cardboard a few times with the finger. In doing so, ensure that the copper wire remains vertical and cardboard is exactly normal to the wire. You will see, finally, that the iron filings align themselves forming a pattern of concentric circles with the copper wire (i.e.hole) as centre.

What do these concentric circles indicate ? They represent the magnetic field lines produced by the current carrying straight conductor.

What about the direction of the magnetic field ? To ascertain the direction, place a magnetic compass at a point over a circle as shown in the same figure. Notice the direction of deflection of needle. The direction of north pole of the needle would give the direction of the magnetic field lines. Mark the direction using an arrow.

Check whether the direction of the magnetic field lines get reversed or not with the change in the direction of current flow along the copper wire. You will observe that the direction of the field lines gets reversed. The strength of such magnetic field decreases as the distance from the wire increases.

9.2.2 Right-Hand Thumb Rule

The direction of magnetic field generated by a straight conductor carrying current can be conveniently found out. Imagine that you are holding a straight conductor carrying current in your right hand such that the thumb points towards the direction of the current, as shown in Figure 9.9. The other fingers will wrap around the conductor which gives the direction of field lines of the magnetic field associated with the straight current.

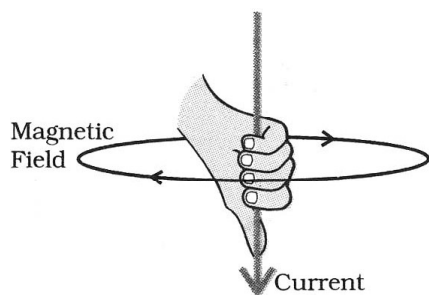


Figure 9.9 Right hand thumb rule

This is known as **right-hand thumb rule**. The above result is also given by Maxwell's corkscrew rule. If we consider ourselves driving a corkscrew using a screw driver, in the direction of advancing current, then the direction of rotation of corkscrew gives the direction of the magnetic field.

Example 9.1 Suppose a current flows along a horizontal conductor in south to north direction. What will be the direction of the magnetic field at points (i) directly below (ii) directly above it?

Solution The current is in south to north direction. Applying right-hand thumb rule, the direction of the magnetic field, at a point below the wire, will be from east to west. While the direction of the magnetic field above the wire will be from west to east.

9.2.3 Magnetic Field due to a Current through a Circular Loop or Coil (of wire)

You are familiar with the direction of magnetic field lines produced around a straight conductor carrying current. Imagine that the same conductor is bent in the form of circular loop and then a current is passed through it. How would the magnetic field lines look like? Let us try to visualise.

We have learnt that the magnetic field associated with a straight conductor carrying current decreases in magnitude with increasing distance from the conductor. As a result, at every point of a current carrying circular loop, the concentric circles representing the magnetic field around it, would become larger and larger as one moves away from the common centre i.e. the conductor.

By the time when we reach the centre of the circular loop, the arcs of these big circles would appear as straight lines, as shown in Figure 9.10. Thus, every point on the wire carrying current would give rise to the magnetic field appearing as straight lines at the centre of the loop. It is easy to check that every section of the wire contribute to the magnetic field lines in the same direction within the loop.

Now, you have already learnt that magnetic field produced by a current carrying wire at a given point depends directly on the magnitude of the current passing through it. Therefore, if there is a circular coil consisting of ' n ' – number of turns, the field produced by this will be n -times as large as that produced by a loop of single turn carrying the same current as that of the coil. The above is supported by the fact that the current in each circular turn has the same direction and strength and hence the field due to each turn just adds up.

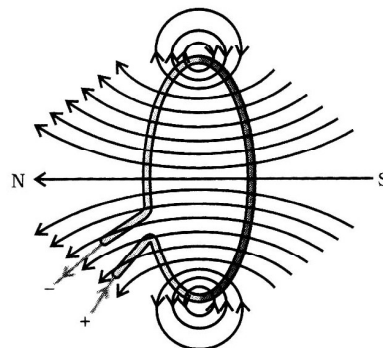


Figure 9.10 Magnetic field lines of the field produced by current carrying circular loop.

To understand magnetic field pattern due to circular coil of large number of turns carrying current, let us perform the following Activity.

Activity 9.6

Prepare a rectangular cardboard with two holes. Then wind a circular coil of fine insulated copper wire through the holes as shown in Figure 9.11 so that winding is normal to the plane of the cardboard.

Connect the ends of the coil with a battery through a plug key as shown in Figure 9.11. Sprinkle some iron filings uniformly on the cardboard. Thereafter, plug the key. Finally, tap the cardboard gently a few times with finger. Note the pattern of the arrangement of the iron filings. The pattern would appear as shown in Figure 9.11. The lines of force are circular near the wire but they become straight and parallel at the middle point M of the coil. In fact, each small segment of the coil is surrounded by such magnetic lines of force. At the centre of the coil, all the lines of force add each other due to which the strength of magnetic field increases.

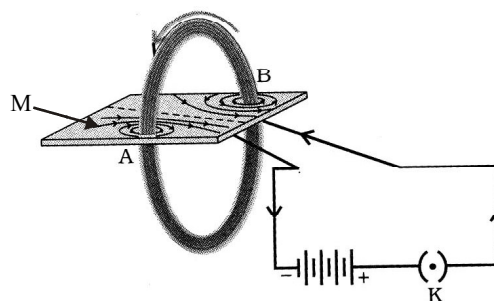


Figure 9.11 Magnetic lines of force due to circular coil or a wire, carrying current.

Thus, the strength of the magnetic field produced by a current carrying circular coil can be increased : (i) by increasing the number of turns of wire in the coil (ii) by increasing the current through the coil (iii) by decreasing the radius of the coil.

Moreover, a circular coil carrying current behaves as thin disc shaped magnet, whose one face is north pole and the other face is south pole.

9.2.4 Magnetic Field due to a Current in a Solenoid

A solenoid is a long coil of many circular turns of insulated copper wire, wrapped closely in the shape of cylinder whose radius is very small in comparison with the length of the winding. (When a long wire is coiled over a non-conducting hollow cylinder in the shape of a spring so that the turns are closely spaced and insulated from each other, it is called a solenoid). The structure of a solenoid is shown in Figure 9.12. In certain solenoid, an iron rod of proper size is inserted inside the hollow tube. Thin rod is called core.



Figure 9.12 A solenoid

The free ends of the solenoid wire are connected to a battery through a key. When a current is passed through the winding, a magnetic field is established. The magnetic field inside the solenoid is almost constant in magnitude and direction. The pattern of the magnetic field is shown in Figure 9.13. Compare the pattern of the field with the magnetic field around a bar magnet (Fig 9.4). Do they look similar? Yes, they are similar. This shows that one end of solenoid behaves as a magnetic north-pole, while the other behaves as the south-pole, due to the passage of current.

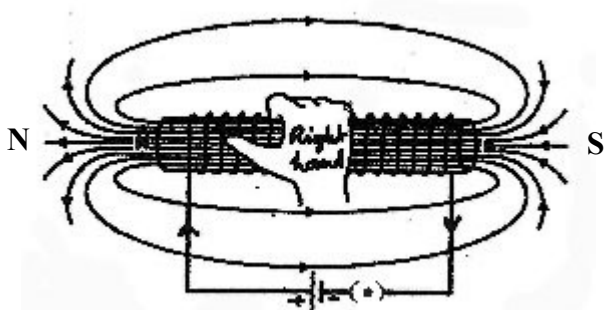


Figure 9.13 Magnetic field lines around a current carrying solenoid.

Again imagine that you are holding the solenoid in your right hand with the fingers curled along the direction of current through the winding. The direction of the thumb points always towards the end where the north pole appears.

The field lines inside the solenoid are in the form of parallel straight lines.

This pattern shows that the strength of field is the same at all points inside the solenoid i.e., the field is uniform inside the solenoid.

The strength of the magnetic field depends on (i) the current : the larger the current the stronger is the magnetic field. (ii) the number of turns per unit length: the larger the number, the stronger is the magnetic field.

The north pole and south pole of a current carrying solenoid may be interchanged by reversing the current direction in it.

The magnet formed by passing an electric current in a solenoid is temporary i.e. magnetism exists so as current flows and it is no more when the current is off.

The strong magnetic field produced inside a current carrying solenoid can be used to magnetize a piece of magnetic material, such as soft iron rod, when placed inside the solenoid as shown in Figure 9.14. The magnet so formed is called an electromagnet. We can easily change the strength of a given electromagnet by changing the value of current flow. The strength of an electromagnet depends on (i) the number of turns per unit length in the coil – the strength increases with the increasing number of turns (ii) the current flowing in the coil – if the current in the coil is increased, the strength increases.

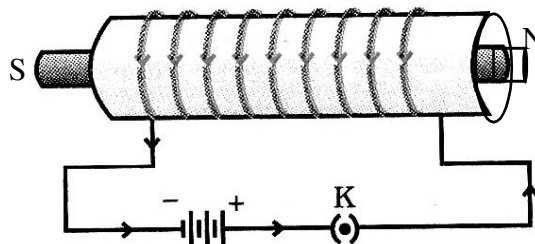


Figure 9.14 An electromagnet

Try to Answer

1. Why don't two magnetic lines of force belonging to the same field intersect each other ?
2. Draw magnetic field lines or magnetic lines of force around a bar magnet.
3. Write the properties of magnetic lines of force.
4. Applying right hand thumb rule, find out the direction of the magnetic field inside and outside a loop of wire carrying current in the clockwise direction and lying on the plane of the table or the page.

9.3 Force on a Current-Carrying Conductor in a Magnetic Field

We have already learnt that an electric current flowing through a conductor produces a magnetic field or in short, a conductor carrying current is associated with a magnetic field. The field so produced can exert a force on a magnet (magnetic needle of a compass) when placed in the vicinity of the conductor. French scientist – Andre Marie Ampere (1775–1836) suggested that the magnet must also exert an equal and opposite force on the current carrying conductor. The nature and direction of the force due to a magnetic field acting on a current-carrying conductor can be studied through the following Activity.

Activity 9.7

Take an aluminium rod XY of about 2mm in diameter and about 5cm in length. Using two plastic rings suspend it from a fixed support through two light strings connected to these rings.

Bring a horse-shoe magnet near the aluminium rod so that the north pole lies on one side of the aluminium rod while the south pole lies on the other side. Here, the line joining the poles of the magnet is vertical and perpendicular to the suspended aluminium rod.

Connect the rod in series to the battery through the plug key K. Now pass a current through the rod from the end X to Y as shown in Figure. 9.15

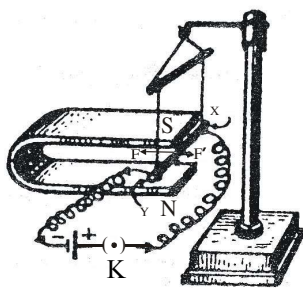


Figure 9.15

What do you observe? You will observe that the rod is pulled towards 'F'. If you remove the magnet the rod will regain its original position. On the other hand, if the current is off by opening the key the rod will also regain its original position.

Thus you can understand that only when the rod of aluminium carries a current, the magnetic field exerts a force on it

Repeat the experiment by reversing magnetic field direction i.e., with the south pole taking the position of the north pole and vice-versa. What will happen to the rod? The rod will be pushed in opposite direction, F' . The same result will be seen if you reverse the direction of current, without changing the position of the poles of horse shoe magnet.

We conclude that

1. When a current carrying wire is placed in a magnetic field, a force acts on the wire.
2. The direction of force depends on the direction of the magnetic field as well as direction of the current.

Experiments have shown that the displacement of the rod is largest or the magnitude of the force is largest, when the direction of current is at right angles to the direction of magnetic field in which the conductor is placed.

In Activity 9.7, the direction of the current and that of the magnetic field are perpendicular to each other and found that the force is perpendicular to both of them. Thus, all are perpendicular to one another.

9.3.2 Fleming's Left -Hand Rule

The direction of the force on a current carrying conductor (or wire) placed in a magnetic field may be easily obtained by a simple rule known as Fleming's Left-Hand rule, which was suggested by Professor J.A Fleming of England.

According to this rule, stretch the thumb, forefinger and middle finger of your left hand such that they are mutually perpendicular (Fig. 9.16). If the forefinger points in the direction of magnetic field and middle finger points in the direction of current then the thumb will point in the direction of motion or the force acting on the conductor.

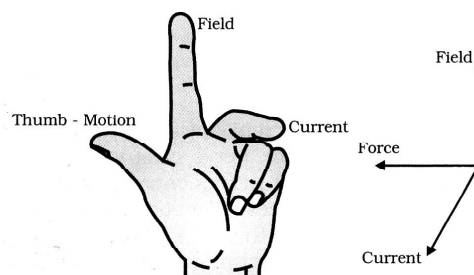


Figure 9.16 Fleming's Left-Hand rule

9.4 Electric Motor

An electric motor is a rotating device that converts electrical energy to mechanical energy of a rotating system known as the **shaft**. Anything connected to the shaft rotates with it. In short an electric motor converts electrical energy into mechanical (Kinetic) energy. It is an important component in electric fans, refrigerators, washing machines, grinders, mixers, computers etc. Let us try to know how an electric motor works.

An electric motor consists of a coil of insulated copper wire. The copper wire is tightly wound over a soft-iron core to form a coil of a large number of turns, as shown in Fig. 9.17. The core with the coil is called the **armature**. The armature is fixed on the shaft of the motor.

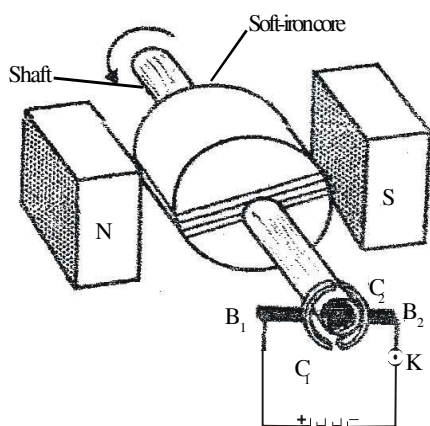


Figure 9.17 A simple electric motor

At any instant of time, one brush touches only one split ring, when the shaft rotates i.e. when the motor works.

Strong and permanent magnetic north and south poles are fixed facing each other. The coil is kept between them, so that the coil lies in a magnetic field directed from the north pole to the south pole. The two free ends of the coil are connected to the two halves C_1 and C_2 of a split ring. The inner sides of C_1 and C_2 are insulated electrically and fixed on the shaft. The external conducting edges of C_1 and C_2 touch two conducting stationary brushes B_1 and B_2 respectively. The brushes are 180° apart from each other, as shown in the Figure 9.17. The brushes are connected to the terminals of a

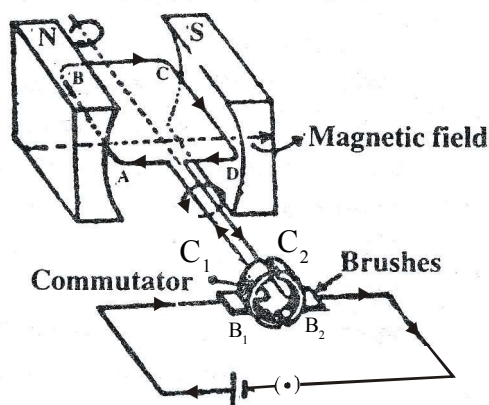


Figure 9.18(a)

As a result, the coil and the shaft together known as the armature mounted free to turn about an axis, rotate anti-clockwise. At half rotation C_2 is in contact with the brush B_1 while C_1 is in contact with the brush B_2 . Therefore, the current in the arms AB and CD gets reversed as shown in Fig. 9.18(b) and flows along DCBA. Here, the change of direction of the current flow through the circuit is

9.4.1 Working of the Motor

When the battery is connected to the motor, the current in the coil ABCD enters through the conducting brush B_1 and flows back to the battery through the brush B_2 . In the portion shown in Fig. 9.18(a). The current in the left arm is along AB while that in right arm is along CD. As these currents are flowing in a magnetic field, forces are exerted on them. As given by Fleming's Left-Hand rule . AB is pushed down while the arm CD is pushed up. As a

carried out by the split rings and the two taken together is called **commutator**. Thus, the current in the coil is from D to C to B to A. On applying Fleming's Left-Hand rule the arm AB of the coil that was earlier pushed down is now pushed up while the arm CD previously pushed up is now pushed down and anti-clockwise rotation of the armature continues.

Therefore, the coil and the shaft together rotates half a turn more in the same direction. The reversing of direction of current flow is repeated at each half rotation and it gives rise to a continuous rotation of the armature, so long as the battery supplies current i.e. key remains close.

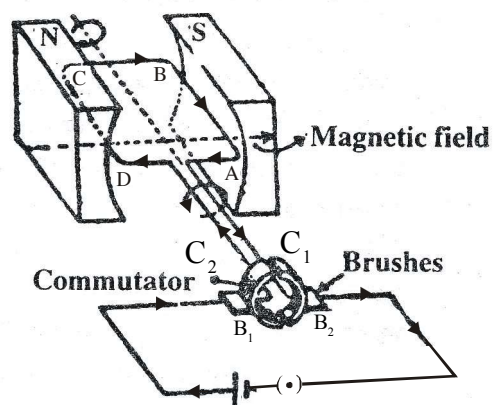


Figure 9.18(b)

The commercial motors use (i) an electromagnet in place of permanent magnet (ii) large number of turns of insulated copper wire in the coil (iii) a soft iron core on which the coil is wound. By doing so, the power of the motor can be increased.

Try to answer

1. State Fleming's Left-Hand rule.
2. What is the principle of an electric motor ?
3. What is the role of commutator ?

POINTS TO REMEMBER

- i. A compass needle is a small magnet pivoted at its centre so as to enable it to rotate freely in a horizontal plane.
- ii. The end which points towards north is its north pole and the other end is called south pole
- iii. A field line is the path along which a hypothetical free north pole would tend to move. These field lines around a magnet are used to represent a magnetic field. The resultant direction of the magnetic field at a point is given by the direction of motion of the north pole which is free to move.

- iv. The field lines are closer in the region of stronger magnetic field.
- v. A metallic conductor carrying an electric current has associated with a magnetic field due to the current, the magnetic field lines are a series of concentric circles with the wire as common centre. The direction of the field is given by the right hand (thumb) rule.
- vi. The magnetic field due to a current carrying solenoid is similar to that of a bar magnet except that the direction of field can be reversed with the change in the direction of current through it.
- vii. An electromagnet consists of a core of soft iron wrapped around with a coil of insulated copper wire.
- viii. A current carrying conductor when placed in a magnetic field experiences a force. The force acting on the conductor is perpendicular to both the direction of magnetic field and the current which are also perpendicular to each other and is governed by the Fleming's Left-Hand Rule. This is the basis of an electric motor.
- ix. Electric motor is a device which can convert electric energy into mechanical energy.

EXERCISES

1. Draw a sketch to show the magnetic lines of force due to a current carrying straight conductor.
2. Draw the magnetic lines of force due to a circular wire carrying current.
3. State the effect of inserting an iron core into a current carrying solenoid.
4. Describe how you will locate a current carrying wire embedded in a wall.
5. State right-hand thumb rule.
6. What is a solenoid ? Draw a sketch to show the magnetic lines of force produced by a current carrying solenoid.
7. What is an electric motor ? With the help of a diagram, describe the working of an electric motor.
8. What is the function of commutator in an electric motor ?
9. **A magnetic line of force is used to show the direction of**
 - (A) south-north
 - (B) a bar magnet
 - (C) a compass needle
 - (D) magnetic field.

10. The magnetic lines of force inside a solenoid due to an electric current in it are nearly
- (A) straight lines (B) circular lines
(C) parabolic lines (D) elliptic lines (A)
11. If the number of turns in a solenoid is increased, the strength of the electromagnet so formed will
- (A) decrease (B) increase
(C) remain constant (D) become zero. (B)

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