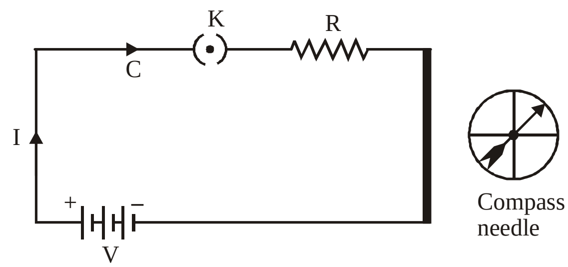
Lesson-4

MAGNETIC EFFECTS OF ELECTRIC CURRENT

In 1820, Hans Christian Oersted, a Danish physicist discovered a relationship between electricity and magnetism. He found that a compass needle got deflected when an electric current passed through a metallic wire placed nearby.



Compass needle is deflected on passing an electric current through a metallic conductor

A magnet is that which attracts magnetic substances such as iron, steel, cobalt, nickel, etc., towards it. A compass needle gets deflected when brought near a bar magnet. If a magnet or a magnetic compass needle is freely suspended, it comes to rest in almost north-south direction.

The end pointing towards north is called north pole and the other end that points towards south is called south pole.

Two poles of a magnet cannot be separated. That is Magnetic poles are always found in pair (A magnetic monopole does not exist).

Like magnetic poles repel while unlike magnetic poles attract each other

Magnetic Field:

The region surrounding a magnet, (or space around a current carrying conductor) in which the force of attraction or repulsion due to it can be detected is called its magnetic field. The direction of a magnetic field is the direction in which an isolated imaginary north pole, would tend to move if it is free to do so. Magnetic field is a vector quantity. The SI unit of magnetic field is tesla (T) or weber/metre^2.

Magnetic Field Lines (or Magnetic Lines of Force): A magnetic field is represented by a series of hypothetical lines around a magnet. The concept of magnetic field lines was developed to visualize the effect of the magnetic field.

Magnetic field lines is defined as the path along which an isolated north pole would move, if it is free to do so.

Properties of Magnetic Field Lines

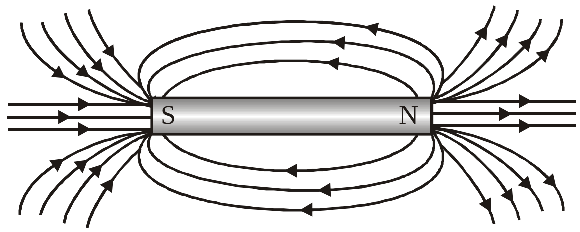
(i) Magnetic field lines are closed continuous curves.

(ii) Outside the body of the magnet, the direction of magnetic field lines is from north pole to south pole. Inside the magnet, the direction of the field lines is from south to its north pole.

(iii) The tangent to the magnetic field line at any point gives the direction of magnetic field at that point.

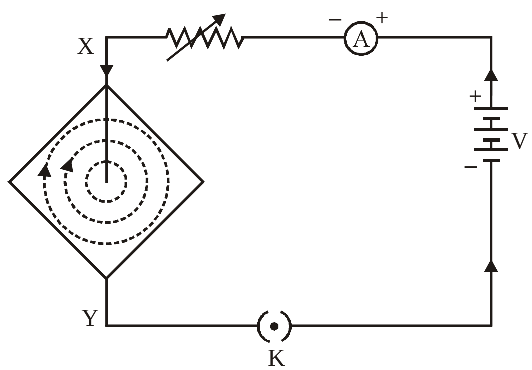
(iv) No two magnetic field lines can intersect each other.

(v) The relative strength of the magnetic field depends on the degree of closeness of the magnetic field lines. Crowding of magnetic field lines represents the stronger magnetic field and vice-versa.



Field lines around a bar magnet

Magnetic Field due to a Current through a Straight Conductor: When a straight conductor carries electric current, a magnetic field is set up around the conductor. The field lines around the conductor are concentric circles whose centres lie on the conductor as shown in the figure.



The magnetic field produced causes the deflection in the compass needle. It is found that the deflection in the needle increases when current increases. Again if the needle is moved away from the conductor, the deflection in the needle decreases i.e., the magnetic field produced by given current in the conductor decreases as the distance from it increases.

Thus the magnitude of magnetic field (B) produced by a straight current carrying conductor at a given point is

(i) Directly proportional to the current flowing through the conductor.

i.e. $B \propto I$

(ii) Inversely proportional to the distance of the point from the conductor

i.e. $B \propto 1/r$

combining these two relations, we get

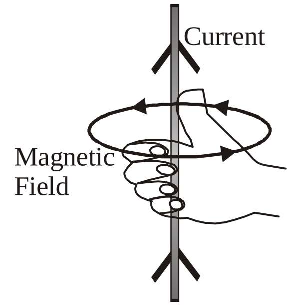
$$B \propto I/r$$

or $$\boxed{B = \frac{\mu_0 I}{2\pi r}}$$

where μ_0 is constant and $\mu_0 = 4\pi \times 10^{-7}$ TmA^{-1} called magnetic permeability of free space or in vacuum.

Right Hand Thumb Rule

The direction of the magnetic field associated with a current carrying straight conductor can be obtained by applying the "right hand thumb rule". According to this rule:



Hold the current carrying conductor in your right hand such that the thumb points in the direction of current, then the direction in which your fingers encircle the conductor will give the direction of the field lines of the magnetic field.

Magnetic Field due to a Current through a Circular Loop: When a current is passed through the circular coil, a magnetic field is produced around it. The pattern of magnetic field lines is shown in the figure. The field lines are circular near the wire but they become straight at the centre of the coil.

The magnitude of the magnetic field produced by a current carrying circular coil at its centre is

(i) Directly proportional to the current passing through the circular coil.

$$i.e.\ B \propto I$$

(ii) Inversely proportional to the radius of the circular coil

$$i.e.\ B \propto 1/r$$

(iii) Directly proportional to the number of turns of the circular coil

$$B \propto n$$

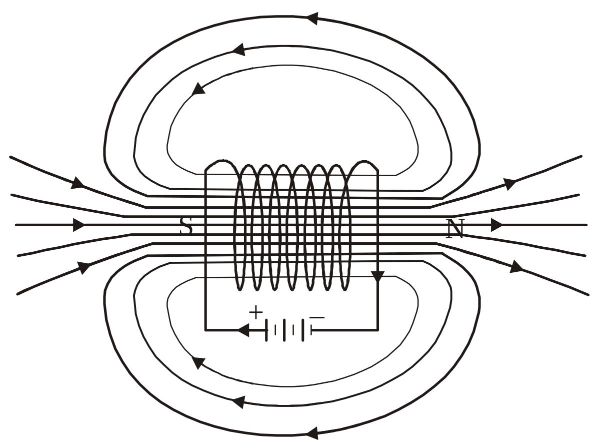
Now combining these three relations, we get

$$B \propto nI\frac{1}{r}$$

or

$$\boxed{B = \frac{\mu_0 nI}{2r}}$$

Magnetic Field due to a Current in a Solenoid



A coil of a large number of circular turns of insulated copper wire wrapped closely in the shape of a cylinder is called a solenoid.

When an electric current is passed through the solenoid, it produces a magnetic field around it which is shown in the figure. The magnetic field produced due to a current carrying solenoid is similar to the magnetic field produced by a bar magnet. The field lines inside the solenoid are in the form of parallel straight lines. This indicates that the magnetic field is the same at all points inside the solenoid, *i.e., the* field is uniform inside the solenoid.

The magnitude of the magnetic field produced by a current carrying solenoid depends on

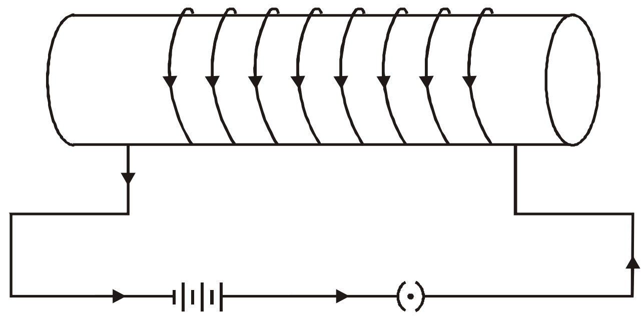
(i) The number of turns in the solenoid (n)

(ii) The strength of the current in the solenoid (I)

(iii) Nature of core material used in making solenoid.

$$\therefore \quad \boxed{B = \mu_0 n I}$$

Electromagnets, (Temporary Magnets)



A strong magnetic field produced inside a solenoid can be used to magnetise a piece of magnetic material, like soft iron, when placed inside the coil (core). The magnet so formed is called an electromagnet. A simple electromagnet is shown in the figure.

Thus, an electromagnet consists of a long coil of insulated copper wire wrapped on a soft iron core. It should be noted that solenoid containing soft iron core in it acts as a magnet only as long as the current is flowing in the coil. All the magnetism of the soft iron core disappears as soon as the current in the coil is switched off.

On the other hand, if steel or other alloys like alnico, nipermag, tinconol, etc., are used for making the core of solenoid, these materials do not lose their magnetism when the current is stopped and hence behave as permanent magnets.

Uses of Electromagnets

(i) Electromagnets are used to lift heavy iron pieces. They are fitted on cranes lifting heavy masses of scrap iron.

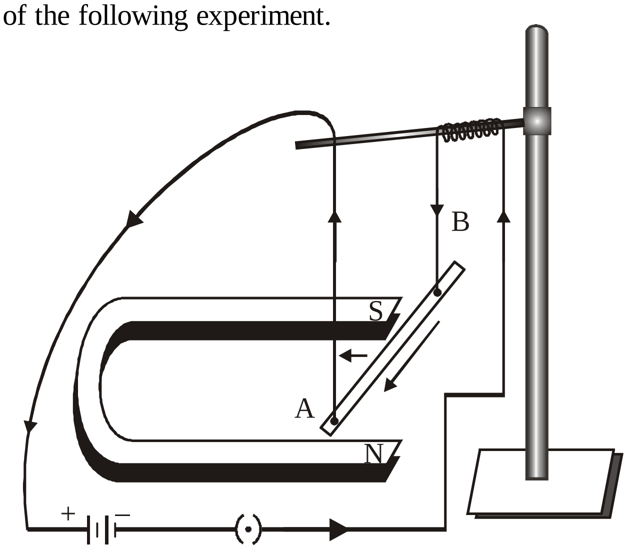
(ii) Electromagnets are also used in devices like electric bell, electric horn, electric relay, telephone receiver, etc.

Difference between Permanent Magnet and Electromagnet

Permanent Magnet	Electromagnet
(i) A permanent magnet produces a comparatively weak force of attraction.	(i) An electromagnet can produce very strong magnetic force.
(ii) The strength of a permanent magnet cannot be changed	(ii) The strength of an electromagnet can be changed by changing the number of turns in its coil or by changing the current passing through.
(iii) The (north south) polarity of a permanent magnet is fixed and cannot be changed	(iii) The polarity of an electromagnet can be canged by changing the direction of current in its coil.

Force on a Current Carrying Conductor in a Magnetic Field: We have already studied that a current carrying conductor produces magnetic field. The field so produced exerts a force on a magnetic needle and deflects it from its usual north-south position. The reverse of this is also true, that is a magnet exerts a force on a current carrying conductor and this force produces a motion in the conductor. Thus, when a current carrying conductor is placed in a magnetic field, a mechanical force is exerted on the conductor which makes it move. This fact can be demonstrated with the help of the following experiment.

Experiment: Take a small aluminium rod AB of length about 5 cm. Suspend the rod AB horizontally from a rigid stand using two connecting wires as shown in the figure.



Place a strong horse-shoe magnet NS in such a way that the rod AB lies between the poles of the magnet with the magnetic field directed upwards. For this, let the north pole N of magnet lies below the rod and the south pole lies above the rod.

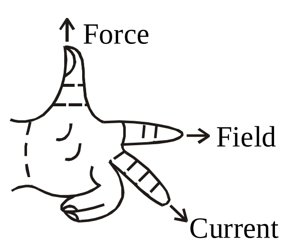
Complete the electrical circuit by connecting the rod in series with a battery, a key (K) and a variable resistance. Now, pass a current through the rod from end B to end A.

We observe that on passing electric current, the rod AB is displaced towards the left. It shows that the aluminium rod exerts a mechanical force due to which it is deflected.

Reverse the connections of battery so that current flows in the rod from end A to B. We now find that the rod AB is deflected to the right.

Now reverse the direction of magnetic field to vertically downward direction by interchanging the two poles of the magnet. It is again observed that the direction of deflection of the rod (or the direction of the force) gets reversed. Thus, it shows that the direction of the force on a current carrying conductor depends upon the direction of current and the direction of the magnetic field.

Fleming's Left Hand Rule



The direction of force acting on a current carrying conductor can be easily determined by applying Fleming's left hand rule.

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

Factors on which force acting on a current carrying conductor placed in the magnetic field:

The magnitude of force acting on a current carrying conductor placed in a magnetic field depends on

(i) the strength of the magnetic field (B) *i.e.*, $F \propto B$

(ii) the strength of the electric current (I) *i.e.*, $F \propto I$.

(iii) the length of the conductor (L) *i.e.*, $F \propto L$

The magnitude of the force will be maximum, when current carrying conductor is placed perpendicular to the direction of the magnetic field. In this case

$$\boxed{F = BIL}$$

From the above equation, we can define magnetic field as

$$B = \frac{F}{I \times L}$$

Thus, magnetic field is defined as the force acting per unit current per unit length of a conductor placed perpendicular to the direction of magnetic field.

SI unit of magnetic field is tesla (T) and

$$\therefore \quad 1 \text{ tesla} = \frac{1 \text{ newton}}{1 \text{ ampere} \times 1 \text{ metre}}$$

Thus, magnetic field is said to be 1 tesla if a conductor 1 metre long carrying 1 ampere current experiences 1 N force, when placed perpendicular to the direction of the magnetic field.

Note: *If a current carrying conductor is placed parallel to the direction of magnetic field, it experiences no force.*

The Force on a Moving Charge in a Magnetic Field: The current (I) flowing in a conductor is due to the moving charged particle. So, a moving charged particle experiences a force due to magnetic field. As we know that

$$F = BIL$$

$$= B \frac{Q}{t} L \qquad [\because I = \frac{Q}{t}]$$

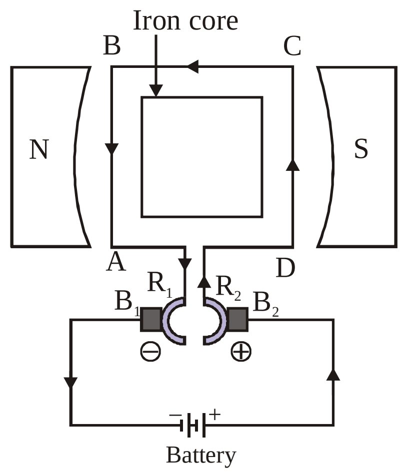
$$= B Q \frac{L}{t}$$

$$\boxed{F = BQv} \qquad [\frac{L}{t} = v = \text{velocity of the charged particle}]$$

Thus, the force acting on a charge Q moving with a velocity v perpendicular to the magnetic field B is given by $F = BQv$

Note:

- If charge Q is at rest (*i.e.,* for static charge) in the magnetic field, then no force acts on this charge.
- If a charge Q moves in the direction of magnetic field, then no force acts on the charge.
- If a charge Q moves perpendicular to the magnetic field, then maximum force acts on this charge.



Electric Motor

An electric motor is a rotating device which converts electrical energy into mechanical energy. An electric motor works on the principle that a current carrying conductor placed in a magnetic field experiences a force which tends to move the conductor.

Construction: It consists of a rectangular coil ABCD of insulated copper wire. The coil is placed between two poles of a strong magnet. The ends of the coil are connected to the two halves P and Q of split ring (commutator). The inner sides of these halves are insulated and attached to an axle. The external conducting edges of P and Q are connected to two stationary conducting brushes X and Y.

Working: Let current in the coil ABCD of motor enters from the source of battery through the conducting brush X, flows along ABCD and finally back to the battery through Y. On applying fleming' Left hand rule we find that force acting on arm AB due to magnetic field pushes it downward. But the force acting on the arm CD pushes it upward. Thus, the coil and the axle rotate anticlockwise. Due to action of split ring commutator at half rotation, P and Q change their contacts with brushes. As a result, current begins to flow in the coil along DCBA. Now, AB arm is being pushed upward and arm CD downward by the magnetic force. So, coil rotate half a turn more in the same direction. This reversing of current direction is repeated at each half rotation and so the coil continues to rotate in the same direction.

Uses of Motor : Electric motors are used in all such devices where we want to convert electrical energy into mechanical energy so as to drive the machines. In our houses, electric motors are used in electric fans, coolers, air conditioners, mixer and grinder, washing machines, refrigerators, computers, MP-3 players, *etc.* In Factories, electric motors are used in almost all machines.

Electromagnetic Induction

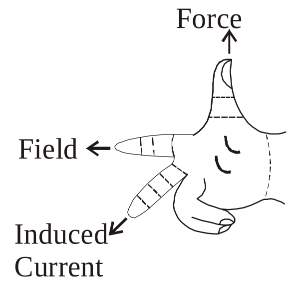
In most simple terms, electromagnetic induction means production of electricity from magnetism.

The phenomenon due to which an induced current is set up in a closed coil whenever magnetic field around it is changing is called electromagnetic induction. Induced current lasts as long as change in magnetic field continues.

Fleming's Right Hand Rule

The direction of induced current produced in a conductor can be easily determined by applying Fleming's right hand rule.

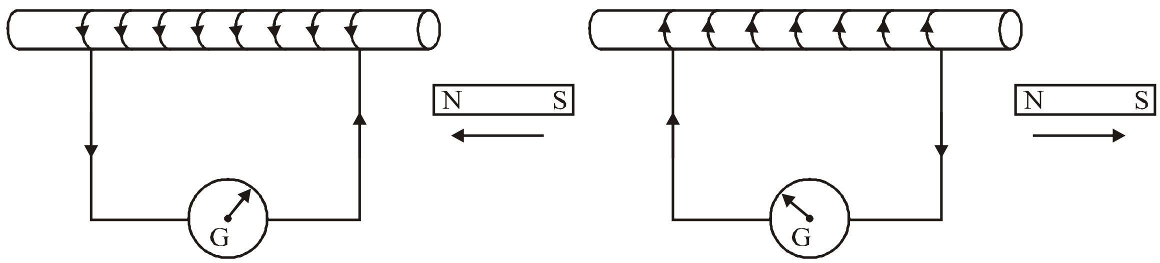
According this rule, stretch the thumb, forefinger and middle finger of right hand such that they are perpendicular to each other. If the forefinger points in the direction of the magnetic field and the thumb points in the direction of motion of the conductor, then the middle finger will show the direction of induced current.



Faradays Experiment

In, 1831, Michael Faraday made an important breakthrough by discovering how a moving magnet can be used to generate electric current.

Experiment: Take a solenoid coil of insulated copper wire AB having large number of turns. Connect the ends of coil to a sensitive galvanometer. Now take a strong bar magnet NS and rapidly bring the magnet towards the end B of coil as shown in the figure.



The galvanometer suddenly gives momentary deflection in one direction. Now take the magnet away from the coil, the galvanometer again gives momentary deflection but in opposite direction. It clearly shows that motion of magnet induces a current in the coil. The current becomes zero when the motion of the magnet stops.

Now place the magnet stationary at a point near the coil, keeping its north pole N towards the end B of the coil. In this core, the galvanometer needle deflects toward right when the coil is moved towards the north pole of the magnet. Similarly the needle moves towards left when the coil is moved away from the magnet.

Note:

- The induced current due to electromagnetic induction is produced whenever there is a relative motion between the coil and the magnet. when the coil and the magnet are both stationary, no induced current is produced.
- An induced current can also be produced in the coil-2 (secondary coil) whenever the electric current through the coil -1 (primary coil) is changing. Thus the process by which a changing magnetic field in a conductor induces a current in another conductor is called electromagnetic induction.

Electric Generator

An electric generator or dynamo converts mechanical energy into kinetic energy. It works on the principle of electromagnetic induction.

The basic **electric generator** uses a set-up similar to the electric motor of but in this case one does not send a current through the wire loop, but instead rotates it in the magnetic field. This rotation comes from the action of falling water (in a hydroelectric plant) or steam (in a coal or nuclear power plant) hitting turbine blades, causing them to turn. A changing magnetic field subsequently is established through the plane of the wire loops, which causes a current to be generated. In this way mechanical or rotational energy is converted to electrical energy. It turns out that as the loop rotates through one complete revolution the direction of the current reverses, which is an AC current.

Direct Current (DC): An electric current whose magnitude is either constant or variable but direction of flow remains the same is called direct current. Frequency of DC is zero.

Alternating Current (AC): An electric current whose magnitude changes with time and direction reverses periodically is called alternating current.

The frequency of household supply of AC in India is 50 Hz. this means, AC completes 50 cycles in one second. Thus, AC changes direction after every 1/100 second.

Advantage of AC over DC

(i) AC can be easily converted to DC by using rectifier.

(ii) AC can be easily varied by using transformers

(iii) AC can be transmitted over long distances without much loss of energy.

Domestic Electric Circuits

Electricity is generated at the power station. We receive supply of electric power through a main supply (also called mains), either supported through overhead electric poles or by underground cables.

The domestic supply circuit consists of three types of wires, namely, (i) Red insulation cover is called live wire (or positive), (ii) Black insulation cover is called neutral wire (or negative), and (iii) Green insulation cover is called earth wire. The potential difference between the live wire and the neutral wire is 220 V.

The earth wire, which has insulation of green colour, is usually connected to metal plate deep in the earth near the house. This is used as a safety measure, especially for those appliances that have a metallic body, for example, electric press, toaster, table fan, refrigerator, *etc*. The metallic body is connected to the earth wire, which provides a low-resistance conducting path for the current. Thus, it ensures that any leakage of current to the metallic body of the appliance keeps its potential to that of the earth, and the user may not get a severe electric shock.

Electric Fuse: A fuse is a very important device used for protecting electric circuits. It is a thin wire made of tin or copper-tin alloy having very low melting point. When high current flows through a circuit, the fuse wire gets heated and melts. As a result, circuit is broken and the current stops flowing. Fuse wires are of various capacities. The thicker the wire, the greater is its capacity. For fans, lights and other light appliances, 5 A fuse is used. For heavy appliances like electric stove, immersion heater, geyser, *etc*., 15 A fuse is used.

Overloading and Short Circuit: Overloading can occur when the live wire and the neutral wire come into direct contact. This occurs when the insulation of wires is damaged or there is a fault in the appliance. In such a situation, the current in the circuit abruptly increases. This is called short-circuiting.

Note: Overloading can also occur due to an accidental hike in the supply voltage. Sometimes overloading is caused by connecting too many appliances to a single socket.

SOLVED EXAMPLES

Ex.1: A transmission line carries a current of 100 A in east to west direction. Find the magnitude and direction of the magnetic field due to the current at a distance 1 m below the line.

Sol.: Here, I = 100 A

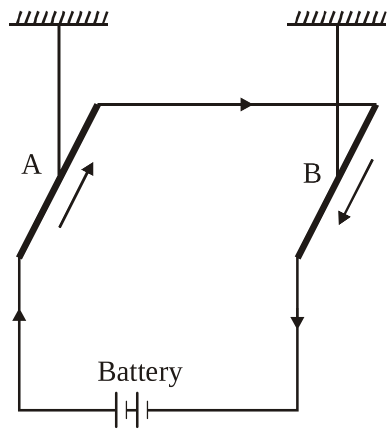
r = 1 m

using, $B = \left(\frac{\mu_0}{4\pi}\right)\frac{2I}{r}$, we get

$$B = \frac{10^{-7} \times 2 \times 100}{1} = 2 \times 10^{-5} \text{ T}$$

Thus, magnitude of magnetic field = 2×10^{-5} T. As per right hand thumb rule, direction of magnetic field is form south to north.

Ex.2: Two wires A and B are suspended freely. These wires are connected in series with a battery as shown in the figure. Will these wires remain in their positions or move closer to each other or move away from each other? Explain.



Sol.: When the wires are connected to a battery in series, then the flow of currents in these wires are in opposite directions. Hence, these wires repel each other. Therefore, these wires move away from each other.

Ex.3: Distinguish between a direct current and an alternating current.

Sol.:

Direct Current (DC)	Alternating Current (AC)
1. Direct current always flows in one direction.	1. Alternating current reverses its direction periodically.
2. The magnitude of current may or may not remain constant.	2. Magnitude of current continuously changes with time.
3. Current obtained from a battery and DC generator is DC	3. Current obtained from an AC generator and current in our domestic circuit are AC.

Ex.4: A wire of length 0.04 m is placed perpendicular to a uniform magnetic field of magnitude 0.30 T. Calculate the force on the wire when the current flowing through it is 5.0 A.

Sol.: The force acting on a current-carrying wire placed in a magnetic field is given by

$$F = B \times I \times L$$

Here, Magnitude of magnetic field, $B = 0.30$ T

Current, $I = 5.0$ A

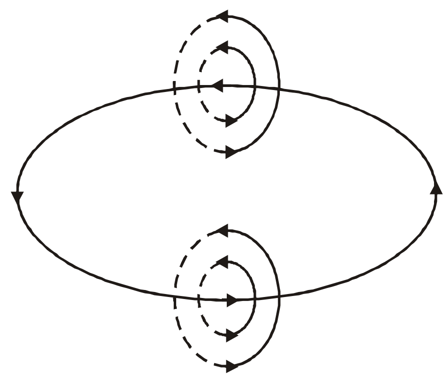
Length of wire, $L = 0.04$ m

Putting these values in the above formula, we get

Force, $F = 0.30 \times 5.0 \times 0.04 = 0.06$ N

Ex.5: Current is flowing anticlockwise in a circular coil lying in the plane of a table. Using Right Hand Thumb Rule, state the direction of the magnetic field inside and outside the coil.

Sol.: Magnetic field inside the coil is perpendicular to the plane of the table and in upward direction. However, the magnetic field outside the coil is perpendicular to the plane of the table and in downward direction as shown in the figure.



ASSIGNMENTS

1. What are magnetic field lines? How is the direction of a magnetic field at a point determined? Mention two important properties of the magnetic field lines.

2. Why don't two magnetic lines of force intersect each other?

3. The magnetic field in a given region is uniform. Draw a diagram to represent it.

4. Draw a rough sketch of the pattern of field lines due to a

(i) current flowing into a circular coil (ii) solenoid carrying current.

5. State the rule to determine the direction of a

(i) magnetic field produced around a current-carrying conductor.

(ii) force experienced by a straight conductor carrying current placed in a magnetic field, which is perpendicular to it.

(iii) current induced in a circuit by the changing magnetic flux due to the motion of a magnet.

6. Explain the principle and working of an electric motor with the help of a diagram. What is the function of a split-ring commutator?

7. A coil of copper wire is connected to a galvanometer. What would happen if a bar magnet is

(i) pushed into the coil with its north pole entering first?

(ii) pulled out of the bar magnet?

(iii) held stationary inside the coil?

8. Draw a labelled diagram to explain the principle underlying the working of an electric generator.

9. Name some sources of direct current.

10. What is the function of an earth wire? Why is it necessary to earth the metallic appliances?

11. Explain what is short circuiting and overloading in an electric supply.

12. Describe an experiment to illustrate the action of an electric fuse.

13. Name two safety measures commonly used in electric circuits and appliances.

14. An electric oven of 2 kW power rating is operated in a domestic electric circuit (220 V) that has a current rating of 5A. What result do you expect? Explain.

15. What precaution should be taken to avoid the overloading of domestic electric circuits?

16. Check the following statements. Write true or false against each.

(a) Like magnetic poles attract each other; unlike poles repel.

(b) If you strike a sharp edge of a metallic knife against the north pole of a bar magnet, it will induce a north pole.

(c) The magnetic field produced by a current in a straight wire has no poles.

(d) An electric generator is a device that converts electrical energy into mechanical energy.

17. (a) On what factors does the magnetic field produced at the centre of a current carrying circular loop depend?

(b) State Fleming's right hand rule.

(c) How does a solenoid behave like a magnet? How can you determine the north and south poles of a current carrying solenoid with the help of a bar magnet?

18. Imagine that you are sitting in a chamber with your back to one wall. an electron beam, moving horizontally from back wall towards the front wall, is deflected by a strong magnetic field to your right side. What is the direction of magnetic field?

ANSWERS

14. Circuit will be damage

16. (a) False (b) False (c) True (d) False