Magnetic Effects of Electric Current

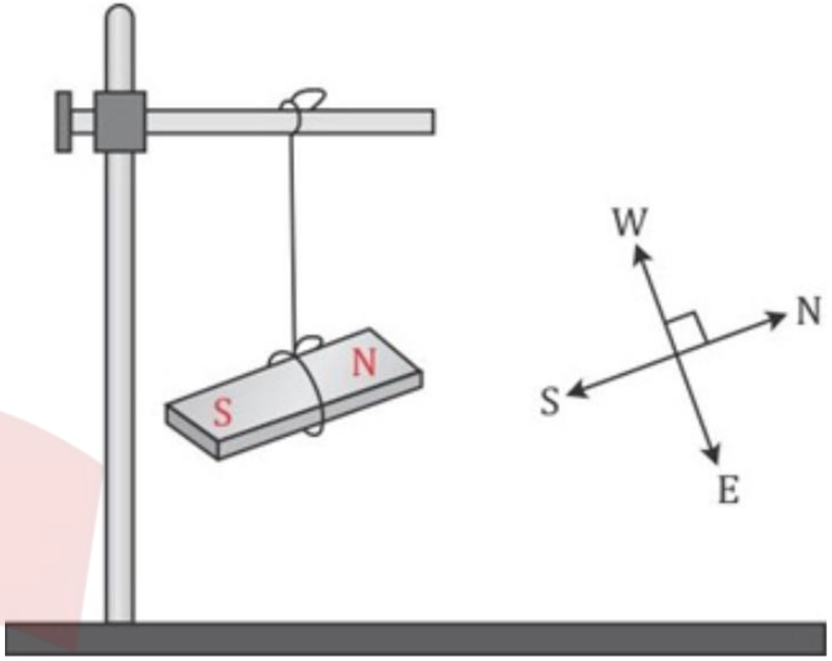
Introduction

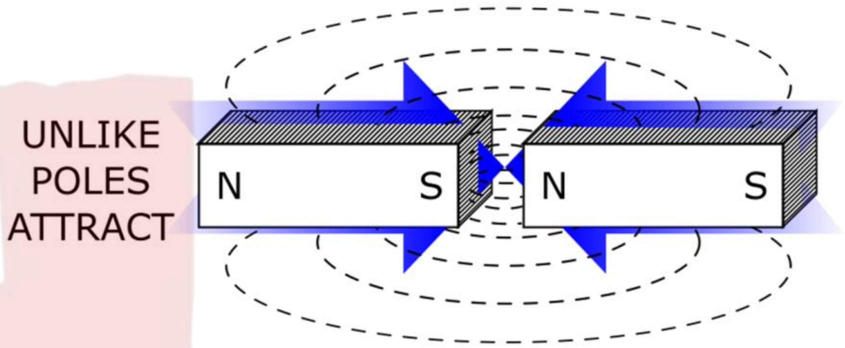
- A magnet is an object an object which attracts pieces of iron, steel, nickel and cobalt.

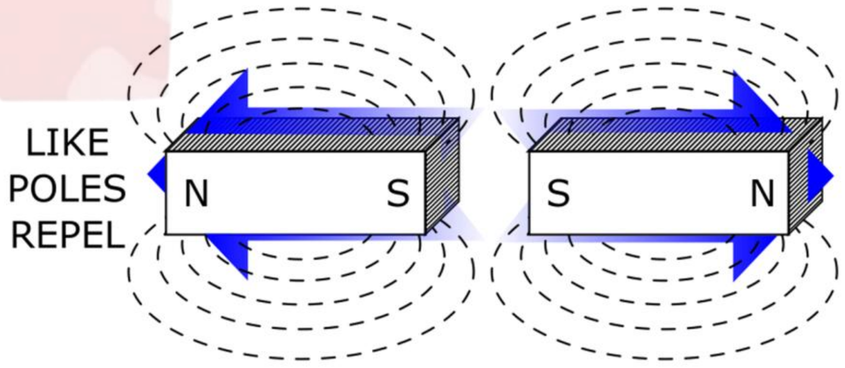
- The end of freely suspended magnet always points towards North-South direction.

- The end which points towards North is called North seeking Or North Pole whereas the end which points towards South Direction is the South seeking or south pole of the magnet.

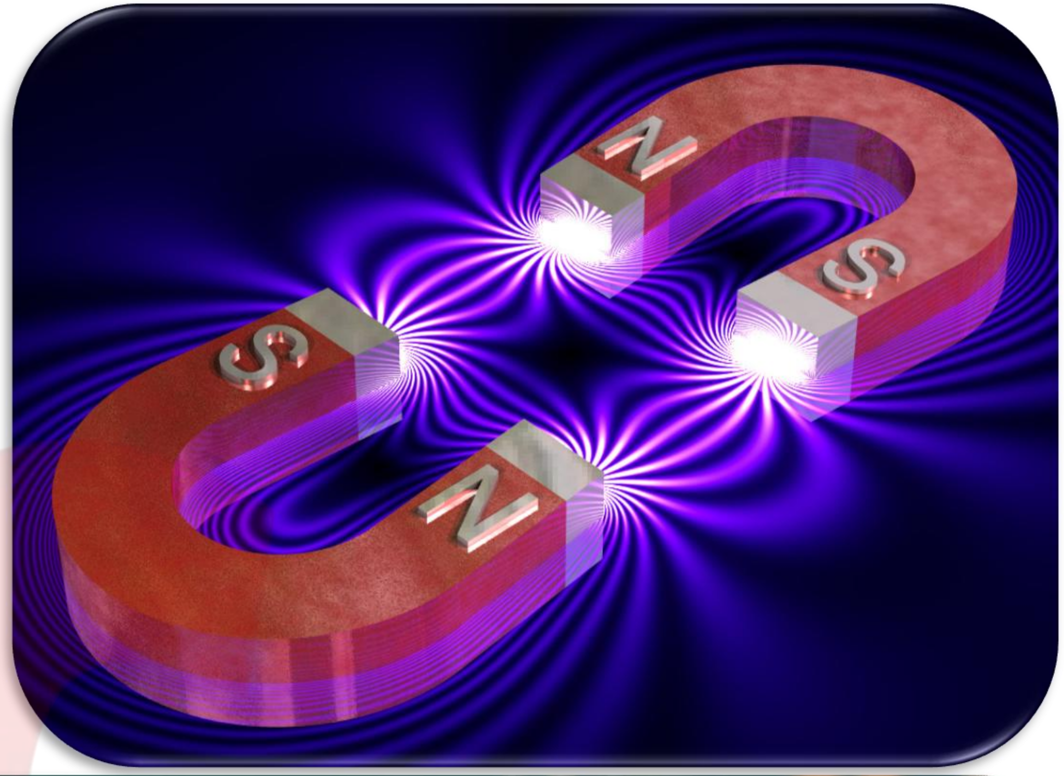
- Same pole repel each other and opposite pole attract each other.







Oersted's Experiment



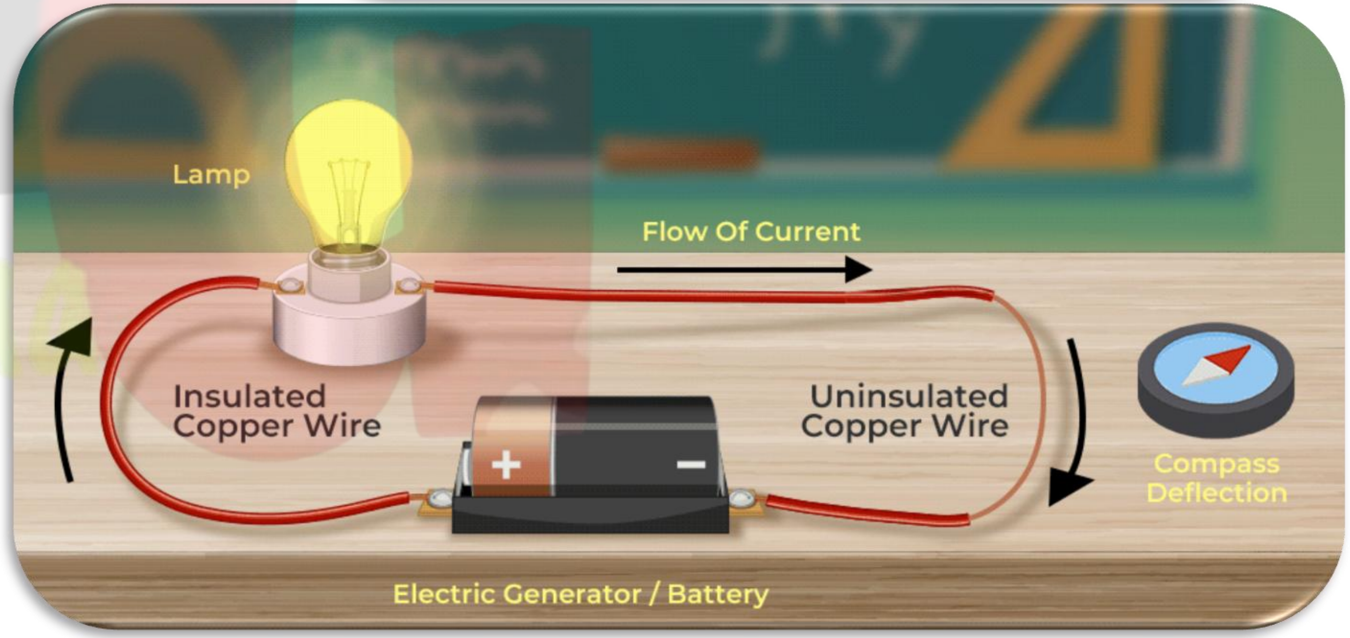
Observation

When an electric current flows through a wire, the **compass needle placed near it deflects**.

Conclusion

Electric current produces a magnetic field.

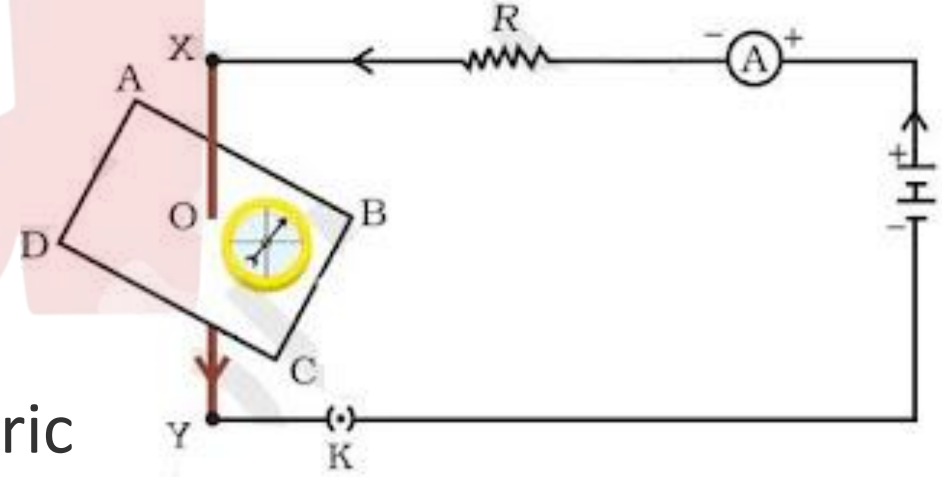
- When an electric current flows through a conductor, it produces a **magnetic field** around it. This phenomenon is called the **Magnetic Effect of Electric Current**, discovered by **Hans Christian Oersted** in 1820 by accidently.



Hans Christian Oersted (1777–1851)

Hans Christian Oersted, one of the leading scientists of the 19th century, played a crucial role in understanding *electromagnetism*. In 1820 he accidentally discovered that a compass needle got deflected when an electric current passed through a metallic wire placed nearby. Through this observation Oersted showed that electricity and magnetism were related phenomena. His research later created technologies such as the radio, television and fiber optics. The unit of magnetic field strength is named the oersted in his honor.

Electromagnets and electric motors involve the magnetic effect of electric current, and electric generators involve the electric effect of moving magnets.



Deflection of compass needle

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

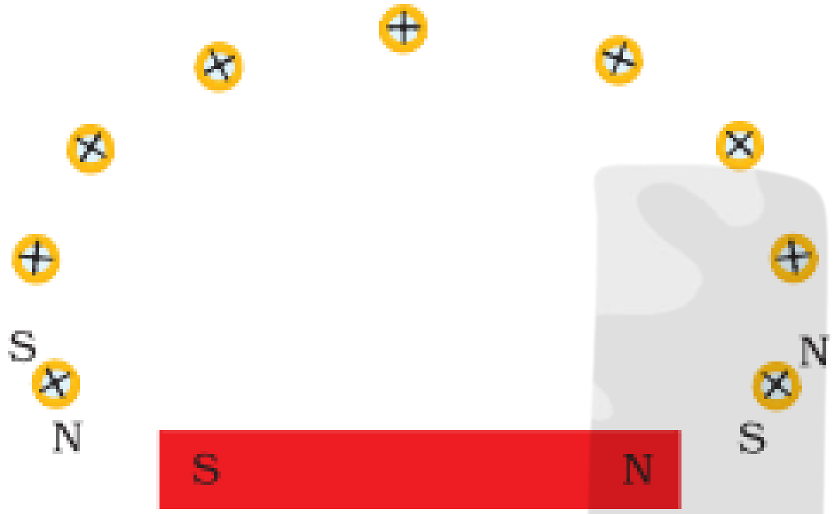
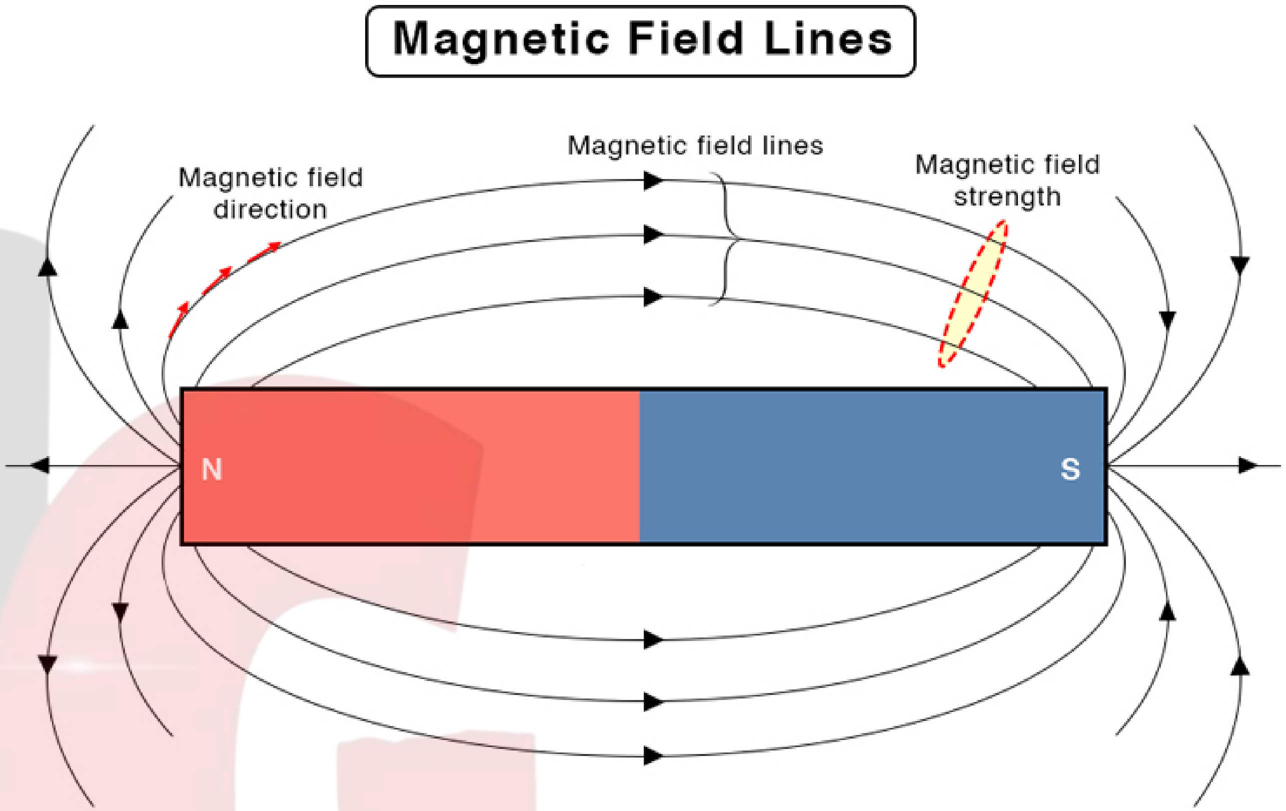
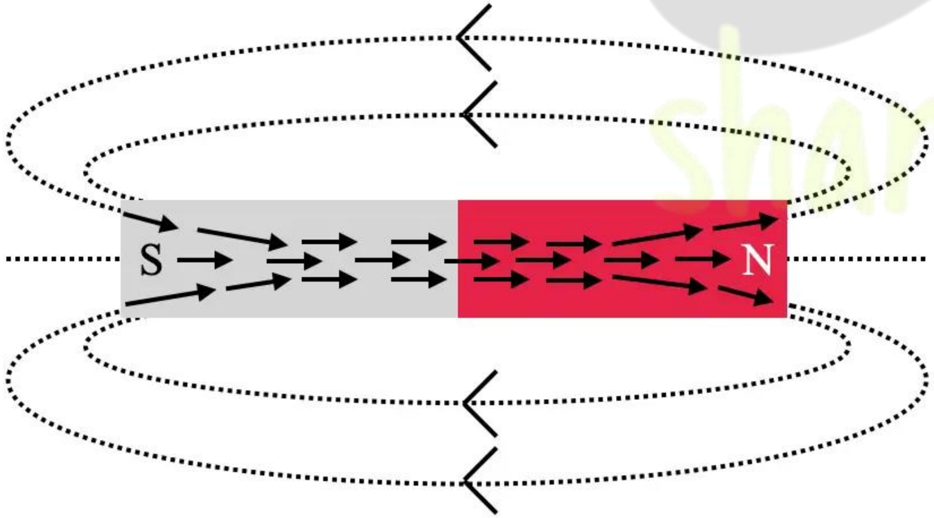
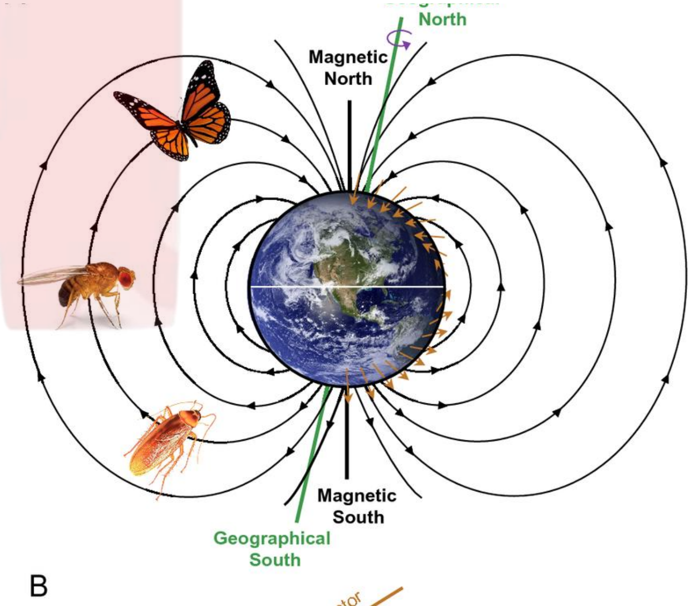


Figure 12.3
Drawing a magnetic field line with the help of a compass needle







Magnetic Field & Field Lines

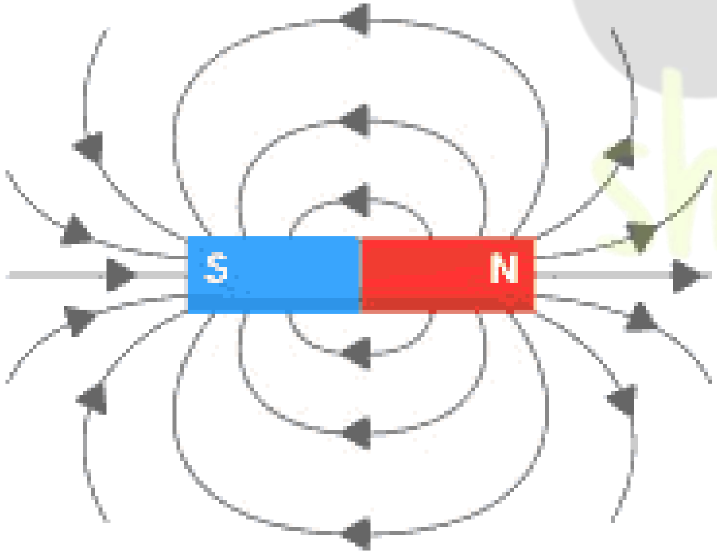
✓ Magnetic Field

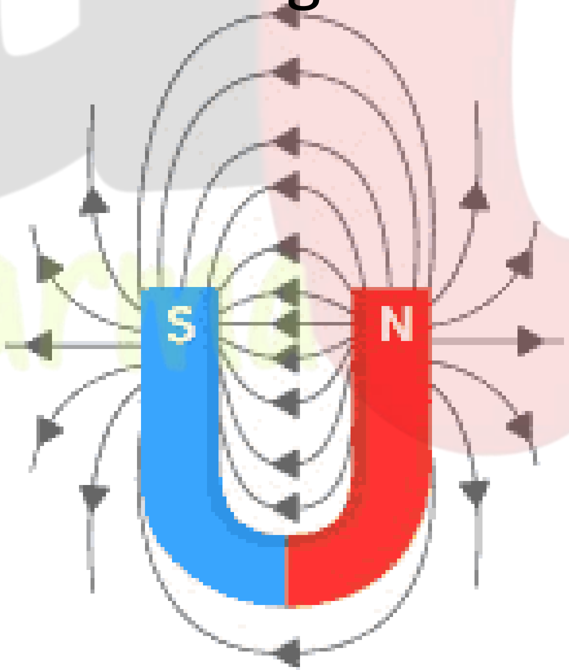
A region around a magnet or a current-carrying conductor where its magnetic influence can be felt.

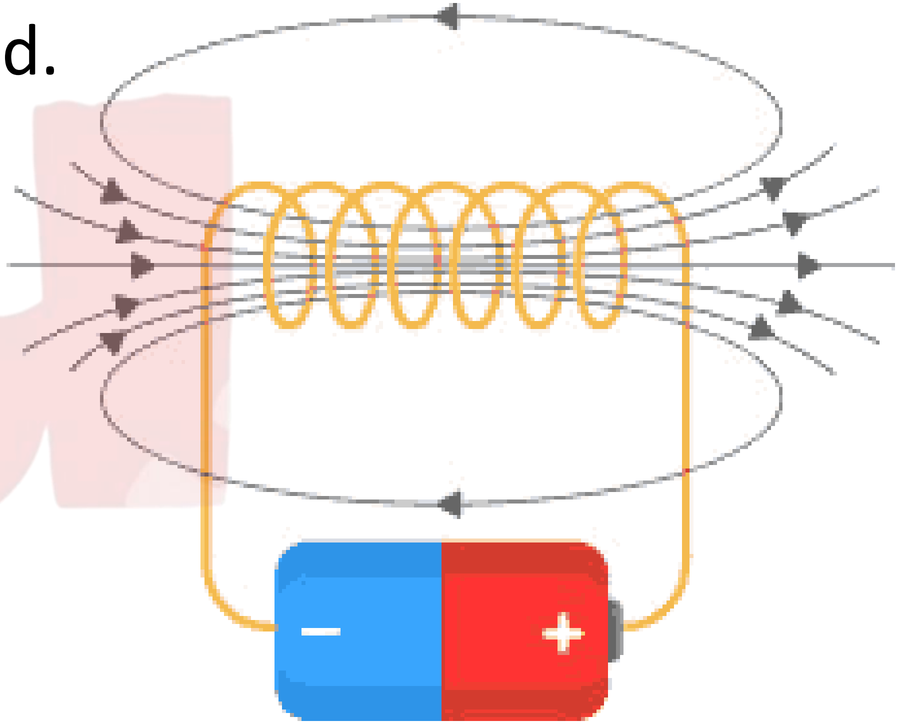
- S.I unit of magnetic field is tesla.
- It has both magnitude as well as directions.

✓ Magnetic Field Lines

Imaginary lines that represent the magnetic field.

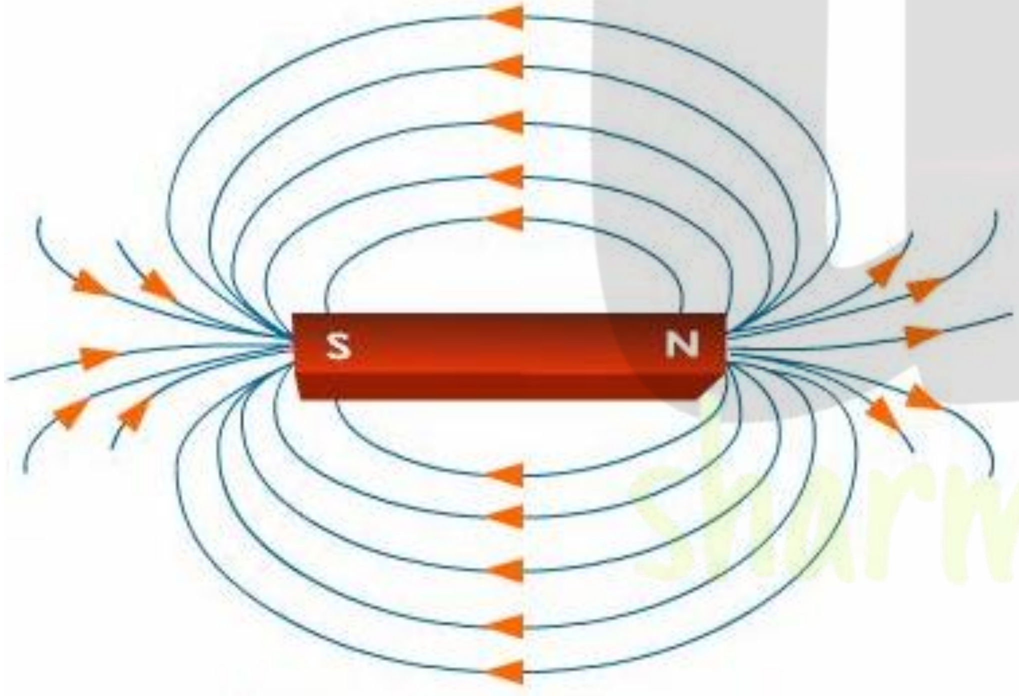


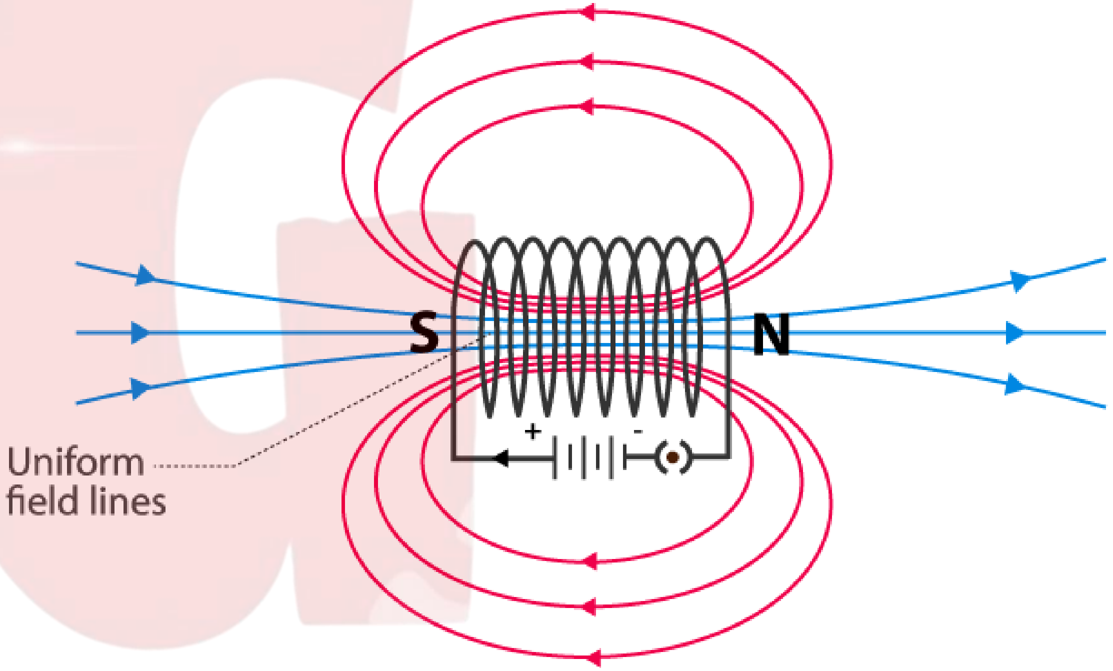




Properties of Magnetic Field Lines

1. Always form closed loops.
2. Direction: **North → South outside**, **South → North inside**.
3. Closer lines = stronger magnetic field.
4. They never intersect (otherwise 2 directions at one point – impossible).





Note :- The strength of magnetic field is stronger at pole and it decrease with increase in distance from the magnet

MAGNETIC FIELD

Magnetic field lines have the following properties:

- magnetic field lines are continuous loops that never cross
- inside the magnet, the magnetic field lines point from the south pole to the north pole
- outside the magnet, the magnetic field lines point away from the north pole toward the south pole
- the closeness of the lines represents the strength of the magnetic field (the closer the lines are together, the stronger the magnetic field)
- • if the field lines are parallel, the magnetic field is uniform

Why magnetic field lines never intersect each other ?

Ans :- Magnetic field lines never intersect each other because resultant force at north pole can only be in one direction. Had the lines intersected, it would be in two directions which is not possible.

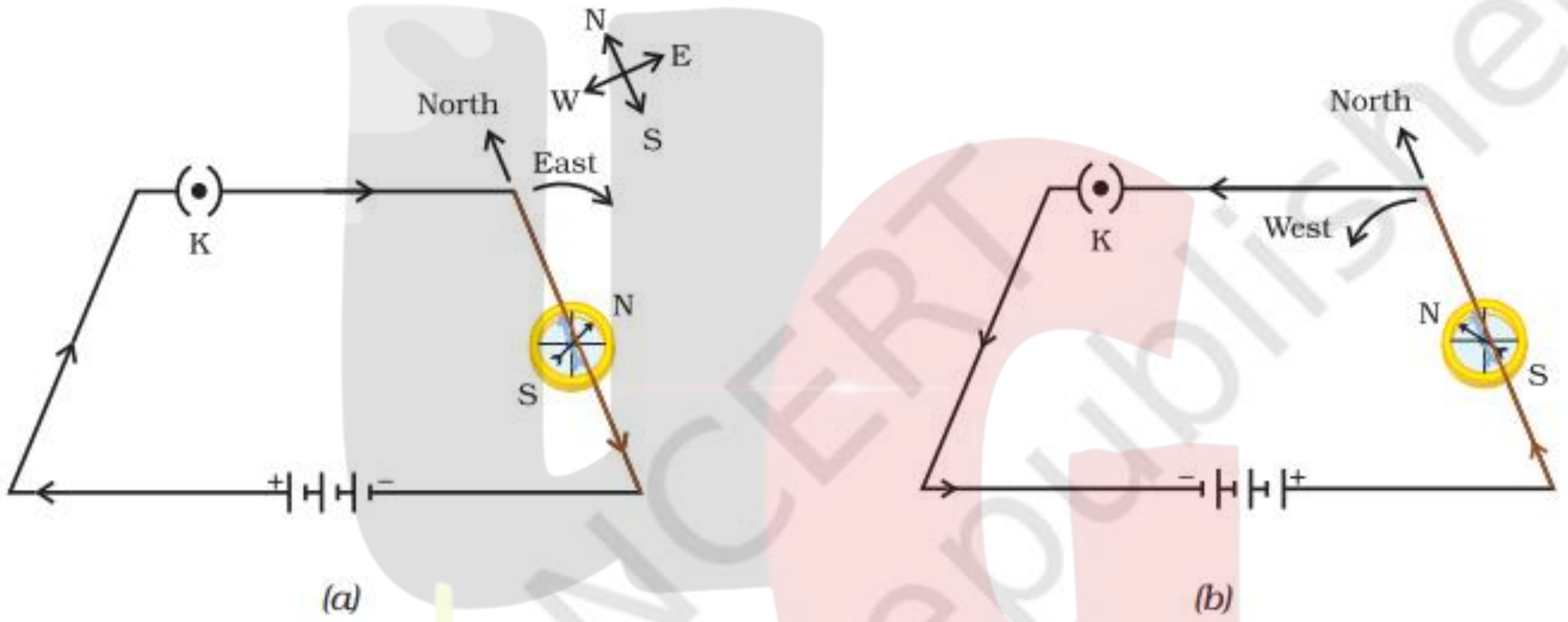
OR,

Magnetic field lines never intersect each other because if they cross, it would mean that needle of compass point in two different direction which is not possible.

Q U E S T I O N

1. Why does a compass needle get deflected when brought near a bar magnet?

MAGNETIC FIELD DUE TO A CURRENT-CARRYING ARRYING CONDUCTOR



A simple electric circuit in which a straight copper wire is placed parallel to and over a compass needle. The deflection in the needle becomes opposite when the direction of the current is reversed.

Magnetic Field due to a Straight Current-carrying Conductor

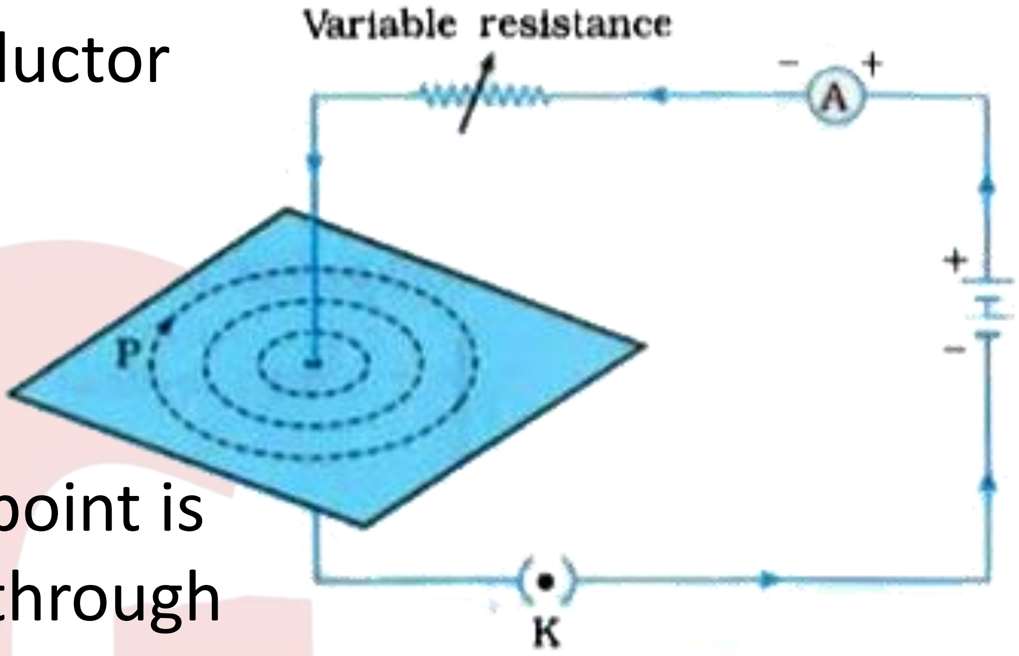
The magnetic field lines around a straight conductor carrying a current are concentric circles whose circle lies on the wire.

- Magnetic field lines are circular in nature.

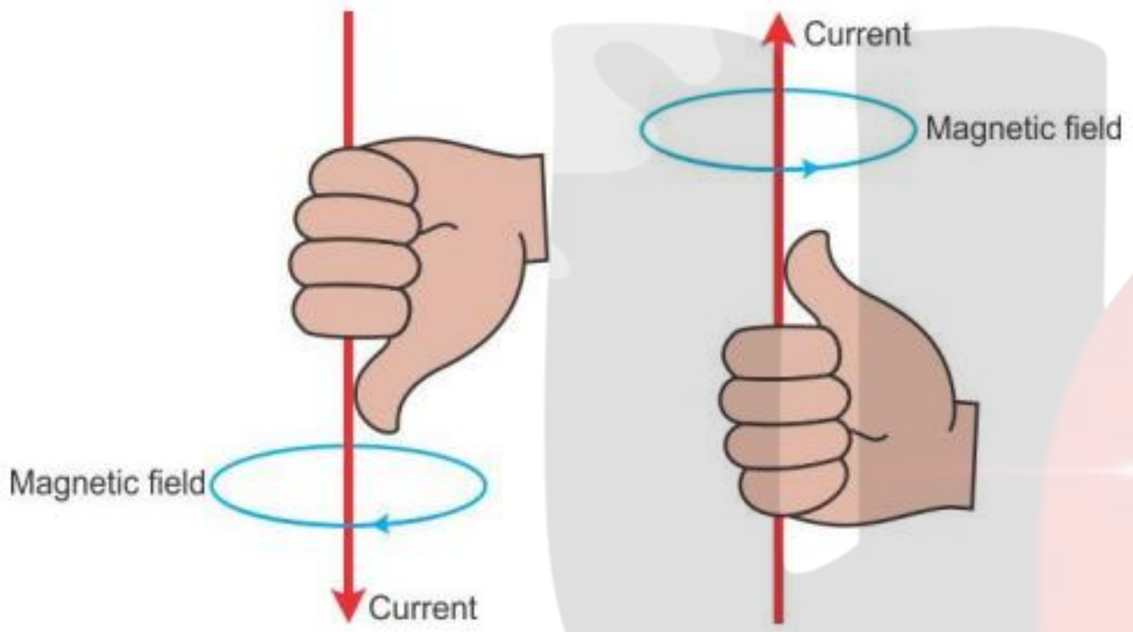
The magnitude of the magnetic field due to a straight current-carrying conductor at a given point is

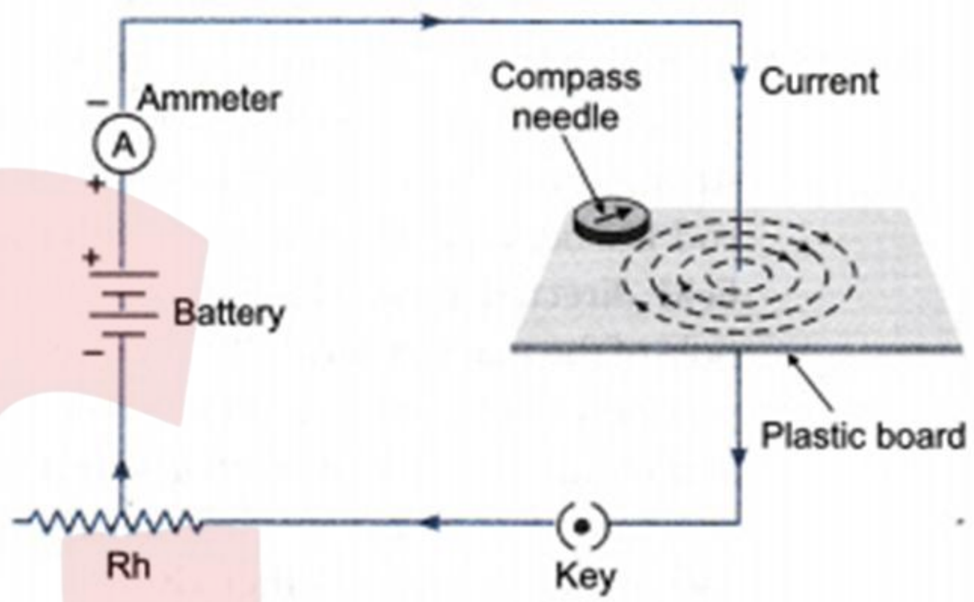
- ➢ Directly proportional to the current flowing through the conductor
- ➢ Inversely proportional to the distance of that point from the conductor
- ➢ Circles are closer near the conductor and become larger and larger as we move away from it..

❖ The direction of a magnetic field is given by the **Right-Hand Thumb Rule.**



Right Hand's thumb Rule





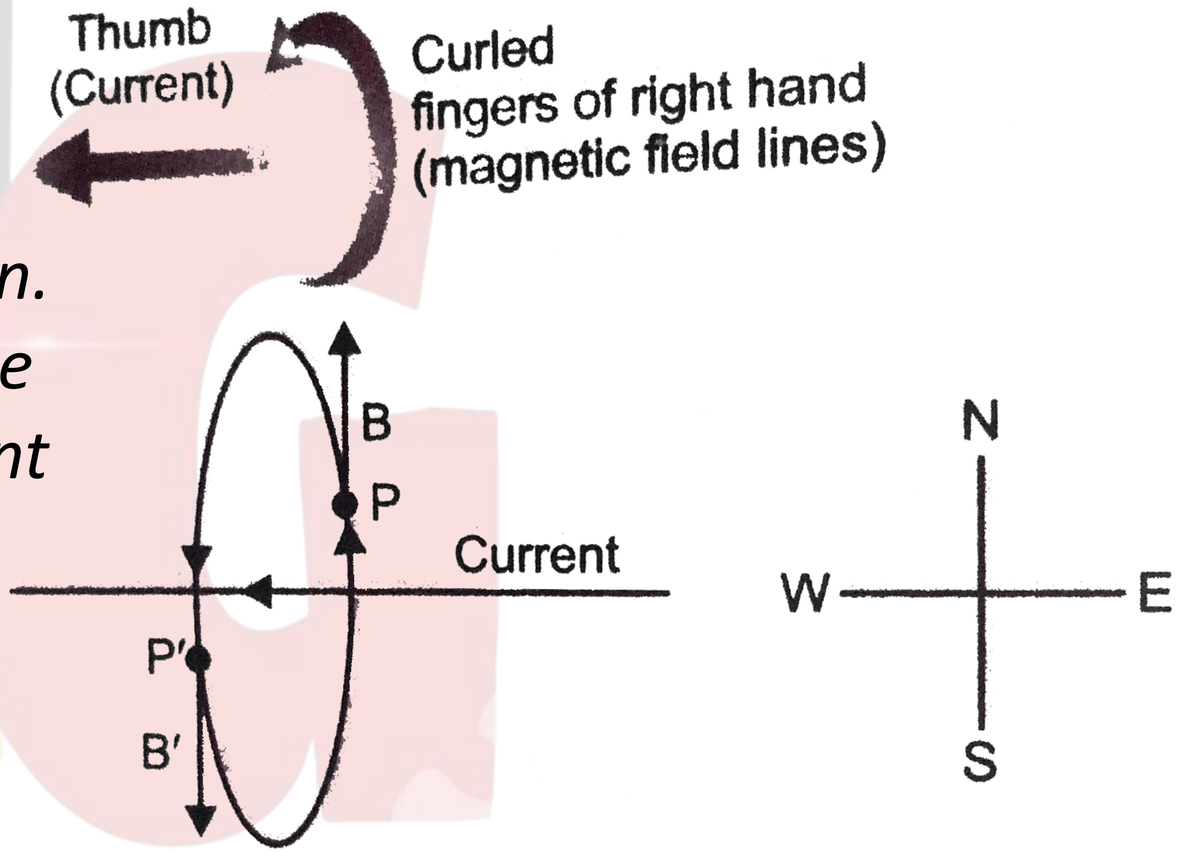
Right-Hand Thumb Rule:
Imagine that you are holding a straight current-carrying conductor in your right hand such that the thumb points towards the direction of the current. Then, your curved fingers wrapped around the conductor point in the direction of the field lines of the magnetic field.

Example 12.1

A current through a horizontal power line flows in east to west direction. What is the direction of magnetic field at a point directly below it and at a point directly above it?

Solution

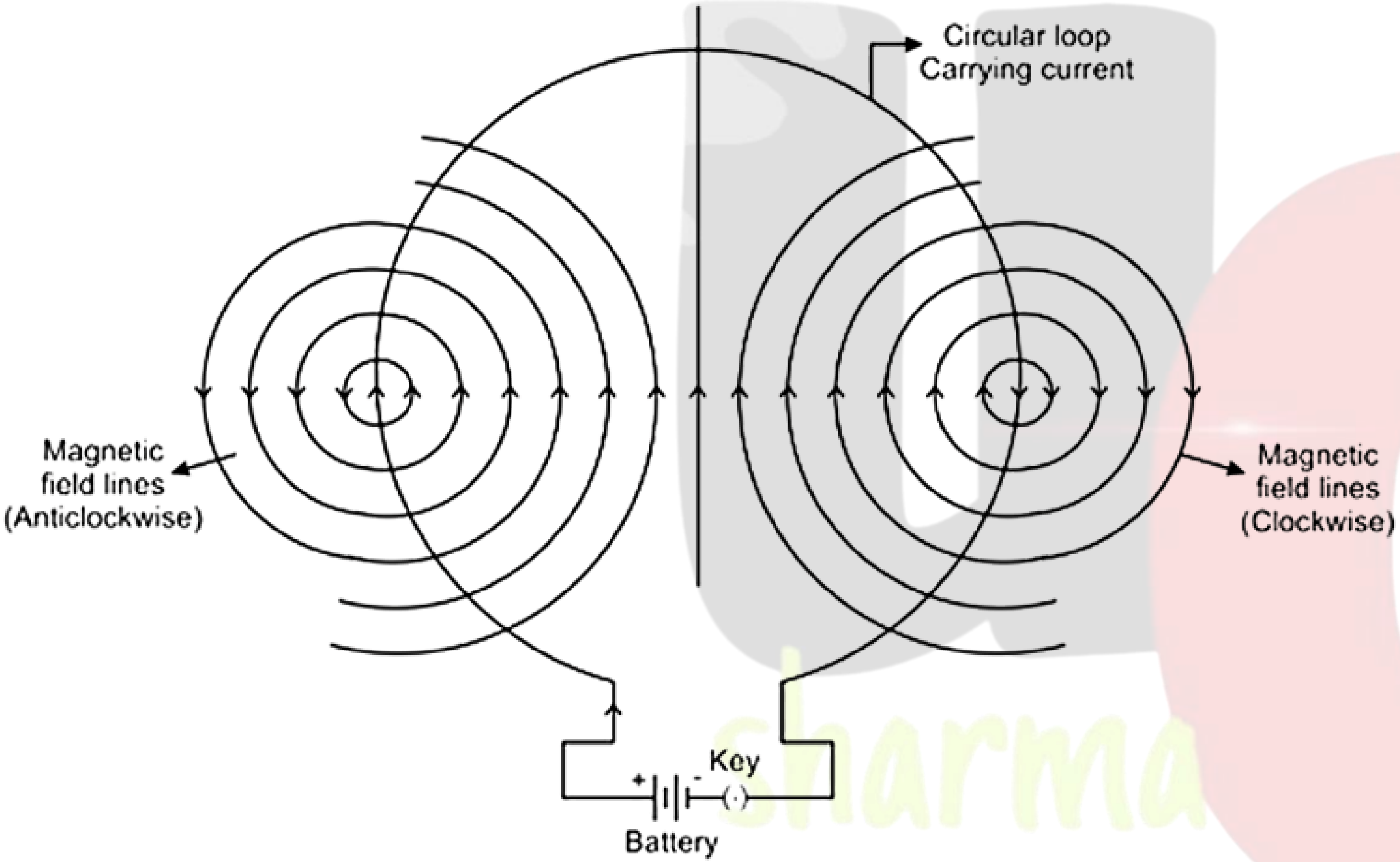
The current is in the east-west direction. Applying the right-hand thumb rule, we get that the magnetic field (at any point below or above the wire) turns clockwise in a plane perpendicular to the wire, when viewed from the east end, and anti-clockwise, when viewed from the west end.

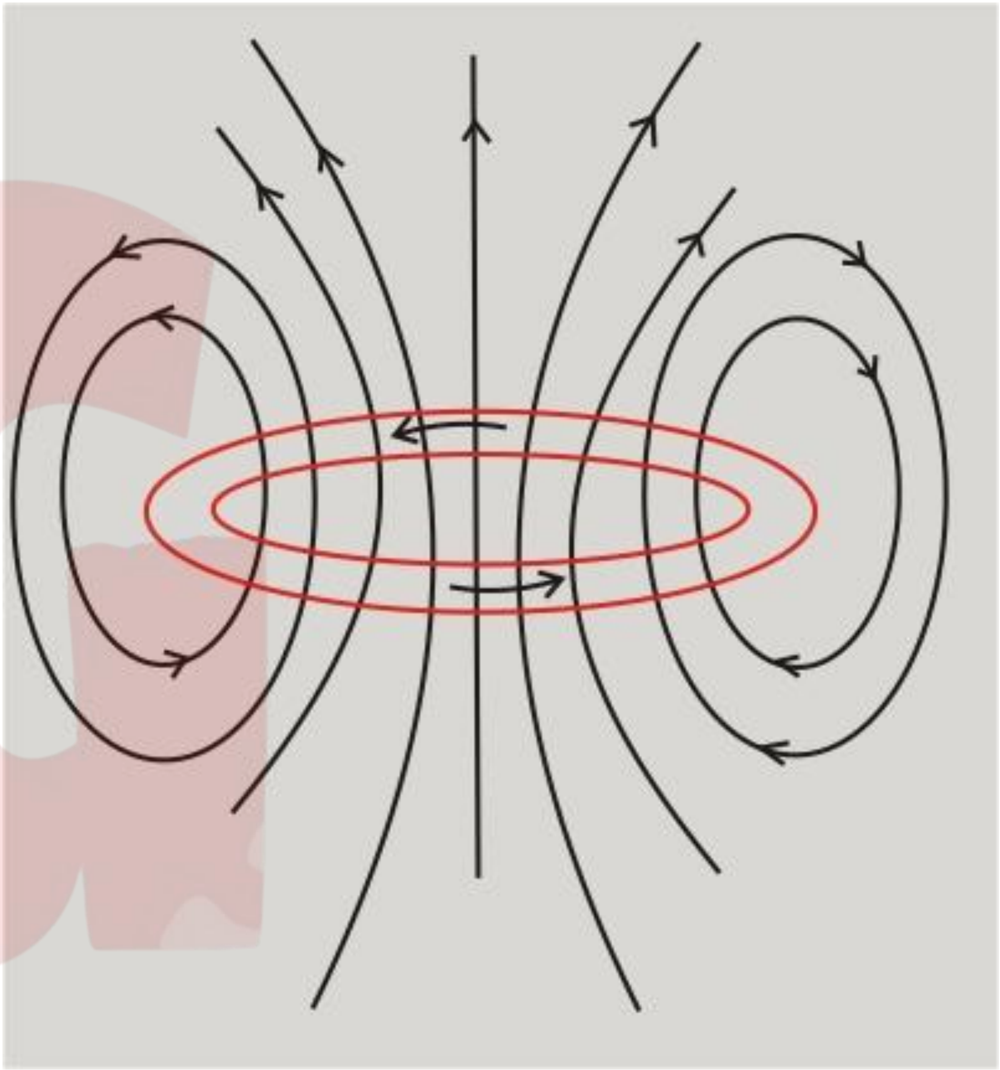


QUESTIONS

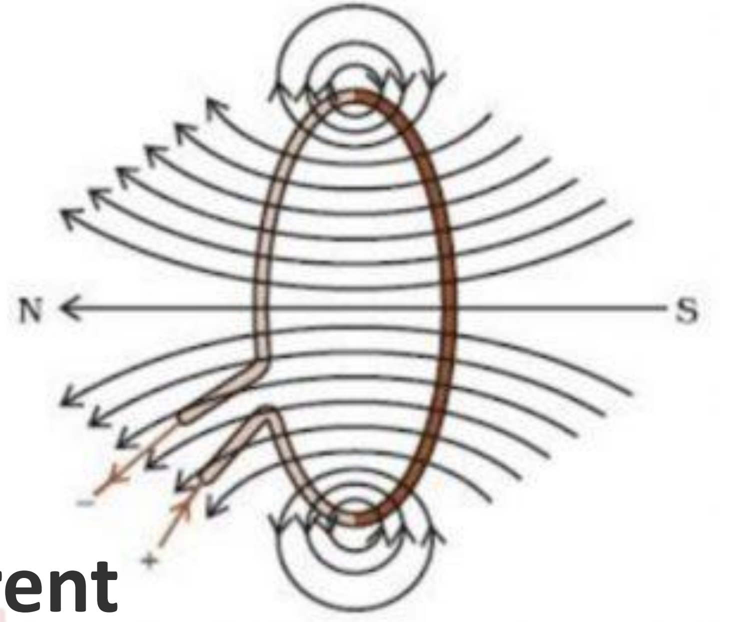
1. Draw magnetic field lines around a bar magnet.
2. List the properties of magnetic field lines.
3. Why don't two magnetic field lines intersect each other?

Magnetic Field due to a Current-carrying Circular Coil/loop



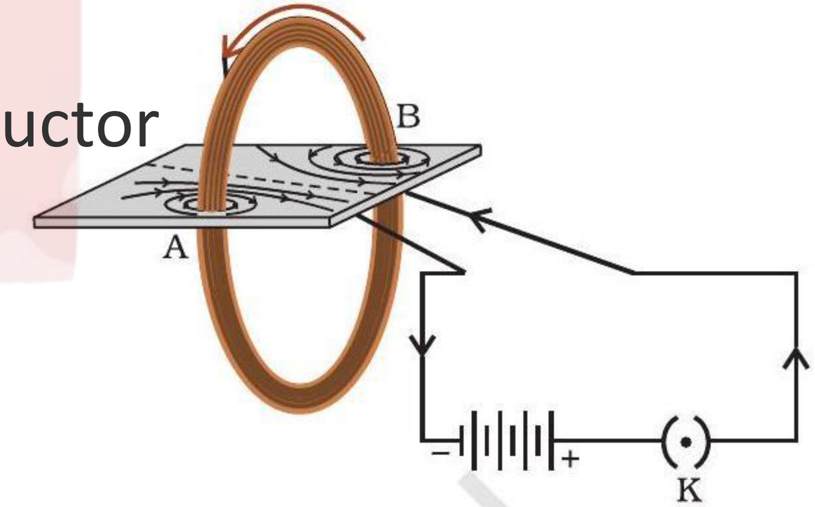


Magnetic Field due to a Current-carrying Circular loop



- The magnetic field lines near the wire(loop) are nearly circular or concentric.
- As we move away, the concentric circles becomes bigger & bigger. At the centre of the circular loop, the magnetic field lines are straight.

Factors affecting magnetic field of a circular current carrying conductor



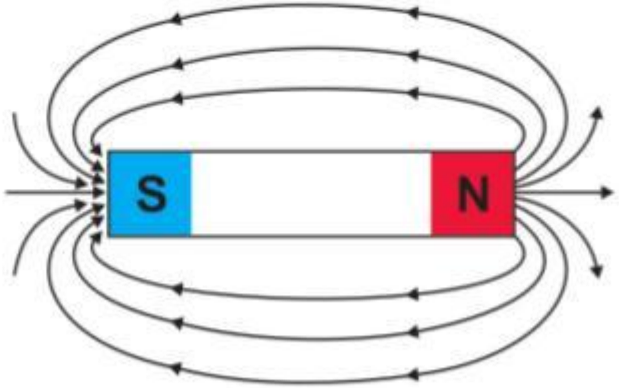
→ Magnetic field ∝ Current passing through the conductor

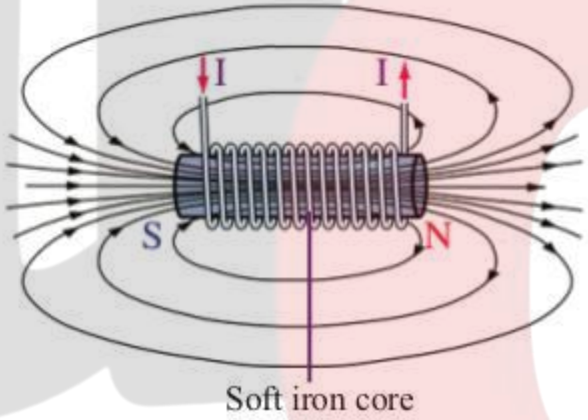
→ $Magnetic \propto 1/Distance\ from\ conductor$

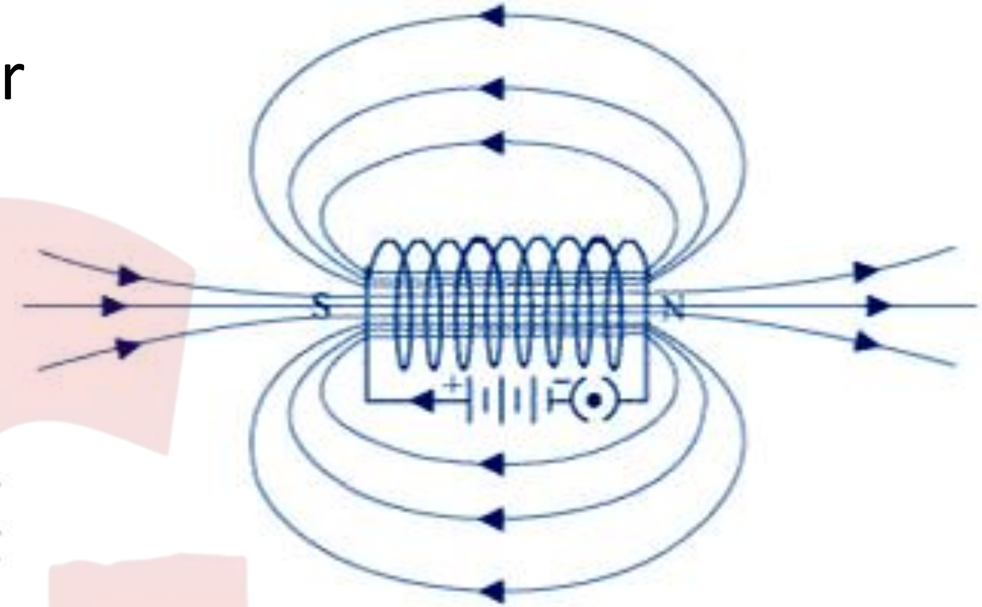
→ Magnetic field ∝ No. of turns in the coil

Magnetic Field due to a Current-carrying Solenoid

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

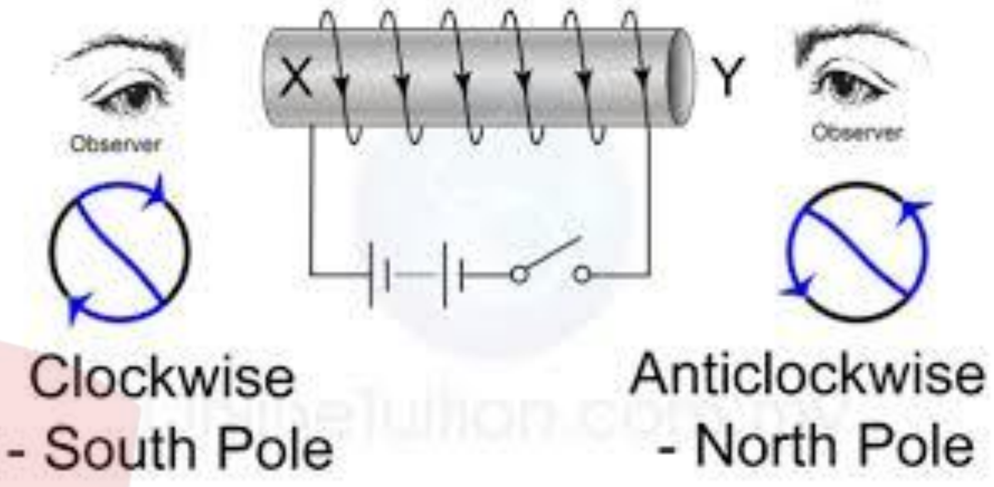


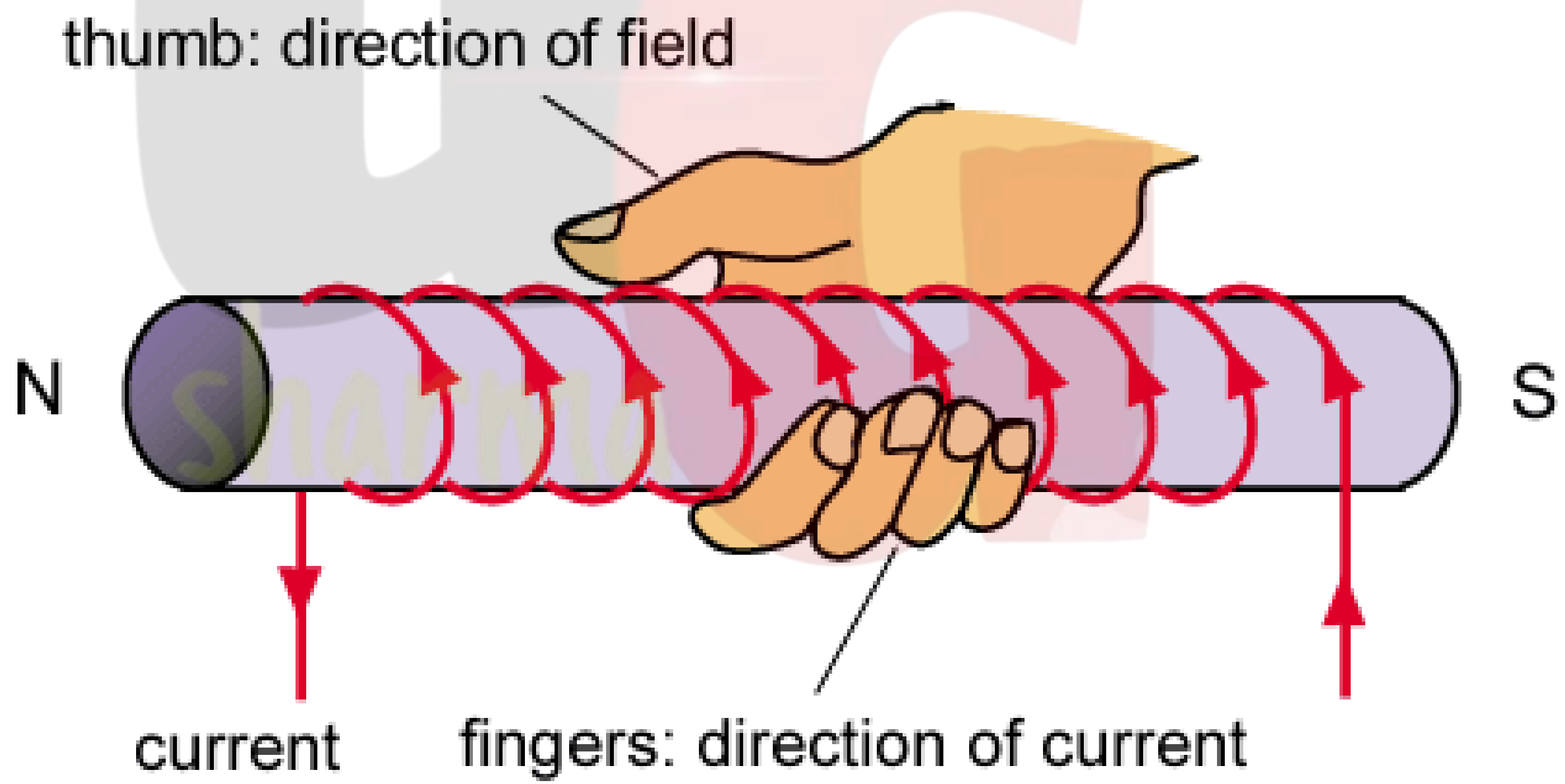




- Magnetic field of a solenoid is similar to that of a bar magnet.
- Magnetic field is uniform inside the solenoid and represented by parallel field lines.

In accordance with the **Clock rule**, the end of the solenoid at which the current flows in the anticlockwise direction behaves as a North Pole, while the end at which the current flows in the clockwise direction behaves as a South Pole.





- Solenoid can be used to magnetise a magnetic material like soft iron, when placed inside coil.
- The magnet so formed is called an electromagnet.
- Soft iron core is used because it loose magnetism when current in coil is switch off

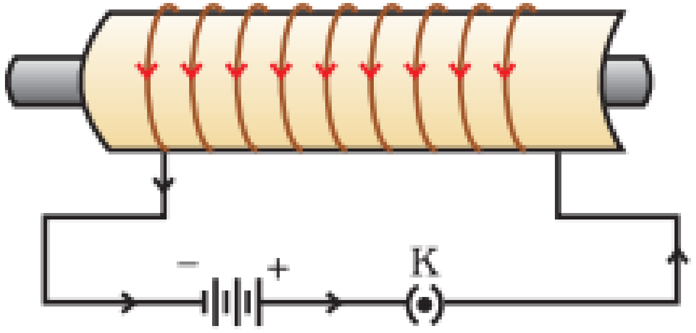
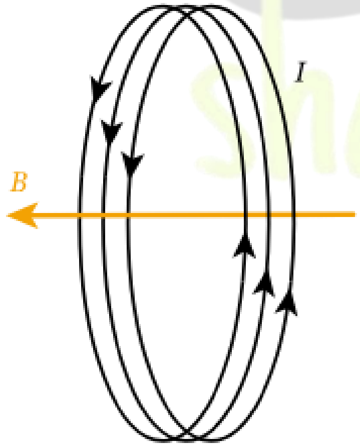
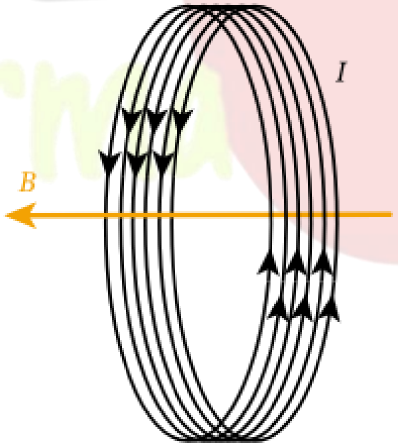


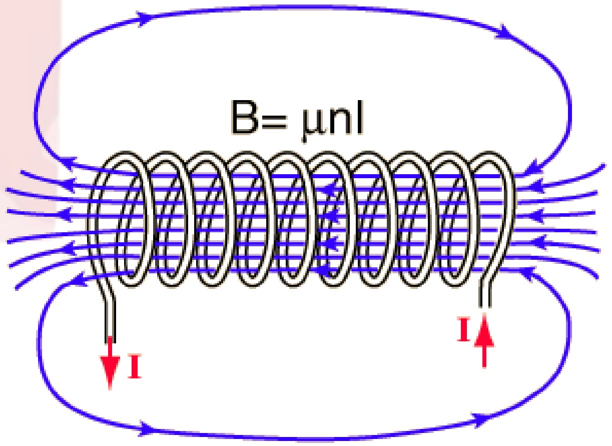
Figure 12.11
A current-carrying solenoid coil is used to magnetise steel rod inside it – an electromagnet.

The magnitude of the magnetic field inside the solenoid is directly proportional to the

- Current flowing through it
- Number of turns per unit length of the solenoid.
- The nature of "core material" used in making electromagnet.



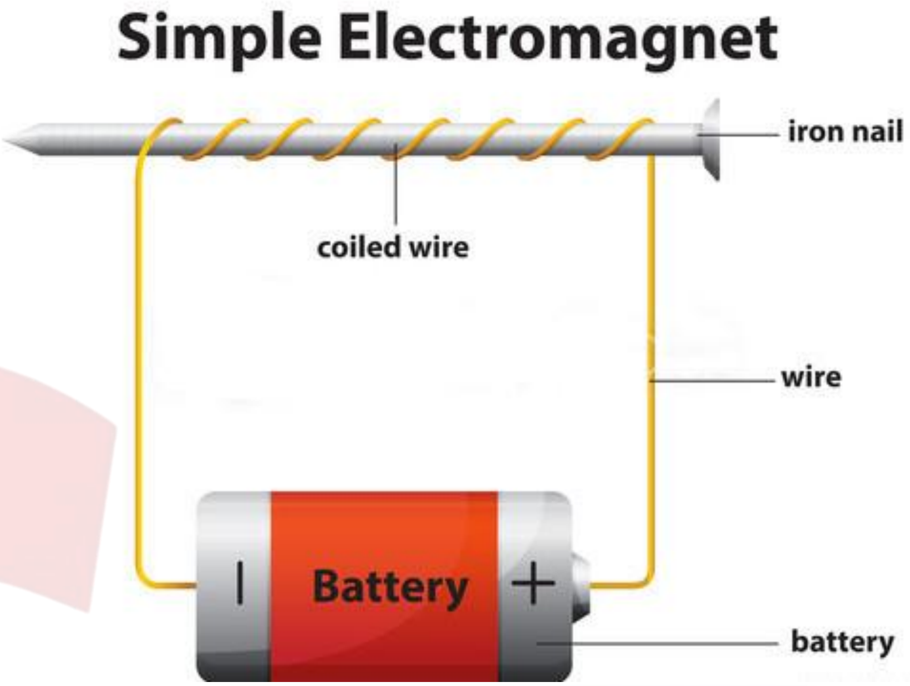




The magnetic field is concentrated into a nearly uniform field in the center of a long solenoid. The field outside is weak and divergent.

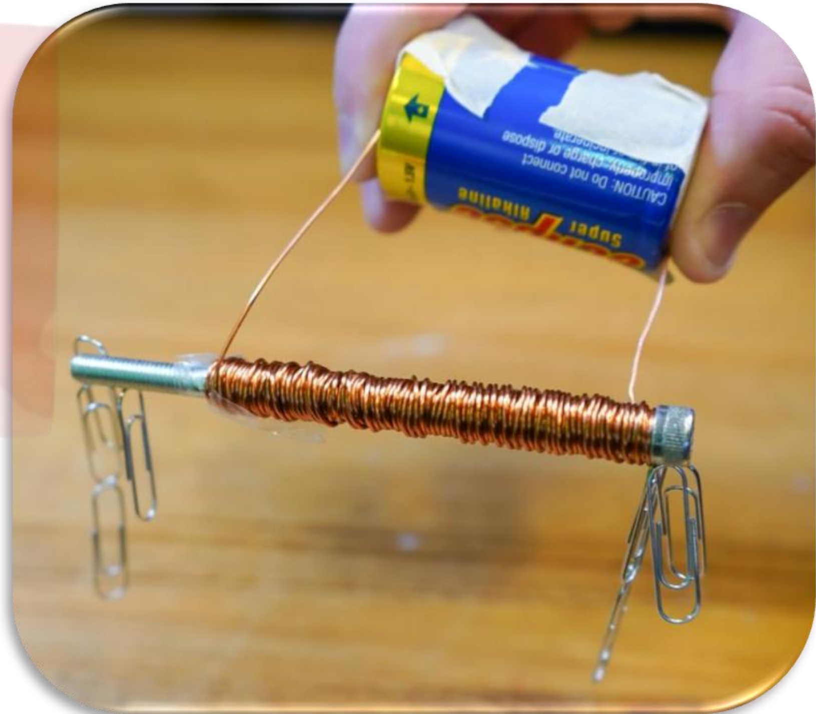
Electromagnet

- It is a temporary magnet, so, can be easily demagnetized.
- Strength can be varied.
- Polarity can be reversed.
- Generally strong magnet.



Permanent Magnet

- Cannot be easily demagnetised.
- Strength is fixed.
- Polarity cannot be reversed.
- Generally weak magnet.



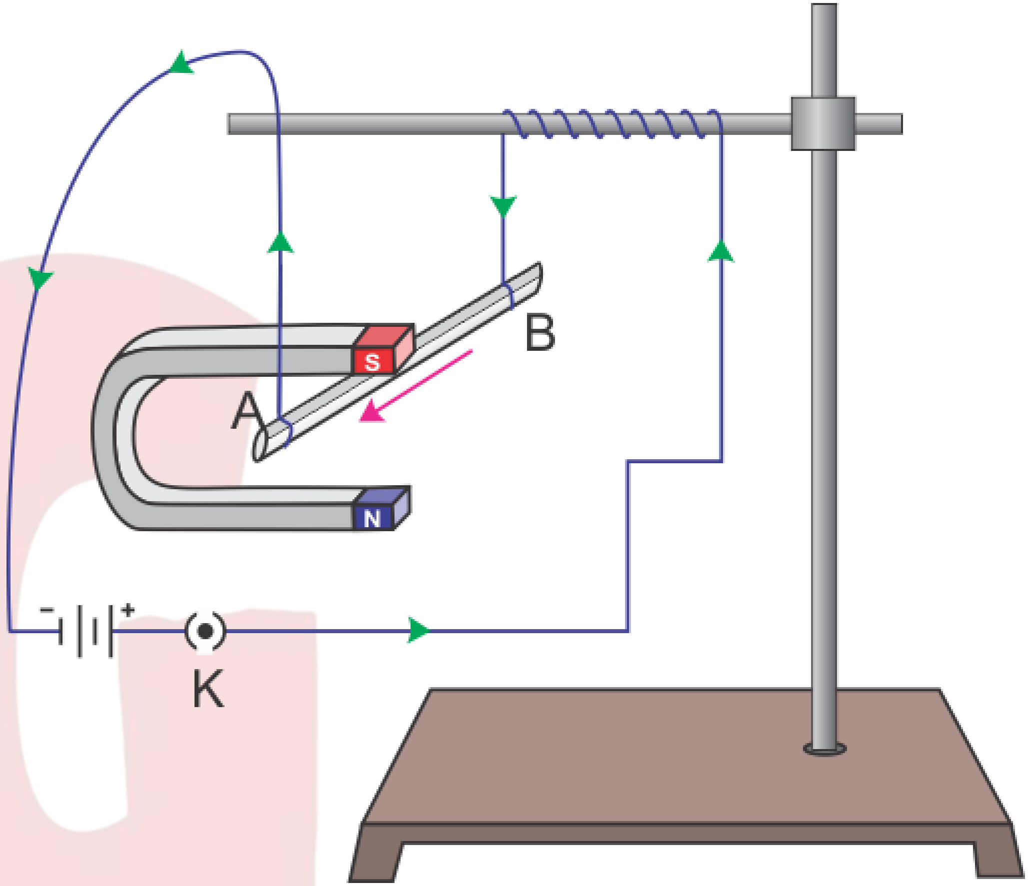
QUESTIONS

1. Consider a circular loop of wire lying in the plane of the table. Let the current pass through the loop clockwise. Apply the right-hand rule to find out the direction of the magnetic field inside and outside the loop.
2. The magnetic field in a given region is uniform. Draw a diagram to represent it.
3. Choose the correct option. The magnetic field inside a long straight solenoid-carrying current

(a) is zero.
(b) decreases as we move towards its end.
(c) increases as we move towards its end.
(d) is the same at all points

Force on a Current carrying Conductor in a Magnetic Field

French scientist Andre Marie Ampere (1775–1836) suggested that the magnet must also exert an equal and opposite force on the current-carrying conductor.



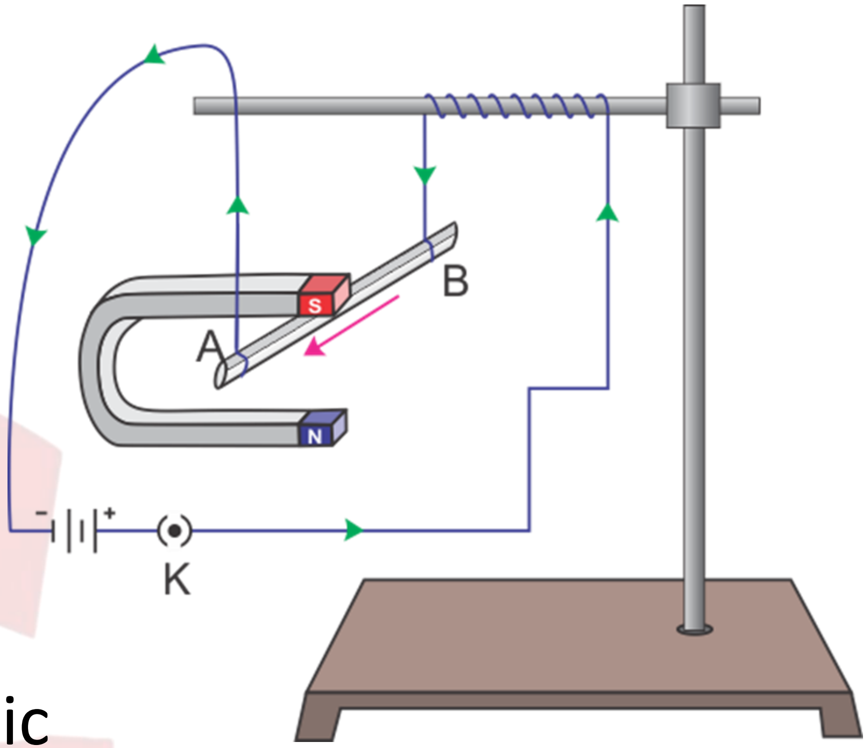
When a current-carrying conductor is placed in a magnetic field, it experiences a **force**.

- The displacement in the conductor is the maximum when the direction of current is at right angle to the direction of magnetic field.

- Direction of force is reversed on reversing the direction of current.

The magnitude of the force is given by the equation:

$$F = ILB\sin\theta$$

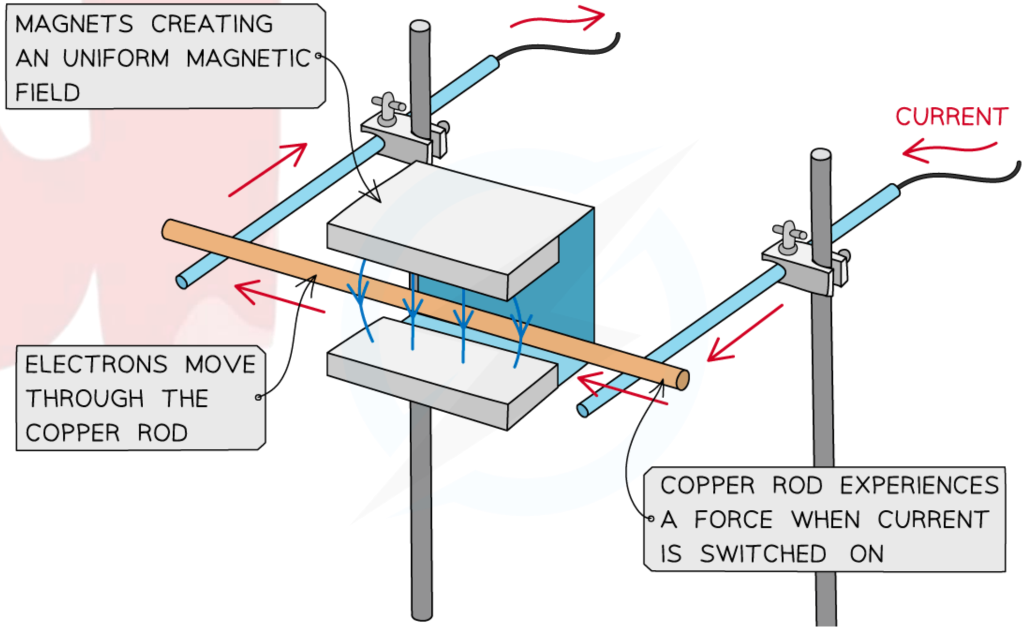


The magnitude of force is directly proportional to :-

I. Current (I)
II. Length of the wire (L), and
III. Magnetic field (B)

When the conductor is placed parallel to the magnetic field (i.e. $\theta = 0$), no force acts on it.

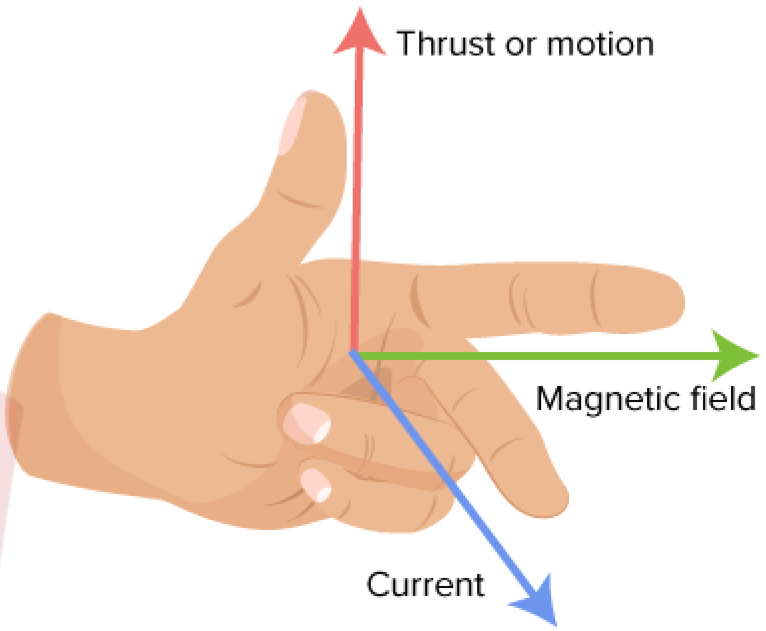
Fleming's Left-Hand Rule gives the direction of the magnetic force acting on the conductor.



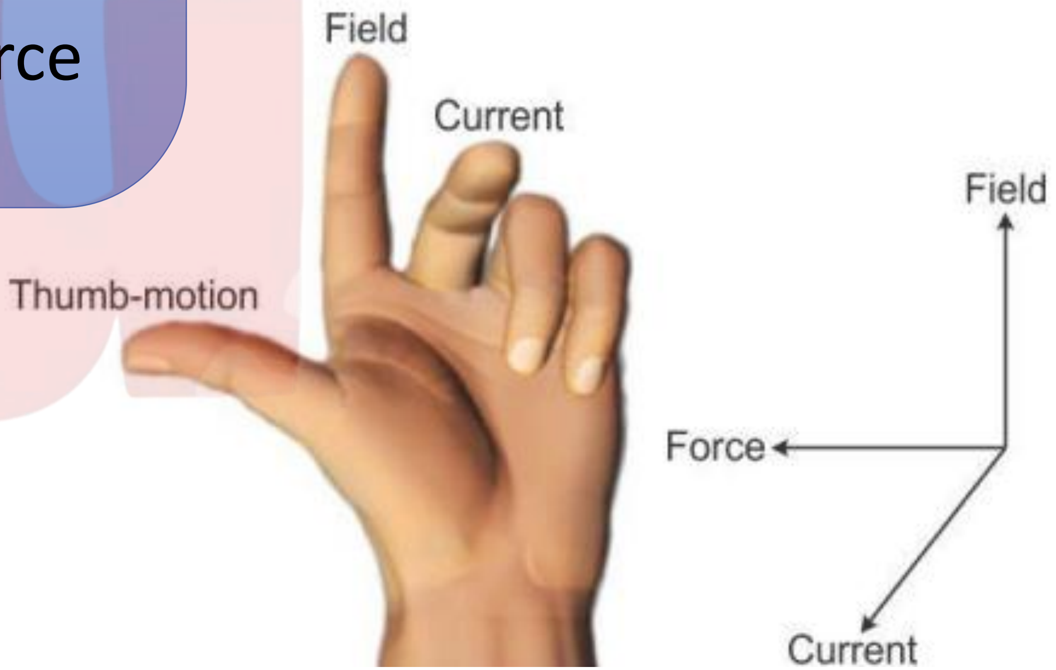
Note :- Direction of force depends on direction of current and magnetic field.

Fleming's Left-Hand Rule

Fleming's Left-Hand Rule:
Stretch the thumb, forefinger and middle finger of the left hand such that they are mutually perpendicular to each other. If the forefinger points in the direction of the field, and the middle finger in the direction of the current, then the thumb gives the direction of motion or the force acting on the conductor.



Thumb → Force / **motion**
First finger (**Forefinger)** → Magnetic **field**
Second finger (**centre finger**)→ **Current**



Heart and brain in the human body have significant magnetic field.

- **MRI (Magnetic Resonance Imaging):** Image of internal organs of body can be obtained using magnetic field of the organ.
- **Galvanometer:** Instrument that can detect the presence of current in a circuit. It also detects the direction of current.

More to Know!

Magnetism in medicine

An electric current always produces a magnetic field. Even weak ion currents that travel along the nerve cells in our body produce magnetic fields. When we touch something, our nerves carry an electric impulse to the muscles we need to use. This impulse produces a temporary magnetic field. These fields are very weak and are about one-billionth of the earth's magnetic field. Two main organs in the human body where the magnetic field produced is significant, are the heart and the brain. The magnetic field inside the body forms the basis of obtaining the images of different body parts. This is done using a technique called Magnetic Resonance Imaging (MRI). Analysis of these images helps in medical diagnosis. Magnetism has, thus, got important uses in medicine.

Example 12.2

An electron enters a magnetic field at right angles to it, as shown in Fig. 12.14. The direction of force acting on the electron will be

(a) to the right.

(b) (b) to the left.

(c) (c) out of the page.

(d) (d) into the page.

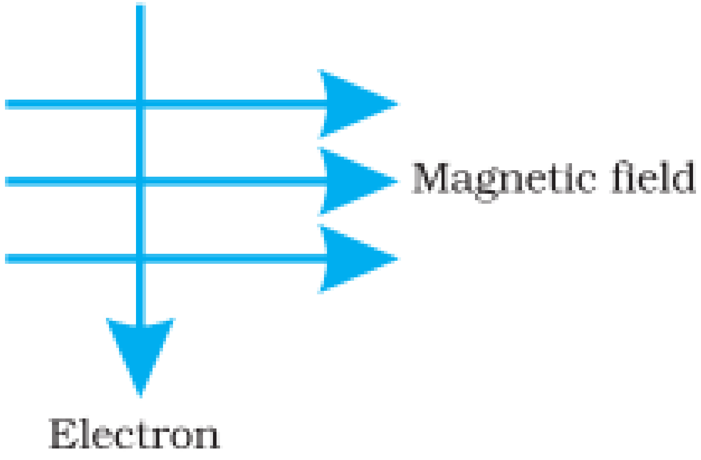


Figure 12.14

Solution

Answer is option (d). The direction of force is perpendicular to the direction of magnetic field and current as given by Fleming's left hand rule. Recall that the direction of current is taken opposite to the direction of motion of electrons. The force is therefore directed into the page.

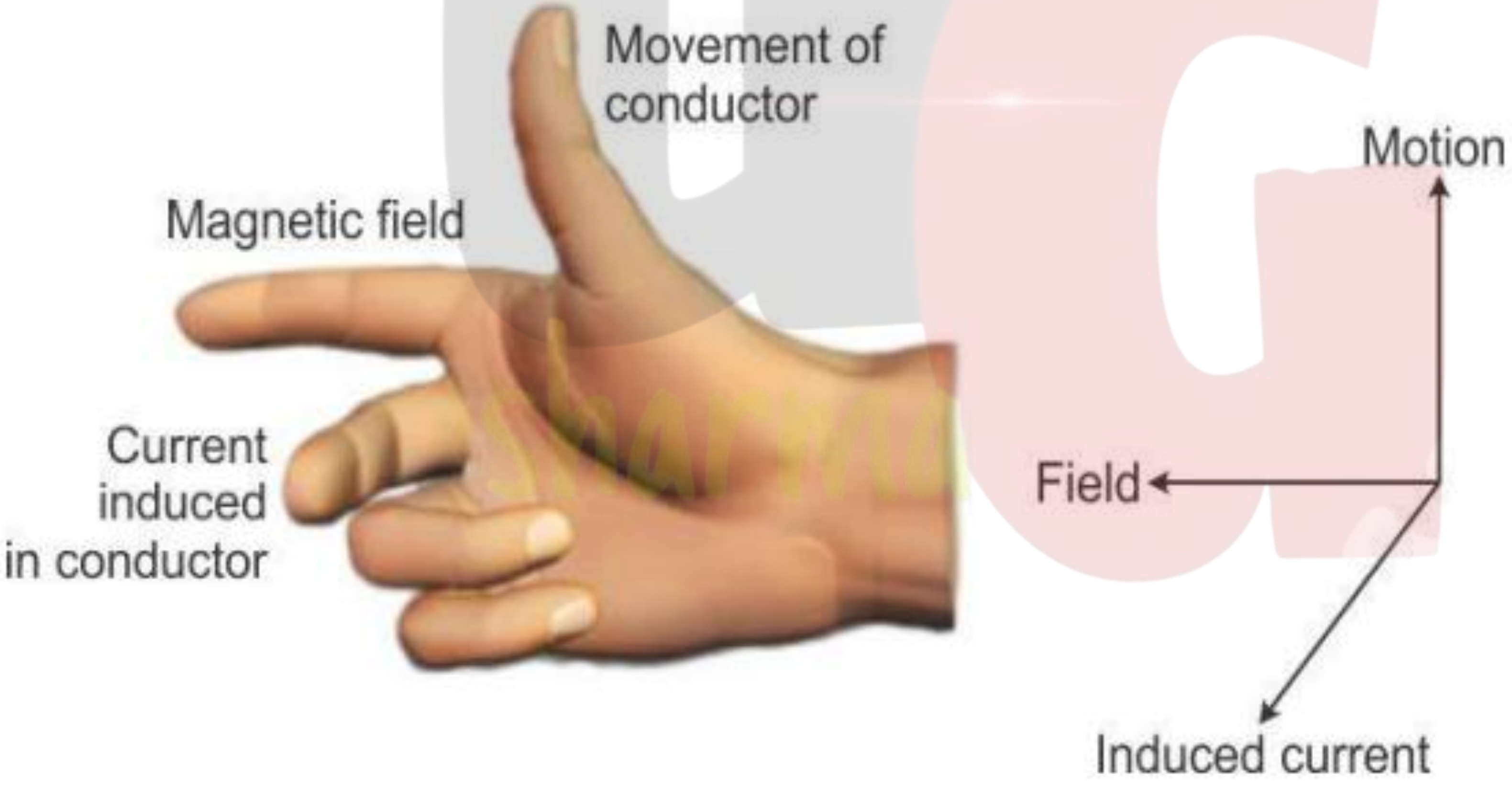
QUESTIONS

1. Which of the following property of a proton can change while it moves freely in a magnetic field? (There may be more than one correct answer.)
   (a) mass (b) speed (c) velocity (d) momentum
2. In Activity 12.7, how do we think the displacement of rod AB will be affected if (i) current in rod AB is increased; (ii) a stronger horse-shoe magnet is used; and (iii) length of the rod AB is increased?
3. A positively-charged particle (alpha-particle) projected towards west is deflected towards north by a magnetic field. The direction of magnetic field is
   (a) towards south (b) towards east
   (c) downward (d) upward

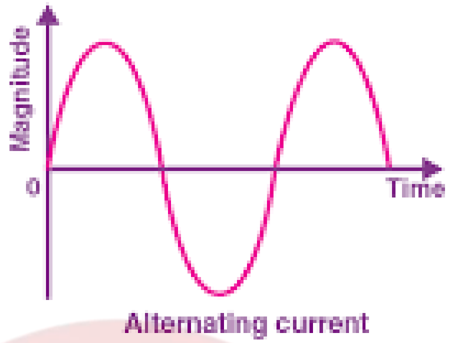
Electromagnetic Induction

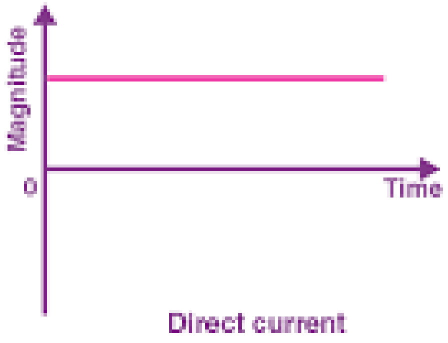
When a conductor is placed in a changing magnetic field, some current is induced in it and the phenomenon is called electromagnetic induction.

Fleming's Right-Hand Rule is used to find the direction of induced current.



Alternate Current (A. C.)





The current which reverses its direction periodically.

In India, A. C. reverses its direction in every 1/100 second.
Time period = 1/100 + 1/100 = 1/50 s
Frequency = 1/time period = 1/50 = 50 Hz

Advantage of A.C.

→ A. C. can be transmitted over long distance without much loss of energy.

Disadvantage of A.C.

→ A. C. cannot be stored.

Direct Current (D. C.)

The current which does not reverse its direction.

- D. C. can be stored.
- Loss of energy during transmission over long distance is high.
- Sources of D. C.: Cell, Battery, Storage cells.

3 Marks

1. Distinguish between AC and DC.
2. Explain why DC is used in electronic devices but AC in home supply.

Important NCERT/Board Questions

1 Mark

1. What is the direction of magnetic field inside a solenoid?
2. State the Right-Hand Thumb Rule.

2 Mark

1. Why is a soft iron core used in electromagnets?
2. Distinguish between AC and DC.

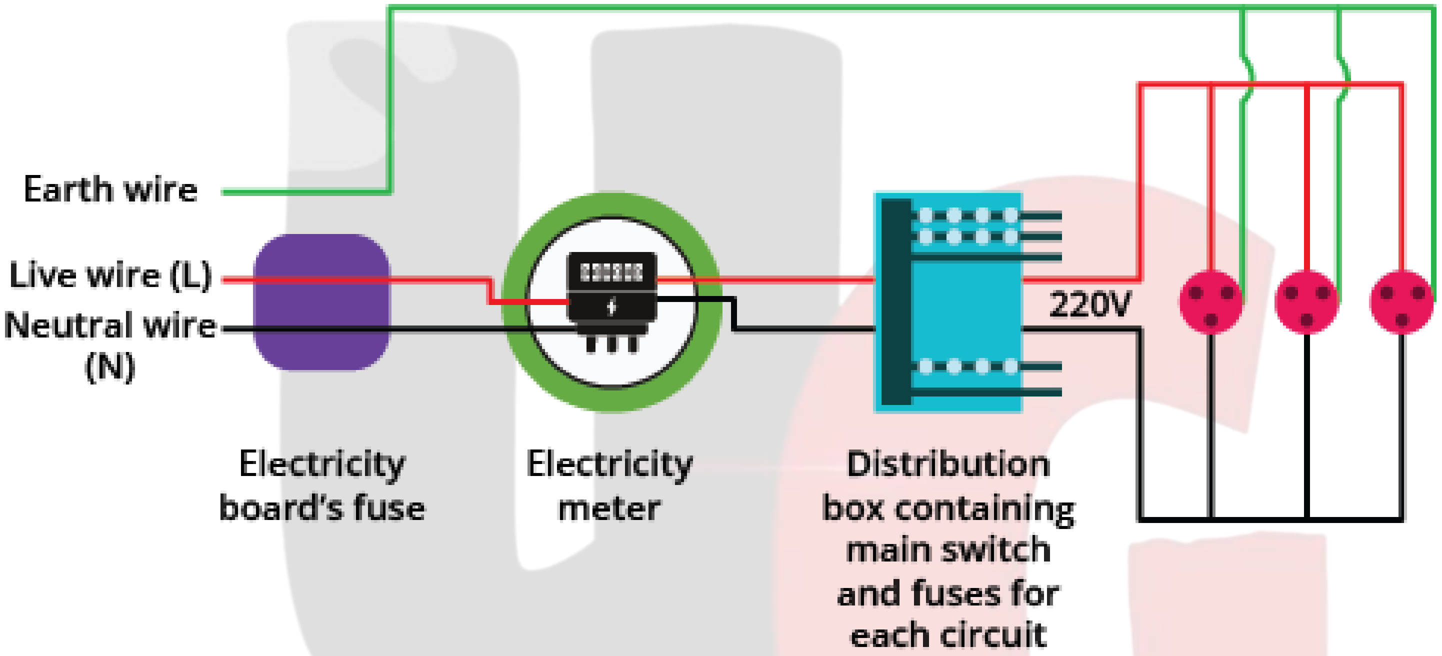
3 Mark

1. Draw field lines of solenoid.
2. Explain the working of an electric motor with diagram.

5 Mark

1. Derive force on a conductor & state Fleming's Left-Hand Rule.

Domestic Electric Circuits



A **domestic electric circuit** refers to the complete system through which electricity is supplied and distributed in homes.

In India, electricity is supplied as:

- **AC (Alternating Current)**
- **Frequency = 50 Hz**
- **Voltage = 220 V**

Types of Wires in Household Wiring

(1) Live Wire (Phase Wire)

•Usually **red** in color.

•Carries **current at 220 V** from the power station to the house.

(2) Neutral Wire

•Usually **black** in color.

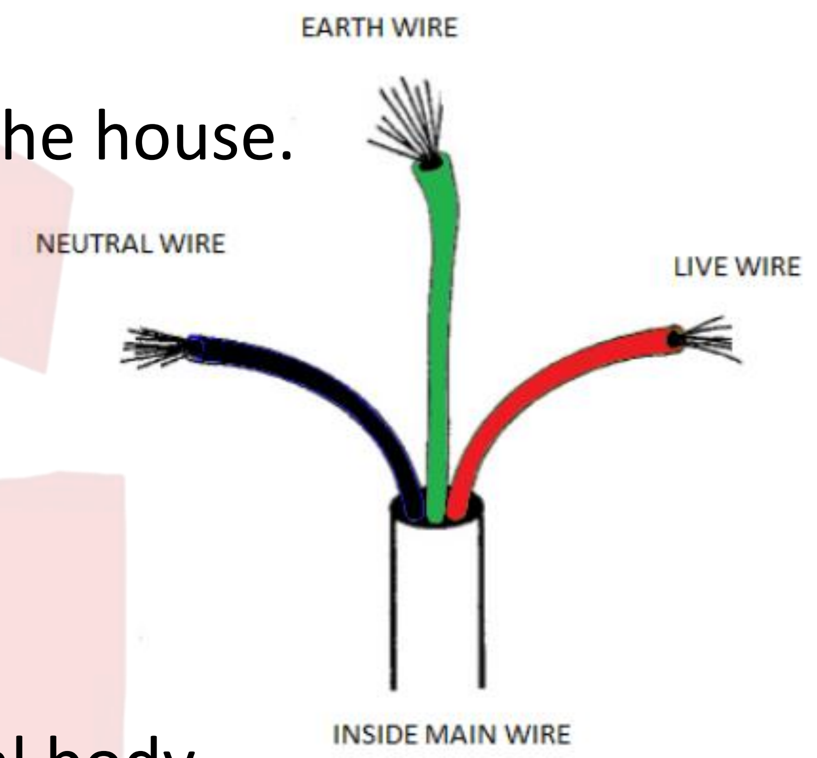
•Completes the circuit by returning current back.

(3) Earth Wire (Earthing Wire)

•Usually **green** in color.

•Connected to metallic body of appliances.

•Prevents **electric shock** if live wire touches the metal body.



Main Components of Domestic Wiring System

1. Electric Meter

•Also called **Energy Meter**.

•Measures **electrical energy consumed**, in **kWh (kilowatt-hour)** or **unit**.

2. Main Fuse / MCB (Miniature Circuit Breaker)

•Installed after the meter.

•Protects the entire house from:

- Overloading
- Short circuit

•Modern houses use **MCBs**, which automatically trip during faults.

Distribution Board

Contains:

(a) Main Switch

•Controls power supply to the entire house.

(b) Individual Circuit MCBs

Different circuits for:

•Lights and fans

•Power plugs

•AC or refrigerator

Prevents complete blackout if one circuit fails.

Household Wiring System

There are two types:

⭐ A. Series Circuit (NOT used in houses)

- All devices connected one after another.
- If one device fails, **entire circuit stops**.
- Voltage is **distributed**, appliances do not get rated voltage.

Therefore, **series connection is dangerous for home use**.

⭐ B. Parallel Circuit (USED in houses)

- All appliances connected separately across the same two points.
- **Advantages:**
  - Each appliance gets **220 V** independently.
  - If one appliance stops, others keep working.
  - Each appliance can be controlled separately with switches.
  - Total resistance decreases → less power loss.

Thus, **parallel connection is ideal for household wiring**.

Earthing (Grounding)

Earthing is a safety measure where the metal body of electrical appliances is connected to the earth.

Purpose of Earthing

- Prevents **electric shock**.
- Provides a **low-resistance path** for leakage current.
- Keeps the metal body of appliances at **zero potential**.

When is Earthing Needed?

Appliances with metal body such as:

- Iron, Refrigerator
- Geyser, Microwave
- Washing machine

Earthing wire is connected to the **outer body**, so if live wire touches the body:

- Current flows to ground
- **User remains safe**

Fuse

What is a Fuse?

A fuse is a safety device made of thin metal wire that **melts** when excessive current flows.

Function of a Fuse

•Protects appliances from **overloading** and **short circuit**.

•Breaks the circuit when current is high.

Why fuse wire melts?

•Fuse wire has **low melting point**.

•High current → high heat → fuse melts → circuit breaks.

Overloading & Short Circuit

(A) Overloading

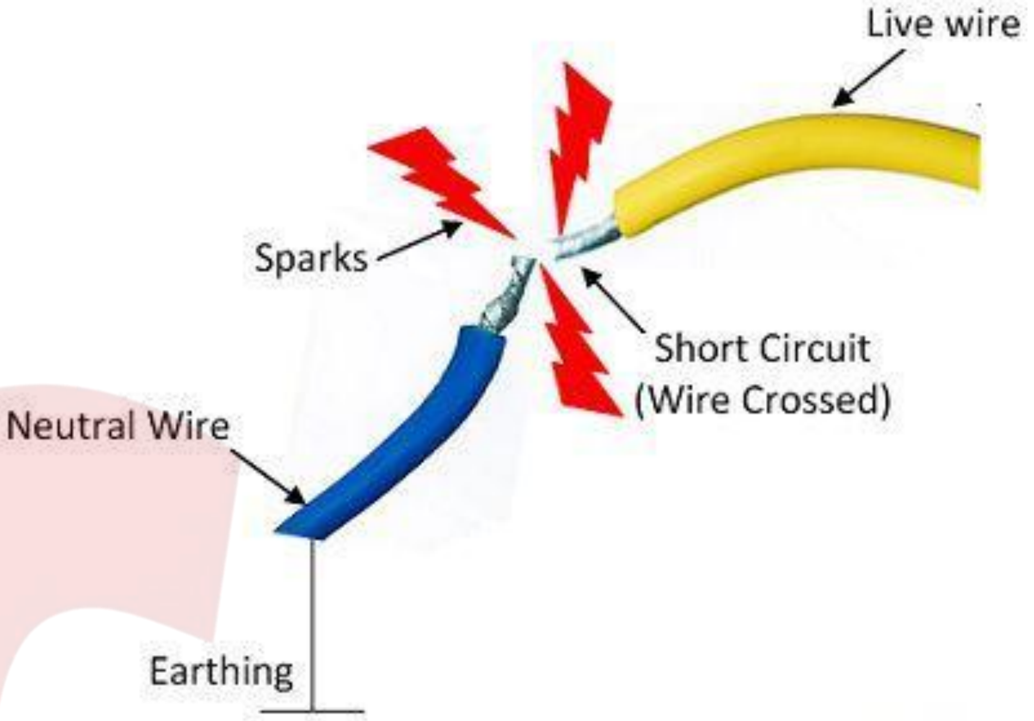
Occurs when:

•Too many appliances used simultaneously

•High current flows through circuit

•Wires heat up

Result: MCB trips or fuse blows.



(B) Short Circuit

Occurs when:

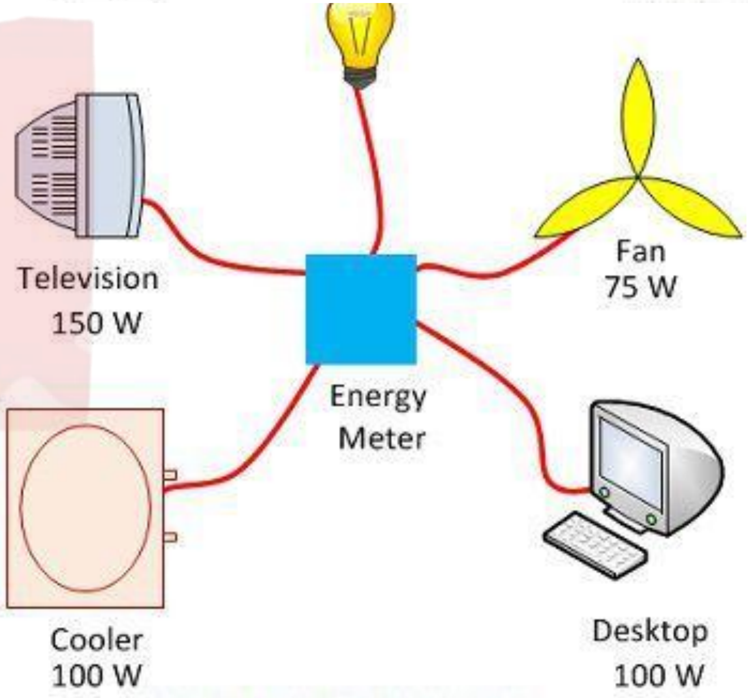
•Live and neutral wires touch each other

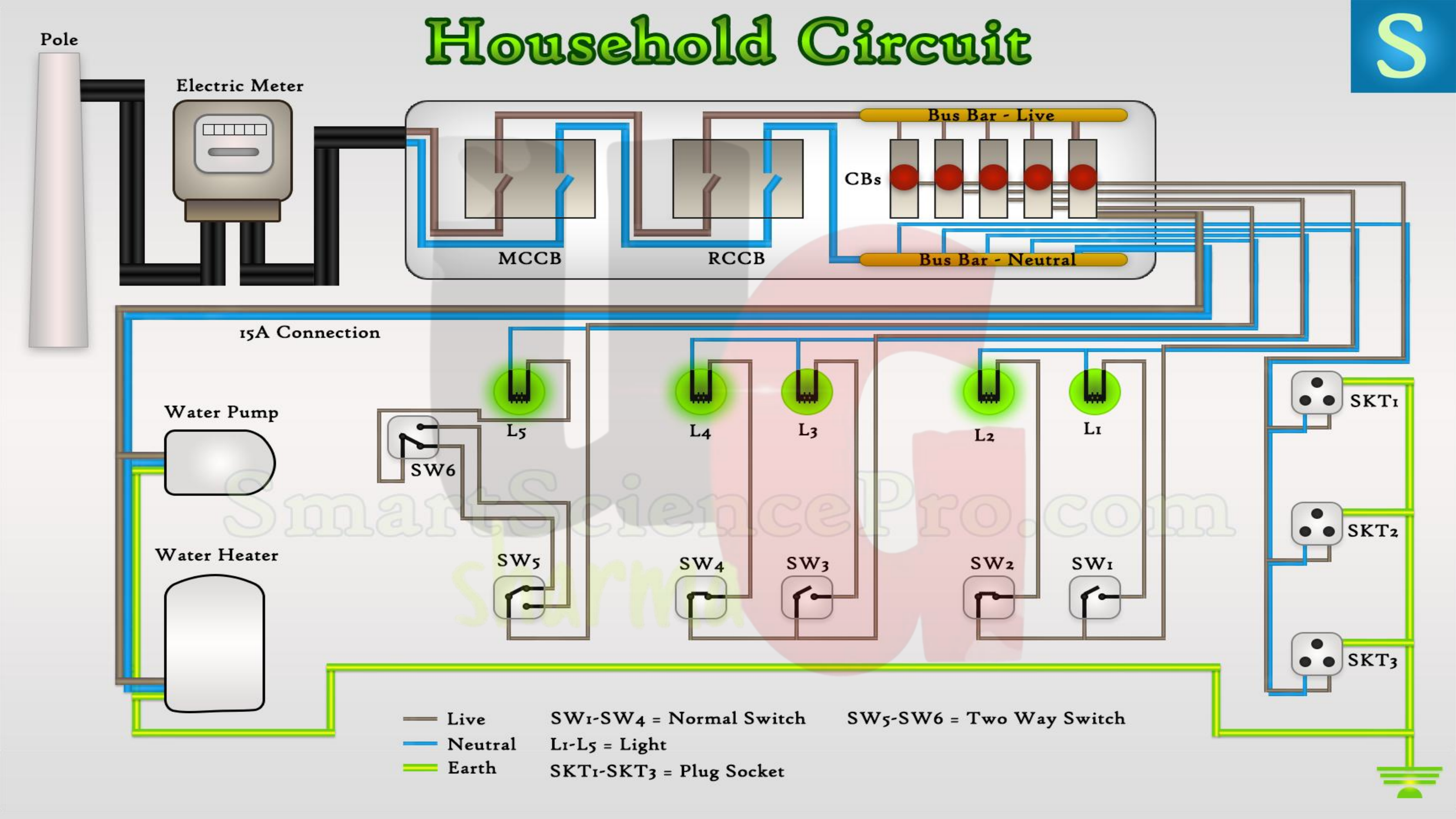
•Resistance becomes almost zero

•Huge current flows instantly

•Sparks, fire, melting of wires may occur

MCB trips immediately to prevent fire.




Household Circuit
Pole
Electric Meter
MCCB
RCCB
Bus Bar - Live
Bus Bar - Neutral
CBs
15A Connection
Water Pump
Water Heater
L5
L4
L3
L2
L1
SW6
SW5
SW4
SW3
SW2
SW1
SKT1
SKT2
SKT3
Live
Neutral
Earth
SW1-SW4 = Normal Switch
L1-L5 = Light
SKT1-SKT3 = Plug Socket
SW5-SW6 = Two Way Switch
SmartSciencePro.com

Board Exam Common Questions

1 Mark

- Why is earthing important?
- What is the function of MCB?

2 Mark

- Why is parallel connection used in homes?

3 Mark

- Explain short circuit and overloading.

5 Mark

- Draw and explain a domestic wiring diagram (expected frequently!).

Why is earth pin longest?

- Connects first for safety
- Disconnects last when unplugged

QUESTIONS

1. Name two safety measures commonly used in electric circuits and appliances.
2. An electric oven of 2 kW power rating is operated in a domestic electric circuit (220 V) that has a current rating of 5 A. What result do you expect? Explain.
3. What precaution should be taken to avoid the overloading of domestic electric circuits?

EXERCISES

1. Which of the following correctly describes the magnetic field near a long straight wire?
   (a) The field consists of straight lines perpendicular to the wire.
   (b) The field consists of straight lines parallel to the wire.
   (c) The field consists of radial lines originating from the wire.
   (d) The field consists of concentric circles centred on the wire.
2. At the time of short circuit, the current in the circuit
   (a) reduces substantially.
   (b) does not change.
   (c) increases heavily.
   (d) vary continuously.
3. State whether the following statements are true or false.
   (a) The field at the centre of a long circular coil carrying current will be parallel straight lines.
   (b) A wire with a green insulation is usually the live wire of an electric supply.
4. List two methods of producing magnetic fields.
5. When is the force experienced by a current–carrying conductor placed in a magnetic field largest?
6. 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?
7. State the rule to determine the direction of a (i) magnetic field produced around a straight conductor-carrying current, (ii) force experienced by a current-carrying straight conductor placed in a magnetic field which is perpendicular to it, and (iii) current induced in a coil due to its rotation in a magnetic field.
8. When does an electric short circuit occur?
9. What is the function of an earth wire? Why is it necessary to earth metallic appliances?