Practical Applications of Heating Effect

Exploring Joule's Heating in Electric Circuits and Everyday Appliances

Joule's Heating Effect

- The generation of heat in a conductor is an **inevitable consequence** of electric current.
- In some circuits, this is undesirable as it converts useful electrical energy directly into heat.
- However, this heating effect has many **highly useful applications** in familiar devices.
- These devices harness thermal energy efficiently for everyday tasks.

Household Appliances

Electric

Iron

Electric

Toaster

Electric

Kettle

The Electric Oven

- The electric oven is another prime example of Joule's heating in action.
- It utilizes internal high-resistance heating elements to convert electrical energy into intense thermal energy.
- The insulated chamber traps the heat, allowing for efficient baking and roasting of food.

The Electric Bulb

- Electric heating is used to produce light. The filament retains heat until it emits light.
- The filament must not melt. It requires a strong metal with a high melting point, such as **Tungsten**.
- Tungsten's melting point: $3380°C$
- Bulbs are filled with chemically inactive **nitrogen and argon** gases to prolong the filament's life.

The Electric Fuse

- Protects circuits and appliances by stopping the flow of unduly high electric current.
- Placed in **series** with the device.
- Consists of a piece of wire made of metal/alloy (e.g., aluminum, copper, iron, lead) with an appropriate melting point.
- If a high current flows, the fuse temperature rises, melting the wire and breaking the circuit.

Fuse Ratings & Calculation

Standard Ratings

Fuses for domestic purposes are commonly rated as **1 A, 2 A, 3 A, 5 A, 10 A**, etc.

Current Calculation

$$I = \frac{P}{V} = \frac{1000\ \mathrm{W}}{220\ \mathrm{V}} = 4.54\ \mathrm{A}$$

Example Scenario

An electric iron consumes **1 kW (1000 W)** of power when operated at **220 V**.

Required Fuse

Therefore, a 5 A fuse must be used in the circuit.

Understanding Electric Power

The Rate of Energy Consumption in Electric Circuits

What is Electric Power?

General Definition

Recall that **power** is the rate of doing work.

Energy Aspect

It is also defined as the **rate of consumption of energy**.

In Electrical Circuits

In an electric circuit, the rate at which electric energy is dissipated or consumed is termed **electric power**.

Power Equations

$$P = VI$$

$$P = I^2 R = \frac{V^2}{R}$$

(Eq 11.22)

The SI Unit of Power

- The SI unit of electric power is the **watt (W)**.
- It represents the power consumed by a device that carries
  1 A of current when operated at a potential difference of **1 V**.

$$1 \text{ W} = 1 \text{ volt} \times 1 \text{ ampere} = 1 \text{ V A}$$

(Eq 11.23)

Commercial Unit of Energy

- The unit 'watt' is very small for practical use.
- A much larger unit is used: the **kilowatt (kW)**, which equals 1000 watts.
- Since Electrical Energy = Power × Time, the unit of energy is **watt hour (W h)**.
- 1 W h = energy consumed when 1 watt is used for 1 hour.
- The commercial unit is the **kilowatt hour (kW h)**, commonly known as a **'unit'**.

Converting kW h to Joules

How many Joules are in one commercial 'unit' of electricity?

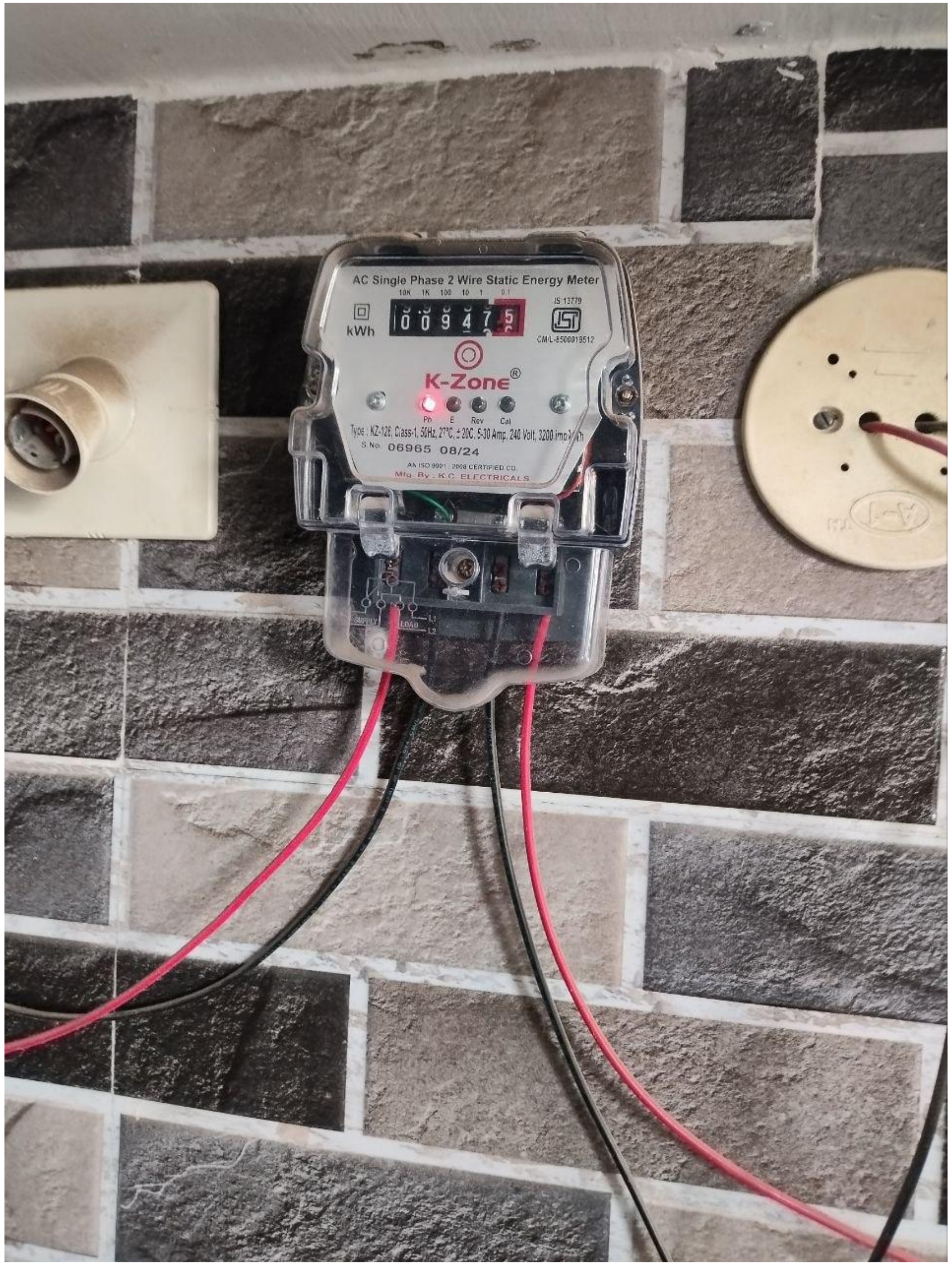
$$1 \text{ kW h} = 1000 \text{ watt} \times 3600 \text{ second}$$

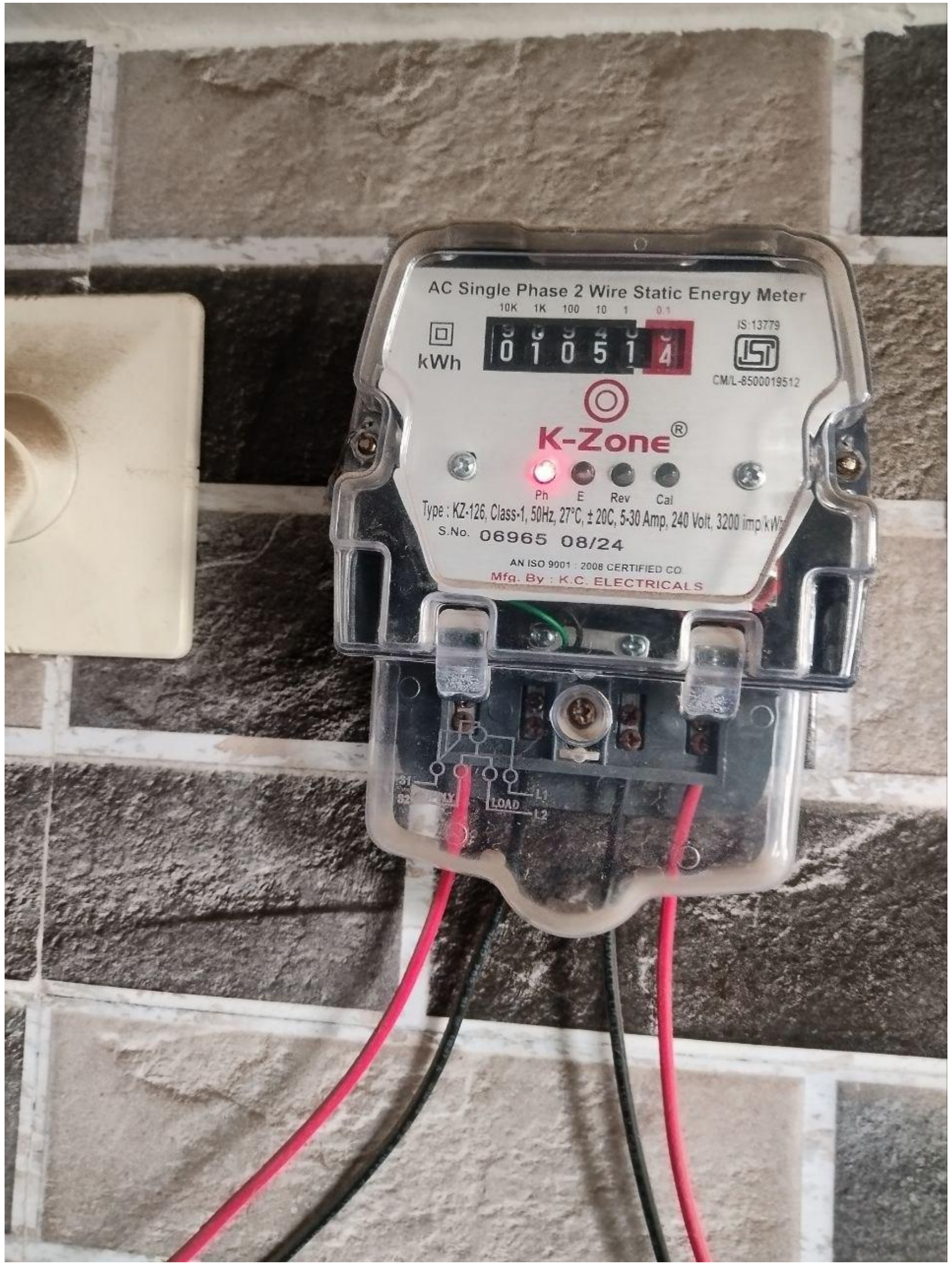
$$= 3.6 \times 10^6 \text{ watt second}$$

$$\mathbf{= 3.6 \times 10^6 \text{ joule (J)}}$$

How to Calculate Your Electricity Bill!

A step-by-step math guide based on your notes.


AC Single Phase 2 Wire Static Energy Meter
10K 1K 100 10 1 0.1
0 0 9 4 7 5
kWh
IS:13779
CM/L-8500019512
K-Zone
S.No. 06965 08/24
AN ISO 9001 : 2008 CERTIFIED CO.
Mfg. By : K.C. ELECTRICALS


AC Single Phase 2 Wire Static Energy Meter
10K 1K 100 10 1 0.1
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kWh
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Ph E Rev Cal
Type : KZ-126, Class-1, 50Hz, 27°C, ± 20C, 5-30 Amp, 240 Volt, 3200 imp/kWh
S.No. 06965 08/24
AN ISO 9001 : 2008 CERTIFIED CO
Mfg. By : K.C. ELECTRICALS
SUPPLY
LOAD

Step 1: Find the Units Used

This Month - Last Month = Units Used

1051 - 947 = 104

Reading the Meter

To find out how much electricity we used this month, we take the new meter reading and subtract the old reading.

According to the notes, the reading went from 947 up to 1051.

That means we used a total of 104 units!

Wait, what is a "Unit"?

1 Unit = 1 kWh

As written in the notes, every one Kilowatt Hour (kWh) of electricity used is called a "Unit".

The Price

The electricity company charges a specific price for every single unit used. The notes show the price of 1 unit is ₹7.15.

Step 2: Calculate the Total Bill

Doing the Math

Now that we know we used 104 units, and each unit costs ₹7.15, we just need to multiply them together!

When we multiply the units by the price, we get the grand total for this month's light bill.

Price × Units = Total Bill

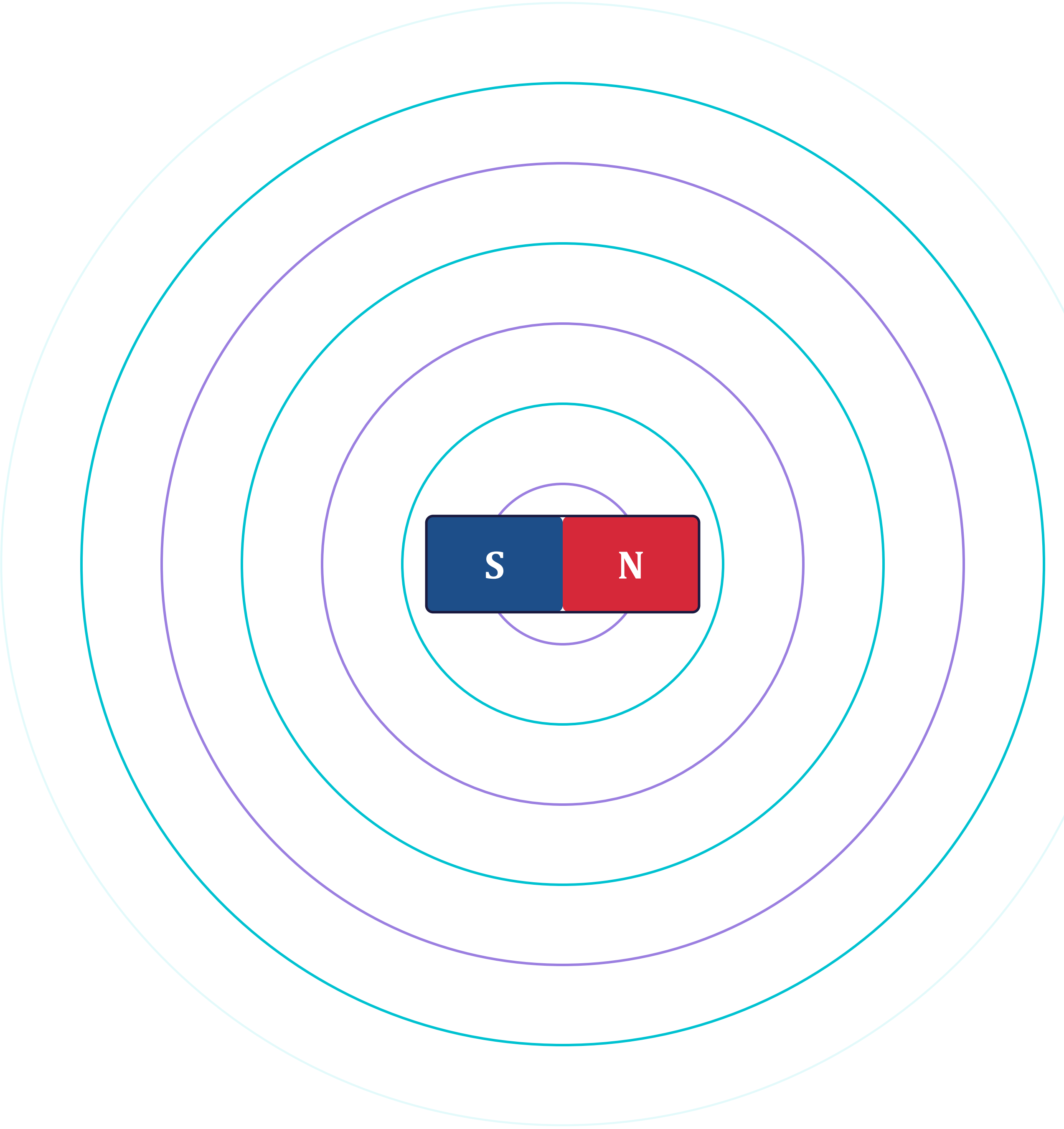
$$7.15 \times 104 = 743$$

PHYSICS • ELECTROMAGNETISM

Magnetic Effects of Electric Current

How a flow of charge creates a magnetic field — from Oersted's accidental discovery to the field around a straight current-carrying wire.

- Oersted's Experiment
- Field Lines
- Straight Conductor



Electricity Meets Magnetism

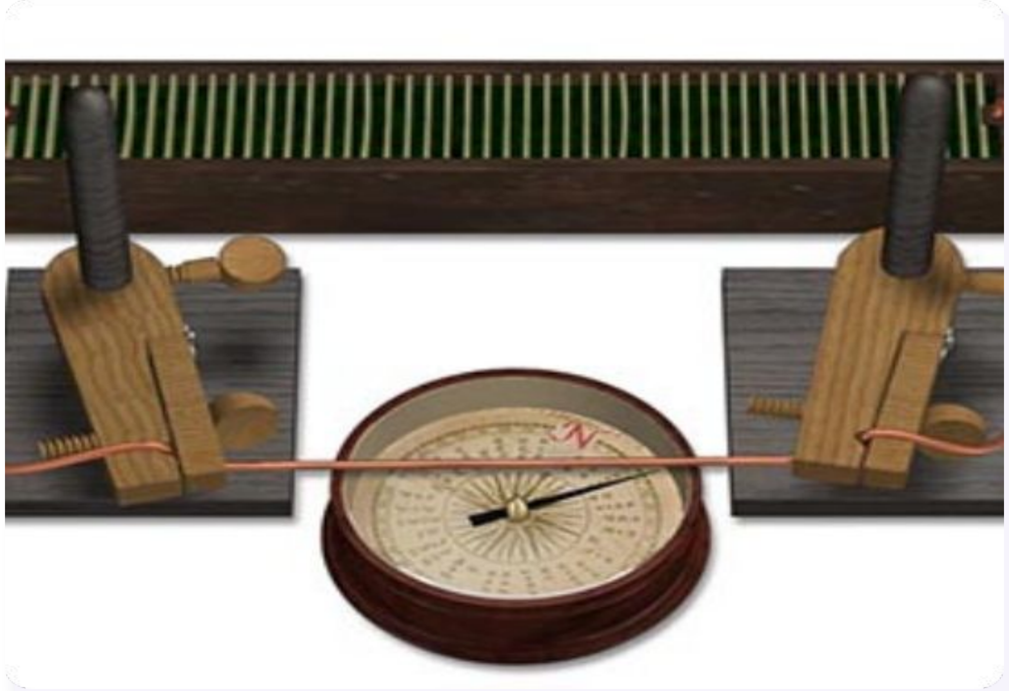
A simple experiment shows that electricity and magnetism are linked.

1. **Set up the circuit**
   Place a straight, thick copper wire between points X and Y in an electric circuit, held perpendicular to the plane of the paper.

2. **Position a compass**
   Horizontally place a compass close to the copper wire, undisturbed by any current.

3. **Pass the current**
   On closing the key, the compass needle deflects — current through the wire produces a magnetic effect.

4. **Draw the conclusion**
   A current-carrying wire behaves like a magnet.



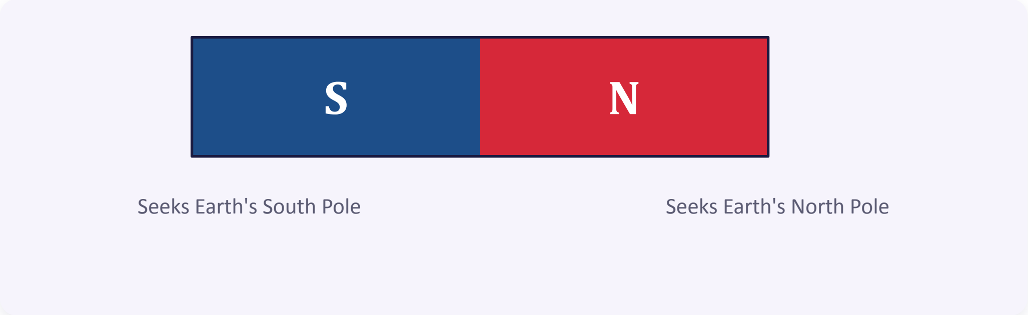
Hans Christian Oersted (1820) accidentally discovered the deflection of a compass needle near a current-carrying wire. **Unit of magnetic field strength: oersted.**

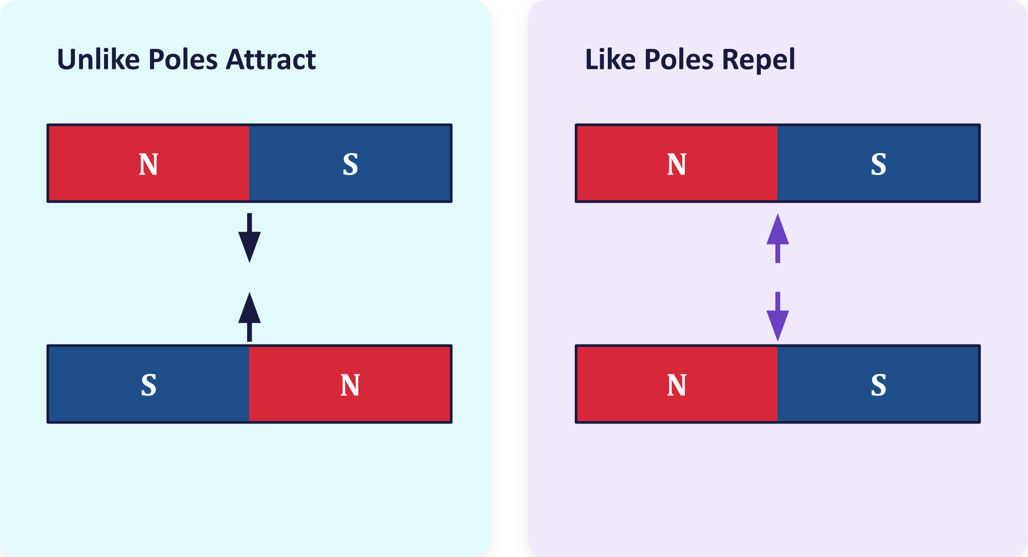
A Compass Needle Is a Tiny Bar Magnet

1. **North & south seeking ends**
   Its ends point toward the north and south — it gets deflected when brought near a bar magnet.

2. **Naming the poles**
   The end pointing north is the north-seeking (north) pole; the other, pointing south, is the south-seeking (south) pole.

3. **The golden rule**
   Like poles repel each other; unlike poles attract each other.

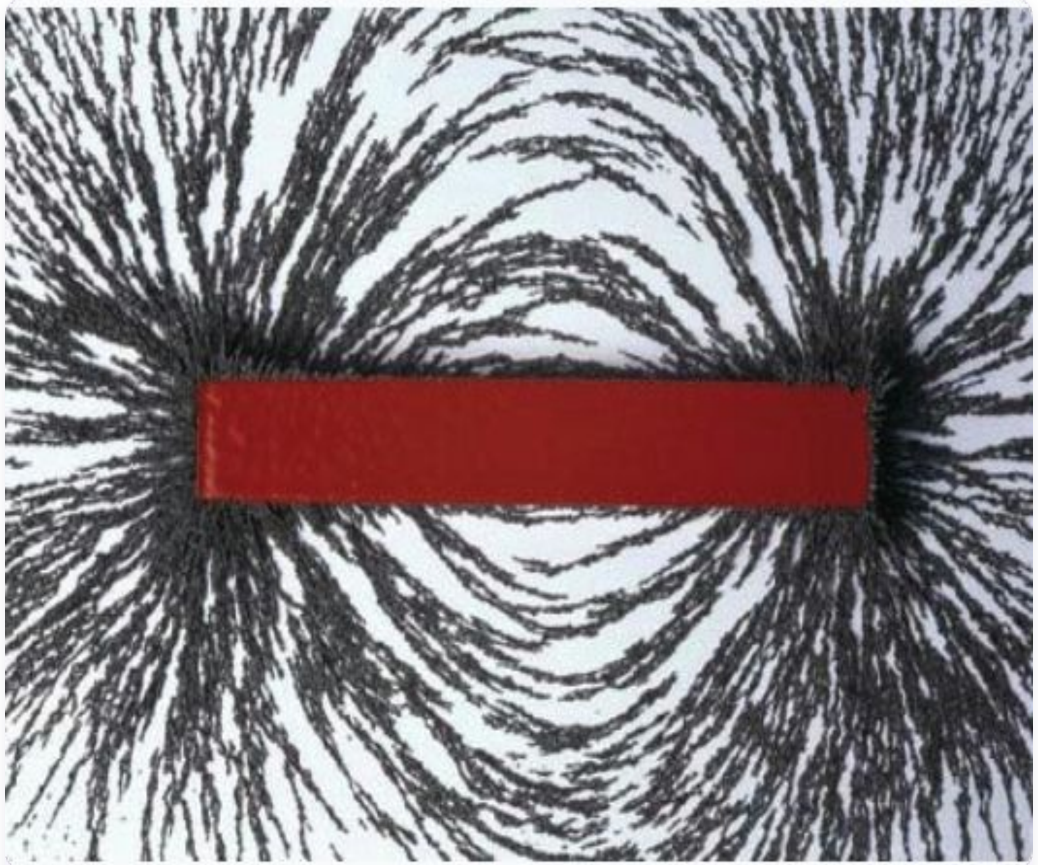




Mapping a Field with Iron Filings

1. **Fix the setup**
   Fix a white paper on a drawing board and place a bar magnet at its centre.
2. **Sprinkle iron filings**
   Sprinkle iron filings uniformly around the bar magnet.
3. **Tap gently**
   Tap the board gently — iron filings near the magnet align along the field lines.

Reason: The magnet exerts an influence in its surroundings — this region is the **magnetic field.** The iron filings experience a force that arranges them along the **magnetic field lines.**



EXPERIMENTS TO OBTAIN FIELD LINES · EXPERIMENT 2

Plotting a Field Line with a Compass

1. **Mark the magnet**
   Place a bar magnet on white paper fixed to a drawing board and mark its boundary.

2. **Track the needle**
   Place a compass near the north pole. The needle's south pole points toward the magnet's north pole — mark both ends.

3. **Step forward**
   Move the compass so its south pole occupies the spot the north pole just marked. Repeat until you reach the magnet's south pole.

4. **Join the dots**
   Joining the marked points with a smooth curve gives one magnetic field line; repeating gives many.

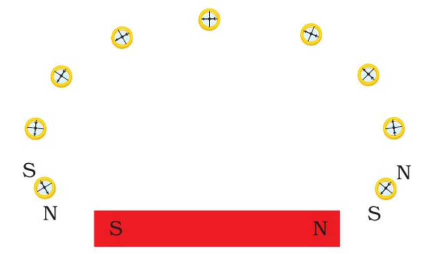


Figure 12.3
Drawing a magnetic field line with the help of a compass needle

Figure 12.3

Drawing a magnetic field line with the help of a compass needle.

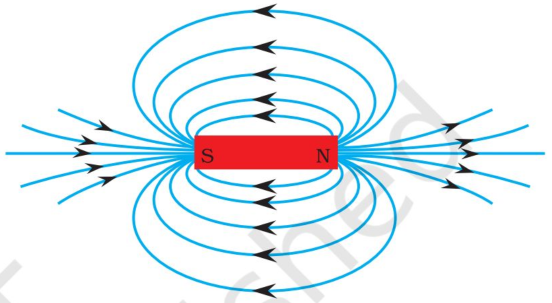


Figure 12.4
Field lines around a bar magnet

Figure 12.4

Magnetic field lines around a bar magnet, demonstrating closed loops.

Properties of Magnetic Field Lines

1

Direction

A vector quantity: lines emerge from the north pole and merge at the south pole outside the magnet; inside, they run south to north — so field lines are closed curves.

2

Relative strength

The field is stronger where lines are crowded closer together, and weaker where they spread apart.

3

Never cross

Two field lines never intersect — a compass needle cannot point in two directions at the same point.

4

Magnitude & direction

The direction of the field is taken as the direction the compass needle's north pole moves.

Finding the Direction of the Field

1 **Build the circuit**

Take a long, straight copper wire, 2–3 cells of 1.5 V, and a plug key — connect them in series.

2 **Position the wire**

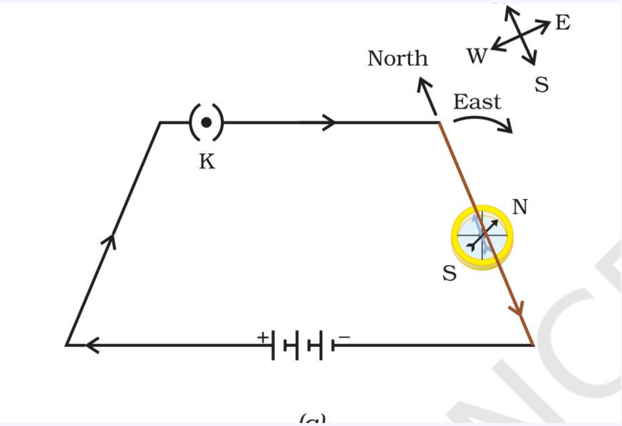
Place the copper wire parallel to, and directly over, a compass needle.

3 **Observe: current N ⟶ S**

The north pole of the compass needle moves toward the east.

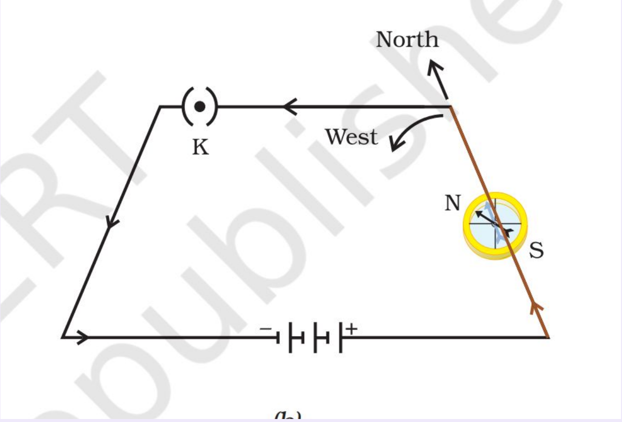
4 **Observe: current S ⟶ N**

The needle moves the opposite way, toward the west — reversing the current reverses the field's direction.



Setup (a): Current N ⟶ S

With current flowing north to south, the compass needle deflects towards the East.



Setup (b): Current S ⟶ N

Reversing the current flow from south to north causes the needle to deflect towards the West.

Concentric Circles Around a Wire

1. **Pierce the cardboard**

   Insert a straight, thick copper wire through the centre, normal to the plane of a rectangular cardboard.

2. **Wire it up**

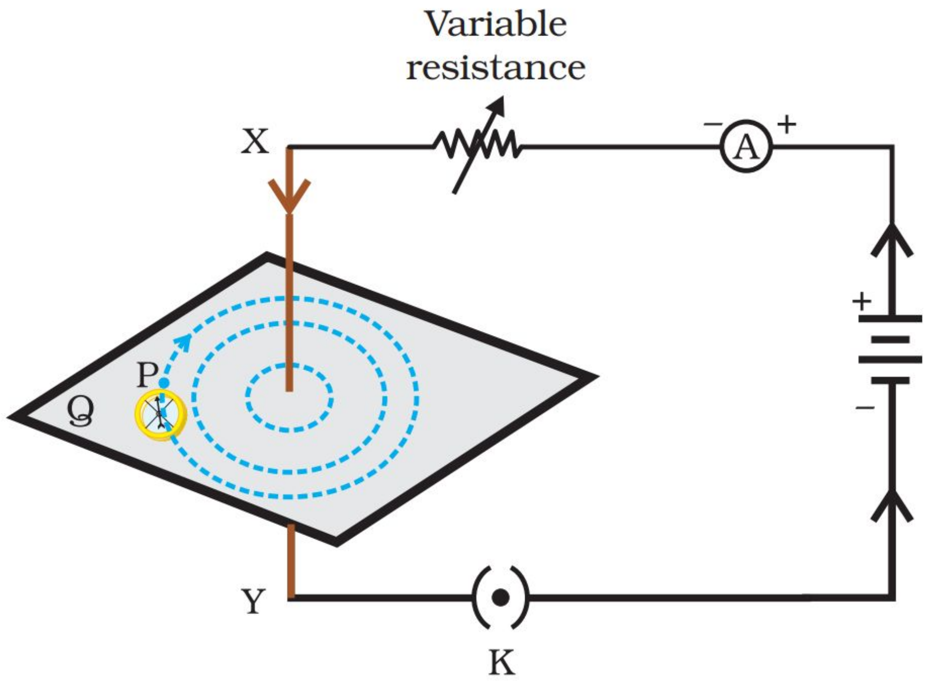
   Connect the wire vertically between points X and Y, in series with a 12 V battery, a variable resistance (rheostat), an ammeter (0–5 A), and a plug key.

3. **Sprinkle & tap**

   Sprinkle iron filings uniformly on the cardboard, close the key, and gently tap the board a few times.

4. **Read the pattern**

   The iron filings align into a pattern of concentric circles — these represent the magnetic field lines around the wire.



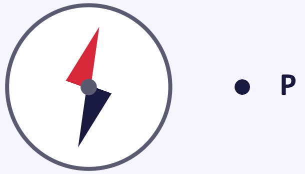
(a)

Direction & Strength of the Field

1

Compass gives the direction

Place a compass at a point (say P) over a circle — the direction its north pole points gives the field's direction at P.



2

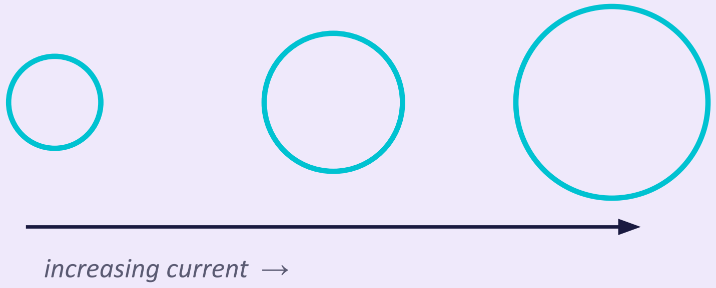
Reverse the current, reverse the field

The direction of the magnetic field lines is reversed if the direction of current through the wire is reversed.

3

Strength grows with current

If the current in the wire is varied, the needle's deflection changes too. As the current increases, the deflection increases.



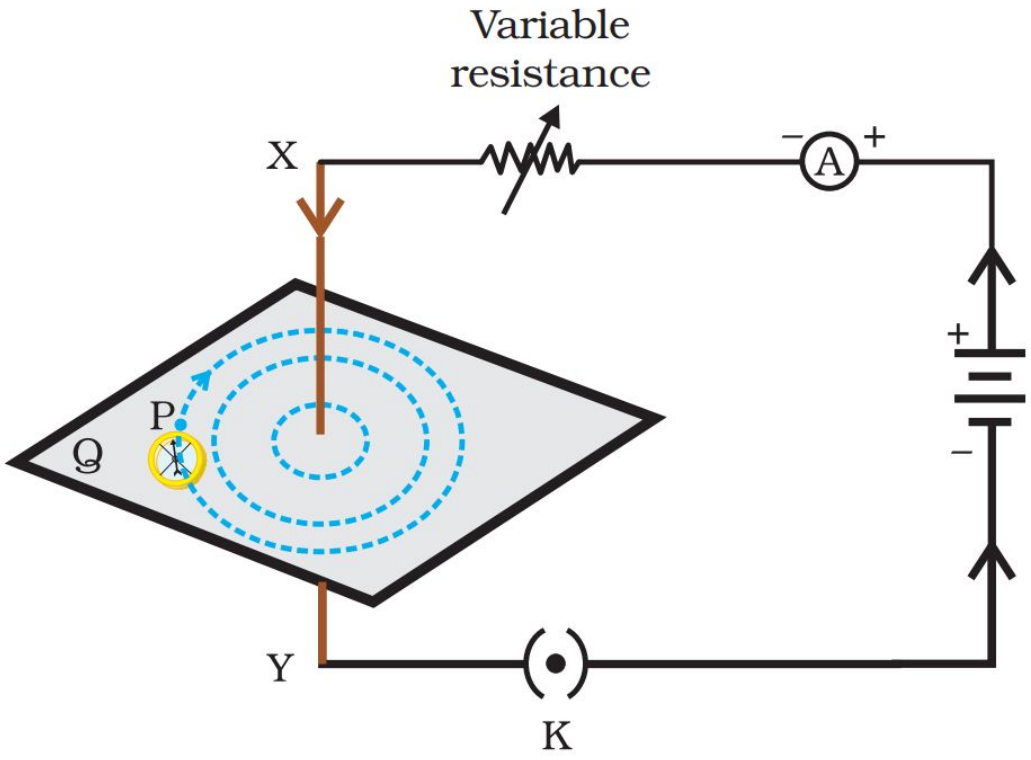
Conclusion: the magnitude of the magnetic field produced at a given point increases as the current through the wire increases.

SUMMARY

Field Strength Decreases with Distance

If the compass is moved farther from the wire (say to point Q), the deflection decreases. The magnetic field produced by a current-carrying conductor decreases as the distance from it increases — the field strength is inversely proportional to distance.

- Current-carrying conductors produce a magnetic field (Oersted, 1820).
- Field lines run from a magnet's north pole to its south pole outside it, and never cross.
- Around a straight wire, field lines form concentric circles centred on the wire.
- Reversing the current reverses the field's direction; increasing the current strengthens it.



(a)

PHYSICS · ELECTRICITY & MAGNETISM

Magnetic Effects of Electric Current

The right-hand thumb rule, fields from loops and solenoids, the force on a current-carrying conductor, and Fleming's left-hand rule.

(b)

Right-Hand Thumb Rule

MAGNETIC FIELD DUE TO A CURRENT-CARRYING CONDUCTOR

CORE PRINCIPLE

An easy way to find the direction of the magnetic field associated with a current-carrying conductor.

01

Align the Thumb

Imagine holding a straight current-carrying conductor in your right hand so the thumb points along the direction of current.

02

Curled Fingers Wrap

The curled fingers then wrap around the wire in the direction of the magnetic field lines.

NOTE: *Also known as Maxwell's corkscrew rule.*

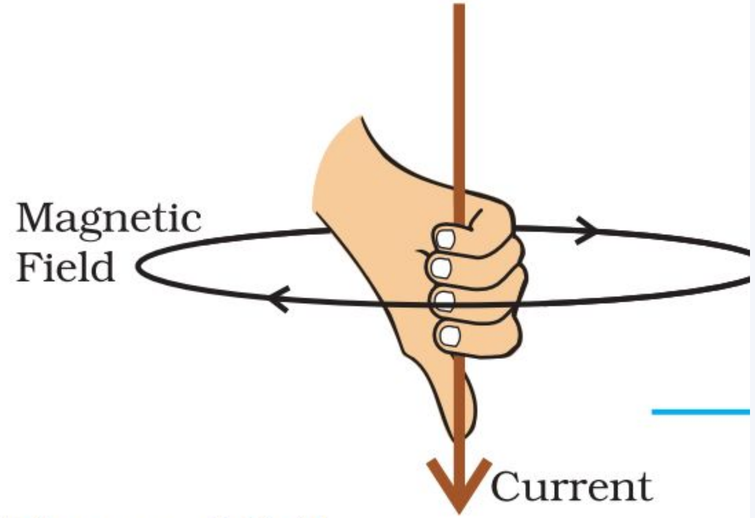


Figure 12.7
Right-hand thumb rule

Worked Example

RIGHT-HAND THUMB RULE

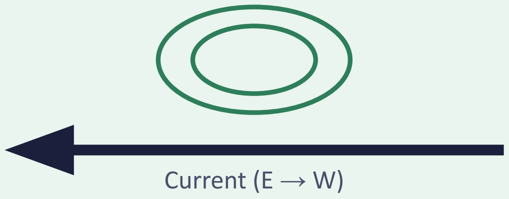
PROBLEM

A current through a horizontal power line flows from east to west.

What is the direction of the magnetic field at a point directly below it, and at a point directly above it?

SOLUTION

Applying the right-hand thumb rule, 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 anticlockwise when viewed from the west end.



Field Due to a Circular Loop

MAGNETIC FIELD DUE TO A CURRENT-CARRYING CONDUCTOR

- Bend a straight wire into a circular loop and pass a current through it. The concentric circles of field around every point on the wire grow larger as distance from the wire increases.
- At the centre of the loop, the arcs of these larger circles appear as straight lines — every point on the wire contributes a field in the same direction there, by the right-hand rule.
- For a coil of n turns, the field produced is n times as large as that of a single turn, since each turn's contribution simply adds up.

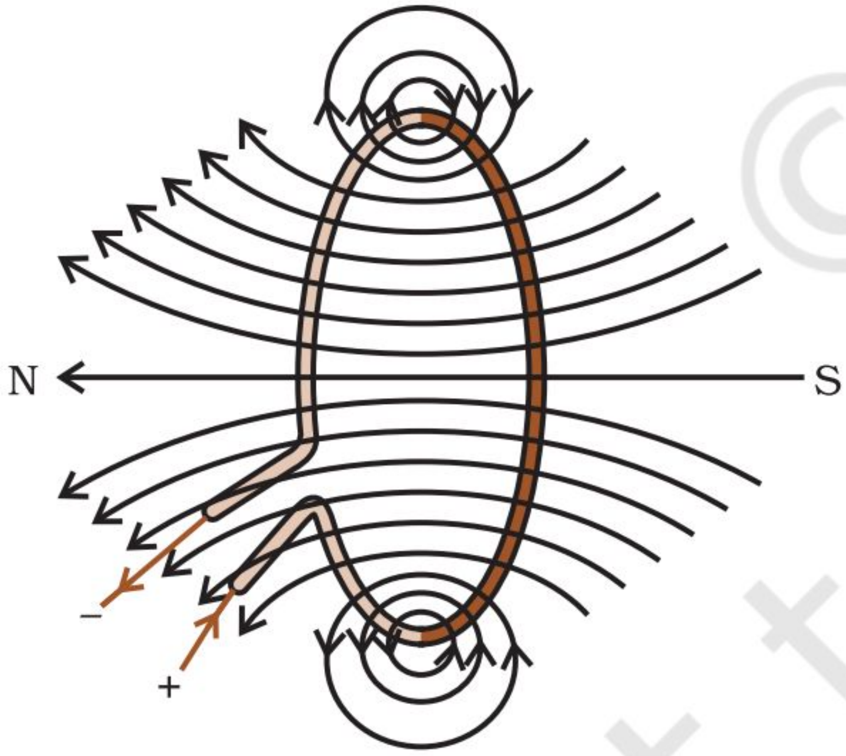


Figure 12.8
Magnetic field lines of the field produced by a current-carrying circular loop

Seeing the Field: An Experiment

FIELD DUE TO A CIRCULAR LOOP

1. Take a rectangular cardboard sheet with two small holes in it.
2. Insert a circular coil of many turns through the holes, normal to the plane of the cardboard.
3. Connect the ends of the coil in series with a battery, a key, and a rheostat.
4. Sprinkle iron filings evenly over the cardboard.
5. Plug the key and tap the cardboard gently a few times.
6. Concentric circles of iron filings appear around the wire; at the centre of the coil, they line up straight.

Field Due to a Current in a Solenoid

MAGNETIC FIELD DUE TO A CURRENT-CARRYING CONDUCTOR

- A solenoid is a coil of many circular turns of insulated copper wire, wrapped closely in the shape of a cylinder.
- The pattern of field lines around a current-carrying solenoid looks similar to the pattern around a bar magnet.
- One end behaves as a magnetic north pole and the other as a south pole. Inside the solenoid, the field lines are parallel straight lines — the field is uniform there.
- Placing a magnetic material such as soft iron inside a current-carrying solenoid magnetises it, forming an electromagnet.

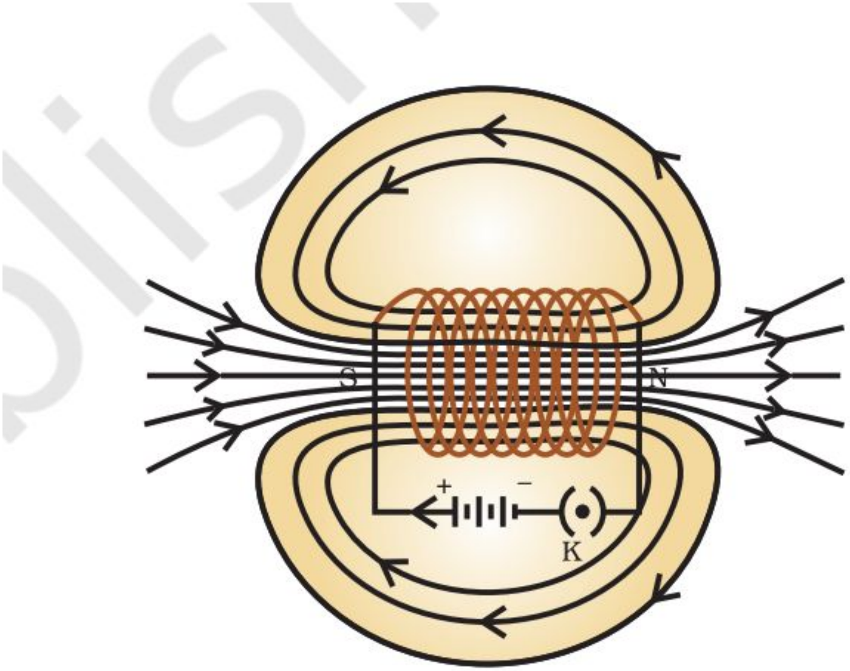


Figure 12.10
Field lines of the magnetic field through and around a current carrying solenoid.

Ampère's Discovery

FORCE ON A CURRENT-CARRYING CONDUCTOR IN A MAGNETIC FIELD

- An electric current through a conductor produces a magnetic field. This field exerts a force on a magnet placed near the conductor.
- French scientist André-Marie Ampère (1775–1836) suggested that the magnet also exerts an equal and opposite force on the current-carrying conductor — shown by suspending a rod between the poles of a magnet.
- Displacement of the rod shows a force acts on it, perpendicular to both its length and the field, whenever current flows.
- Reversing either the current direction or the magnetic field direction reverses the direction of that force.

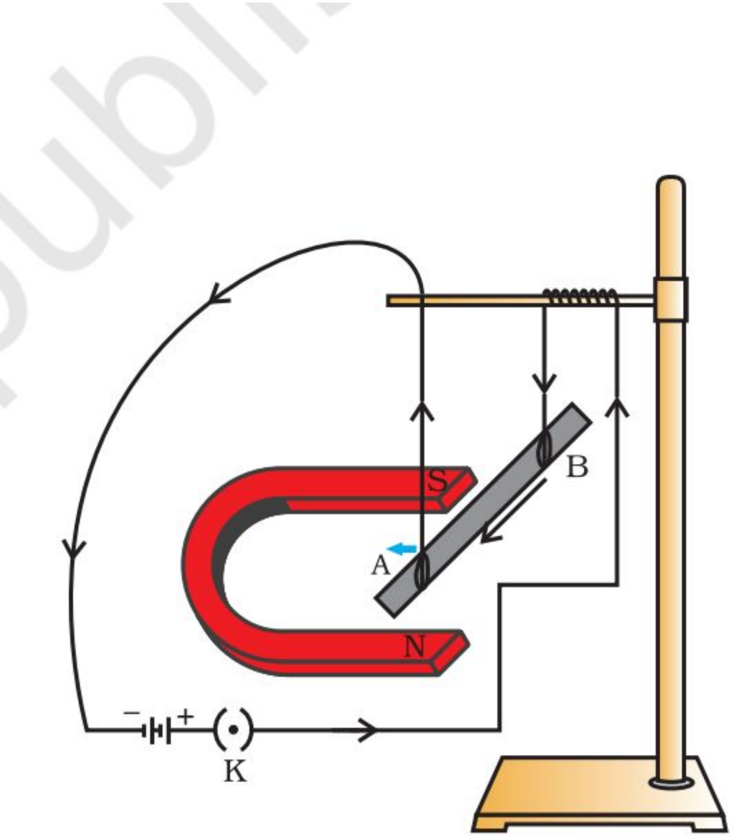


Figure 12.12
A current-carrying rod, AB, experiences a force perpendicular to its length and the magnetic field. Support for the magnet is not shown here, for simplicity.

Fleming's Left-Hand Rule

- The displacement of the rod — and so the force — is greatest when the current is at right angles to the magnetic field.
- Stretch the thumb, first finger, and middle finger of the left hand so all three are mutually perpendicular.

First finger — Direction of the magnetic Field

Second finger — Direction of the Current

Thumb — Direction of motion / the Force on the conductor

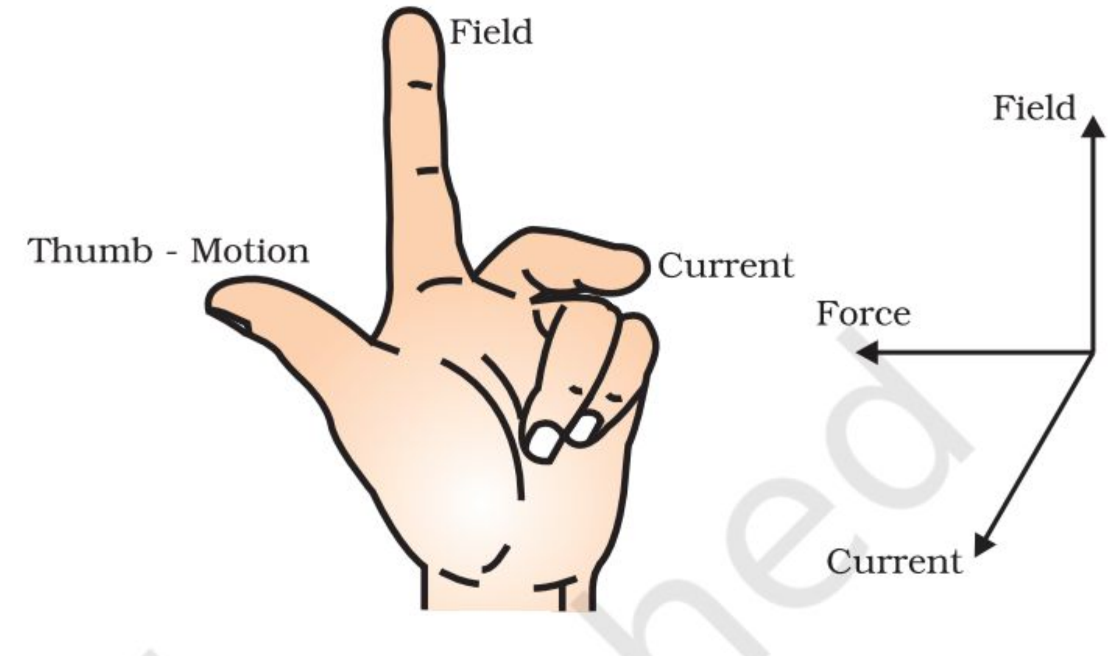


Figure 12.13
Fleming's left-hand rule

Practical Applications

Electric motor, electric generator, loudspeakers, microphones & measuring instruments are the devices that use current-carrying conductors & magnetic fields.

Electric Motor

Electric Generator

Loudspeaker

Microphone

Measuring Instrument

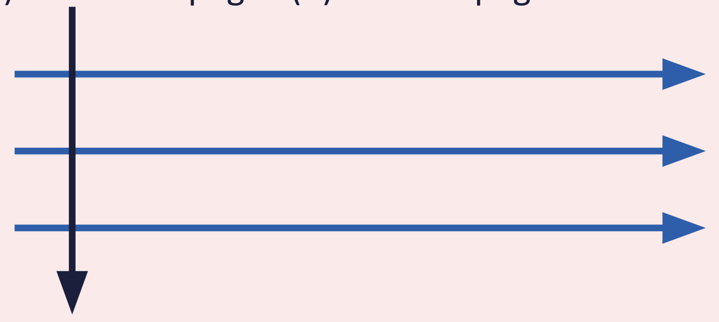
Worked Example

FORCE ON A CURRENT-CARRYING CONDUCTOR IN A MAGNETIC FIELD

PROBLEM

An electron enters a magnetic field at right angles to it, as shown. What is the direction of the force acting on the electron?

(a) to the right (b) to the left
(c) out of the page (d) into the page



SOLUTION

Answer: (d) into the page.

By Fleming's left-hand rule, the force is perpendicular to both the field and the current. Since the current direction is opposite to the electron's motion (electrons carry negative charge), the resulting force points into the page.

Force (into page)

Magnetism in Medicine

Nerve Impulses — Electric impulses carried through nerves produce a temporary magnetic field. This field is extremely weak, about one-billionth of the Earth's magnetic field.

Significant Fields — The heart and the brain are highly active organs that can produce significant and measurable magnetic fields inside the body.

MRI Diagnosis — These internal magnetic fields are utilized to obtain clear images of body parts using Magnetic Resonance Imaging (MRI), aiding in accurate medical diagnosis.

MRI: Imaging with the body's own magnetic signals

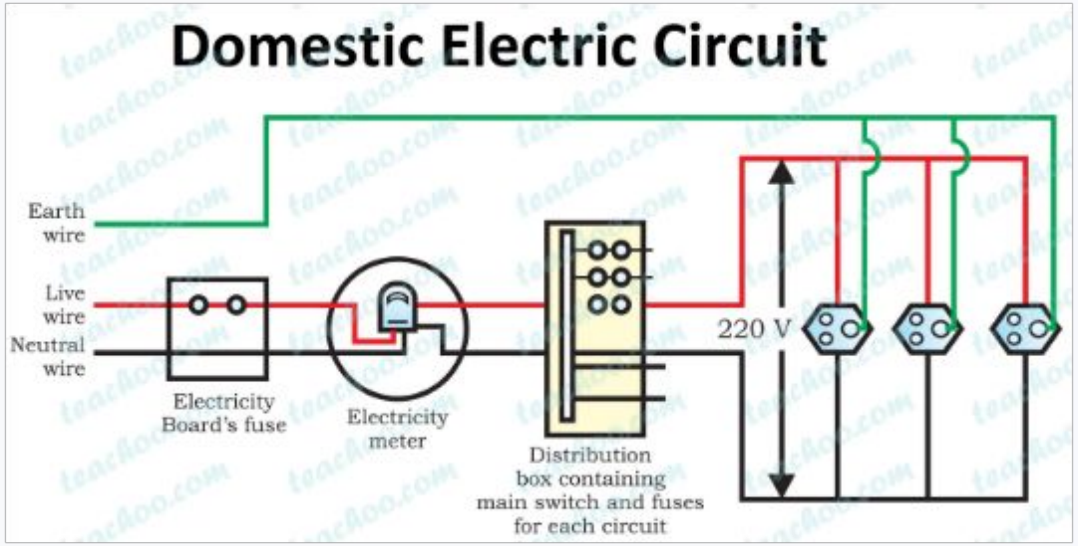
Magnetic Effects of Electric Current

Domestic Electric Circuits

Understanding home power supply, wiring, and distribution.

DOMESTIC ELECTRIC CIRCUITS

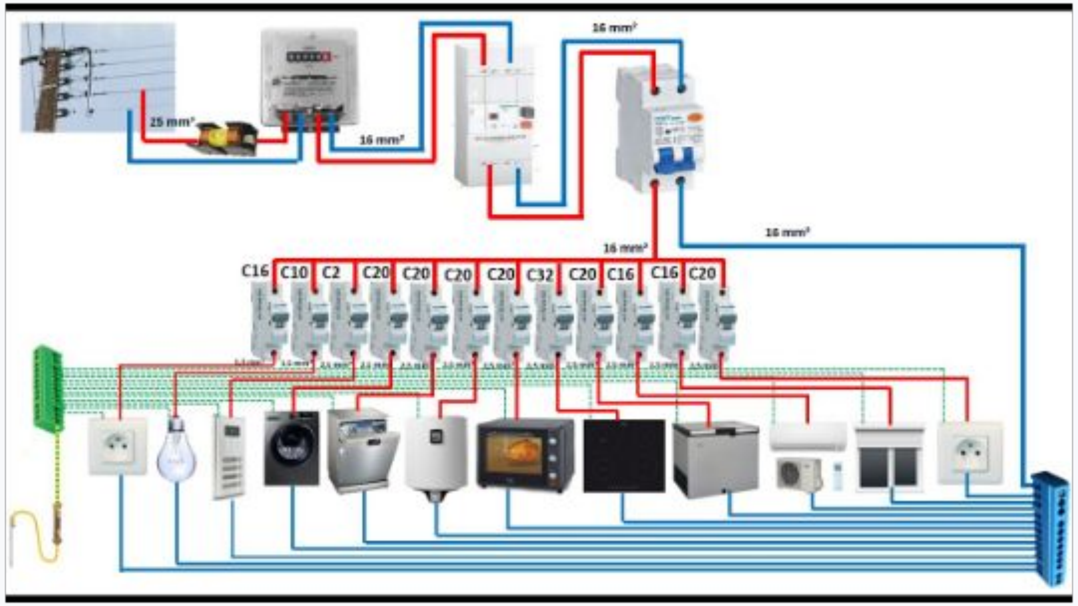
- In homes, electric power is supplied through a **main supply (mains)**, supported through overhead **electric poles** or by **underground cables**.
- In this, one wire is with **red insulation** cover (**live wire** or **positive**) and other wire is with **black insulation** (**neutral wire** or **negative**).
- In our country, the **potential difference** between the two is **220 V**.



A schematic diagram of common domestic circuits

DOMESTIC ELECTRIC CIRCUITS

- At the **meter-board**, these wires pass into an electricity meter through a **main fuse**.
- Through the main switch, they are connected to the line wires.
- These wires supply electricity to separate circuits in the house.



Electricity meter and distribution box

DOMESTIC ELECTRIC CIRCUITS

- In each separate circuit, different appliances can be connected across live and neutral wires. Each appliance has a separate switch to ON/OFF the flow of current. The appliances are connected in **parallel** so that they have same potential difference.
- When the **live wire** and **neutral wire** come into direct contact, it causes **overloading**. This occurs due to:
  - ➢ Damaged insulation of wires or fault in the appliance.
  - ➢ Accidental hike in voltage.
  - ➢ Connection of many appliances to a single socket.