UNIT 5

ELECTRICITY AND MAGNETISM

Unit outcomes: After completing this unit you should be able to:

- ✓ understand concepts related to electricity and magnetism;
- ✓ develop skill of manipulating problems related to electricity and magnetism;
- ✓ appreciate the interrelatedness of all things;
- ✓ use a wide range of possibilities for developing knowledge of the major concepts with in physics.

Introduction

You learnt about electricity and magnetism in grade 7 physics. You will continue to learn more about this topic in this grade and in this unit. The relationship between electricity and magnetism and its uses for our country's economic and social development will be learnt.

5.1 Modeling Electric Current, a Circuit Loop and Voltage

Activity 5.1

Discuss the following questions with your friends or parents:

a) How is electric current generated?

b) What is the function of a voltage (battery)?

c) What is an electric circuit?

d) Identify the similarities and differences between water flow in pipe and electron flow in a wire. (Fig 5.1)

In this unit you will focus on motion of charges or current electricity. The flow of charge in an electric circuit is much like the flow of water through a closed path (See Fig 5.1). The power supply (battery) corresponds to the water pump and the resistance corresponds to the narrow segment of pipe. The pressure on the output side of the pump is much like the voltage on the ‘’+’’ terminal of the power supply. The electric current corresponds to the rate of flow of the water.

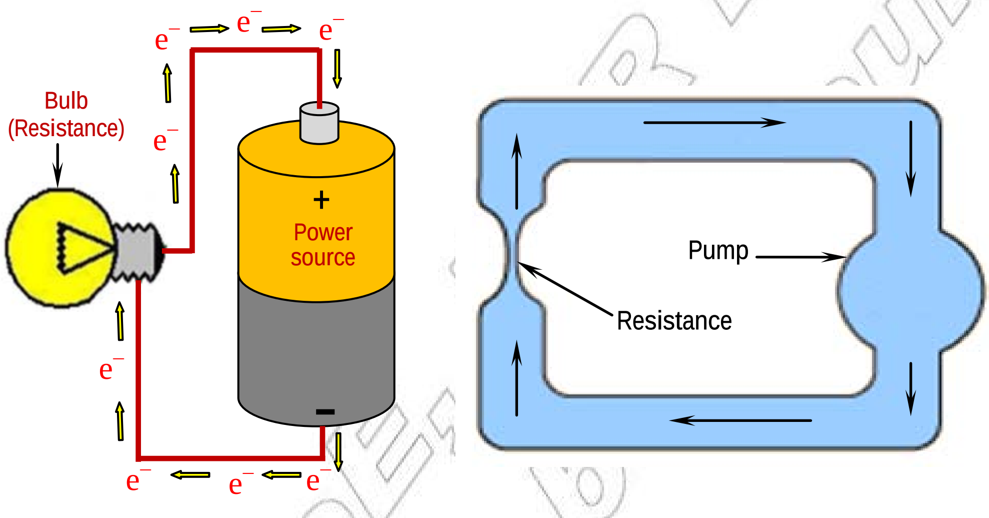


Fig. 5.1 Comparing water flow in pipe and electron flow in wire

To develop a reliable understanding of the concepts: **current, circuit loop** and **voltage** modeling human being as the "human wire" would be an interesting activity.

Modeling motion of charge in a conductor

The whole students in the class can become a model for motion of charges in a conductor. Let us start with one row of students (front to back) becomes one wire. A box at the front of the class models the battery. The box has "battery" painted on it with negative on one end and positive on the other. Assume, in the box there are about 100 small stones the sizes of marbles. They can be labeled with an "e" on them. They represent the electrons.

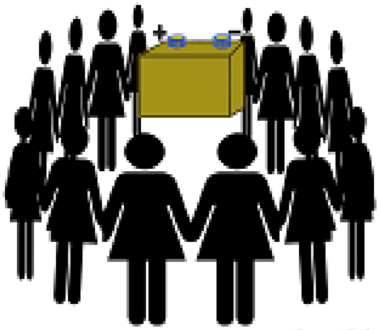


Fig. 5.2 Modeling motion of charge

A student stands at the box and pushes all of them to the minus side. That student is the model for the electromotive force (EMF). EMF is a potential energy that does work by separating charges and making them available for travel else where. For a battery, the potential difference comes from a chemical reaction that separates charges and pushes electrons to the negative end. The potential differece could be a generator or a photovoltaic cell.

To begin the current a student nearest to the "battery" gets a stone electron. The potential difference person hands out the stone electrons one after another. The first student passes the stone along the row of students. This process continues until the "human wire" has brought stone electrons back to the positive side of the box where the electron is placed. The potential difference quickly pushes the electron from the positive end to the negative end. Here, we assume that the conductor is full of free electrons. As one electron comes out of the negative end automatically another electron enters the positive end of the battery. The "human wire" models the motion of electrons in a conductor, as it occurs in an electric circuit.

Conventionally, current is taken as the flow of positive charges. When current was defined centuries ago nothing was known about electrons. Scientists guessed that positive charges move in a wire; but they don't. You should note that current is a flow of negative charges. Though by convention, we take electric current as the flows of positive charges from the positive side of the battery. You should appreciate the role of the potential difference as the separator of charges and the role of the initiator of charge concentration.

Modeling a broken Electric Circuit

The connected students from the negative terminal to the positive terminal is a path for the electron flow. This path is called electric circuit. The circuit is closed if there is no break/opening along the line of students. (see Fig 5.3)

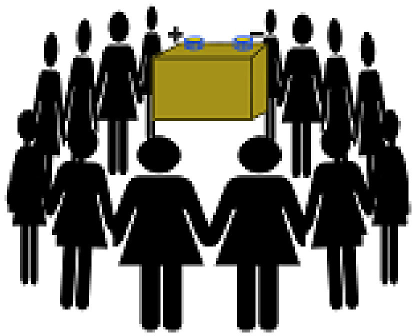


Fig. 5.3 Modeling a closed circuit

The circuit is broken if there is break/opening along the line of students. (see Fig 5.4)

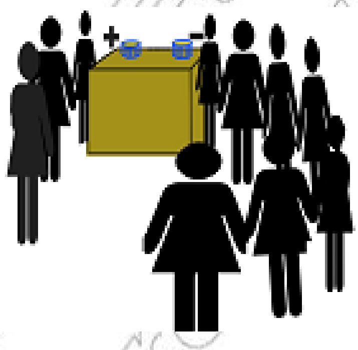


Fig 5.4 Modeling a broken electric circuit

Modeling thicker wires

Now consider two rows of students to form the human wire, instead of one row. (see Fig 5.5)

Fig 5.5 modeling thicker wires

The electrons pushed by the EMF at negative terminal are transferred by two students at a time. Here, electrons are transferred faster than in one row. Having thicker wire means having faster flow of electrons in an electric circuit.

Electric circuits

An electric circuit is a complete path for the flow of electric current. It may consist of different items like a source of potential difference, switches connecting wires, lamp, etc. You can represent any complicated circuit using symbols. The standard electric symbols are used to draw electric circuit diagrams.

Modeling a parallel circuit

Next, consider the two rows of student to split into two branches, to form two paths. The two rows of students accept the electrons from negative terminal and transfer them to the positive terminal of the EMF. This model demonstrates that electrons pushed by the EMF at the negative terminal have two options to travel/flow through the conductor. Again these electrons combine at the positive terminal. (See Fig.5.6)

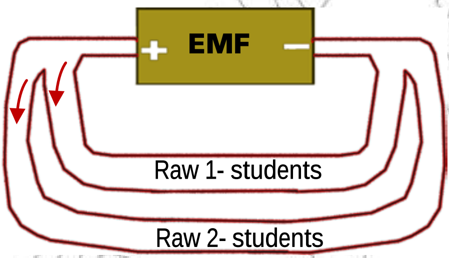


Fig 5.6 Modeling a parallel circuit

Check point 5.1.

1. **Describe how an electric current flows through a conductor. (use human beings as a wire)**
2. **State the role of an electromotive force (EMF) in a current flow.**
3. **Draw**
   a) closed electric circuit
   b) a broken electric circuit and explain their differences.

5.2 Modeling an Electric Light Bulb

Activity 5.2

Investigating what light bulb looks like.

1. Take a burnt (useless) electric bulb.
2. Study the parts of the electric lamp. Identify-filaments, screw base, tip and support posts
3. Draw the diagram of the bulb and label its parts.
4. Explain the importance of the filament
5. When do you say the bulb is burnt? or not working?

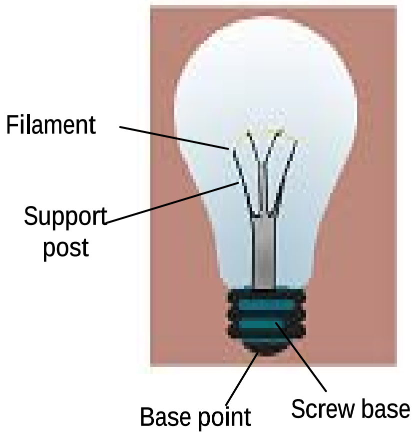


Fig 5.7 Electric bulb

Filaments are made from metallic substance called **tungsten**. Tungsten has the highest melting point. The filament is much thinner than the support posts. In a bulb, the filaments are connected to the support posts. One of the posts is connected to the screw base and the other post to the base point. A functioning bulb makes complete circuit when connected to a battery (see Fig 5.7).

Modeling a fuse

- Construct an electric circuit using a bulb, 12V battery, switch, connecting wires and different wires thick, thin and very thin.
- Leave a gap in the circuit to insert the different wires.
- The bulb gives light when the switch is closed for the different thick and thin wires.

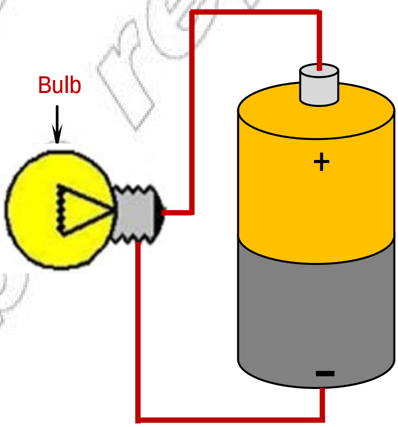


Fig 5.8 Modeling circuit flow in a bulb

- When the thinnest wire (very thin wire) is inserted in the gap it glows and melts. At this time the bulb stops giving light.
- A piece of wire made of metal alloy having low melting point is called a **fuse**. A fuse melts and breaks the circuit when excess current flows through it.

A fuse makes a circuit open (incomplete) in a high flow of current.

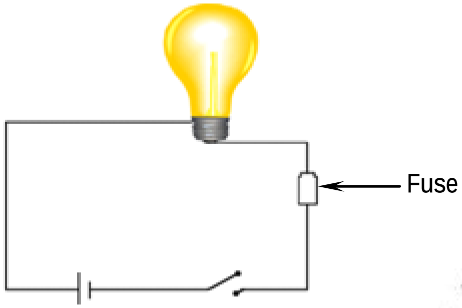


Fig 5.9 Modeling a fuse

Parallel Circuit

Activity 5.3

Building a parallel circuit (see Fig 5.10)

1. What happens to the brightness of the light when both bulbs are on?
2. What happens to the brightness when one of the bulbs is removed out?
3. Why does the difference in brightness happen?

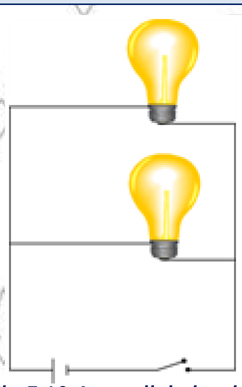


Fig.5.10 A parallel circuit

Check point 5.2

1. What effects of an electric current does a bulb use?
2. Draw the structure of a real light bulb and label its parts.
3. Describe the role of a fuse.

5.3 Relationship of Current, Voltage and Resistance

Electric current

In grade 7, you studied how electric charges are produced and how they are distributed on conductors. When a potential difference is applied across a conductor free electrons in the conductor start to move. For instance, if a dry cell or battery is connected between the end points of a conducting wire, a systematic transfer of charged particles occur from one terminal to another. This ordered motion of charged particles is said to set up an **electric current.**

Electric current is the rate of flow of electric charges across a given cross-sectional area in a conductor.

$$\text{Electric current} = \frac{\textbf{charge moved}}{\textbf{time taken}}$$

In symbols, $I = \frac{Q}{t}$ where I is electric current

Q is charges moved

t is time taken.

Current is a scalar quantity.

Challenging question

- Do you remember the unit of electric current? Name it.

The unit of electric current is Ampere (A) named after the French scientist Andre **'Marie Ampere.**

$$1 \text{ Ampere} = \frac{1 \text{ coulomb}}{1 \text{ second}}; \qquad 1A = \frac{1C}{1\ s} = 1\ C/s$$

One ampere is equal to one coulomb of charge per second;

An electric current of one Ampere is obtained when a charge of one coulomb (6.25× 10^{18} electrons) passes a point through a conductor in one second. Electric current can also be measured in smaller units such as milliAmpere and micro Ampere,

1milliAmpere = 0.001A = 10^{-3}A = 1 mA

1microAmpere = 0.000,001A = 10^{-6}A = 1μA

Worked Example 5.1

1. What constant current is transferred when a charge of 120 C passes through a conductor in 1minute?

Given	Required	Solution
Q = 120C	I = ?	$I = \frac{Q}{t}$
t = 1minute = 60 s		$= \frac{120c}{60s}$
		= 2C/s
		= 2A

Therefore, the current is 2 C/s = 2A

2. If a current of 90 milliAmpere (mA) flows for 150 s, then what is the charge transferred?

Given	Required	Solution
I = 90mA = 0.09A	Q = ?	$I = \frac{Q}{t}$, then Q = It
t = 150s		Q = (0.09A) (150s)
		= (0.09 C/s) (150s)
		= 13.5C

The charge transferred is = 13.5C

Voltage

Voltage is a measure of the ability to do work. It is a scalar quantity. It can be taken as a "potential push" or "pressure" in an electric circuit. It is not a force. Voltage is supplied by some sources of electromotive force (EMF) like a battery or a generator or a photovoltaic cell. An EMF is used in an electric circuit as a separator of charges and as an initiator of charge concentration.

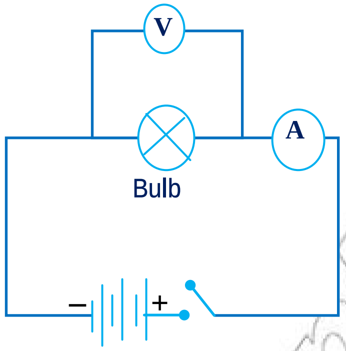


Fig 5.11 Circuit diagram for Ohm's law

Relation between current and voltage

Activity 5.4

Investigating the relationship between current and voltage

Material Required: 4 dry cells (1. 5V each), voltmeter, ammeter, a bulb, switch and connecting wires.

Procedure:

i) Connect the suggested materials as shown in Fig.5.11
ii) Connect one cell first and take the readings of the voltmeter and Ammeter.
iii) Repeat the above procedure each time for two, three and four cells being in series.
iv) Fill in the table below from the reading of the meters.
v) Calculate the ratio of voltage (V) to current (I). for each trial

Number of cells connected in series	1	2	3	4
Potential difference (in V)				
Current, I (in A)				
Ratio $\frac{V}{I}$				

vi) Draw the graph of V versus I.
vii) Compare the ratio and the slope of your graph. (Fig 5.12)

- What do you observe?
- How does the current increase or decrease with an increase or decrease in voltage?

The current in the Activity 5.4 increases with an increase in potential difference and decreases with the decrease of the potential difference.

George Simon Ohm, a German physicist measured electric current through a conductor by applying different potential differences across it and arrived at a law called "**Ohm's law**".

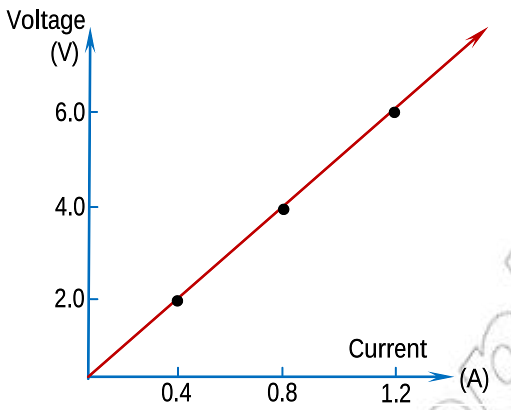


Fig 5.12 Graph of voltage against current

Ohm's law states that:

"The current flowing through a metallic conductor at a constant temperature is directly proportional to the voltage between the two ends."

Mathematically Ohm's law is expressed as: $\frac{\text{Voltage}}{\text{Current}}$ **= constant**

The proportionality constant is a peculiar property of the metallic conductors. This constant is called the resistance of a conductor.

What is a resistance?

Resistance is defined as the measure of the opposition to the flow of current through the conductor. From your Activity 5.4,

The resistance of a conductor is defined as the ratio of voltage to current.

In symbols, $R = \frac{V}{I}$ where V= voltage in volt (V)

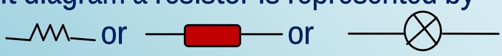
I = current in ampere (A)

R = resistance is ohm (Ω)

The unit of resistance is ohm (Ω read as omega)

$$1 \text{ ohm} = \frac{\textbf{1 volt}}{\textbf{1 Amp}}$$

In a circuit diagram a resistor is represented by

a symbol 

Ohm's law is valid only under certain condition. That is, it is valid for metallic conductors kept at a constant temperature.

Worked Example 5.2

1. What is the resistance of a lamp that draws 0.5A current when connected to 2V dry cell?

Given	Required	Solution
V = 2V	R = ?	$R = \frac{V}{I}$
I = 0.5A		$R = \frac{2V}{0.5A}$ = 4 ohms (4Ω)

∴ The resistance of the lamp is = 4Ω

2. What current flows when a 10 Ω resistor is connected to a 2V supply?

Given	Required	Solution
R = 10 Ω	I = ?	V = IR
V = 2V		$I = V/R = \frac{2v}{10\Omega}$
∴ The currant is 0.2A		I = 0.2A

3. When a 200Ω resistance is joined to a mains supply the current is 1.15A. What is the mains voltage?

Given	Required	Solution
R = 200Ω	V = ?	V = IR
I = 1.15A.		V = 1.15A × 200Ω
		V = 230V

∴ The main voltage is 230V

Check point 5.3

1. **Define the following terms**
   - **a) Electric current.** **c) Ampere**
   - **b) Voltage** **d) Resistance**
2. **What is the other name for a voltage?**
3. **State Ohm's law**
4. **Fill the units and symbols for both physical quantities in the table below.**

	Physical quantities	Unit	Symbols of quantity	Symbol of Unit
1	Electric current			
2	Voltage			
3	Resistance			

5.4 Measuring Electric Current, Voltage and Resistance

You have noticed that the important electrical quantities are current, voltage and resistance. You can measure these quantities in an electric circuit using different instruments.

Measuring electric current with an ammeter

The electric current in a circuit is measured by an instrument called ammeter.

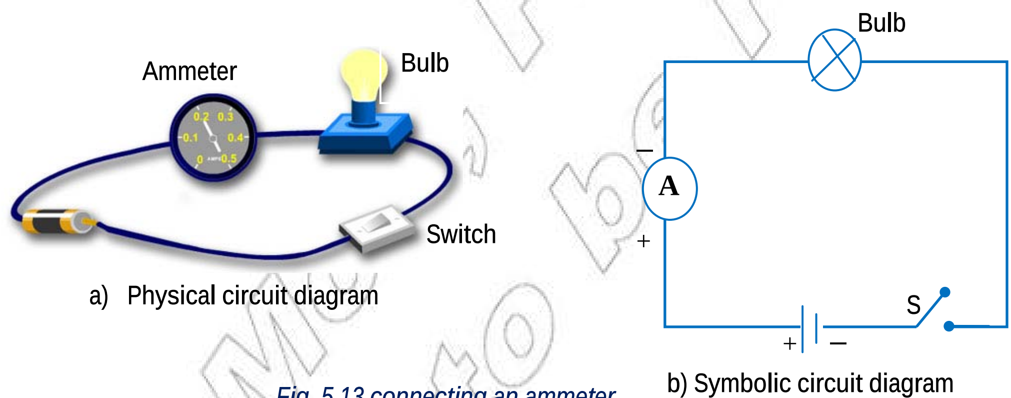


Fig. 5.13 connecting an ammeter

In using an ammeter:

- Connect it in series to a resistor or an appliance as shown in Fig 5.13.
- Never connect it across the ends of a battery without having at least a resistor (electrical appliance) in series with it.
- Never connect in parallel to a resistor.

Activity 5.5

Measuring electric current is parallel circuits (Fig 5.14)

Materials required: An ammeter, 2 light bulbs, and 6v battery.

1. Connect the ammeter at position 1 to measure the current that comes out of the battery.
2. Connect the ammeter to measure the current in each of the branch (positions 2 and 3).
3. What do you observe (conclude) about the current in positions 1, 2 and 3
4. Which part of the parallel circuit has more current? Why?

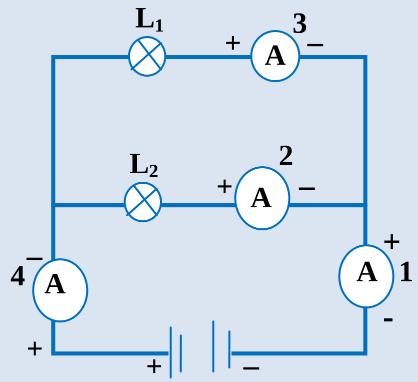


Fig. 5.14 Measuring current in parallel circuit

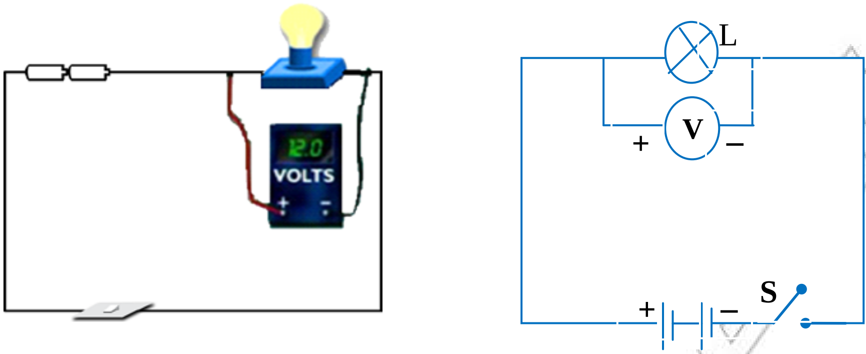
The sum of the currents in the parallel circuit is the same as the current from the battery.

Measuring voltage with a voltmeter

The potential difference across any two points in a circuit is measured by an instrument called **voltmeter**.

In using a voltmeter:

- Connect it in parallel to a resistor to measure the voltage across the resistor.
- Connect it in parallel to a battery or a cell whose voltage you want to measure. As in Fig 5.15.
- Never connect it in series with resistors or voltage source.



a) Physical circuit diagram b) symbolic circuit diagram

Fig. 5.15 Connecting a voltmeter

Activity 5.6 Measuring voltage in parallel circuit (Fig 5.16)

Materials required: a voltmeter, 2 light bulbs and 6V battery.

1. Connect the voltmeter across the battery. Record its readings.
2. Connect the voltmeter across each of the bulbs in the parallel circuit separately. Record their readings.
3. Compare the voltages across each of the bulb.

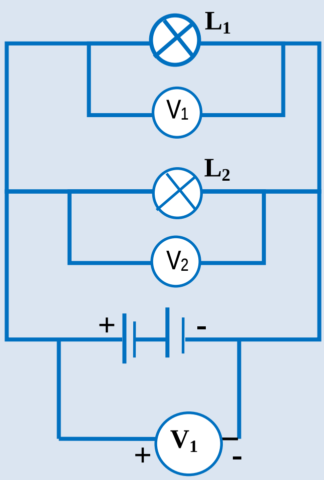


Fig.5.16 Measuring voltage in parallel circuit

The voltages across each of the bulbs in parallel circuits are the same.

Voltmeters and ammeters work making use of the magnetic effect of electric current. In using these instruments, their positive (+) terminals must be connected to the positive terminals of the source of EMF and their negative (-) terminals to the negative terminal of the source of EMF. As shown in Fig 5.13a and Fig 5.15b

Measuring resistance with a voltmeter and an ammeter

The resistance of a bulb can be measured using a combination of voltmeter, an ammeter and Ohm's law. From ohm's law, you can measure the resistance of the bulb. (See Fig 5.17)

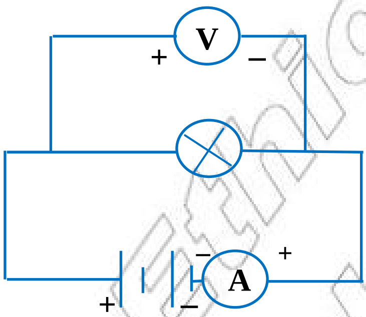


Fig.5.17 Measuring the resistance of a bulb

Activity 5.7
Measuring the resistance of a bulb *Materials required:* different bulbs, ammeter, voltmeter, 6V battery and connecting wires. *Procedure:* 1. Connect the ammeter, voltmeter, bulb and the battery by connecting wires. As shown in Fig 5.17 2. Measure the current in the circuit and record its reading. 3. Measure the voltage across the bulb using the voltmeter and record its reading. 4. Calculate the ratio of the voltage to the current using Ohm's law.

The ratio of the voltage to the current through the bulb gives the resistance of the bulb filament. Different bulbs have different resistances.

Resistors are electrical devices made to resist an electric current. There are many resistors in your electrical appliances. Example: in radio or television. Most resistors are made from a wire having a certain length, or from layer of carbon. (See Fig 5.18)

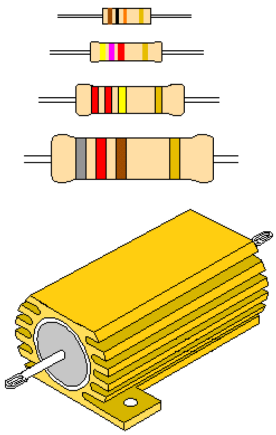
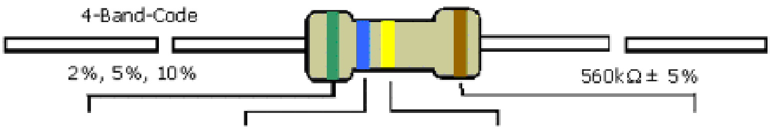


Fig 5.18 Different types of resistor

Color coding of resistors

Values of a resistor is some time shown using color mark. Fig 5.19 shows color marking of a resistor.

The value of the resistance of resistors given at the top of Fig 5.19 is calculated as: Green is 5, blue is 6, Yellow is 10kΩ thus the resistance of the resistor 560kΩ (560, 000Ω). Similarly you can find the resistance of the resistor given at the bottom of Fig 5.19.



COLOR	1st BAND	2nd BAND	3rd BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	±0.5% (D)
Blue	6	6	6	1MΩ	±0.25% (C)
Violet	7	7	7	10MΩ	±0.10% (B)
Grey	8	8	8		±0.05%
White	9	9	9		
Gold				0.1	± 5% (J)
Silver				0.01	± 10% (K)

Fig 5.19 color markings of resisters

Factors affecting the resistance of conductors

The resistance of a conductor depends on the nature of materials, lengths and cross-sectional areas provided the temperature remains constant. The following factors affect the resistance of a conductor.

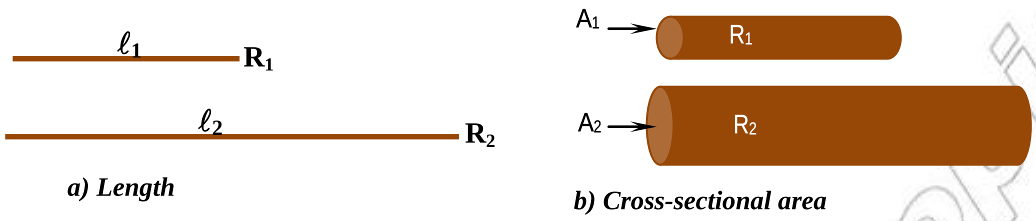


Fig 5.20 Factors affecting resistance

i) *Length:* The resistance of a conductor is directly proportional to the length of the conductor (wire). That is the longer the wire, the higher its resistance is and the shorter the wire, the lower its resistance is for a given material and cross-section area.

This relation can be explained using the collision of free electron in a conductor.

As the length of the conductor increases, the number of collisions that electrons make in traveling through the conductor also increases. Thus, current is slower in long wires and is faster in short wire (Fig 5.20 (a))

ii) *Cross-sectional area:* The resistance of a conductor is inversely proportional to its cross-sectional area i.e. The cross-sectional area indicates the thickness of the conductor. The thicker a wire is, the wider the cross sectional area is. The resistance of a conducting wire increases as the cross-sectional area is small. The resistance of a conducting wire decreases as the cross-sectional area is wide. (Fig 5.20 (b)).

You can compare this relationship to the human wiring model learnt in section 5.1.

In our homes thick wires are used for “mitad” electric iron and welding machines. While thin wires are used for electric bulbs, radio, television, battery charger, etc.

iii) *Nature of the conducting material:* The nature of material also determines the resistance of the conductor i.e. Different conducting materials have different ability to conduct electric currents.

iv) *Temperature*: The resistance of a conductor depends upon its temperature. As the temperature of the conductor increases, its resistance increases. However, Ohm’s law holds true for a material whose temperature does not change.

Check point 5.4

1. **Describe how to connect ammeters and voltmeters in a circuit.**
2. **Draw a circuit diagram using symbols of an ammeter and voltmeter.**
3. **Explain how you can measure the resistance with a voltmeter and an ammeter.**
4. **Describe the color coding of resistors.**
5. **What are the factors that affect the resistance of a conductor?**

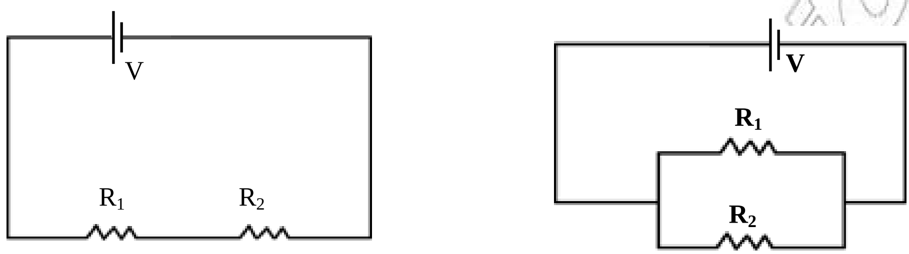
5.5 Formulae to Calculate Series and Parallel Combinations of Resistors

Activity 5.8

- Explain what is meant by series and parallel connections of bulbs?
- How are light bulbs in your home connected?
- Can you turn-on or turn off all the bulbs in your home using one switch only? Explain how.

Many electrical appliances in our homes are products of combined circuit system. Ohm's law is used to find the current in a circuit or part of a circuit. When conductors are connected together to make up a circuit they may all be connected together like a chain as shown in (Fig.5.21 (a) or some may be connected in parallel as shown in Fig. 5.21 (b). The way in which parts of a circuit are arranged affects the flow of current through the circuit. Basically there are two types of circuits. These are **Series circuit and Parallel circuit.**

- In Fig 5.21 (a) resistors R_1 and R_2 are connected is series and
- In Fig 5. 21 (b) resistors R_1 and R_2 are connected in parallel.



a) Series connection of R_1 and R_2 **b) Parallel connections of R_1 and R_2**

Fig 5.21 connections of resistors

Resistors in Series Circuit

A circuit without any branch is called a series circuit. Resistors are connected one after another.

When resistors are connected in series, current passes through each resistor one after the other.

Fig 5.22 shows a series connection of two bulbs.

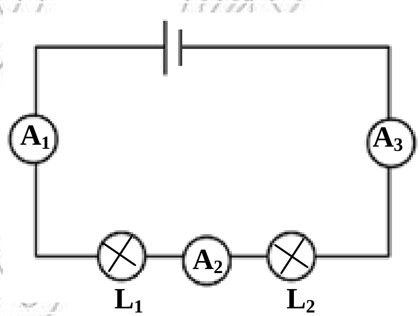


Fig.5.22 Current in series circuit is the same

The current through each resistor is the same for series connection. That is, from Fig. 5.22 the ammeters A_1, A_2 and A_3 read the same current.

Activity 5.9

To show that current in series circuit is the same.

Materials Required: 2 voltmeters, an ammeter, two flashlight bulbs, connecting wire, and 2 dry cells (1.5V each).

Procedure: 1. Connect the bulbs (L_1 and L_2) and the voltmeters as shown in the Fig.5.23.

2. By placing the ammeter in different points (like in a, b and c) take the values of the currents.
3. Take the values of the voltage drops across lamp L_1 and lamp L_2. (Fig 5.23)
   - Is the value of the current the same or different?
   - compare the sum of the voltage across each lamp with the total voltage

If you perform Activity 5.9 properly, you will then get the following important results.

1. The current flowing through each resistor or bulbs is the same for series connection. i.e. $I_1 = I_2 = I$
2. In a series circuit the sum of the voltages across each resistor equals the total voltage i.e. $V = V_1 + V_2$

Now based on the above two equations and the definition of resistance from ohm's law, you can calculate for the equivalent or effective resistance of a series combination of resistors.

If $V = V_1 + V_2$, $R_1 = \frac{V_1}{I}$ and $R_2 = \frac{V_2}{I}$

then $V_1 = R_1 I$ and $V_2 = R_2 I$

$\Rightarrow V = R_1 I + R_2 I$ since $V = I R_t$

$\Rightarrow I R_t = I(R_1 + R_2)$

$$R_t = R_1 + R_2$$

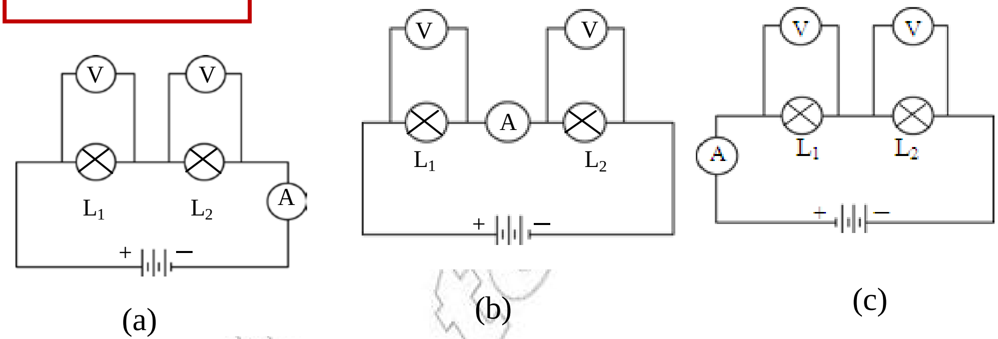


Fig.5.23 Measuring current in series circuit

In a series circuit, the total resistance (equivalent resistance) equals the sum of the resistances of each resistor. This means, the two resistors can be replaced by one equivalent resistor.

Worked Example 5.3

1. Two resistors of 6Ω each are connected in series to a battery which provides 36V. For this circuit, calculate
   a) the total resistance,
   b) the current through the circuit.

Given	Required	Solution
$R_1 = R_2 = 6\Omega$	a) R_t = ?	a) For series circuit, $R_t = R_1 + R_2$,
V= 36V	b) I = ?	$\Rightarrow R_t = (6+6)\Omega = 12\Omega$
		∴ The equivalent resistance is 12Ω
		b) According to ohm's law
		$V = IR$ and $I = \frac{V}{R_t} \Rightarrow I = \frac{36V}{12\Omega} = 3A$
		∴ The current through the circuit is 3A

2. For the circuit diagram shown in Fig.5.24, find out;
   1. the total resistance
   2. the ammeter reading
   3. the voltmeter's readings

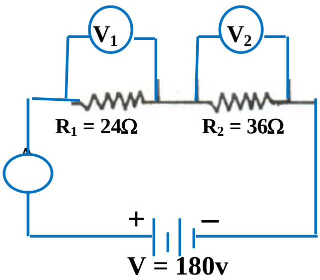


Fig. 5.24 Resistors in series combination

From Fig 5.24 we see that $R_1 = 24\Omega$, $R_2 = 36V$ and V=180V are in series. Thus

a) The total resistance $R_t = R_1 + R_2 = 24\Omega + 36\Omega = 60\Omega$

b) The ammeter reads the same current I through the circuit

$$\text{Thus } I = \frac{V}{R} = \frac{180V}{60\Omega} = 3A$$

c) The voltages across R_1 equals $V_1 = IR_1 = (3A)(24\Omega) = 72V$

$V_2 = I_2R_2 = (3A)(36\Omega) = 108V$

Resistors in Parallel Circuit

A circuit that branches out into two or more branches is called a parallel circuit. For example two resistors are said to be connected in parallel when they are placed side by side and their corresponding ends are joined together. Fig.5.25 shows parallel connection of two resistors.

In Fig 5.25 the total current (I) is split into I_1 and I_2 at a junction point A. and I_1 and I_2 join together at point B to give back the total current.

That is $I = I_1 + I_2$

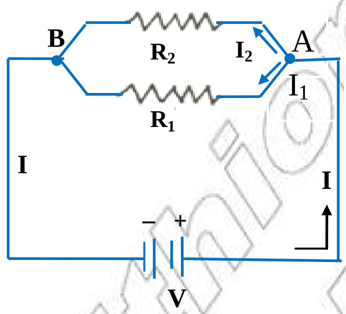


Fig. 5.25 parallel connection of two resistors

Activity 5.10 To measure current in every branch of the parallel resistor

Materials Required: Two cells of 1.5V each, connecting wires, two flashing bulbs, and ammeter.

Procedure:

1. Connect the bulbs in parallel.
2. Take the readings of the ammeter by placing it in different positions as shown in Fig 5.26
3. Compare the total current with the sum of the currents through the two bulbs. Is the sum of the currents through the two bulbs the same as that of the total current?

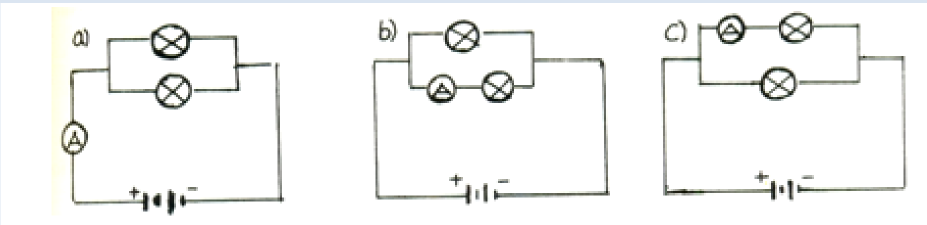


Fig. 5.26 Measuring current in parallel circuit

Activity 5.11 To measure the voltage across each resistor

Materials Required: Two cells of 1.5V each, connecting wires two flash light bulbs, and a voltmeter.

Procedure: 1. Connect the bulbs in parallel

2. Place the voltmeter across each resistor turn by turn as shown in Fig 5.27

3. Take the readings of the voltmeter and compare it with the total voltage of the cells.

- Is the voltage across each resistor the same?
- Is the voltage across each resistor the same as that of the total voltage of the cells?

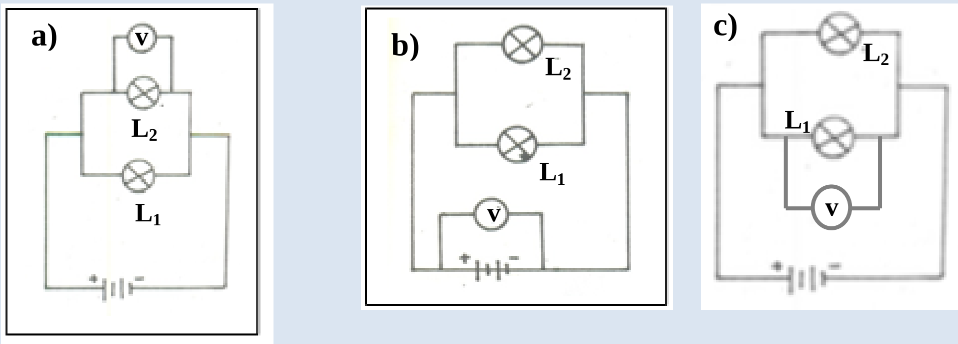


Fig 5.27 Measuring voltage in parallel circuit

If Activities 5.10 and 5.11 are done correctly then you will have the following results.

1. The sum of the currents flowing through the two bulbs is equal to the total current. That is:

   $I = I_1 + I_2$

2. The voltage across each bulb is the same as that of the total voltage supply. That is

   $V = V_1 = V_2$

3. Using Ohm's law and the above equations you can find an important relationship for the total resistance of two resistors connected in parallel.

   If $I = I_1 + I_2$ and $I = \frac{V}{R_t}$ (ohm's law)

Where $I_1 = \frac{V_1}{R_1}$ and $I_2 = \frac{V_2}{R_2}$ then;

$I = \frac{V}{R_t} = \frac{V_1}{R_1} + \frac{V_2}{R_2}$ But $V_1 = V_2 = V$

Thus $\frac{V}{R_T} = v\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$

Or $$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2}$$

Total resistance of two resistors R_1 and R_2 connected in parallel is less than the resistance of each resistor. Connecting resistors in parallel reduces the equivalent resistance and increases the total current. Use the following simplified form to find the equivalent resistance R_t.

$$R_t = \frac{R_1 R_2}{R_1 + R_2}$$

This formula works only for two resistors in parallel and you can use the mathematical method of adding fractions to get the value of R_t.

Worked Examples 5.4

1. Two resistors of 9Ω and 18Ω are connected in parallel across a 24V supply. For this circuit calculate;

   a) The total resistance b) The total current

Given	Required	Solution
$R_1 = 9\Omega$	a) $R_t = ?$	a) from equation above $\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{9\Omega} + \frac{1}{18\Omega}$
$R_2 = 18\Omega$	b) $I = ?$	$R_t = \frac{9\Omega \times 18\Omega}{9\Omega + 18\Omega} = \frac{162\Omega^2}{27\Omega} = 6\Omega$
$V = 24V$		$\therefore R_t = 6\Omega$
		b) From ohm's law we have $I = \frac{V}{R} = \frac{24v}{6\Omega} = 4A$
		That is; $I = 4A$

2. Two resistors of 12Ω and 24Ω are connected in parallel across a 48V battery (see Fig. 5.28). For this circuit system, calculate;
   a) the total resistance,
   b) the total current,
   c) the currents I_1 and I_2,
   d) compare the sum of I_1 and I_2 with I,

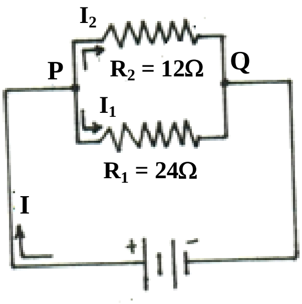


Fig 5.28 Resistors in parallel

Given	Required
R_1= 9Ω	a) R_t =?
R_2= 12Ω	b) I = ?
V = 48V	c) I_1 = ?, I_2 = ?
	d) $I = I_1 + I_2$ =?

Solution

a) Equivalent resistance in parallel combination is

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \text{ Thus, } \quad \frac{1}{R} = \frac{1}{12\Omega} + \frac{1}{24\Omega}$$

$$\frac{1}{R} = \frac{2+1}{24\Omega} = \frac{3}{24\Omega} = \frac{1}{8\Omega}$$

$$\frac{1}{R} = \frac{1}{8\Omega}$$

∴ The equivalent resistance R =8Ω

b) From Ohm's law, $I = \frac{V}{R_t}$

$$I = \frac{48V}{8\Omega} = 6A$$

I = 6A

c) For parallel connection of resistors

$$V_1 = V_2 = V$$

$$\text{Thus } I_1 = \frac{V}{R_1} = \frac{48V}{24\Omega} = 2A$$

$$I_2 = \frac{V}{R_2} = \frac{48V}{12\Omega} = 4A$$

d) $I = I_1+I_2$ = 2A +4A = 6A

Total current is the sum of currents in each resistor.

Energy and Power in an Electric Circuit

Many electrical appliances are used in our homes to convert electrical energy into other forms of energy. For example, a torch is used to convert electrical energy into light and electric heater converts electric energy into heat.

The amount of energy drawn from an electrical appliance depends on how long (time) it is used. Thus, it is preferred to talk about the amount of energy transferred every second. The energy transferred per second is called **power**.

$$\text{Power} = \frac{\text{Energy transeferred}}{\text{time taken}}$$

$$P = \frac{E}{t}, \; E = Pt$$

Challenging question

Does the power in an electric circuit depend on the voltage and current?

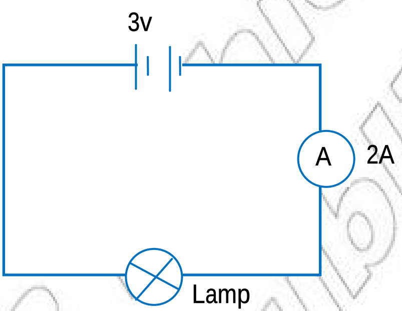


Fig 5.29 Power depends on voltage and current

Think about a 3V battery connected to a lamp as shown in Fig.5.29. The current in the circuit is 2A. This means that 2 coulombs of charge flow per second through the lamp. Now the voltage is 3V. This means that each coulomb transfer 3J of energy as it flows through the lamp. Since 1volt is equal to the energy used to move 1C of charge across the terminal points.

If there are 2C per second, and each coulomb transfers 3J, how many Joules are transferred each second?

The answer is 6 J /s, so, the power is 6 J/s or 6W.

The unit of electric power is Watt represented by W where 1W = 1J/s.

Electric power is the product of voltage and current.

$$P = IV$$

Using Ohm's law V = IR, we can express P in terms of R, V, and I.

Thus, $P = I^2R$ where $(V = IR)$

$$P = \frac{V^2}{R} \text{ where } (I = \frac{V}{R})$$

Worked Examples 5.5

1. A bulb uses 1,500J of energy in 25 second. What is its power?

Given	Required	Solution
E = 1500J	P = ?	$P = \frac{E}{t}$
t= 25second		$P = \frac{1500J}{25s} = 60W$

∴ The power of the bulb P = 60 W

2. An electric lamp is labeled as 220V, 60W.
   a) What do these numbers mean?
   b) What is the current produced when the lamp is connected to 220V?
   c) What is the resistance of the lamp filament?

Solution

a) 220V is the voltage across which the lamp has to be connected. This means 220J of energy is transferred whenever one coulomb of charge flows.
 60W is the electric power. It means 60Joules of electrical energy will be converted into light every second when connected to 220 V supply.

b) To calculate the current in the lamp.

$$P = IV, I = P/V = \frac{60W}{220V} \Rightarrow I = 0.27A$$

c) The resistance of the lamp

$$P = \frac{V^2}{R} \Rightarrow R = \frac{V^2}{P} = \frac{220V \times 220V}{60W} = 806.6\ \Omega$$

Check Point 5.5

1. Write the advantages and disadvantages of connecting lamps (a) in series and (b) in parallel.
2. a) Draw Fig 5.30 into your exercise book and name the way in which the lamps are connected and answer questions b and c
   b) If A_3 read 0.2A, what do the other two ammeters read?
   c) If one of the lamps is removed explain what would happen to the other lamp.

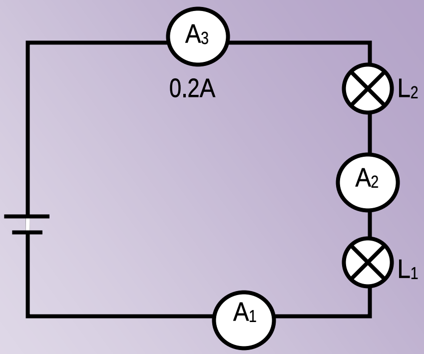


Fig 5.30 Reading of ammeter in series circuit

3. Draw Fig 5.31 into your exercise book, and answer the following questions.
   a) Name the way in which the lamps (bulbs) are connected.
   b) If the lamps are identical and A_3 reads 0.4 A, show on your diagram what the other ammeters read.
   c) What would the ammeter A_4 read?
   d) If the lamp next to A_3 is removed, what would happen to the other lamp?

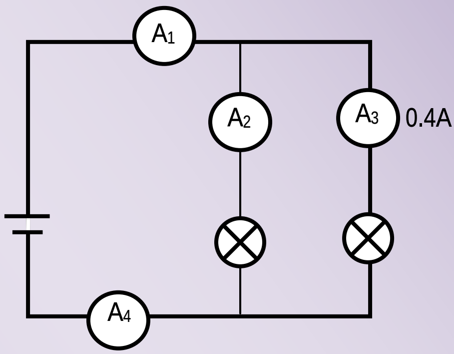


Fig 5.31 Reading of ammeter in parallel circuit

4. Describe series and parallel connections of resistors by drawing their diagram.
5. What happens to the resistance of two resistors when connected in a) series and b) parallel?
6. Define electric power in terms of current and voltage.

5.6 Electromagnetism

The interaction between electricity and magnetism is called **electromagnetism**. In this section you will study the magnetic effect of an electric current and its applications. However, you need to revise some properties of magnetism.

Activity 5.12

Discuss the following questions with your friends. (Revise your grade 7 physics on magnetism).

1. What is a magnetic field? How do you represent a magnetic field?
2. Draw and describe the magnetic field lines around a bar magnet.
3. What is a compass? What is it used for?

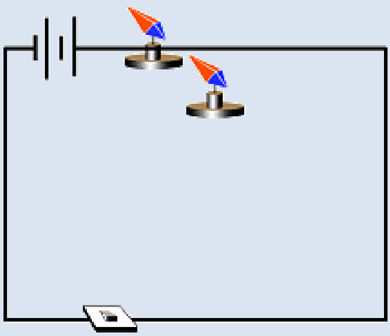
Magnetic effect of a current

In grade 7 physics you learnt that electric current can produce magnetism. The easiest way to show the magnetic effect of electric current is to hold a compass near a current carrying wire. Do the following activity.

Activity 5.13 Observing the magnetic effect of an electric current

Do the practical activity and answer the questions followed.

Materials required: Dry cell, switch, a resistor, a compass and a long connecting wire.



Hans Christain Oersted

Fig. 5. 32 Circuit connection for Oersted experiment

Procedures

1. Connect the resistor, switch and dry cells in series, as in Fig 5. 32
2. Close the switch and keep the compass below the wire. Observe the direction of deflection of the compass.
3. Then exchange the terminals connected to the battery. Keeping the compass needle below the wire, observe its direction of deflection.
4. Repeat steps (2) & (3) keeping the compass needle above the wire.
   - What do your observations show?
   - How would the electric current affect the magnetic field of the surrounding like a compass?
   - Can you conclude that magnetic field exists around a current carrying conductor?

From Activity 5.13 you observe that the compass needle is deflected from its original position when electric current flows through a wire placed on or below the compass. Thus, an electric current produces a magnetic field. This effect was first discovered by a Danish scientist called **Hans Christain Oersted.**

An electric current passing through a conductor produces a magnetic field in the surrounding. This phenomenon is called the magnetic effect of electric current.

Challenging question

Can you name other effects of electric current?

Magnetic field due to a straight current carrying wire

An electric current in a long straight wire produces magnetic lines which are circular in planes at right angles to the wire.

Activity 5.14

To observe the direction of magnetic field around a straight current carrying conductor.

Materials required: Dry cells, straight wire, a resistor, iron filings, switch, compass needle and cardboard

Procedure:

1. Connect the straight wire in series with the resistor, the switch and the battery (as shown in Fig 5.33. Stand the straight wire in a vertical direction.

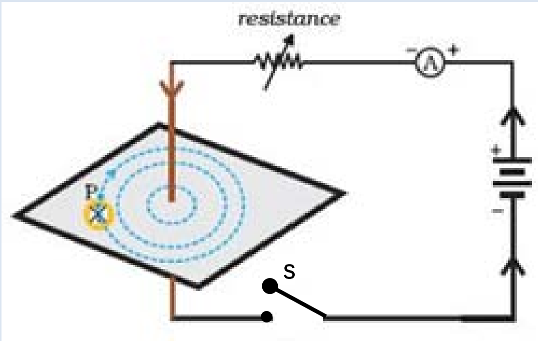


Fig 5.33

2. Mount the card board to the straight wire and attach it to the stand.
3. Gently sprinkle iron filings on the card board. Observe the pattern of the iron filings on the card board.
4. Remove the iron filings from the card board and place the compass on the card board. Slowly move the compass on the card board around the current carrying wire. Observe the direction of the needle at each point.
5. Sketch the direction of the compass needle on the card board. The direction of the compass indicates the magnetic field lines around a straight wire carrying current.
6. Exchange the connection of the terminals of the battery and repeat step 4 and 5

Activity 5.14 shows that magnetic field lines around current carrying straight conductor are circular. You might have observed that the direction of the magnetic field lines depends on the direction of current. The direction of the field lines due to a straight current-carrying conductor can be easily shown using the "Right Hand" rule.

Right–hand rule for a straight current carrying conductor

Grasp the current carrying conductor in your right hand with the thumb extended in the direction of current. The fingers will then point in the direction in which the field lines encircle the wire (see Fig 5.34).

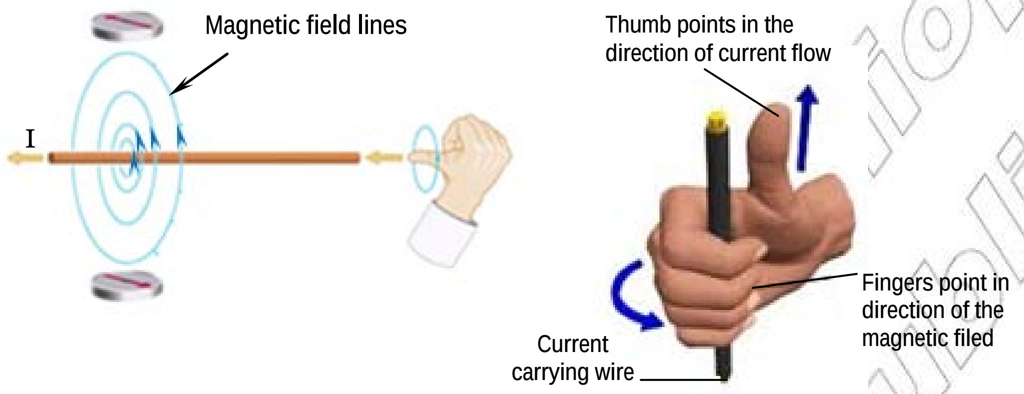


Fig 5.34 A schematic diagram showing the right-hand -rule

Using this rule, you can determine the

1) direction of magnetic field lines, if the directions of current is known,
2) direction of current, provided the direction of magnetic field lines are known.

Now you will examine what factors affect the magnitude (strength) of magnetic field around current carrying conductor. In Activity 5.14 you might have observed the region where the density of iron filings is more and sparse. Did you notice that the iron filings are concentrated near the wire? This shows that the magnetic field near the wire is stronger than that at a further distances. (Fig 3.34).

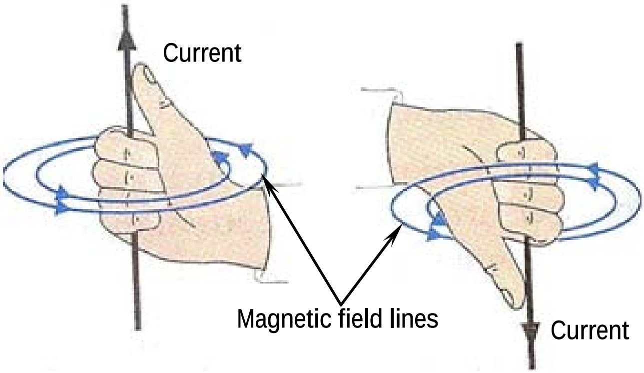


Fig 5.35 The directions of magnetic field lines around straight wires carrying current

Does the field strength depend on the current? Yes it does. To observe this repeat Activity 5.14 for different numbers of cells. A larger number of cells corresponds to stronger current. Did you notice that density of iron filings in a particular region increases as current increases? Thus, magnetic field of stronger current is stronger than that of weaker current.

The magnitude of the magnetic field of a current carrying wire depends on:

i) the magnitude of the electric current, and
ii) the distance from the wire.

Magnetic field around a solenoid

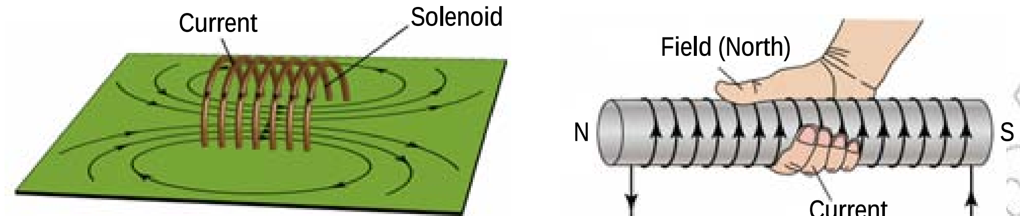
What is a solenoid? **Solenoid** is a coiled wire with a large number of turns. It is cylindrical in shape as shown in Fig 5.36 a) and b).

Fig 5.36 Solenoid

The magnetic field strength of a current carrying solenoid depends on;

i) the number of windings (turns),
ii) the magnitude of current passing through the solenoid and
iii) the types of core material inside the solenoid,

The magnetic field in the interior of a solenoid is nearly uniform. The magnitude of the magnetic field surrounding a current carrying solenoid increases when the solenoid has an iron core.



Magnetic field generated by a solenoid. The field pattern is similar to long bar magnet.

Fig 5.37 Magnetic field line in solenoid

As shown in Fig 5.37 the magnetic field lines due to each loop of wire help each other, inside the solenoid. Therefore, magnetic field inside a solenoid is stronger than that of the magnetic field outside a single loop.

The magnetic field of a solenoid increases as the number of turns and current in the coils increases. In addition to this the magnetic felid of a solenoid also increases when an iron core is inserted inside the solenoid.

Electromagnet

An electromagnet is a solenoid with an iron core. It consists of an insulated wire wound around an iron core. The coil can have different shapes. It can be wound in the shape of a bar or a horse-shoe shape or a nail. Fig 5.38 shows an electromagnet made from iron nail.

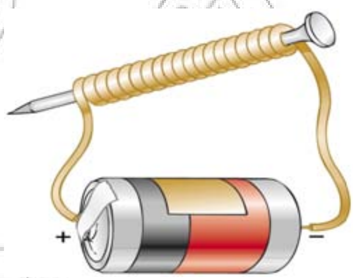


Fig.5.38 An electromagnet

Electromagnets are very useful in lifting iron materials. It serves as a temporary magnet. When the current in the coils is turned off the iron core loses its magnetism.

The magnetic field of an electromagnet depends on the following factors.

- The current passing through the coil.
- The number of turns of the coils.
- The types of core material inside the coil.

To determine the direction of the magnetic field lines of an electromagnet you need to apply, the right-hand rule for each loop. That is, grasp the solenoid inside your right hand and point the fingers in the direction of the current. Then the thumb points in the direction of the north pole of the electromagnets.

Similarities and differences between an electromagnet and bar magnet (Fig 5.39)

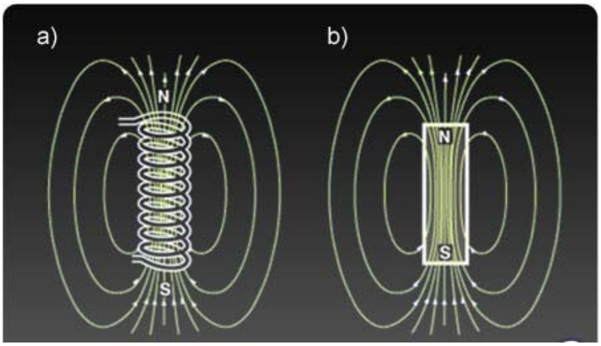


Fig. 5.39 Similarities between an electromagnet and a bar magnet

A. Similarity between electromagnet and a bar magnet

1. Both have the magnetic properties.
2. Both have similar magnetic field line patterns
3. Both have North and South poles.
4. Both attract metals.

B. Differences between electromagnet and bar magnet

Electromagnet	Bar magnet
- Magnetism is temporary - The field strength can be increased or decreased - The polarities can be changed - The magnetic field disappears when the current is turned off.	- Magnetism is permanent - The field strength cannot be changed. - The polarities are fixed.

Check point 5.6

1. Explain the shape of a magnetic field lines around a straight current carrying wire.
2. Fig 5.40 shows a current carrying straight wire. Draw the magnetic field line around it.

Fig 5.40 Current carrying straight wire

3. What is a solenoid?
4. Draw the magnetic field lines inside and around a current carrying solenoid.
5. Write down the factors that make an electromagnet strong.
6. Draw the magnetic field lines around a bar magnet and a current carrying solenoid. Describe their similarities and differences.

5.7 Electric Motor

An electric motor is a device that rotates when current passes through it. It is used to convert electrical energy into mechanical energy (kinetic energy.)

How does an electric motor works? What principle does it apply?

A current carrying wire in an external magnetic field experiences a force. The direction of the magnetic force on the wire depends on the direction of the current in the wire and the direction of the magnetic field lines.

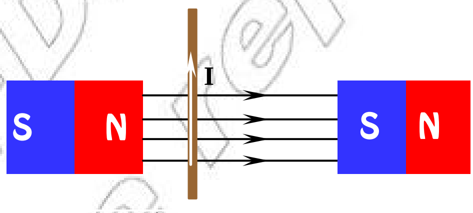
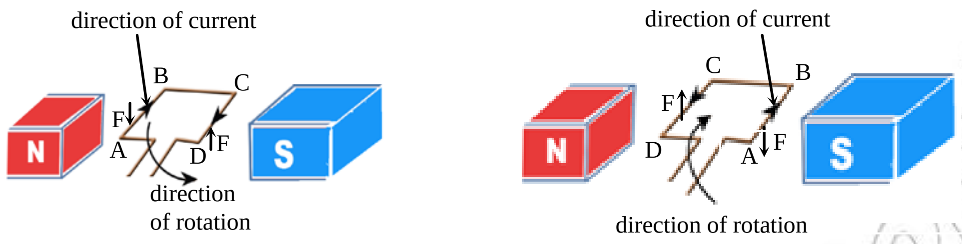


Fig 5.41 Current carrying wire crossing a magnetic field

We use the Right hand rule to indicate the direction of the force. Point your right hand thumb in the direction of the current and the remaining fingers in the directions of magnetic field. Then the palm of your hand shows the direction of the force. Fig 5.42 illustrates a force exerted on current carrying wire found inside a magnetic field.

In grade 7 physics, you also learnt that a force applied to a body produces a turning effect called torque. Thus, a torque produced in opposite direction causes bodies to rotate around an axis. This principle is applied in the working principle of an electric motor.



a) Force on AB is downward and force on CD is upward

b) After half cycle force on CD is upward and force on AB is downward,

Fig. 5.42 Rotations of a coil in magnetic filed

An electric motor consists of a strong permanent magnet and a flat coiled wire. The rotation of the coil obeys the principle of torque as the above example. The principle is that two opposing forces act on opposite segments of the flat current carrying coil. Then, the coil rotates about an axis. The forces are perpendicular to the plane of the segments.

Consider the rectangular coil shown in Fig 5.42a.

The segments $\overline{AB}$ and $\overline{CD}$ are perpendicular to the magnetic lines of force. The arrows on the segments show direction of current through the coil. A conductor kept perpendicular to the magnetic field experiences a force (when current flows). The direction of the force depends on direction of the current. The direction of current in $\overline{AB}$ is opposite to that in $\overline{CD}$. Therefore, opposing forces act on these two segments. This causes rotation of the coil.

After a half cycle (Fig 5.42b) the force on each segment is still the same as before. But, the positions of the segments are exchanged. Therefore, the direction of rotation is reversed.

The main parts of an electric motor are: the commutator or split ring brushes, magnetic field and armature or coiled wire.

To make the motor rotate in one direction a commutator is used. A commutator is a pair of half rings (split ring) insulated at the separation. The terminals of the coil rotate inside the half rings. One of the terminals of battery is connected to one half ring and the other terminal to the second half ring. As a result, the direction of current in each segment is reversed after a half cycle. This causes rotation of the coil in one direction. This is illustrated in Fig 5.43. What are the main parts of an electric motor? Name them using Fig 5.43.

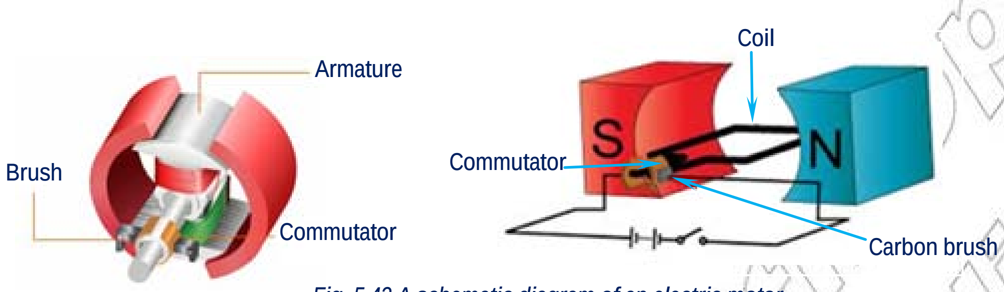


Fig. 5.43 A schematic diagram of an electric motor

To increase the speed of an electric motor you can do one of the followings.

1. **Wind the coil on a soft-iron core.** The iron core is called an armature. This increases the magnetic field strength.
2. **Increase the number of turns of the coil.** Slot the iron core and wind more turns on the slots. This helps for smooth turning.
3. **Use an electromagnet instead of a permanent magnet**

Where do you find electric motors in use? Electric motors are found in our every day life. They are used in video players, in electric singers (sawing machine), in drilling machine, in ventillaters, in cars,etc.

Project work

Construct a simple electric motor in group with your friends.

Materials required:

1) An electromagnet (a horse-shoe or a bar magnet can also be used).
2) A long insulated wire

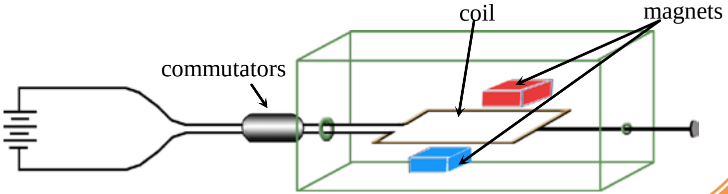
3) A metal ring
4) Battery (dry cells)
5) Iron slabs (three in number)
6) Brushes (made of insulators)
7) A box (wooden or metal) for enclosure

Procedure

1) Bisect the metal ring through its diameter. Insulating, at the cuts mount them together to the hole on the box. These are your commutators mentioned in step 4.
2) Slot one of the iron slabs and wind insulated wire in the slots (in a rectangular shape). Each wire has to be wound once. The terminals of all wires, which are to one side of the axis of the coil(see fig 5.41) should be connected together. (you can find some pieces of iron in a mechanic's shop) you may also use a single coil without a slab.
3) Use the remaining two slabs as cores for the electromagnet. The wire wound around the electromagnet should be insulated. The electromagnet has to be fixed to the bottom of the box. Leave a space, which is slightly larger than the width of the coil (between the two slabs). Connect the circuit as shown in Fig 5.42. The coil is connected to the battery in parallel with the electromagnet. The electromagnet and the coil can both be connected from the commutator. The terminals of the coil are pushed gently to the inner surface of the commutator by using brushes. The brushes should freely rotate inside the commutator.

   Instead of the electromagnet you can use a horse-shoe magnet, the north and South Pole of which are very close to each other. Or you may also use two bar magnets.
4) Make two holes on the box at a height half the width of the electromagnet (magnet) measured from the bottom of the box. Fix the commutators to one of the holes. Connect a straight wire to the center of the coil (as shown in Fig 5.43) pass the wire through the other hole on the box.

   You can use a switch between one terminal of the battery and the commutator. When the switch is closed you will observe that the wire, which is connected to the rectangular coil, rotates.



A model-type simple electric motor

An electric motor is a device that converts electrical energy into mechanical energy. There are several other devices which operate by the magnetic effect of electric current'. Some of these are electrical measuring instruments, such as; voltmeter, ammeter, ohmmeter, galvanometer, etc.

Check point 5.7

1. **Indicate the direction of a force on a current carrying wire in a magnetic field shown in fig 5.44.**
2. **Draw an electric motor diagram and label its parts.**
3. **Name some electrical appliances that have electric motors.**

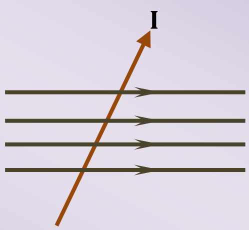


Fig 5.44 Magnetic field

5.8 Electromagnetic Induction

In the previous sections you learnt that an electric current in a conductor produces a magnetic field. How about the reveres action? Does magnetic field produce an electric current?

Activity 5.15

Observing magnetic lines of force cutting a conductor produces an electric current through the conductor.

Materials required: A sensitive centre zero galvanometer, a conducing wire, and U-shaped magnet.

Procedure

1. Connect the end points of the conductor, to the terminals of a galvanometer. A galvanometer is sensitive electrical instrument used to measure the presence of an electric current.

2. Move the magnet down ward and observe in which direction the galvanometer deflects. What does the deflection show?
3. Move the magnet up wards and observe the direction of deflection of the galvanometer.
   What do you observe about the deflection?
4. Now move the magnet horizontally, keeping the wire between the poles. Is there any deflection of galvanometer pointer? Why?

In the above activity, in step 2, when the magnet moves downward, the galvanometer deflects. This deflection shows that current is created in the conductor.

In step 3, when the magnet is moved upwards, the galvanometer deflects in opposite direction of the previous deflection.

When the magnet is kept horizontally, and moved, there is no deflection.
You will notice similar effects when you move a conductor in a magnetic field. Follow the next activity.

Instead of the U-shaped magnet, you can use two bar magnets. Keep the opposite poles of the two magnets close to each other. Connect the end points of a straight wire to the terminals of zero galvanometer. Move the wire upward, downward and horizontally between the poles. Vary the speed of motion of the wire. In each case observe the deflection on the galvanometer.

If the motion of the conductor is parallel to the magnetic lines, there is no effect observed
In this activity you could have observed that;

1. There is no deflection when the wire moves parallel to the magnetic field lines.
2. The deflections change in directions when the wire moves upward and down ward.
3. The induced current is stronger when the conductor moves faster.

You will observe similar effects when you move a bar magnet inside a solenoid.
Generally, a current is produced in a conductor whenever it cuts (move) across magnetic lines of force. This phenomenon is known as the **electromagnetic**

induction. Michael Faraday was the first scientist who demonstrated the generation of an electric current from a magnet. Activity 5.15 is known as Michael Faraday's experiment.

Electromagnetic induction is the process of inducing EMF in a coil by moving it relative to a magnet.

The current produced in the coil is called *induced current* and the EMF is called *induced EMF*

In the process of an electromagnetic induction, mechanical energy is converted to electrical energy. The mechanical work done in moving the coil or the magnet relative to one another results in inducing an electric current in the coil.

The direction of the induced current changes when the direction of the magnetic field changes.

Check point 5.8

1. Define the terms a) electromagnetic induction
b) induced current

2. Describe the generation of electricity by the movement of a magnet with in a coil of wire or a solenoid.

5.9 Generator

In the previous section you learnt that current is induced in a coil that moves in a magnetic field. The strength of induced current is weak in a single coil. In real life, many turns of rectangular coils are used. In addition, these turns are wound out of a single wire on slotted iron-core. A coiled wire around the iron-core is known as an **armature**. A shaft links the armature with a source of mechanical energy. The **armature** then rotates in a magnetic field. As a result, current is induced in the coil. Such a device is called a **generator**.

A generator is a device used to convert mechanical energy into electrical energy. It makes use of the principle of electromagnetic induction.

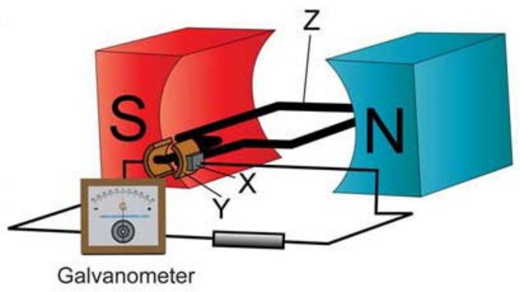


Fig 5.45 The structure of an ac generator

When a coil of wire is rotated inside a magnetic field or when a magnet is made to rotate around a stationary coil, current is induced in the coil. The induced current in the coil is supplied to the external circuit by means of slip-rings and brushes.

The slip rings are fastened tightly to the coil and rotate with it. The slip rings and the external circuits are in contact by means of brushes.

The main parts of a generator are the **armature, brushes, slip rings and magnetic field.**

- **An armature** is a coiled wire around an iron core.
- **Slip ring** is a metallic ring splitted into two half. It is attached to the armature.
- **Brushes** are carbon rods used to attach the external circuit to the armature.

When the coil makes half a turn, the direction of the currents is reversed. A current that changes its direction with time is called an alternating current (AC). A generator that produces alternating current is called an AC generator.

A current that does not change its direction with time is called a direct current (DC). For example, a dry cell and a car battery are sources of direct current.

A bicycle dynamo is an electric motor that produces direct current when it rotates with the wheel of a bicycle. In this case, an electric motor acts as a D.C generator.

Check point 5.9

1. **What is a generator?**
2. **Draw an AC generator and label its parts.**
3. **Explain the differences between AC and DC current**

5.10 Transformer

A transformer is a device that transfers electrical energy from one circuit to another by the process of electromagnetic induction. It is used on an alternative currents (AC) only not on a DC current.

A transformer consists of two coils of wire, wound on an iron core. The two coils of wire are called **primary coil** and **secondary coil,** as shown in Fig 5.46. When an alternating current is passed through the primary coil, the changing magnetic field gives rise to induced alternating current in the secondary coil.

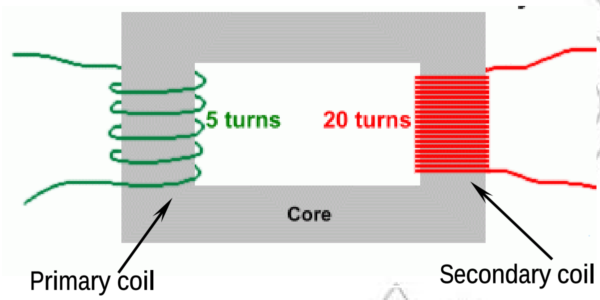


Fig 5.46 Structure of a transformer

Fig 5.47 A transformer

A transformer in which the output coils (secondary coils) have more turns than the input coils (primary coils) is called a step-up transformer. **A step-up** transformer changes a voltage to a higher value and it has more numbers of turns in its secondary coil than in its primary coil (Ns>Np).

A transformer in which the output coils have fewer turn is called a step-down transformer. **A step-down** transformer changes a voltage to a lower value and it has more number of turns in its primary coil than in its secondary coil ($N_p > N_S$).

In an ideal transformer the electric power is the same in both primary and secondary coils.

Electric power in primary coil; $P_p = I_P V_P$ and the electric power in secondary coil $P_s = I_S V_S$.

Since the power $I_p V_p$ going into a transformer must be equal to the power $I_s V_s$ going out where I_p and I_s are the primary and secondary currents respectively. The ratio of turns;

$$\frac{I_P}{I_S} = \frac{N_S}{N_P}$$

$$\frac{\text{Primary voltage}}{\text{Secondary voltage}} = \frac{\text{Primary turns}}{\text{Secondary turns}} \Rightarrow \frac{V_P}{V_S} = \frac{N_P}{N_S} = \frac{I_s}{I_p}$$

Examples

1. A transformer is being designed to have a 600-volt output with a 120-volt input. If there are to be 800 turns of wire in the input coil, how many turns must there be in the output coil?

Given	Required	Solution
$V_p = 120$ V	$N_s = ?$	$\frac{V_p}{V_s} = \frac{N_p}{N_s}$
$V_s = 600$ V		$\frac{120\text{ V}}{600\text{ V}} = \frac{800}{N_2} \Rightarrow 800 \times 5 =$
N_2		
$N_p = 800$		$\Rightarrow$ Number = 4,000
		The number of turns in the Secondary coil $N_s = 4{,}000$

Uses of Transformers

Electric power transmission lines use transformers to either step-up or step-down the generated electric power. You probably have a number of transformers in your home. Your mobile telephone charger is a transformer. It operates at 9V voltage. It transforms 240 V from the main to 9 V. Your cassette player, computer, radio, etc have transformers in them.

Transformers play a significant role in distribution of electrical energy over wide areas in the country. This is done by means of high voltage lines carrying relatively small current to avoid losses caused by heating the lines.

Check point 5.10

1. What is a transformer?
2. Name the two kinds of transformers. Explain the functions of each type of transformer.
3. Draw a transformer and label its parts.
4. Write down some electric appliances in life that have transformers.

5.11 Power Transmission

Ethiopia is using hydroelectric power plants to supply electrical energy to cities to light roads, industries, homes and other sectors.

Can you name some hydroelectric power plants in your locality? From where does your city /town or village get electric energy? The main hydroelectric power stations in our country are given in Table 5.3

Activity 5.17 Observation

Make a visit to a nearby electric power station (plant)

1. Identify the voltages stepped up or stepped down along the transmission process.
2. For what purposes are the voltages stepped down?

Let us see how an electric energy is transmitted from the power station to our home. Let us say, Koka Electric Power Plant generates 25kV at the station. This voltage is stepped up by a transformer to about 270kV or 400kV at different points. High voltage is used to reduce the electric energy loss as it travels long distances. As it reaches towns the 400 kV is stepped down by a transformer to 11kV for industries and to 240 V for homes, schools, shops, etc. Fig 5.48 illustrates electric power transmission from a power station.

Fig 5.48 Electric power Transmission lines

At home, the 240V mains are stepped down to 110V or 9V as required.

Table 5.3

Name of some hydro electric power plants	Power being transmitted	Where it is found
1. Melka wakana	150MW	Oromia Reginal state
2. Koka	43.2MW	Oromia Reginal state
3. Fincha	100MW	Oromia Reginal state
4. Tekeze	300MW	Tigrai Regional state
5. Tanabeles	460MW	Amhara Regional state
6. Tise Abai	11.5MW	Amhara Regional state
7. Gelgel Gibe I	180MW	Oromia Regional state
8. Gilgel Gibe II	420MW	SNNPR state

Check point 5.11

1. What is the function of a transformer?
2. Draw the symbol of a transformer.
3. Why is a high voltage used to transmit electricity?

Electrical Safety Rules

Electricity is very useful to people. It could become a curse due to people's ignorance and carelessness. You need to know electrical safety rules so that you can protect yourself and others and properties from the dangers of electricity. Some of the precautions which should be taken as a safety rule are stated below.

- Don't plug something in or unplug something unless you have your teachers'/parents' permission.
- Never touch appliances, electrical outlets or switches with wet hands.
- Only trained people should install and repair electrical wirings.
- Bare wires should be well insulated or replaced.
- Make a change in the wiring only after the mains has been put off.
- Every circuit must be fused with the proper size. Fuse is used to protect the line or instrument in the circuit from damage.
- Tell your teacher or parent about any damaged electrical cords so they can be replaced right away.
- Never climb an electric pole or tower.

SUMMARY

In this unit you learnt that:

- an electric circuit is a complete path for the flow of electric current. It may consist of different items like a source of potential difference, switches connecting wires, and a lamp.
- the structure of an electric bulb and the function of a fuse. A fuse makes a circuit open (incomplete) in a time of high flow of current.
- electric current is the rate of flow of electric charges across a given cross-sectional area in a conductor.
- electron current is the flow of electrons from negative terminal to positive terminal of the source. Conventional current is a theoretically assumed current that flows to opposite direction to that of an electron current.
- voltage is a measure of the ability to do work.
- Ohm's law states the relationship between current and voltage. It states that: ''The current flowing through a metallic conductor at a constant temperature is directly proportional to the voltage between the two ends."
- measuring electric current, voltage and resistance in a given circuit, using voltmeter and ammeter. An electric current passing through a conductor produces a magnetic field in the surrounding.
- a current carrying wire in an external magnetic field experiences a force.
- an electric motor is a device that converts electrical energy into mechanical energy (kinetic energy.)
- electromagnetic induction is the process of inducing EMF in a coil by moving it relative to a magnet.
- a generator is a device used to convert mechanical energy into electrical energy. It makes use of the principle of electromagnetic induction.
- a transformer is a device that transfers electrical energy from one circuit to another by the process of electromagnetic induction. Transformers are of two types: step up and step down.
- the major source of electrical energy is hydroelectric power. In hydroelectric power stations potential energy of falling water is converted in to electrical energy.

Review Questions and Problems

I. *Say True or False for the following statements.*

1. The current through two resistors in series branches out (splits).
2. The sum of potential differences across each resistor in series is the same as that of the voltage of the source.
3. The sum of currents through two equal resistors in parallel are equal to the total current.
4. For two resistors in parallel the voltage across each resistor is the same as that of the voltage of the source.
5. If two resistors are in parallel then the reciprocal of net (total) resistance is the sum of reciprocal of the two resistances.
6. A current carrying wire produces a magnetic field around it.
7. A current carrying conductor experiences no force when found in an external magnetic field.
8. An electric motor converts electric energy in to energy of motion.
9. Magnetic field in an electromagnet is not affected by the number of turns of the coil.
10. A transformer transfers energy from one body to another.

II. *Choose the best answer among the given alternative answers.*

1. Two opposite forces acting perpendicular to an axis cause
   a. Back and forth motion
   b. Rotation
   c. Sliding motion
   d. No motion (at rest)
2. The part of an electric motor that reverses current in a segment of the coil is.
   a. Armature
   b. Commutator
   c. Brushes
   d. Battery

III. *Choose the proper word from the given options that makes the statement true.*

1. A current carrying conductor is aligned (parallel/perpendicular) to magnetic lines of forces so as to experiences force.
2. After a half cycle a motor without a commutator rotates (forward/ backward).
3. Electric motor converts (electrical/mechanical) energy to (electrical/mechanical) energy.

IV. Solve the following problems

1. A current of 15 A flowed through a conductor for 1hr. What amount of charge would move through the conductor in this time?
2. Two resistors of 40Ω each are connected in series across a 120V supply.
   a) What is the total resistance of the circuit?
   b) What is the current through the circuit?
   c) What is the potential difference across each resistor?
3. A 75Ω lamp and 150Ω heater are connected in parallel across a 150V potential difference.
   a) What is the equivalent resistance of the two items?
   b) Find the currents flowing through the two items.
   c) What current flows through the entire circuit?
   d) Compare the sum of the currents through the lamp and heater with total current.
4. Calculate the total resistances and the current through each resistor. Fig 5.49

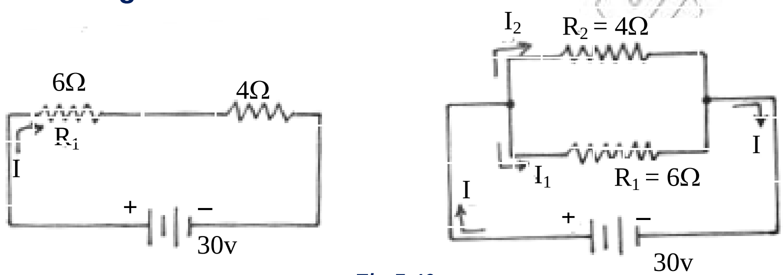


Fig 5.49

(a) (b)

V. Answer the following questions

1. What is the use of insulation between the half rings of a commutator?
2. What is the purpose of winding many turns of wire on an armature?
3. Using a diagram, describe how an electric motor works.
4. State and demonstrate the right hand rule for current carrying wire in a magnetic field
5. Explain Faraday's Experiment using a coil and a magnet
6. State an electromagnetic induction
7. What is meant by a step up transformer and a step down transformer?
8. What is a fuse? How does it work?