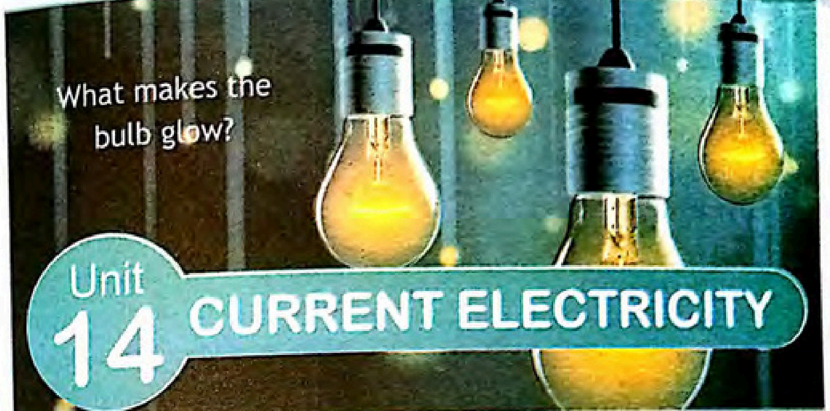
4. State and explain Coulomb's Law.
5. What is meant by electric field and electric field intensity? How the field lines represent the electric field for isolated positive and negative point charges?
6. What is electric potential? In what units we measure electric potential?
7. Give some practical applications in which electric field is useful.
8. How lightning occurs? How can we safeguard ourselves from lightning hazard?
9. What is capacitor? Define capacitance and its units.
10. What is series combination of capacitors? How we can determine equivalent capacitors for different capacitors connected in series?
11. What is parallel combination of capacitors? How we can determine equivalent capacitors for different capacitors connected in parallel?

NUMERICAL QUESTIONS

1. Determine the magnitude of the electric force on the electron of a hydrogen atom exerted by the single proton that is the atom's nucleus. Assume the average distance between the electron and the proton is $r = 5.3 \times 10^{-11}$ m and charge on electrons and proton is 1.6×10^{-19} C.
2. A 5 μC point charge is placed 20 cm from a 10 μC point charge. (a) Calculate the force experienced by the 5 μC charge. (b) What is the force on the 10 μC charge? (c) What is the field strength 20 cm from the 10 μC point charge?
3. In a certain region of space, a uniform electric field has a magnitude of 4.60×10^4 N/C and points in the positive x-direction. Find the magnitude and direction of the force this field exerts on a charge of (a) +2.80 μC (b) -9.30 μC.
4. The potential difference between two points is 110 V. When an unknown charge is moved between these two points, the work done is 550 J. What is the amount of charge?
5. The capacitance of a capacitor is 3200 pF. If the potential difference between its plates is 220 V. What is the charge on each of its plates?
6. Three capacitors of capacitance 1 μF, 2 μF and 3 μF are connected in series to a 110 V battery. Calculate the equivalent capacitance and voltage across each capacitor.
7. Two capacitors of capacitance 2 pF and 3 pF are connected in parallel to a 9V battery. Calculate the equivalent capacitance and the charge on each capacitor.



Unit 14 CURRENT ELECTRICITY

STUDENT LEARNING OUTCOME

After studying this chapter you should be able to

- ✓ define electric current.
- ✓ describe the concept of conventional current.
- ✓ understand the potential difference across a circuit component and name its unit.
- ✓ describe Ohm's law and its limitations.0.12
- ✓ define resistance and its unit(Ω).
- ✓ calculate the effective resistance of a number of resistances connected in series and also in parallel.
- ✓ describe the factors affecting the resistances of a metallic conductor.
- ✓ distinguish between conductors and insulators.
- ✓ sketch and interpret the V-I characteristics graph for a metallic conductor, a filament lamp and a thermistor.
- ✓ describe how energy is dissipated in a resistance and explain Joule's law.
- ✓ apply the equation $E = I.Vt = I^2Rt = V^2\,t/R$ to solve numerical problem.
- ✓ calculate the cost of energy when given the cost per kWh.
- ✓ distinguish between D.C and A.C.
- ✓ identify circuit components such as switches, resistors, batteries etc.
- ✓ describe the use of electrical measuring devices like galvanometer, ammeter and voltmeter (construction and working principles not required).
- ✓ construct simple series (single path) and parallel circuits (multiple paths).
- ✓ predict the behaviour of light bulbs in series and parallel circuit such as for celebration lights.
- ✓ state the functions of the live, neutral and earth wires in the domestic main supply.
- ✓ state reason why domestic supplies are connected in parallel.
- ✓ describe hazards of electricity (damage insulation, overheating of cables, damp conditions).
- ✓ explain the use of safety measures in household electricity, (fuse, circuit breaker, earth wire).

UNIT14: CURRENT ELECTRICITY

CONTENTS

The previous chapter was concerned with static charges, current electricity deals with charges in motion. Making charges move has many advantages for example it helps us light our homes, entertain ourselves with the television and even inside the human body it carries signals to and from our brain as nerve impulses. We have harnessed electricity to improve our quality of living and understand the life within us. This unit introduces the basic concepts of electricity and will make us aware of our household electricity and safety considerations.

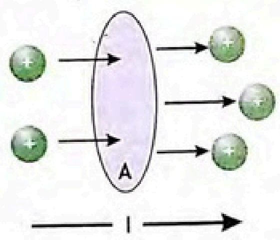
14.1 ELECTRIC CURRENT

'Time rate of flow of charge is called current'.

A charge 'ΔQ' flowing through any cross-sectional area in time 'Δt', corresponds to a current I that is defined mathematically as

$$I = \frac{\Delta Q}{\Delta t} \qquad (14.1)$$

FIGURE 14.1 - *Electric current*



The time rate at which charge flows through the area is defined as the current I.

When charges flow, they can be positive, negative, or both. For example the current in metals is due to flow of negatively charged electrons. The current in the beam of a particle accelerator is due to positively charged protons, while in some cases such as gases and electrolytes, the current is due to the flow of both positive and negative charges. Moving charges, whether positive or negative, are referred to as charge carriers. The total current is $I = I_+ + I_-$.

The SI unit of current is **ampere** and is represented by capital letter A. When one coulomb charge flows through any cross-sectional area in one second, the current is one ampere.

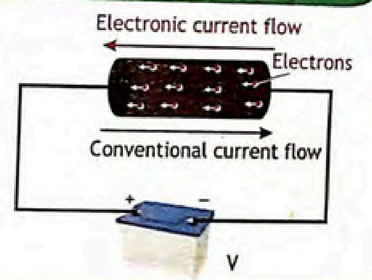
$$1\ A = 1\ C/s.$$

Since coulomb is large amount of charge, therefore ampere is also a large unit of current. In real life situations, we deal with small values of current like milli-amperes (mA $= 10^{-3}$ A) and micro-amperes (μA $= 10^{-6}$ A)

Conventional flow of current: *The direction of conventional current is the direction in which positive charges flow.*

In conductors (e.g metals), the actual flow of current is due to electrons which flow from negative terminal to the positive terminal of battery. However, before the discovery of electron, the current was assumed to flow from positive to negative terminal of the battery even for conductors.

FIGURE 14.2 - *Direction of current*



This assumed direction of current flow is now called conventional current. For practical purposes, positive charge moving in one direction is equivalent to negative charge moving in opposite direction. Both conventional current and electron flow are used by industry.

EXAMPLE 14.1: AMOUNT OF CHARGE TO BATTERY

A new battery is charged at the battery shop charging station using a current of 6.7 A for 5.0 h. How much charge passes through to the battery?

GIVEN

Current 'I' = 6.7 A

Time 'Δt' = 5 hrs = $5 \times 60 \times 60 = 18000$ s

REQUIRED

Charge 'ΔQ' = ?

SOLUTION: By definition of electric current $I = \frac{\Delta Q}{\Delta t}$ or $\Delta Q = I \times \Delta t$

Putting values $\Delta Q = 6.7\,A \times 18000\,s$ or $\Delta Q = 6.7\,C/\cancel{s} \times 18000\,\cancel{s}$

$\Delta Q = 120600\,C = 1.2 \times 10^5\,C$ — Answer

Thus, in charging battery 0.12 MC of charge was provided.

ASSIGNMENT 14.1: TRUCK STARTER CURRENT

While starting an engine of a truck, its battery sets 720 C of charge in motion for 4.00 s. How much current is flowing?

INFO — CONDUCTORS AND INSULATORS

Materials are broadly divided into two categories based on their electrical properties. They are either conductors, in which charge flows freely, or insulators that do not allow easy flow of charges.

The electronic structure of a material refers to the way in which electrons are bound to nuclei, conductors have an electronic structure that allows the free movement of some electrons. The positive charges of the atoms of a conducting material do not move, since they reside in a heavy nuclei. Metals are a typical example of solid conductors. Copper, for example, is a very good conductor used in electrical wiring.

For insulators, no free movement of electrons occurs because the material has no loosely bound electrons that can escape from its atoms and thereby move freely throughout the material. Typical insulators are glass, plastic, and cloth.

14.2 POTENTIAL DIFFERENCE AND EMF

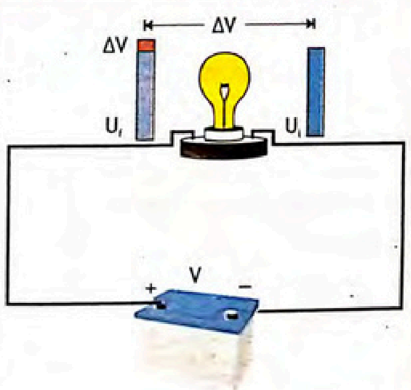
The electric potential at one point can be higher, lower or equal to the potential difference at other point. *'The difference of electric potential between two points is called potential difference'.*

Table 14.1 SOME CURRENT VALUES

Sr	Situation	Current (A)
1	Advanced technology computer chips	10^{-12} to 10^{-6}
2	Electron beam of a TV set	10^{-3}
3	Minimum current that is dangerous when it passes through the body	10^{-2} to 10^{-1}
4	Flash light bulb	0.3
5	House hold light bulb	1
6	Automobile starter	200
7	Maximum current in lightning strike	10^{4}
8	Maximum current carried by a superconducting niobium of 1 cm^2 cross-section	10^{7}

For example in an electric circuit which has an electric device (electric bulb) connected across a battery through conducting wires as shown in figure 14.3. The charge leaving the positive terminal of the battery has potential energy in device; part of this energy is lost (converted to other forms of energy). Thus, there is a difference of potential energy per coulomb of charge (q) from once side of the electric device to the other, which is termed as potential difference.

FIGURE 14.3 - *Potential difference*

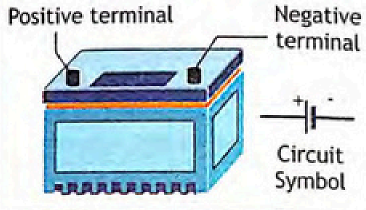


$$\Delta V = \frac{\Delta U}{q} \quad (14.2)$$

The potential difference developed and maintained by source of electrical energy is called electromotive force (emf or ξ).

To sustain steady current in a circuit, emf source (*A device which converts a non-electrical energy into electrical energy*) is required which maintains a constant potential difference across its ends. Figure 14.4 shows battery as an emf source with positive and negative terminals.

FIGURE 14.4 - EMF



When battery is connected through conducting wires with a device. The positive charges enter the negative terminal of the battery. Therefore, work has to be done inside the battery to bring the positive charge from lower potential to higher potential. The influence that makes current flow from lower to higher potential (inside the battery) is called electromotive force (emf or E). If W is the work done by battery in taking a charge q from negative terminal to positive terminal, then electromotive force (emf or E) of the battery is:

$$E = \frac{W}{q} \quad (14.3)$$

Equation 14.3 is the equation for emf, thus electromotive force (emf) is also defined as ***the energy spent per unit positive charge by the source to move it from negative terminal to the positive terminal within source.***

The units of electromotive force is the same as units for electric potential or potential difference as J/C = V.

$$1V = \frac{1J}{1C}$$

TIP: Arbitrary Reference

Recall that the reference point for determining the electric potential at a location is arbitrary. For example, consider a typical 9 V alkaline battery. It means that the positive terminal has an electric potential that is 9 V higher than the electric potential of the negative terminal. If we designate that the negative terminal of the battery is at zero potential, the positive terminal would have a potential of 9 V. We could just as correctly choose the potential of the negative terminal to be -4.5 V and the positive terminal to be +4.5 V.

14.3 OHM'S LAW

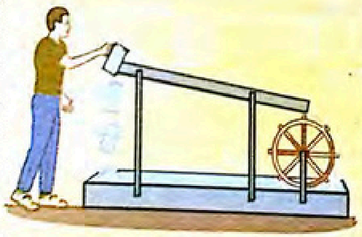
Statement: ***The current in a conductor is directly proportional to the applied voltage across the conductor as long as temperature and the physical state of the conductor is kept constant.***

Those devices which obey Ohm's law are called Ohmic devices and are commonly reffered to as "resistors".

INFO

ANALOGY BETWEEN GRAVITATIONAL POTENTIAL AND EMF

In this system, the person raising the water from a low to a high level is analogous to the battery, the paddle wheel is analogous to the lightbulb and the water is analogous to the electric charge. Notice that the person does work in raising the water; later, as the water falls to its original level, it does work on the external world by turning the paddle wheel.



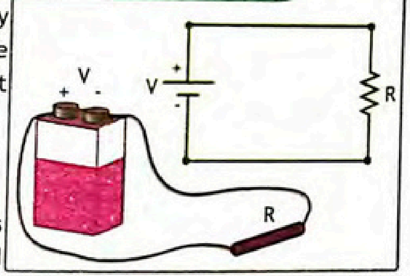
This means if we connect an ohmic device first to 1.5 V battery, and then we double the battery voltage to 3V, the current will also double. The current *I* flows through ohmic device when voltage *V* is applied across its ends, then according to Ohm's Law, we have

$$I \propto V \quad \text{or} \quad I = kV$$

Where k is the constant of proportionality and is equal to 1/R, where *R* is the opposition to the flow of current therefore

$$I = \frac{V}{R}$$

FIGURE 14.5 - Ohm's law



Here R is called resistance and is independent of the value of *V* and *I* and depends upon the nature of the conductor (its material), the dimensions of the conductor (such as length and cross-sectional area) and temperature of the conductor. All devices does not obey Ohm's Law. The devices that follow Ohm's law are called Ohmic devices and are commonly referred to as 'resistors'.

Limitations of Ohm's law: For Ohm's law to hold good, the resistance '*R*' must not change. However, only metallic conductors (for example copper, silver and gold wires) show this behavior and that too only over limited range of voltages.

Many important devices do not obey Ohm's law. Even a lightbulb has resistance that depends on its temperature and does not obey Ohm's law.

EXAMPLE 14.2: CURRENT THROUGH RESISTOR

A 30.0-V battery is connected to a 10.0 Ω resistor. What is the current in the circuit?

GIVEN

Potential difference 'V' = 30.0 V

Resistance 'R' = 10.0 Ω

REQUIRED

Current 'I' = ?

SOLUTION: By Ohm's law $I = \frac{V}{R}$

Putting values $I = \frac{30.0V}{10.0\Omega}$

$I = 3.00\,A$ — Answer

EXTENSION EXERCISE 14.1

How V/Ω gives amperes? 3.00 A is a large current, is this current realistic?

ASSIGNMENT 14.2: CURRENT THROUGH ELECTRIC RANGE

A heating element on an electric range operating on 240 V has a resistance of 30.0 Ω. What current does it draw?

14.4 ELECTRICAL RESISTANCE (R)

The opposition offered to the flow of charges is called electrical resistance.

In metallic conductors, the charge is transported by free electrons. Resistance is due to collisions between these free electrons and fixed atoms inside the conductor. By Ohm's law, the resistance is the ratio of the voltage V across the conductor to the current I it carries, mathematically

$$\boxed{R = \frac{V}{I}} \quad (14.4)$$

The **SI unit of resistance is ohm** and is represented by Greek letter (omega) Ω. *The resistance of wire is one ohm if potential difference of one volt applied across its ends and causes a current of one ampere to flow through it.*

$$1\Omega = \frac{1V}{1A}$$

For example, a wire or an electrical device that offers resistance to the flow of charges is called a resistor. The resistance can have a wide range of values. The copper wires in a television set, for instance, have a very small resistance. On the other hand, commercial resistors can have resistence up to many kilo-ohms (1 kΩ = 10^3 Ω) or mega-ohms (1 MΩ = 10^6 Ω).

The circuit symbol for a resistance in circuit diagrams is a zigzag line.

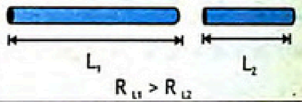
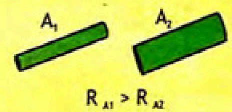
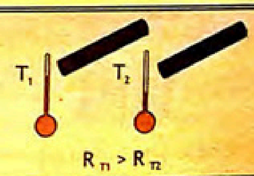
Resistance symbol

Factors on which Resistance depend: Since the resistance is provided by collisions of the free electrons with the lattice atoms, thus, any factor that affects the number of collisions will also affect a material's resistance. These factors include

A. Length B. Cross sectional Area C. Temperature D. Material

The effect of these factors is shown in table 14.2.

Table 14.2 FACTORS AFFECTING RESISTANCE OF METALLIC CONDUCTORS

Factor	How resistance changes	Example
Length	Resistance increases with increase in length $R \propto L$	
Cross sectional Area	Resistance increases by decreasing cross sectional area $R \propto \frac{1}{A}$	
Temperature	Resistance increase as temperature increases	
Material	Keeping length, cross-sectional area and temperature constant, resistance also varies by using different materials.	R Increases ↑ Platinum, Iron, Aluminum, Gold, Copper, Silver

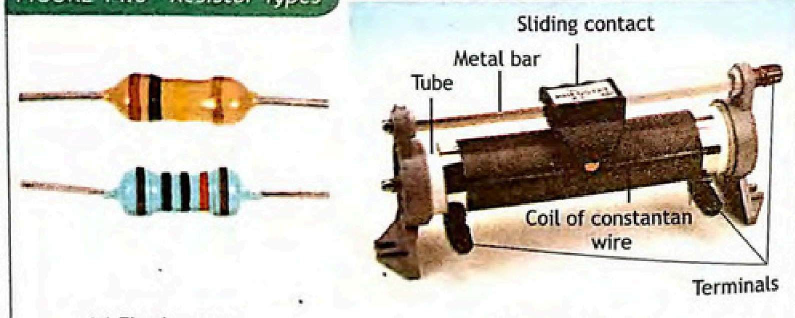
NOTE: The increases in resistance with temperature is not directly proportional.

POINT TO PONDER

Wire Resistance: Although copper wire conducts electricity extremely well, it still has some resistance, as do all conductors. The resistance of a particular wire depends on all the three physical characteristics mentioned above such as (a) type of material, (b) length of wire, and (c) cross-sectional area. In addition, temperature can also affect the resistance.

Resistors: Devices intended to have a specific value of resistance are called resistors and are made either from wires of special alloys or from carbon, a type of carbon resistor is shown in the figure 14.6 (a). Those used in radio and television sets have values from a few ohms up to millions of ohms. Variable resistors are used in electronics as volume and other controls. Variable resistors that take larger currents, like the one shown in Figure 14.6 (b) are useful in laboratory experiments. These consist of a coil of constantan wire (an alloy of 60% copper, 40% nickel) wound on a tube with a sliding contact on a metal bar above the tube.

FIGURE 14.6 - *Resistor Types*



(a) Fixed resistors (b) Variable resistors

LAB WORK

Verify Ohm's law (using wire as conductor).

EXAMPLE 14.3: FLASHLIGHT BULB'S RESISTANCE

A small flashlight bulb draws 300 mA from its 1.5-V battery. What is the resistance of the bulb?

GIVEN

Potential difference 'V' = 1.5 V

Current 'I' = 300 mA = 0.3 A

REQUIRED

Resistance 'R' = ?

SOLUTION: By definition of resistance $R = \frac{V}{I}$

Putting values $R = \frac{1.5V}{0.3A}$ therefore $R = 5\Omega$ —— Answer

Thus, the resistance of the bulb is 5 Ω.

ASSIGNMENT 14.3: RESISTANCE OF WIRE

Calculate the resistance of wire when the current through it is 2.0 A and the voltage across its ends is 3.0 V.

14.4 COMBINATION OF RESISTANCES

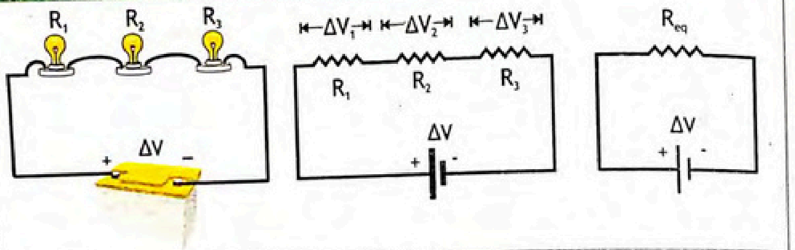
Electric circuits often contain a number of resistors connected in various ways. The connection and arrangement of resistors in a circuit affects the current and voltage drops in a circuit, therefore, they are used to control current and voltages in it. You are already familiar with series and parallel circuits from general science for grade 7, unit 11 "circuits and electric current", in which light bulbs were used. These light bulbs have resistance, therefore, they can be treated as resistors. There are two basic arrangements in which resistors can be connected.

A. Series Combination of resistors: When the resistors are connected end to end in such a way that there is a single path for the flow of current are said to be connected in series. Three resistors (e.g. light bulbs) having resistances R_1, R_2 and R_3 are shown in the figure 14.7 as series combination.

In a series connection, the same amount of charge passes through all resistors in a given time interval and therefore currents is the same in all resistors, such that

$$I_1 = I_2 = I_3 = I \quad \text{——} (1)$$

FIGURE 14.7 - Series combination of resistors



Where I is the current leaving the battery, I_1 is the current in resistor R_1, I_2 is the current in resistor R_2 and I_3 is the current in resistor R_3. The potential difference applied across the series combination of resistors divides between the resistors:

$$\Delta V = \Delta V_1 + \Delta V_2 + \Delta V_3 \quad \text{———} (2)$$

Since by Ohm's Law, the potential difference across the battery is also applied to the equivalent resistance R_{eq} in Figure 14.5

$$\Delta V = IR_{eq}$$

Where R_e is the equivalent resistance; a single resistor that has the same effect on the circuit as the series combination of all resistors when it is connected to the battery. Therefore, the voltage across each resistor by Ohm's Law can be written as

$$\Delta V_1 = I_1 R_1 \quad \text{and} \quad \Delta V_2 = I_2 R_2 \quad \text{and} \quad \Delta V_3 = I_3 R_3$$

Hence equation 2 can be written as $\quad IR_e = I_1R_1 + I_2R_2 + I_3R_3 \quad \text{———} (3)$

Putting equation 1 in equation 3, we get

$$IR_e = IR_1 + IR_2 + IR_3$$

or $$\cancel{I}R_e = \cancel{I}(R_1 + R_2 + R_3)$$

Therefore $\boxed{R_e = R_1 + R_2 + R_3}$ ——— 14.5

Generally for 'n' number of resistors connected in series

$\boxed{R_e = R_1 + R_2 + R_3 + \bullet\bullet\bullet\bullet\bullet + R_n}$ ——— 14.6

TIP: Equivalent Circuit

A resistor R_{eq} is 'equivalent' to a certain arrangement of several resistors mean that if that arrangement of resistors is replaced by R_{eq}, the current through the rest of the circuit is unchanged. This notion of equivalence applies to many types of circuit elements, including capacitors.

From equation 14.5 and equation 14.6, it is clear that in series combination the equivalent resistance is always greater than any individual resistance in combination.

EXAMPLE 14.4: RESISTORS CONNECTED IN SERIES

Four resistors $R_1 = 5\ \Omega$, $R_2 = 12\ \Omega$, $R_3 = 13\ \Omega$ and $R_4 = 96\ \Omega$ are connected in series across a 90 V battery. What is the current in the circuit?

GIVEN

Resistance $R_1 = 5\ \Omega$,

Resistance $R_2 = 12\ \Omega$,

Resistance $R_3 = 13\ \Omega$

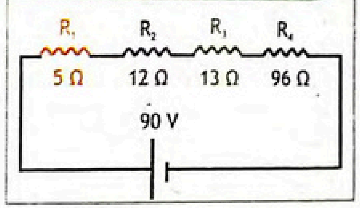
Resistance $R_4 = 96\ \Omega$

Potential difference 'V' = 90 V

REQUIRED

Circuit Current 'I' = ?

FIGURE 14.8 - Example 14.4



SOLUTION: For series combination as shown in figure 14.8, the equivalent resistance is

$$R_{eq} = R_1 + R_2 + R_3 + R_4$$

Putting values $\quad R_{eq} = 5\Omega + 12\Omega + 13\Omega + 96\Omega \quad$ therefore $\quad R_{eq} = 126\Omega$

By Ohm's law $\quad I = \dfrac{V}{R_{eq}} \qquad$ Putting values $\quad I = \dfrac{90V}{126\Omega}$

Therefore $\quad I = 0.71A$ ——— Answer

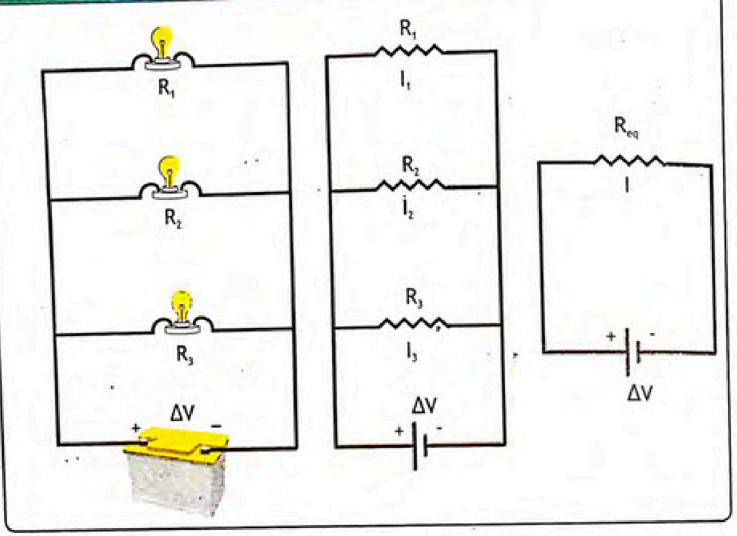
The current through the circuit is 0.71 A.

ASSIGNMENT 14.4: RESISTORS IN SERIES

Four resistors all having similar resistance of 15 Ω are connected in series across a 30 V battery. What is the current in the circuit?

B. Parallel Combination of resistors: When the resistors are connected in different branches of the circuit in such a way that there is more than one path for the flow of current, resistors are said to be connected in parallel. Consider three light bulbs as resistors having resistance R_1, R_2 and R_3 are shown in the figure 14.9 as parallel combination.

FIGURE 14.9 - *Parallel combination of resistors*



In a parallel combination of resistors the potential difference across each resistor is the same (since their ends are connected) while the current is split between them since it has multiple available paths.

$$\Delta V_1 = \Delta V_2 = \Delta V_3 = \Delta V \quad \text{——— (1)}$$

Where ΔV is the terminal voltage of the battery, ΔV_1 is the voltage across resistor R_1, ΔV_2 is the voltage across resistor R_2 and ΔV_3 is the voltage across resistor R_3.

The total current I in parallel combination of resistors divides between the resistors:

$$I = I_1 + I_2 + I_3 \quad \text{——— (2)}$$

Since by Ohm's Law, the current in the equivalent resistance R_{eq} in Figure 14.9 is

$$I = \frac{V}{R_{eq}}$$

Where R_e is the equivalent resistance; a single resistor that has the same effect on the circuit as the parallel combination of all resistors when it is connected to the battery. Therefore, the current through each resistor by Ohm's Law is

$$I_1 = \frac{V_1}{R_1} \quad \text{and} \quad I_2 = \frac{V_2}{R_2} \quad \text{and} \quad I_3 = \frac{V_3}{R_3}$$

Hence equation 2 can be written as $$\frac{V}{R_e} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} \quad \text{——— (3)}$$

Putting equation 1 in equation 3 we get $$\frac{V}{R_e} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\text{or} \quad \frac{\cancel{V}}{R_e} = \cancel{V}\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]$$

Therefore $$\boxed{\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} \quad \text{——— } \boxed{14.7}$$

Generally for '*n*' number of resistors connected in parallel

$$\boxed{\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \bullet\bullet\bullet\bullet\bullet + \frac{1}{R_n}} \quad \text{——— } \boxed{14.8}$$

From equation 14.7 and equation 14.8 it is clear that in parallel combination the equivalent resistance is always smaller than any individual resistance in combination.

EXAMPLE 14.5: RESISTORS IN PARALLEL

Three resistors $R_1 = 5.0\ \Omega$, $R_2 = 10.0\ \Omega$ and $R_3 = 20.0\ \Omega$ are connected in parallel across a 90.0 V battery. What is the total current in the circuit?

GIVEN

Resistance $R_1 = 5.0\ \Omega$,

Resistance $R_2 = 10.0\ \Omega$,

Resistance $R_3 = 20.0\ \Omega$

Potential difference 'V' = 90 V

REQUIRED

Circuit Current 'I' = ?

SOLUTION: For parallel combination as shown in figure 14.10 the equivalent resistance is

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Putting values

$$\frac{1}{R_{eq}} = \frac{1}{5.0\Omega} + \frac{1}{10.0\Omega} + \frac{1}{20.0\Omega}$$

Therefore $$\frac{1}{R_{eq}} = \frac{1\times4+1\times2+1\times1}{20.0\Omega}$$

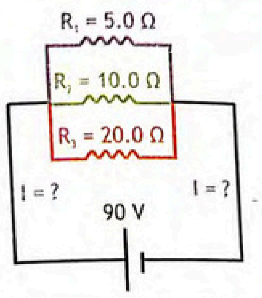
or $$\frac{1}{R_{eq}} = \frac{7}{20.0\Omega}$$

Hence $R_{eq} = 2.9\Omega$

By Ohm's law $I = \frac{V}{R_{eq}}$ Putting values $I = \frac{90V}{2.9\Omega}$

Therefore $I = 31.03A$ — Answer

FIGURE 14.10 - Example 14.5



The total current through the circuit is 31.0 A.

ASSIGNMENT 14.5: RESISTORS IN PARALLEL

Three resistors of 60 Ω, 30 Ω and 20 Ω are connected in parallel across a 90 V battery. Calculate the current flowing through the circuit?

LAB WORK

To study resistors in series circuit.

To study resistors in parallel circuit.

14.5 THE I-V CHARACTERISTICS FOR OHMIC AND NON OHMIC CONDUCTORS

The conductors for which Ohm's law hold are called Ohmic conductors. Thus, these conductors obey

$$I \propto \Delta V$$

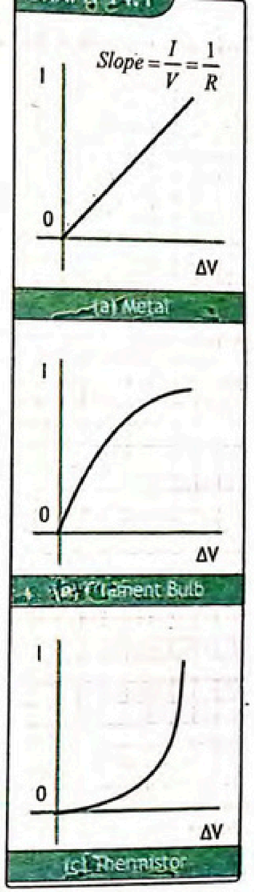
It means that if we plot a graph between current 'I' and potential difference 'ΔV' (called IV graph), we get a straight line; as for constant resistance the slope 1/R is a straight line. However, not all the materials have straight line graph as we can see from the graph 4.1, only metals show Ohmic behavior. The graphs of filament bulb and thermistor are curved, therefore, they are termed as non-ohmic conductors.

A. Metallic Conductors: For metallic conductors and some alloys the graph of 'I' verses 'V' is a straight line as shown in graph 14.1 (a). For example, when the potential difference doubled, the current through metallic conductors also doubles.

B. Filament Bulb: The graph of filament bulb shows that current saturates as it is increased and at large value even a large change in voltage V will show small change in current I as shown in graph 14.1 (b). This is because the tungsten wire in the filament of the bulb heats up with the increase in applied potential difference and free electrons collide more with lattice atoms causing the resistance to increase and consequently the rate and the rate of change in current decreases.

C. Thermistor: Thermistor is a device whose resistance changes significantly (highly) with temperature. Usually thermistor's resistance decreases with increase in temperature. The IV Graph of the thermistor shows that resistance decreases sharply. Thus, at a large value even for a small change in applied voltage ΔV, it will show a large change in current I as shown in graph 14.1 (c).

GRAPH 14.1



14.6 ELECTRICAL POWER AND JOULE'S LAW

Every appliance is rated for its power output (P) – the rate at which it can transform electrical energy to a desired form (for example light, sound, or heat). An electric clothes dryer might be rated at 5000 W and an electric shaver might be rated at 15 W.

A. Electrical Energy: The electrical energy lost or work done by a charge Q, going through a potential difference V, can be written as

$$V=\frac{W}{Q}=\frac{E}{Q} \quad \text{or} \quad E=Q\times V \quad \text{——(1)}$$

We can use the definition of current

$$I=\frac{Q}{t} \quad \text{or} \quad Q=It \quad \text{——(2)}$$

Putting equation 2 in equation 1, we get

$$\boxed{E=It\times V} \quad \text{—— } 14.9$$

Equation 14.9 gives the equation for electrical energy consumed in a device. Also by Ohm's law V = IR, therefore, the electrical energy E from equation 14.9 can also be written as

$$E=It\times IR \quad \text{or} \quad \boxed{E=I^2Rt} \quad \text{—— } 14.10$$

Also by Ohm's law I = V/R, therefore, electrical energy from equation 14.9 can also be written as

$$E=\frac{V}{R}t\times V \quad \text{or} \quad \boxed{E=\frac{V^2}{R}t} \quad \text{—— } 14.11$$

All the three equations 14.9, 14.10 and 14.11 are equally valid for calculation of electric energy.

EXAMPLE 14.6: ELECTRIC KETTLE

If a current of 10.0 A takes 5 minutes to boil a kettle of water requiring 3.6×10^5 J of energy, what is the potential difference (in voltage) across the kettle?

GIVEN

Energy 'E' = 3.6×10^5 J

Time 't' = 5.0 min = 300 s = 3.0×10^2 s

Current 'I' = 10.0 A

REQUIRED

Voltage 'V' = ?

SOLUTION: The electric energy is $E=It\times V$ or $V=\frac{E}{It}$

Putting values $V=\frac{3.6\times10^5\ \text{J}}{10.0\ \text{A}\times3.0\times10^2\ \text{s}}$ or $V=\frac{3.6\times10^5\ \text{J}}{10.0\ \frac{\text{C}}{\cancel{\text{s}}}\times3.0\times10^2\ \cancel{\text{s}}}$

NOT FOR SALE

Hence $V=1.2\times10^2\ \text{J}/\text{C}=1.2\times10^2\ \text{V}$ —— **Answer**

There is a potential difference of 1.2×10^2 V across the kettle.

ASSIGNMENT 14.6: CLOTHES DRYER

For how long a clothes dryer is operated, if it uses 32 kJ of energy to dry cloths at 220 V, running 16 A of current through it?

B. Joule's Law: The electrical energy lost in a device due to potential difference across it can be represented as equation called Joule's law of heating.

Statement: The amount of heat generated in resistor is proportional to the product of square of current 'I', resistance 'R' and duration of time for which the current passes through the resistor.

$$H\propto I^2Rt \quad \text{or} \quad \boxed{H=\frac{I^2Rt}{J}} \quad \text{—— } 14.12$$

Where J is called Joule's Mechanical Equivalent of heat. Its value depends upon choice of units of work and heat. This energy can be utilized for different useful purposes, for example, in light bulb we get this energy in the form of light and heat and in fan we get this energy in the form of mechanical energy and heat.

C. Electric Power: *The time rate at which the work is done in electric circuit is called electric power.* The electric power is the work done W in electric circuit divided by time t, mathematically

$$P=\frac{W}{t} \quad \text{——(1)}$$

By definition of electric potential V $\quad V=\frac{W}{Q}$ or $W=V\times Q$ ——(2)

By definition of current $\quad I=\frac{Q}{t}$ or $Q=It$ ——(3)

Putting equation 3 in equation 2, we get $\quad W=V\times It$ ——(4)

Putting equation 4 in equation 1, we get $\quad P=\frac{V\times I\cancel{t}}{\cancel{t}}$

or $\boxed{P=IV}$ —— 14.13

NOT FOR SALE

Equation 14.13 gives the relation for electric power. As by Ohm's law V = IR, therefore, the electrical power P from equation 14.13 can also be written as

$$P = I \times IR \quad \text{or} \quad \boxed{P = I^2R} \text{ — } 14.14$$

Also by Ohm's law I = V/R, therefore, electrical power from equation 14.13 can also be written as

$$P = \frac{V}{R} \times V \quad \text{or} \quad \boxed{P = \frac{V^2}{R}} \text{ — } 14.15$$

All the three equations 14.13, 14.14 and 14.15 are equally valid for calculation of electric power.

Units of Power: The S.I units for electrical power is **watt (W)**. A power of 1 W is said to be consumed in an electrical circuit if potential difference of 1 V, causes a current of 1 A to flow through a circuit.

$$1W = 1A \times 1V$$

FIGURE 14.11 - *Electric Power*

The power rating (sometimes called the "wattage") of a light bulb 12 W and tube light 40 W tells us how fast it will convert electric energy into heat and light. For an incandescent bulb, only about 2 percent of the transformed energy is actually emitted as light; the rest is emitted as heat. A fluorescent bulb, on the other hand, converts about 9.5 percent of its energy into light, making it more than four times as efficient as an incandescent bulb.

It is energy, not power, that we pay for in our electricity bill. Since power is the rate at which energy is transformed, the total energy used by any device is simply its power consumption multiplied by the time for which it is operated. If the power is in watts and the time is in seconds, the energy will be in joules.

EXAMPLE 14.7: FLASHLIGHT

In the flashlight the current is 0.40 A, and the voltage of 3.0 V is delivered by cell. Find the power delivered to the bulb.

GIVEN

Current 'I' = 0.40 A

Voltage 'V' = 3.0 V

REQUIRED

Electric Power 'P' = ?

SOLUTION: The electric power is $P = I \times V$

Putting values $P = 0.40A \times 3.0V$ or $P = 0.40 \cancel{C}/s \times 3.0 J/\cancel{C}$

Hence $P = 1.2 J/s = 1.2W$ — Answer

The 'wattage' rating of this bulb would, therefore, be 1.2 W.

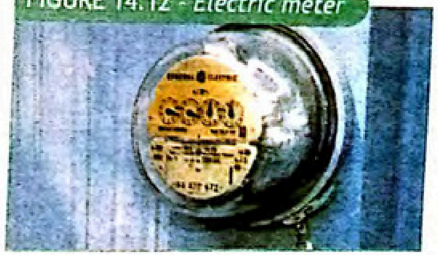
ASSIGNMENT 14.7: AUTOMOBILE HEADLIGHT

Calculate the resistance of a 40-W automobile headlight designed for 12 V.

D. Electrical energy and Kilowatt-hour (kWh): The electric metre in our homes measures how much energy (in kWh) we use, not the electrical power. Electrical energy is consumed in large quantities for which joule is a very small unit, therefore **Kilowatt-hour** (kWh) is preferred. It is the amount of energy consumed by a device of power 1 kW running continuously for one hour.

$$\begin{aligned} E &= 1 \text{ kW-hr} \\ &= 1000 \text{ W} \times 1\text{hr} \\ &= 1000 \text{ J/s} \times 3600\text{s} \\ &= 3.6 \times 10^6 \text{ J} \end{aligned}$$

FIGURE 14.12 - *Electric meter*



kWh is the unit for which the tariff (cost of electricity) is decided by electricity supply company.

EXAMPLE 14.8: COST OF ELECTRICITY FOR CRICKET TOURNAMENT

You are arranging night cricket tournament, you have arranged five 1000 W light bulbs. These bulbs will remain lit for 6 hours for 29 days. Estimate the cost of electricity consumption if the cost of electricity is 8.11 Rs/kWh.

GIVEN

Power 'P' = 5 ×1000 W = 5000 W = 5 kW

Time 't' = 29 × 6 h = 174 h

Tariff rate = 8.11 Rs/kWh

REQUIRED

Energy consumed '$E_{(kWh)}$' = ?

Cost of electricity 'C' = ?

SOLUTION: The electric power is defined as $P = \frac{E}{t}$

$E = P \times t$ Putting values $E = 5\,kW \times 174\,h$

$E = 870\,kWh$ — Answer

The total consumed energy is 870 kWh, the cost can be calculated as

$$Cost = E \times Tariff\ Rate$$

$$Cost = 870\,\cancel{kWh} \times 8.11\ ^{Rs}/_{\cancel{kWh}}$$

$Cost = 7055.7\,Rs$ — Answer

The total cost of electricity for whole tournament is Rs. 7056.

EXTENSION EXERCISE 14.2

It is found that if eight 35 watt LED Lights are used, it will serve the same purpose. Will this reduce the cost of electricity?

ASSIGNMENT 14.8: WINTER COST

A 100-W bulb is left on, in an outdoor storage room to keep paint from freezing. The 100-W rating refers to the power dissipated in the bulb's filament, which is a resistor. If electricity costs 8.11 Rs/kWh, about how much does it cost to burn the lightbulb for three months during winter?

14.7 USE OF CIRCUIT COMPONENTS

a. **Wires and Connectors:** Wires and connectors are used to direct current from one part of the circuit to another. A blob should be drawn where wires are connected. In complex diagrams, it is sometimes necessary to draw crossed wires even when they are not connected. In such cases a bridge; joined and not joined wires are shown in figure 14.13 a.

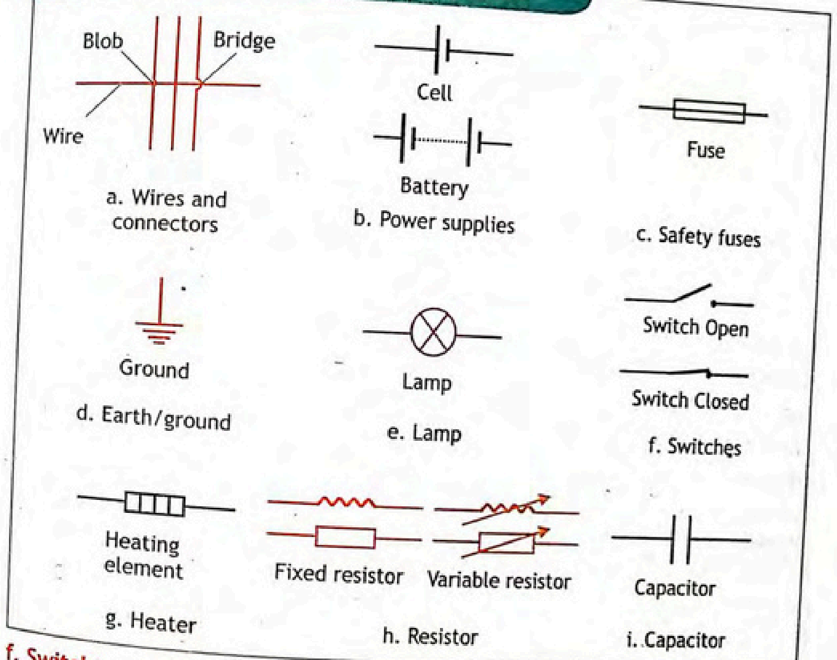
b. **Power Supply:** Source of electrical energy to the circuit, such as cells and batteries whose symbols are shown in figure 14.13 b.

c. **Fuse:** Safety device which blows (melts) if the current through it exceeds a specified value, its circuit symbol is given in figure 14.13 c.

d. **Earth (Ground):** This is the zero volt connection of a power supply. But for electricity mains and the radio circuits it really means the earth or ground. The circuit symbol is given in figure 14. 13 d.

e. **Lamp:** The device which converts electrical energy into light, its circuit symbol is shown in figure 14.13 e.

FIGURE 14.13: *Circuit components symbols*



f. **Switch:** A device that allows or blocks the flow of current. The circuit symbol is shown in figure 14.13 f.

g. **Heater:** A device that converts electrical energy into heat. The circuit symbol is shown in figure 14.13 g.

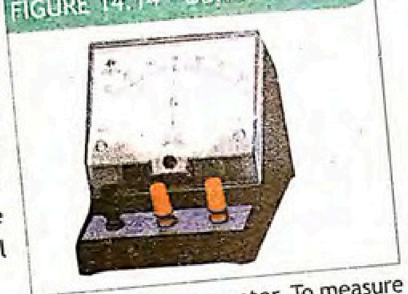
h. Resistor: The materials that provide resistance to the current in a circuit are called resistors. The variable resistors can be used to control the volume in radio and TV or regulate fan speed. The circuit symbol is shown in figure 14.11 h.

i. Capacitor: A capacitor is a device that store electric charge. A capacitor is used with resistor in a timing circuit. Capacitors can be used as block and pass filters as well. The circuit symbol is shown in figure 14.11 i.

14.8 ELECTRICAL MEASURING INSTRUMENTS

Electrical measuring instruments are devices used for measuring various electrical aspects such as the presence and amount of current, voltage, resistance and power of electrical devices.

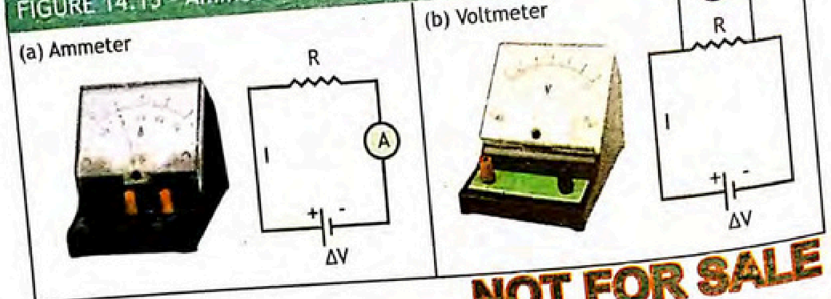
FIGURE 14.14 - Galvanometer



A. Galvanometer: Galvanometer is an instrument used to detect the presence of current or indicate potential difference between two points. It is a very sensitive device capable of detecting very small currents and voltages.

B. Ammeter: A device used to measure current is called an ammeter. To measure the current, an ammeter must be connected in a circuit in series. Figure 14.15 (a) shows an ammeter connected in a circuit. Since the ammeter must be able to make measurements by disturbing the current in the circuit as little as possible. Ammeters are designed to have as low resistance as possible (because they are connected in series), usually of the order of. 1 Ω, so they do not have an appreciable effect on the currents they measure.

FIGURE 14.15 - Ammeter and Voltmeter



NOT FOR SALE

C. Voltmeter: A device used to measure potential difference is called an voltmeter. To measure the potential difference, voltmeter must be wired in parallel with the component across which the potential difference is to be measured. Figure 4.15 (b) shows a voltmeter placed in the circuit to measure the potential drop across resistor R. Since the voltmeter must be able to make measurements while disturbing the circuit as little as possible, voltmeters are designed to have as high a resistance as possible, usually of the order of 10 M Ω (10^7 Ω), so they have a negligible effect on the potential differences they are measuring.

FIGURE 14.16 - Multi-meter

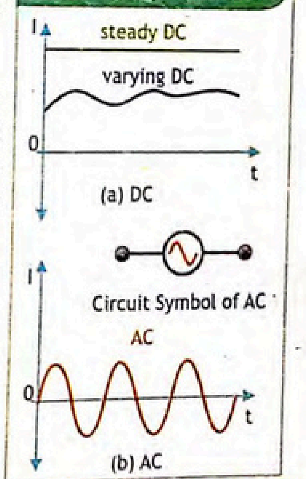
D. Multimeter: In practice, measurements of current and potential difference are made with a digital multimeter that can switch between functioning as an ammeter and functioning as a voltmeter. It displays the results with an auto-ranging numerical digital display, which includes the sign of the potential difference or current. Most digital multimeters can also measure the resistance of a circuit component; that is, they can function as an ohmmeter.

14.9 DIRECT AND ALTERNATING CURRENT

In a direct current (DC), the charge flows in one direction only. Graphs for steady DC and varying DC are shown in Figure 14.17 (a). The current from cell or battery is direct current because of fixed positive and negative terminals.

In an alternating current (AC), the direction of charge flow, reverses regularly and therefore, the current also changes direction, as shown in the graph in Figure 14.17 (b). When alternating voltage is applied, the current first flows in one direction and then in the opposite direction.

FIGURE 14.17 - DC & AC



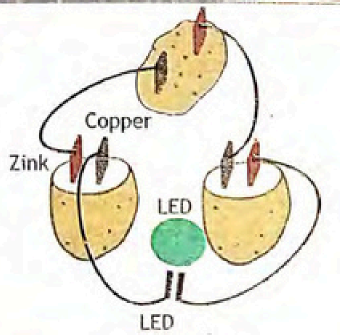
NOT FOR SALE

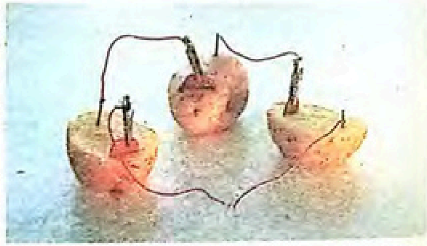
The direction of current in the circuit depends upon the changing polarity of alternating voltage source. The circuit symbol for AC is also given in figure 14.17(b). Electric generators can produce either DC or AC.

Most of the electric power in the world is AC, since it is easier to transmit it from one place to another. Therefore the electricians work with AC about 99% of the time. Digital multi-meter shown above can measure both DC and AC.

ACTIVITY: LIGHT AN LED WITH POTATOES

Take two potatoes, cut one potato in half, insert one Zink and Copper electrode deep to each piece of halved potato and single potato. Take a sensitive voltmeter you will notice some reading across each arrangement. Now connect these three arrangement (batteries) in series as shown in figure (Zink to Copper and Copper to Zink) to produce a higher voltage. An LED (Light Emitting Diode) which is a low power light bulb and uses little energy, can be lit using this arrangement. Using this energy, you can run a small clock or any other low power electronic equipment. Try to answer the following questions.





- Why LED cannot be lit by using single potato? A minimum of how many potatoes are required to lit an LED?
- What happens to the Copper and Zink electrode over time?
- Is potato a good alternate energy source? If we use large number of potatoes, can we power heavy load devices?

LAB WORK

To find the resistance of galvanometer by half deflection method.

INFO: BEHAVIOUR OF LIGHT BULBS IN SERIES AND PARALLEL CIRCUIT

When the light bulbs are connected in series and parallel combination interesting observations can be made. Celebration lights in series and parallel combination are shown in the figures.

Series Circuit: If one lamp in a series circuit burns out, the circuit is broken and all lamps cease to glow.

The brightness of light from each lamp in a series circuit decreases when more lamps are added to the circuit. Because adding more lamps in series produces a greater circuit resistance. This decreases the current in the circuit. All voltages have to add up to the same total voltage, so the voltage drop across each lamp also decreases. Since power is the product of voltage and current, both these changes act to dim the lamps.

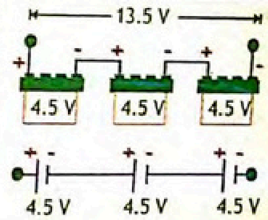
Celebration lights series circuit

Parallel Circuit: If one lamp burns out, the other lamps are unaffected. This is because current in each branch, according to Ohm's law, is equal to voltage/resistance and since neither voltage nor resistance is affected in the other branches, the current in those branches is unaffected.

The brightness of light from each lamp in a parallel circuit is not affected when more lamps are added to the circuit because the current in the battery increases by an amount that feeds the added branch(es). In the overall circuit, added paths means decreased resistance.

Celebration lights parallel circuit

A series connection adds the voltage of the two batteries but it keeps the same amperage rating (also known as Amp Hours). For example, these three 4.5-volt batteries joined in series now produce 13.5 volt but they still have a total capacity of 10 amps. To connect batteries in a series, use a jumper wire to connect the negative terminal of the first battery to the positive terminal of the second battery.



Series Combination of batteries

14.10 HOUSE CIRCUITS

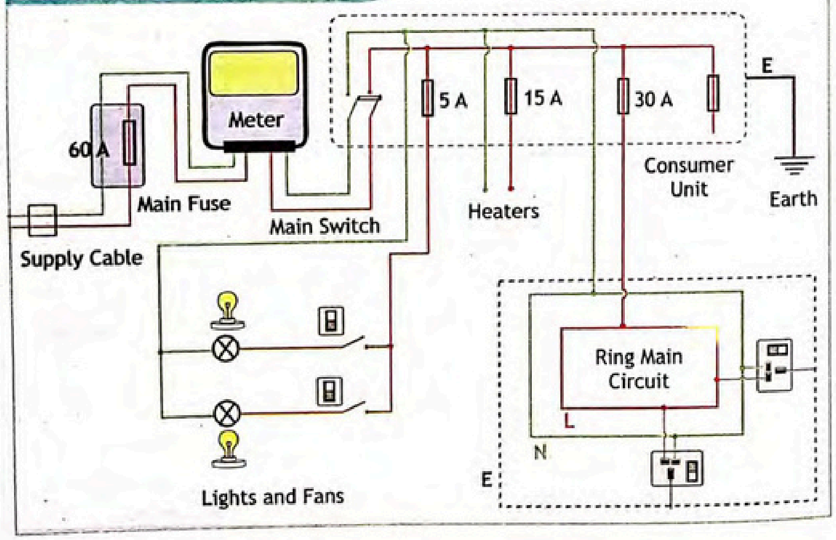
Electricity usually comes to our homes by supply cable containing two wires, the live (L) and the neutral (N). The neutral is earthed at the local sub-station and so there is no p.d. between it and earth. The supply is AC and the live (L) wire is alternately positive and negative. Typical house circuits are shown in figure 14.18.

A. Parallel Circuitry: Every circuit is connected in parallel with the supply, i.e. across the live and neutral, and receives the p.d. of 220 V from supply mains. The advantages of having appliances connected in parallel rather than in series, can be seen by studying the lighting circuit in figure 14.18.

(i) The p.d. across both lamps is fixed (same as the supply potential difference) so the lamp shines with the same brightness irrespective of how many other lamps are switched on.

(ii) Each lamp can be turned on and off independently; if one lamp fails, the others can still be operated.

FIGURE 14.18: House Circuit



B. Switches and fuses: In figure 14.18, it is seen that switches and fuses are employed only to the live wire. If they are installed to the neutral wire, electrical appliances and power sockets would be 'live' even when switches are in 'off mode' or fuses 'blown'. A fatal shock could then be obtained even in switched off condition.

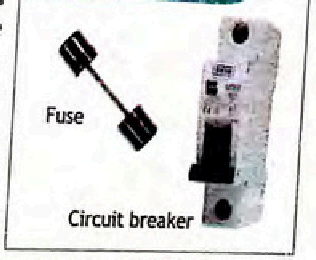
C. Ring main circuit: Most houses have live and neutral wires running in two complete rings with power sockets attached, as shown in fig. 14.18. Having a ring allows current to be split into two parts allowing heavy appliances to be powered using relatively thinner wires. The live and neutral wires each run in two complete rings around the house and the power sockets. The ring has a 30 A fuse and if it has, say, ten sockets, then all can be used as long as the total current does not exceed 30 A, otherwise the wires overheat. A house may have several ring circuits, each serving a different area.

14.11 ELECTRICAL SAFETY IN HOUSEHOLD ELECTRICITY

The devices and appliances that we operate in our home runs with 220 V of AC, which is hazardous. For safe use of electricity, fuses should be installed and earthing should be made in the household circuitry.

A. Fuses and Circuit breakers: Fuse consist, of a thin piece of metal wire, having low melting temperature. When excessive current, above fuse rating, flows through it, the wire piece inside it get hot and melts. This disconnects the current through the live wire, thus preventing any damage to the appliances they are connected. Circuit breakers (figure 14.19) are now used instead of fuses in consumer units.

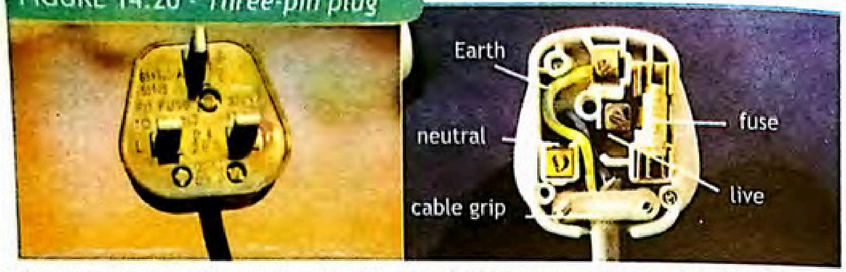
FIGURE 14.19 Fuse



When the current exceeds the rated value of the circuit breaker, it separate a contact and breaks the circuit. They operate much faster than fuses and have the advantage that they can be reset by pressing a button.

B. Earthing: A ring main has a third wire which goes to the top sockets on all power points (figure 14.18) and is earthed by being connected either to a metal water pipe entering the house or to an earth connection on the supply cable. This third wire is a safety precaution to prevent electric shock.

FIGURE 14.20 - Three-pin plug



The earth pin on a three-pin plug (figure 14.20) is connected to the metal case of the appliance which is thus joined to earth by a path of almost zero resistance. If for example, an electric device breaks or sags and touches the case, a large current flows to earth and 'blows' the fuse. Otherwise, the case would become 'live' and anyone touching it would receive a shock which might be fatal, especially if standing in a damp environment, such as on a wet concrete floor.

14.12 DANGERS OF ELECTRICITY

A. Electric shock: Electric shock occurs if current flows from an electric circuit through a person's body to earth. This can happen if there is a damaged insulation or faulty wiring. The typical resistance of dry skin is about 10,000 Ω, so if a person touches a wire carrying electricity at 240 V, an estimate of the current flowing through them to earth would be $I = V/R = 240/10\,000 = 0.024\ A = 24\ mA$. For wet skin, the resistance is lowered to about 1000 Ω (since water is a good conductor of electricity) so the current would increase to around 240 mA.

It is the size of the current (not the voltage) and the length of time for which it acts which determines the strength of an electric shock.

TipBits

The human body: The human body acts as a variable resistor. When dry, the skin's resistance is high enough to keep currents that are produced by small and moderate voltages low. If the skin becomes wet, however, its resistance is lower, and the electric current can rise to dangerous levels. A current as low as 1 mA can be felt as a mild shock, while currents of 15 mA can cause loss of muscle control and currents of 100 mA can cause death.

- If your body resistance is 100,000 Ω, how much current will you experience if you touch the terminals of a 12-V battery?
- If your skin is very moist, so that your resistance is only 1000 Ω and you again touch the battery terminals, how much current will you experience? Will it hurt?

The path the current takes influences the effect of the shock; some parts of the body are more vulnerable than others. A current of 100 mA through the heart is likely to be fatal. Damp conditions increase the severity of an electric shock because water lowers the resistance. Wearing rubber-soled shoes or standing on a dry insulating floor increases the resistance between a person and earth and will reduce the severity of an electric shock.

To avoid the risk of getting an electric shock:

- Switch off the electrical supply to an appliance before starting repairs.
- Use plugs that have an earth pin and a cord grip; an insulating casing (a rubber or plastic case) is preferred.
- Do not allow appliances or cables to come into contact with water. For example it is dangerous to hold a hair straightener with wet hands in a bathroom. Keep electrical appliances well away from baths tubs and wash basins.
- Do not have long cables trailing across a room,.because the insulation can become damaged.

Table 14.3: EFFECT OF CURRENT ON HUMAN BODY

Current (mA)	Effect
1	Threshold of sensation
5	Maximum harmless current
10-20	Onset of sustained muscular contraction; cannot let go for duration of shock; contraction of chest muscles; may stop breathing during shock
50	Onset of pain
100-300	Ventricular fibrillation possible; often fatal
300+	Onset of burns depending on concentration of current
600	Onset of sustained ventricular contraction and respiratory paralysis; both cease when shock ends; heartbeat may return to normal; used to defibrillate the heart

B. Fire risks: If the electrical wiring in the walls of a house becomes overheated, a fire may start. Wires become hot when they carry electrical currents - the larger the current carried, the hotter a particular wire will become, as we studied in joules law. To reduce the risk of fire through overheated cables, the maximum current in a circuit should be limited by taking these precautions:

- Use plugs that have a correct fuse.
- Do not attach too many appliances to a circuit (for example an extension box).
- Don't overload circuits by using too many adapters.
- Thick wires have lower resistance, therefore appliances such as heaters requiring large amounts of power (and hence current) must not be operated with thin wires.
- Damaged insulation or faulty wiring which leads to a large current flowing to earth through flammable material can also start a fire.

KEY POINTS

Current: Time rate of flow of charge.

Conventional Current: The current conventionally considered due to flow of positive charges in conductors.

Potential Difference: The difference of electric potential between two points

EMF: The energy per unit positive charge supplied by the source to the charge to move it from negative terminal to the positive terminal within source.

Ohm's Law: The electric current through a conductor is directly proportional to the applied voltage provided the physical conditions are kept same.

Resistance: The measure of opposition to the flow of current.

Resistor: Device intended to offer resistance is called resistor.

Series combination of resistors: The combination of resistors connected end to end.

Parallel combination of resistors: The combination of resistors connected in different branches of circuit, providing alternative paths for current to flow.

Electrical Energy dissipation: Energy consumed by appliances such as light bulbs, fans, heater, cell phone, TV e.t.c.

Joule's Law: The amount of heat generated in resistor is proportional to the product of square of current 'I', resistance 'R' and duration of time for which the current passes through the resistor.

Commercial Electricity Consumption Units: kWh is the unit used for commercial electricity consumption.

Direct Current: The current in which the flow of charge is in one direction.

Alternating Current: The current in which the flow of charge reverses its direction regularly.

PROJECTS

GROUP A 'HOME CIRCUITS': Contact an electrician, builder, or contractor, and ask to see a house electrical plan. Study the diagram to identify the circuit breakers, their connections to different appliances in the home, and the limitations they impose on the circuit's design. Find out how much current, on average, is in each appliance in the house. Draw a big chart diagram to be presented in class of the house, showing which circuit breakers control which appliances. Your diagram should also keep the current in each of these appliances under the performance and safety limits.

GROUP B 'IMPROVING POTATO BATTERY - I': The chemical reaction that takes place inside the potato is responsible for creating electricity. To see if you can improve the effectiveness or speed of this reaction, try using different types of metals in various combinations. First, test what happens when you use two pieces of the same metal. Then test a series of metals in different combinations with each other. In addition to zinc and copper, you could test a nickel, an iron nail, an aluminum foil, a brass button or a paper clip.

You can also test different types of potatoes, different sizes of potatoes, you can even boil a potato, non-metallic electrodes or different types of connecting wires. Write a research presentation for your school magazine.

GROUP C 'IMPROVING POTATO BATTERY - II': Potatoes are not the only food product that produces the necessary chemical reaction to produce a flow of electrons. Citrus fruits also contain a special chemical, citric acid, that reacts with metal to produce electricity. Compare the voltage and current produced by a potato battery to that of a lemon, tomato, orange, apple, watermelon, loaf of bread or any other type of food you want to test. Hypothesize which food you think will make the best battery and compare your results, explaining how each food reacted and why? Write a research article about your findings for the school magazine.

GROUP D 'LIFE WITHOUT ELECTRICITY': Prepare a presentation to be presented in class room about the dependence of modern life on electricity. Also emphasize on how difficult life would be, without electricity?

GROUP E 'ELECTRICITY COST REDUCTION': Identify ways to reduce electricity consumption in everyday life. Calculate the total cost of electrical energy used in one month (30 day) at home. Suggest ways how it can be reduced without compromising the comforts and benefits of electricity. Prepare a presentation to share with your class fellows.

EXERCISE

MULTIPLE CHOICE QUESTIONS

Choose the best possible answer:

1. Batteries are rated with unit 'ampere - hour', it is the unit of
   A. charge B. current C. power D. energy
2. When connected to a battery, a lightbulb glows brightly. If the battery is reversed and reconnected to the bulb, the bulb will glow
   A. brighter B. dimmer C. with the same brightness D. and fuse
3. The resistance of wire will decrease by increasing
   A. temperature B. length C. diameter D. both A & B
4. The wire made from which of the following material is a conductor
   A. glass B. rubber C. silver D. silk
5. The current which reverses direction after regular interval of time is
   A. DC B. AC C. conventional current D. both A and B
6. Electricity main supply meters measures it in units of 'kilowatt - hour'; it is the unit of
   A. charge B. current C. power D. energy
7. The device that is used to protect a circuit against overload is
   A. heater B. fuse C. lamp D. All of these
8. Which of the following represent one ohm
   A. VA^{-1} B. JS^{-1} C. WA^{-1} D. JC^{-1}
9. Two resistances of 1 ohm are connected in parallel, the equivalent resistance is
   A. $2\,\Omega$ B. $1.5\,\Omega$ C. $1\,\Omega$ D. $0.5\,\Omega$
10. 1 kWh =
    A. 3600 W B. 1000 J C. 3.6×10^6 J D. 0.36 hrs

CONCEPTUAL QUESTIONS

Give a brief response to the following questions

1. As water is made of atoms having protons (charge +e) and electrons (charge -e), does the water flowing through pipe carry an electric current? Explain.
2. A car has two headlights, when the filament in one headlight burns out, the other headlight stays on. Are the headlights connected in series or in parallel?

3. Qurat-ul-Ain needs a 100-Ω resistor for a circuit, but she only has a box of 300-Ω resistors. What can she do?
4. A number of light bulbs are connected to a single power outlet. Will they provide more illumination when connected in series or in paralel? Why?
5. Explain why light bulbs almost always burn out just as they are turned on and not after they have been on for some time.
6. Explain why is it possible for birds to perch safely on high tension wires without being electrocuted?
7. An electrician working on "live" circuits wears insulated shoes and keeps one hand behind his or her back. Why?
8. Explain why is it dangerous to turn on a lightbulb when you are in a bath tub?
9. Why circuit breaker, fuses and switches are installed to 'live wire'?

COMPREHENSIVE QUESTIONS

Give an extended response to the following questions

1. Define electric current. In what units it is measured? Discuss briefly the direction of current through the conductor.
2. What is potential difference and emf? Differentiate between them.
3. State and explain Ohm's Law. What are its limitations?
4. What is resistance and in what units we measure resistance?
5. What is series combination of resistors? How we can determine equivalent resistance for different resistors connected in series?
6. What is parallel combination of resistors? How we can determine equivalent resistance for different resistors connected in parallel?
7. Explain the factors on which the resistance of metallic conductor depends.
8. What are ohmic and non-ohmic devices? Sketch and interpret the VI characteristic graph to justify metallic conductor, filament lamp and thermistor as ohmic or non-ohmic materials.
9. Explain the concept of electric energy and electric power. What is the commercial unit for the consumption of electric energy?
10. State the functions of live, neutral and earth wires in domestic main supply. Explain why the domestic appliances are connected in parallel?
11. Differentiate between alternating current and direct current.
12. What are the hazards of electricity? What safety measures are taken in household electricity to safeguard for these hazards?