Chapter 16

ELECTRICITY AND ENERGY

Name	*: Michael Faraday*
Born	*: 22nd September 1791*
Birth-place	*: Newington, England*
Died	*: 25th August 1867*
Best known as	*: Inventor of the first dynamo*

Electricity has an important place in modern society. It is a controllable and convenient form of energy for a variety of uses in homes, schools, hospitals, industries and so on.

What constitutes electricity? How does it flow in an electric circuit? What are the factors that regulate electricity through an electric circuit?. In this chapter, we shall answer such questions.

16.1. ELECTRIC CURRENT AND CIRCUIT

We are familiar with air current and water current. We know that flowing water constitutes water current in rivers. Similarly if the electric charge flows through a conductor (metallic wire), we say that there is an electric current in the conductor. In a torch we know that a battery provide flow of charges or an electric current through a torch bulb to make it glow. We have also seen that it gives light only when it is switched on. What does a switch do? A switch creates a conducting link between the cell and the bulb. A continuous and closed path of an electric current is called an electric circuit. Now if the circuit is broken anywhere, the current stops flowing and the bulb does not glow.

How do we express electric current? Electric current is expressed by the amount of charge flowing through a particular area of cross section of a conductor in unit time. In other words it is the rate of flow of electric charges. In a circuit using metallic wires, electrons constitute flow of charges. The conventional direction of electric current is taken as opposite to the direction of the flow of electrons.

If a net charge Q, flows across any cross-section of a conductor in time t, then the current I through the cross-section is

$$I = \frac{Q}{t}$$

The SI unit of electric charge is coulomb. One coulomb is equal to the charge contained in 6.25×10^{18} electrons. The electric current is expressed by a unit called ampere (A), named after the French Scientist Andre- Marie Ampere.

From the above equation,

If, $Q = 1$ C, $t = 1$s, then $I = 1$A.

When one coulomb of charge flows in one second across any cross section of a conductor, the current in it is one ampere. An instrument called ammeter is used to measure current in a circuit.

Example 16.1

A current of 0.75 A is drawn by the filament of an electric bulb for 10 minutes. Find the amount of electric charge that flows through the circuit.

Solution:

Given, $I = 0.75$ A,
$t = 10$ minutes $= 600$ s

We know, $Q = I \times t$
$= 0.75 \times 600$
$$\mathbf{Q = 450\ C}$$

The Fig.16.1 shows a schematic diagram of an electric circuit comprising battery, bulb, ammeter and a plug key.

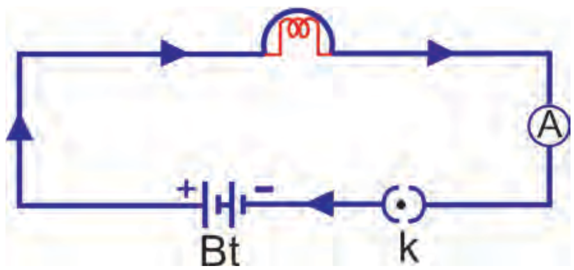


Fig. 16.1 Electric circuit

16.2. ELECTRIC POTENTIAL AND POTENTIAL DIFFERENCE

What makes the electric charge to flow? Charges do not flow in a copper wire by themselves, just as water in a perfectly horizontal tube does not flow. One end of the tube is connected to a tank of water. Now there is a pressure difference between the two ends of the tube. Water flows out of the other end of the tube. For flow of charges in a conducting metallic wire, the electrons move only if there is a difference of electric pressure called potential difference, along the conductor.

This difference of potential may be produced by a battery, consisting of one or more electric cells. When the cell is connected to a conducting circuit element, the potential difference sets the charges in motion in the conductor and produces an electric current.

The electric potential difference between two points in an electric circuit is the work done in moving a unit positive charge from one point to the other.

$$\text{Potential difference (V)} = \frac{\text{Work done}}{\text{Charge}}$$

$$V = \frac{W}{Q}$$

The S.I Unit of potential difference is volt (V).

$$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$$

One volt is the potential difference between two points in a current carrying conductor when 1 joule of work is done to move a charge of 1 coulomb from one point to the other.

The potential difference is measured by an instrument called voltmeter.

16.3. CIRCUIT DIAGRAM

The schematic diagram, in which different components of the circuit are represented by the symbols conveniently used, is called a circuit diagram. Conventional symbols used to represent some of the most commonly used electrical components are given in table 16.1.

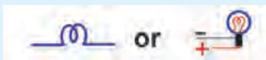
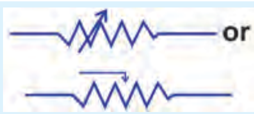
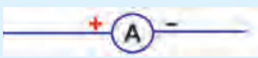
COMPONENTS	SYMBOLS
An electric cell	
A battery or a combination of cells	
Plug key or switch (open)	
Plug key or switch (closed)	
A wire joint	
Wires crossing without joining	
Electric bulb	
A resistor of resistance R	
Variable resistance or rheostat	
Ammeter	
Voltmeter	
Light Emitting Diode	

Table 16.1.

Example 16.2.

How much work is done in moving a charge of 5 C across two points having a potential difference 10 V ?

Solution:

Given charge Q = 5 C

Potential difference V = 10 V

The amount of work done in moving the charge, $W = V \times Q$

$W = 10 \times 5$

W= **50 J**

16.4. OHM'S LAW

Name : George Simon Ohm
Born : 16th March 1789
Birth place : Erlangen, Germany
Died : 6th July 1854
Best known for : Ohm's law

Is there any relationship between the potential difference across a conductor and the current flowing through it? Let us explore this with an activity.

ACTIVITY 16.1

- *Set up a circuit as shown in Fig. 16.2. consisting of a nichrome wire XY of length 0.5m, an ammeter, a Voltmeter and four cells of 1.5V each. (Nichrome is an alloy of Nickel and Chromium).*
- *First use only one cell as the source in the circuit.*
- *Note the reading in the ammeter I for the current and reading of the voltmeter V for the potential difference across the nichrome wire XY in the circuit.*
- *Tabulate them in the table given.*
- *Repeat the above steps using two, three cells and then four cells in the circuit separately.*
- *Calculate the ratio of V to I for each pair of potential difference V and current I.*

S. No.	Number of cells used in the circuit	Current through the nichrome wire I (ampere)	Potential difference across the nichrome wire. V (volt)	R=V/I (volt/ampere) Ω (ohm)
1.				
2.				
3.				
4.				
5.				
6.				

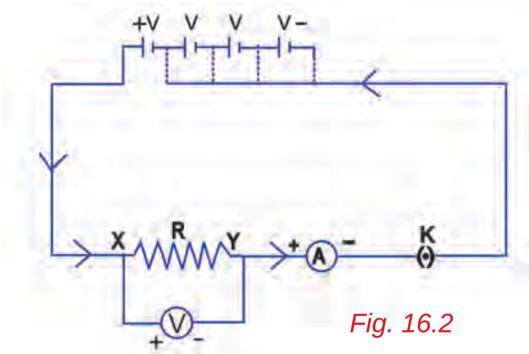


Fig. 16.2

In this activity you will find the ratio V/I is a constant.

In 1827, a German Physicist George Simon Ohm found out the relationship between the current I flowing in a metallic wire and the potential difference across its terminals.

Ohm's law states that at constant temperature the steady current (I) flowing through a conductor is directly proportional to the potential difference (V) between its ends.

$$I \propto V \text{ (or) } \frac{V}{I} = \text{constant.}$$

16.5. RESISTANCE OF A CONDUCTOR

From Ohm's law,

$$V = IR$$

R is a constant for a given metallic wire at a given temperature and is called its resistance. It is the property of a conductor to resist the flow of charges through it. Its SI unit is ohm. It is represented by the symbol Ω.

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

$$1 \text{ ohm} = \frac{1 \text{ volt}}{1 \text{ ampere}}$$

If the potential difference across the two ends of a conductor is 1 volt and the current through it is 1 ampere, then the resistance of the conductor is 1 ohm.

Example 16.3

The potential difference between the terminals of an electric heater is 60 V when it draws a current of 5 A from the source. What current will the heater draw if the potential difference is increased to 120 V ?

Solution:

Potential difference, V = 60 V

Current, I = 5 A

According to Ohm's law,

$$R = \frac{V}{I} = \frac{60}{5} = 12\ \Omega$$

When the potential difference is increased to 120 V, the current

$I = V / R = 120 / 12 = 10$ A

The current drawn by the heater =10 A

ACTIVITY 16.2

- *Set up the circuit by connecting four dry cells of 1.5 V each in series with the ammeter leaving a gap XY in the circuit, as shown in Fig. 16.3.*
- *Complete the circuit by connecting the nichrome wire in the gap XY. Plug the key. Note down the ammeter reading. Take out the key from the plug.*
- *Replace the nichrome wire with the torch bulb in the circuit and find the current through it by measuring the reading of the ammeter.*
- *Now repeat the above steps with the LED bulb in the gap XY.*
- *Do the ammeter readings differ for various components connected in the gap XY? What do the above observations indicate?*

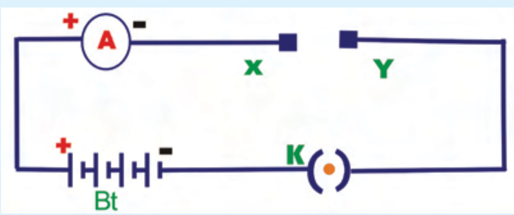


Fig. 16.3

16.6. SYSTEM OF RESISTORS

In various electrical circuits we often use resistors in various combinations. There are two methods of joining the resistors together. Resistors can be connected in

(a) series (b) parallel.

Resistors in Series

Consider three resistors of resistances R_1, R_2, R_3 in series with a battery and a plug key as shown in Fig. 16.4.

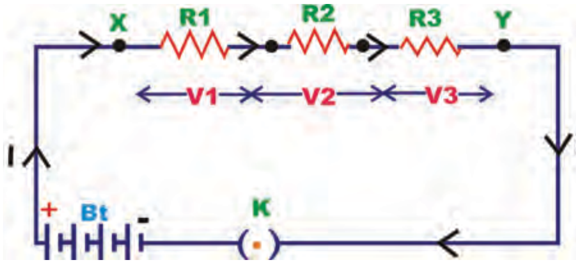


Fig. 16.4

The current (I) through each resistor is the same.

The total potential difference across the combination of resistors in series is equal to the sum of potential difference across individual resistors. That is,

$$\mathbf{V = V_1 + V_2 + V_3} \qquad \mathbf{(1)}$$

According to Ohm's law ,

$$V_1 = IR_1, \quad V_2 = IR_2, \quad V_3 = IR_3$$

Substituting these values in equation (1)

$$V = IR_1 + IR_2 + IR_3$$

Let $\mathbf{R_s}$ be the equivalent resistance, then

$$V = IR_s$$

$$IR_s = IR_1 + IR_2 + IR_3$$

$$\mathbf{R_s = R_1 + R_2 + R_3}$$

When several resistors are connected in series, the equivalent resistance (R_s) is equal to the sum of their individual resistances.

Equivalent resistance (R_s) is always greater than any individual resistance.

Example 16.4

Two resistances 18 Ω and 6 Ω are connected to a 6 V battery in series. Calculate (a) the total resistance of the circuit, (b) the current through the circuit.

Solution:

(a) $R_1 = 18\ \Omega$ $\quad R_2 = 6\ \Omega$

$R_S = R_1 + R_2$

$R_S = 18 + 6 = \mathbf{24}\ \Omega$

(b) The potential difference V = 6 V

$$I = \frac{V}{R_S} = \frac{6}{24}$$

$I = \mathbf{0.25\ A}$

Resistors in Parallel

Consider three resistors having resistances R_1, R_2, R_3 connected in parallel. This combination is connected with a battery and plug key as shown in Fig. 16.5

In parallel combination the potential difference (V) across each resistor is the same.

The total current I is equal to the sum of the current through each resistor.

$$I = I_1 + I_2 + I_3 \qquad (1)$$

According to Ohm's law

$$I_1 = \frac{V}{R_1} \qquad I_2 = \frac{V}{R_2} \qquad I_3 = \frac{V}{R_3}$$

Substituting these values in equation (1)

$$I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

Let R_P be the equivalent resistance.

$$I = V/R_P$$

$$\frac{V}{R_p} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

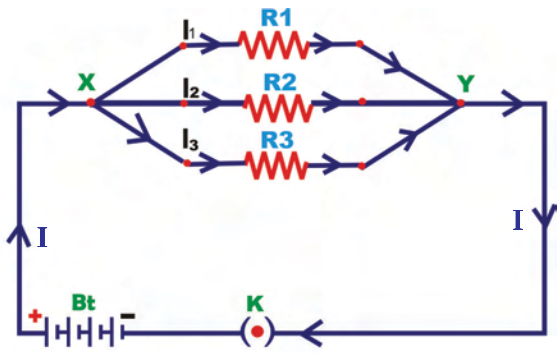


Fig. 16.5

Thus the reciprocal of the equivalent resistance ($1/R_P$) in parallel is equal to the sum of the reciprocals of the individual resistance.

Equivalent resistance (R_P) is always less than the least of the combination.

Example 16.5

Three resistances having the values 5 Ω, 10 Ω, 30 Ω are connected parallel to each other. Calculate the equivalent resistance.

Solution:

Given, $R_1 = 5\ \Omega$, $R_2 = 10\ \Omega$, $R_3 = 30\ \Omega$

These resistances are connected parallel

Therefore, $1 / R_p = 1 / R_1 + 1 / R_2 + 1 / R_3$

$$\frac{1}{R_p} = \frac{1}{5} + \frac{1}{10} + \frac{1}{30} = \frac{10}{30}$$

$$R_p = \frac{30}{10} = 3\ \Omega$$

16.7. HEATING EFFECT OF ELECTRIC CURRENT

We know that a battery is a source of electrical energy. Its potential difference between the two terminals sets the electrons in motion for the current to flow through the resistor.

For the current, to flow the source has to keep spending its energy. Where does this energy go? What happens when an electric fan is used continuously for a long period of time?

ACTIVITY 16.3

- *Take an electric cell, a bulb, a switch and connecting wires. Make an electric circuit as shown in Fig. 16.6. By pressing the key allow the current to pass through the bulb.*
- *The bulb gets heated when current flows continuously for a long time (when the key is on).*

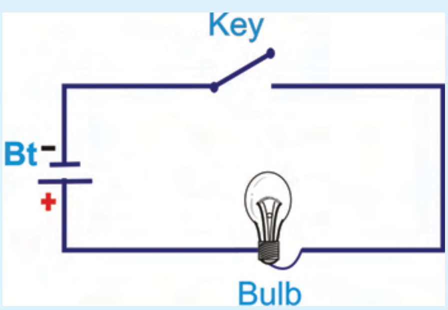


Fig. 16.6

A part of the energy may be consumed in useful work (like in rotating the blades of the fan). The rest of the energy may be expended in heat to raise the temperature of the gadget. If the electric circuit is purely resistive, the energy of the source continuously gets dissipated entirely in the form of heat. This is known as heating effect of electric current. Heating effect of electric current is used in many appliances. The electric iron, electric toaster, electric oven and electric heater are some of the familiar devices which uses this effect.

16.8. JOULE'S LAW OF HEATING

Consider a current I flowing through a resistor of resistance R. Let the potential difference across it be V. Let t be the time during which a charge Q flows across. The work done (W) in moving the charge Q through the potential difference V is VQ. Therefore the source must supply energy equal to VQ in time t.

What happens to this energy expended by the source? This energy gets dissipated in the resistor as heat. Thus for a steady current I, the amount of heat H produced in time t is

$$\mathbf{H = W = VQ}$$

$$\textbf{since, } \mathbf{Q = It}$$

$$\boxed{\mathbf{H = V\,I\,t}}$$

Applying Ohm's law we get $\mathbf{H = I^2 Rt}$.

This is known as Joule's law of heating. The law implies that heat produced in a resistor is

(1) directly proportional to the square of current ($\mathbf{I^2}$) for a given resistance,

(2) directly proportional to the resistance (R) for a given current,

(3) directly proportional to the time(t) for which the current flows through the resistor.

Example 16.6

A potential difference 20 V is applied across a 4 Ω resistor. Find the amount of heat produced in one second.

Solution:

Given potential difference, V = 20 V

The resistance, R = 4 Ω

The time, t = 1 s

According to Ohm's law, $I = \frac{V}{R}$

$$I = \frac{20}{4} = 5\text{ A}$$

The amount of heat produced,

$$H = I^2Rt$$

$$H = 5^2 \times 4 \times 1 = \mathbf{100\ J}$$

16.9. ROLE OF FUSE

A common application of Joule's heating is the fuse used in electric circuits. It consists of a piece of wire made up of an alloy (37% Lead, 63% Tin). It has high resistance and low melting point. The fuse is connected in series with the device. During the flow of high current, the fuse wire melts and protects the circuits and the appliances.

16.10. DOMESTIC ELECTRIC CIRCUITS

In our homes, we receive supply of electric power through a main supply (also called mains), either supported through overhead electric poles or by underground cables. One of the wires in the supply, usually with **red** insulation, is called live wire. Another wire, with **black** insulation, is called neutral wire. In our country, the potential difference between the two are 220 V. Another wire in **green** insulation is called earth wire.

At the meter-board in the house, these wires pass into an Wattmeter through a main fuse. Through the main switch they are connected to the line wires in the house. These wires supply electricity to separate circuits within the house. Often, two separate circuits are used, one of 15 A current rating for appliances with higher power ratings such as geysers, air coolers, etc. The other circuit is of 5 A current rating for bulbs, fans, etc.

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

Fig.16.7 gives a schematic diagram of one of the common domestic circuits. In each separate circuit, different appliances can be connected across the

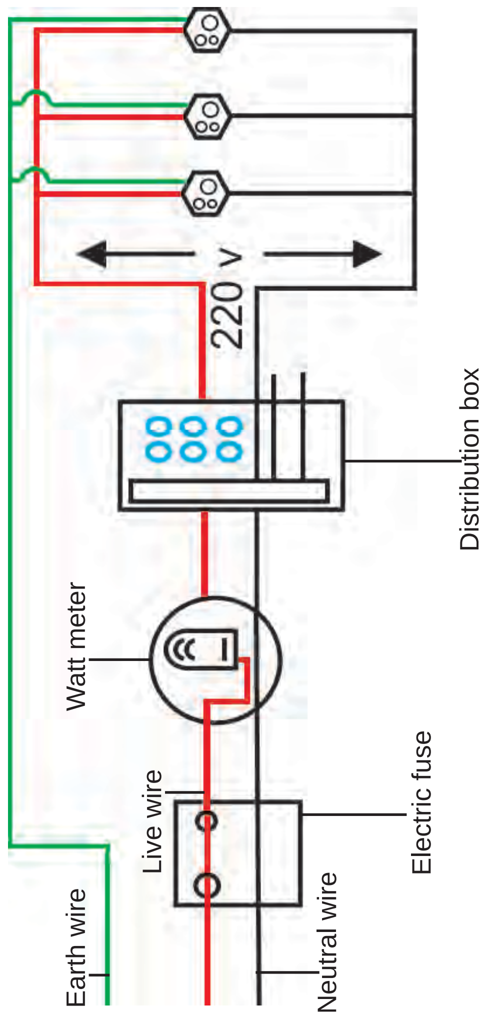


Fig. 16.7

live and neutral wires. Each appliance has a separate switch to switch ON or OFF the flow of current through it. In order that each appliance has equal potential difference, they are connected parallel to each other.

The electric fuse is an important component of all domestic circuits. Overloading can occur when the live and the neutral wire come into direct contact. In such a situation, the current in the circuit abruptly increases. This is called short circuiting. The use of an electric fuse prevents the electric circuit and appliance from a possible damage by stopping the flow of high electric current.

16.11. ELECTRIC POWER

We know already that the rate of doing work is power. The rate of consumption of electric energy is termed as electric power.

The power P is given by

$$P = \frac{W}{t} = VI$$

$$\text{(or)} \quad \mathbf{P = I^2R} = \frac{V^2}{R}$$

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

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

The unit watt is very small. Therefore, in actual practice we use a much larger unit called kilowatt. It is equal to 1000 watt. Since electric energy is the product of power and time, the unit of electric energy is, therefore, watt hour (Wh). One watt hour is the energy consumed when one watt of power is used for one hour. The commercial unit of electric energy is kilowatt hour (KWh), commonly known as unit.

$$1\ KWh = 1000\ \text{watt} \times 3600\ \text{second}$$
$$= 3.6 \times 10^6\ \text{watt second}$$
$$= 3.6 \times 10^6\ \text{joule}$$

Example 16.7

An electric bulb is connected to a 220 V generator. The current is 0.50 A. What is the power of the bulb?

Solution:

V = 220 V, I = 0.50 A

The power of the bulb,

P = VI = 220 x 0.50 = 110 W

16.12. CHEMICAL EFFECT OF ELECTRIC CURRENT

ACTIVITY 16.4

- *Carefully take out the carbon rods from two discarded cells.*
- *Clean their metal caps with sand paper.*
- *Wrap copper wire around the metal caps of the carbon rods.*
- *Connect these copper wires in series with a battery and an LED.*
- *Dip the carbon rods into lemon juice taken in a plastic or rubber bowl.*
- *Does the bulb glow?*
- *Does lemon juice conduct electricity?*

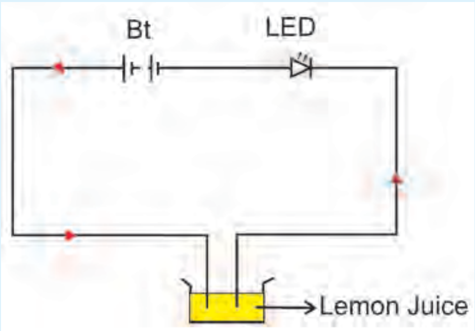


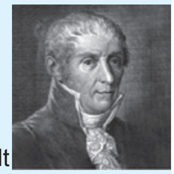
Fig. 16.8

It is observed that lemon juice conducts electricity.

16.13. ELECTROLYSIS- ELECTRO CHEMICAL CELLS

When the current is passed through aqueous or molten solutions of inorganic acids, bases and salts, the conduction of electricity is always accompanied by chemical decomposition of the solutions. Such solutions are called electrolytes and the phenomenon of the conduction of electricity through electrolytes by chemical decomposition is called electrolysis.

Name	:	Alessandro Volta
Born	:	18th February 1745
Birth place	:	Como, Italy
Died	:	5th March 1827
Best known for	:	The Italian who built the first battery



Electrochemical cell

The cells in which the electrical energy is derived from the chemical action are called electrochemical cells.

Voltaic cell consists of two electrodes, one of copper and the other of zinc dipped in a solution of dilute sulphuric acid in a glass vessel. This is shown in Fig. 16.9.

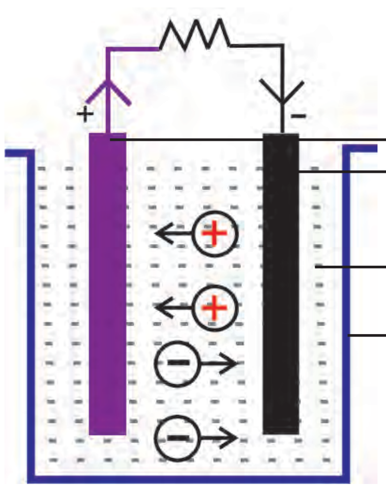


Fig. 16.9

On connecting the two electrodes externally, with a piece of wire, current flows from copper to zinc outside the cell and from zinc to copper inside it. The copper and zinc rods act as positive and negative electrodes respectively. The electrolyte is dilute sulphuric acid.

The action of the cell is explained in terms of the motion of the charged ions. At the zinc rod, the zinc atoms get ionized and pass into solution as Zn^{++} ions. This leaves the zinc rod with two electrons more, making it negative. At the same time, two hydrogen ions ($2H^+$) are discharged at the copper rod, by taking these two electrons. This makes the copper rod positive. As long as excess electrons are available on the zinc electrode, this process goes on and a current flows continuously in external circuit. This simple cell is thus seen as a device which converts chemical energy into electrical energy.

Due to opposite charges on the two plates, a potential difference is set up between copper and zinc. Copper being at a higher potential than zinc, the difference of potential between the two electrodes is 1.08 V.

16.14. PRIMARY AND SECONDARY CELLS

Primary Cell

The cells from which the electric energy is derived by irreversible chemical reaction are called primary cells. The primary cell is capable of giving an electro motive force(emf), when its constituents, two electrodes and a suitable electrolyte, are assembled together. The main primary cells are Daniel cell and Leclanche cell. These cells cannot be recharged.

Leclanche cell

A Leclanche cell consists of a glass vessel which is filled with ammonium chloride solution. Ammonium chloride solution acts as an electrolyte. In it there stands a zinc rod and porous pot containing a carbon rod which is packed round with a mixture of manganese dioxide and powdered carbon. The carbon and zinc rods act as positive and negative electrodes respectively.

At the zinc rod, the atoms get ionised and pass into the solution as Zn^{++} ions. This leaves the zinc rod with two electrons more making it negatively charged. At the same time, Ammonium chloride splits into ammonia gas, two Hydrogen ions ($2H^+$) and two chloride ions ($2Cl^-$). Zn^{++} ions and $2Cl^-$ ions recombine to form zinc chloride. The $2H^+$ ions migrate to the carbon rod and make it positively charged. When the carbon rod and zinc rod are connected by a wire, the current flows from carbon to zinc through the wire. The e.m.f of the cell is about 1.5V.

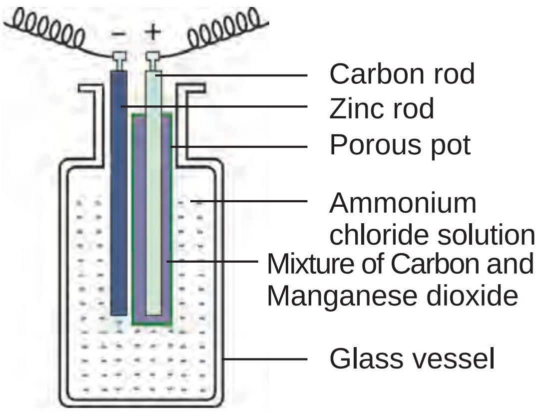


Fig.16.10

Secondary Cells

The advantage of secondary cells is that they are rechargeable. The chemical reactions that take place in secondary cells are reversible. The active materials that are used up when the cell delivers current can be reproduced by passing current through the cell in opposite direction. The chemical process of obtaining current from a secondary cell is called discharge. The process of reproducing active materials is called charging. One of the most commonly used secondary cell is lead acid accumulator.

Lead-acid Accumulator

In a lead-acid accumulator, the anode and cathode are made of lead dioxide and lead respectively. The electrolyte is dilute sulphuric acid. As power is discharged from the accumulator, both the anode and cathode undergoes a chemical reaction that progressively changes them into lead sulphate. When the anode and cathode are connected by a wire, the current flows from anode to cathode through the wire.

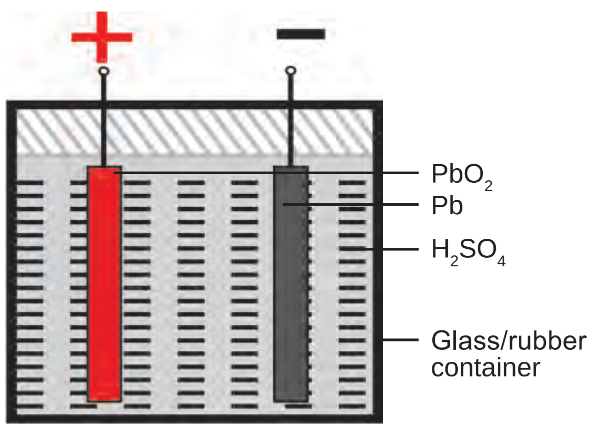


Fig. 16.11

When current is applied to a lead-acid accumulator, the electrochemical reaction is reversed. This is known as recharging of the accumulator. The e.m.f of freshly charged cell is 2.2V.

16.15. SOURCES OF ENERGY

Energy comes in different forms and one can be converted to another. If energy can neither be created nor destroyed, we should be able to perform endless activities without thinking about energy resources. Then why do we hear so much about the energy crises?

If we drop a plate from a height, the potential energy of the plate is converted mostly to sound energy when it hits the ground. If we light a candle, the chemical energy in the wax is converted to heat energy and light energy on burning.

In these examples we see that energy, in the usable form, is dissipated into the surroundings in less usable forms. Hence any source of energy we use to do work is consumed and cannot be used again. We use muscular energy for carrying out physical work, electrical energy for running various appliances, chemical energy for cooking food or running a vehicle. They all come from a source. We should know how to select the source needed for obtaining energy in its usable form, and only then will it be a useful source.

A good source of energy would be one

- which would do a large amount of work per unit volume of mass
- be easily accessible
- be easy to store and transport
- most importantly be economical.

16.15.1. Conventional Sources of Energy

1. Fossil Fuels

In ancient time's wood was the most common source of energy. The energy of flowing water and wind was also used for limited activities. Can you think of some of these uses? The exploitation of coal as a source of energy made the industrial revolution possible. Industrialisation has caused the global demand for energy to grow at a tremendous rate. The growing demand for energy was largely met by fossil fuels like coal and petroleum. These fuels were formed over millions of years ago and there are only limited reserves. Fossil fuels are a non-renewable source of energy. So we need to conserve them. If we were to continue consuming these sources at such alarming rates, we would soon run out of energy. In order to avoid this, alternate source of energy have to be explored.

Burning fossil fuels has other disadvantages like air pollution, acid rain and production of green house gases.

2. Thermal Power Plant

Large amount of fossil fuels are burnt everyday in power stations to heat up water to produce steam which further runs the turbine to generate electricity. The transmission of electricity is more efficient than transporting coal or petroleum over the same distance. Therefore, many thermal power plants are set up near coal or oil fields. The term thermal power plant is used since fuel is burnt to produce heat energy which is converted into electrical energy.