12

Electrical Energy

The tiny electrons, about which you have studied in lesson 3. on structure of atoms, exhibit very interesting behaviour when at rest and very useful effects when in motion. Electrical energy is the energy, basically associated with the electrons and other such particles called charged particles.

The wonderful genie of electrical energy brings all comforts to our command just with the press of a button. It is impossible to think of a world devoid of electrical energy. We start feeling very uncomfortable even if electricity, in our houses, is not available even for a short duration. Would you not like to know the nature of electrical energy, and the way it works. This is exactly what you are going to study in this lesson.

OBJECTIVES

After completing this lesson, you will be able to:

- cite examples of production of static electricity from everyday life;
- describe experiments to show the existence of two types of charges and state Coulomb's law for the force between them;
- define the terms electrostatic potential energy, potential difference, electric current and electric resistance;
- state Ohm's law and describe its experimental verification;
- apply Ohm's law for finding equivalent resistance of series and parallel combinations of resistances;
- describe experiments to illustrate thermal and magnetic effects of electric current;
- define the commercial units of electric power and electric energy;
- solve numerical problems based on Coulomb's law, Ohm's law, combination of resistors and consumption of electric power and electric energy in our houses.

12.1 ELECTROSTATICS

Ordinarily, if you bring a plastic comb near a piece of paper, you would not find any attraction between them. But, if you comb your dry hair with a comb and bring it close to a small piece of paper, you will find that the piece of paper is attracted towards the comb. We say that the comb gets charged or electrified in the process of combing. **Thales of Miletus** (600 BC), a Greak philosopher, knew that amber when rubbed with fur acquires the property of attracting small bits of wood. However, the systematic study of electricity started with **Dr. Gilbert**, the personal physician of queen Elizabeth-I, who published his work in 1600 AD about charges and magnets. It was Dr. Gilbert, who using the word "electron" for amber coined the word electricity. Dr. Gilbert, through his experience also indicated that the process of charging is not limited to amber only. Many other materials, like glass, ebonite and sealing wax can also be charged similarly.

The electricity (or charge) developed on a body, when it is rubbed in intimate contact with another body is called **frictional electricity.** It was realised that metals cannot be charged that way, whereas, non-metallic solids can be charged.

12.1.1 Nature of charges

A French chemist **Charles Dufay**, while performing experiments on charged bodies, found that charge acquired by a glass rod on getting it rubbed with silk is different from the charge acquired by an ebonite rod rubbed with wool. Let us perform the activity performed by Dufay to understand the difference.

ACTIVITY 12.1

Aim : To identify two different types of charges

What do you need?

Two glass-rods, two ebonite rods, a piece of silk, a piece of woolen cloth, an insulating stand with which a stirrup is hanging vertically with the help of a silken thread.

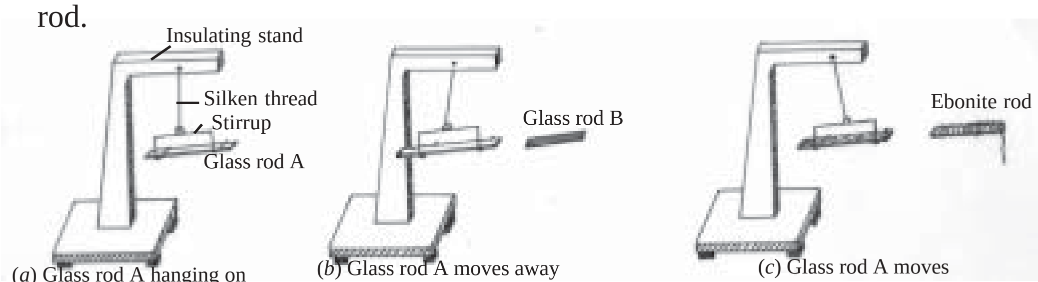
What should you do?

(i) Rub a glass-rod with a piece of silk and place it on the stirrup so that it stays horizontally. Let it come to rest.

(ii) Rub the second glass-rod with silk and bring it close to one end of the first glass-rod. Observe carefully the position of first glass rod.

(iii) Rub an ebonite-rod with a piece of wool and bring it close to the end of glass rod on stirrup as in step (ii). What difference do you note in the position of the glass-rod ?

(iv) Repeat the experiment by placing an ebonite-rod on the stirrup instead of glass-rod.



(*a*) Glass rod A hanging on a stirrup
(*b*) Glass rod A moves away from Glass rod B
(*c*) Glass rod A moves towards the ebonite rod

Fig. 12.1 Glass-rod rubbed with silk has a charge different than the charge acquired by ebonite rod rubbed with wool

What do you observe?

We observe that (i) two charged glass-rods repel each other, (ii) two charged ebonite-rods also repel each other, but, (iii) a charged glass-rod attracts a charged ebonite rod.

What do you conclude?

We conclude that:

(i) Charge developed on glass-rod on rubbing it with silk has a different nature that the charge developed on ebonite rod rubbed with wool.

(ii) Like charges repel each other while unlike charges attract each other.

Dufay called the charge acquired by glass-rod on rubbing it with silk as **vitreous electricity** and the charge acquired by ebonite-rod on rubbing it with wood as **resinuous electricity.** Later, **Benjamin Franklin** termed the former as **positive charge** and the latter as **negative charge.**

Dr. Gilbert also constructed a device for detecting charge. Such a device is called **electroscope**. Let us also construct a simple electroscope and do another activity using it.

ACTIVITY 12.2

Aim : To verify that in the process of charging by friction, equal and opposite charges are developed on the bodies rubbed together

What should you need?

A pith-ball with acqua-dag coating, a small silk thread, an insulating stand, an ebonite-rod, 4″ long woollen cap which fits on the ebonite rod.

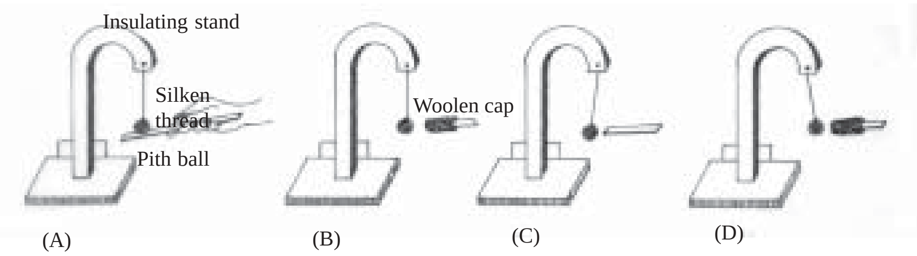


Fig. 12.2 Using pith ball electroscope to show that equal and opposite charges are produced by friction.

What should you do?

(i) Pass the silk thread through the pith ball, put a knot at the lower end and attach the other end with the insulating stand as shown in Fig. 12.2 (a)

(ii) Insert the ebonite rod in woollen cap, rub them with each other for some time and then touch the ebonite rod with path ball. The pith ball will, thus, get negatively charged, which is indicated by its repulsion with ebonite rod.

(iii) Now put woollen cap on the ebonite rod, and bring the rod close to the pith ball. Is there any attraction or repulsion shown by the pith ball?

(iv) Check again with and without woollen cap on ebonite rod one by one.

What do you observe?

We observe that (i) negatively charged ebonite rod repels negatively charged pith ball, (ii) woollen cap attracts the negatively charged pith ball, (iii) when ebonite rod with woollen cap is brought near the pith ball no attraction or repulsion takes place.

What do you conclude?

We conclude that ebonite rod has negative charge and woollen cap has equal amount of positive charge.

Remember : Charging by friction always produces equal and opposite charges on the two bodies which are rubbed in intimate contact.

How to explain this?

A material as such may be neutral but it is made of atoms. An atom possesses a positively charged nucleus surrounded by negatively charged electrons. When we rub two materials in intimate contact with each other, some of the weakly bound electrons from one body are transferred to the other body. The body which gains electrons becomes negatively charged and the body which loses electrons becomes positively charged.

The charge of an electron (e) = 1.6×10^{-19}C

If a body gains n electrons it will acquire a negative charge q = n e ....(12.1)

12.1.2 Force between electrical charges : Coulomb's law

In the previous section we have seen experimentally that we can give different amounts of charge to bodies by friction. Also, that some of its charge can be transferred from a charged body to an uncharged body by contact. We have also learnt that like charges repel each other while unlike charges attract. The factors on which this force of attraction or repulsion depends was studied first by the french physicist **Charles Augustin de Coulomb**. Coulomb presented the inferences of his experiments in the form of a law which is stated below.

Coulomb's law

The magnitude of the force of attraction (or repulsion) between two point charges is directly proportional to the quantity of charge present on each of them and inversely proportional to the square of the distance separating them.

If a charge q_1 is placed at a distance from a similar charge q_2, then the two charges will continue to repel each other with a force,

$$f = \frac{kq_1q_2}{r^2} \quad (12.2),$$

where k is a constant of proportionality depending on the nature of the medium in which the charges are placed.

In SI units, $k = 9 \times 10^9$ Nm^2 c^{-2}, for vacuum (or for air)

Charge is a scalar quantity. Its SI unit is coulomb. Equation 12.2 may be used to define 1C. If q1=q2 q2=1C and r=1 m, f=9×10^9 N. Thus, *1C charge is the charge which when placed at a distance of 1 m from an equal like charge in vacuum, experiences a repulsive force on 1N*.

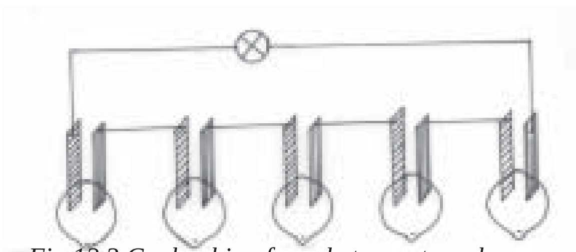


Fig 12.3 Coulombian force between two charges seperated by a distance r

Coulomb is a very big unit of charge. Normally charge acquired by bodies are of the order of micro coulomb or at the most milli coulomb. You may recollect that

1 micro coulomb = 10^{-6}C
and 1 milli coulomb = 10^{-3}C

12.1.3 Electric potential

Consider a big charge 'Q' fixed at a point. Let us call it **source charge**. At a very large distance from 'Q' a small charge 'q' will experience negligibly small force. As we bring 'q' towards 'Q' the magnitude of force between Q and q increases. If Q and q both are of the same nature (i.e. both positive or both negative) there will be a force of repulsion between them. Hence in moving charge 'q' towards 'Q' work will (1890) have to be done on the charge 'q'. This will be stored up as **potential energy** in the charge.

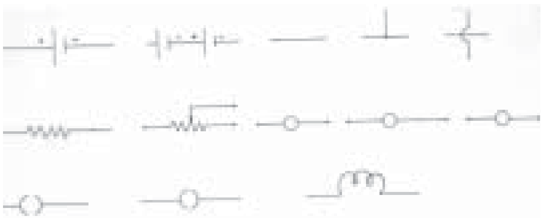


Fig. 12.4 Potential energy of charge q place at a distance r from charge Q

It is because of this **electrostatic potential energy**, that a charge when left of itself in the region surrounding a fixed charge, moves from one point to another point. The electrostatic potential energy possessed by a charge q when it is at a distance r from charge Q is given by :

$$U = \frac{KQq}{r} \quad .... (12.3)$$

In electricity, potential energy per unit charge is called **electrostatic potential.** Potential is more significant than potential energy itself. Using equation 12.3 we can say that potential at a point

$$V = \frac{U}{q} = \frac{KQ}{r} \quad ------------ (12.4)$$

Electrostatic potential is a scalar quantity and its SI unit is JC^{-1}, the other name for which is volts (V).

The potential at a point is 1 V if a + 1C charge placed at that point possesses a potential energy of 1J.

It may be noted that potential due to a positive source charge, at any point around it, is positive and decreases with distance. Whereas the potential due to a negative source charge is negative at any point around it and increases with increasing distance.

The importance of electrostatic potential lies in the fact that it is this quantity which determines the direction of flow of charge. Positive charges always move from higher potential to lower potential. On the other hand, negative charges move from lower potential to higher potential.

Example 12.1 : How many electrons make one coulomb?

Solution : Let n electrons make 1 C

Since charge is built by the excess or deficiency of electrons only

Charge on 1 electron is 1.6×10^{-19}C

Charge $q = + n\,|e|$

$$n = \frac{q}{|e|} = \frac{1}{1.6 \times 10^{-19}} = 6.25 \times 10^{18} \text{ electrons}$$

Example 12.2 : Two point charges having magnitudes 1 microcoulmb and 2 microcoulombs respectively are kept separated by a distance of 2 m. Calculate (i) the force of repulsion between them, (ii) the electrostatic potential energy of the charge system.

Solution :

$$\text{(i)}\quad F = \frac{KQq}{r^2} = \frac{9 \times 10^9 \times 1 \times 10^{-6} \times 2 \times 10^{-6}}{(2)^2} = 4.5 \times 10^{-3}\ \text{N}$$

$$\text{(ii)}\quad U = \frac{KQq}{r} = \frac{9 \times 10^9 \times 10^{-6} \times 2 \times 10^{-6}}{2} = 9 \times 10^{-3}\ \text{J}$$

Example 12.3 : Calculate the potential at a point, distant 30 cm from a 60 micro coulomb negative charge.

Solution : $$V = \frac{KQ}{r} = \frac{-9 \times 10^9 \times 60 \times 10^{-6}}{30 \times 10^{-2}} = -1.8 \times 10^6\ \text{volts}$$

CHECK YOUR PROGRESS 12.1

1. What type of charge does an ebonite rod acquire when it is rubbed with wool? What is the nature of the charge acquired by wool?
2. When a glass rod is rubbed with a piece of silk it acquires +10 micro coulomb of charge. How many electrons have been transferred from glass to silk ?
3. If the charge on two particles be doubled and separation between them be halved, how many times will become the Coulombian force between them?
4. A charged particle placed at a distance of 50 cm from a fixed charge has a potential energy of 10J. If the charge of the particle is 1 micro coulomb
   (i) what is the potential at the position of the particle
   (ii) what is the value of the fixed charge?
5. Define the unit of (i) charge (ii) potential

12.2 CURRENT ELECTRICITY

Can charge produced at one place be transferred to some other place without actually moving the charged body? Yes, you will say, by connecting the charged body to an uncharged body through a metallic wire. But, can you do so by holding the naked wire in your hand? You will say, no, the wire should be insulated. What you know by sheer experience today, was shown by **Stephen Gray** in 1729 by extensive and expensive research of several months.

12.2.1 Electric cells–Sources of potential difference

As you have learnt in the previous section, positive charge flows from higher to lower potential. So if you want to pass charge continuously, from one body to another body through a wire, you have to maintain a potential difference between them. You are familiar with a device which can be used to maintain potential difference between the two ends of a wire-the **dry cell**. The dry cell is a type of **electric cell**.

An electric cell is a device which converts chemical energy into electrical energy.

A group of cells is called battery. In a torch having many cells you are using a battery of cells.

ACTIVITY 12.3

Aim : To construct a battery of cells and use it to light up an LED

What you need?

5 lemons, 5 thin strips of copper, 5 thin strips of zinc, an LED, copper connecting wires.

What to do?

(i) Arrange the lemons in a line on a table.

(ii) Insert one copper and one zinc strip in each of the lemons as shown in Fig. 12.5

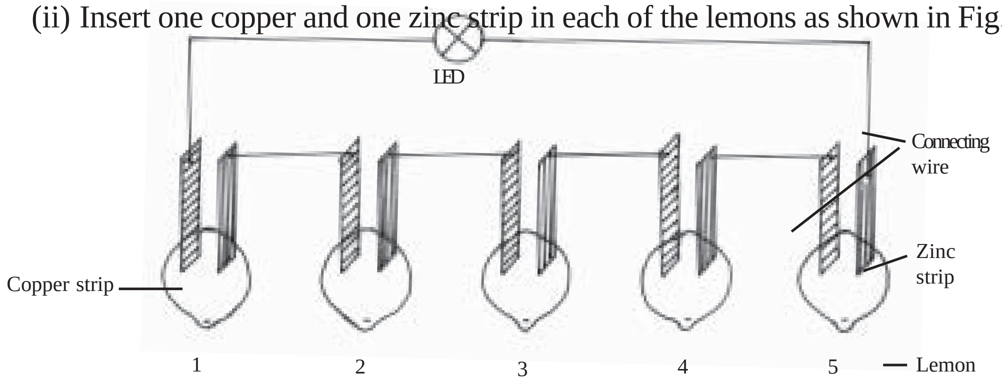


Fig 12.5 A battery of 5 lemon cells used to light up an LED

(iii) Connect zinc strip of first lemon with the copper strip of the second lemon and this way connecting all the cells, leaving one copper strip free at the end of first lemon and one zinc strip at the end of last lemon.

(iv) Connect LED between these free strips.

(v) Repeat the experiment using cotton threads instead of copper wires with LED.

(vi) Repeat experiment using 3V bulb instead of LED.

What do you observe ?

You will observe that (i) the LED glows continuously when connected across the battery using copper connecting wires, (ii) LED does not glow when we use cotton thread instead of copper wire, (iii) 3V bulb does not glow in this arrangement.

What do you infer ?

We infer that (i) the LED glows continuously, because, continuous charge flows through it due to a constant potential difference applied across its ends with the help of battery of lemon cells, (ii) copper wire conducts charge but cotton thread does not, (iii) The arrangement does not supply enough charge to glow a 3V bulb.

Remember:

1. There are two types of substances: (i) those through which electric charge can flow easily are called **conductors.** All metals are good conductors of electricity, (ii) Those through which charge does not pass are called **insulators.** Non-metals are generally insulators. It is the structure of the material which determines whether it will conduct charge or not. A conductor has a large number of **free electrons,** whereas insulators have none.
2. A directed flow of charge is called electric current. The **electric current** flowing through a conductor is defined as the charge flowing through any section of the conductor in 1 second.

i.e. $$I = \frac{Q}{t} \qquad (12.5)$$

Current is a scalar quantity and its SI unit is ampere (A). Current through a conductor is 1A if 1C charge flows through it in 1 second. The current flowing through a conductor is measured with the help of a device called ammeter.

3. As a convention, the direction of flow of positive charge is taken as the direction of flow of electric current. Thus in an **electric circuit** current is considered to be flowing from the positive terminal of the battery towards negative terminal.
4. In conductors it is the negatively charged free electrons which move to constitute current. They flow in opposite direction to the direction of conventional current.
5. A dry cell bears a marking 1.5V. This figure indicates the maximum potential difference that can be applied to this cell, when no current is being drawn from it. This is called **emf** of the cell. The emf of a cell is its characteristic property. Actual potential difference which we can apply with the help of the cell is slightly less than its emf.

12.2.2 Electric circuits and Ohm's law

When we connect some devices like electric bulb across a cell through connecting wires, current flows through the arrangement in a closed path. This type of arrangement of cells, conductors and bulbs is called **electric circuit.** In circuit diagrams various components are represented by definite symbols, some of which are given in Fig. 12.6.

Cell

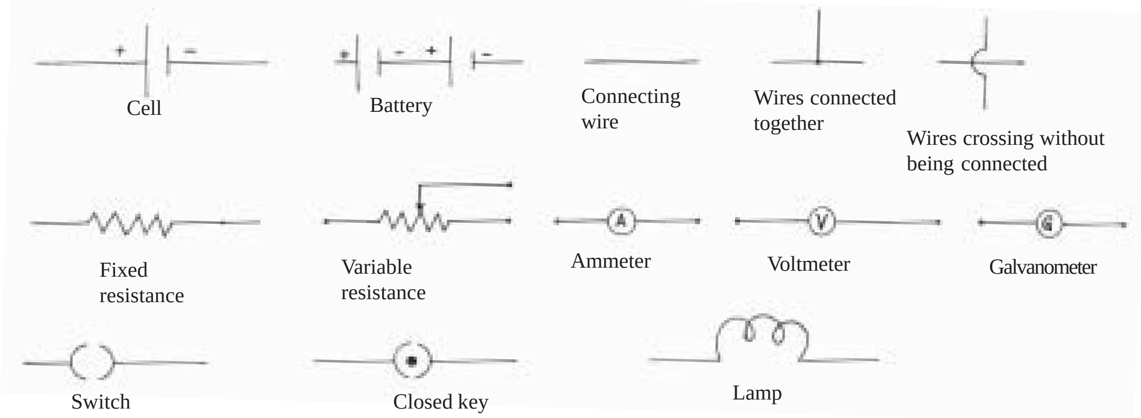


Fig. 12.6 Some important symbols used in electric circuits

In this list of symbols, voltmeter is a device used to measure potential difference between any two points of a circuit, galvanometer - a device to detect current and rheostat to change current in the circuit.

During contact programme request your tutor to show you various electrical devices they use in laboratories.

12.2.2a Ohm's Law

In section 12.2.1 we have seen that current flows through a conductor when we apply a potential difference between its ends with the help of an electric cell. The question arises how does the value of current flowing through a wire change when the potential difference applied across it is changed. To answer this let us perform the following activity.

ACTIVITY 12.4

Aim : To find the relation between the current flowing through a wire and the potential difference applied across it

What you need?

A dry cell, a voltmeter (range 0–1.5V), an ammeter (range 0–1A), a standard fixed resistance coil (1 Ohm), rheostat (0–1 Ohm), connecting wires and a plug key.

What to do?

(i) Connect the fixed resistor (R), ammeter (A), dry cell (D), plug key (K) and rheostat (Rh) is series (end to end) and voltmeter (V) in parallel to R, as shown in Fig. 12.8.

(ii) When the key K is open check that the readings in ammeter and voltmeter is zero.

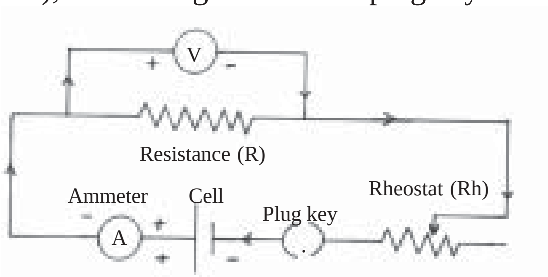


Fig 12.7 Circuit diagram to show relationship between voltage and current

(iii) Insert the plug in the key and move the sliding contact of the rheostat so that there is some small reading in ammeter and voltmeter. Record these readings.

(iv) Increase the value of current with the help of rheostat. Record ammeter and voltmeter readings again.

(v) After changing the readings 4 to 5 times, record the corresponding values current and voltage from ammeter and voltmeter.

(vi) Plot a graph between ammeter and voltmeter readings.

What do you observe?

You will observe that : (i) on increasing ammeter reading voltmeter reading increases in the same proportion. (ii) the voltage-current graph is a straight line as shown in Fig. 12.8.

What do you conclude?

We conclude that the current flowing through a wire is directly proportional to the potential difference applied between its ends.

i.e. $V \propto I$

or $V = RI$ .... (12.6)

Here, R is a constant of proportionality and is called the resistance of the given wire.

This observation was first made by **George Simon Ohm** and is called **Ohm's Law.**

Remember :

1. The law can be applied only to conducting wires and that too when its temperature and other physical conditions remain unchanged. If the temperature of the conductor increases its resistance also increases.
2. 'R' i.e. resistance of wire, is a constant for a given wire. It can be easily shown that resistance of a wire depends on :

- its length – longer the wire, more the resistance
- its thickness – thicker the wire, lesser the resistance
- the nature of material – copper wire has lesser resistance than iron wire of same length and thickness.

3. Resistance is a scalar quantity and its SI unit is Ohm (Ω).
4. The resistance of a wire can never be negative.

Ohm is the resistance of a wire across, which when 1V potential difference is applied, 1A current flows through it.

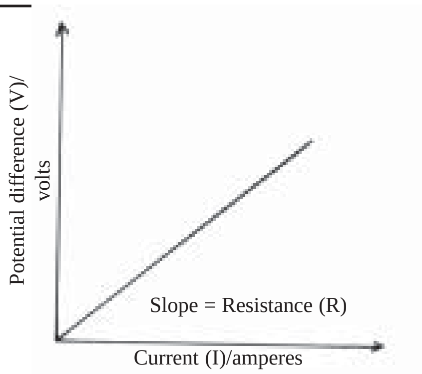


Fig 12.8 Graph showing variation in voltage with the variation in current

12.2.3 Combinations of resistors

In electrical circuits, we connect a number of devices having different resistance values. This we can do in two different ways.

(a) **Series combination**

In this combination a number of resistances are connected end to end, so that, same current flows through all of them (Fig. 12.9), when the combination is connected to a cell.

R_1

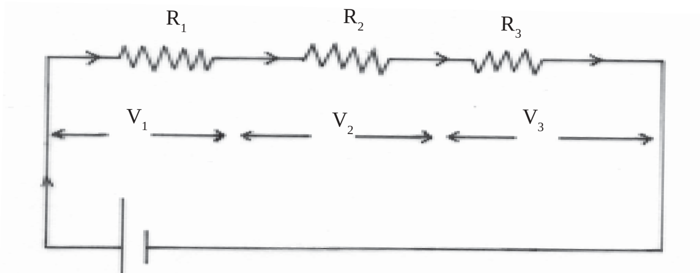


Fig 12.9 Series combination of resistances

If we measure voltage across each of the resistances with the help of a voltmeter, we will find that more the resistance more the potential difference across it. Thus, voltage across r_1, i.e., $V_1 = Ir_1$, across r_2 is $V_2 = I\,r_2$ and so on.

Also, the total voltage across the combination is the sum of the voltage across individual resistors.

i.e. $V = V_1+V_2+V_3+$ ---------------- (12.7)

$= Ir_1+Ir_2+ Ir_3 +$ ----------------

$\frac{V}{I} = r_1+r_2+$ ---------------- (12.7a)

$\frac{V}{I}$ gives the resistance of the combination R

$R = r_1 + r_2 +$ -------------- (12.8)

The resistance of a number of resistances in series is equal to the sum of the resistances of the component resistors.

(b) Parallel combination

Resistances are said to be connected in parallel when one end of all the resistors is connected to the positive terminal of the battery and the other end to the negative terminal, as shown in Fig. 12.10.

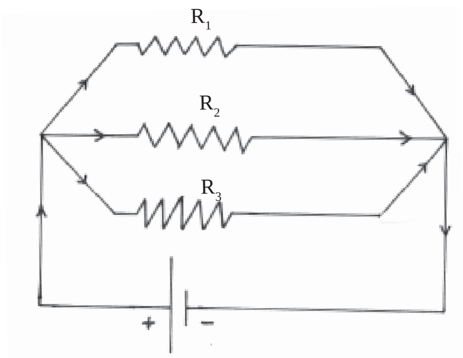


Fig. 12.10. Parallel combination of resistances

In parallel combination equal potential difference is applied across each resistor. The current drawn from the cell is inversely proportional to the resistance, i.e.

R_1

$$I_1 = \frac{V}{r_1},\quad I_2 = \frac{V}{r_2},\quad I_3 = \frac{V}{r_3}$$

Also, total current drawn from the cell by the combination is equal to the sum of currents drawn by the individual resistors. If the resistance of the combination be R, then

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

and $I = I_1 + I_2 + I_3$ --------------------(12.9)

$$\frac{V}{R} = \frac{V}{r_1} + \frac{V}{r_2} + \frac{V}{r_3}$$

$$\Rightarrow \frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} \quad \text{------------------------(12.10)}$$

The reciprocal of the resistance of a combination of a number of resistors connected in parallel is equal to the sum of the reciprocal of the individual resistances.

Remember :

1. Normally all the appliances in our household circuits are connected in parallel. But the chain of small bulbs that we use for decoration on Deewali has the bulbs connected in series.
2. As we add resistances in series the circuit resistance increases but when we connect resistances in parallel the total resistance is smaller than the smallest of the resistances involved.

Example 12.4 : Find the equivalent resistance of the following combination of resistors.

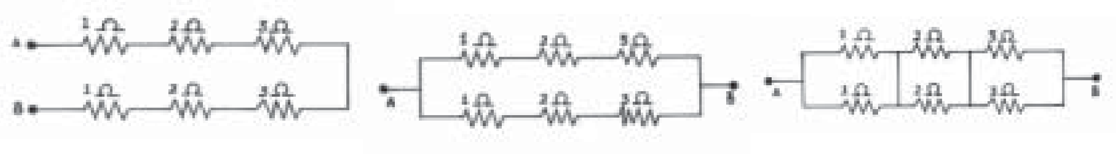


Fig. 12.11.

Solution :

(a) Here all resistors are connected in series

$R = r_1 + r_2 + r_3 + r_4 + r_5 + r_6 = 1+2+3+3+2+1 = 12\Omega$

(b) Here we have two series combination of 3 resistors in parallel.

$R_1 = 1+2+3 = 6\Omega$, $R_2 = 1+2+3 = 6\Omega$

$$R = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{6 \text{ x } 6}{6 + 6} = \frac{36}{12} = 3\Omega$$

(c) Here we have 3 parallel combinations of 2 resistances each connected in series.

$$R = \frac{r_1 \text{ x } r_2}{r_1 + r_2} = \frac{1 \text{ x } 1}{1 + 1} = \frac{1}{2}\ \Omega$$

$$R = \frac{2 \text{ x } 2}{2+2} = 1\Omega$$

$$R = \frac{3 \text{ x } 3}{3 + 3} = \frac{9}{6} = \frac{3}{2} = 1.5\ \Omega$$

$$R = R_1 + R_2 + R_3 = \tfrac{1}{2} + 1 + {}^{3}/_{2} = 3\Omega$$

CHECK YOUR PROGRESS 12.2

1. Define the units of (i) current (ii) resistance
2. A number of bulbs are connected in a circuit. Decide whether the bulbs are connected in series or in parallel, when (i) the whole circuit goes off when one bulb is fused (ii) only the bulb that gets fused goes off.
3. When the potential difference across a wire is doubled, how will the following quantities be affected (i) resistance of the wire (ii) current flowing through the wire.
4. How will the readings of ammeter and voltmeter change in the adjoining circuit (Fig. 12.12), when an extra resistance R is connected (i) series with the battery (ii) parallel to the resistance R. Assume ammeter, voltmeter and cell to be ideal devices.
5. What is the reading of ammeter in the adjoining curcuit (Fig. 12.13).

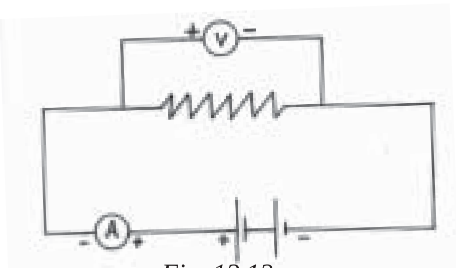


Fig. 12.12

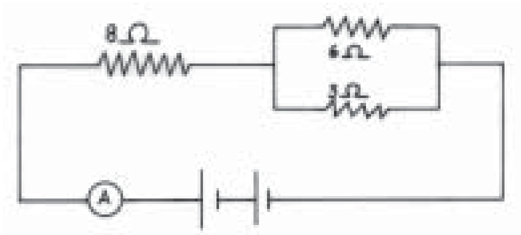


Fig. 12.13

12.3 Effects of electric current

When current is passed through a conductor some changes take place in and around its material. These changes, produced due to electric current, are called effects of electric current.

There are two effects of electric current flowing through a conductor that we come across in our day to day life. They are :

(i) Thermal effect (ii) Magnetic effect

Let us study these effects of electric current one by one.

12.3.1 Thermal effect of electric current

When current is passed through a conductor it gets heated up. To study the heating effect of electric current let us perform the following activity.

ACTIVITY 12.5

Aim : To study thermal effect of electric current

What you need?

Two pieces of the element of electric heater (one of which has 10 turns and the other 20 turns), two dry cells, connecting wires.

What to do?

(i) Attach connecting wires to the free ends of 10-turn coil permanently.

(ii) Touch the free ends of the connecting wires to the two terminals of dry cell, thus passing current through it. Detach the contacts after 10 seconds. Now touch the coil and feel it.

(iii) Repeat the experiment by passing current for 20 seconds.

(iv) Place two dry cells in contact, making series battery and repeat the second step.

(v) Repeat steps 2,3,4 with 20-turn heater coil.

Fig. 12.14. Study of thermal effect

What do you observe ?

You will observe that

(i) On passing current through a conductor it gets heated up.

(ii) The coil is found to be heated when current is passed for a second.

(iii) The coil is found to be hotter when greater voltage is applied across it.

(iv) When same voltage is applied across bigger coil less heat is produced in it.

What do you infer ?

Thus, we conclude that

(i) Current has a heating effect, i.e. when current is passed through a conducter it gets heated up.

(ii) More heat is produced in a conductor when

- more potential difference is applied across it
- current is passed through it for more time (t)
- more current is passed through the same conductor.

Thus it can be seen that heat produced Q α VIt or Q = kVIt

If V = 1 volt, I = 1 A, t = 1 second, Q = 1 J K = 1

Then Q = V I t .... (12.12)

According to Ohm's Law : V = IR $Q = I^2 Rt = \frac{V^2 t}{R}$ (12.13)

12.3.2 Magnetic effect of electric current

All of you, I am sure, might have played with magnetics. A magnet has such interesting properties that you cannot resist possessing one. A pivoted magnetic needle always stays in north-south direction and is used as a magnetic compass. A magnet attracts small pieces of iron, nickel and cobalt. It also attracts unlike poles of another magnet and repels like poles. But a stationary magnet does not attract or repel a stationary charge. Still electricity and magnetism are intimately related. In fact, magnetism is just an effect of electric current. This was for the first time discovered by **H.C. Oersted**, in 1820, accidently. Let us perform an activity to understand oersted's discovery.

ACTIVITY 12.6

Aim : To study the magnetic effect of electric current

What do you need?

A compass needle, a dry cell, connecting wires, a thick copperwire, two wooden stands

What to do?

1. Place the magnetic needle on the table. It will stay in north-south direction.
2. Stretch the thick copper wire over the magnetic needle, using wooden stands, so that the wire is parallel to the axis of the magnetic needle.
3. Attach connecting wires at the two ends of the thick copper wire.

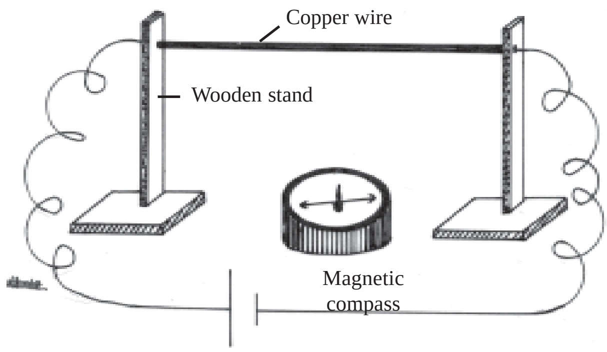


Fig. 12.15 Set-up to study the magnetic effect of electric current

4. Touch the free ends of the connecting wires to the two terminals of the battery. Observe the magnetic needle carefully.
5. Touch the reverse terminals of the battery with the free ends of the connecting wires, observe the magnetic needle again.

What do you observe ?

(i) The magnetic needle gets deflected whenever an electric current is passed through the thick copper wire.

(ii) The deflection in magnetic needle gets reversed when the direction of flow of current through the wire is reversed.

We conclude that a magnetic field is developed around a conductor when electric current is passed through it. This observation is called **magnetic effect of electric current**. The magnetic field around a conductor carrying conductor is in the form of closed circular loops, in a plane perpendicular to the conductor, and is given by right hand grip rule. According to the rule, hold the conductor is your right hand with thumb pointing in the direction of electric current, then, the curling figures point is the direction of the magnetic field.

Making use of these devices, scientists have devised a number of electric gadgets that we use in our houses for our comfort. You will learn about some of these devices in the next lesson.

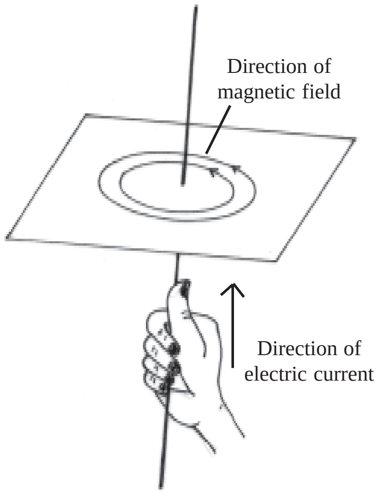


Fig. 12.16 Right hand grip rule

CHECK YOUR PROGRESS 12.3

1. Which will produce more heat in 1 second – a 1 ohm resistance on 10V or a 10 ohm resistance on the same voltage? Give reason for your answer.
2. How will the heat produced in a conductor change in each of the following cases?
   (i) The current flowing through the conductor is doubled.
   (ii) Voltage across the conductor is doubled.
   (iii) Time for which current is passed is doubled.
3. 1 A current flows though a conductor of resistance 10 ohms for 1/2 minute. How much heat is produced in the conductor?
4. When plug is inserted in key K, indicate the direction of magnetic field developed around wire AB in Fig. 12.17.
5. Name a household electric device based on (i) thermal effect (ii) magnetic effect of electric current.

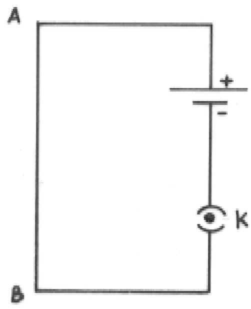


Fig. 12.17

12.4 ELECTRIC ENERGY AND ELECTRIC POWER

We have seen in the previous section that when V volts is applied across a conductor and I amperes flows through it, then the energy produced in the conductor in t seconds is given by

$$Q = VIt$$

Actually this equation holds true in whatever form the electrical energy may be consumed. The electrical energy consumed in one second is called electric power and is given by

$$P = \frac{Q}{t} = VI \qquad (12.14)$$

Equation 12.13 then becomes

$$Q = Pt = VIT = qv \qquad (12.15)$$

12.4.1 Commercial units of electrical energy and electric power

In SI units, energy in each of its form, has the same unit, joule (J). But in our houses we consume so much of electrical energy daily that joule proves to be a small unit for practical purposes. Therefore for commercial purposes we use a very big unit for measuring electrical energy, called kilo watt hour (kWh)

$$\text{IkWh} = 1000 \times 3600 = 3.6 \times 10^6 \text{ J.} \qquad (12.17)$$

For electric power also commercially we use a bigger unit, horse power (HP).

$$1 \text{ HP} = 746 \text{ watt} \qquad (12.18)$$

12.4.2 Electric power generation and consumption in India

One of the criteria, for judging the progress of a nation and the standard of living of its people, is the electrical energy generated and used by it. India has come a long way in its efforts to generate and use electrical energy. Till 31st December 2001, we had developed a total installed capacity of more than 103 billion watts of power utilities, with high targets of capacity additions in our future plans. Though per capita electricity available to our people is still very low as compared to the per capita electricity available in developed and oil rich countries, the situation is not very unsatisfactory when it comes to the considerations of resources available.

There are three types of large scale electricity, generating plants :

(i) Hydroelectric power plants - where potential energy of water stores in a dam is used for generating electricity.

(ii) Thermal power plant - where a fossil fuel is burnt to produce steam which runs a turbine to convert mechanical energy into electrical energy.

(iii) Atomic power plant - where nuclear energy obtained from a fissionable material like uranium is used to run a turbine.

Some of the important power plants of India are listed below :

1. Hydel power plants
   - (a) Bhakra -Nangal hydroelectric power plant, Punjab
   - (b) Rihand hydel power house, Uttar Pradesh.
   - (c) Periyar hydroelectric power station, Tamilnadu
   - (d) Iddika hydroelectric power house, Kerala.
   - (e) Umiam hydroelectric power station, Assam
2. Thermal power plants
   - (a) Badarpur thermal Power Station, Delhi
   - (b) Talcher thermal power house, Orissa.
   - (c) Barauni thermal power station, Bihar.
   - (d) Neyveli thermal power station, Tamil Nadu.
   - (e) Namrup thermal power station, Assam.
3. Nuclear power plants
   - (a) Tarapore atomic power station, Maharashtra.
   - (b) Rajasthan atomic power station, Rana Pratap Sagar, Kota.

(c) Madras atomic power station, Kalpakkam, Tamil Nadu.

(d) Narora atomic power station, Uttar pradesh.

Of the total electrical power generation facilities available in India about 25% are hydel, 7% thermal, 2.5% nuclear and the rest use other resources like wind energy, solar power, geothermal energy or oceanic energy. This shows that main thrust by now has been on thermal power plants which use coal, natural gas and diesel as fuel. Because, we have to import fossil fuels the production is not to the full installed capacity. Thus a change in shift to other sources becomes imperative.

In India all the major plants produce A.C. (alternating current) at 50 hertz, 11000 volts or more. This power can be further stepped up to higher voltages using transformers and hence can be transmitted to long distances without much loss of power.

Example 12.5 Find the resistance of the filament of 100W, 250V electric bulb.

Solution :

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

$$= \frac{250 \times 250}{100} = 625\ \Omega$$

Example 12.6 Calculate the energy consumed in a 2 kW electric heater in 2 hours. Express the result in joules.

Solution :

$$Q = Pt = 2 \times 2 \text{ kWh} = 4 \text{ kWh}$$

$$= 4 \times 3.6 \times 10^6 \text{J} = 14.4 \times 10^6 \text{ J}$$

Example 12.7 How much time will a 2 kW immersion rod take to raise the temperature of 1 litre of water from 30^0 to 60°.

Solution :

$$Q = Pt$$

$$Q = mc\theta$$

$$mc\theta = pt \qquad \text{....(12.19)}$$

Mass of 1 litre of water (m)= 1 kg

Specific heat of water (c) = $4.18 \times 10^3 \text{ J kg}^{-1} \text{ C}^{-1}$

Rise in temperature of water (θ) = $60 - 30 = 30^0$C.

$P = 2 \text{ kW} = 2000\text{W}$

Substituting in equation (12.19) we get

$$1 \times 4.18 \times 10^3 \times 30 = 2000 \times t$$

$$t = \frac{125.4 \times 10^3}{2 \times 10^3} = 62.7 \text{ s}$$

Example 12.8 : How many kilowatt hour of energy will be consumed by a 2HP motor in 10 hours?

Solution :

$$P = 2 \text{ HP} = 2 \times 746 \text{ W} = 1.492 \text{ kW}$$

$$Q = Pt = 1.492 \times 10 \text{ kWh} = 14.92 \text{ kWh}$$

Example 12.9 : A potential difference of 250V is applied across a resistance of 1000 ohm. Calculate the heat energy produced in the resistance in 10 s.

Solution : $Q = \frac{V^2t}{R} = \frac{250 \times 250 \times 10}{1000} = 625 \text{ J}$

CHECK YOUR PROGRESS 12.4

1. Which has a higher resistance a 40W, 220W bulb or a 1 kW electric heater?
2. What is the maximum current that a 100W, 220V lamp can withstand?
3. How many units of electricity will be consumed by a 60W lamp in 30 days, if the bulb is lighted 4 hours daily.
4. How many joules of electrical energy will a quarter horse power motor consume in one hour.
5. An electric heater is used on 220V supply and draws a current of 5 A. What is its power?

LET US REVISE

- When two bodies are rubbed together in contact, they acquire a peculiar property of attracting small bits of paper. We say the bodies are electrified or charged by friction.
- Charges are of two types. Charge acquired by a glass rod rubbed with silk is positive and that acquired by an ebonite rod rubbed with fur is negative.
- Like charges repel each other and unlike charges attract each other.
- The force between two charges is given by Coulomb's law according to which

  $$F = \frac{K q_1 q_2}{r_2}$$
- Force per coulomb of charge at a point is called electric field, E = F/q
- Work is done in moving a charge against electric field which is stored up as potential energy of the charge. Hence, when charge is placed at a point in the field it possesses potential energy.
- Potential energy per coulomb of charge at a point is called potential. Positive charge always moves from a higher potential to a lower potential and vice-versa.
- Electric cell is a device with the help of which we can apply a potential difference between the two ends of a wire due to which current will flow through the wire.
- Ohm's law states that current flowing through a conductor is directly proportional to the potential difference applied between its ends, provided temperature and other physical conditions of the conductor remain unchanged.
- Ratio of voltage applied across a conductor and the current flowing through it is called resistance of the conductor. S.I. Unit of resistance is ohm.
- Resistances may be connected in two different independent ways

  (i) in series, (ii) in parallel.
- In series, total resistance of the combination is equal to the sum of the individual resistances.
- In parallel, reciprocal of the combined resistance is equal to the sum of the reciprocals of the individual resistances.

- Current when passed through a conductor produces two effects.
  (i) Thermal effect,(ii) Magnetic effect.
- Commercial unit of electrical energy is kWh and that of electric power is HP.
- India is gradually moving towards its target of providing enough electric power to its people but still we have a long way to go.

TERMINAL EXERCISES

A. Multiple choice type questions.

1. A charged conductor 'A' having charge is touched to an identical uncharged conductor 'B' and removed. Charge left on A after separation will be :-
   (a) Q (B) Q/2 (C) Zero (D) 2 Q
2. J C^{-1} is the unit of
   (a) Current (b) Charge (c) Resistance (d) Potential
3. Which of the following materials is an electrical insulator?
   (a) Mica (b) Copper (c) Tungsten (d) Iron
4. The device which converts chemical energy into electrical energy is called
   (a) electric fan (b) electric generator (c) electric cell (d) electric heater.
5. The resistance of a conductor does not depend on its
   (a) temperature (b) length (c) thickness (d) shape

B. Fill in the blanks.

1. When current is passed through a conductor its temperature ___________.
2. A current carrying conductor carries a ___________ field arount it.
3. The director of magnetic field around a current carrying conductor is determined using ___________.
4. Unit of electric power is ___________.
5. of the two wires made of the same material and having same thickness the longer one has ___________ resistance

C. Descriptive type questions.

1. Name the instruments used to measure (a) current (b) potential difference.
2. Name the quantity measured by the unit (a) NC^{-1} (b) C S^{-1}
3. Give a one word name for the unit (a) J C^{-1} (b) C S^{-1}
4. What is the potential difference between the terminals of a battery if 250 J of work is required to transfer 20C of charge from one terminal of the battery to the other.
5. Give the symbols of (a) cell (b) battery (c) resistor (d) voltmeter.
6. What is the conventional direction of flow of electric current? Do the charge carriers in the conductor flow in the same direction ? Explain ?
7. Out of ammeter and voltmeter which is connected us series and which is connected in parallel ?
8. You are given two resistances of 3 ohm and 6 ohm, respectively. Combining these two resistances what other resistances can you obtain?

9. Two resistances when connected in series give 8 Ω and when connected in parallel give 1.5 Ω. What is the value of these resistances ?

10. Which effect of electric current can be utilized in detecting a current carrying wire concealed in a wall? Name the scientist who discovered this effect.

11. Two resistances are connected in series as shown in fig. 12.18.

(i) What is the current through 5 ohm resistance?

(ii) What is the value of R?

(iii) What is the value of V?

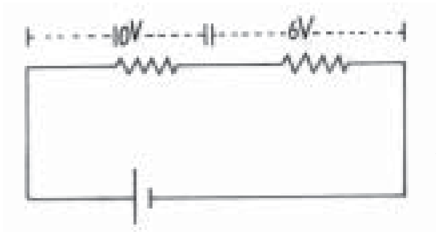


Fig. 12.18

12. In the circuit shown alongside (Fig. 12.19),

(i) Total resistance of the circuit.

(ii) Ammeter (A) reading

(iii) Current flowing through 2 ohm resister

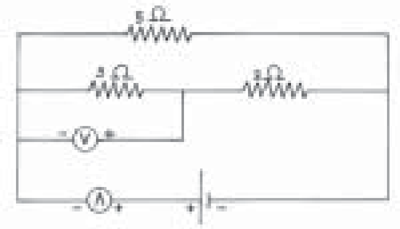


Fig. 12.19

13. For the circuit shown alongside (Fig. 12.20), find the value of :

(i) Current through 6 ohm resistor.

(ii) Potential difference across 12 ohm resistor

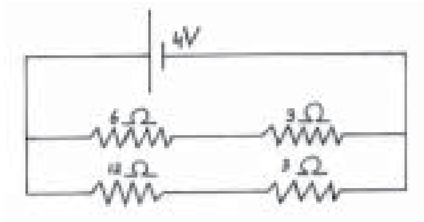


Fig. 12.20

14. You are given three resistors of 1 ohm, 2 ohm and 3 ohm. Show by diagrams, how will you connect these resistors to get (a) 6/11 Ω (b) 6 Ω (e) 1.5 Ω

15. A resistor of 8 Ω is connected in parallel with another resistor of X Ω. The resultant resistance of the combination is 4.8 ohm. What is the value of resistor X

16. In the adjoining circuit (Fig. 12.21), find :

(i) Total resistance of the circuit.

(ii) Total current flowing through the circuit

(iii) The potential difference across 4 Ω resistor

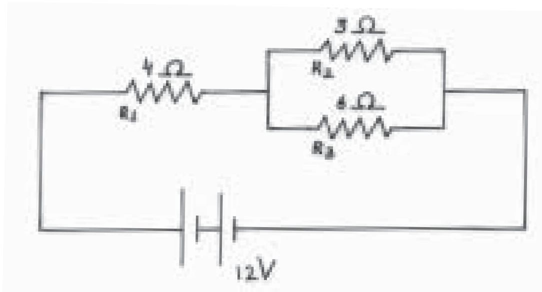


Fig. 12.21

17. What is the fuel used in :

(a) an atomic power plant (b) a thermal power plant

18. What is the (a) frequency (b) voltage of electricity, supplied in our homes ?

19. Name two of each of the following types of power plants in India. Also give their location.

(a) Hydel power plants (b) Thermal power plants (c) Nuclear power plants

20. What are the three types of electric power plants in India? How do they differ from one another?

ANSWERS TO CHECK YOUR PROGRESS

12.1

1. Negative charge. Wool acquires postive charge.

2. $n = \frac{q}{|e|} \quad \frac{10 \times 10^{-6}}{1.6 \times 10^{-19}} = 6.25 \times 10^{13}$ electrons

3. $F = k\frac{q_1 q_2}{r^2} \Rightarrow F' = K\frac{2q_1 \times 2q_2}{(r/2)^2} = 8F$

4. (i) $v = \frac{U}{q} = \frac{10}{10^{-6}} = 10^7 V$

(ii) $U = \frac{KQq}{r} = r = \frac{Ur}{Kq} = \frac{10 \times 0.5}{9 \times 10^9 \times 10^{-6}} = \frac{5}{9} \times 10^{-3} C$

5. (i) Unit of charge is Coulomb. IC charge is the charge which when placed at a distance of 1 m from an equal like charge repels it with of force of 9 x 10^9 N.

(ii) Unit of potential is 1 volt. Volts is the potential at a point in an electric field such that if IC positive charge is brought from outside the field to this point against the field 1 J work is done.

12.2

1. (i) Unit of current is ampere. 1A is the current in a wire in which 1C charge flows in 1 second.

(ii) Unit of resistance is ohm .1 ohm is the resistance of a wire across which when 1V potential difference is applied 1A current flows through it.

2. (i) If the whole circuit goes off when one bulb is fused the bulbs are connected in series.

(ii) If only one bulb goes off and the rest of the circuit remains working the bulbs are connected in parallel.

3. (i) Resistance of the wire remains unaffected

(ii) current flowing through the wire is doubled.

4. (i) When R is connected in series readings of voltmeter and ammeter will reduce to half.

(ii) When R is connected in parallel to R, reading of ammeter is doubled but reading of voltmeter remains unchanged.

5. 1A.

12.3

1. $\frac{Q}{t} = \frac{V'}{R}$ This implies that more the resistance less the power. Therefore, more heat will flow is 1s in 1 ohm resistor.

2. (i) Heat produced becomes four times (ii) heat produced becomes four times

(iii) heat produced is doubled.

3. $Q = I^2Rt = 1 \times 10 \times 30 = 300$ J.

4. refer section 12.3.2

5. (i) Electric heater (ii) Electric fan

12.4

1. $R = \frac{V^2}{P}$ = 40W lamp has higher resistance.

2. $I = \frac{P}{V} = \frac{100}{220} = \frac{5}{11}$ A.

3. $Q = Pt = 60 \times 30 \times 4 = 7200$ Wh = 7.2 kWh.

4. $Q = Pt = \frac{746}{4} \times 3600$ J = 675400 J.

5. $P = VI = 220 \times 5 = 1100$ watt.