1 Basic Quantities of Electricity

1.1. INTRODUCTION

It is well known that electricity plays a very important role in our daily life. Recent developments have shown the use of electricity in calculators and computers. In this chapter, we shall confine our focus about the idea of voltage, idea of current, idea of power and idea of energy etc.

1.2. DEFINITION OF VOLTAGE, CURRENT, POWER AND ENERGY WITH THEIR UNITS

1.2.1. Electric Potential or Voltage

When a body is charged negatively or positively (electrons are supplied or removed from the body), work is done in both the cases. This work done is stored in the body in the form of electric potential or potential energy. So, the charged body has the capacity to do work by moving other charges either by the force of attraction or repulsion. (The capacity of a charged body to do work is called *Electric Potential*.

The greater the capacity of a charged body to do work, the greater is its electric potential. Electric potential is denoted by V.

$$\therefore \qquad \text{Electric potential, } V = \frac{\text{Work done}}{\text{Charge}} = \frac{W}{Q}$$

Work done is measured in joule and charge in coulomb. Therefore, the unit of electric potential will be joule/coulomb or volt.

If W = 1 joule, Q = 1 coulomb, then $V = \frac{1\,J}{1\,C} = 1$ volt.

Hence, a body is said to have an electric potential of 1 volt if 1 joule of work is done to give a charge of 1 coulomb.

Potential Difference : If two bodies have different electric potentials, then a potential difference will exist between them. Consider two bodies A and B having potentials of + 6 volt and + 4 volt respectively.

If two bodies are connected through a conductor, the electrons will flow from body B to body A. When the two bodies attain the same potential, the flow of electrons stops. Thus, we arrive at a conclusion that current will remain flowing in the conductor if potential difference exists. No potential difference, no current flow. Sometimes potential difference is also called voltage.

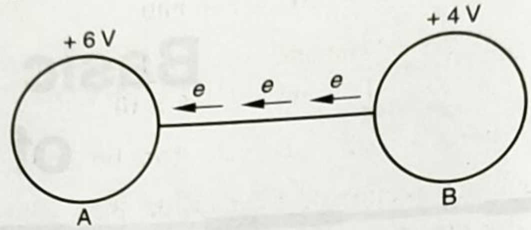

Fig. 1.1.

Units of Voltage : The units of the voltage are volt, kilovolt and the smaller unit is millivolt.

$$1000 \text{ volt} = 1 \text{ kilovolt, which is abbreviated as } 1 \text{ kV}$$

$$\frac{1}{1000} = 1 \text{ millivolt, which is abbreviated as } 1 \text{ mV}.$$

Note : *The normal domestic supply is of 230 volt.*

Measurement of voltage : Voltage is measured by an instrument, known as **Voltmeter**.

1.2.2. Electric Current

The flow of electric charge is called electric current.

Whenever electric charges move, a current is said to exist. To explain electric current, let us consider a surface area A through which charges are moving (see Fig.1.2). The current is the rate at which charge flows through this surface.

If Q is the net charge that passes through any section of a conductor in time t, then current i is given by,

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

If the rate of flow of charge with time is not constant, the current varies with time and is given by,

$$i = \frac{dQ}{dt}$$

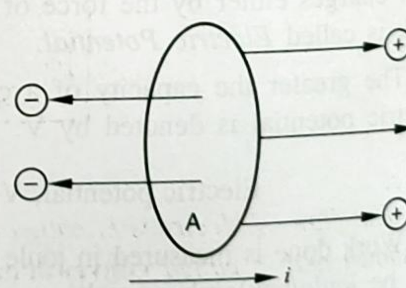

Fig. 1.2.

If through any section of a conductor n electrons are passing in time t seconds, then total charge passing through that section is $Q = ne$.

where, e is the charge on an electron ($e = 1{\cdot}6 \times 10^{-19}$ coulomb).

Therefore, current in the conductor is given as,

$$i = \frac{Q}{t} = \frac{ne}{t}$$

The SI unit of current is ampere (A) where

$$1 \text{ ampere} = \frac{1 \text{ coulomb}}{1 \text{ second}}$$

Thus, one ampere is the current corresponding to a charge of one coulomb passing through any section of the conductor per second.

Now, charge on one electron $= 1{\cdot}6 \times 10^{-19}$ coulomb

$$\therefore \quad 1 \text{ ampere} = \frac{1 \text{ coulomb}}{1 \text{ second}} = \frac{1}{1{\cdot}6 \times 10^{-19}} \text{ electrons per second.}$$

$$= 625 \times 10^{16} \text{ electrons per second.}$$

When charges flow through any section of a conductor, they can be positive, negative or both. *It is conventional to choose the direction of the current to be in the direction of flow of positive charge.*

In a conductor such as copper, the current is due to the motion of the negatively charged electrons. Therefore, when we speak of current in an ordinary conductor, *the direction of the current will be opposite to the flow of electrons.*

In metals, there are a large number of free electrons. When potential difference is applied across a copper wire, then free electrons (negative charges) being loosely attached, start moving towards the positive terminal of the cell as shown in Fig. 1.3.

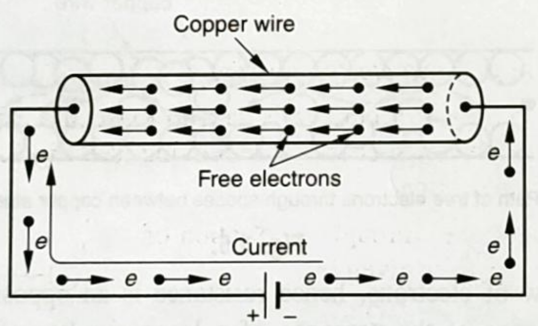

Fig. 1.3.

This flow of electrons is called electric current. The assumed direction is shown and is called **conventional current**.

Therefore, in this book the reader should remember that the current is assumed to flow from the positive terminal of the source through the electric circuit and then to the negative terminal of the source (see Fig. 1.4).

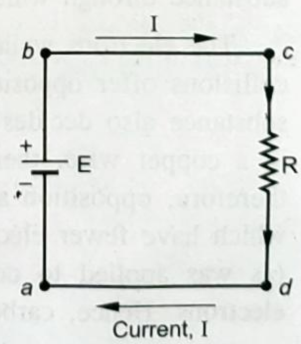

Fig. 1.4.

But the reader should bear in mind that actual current flow is opposite to the conventional current.

Unit of electric current : The unit of electric current is **ampere**.

One ampere *of electric current is said to flow through a wire if at any section 1 coulomb of charge or* 625×10^{16} *electrons pass in one second.*

Measurement of Current : Current is measured by means of an instrument called **Amperemeter** or in short as **ammeter**.

Properties of Electric Current : An electric current has the following properties :

1. Heating properties : *In general, an electric current heats any body through which it passes*. The heating properties of an electric current are utilised in a number of electric heating devices, such as *stoves, radiators, water heaters, welding, electric lamps etc.*

2. Magnetic properties : *An electric current flowing through a conductor produces a magnetic field*. The magnetic properties of an electric current are utilised in a number of electrical machines such as *electric generators, electric motors etc.*

3. Electrochemical properties : *An electric current causes chemical action when passed through an electrolyte*. The electrochemical properties of an electric current are utilised in electrochemical industries such as *electroplating, electrolytic refining, battery industry* and *manufacture of various synthetic products*.

1.2.3. Resistance

Resistance is the property of a material by virtue of which it opposes the flow of electric current.

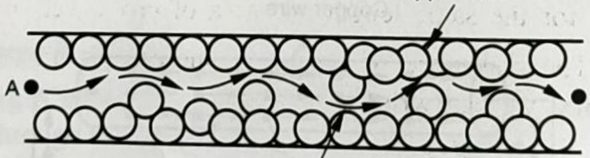

Fig. 1.5.

Since current is the flow of electrons, hence resistance is an opposition to the flow of electrons. This opposition occurs because of the presence of a large number of atoms and molecules in the substance through which current flows.

The electrons while moving through a substance collide with these atoms and molecules, these collisions offer opposition to the flow of electric current. Moreover, the atomic structure of the substance also decides the extent of opposition. If there are a large number of free electrons as in a copper wire, then by a small potential difference, these free electrons can be moved and therefore, opposition and hence resistance is less. On the other hand, there are other substances which have fewer electrons, for example, carbon. When the same potential difference is applied (as was applied to copper wire), far fewer electrons will flow because there are fewer free electrons. Hence, carbon has high resistance.

The resistance of a wire is represented by a concentrated wire (zig-zag) as shown in Fig. 1.6.

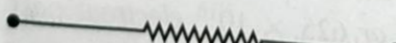

Fig. 1.6.

Unit of resistance : The unit of resistance is ohm and is denoted by the symbol Ω.

A wire is said to have a resistance of **one ohm** *if it develops* 0·24 *calories of heat when one ampere of current flows through it for one second.*

For example, when we say that a wire has a resistance of R ohm, it means that if one ampere current flows through this wire for one second, then R × 0·24 calories of heat will be produced.

Factors Upon Which Resistance Depends : Resistance of a conductor depends upon the following factors :

(i) Length : *The resistance* R *of a conductor is directly proportional to the length of the conductor*. Greater the length, greater is the resistance *i.e.*,

$$R \propto l$$

(ii) Area of cross-section : *The resistance* R *of a conductor is inversely proportional to the area of cross-section*. Greater the area of cross-section, lesser is the resistance and vice-versa *i.e.*,

$$R \propto \frac{1}{a}$$

(iii) Nature of material : Different substances have different atomic structures and therefore, offer different resistances for the same length and area of cross-section.

(iv) Temperature : The resistance of conductor increases with temperature and vice-versa.

From the first three factors, we can write

$$R \propto l \qquad \ldots(i)$$

and

$$R \propto \frac{1}{a} \qquad \ldots(ii)$$

or

$$R \propto \frac{l}{a} \quad \text{or} \quad R = \rho\frac{l}{a}$$

where, ρ (Rho) is constant of proportionality and is called **Resistivity** or **Specific Resistance** of the material and has different values for different materials. In fact, ρ refers to the nature of the material.

Definition of Specific-Resistance or Resistivity

We know that $R = \rho\frac{l}{a}$

If $l = 1$ m and $a = 1$ m^2

Then, $R = \rho \times \frac{1}{1} = \rho$ or $\rho = R$

Hence, **specific resistance** *of the material of a conductor can be defined as the resistance offered by 1 metre length of the conductor of the material having an area of cross-section of one square metre.*

The resistivity can also be defined by taking a cube of the material having each side one metre. Any two opposite faces, have area of cross-section of 1 square metre and the length is one metre (see Fig. 1.7).

i.e.
$$l = 1 \text{ m}$$
$$a = 1 \text{ sq. m}$$

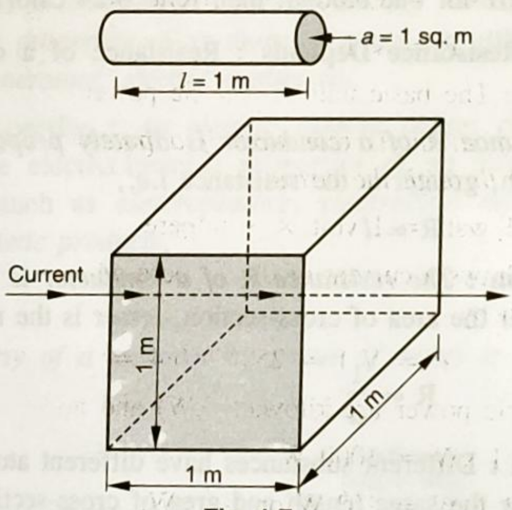

Fig. 1.7.

Hence, **specific resistance** or **resistivity** *of a material can also be defined as the resistance offered by opposite faces of a metre cube of the material.*

Measurement of Resistance : The instrument used for the measurement of resistance is known as **Ohmmeter**.

1.2.4. Electric Power

The rate at which work is done in an electric circuit is called **electric power** *i.e.*,

$$\text{Electric power} = \frac{\text{Work done in an electric circuit}}{\text{Time}}$$

The electric power (P) is measured by the product of voltage (V) and current (I) *i.e.*,

$$\text{Power} = \text{Voltage} \times \text{Current}$$

or
$$P = VI$$

Illustration. Consider an electric circuit in which voltage applied is V volt and current flowing is I ampere. The voltage is causing the electric current *i.e.*, electrons to flow through the circuit. Therefore, work is being done in moving the electrons (current) in the circuit. The rate at which the work is done in moving the electrons is called as the *electric power*.

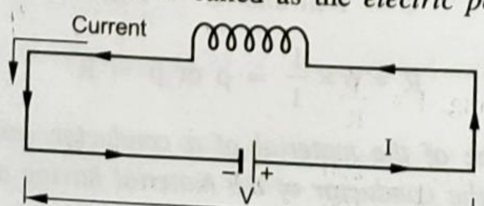

Fig. 1.8.

It is clear that the rate at which work is done in moving the electrons in the circuit depends upon :

(i) How many electrons are to be moved (*voltage*).
(ii) The speed at which electrons are to travel (*current*).

$\therefore$
$$\text{Power} = \text{Voltage} \times \text{Current}$$
or
$$P = V\,I$$

Units of Electric Power : The basic unit of electric power is **watt**.

The power consumed in a circuit is **one watt** *if a potential difference of one volt causes one ampere of current to flow through the circuit.*

i.e.,
$$1 \text{ watt} = 1 \text{ volt} \times 1 \text{ ampere}$$

Thus, if an electric bulb draws a current of 0·4 ampere when connected across 250 V supply, then power consumed is given by,

$$P = V\,I = 250 \times 0{\cdot}4 = 100 \text{ watt}$$

The bigger units of electric power are kilowatt (kW) and megawatt (MW).

$$1 \text{ kW} = 1000 \text{ W}$$
$$1 \text{ MW} = 10^6 \text{ W or } 10^3 \text{ kW}.$$

Different Power formulae : The power consumed in an electric circuit can be expressed in various ways.

$$P = V\,I \qquad \ldots(i)$$
$$P = I^2 R \qquad \ldots(ii)\ \{\because V = IR\}$$
$\therefore$
$$P = \frac{V^2}{R} \qquad \ldots(iii)\ \left\{\because I = \frac{V}{R}\right\}$$

Measurement of Power : The instrument which is used for the measurement of power is called **Wattmeter.**

Example 1.1. *A coil of resistance 100 Ω is connected across a 250 volt supply. Calculate (i) current flowing (ii) power rating of the coil.*

Sol. Given :

Resistance of coil, R = 100 ohm

Supply voltage, V = 250 volt

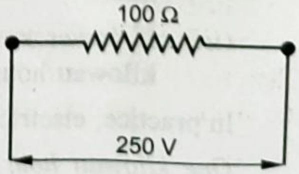

Fig. 1.9.

By Ohm's law :

(i) Current flowing, $I = \frac{V}{R}$

$\therefore$ $I = \frac{250}{100} = \mathbf{2{\cdot}5\ A\ (Ans.)}$

(*ii*) Power rating of the coil,

$$P = I^2 \cdot R = (2 \cdot 5)^2 \times 100 = \mathbf{625\ watt\ (Ans.)}$$

Example 1.2. *Two lamps rated 250 V, 100 watt and 250 V, 60 watt are connected in parallel, across 250 V supply mains. Calculate the total current taken from the supply mains.*

Sol. Given :

Supply voltage, V = 250 V

Rating of lamp, L_1 = 100 W, 250 V

Rating of lamp, L_2 = 60 W, 250 V

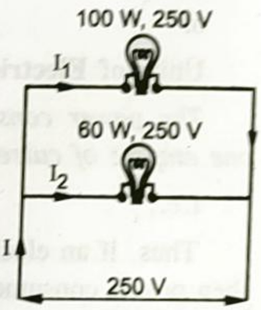

Fig. 1.10.

$\therefore$ Current I_1 through lamp $L_1 = \dfrac{\text{Wattage of lamp } L_1}{\text{Voltage across } L_1}$

So, $$I_1 = \frac{100}{250} = 0 \cdot 4\ A$$

$\therefore$ Current I_2 through lamp $L_2 = \dfrac{\text{Wattage of lamp } L_2}{\text{Voltage across } L_2} = \dfrac{60}{250} = 0 \cdot 24\ A$

Total current I from the mains, $I = I_1 + I_2 = 0 \cdot 4 + 0 \cdot 24 = \mathbf{0 \cdot 64\ A\ (Ans.)}$

1.2.5. Electrical Energy

The total amount of work done in an electric circuit is called Electrical Energy.

$$\text{Electrical energy} = \text{Electric power} \times \text{Time}$$
$$= V \cdot I \cdot t \quad \ldots(i)$$
$$= I^2 \cdot R \cdot t \quad \ldots(ii)$$
$$= \frac{V^2}{R} \cdot t \quad \ldots(iii)$$

Units of Energy :

(*i*) If power is taken in watt and time in seconds, then the unit of electrical energy is watt second.

(*ii*) If power is taken in watt and time in hours, then the unit of electrical energy is watt hour.

(*iii*) If power is taken in kilowatt and time in hours, then the unit of electrical energy is kilowatt hour, kW h.

In practice, electrical energy is measured in kilowatt hours. Therefore, it can be defined as :

One kilowatt hour (kW h) of electrical energy is expended in a circuit if 1 kW of power is supplied for 1 hour.

$$\text{Energy in kW h} = \text{Power in kW} \times \text{Time in hours.}$$

Measurement of Energy : The meter which is used for the measurement of energy is known as **Energymeter or kW h meter.**

Example 1.3. *Determine the consumption of electrical energy in units for operating the following :*

(*i*) *100 watt lamp for 10 hours*

(*ii*) *1000 watt electric heater for 4 hours*

(*iii*) *500 watt electric iron for 3 hours.*

Sol. (*i*) Energy consumed in first case $= \frac{100 \times 10}{1000} = 1$ kW h **(Ans.)**

(*ii*) Energy consumed in second case $= \frac{1000 \times 4}{1000} = 4$ kW h **(Ans.)**

(*iii*) Energy consumed in third case $= \frac{500 \times 3}{1000} = 1{\cdot}5$ kW h **(Ans.)**

Example 1.4. *An electric motor of 5 H.P. having an efficiency of 85% is used for 8 hours. If the electrical energy costs Rs. 0·75 per unit. Find the cost of using the motor.*

Sol. Output power of motor = 5 H.P.

$= 5 \times 735{\cdot}5 = 3677{\cdot}5$ W

Efficiency of motor = 85% = 0·85

Cost of electric energy per unit = Rs. 0·75

$$\text{Input of the motor} = \frac{\text{Motor output}}{\text{Efficiency}} = \frac{3677{\cdot}5}{0{\cdot}85} = 4326 \text{ W}$$

$$\text{Electrical energy consumed in 8 hours} = \frac{4326 \times 8}{1000} = 34{\cdot}6 \text{ kW h}$$

Cost for using the motor $= 34{\cdot}6 \times 0{\cdot}75 =$ **Rs. 25·95 (Ans.)**

1.3. CONNECTIONS OF AMMETERS, VOLTMETERS, WATTMETERS AND ENERGYMETERS IN ELECTRIC CIRCUIT

(*i*) Connections of Ammeters : Ammeters are used for measuring the current in a circuit. An ammeter has essentially a low resistance and is connected in series as shown in Fig. 1.11.

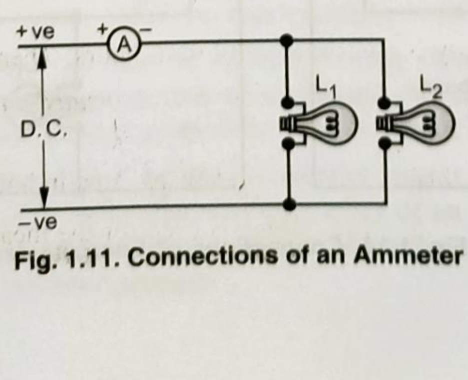

Fig. 1.11. Connections of an Ammeter

(ii) **Connections of Voltmeters :** The voltmeters have high resistance. They are used for measuring voltages. They are connected in parallel as shown in Fig. 1.12.

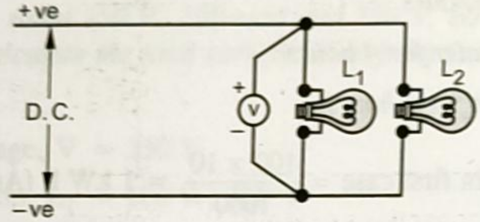

Fig. 1.12. Connections of a Voltmeter

(iii) **Connections of Wattmeters :** Wattmeters are used for the measurement of power. They have two coils, the current coil and the pressure coil. The current coil is connected in series and the pressure coil in parallel as shown in Fig. 1.13.

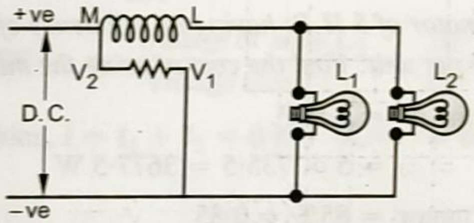

Fig. 1.13. Connections of a Wattmeter

(iv) **Connections of Energymeters :** The energymeters are used for the measurement of electrical energy. The induction type kW h meter has two coils as in case of wattmeter and is connected in the same way.

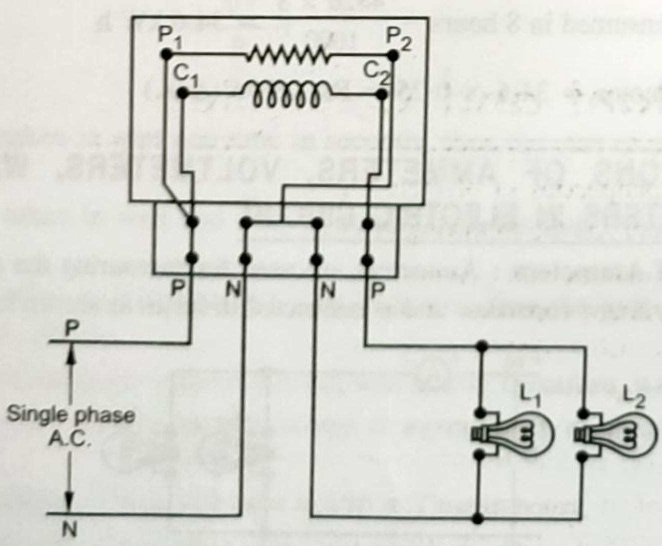

Fig. 1.14. Connections of Energymeter

(*v*) **Connections of wattmeter, voltmeter and ammeter.**

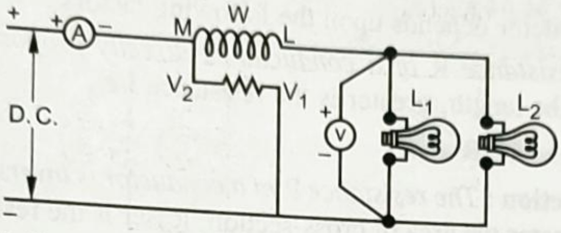

Fig. 1.15. Connections of Wattmeter, Voltmeter and Ammeter

(*vi*) **Connections of Energymeter, Wattmeter, Voltmeter and Ammeter :**

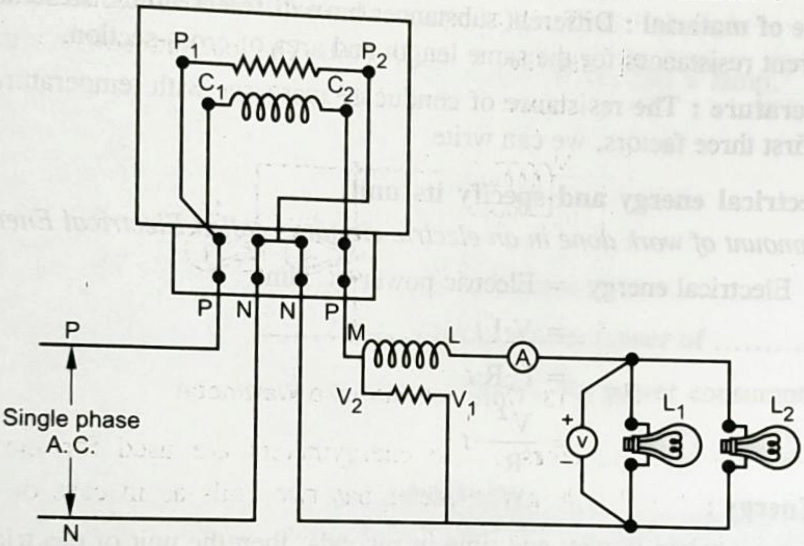

Fig. 1.16.

Important and Expected Questions

Q.1. What are the properties of electric current ?

Ans. An electric current has the following properties :

1. Heating properties : *In general, an electric current heats any body through which it passes*. The heating properties of an electric current are utilised in a number of electric heating devices, such as *stoves, radiators, water heaters, welding, electric lamps etc.*

2. Magnetic properties : *An electric current flowing through a conductor produces a magnetic field*. The magnetic properties of an electric current are utilised in a number of electrical machines such as *electric generators, electric motors etc.*

3. Electrochemical properties : *An electric current causes chemical action when passed through an electrolyte*. The electrochemical properties of an electric current are utilised in electrochemical industries such as *electroplating, electrolytic refining, battery industry* and *manufacture of various synthetic products*.

Fill in The Blanks

1. Energy meter is used to measure electrical ....
2. Household appliances such as heater, fan, geyser, refrigerator require .... phase supply.
3. Bulbs in street lighting are all connected in ....
4. Electric power, P = ... watt.
5. The practical unit of electrical energy is ....
6. An iron takes 5 A at 250 V, its power rating is ....
7. 60 W, 230 V has .... resistance as compared to 60 W, 250 V lamp.
8. The element of electric heater is made of ....
9. A variable resistance is commonly called ....
10. Voltage across a resistance is called the ....
11. An instrument which detects the electric current is known as ....
12. A 2 ohm resistor having current of 2 A will dissipate the power of ....
13. The voltage applied across an electric iron is halved, the power consumption of the iron will reduce to ....

ANSWERS

1. energy	2. single	3. parallel
4. VI	5. kW h	6. 1·25 kW
7. less	8. nichrome	9. rheostat
10. voltage drop	11. ammeter	12. 8 watt
13. one-fourth.		

Review Questions

1. How do you define the resistance of a conductor ? What are the factors upon which it depends ?
2. What is the relation between power, voltage and current ?
3. What do you understand by electrical power and electrical energy ? Give their practical units also ?