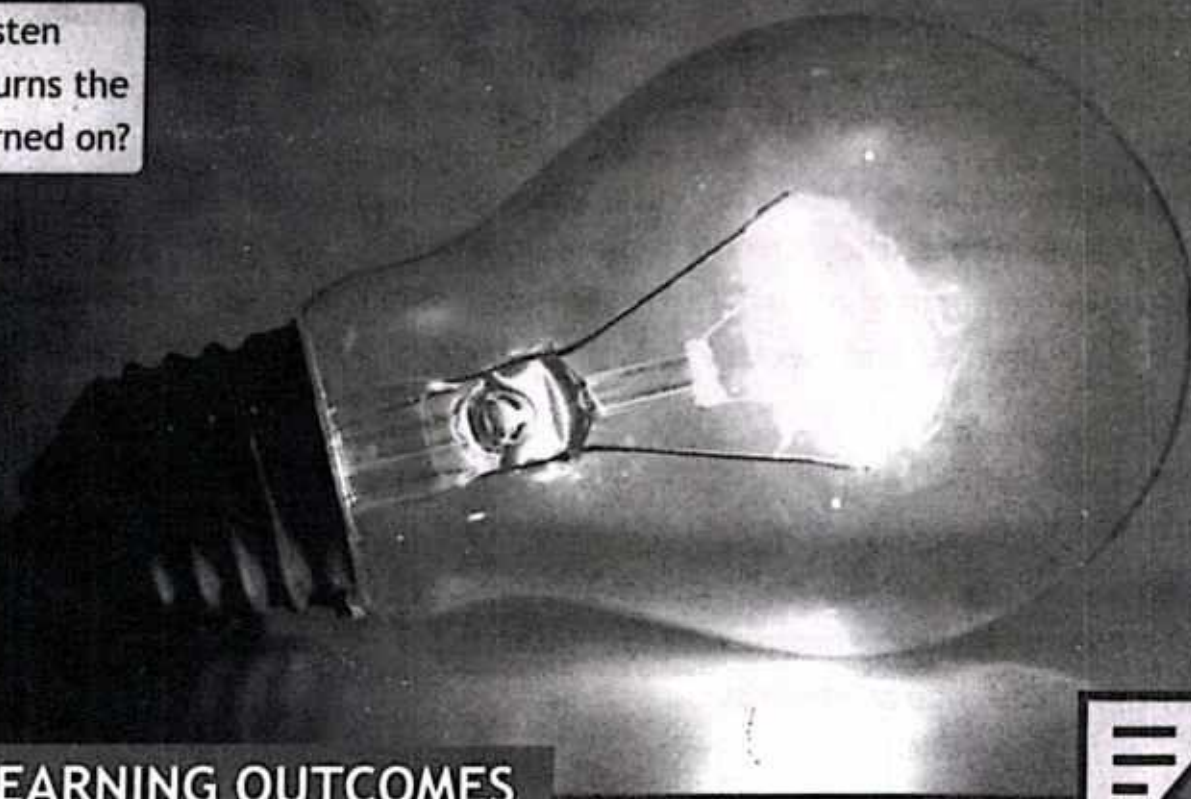


Why a tungsten filament bulb burns the moment it is turned on?



## STUDENT LEARNING OUTCOMES

The students will:

- ✓ [SLO: P-10-E-20] Define and calculate electric current.
- ✓ [SLO: P-10-E-21] Explain electrical conduction.
- ✓ [SLO: P-10-E-22] state that current is measured in amps (amperes) and that the amp is given by coulomb per second (C/s).
- ✓ [SLO: P-10-E-23] Differentiate between direct current (d.c.) and alternating current (a.c.).
- ✓ [SLO: P-10-E-24] Differentiate between conventional and actual current.
- ✓ [SLO: P-10-E-25] Justify and illustrate the use of ammeters.
- ✓ [SLO: P-10-E-26] Define e.m.f.
- ✓ [SLO: P-10-E-27] Define p.d. (potential difference).
- ✓ [SLO: P-10-E-28] State that e.m.f. and p.d. are measured in volts and that the volt is given by joule per coulomb (J/C).
- ✓ [SLO: P-10-E-29] Justify and illustrate the use of voltmeters.
- ✓ [SLO: P-10-E-32] Describe an experiment to determine resistance.
- ✓ [SLO: P-10-E-33] Define and calculate resistivity.
- ✓ [SLO: P-10-E-34] Define and apply Ohm's law.
- ✓ [SLO: P-10-E-35] Describe the effect of temperature increase on the resistance of a resistor.
- ✓ [SLO: P-10-E-36] Interpret current-voltage graphs.



In this unit, we delve into the intriguing world of electric current—a stream of charged particles, visualized as tiny marbles with an electric charge, coursing through a conductive pathway like a wire. This stream, known as electric current, is the cornerstone of electrical operations, fuelling our households and energizing gadgets. As we traverse through this chapter, we will dissect the nature of electric current, ascertain how to compute it using formulas, and grasp its crucial role within electrical networks, electricity hazards, and safety considerations.

## 16.1 ELECTRIC CURRENT

Electric current is produced due to the flow of either positive or negative charges or sometimes both. For example, the current in metals is due to flow of negatively charged electrons. The current in the beam of a particle accelerator is due to positively charged protons, while in some cases such as gases and electrolytes, the current is due to the flow of both positive and negative charges.

The time rate of flow of electric charges through a cross-sectional area is called electric current.

Consider charge ' $\Delta Q$ ' flowing through any cross-sectional area in time ' $\Delta t$ ', as shown in figure 16.1, the electric current ' $I$ ' will then be given by:

$$I = \frac{\Delta Q}{\Delta t} \quad \text{16.1}$$

The SI unit of current is the ampere, which is denoted by (A). One ampere current in terms of flow of charge is stated as "when one coulomb of charge flows through any cross-sectional area in one second". Mathematically:

$$1A = \frac{1C}{1s}$$

Ampere is a large unit of electric current, that's why the following sub-multiples of ampere are most commonly used:

$$1 \text{ milliampere} = 1 \text{ mA} = 10^{-3} \text{ A}$$

$$1 \text{ microampere} = 1 \text{ }\mu\text{A} = 10^{-6} \text{ A}$$

### 16.1.1 CONVENTIONAL FLOW OF CURRENT

Before the discovery of electron it was thought that electric current is due to the flow of positive charges in conductors. This assumed direction of current flow is now called conventional current. Current flowing from positive terminal to negative terminal of a battery due to the flow of positive charges is called conventional current.

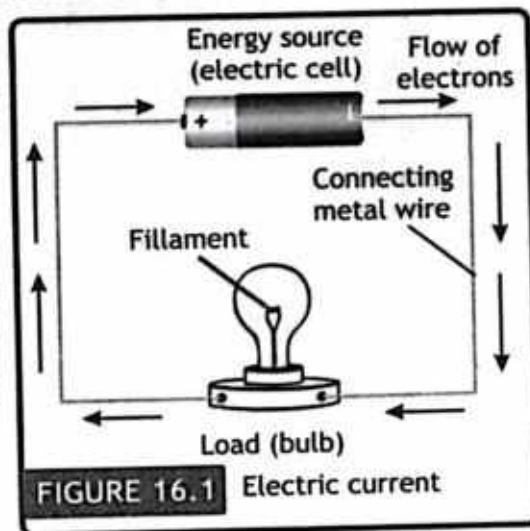


FIGURE 16.1 Electric current

Current flowing from positive terminal to negative terminal of a battery due to the flow of positive charges is called conventional current.

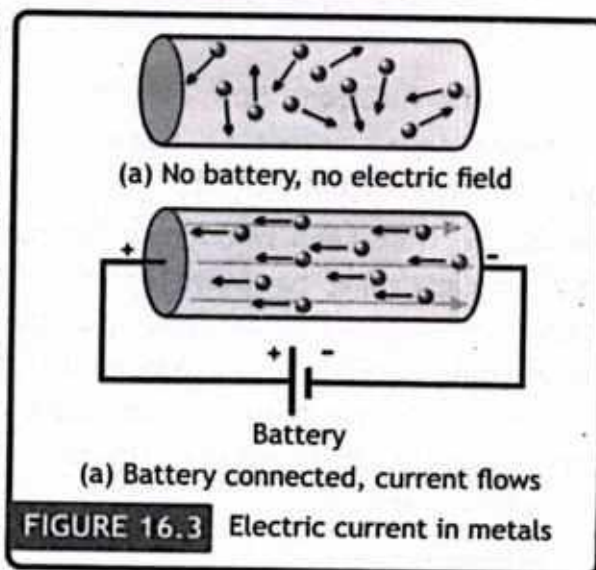
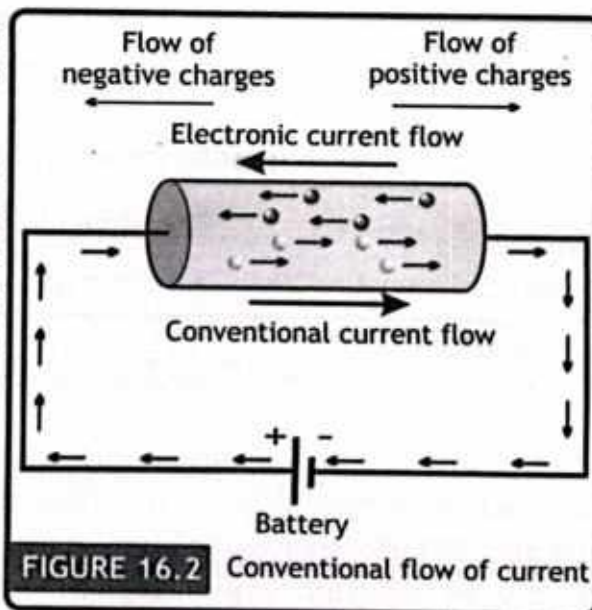
For practical purposes positive charges moving in one direction is equivalent to negative charges moving in opposite direction. Conventional current produces the same effect as the current flowing from negative terminal to the positive terminal due to the flow of negative charges. That's why both are used in electrical circuit problems as shown in 16.2.

### 16.1.2 ELECTRICAL CONDUCTION IN METALS

In metals, the valence electrons are not tightly bound by the nucleus and can move around freely like the movement of gas molecules in a container. When there is no battery or power supply connected to a metal piece like a copper wire, as shown in figure 16.3 (a), the net motion of free electrons is zero and hence no electrical current. When a battery is connected to the end of this copper wire piece, free electrons start motion in one direction as shown in figure 16.3 (b). The positive plate of the battery will attract free electrons while the negative plate will push.

The electrons start drifting in the metal, like leaves carried by a gentle breeze. These electrons will collide with each other and with nuclei of other atoms, which slows them down.

The net movement of these free electrons in one direction creates what we call an electric current. So, the electrical conduction in metals happens because of the movement of free electrons when an electric field is applied across it, creating an electric current.



### Example 16.1

A battery of an electric car is charged at a charging station using a current of 10.0 A for two hours. How much charge passes to the battery?

**GIVEN:**

Current ' $I$ ' = 10.0 A, Time ' $\Delta t$ ' = 2 hr =  $2 \times 3600$  s = 7200 s

**REQUIRED:**

Charge ' $\Delta Q$ ' = ?

**SOLUTION:**

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

putting values:  $\Delta Q = 10.0 \text{ A} \times 7,200 \text{ s}$

Therefore  $\Delta Q = 72,000 \text{ C}$  — **ANSWER**

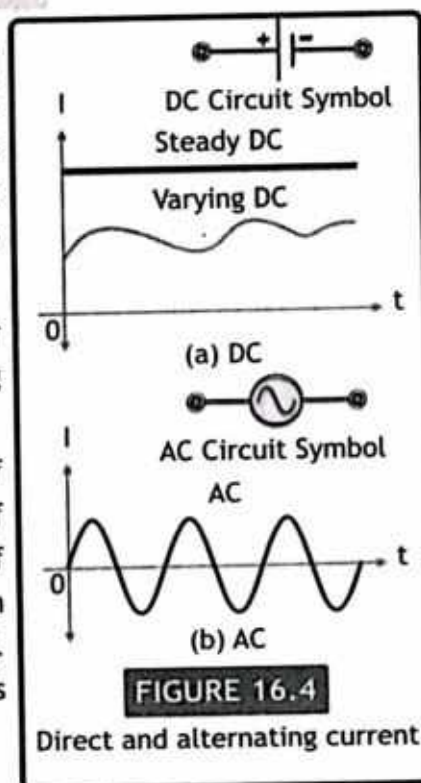
Which is equal to 20 Ah, a most commonly used specification for batteries.

## 16.2 ALTERNATING AND DIRECT CURRENT

Electricity flows in two ways; either changing direction called alternating current (AC), or in a fixed direction called direct current (DC). Electricity or "current" is nothing but the movement of charges (electrons here) through a conductor, like a wire. The difference between AC and DC lies in the direction in which the charges flow.

In DC, the electrons flow steadily in a single direction, or "forward." Direct current may be steady (i.e., uniform) or varying as shown in the figure 16.4 (a).

In AC, electrons keep switching directions, going "forward" half the time and going "backward" other half time. The direction of current in the circuit depends upon the changing polarity of alternating voltage source. The circuit sign for AC is also given in Figure 16.4 (b). Electric generators can produce either DC or AC. Both AC and DC can be measured by using a multimeter as there is an option for both.



### POINT TO PONDER



Is AC more dangerous than DC?

Alternating current at high voltage (above 500 V) is more dangerous than direct current at the same voltage. When a person touches a high-voltage DC source, it usually causes a single muscle contraction that can be strong enough to push the person away from the source. By contrast, touching a high-voltage AC source can cause a continuing muscle contraction that prevents the victim from letting go of the source.



### 16.3 POTENTIAL DIFFERENCE

Connecting one end of a conductor to positive terminal of the battery and another with negative terminal, a potential difference will be produced between the two ends of the conductor.

**The difference of electric potential between two points is called potential difference.**

Conventionally, positive terminal of a battery is at higher potential while negative terminal is at lower potential. So, the end of a circuit component connected to positive terminal will be at higher potential as compared to the other end connected to the negative terminal of the battery.

Consider an electric circuit in which a light bulb is connected to a battery as shown in figure 16.5. Connecting one end of a conductor to positive terminal of the battery and another with negative terminal, a potential difference will be produced between the two ends of the conductor.

The flow of current continues as long as there is a potential difference. The device which provides the potential difference for the steady flow of current in the copper wire or any other conductor is the battery (or any other source, which we will study in emf topic).

The charge leaving the positive terminal of the battery has potential energy, a part of which is lost in the device. Thus, there is difference of potential energy per coulomb of charge between the ends of the battery that is also transferred to the device and is termed as potential difference. Mathematically:

$$\Delta V = \frac{\Delta U}{\Delta q} = \frac{\Delta W}{\Delta q} \quad \text{--- 16.2}$$

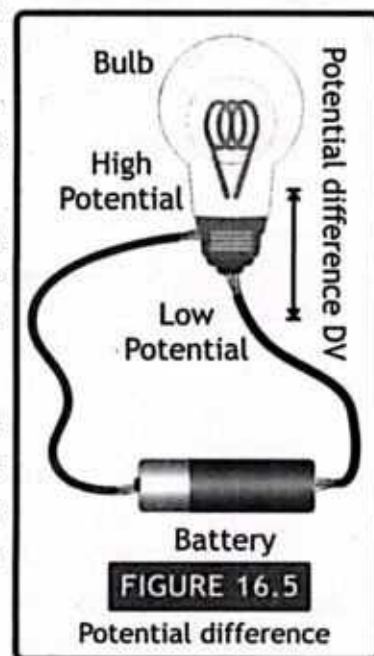
SI unit of potential difference is volt. One volt of potential difference is defined as “when a potential energy of 1 joule is needed to move a charge of 1 coulomb from one point to another inside the field.

### 16.4 EMF

To maintain a steady current in the circuit, there must be a source that continuously converts non-electrical energy into electrical energy.

**The energy supplied by a battery per unit positive charge when it flows through the closed circuit is called electromotive force (emf).**

emf source is a device which converts nonelectrical energy into electrical energy, and is required in a circuit to maintain a constant potential difference across the its components i.e., devices.



Consider a battery is connected through conducting wires with a device (light bulb) as shown in figure 16.6. The positive charge leaves the positive terminal of the battery, passes through the conductor and reaches the negative terminal of the battery. As positive charge enters the battery at its lower potential point (negative terminal), the battery has to perform work on the positive charge to drive it to a point of higher potential i.e., positive terminal.

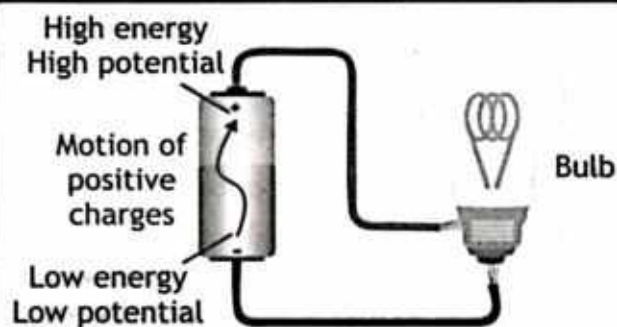


FIGURE 16.6 Electromotive Force (emf)

If 'W' is the work done by battery on positive charges 'q' then electromotive force (emf or  $\epsilon$ ) of the battery is given by:

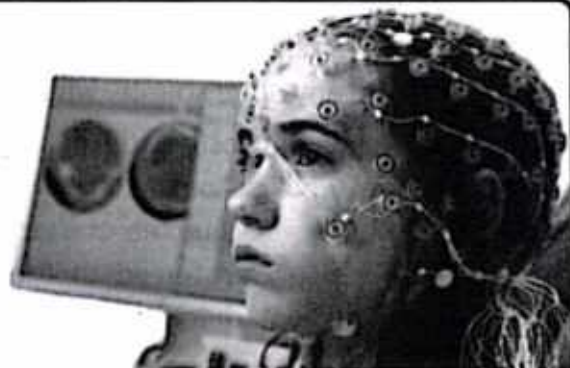
$$\epsilon = \frac{W}{q} \quad \text{--- 16.3}$$

### SCIENCE TIDBITS



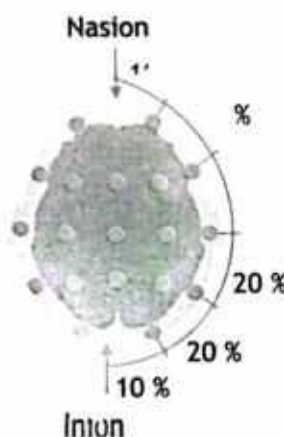
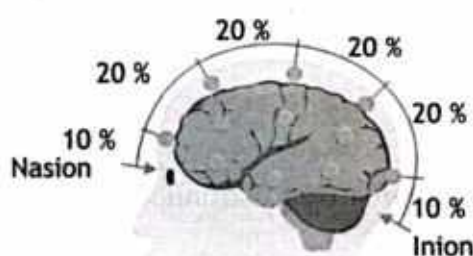
**Electroencephalography (EEG)** is a neurological test that uses electronic monitoring device to measure and record the electrical activity of brain.

To record the electrical activity of the brain, 8 to 16 pairs of electrodes are attached to the scalp.



Each pair of electrodes transmits a signal to one of several recording channels of the electroencephalograph.

This signal consists of the difference in the voltage between each pair of electrodes. The rhythmic fluctuation of this potential difference is shown through graph by the recording channel.



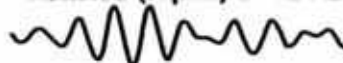
Deep Sleep (Delta) 1 - 4 Hz



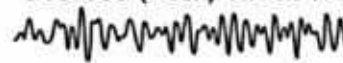
Drowsy (Theta) 4 - 8 Hz



Relaxed (Alpha) 8 - 12 Hz



Focused (Beta) 12 - 30 Hz



S.I unit of electromotive force is same as that of electric potential as  $J/C = V$ . Examples of emf sources are batteries (converts chemical energy into electrical energy), solar panels (solar to electrical), thermocouples (thermal to electrical) and generators (mechanical to electrical).

## 16.5 OHM'S LAW

Ohm's law states the relationship between electric current flowing through a conductor and potential difference applied across it.

The current between two points, in a conductor, is directly proportional to the applied voltage across these points as long as temperature and the physical state of the conductor is kept constant.

If 'V' is the potential difference across the two ends of a conductor, then current 'I' will flow through it. Mathematically:

$$I \propto V \quad (\text{Temperature } T = \text{Constant})$$

Replacing sign of proportionality with equality and putting a constant:

$$I = \frac{V}{R} \quad \text{or} \quad V = IR \quad \text{--- 16.4}$$

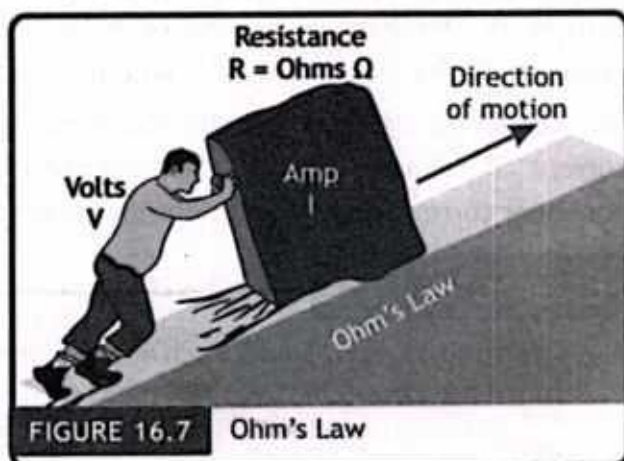


FIGURE 16.7 Ohm's Law

Whereas 'R' is proportionality constant and is called resistance.

Ohm's law is not applicable to all devices. It can only be applied to certain devices, mostly metals, which are called ohmic devices. Examples of ohmic devices are copper and silver wires and resistors.

Devices which do not obey Ohm's law are called non-ohmic devices. Examples of non-ohmic devices are filament bulb, thermistor and semiconductor diode.

### 16.5.1 LIMITATIONS OF OHM'S LAW

Ohm's law is applicable only for materials for which V versus I graph is a straight line. However only metallic conductors show this behavior and that too only over limited range of voltages. Many important devices do not obey Ohm's law and are called non-ohmic devices.

### 16.5.2 OHMIC AND NON-OHMIC DEVICES

Figure 16.8 (a) shows that 'R' is constant the slope 'I' Vs 'V' graph is a straight line. However all the materials have no straight line graph as we can see from the graph given in figure 16.8 (b, c, d). The graph of filament bulb, thermistor and semiconductor diode are all curved therefore they are termed as non-ohmic materials. The graph of filament bulb shows that current saturates as the

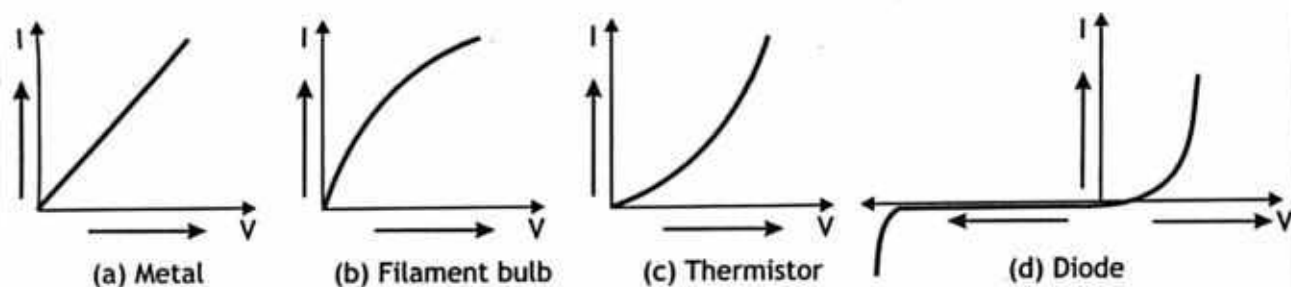


FIGURE 16.8 Ohmic and non-ohmic devices

current is increased and at large value even a large change in voltage 'V' will show small change in current 'I'. The graph of thermistor shows that resistance decreases sharply thus at large value even a small change in voltage 'V' will show large change in current 'I'.

Semiconductor Diode graph also deviates very strictly from the straight line voltage 'V' and current 'I' relationship. In fact most modern electronic devices, such as transistors, have nonlinear current-voltage relationships; therefore they are non-ohmic.

### Example 16.2

A torch bulb uses two cells each of 1.5 V, connected in series, to glow. What current will flow through the circuit of torch when its resistance is 20.0  $\Omega$ .

**GIVEN:**

Potential difference 'V' =  $2 \times 1.5 \text{ V} = 3.0 \text{ V}$

Resistance 'R' = 20.0  $\Omega$

**REQUIRED:**

Current 'I' = ?

**SOLUTION:**

By Ohm's law:  $V = IR$  or  $I = \frac{V}{R}$  putting values:  $I = \frac{3.0 \text{ V}}{20 \Omega}$

Therefore

$$I = 0.15 \text{ A} = 150 \text{ mA}$$

**ANSWER**

Thus, a current of 0.15 A pass through the circuit of torch.

## 16.6 RESISTANCE

Resistance is defined as 'the opposition to the flow of charges'. From equation 16.6, resistance can be given by:

$$R = \frac{V}{I} \quad \text{--- 16.5}$$

Its unit is volt per ampere called ohm ( $\Omega$ ). The resistance of a wire will be one ohm if a voltage of one volt causes a current of one ampere to flow through the wire.

Usually following multiples are used for a wide range of resistance values.

$$1 \text{ kilo - ohm} = 1 \text{ k}\Omega = 10^3 \Omega$$

$$1 \text{ mega - ohm} = 1 \text{ M}\Omega = 10^6 \Omega.$$

Value of resistance is independent of the voltage and current as increase in voltage will increase current and the ratio  $V/I$ , will remain constant. Resistance depends upon nature of the material, geometrical properties (length and cross-sectional area) and temperature of the material. There are many types of resistors shown in figure 16.9.

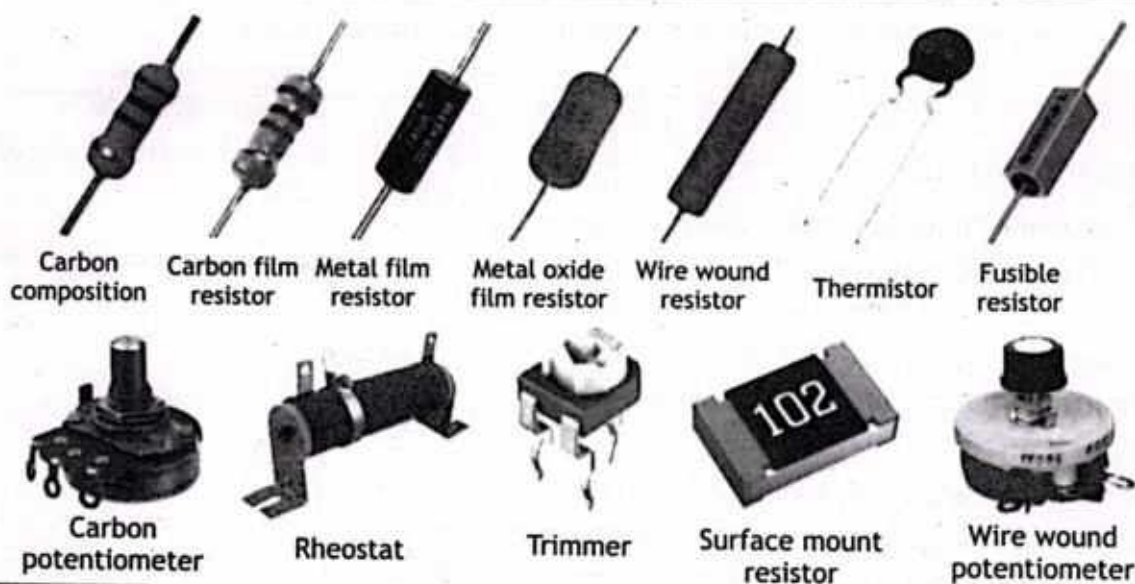


FIGURE 16.9 Types of resistors

### Example 16.3

What will be the resistance of a device when connected to a battery of 12 V and it allows a current of 200 mA?

**GIVEN:**

Potential difference ' $V$ ' = 12.0 V

Current ' $I$ ' = 200 mA =  $200 \times 10^{-3}$  A

**REQUIRED:**

Resistance ' $R$ ' = ?

**SOLUTION:**

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

putting values:  $R = \frac{12.0 \text{ V}}{200 \times 10^{-3} \text{ A}}$

Therefore

$$R = 60 \Omega$$

**ANSWER**

So, the device connected in the circuit has 60 ohms resistance.

Since the resistance is provided by collisions of the free electrons with the lattice atoms, thus, any factors that affect the number of collisions will also affect a material's resistance.

### 16.6.1 LENGTH OF WIRE

Greater the length of a conductor (wire), greater will be its resistance i.e., resistance is directly proportional to length. Mathematically:

$$R \propto L \quad \text{--- 1}$$

### 16.6.2 CROSS-SECTIONAL AREA OF WIRE

Greater the cross-sectional area of a conductor (wire), smaller will be its resistance i.e., resistance is inversely proportional to cross-sectional area. Mathematically:

$$R \propto \frac{1}{A} \quad \text{--- 2}$$

### 16.6.3 TEMPERATURE

The resistance of a material changes as the temperature changes, depending upon nature of material. For conductor, as the temperature rises its resistance increases because when free electrons in a conductor get heated, the chances of collisions with each other increases.

In case of insulators and semiconductors, the resistance decreases as the temperature increases because the thermal energy will generate more charge carriers.

Therefore, we conclude that as the temperature changes the resistance of material also changes. Mathematically:

$$\Delta R \propto \Delta T \quad \text{--- 3}$$

The filament of a bulb is made of tungsten, which is a conductor. Initially, the temperature of tungsten is low and so its resistance, so a maximum current passes through it. This will heat up the tungsten and its

temperature increases. As the temperature increases, its resistance increases and the current drops as shown in the figure 16.10.

### 16.6.4 MATERIAL NATURE OF WIRE

The resistance of a body also depends upon the nature of material. Its value changes from material to material. Usually, insulators have greater resistivity while conductors have smaller. Different conductors have different resistivities depending upon their internal structure.

#### SCIENCE FACT

A dry human body has a resistance of the order of  $10 \text{ k}\Omega$  or  $10^4 \Omega$ .

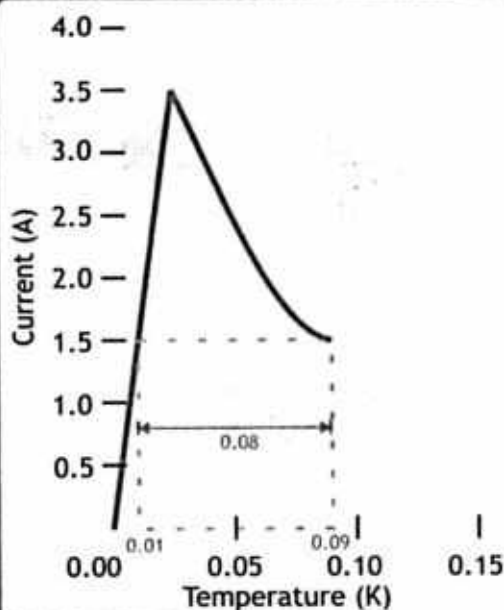


FIGURE 16.10 Resistance of tungsten

## SCIENCE FACT

Conductance is reciprocal of resistance ( $G = \frac{1}{R}$ ) and is defined as how easy charge can flow through a material. Its unit is per ohm or mho or Siemens.

Conductivity is reciprocal of resistivity ( $\sigma = \frac{1}{\rho}$ ) and is defined as the conductance of unit length and unit area. Its unit is per ohm per meter or mho-m<sup>-1</sup> or Siemens per meter.

## 16.7 RESISTIVITY

Specific resistance or resistivity  $\rho$  of a material is the resistance offered by a wire of length 1 m having cross-sectional area 1 m<sup>2</sup>.

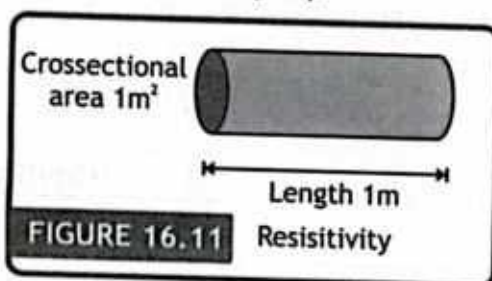
Keeping the temperature constant, the resistance of conductor is directly proportional to length 'L' and inversely proportional to its cross-sectional area 'A',

$$\text{mathematically: } R \propto \frac{L}{A} \quad \text{or} \quad R = \rho \frac{L}{A} \quad \text{--- 16.6}$$

Whereas 'ρ' is proportionality constant and is called resistivity of the material. Mathematically:

$$\rho = R \frac{A}{L} \quad \text{--- 16.7}$$

The unit of resistivity is ohm-m (Ωm).



Every material has a characteristic resistivity that depends on its nature and on temperature. Good electric conductors have very low resistivities, and good insulators have very high resistivities. If  $L = 1$  m and  $A = 1$  m<sup>2</sup> as shown in figure 16.11, then  $R = \rho$ . The resistivity of some materials is given in the table 16.1.

TABLE 16.1 RESISTIVITIES OF SOME MATERIALS AT (20°C)

| Material                      | Resistivity, $\rho$<br>(Ω.m) |
|-------------------------------|------------------------------|
| Typical Metals                |                              |
| Silver                        | $1.59 \times 10^{-8}$        |
| Copper                        | $1.72 \times 10^{-8}$        |
| Gold                          | $2.24 \times 10^{-8}$        |
| Aluminum                      | $2.56 \times 10^{-8}$        |
| Tin                           | $11.0 \times 10^{-8}$        |
| Tungsten                      | $5.52 \times 10^{-8}$        |
| Iron                          | $9.71 \times 10^{-8}$        |
| Lead                          | $20.6 \times 10^{-8}$        |
| Typical Semiconductors (pure) |                              |
| Carbon                        | $3.5 \times 10^{-5}$         |
| Germanium                     | $1 - 500 \times 10^{-3}$     |
| Silicon                       | $0.1 - 60$                   |
| Typical Insulators            |                              |
| Glass                         | $1 - 1000 \times 10^9$       |
| Fused quartz                  | $7.5 \times 10^{17}$         |
| Rubber                        | $1 - 100 \times 10^{13}$     |

UNIT  
OPENER

The tungsten filament bulb burns out when switched on is because of large amount of current flows through the filament. As tungsten is a conductor, so when it is cold its resistance is low and hence a large amount of current passes through it. When a large current passes through the filament, it gets heated and its temperature increases to a much greater value.



Over time, the filament oxidizes and becomes more and more brittle. So, it cannot withstand such a high temperature and burns out. Since the oxidation occurs gradually and builds up, the light bulb should give out randomly, at any time.

Modern lights use LEDs and so don't fail the same way. They often do things like flicker because the electronic circuit powering them has a fault.

The resistivity of metals and alloys is very small therefore they are very good conductors of electricity. On the other hand resistivity of insulators is very high, that is why they difficultly conduct current. Whereas the resistivity of semiconductor lies between those of conductors and insulators. By doping semiconductors (introducing controlled amounts of impurities), their resistivities can be changed dramatically, which is one reason that semiconductors are used to make computer chips and other electronic devices.

**Example 16.4**

A 1 m silver wire (resistivity =  $1.6 \times 10^{-8} \Omega\text{m}$ ) has a cross-section area of  $0.4 \text{ cm}^2$ . Calculate its resistance.

**GIVEN:**

Length of silver wire ' $L$ ' = 1 m

Cross-section area ' $A$ ' =  $0.4 \text{ cm}^2 = 0.4 \times 10^{-4} \text{ m}^2$

Resistivity of silver ' $\rho$ ' =  $1.6 \times 10^{-8} \Omega\text{m}$

**REQUIRED:**

Resistance ' $R$ ' = ?

**SOLUTION:**

The relation for resistance is:  $R = \frac{\rho L}{A}$  putting values:  $R = \frac{(1.6 \times 10^{-8} \Omega\text{m})(1\text{m})}{0.4 \times 10^{-4} \text{ m}^2}$

Therefore  $R = 4 \times 10^{-4} \Omega = 0.4 \text{ m}\Omega$  — **ANSWER**

So, the given silver wire will have a resistance of 0.4 m $\Omega$ .

**16.7.1 TEMPERATURE DEPENDENCE OF RESISTIVITY**

The resistance of every conductor varies with temperature. At higher temperatures, the internal energy of the material increases, causing the positive ions to vibrate with greater amplitudes. This increased vibration leads to more frequent collisions between electrons and ions.

Consequently, the motion of electrons is hindered, reducing the current for a given electric field. This phenomenon explains why the resistivity of metals typically increases with rising temperature.

Consider a conductor having resistivity ' $\rho_0$ ' at  $0^\circ\text{C}$  and ' $\rho_T$ ' at  $T^\circ\text{C}$ . It is found that for normal temperatures the change in resistivity ' $\Delta\rho = \rho_T - \rho_0$ ' is directly proportional to:

- I. initial resistivity  $\rho_0$   $\rho_T - \rho_0 \propto \rho_0$  — **1** and
- II. rise in temperature  $T$   $\rho_T - \rho_0 \propto \Delta T$  — **2**

combining proportionalities in 1 and 2, we get:

$$\rho_T - \rho_0 \propto \rho_0 \Delta T$$

Changing the sign of proportionality into equality, we get:

$$\rho_T - \rho_0 = \alpha \rho_0 \Delta T$$

Where ' $\alpha$ ' is the constant of proportionality and is called **temperature coefficient of resistivity**. Its value depends only upon the nature of material. Mathematically:

$$\alpha = \frac{\rho_T - \rho_0}{\rho_0 \Delta T} \quad \text{--- 16.8}$$

The units of temperature coefficient of resistance or resistivity are  $^\circ\text{C}^{-1}$  or  $\text{K}^{-1}$ . For common metals, ' $\alpha$ ' typically has a value of 0.003 to  $0.005\ ^\circ\text{C}^{-1}$ . That is, an increase in temperature of  $1^\circ\text{C}$  increases the resistance by 0.3% to 0.5%.

The resistivity of a metallic conductor nearly always increases with increasing temperature, this relationship is quantified by the temperature coefficient of resistivity, which is positive for metals, as indicated in Table 16.2.

Interestingly, the temperature coefficient of resistivity is negative for semiconducting materials. This means that, unlike metals, the resistivity of semiconductors decreases with increasing temperature. However, the specific mechanisms and processes by which this decrease in resistivity is achieved in semiconductors are complex and beyond the scope of this book.

Understanding these principles is crucial for the practical application and manipulation of metals in electrical and electronic systems.

TABLE 16.2 TEMPERATURE COEFFICIENTS OF SOME MATERIALS (AT  $20^\circ\text{C}$ )

| Material                             | $\alpha\ (^{\circ}\text{C}^{-1})$ |
|--------------------------------------|-----------------------------------|
| <b>Typical Metals</b>                |                                   |
| Silver                               | $3.8 \times 10^{-3}$              |
| Copper                               | $3.9 \times 10^{-3}$              |
| Gold                                 | $3.4 \times 10^{-3}$              |
| Aluminum                             | $3.9 \times 10^{-3}$              |
| Manganin                             | $0.002 \times 10^{-3}$            |
| Tungsten                             | $4.5 \times 10^{-3}$              |
| Iron                                 | $6.5 \times 10^{-3}$              |
| Lead                                 | $3.9 \times 10^{-3}$              |
| <b>Typical Semiconductors (pure)</b> |                                   |
| Carbon                               | $-0.5 \times 10^{-3}$             |
| Germanium                            | $-50 \times 10^{-3}$              |
| Silicon                              | $-75 \times 10^{-3}$              |

**Example 16.5**

At some temperature, the resistivity of a metallic conductor is  $5.6 \times 10^{-8} \Omega \text{ m}$ . If the temperature is increased by 30 K, find the new resistivity. Take temperature coefficient of resistivity as  $0.0045 \text{ K}^{-1}$ .

**GIVEN:**

Initial resistivity ' $\rho_0$ ' =  $5.6 \times 10^{-8} \Omega \text{ m}$

Temperature difference ' $\Delta T$ ' = 30 K

Temperature co-efficient of resistivity ' $\alpha$ ' =  $0.0045 \text{ K}^{-1}$

**REQUIRED:**

Final resistivity ' $\rho_T$ ' = ?

**SOLUTION:**

The temperature coefficient of resistivity is:  $\alpha = \frac{\rho_T - \rho_0}{\rho_0 \Delta T}$  or  $\rho_T = \rho_0(1 + \alpha \Delta T)$

putting values,  $\rho_T = (5.6 \times 10^{-8} \Omega \text{ m})\{1 + (0.0045)(30 \text{ K})\}$

Therefore  $\rho_T = 6.3 \times 10^{-8} \Omega \text{ m}$  — **ANSWER**

So, the resistivity of the metallic conductor will become  $6.3 \times 10^{-8} \Omega \text{ m}$  when the temperature is raised by 30 K.

**16.8 ELECTRICAL MEASURING INSTRUMENTS**

Devices used for measuring different electrical aspects such as current, voltage, resistance, power etc. are called Electrical measuring instruments.

**16.8.1 AMMETER**

Ammeter is a device used to measure current. To measure the current, an ammeter must be connected in a circuit in series as it finds current flowing through a component of the circuit. Figure 16.12 shows an analogue and digital ammeter along with circuit diagram. Since the ammeter must be able to make measurements by disturbing the current in the circuit as little as possible, ammeters are designed to have as low a resistance as possible (because they are

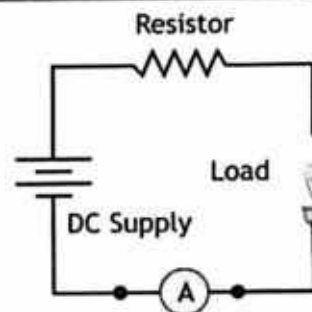


**FIGURE 16.12** Analogue and digital ammeter along with circuit connection.

connected in series), usually of the order of  $1\ \Omega$ , so they do not have an appreciable effect on the currents they measure.

**Range of ammeter:** Generally ammeters of different ranges are used based on the amount of current in the circuit. When you are measuring current in your home appliances, usually an ammeter with ampere values ranging from 1 A to 100 A is used. For small currents we use milli-ammeter (mA) or micro-ammeter ( $\mu\text{A}$ ) as shown in figure 16.13.

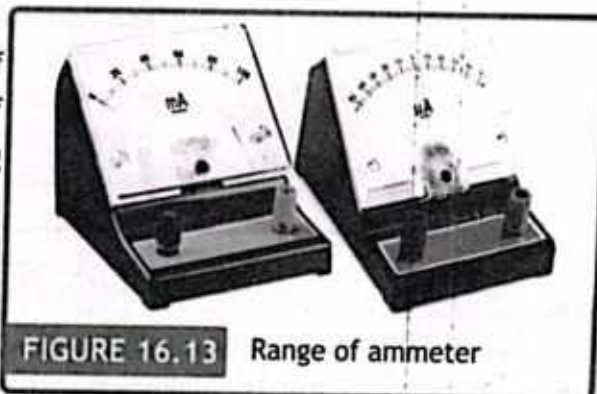


FIGURE 16.13 Range of ammeter

### 16.8.2 VOLTMETER

Voltmeter is a device used to measure potential difference. To measure the potential difference, voltmeter must be connected in parallel with the component across which the potential difference is to be measured. Figure 16.14 shows a voltmeter placed in the circuit to measure the potential drop across resistor R. Since the voltmeter must be able to make measurements while

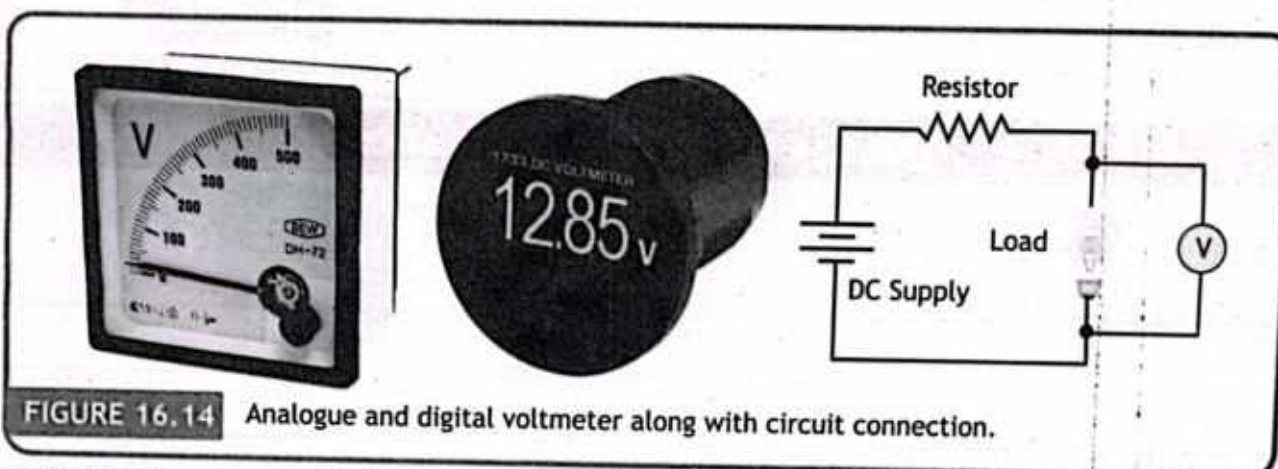


FIGURE 16.14 Analogue and digital voltmeter along with circuit connection.

disturbing the circuit as little as possible voltmeters are designed to have as high resistance as possible, usually of the order of  $10\ \text{M}\Omega$  ( $10^7\ \Omega$ ), so they have a negligible effect on the potential differences they are measuring.

**Range of voltmeter:** Like ammeters, voltmeters also have different ranges based on its use. For home voltage measurement voltmeter with volt values ranging from 1 V to 500 V is used. Milli-voltmeter (mV) is used for small voltage measurements as shown in figure 16.15.

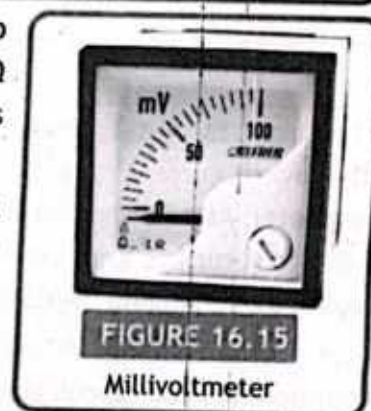


FIGURE 16.15  
Millivoltmeter

## POINT TO PONDER



It is said that voltmeter and ammeter are the modified forms of another device called galvanometer. Can you explain how?



## 16.9 EXPERIMENT FOR DETERMINATION OF RESISTANCE

The experimental setup for finding an unknown resistance is shown in figure 16.16. The unknown resistance is connected in series with the ammeter while the voltmeter is connected in parallel with the unknown resistance. A variable resistance called rheostat is also connected in series with the unknown resistance and ammeter. Ensure the indicators on both the voltmeter and the ammeter align with the zero mark on their scales.

Record the full scale and smallest division value (least count) for both the voltmeter and the ammeter provided. Engage

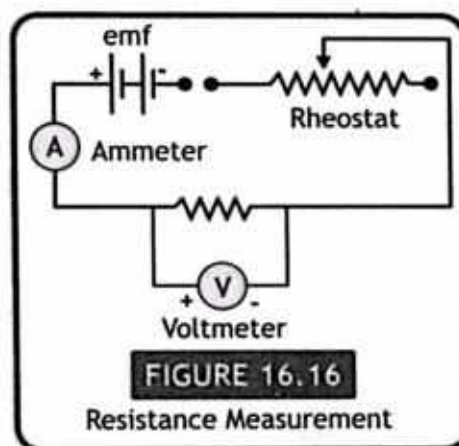


TABLE 16.3 RESISTANCE CALCULATION

| Sr. No. | Ammeter reading (A) | Voltmeter reading (V) | Resistance $R = \frac{V}{I}$ |
|---------|---------------------|-----------------------|------------------------------|
| 1.      |                     |                       |                              |
| 2.      |                     |                       |                              |
| 3.      |                     |                       |                              |
| 4.      |                     |                       |                              |

the circuit by closing the switch (key K) and adjust the rheostat towards the position that yields the lowest current flow. Observe and make a note of the readings from both the voltmeter and ammeter. After disconnecting the circuit by opening the switch (removing the key K), allow the wire to return to ambient temperature. Then, initiate the circuit again and gradually raise the voltage by changing the position of the rheostat.

Record the readings of the ammeter and voltmeter. Put values of current and voltage in the relation  $V/I$  for calculation of resistance given in table 16.3. Continue with this procedure, adjusting the rheostat incrementally to achieve four distinct voltage levels.

**SUMMARY**

- **Electric Current** is the rate of flow of charges
- **Ampere** is the unit of electric current and is defined as one coulomb charge per second.
- **Conventional Current** is the direction of flow of positive charges per unit time.
- **DC** is the type of electric current that is unidirectional and does not change its direction.
- **AC** is the type of electric current which changes its direction continuously.
- **Potential Difference** is the amount of work done in moving a unit positive charge from one point to another inside an electric field.
- **emf Source** is any device that converts non-electrical energy into electrical energy.
- **Ohm's Law** states that the amount of electric current in a circuit depends upon the potential difference while keeping temperature constant.
- **Resistance** is the opposition to the flow of charges or opposition to electric current.
- **Resistivity** is the resistance of unit length and unit area.
- **Temperature Coefficient of Resistance** is a measure of how a material's resistance changes with temperature.
- **Ammeter** is a device used to measure electric current through any device.
- **Voltmeter** is a device used to measure potential difference across any device.

**EXERCISE****MULTIPLE CHOICE QUESTIONS**

Q1. Choose the best possible option in the following questions.

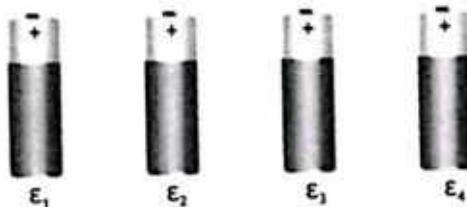
1. Ampere-hour (Ah) is the unit of:  
A. electric current      B. charge      C. energy      D. resistance
2. Which of the following is a non-ohmic device?  
A. Copper wire      B. Carbon resistor      C. Diode      D. all of these
4. Electric current is measured using:  
A. ammeter      B. voltmeter      C. ohmmeter      D. meter rod
5. Voltmeter measures  
A. Potential difference      B. electric current      C. resistance      D. resistivity

6. If 3 A of current flows for 2 minutes, the amount of charge crosses the cross-section of a conductor will be:  
A. 3 C                      B. 6 C                      C. 60 C                      D. 360 C
7. A current of 1 mA is passing through a wire. Number of electrons passing through a point in the wire in 10 seconds is:  
A.  $6.25 \times 10^{19}$                       B.  $6.25 \times 10^{18}$                       C.  $6.25 \times 10^{17}$                       D.  $6.25 \times 10^{16}$
8. Resistance of a material always decreases when:  
A. its temperature increases                      B. its temperature decreases  
C. Number of free electrons increases                      D. Number of free electrons decreases
9. The resistance of a metallic conductor varies inversely as:  
A. area of cross section    B. length                      C. temperature                      D. all of these
10. Directions of actual current and conventional current are:  
A. same                      B. opposite to each other  
C. perpendicular to each other                      D. none of these
11. As temperature of a semiconductor increases, its resistance:  
A. increases                      B. decreases                      C. remains constant                      D. becomes zero
12. The SI unit of temperature coefficient of resistance ( $\alpha$ ) is:  
A. K                      B.  $K^{-1}$                       C.  $\Omega K$                       D.  $\Omega / K$
13. By increasing temperature, the resistivity of semiconductors:  
A. increases                      B. decreases  
C. remains constant                      D. first increases then decreases

### CONSTRUCTED RESPONSE QUESTIONS

QII. Follow the directions to respond to the following questions.

1. Draw connections so that the emf sources given in figure become in series and parallel.



2. Compare and contrast the roles of ammeters and voltmeters in electrical circuits. Include a discussion on how each instrument measures different electrical properties.

**SHORT RESPONSE QUESTIONS**

**QIII. Give a short response to the following questions.**

1. Why is copper preferred over silver for household wiring, considering cost, conductivity, and durability?
2. Why free electrons in metals don't create a current without a potential difference?
3. How conventional and actual current directions affect circuit behaviour, and why conventional current is important in diagrams and calculations.
4. Compare emf and potential difference, and why this distinction matters in circuit analysis.
5. How is a current-carrying wire electrically neutral?
6. Would the lights still work if a car battery's positive and negative terminals were interchanged?
7. Evaluate the limits of Ohm's law for different materials, especially under extreme conditions.
8. How does a wire's shape affect its resistance, whether bending changes it?
9. The temperature coefficient of copper is  $0.004\text{ }^{\circ}\text{C}^{-1}$ . How does this affect copper's performance in electrical systems under varying temperatures?
10. How would you define fluid resistance for a water-carrying pipe?

**LONG RESPONSE QUESTIONS**

**QIV. Give a detailed response to the following questions.**

1. Explain electric current and its unit (ampere) by exploring charge flow. Discuss the difference between conventional and actual current and when this distinction matters.
2. Analyse electrical conduction in metals and how external factors like temperature and magnetic fields affect electron movement and conduction efficiency.
3. Compare DC and AC in terms of their behaviour in circuit elements. Discuss the pros and cons of each in applications like power transmission and electronics.
4. Examine electromotive force (emf) and its role in maintaining current.
5. Distinguish between emf and potential difference, using real-world examples like batteries.
6. Critically analyse Ohm's law and its limitations for non-ohmic devices. Discuss the importance of I-V graphs and propose experiments to explore non-linear materials.
7. Investigate the relationship between resistance and resistivity and design an experiment to measure resistance. Discuss factors affecting accuracy, such as temperature.

8. Analyse how factors like temperature, material, length, and area affect resistance. Discuss practical applications, such as wiring or heating elements, and ways to optimize resistance.
9. How does temperature influence the resistance of materials, and what implications does this have for electrical components in different environments?
10. Examine the placement of ammeters and voltmeters in circuits and how misconnection affects measurement. Propose strategies to avoid errors.

### NUMERICAL RESPONSE QUESTIONS

**QV. Solve the questions given below.**

1. How much time will it take to charge a 200 Ah battery when it is connected to a current of 25 A? (Answer: 8 hr)
2. A 12.0 V emf source is connected to a purely resistive electrical appliance (a light bulb). An electric current of 2.0 A flows through it. Consider the conducting wires to be resistance-free, calculate the resistance offered by the electrical appliance. (Answer: 6  $\Omega$ )
3. The potential difference across the two ends of the component decreases to one fourth of its initial value while its resistance remains constant. What change will occur in the current through it? (Answer: 1/4)
4. What voltage is necessary to pass a current of 50 amperes through a resistance of 100  $\Omega$ ? (Answer: 5,000 V)
5. The current passing through a resistor in a circuit is 0.5 A when the voltage across it is 6.0 V. What current will pass through the same resistor when the voltage across it is 9.0 V? (Answer: 0.75 A)
6. The length and area of wire are given as 2 m and 0.4 mm<sup>2</sup> respectively. The resistance of that wire is 0.085  $\Omega$ , calculate the resistivity? (Ans.  $1.7 \times 10^{-8} \Omega \text{ m}$ )
7. Resistivity of a given copper wire of length 2 m is  $1.7 \times 10^{-8} \Omega \text{ m}$ . (a) If the wire is stretched to double of its length, what will be the new resistivity? (b) If its temperature is increased by 20 K, find the new resistivity. (Take  $\alpha = 3.9 \times 10^{-3} \text{ K}^{-1}$ ) (Ans. (a)  $1.7 \times 10^{-8} \Omega \text{ m}$  (b)  $1.83 \times 10^{-8} \Omega \text{ m}$ )
8. At some temperature  $T_0$ , the resistivity of a metallic conductor is  $1.7 \times 10^{-8} \Omega \text{ m}$ . If the temperature is increased by 50 K, find the new resistivity by taking temperature coefficient of resistivity as 0.004. (Ans.  $2.04 \times 10^{-8} \Omega \text{ m}$ )