Unit 12 CURRENT ELECTRICITY

Major Concepts **(36 PERIODS)**

- Steady current
- Electric potential difference
- Resistivity and its dependence upon temperature.
- Internal resistance
- Power dissipation in resistance
- Thermoelectricity
- Kirchhoff's Laws
- The potential divider
- Balanced potentials (Wheatstone bridge and potentiometer)

Conceptual Linkage

This chapter is built on Current Electricity Physics X

Students Learning Outcomes

After studying this unit, the students will be able to:

- described the concept of steady current.
- state Ohm's law.
- define resistivity and explain its dependence upon temperature.
- define conductance and conductivity of conductor.
- state the characteristics of a thermistor and its use to measure low temperatures.
- distinguish between e.m.f. and p.d. using the energy considerations.
- explain the internal resistance of sources and its consequences for external circuits.
- describe some sources of e.m.f.
- describe the conditions for maximum power transfer.
- describe the thermocouple and its function.
- explain variation of thermoelectric e.m.f. with temperature.
- apply Kirchhoff's first law as conservation of charge to solve problem.
- apply Kirchhoff's second law as conservation of energy to solve problem.
- describe the working of rheostat in the potential divider circuit.

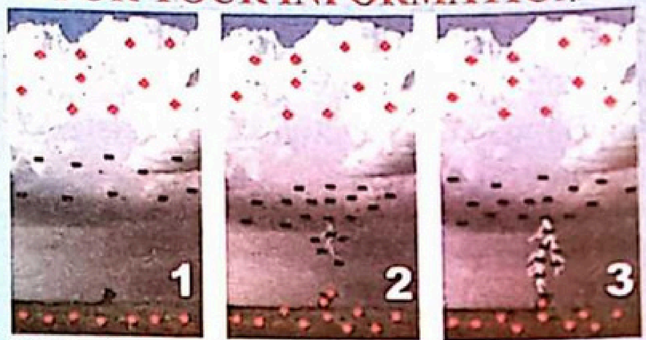
- describe what is a Wheatstone bridge and how it is used to find unknown resistance.
- describe the function of potentiometer to measure and compare potentials without drawing any current from the circuit.

INTRODUCTION

In the previous unit, we have studied the electrostatics i.e., the charges at rest. In this unit, we will study the rate of flow of electric charges passing through a point which is termed as electric current. Such motion of charges take place within a conducting closed path, the path is called an electric circuit. The main function of the electric circuit is to transfer the electrical energy (current) from electrical source to the loads. The loads may be bulb, heating element, fan, motor, etc., which convert the electrical energy into the other forms of energy, such as: sound, light, heat, mechanical energy, chemical energy etc. For example, a stereo system converts electrical energy into sound, a toaster or bulb into heat and light, a motor into a mechanical energy etc. Moreover, the electrical energy or current powers our computers, televisions, CD players, air conditioners, refrigerators etc.

In this unit, we will explain not only the sources of electric current but also the factors which are related with the current, such as resistance and resistivity, conductance and conductivity, potential difference and electromotive force etc. We will discuss power generation in a source and its dissipation in an electric circuit. Similarly, we will also introduce the circuits analysis by using ohm's law as well as Kirchhoff's two laws. i.e., node analysis and loop analysis. In the same way, we will explain the potential dividers (Wheatstone bridge and potentiometer) in the last section of this unit.

FOR YOUR INFORMATION



Lightening occurs mainly in warm climates. As warm water vapors rise in air, they bushes against ice crystals high in the air above, producing charges. The ice crystals gain a slight positive charges and the undraft carries them to the top of a cloud is usually positively charged with the bottom negatively charged. Lightening is the bolt that arcs between these regions and between the cloud and the ground below.

DO YOU KNOW

An electric shock is a violent disturbance of the nervous system caused by an electrical discharge or current through the body.

12.1 STEADY CURRENT

The study of flow of either positive or negative charges through a conducting medium with time is known as electric current. Usually, it is represented by 'I' and it is defined as **the rate of flow of charges**. If the amount of charge ΔQ flow through a conductor in time Δt, then the electric current can be expressed as:

$$I = \frac{\Delta Q}{\Delta t} \quad ......(12.1)$$

The SI unit of current is Ampere. **When one coulomb charge flows in a conductor in one second, then the current is said to be one ampere.** In other words, the current of one ampere is equal to the flow of combined charge of 6.25×10^{18} electrons through a conductor in one second. Now if the magnitude of rate of flow of charges remain constant then it is called a steady current.

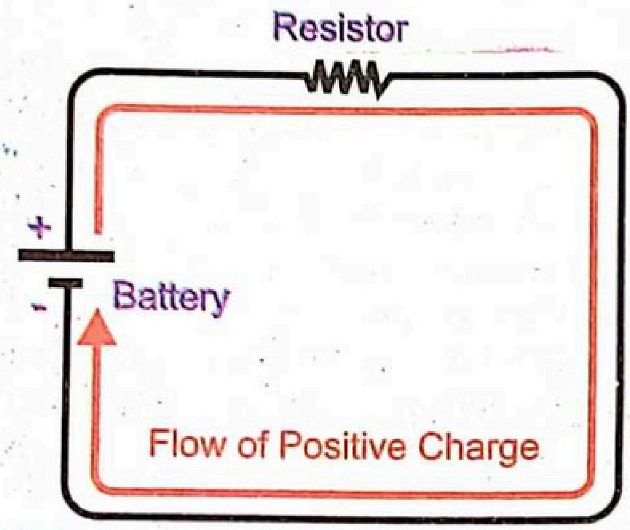


Fig.12.1(a) Conventional current due to flow of charges from positive terminal to negative terminal of the battery.

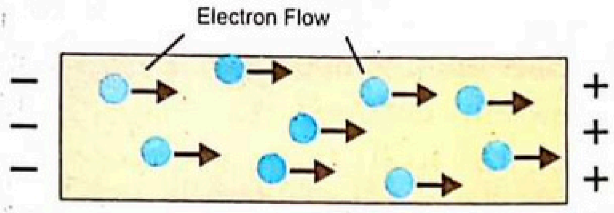


Fig.12.1(b) Electronic current due to flow of electrons.

The flow of charges may be positive or negative charges. The current due to flow of positive charges from positive terminal of the battery towards the negative terminal as shown in Fig. 12.1(a) is called conventional current. The current in metals is due to flow of free electrons as shown in Fig. 12.1(b), is known as electronic current. In semiconductor materials such as germanium and silicon, the current is due to the flow of electrons and holes, this is also known as electronic current. Similarly, in case of conducting liquid called electrolyte or ionized gas called plasma, the current in these medium is due to both negatively and positively charged ions as shown in Fig. 12.1(c) and its resultant current (I) is given by

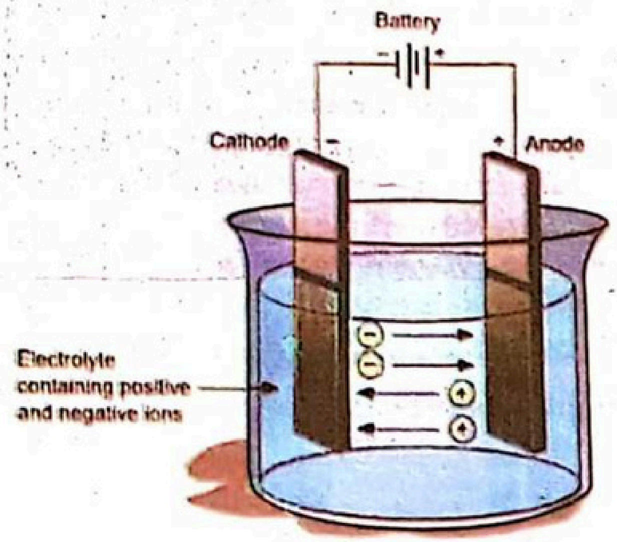


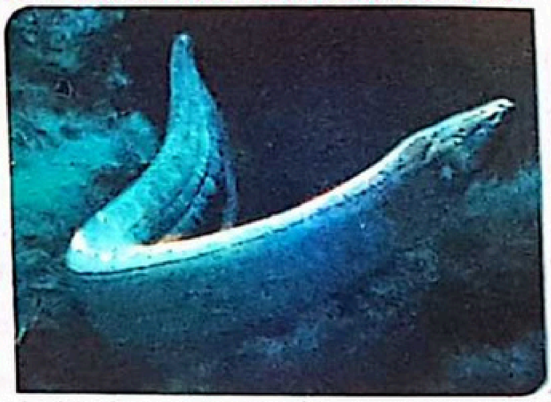
Fig.12.1(c) Current due to flow of positive and negative ions in electrolyte.

$$I = I_{+} + I_{-} \quad ......(12.2)$$

12.1.1 The direction of current through a metallic conductor

In the beginning, the scientists believed that the current is due to the flow of positive charges through a conductor when it is connected with the terminals of the battery. It is therefore, the positive terminal of the battery has high potential while its negative terminal has low potential. Later on, the experimental observations proved that the current is indeed due to the flow of electrons through a conductor when it is connected with the terminals of the battery. For example, metals such as silver, copper, aluminum etc. have free electrons which are moving randomly in the absence of any electric field and their speed depends upon temperature. Now when one of the metallic conductor say copper is connected across the source (cell) than an electric field is produced across the copper and it is directed from positive towards the negative plate of the cell as shown in Fig.12.2. The free electrons of the copper experience attractive force ($F = qE$) due to the anode and repulsive force due to the cathode. As a result, the free electrons of the copper start drifting in one direction from –ve terminal towards the +ve terminal of the cell as shown in Fig.12.2. Hence, this result has confirmed that the current is actually due to the flow of negative charges in a metallic conductor but its direction is taken as in its opposite direction.

INTERESTED INFORMATION



A 20 foot long electric eel is a south American electric fish has a number of cells called electro plaques that produces emf of 600V. The current due to this emf is used to stun its enemies and to kill its prey.

POINT TO PONDER

Why is it advised to wear rubber soled shoes while handling electric appliances?

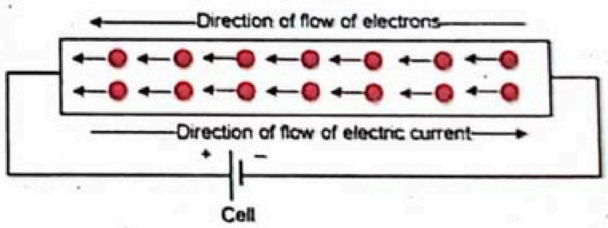


Fig.12.2 The flow of electrons toward the positive terminal of the battery while the direction of current from positive to negative terminal.

Example 12.1

If 1×10^{13} electrons flow through a conductor in 1ms, calculate the current in Ampere through the conductor.

Solution:

$$\text{Number of electrons} = n = 1\times 10^{13}\ \text{electrons}$$

$$\text{Charge on an electron} = e = 1.6\times 10^{-19}\ \text{C}$$

$$\text{Time taken} = t = 1\text{ms} = 1\times 10^{-3}\ \text{s}$$

So, Charge on 1×10^{13} electrons $= Q = ne = 1.6 \times 10^{-19}\,C \times 1 \times 10^{13}$

$$Q = 1.6 \times 10^{-6}\,C$$

Thus, the flow of current through the conductor is given by

$$I = \frac{Q}{t} = \frac{1.6\times10^{-6}\,C}{1\times10^{-3}\,s}$$

$$I = 1.6 \times 10^{-3}\,A$$

$$I = 1.6\,mA$$

12.2 SOURCES OF STEADY CURRENT

As the flow of fluid between two points requires a difference in pressure between the given points, similarly flow of charges between two points through a conducting medium takes place only when a potential difference exists across these two points. For example, let two conductors at different potential are connected by a metallic wire. Then there will be flow of current through the wire but such current is for very short period of time because the potential of both conductors become same due to decreasing the flow of charges. Like a steady flow of river, we require a steady current in our circuit. It is possible only when we have suitable source. Such source was discovered by Italian scientist Volta in 1800 and is called voltaic cell. A simple source of current as shown in Fig.12.3 consists of two metallic plates which are immersed in a dilute sulfuric acid (H_2SO_4) known as electrolyte. One plate is made of copper called anode and the other plate is made of zinc called cathode. Now due to the chemical action within the source, the electrons are released by the copper plate and collected by the zinc plate. Thus, under this process the copper plate becomes positively charged while the zinc plate becomes negatively charged. In this way, Volta was

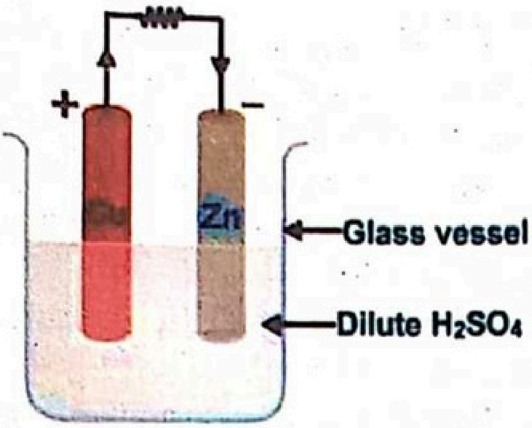
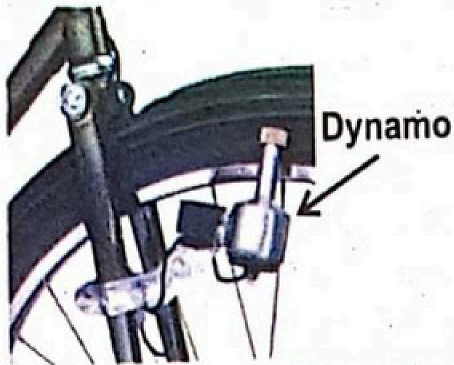


Fig.12.3 A schematic diagram for source of a current.

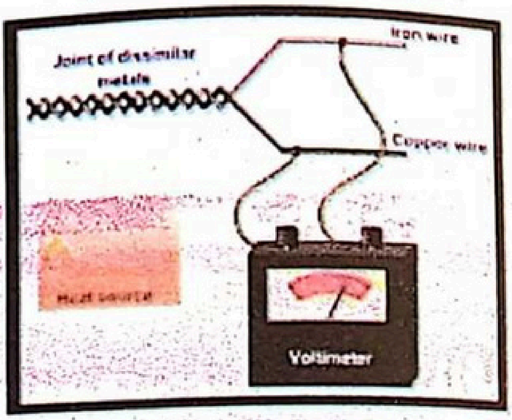


A dynamo as a source of electricity

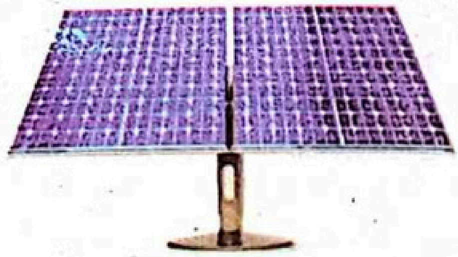
An electric generator

succeeded in the development of potential difference. When these two plates (electrodes) are connected externally by a wire, then there will be flow of electrons from the cathode towards the anode and its uniform flow depends upon the continuous chemical reaction.

After voltaic cells, other cells were also discovered by using different materials and different electrolytes; such as Daniell cell, Laclanche cell etc. All these cells are not rechargeable and called primary cells. Later on, the rechargeable cells, such as nickel cadmium cell, lead acid cell have also been constructed. These are called a secondary cells. There are number of other sources of current which are summarized as;



A thermocouple


A solar cell

i. **Dynamo:** It converts mechanical energy into electrical energy.

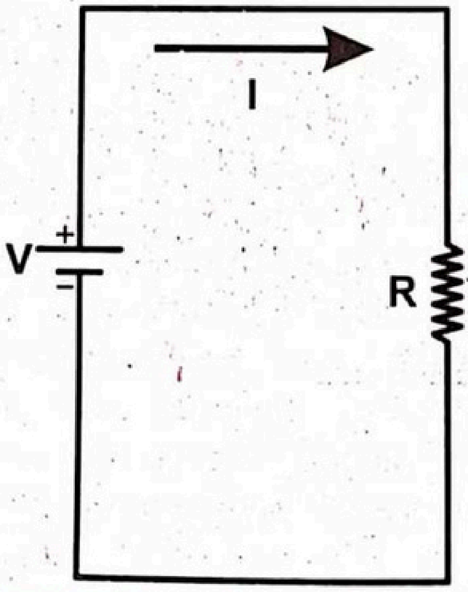
ii. **Generators:** It also converts mechanical energy into electrical energy.

iii. **Thermo-couple:** It converts the heat energy into electrical energy.

iv. **Solar or photo cell:** It converts solar energy into electrical energy.

12.3 OHM'S LAW

As we have discussed that when the potential difference is applied across the conductor, its free electrons start drifting in one direction. As a result, there are collision between the free electrons with the atoms or ions of the conductor. These collisions cause of opposition to the flow of current and such opposite to the flow of current is called resistance of the conductor.



At constant resistance, the applied voltage across the conductor is directly proportional to the current

A German scientist G.S Ohm studied the relation among the following three parameters, i.e., the voltage applied across the conductor, the current through the conductor and the resistance of the conductor. Thus, by summing his experimental results, he formulated a law in 1826, known as Ohm's Law which relates the above stated parameters and it is stated as; **the applied voltage across the conductor is directly proportional to the steady current, if the temperature and other physical conditions of the conductor remain constant.**

Mathematically, Ohm's law can be expressed as

$$V \propto I$$

$$V = I R \quad ......(12.3)$$

where 'R' is the constant of proportionality and it is known as resistance of the conductor. The value of resistance depends upon temperature and other physical states of the conductor. Its SI unit is ohm and it is denoted by 'Ω'. **A conductor has a resistance of one ohm, if a current of one ampere flows through it by applying a potential difference of 1volt across its ends.**

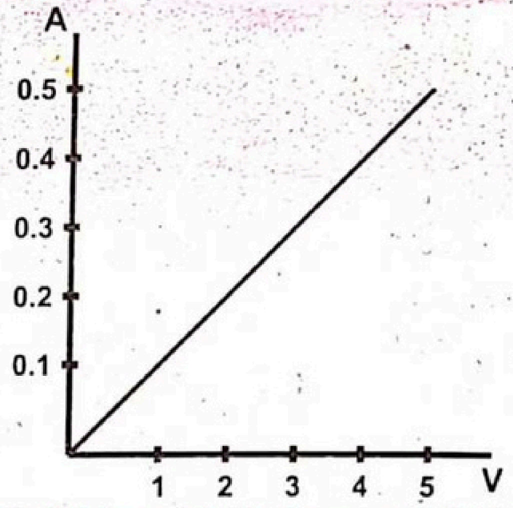


Fig.12.4(a) A straight line between V & I due to Ohmic device.

The materials which obey Ohm's law and have constant resistance over a large range of voltage are known an Ohmic materials. For example, a carbon resistor, nichrome or eureka wire, and metallic conductors etc. are known as Ohmic materials.

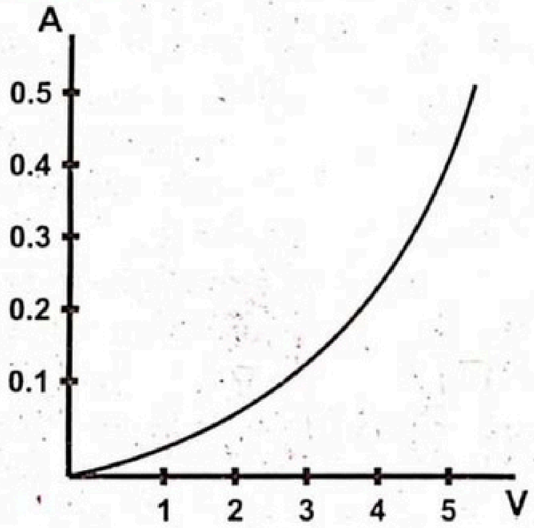


Fig.12.4(b) A curved line between V & I due to a non-ohmic device

For ohmic materials, the graph of voltage versus current is a straight line as shown in Fig. 12.4(a). Such straight line graph is known as ohmic characteristics.

On the other hand, those materials having resistance that varies with current or voltage non-linearly are known as non-ohmic materials. For example, filament of a bulb, semiconductor diode etc. are non-ohmic devices and the graph of voltage versus current is a curved line i.e. not linear as shown in Fig.12.4(b). Such curved line is known as non-ohmic characteristics of a non-ohmic device.

DO YOU KNOW?

- Flow of current is directly proportional to the potential difference.
- Flow of heat is directly proportional to the temperature difference.
- Flow of fluid is directly proportional to the pressure difference.

Example 12.2

What is the current through a resistor of 16Ω when the potential difference of 240 volts is applied across it.

Solution:

Current = I = ?

Resistance of the resistor = R = 16Ω

Applied voltage = V = 240v

According to Ohm's law

$$V = I R$$

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

$$I = \frac{240V}{16\Omega}$$

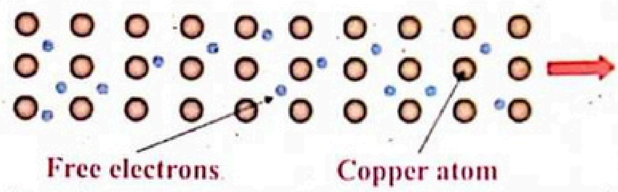
$$I = 15A$$

> ***FOR YOUR INFORMATION***
> Current is a flow of charge, pressured into motion by voltage and hampered by resistance.

> ***FOR YOUR INFORMATION***
> An ohmic device is one for which, under constant physical condition such as temperature, the resistance is constant for all current that pass through it.
> A non-ohmic device is one for which the resistance is different for different currents passing through it.

12.4 RESISTIVITY

Nearly, all the materials have some resistance to flow of current. e.g., silver, copper, aluminum etc. have small resistance and they are called conductors. While, some materials such as glass, rubber, wood etc. offer high resistance to the flow of current and they are called insulators. **Therefore, the resistance of a material or conductor in its one cubic metre is known as its specific resistance or resistivity. In other words, the resistance of a wire of 1m length and has cross section area of $1m^2$ is called its resistivity.** Its value can be calculated as, since the resistance of a conductor is due to the collision between the free moving electrons with the atoms or ions of the conductor when a potential difference is applied across it. So one can say that the resistance of the conductor depends upon its length and cross-sectional area, because for a long conductor, the electrons undergo greater number of collision and hence there will be more resistance of the conductor. Also resistance increases by decreasing cross-sectional area of the conductor. Thus the experimental results show



A resistance due to the collision between the moving charges and the atoms of the conductor.

A resistance is directly proportional to the length and inversely proportional to the cross sectional area of conductor that the resistance of a conductor is directly proportional to its length ℓ and inversely proportional to its cross-sectional area A. i.e.,

$$R \propto \ell$$

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

> *DO YOU KNOW*
> A single cell supplies 1.5V. Inside a 12V battery, there are eight cells of 1.5V each.

Combing these two relations

$$R \propto \frac{\ell}{A}$$

$$R = \rho\frac{\ell}{A} \quad ......(12.4)$$

where 'ρ' is a constant of proportionality known as specific resistance or resistivity of the material and it depends upon the nature of the material. That is, conductors have low resistivity and insulators have high resistivity. The value of the resistivity of different materials are shown in table 12.1. Mathematically the value of 'ρ' can be calculated as

$$\rho = \frac{RA}{\ell} \quad ......(12.5)$$

The unit of 'ρ' is Ωm.

Table 12.1

Resistivity (Ωm) of some materials

Material	Resistivity
Carbon (graphene)	1×10^{-8}
Silver	1.59×10^{-8}
Copper	1.68×10^{-8}
Gold	2.44×10^{-8}
Calcium	3.36×10^{-8}
Zinc	5.90×10^{-8}
Latium	9.28×10^{-8}
Iron	1.0×10^{-8}
Platinum	1.06×10^{-7}
Tin	1.09×10^{-7}
Lead	2.2×10^{-7}
Carbon (graphite)	2.5×10^{-6} to 5.0×10^{-6}
Sea water	2×10^{-1}
Drinking water	2×10^{1} to 2×10^{3}
Silicon	6.40×10^{2}
Deionized water	1.8×10^{5}
Glass	1×10^{10} to 1×10^{14}
Carbon (diamond)	1×10^{12}
Hard rubber	1×10^{13}
Sulfur	1×10^{15}
Air	1.3×10^{16} to 3.3×10^{16}
Teflon	10×10^{22} to 10×10^{24}

12.4.1 Conductance

Conductance is the reciprocal of resistance. It is represented by G and is expressed as;

$$\text{Conductance} = \frac{1}{\text{Resistance}}$$

$$G = \frac{1}{R} \quad ......(12.6)$$

The SI unit of conductance is per ohm or 'mho' (Ω^{-1}) also known as Siemen.

It is defined as the ability to which an object conducts electricity. It may be expressed in terms of ratio of the current to the potential difference and mathematically, $G = \frac{I}{V} = \frac{1}{R}$, i.e., the lower the resistance, the higher the conductance.

12.4.2 Conductivity

Conductivity is also an electrical property of materials which is reciprocal of the resistivity of the conductor. It is denoted by 'σ' (sigma) and it is expressed in terms of the reciprocal of resistivity i.e.,

$$\text{Conductivity} = \frac{1}{\text{Resistivity}}$$

$$\sigma = \frac{1}{\rho} \quad \text{......(12.7)}$$

FOR YOUR INFORMATION

Since R and G are reciprocal to each other, their value can be calculated as:

$$R = \frac{V}{I} \text{ and } G = \frac{I}{V}$$

By definition of resistance in terms of resistivity

$$R = \rho\frac{\ell}{A} \quad \text{(from Eq.12.4)}$$

But $R = \frac{1}{G}$ and $\rho = \frac{1}{\sigma}$

$$\frac{1}{G} = \frac{1}{\sigma}\frac{\ell}{A}$$

$$\Rightarrow \quad G = \sigma\frac{A}{\ell}$$

$$\sigma = \frac{G\ell}{A}$$

The SI unit of conductivity is $\Omega^{-1}m^{-1}$ or $mho.m^{-1}$. The values of conductivity of different materials are listed in table 12.2.

Table 12.2

Electrical Conductivity of Some material	
Material	**Conductivity $(\Omega^{-1}m^{-1})$**
Silver	66.7×10^6
Copper	64.1×10^6
Gold	49.0×10^6
Aluminum	40.8×10^6
Rhodium	23.3×10^6
Zinc	28.2×10^6
Nickel	16.4×10^6
Cadmium	14.7×10^6
Iron	11.2×10^6
Platinum	10.2×10^6
Palladium	9.3×10^6
Tin	8.7×10^6
Chromium	7.9×10^6
Lead	5.3×10^6
Titanium	2.3×10^6
Mercury	1.0×10^6
Carbon-graphite	$(1.5-20) \times 10^4$

12.4.3 Variation of resistivity with temperature

It is an experimental fact that the resistance of a conductor depends upon the temperature i.e., the resistance of a material increases with increase in its temperature. For example, the atoms in a solid are always vibrating about their mean position at room temperature. Now when the temperature increases, the amplitude of vibration of atoms also increases and the free electrons undergo greater number of collisions. Hence the resistance of the conductor increases with increase in temperature.

Let a metallic conductor having resistivity R_o at temperature 0°C, when its temperature is increased to t°C then its resistance becomes R_t.

Thus, change in resistivity $= \Delta R = R_t - R_o$

change in temperature $= \Delta T = t - 0 = t$

The analysis of experimental data on resistance as a function of temperature shows that change in resistance of the conductor is directly proportional to both initial resistance of the conductor and raise in temperature. That is,

$$\Delta R \propto R_0$$

$$\Delta R \propto \Delta T$$

By combining these two relations

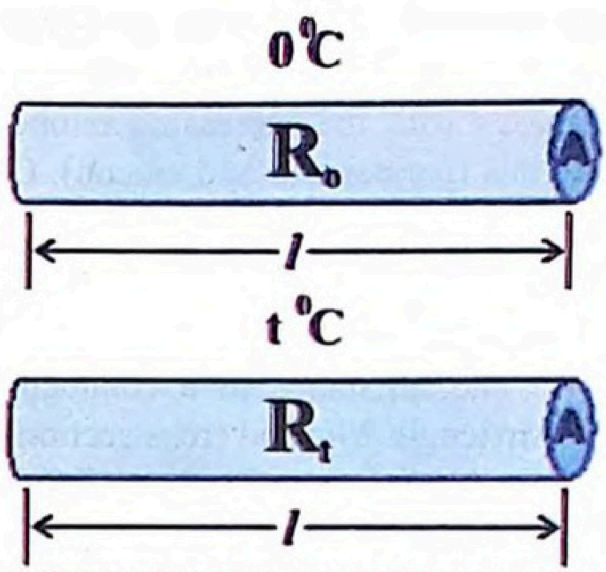
$$\Delta R \propto R_0 \Delta T$$

$$\Delta R = \alpha R_0 \Delta T \quad ......(12.9)$$

where ' α ' is constant of proportionality and it is known the temperature co-efficient of resistivity. Its value can be calculated as,

$$\alpha = \frac{\Delta R}{R_o \Delta T}$$

$$\alpha = \frac{R_t - R_o}{R_o t} \quad ......(12.10)$$



Different values of resistance of a conductor at different temperatures.

DO YOU KNOW

A fuse is a safety device that serves to protect the circuit components and wiring in the event of short circuit. Excessive current melt the fuse conductor which blows the fuse.

The SI unit of 'α' is K^{-1}. Let 'ℓ' be the length of the uniform conductor and 'A' be its cross-sectional area. Similarly, ρ_0 be its resistivity at 0°C and ρ_t be its resistivity at t°C then Eq.12.10 can be expressed in terms of resistivity as;

$$\alpha = \frac{\frac{\rho_t \ell}{A} - \frac{\rho_o \ell}{A}}{\frac{\rho_o \ell}{A} \cdot t}$$

$$\alpha = \frac{\rho_t - \rho_o}{\rho_o t}$$

$$\rho_t - \rho_o = \alpha \rho_o t$$

$$\rho_t = \rho_o + \alpha \rho_o t$$

$$\rho_t = \rho_o (1 + \alpha t) \quad ......(12.11)$$

Table 12.3

Color	Temperature Coefficient $[(°C)^{-1}]$
Silver	3.8×10^{-3}
Copper	3.9×10^{-3}
Gold	3.4×10^{-3}
Aluminium	3.9×10^{-3}
Tungsten	4.5×10^{-3}
Iron	5.0×10^{-3}
Platinum	3.92×10^{-3}
Lead	3.9×10^{-3}
Nichrome	0.4×10^{-3}
Carbon	-0.5×10^{-3}
Germanium	-48×10^{-3}
Silicon	-75×10^{-3}

The values of temperature co-efficient for various materials are given in Table 12.3. The results show that the value of ' α ' is positive when resistance of the material increases with the increasing temperature such as copper, silver tungsten etc. Similarly, the value of 'α' is taken as negative when the resistance of the material decreases with the increasing temperature such as carbon and all semiconductor materials (germanium and silicon). On the other hand, the value of 'α' is taken as zero, when the resistance of the material remains constant with changes in temperature.

Example 12.3

The resistance of a conductor of uniform length 20m and cross-section area $1mm^2$ is 0.4Ω. Determine the resistivity of the conducting material.

Solution:

Resistance of the conductor $R = 0.4\Omega$

Length of the conductor $\ell = 20m$

Cross-section area of the conductor $A = 1mm^2$

Or $A = 1 \times 10^{-6}m^2$

Resistivity of the conductor $\rho = ?$

Resistivity of the conductor can be calculated by using Eq.12.4, that is,

$$R = \rho\frac{\ell}{A}$$

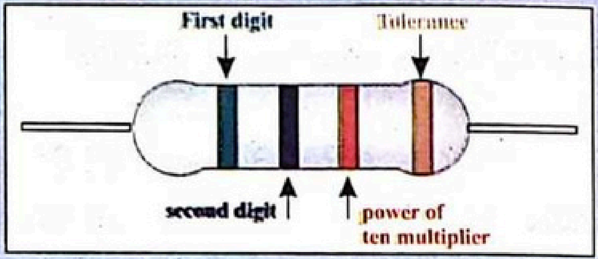
$$\rho = \frac{RA}{\ell}$$

$$\rho = \frac{(0.4\Omega)\times(1\times10^{-3}m^2)}{20m}$$

$$\rho = 0.02 \times 10^{-3}\ \Omega m$$

$$\rho = 2\times10^{-5}\Omega m$$

FOR YOUR INFORMATION



The resistor colour code

Colour	Digit	Multiplier	Tolerance
Black	0	10^0 or 1	
Brown	1	10^1	
Red	2	10^2	±2%
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Grey	8	10^8	
White	9	10^9	
Gold		10^{-1}	±5%
Silver		10^{-2}	±10%
No colour			±20%

The numerical value of resistance of a carbon resistor can be determined by its color code, which consist of four bands, three at one end, fourth on the other. Where the first two bands specify the first two digits and the third band gives the number of zeroes. The fourth band at the other end gives the value of tolerance in percentage.

Example 12.4

A tungsten filament of a bulb has a resistance of 50Ω at 20°C and 467Ω at 2000°C. Determine the value of temperature co-efficient of resistance of the tungsten.

Solution:

$$R_1 = 50\Omega$$

$$R_2 = 467\Omega$$

$$t_1 = 20°C$$

$$t_2 = 2000°C$$

Change in temperature $\Delta T = 2000 - 20 = 1980°C$

Now, by using Eq.12.11,

$$R_2 = R_1(1+\alpha\Delta T)$$

$$\alpha = \frac{R_2 - R_1}{R_1 \Delta T}$$

$$\alpha = \frac{467\Omega - 50\Omega}{(50\Omega)(1980^{\circ}C)}$$

$$\alpha = 0.0042^{\circ}C^{-1}$$

12.5 THERMISTOR

Thermistor is a temperature dependent resistor, its resistance changes very fast even with small change of temperature. The term thermistor is combination of thermal and resistor. Majority of the thermistors are working under the negative temperature co-efficient of resistance, however the positive temperature coefficient of a thermistors are also available. Thermistors are made from the semiconductor oxides of nickel, cobalt, copper, iron etc. They are constructed in different shapes such as beads, discs or rods etc. under different conditions as shown in Fig.12.5.

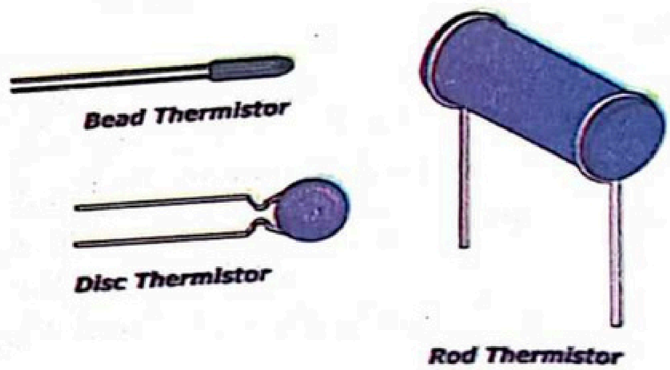


Fig.12.5 Different types of thermistors.

Thermistors have several applications which are summarized as:

i. A negative temperature coefficient thermistor is being used to safeguard against current surge in a circuit.
ii. Thermistors are being used for voltage stabilization.
iii. It is being used as a temperature sensor.
iv. Thermistors are used to measure very low temperatures of the order of 10K.

12.6 ELECTROMOTIVE FORCE (e.m.f.) AND POTENTIAL DIFFERENCE

To maintain a steady current in a closed electric circuit, a source of electrical energy is required. The source may be battery, generator, solar cell, thermocouple etc. All these are known as sources of electromotive force (e.m.f.). When any one of them is connected to a circuit which consists of a resistor 'R', then an electric field is produced in the circuit directed from the high potential to the low potential as shown in Fig.12.6. The electrons from the negative terminal are forced by the source of e.m.f.

to move against the direction of the field. Thus, **the energy supplied, by the source per unit charge to move the charge in circuit from the low potential to the high potential is called its electromotive force.** It always raises the potential of the charges and it is expressed as

$$\text{e.m.f. (E)} = \frac{W}{q}$$

$$W = qE \;......(12.12)$$

The SI unit of e.m.f. is volt.

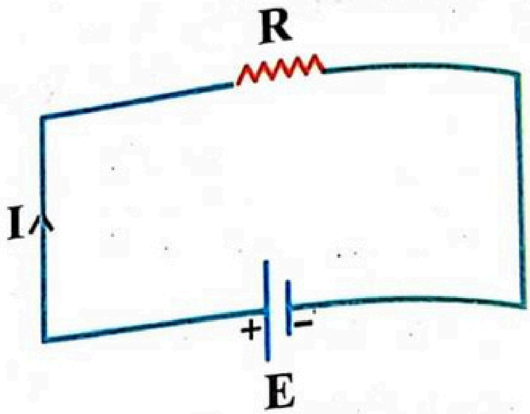


Fig.12.6 An electric circuit consists of a resistor and a source of e.m.f. (E).

On the other hand, when the source delivers the electrical energy into the circuit, then **work done per unit charge between two points (A and B) as shown in Fig.12.7, is known as the potential difference.** It is represented by V and it is expressed as;

$$W = qV \;......(12.13)$$

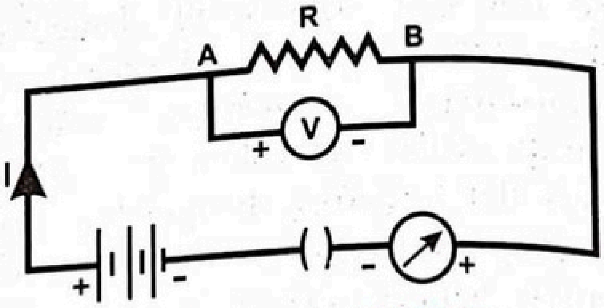


Fig.12.7 The electric potential between point A and point B in an electric circuit.

An ideal source of e.m.f. is one which maintains a constant potential difference between the two points in the circuit. Thus, by comparing Eq.12.12 and Eq.12.13 we get;

$$qE = qV$$

$$E = V \quad \text{(As } V = IR\text{)}$$

$$E = IR$$

$$I = \frac{E}{R} \;......(12.14)$$

DO YOU KNOW

The word 'open' means no flow of charges (current) in the given circuit and the word 'closed' is applied for the flow of charges (current) in the circuit.

Each real source of e.m.f. always has some internal resistance 'r' as show in Fig.12.8, and this resistance is due to the electrolyte present inside the source. Thus, in the presence of internal resistance, the potential difference across a real source in a circuit is not equal to the e.m.f. because some energy is dissipated through 'r'. Thus, when a current I is

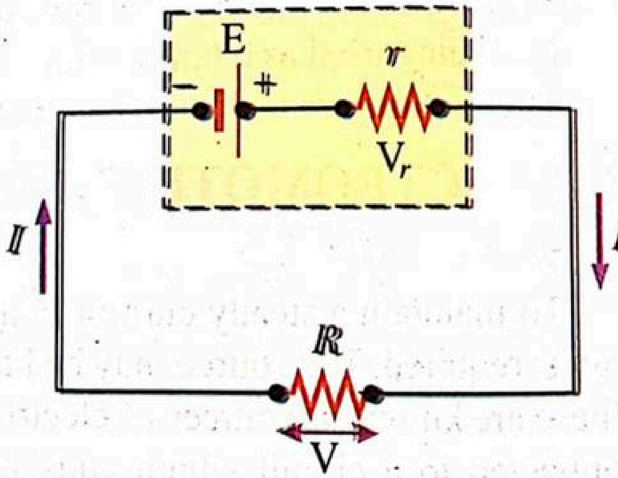


Fig.12.8 A source of e.m.f. which has an internal resistance r.

flowing from the negative terminal of the source to the positive terminal through the external resistance 'R' and internal resistance 'r', then the potential difference 'V' between the terminals of the source is given by

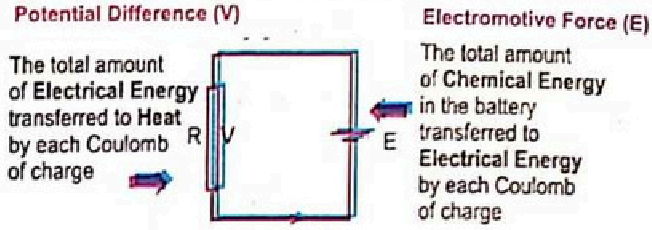
$$V = E - V_r$$

$$IR = E - Ir$$

$$E = I(R + r)$$

$$I = \frac{E}{R + r} \quad \text{......(12.15)}$$

Potential difference vs Electromotive force



This equation gives us few important results about the e.m.f. and the potential difference. That is,

1. If $r \neq 0$ and the source delivers the current into the circuit then the e.m.f. of the source will be greater than the potential difference ($E > V$).
2. If the switch is opened and there is no flow of current in the given circuit i.e. there is no voltage drop across the internal resistance. Then the e.m.f. will be equal to the potential difference ($E = V$)
3. The e.m.f. also equals to the potential difference if the internal resistance is zero ($r = 0$). But it is an ideal case.

12.6.1 Maximum power transfer

We have discussed that a source of e.m.f. generates electrical energy and transfers it in an electrical circuit. The rate of transfer of this electrical energy is termed as electrical power which is dissipated in resistor R in terms of voltage 'V' and current 'I'. Now if we neglect the internal resistance of the source, then according to law of conservation of energy, the power delivered by source is equal to power dissipation in load resistor R i.e.,

Power delivered to R = Power generation

$$P_{out} = \frac{\text{energy transferred}}{\text{time}}$$

$$P_{out} = \frac{V\Delta Q}{\Delta t}$$

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

$$P_{out} = VI$$

and $V = IR$

$$P_{out} = I^2R \quad \text{......(12.16)}$$

> **POINT TO PONDER**
> Since power is directly proportional to I^2 or V^2, if current through resistor or voltage across resistor is doubled then power will be?

A real source has some internal resistance. Substitute the value of current in terms of resistance 'r' from Eq.12.15 into Eq.12.16.

$$P_{out} = \frac{E^2}{(R+r)^2}R$$

$$= \frac{E^2 R}{(R-r)^2 + 4rR}$$

$$= \frac{E^2}{\frac{(R-r)^2 + 4rR}{R}}$$

$$P_{out} = \frac{E^2}{\frac{(R-r)^2}{R} + 4r} \quad ......(12.17)$$

If R = r then the denominator of Eq.12.17 is minimum and then the power P_{out} will be maximum. Thus, it is concluded that a load resistor 'R' will receive maximum power only if its resistance is equal to the internal resistance 'r' of the source of e.m.f. which may be a cell, battery or power supply etc. Hence, we get the value of maximum power by putting R = r in Eq.12.17.

$$P_{max} = \frac{E^2}{4r} \quad ......(12.18)$$

FOR YOUR INFORMATION

Table for power consumption of various household appliances.

Appliances	Power Consumption
Phone Charger	5w
LED	8w
Tube Light	22w
Computer Monitor	25w
LED TV (32")	30w
DVD Player	26w
Freezer	40w
Wall Fan	50w
Ceiling Fan	60w
Deep Freezer	70w
Laptop Computer	75w
Incandescent Bulb (100w)	100w
Refrigerator	150w
Television (25")	150w
Washing Machine	500w
Laser Printer	700w
Air Conditioner	2000w
Oven	2150w

Example 12.5

The potential difference of a cell on open circuit is 6V which falls to 4V when current of 2A is drawn from the cell. Find the internal resistance of the cell.

Solution:

Electromotive force of a cell = E = 6V

Potential difference = V = 4V

Current drawn from source = I = 2A

Internal resistance = r = ?

As we know

$$V = E - Ir$$

$$r = \frac{E - V}{I}$$

POINT TO PONDER

A same voltage of 220V is applied across the two bulbs but the resistance of one bulb is higher than the other. Explain which of the bulb glows more brightly?

$$r = \frac{6V - 4V}{2A}$$

$$r = 1\Omega$$

> ***FOR YOUR INFORMATION***
> A node is a point in an electric circuit which joins two or more branches. The total current at the nod is zero.

12.7 THERMOCOUPLE

A thermocouple produces a temperature dependent voltage as a result of the thermoelectric effect, and this voltage can be used to measure temperature. The thermocouple was discovered by the German physicist Thomas Johann Seeback in 1821. It consists of two wires of different metallic conductors forming an electrical junction as shown in Fig.12.9, such that one junction is the cold and the other junction is hot. If the temperature difference between these two junctions exists, then an e.m.f. of a few millivolt can be obtained. It is measured by a device attached with the thermocouple.

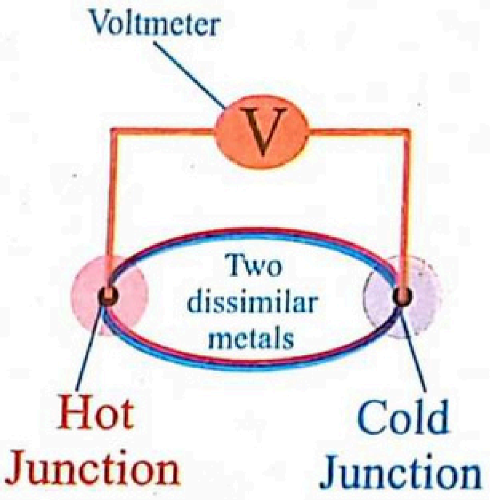


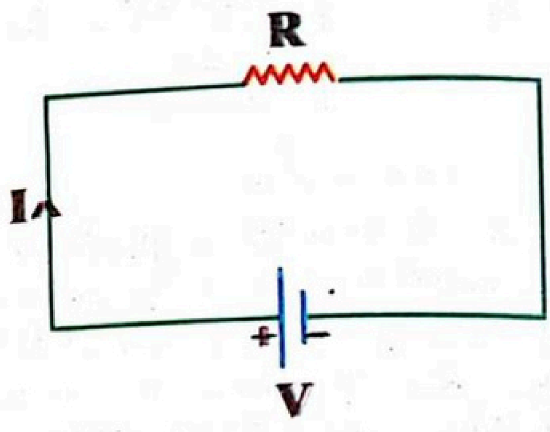
Fig.12.9 A schematic diagram of a thermocouple.

For example, let one wire is of bismuth and the other one is the antimony. If the one junction is placed in melting ice of temperature 0°C and the other one is at temperature 100°C then an e.m.f. of about 10mV is produced for a temperature difference of 100°C. If the temperature of both the junction is same, equal and opposite e.m.f. will be produced at both junctions and the resultant current flowing through the junction is zero. Thus, the total e.m.f. of a thermocouple does not only depend upon the nature of the metal of the wires but also on the temperature difference between two junctions.

Thermocouple are widely used in science and industry. Their applications include temperature measurement for furnaces, gas turbine exhaust, diesel engines, and other industrial processes. They are also used in homes, offices and markets as the temperature sensors in thermostats and as flame sensors in safety devices.

12.8 KIRCHHOFF'S LAW

An electric circuit consists of a source of e.m.f. and a number of resistors connected in either series or parallel. When potential difference 'V' is applied then there is flow of current 'I' through a resistor. The specification of the three parameters, i.e., the applied voltage, current and resistance for a given circuit is termed as circuit analysis. When the circuit is simple, which consists of a single source and a single resistor, then we can apply Ohm's law for its analysis. However, when the circuit is complex, which contains more than one source and a number of resistors then we cannot use Ohm's law directly for its analysis. For this, Kirchhoff has introduced two rules known as Kirchhoff's rules or Kirchhoff's laws. In the first rule, we can determine the flow of current in different branches of the circuit with the help of node in the given circuit. While, in the second rule, we can determine the voltage drop by using loop.



A simple circuit contains a single source of e.m.f. and a single resistor.

Node: A point in an electric circuit where two or more branches meet is called node or junction. The current at such point (node) has its minimum value.

Loop: A closed path in an electric circuit is called loop.

12.8.1 Kirchhoff's current law

The Kirchhoff's first law is also known as Kirchhoff's current law (KCL). This law is based upon law of conservation of charges and it is stated as **"the algebraic sum of current at node point in an electric circuit is zero"**, that is,

$$\sum I = 0 \;\ldots\ldots(12.19)$$

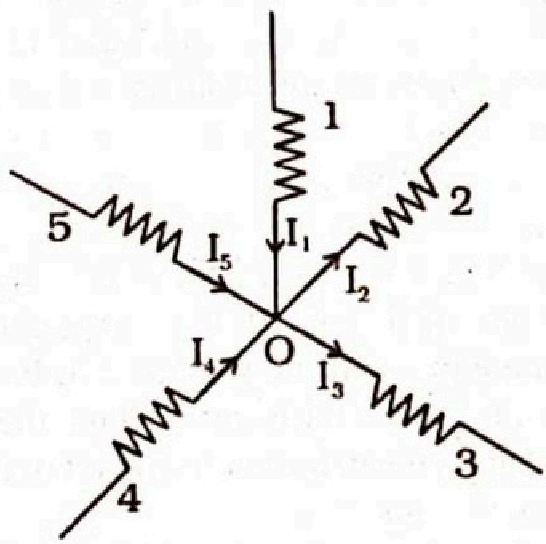


Fig.12.10 The sum of flow of current towards the node equals to the sum of flow of current away from the node.

Consider five resistors which meet at a node point 'O' as shown in Fig.12.10. The currents I_1, I_4 and I_5 are flowing towards the node and the current I_2 and I_3 are flowing away from the node. If we take the current flowing towards the node as positive and the current flowing away from the node as negative, then by applying Kirchhoff's current law at the node point 'O' we have;

$$I_1 + I_4 + I_5 + (-I_2) + (-I_3) = 0$$

$$I_1 + I_4 + I_5 = I_2 + I_3 \;\ldots(12.20)$$

This is a mathematical form of KCL and it shows that the sum of current entering any node in circuit must be equal to the sum of the

> ***DO YOU KNOW?***
> **The node which potential is taken as zero called datum node.**

currents leaving that node. In other words, the amount of charge arriving at the node is equal to the amount of charge leaving the node. This is named as conservation of charges.

Node analysis

Node analysis is based upon KCL and a number of steps are employed for the analysis of a given circuit. These steps are summarized as

1. Label all the nodes. i.e., the points in a circuit where two or more elements are met.
2. Mark the potential of the nodes such as: V_1, V_2, V_3 etc.
3. Identify the node at which potential is zero. Such node is called reference or datum node.
4. Apply KCL at each node except the datum node where incoming current is taken as positive and the outgoing as negative.
5. Determine the number of equations which are equal to the number of nodes excluding the datum node.
6. Solve all the obtained equations simultaneously and calculate the unknown required quantities.

Example 12.6

Calculate the currents I_1, I_2 and I in the given electric circuit as shown in Fig.12.11.

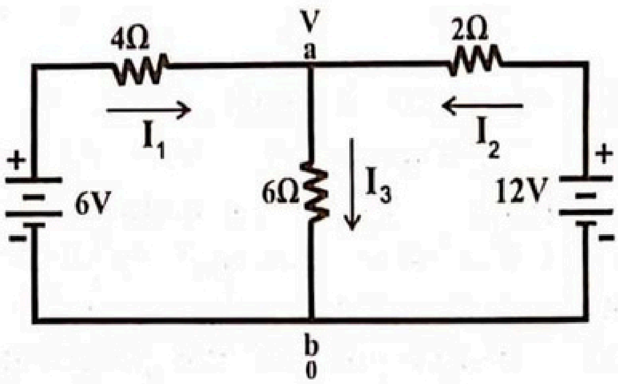


Fig.12.11

Solution:

We have

$$R_1 = 4\Omega$$
$$R_2 = 2\Omega$$
$$R_3 = 6\Omega$$
$$E_1 = 6V$$
$$E_2 = 12V$$
$$I_1 = ?$$
$$I_2 = ?$$
$$I_3 = ?$$

> ***FOR YOUR INFORMATION***
> A loop is a closed path in an electric circuit. The total voltage drop in the loop is taken as zero.

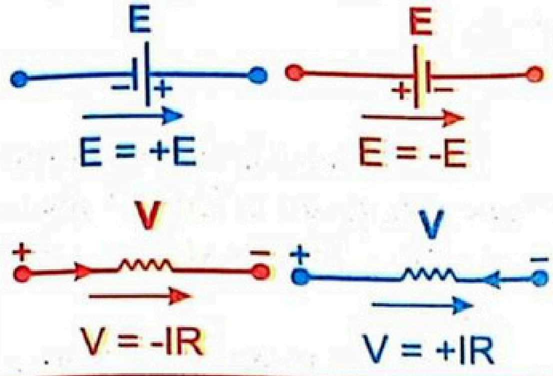
Applying KCL on node 'a' which is at potential 'V'. The potential of node 'b' is taken 0.

$$I_1 + I_2 - I_3 = 0 \quad ......(12.21)$$

But according to Ohm's law

FOR YOUR INFORMATION

Signs for E and I



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

Eq. 12.21 becomes

$$\frac{E_1 - V}{R_1} + \frac{E_2 - V}{R_2} - \frac{V - 0}{R_3} = 0$$

$$\frac{6 - V}{4} + \frac{12 - V}{2} - \frac{V}{6} = 0$$

$$18 - 3V + 72 - 6V - 2V = 0$$

$$11V = 90$$

$$V = 8.18V$$

Thus

$$I_1 = \frac{E_1 - V}{R_1} = \frac{6 - 8.18}{4} = -0.4545\,A$$

$$I_2 = \frac{E_2 - V}{R_2} = \frac{12 - 8.18}{2} = 1.91A$$

$$I_3 = \frac{V}{R_3} = \frac{8.18}{6} = 1.36A$$

12.8.2 Kirchhoff's voltage law

The Kirchhoff's second law is also known as Kirchhoff's Voltage Law (KVL). This law is based upon the law of conservation of energy and it is stated as **"the algebraic sum of the potential difference in a closed loop is equal to zero"**, that is;

$$\sum V = 0 \;......(12.22)$$

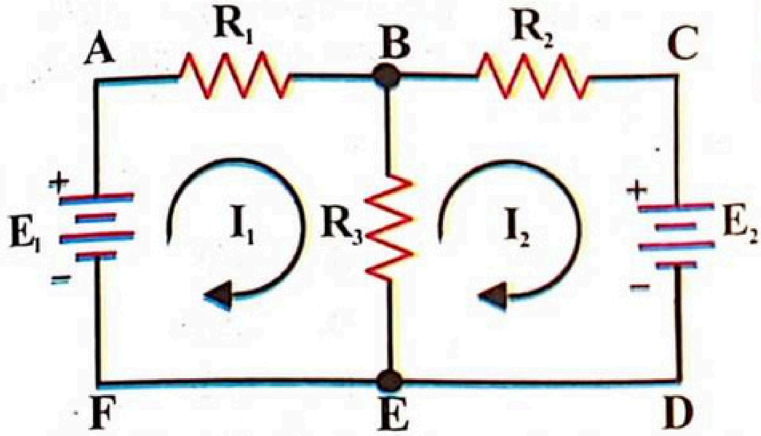


Fig.12.12 An electrical circuit consist of two loops with two sources of e.m.f. and three resistors.

In order to explain Kirchhoff's voltage law, we consider an electrical circuit which consist of two loops ABEF and BCDE with two sources of e.m.f. E_1 and E_2 as shown in Fig. 12.12. The voltage drop across resistors R_1, R_2 and R_3 are taken as V_1, V_2 and V_3 respectively. While applying KVL, it is very important to assign proper signs to voltage drop and e.m.f. in the given closed circuit. In this regard, the flow of the current in each loop is taken as clockwise. That is, when current passes through a resistor 'R' in clockwise direction than there is fall in potential because current flows a higher to a lower potential. So the term IR is taken as negative. For anticlockwise direction, there is rise in potential because current flows a lower to a higher potential. Hence the term IR is taken as positive. Similarly, if the direction of the current is from negative terminal to positive terminal of the battery then there is rise in potential and E is taken as positive. When the direction of current is from positive terminal to negative terminal of the battery then there is fall in potential and E is taken as negative. Hence under these conditions, we apply KVL on the given two loops:

Loop ABEF

$$E_1 - V_1 - V_3 = 0$$

$$E_1 - I_1R_1 - (I_1 - I_2)R_3 = 0 \qquad \ldots\ldots(12.23)$$

Loop BCDE

$$-E_2 - V_2 - V_3 = 0$$

$$-E_2 - (I_2 - I_1)R_2 - I_2R_3 = 0 \qquad \ldots\ldots(12.24)$$

Loop analysis

Loop analysis is based upon KVL and a number of steps are employed for the analysis of the given circuit. These steps are summarized as

1. Identify the number of loops in the given circuit.
2. The current must be taken as clockwise in each loop.
3. Label the current in each loop such as I_1, I_2, I_3 etc.
4. Apply KVL for each loop.
5. Determine the number of equations. Note that the number of equations is equal to the number of loops.
6. Solve the equations and calculate the unknown quantities.

Example 12.7

Determine the current in each loop of the circuit which consists of three resistors of resistance 1Ω, 2Ω and 3Ω respectively and two sources of e.m.f. as shown in Fig.12.13. The potential differences of the two sources are 5V and 10V.

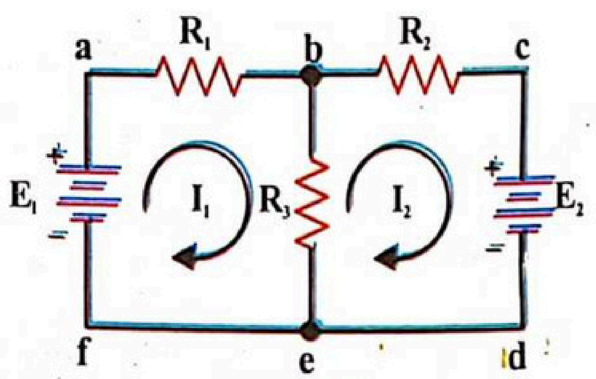


Fig.12.13

Solution:

We have

$$R_1 = 1\Omega$$
$$R_2 = 2\Omega$$
$$R_3 = 3\Omega$$
$$E_1 = 5V$$
$$E_2 = 10V$$
$$I_1 = ?$$

$$I_2 = ?$$

By applying KVL to the loop abef

$$I_1R_1 + (I_1 - I_2)R_3 - E_1 = 0$$

$$I_1(1) + (I_1 - I_2)(3) - 5 = 0$$

$$-4I_1 - 3I_2 = 5 \;......(12.25)$$

Again by applying KVL to the loop bcde

$$(I_2 - I_1)R_3 + I_2R_2 + E_2 = 0$$

$$(I_2 - I_1)(3) + I_2(2) + 10 = 0$$

$$-3I_1 + 5I_2 = -10 \;......(12.26)$$

Multiplying eq. 12.25 by 5 and eq. 12.26 by 3 then adding them

$$20I_1 - 15I_2 = 25$$

$$-9I_1 + 15I_2 = -30$$

$$11I_1 + 0(I_2) = -5$$

Or $$I_1 = -\frac{5}{11}A\;]$$

From eq. 12.26

$$5I_2 = -10 + 3I_1 = -10 + 3\left(\frac{-5}{11}\right) = -10 - \frac{15}{11}$$

$$5I_2 = \frac{-125}{11}$$

Or $$I_2 = -\frac{25}{11}A$$

The negative signs of I_1 and I_2 indicate that these currents are in the anticlockwise direction i.e. opposite to assumed clockwise direction.

Example 12.8

An electrical network consists of five resistors R_1, R_2, R_3, R_4 and R_5 of resistance $3\Omega, 5\Omega, 2\Omega, 6\Omega$ and 4Ω respectively are connected with a source of e.m.f. (E) about 2V as shown in Fg.12.14. Calculate the current in each resistance.

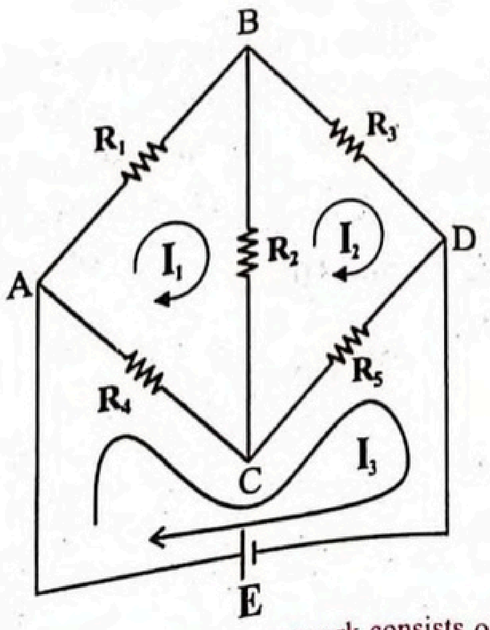


Fig.12.14 An electric network consists of five resistance and a source of e.m.f.

Solution:

We have

$$R_1 = 3\Omega$$

$$R_2 = 5\Omega$$
$$R_3 = 2\Omega$$
$$R_4 = 6\Omega$$
$$R_5 = 4\Omega$$
$$E = 2V$$
$$I_1 = ?$$
$$I_2 = ?$$
$$I_3 = ?$$

Applying KVL to the three loop of the given circuit.

Loop ABCA

$$-I_1R_1 - (I_1 - I_2)R_2 - (I_1 - I_3)R_4 = 0$$
$$-3I_1 - (I_1 - I_2)5 - (I_1 - I_3)6 = 0$$
$$-14I_1 + 5I_2 + 6I_3 = 0$$

or $$14I_1 - 5I_2 - 6I_3 = 0 \quad ......(12.27)$$

Loop BCDB

$$-I_2R_3 - (I_2 - I_1)R_2 - (I_2 - I_3)R_5 = 0$$
$$-2I_2 - 5(I_2 - I_1) - 4(I_2 - I_3) = 0$$
$$5I_1 - 11I_2 + 4I_3 = 0 \quad ......(12.28)$$

Loop ACDA

$$-(I_3 - I_1)R_4 - (I_3 - I_2)R_5 + E = 0$$
$$-6(I_3 + I_1) - 4(I_3 - I_2) + 2 = 0$$
$$6I_1 + 4I_2 - 10I_3 = -2 \quad ......(12.29)$$

Multiplying Eq.12.27 by 4 and Eq.12.28 by 6 and adding them

$$56I_1 - 20I_2 - 24I_3 = 0$$
$$30I_1 - 66I_2 + 24I_3 = 0$$
$$86I_1 = 86I_2$$
$$I_1 = I_2 \quad ......(12.30)$$

Now Eq.12.27 becomes

$$14I_1 - 5I_2 - 6I_3 = 0$$
$$9I_1 - 6I_3 = 0$$
$$3I_1 = 2I_3$$
$$I_3 = \frac{3}{2}I_1 \quad ......(12.31)$$

Putting the values of I_2 and I_3 from Eq.12.30 and Eq.12.31 in Eq.12.29 we get

$$6I_1 + 4I_1 - 10\cdot\left(\frac{3}{2}I_1\right) = -2$$

$$-5I_1 = -2$$

$$I_1 = \frac{2}{5} = 0.4A$$

$$I_2 = \frac{2}{5} = 0.4A$$

$$I_3 = \frac{3}{2}I_1 = 0.6A$$

> ***POINT TO PONDER***
> Why is a three pin plug used in some electrical appliances?

Thus, current through $R_1 = I_1 = 0.4A$

current through $R_2 = I_1 - I_2 = 0$

current through $R_3 = I_2 = 0.4A$

current through $R_4 = I_3 - I_1 = 0.2A$

current through $R_5 = I_3 - I_2 = 0.2A$

12.9 RHEOSTAT

A rheostat is a variable resistance used to control the current or as a voltage divider to control voltage in an electric circuit. It is connected in series with a load resistor to adjust the current by increasing or decreasing its resistance. A rheostat is made by winding the nichrome (resistance) wire around an insulating ceramic core in a cylindrical form as shown in Fig.12.15(a). It has three terminals A, B and C such that the terminal A and terminal B are fixed at the two ends of the resistance coil while the terminal C is the adjustable terminal connected with a slider contact. The slider contact is connected with the resistance coil and it can move along the coil from

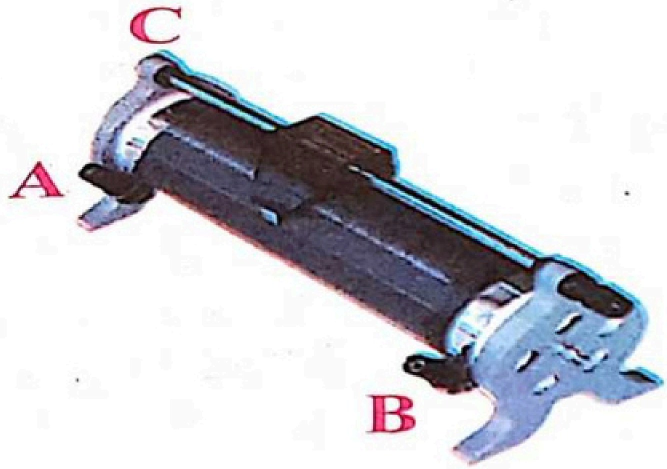


Fig.12.15(a) A Rheostat

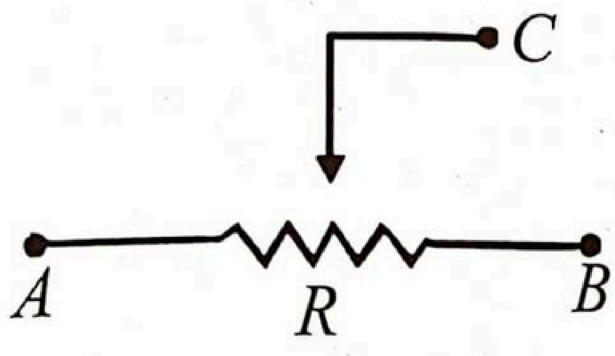


Fig.12.15(b) Circuit diagram of a Rheostat

its one end to the other end. The resistance of the rheostat is varied when the slider is moved over its resistive path. The equivalent circuit of rheostat is shown in Fig.12.15(b) In order to get a variable resistance from rheostat, the set of connections A and C or B and C are used in the circuit.

Rheostat as a variable resistance

The resistance of rheostat depends upon its resistive path. For example, let we use the terminals A and C. Now if the slider is moved towards the terminal 'A' and when they are close to each other than the rheostat offers minimum resistance and allows a large amount of current. Similarly, if the slider is moved towards the terminal 'B' and they are close to each other, then the rheostat offers a maximum resistance and allows a small amount of current. This is the function of a rheostat as a variable resistance.

Rheostat as a potential divider

A rheostat can also be used as a potential divider. For instance, supply voltage E is applied across the fixed terminals 'A' and 'B' as shown in Fig.12.16. The applied potential E is divided by the variable terminal 'C' connected with the slider in the ratio of the resistance between AC and BC. Let 'R' be the total resistance of the rheostat between the fixed terminal A and B then the flow of current between them can be calculated by using Ohm's law

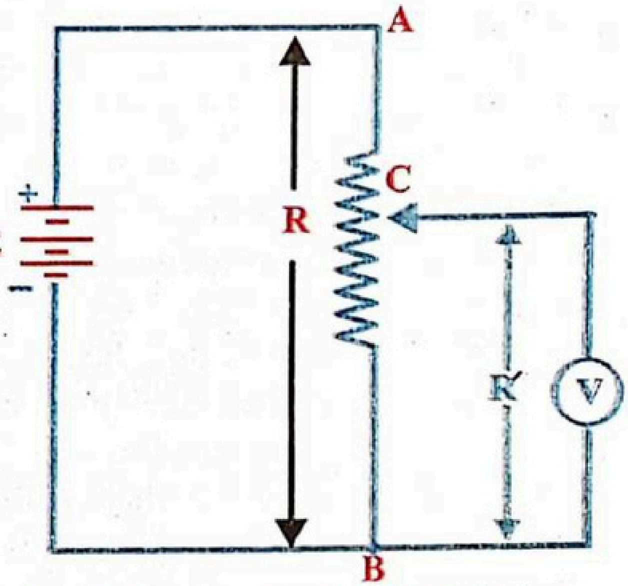


Fig.12.16 A rheostat as a potential divider.

$$E = IR$$

$$I = \frac{E}{R} \quad \text{...(12.32)}$$

Similarly, let R' be the resistance between the fixed terminal 'B' and the variable sliding terminal 'C' then the potential difference V across BC is given by

$$V = IR' \quad \text{......(12.33)}$$

Putting the value of I from eq. 12.32 in eq. 12.33

$$V = \frac{E}{R}R'$$

$$V = \left(\frac{R'}{R}\right)E \quad \text{......(12.34)}$$

This is the basic principle of rheostat as a potential divider, that is the potential difference 'V' varies by varying the resistance R'.

12.10 WHEATSTONE BRIDGE

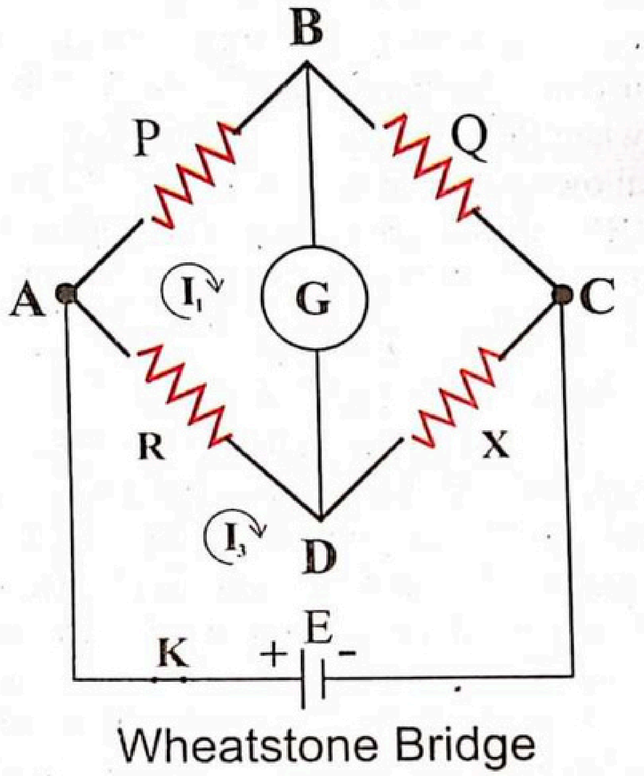


Fig.12.17 A Wheatstone bridge circuit consists of four resistors with a source of e.m.f.

A Wheatstone bridge is an electrical network which is used to measure the unknown resistance. It was introduced by Charles Wheatstone. It consists of four resistances 'P', 'Q', 'R' and 'X', such that the value of resistances P and Q are known. The value of the resistance R is also known but it is variable, and the value of the resistance X is unknown, which is to be determined. All the resistances are connected in the form of a closed loop ABCDA as shown in Fig.12.17. The source of e.m.f. is connected across the junctions A and C and the galvanometer is connected across the junctions B and D. This electrical network is called a bridge, because, the galvanometer bridges the two circuit branches by a third branch B and D. When the key (K) is closed then there is flow of current through galvanometer. Now by varying the value of variable resistance 'R' until galvanometer shows no deflection that is, there is no flow of current through the galvanometer then the bridge is said to be balanced and this is the working principle of the Wheatstone bridge.

Fig.12.16 shows that there are three loops ABDA, BCDB and ADCA having current I_1, I_2 & I_3 respectively. If we take all the current clockwise then by applying KVL to we get first two loops.

For loop ABDA

$$I_1P+(I_1-I_2)G+(I_1-I_3)R=0 \quad ......(12.35)$$

For loop BCDB

$$I_2Q+(I_2-I_3)X+(I_2-I_1)G=0 \quad ......(12.36)$$

As the flow of current through galvanometer is zero, so

$$I_1-I_2=0 \quad \text{i.e.,} \quad I_1=I_2$$

Thus Eq.12.35 and Eq.12.36 become

$$I_1P = -(I_1 - I_3)R \quad ......(12.37)$$

$$I_2Q = -(I_2 - I_3)X$$

But

$$I_1 = I_2$$

$$I_1Q = -(I_1 - I_3)X \quad ......(12.38)$$

Dividing Eq.12.38 by Eq.12.37

$$\frac{Q}{P} = \frac{X}{R}$$

$$X = R\frac{Q}{P} \quad ......(12.39)$$

Thus, to determine the value of the unknown resistance we can use Eq.12.39. It is true only, under the balanced condition of the bridge i.e., when the flow of current through the galvanometer is zero.

12.11 POTENTIOMETER

A potentiometer is a device used to measure the unknown potential difference or to compare the e.m.f. of sources. Although, we have other devices for the measurement of potential difference between two points, such as, voltmeter, cathode ray oscilloscope etc., but the potentiometer has more advantages over the others. For example, a potentiometer is a simple, inexpensive, has high degree of accuracy and does not draw any current.

A potentiometer consists of a long conducting wire with uniform area of cross-section. Usually its length is 4m to 5m which is stretched on a wooden board as shown in Fig.12.17. A potentiometer contains three terminals A, B and C. The terminal 'A' and the terminal 'B' are at the two opposite ends of the potentiometer. The terminal 'C' through galvanometer is connected with the Jockey and it can slide over the wire AB. A cell which is known as the divider cell is used across the ends of the wire. With the help of rheostat, a constant potential difference can

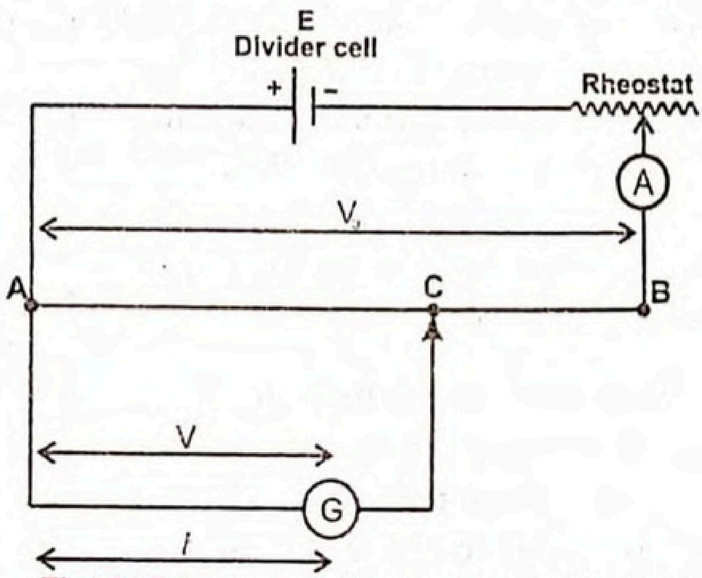


Fig.12.17 A schematic diagram of a potentiometer.

be maintained across the ends of the wire. An ammeter is also used in order to observe the current in the given circuit.

As the wire is of uniform cross-section therefore the potential difference 'V_0' across the two fixed terminals 'A' and 'B' is uniformly distributed over the entire length AB of the wire. However, the potential difference 'V' between the terminal 'A' and the sliding contact point 'C' is proportional to the length of wire between them. If ℓ be the length between terminals 'A' and 'C'. Then

$$V \propto \ell$$

$$V = k\ell$$

$$k = \frac{V}{\ell} \quad ......(12.40)$$

Where 'k' is constant known as potential gradient, i.e., fall of potential per unit length.

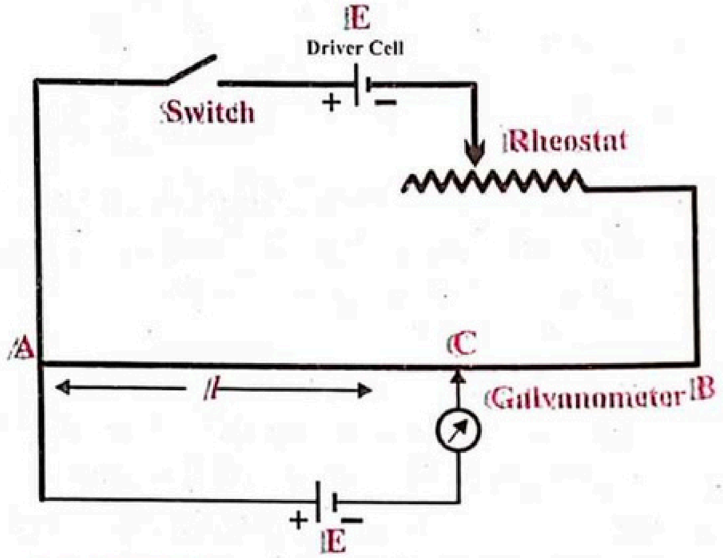
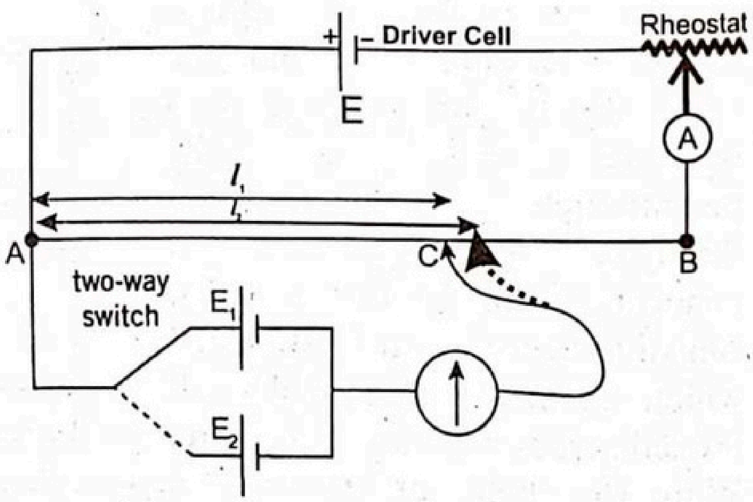


Fig.12.18 Measurement of e.m.f. of a cell by using potentiometer.

Determination of potential difference by potentiometer

A potentiometer can be used to measure the potential difference between two points in an electric circuit. Fig.12.18 shows how the potentiometer can be used to determine the e.m.f. (E_1) of a cell. The positive terminal of the given cell is connected with the positive terminal of the driver cell and the negative terminal of E is connected with the jockey through the galvanometer. Now the sliding contact jockey is tapped along the slide wire AB until the galvanometer shows no deflection, i.e. the current through the galvanometer is zero. Then the e.m.f. of the given cell (E) is equal to the potential difference across the points A and C of length ℓ.



Comparison of e.m.f. of two cells by potentiometer

A potentiometer can also be used to compare the e.m.f. of two cells. The arrangement for comparing the e.m.f. of two cells as shown in

Fig.12.19 which consists of two cells E_1, and E_2. The e.m.f. of cell E_1 is known and it is called standard cell, while, the e.m.f. of cell E_2 is unknown. It is called a test cell and its e.m.f. is to be compared with the standard cell. The positive terminals of the cells are connected with the positive terminal of the driver cell. The negative terminals of the cells are connected to the two terminals of two way key. The third common terminals of the two way key is connected to jockey through the galvanometer. An ammeter is also used for the measurement of current flowing in the circuit.

Let ℓ_1 be the balanced length from the terminal A to the terminal C, for standard cell (E_1), then

$$\text{e.m.f. of cell } (E_1) = \text{P.D across the length } \ell_1.$$

$$E_1 = k\ell_1 \quad ......(12.41)$$

Similarly, let 'ℓ_2' be the balanced length between A and 'C' for test cell (E_2), then

$$E_2 = k\ell_2 \quad ......(12.42)$$

Dividing Eq.12.41 by Eq.12.42

$$\frac{E_1}{E_2} = \frac{\ell_1}{\ell_2} \quad ......(12.43)$$

This result shows that the ratio of the e.m.f.s is equal to the ratio of balancing lengths and this is the working principles of comparing of e.m.f. of two cells.

SUMMARY

- **Electric Current:** The rate of flow of charges through a conductor is called electric current.
- **Ampere:** If one coulomb charge is moving through a point in the given circuit in one second then its corresponding current is one ampere.
- **Steady Current:** A continuous flow of current whose magnitude remains constant is known as steady current.
- **Ohm's Law:** This law states that at constant temperature, the applied voltage across the conductor is directly proportional to the current. Mathematically,

$$V = IR$$

- **Resistance:** Resistance is the measurement of opposition to the flow of electric current, its SI unit is ohm.
- **Conductance:** The reciprocal of the resistance is called conductance.
- **Resistivity:** The resistance in one metre cube of a conductor is called its resistivity or specific resistance.
- **Conductivity**: The reciprocal of resistivity is called conductivity.

- **Thermistor:** Thermistors is a temperature dependent resistor, its resistance varies even with small change of temperature. Most thermistor have negative temperature coefficient of resistance.
- **Electromotive Force:** The work done by the source per unit charge to move the charge in a circuit from the low potential to the high potential is called electromotive force.
- **Thermocouple:** A thermocouple is an electric device to produce an e.m.f. by heat and it is being used to measure the temperature.
- **Kirchhoff's First Law:** The algebraic sum of current at a junction in an electric circuit is equal to zero.
- **Kirchhoff's Second Law:** The algebraic sum of potential difference in a closed loop or closed electric circuit is equal to zero.
- **Rheostat:** A rheostat is a variable resistance used to control the electric current.
- **Wheatstone Bridge:** A Wheatstone bridge is an electric circuit used to measure the unknown resistance.
- **Potentiometer:** A potentiometer is a device used to measure potential difference and e.m.f. of a source.

EXERCISE

Choose the best option.

1. A flow of 10^7 electrons per second through a conductor produces a current of
   (a) 1.6×10^{-12}A (b) 1.6×10^{12}A (c) 1.6×10^{-26}A (d) 1.6×10^{26}A
2. The first source of e.m.f. was discovered by
   (a) Ampere (b) Volta (c) Ohm (d) Coulomb
3. Which one of the given cells is not rechargeable?
   (a) Laclanche (b) Nickel (c) Cadmium (d) Lead acid
4. Which one of the given sources converts light energy into electrical energy?
   (a) Dynamo (b) Generator (c) Photocell (d) Thermocouple
5. Which one of the following material is non-ohmic:
   (a) Gold (b) Germanium (c) Copper (d) Silver
6. What will be resistance of the wire when its length is doubled
   (a) Remain Same (b) Half
   (c) Double (d) Triple
7. If the resistivity of the conductor is $2\times10^{-6}\Omega m$ then its conductivity is
   (a) $2\times10^{6}\Omega^{-1}m^{-1}$ (b) $5\times10^{6}\Omega^{-1}m^{-1}$
   (c) $5\times10^{-5}\Omega^{-1}m^{-1}$ (d) $5\times10^{5}\Omega^{-1}m^{-1}$
8. Siemen is a unit of conductance and it is equal to

(a) ohm (b) mho (c) mho . m (d) mho .m^{-1}

9. When resistance of the material increases by increasing the temperature then the value of co-efficient of resistivity will be
(a) Constant (b) Zero (c) Positive (d) Negative

10. The unit of temperature co-efficient is
(a) °C (b) $°C^{-1}$ (c) °C . m (d) $°C^{-1}$. m

11. In the presence of internal resistance of the source, which one of the following relations between potential difference (V) and e.m.f. (E) is correct
(a) $E = 0$ (b) $E = V$ (c) $E > V$ (d) $E < V$

12. The unit of electromotive force is
(a) Newton (b) Joule (c) Watt (d) Volt

13. The source of e.m.f. transfers its maximum power to the external circuit when (r = internal resistance, R = load resistance)
(a) $r = 0$ (b) $r = R$ (c) $r < R$ (d) $r > R$

14. Kirchhoff's 1st law is based upon law of conservation of
(a) Current (b) Charge (c) Voltage (d) Energy

15. The node in an electric circuit which has zero potential is known as
(a) Node (b) Antinode (c) Negative node (d) Datum node

16. When the direction of current is from negative to positive terminal of the battery then 'E' is taken as
(a) Zero (b) Normal (c) Positive (d) Negative

17. If current passes through a resistor in anticlockwise direction. Then the electric potential will be
(a) Zero (b) Remain same (c) Raised (d) Fall down

18. An electrical device which controls the current is known as
(a) Thermocouple (b) Rheostat
(c) Thermistor (d) Wheatstone bridge

19. The electrical device which is being used to compare the e.m.f. of two cells is known as
(a) Rheostat (b) Wheatstone Bridge
(c) Potentiometer (d) Galvanometer

SHORT QUESTIONS

1. How does the conventional current differ from the electronic current?
2. How can you point out the direction of electric current?
3. What do you know about the drift of the free electrons in a conductor?
4. Which kind of current you observe in electrolyte plasma?
5. What are the functions of copper and zinc plates in the source of e.m.f.?
6. What do you know about the ohmic characteristics of a ohmic device?

7. Which type of graph will be obtained between V and I for non-ohmic conductor?
8. How does resistivity of a conductor depend upon temperature?
9. Distinguish between positive and negative temperature coefficients of resistance.
10. Under what condition, the potential difference and electromotive force give the same value.
11. When the source delivers its maximum power?
12. What is the working principle of a thermocouple?
13. What do you know about the circuit analysis?
14. What do you know about node and loop in an electric circuit?
15. What are the sign of currents when it flows toward and away from the node?
16. What are the basic principles of Kirchhoff's two laws?
17. Under what condition you use Kirchhoff's Laws for circuit analysis?
18. Which electrical device is being used as a potential divider?
19. What is the difference between Rheostat and Potentiometer?
20. What is the working principle of Wheatstone Bridge?

COMPREHENSIVE QUESTIONS

1. Define and explain steady current, direction of current and sources of current.
2. State and explain Ohm's law. Also discuss its applications for ohmic and non-ohmic devices.
3. What do you know about resistivity and conductivity of a conductor? Describe how the resistivity of a conductor depends upon the variation of its temperature.
4. Describe thermistor and its application in daily life.
5. What do you know about electromotive force and potential difference? Under what conditions, their values are same in an electric circuit.
6. What is electrical power? How does the maximum power transfer take place in an electric circuit?
7. What do you know about a thermocouple and its function?
8. State and explain Kirchhoff's two rules for circuit analysis.
9. State and explain node analysis and loop analysis by using Kirchhoff's two rules.
10. Describe a rheostat and its working principle. Explain how a rheostat can be used as a variable resistance as well as a potential divider.
11. What do you know about Wheatstone bridge? Draw its circuit diagram and explain its working principle.
12. State and explain potentiometer, its function and applications.

NUMERICAL PROBLEMS

1. How many electrons flow through a light bulb each second, if the current through the bulb is 0.8A. **(5×10^{18})**
2. A flow of charges of 150C through a wire in 2 hours what is the amount of current in the wire. **(21mA)**
3. A metal rod is 4m long and 6mm in diametre. Compute its resistance if the resistivity of the metal is $1.76 \times 10^{-8} \Omega m$. **($2.5 \times 10^{-3} \Omega$)**
4. Calculate the potential difference across the two ends of the wire of resistance 5Ω. If the charges of 720C pass through it per minute. **(60V)**
5. A 10m long wire of diametre 0.2cm has a resistance 3Ω. Find the resistivity of the material of the wire also calculate its conductivity. **($9.4 \times 10^{-7} \Omega m$, $1.06 \times 10^{6} \Omega^{-1} m^{-1}$)**
6. The resistance of a coil is 140Ω at 20°C. If current is passed through it, its temperature rises, and its resistance becomes 160Ω at 40^0C. Calculate the temperature co-efficient of resistance of the coil. **(0.0071^0C^{-1})**
7. A copper wire has resistance of 3Ω at 0^0C. What is its resistance at 60^0C. The temperature coefficient of resistance of copper is 0.0039^0C^{-1}. **(3.77Ω)**
8. A battery has an e.m.f. of 12.5v and an internal resistance of $2.4 \times 10^{-3} \Omega$. If the load current is 20A. Find the terminal voltage. **(12.45V)**
9. Determine the current through each resistor in the electric circuit as shown in Fig.12.20, where R_1 is 10Ω, R_2 is 6Ω, R_3 is 10Ω, E_1 is 6V and E_2 is 3V. **($I_1 = 0.3A, I_2 = 0, I_3 = 0.3A$)**
10. Find the current through each resistor in the electrical network as shown in Fig.12.21. **($I_1 = 0.21A, I_2 = 0.14A, I_3 = 0.36A$)**
11. If the e.m.f. of a battery is balanced by a length of 80cm on a potentiometer wires while, the e.m.f. of 1.03v of a standard cell is balanced by a length of 55cm. Then determine the e.m.f. of the battery? **(1.5V)**

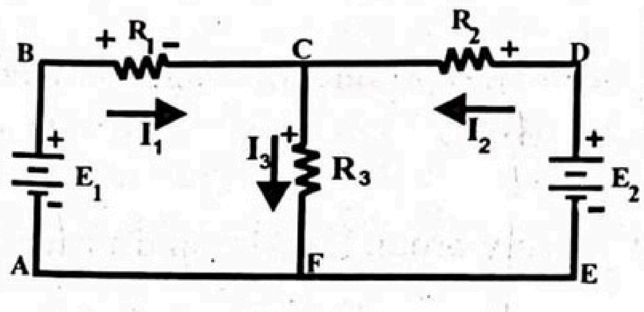


Fig.12.20

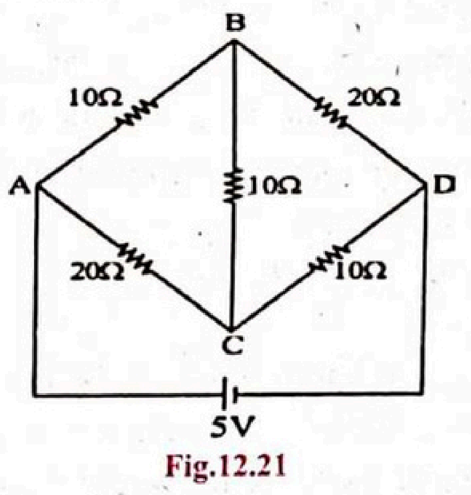


Fig.12.21