UNIT 12

.....Current Electricity.....

After studying this chapter the students will be able to

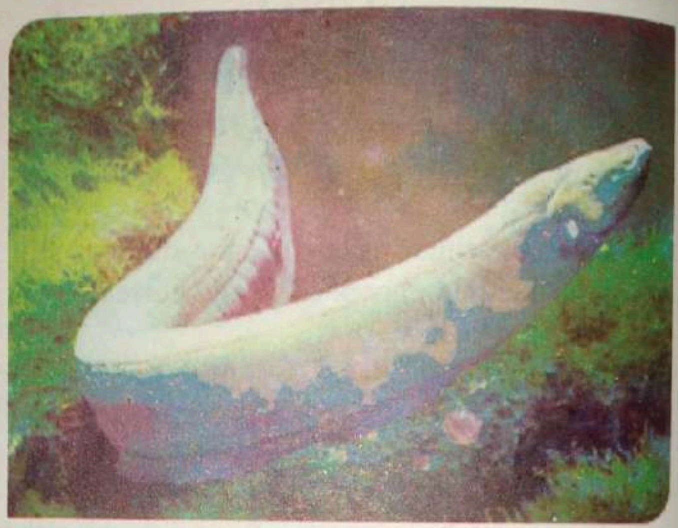
- describe the concept of steady current.
- state Ohm's law.
- define resistivity and explain its dependence upon temperature.
- define conductance and conductivity of conductor.
- state the characteristics of a thermistor and its use to measure low temperatures.
- distinguish between e.m.f and p.d. 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 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.

Current electricity is the study of charges in motion. Simple electrical circuits can be solved by applying Ohm's law. For other circuits, Kirchhoff rules are applied.

We all enjoy the comforts and benefits of using electricity. Electricity has characteristics that have made it uniquely appropriate for powering an emerging technological society. Electricity is also relatively easy to distribute.

Electricity authorities use high-voltage transmission lines and transformers to distribute electricity to homes and industries in a town. Voltages can be as high as 5×10^5 volts from power stations but by the time this reaches homes, the electricity has been transformed to 220 volts in Pakistan. While it is relatively economical to generate electric power at a steady rate, there are both financial and environmental issues that should be considered when assessing the long-term impact of supplying commercial and household power.

For Your Information



The electric eel is an electric fish which is capable of generating powerful electric shocks of up to 600 volts. It uses electric shock for hunting and self-defense.

In making transition from electrostatics to moving charges, we have to study phenomena like magnetic field produced due to the motion of charges, resistance offered but the materials to the moving charges through them and lastly the dissipation of energy when the charges move through the conductors. In this chapter we shall discuss briefly the various features associated with the moving charges.

12.1 STEADY CURRENT

The continuous flow of free electrons is called steady current. The flow of electronic current can be easily explained by referring Fig 12.1 The conductor has a large number of free electrons when electric field or voltage is applied, then free electrons, being negatively charged, will start moving towards the positives terminal around the circuit.

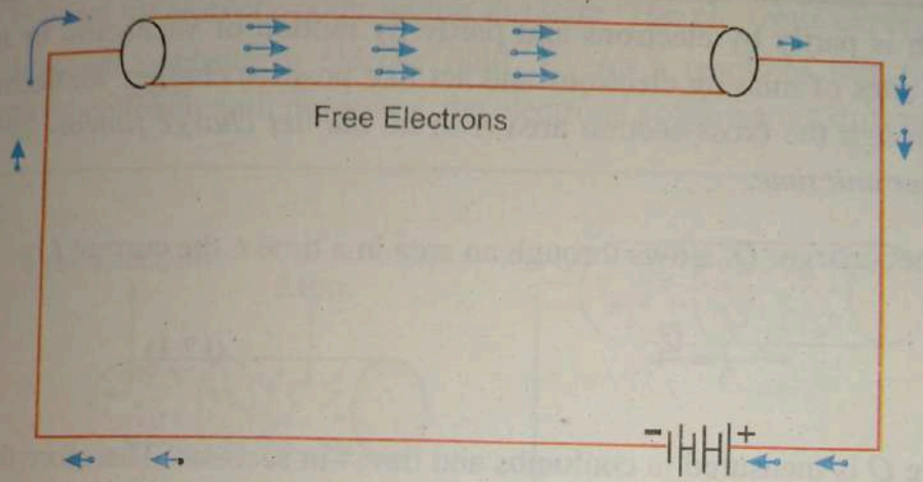


Fig: 12.1: Flow of electrons in a conductor.

This directed flow of electrons is called electric current.

Following are the main points:

1. Current is due to flow of electrons and electrons are the constituents of matter. Therefore, electric current is matter (i.e. free electrons) in motion.
2. The actual direction of current is from negative terminal to the positive terminal throughout that part of the circuit external to the cell. However, prior to electron theory, it was assumed that current flows from positive terminal to the negative terminal of the cell via the circuit. This convention is so firmly established that it is still in use. This assumed direction is now called conventional current.
3. Those substances which have larger number of free electrons will permit current flow easily. Such substances are called conductors, for example Copper, Zinc, Silver, Aluminum etc.

In different current carrying materials the charges on the moving particles may be positive or negative. In metals the moving charges are always electrons (negative charges). While in gases the moving charges are negative and positive ions. In semiconductor material such as germanium or silicon conduction is partly by electrons and partly by motion of vacancies, or holes. These are sites of missing electrons and act like positive charges we define the current through the cross-section area A to be *the net charge flowing through the area per unit time.*

Thus if a net charge 'Q' flows through an area in a time t, the current I is

$$I = \frac{Q}{t} \qquad (12.1)$$

The charge Q is measured in coulombs and time t in seconds. Therefore the unit of electric current will be coulombs/sec or ampere (A). *One ampere is the current when one coulomb of charge flows across any cross section of a conductor in one second.* The submultiples of ampere are:

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

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

Do you know?

Current is a scalar quantity as it does not follow vector law of addition.

12.2 DRIFT VELOCITY IN CONDUCTOR

Every metal has a large number of free electrons which wander randomly within the body of the conductor. The average speed of free electrons is sufficiently high ($\approx 10^5\ \text{ms}^{-1}$). During random motion, the free electrons collide with atoms of conductor again and again and after each collision their direction of motion changes. Due to random motion of all free electrons there is no net flow of charges in any particular direction.

Consequently no current is established in the conductor.

When the potential difference is applied across the ends of a conductor, an electric field $\bar{E}$ is set up at every point within the wire. The electrons experience a force in a direction opposite to electric field, $\bar{E}$. As a result of this force and the continuous collision with the atoms, the electrons acquire a net drift velocity.

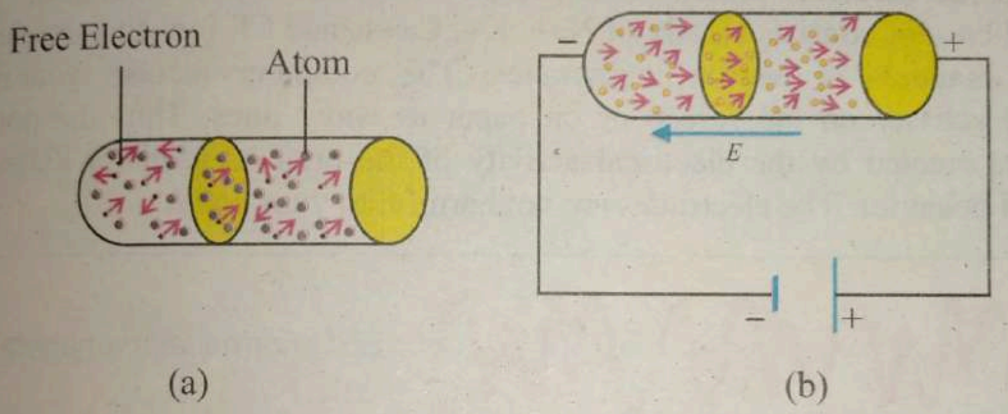


Figure 12.2 : drift of free electrons

The average velocity with which free electrons get drifted in a metallic conductor under the influence of electric field is called drift velocity ($\vec{V}_d$).

The drift velocity of free electrons is of the order of 10^{-5} m/s.

Do you know?

Now if electrons drift so slowly, how room light turns on quickly when switch is closed? The answer is that propagation of electric field takes place with the speed of light.

Electroencephalogram (EEG)

Electroencephalography, or EEG, is a neurological test that uses an electronic monitoring device to measure and record electrical activity in the brain. Special sensors (electrodes) are attached to your head and hooked by wires to a computer. EEG measures voltage fluctuations resulting from ionic current flows within the neurons of the brain. The brain's electrical charge is maintained by billions of neurons. Neurons are electrically charged (or "polarized ") by membrane transport proteins that pump ions across their membranes. Brain electrical current consists mostly of Na^+, K^+, Ca^{++}, and Cl^- ions that are pumped through channels in neuron membranes. The computer records your brain's electrical activity on the screen or on paper as wavy lines. Thus the potential difference created by the electrical activity of the brain is used for diagnosing abnormal behavior. The electrodes are not harmful to your body.

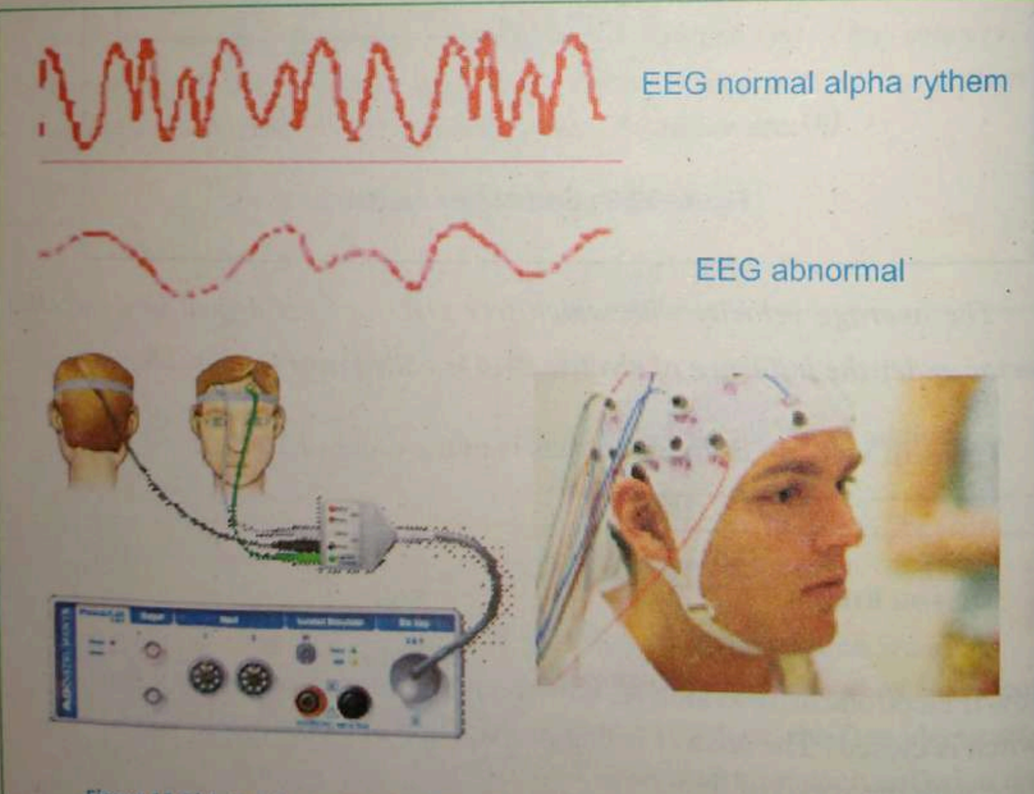


Figure 12.2(c): An electroencephalograph, or EEG, detects and measures electrical signals.

Example 12.1

Each second 10^{18} electrons flow from right to left across a cross-section of a wire attached to the two terminals of a battery.(a) Calculate the current in the wire, (b) in which direction the current is flowing.

Solution:

Electric current $I = \frac{Q}{t} = \frac{ne}{t}$

Here $n = 10^{18}$;

Charge on single electron: $e = 1.6 \times 10^{-19}$ C,

$t = 1$ s

$$I = \frac{10^{18} \times 1.6 \times 10^{-19}}{1} = 1.6 \times 10^{-1}\,\text{A} = 160\,\text{mA}$$

The current is flowing from left to right i.e. in opposite direction of electron flow.

12.3 OHM'S LAW

Many materials contain some 'free' electrons which can move in response to an applied electric field. By attaching a pair of metal wires and applying a voltage between them we can move these charge carriers through the material. Ohm's law is the most important, basic law of electricity. The relationship between the three fundamental electrical quantities: voltage (V), the current (I) and resistance (R) in a D.C. circuit was first discovered by German scientist George Simon Ohm in (1826). When a voltage is applied to a circuit containing only resistive elements, current flows according to Ohm's Law, which is $I = V / R$. If a voltage V is applied across a conductor and current (I) flows through it then according to ohm law

The magnitude of the current in metals is proportional to the applied voltage as long as the temperature of the conductor is kept constant.

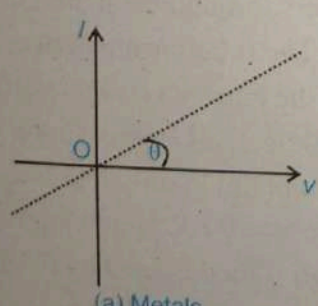
Mathematically $I \propto V \ or \ I = \frac{V}{R}$

or $V = IR$ (12.2)

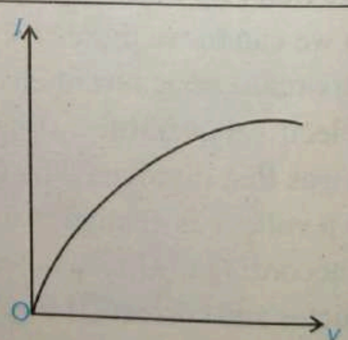
Where R is constant, which is known as the resistance of the conducting material. Resistance depends upon the nature, dimension and physical state of the conductor. For a conductor that obeys Ohm's law, a graph of current I as a function of voltage 'V' is a straight line passing through the origin Fig. (12.3(a).

The slope of the line is $\tan\theta = \frac{I}{V} = \frac{1}{R}$

As R is constant the slope is constant for ohmic conductors. The Ohm's law is not valid for all conducting material. Those materials for which the slope of I verses V graph is not constant are called non-Ohmic materials. For examples Fig 12.3 (b, c & d) illustrates the non-Ohmic characteristics of the filament of an electric bulb, a thermistor and of a semiconductor diode respectively. The I-V graph for a filament bulb shows that graph bends over as V and I increases, indicating that a given change of V causes a correspondingly smaller change in I at larger values of V. Thus slope decreases with the increase of voltage.



(a) Metals



(b) Filament bulb

Figure 12.3: V-I graph

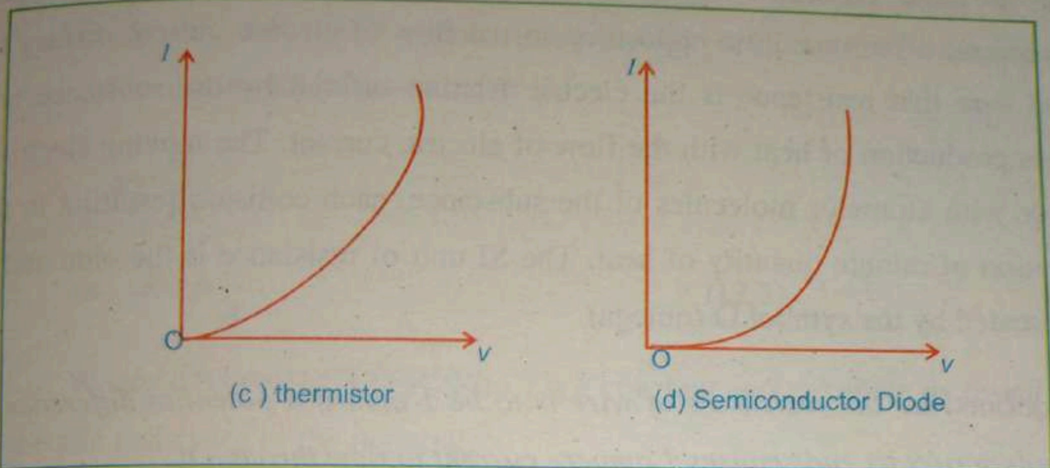


Figure 12.3: V-I graph

The I-V graph for thermistor bends upward shows that resistance decreases sharply as their temperature rises. The I-V graph of a semiconductor diode shows that it is also non-linear graph. The current passes when the voltage is applied in one direction but it is almost zero when its acts in the opposite direction.

Example: 12.2

The high voltage in a TV receiver is 17 kV. The maximum allowable current is 150μA. What is the least permissible value of load resistance?

Solution

$$V = 17\text{KV} = 17\times10^3\ \text{V}$$

$$I = 150\mu\text{A} = 150\times10^{-6}\ \text{A}$$

$$R = \frac{V}{I} = \frac{17\times10^3}{150\times10^{-6}} = 113.3\times10^6\,\Omega$$

12.4 ELECTRICAL RESISTANCE

Resistance is the opposition offered by the substance to the flow of free electrons. This opposition occurs because atoms and molecules of the substance obstruct the flow of these electrons. Certain substances (metals such as silver, copper, aluminium) offer very little opposition to the flow of electric current. It may be noted here that resistance is the electric friction offered by the substance and causes production of heat with the flow of electric current. The moving electrons collide with atoms or molecules of the substance, each collision resulting in the liberation of minute quantity of heat. The SI unit of resistance is the ohm and is represented by the symbol Ω (omega).

It is defined as, *the resistance of wire is to be 1 ohm if a potential difference of one volt across its ends causes 1 ampere current to flow through it.*

$$1\Omega = \frac{1V}{1A}$$

12.4.1 FACTORS UPON WHICH RESISTANCE DEPENDS

When electrons flow through a wire they experience resistance and lose energy, as the electrons flow on longer path they lose more energy. It is observed experimentally that the total resistance of a wire

1) Is directly proportional to its length i.e.

$$R \propto L$$

2) Is inversely proportional to its area of cross-section i.e.

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

Therefore thicker wires have less resistance per meter and will cause less energy to be lost as heat.

3) Depends upon the nature of material

4) Is directly proportional to the temperature.

From the first three points (keeping the temperature constant), the resistance of a conductor is,

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

or $$R = \rho \frac{L}{A} \qquad (12.3)$$

Where ρ (Greek LETTER 'Rho') is a constant and is known as resistivity or specific resistance of the material.

12.5 SPECIFIC RESISTANCE OR RESISTIVITY

We have seen above that

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

If $L = 1\text{m}$, $A = 1\text{m}^2$, then $R = \rho$

Hence specific resistance of a material is the resistance offered by 1m length of wire of a material having an area of cross-section of 1m^2. The unit of resistivity is ohm-meter (Ω.m). The resistivity of a substance varies over a wide range. To give an idea to the reader, the following table may be referred.

Table 12.1: The resistivity's of some metals.

Metals	Resistivity(μΩm)
Copper (hard drawn)	0.0178
Aluminium	0.0285
Tin	0.114
Silver	0.0163
Brass	0.06-0.09
Iron	0.1
Lead	0.219

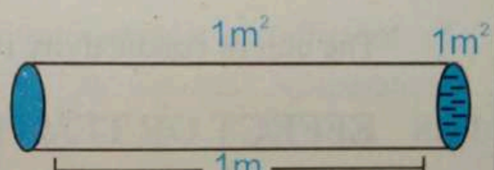


Fig: 12.4:cross-section area of a material

The resistivity of metals and alloys is very small. Therefore, these materials are good conductors of electric current. On the other hand, resistivity of insulators is extremely large. As a result, these materials hardly conduct any current. There is also an intermediate class of material known as semiconductors. The resistivity of these substances lies between conductors and insulators.

12.6 CONDUCTANCE

The Reciprocal of resistance of a conductor is called conductance (G) if a conductor has resistance R, then its conductance G is given by

$$G=\frac{1}{R} \qquad ...(12.4)$$

The SI unit of conductance is mho (i.e. ohm spelt back ward) these days, it is a usual practice to use Siemen as the unit of conductance. It is denoted by symbol S.

12.7 CONDUCTIVITY

The reciprocal of resistivity of a conductor is called its conductivity. It is denoted by the symbol σ. If a conductor has resistivity ρ, then its conductivity is given by

$$\sigma=\frac{1}{\rho}=\frac{L}{RA} \qquad (12.5)$$

The unit of conductivity is mho m^{-1} or siemen meter^{-1} ($S.m^{-1}$)

12.8 EFFECT OF TEMPERATURE ON RESISTANCE

The resistance of a material changes with the change in temperature. The effect of temperature upon resistance varies according to the type of material.

i) Thus resistance of pure metal (e.g. copper, aluminum) increases with the increase of temperature. The change in resistance is fairly regular for normal range of temperatures.

ii) The resistance of electrolytes, insulators (e.g. glass, mica, rubber etc.) and semiconductors (e.g. germanium, silicon etc.) decreases with the increase in temperature.

12.8.1 TEMPERATURE CO-EFFICIENT OF RESISTANCE

Consider a conductor having resistance R_o at 0°C and R_T at T° C. It has been found that in the normal range of temperatures, the increase in resistance $(R_T - R_o)$ is

i) Directly proportional to the initial resistance i.e.

$$R_T - R_o \propto R_o$$

ii) Directly proportional to the rise in temperature i.e.

$$R_T - R_o \propto T$$

Combining the above two relations, we get

$$R_T - R_o \propto R_o T$$

$$R_T - R_o = \alpha\, R_o T \qquad (12.6)$$

Where α is the constant and is called temperature co-efficient of resistance. Its value depends upon the nature of material and temperature. Rearranging equation (12.6) we get:

$$R_T = R_o(1 + \alpha\, T) \qquad (12.7)$$

From equation (12.6) we get:

$$\alpha = \frac{R_T - R_o}{R_o T} \quad (12.8)$$

Temperature co-efficient of resistance α may be defined as *increase in resistance per ohm original resistance per degree rise in temperature.*

The unit of α, as derived from the definition is K^{-1}. Since the resistance of metals increases with the rise in temperature, they have positive temperature co-efficient of resistance, while co-efficient α is negative for semiconductor because they show decrease in resistance as the temperature raises.

12.8.2 VARIATION OF RESISTIVITY WITH TEMPERATURE

The resistivity or specific resistance of most materials increases linearly with increasing temperature. The equation, (12.7) also apply to ρ. At temperature 'T' the resistivity 'ρ_T' of a material is given by

$$\rho_T = \rho_o (1 + \alpha T) \quad ...(12.9)$$

$$\alpha = \frac{\rho_T - \rho_o}{\rho_o T} \quad ...(12.10)$$

Where α is called the temperature co-efficient of resistivity and may be defined as the fractional change in resistivity per Kelvin. The temperature co-efficient of resistivity is positive for metals. But the resistivity of Graphite (non-metal) decreases with the increasing temperature. Since at higher temperatures more electrons are "Shaken Loose" from the atoms and become mobile, hence the temperature co-efficient of resistivity of Graphite is negative. This same behavior occurs for semiconductors.

Example 12.3

A transmission line made of copper has a resistance of 100 Ω at 0C°. calculate the change in resistance between summer and winter, knowing that temperature varies from +35C° to -30C°. Assume the temperature co-efficient of copper to be 0.00427/C° at 0C°.

Solution:

$$R_T = R_o (1 + \alpha T)$$

$$\Rightarrow R_{-30} = 100(1 + 0.00427(-30))$$

$$\Rightarrow R_{-30} = 87.2\Omega$$

$$\text{similarly } R_{+35} = 100(1 + 0.00427(35))]$$

$$R_{+35} = 115\Omega$$

Change in resistance = 115 – 87.2 = 27.8 Ω

Example 12.4

Calculate the resistance of copper conductor having a length of 2 km and a cross-section of 22 mm^2. Assume the resistivity is 18×10^{-9} Ω.m.

Solution:

The resistance of copper wire of length L, cross-sectional area A and resistivity ρ is given by

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

L = 2 km = 2000 m

A = 22 mm^2 = 22×10^{-6} m^2

$\rho = 18 \times 10^{-9}$ Ω-m

Thus resistance of copper conductor is

$$R = 18\times10^{-9}\times\frac{2000}{22\times10^{-6}}$$

$$R = 1.64\Omega$$

12.9 Wire-Wound Variable Resistors

High stability and high accuracy resistors are always wire-wound. It is then enclosed in an insulating cover.

Generally, nickel chromium is used because of its very small temperature co-efficient of resistance. Wire wound resistors can safely operate at higher temperatures than carbon type resistors. Wire wound variable resistor can be used in two ways.

i) Rheostats ii) Potential divider

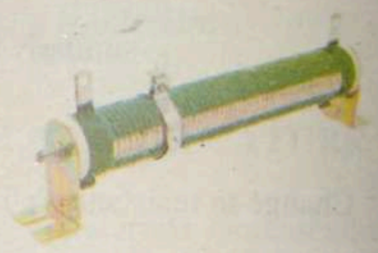


Figure 12.5 : Wire wound variable resistor

i) Rheostats

To use the variable resistor as a current control device one of the two fixed terminals say A, and the sliding terminal C are inserted in the circuit as shown in figure12.6. In this way the resistance of the wire between A and the sliding contact C is used. If the sliding contact is shifted away from the terminal A, the length and hence the resistance included in the circuit increase.

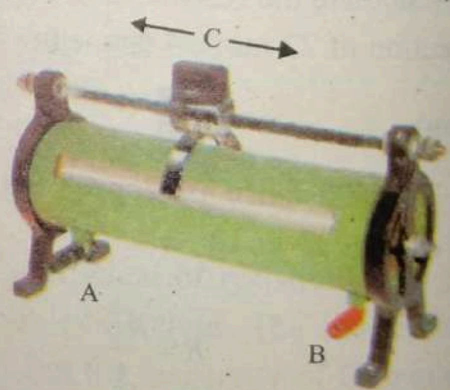


Figure 12.6 : Rheostats

If the sliding contact is moved towards A, the resistance decreases. Adjusting the resistance in the circuit controls the current in a circuit.

ii) Potential Divider

A potential divider provides a convenient way of getting a variable PD from a fixed potential difference. With the help of the battery, a potential difference V is applied across the ends A and B of the resistor. Let R be the resistance of wire AB. The current I passing through it is

$$I = V/R$$

If R_{BC} is the resistance of the portion of the wire BC and the current passing through BC is I. The PD between the points B and C is given by

$$V_{BC} = IR_{BC}$$

$$\Rightarrow \quad V_{BC} = \frac{V}{R} R_{BC}$$

$$\Rightarrow \quad V_{BC} = \frac{R_{BC}}{R} V$$

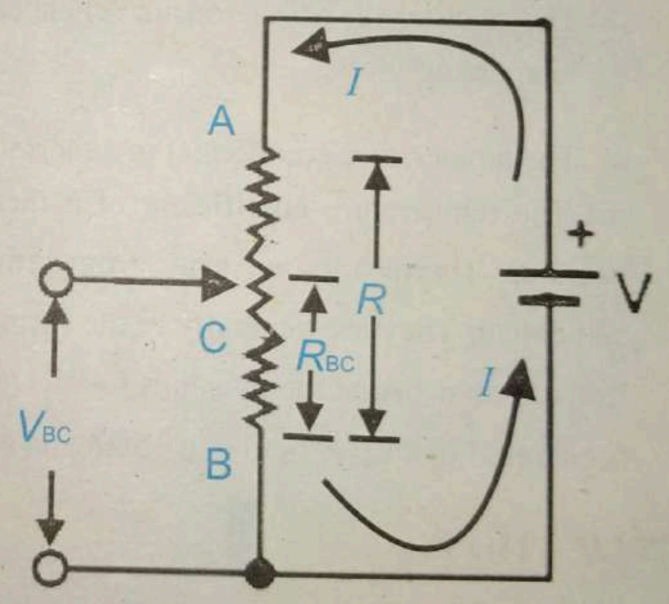


Figure 12.7 : potential divider

Depending on the position of the sliding contact C, the value of the fraction R_{BC}/R can be varied from 0 to 1. When the contact C, moving towards B, the length and hence the resistance R_{BC} of the portion of the wire decreases.

Thus V_{BC} decreases. On the other hand if the sliding contact C is moved towards the end A, the length and the resistance R_{BC} of the wire increases and hence the voltage V_{BC} increases.

12.10 Thermistor

A resistor made of semiconductors having resistance that varies rapidly and predictably with temperature is known as thermistor.

A thermistor (short for thermal resistor) is a heat sensitive device usually made of a semiconductor material whose resistance changes very rapidly with change of temperature. A thermistor has the following important properties.

i) The resistance of thermistor changes very rapidly with change of temperature.

ii) The temperature co-efficient of a thermistor is very high.

iii) The temperature co-efficient of a thermistor can be both positive and negative. Thermistors are made from semiconductor oxides of iron, nickel and cobalt. They are generally in the form of discs or rods. Pair of platinum leads are attached at the two ends for electrical connections. The arrangement is enclosed in a very small glass bulb and sealed.

APPLICATIONS

a) A thermistor with negative temperature co-efficient of resistance may be used to safeguard against current surges in a circuit where this could be harmful e.g. in a circuit where the heaters of the radio valves are in series as shown.

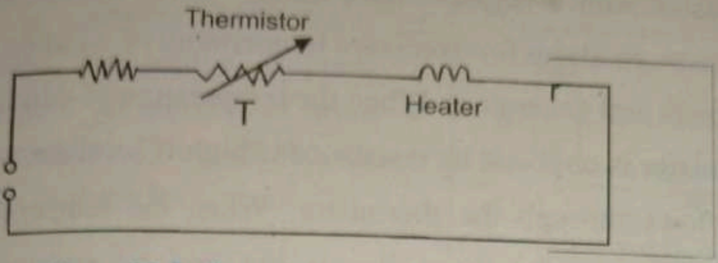


Figure 12.8 : thermistor

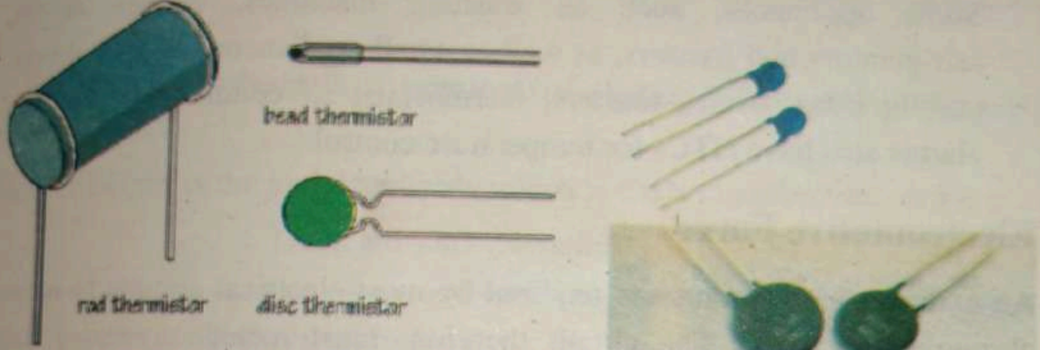


Figure12.9: types of thermistor

A thermistor T is included in the circuit. When the supply voltage is switched on the thermistor has a high resistance at first because it is cold. It thus limits the current to a moderate value. As it warm up, the thermistor resistance drops appreciably and an increased current then flow through the heaters.

Modern appliances, communication tools and accessories like mobile phones, computers, LCD displays, CPUs, rechargeable batteries, and medical and patient monitoring equipment are all equipped with thermistors so they can be used continuously without fear of overheating and appliance damage.

b) A thermistor with a negative temperature co-efficient (NTC) can be used to issue an alarm for excessive temperature of winding of motors, transformers and generators. When the temperature of windings is low, the thermistor is cool and its resistance is high. Therefore, only a small current flows through the thermistor. When the temperature of the windings is high, the thermistor is hot and its resistance is low. Therefore, a large current flows in the coil to close the contact.

c) Some appliances, such as washing machines, clothes dryers, refrigerators and freezers, as well as small appliances like hair dryers, curling irons, ovens, toasters, thermostats, air conditioners and fire alarms also have NTCs for temperature control

12.11 Electromotive Force

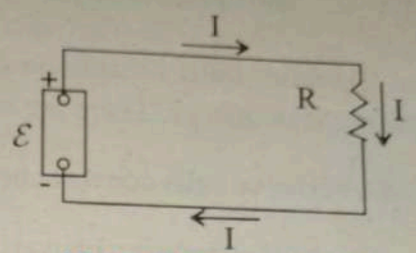
An external energy source is required by most electrical circuits to move charge through the circuit. The circuit therefore must include a device that maintains a potential difference between two points in the circuit, just as a circulating fluid requires as analogous device (pump).

Such a device which converts non-electrical energy into electrical energy is called a source of electromotive force (emf).

This reminds us a pump, which can cause water to move from a place of low gravitational potential to a place of high potential. The Fig.(12.10) shows the e.m.f. source $\mathcal{E}$, considered to be a battery connected to a resistor R. It maintains its upper terminal at a high potential and its lower terminal at a low potential, as indicated by the + and – signs. In the external circuit positive charge carriers would be driven in the direction shown by the arrows marked I.

We define emf $\mathcal{E}$ of a source equal to the work done in carrying 1 coulomb of charge through the source. Suppose q coulombs require an amount of work W joule to be transported through the source then $\mathcal{E}$ in volts is given by

$$\mathcal{E} = \frac{W}{q} \qquad ...(12.11)$$



12.10:Electromotive force:

The potential at the ends of terminals of a battery when circuit is open is also called e.m.f.

The unit of emf is the joule/coulomb, which is the volt (abbreviation V):

1 volt = 1 joule/coulomb

For your Information

Just as a water fountain requires a pump, an electric circuit requires a source of electromotive force to sustain a steady current. In an electronic circuit there must be a device somewhere in the loop that acts like the water pump in a water fountain. In this device a charge travels uphill's from lower to higher potential energy even though the electrostatic force is trying to push it from higher to lower potential energy. The direction of current in such a device is from lower to higher potential, just the opposite of what happens in an ordinary conductor. The influence that makes current flow from lower to higher potential is called electromotive force.

12.11.1 Sources of e.m.f

The work done by emf on charge carriers in its interior must be derived from a source of energy. There are many sources of e.m.f. A few examples are

1. Batteries or cells convert chemical energy into electrical energy.
2. Electrical generators convert mechanical energy into electrical energy.
3. Thermocouples convert heat energy into electrical energy.
4. Radiant (a solar cell) converts sunlight directly into electrical energy.

12.12 Internal Resistance of a Supply.

All supplies (e.g. a cell) must have some internal resistance, however small. When the cell is delivering no current i.e. no load, the P.D across the terminals will be equal to e.m.f ($\mathcal{E}$) of the cell. When some load resistance 'R' is connected across the terminals of the cell, the current I starts flowing in the circuit as shown in Fig 12.11. This current causes a voltage drop across internal resistance r of the cell so that terminal voltage V available will be less than $\mathcal{E}$. The relationship between $\mathcal{E}$ and V can be easily established.

$$I = \frac{\mathcal{E}}{R+r}$$

$\Rightarrow \quad IR = \mathcal{E} - Ir$

But $\quad IR = V$, the terminal voltage of the cell

$$V = \mathcal{E} - Ir$$

Now, if

$$r = 0,$$

(Open Circuit); $I = 0$

Then $\quad V = \mathcal{E}$

But, when the circuit is closed, the current move through it experiences an associated drop in potential equal to Ir. Thus when a current is flowing through a source, the Potential difference V between the terminals of the source is $V = \varepsilon - Ir$ the Potential V called the terminal voltage, is less than the emf ε because of the term Ir representing the Potential drop across the internal resistance r.

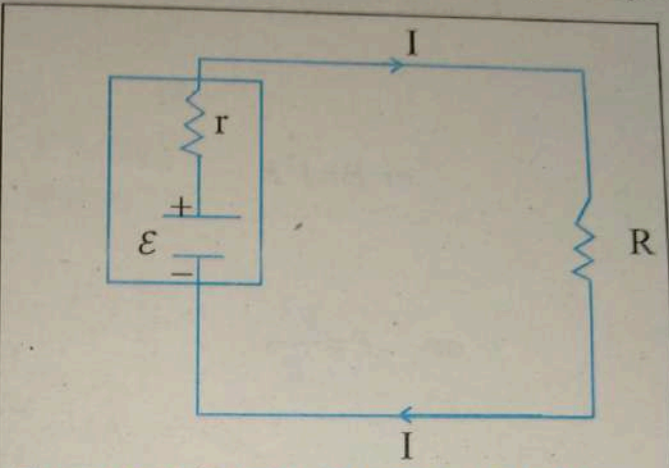


Figure 12.11: internal resistance of a battery

12.13 Electric Power

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

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

When voltage is applied to a circuit, (Fig 12.12). It causes current to flow through the resistance R in time t.

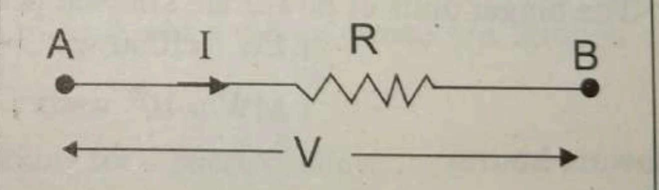


Figure 12.12 : work done on a charge

Clearly work is being done in moving the charges in the circuit. This work done in moving the charges in a unit time is called the electric power.

Thus total charge Q flows in t second is Q I x t and V $\frac{W}{Q}$

$$W = QV = VIt$$

$$\text{Electric power} = P = \frac{W}{t} = \frac{VIt}{t}$$

$$= VI \qquad ...(12.12)$$

$$\text{or } P = I^2R \qquad ...(12.13)$$

$$\therefore V = IR$$

$$\text{or } P = \frac{V^2}{R} \qquad ...(12.14)$$

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

The above three formulas are equally valid for calculation of electric power in a d.c. circuit. Which one is to be used depends simply on the known quantities.

Unit of electric Power: The unit of power in SI is watt . *A power of 1 watt is said to be consumed in a circuit if a potential difference of 1 volt causes a current of 1 ampere to flow through it.*

$$1 \text{ Watt} = 1\text{V} \times 1\text{A}$$

The bigger units of power are kilowatt (kW) and mega watt (MW)

$$1 \text{ kW} = 1000 \text{ watts} = 10^3 \text{ watts}$$

$$1 \text{ MW} = 10^6 \text{ watts}$$

Kilowatt-hours:

Electric energy is commonly consumed in very large quantity for the measurement of which Joule is a very small unit. Hence a large unit of energy is required which is called kilowatt-hour. On kilowatt-hour is commonly termed as one commercial unit of electrical energy. It is the amount of energy obtained by a power of 1 kilowatt in one hour.

$$1 \text{ kWh} = 1000 \text{ W} \times 3600 \text{s} = 3.6 \times 10^6 \text{ W s}$$

$$1 \text{ kWh} = 3.6 \times 10^6 \text{ J} \qquad \therefore 1\text{J} = 1\text{W} \times 1\text{s}$$

Example 12.5

A heating coil has a resistance of $20\,\Omega$. It is designed to operate on 220 V. What electric energy in joules is supplied to the heater in 10 s?

Solution:

$$R = 20\ \Omega, \quad V = 220\,\text{V}$$
$$t = 10\,\text{s}, \quad W = \ ?$$

From Ohm's law $V = IR \ \ or\ \ I = \dfrac{V}{R}$

$$I = \frac{220\ \text{V}}{20\ \Omega} = 11\,\text{A}$$

Now applying the formula

$$W = I^2 R t$$
$$W = (11\ \text{A})^2 (20\Omega)(10\ \text{s})$$
$$W = 24200\ \text{J}$$

Example: 12.6

The following are the details of load and a circuit connected through a supply meter.

(i) Six lamps of 40 watts each working for 4 hours per day.

(ii) Two fluorescent tubes 125 watts each working for 2 hours per day.

(iii) 1000 watts heater working for 3 hours per day.

Find the cost of electrical energy consumed in 30 days of a month when the rate of electricity i.e, energy costs is Rs 7.0 per unit?

Solution

Total watts for lamps $= 40 \times 6 = 240\,watts$

Total watts for tubes = $125\times2=250\,watts$

Heater = 1000 watts

Energy consumed per day =

$$=(240\times4)+(250\times2)+(1000\times3)$$

= 4460 watt hours

= 4.46 Kwh

Total energy consumed in the month of June

$$=4.46\times30=133.8kwh$$

Bill for the month of June = 7×133.8

$$=936.6\,Rs$$

Example: 12.7

Determine the resistance of a resistor which must be placed in series with a 75 Ω resistor across 120 V source in order to limit the power dissipation in the 75Ω ,resistor to 90 watts.

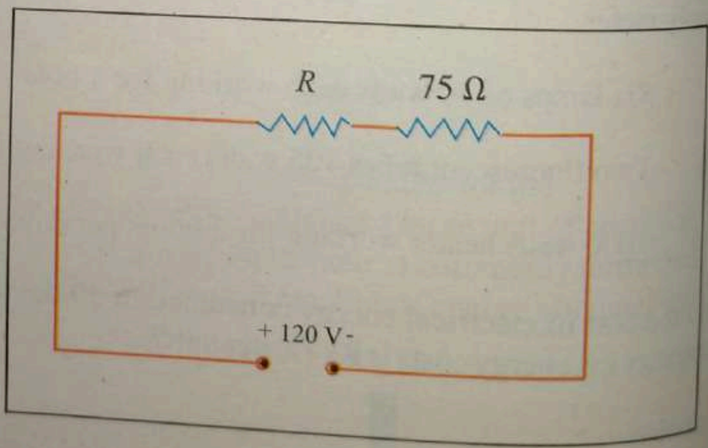
Solution

$$I^2\times75=90$$

$$I=\sqrt{\frac{90}{75}}$$

$$I=1.095A$$

Now $I=\dfrac{120}{R+75}$



$$1.095 = \frac{120}{R+75}$$

$$\Rightarrow \quad R+75 = \frac{120}{1.095}$$

$$R = 34.6\Omega$$

12.14 Maximum Power output

In many electronic circuits and systems it is important to have maximum transfer of power from the source to the load. For example, in radio or TV transmitting systems, it is desired to transfer the maximum power possible from the transmitting medium to the antenna systems. We want maximum power transfer from amplifier to speaker system. This is accomplished by proper matching of load resistance R and source resistance r.

If the load resistance is less or greater than the source resistance, then the power delivered to the load will be minimum.

Consider the circuit of fig:12.13, as the current I flows through, the load R the charges flow from a point of higher potential to a point of lower potential. In this process, they lose potential energy. If V is the P.D. across R, the loss of potential energy per second is known as power delivered to R by the current I.

From electrical power

$$P_{out} = IV$$

$$P_{out} = I^2R$$

$$P_{out} = \frac{\varepsilon^2 R}{(R+r)^2} \qquad \therefore I = \frac{\varepsilon}{(R+r)}$$

$$P_{out} = \frac{\varepsilon^2 R}{(R-r)^2 + 4Rr}$$

When $R = r$, the denominator of the expression for P_{out} is minimum and so P_{out} is maximum.

Thus it can be concluded that *maximum power is delivered to a load R when the internal resistance of the source of emf is equal to the load resistance*, also called maximum power transfer theorem.

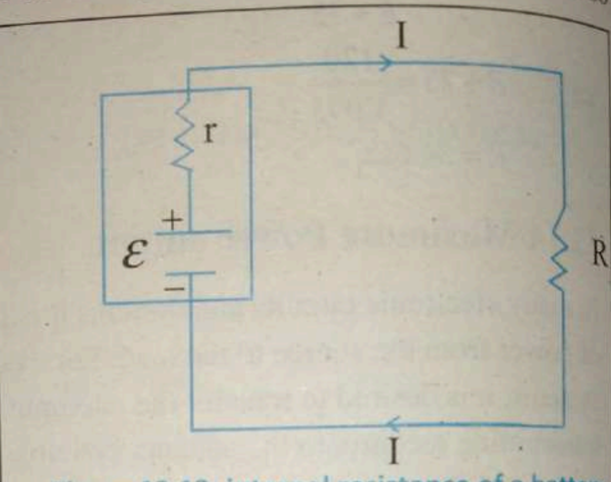


Figure 12.13: internal resistance of a battery

The value of the maximum output power is

$$(P_{out})_{max} = \frac{\varepsilon^2}{4r} = \frac{\varepsilon^2}{4R} \qquad ...(12.15)$$

12.15 Thermocouples

In early 1821, Thomas Seebeck searched experimentally for a relation between electricity and heat. He joined two wires of two dissimilar metals to form a circuit. He discovered that if one junction is heated to a high temperature, and the other junction remained at a cooler temperature then the galvanometre connected at their ends shows a deflection. This is known as Seebeck Effect. The e.m.f. generated in the circuit is called thermoelectric e.m.f. The resulting current is known as thermoelectric current.

The two junction circuit is called a thermocouple. In this process heat energy is directly converted into electrical energy. The wire pairs can be composed of noble metals (such as platinum, iridium, silver, osmium, gold, and rhodium) or base metals, (such as copper, iron or nickel-copper alloy, lead and zinc).

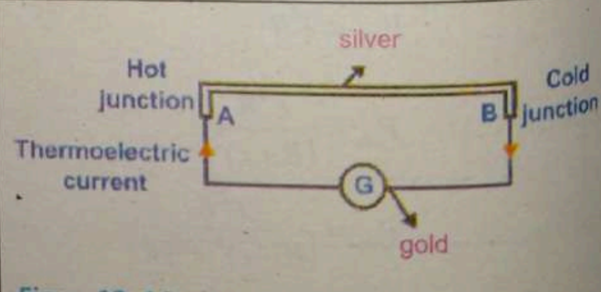


Figure12. 14: thermocouple

Thus it remains true for any pair of metals. Thermocouples are the most widely used temperature sensors in industry due to their low cost, simplicity, size and useable temperature range. The electromotive force $\mathcal{E}$ is a function of the temperature gradient.

The thermo- e.m.f. produced is very small, of the order of mV per every degree of temperature difference. The Seebeck effect is reversible, i.e., if the hot and cold junctions are interchanged, the direction of e.m.f. (and hence current) reverses. The greater the separation of the metals forming the thermocouple in the series, greater is the thermo e.m.f. produced. The thermo e.m.f. of many thermocouples has been measured as a function of the temperature T of the hot junction, when the cold junction is maintained at 0°C. Its temperature dependence is given by

$$\varepsilon = \alpha T + \frac{1}{2}\beta T^2 \qquad ...(12.16)$$

Where α and β are constants (called thermoelectric coefficients) which depends on the nature of the metals.

12.15.1 Variation in thermoelectric e.m.f. with Temperature

Fig:12.15(a) shows an arrangement to study the effect of temperature difference between the two junctions in a Cu-Fe thermocouple. Keeping the junction B at 0°C, the temperature of junction A is increased. When both the junctions are at the same temperature, there is no thermo e.m.f.

The thermo e.m.f. increases with temperature and reaches a maximum value at a certain temperature, called the neutral temperature T_n.

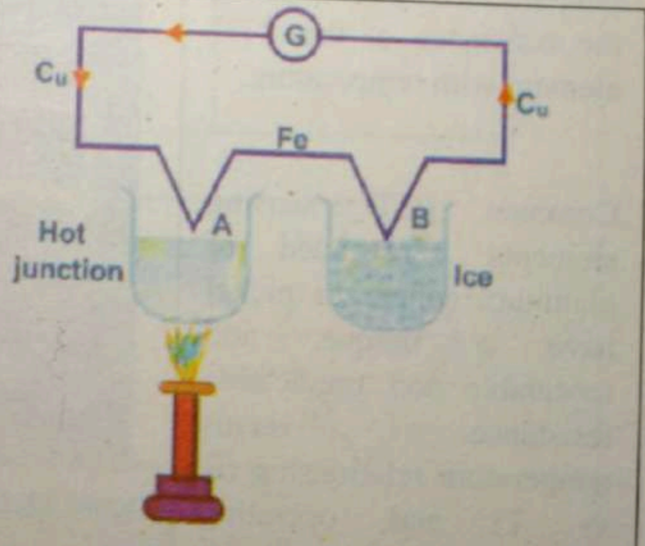


Figure 12.15 (a) : variation of thermo emf with temperature

The value of the neutral temperature is constant for a thermocouple, depends on the nature of materials and is independent of the temperature of the cold junction.

As the temperature of the hot junction is increased, the thermo e.m.f. starts decreasing instead of increasing. The particular temperature at which, the thermo e.m.f. becomes zero is called the inversion temperature. The graph shows the variation of the thermo e.m.f. with the temperature of hot junction, with the cold junction.

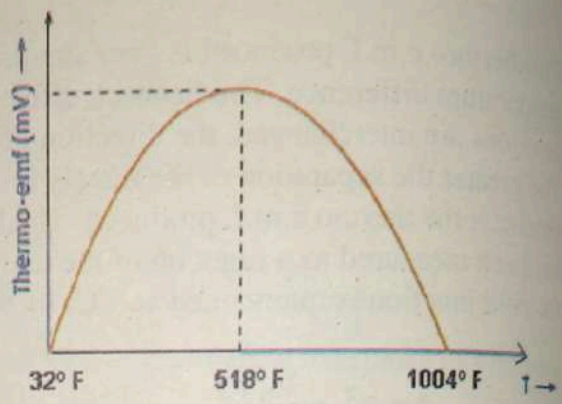


Figure 12.15 (b): variation of thermo emf with temperature T for copper-iron thermocouple

12.16 Resistance thermometers

Resistance thermometers, also called resistance temperature detectors (*'RTD's*), are sensors used to measure temperature by correlating the resistance of the RTD element with temperature.

Common RTD sensing elements constructed of platinum, copper or nickel have a unique, and repeatable and predictable resistance versus temperature relationship (R vs T) and operating temperature range.

Figure 12.15 (c): Resistance thermometers

The R vs T relationship is defined as *the amount of resistance change of the sensor per degree of temperature change.* The relative change in resistance (temperature coefficient of resistance) varies only slightly over the useful range of the sensor.

Platinum is the best metal for RTDs because it follows a very linear resistance-temperature relationship and it follows the R vs T relationship in a highly repeatable manner over a wide temperature range. The unique properties of platinum make it the material of choice for temperature standards over the range of -185 °C to 630 °C. They are slowly replacing the use of thermocouples in many industrial applications below 600 °C, due to higher accuracy and repeatability.

12.17 Kirchoff's Law

Sometimes we encounter circuits where simplification by series and parallel combinations is impossible consequently. Ohm's law cannot be applied to solve such circuits. This happens when there is more than one emf in the circuit or when resistors are connected in a complicated manner. Such circuits are called complex circuits. Fig 12.16(a) shows a circuit containing two sources of emf $\mathcal{E}_1$ and $\mathcal{E}_2$ and three resistors. This circuit cannot be solved by series parallel combinations. Are resistors R_1 and R_3 in parallel? Not quite, because there is an e.m.f source $\mathcal{E}_1$ between them. Are they in series? Not quite, because same current does not flow between them.

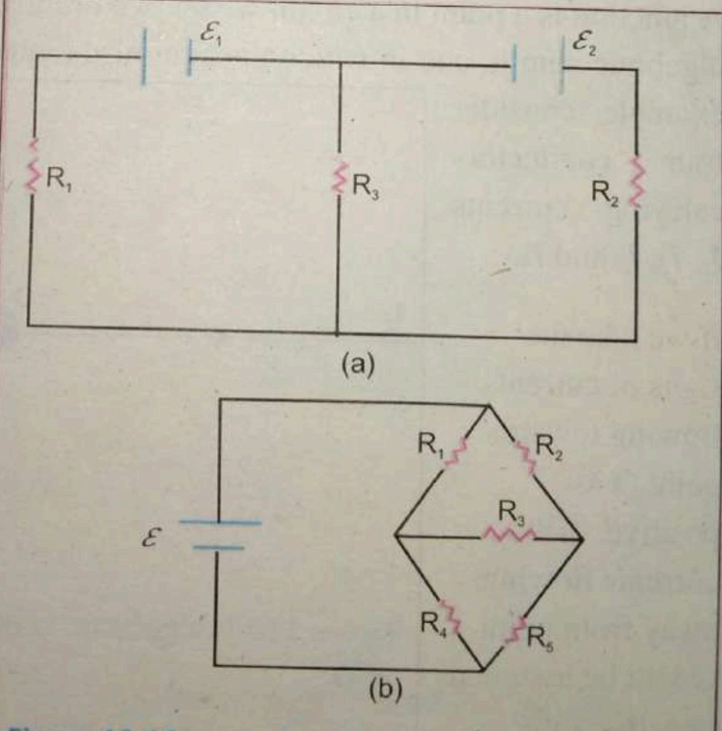


Figure 12.16 : complex circuit

Figure:12.16b shows another circuit which cannot be solved by series–parallel combinations. Though this circuit has one source of e.m.f ($\mathcal{E}$), it cannot be solved by using series and parallel combinations. These resistors R_1 and R_2 are neither in series nor in parallel.

In order to solve such complex circuits, German physics Gustar Robert Kirchhoff's (1824-1887) gave two laws, known as Kirchhoff's laws

Kirchoff's current law (KCL)

This law is related to the currents at the junctions of an electric circuit and may be stated as under:

The algebraic sum of all the currents meeting at a junction in an electrical circuit is zero. $\sum I = 0$

A junction is a point in a circuit where two or more components are connected. As algebraic sum is one in which the sign of the quantity is taken into account. For example, consider four conductors carrying currents I_1, I_2, I_3 and I_4.

If we take the signs of currents flowing towards point O as positive, then currents flowing away from point O will be assigned negative sign.

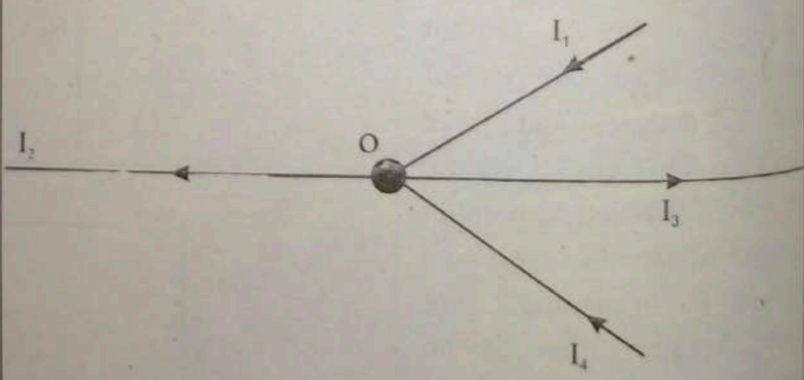


Figure 12.17: algebraic sum of the currents with junction at O.

Thus applying Kirchhoff's current laws to the junction

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

Or $$I_1+I_4=I_2+I_3 \quad ...(12.17)$$

i.e. sum of incoming currents = sum of outgoing current.

Hence, Kirchhoff's current law may also be stated as *the algebraic sum of currents flowing towards the junction in an electrical circuit is equal to the algebraic sum of currents flowing away from that junction.*

Kirchoff's current law is true because electric current is merely the flow of free electrons and they cannot accumulate at any point in the circuit. This is in accordance with the law of conservation of charge. Hence Kirchoff's current law is based on the law of conservation of charge.

Kirchoff's Voltage Law (KVL)

This law refers to e.m.f and voltage drops in a closed circuit or closed loop and may be stated as under:

In any closed electrical circuit, the algebraic sum of all the electromotive force, (e.m.f) and voltage drops in resistor is equal to zero i.e.

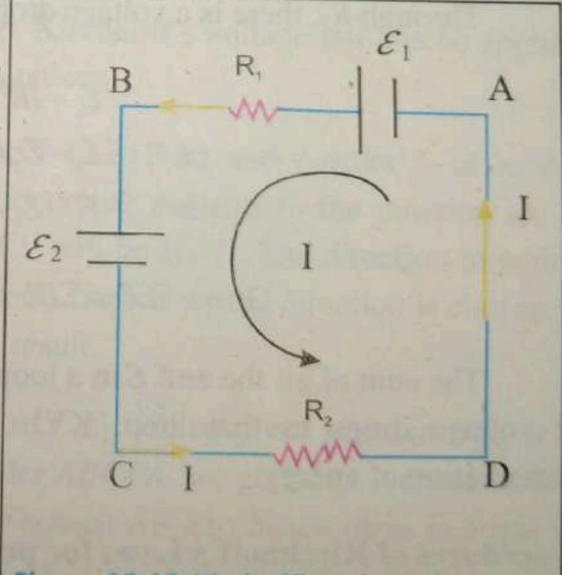


Figure 12.18 Kirchoff's voltage law

Algebraic sum of emf + algebraic sum of voltage drops = 0.

The validity of Kirchoff's voltage law can be easily established by referring to the closed loop ABCDA shown in Fig. 12.18

Starting from any point (say point A) in this closed circuit and go back to this point (i.e. point A) after going around the circuit, then there is no increase or decrease in potential.

Consider the circuit shown in figure. The following convention is adopted to solve the circuit.

i) A rise in potential is taken positive.
ii) A drop in potential is taken negative.
iii) For batteries, the positive end is always at higher potential.
iv) Current flows from high potential to the low potential.
v) Assume the direction of current either clock wise or counter clockwise.

Let's take counter–clockwise round. Consider current from +ve terminal of $\mathcal{E}_1$, we take the rise of potential as $+\mathcal{E}_1$, through R_1, the voltage drop is $-IR_1$. Across $\mathcal{E}_2$, from the +ve to –ve side there is a fall of potential $-\mathcal{E}_2$. Through R_2, there is a voltage drop of $-IR_2$, apply KVL, we get

$$\mathcal{E}_1 - IR_1 - \mathcal{E}_2 - IR_2 = 0$$

$$\Rightarrow \quad \mathcal{E}_1 - \mathcal{E}_2 = IR_1 + IR_2$$

$$\Rightarrow \quad \mathcal{E}_1 - \mathcal{E}_2 = IR_1 + IR_2$$

$$\text{Or} \quad \Sigma\mathcal{E} = \Sigma IR \qquad ...(12.18)$$

The sum of all the emf $\mathcal{E}$ in a loop in a circuit is equal to the sum of all the IR voltage drops in that loop. KVL is in fact, a statement of the law of conservation of energy.

Procedures of Kirchhoff's Laws for problem solution

In order to solve problems by using Kirchhoff's Laws consider the circuit shown in Fig12.19

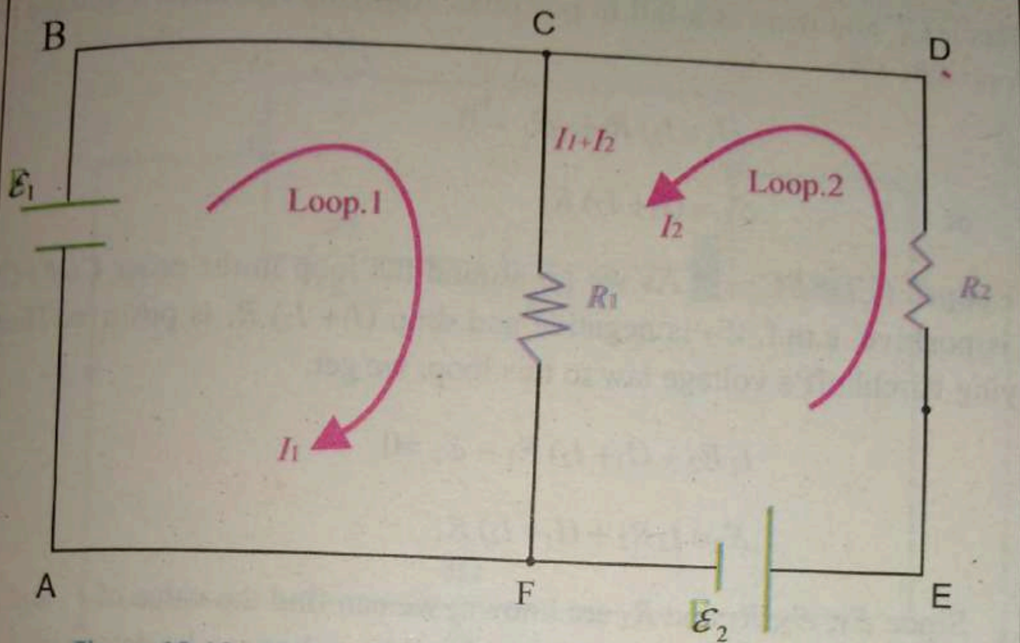


Figure 12.19 : Kirchhoff's law procedure

Let us take two closed loops in Fig.12.19 loop.1 (ABCFA) and loop.2 (CDEFC). The choice of loops is quite arbitrary, but it should be such that each resistance is included at least once in the selected loop. Kirchhoff's voltage law can be applied to these closed loops to get the desired equations.

Suppose a current I_1 is flowing in loop.1 (ABCFA) and current I_2 in loop.2 (CDEFC). Thus at junction C in Fig. the incoming currents to the junction are I_1 and I_2. Obviously, the current in branch CF will be I_1+I_2. The direction in which currents are assumed to flow is un-important, since if wrong direction is chosen, it will be indicated by a negative sign in the result.

Loop:1(ABCFA). In this loop, e.m.f. $\mathcal{E}_1$ will be given positive sign. It is because as we consider the loop in the order *ABCFA*, we go from –ve terminal to the positive terminal of the battery in the branch *AB* and hence there is a rise in potential. The voltage drop in branch *CF* is $(I_1+I_2)R_1$ and shall bear negative sign. It is because as we consider the loop in the order *ABCFA*, we go with current in branch CF and there is a fall in potential. Applying Kirchhoff's voltage law to the loop $ABCFA$,

$$-(I_1+I_2)R_1+\mathcal{E}_1=0$$

or

$$\mathcal{E}_1=(I_1+I_2)R_1$$

Loop:2 (CDEFC). As we go around the loop in the order $CDEFC$, drop I_2R_2 is positive, e.m.f. $\mathcal{E}_2$ is negative and drop $(I_1+I_2)R_1$ is pøsitive. Therefore, applying Kirchhoff's voltage law to this loop, we get,

$$I_2R_2+(I_1+I_2)R_1-\mathcal{E}_2=0$$

Or

$$\mathcal{E}_2=I_2R_2+(I_1+I_2)R_1$$

Since $\mathcal{E}_1$, $\mathcal{E}_2$, R_1 and R_2 are known, we can find the value of I_1 and I_2 from the above two equations. Hence currents in all branches can be determined.

Example 12.8

The emfs of two batteries are 6V and 2V and internal resistances of 2Ω and 3Ω respectively which are connected in parallel across a 5Ω resistor. Calculate (a) current through each battery and (b) terminal voltage.

Solution:

Fig. 12.20 shows two loops having two unknown quantities I_1 and I_2. The direction of current are marked in the various branches. Let $\mathcal{E}_1$ and $\mathcal{E}_2$ be the potential difference of these batteries.

(a) Loop *HBCDEFH*:

Applying Kirchhoff's voltage law to the loop $HBCDEFH$, we get,

$$-\mathcal{E}_1+\mathcal{E}_2+I_1R_1-I_2R_2=0$$

$$2I_1-6+2-3I_2=0$$

Or

$$2I_1-3I_2=4 \qquad (1)$$

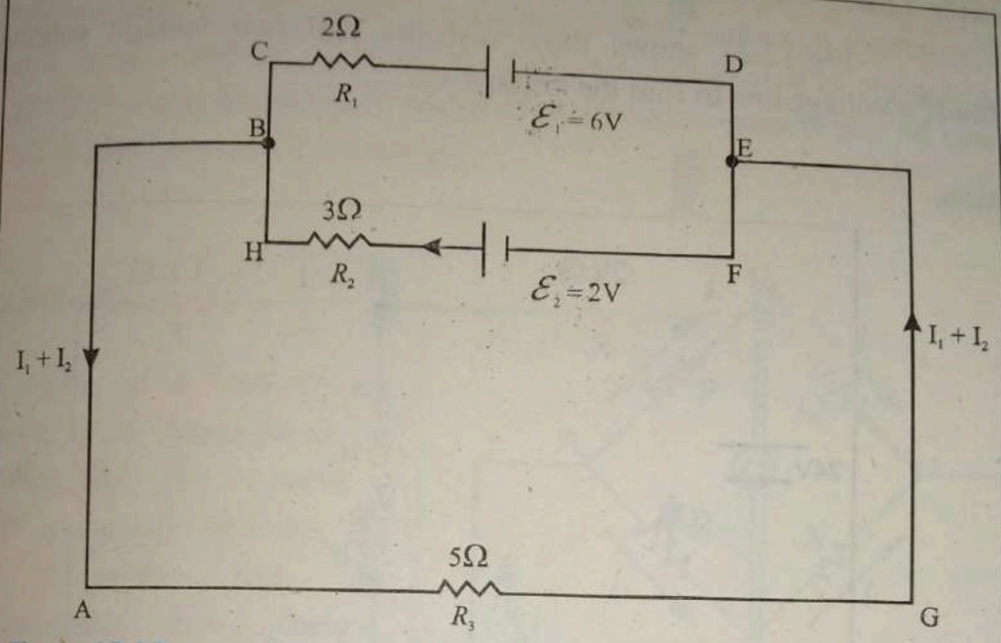


Figure 12.20 : complex circuit solution through Kirchhoff's rule

(b) Loop *ABHFEGA*:

Applying Kirchhoff's voltage law to the loop *ABHFEGA*, we get,

$$R_2 I_2 - \mathcal{E}_2 + R_3 (I_1 + I_2) = 0$$

$$3I_2 - 2 + 5 (I_1 + I_2) = 0$$

Or $$5I_1 + 8I_2 = 2 \qquad (2)$$

Multiplying eq. (1) by 8 and eq. (2) by 3 and then adding them, we get,

$$31\, I_1 = 38 \quad \text{or} \quad I_1 = 38/31 = 1.23\text{A}$$

i.e. battery $\mathcal{E}_1$ is being discharged at 1.23A. Substituting $I_1 = 1.23$ A in eq. (1), we get, $I_2 = 0.52$A i.e. battery $\mathcal{E}_2$ is being charged.

(ii) Terminal voltage $= (I_1 + I_2)\, 5 = (1.23 - 0.52)\, 5 = 3.55$V

Example 12.9

Fig:12.21 shows three resistors and two voltage sources. Use Kirchhoff's voltage law to find the voltage V_{ab}.

Solution

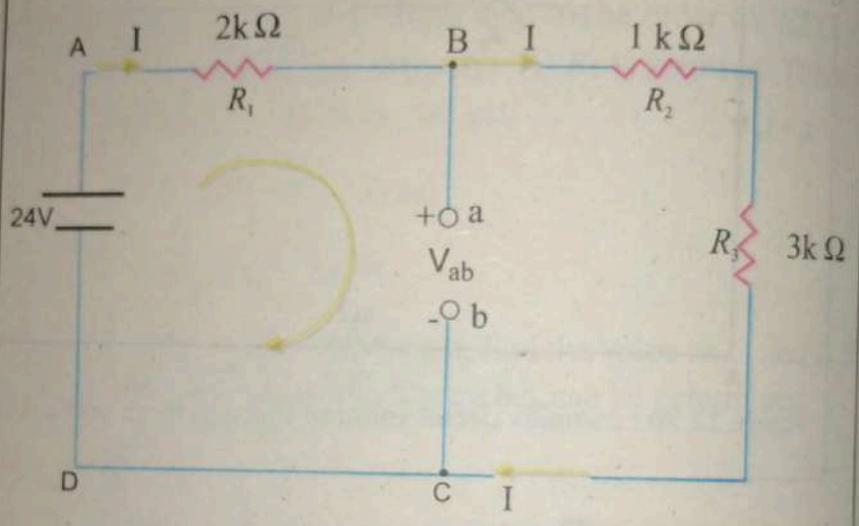


Figure 12.21: complex circuit solution through Kirchhoff's rule

Total circuit resistance, $R_T = 2 + 1 + 3 = 6k\Omega$

Circuit current, $I = \frac{V}{R_T} = \frac{24V}{6k\Omega} = 4mA$

Applying Kirchhoff's voltage law to loop *ABCDA*, we have

$$\mathcal{E}_1 - IR - V_{ab} = 0$$

$$24 - 4\ mA \times 2k\Omega - V_{ab} = 0$$

$$24 - 8 - V_{ab} = 0 \quad \therefore \quad V_{ab} = 24 - 8 = 16V$$

12.18 WHEATSTONE BRIDGE

- This bridge was first proposed by Wheatstone an English telegraph engineer for measuring accurately the value of an unknown resistance.

It consist of four resistors (two fixed resistances P and Q which are known, one variable resistance R which is also known and one unknown resistance X whose value is to be found) as shown in fig12.22. Across one pair of opposite junctions (A and C) battery is connected and across the other opposite pair of junctions (B and D), a galvanometer is connected.

WORKING

The value of P and Q are properly fixed. When the key is switched on, the current I divide unequally between the two branches and the galvanometer shows current. The value of resistance R is varied until the galvanometer shows zero current. Under such conditions, the bridge is said to be balance. The point at which the bridge is balanced is called null point. Let I_1 and I_2 be the currents through P and R respectively when the bridge is balanced. Since there is no current through Galvanometer, the current in Q and X are also I_1 and I_2 respectively. As the Galvanometer reads zero, points B and D are at the same potential. This means that voltage drops from A to B and A to D must be equal. Also voltage drops from B to C and D to C must be equal. Hence

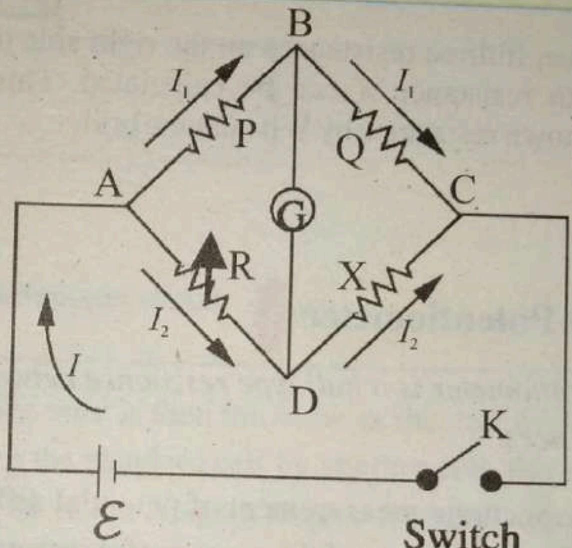


Figure 12.22 ; wheat stone bridge

For balanced bridge the potential drop across AB= the potential drop across AD

$$I_1P = I_2R \qquad (i)$$

similarly the potential drop across BC= the potential drop across DC

and $$I_1Q = I_2X \qquad (ii)$$

Dividing Eq:(i) by Eq:(ii), we get

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

$$PX = RQ$$

$$\Rightarrow \quad X=\frac{RQ}{P} \qquad ...(12.19)$$

Hence, if three resistances on the right side of equation (12.19) are known, the fourth resistance X can be calculated. This is the principle of determining unknown resistance by Wheatstone bridge.

12.19 Potentiometer

A potentiometer is a null type resistance network device for measuring potential differences.

For the accurate measurement of potential difference, current and resistance the potentiometer is one of the most useful instruments. Its principle of action is that an unknown emf or P.D. is measured by balancing it, wholly or in part, against a known potential difference.

Construction

: Asimplest potentiometer consists of wire LM of uniform cross-section, stretched alongside a scale and connected across battery of potential V as shown in fig12.23. A standard cell of known emf $\mathcal{E}_1$ is connected between L and terminal 1 of a two way switch S.

Working:

Slider N is pressed momentarily against wire LM and its position is adjusted until the galvanometer deflection is zero when N is making contact with LM. Let l_1 be the corresponding distance between L and N.

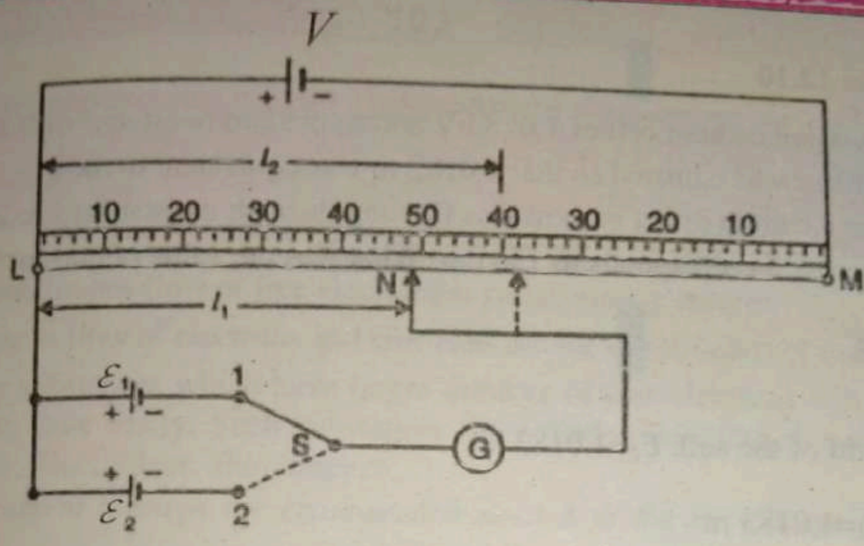


Figure 12.23 : simplest potentiometer circuit

The fall of potential over length l_1 of the wire is then the same as the emf $\mathcal{E}_1$. Then move the switch to 2, thereby replacing the standard cell by another cell, the e.m.f $\mathcal{E}_2$ of which is to be measured. Adjust the slider N again to give zero deflection on G. If l_2 be the new distance between L and N, then

$$\frac{\mathcal{E}_2}{\mathcal{E}_1} = \frac{l_2}{l_1}$$

$$\mathcal{E}_2 = \frac{l_2}{l_1} \times \mathcal{E}_1 \qquad \ldots(12.20)$$

Applications of potentiometer: following are the applications of potentiometer.

1. Measurement of small e.m.f (upto 2V)
2. Comparison of e.m.f of two cells.
3. Measurement of high e.m.f (say 250 V).
4. Measurement of resistance.
5. Measurement of current.
6. Calibration of ammeter.
7. Calibration of voltmeter.

Example: 12.10

Using a weston cadium cell of 1.0183 V and a standard resistance of 0.1Ω a potentiometer was adjusted so that 1.0183 m was equivalent to the e.m.f of the cell: when a certain direct current was flowing through the standard resistance, the voltage across it corresponds to 150 cm. What was the value of current?

Solution:

Emf of the cell, $\mathcal{E}_1$=1.0183 V

L_1=1.0183 m

L_2=150 cm = 1.5 m

Resistance R= 0.1Ω

$\mathcal{E}_1$= ?

$$\frac{\mathcal{E}_2}{\mathcal{E}_1}=\frac{\ell_2}{\ell_1}$$

$$\mathcal{E}_2=\frac{\ell_2}{\ell_1}\times\mathcal{E}_1=\frac{1.5}{1.0183}\times 1.0183=1.5\,\text{V}$$

current flowing through the standard resistance,

$$I_2=\frac{\mathcal{E}_2}{R}=\frac{1.5}{0.1}=15\text{A}$$

Key points

- The continuous flow of free electrons is called steady current.
- Current is flow of electrons and electrons are the constituents of matter.
- Those substances which have larger number of free electrons will permit current flow easily. Such substances are called conductors, for example copper, Zinc, Silver, aluminum etc.
- *The current through the cross-section area A is the net charge flowing through the area per unit time.* $I = Q/t$
- *The average velocity with which free electrons get drifted in a metallic conductor under the influence of electric field is called drift velocity* ($\vec{v}_d$).
- Ohm law states that *the magnitude of the current in metals is proportional to the applied voltage as long as the temperature of the conductor is kept constant.* $V = IR$
- *Resistance is the opposition offered by the substance to the flow of free electrons.*
- The resistance R of a conductor is directly proportional to its length and inversely proportional to its area of cross-section and is given by

$$R = \rho L/A$$

- The Reciprocal of resistance of a conductor is called conductance (G) .
- The increase in resistance $(R_T - R_o)$ is directly proportional to the initial resistance, rise in temperature and nature of material and is given by

$R_T - R_o = \alpha R_o T$

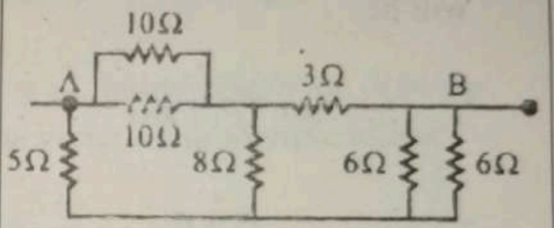
- Temperature co-efficient of resistance α may be defined as *Increase in resistance per ohm original resistance per degree rise in temperature.*
- *The temperature co-efficient of resistivity α may be defined as the fractional change in resistivity per unit resistivity per Kelvin.*
- High stability and high accuracy resistors are wire-wound. Wire wound variable resistor can be used in two ways. i) Rheostats ii) Potential divider
- A thermistor is a heat sensitive device usually made of a semiconductor material whose resistance changes very rapidly with change of temperature.
- *Such a device which converts non-electrical energy into electrical energy is called a source of electromotive force (emf).*
- Batteries or cells, Electrical generators, Thermocouples etc, are the sources of emf.
- *The rate at which work is done in an electric circuit is called electric power.*
- Maximum power will be delivered to a load R when the internal resistance of the source of emf equals the load resistance.
- When the circuit has two sources of emf or it has many resistors neither connected in series nor in parallel to solve such complex circuit we use Kirchoff's law. Which states that *the algebraic sum of the currents meeting at a junction in an electrical circuit is zero.* $\sum I = 0$

Exercise ?

Multiple choice questions:

Each of the following questions is followed by four answers. Select the correct answer in each case.

1. Seven resistances are connected as shown in the figure. The equivalent resistance between A and B is



a) 3 Ω b) 4 Ω

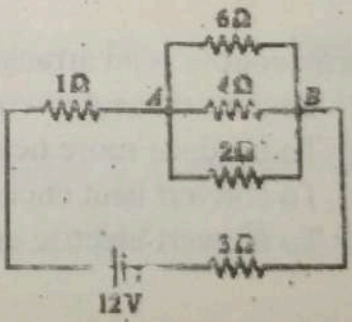
c) 4.5 Ω d) 5 Ω

2. Three resistors of resistance R each are combined in various ways. Which of the following cannot be obtained?

(a) $3R\,\Omega$ (b) $\frac{2R}{4}\Omega$

(c) $\frac{R}{3}\Omega$ (d) $\frac{2R}{3}\Omega$

3. Calculate current in 2Ω resistor.



a) 1 A b) 1.29A

c) 0.73A d) 1.43A

4. 10^6 electrons are moving through a wire per second, the current developed is

a) 1.6×10^{-19}A b) 1 A

c) 1.6×10^{-13} A d) 10^6 A

5. When a wire is stretched and its radius becomes $r/2$, then its resistance will be

(a) $16R$ (b) $4R$

(c) $2R$ (d) 0

6. A wire of uniform cross-section, A length L and resistance R is cut into two equal parts. The resistivity of each part will be

(a) doubled (b) halved

(c) remains the same (d) one fourth.

7. The resistivity of two wires is ρ_1 and ρ_2 which are connected in series. If there dimensions are same then the equivalent resistivity of the combination will be

(a) $(\rho_1 + \rho_2)$ (b) $\frac{1}{\rho_1} + \frac{1}{\rho_2}$

(c) $\frac{\rho_1 + \rho_2}{2}$ (d) $\frac{\rho_1}{\rho_2}$

8. The powers of two electric bulbs are 100w and 200 w. Which are connected to power supply of 220 V. The ratio of resistance of their filament will be,
(a) 1:2 (b) 2:1 (c) 1:3 (d) 4:3

9. Thermocouple is an arrangement of two different metals
a) To convert heat energy in to electrical energy
b) To produce more heat
c) To convert heat energy into chemical energy
d) To convert electric energy in to heat energy

Comprehensive questions

1. Describe the concept of steady state current as a flow of positive negative or both. Define the unit of current.
2. Explain the electronic current in a metallic wire as due to the drift of free electrons in the wire.

3. State Ohms law. Discuss its scope and validity (a) discuss resistivity and conductivity of a material (b) how does resistance change with temperature?
4. Explain the term: emf, internal resistance and terminal potential difference of a battery.
5. Explain the construction of rheostat. How is it used as a, (a) control the current, (b) as a potential divider?
6. What is wheat stone bridge? Explain with diagram the balancing, the principle and the working of this bridge?
7. What is a potentiometer? Explain its principle, construction, and working. What is the advantage of using potentiometer for measuring potential difference?
8. What is thermocouple? Explain the working of thermocouple by drawing its diagram. By sketching curve explain the variation in thermoelectric e.m.f. with Temperature.
9. Why we use Kirchoff's law for circuit problems solution. Explain its rules for circuit solution by giving proper example.
10. What is EEG. How it is used to measure brain electrical activity through electrical signals?

Conceptual questions

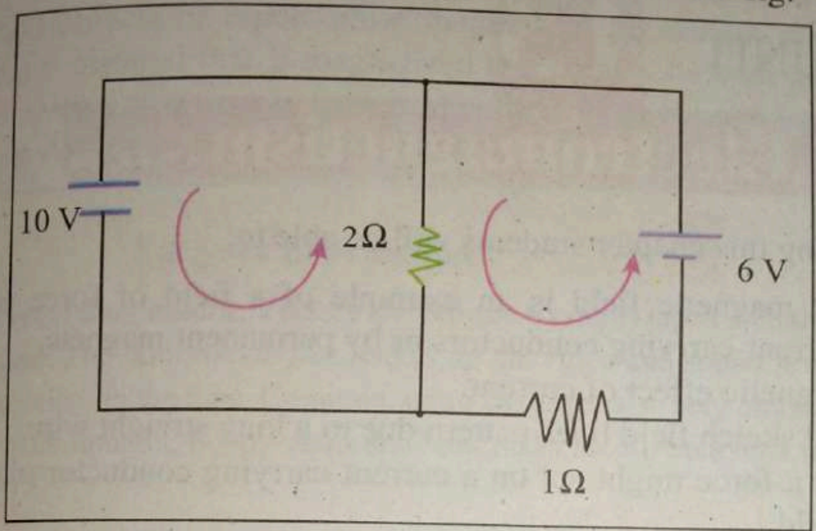
1. Why it is not possible to measure the drift speed for electron by timing their travel along a conductor?
2. The relationship $R = V/I$ tells us that the resistance of a conductor is directly proportional to the potential difference applied to it. What do you think of this proportion?
3. A heavy duty battery of a truck maintains a current of 3A for 24 hour. How much charge flows from the battery during this time?
4. While analysing a circuit the internal resistance of e.m.f. sources are ignored why?
5. Under what circumstances can the terminal P.D. of a battery exceed its e.m.f.?
6. What is the difference between an e.m.f. and a P.D.?

7. The loop rule is based on the conservation of energy principle and the junction rule on conservation of charge principle. Explain just how these are based on these principles?
8. Why rise in temperature of a conductor is accompanied by a rise in the resistance?
9. Does the direction of e.m.f. provided by a battery depend on the direction of current flow through the battery?

Numerical Problems

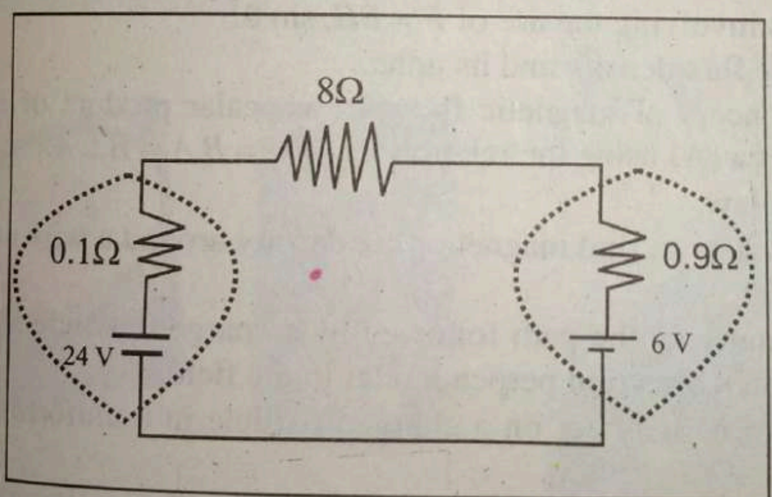
1. A battery has an e.m.f. of 12.8V and supplies a current of 3.2A. What is the resistance of the circuit? How many coulombs leave the battery in 5 minute? (4 Ω, 1200 C)
2. A carbon electrode has a resistance of 0.125 Ω at 20 C°. The temperature co-efficient of carbon is -0.0005 at 20C°. What will be the resistance of the electrode at 85 C°. (0.12 Ω)
3. Calculate the resistance of wire 10 m long that has a diameter of 2mm and resistivity of 2.63×10^{-2} Ω m. (0.0838 Ω)
4. A typical 12V automobile battery has a resistance of 0.012 Ω. What is the terminal voltage of this battery when the starter draws a current of 100A? calculate the R, $P_{\mathcal{E}}$, P_R and P_r. (0.108 Ω , 1200W, 1080W, 120 W)
5. A 10 watt resister has a value of 120 Ω. What is the rated current through the resister? (0.2886 A)
6. A resistor of 50 Ω has a P. D. of 100V, D.C. across 1 hour. Calculate (a). Power and (b). Energy. ((a) 200W, (b) 0.72 MJ)
7. Calculate the current through a single loop circuit if $\mathcal{E} = 120$V, $R = 1000\,\Omega$ and internal resistance $r = 0.01\ \Omega$. (120 mA)

9. Find the current flowing through the resistors of the fig:



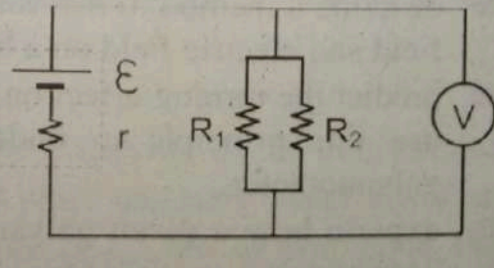
(-4 A, -9A)

10. Find the terminal potential difference of each cell in circuit of figure.



(23.8 V, 7.8 V)

11. The voltmeter in the circuit at the right may be considered to be ideal. Values are, $\mathcal{E}$= 15.0 V; internal resistance, r = 5.00 Ω; R_1= 100 Ω; R_2= 300 Ω. Calculate the current in R_1.



(0.01406A)