1 ELECTRICITY

1.1 INTRODUCTION

Electricity has great importance in the modern society. The modern devices in our day to day life require electricity for their operation. The most clean and convenient form of energy in our day to day life is electricity.

1.2 CHARGE

Charge is defined as the property of matter. When a charge is at rest, it produces electric field only, but when in motion, it also produces magnetic field . Charge can be positive or negative. The smallest possible charge is the charge on an electron. The SI unit of charge is coulomb.

1.2.1 Nature of Charge

Charge can be positive or it can be negative. A body can acquire positive or negative charge depending upon whether it gains or loses electrons. Since an atom is electrically neutral the number of electrons in an atom is equal to the number of protons present in the nucleus. If the atom becomes electron deficit then the atom become positively charged and if it gains electrons it becomes negatively charged. The magnitude of positive charge on a proton is equal to the negative charge present on an electron. The charge on the electron is given by

$e = -1.6 \times 10^{-19}$ C

Quantization of charge: The charge exists in fixed packets i.e. when a body is charged the charge on it is an integral multiple of the charge on an electron.

$q = \pm ne$

A body having a charge of +1C has an electron deficit of 6.25×10^{18} electrons.

Important points regarding electric charge

(i) Charge is scalar quantity and its unit is coulomb.

(ii) There are two types of charges i.e. positive charge and negative charge. Similar charges repel each other while opposite charges attract each other. The magnitude of elementary positive or negative charge is same and is equal to 1.6×10^{-19} C.

(iii) The electric charge is additive in nature.

(iv) Charge is quantized

(v) Charge is conserved

(vi) Charge is invariant

(vii) Charge resides on the outer surface of the conductor. In insulators it remains where it is placed.

(viii) Charge cannot exist without mass but mass can exist without charge.

*1.3 ELECTRIC FIELD

The region of influence around a charge is called the region of electric field.

1.3.1 Interaction of electric field between two charged particles.

Two charged particles always interact with each other due to their electric field. There may be force of repulsion or attraction between two charged particles.

This force of attraction exists between unlike charges and force of repulsion exist between like charges. The force between two point charges q_1 and q_2 separated by distance 'r' is given by Coulomb's law.

*1.3.2 Coulomb's law

In 1785, Coulomb gave two laws for the force of attraction or repulsion between two electrically charged bodies separated from each other by a definite distance. The laws are stated as follows

(i) The force of attraction or repulsion between two electron charges is directly proportional to the product of two charges.

(ii) The force of attraction or repulsion between two electric charges is inversely proportional to the square of the distance between them. This is known as inverse square law.

$$F \propto q_1 q_2$$

$$\propto \frac{1}{r^2}$$

$$F \propto \frac{q_1 q_2}{r^2} \Rightarrow F = \frac{1}{4\pi\varepsilon_o} . \frac{q_1 q_2}{r^2}$$

where $\left(\frac{1}{4\pi\varepsilon_o}\right)$ is proportionality constant. Its value depends upon the medium between charges and units used for charge, distance and force.

The constant ε_0 is called the permittivity of free space. Its value is 8.9×10^{-12} $C^2/N\text{-}m^2$.

The value of $\frac{1}{4\pi\varepsilon_o} = 9 \times 10^9 \frac{Nm^2}{C^2}$

*1.3.3 Intensity of electric field E

The intensity of electric field at a point in the field is defined as the force experienced by a unit positive charge placed at that point

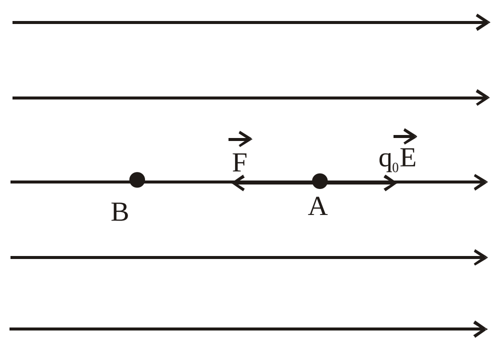
$$E = \frac{F}{q_0}$$

$$F = \frac{1}{4\pi\varepsilon_o} \frac{q \times 1}{r^2}$$

$$E = \frac{F}{1} = \frac{1}{4\pi\varepsilon_o} \frac{q}{r^2}$$

SI unit of electric field is N/C

1.4 ELECTRIC POTENTIAL AND POTENTIAL DIFFERENCE



If a positive test charge q_0 is placed at a point A in an uniform electric field (see figure) then, a force q_0E will act on this charge along the direction of electric field. Now if test charge q_0 is displaced from A to B, by applying force $F = (q_0E)$ in opposite direction to electric field intensity, then we have to do some work.

Let this work be W_{AB}.

In this way, work done in carrying a unit positive charge from point A to B is defined as potential difference between points B and A. i.e. potential difference between point B and A –

$$V_B - V_A = \frac{W_{AB}}{q_0}$$

If point A is considered as a reference point (initial point where potential is zero) at infinity, then–

$$V_B = V_B - 0 = \frac{W_{\infty B}}{q_0}$$

Electric potential at point B is defined by equation. That is, work done in carrying a unit positive charge from infinity (V = 0) to the point under consideration in electric field, without change of its kinetic energy, is called the electric potential of that point.

The S.I. unit for electric potential and potential difference is **joule/coulomb**, which is also known as **Volt**. One volt potential at a point means that work done in carrying one coulomb charge from infinity to this point would be one joule. Electric potential and potential difference are scalars. It is to be noted that positive charge always moves from high potential to low potential, similarly negative charge moves from low potential to high potential. From reference point of view, the electric potential of earth is considered as zero.

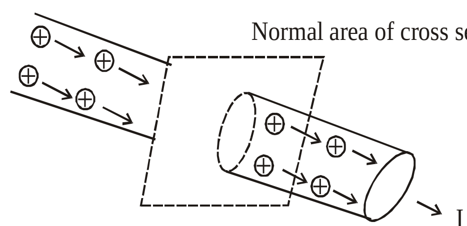
The electrons move only if there is a difference of electric pressure – called the potential difference – along the conductor. This difference of potential may be produced by a battery, consisting of one or more electric cells.

The potential difference is measured by means of an instrument called the voltmeter. The voltmeter is always connected in parallel across the points between which the potential difference is to be measured.

A continuous an closed path of an electric current is called an electric circuit.

1.5 FLOW OF CHARGE (ELECTRIC CURRENT)

Electric current is defined as continuous rate of flow of electric charge. Consider flow of charges through a conductor normal to its surface as shown in figure. If ΔQ charge flows in time Δt through the surface under consideration then the average value of current over this time interval is defined as –



$$i_{av} = \frac{\Delta Q}{\Delta t}$$

The S. I. unit of current is the **ampere** symbolically represented as **A**. Therefore–

$$I\,A = 1\,C/s \qquad \boxed{1\,mA = 10^{-3} A, 1\,\mu A = 10^{-6} A}$$

That is, 1 A of current is equivalent to one coulomb of charge passing through conductor in 1 second.

Conventionally, we define the direction of the current on the direction of flow of positive charge. The direction of current is considered opposite to the direction of flow of electrons.

An instrument called ammeter measures electric current in a circuit. It is always connected in series in a circuit.

1.5.1 Types of electrical Materials

(1) Insulators

(2) Semiconductors

(3) Conductors

Charge flow or conduction of electric current takes place only if free charge carries are present. Since protons are bounded and present in the nuclues so the conduction takes place only due to electrons.

(1) Insulators do not conduct electricity because of the absence of free electrons in them.

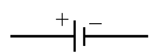
(2) Conductors conduct electricity due to presence of free electrons in them.

(3) Semiconductors behave as insulators at low temperature whereas they behave as conductors at high temperatures.

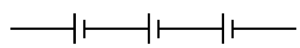
Conventionally positive charge is at higher potential than negative charge charge flow always takes place from higher potential to lower potential. The flow of current takes place from positive charge to negative charge. The direction of electronic current is from negative charge to positive charge i.e. the flow of electrons.

1.5.2 Symbols of some commonly used components in circuit diagrams.

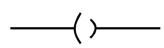
(1) An electric cell



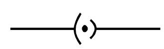
(2) A battery or a compination of cells



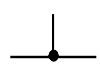
(3) Plug key or switch (open)



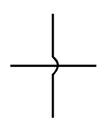
(4) Plug key or switch (closed)



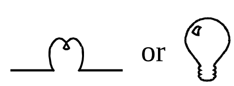
(5) A wire joint



(6) Wires crossing without joining

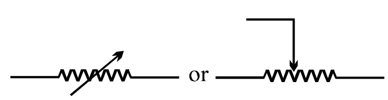


(7) Electric bulb

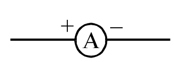


(8) A resistor of resistance R

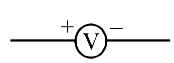
(9) Variable resistance or rheostat



(10) Ammeter



(11) Voltmeter



1.6 ELECTRIC RESISTANCE

1.6.1 Electric Circuit

A continuous conducting path between the terminals of a source of electric energy, conducting wires and other electrical components is called an electric circuit. An electric circuit can be open or closed. It is open if there is a gap or break in the circuit and closed if there is no gap in the circuit. In an open circuit there is no current flow while in a closed circuit current flow takes place.

1.6.2 Electrical Resistance

In a conductor whenever current flow takes place the motion of electrons takes place. During motion they are opposed to flow and this is known as electrical resistance. The SI unit of electrical resistance is Ohm denoted by Ω .

Factors which determine the electric resistance of a conductor

(1) The resistance of a conductor is directly proportional to its length $R \propto l$

(2) The resistance is inversely proportional to the area of crossection of the conductor $R \propto \frac{1}{A}$

(3) The resistance depends upon the nature of the material of the conductor $R \propto \frac{l}{A}$

(4) Removing the proportionality sign we have $R = \rho \frac{l}{A}$

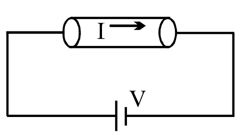
(5) ρ - Resistivity of the conductor.

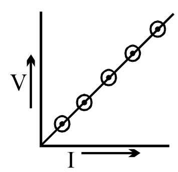
Resistivity :- The resistance of a unit cube of a substance is known as its resistivity.

Resistivity is also known as specific resistance and its SI unit is ohm m.

1.7 OHM'S LAW

Physical conditions (temperature, legth, cross section) remaining same, the current flowing through a conductor is directly proportional to the potential difference across the ends of a conductor.





$\therefore I \propto V$

So we can also write

$V \propto I$

$$\boxed{V = IR}$$

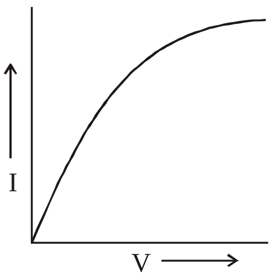
$R = \dfrac{V}{I}$ = Constant, provided length, cross section and temperature of the conductor remains same.

$$\Rightarrow 1\,ohm = \frac{1\,Volt}{1\,Ampere}$$

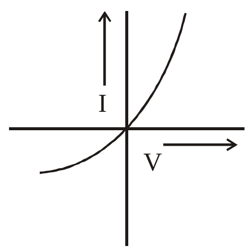
1 ohm is the resistance of a conductor whose ends have a potential difference of 1 volt and a current of 1 Ampere flows through it.

Exception of Ohm's law– In general almost all metal conductors obey the Ohm's law V = IR for which graph between V and i is a straight line as shown in figure. The conductors (or devices) obeying the ohm's law are called ohmic. Howerver, there are some exceptions such as vacuum tube, semiconductor diode, transistor, liquid electrolytes etc. in which relation V = IR does not hold good. These devices are called **non-ohmic**.

Figure (a) shows V – I curve for a bulb. This appears from the figure that this device do not obey the relation V = IR.



(a)



(b)

Figure (b) shows V – i curve for a semiconductor device such as diode or transistor. Again this graph is not fitted in the form of standard Ohm's law. Hence such devices are non-ohmic.

*1.7.1 Variation of Resistance with temperature

Resistance offered by a metallic conductor is due to the collisions between drifting electrons, and the ions present in the metallic conductor. When the temperature of the conductor increases, the amplitude of vibration of ions in the lattice increases and hence the collisions between electrons and the ions become more frequent. Therefore, the opposition to the flow of electrons (constituting the electric current) increases. In other words, resistance of the metallic conductor increases or decreases with the increase or decrease of the temperature respectively.

Then,

$R_2 = R_1\,[1 + \alpha(t_2 - t_1)]$

Where, α is the temperature coefficient of the resistance.

$$\alpha = \frac{(R_2 - R_2)}{R_1(t_2 - t_1)}$$

Thus, temperature coefficient of resistance (α) is defined as the change in resistance per unit original resistance per degree rise in temperature.

S.I. unit of α is $\frac{\text{ohm}}{\text{ohm kelvin}}$ or kelvin^{-1} or K^{-1}

α is positive for metallic condactors i.e. their resistance increases with the the rise of temperature (i.e. $R_2 > R_1$).

α is negative for insulators and semi - conductors i.e., their resistance decreases with the rise of temperature (i.e., $R_2 < R_1$).

α is very - very small for high resistivity alloys like manganin ($\approx 10^{-5}$ °C^{-1}). i.e. their resistance does not change appreciably with change in temperature. It is for this reason that mangamin and constantan are used in making standard resistance coils.

*1.7.2 Simple Electric Circuit

(1) Electric Cell: An electric cell is a device which maintains a continuous flow of charge in a circuit. The Cell changes Chemical energy into electrical energy.

(2) E.M.F. of a cell: The work done by the cell in forcing unit positive charge to flow in the whole circuit is called the electromotive force' (e.m.f.) of the cell.

$$E = \frac{w}{q}\left(J/C\right)$$

The unit of emf is called 'volt'(V). If in the flow of IC of charge in a circuit the energy given by the cell by IJ, then the emf of the cell is IV.

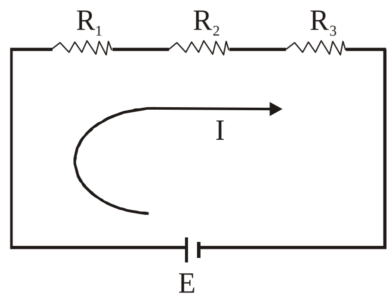
(3) Internal Resistance of a cell :- When we connect the plates of a cell by a wire, an electric current flows in the wire from the positive plate of the cell towards the negative plates, and in the electrolyte (inside the cell) it flows from the negative plate towards the positive plate. The resistance offered by the electrolyte of the cell to the flow of current (ions) through it is called the 'internal Resistance' of the cell.

(4) Terminal Potential Difference :-The potential difference across the terminals of a cell or battery when the cell is in charging or discharging mode is called terminal potential difference.

*1.8 COMBINATION OF RESISTANCES

1.8.1 Series Combination

In this combination, the resistances are joined end to end. In series combination the current across each resistance are the same but the potential difference across each R_1, R_2 and R_3 are V_1, V_2 and V_3. To replace R_1, R_2 and R_3 by an equivalent resistance the potential difference across equivalent should be equal to the sum of the potential difference across the three resistances.



$E = V_1 + V_2 + V_3$

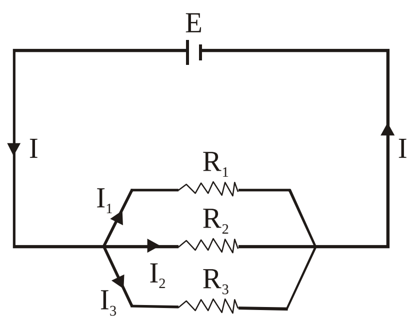
$IR_{eq} = IR_1 + IR_2 + IR_3$

$R_{eq} = R_1 + R_2 + R_3$

1.8.2 Parallel Combination

When two or more resistances are combined in such a way that their first ends are connected to one point and the second ends to another point then this combination is in parallel. In this combination the potential difference between the ends of all the resistances is same but the current in different resistances are different.

$I = I_1 + I_2 + I_3$



$$I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\Rightarrow \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

The reciprocal of the equivalent resistance of the resistances connected in parallel is equal to the sum of the reciprocal of those resistances.

<u>Advantages of connecting electrical devices in parallel</u>

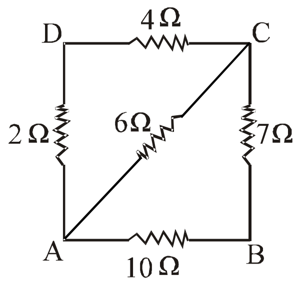
1. In a series circuit the current is constant thoughout the electric circuit. Thus it is obviously impracticable to connect an electric bulb and an electric heater in series, because they need currents of widely different values to operate properly.

2. Another major disadvantage of a series circuit is that when one component fails the circuit is broken and none of the components works.

3. On the other hand, a parallel circuit divides the current through the electrical gadgets. The total resistance in a prallel circuit is decreased. This is helpful particularly when each gadget has different resistance and requires different current to operate properly.

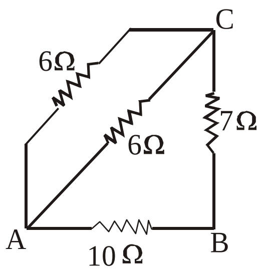
Illustration 1

Determine the equivalent resistance between points A and B in the following circuits



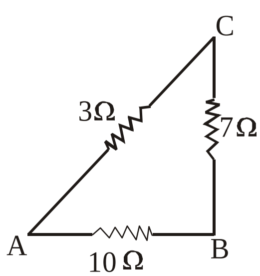
Solution

1Ω and 2Ω in series



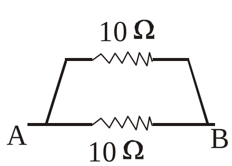
$$R_{eq_1} = 4 + 2 = 6\Omega$$

6Ω and 6Ω in parallel reduces to



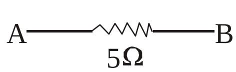
$$\frac{1}{R_{eq_2}} = \frac{1}{6} + \frac{1}{6} = 3\Omega$$

3Ω and 7Ω in series



$$R_{eq_3} = 3 + 7 = 10\Omega$$

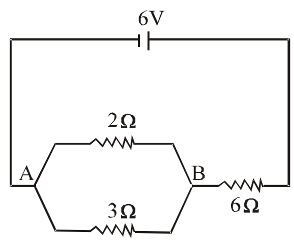
10Ω and 10Ω in parallel



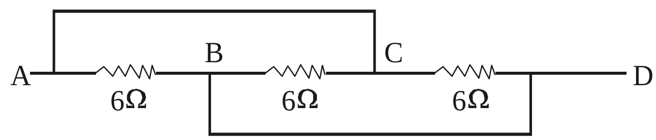
$$\frac{1}{R_{eq}} = \frac{1}{10} + \frac{1}{10} = 5\Omega$$

Try yourself

1. Determine the value of current in the 2Ω resistance and the potential difference between A and B in the circuit diagram given



2. Find the equivalent resistance between the points A and D of the adjoining circuit diagram.



*1.9 KIRCHHOFF'S LAW

1.9.1 Kirchhoff's First law or Junction Rule

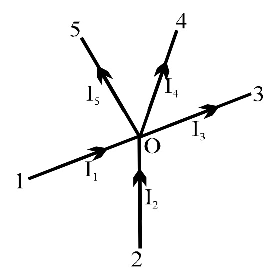
In an electric circuit, the 'algebraic'
sum of the currents meeting at any junction in the circuit is Zero, that is

$$\sum i = 0$$

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

$I_1 + I_2 = I_3 + I_4 + I_5$

Kirchhoff's First law is a statement of the conservation of charge.

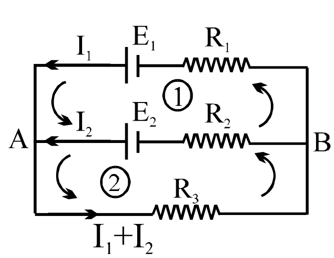


1.9.2 Kirchhoff's second law or Mesh (loop) Rule

In any 'closed' mesh of a circuit the algebraic sum of the products of the current and the resistance in each part of the mesh is equal to the algebraic sum of the emf's in that mesh

$$\sum E = 0$$

Kirchoff's second law is simply a statement of the conservation of energy.



Kirchhoff's second law for mesh 1, we have

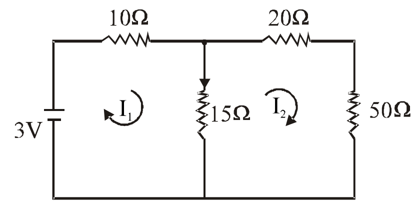
$- I_1R_1 + E_1 - E_2 + I_2R_2 = 0$ (1)

Kirchoff's second law for mesh 2, we have

$- I_2R_2 + E_2 -(I_1 + I_2)R_3 = 0$ (2)

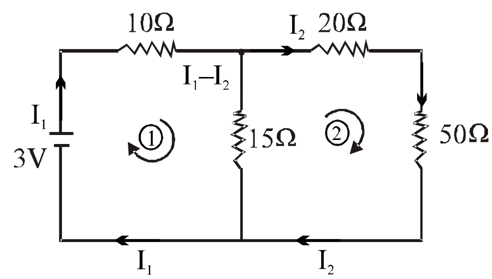
Illustration 2

Apply Kirchhoff's Voltage law to the adjoining circuit and obtain two equations for I_1 and I_2.



Solution

Mark the current distribution for the circuit.



Apply Kirchoff's law for the first closed mesh, we have

$I_1 \times 10 + (I_1 - I_2) \times 15 - 3 = 0$

$25I_1 - 15I_2 = 3$ ..(1)

Applying Kirchoff's voltage law for the second closed mesh, we have

$I_2 \times 20 + I_2 \times 50 -(I_1 - I_2)15 = 0$

$17I_2 - 3I_1 = 0$ ..(2)

Solving equation (1) and (2), we get

$$I_1 = \frac{51}{380} = 0.134\,A \text{ and } I_2 = \frac{9}{380} = 0.024\,A$$

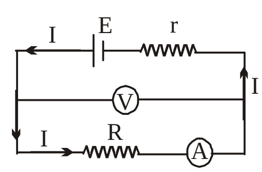
*1.9.3. Relation among Terminal Potential Difference, EMF and Internal Resistance of a cell

Let

E = Emf of cell

V = Terminal Potential difference

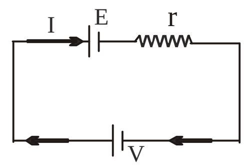
r = Internal resistance of cell



During discharging Mode

V = E – Ir

Where $I = \dfrac{E}{R+r}$



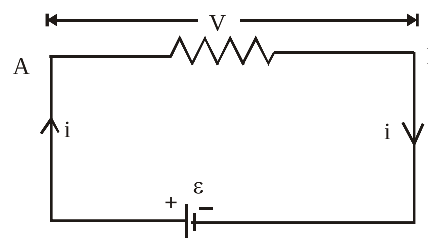
During charging Mode

V = E + Ir

1.10 HEATING EFFECT OF ELECTRIC CURRENT

When an e.m.f. is applied across the ends of a conductor, an electric field is developed across its ends and due to this field the free electrons of the conductor get moving in a definite direction. During their motion these free electrons experience the resistance due to the collisions with the ions or atoms already present in that conductor. Therefore, some energy of the electrons gets lost in this process which appears in the form of heat energy. This effect of electric current is known as **heating effect of electric current**. The electric appliances like electric kettle, heater, press etc. operate their functioning based on the heating effect of electric current.

Passing of an electric current of strength 'i' through a conductor of resistance 'R' for time-interval Δt produces a potential difference 'V' across its ends then the total charge passing through the conductor in time-interval Δt will be



q = Strength of Current × time-interval or $q = i \times \Delta t$

In this process the work done in carrying q coulomb of charge from one end to the other at potential difference V will be

$$W = q.V \text{ or } W = (i \times \Delta t) \times V = i + \Delta t \times (i \times R) = i^2 \times R\,\Delta t$$

If this entire work is converted into heat then heat produced is;

$$H = \frac{W}{J} = \frac{Vi\,\Delta t}{J}$$

Here J is a conversion constant and known as the **Mechanical equivalent of heat**. Its value is 4.18 joiule/calorie.

Hence the heat produced due to flow of current through a conductor.

$$H = \frac{Vi\,.\,\Delta t}{4.18} = 0.239\ Vi\,.\,\Delta t = 0.239\ i^2 R\Delta t \qquad \text{(in calorie)}$$

1.11 JOULE'S LAW

These are as follows –

(i) The amount of heat (H) produced in a conductor in a definite time interval Δt is directly proportional to the square of the strength of current passing through it.

Hence $H \propto I^2$

It is also known as law of current.

(ii) If the current of definite strength i passes through a conductor of resistance R for a definite time interval Δt then the amount of heat (H) produced in the conductor is directly proportional to its resistance R.

Hence $H \propto R$

It is also known as the law of resistance.

(iii) If the current of definite strength i passes through a conductor of resistance R then the amount of heat (H) produced in the conductor is directly proportional to the time interval Δt for which the current flows in it.

Hence $H \propto \Delta t$

It is also known as the law of time.

Therefore the amount of heat produced (H) when a current of strength i passes through a conductor of resistance R for a time interval Δt is given by

$H \propto I^2 R \Delta t$ $\qquad H = I^2Rt$ Joule

or $\qquad H = \frac{1}{J} I^2 R\Delta t = 0.239\ I^2 R\Delta t$ calorie

This equation is a mathematical expression of Joule's law.

1.12 PRACTICAL APPLICATIONS OF HEATING EFFECT OF ELECTRIC CURRENT

The generation of heat in a conductor is an inevitable consequence of electric current. In many cases, it is undesirable as it converts useful electrical energy into heat. In electric circuits, the unavoidable heating can increase the temperature of the components and alter their properties. The electric laundry iron, electric toaster, electric oven, electric kettle and electric heater are some of the familiar devices based on Joule's heating.

The electric heating is also used to produce light, as in an electric bulb. A strong metal with high melting point such as tungsten (melting point 3380°C) is used for making bulb filaments. The bulbs are usually filled with chemically inactive nitrogen and argon gases to prolong the life of filament.

Another common application of Joule's heating is the fuse used in electric circuits. It protects circuits and applicances by stopping the flow of any unduly high electric current. The fuse is placed in series with the device. It consists of a piece of wire made of a metal or an alloy of appropriate melting point, for example aluminium, copper, iron, lead etc. If a current larger than the specified value flows through the circuit, the temperature of the fuse wire increases. This melts the fuse wire and breaks the circuit.

1.13 ELECTRIC POWER

The rate of doing work, in an electric device due to flow of current in it, is defined as the power of that electric device.

If, in a circuit with an electric source, the potential difference V is developed ascross the two ends of a conductor of resistance R as current of strength i passes through it for a time-interval Δt then work done in carrying a charge q through a potential difference V in the circuit will be–

$$W = q \times V = i \times \Delta t \times V$$

So the rate of work done, i.e., Power of the electric device (P);

$$P = \frac{W}{\Delta t} = \frac{i \times \Delta t \times V}{\Delta t} = i \times V$$

or $$P = V \times i = \frac{V^2}{R} = i^2 R$$

The S.I. unit of electric power is **watt**. Therefore in an electric circuit if 1 ampere current flows for a time-interval of 1 second through a potential difference of 1 Volt then the power of the electric device is termed as 1 watt.

In general kilowatt & Megawatt are used for measurement of electric power, Hence–

1 Kilowatt = 1000 watt = 10^3 watt

and 1 Megawatt = 1000 kilowatt = 10^6 watt

In practice, Horse Power (H.P.) is also used for the measurement of electric power. The value of 1 Horse Power is 746 Watt.

1.14 ELECTRIC ENERGY

The work done by an electric source for the flow of current for a certain time interval is known as electric energy of the circuit. If electric power P is given for a small time Δt in a electric circuit then electric energy of the circuit will be $W = P \times \Delta t$ so the electric energy of the electric circuit is–

$$W = P \times \Delta t = Vi\,\Delta t = i^2 R\Delta t$$

The unit for the measurement of electric energy is **watt × sec** or **joule**. In practice **kilo-watt** hour is used for the measurement of Electric Energy. It is also known as Board of Trade Unit (B.O.T.U.) or simply Electric Unit i.e.,

1 Electric Unit = 1 k.w.h.

= 1 kilo watt × 1 hour = 1000 watt × 3600 second

or 1 Electric Unit = 3.6×10^6 watt × second or joule. The rate of doing work, in an electric device due to flow of current in it, is defined as the power of that.

Solved Examples

Example 1

How many electrons must be removed from a piece of metal so that a positive charge of 1.0×10^{-7} C remains on it ?

Solution

An electron has a negative charge of 1.6×10^{-19} C. Therefore, on removing one electron from an elecrtically neutral metal, a positive charge of 1.6×10^{-19} C will remain on the metal. Hence to keep a positive charge of 1.0×10^{-7} C on the metal, the number of electrons to the removed from it is

$$\frac{total\ positive\ charge}{charge\ on\ one\ electron} = \frac{1.0\times10^{-7}C}{1.6\times10^{-19}C} = \mathbf{6.25 \times 10^{11}}.$$

Example 2

Compute the electric fields intensity at a point 30 cm away in vacuum from a charge of 4 × 10⁻⁹ C.

Solution

The intensity of electric field at a distance of r meter in vacuum from a charge of q cuulomb is

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$$

Here, $q = 4 \times 10^{-9}$ C, r = 30 cm = 0.30 m and $\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9$ N m^2 C^{-2}

$$\therefore E = \left(9\times10^9\right)\times\frac{4\times10^{-9}}{(0.30)^2} = 400\,N\,C^{-1}$$

Example 3

Two wires A and B of equal masses and of the same metal are taken. The diameter of the wire A is half the diameter of the wire B. If the resistance of the wire A be 24 ohm, calculate the resistance of the wire B.

Solution

Let r_A be the redius and l_A the length of the wire A, and r_B the radius and l_B the length of the wire B. Both the wires are of the same material (density d). Since the masses of the two wires are equal, we have

$$\pi r_A^2 l_A \times d = \pi r_B^2 l_B \times d$$

$$\therefore \frac{l_A}{l_B} = \frac{r_B^2}{r_A^2}$$

Resistance of the wire A is $R_A = \rho\frac{l_A}{\pi r_A^2}$

And the resistance of the wire B is $R_B = \rho\frac{l_B}{\pi r_B^2}$

Where ρ is the specific resistance of the material of the wires.

$$\therefore \frac{R_A}{R_B} = \frac{l_A}{l_B}\times\frac{r_B^2}{r_A^2} = \frac{r_B^4}{r_A^4}$$

But $r_A = \frac{1}{2} r_B$ (given) $\therefore \frac{R_A}{R_B} = 16$

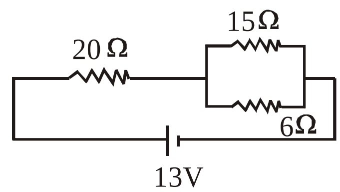
or $R_B = \frac{1}{16} R_A = \frac{1}{16}\times 24$ ohm = **1.5 ohm.**

EXERCISE-I

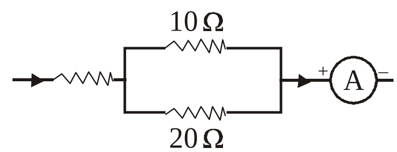
1. When are resistors said to be connected in series?
2. When are resistors said to be connected in parallel?
3. State Ohm's law. How can it be verified?
4. Define electric current and state is unit. How can ohm's law be used to define ohm?
5. Derive an expression for the heat produced in time t in a wire of resistance R, which is carrying a current i.
6. Write the unit of electric potential.
7. Define the potential at a point.
8. Define the potential difference between two points.
9. Name three electric appliances in which the heating effect of electric current is used.
10. Two bulbs have ratings 100 W, 220 V and 60 W, 220 V. Which one has a greater resistance?
11. What is the shape of the graph between V and i, where v is the potential difference between the ends of a wire and i is the current in it?
12. Calculate the number of electrons constituting one coulomb of charge?
13. What is meant by saying that the potential difference between two points is 1 V?
14. How much energy is given to each coulomb of charge passing through a 6V battery?
15. How is a voltmeter connected in the circuit to measure the potential difference between two points?
16. Will current flow more easily through a thick wire or a thin wire of the same material, when connected to the same source? Why?
17. Why are coils of electric toasters and electric irons made of an alloy rather than a pure metal?
18. Let the resistance of an electrical component remains constnat while the potential difference across the two ends of the component decreases to half of its former value. What change will occur in the current through it?
19. What are the advantages of connecting electrical devices in parallel with the battery instead of connecting them in series?
20. Name a device that can be used to maintain potential difference across a conductor. Also draw its circuit symbol.
21. Derive an expression for the equivalent resistance when two resistances are connected in series.
22. Derive an expression for equivalent resistance when two resistances are connected in parallel.
23. What is the commercial unit of electrical energy? Convert it into joules. What is the other name of the commercial unit?
24. State Joule's law of heating. Write its mathematical form both in C.G.S. system and S.I.

EXERCISE-II

1. Find the current through the circuit shown in figure. Also find the potential difference across the 20Ω resistor and current through 15Ω resistor.



2. Figure shows a part of an electric circuit. The reading of the ammeter is 3 A. Find the currents through the 10Ω and 20Ω resistors



3. Calculate the current passing through a bulb rated 60 W, 240 V when it is connected to a supply of 220 V.
4. A hot plate of an electric oven connected to a 220 V line has two resistance coils A and B, each of 24Ω resistance, which may be used separately, in series, or in paralle. What are the currents in the three cases?
5. Calculate the energy consumed in kilowatt hours by a 60 W fan in 2 hours.
6. A heater draws 1100 W at 220 V.

   (a) Find the resistance of the heater

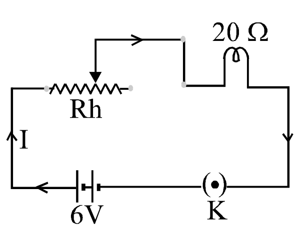
   (b) Calculate the kilowatt hours consumed in a week if the heater is used daily for four hours at the rated voltage.
7. Compare the power used in the 2Ω resistor in each of the following circuits:

   (i) a 6 V battery in series with 1Ω and 2Ω resistors, and

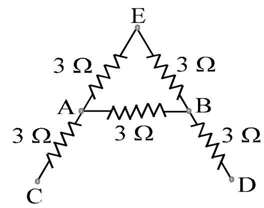
   (ii) a 4 V battery in parallel with 12Ω and 2Ω resistors.
8. Which uses more energy, a 250 W TV set in 1 hr or a 1200 V toaster in 10 minutes?
9. An electric lamp of 100 Ω, a toaster of resistance 50 Ω and a water filter of resistance 500 Ω are connected in parallel to a 220 V source. Wht is the resistance of an electric iron connected to the sme source that takes as much current as all three appliances, and what is the current through it?
10. Two copper wires A and B of length 30 m and 10 m have radii 2 cm and 1 cm respectively. Compare the resistances of the two wires. Which will have less resistence?

11. When two resistors of resistances R_1 and R_2 are connected in parallel, the net resistance is 3 Ω. When connected in series, its value is 16 Ω. Calculate the values of R_1 and R_2.

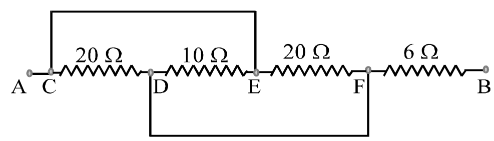
12. Suppose a 6-volt battery is connected across a lamp whose resistance is 20 Ω through a variable resistor as shown in Figure. If the current in the circuit is 0.25 A, calculate the value of the resistance from the resistor which must be used?



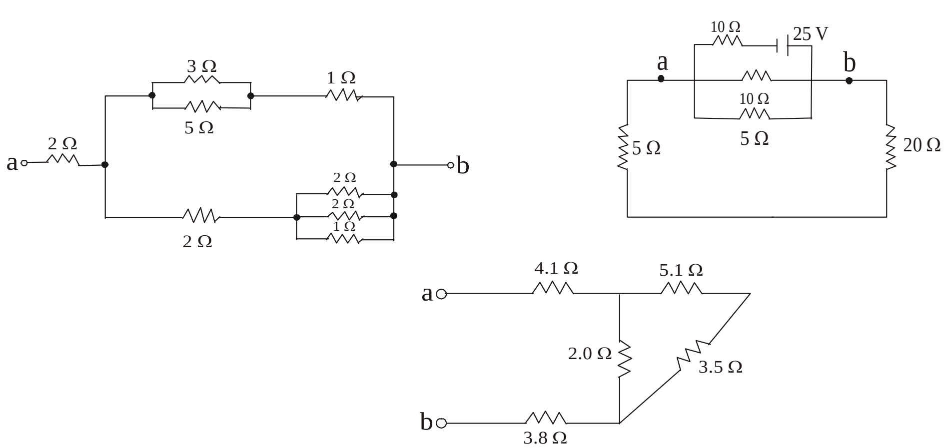
13. Five resistors, each 3 Ω, are connected as shown in figure. Calculate the resistance between the points (i) A and B (ii) between the point C and D.



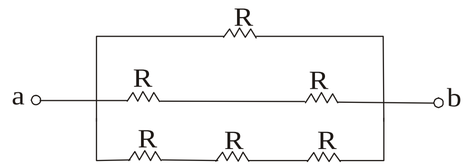
14. A wire having a resistance of 18 Ω is cut into three equal parts. What is the equivalent resistance if these three parts are joined in parallel?
15. A wire of resistance 20 Ω is bent in the form of a closed circle. What is the effective resistance between the two points at the ends of any diameter of the circle?
16. Calculate the equivalent resistance between the points A and B in the following combination.



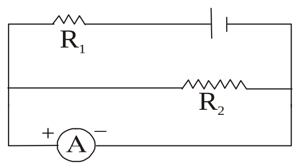
17. (i) State the formula showing how the current I in a conductor varies when the potential difference V applied across it is increased stepwise (ii) Show this relationship also on a schematic graph. (iii) Calculate the resistance of a conductor if the current flowing through it is 0.2 ampere when the applied potential difference is 0.8 volt.
18. A torch bulb is rated 5.0 V and 500 mA. Calculate its (i) power (ii) resistance and (iii) energy consumed when it is lighted for 4 hours.
19. Explain the terms potential and potential difference. Give their S.I. units.
20. How much work in done in moving a charge of 2 coulomb from a point at 20 volts to 40 volts?
21. 100 J of work is done in moving a charge of 5 coulomb from the one terminal of the battery to another. What is the potential difference of the battery?
22. If 20 coulomb of charge flows through a conductor in 10 second. What is the current through the conductor?
23. A parallel combination of three resistors takes a current of 7.5 ampere from a 30 V battery. If two of the resistors have a resistance of 10 ohm and 12 ohm, find the resistance of the third resistor.
24. A student obtains resistance of 3, 4, 12 and 16 ohm using two metallic resistors either separately or joined together. What is the value of resistance of each of these wires?
25. Find the equivalent resistance between a and bin the following circuits.



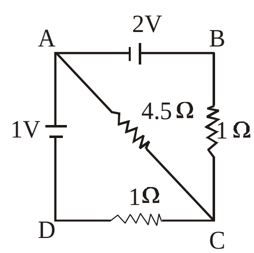
26. Find the equivalent resistance if the value of R in the circuit is 11 ohm.



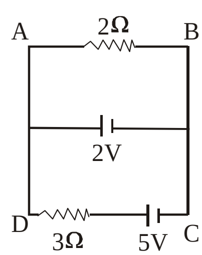
27. In the circuit given below, there is a mistake, correct the mistake and tell whether the resistors are in series or 'parallel'.



28. Two resistance of 20 ohm and 40 ohm are connected in series to a battery of potential difference 10 V. Compare the ratio of heat produced in one minute by the two resistance.
29. An electric heater rated 220 V, 2.2 kW works for 3 hours. Find the energy consumed and the current drawn.
30. In a household 5 tube lights of 40 W each are used for 5 hours and an electric press of 500 W for 4 hours everyday. Calculate the total electrical energy consumed by the tube lights and the press in a month of 30 days.
31. Calculate in the given electrical circuit, current in each resistance. The internal resistances of the cells are negligible.



32. Determine the current in 3Ω resistance and potential difference between points A and B in the given circuit.



EXERCISE-III

SECTION-A

- **Fill in the blanks**

1. If we add electrons to a body then the body becomes__________.
2. Current is a __________quantity.
3. In series circuit the current flowing throw each resistor is __________and potential difference across each will be __________.
4. The resistance offered by a cell is called __________of cell.
5. In a parallel circuit the current resistor is __________.

SECTION-B

- **Multiple choice question with one correct answers**

1. A wire of resistance 40Ω is stretched to double its length. Its new resistance is

   (A) 20Ω (B) 80Ω (C) 160Ω (D) 320Ω
2. The resistances of 200 W and 100 W bulbs of the same voltage are respectively R_1 and R_2. Then

   (A) $R_1 = 2R_2$ (B) $R_2 = 2R_1$ (C) $R_2 = 4R_1$ (D) $R_1 = 4R_2$
3. Three resistances of 2, 3 and 5Ω cell connected in parallel to a 10 V battery of negligible internal resistance. The potential difference across the 3Ω resistance will be

   (A) 2V (B) 3V (C) 5V (D) 10V
4. Two bulbs marks 25W–220V and 100W–220V are connected in series with a 440 V supply. Which of the bulbs will fuse?

   (A) 100 W bulbs (B) 25 W bulb (C) neither (D) both

SECTION-C

- **Assertion & Reason**

Instructions: In the following questions as Assertion (A) is given followed by a Reason (R). Mark your responses from the following options.

(A) Both Assertion and Reason are true and Reason is the correct explanation of 'Assertion'

(B) Both Assertion and Reason are true and Reason is not the correct explanation of 'Assertion'

(C) Assertion is true but Reason is false

(D) Assertion is false but Reason is true

1. **Assertion:** Current is a vector quantity

   Reason: Current is charge flowing per unit time.
2. **Assertion:** Current flows from positive to negative terminal of the battery

   Reason: This is the conventional direction of current.

3. **Assertion:** The resistance of a conductor is proportional to the square of its length

Reason: $R = \rho \frac{l}{A}$

4. **Assertion:** Resistivity changes when conductor is stretched or contracted.

Reason: Resitivity is a material property

5. **Assertion:** Kirchoff's current law states that the net current at a junction is zero.

Reason: This law is based on the conservation of charge principle.

SECTION-D

- **Match the following (one to one)**

Column-I and **column-II** contains **four** entries each. Entries of column-I are to be matched with some entries of column-II. Only One entries of column-I may have the matching with the some entries of column-II and one entry of column-II Only one matching with entries of column-I

1. **Column I** / **Column II**

Column I	Column II
(A) Ohms law	(P) Series combination
(B) $R_{eq} = R_1 + R_2 + ... + R_n$	(Q) Terminal potential difference
(C) V = E – Ir	(R) V = IR
(D) $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + ... + \frac{1}{R_n}$	(S) Parallel combination

EXERCISE-IV

SECTION-A

- **Multiple choice question with one correct answers**

1. A 220V–100 W bulb is connected to a supply of 110 V. The power dissipated will be

(A) 100 W (B) 50 W (C) 25 W (D) 2 W

2. A wire of resistance R is cut into ten equal parts which are then joined in paralle. The new resistance is

(A) 0.01 R (B) 0.1 R (C) 10R (D) 100R

3. A 90 W, 30 V bulb is run on a 120V supply. For this, a wire is connected in series with the bulb. The resistance of the wire is

(A) 10 Ω (B) 20 Ω (C) 30 Ω (D) 40 Ω

4. Four wires of equal lengths, each of resistance 5 Ω are joined to form a square. The equivalent resistance between two diagonally opposite corners of the square is

(A) 5 Ω (B) 10 Ω (C) 20 Ω (D) 5/4 Ω

SECTION-B

- **Multiple choice question with one or more than one correct answers**

1. The terminal potential difference of a cell of EMF 'E' and internal resistance 'r' is given by the formula

(A) V = E – Ir (B) V = E (C) V = 0 (D) V = E + Ir

2. The voltage across a conductor is directly proportional to the current flowing across it under constant conditions of

(A) Pressure (B) Humidity (C) Temperature (D) Density

3. Choose all correct alternatives

(A) 1 volt × 1 coulomb = 1 joule (B) 1 volt × 1 ampere = 1 J/s

(C) 1 volt × 1 watt = 1 HP

(D) Watt-hour can be measured in terms of electron-volt

SECTION-C

- **Comprehension**

A battery of EMF 10 V having internal resistance of 2Ω is connected to an external resistance of 3Ω. The battery is first in charging mode and then in discharging mode.

1. The current flowing through the external resistance is

(A) 1A (B) 3A (C) 2A (D) 10A

2. The terminal potential difference during discharging mode of battery

(A) 6V (B) 2V (C) 1V (D) 10V

3. The terminal potential difference during the charging mode of battery

(A) 5V (B) 10V (C) 14V (D) 9V

SECTION-D

- **Match the following (one to many)**

Column-I and **column-II** contains **four** entries each. Entries of column-I are to be matched with some entries of column-II. One or more than one entries of column-I may have the matching with the some entries of column-II and one entry of column-II may have one or more than one matching with entries of column-I

1.

Column I	**Column II**
(A) Ohm's law	(P) Nichrome wire
(B) Heating effect	(Q) Battery
(C) EMF	(R) V = IR
(D) Terminal potential difference	(S) Ohmic resistance

Answers

TRY YOURSELF

1. 0.5 A, 1 V 2. 2Ω

EXERCISE-III

SECTION-A

1. Negatively
2. Scalar
3. Same, different
4. Internal resistance
5. different

SECTION-B

1.	(C)	2.	(B)	3.	(D)	4.	(B)

SECTION-C

1.	(D)	2.	(A)	3.	(D)	4.	(D)	5.	(A)

SECTION-D

1. (A)-(R), (B)-(P), (C)-(Q), (D)-(S)

EXERCISE-IV

SECTION-A

1.	(C)	2.	(B)	3.	(C)	4.	(A)

SECTION-B

1.	(A,D)	2.	(A,C)	3.	(A,D)

SECTION-C

1.	(C)	2.	(A)	3.	(C)

SECTION-D

1. (A)-(R,S), (B)-(P), (C)-(Q), (D)-(R,S)