ELECTRICITY

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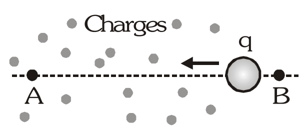
The source of all electricity is charge. As charge is the basis of all electrical phenomena, we need to know the amount of charge on a body. It is measured in coulombs. The coulomb is the SI unit of charge and its symbol is C.

Matter is generally made of protons, electrons and neutrons. Each proton carries a charge of 1.6×10^{-19} coulomb, and each electron carries an equal negative charge. Neutrons do not carry any net charge. Normally, a body has equal number of protons and electrons, and is therefore, electrically neutral.

In certain situations, the balance of charges in a body is disturbed. For example, when a glass rod is rubbed with a silk cloth, some electrons get transferred from the glass rod to the silk. The silk cloth, which gains electrons, becomes negatively charged. And the glass rod, which is left with more protons than electrons, becomes positively charged.

Charged particles or objects can exert forces on each other. While like (similar) charges repel each other, unlike charges attract. Another important thing about charged particles is that they can flow, i.e., they can move in a particular direction. This flow of charged particles is called an electric current. Charged particles such as electrons are present in all substances. But they do not flow on their own. For flow of charges, there has to be a potential difference.

POTENTIAL DIFFERENCE AND THE FLOW OF CHARGE



The potential difference between two points A and B is the work done per unit charge in taking a charge from B to A. We express this mathematically as

$$\boxed{V = V_A - V_B = \frac{W}{q}}$$

Here, V is the potential difference between the points A and B, and V_A and V_B are the potentials at these points. The potential at infinity is chosen as zero.

If B be the reference point, the potential at B is V_B = O. From Equation, the potential at A is $V_A = W/q$. So, the potential at a point is the work done per unit charge in taking a charge to that point from a chosen reference point. Equation may also be written as

$W = qV$.

The work done on the charge q is stored as the electric potential energy (U) of the group of charges. So,

$U = qV$

UNIT OF POTENTIAL DIFFERENCE

The unit of potential difference (and potential) is the volt, whose symbol is V. One volt is the potential difference between two points in a current carrying conductor when 1 joule of work is done to move a charge of 1 coulomb from one point to the other.

$$\boxed{\frac{1\ \text{Joule}}{1\ \text{Coulomb}} = 1\,\text{volt or } 1\,V = 1\,JC^{-1}}$$

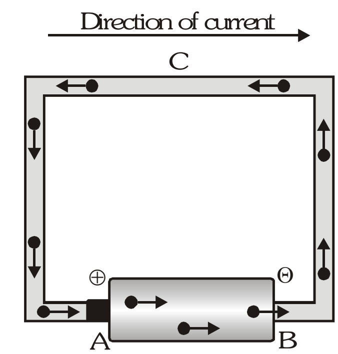
The potential difference between two points is sometimes also called the voltage.

FLOW OF CHARGE

Consider two identical metallic spheres P and N, carrying equal amounts of positive and negative charges respectively. A positive charge is to be taken from B to A. It is attracted by the negatively charged sphere N and repelled by the positively charged sphere P. So, to move the charge towards A, one has to apply a force on it towards the left. Thus, the work done is positive. Hence, the potential difference $V_A - V_B$ is positive. This means $V_A > V_B$.

ELECTRIC CURRENT

Consider a metallic wire ACB connected across a cell of potential difference V. Since the end A is connected to the positive terminal, it is at a higher potential than the end B. In metals, some electrons are loosely bound to the atoms, and can move within it. These are called free electrons. In the metallic wire, these electrons (negative charges) move from the low-potential side B to the high-potential side A. After reaching A, they enter the cell. The chemical reactions in the cell drive these electrons to the negative terminal. From there, they re-enter the wire at the end B. Thus, there is a continuous flow of electrons in the wire from B to C to A. We say that there is an electric current in the wire. In a metal, the flow of negative charges constitutes the current.



Current in a wire connected to a cell

An electric current can also be a flow of positive charges. So, a flow of charge is called an electric current.By convention, the direction of current is taken as the direction of flow of positive charges. Thus, the direction of current is opposite to the direction of flow of negative charges. So, when a wire is connected to a cell, the current in the wire is from the positive-terminal end to the negative-terminal end.

MEASUREMENT OF CURRENT

The charge passing per unit time through a given place(area) is the magnitude of the electric current at that place. Thus,

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

Here Q is the charge that passes through a place in time t.

Unit of current From Equation, we find that current is charge divided by time. The SI unit of charge is the coulomb and that of time is the second. The SI unit of current, therefore, is coulomb / second. This unit is called the ampere, whose symbol is A. Thus, if one coulomb of charge passes through a place in one second, the current there is 1 ampere.

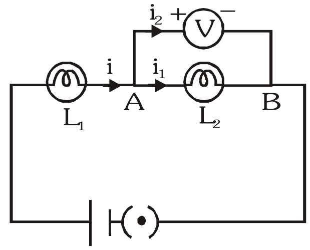
CONDUCTORS AND INSULATORS

Materials that conduct electricity easily are called good conductors or simply, conductors. And, materials that do not conduct electricity easily are called insulators.

All metals conduct electricity because they have some loosely bound free electrons, which flow when a potential difference is applied. However, some metals conduct electricity better than others. Silver is the best conductor. But because of the high cost of silver, electric wires are made of copper, or in some cases aluminium.

Most nonmetallic solids do not conduct electricity. Although diamond and graphite are both forms of carbon (a nonmetal), graphite is a conductor while diamond is an insulator. Insulators do not conduct electricity because their electrons are tightly bound to the atoms. Rubber, plastics, wood, glass and porcelain are some examples of insulators. Insulators have many uses. For example, they are used as protective covers on electric wires and electrician’s tools.

Certain liquids also conduct electricity. While distilled water is an insulator, addition of certain salts, acids or bases allows it to conduct electricity. Under normal circumstances, gases do not conduct electricity.



Voltmeter in a circuit

Two or more electric elements are said to be connected in parallel if the same potential difference exists across them.

OHM'S LAW

The electric current through a metallic element or wire is directly proportional to the potential difference applied between its ends, provided the temperature remains constant.

If a potential difference V is applied to an element and a current i passes through it, $i \propto V$

or $$i = \left(\frac{1}{R}\right)V$$

Thus Ohm's Law $V = iR$

Here R is a constant for the given element (metallic wire) at a given temperature and is called its resistance. It is the property of a conductor to resist the flow of charges through it.

RESISTANCE

From equation, $\boxed{i = \frac{V}{R}}$

So, for a given potential difference, $i \propto \frac{1}{R}$

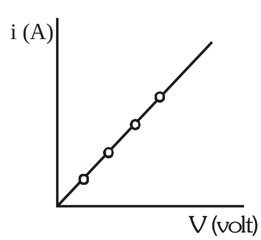
Thus, for a given potential difference, the current is inversely proportional to the resistance. The higher is the resistance, the lower is the current. If the resistance is doubled, the current is halved. Good conductors have low resistance, while insulators have very high resistance.

UNIT OF RESISTANCE

Potential difference is measured in volts, and current is measured in amperes. From Equation, R = V/i. So, the unit of resistance is volt/ampere. This unit is called the ohm, and its symbol is Ω. We can define one ohm as follows.

If a potential difference of 1 volt is applied across an element, and a current of 1 ampere passes through it, the resistance of the element is called 1 ohm.

$$1\,\text{ohm} = \frac{1\,\text{volt}}{1\,\text{ampere}}$$



ON WHAT DOES RESISTANCE DEPEND ?

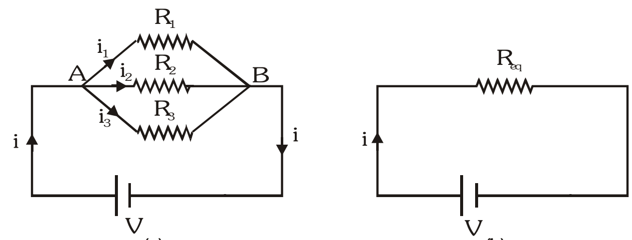
The resistance of the conductor depends (i) on its length, (ii) on its area of cross-section, and (iii) on the nature of its material. Resistance of a uniform metallic conductor is directly proportional to its length (ℓ) and inversely proportional to the area of cross-section (A).

$$R \propto \ell \quad \text{and} \quad R \propto \frac{1}{A}$$

If resistors are connected in such a way that the same potential difference gets applied to each of them, they are said to be connected in parallel.

EQUIVALENT RESISTANCE IN PARALLEL CONNECTION

Figure (a) shows three resistors of resistances R_1, R_2 and R_3 connected in parallel across the points A and B. The cell connected across these two points maintains a potential difference V across each resistor. The current through the cell is i. It gets divided at A into three parts i_1, i_2 and i_3, which flow through R_1, R_2 and R_3 respectively.



(a) (b)

Let us replace the combination of resistors by an equivalent resistor R_{eq} such that the current i in the circuit does not change (Fig). The equivalent resistance is given by Ohm's law as $R_{eq} = V/i$.
Thus,

$$i = \frac{V}{R_{eq}}$$

The currents i_1, i_2 and i_3 through the resistors R_1, R_2 and R_3 respectively are given by Ohm's law as

$$i_1 = \frac{V}{R_1}, \quad i_2 = \frac{V}{R_2}, \quad i_3 = \frac{V}{R_3}$$

Since the resistors are in parallel,

$$i = i_1 + i_2 + i_3$$

Substituting the values of the currents in the above equation,

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

or

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

Similarly, if there are n resistors connected in parallel, their equivalent resistance R_{eq} is given by

Equivalent Resistance of resistors in parallel :

eq 1 2 n

For two resistances R_1 and R_2 connected in parallel,

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_1 + R_2}{R_1 R_2} \quad \text{or} \quad R = \frac{R_1 R_2}{R_1 + R_2}$$

The equivalent resistance in a parallel connection is less than each of the resistances.
When a resistance is joined parallel to a comparatively smaller resistance, the equivalent resistance is very close to the value of the smaller resistance.

$$P = \frac{V^2}{R}$$

DISADVANTAGES OF THE HEATING EFFECT OF CURRENT

A current always produces some heat, whether we use the heat or not. If the heat produced cannot be utilized, it represents a wastage of energy. A considerable amount of energy is thus wasted in the transmission of electricity from the generating station to our homes. Sometimes, the heat produced in a device is so much that it can damage the device, unless proper cooling arrangements are made. To dissipate the heat produced in TV sets, monitors, etc., their cabinets have grills for air to pass. Certain components of a computer get so hot that they have fans to cool them.

RATING OF ELECTRIC APPLIANCES

Take an electric bulb and see what is written on it. Apart from the name and the symbol of the company, we will find values of power and potential difference. For example, it could be 60W, 220V. It means that 220V should be applied across this bulb, and when 220V is applied, the power consumed will be 60W. We will find similar markings on all electric· appliances. For an electric appliance, the values of power and voltage taken together form what is called the rating of the appliance.

From the rating of an appliance, you can easily calculate its resistance by using the equation $P = \frac{V^2}{R}$.

Note that higher the power rating, smaller the resistance. So, a 1000W heater has less resistance than a 100W bulb. We can also calculate the current drawn by an appliance by using the relation $i = \frac{P}{V}$.

KILOWATT HOUR

Power is the rate of energy consumed or produced. If 1 joule of energy is used per second, the energy is used at the rate of 1 watt. In other words, if energy is used at the rate of 1 watt, the total energy used in 1 second is 1 joule. How much energy is used in 1 hour if it is used at the rate of 1000 watt?

It is (1000 watt) × (3600 second) = 3,600,000 joule.

This amount of energy is called 1 kilowatt hour, written in short as kWh.

Thus, 1 kWh = 3,600,000 J = 3.6×10^6 J.

The electrical energy used in houses, factories, etc., is measured in kilowatt hours. The cost of electricity is fixed per kilowatt hour. One kilowatt hour of electrical energy is called one unit.

For V = 4V (i.e., 9V – 5V), I = 1.25 A (i.e., 2.65 A – 1.40 A).

Therefore, $R = \frac{V}{I} = \frac{4V}{1.25A} = 3.2\ \Omega$

The value of R obtained from the graph depends upon the accuracy with which the graph is plotted.

Ex.5 When a 12 V battery is connected across an unknown resistor, there is a current of 2.5 mA in the circuit. Find the value of the resistance of the resistor.

Ans. Here, V = 12 V, I = 2.5 mA = 2.5×10^{-3} A

Resistance of the resistor, $R = \frac{V}{I} = \frac{12V}{2.5\times10^{-3}A} = 4800\ \Omega = 4.8\ k\Omega$

Ex.6 A battery of 9 V is connected in series with resistors of 0.2 t, 0.3 t, 0.4 t, 0.5 t and 12 t. How much current would flow through the 12 t-resistor?

Ans. Since all the resistors are in seies, equivalent resistance,

$R_s = 0.2\ \Omega + 0.3\ \Omega + 0.4\ \Omega + 0.5\ \Omega + 12\ \Omega = 13.4\ \Omega$

Current through the circuit, $I = \frac{V}{R_S} = \frac{9V}{13.4\Omega} = 0.67A$

In series, same current (I) flows through all the resistors.

Thus, current flowing through 12 Ω resistor = 0.67 A

Ex.7 How many 176 t-resistors (in parallel) are required to carry 5 A in 220 V line?

Ans. Here, I = 5A, V = 220 V.

Resistance required in the circuit, $R = \frac{V}{I} = \frac{220V}{5A} = 44\Omega$, Resistance of each resistor, r = 176 Ω

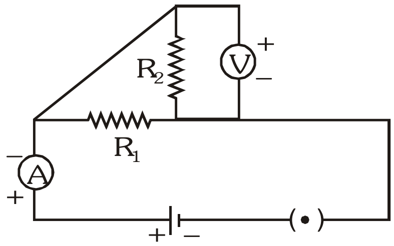
If n resistors, each of resistance r, are connected in parallel to get the required resistance R, then

$R = \frac{r}{n}$

or $44 = \frac{176}{n}$

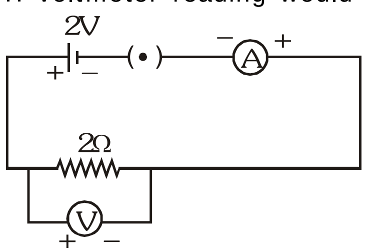
or $n = \frac{176}{44} = 4$

Q.15 Which of the circuit components in the following circuit diagram are connected in parallel ?

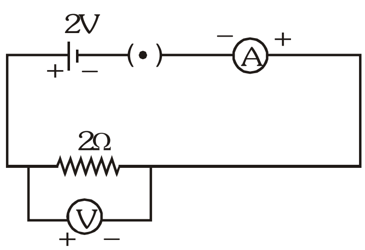


(A) R_1 and R_2 only (B) R_2 and V only
(C) R_1 and V only (D) R_1, R_2 and V only

Q.16 For the circuit diagram shown in figures I and II voltmeter reading would be



(I)



(II)

(A) 2 V in circuit (I) and 0 V in circuit (II)
(B) 0 V in both circuits
(C) 2 V in both circuits
(D) 0 V in circuit (I) and 2 V in circuit (II)

Q.17 The following instruments are available in a laboratory
milliammeter A_1 of least count 10 mA and range 0-300 mA
milliammeter A_2 of least count 20 mA and range 0-200 mA
voltmeter V_1 of least count 0.2 V and range 0-5 V
voltmeter V_2 of least count 0.3 V and range 0-3 V.
Out of the following pairs of instruments which pair would be the best choice for carrying out the experiment to determine the equivalent resistance of two resistors connected in series
(A) milliammeter A_1 and voltmeter V_2
(B) milliammeter A_2 and voltmeter V_1
(C) milliammeter A_1 and voltmeter V_1
(D) milliammeter A_2 and voltmeter V_2

Q.18 How many electrons constitute a current of one microampere?
(A) 6.25×10^6 (B) 6.25×10^{12}
(C) 6.25×10^9 (D) 6.25×10^{15}

Q.19 If a wire of resistance 1Ω is stretched to double its length, then the resistance will become :-
(A) $\frac{1}{2}\Omega$ (B) 2Ω (C) $\frac{1}{4}\Omega$ (D) 4Ω

Q.20 The SI unit of specific resistance is :-
(A) ohm m (B) ohm m^{-1}
(C) ohm m^2 (D) $(ohm)^{-1}$

Q.21 The effective resistance of a circuit containing resistances in parallel is -
(A) equal to the sum of the individual resistances
(B) smaller than any of the individual resistances
(C) greater than any of the individual resistances
(D) sometimes greater and sometimes smaller than the individual resistances

Q.22 The variable resistance is called :-
(A) resistor (B) rheostat
(C) open switch (D) none of these

Q.23 How much work is done in moving a charge of two coulombs from a point at 118 volts to a point at 128 volts?
(A) 10J (B) 20J
(C) $\frac{1}{10}$ J (D) None of these

Q.24 If a 0.1% increase in length due to stretching, the percentage increase in its resistance will be -
(A) 0.2% (B) 2% (C) 1% (D) 0.1%