BY AKRAM SIR

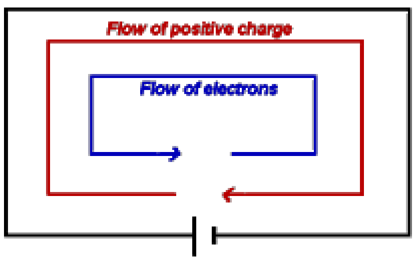
Electric Current and Electric Circuit

Electric Current: The flow of electric charge is known as electric current. Electric current is carried by moving electrons through a conductor.

By convention, electric current flows in opposite direction to the movement of electrons.

Electric Circuit: Electric circuit is a continuous and closed path of electric current.

Expression of Electric Current: Electric current is denoted by letter 'I'. Electric current is expressed by the rate of flow of electric charges. Rate of flow means the amount of charge flowing through a particular area in unit time.



If a net electric charge (Q) flows through a cross section of conductor in time t, then;

$$Electric\ current\ (I) = \frac{Net\ charge\ (Q)}{Time\ (t)}$$

$$Or, I = \frac{Q}{t}$$

Where, I is electric current, Q is net charge and t is time in second.

SI unit of Electric Charge and Current:

SI unit of electric charge is coulomb (C).

One coulomb is nearly equal to 6 x 10^{18} electrons. SI unit of electric current is ampere (A). Ampere is the flow of electric charges through a surface at the rate of one coulomb per second. This means if 1 coulomb of electric charge flows through a cross section for 1 second, it would be equal to 1 ampere.

Therefore; 1 A = 1 C/1 s

Small quantity of Electric Current: Small quantity of electric current is expressed in milliampere and microampere. Milliampere is written as mA and microampere as µA

1mA (milliampere)= 10^{-3} A

1µA(microampere)=10^{-6} A

Ammeter: An apparatus to measure electric current in a circuit.

Electric Potential: The amount of electric potential energy at a point is called electric potential.

Electric Potential difference: The difference in the amount of electric potential energy between two points in an electric circuit is called ELECTRIC POTENTIAL DIFFERENCE.

Electric potential difference is known as voltage, which is equal to the work done per unit charge to move the charge between two points against static electric field. Therefore;

$$Voltage = \frac{Work\ done}{Charge}$$

Voltage or electric potential difference is denoted by 'V'. Therefore;

$$V = \frac{W}{Q} \quad ------(1)$$

Where, W = work done and Q = Charge

SI unit of electric potential difference (Voltage):

SI unit of electric potential difference is volt and denoted by 'V'. This is named in honour of Italian Physicist Alessandro Volta.

$$V = \frac{Joule}{Coulomb} = \frac{J}{C}$$

$$or, V = J\,C^{-1}$$

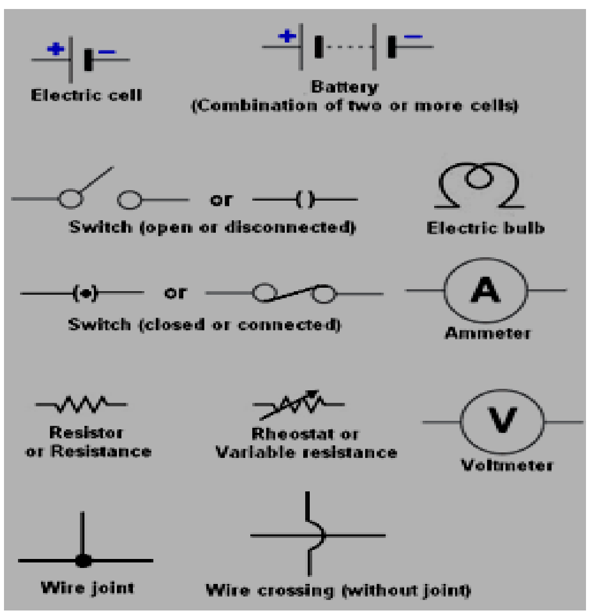
Since joule is the unit of work and coulomb is the unit of charge; 1 volt of electric potential difference is equal to the 1 joule of work to be done to move a charge of 1 coulomb from one point to another in an electric circuit. Therefore,

$$1V = \frac{1\,joule}{1coulomb} = \frac{1J}{1C}$$

$$or, 1V = 1\,JC^{-1}$$

Voltmeter: An apparatus to measure the potential difference or electric potential difference between two points in an electric circuit.

Symbols used in a Circuit diagram



Ohm's Law

Ohm's Law states that the potential difference between two points is directly proportional to the electric current.

This means; potential difference V varies as electric current.

Or, V α I

$$\Rightarrow \frac{V}{I} = R ------(i)$$

$$\Rightarrow \frac{1}{I} = \frac{R}{V} \quad \Rightarrow I = \frac{V}{R} ------(ii)$$

$$\Rightarrow V = RI -----(iii)$$

Where R is constant for the given conductor at a given temperature and called resistance. Resistance is the property of conductor which resists the flow of electric current through it

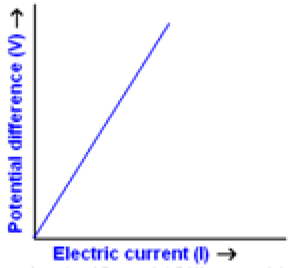
SI Unit of resistance is ohm. Ohm is denoted by Greek letter 'Ω'.

1 ohm (Ω) of Resistance (R) is equal to the flow of 1 A of current through a conductor between two points having potential difference equal to 1 V.

$$This\ means\ 1\,\Omega = \frac{\mathbf{1V}}{\mathbf{1A}}$$

From the expression of Ohm's Law it is obvious that electric current through a resistor is inversely proportional to resistance. This means electric current will decrease with increase in resistance and vice versa.

The graph of V (potential difference) versus I (electric current) is always a straight line.



Graph of Potential Difference (V) Vs Electric Current (I)

Resistance

Resistance is a property of conductor due to which it resists the flow of electric current through it. Component that is used to resist the flow of electric current in a circuit is called resistor.

In practical applications, resistors are used to increase or decrease the electric current.

Variable Resistance: The component of an electric circuit which is used to regulate the current; without changing the voltage from the source; is called variable resistance.

Rheostat: This is a device which is used in a circuit to provide variable resistance.

Cause of Resistance in a Conductor:

Flow of electrons in a conductor is electric current. The particles of conductor create hindrance to flow of electrons; because of attraction between them. This hindrance is the cause of resistance in the flow of electricity.

Resistance in a conductor depends on nature, length and area of cross section of the conductor.

Nature of material: Some materials create least hindrance and hence are called good conductors. Silver is the best conductor of electricity. While some other materials create more hindrance in the flow of electric current, i.e. flow of electrons through them. Such materials are called bad conductors. Bad conductors are also known as insulators. Hard plastic is the one of the best insulators of electricity.

Length of conductor: Resistance R is directly proportional to the length of the conductor. This means, Resistance increases with increase in length of the conductor. This is the cause that long electric wires create more resistance to the electric current.

Thus, Resistance (R) ∝ length of conductor (l)

or R ∝ l --------(i)

Area of cross section: Resistance R is inversely proportional to the area of cross section (A) of the conductor. This means R will decrease with increase in the area of conductor and vice versa. More area of conductor facilitates the flow of electric current through more area and thus decreases the resistance. This is the cause that thick copper wire creates less resistance to the electric current.

Thus, resistance ∝ 1/Area of cross section of conductor (A)

$$or, R \propto \frac{1}{A} - - - - -(ii)$$

From equation (i) and (ii)

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

$$\Rightarrow R = \rho \frac{l}{A} - - - -(iii)$$

Where ρ (rho) is the proportionality constant. It is called the electrical resistivity of the material of conductors.

From equation (iii)

$$RA = \rho l$$

$$\Rightarrow \rho = \frac{RA}{l} - - - - - (iv)$$

The SI unit of resistivity: Since, the SI unit of R is Ω, SI unit of Area is m^2 and SI unit of length is m. Hence

$$unit\ of\ resistivity\ (\rho)$$

$$= \frac{\Omega \times m^2}{m} = \Omega m$$

Thus, SI unit of resistivity (ρ) is Ω m

Materials having resistivity in the range of 10^{-8} Ω m to 10^{-6} Ω m are considered as very good conductors. Silver has resistivity equal to 1.60 X 10^{-8} Ω m and copper has resistivity equal to 1.62 X 10^{-8} Ω m.

Rubber and glass are very good insulators. They have resistivity in the order of 10^{12} Ω m to 10^{17} Ω m.

Resistivity of materials varies with temperature.

Resistance: Part 2

Resistance Of A System of Resistors:

Resistors are joined in two ways, i.e. in series and in parallel.

Resistors in Series: When resistors are joined from end to end, it is called in series. In this case, the total resistance of the system is equal to the sum of the resistance of all the resistors in the system.

Let total resistance = R

Resistance of resistors are R_1, R_2, R_3, … R_n

Therefore, $R = R_1 + R_2 + R_3 + \ldots\ldots\ldots.. + R_n$

Resistors in parallel: When resistors are joined in parallel, the reciprocal of total resistance of the system is equal to the sum of reciprocal of the resistance of resistors.

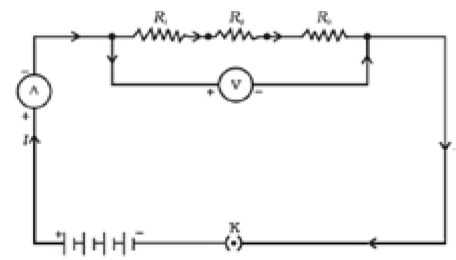


Fig: Resistance in Series

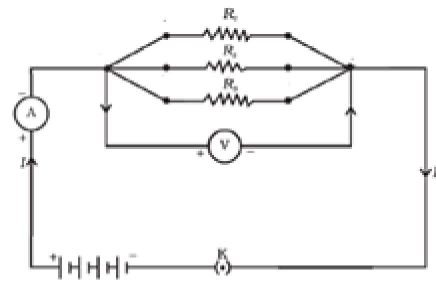


Fig: Resistance in Parallel

Let total resistance = R

Resistance of resistors are R_1, R_2, R_3, … R_n

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_n}$$

Heating Effect of Electric Current

When electric current is supplied to a purely resistive conductor, the energy of electric current is dissipated entirely in the form of heat and as a result, resistor gets heated. The heating of resistor because of dissipation of electrical energy is commonly known as Heating Effect of Electric Current. Some examples are as follows:

When electric energy is supplied to an electric bulb, the filament gets heated because of which it gives light. The heating of electric bulb happens because of heating effect of electric current.

When an electric iron is connected to an electric circuit, the element of electric iron gets heated because of dissipation of electric energy, which heats the electric iron. The element of electric iron is a purely resistive conductor. This happens because of heating effect of electric current.

Cause of heating effect of electric current: Electric current generates heat to overcome the resistance offered by the conductor through which it passes. Higher the resistance, the electric current will generate higher amount of heat. Thus, generation of heat by electric current while passing through a conductor is an inevitable consequence. This heating effect is used in many appliances, such as electric iron, electric heater, electric geyser, etc.

Joule's Law of Heating:

Let; an electric current I is flowing through a resistor having resistance equal to R.

The potential difference through the resistor is equal to V.

The charge Q flows through the circuit for the time t.

Thus, work done in moving of charge Q of potential difference V = VQ

Since, this charge Q flows through the circuit for time t

Therefor; power input (P) to the circuit can be given by following equation:

$$P = V \times \frac{Q}{t} ------(i)$$

We know, electric current I = Q/t

Substituting Q/t = I in equation (i), we get;

P = VI ....(ii)

Since the electric energy is supplied for time t, thus after multiplying both sides of equation (ii) by time t, we get

P x t = VI x t = VIt .....(iii)

Thus, for steady current I, the heat produced (H) in time t is equal to VIt

Or, H = VIt ....(iv)

We know; according to Ohm's law; V = IR

By substituting this value of V in equation (iv), we get;

H = IR x It

Or, $H = I^2Rt$ ....(v)

The expression (v) is known as Joule's Law of Heating, which states that heat produced in a resistor is directly proportional to the square of current given to the resistor, directly proportional to the resistance for a given current and directly proportional to the time for which the current is flowing through the resistor.

Heating Effect of Electric Current-Practical Application

Practical Application of Heating Effect of Electric Current & Electric Power

For exploiting the heating effect of electric current, the element of appliances must have high melting point to retain more heat. The heating effect of electric current is used in the following applications:

Electric Bulb: In an electric bulb, the filament of bulb gives light because of heating effect of electricity. The filament of bulb is generally made of tungsten metal; having melting point equal to 3380°C.

Electric iron: The element of electric iron is made of alloys having high melting point. Electric heater and geyser work on the same mechanism.

Electric fuse: Electric fuse is used to protect the electric appliances from high voltage; if any. Electric fuse is made of metal or alloy of metals, such as aluminum, copper, iron, lead, etc. In the case of flow of higher voltage than specified, fuse wire melts and protects the electric appliances.

Fuse of 1A, 2A, 3A, 5A, 10A, etc. are used for domestic purpose.

Suppose, if an electric heater consumes 1000W at 220V.

Then electric current in circuit I = P/V

Or, I = 1000 W − 220 V = 4.5 A

Thus, in this case a fuse of 5A should be used to protect the electric heater in the case of flow of higher voltage.

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Electric Power:

SI unit of electric power is watt (W).

1W = 1 volt x 1 ampere = 1V x 1A

1 kilo watt or 1kW = 1000 W

Consumption of electricity (electric energy) is generally measured in kilo watt.

Unit of electric energy is kilo watt hour (kWh)

1 kWh = 1000 watt X 1 hour = 1000 W x 3600 s

Or, 1kWh = 3.6×10^6 watt second = 3.6×10^6 J