Electricity

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Electricity is a basic part of our nature and it is one of our most widely used forms of energy. We use electricity virtually every minute of every day for example in lighting, heating, refrigeration, air conditioning, power electromagnets, power computers, power televisions, power pumps, power our vehicles etc.

Charge

Each matter contains some protons, electrons and neutrons. The charge possessed by proton is called positive charge () while the charge possessed by electron is called negative charge (). Neutron has the particle that has no charge.

Like charges repel each other while unlike charges attract each other.

Electric charges are made up of positive charges (protons) and negative charges (electrons).

Conductors and Insulators

Conductors are those materials in which electrons are free to move anywhere inside the matter like, aluminium, copper etc. All metals are conductors.

Insulators are those materials in which electrons are not free to move anywhere like, plastic, wood etc.

Electric Current

The flow of electric charge is known as 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 any matter in time t,

Electric current = $\frac{\text{Net charge}}{\text{Time}}$ \Rightarrow $i = \frac{Q}{t}$

SI unit of electric current is ampere (A).

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1\text{Ampere} = \frac{1\text{Coulomb}}{1\text{second}}
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- If positive charge flows, direction of electric current is same as direction of flow of charge.
- If negative charge flows, direction of electric current is opposite to direction of flow of charge.



Electric current can't flow through insulator because in insulator, protons and electrons are fixed at their position.

Potential Difference

$$\xrightarrow{\text{Work}} q$$

Potential difference between two points is the workdone per unit charge in taking the charge from one point to another.

Potential Difference between A&B (V) = $\frac{\text{Workdone}(W)}{\text{Charge}(q)}$

B.

1 volt is the potential difference between two points if 1 J of work has to be done in taking 1 C charge from one point to another.

$$1V = \frac{1J}{1C}$$

As water flows from high level to low level similarly, electric current flows from high potential to low potential.

Cell: The Difference of potential may be produced by a battery, consisting of one or more electric cells. Potential difference across the terminals of the cell generated due to chemical reaction within the cell. When cell is connected to a conducting wire, current flows from high potential to low potential.

Electric circuit

Electric circuit is a continuous and closed path of electric current. For example figure given below shows a typical electric circuit comprising a cell, an electric bulb and a switch.



Note: Current flows only if electric circuit forms closed loop.

Circuit Diagram

We know that electric circuit is a continuous path consisting of cell, switch (plug key), electric components and connecting wires. Electric circuits can be represented conveniently through a circuit diagram.

A diagram which indicates how different components in a circuit have to be connected by using symbols for different electric components is called a circuit diagram.



Ammeter: An apparatus to measure the value of current. It is always connected in series in a circuit through which the current is to be measured.



Voltmeter: An apparatus to measure the potential difference between two points in an electric circuit. It is always connected in parallel across the points between which the potential difference is to be measured.





Some commonly used Electrical Components

Sl. No.	Components	Symbols
1	An electric cell	+ -
2	A battery or a combination of cells	<u> </u> + ⊢
3	Plug key or switch (open)	—()—
4	Plug key or switch (closed)	—(•)—
5	A wire joint	_ _
6	Wires crossing without joining	<u> </u>
7	Electric bulb	or 📮
8	A resistor of resistance R	
9	Variable resistance or rheostat	or
10	Ammeter	
11	Voltmeter	+

Ohm's Law

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

Electric Current \propto Potential Difference Or i \propto V => i = V/R => V = iR

Where R is constant for the given conductor and called resistance. Resistance is the property of conductor which 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.

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.

 $1 \Omega = 1V / 1A$

Factors on which Resistance Depends

Resistance in a conductor depends on following factors.

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.

 $\mathbf{R} \propto l \dots (\mathbf{i})$

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. $R \propto 1/A...$ (ii)

x 1/A ... (11)

Nature of material: Wire used in electric circuit is made up of different materials and different materials have different value of resistivity (). It is the property of material.

Resistance R is directly proportional to resistivity of material.

 $R \propto p...$ (iii)

From equation (i), (ii) and (iii)

 $\mathbf{R} \propto \mathbf{p}l/A$

Temperature: Resistance also varies with temperature. Resistance increases with increase in temperature and decreases with decrease in temperature.

Resistivity

It is the property of material. Since, the SI unit of R is Ω , SI unit of Area is m² and SI unit of length is m,

:. Unit of resistivity (p) = $\Omega \ge m^2 / m = \Omega m$ [p = RA / l]

- 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 bad conductors or very good insulators. They have resistivity in the order of 10 12 Ω m to 10 17 Ω m.

li	Material	Resistivity (Ω m)	
Conductors	Silver	1.60 × 10 ⁻⁸	
	Copper	1.62×10^{-8}	
	Aluminium	2.63×10^{-8}	
	Tungsten	5.20×10^{-8}	
	Nickel	6.84 × 10 ⁻⁸	
	Iron	10.0×10^{-8}	
	Chromium	12.9×10^{-8}	
	Mercury	94.0×10^{-8}	
	Manganese	1.84×10^{-6}	
Alloys	Constantan	49 × 10-6	
	(alloy of Cu and Ni)		
	Manganin (allow of Cu. Mp and Ni)	44 × 10 ⁻ⁿ	
	(alloy of Ni Cr. Mn and Fe)	100 × 10-6	
Insulators	Glass	1010 - 1014	
	Hard rubber	$10^{13} - 10^{16}$	
	Ebonite	$10^{15} - 10^{17}$	
	Diamond	1012 - 1013	
	Paper (dry)	1012	

Resistivity of different materials

Variable Resistance (Rheostat)

The device which is used to vary the resistance in an electric circuit; without changing the voltage from the source; is called Rheostat and that resistance is called variable resistance.



Symbol of Variable Resistance

Verification of Ohm's Law



Set up a circuit as shown above. Note reading in the ammeter and voltmeter; at different values of potential (by changing the battery). Every time you will find different values of current i and potential difference V in ammeter and voltmeter.

Plot these values on graph and observe the nature of the graph. The graph of V (potential difference) versus i (electric current) is always a straight line.



From above discussion it is proved that i∝V i = V / R [Ohm's Law]

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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, they are said to be in series combination.



Value of current in the ammeter is same irrespective of its position in the circuit. So we conclude that in a series combination of resistors the current is same in every part of the circuit or same current flow through each resistor. If we add potential difference across each one of resistors (R₁, R₂ and R₃) then we get $V = V_1 + V_2 + V_3$

Or

$$\mathbf{i} \mathbf{R} = \mathbf{i} \mathbf{R}_1 + \mathbf{i} \mathbf{R}_2 + \mathbf{i} \mathbf{R}_3$$

=>

$$R = R_1 + R_2 + R_3$$

So in this case, the total resistance of the system is equal to the sum of the resistance of all the resistors in the system

If n resistors are connected in series combination then,

$$R = R_1 + R_2 + R_3 + \dots + R_n$$

Resistors in parallel: When resistors are joined in parallel, they are said to be in parallel combination.



In parallel combination, the potential difference across each resistor is equal to the voltage of the battery applied.

When resistors are connected in parallel, the sum of the currents flowing through all the resistances is equal to total current flowing in the circuit. $i = i_1 + i_2 + i_3$

Or

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

=>

So in this case, the reciprocal of total resistance of the system is equal to the sum of reciprocal of the resistance of resistors

If n resistors are connected in parallel combination then,

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

Note: When number of resistors are connected in parallel then their combined resistance is less than the smallest individual resistance. While in series combination, equivalent resistance is always greater than any individual resistance.

Devices in Series and Parallel

There are 2 ways to connect multiple devices to a power source, series and parallel.



Series and Parallel Connection

Advantages of Parallel connection

1. In series connection, either all devices are ON or all are OFF. But in parallel connection, devices can be selectively switched ON or OFF.

2. In series connection, if one device fails, all devices will turn OFF. But in parallel connection, if one device fails, rest all work fine.

3. In series connection, all devices will get same current. But in parallel connection, different devices need different current for proper working.

That's why all devices like fan, TV, refrigerator, bulbs are connected in parallel.

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

Heating Effect of Electric Current

Let I current flowing through a resistor of resistance R and potential across the resistor is V. When charge Q moves against the potential difference V in time t, the amount of work is

Or

$W = Q \times V$
$W = V \times \frac{Q}{t} \times t$
W = Vit

=>

Thus

workdone by battery for moving the charge in electric circuit (W) = Vit

Battery has chemical energy due to which it can do work. As battery does work, it's chemical energy decreases. But total energy is always conserved. Chemical energy of battery is converted to heat energy in the resistor.

Therefore, heat produced in resistor (H) = Vit

This heating of resistor is commonly known as Heating Effect of Electric Current.

By using Ohm's law

 $H = (iR)it = i^2Rt$

This is known as **Joule's Law of Heating**. It 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.

Practical Application of Heating Effect

For exploiting the heating effect, 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:

(a) Electric Bulb: 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. The filament of bulb is generally made of tungsten metal; having melting point equal to 3380°C.

(b) Electric iron: When an electric iron is connected to an electric circuit, the element of electric iron gets heated, which heats the electric iron. The element of electric iron is made of alloys having high melting point.

(c) 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 aluminium, 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 the electric current (i) in the electric circuit = $\frac{Power input}{volt} = \frac{1000W}{220V} = 4.5A$

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

Electric Power –

The rate at which electric work is consumed is called Electric Power. We know,

Heat produced = Vit

$$=\frac{V^2}{R}t=i^2Rt$$

Power P = Heat produced per unit time = $\frac{\text{Heat Produced}}{t}$

$$=\frac{i^2Rt}{t}=i^2R=Vi$$

SI unit of electric power is watt (W). 1W = 1 volt x 1 ampere = 1V x 1A 1 kilo watt or 1kW = 1000 WUnit of energy is kilo watt hour (kWh) 1 kWh = 1000 watt X 1 hour = 1000 W x 3600 s $\Rightarrow 1kWh = 3.6 \text{ x } 10^6 \text{ watt second} = 3.6 \text{ x } 10^6 \text{ J}$

Rating of Devices

Rating of device is the value of electric power and potential of that electric device. If we know the rating of any electrical device we can easily find the value of resistance.

For example, an electric bulb is rated 220V and 100W. Find the resistance of the device. Given,

Voltage rating = 220 V Power rating = 100 W

As we know,

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

=> R = $\frac{V^2}{P}$
=> Resistance of device = $\frac{(Voltage rating)^2}{Power rating}$
= $\frac{(220)^2}{100} = 484\Omega$