Electricity

Topic Covers

- Electric Current
- Electric Symbols
- Ohm's Law
- Resistance of Conductor
- Resistivity
- Classification of Material on Basis of Resistivity
- Combination of Resistances
- Kirchhoff's Laws
- Heating Effect of Electric Current

Current Electricity

● Electric Current (Charge in Motion)

❍ Defination :

The quantity of electric charge flowing through a conductor in one second is called current. Thus, if Q is the charge which flows through a conductor in time t, then the current (I) is given by

$$\text{Current (I)} = \frac{\text{Charge (Q)}}{\text{Time (t)}}$$

The electric current (or current) is a scalar quantity.

❍ Unit of current

We have

$$\text{Current (I)} = \frac{\text{Charge (Q)}}{\text{Time (t)}}$$

The SI unit of charge (Q) is coulomb (C), and that of time (t) is second (s). So,

$$\text{SI unit of current} = \frac{1 \text{ coulomb}}{1 \text{ second}} = 1 \text{ C s}^{-1}$$

The unit coulomb per second ($C\ s^{-1}$) is called ampere (A). So, the SI unit of current (I) is ampere. The unit ampere is denoted by the letter A.

Sometimes a smaller unit of current called milliampere (mA) is also used.

$$1 \text{ milliampere} = \frac{1}{1000} \text{ ampere}$$

$$\text{or, } 1 \text{ mA} = \frac{1}{1000} \text{ A} = 10^{-3} \text{ A}$$

❍ Definition of Ampere :

From above,

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

If Q = 1 coulomb and

t = 1 second, then

$$I = \frac{1\ \text{coulomb}}{1\ \text{second}}$$

= 1 coulomb per second

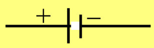
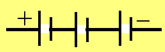
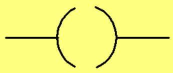
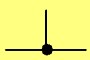
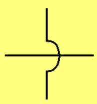
$= 1\ C\ s^{-1} = 1\ A$

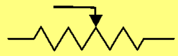
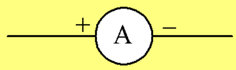
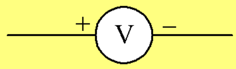
❍ Direction of Electric Current :

The direction of flow of the positive charge taken as the direction of the electric current. When we consider the flow of electric current in an ordinary conductor, such as a copper wire, the direction of current is taken as opposite to the direction of the flow of electrons.

● Electric Symbols

Many different kinds of equipments or components are used in setting up electrical circuits. To draw the diagrams of electrical circuits on paper these equipments/components are shown by their symbols. Here are some symbols used in the electric circuit diagrams.

S.N.	Components	Symbols
1.	Electric cell	
2.	Battery	
3.	Plug key (switch open)	
4.	Plug key (switch closed)	
5.	A wire joint	
6.	Wires crossing without joining	
7.	Elecctric bulb	 or 
8.	A resistor of resistance R	

S.N.	Components	Symbols
9.	Variable resistance or rheostat	 or 
10.	Ammeter	
11.	Volmeter	
12.	Fuse	

● Ohm's Law

❍ **Definition :** According to the Ohm's law at constant temperature, the current flowing through a conductor is directly proportional to the potential difference across the conductor.

Thus, if I is the current flowing through a conductor and V is the potential difference (or voltage) across the conductor, then according to Ohm's law.

$I \propto V$ (when T is constant)

or, $I = \frac{V}{R}$ ...(i)

where R is a constant called the **resistance of the conductor.**

Equation (i) may be written as,

$V = I \times R$ ...(ii)

❍ **Unit of resistance :**

The SI unit of resistance (R) is ohm. Ohm is denoted by the Greek letter omega (Ω).

From Ohm's law, $R = \frac{V}{I}$

Now, if, V = 1 volt and I = 1 ampere

Then, $R = \frac{1 \text{ volt}}{1 \text{ ampere}}$

Then ratio, 1 volt / 1 ampere is taken as one unit of resistance, i.e. equals 1 ohm.

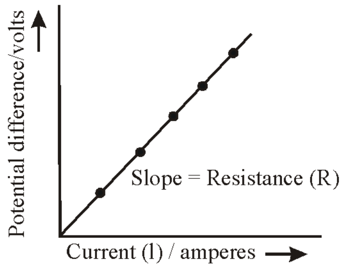
So, $1 \text{ ohm} = \frac{1 \text{ volt}}{1 \text{ ampere}}$

Thus, 1 ohm is defined as the resistance of a conductor which allows a current of 1 ampere to flow through it when a potential difference of 1 volt is maintained across it.

❍ **Results of Ohm's law**

◆ Current flowing through a conductor is directly proportional to the potential difference across the conductor.

$$I \propto V$$



- When the potential difference in a circuit is kept constant, the current is inversely proportional to the resistance of the conductor.

$$I \propto 1/R$$

- The ratio of potential difference to the current is constant. The value of the constant is equal to the resistance of the conductor (or resistor).

$$V/I = R$$

Resistance of Conductor

The movement of electron gives rise to the flow of current through metals. The moving electrons collide with each other as well as with the positive ions present in the metallic conductor. These collisions tend to slow down the speed of the electrons and hence oppose the flow of electric current.

The property of a conductor by virtue of which it opposes the flow of electric current through it is called its resistance.

- Resistance is denoted by the letter R.
- The SI unit of resistance is **ohm**. The ohm is denoted by the Greek letter (Ω) called **omega.**
- Resistance is a scalar quantity.

Factors on which resistance of conductor depends

- **Effect of the length on the resistance of a conductor**

  The resistance of a conductor is directly proportional to is length. That is

  R → Resistance of a conductor

  l → Length of the conductor

  $$R \propto l \quad \text{(area of cross-section 'a' is constant)}$$

- **Effect of the area of cross-section on the resistance of a conductor**

  The resistance of a conductor is inversely proportional to its area of cross-section. That is, Resistance of a conductor

  $$(R) \propto \frac{1}{\text{Area of cross-section (a) of the conductor}}$$

  If the area of cross-section of the conductor is **doubled**, its resistance gets **halved**.

- **Effect of temperature on the resistance of a conductor**

  The resistance of all pure metals increases with a rise in temperature. The resistance of alloys increases very slightly with a rise in temperature. For metal when temperature increases resistance increases and for semiconductors when temperature increases resistance decreases

◆ **Effect of the nature of material on the resistance of a conductor**

Some materials have low resistance, whereas some others have much higher resistance. In general, an alloy has higher resistance than pure metals which from the alloy.

☞ Copper, silver, aluminium etc., have very low resistance.

☞ Nichrome, constantan etc., have higher resistance. Nichrome is used for making heating elements of heaters, toasters, electric iron etc.

● Resistivity

$R \propto \ell$

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

So, $R \propto \frac{\ell}{a}$

or, $R = \rho \times \frac{\ell}{a}$ ...(i)

where ρ (Read rho) is called resistivity of the material of conductor.

If, $l = 1$ m and $a = 1\ m^2$

Then $R = \rho$ ...(ii)

Thus, if we take 1 metre long piece of a substance having a cross-sectional area of 1 meter^2, then the resistance of that piece of the substance is called its resistivity.

Resistivity of a substance can also be defined as follows :

The resistance offered by a cube of a substance having side of 1 metre, when current flows perpendicular to the opposite faces, is called its resistivity.

❍ Units of resistivity

From equation (i), we can write

$$\rho = \frac{R \times a}{\ell}$$

SI unit of resistance (R) is ohm (Ω)

SI unit of length (l) is metre (m)

SI unit of area of cross-section (a) is metre^2 (m^2)

So, SI unit of resistivity (ρ) $= \frac{\text{ohm} \times m^2}{m} = \text{ohm}\,.\,m$

Thus, the SI unit of resistivity is ohm . m (or Ω . m)

❍ Classification of Material on Basis of Resistivity

◆ **Substances showing very low resistivities :** The substances which show very low resistivities allow the flow of electric current through them. These type of substances are called *conductors*. For example, copper, gold, silver, aluminium and electrolytic solutions are conductors.

◆ **Substances having moderate resistivity :** The substances which have moderate resistivity offer appreciable resistance to the flow of electric current through them. Therefore, such substances are called *resistors*. For example, alloys such as nichrome, manganin, constantan and carbon are typical resistors.

◆ **Substances having very high resistivity :** The substances which have very high resistivities do not allow electricity to flow through them. The substances which do not allow electricity to pass through them are called *insulators*. For example, rubber, plastics, dry wood, etc. are insulators.

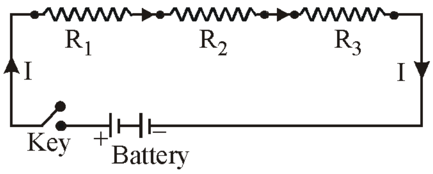
◆ **Super conductor :** It was found that many other elements and compounds showed similar behaviours at different low temperatures, called *critical (transition) temperatures*.

Such elements with zero resistance, are called *superconductors*.

● Combination of Resistances

❍ Series Combination

When two or more resistances are joined end-to-end so that the same current flows through each of them, they are said to be connected in series.



When a series combination of resistances is connected to a battery, the same current (I) flows through each of them.

◆ **Law of combination of resistances in series :** The law of combination of resistances in series states that *when a number of resistances are connected in series, their equivalent resistance is equal to the sum of the individual resistances.* Thus, if R_1, R_2, R_3 ..., etc. are combined in series, then the equivalent resistance (R) is given by,

$$R = R_1 + R_2 + R_3 + \ldots \qquad \text{....(i)}$$

◆ **Derivation of mathamatical expression of resistances in series combination :** Let, R_1, R_2 and R_3 be the resistances connected in series, I be the current flowing through the circuit, i.e., passing through each resistance, and V_1, V_2 and V_3 be the potential difference across R_1, R_2 and R_3, respectively. Then, from Ohm's law,

$$V_1 = IR_1,\ V_2 = IR_2 \text{ and } V_3 = IR_3 \quad \text{...(ii)}$$

If, V is the potential difference across the combination of resistances then,

$$V = V_1 + V_2 + V_3 \qquad \text{...(iii)}$$

If, R is the equivalent resistance of the circuit, then $V = IR$ ...(iv)

Using Eqs. (i) to (iv) we can write,

$$IR = V = V_1 + V_2 + V_3$$

$$= IR_1 + IR_2 + IR_3$$

or, $IR = I(R_1 + R_2 + R_3)$

or, $R = R_1 + R_2 + R_3$

Therefore, when resistances are combined in series, the equivalent resistance is higher than each individual resistance.

❍ Some results about series combination.

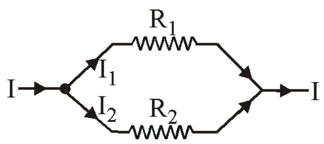
(i) When two or more resistors are connected in series, the total resistance of the combination is equal to the sum of all the individual resistances.

(ii) When two or more resistors are connected in series, the same current flows through each resistor.

(iii) When a number of resistors are connected in series, the voltage across the combination (i.e. voltage of the battery in the circuit), is equal to the sum of the voltage drop (or potential difference) across each individual resistor.

❍ Parallel Combination

When two or more resistances are connected between two common points so that the same potential difference is applied across each of them, they are said to be connected is parallel.



When such a combination of resistance is connected to a battery, all the resistances have the same potential difference across their ends.

❍ Derivation of mathematical expression of parallel combination.

Let, V be the potential difference across the two common points A and B. Then, from Ohm's law

Current passing through $R_1, I_1 = V/R_1$ ...(i)

Current passing through $R_2, I_2 = V/R_2$ ...(ii)

Current passing through $R_3, I_3 = V/R_3$ ...(iii)

If R is the equivalent resistance, then from Ohm's law, the total current flowing through the circuit is given by,

$I = V/R$ ...(iv)

and $I = I_1 + I_2 + I_3$ ...(v)

Substituting the values of I, I_1, I_2 and I_3 in Eq. (v),

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \quad \text{...(vi)}$$

Cancelling common V term, one gets

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

The equivalent resistance of a parallel combination of resistance is less than each of all the individual resistances.

❍ Important results about parallel combination.

(i) Total current through the circuit is equal to the sum of the currents flowing through it.

(ii) In a parallel combination of resistors the voltage (or potential difference) across each resistor is the same and is equal to the applied voltage i.e. $v_1 = v_2 = v_3 = v$.

(iii) Current flowing through each resistor is inversely proportional to its resistances, thus higher the resistance of a resistors, lower will be the current flowing through it.

Points to be Remember

- **Current (or electrical current) :** The rate of flow of charge through a conductor is called current. Current is measured in ampere unit, denoted by A.
- **Current :** The rate of flow of charge (Q) through a conductor is called current .

  Current (I) is given by,

  $$\text{Current} = \frac{\text{Charge}}{\text{Time}} \quad \text{or} \quad I = \frac{Q}{t}$$

  The SI unit of current is ampere (A) : 1A = 1 C/s

  The current flowing through a circuit is measured by a device called ammeter. **Ammeter** is connected in series with the conductor. The direction of the current is taken as the direction of the flow of positive charge.
- **Ohm's law :** At any constant temperature, the current (I) flowing through a conductor is directly proportional to the potential (V) applied across it.

  Mathematically,

  $$I = V/R \quad \text{or} \quad V = IR$$
- **Resistance :** Resistance is the property of a conductor by virtue of which it opposes the flow of electricity through it. Resistance is measured in ohms. Resistance is a scalar quantity.
- **Resistivity :** The resistance offered by a cube of a substance having side of 1 meter, when current flows perpendicular to the opposite faces, is called its resistivity (ρ). The SI unit of resistivity is ohm.m.
- **Equivalent resistance :** A single resistance which can replace a combination of resistances so that current through the circuit remains the same is called *equivalent resistance*.
- **Law of combination of resistances in series :** When a number of resistance are connected in series, their equivalent resistance is equal to the sum of the individual resistances.

  If R_1, R_2, R_3, etc. are combined in series, then the equivalent resistance (R) is given by,

  $$R = R_1 + R_2 + R_3 + ...$$

  The equivalent resistance of a number of resistances connected in series is higher than each individual resistance.
- **Law of combination of resistances in parallel :** When a number of resistances are connected in parallel, the reciprocal of the equivalent resistance is equal to the sum of the reciprocals of the individual resistances.

  If R_1, R_2, R_3, etc. are combined in parallel, then the equivalent resistance (R) is given by.

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

  The equivalent resistance of a number of resistances connected in parallel is less than each of all the individual resistances.

● Kirchhoff's Laws :

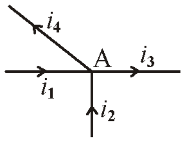
Kirchhoff gave the following two laws which enable us to find the distribution of current in complicated electrical circuits.

◗ Kirchhoff's First Law (KCL) :

❍ **Statement :** In an electrical circuit the algebraic sum of currents meeting at a point is zero.

❍ **Rule of sign :** While applying this law the sign convention is that the currents entering the point are taken as positive, while leaving it are taken as negative

❍ **Explanation of the law :** To explain this law, let us consider a number of wires connected at a point A. Current i_1, i_2, i_3 and i_4 flow through these wires in the direction as shown in the following figure. Here currents i_1 and i_2 are approaching towards the point A. Hence, they are positive. On the other hand currents i_3 and i_4 are leaving the point A. Hence, they are negative. So according to the first law of Kirchhoff.



$$i_1 + i_2 - i_3 - i_4 = 0$$

Equation (1) can be written as, $-i_1 - i_2 + i_3 + i_4 = 0$

The meaning of the above relation is that the opposite rule of sign may be used i.e., approaching current may be taken as negative and leaving current may be taken as positive.

❍ **Conservation of electric charge :** If we write equation (1) in the form i.e., $i_1 + i_2 = i_3 + i_4$. We can say that sum of the currents approaching a connecting point = sum of the currents leaving the point If the current flows for time t we have,

$$i_1t + i_2t = i_3t + i_4t \quad \text{or,} \quad q_1 + q_2 = q_3 + q_4$$

i.e., the sum of the charges approaching the connecting point = sum of the charges leaving the point. The significance of the above equation is discussed below.

(i) There cannot be any accumulation of charge at any connecting point in an electrical circuit.

(ii) Total charge cannot be created or destroyed i.e., total charge will remain constant.

◗ Kirchhoff's Second Law (KVL) :

❍ **Statement :** The algebraic sum of the product of the current and resistance in any closed loop of a circuit is equal to the algebraic sum of electromotive force acting in that loop. i.e., $\sum i\,r = \sum e$.

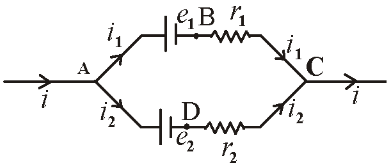
- **Rule of sign :**
  (i) In the closed loop current flowing in the clockwise direction is taken to be positive while current flowing in the anticlockwise direction is taken as negative.
  (ii) In the closed loop the electromotive force of the source which sends current in the clockwise direction is taken to be positive and the emf of the source which sends current in the anticlockwise direction is taken as negative.
- **Explanation of the law :** In the figure below a closed loop ACBDA within an electrical circuit is shown. With respect to this closed loop, current i_1 is positive as it is flowing in the clockwise direction and current i_2 is negative as its is flowing in the anticlockwise direction.

  Again, by the rule of sign of emf, e_1 is negative and e_2 is positive. So, according to the second law of Kirchhoff, for the closed loop ACBDA.

  $i_1r_1 - i_2r_2 = -e_1 + e_2$ ... (2)

  Equation (2) may be written as $-i_1r_1 + i_2r_2 = e_1 - e_2$. The meaning of the above equation is that opposite rule of sign for current and emf may be taken i.e., anticlockwise current and emf may be taken as positive and clockwise current and emf as negative

  We can write applying Kirchhoff's first law at the point A in the following figure.



  $i - i_1 - i_2 = 0$ or, $i_2 = i - i_1$

  So equation (2) can be written as $i_1r_1 - (i - i_1)r_2 = -e_1 + e_2$

  or, $i_1(r_1 + r_2) = e_2 - e_1 + ir_2$

  or, $i_1 = \dfrac{(e_2 - e_1) + ir_2}{r_1 + r_2}$ .... (3)

  Knowing the values of the quantities of equation (3) we can determine i_1 and i_2.

Heating Effect of Electric Current:

- When an electric current is passed through any metallic wire, it gets heated up. Here, the electrical energy is converted into heat energy. This effect of the electric current is called **heating effect of electric current.** This effect is utilised in devices such as electric heater, electric iron etc

Electrical Energy:

The work required to keep the charge Q moving by a battery of voltage V is given by:

W=VQ

But charge Q=It

Therefore, W=VIt

From Ohm's law, V=IR

Therefore, $W=I^2Rt$

- The electrical energy flowing through a conductor with resistance R for time t is converted into heat energy.

  Thus, Heatenergy,$H=I^2Rt$

- The formula for the heating effect of electric current is H = I2Rt Joules. This relation is called the Joule's law of heating.

- The amount of heat produced in the wire depends on the following three factors:

  The amount of electric current flowing through the wire (H is directly proportional to I2).

  The amount of resistance of the wire HisdirectlyproportionaltoR.

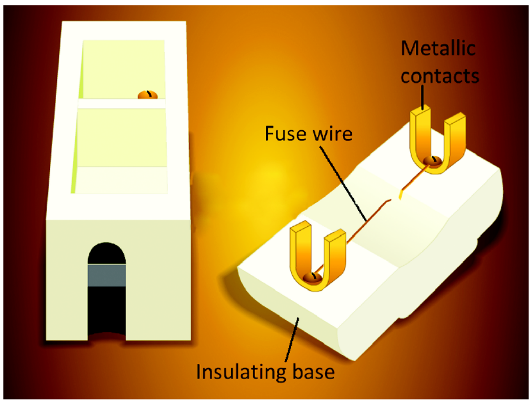
  The time taken by the current to flow Hisdirectlyproportionaltot.

Practical Applications of Heating Effect of Electric Current:

- Examples of electrical appliances which work on Joule's law of heating: electric iron, fuse, room heater, etc.

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

- Another important application of Joule's heating is the fuse used in electric circuits. It protects circuits and appliances by stopping the flow of any unduly high electric current. It is placed in series with the device and consists of a piece of wire made of a metal or an alloy of appropriate melting point. When large amount of current flows through it results in melting of the fuse wire and breaks the circuit. The fuses used for domestic purposes are rated as 1 A, 2 A, 3 A, 5 A, 10 A, etc.



Electric Power

- Electrical power is the rate of electrical work done.
- In other words, the work done or the energy consumed in 1 second is electrical power.
- The formula for the electrical power is $P=\dfrac{\text{Electrical Energy Consumed}}{\text{Time}}$

  $P =\dfrac{W}{t}= \dfrac{I2Rt}{t}$

  $P=I^2R=\dfrac{V^2}{R}=VI$
- The S.I. unit of electrical power is Joule per second which is called Watt W.
- One Watt is the power consumed by a device that carries 1 A of current when operated at a potential difference of 1 V.

  1W=1volt × 1 ampere = 1VA
- Other units of electrical power are kilowatt, megawatt, horse power, etc.

  1 kilowatt = 1000 watt, 1 megawatt = 106 watt
- We know that Electrical Energy = Electrical Power × Time. Thus watt hour is the unit for electrical energy.
- One watt hour is the energy consumed when 1 watt of power is used for 1 hour.
- The commercial unit of electrical energy is kilo watt hour kWh.

  1 kWh = 3.6×10^6 joule
- In our house for domestic purpose, electricity is calculated in kWh. It is called a 'unit'.

ASSIGNMENT

Very Short Answer Type Questions

1. Define the SI unit of (one mark each)
(a) Current
(b) Potential Difference
(c) Resistance
(d) Electric Power
(e) Electric Energy (Commercial)

2. What is the conventional direction of flow of current?

3. Define the term resistivity?

4. On what factors does the resistance of a conductor depend?

5. How is the voltmeter and ammeter connected in the electric circuit.

6. Heating effect of current carrying conductor is due to ....

7. Why the filament of bulb has high melting point?

Short Answer Type Questions

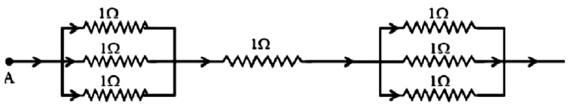
8. Draw a schematic diagram of a circuit consisting of a battery of six cell of 1.5V each, three resistor each of 3W in series and a plug key.

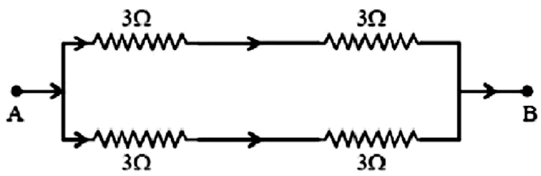
9. State Ohm's law. Draw the graph between V&I?

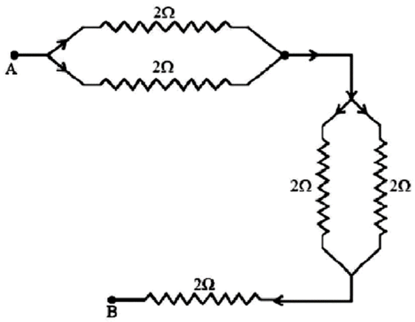
10. What is joule's Heating effect of current, derive its expression?

11. A wire of length L and R is stretched so that its length's doubled and the area of cross section is halved. How will its
(i) Resistance change
(ii) Resistivity change

12. Calculate the total effective resistance between points A and B

(i)


(ii)


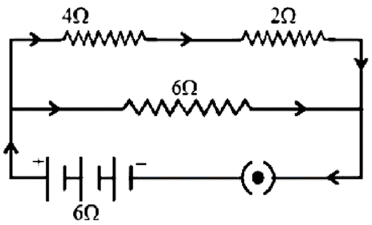
(iii) 

Long Answer Type Questions

13. On what factor the resistance of conductor depends give its mathematical expression. Give the SI unit of resistivity?

Calculate the resistivity of a metal of length 2m at 20°C having the resistance of 20W and diameter 0.3mm?

14. In a circuit below, calculate



(a) Calculate total effective resistance
(b) The total current through the circuit.
(c) Potential difference across 4Ω and 2Ω.

15. Three resistance of 2Ω, 3Ω and 5Ω are connected in the electric circuit.
Calculate the
(a) Maximum effective resistance
(b) Minimum effective resistance

16. Explain Joulie how of hearing. How and on what factor does the heat produced in a conduct depends?

Hots

17. The relationship between the current I, flowing in a metallic wire and the potential difference across its terminals can be explained with the help of a Law. Explain this Law.

18. In practical cases it is necessary to increase or decrease the current in an electric circuit. What helps regulate the resistance in a circuit.

19. A battery or cells help in transmission of electricity in a circuit. Explain the role of a battery in a circuit.

20. The motion of electrons through a conductor is retarded by its resistance. Do all materials retard the motion of electrons? Explain.

21. Tungsten filament is used for most bulbs. Explain.

22. Resistors can be connected in series of parallel. Where will you place an ammeter in a circuit containing three resistors in series in order to find out the current in the circuit?

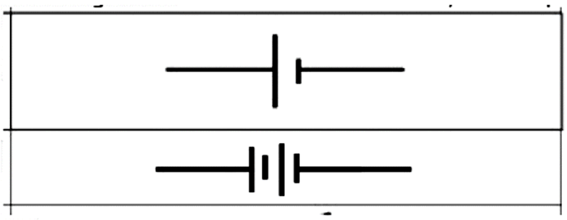
Value Based Questions

23. Hiten was working on circuits in his physics lab. He wanted to reduce the flow of current in the circuit. He went to his physics teacher who explained him the concept.

(a) How can length of the wire help decide the amount of current flowing through it?

(b) Mention the values shown by Hiten's teacher.

24. Aanya was given the following circuit symbols. As both looks similar, she went to the lab in charge to understand the difference; who explained the same to her.



(a) What do these symbols represent?

(b) What value was shown by the lab in charge?