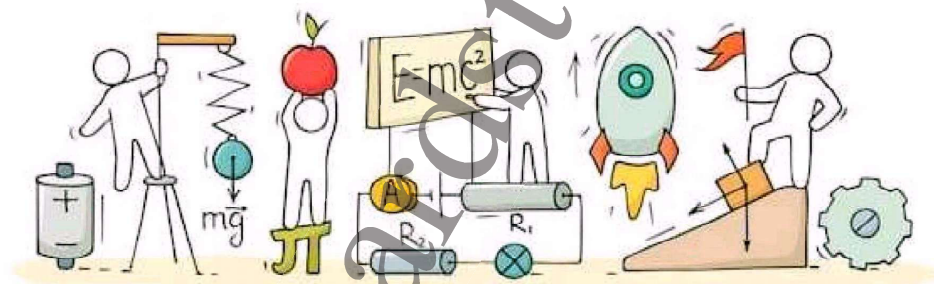


PHYSICS



CURRENT ELECTRICITY

Introduction:

We considered all charges whether free or bound to be at rest in previous two chapters. Charges in motion constitute an electric current. Lightening is one of the natural phenomena in which charges flow from clouds to earth through the atmosphere.

In this chapter we will study some basic laws concerning steady electric current and their applications.

Electric Current:

The rate of flow of electric charge through any cross-section of a conductor is known as electric current. If ΔQ amount of charge flows through any cross-section of conductor in the interval t to $(t + \Delta t)$, then it is defined as

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

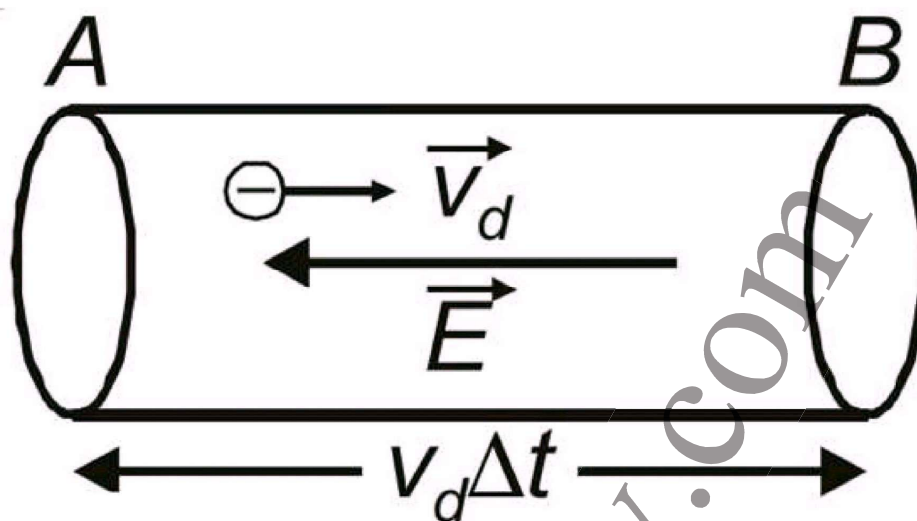
Direction of current is taken as direction of motion of positively charged particles and opposite to the direction of negatively charged particles. SI unit of current is ampere (A). It is a scalar quantity.

$$\vec{j} = \frac{\Delta i}{\Delta A}$$

The SI unit of current density is A/m^2 .

Drift Speed:

Drift Velocity is defined as the average velocity with which the free electrons move towards the positive end of a conductor under the influence of an external electric field applied. It is denoted by v_d .



$$v_d = \frac{eE}{m}$$

Relation between Current Density and Drift Speed:

Let, cross sectional area of any conductor be A , number of electrons per unit area be n , drift velocity be v_d , then number of total moving electrons in t second will be.

$$N = (nAv_d t)$$

So, moving charge in t second $Q = (nAv_d t) \cdot e$

Hence, electric current in t second $= \frac{Q}{t}$

$$i = \frac{nAv_d t e}{t}$$

$$i = neAv_d$$

$$\text{We know } J = \frac{i}{A}$$

Putting $i = neAv_d$ in above equation

$$\vec{J} = nev_d$$

Ohm's Law:

According to this law, "At constant temperature, the potential difference V across the ends of a

given metallic wire (conductor) in an circuit (electric) is directly proportional to the current flowing through it". i.e.,

$$V \propto i$$

$$V = i.R$$

where, R = resistance of conductor

Mobility:

Mobility is defined as the magnitude of the drift velocity per unit electric field. It is denoted by μ ,

$$\mu = \frac{v_d}{E}$$

Its SI unit is $m^2V^{-1}s^{-1}$.

Resistance:

Resistance is the ratio of potential difference applied across the ends of conductor to the current flowing through it.

$$R = \frac{V}{i}$$

The SI unit of R is ohm (Ω).

Resistivity:

Resistivity is defined as the ratio of electric field applied at conductor to current density of conductor. It is denoted by ρ

$$\rho = \frac{E}{J} \dots (1)$$

If the length of conductor be 'l', cross sectional area be 'A', potential difference at the end of conductor be 'V' and electric current be 'i', then $\vec{E}$ and $\vec{J}$ given by.

$$\vec{E} = \frac{V}{l} \dots (2)$$

$$\vec{J} = \frac{i}{A} \dots (3)$$

Putting the value of E and J, from equation (2) and (3) into (1), we get.

$$\rho = \frac{V}{i \frac{l}{A}}$$

$$\rho = \frac{V}{i} \cdot \frac{A}{l}$$

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

The constant of proportionality ρ depends on the material of the conductor but not on its dimensions. ρ is known as resistivity or specific resistance.

Conductivity:

Conductivity is defined as the reciprocal of resistivity of a conductor. It is expressed as,

$$\sigma = \frac{1}{\rho}$$

SI unit is mho per meter ($\Omega^{-1} \text{ m}^{-1}$).

Superconductivity:

The resistivity of certain metal or alloy drops to zero when they are cooled below a certain temperature is called superconductivity.

Electrical Energy:

When electric current is moved in any electric circuit, then energy of work done by taking a charge from one point to another point is called electric energy.

If a charge q at potential difference V is moved from one point to another point, then doing work will be.

$$W = V \cdot q \dots\dots (1)$$

Putting $q = i \cdot t$ in equation (1), we get

$$W = V i t$$

Putting $V = i \cdot R$ in equation (1), we get

$$W = i^2 R t$$

Putting $i = V/R$ in equation (1), we get

$$W = \frac{V^2}{R} t$$

Power: Electric power is the rate of doing work by electric charge. It is measured in watt and represented by P.

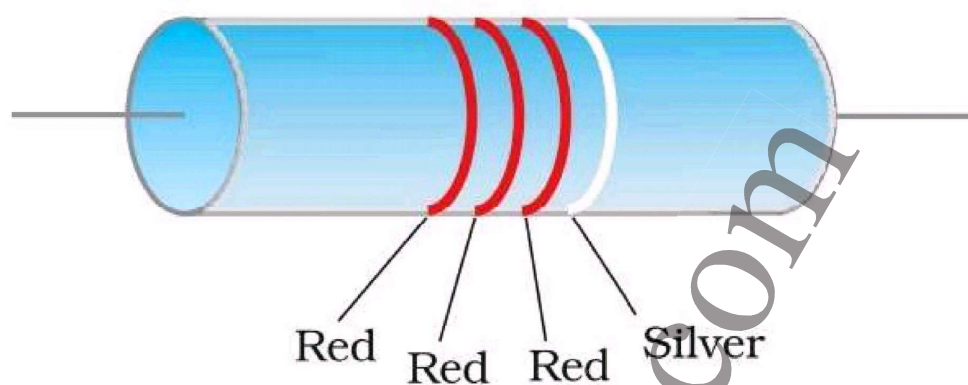
$$P = \frac{W}{t} [\because 1 \text{ HP} = 746 \text{ watt}]$$

Hence, $P = Vi = i^2 R = \frac{V^2}{R}$

Resistor Color Codes:

Colour	Number	Multiplier	Tolerance (%)
Black	0	1	
Brown	1	10^1	
Red	2	10^2	
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Gray	8	10^8	
White	9	10^9	
Gold		10^{-1}	5
Silver		10^{-2}	10
No colour			20

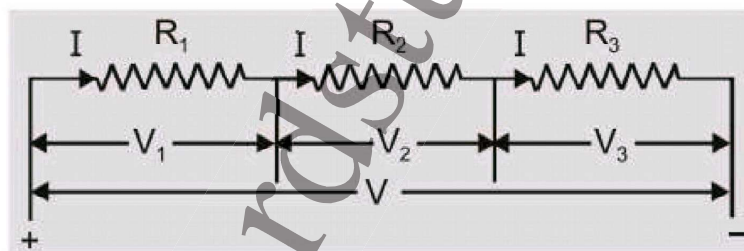
A carbon resistor has a set of coaxial colored rings in them, whose significance are listed in above table. First two bands formed: First two significant figures of the resistance in ohm. Third band; Decimal multiplier as shown in table. Last band; Tolerance or possible variation in percentage as per the indicated value. For Gold $\pm 5\%$, for silver $\pm 10\%$ and No color $\pm 20\%$.



Combination of Resistors:

There are two types of resistance combinations.

Series Combination:

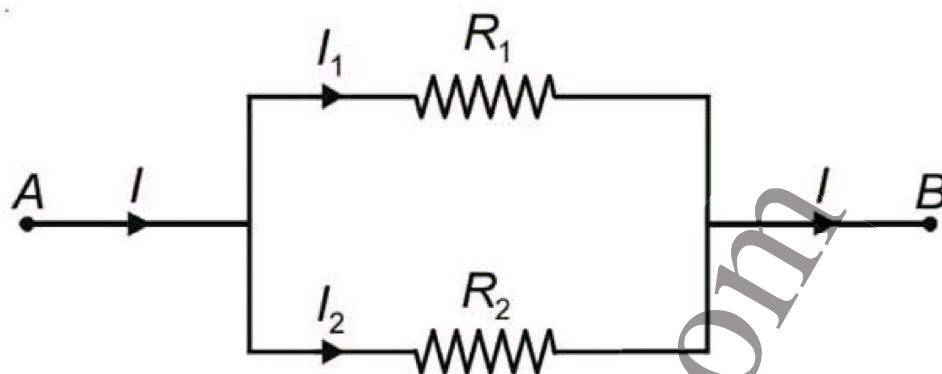


In Series Combination, different resistances are connected end to end. Equivalent resistance can be obtained as the formula,

$$R = R_1 + R_2 + R_3$$

NOTE: The total resistance in the series combination is more than the greatest resistance in the circuit.

Parallel Combination:



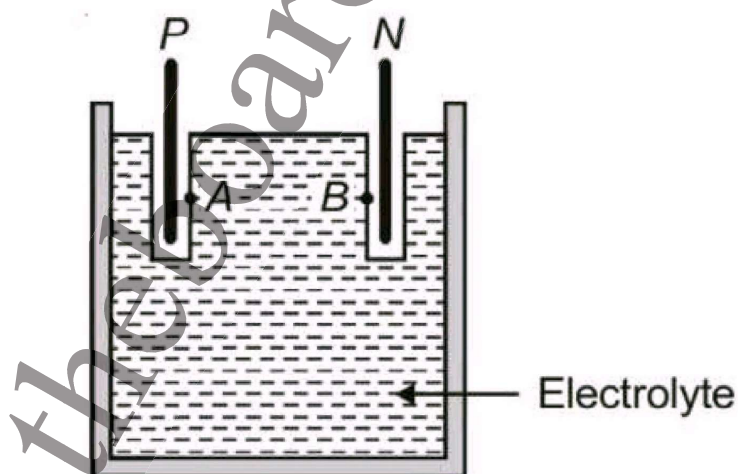
In Parallel combination, first end of all the resistances are connected to one point and last end of all the resistances are connected to other point. Equivalent resistance can be obtained by the formula.

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

NOTE: The total resistance in parallel combination is less than the least resistance of the circuit.

Cells, EMF, Internal Resistance:

Cells: An electrolytic cell consisting of two electrodes, called positive (P) and negative (N) immersed in an electrolytic solution as shown in figure.



Electrodes exchange charges with the electrolyte. Positive electrode P has a potential difference V_+ between itself and electrolyte solution A immediately adjacent to it. Negative electrode N has a potential difference (V_-) relative to electrolyte B adjacent to it.

$$\varepsilon = V_+ - V_-$$

EMF: It is the difference of chemical potentials of electrodes used. It is also defined as the difference of potential across the electrodes of cell, when the electrodes are in open loop.

$$\varepsilon = V_+ - V_-$$

Internal Resistance: It is the opposition offered by the electrolyte of the cell to the flow of current through itself. It is represented by r and given by.

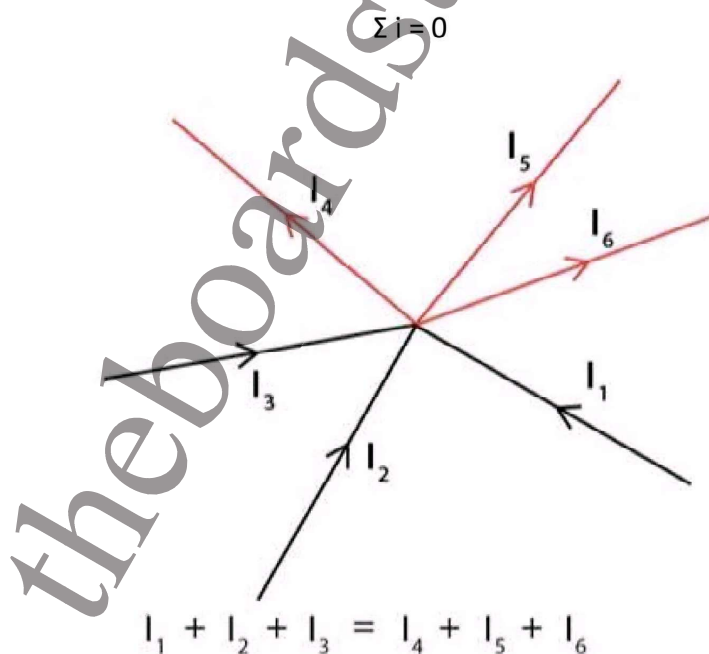
$$r = \frac{V}{i}$$

Kirchhoff's Laws:

Kirchhoff's two rules are used for analyzing electric circuits consisting of a number of resistors and cells interconnected in a complicated way.

Kirchhoff's first rule: Junction rule

At any junction, the sum of the currents entering the junction is equal to the sum of currents leaving the junction.



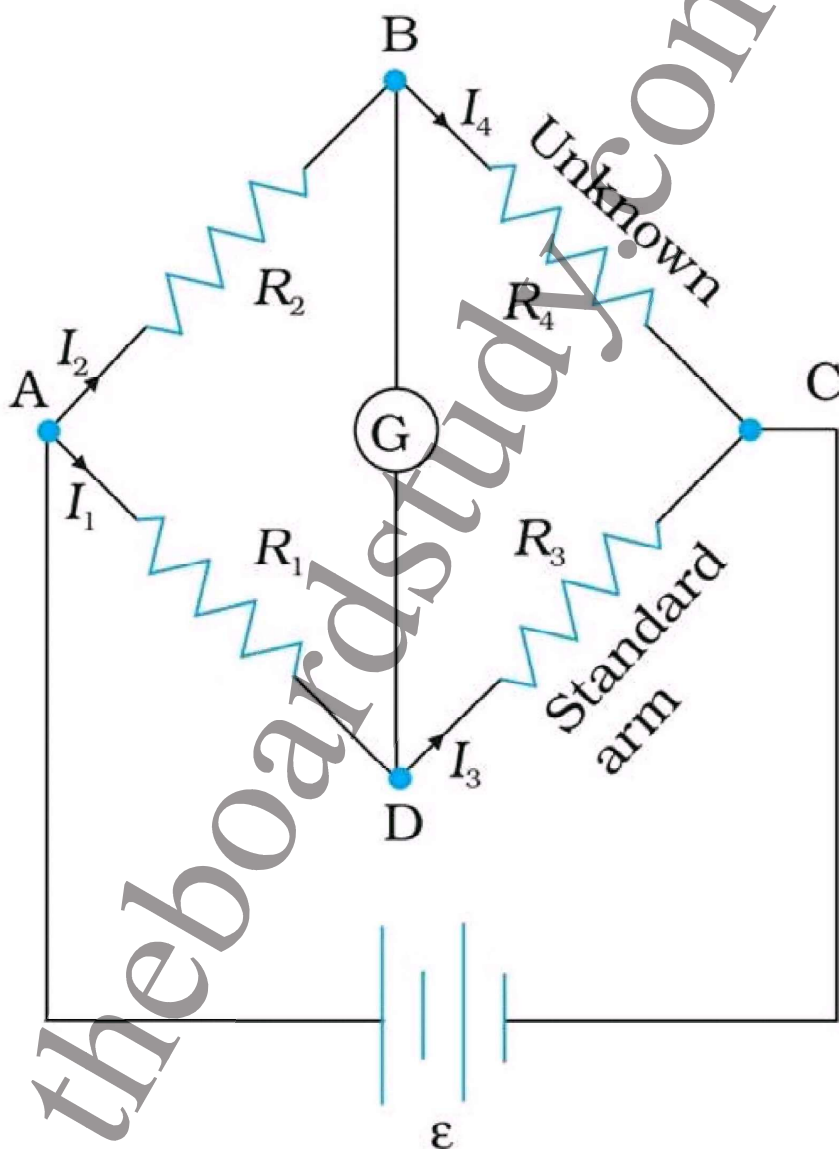
Kirchhoff's second rule: Loop rule

The algebraic sum of changes in potential around any closed loop involving resistors and cells in the loop is zero.

$$\sum iR = \sum E$$

Wheatstone Bridge:

It is an application of Kirchhoff's rules. The bridge is consisting of four resistances R_1 , R_2 , R_3 and R_4 as four sides of a square ABCD as shown in figure.



Across the diagonally opposite points between A and C, battery E is connected. This is called battery arm. To remaining two diagonally opposite points B and D, a galvanometer G is connected to detect current. This line is known as galvanometer arm.

Currents through all resistances and galvanometer are as shown in figure. In balanced Wheatstone bridge we consider the special case $I_g = 0$. Applying junction rule to junction B and D, we have

$$I_2 = I_4 \text{ and } I_1 = I_3$$

Applying loop rule to loop ABDA

$$I_2 R_2 + 0 - I_1 R_1 = 0$$

$$\frac{I_1}{I_2} = \frac{R_2}{R_1} \dots\dots (i)$$

Applying loop rule to loop BCDB

$$I_4 R_4 - I_3 R_3 + 0 = 0$$

$$I_2 R_4 - I_1 R_3 = 0 \text{ (Using } I_4 = I_2 \text{ and } I_3 = I_1)$$

$$\frac{I_1}{I_2} = \frac{R_4}{R_3} \dots\dots (ii)$$

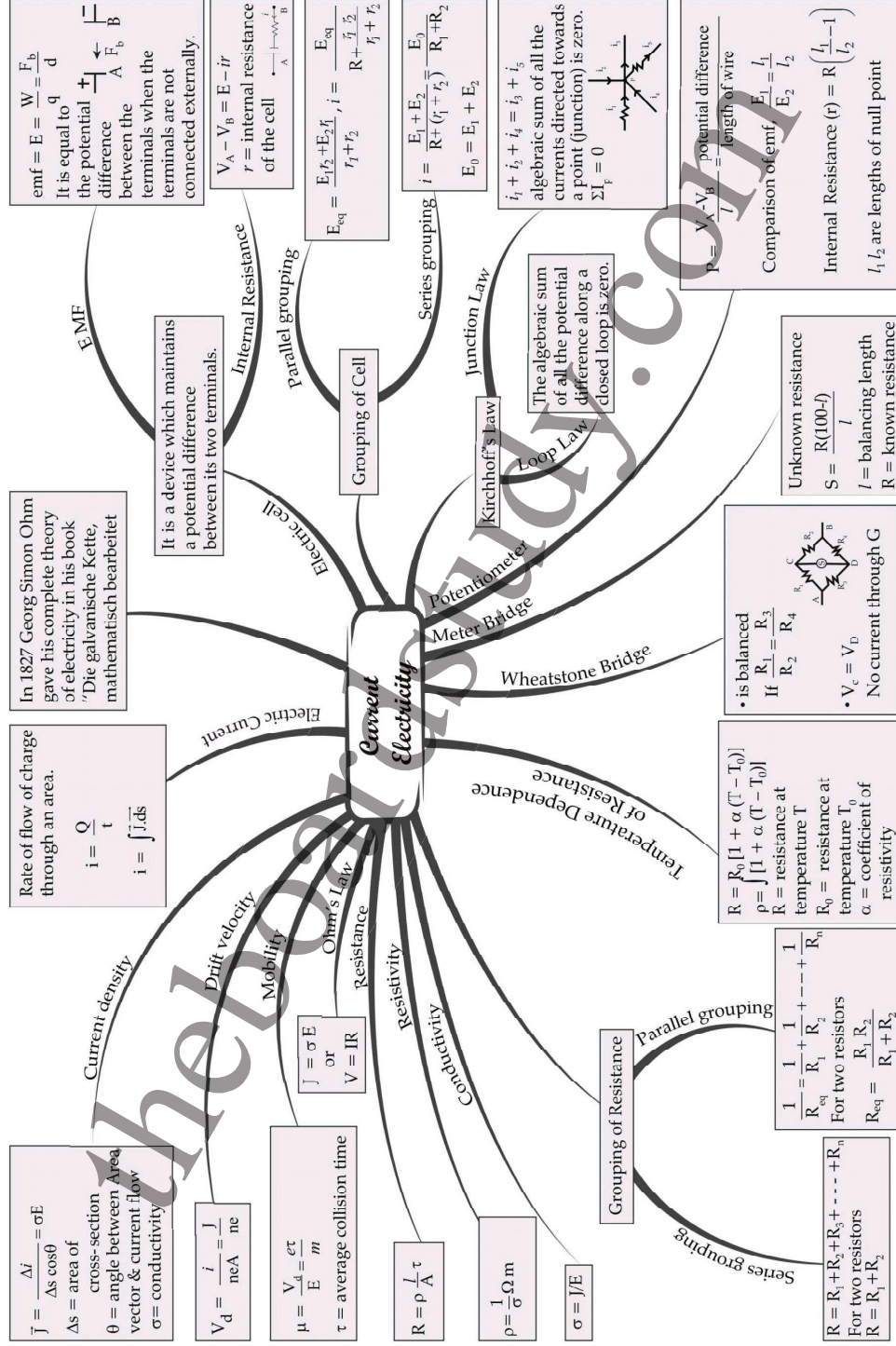
The equation (iii) relating the four resistor is called the balance condition for the galvanometer to give zero or null deflection.

Potentiometer:

It is a versatile instrument consisting of a long piece of uniform wire AC across which a standard cell B is connected.

MIND MAP : LEARNING MADE SIMPLE

CHAPTER - 3



Important Questions

Multiple Choice questions-

1. An electric heater is connected to the voltage supply. After few seconds, current gets its steady value then its initial current will be

- (a) equal to its steady current
- (b) slightly higher than its steady current
- (c) slightly less than its steady current
- (d) zero

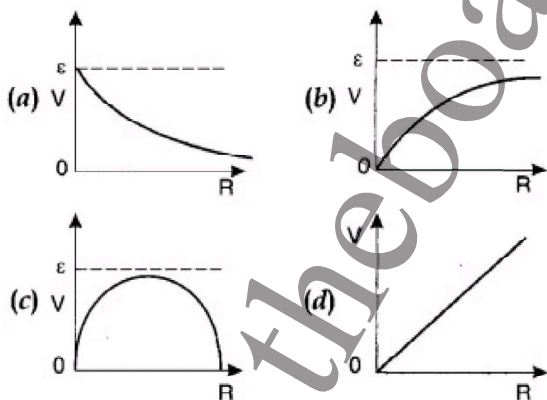
2. In the series combination of two or more than two resistances

- (a) the current through each resistance is same.
- (b) the voltage through each resistance is same.
- (c) neither current nor voltage through each resistance is same.
- (d) both current and voltage through each resistance are same.

3. Combine three resistors 5 Ω , 4.5 Ω and 3 Ω in such a way that the total resistance of this combination is maximum

- (a) 12.5 Ω
- (b) 13.5 Ω
- (c) 14.5 Ω
- (d) 16.5 Ω

4. A cell having an emf E and internal resistance r is connected across a variable external resistance R . As the resistance R is increased, the plot of potential difference V across R is given by



5. In parallel combination of n cells, we obtain

- (a) more voltage
- (b) more current
- (c) less voltage

(d) less current

6. If n cells each of emf e and internal resistance r are connected in parallel, then the total emf and internal resistance will be

- (a) $\varepsilon, \frac{r}{n}$ (b) ε, nr
 (c) $n\varepsilon, \frac{r}{n}$ (d) $n\varepsilon, nr$

7. In a Wheatstone bridge if the battery and galvanometer are interchanged then the deflection in galvanometer will

- (a) change in previous direction
 (b) not change
 (c) change in opposite direction
 (d) none of these.

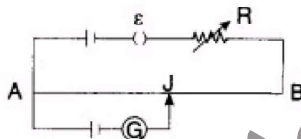
8. When a metal conductor connected to left gap of a meter bridge is heated, the balancing point

- (a) shifts towards right
 (b) shifts towards left
 (c) remains unchanged
 (d) remains at zero

9. In a potentiometer of 10 wires, the balance point is obtained on the 7th wire. To shift the balance point to 9th wire, we should

- (a) decrease resistance in the main circuit.
 (b) increase resistance in the main circuit.
 (c) decrease resistance in series with the cell whose emf is to be measured.
 (d) increase resistance in series with the cell whose emf is to be determined.

10. AB is a wire of potentiometer with the increase in the value of resistance R , the shift in the balance point J will be

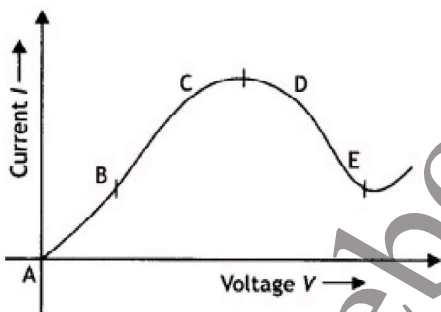


- (a) towards B
 (b) towards A
 (c) remains constant
 (d) first towards B then back towards A.

Very Short:

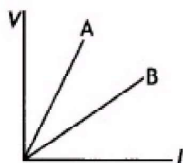
1. A wire of resistivity ρ is stretched to double its length. What will be its new resistivity?

2. What is the effect of temperature on the relaxation time of electrons in a metal?
3. Which physical quantity does the voltage versus current graph for a metallic conductor depict? Give its SI unit.
4. Define drift velocity of electrons.
5. A resistance R is connected across a cell of emf ϵ and internal resistance r . A potentiometer now measures the potential difference between the terminals, of the cell as V . Write the expression for ' r ' in terms of ϵ , V and R . (CBSE Delhi 2011)
6. How is the drift velocity in a conductor affected by the rise in temperature? (CBSE Delhi 2019)
7. Two students A and B were asked to pick a resistor of $15\text{ k}\Omega$ from a collection of carbon resistors. A picked a resistor with bands of colours brown, green, orange, while B chose a resistor with bands of black, green, red. Who picked the correct resistor? (CBSE AI 2013C)
8. Define the term 'Mobility' of charge carriers in a conductor. Write its S.I. unit. (CBSE Delhi 2014, AI 2015)
9. How does the mobility of electrons in a conductor change, if the potential difference applied across the conductor is doubled, keeping the length and temperature of the conductor constant? (CBSE Delhi 2019)
10. Graph showing the variation of current versus voltage for a material GaAs is shown in the figure. Identify the region of
(i) negative resistance (ii) where Ohm's

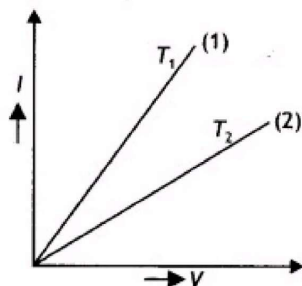


Short Questions:

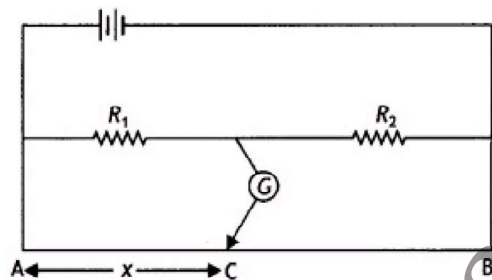
1. Find the potential energy of this system. (CBSEAI, Delhi 2018)
2. The figure shows the $V-I$ graph for a parallel and series combination of two resistors A and B. Which line represents the parallel combination?



3. $V - I$ graph for a given metallic wire at two temperatures is shown. Which of these is at a higher temperature?



4. In an experiment on a metre bridge, if the balancing length AC is ' x ', what would be its value, when the radius of the metre bridge wire AB is doubled? Justify your answer. (CBSE AI 2011C)



5. The emf of a cell is always greater than its terminal voltage. Why? Give reason. (CBSE Delhi 2013)

6. Draw a graph showing the variation of resistivity with temperature for nichrome. Which property of nichrome is used to make standard resistance coils? (CBSEAI 2013C)

7. Define the term 'mobility' for a charge carrier and state its SI unit.

Name the mobile charge carriers in

(i) an electrolyte,

(ii) a semiconductor and

(iii) an ionised gas. (CBSE AI 2015)

8. Define the term current density of a metallic conductor. Deduce the relation connecting current density (J) and the conductivity (α) of the conductor, when an electric field E is applied to it. (CBSE AI 2015).

Long Questions:

1. Explain the term 'drift velocity' of electrons in a conductor. Hence obtain the expression for the current through a conductor in terms of 'drift velocity'. (CBSE AI 2013, 2013C)
2. Draw a plot showing the variation of resistivity of an (i) conductor and (ii) semiconductor, with the increase in temperature.

How does one explain this behaviour in terms of the number density of charge carriers and the relaxation time? (CBSE Delhi 2014C)

Assertion and Reason Questions-

1. For two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

- a) Both A and R are true, and R is the correct explanation of A.
- b) Both A and R are true, but R is not the correct explanation of A.
- c) A is true, but R is false.
- d) A is false, and R is also false.

Assertion: The current in a wire is due to flow of free electrons in a definite direction.

Reason: A current carrying wire should have non-zero charge.

2. For two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

- a) Both A and R are true, and R is the correct explanation of A.
- b) Both A and R are true, but R is not the correct explanation of A.
- c) A is true, but R is false.
- d) A is false, and R is also false.

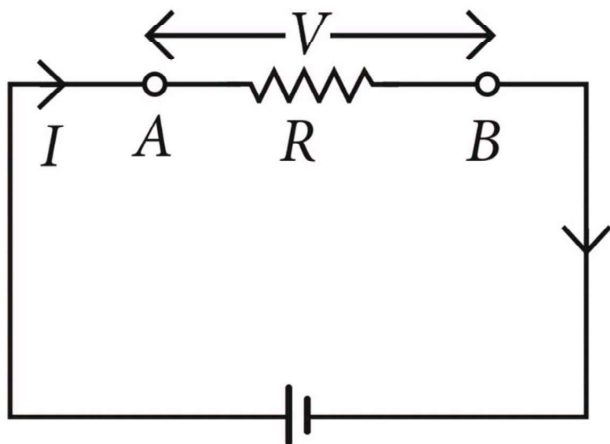
Assertion: Though the same current flows through the live wires and the filament of the bulb but heat produced in the filament is much higher than that in live wires.

Reason: The filament of bulbs is made of a material of high resistance and high melting point.

Case Study Questions-

1. Whenever an electric current is passed through a conductor, it becomes hot after some time. The phenomenon of the production of heat in a resistor by the flow of an electric current through it is called heating effect of current or Joule heating. Thus, the electrical energy supplied by the source of emf is converted into heat. In purely resistive circuit, the energy expended by the source entirely appears as heat. But if the circuit has an active element like a motor, then a part of the energy supplied by the source goes to do useful work and the rest

appears as heat. Joule's law of heating form the basis of various electrical appliances such as electric bulb, electric furnace, electric press etc.



- (i) Which of the following is a correct statement?
- a) Heat produced in a conductor is independent of the current flowing.
 - b) Heat produced in a conductor varies inversely as the current flowing.
 - c) Heat produced in a conductor varies directly as the square of the current flowing.
 - d) Heat produced in a conductor varies inversely as the square of the current flowing.
- (ii) If the coil of a heater is cut to half, what would happen to heat produced?
- a) Doubled.
 - b) Halved.
 - c) Remains same.
 - d) Becomes four times.
- (iii) A 25W and 100W are joined in series and connected to the mains. Which bulbs will glow brighter?
- a) 100W.
 - b) 25W.
 - c) Both bulbs will glow brighter.
 - d) None will glow brighter.
- (iv) A rigid container with thermally insulated wall contains a coil of resistance 100Ω , carrying current 1A. Change in its internal energy after 5 min will be:
- a) 0kJ
 - b) 10kJ
 - c) 20kJ

d) 30kJ

(v) The heat emitted by a bulb of 100W in 1 min is:

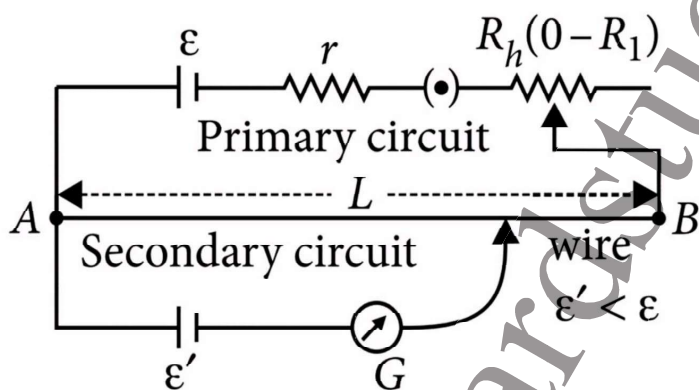
a) 100J

b) 1000J

c) 600J

d) 6000J

2. Potentiometer is an apparatus used for measuring the emf of a cell or potential difference between two points in an electrical circuit accurately. It is also used to determine the internal resistance of a primary cell. The potentiometer is based on the principle that, if V is the potential difference across any portion of the wire of length l and resistance R , then $V \propto l$ or $V = kl$ where k is the potential gradient. Thus, potential difference across any portion of potentiometer wire is directly proportional to length of the wire of that portion. The potentiometer wire must be uniform. The resistance of potentiometer wire should be high.



(i) Which one of the following is true about potentiometer?

a) Its sensitivity is low.

b) It measures the emf of a cell very accurately.

c) It is based on deflection method.

d) None of the above.

(ii) A current of 1.0mA is flowing through a potentiometer wire of length 4cm and of resistance 4Ω . The potential gradient of the potentiometer wire is:

a) 10^{-3}Vm^{-1}

b) 10^{-5}Vm^{-2}

c) $2 \times 10^{-3}\text{Vm}^{-1}$

d) $4 \times 10^{-3}\text{Vm}^{-1}$

- (iii) Sensitivity of a potentiometer can be increased by:
- a) Decreasing potential gradient along the wire.
 - b) Increasing potential gradient along the wire.
 - c) Decreasing current through the wire.
 - d) Increasing current through the wire.
- (iv) A potentiometer is an accurate and versatile device to make electrical measurements of EMF because the method involves:
- a) Potential gradients.
 - b) A condition of no current flow through the galvanometer.
 - c) A combination of cells, galvanometer and resistances.
 - d) Cells.
- (v) In a potentiometer experiment, the balancing length is 8m, when the two cells E_1 and E_2 are joined in series. When the two cells are connected in opposition the balancing length is 4m. The ratio of the e.m.f. of two cells $\left(\frac{E_1}{E_2}\right)$ is:
- a) 1 : 2
 - b) 2 : 1
 - c) 1 : 3
 - d) 3 : 1

✓ Answer Key:

Multiple Choice Answers-

1. Answer: b
2. Answer: a
3. Answer: a
4. Answer: b
5. Answer: b
6. Answer: a
7. Answer: b
8. Answer: a
9. Answer: d
10. Answer: a

Very Short Answers:

1. Answer: The resistivity remains the same as it does not depend upon the length of the wire.
2. Answer: The relaxation time of electrons decreases with the rise in temperature of the metal.
3. Answer: It represents resistance. It is measured in ohm.
4. Answer: The mean velocity acquired by electrons in a conductor when an external electric field is applied to it.
5. Answer:

$$\text{The required relation is } r = \left(\frac{\epsilon}{V} - 1 \right) R$$

6. Answer: It decreases.
7. Answer: A
8. Answer: Mobility of charge carriers in a conductor is defined as the magnitude of their drift velocity per unit applied electric field. Its SI unit is $\text{m}^2 \text{V}^{-1} \text{s}^{-1}$.
9. Answer: No change.
10. Answer: (i) DE (ii) AB

Short Questions Answers:

1. Answer: The potentiometer is based on the null method, or it does not draw any (net) current from the cell and measures emf. However, the voltmeter draws some current from the cell when connected across it, hence measures terminal voltage.
2. Answer: For the same potential, the current is less in series combination than parallel combination. Therefore, from the graph, it is apparent that the same potential current is less in A. Therefore, B represents the parallel combination.

$$\text{As, } R = \frac{V}{I}$$

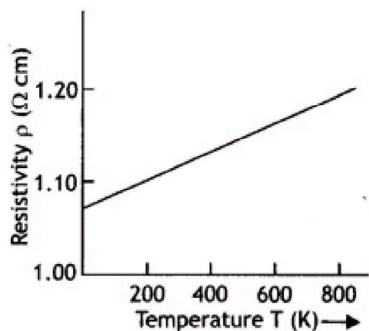
The slope of B > Slope of A

3. Answer: At higher temperature resistance of a metallic wire is more or its conductance is low. Hence, graph (2) is at a higher temperature, i.e., $T_2 > T_1$.
4. Answer: In a metre bridge, at the balance point we have

$$\frac{R_1}{R_2} = \frac{x}{100-x}$$

As R_1 and R_2 remain the same, x will also remain the same. It does not depend upon the diameter of the wire.

5. Answer: When current passes through a cell, there is a drop in potential across it due to its internal resistance. This is called the lost volt. Thus, terminal voltage is less than the emf of the cell.
6. Answer: The graph is as shown.



The property has a low-temperature coefficient of resistance.

7. Answer: Mobility is defined as the ratio of the drift velocity of the charge to the applied electric field.
- (i) Anions and cations.
 - (ii) Electrons and holes
 - (iii) Free electrons.
8. Answer: Current density is defined as the current flowing per unit area of the conductor.

Mathematically current density is given by the expression $J = \frac{I}{A}$

But $I = V/R$ and $R = \frac{\rho L}{A} = \frac{L}{\sigma A}$. Substituting in the above relation, we have

$$J = \frac{I}{A} = \frac{V}{AL} \times \sigma A = \frac{V}{L} \times \sigma = E\sigma$$

Long Questions Answers:

1. Answer:

Drift velocity (V_d) is defined as the average velocity with which the free electrons get drifted inside a conductor under the effect of the electric field, opposite to the direction of the field.

Let n be the electrons per unit volume in the conductor. Here n is called the number density of electrons. Assume that all electrons move with the same drift velocity V_d . In a time, interval dt , each electron moves a distance $v_d dt$. Now the volume of the cylinder covered by the electrons in time dt is

$$V = A v_d dt \dots (1)$$

and the number of electrons in this volume is

$$N = nV = nA v_d dt \dots (2)$$

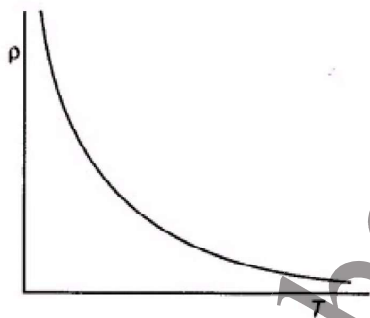
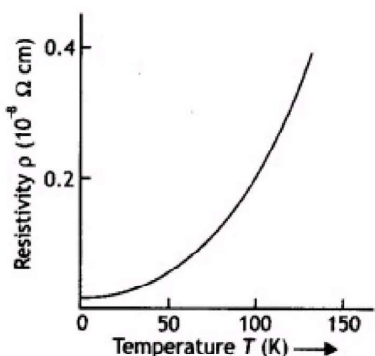
If e is the charge on the electron, then charge flowing through the conductor in small time dt is

$$dQ = e(nA v_d dt) \dots (3)$$

Hence the current through the conductor is

$$I = \frac{dQ}{dt} = nAev_d$$

2. Answer: The plots are as shown.



With a rise in temperature the average relaxation time for a conductor decreases and resistivity increases, while for a semiconductor the number density of charge carriers increases, hence the resistivity decreases.

Assertion and Reason Answers-

1. (c) A is true, but R is false.

Explanation:

The current in a wire is due to flow of free electrons in a definite direction. But the number of protons in the wire at any instant is equal to number of electrons and charge on electrons is equal and opposite to that of proton. Hence, net charge on the wire is zero.

2. (b) Both A and R are true, but R is not the correct explanation of A.

Explanation:

As filament of bulb and live wire are in series, hence current through both is same. Now, because $H = \frac{i^2 R t}{4.2}$ and resistance of the filament of the bulb is much higher than that of live wires, hence heat produced in the filament is much higher than that in live wires.

Case Study Answers-

1. Answer :

(i) (c) Heat produced in a conductor varies directly as the square of the current flowing.

Explanation:

According to Joule's law of heating, Heat produced in a conductor, $H = I^2 R t$ where, I = Current flowing through the conductor R = Resistance of the conductor t = Time for which current flows through the conductor.

$$\therefore H \propto I^2$$

(ii) (a) Doubled.

Explanation:

If the coil is cut into half, its resistance is also halved.

$$\text{As } H = \frac{V^2}{R} t$$

$$\therefore H' = 2$$

(iii) (b) 25W.

Explanation:

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

The bulbs are joined in series. Current in both the bulbs will same.

$\therefore$ The heat produced in them is given by $H = I^2 R t$

$$\text{or } H \propto R \Rightarrow H \propto \frac{1}{P}$$

Therefore the bulb with low wattage or high resistance will glow brighter or we can say the 25W bulb will glow brighter than the 100W bulb.

(iv) (d) 30kJ

Explanation:

$$R = 100\Omega; I = 1A; t = 5\text{min.} = 5 \times 60 = 300\text{s}$$

Change in internal energy = heat generated in coil

$$= I^2 R t = (1)^2 \times 100 \times 300 \text{ J}$$

$$= 30000 \text{ J} = 30 \text{ kJ.}$$

(v) (d) 6000J

Explanation:

Here, $P = 100\text{W}$, $t = 1 \text{ min} = 60\text{s}$

Heat developed in time t

$$H = P \times t = (100\text{W})(60\text{s}) = 6000\text{J.}$$

2. Answer :

(i) (b) It measures the emf of a cell very accurately.

(ii) (a) 10^{-5}Vm^{-2}

Explanation:

Given, $I = 1.0\text{mA} = 10^{-3}\text{A}$;

$$R = 4\Omega; L = 4\text{m}$$

Potential drop across potentiometer wire,

$$V = IR = 10^{-3} \times 4\text{V}$$

$$\text{Potential gradient, } k = \frac{V}{L} = \frac{4 \times 10^{-3}}{4}$$

$$= 10^{-3}\text{Vm}^{-1}$$

(iii) (a) Decreasing potential gradient along the wire.

(iv) (b) A condition of no current flow through the galvanometer.

Explanation:

A potentiometer is an accurate and versatile device to make electrical measurements of EMF because the method involves a condition of no current flow through the galvanometer. It can be used to measure potential difference, internal resistance of a cell and compare EMF's of two sources.

(v) (d) 3 : 1

Explanation:

$$\frac{E_1}{E_2} = \frac{l_1 + l_2}{l_1 - l_2} = \frac{8+4}{8-4}$$
$$= \frac{12}{4} = \frac{3}{1}$$

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