3. CURRENT ELECTRICITY

ONE MARK QUESTIONS WITH ANSWERS

1. What constitutes an electric current?

Ans. Charges in motion constitutes an electric current.

2. Define electric current.

Ans. The amount of charge flowing across an area held normal to the direction of flow of charge per unit time is called electric current.

3. Give the SI unit of current.

Ans. SI unit of current is ampere(A).

4. Define the unit of electric current. Or Write the relation between coulomb and ampere.

Ans. If one coulomb of charge crosses an area normally in one second, then the current through that area is one ampere.

i.e. 1 ampere = $\frac{1 coulomb}{1\ second}$ or 1 A = 1C s^{-1}

5. How many electrons per second constitute a current of one milli ampere?

Ans.We have, $I = \frac{q}{t} = \frac{ne}{t}$

$\therefore n = \frac{It}{e} = \frac{10^{-3} X 1}{1.6\ X\ 10^{-19}} = 6.25 X 10^{15}$ electrons

6.Is electric current is a scalar or vector quantity.

Ans. It is a scalar quantity.

7.What do you mean by steady current?

Ans. A current whose magnitude does not change with time is called steady current.

8. What do you mean by varying current?

Ans. A current whose magnitude changes with time is called varying current.

9.What does the direction of electric current signify in an electric circuit?

Ans. The direction of conventional current in an electric circuit tells the direction of flow of positive charges in that circuit.

10. What is the net flow of electric charges in any direction inside the solid conductor?

Ans. It is zero.

11. Name the current carries in metals (solid conductors), / electrolytic solutions (liquid conductors) and /discharge tubes (gaseous conductors).

Ans. Free electrons in solid conductors ,/ positively and negatively charged ions in liquid conductors and / positive ions and electrons in gaseous conductors.

12. State Ohm's law.

Ans. Ohm's law states that the current (I) flowing through a conductor is directly proportional to the potential difference (V) applied across its ends, provided the temperature and other physical conditions remain constant".

i.e. $I \propto V$ or $V = IR$

13.Define resistance.

Ans. It is defined as the ratio of the potential difference (V) across the ends of the conductor to the electric current (I) through it.

i.e. $R = \frac{V}{I}$

14. Define the SI unit of resistance

Ans.The resistance of a conductor is I ohm if one ampere of current flows through it when the potential difference across its ends is one volt.

15. How does the resistance of a conductor depend on length?

Ans. The resistance (R) of a conductor is directly proportional to its length (l)

I. e. R$\propto l$

16. How does the resistance of a conductor depend on area of cross section of a conductor?

Ans.The resistance (R) of a conductor is inversely proportional to its area of cross section (A).

I. e. R $\propto \frac{1}{A}$

17. Define electrical conductance.

Ans. The reciprocal of resistance is called electrical conductance.

i.e., G = $\frac{1}{R}$

18. Mention the SI unit of conductance.

Ans.Siemen (s)or mho(Ʊ).

19. Define resistivity of a conductor.

Ans. The resistivity of material of a conductor at a given temperature is equal to resistance of unit length of the conductor having unit area of cross section.

20. A wire of resistivity ρ is stretched to three times its length .What will be its new resistivity?

Ans. There will be no change in its resistivity, because resistivity does not depend on length (dimension) of wire.

21. Mention the relation between the resistance and resistivity?

Ans.The resistance R of a conductor is given by R = $\rho \frac{L}{A}$, where L- length of the conductor, A- area of cross section of the conductor.

22. Mention the SI unit of resistivity?

Ans. The SI unit of resistivity is ohm-meter $(\Omega - m)$

23. Define the term current density (j)

Ans. It is defined as the electric current (I) per unit area (A) taken normal to the direction of current.

i.e., j = $\frac{I}{A}$

24. What is the SI unit of current density?

Ans. Ampere / metre^2 (A/m^2)

25. Is current density is a scalar or vector quantity?

Ans. It is a vector quantity.

26. Define electrical conductivity.

Ans. The reciprocal of electrical resistivity of material of a conductor is called conductivity.

i.e. $\sigma = \frac{1}{\rho}$

27. Mention the relation between current density and conductivity.

Ans. The current density j and conductivity σ are related by $\vec{j} = \sigma\vec{E}$.

28. Define drift velocity.

Ans. It is defined as the average velocity gained by the free electrons of a conductor in the opposite of the externally applied electric field.

29. What is the average velocity of free electrons in a metal at room temperature?

Ans. Zero.

30. What is the effect of temperature on the drift speed of electrons in a metallic conductor?

Ans. The drift speed decreases with increase in temperature.

31. Define relaxation time or mean free time.

Ans. The average time that elapses between two successive collisions of an electron with fixed atoms or ions in the conductor is called relaxation time.

32. What is the effect of relaxation time of electrons in a metal?

Ans. Relaxation time decreases with increase in temperature.

33. Define electron mobility.

Ans. Mobility (μ) is defined as the magnitude of drift velocity (v_d) per unit electric field (E).

i.e. $\mu = \frac{v_d}{E}$

34. Mention the SI unit of mobility.

Ans. The SI unit of electron mobility is $m^2\, V^{-1} s^{-1}$

35. Name two materials whose resistivity decreases with the rise of temperature.

Ans. Germanium and Silicon.

36. How does the resistance of an insulator change with temperature?

Ans. The resistance of an insulator decreases with the increase of temperature.

37. What will be the value of resistance of a resistor having four colour bands in the order yellow , violet , orange and silver?

Ans. 47000 Ω $\pm$ 10%

38. The value of resistance of a resistor is 1 KΩ $\pm$ 5%. Write the colour sequence of the resistor.

Ans. The colour sequence is Brown, black, red and gold.

39. The value of resistance of a resistor is 0.1 $\Omega \pm 10\%$. Write the colour sequence of the resistor.

Ans. Resistance= 0.1 $\Omega \pm 10\%$ = 01 X $10^{-1} \pm 10\%$.Thus, the colour sequence is Black, brown and gold. Tolerance of $\pm$ 10% is indicated by silver ring.

40. What is the colour of the third band of a coded resistor of resistance 4.3 X $10^4\,\Omega$?

Ans. Resistance = 4.3 X $10^4\,\Omega$ =43 X $10^3\,\Omega$. Therefore, the colour of third band of a coded resistance will be related to a number 3, i.e., orange.

41. How does the resistance of a conductor vary with temperature?

Ans. The resistance of a conductor increases linearly with increase of temperature and vice-versa.

42. How does the resistivity of a conductor vary with temperature?

Ans. The resistivity of a conductor increases linearly with increase of temperature and vice-versa.

43. How does the resistivity of a semi conductor vary with temperature?

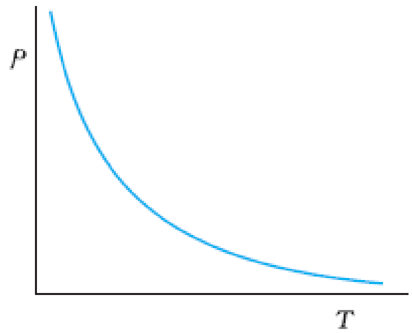
Ans. The resistivity of a semi conductor decreases exponentially with increase of temperature.

44.Name a material which exhibit very weak dependence of resistivity with temperature?

Ans. Nichrome , an alloy of nickel, iron and chromium exhibit very weak dependence of resistivity with temperature.

45.Draw temperature—resistivity graph for a semiconductor.

Ans.



46.When the two resistors are said to be in series?

Ans. Two rersistors are said to be in series if only one of their end points is joined.

47. When the two or more resistors are said to be in parallel?

Ans. Two or more resistors are said to be in parallel if ne end of all the resistors is joined together and similarly the other ends joined together.

48. R_1 and R_2 are the two resistors in series. The rate of flow of charge through R_1 is I_1. What is the rate of flow through R_2?

Ans. Current is the measure of rate of flow of charge. There fore the rate of flow of charge through R_2 is also I_1.

49. If V_1 and V_2 be the potential difference across R_1 and R_2 in series. How much is the potential difference across the combination?

Ans. The potential difference across the combination, $V = V_1 + V_2$.

50. What is the equivalent resistance of P resistors each of resistance R connected in series ?

Ans . $R_{eq} = R_1 + R_2 + R_3 + R_4 + \ldots\ldots\ldots\ldots\ldots$

$\therefore R_{eq} = R + R + R + \ldots\ldots\ldots\ldots\ldots\ldots\ldots$ P times = P(R)

51. What happens to the effective resistance when two or more resistors are connected in series?

Ans. The effective resistance when two or more resistors are connected in series increases and is greater than the greatest of individual resistance.

52. What happens to the effective resistance when two or more resistors are connected in parallel?

Ans. The effective resistance when two or more resistors are connected in parallel decreases and is smaller than the smallest of individual resistance.

53. What is emf of a cell?

Ans. Emf ε is the potential difference between the positive and negative electrodes in an open circuit. i.e. when no current flowing through the cell.

54. Define internal resistance of a cell.

Ans. The finite resistance offered by the electrolyte for the flow of current through it is called internal resistance.

55. Give the expression for the potential difference between the electrodes of a cell of emf ε and internal resistance r?

Ans. The potential difference $\mathbf{V = \varepsilon - I\,r}$.

56. write the expression for equivalent emf when two cells of emf's ε_1 and ε_2 connected in series.

Ans. $\boldsymbol{\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2}$

57. write the expression for equivalent emf when two cells of emf's ε_1 and ε_2 connected in series such that negative electrode of ε_1 to negative electrode of $\varepsilon_{2'}(\varepsilon_1 > \varepsilon_{2'})$

Ans. $\boldsymbol{\varepsilon_{eq} = \varepsilon_1 - \varepsilon_2}$

58. Write the expression for equivalent emf of n cells each of emf ε connected in series.

Ans. $\boldsymbol{\varepsilon_{eq} = n\,\varepsilon}$

59. Write the expression for equivalent internal resistance of n cells each of internal resistance r connected in series.

Ans. $\mathbf{r_{eq} = n\, r}$

60.What is an electric network?

Ans. It is a circuit in which several resistors and cells interconnected in a complicated way.

61. What is a node or junction in an electrical network?

Ans. It is a point in a network where more than two currents meet.

62. What is a mesh or loop in an electric network?

Ans. A mesh or loop is a closed path with in the network for the flow of electric current.

63. State Kirchhoff's junction rule.

Ans. At any junction in an electric network the sum of the currents entering the junction is equal to sum of the currents leaving the junction.

64. What is the significance of junction rule?

Ans. Conservation of charge.

65.State Kirchhoff's loop rule?

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

66. What is the significance of loop rule?

Ans. Conservation of energy.

67.Write the condition for balance of Wheatstone's network.

Ans. At balance of Wheatstone network the resistors are such that the current through the galvanometer is zero.($I_g = 0$)

OR

$\frac{P}{Q} = \frac{R}{S}$ P, Q, S, R are in cyclic order.

68. On what principle a meter bridge work?

Ans. It works on the principle of balanced condition of whetstone's network.

69. Mention one use of meter bridge.

Ans. It is used to determine the unknown resistance of a given coil.

70.Write the expression for Unknown resistance R interms of standard resistance S and balancing length l,

Ans. $\mathbf{R = \frac{Sl}{1-l}}$

71. How the error in finding R in a meter bridge can be minimized?

Ans. The error in finding R in a meter bridge can be minimized by adjusting the balancing point near middle of the bridge (close to 50cm) by suitable choice of standard resistance S.

72 .What is a potentiometer?

Ans. It is an instrument consisting of long piece of uniform wire across which a standard cell is connected.

73. Mention the practical use of potentiometer.

Ans. It can be used to determine emf of a one cell knowing emf of the other and also internal resistance of a given cell.

74.Give the equation to compare emf's of two cells in terms of balancing length.

Ans. If l_1 and l_2 are the balancing length's then $\mathbf{\frac{\varepsilon_1}{\varepsilon_2} = \frac{l_1}{l_2}}$

75.Give the formula to determine the internal resistance of the cell using potentiometer.

Ans. r = R $\left[\frac{l_1}{l_2} - 1\right]$, l_1 and l_2 are the balancing length's without and with the external resistance respectively.

76. What is the advantage of potentiometer?

Ans. The potentiometer has the advantage that it draws no current from the voltage source being measured.

77. Name the device used for measuring emf of a cell.

Ans. potentiometer.

<u>TWO OR THREE MARK QUESTIONS WITH ANSWERS</u>.

1. How is the current conducted in metals ? explain

Ans. Every metal conductor has large number of free electrons which move randomly at room temperature. Their average thermal velocity at any instant is zero. When a potential difference is applied across the ends of a conductor, an electric field is set up. Due to it, the free electrons of the conductor experience force due to electric field and drift towards the positive end of the conductor, causing electric current.

2. Define the term (1) drift velocity (2) relaxation time.

Ans. (1) drift velocity :- It is defined as the average velocity gained by the free electrons of a conductor in the opposite of the externally applied electric field.

(2) relaxation time :- The average time that elapses between two successive collisions of an electron with fixed atoms or ions in the conductor is called relaxation time.

3.State and explain Ohm's law.

Ans. Statement:- Ohm's law states that " the current (I) flowing through a conductor is directly proportional to the potential difference (V) applied across its ends, provided the temperature and other physical conditions remain constant".

If I is the current and V is the potential difference between the ends of the conductor, then

i.e. $I \propto V$ or I= (constant) V

But the constant = conductance = 1 / R

There fore I = V / R or V = IR .

4.Mention the factors on which resistivity of a metal depends.

Ans. Resistivity of a metallic conductor depends on(1) nature of the conductor (2) Temperature

5. Write the expression for resistivity in terms of number density and relaxation time.

Ans. $\boldsymbol{\varrho} = \frac{\boldsymbol{m}}{\boldsymbol{ne^2\tau}}$ where n = number density of electrons, τ = relaxation time of free electrons

6. Mention any two factors on which resistance of a conductor depends.

Ans. Resistance of a conductor depends on (1) length of the conductor (2) Area of cross section of the conductor.

7.Write the relation between current density and conductivity for a conductor.

Ans. $\mathbf{j} = \boldsymbol{\sigma E}$ Where $\sigma = conductivity\ and\ \ E = electric\ field$

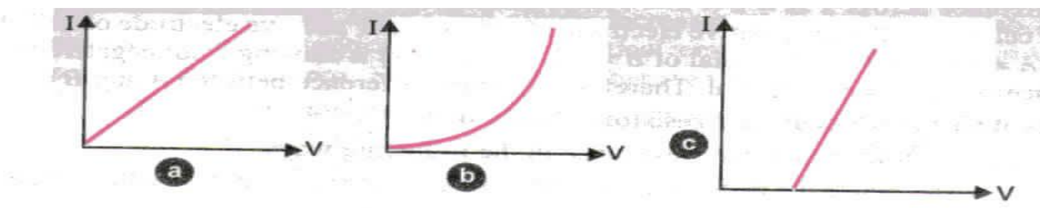
8.Why manganin is used to make standard resistance coils?

Ans. For manganin, the temperature coefficient of resistance is very low and its resistivity is quite high. Due to it, the resistance of manganin wire remains almost unchanged with change in temperature. Hence it is used.

9.Draw V-I graph for ohmic and non- ohmic materials.

Ans. V-I graph for ohmic material is a straight line passing through origin.(a)

V-I graph for non-ohmic material is a curve i.e. non linear or straight line not passing through origin(b and c)



10.Distinguish between resistance and resistivity.

Ans.

Resistance	Resistivity
1.The opposition offered by a conductor to the flow of electric current through.	1. The resistance of unit cube of the material of a conductor is called resistivity.
2. Resistance depends on dimensions i.e. length and area of cross section.	2. Resistivity of a conductor depends on the nature of the material but is independent of the dimensions.
3. Its SI unit is ohm.	3. Its SI unit is ohm-meter

11.How does the resistance of (1) good conductor, (2) semiconductor change with rise of temperature?

Ans.(1) The resistance of a conductor increases with the increase in the temperature.

(2) The resistance of a semiconductor decreases with the increase in the temperature.

12. Distinguish between terminal potential difference and emf of a cell.

Ans.

Terminal potential difference	emf
1.It is the potential difference between the electrodes of a cell in a closed circuit (When current is drawn from the cell). Represented by V. 2. Its SI unit is volt.	1. It is the potential difference between the electrodes of a cell when no current is drawn from the cell. Represented by E. . .2. Its SI unit is volt

13.Terminal potential difference is less than the emf of a cell. Why?

Ans.When circuit is open,the terminal potential difference is equal to emf of the cell . When current is drawn from the cell, some potential drop takes place due to internal resistance of the cell. Hence terminal potential difference is less than the emf of a cell and is given by

$$V = E - Ir$$

14.Mention the factors on which internal resistance of a cell depend.

Ans. The internal resistance of a cell depend on (1) The nature of the electrolyte (2) nature of electrodes (3) temperature.(4) concentration of electrodes (5) distance between the electrodes (Any two)

15. For what basic purpose the cells are connected (1) in series (2) in parallel

Ans. The cells are connected (1) in series to get maximum voltage, (2) in parallel to get maximum current.

16.State Kirchhoff's laws of electrical network.

Ans. Kirchhoff's junction rule:- At any junction in an electric network the sum of the currents entering the junction is equal to sum of the currents leaving the junction.

Kirchhoff's loop rule:-The algebraic sum of changes in potential around any closed loop involving resistors and cells in the loop is zero.

17.What is the cause of resistance of a conductor?

Ans. While drifting, the free electrons collide with the ions and atoms of the conductor i.e., motion of the electrons is opposed during the collisions, this is the basic cause of resistance in a conductor.

18. A large number of free electrons are present in metals. Why there is no current in the absence of electric field across?

Ans.. In the absence of an electric field, the motion of electrons in a metal is random. There is no net flow of charge across any section of the conductor. So no current flows in the metal .

19. State the principle of working of a potentiometer.

Ans. A potentiometer works on the principle that when a steady current flows through a wire of uniform cross section and composition, the potential drop across any length of the wire is directly proportional to that length.

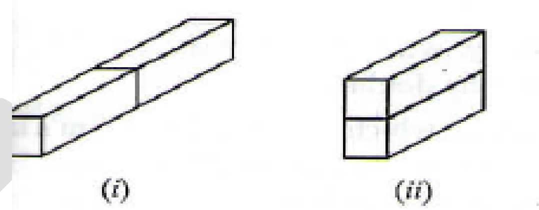
20. Why are the connecting resistors in a meter bridge made of thick copper strips?

Ans. Thick copper strips offer minimum resistance and hence avoid the error due to end resistance which have not been taken in to account in the meter bridge formula.

21. A Carbon resistor has three strips of red colour and a gold strip. What is the value of resistor? What is tolerance?
Ans. The value of resistance is 2200 ± 5 %. The percentage of deviation from the rated value is called tolerance.
22. If the emf of the cell be decreased, what will be the effect of zero deflection in a potentiometer? Explain.

Ans. If the emf of the cell is decreased, the potential gradient across the wire will decrease. Due to this the position of zero deflection will be obtained on the longer length.

23. Two identical slabs of given metal joined together in two different ways, as shown in figs. What is the ratio of the resistances of these two combinations?



Ans. For each slab, R = $\rho \frac{L}{A}$,

$R_1 = \rho \frac{2L}{A}$ =2R ; $R_2 = \rho \frac{L}{2A}$ =R/2,

$\therefore \frac{R_1}{R_2} = \frac{2R}{\frac{R}{2}}$ **= 4: 1**

24. Define the terms electric energy and electric power. Give their units.

Ans. Electric energy:-The total work done by the source of emf in maintaining an electric current in a circuit for a given time is called electric energy consumed in the circuit. Its SI unit is joule.

Electric power:-The rate at which work is done by a source of emf in maintaining an electric current through a circuit is called electric power of the circuit. Its SI unit is watt.

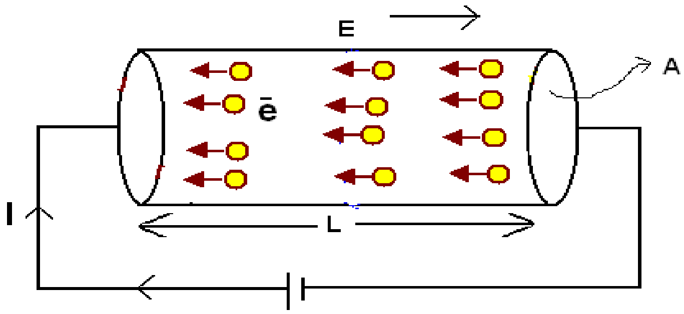
25. Mention the limitations of Ohm's law.

Limitations of Ohm's law:

1. Ohm's law applicable only for good conductors.
2. Ohm's law applicable only, when the physical conditions like temperature, pressure and tension remains constant.
3. Ohm's law is not applicable at very low temperature and very high temperature.
4. Ohm's law is not applicable for semiconductors, thermistors, vacuum tubes, discharge tubes.

FIVE MARK QUESTIONS WITH ANSWERS

1. Derive the expression for electrical conductivity.



Consider a conductor of length of ‘L’ and cross sectional area ‘A’. When electric field ‘E’ is applied across it, the electrons are drifted opposite to the applied field. Let

‘V_d’ be the drift velocity of electrons.

$\therefore$ Volume of a conductor = LA

Let ‘n’ be the number of free electrons per unit volume of conductor.

$\therefore$ Total number of e^- in unit volume = n x volume

$\therefore$ Total charge on all the electrons in the conductor = nLAe

Where e $\rightarrow$ Charge of each electron,

i.e, q = nLAe = neAL

But current $I = \frac{q}{t} = \frac{neAL}{t} = neA \times \frac{L}{t}$

$\therefore$ **$I = neAv_d$, --------(1)**

Where t $\rightarrow$ time taken by e^- to travel a distance ‘L’,

$V_d = L/t \rightarrow$ drift velocity

This is the expression for current through a conductor.

The current through a conductor is directly proportional to drift velocity. i.e. $I \propto V_d$.

From equation (1), $\frac{I}{A} = nev_d$

$\boldsymbol{J} = nev_d$ $\left[\because \boldsymbol{J} = \frac{I}{A}, \textit{current density}\right]$

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

$\therefore$ $j = ne\,\frac{eE}{m}\tau$

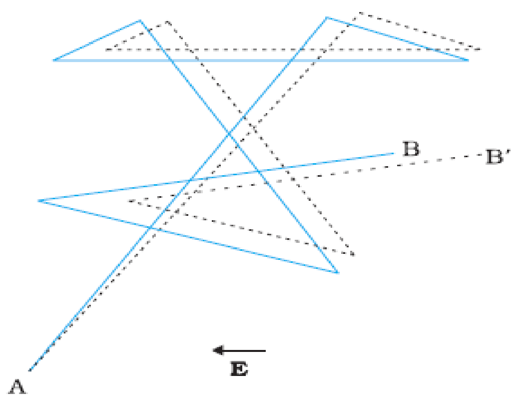
$$\mathbf{j} = \frac{ne^2}{m}\tau\mathbf{E}$$

$$\mathbf{j} = \sigma\,\mathbf{E}$$

$\therefore$ $\sigma = \frac{ne^2}{m}\tau$ Where σ conductivity

Note:

1. As the temperature increases, relaxation time decreases.
2. Drift velocity depends upon 1) the nature of the conductor. 2) applied electric field.



If electrons starting from a point 'A' move to point 'B' in the absence of electric field. If field is applied they move to B^1. BB^1 is called drift velocity.

2. State and deduce Ohm's law. From this law define the resistance of a conductor.

Ans. At a constant temperature, the steady current flowing through a conductor is directly proportional to the potential difference between the two ends of the conductor.

If I is the current and V is the potential difference between the ends of the conductor, then

i.e. $I \propto V$ or I= constant X V

But the constant = conductance = 1 / R

There fore I = V / R or V = IR .

The current flowing through a conductor is,

$I = nAev_d$

But $\quad v_d = \frac{eE}{m} \cdot \tau$

$\therefore \quad I = nAe \frac{eE}{m} \tau$

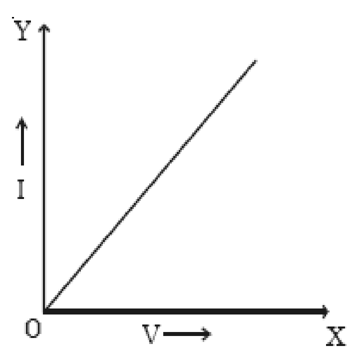
$$I = \frac{nAe^2}{mL} \tau V \quad \left[\because E = \frac{V}{L}\right]$$

where V is the potential difference. The quantity $\frac{mL}{nAe^2\tau}$ is a constant for a given conductor, called electrical resistance (R).

$\therefore \quad I \; \alpha \; V$

(i.e) $\quad I \; \alpha \; V \quad$ or $\quad I = \frac{1}{R} V$

$\therefore \quad V = IR \quad$ or $\quad R = \frac{V}{I}$



Resistance of a conductor is defined as the ratio of potential difference across the conductor to the current flowing through it. The unit of resistance is ohm (Ω)

The reciprocal of resistance is conductance. Its unit is mho (Ω^{-1}).

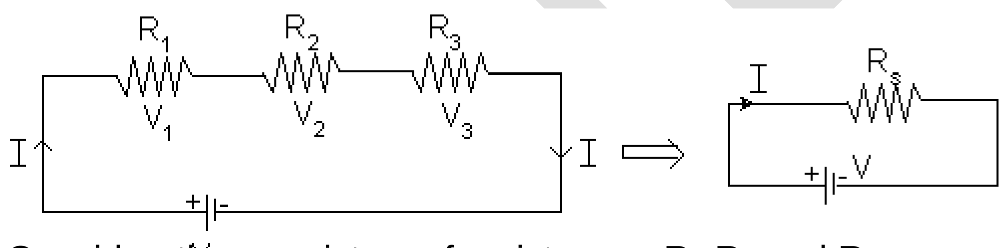
Since, potential difference V is proportional to the current I, the graph between V and I is a straight line for a conductor. Ohm's law holds good only when a steady current flows through a conductor.

3.What is meant by equivalent resistance ? Derive expression for equivalent resistance when the resistors are connected in series.

Ans. <u>Equivalent resistor:</u> A single resistor which produces the same effect as that of the set of resistors together produce in series is called equivalent resistor or Effective resistance.

<u>To derive an expression for effective resistance of three resistors connected in series:</u>

A set of resistors are said to be connected in series combination, if they are connected end to end such that current in each resistor is same but potential difference is different.



Consider three resistors of resistances R_1 R_2 and R_3 connected in series as shown.

Let 'I' be the current through each resistor. Let V_1, V_2 and V_3 be the potential difference across the resistors respectively. Let 'V' be the total potential difference across the combination. Let R_S be the effective resistance.

But, V = IR

$\therefore V_1 = IR_1$, $V_2 = IR_2$, $V_3 = IR_3$, $V = IR_S$

The total potential is

$V = V_1 + V_2 + V_3$

Substituting

$V = IR_1 + IR_2 + IR_3$

$\therefore V = I(R_1 + R_2 + R_3)$

If the combination is replaced by equivalent resistance 'R_s', then $V = I R_s$

$IR_s = I(R_1 + R_2 + R_3)$

$\therefore R_S = R_1 + R_2 + R_3$

This is the expression for effective resistance.

For 'n' resistors

$R_S = R_1 + R_2 + R_3 + \text{-------------} + R_n$

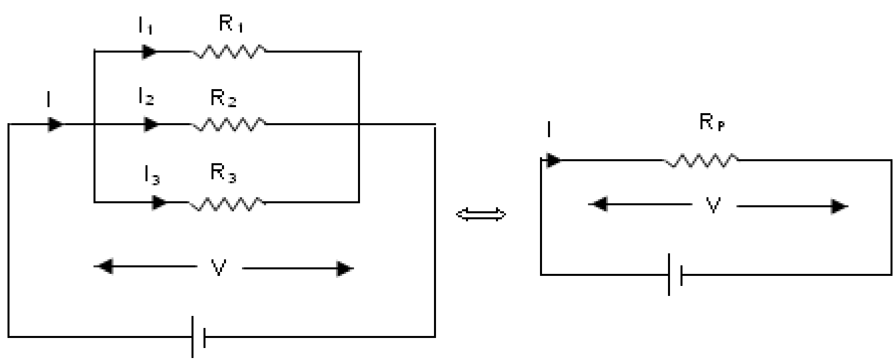
Equivalent resistance of number of resistors connected in series is equal to the sum of the individual resistances.

4.What is meant by equivalent resistance ? Derive expression for equivalent resistance when the resistors are connected in parallel.

Ans <u>Equivalent resistor:</u> A single resistor which produces the same effect as that of the set of resistors together produce in parallel is called equivalent resistor or Effective resistance

<u>To derive an expression for effective resistance of three resistors connected in parallel.</u>

A set of resistors are said to be connected in parallel combination, if they are connected between two common point, such that the potential difference across each resistor is same but current through each resistor is different..



Consider three resistors of resistances R_1 R_2 and R_3 connected in parallel is as shown figure.

Let V be the potential difference across each resistor.

Let I_1, I_2 and I_3 be the current through the resistors respectively.

Let 'I' be the total current in the combination,

Let 'R_P' be the effective resistance.

But, $I = \frac{V}{R}$,

$\therefore I_1 = \frac{V}{R_1}$, $I_2 = \frac{V}{R_2}$, $I_3 = \frac{V}{R_3}$,

But $I = I_1 + I_2 + I_3$ ------(1)

$$I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$I = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right) \quad \text{------(2)}$$

If the combination is replaced by equivalent resistance R_p,

$$I = \frac{V}{R_p}$$

Then Substituting in eqn (2)

$$\frac{V}{R_p} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\frac{V}{R_p} = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

$$\therefore \frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad \text{-----(3)}$$

This is the expression for effective resistance.

For 'n' resistors $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ------- + \frac{1}{R_n}$

The reciprocal of the equivalent resistance of number of resistors connected in parallel is equal to the sum of the reciprocals of the individual resistances.

5.Define emf and terminal potential difference of a cell. Derive an expression for main current using Ohm's law.

Ans. <u>Electromotive force of a Cell (emf of cell):</u>

The emf (E) of a cell is defined as the potential difference between the positive and negative electrodes in an open circuit, i.e., when no current is drawn from the cell.

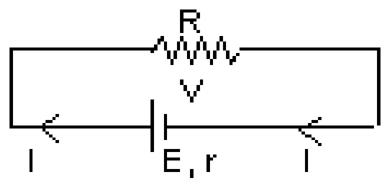
It is denoted by ‘ε’ or ‘E’.

Terminal potential difference:

The potential difference between two electrodes of a cell when it is in closed circuit (when current is drawn from the cell) is called terminal potential difference.

It is denoted by ‘V_T‘

Expression for main current flows in a simple circuit and emf (E) using Ohm’s law:



Consider an external resistance ‘R’ connected across the cell. Let, I be the current flows in the circuit. ‘E’ is the emf of the cell, ‘r’ is the internal resistance of the cell, ‘V’ is the potential difference across ‘R’.When a resistor of resistance ‘R’ is infinite, then ‘I’ = 0 in the circuit. (Open circuit)

The potential difference across ‘R’ is

$V = E = V_+ + V_-$ (terminal potential difference.)

If R is finite, I is not zero. The potential difference between ends of the cell is

$$V = V_+ + V_- - I\,r$$

$$V = E - I\,r \longrightarrow (1)$$

The negative sign in the expression ($I\ r$) indicates that the direction of current is in opposite direction in the electrolyte.

$$I\,r = E - V$$

$$I\,r = E - IR$$

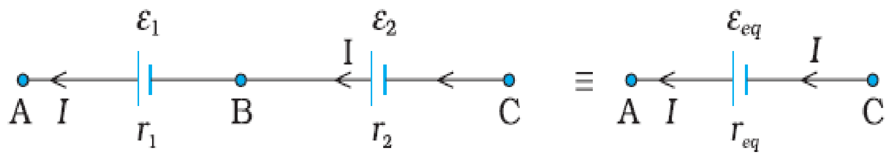
$$IR + I\,r = E$$

$$I\,(R + r) = E$$

$$I = \frac{E}{R + r}$$

6.Discuss the grouping of two unidentical cells in series and find their equivalent emf and internal resistance.

Ans. <u>Cells in series:</u>



Consider two cell connected in series, with negative terminal of one cell is connected to the positive terminal of the other.

Let ε_1, ε_2 are the emf's of the two cells. r_1, r_2 are the internal resistances of the cells. 'I' be the current sent by the cells. Let V_A, V_B, V_C be the potentials at points A, B and C respectively. The potential difference between the positive and negative terminals of the first cell is

$$V_{AB} = V_A - V_B = \varepsilon_1 - I\, r_1$$

The potential difference between the positive and negative terminals of the second cell is

$$V_{BC} = V_B - V_C = \varepsilon_2 - I\, r_2$$

The potential difference between the terminals A and C of the combination is

$$V_{AC} = V_A - V_C$$

$$V_{AC} = (V_A - V_B) + (V_A - V_C)$$

$$V_{AC} = \varepsilon_1 - I\, r_1 + \varepsilon_2 - I\, r_2$$

$$V_{AC} = \varepsilon_1 + \varepsilon_2 - I\, r_1 - I\, r_2$$

$$V_{AC} = \varepsilon_1 + \varepsilon_2 - I\,(r_1 + r_2) \longrightarrow \quad (1)$$

The series combination of two cells can be replaced by a single cell between 'A' and 'C' of emf ε_{eq} and internal resistance r_{eq},

$$V_{AC} = \varepsilon_{eq} - I\, r_{eq} \longrightarrow \quad (2)$$

Comparing equations (1) and (2)

$\boxed{\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2}$ and $\boxed{r_{eq} = r_1 + r_2}$

Result:

1. The equivalent emf of a series combination of 'n' cells is just the sum of their individual emf's

   $\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 - - - - - - + \varepsilon_n$

2. The equivalent internal resistance of a series combination of n cells is the sum of their internal resistances.

   $r_{eq} = r_1 + r_2 + r_3 - - - - - -+ + r_n.$

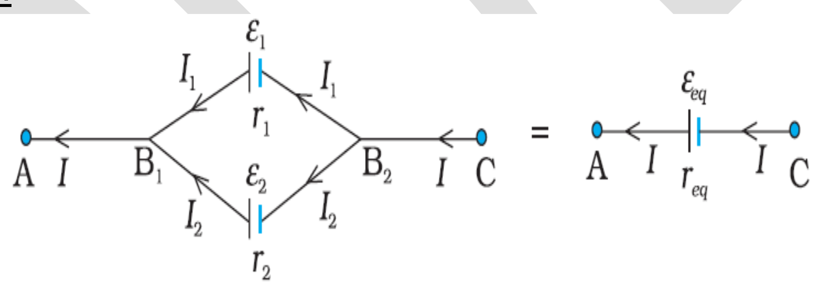
Note:

We have connected the negative electrode of the first to the positive electrode of the second. If instead we connect the two negatives we get

$$\frac{\varepsilon_{eq} = \varepsilon_1 - \varepsilon_2}{r_{eq} = r_1 + r_2}(\varepsilon_1 > \varepsilon_2)$$

6.Discuss the grouping of two unidentical cells in parallel and find their equivalent emf and internal resistance

Cells in parallel:



Consider two cell connected in Parallel, Let ε_1, ε_2 are the emf's of the two cells.r_1, r_2 are the internal resistances of the cells are connected in parallel across points B_1 and B_2.

I_1 and I_2 are the currents leaving the positive electrodes of the cells. At the point B_1, I_1 and I_2 flow in whereas the current 'I' leave out.

$\therefore I = I_1 + I_2$

Let $V(B_1)$ and $V(B_2)$ be the potentials at B_1 and B_2, respectively.

For the first cell,

The potential difference across its terminals is

$V = V(B_1) - V(B_2).$

$V = \varepsilon_1 - I_1 r_1$

$V + I_1 r_1 = \varepsilon_1$

$$I_1 = \frac{\varepsilon_1 - V}{r_1}$$

For the second cell,

The potential difference across its terminals is

$V = V(B_1) - V(B_2).$

$V = \varepsilon_2 - I_2 r_2$

$V + I_2 r_2 = \varepsilon_2$

But, $I_2 = \dfrac{\varepsilon_2 - V}{r_2}$

$$I = I_1 + I_2$$

$$= \frac{\varepsilon_1}{r_1} - \frac{V}{r_1} + \frac{\varepsilon_2}{r_2} - \frac{V}{r_2}$$

$$I + V\left(\frac{r_1 + r_2}{r_1 r_2}\right) = \left(\frac{\varepsilon_1 r_2 - \varepsilon_2 r_1}{r_1 r_2}\right)$$

$$V\left(\frac{r_1 + r_2}{r_1 r_2}\right) = \left(\frac{\varepsilon_1 r_2 - \varepsilon_2 r_1}{r_1 r_2}\right) - I$$

$$V = \frac{\left(\frac{\varepsilon_1 r_2 - \varepsilon_2 r_1}{r_1 r_2}\right) - I}{\left(\frac{r_1 + r_2}{r_1 r_2}\right)}$$

$$V = \left(\frac{\varepsilon_1 r_2 - \varepsilon_2 r_1}{\cancel{r_1 r_2}}\right)\left(\frac{\cancel{r_1 r_2}}{r_1 + r_2}\right) - I\left(\frac{r_1 r_2}{r_1 + r_2}\right)$$

$$V = \left(\frac{\varepsilon_1 r_2 - \varepsilon_2 r_1}{r_1 + r_2}\right) - I\left(\frac{r_1 r_2}{r_1 + r_2}\right) \longrightarrow \textbf{(1)}$$

If the parallel combination of cells is replaced by a single cell between B_1 and B_2 of emf ε_{eq} and internal resistance r_{eq}

$$V_{AC} = \varepsilon_{eq} - I\, r_{eq} \longrightarrow (2)$$

Comparing equation (1) and (2)

$$\varepsilon_{eq} = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2} \longrightarrow (3)$$

Dividing (3) by (4)

$$\longrightarrow (4)$$

$$\frac{\varepsilon_{eq}}{r_{eq}} = \frac{\dfrac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{\cancel{r_1 + r_2}}}{\dfrac{r_1 r_2}{\cancel{r_1 + r_2}}}$$

$$\frac{\varepsilon_{eq}}{r_{eq}} = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 r_2}$$

$$\boxed{\frac{\varepsilon_{eq}}{r_{eq}} = \frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2}}$$

If there an ‘n’ cells of emfs ε_1 , ε_2 , ε_3 , , . . . ε_n and of internal resistances r_1, r_2, r_3,. . . . . r_n respectively, connected in parallel, the combination is equivalent to a single cell of emf ε_{eq} and internal resistance r_{eq}, such that

$$\frac{\varepsilon_{eq}}{r_{eq}} = \frac{\varepsilon_1}{r_1} + \cdots + \frac{\varepsilon_n}{r_n}$$

$$\frac{1}{r_{eq}} = \frac{1}{r_1} + \cdots + \frac{1}{r_n}$$

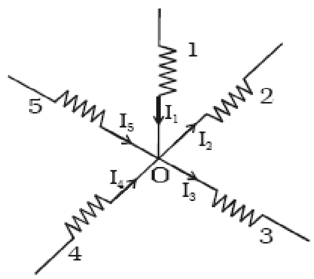
7.State and explain Kirchhoff’s rules.

Ans. *Kirchhoff’s first law (current law)*

Kirchhoff’s current law states that the algebraic sum of the currents meeting at any junction in a circuit is zero.

The convention is that, the current flowing towards a junction is positive and the current flowing away from the junction is negative. Let 1,2,3,4 and 5 be the conductors meeting at a junction O in an electrical circuit

Let I_1, I_2, I_3, I_4 and I_5 be the currents passing through the conductors respectively. According to Kirchhoff's first law.



$I_1 + (-I_2) + (-I_3) + I_4 + I_5 = 0$ or $I_1 + I_4 + I_5 = I_2 + I_3$.

The sum of the currents entering the junction is equal to the sum of the currents leaving the junction. This law is a consequence of conservation of charges.

Kirchhoff's second law (voltage law)

Kirchhoff's voltage law states that the algebraic sum of the products of resistance and current in each part of any closed circuit is equal to the algebraic sum of the emf's in that closed circuit.

This law is a consequence of conservation of energy. In applying Kirchhoff's laws to electrical networks, the direction of current flow may be assumed either clockwise or anticlockwise. If the assumed direction of current is not the actual direction, then on solving the problems, the current will be found to have negative sign. If the result is positive, then the assumed direction is the same as actual direction. In the application of Kirchhoff's second law, we follow that the current in clockwise direction is taken as positive and the current in anticlockwise direction is taken as negative. Let us consider the electric circuit given in Fig.

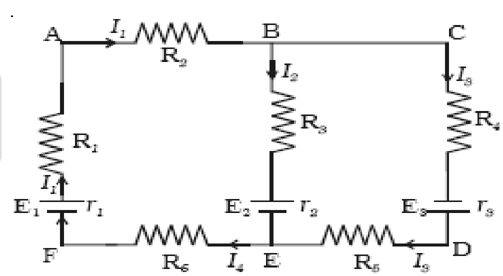
Considering the closed loop ABCDEFA,

$I_1R_2 + I_3R_4 + I_3r_3 + I_3R_5 + I_4R_6 + I_1r_1 + I_1R_1 = E_1 + E_3$

Both cells E_1 and E_3 send currents in clockwise direction.

For the closed loop ABEFA

$I_1R_2 + I_2R_3 + I_2r_2 + I_4R_6 + I_1r_1 + I_1R_1 = E_1 - E_2$



Negative sign in E_2 indicates that it sends current in the anticlockwise direction.

8.Deduce the condition for balance of Wheatstone's network using Kirchhoff's laws.

<u>condition for balance of Wheatstone bridge:</u>

Wheatstone bridge is based on the application of Kirchhoff's rules.

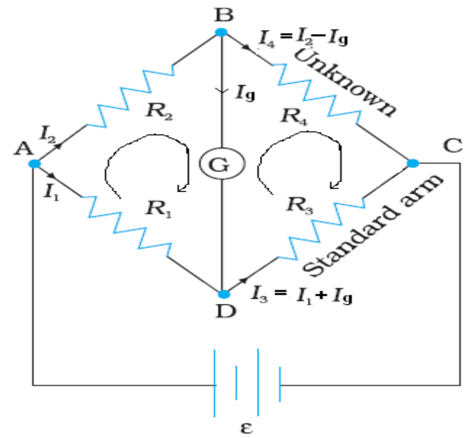
The bridge has four resistors R_1, R_2, R_3 and R_4. Across one pair of diagonally opposite points 'A' and 'C' a source is connected. (battery arm.) Between the other two vertices, 'B' and 'D', a galvanometer of resistance 'G' is connected. (Galvanometer arm.) Let I_g be the current in the galvanometer. The branch currents and the directions are as shown in figure.

Apply Kirchhoff's loop rule to closed loop ADBA

$$I_2R_2 - I_gG - I_1R_1 = 0 \longrightarrow \qquad (1)$$

Apply Kirchhoff's loop rule to closed loop CBDC

$$(I_2 - I_g)\, R_4 - (I_1 + I_g)R_3 - I_gG = 0 \longrightarrow \qquad (2)$$



The bridge is said to be balanced, when the galvanometer show zero deflection. (i.e. $I_g = 0$, current through the galvanometer is zero.)

$\therefore$ the equation (1) and (2) becomes

$$I_2R_2 - 0 \times G - I_1R_1 = 0$$

$$I_2R_2 - I_1R_1 = 0$$

$$I_2R_2 = I_1R_1 \longrightarrow \qquad (3)$$

$$(I_2 - 0)\, R_4 - (I_1 + 0)R_3 - 0 \times G = 0$$

$$I_2 R_4 - I_1 R_3 = 0$$

$$I_2 R_4 = I_1 R_3 \longrightarrow \qquad (4)$$

(3) / (4) gives,

$$\frac{\cancel{I_2}R_2}{\cancel{I_2}R_4} = \frac{\cancel{I_1}R_1}{\cancel{I_1}R_3}$$

$$\frac{R_2}{R_4} = \frac{R_1}{R_3}$$

$$\boxed{\frac{R_2}{R_1} = \frac{R_4}{R_3}}$$

This is the balancing condition of Wheatstone network.

PROBLEMS WITH SOLUTIONS

1.

If 6.25×10^{18} electrons flow through a given cross section in unit time, find the current. (Given : Charge of an electron is 1.6×10^{-19} C)

Data : $n = 6.25 \times 10^{18}$; $e = 1.6 \times 10^{-19}$ C ; $t = 1$ s ; $I = ?$

Solution : $I = \frac{q}{t} = \frac{ne}{t} = \frac{6.25 \times 10^{18} \times 1.6 \times 10^{-19}}{1} = 1$ A

2.

A copper wire of 10^{-6} m^2 area of cross section, carries a current of 2 A. If the number of electrons per cubic metre is 8×10^{28}, calculate the current density and average drift velocity.

(Given $e = 1.6 \times 10^{-19}$C)

Data : $A = 10^{-6}$ m^2 ; Current flowing $I = 2$ A ; $n = 8 \times 10^{28}$

$e = 1.6 \times 10^{-19}$ C ; $J = ?$; $v_d = ?$

Solution : Current density, $J = \frac{I}{A} = \frac{2}{10^{-6}} = 2 \times 10^6$ A/m^2

$J = n e v_d$

or $v_d = \frac{J}{ne} = \frac{2 \times 10^6}{8 \times 10^{28} \times 1.6 \times 10^{-19}} = 15.6 \times 10^{-5}$ m s^{-1}

3.

The resistance of a copper wire of length 5m is 0.5 Ω. If the diameter of the wire is 0.05 cm, determine its specific resistance.

Data : l = 5m ; R = 0.5 Ω ; d = 0.05 cm = 5×10^{-4} m ;

r = 2.5×10^{-4}m ; ρ = ?

Solution : $R = \frac{\rho l}{A}$ or $\rho = \frac{RA}{l}$

$A = \pi r^2 = 3.14 \times (2.5 \times 10^{-4})^2 = 1.9625 \times 10^{-7}\,m^2$

$$\rho = \frac{0.5 \times 1.9625 \times 10^{-7}}{5}$$

$\rho = 1.9625 \times 10^{-8}\ \Omega\,m$

4.

The resistance of a nichrome wire at 0°C is 10 Ω. If its temperature coefficient of resistance is 0.004/°C, find its resistance at boiling point of water. Comment on the result.

Data : At 0°C, R_o = 10 Ω ; α = 0.004/°C ; t = 100°C ;

At t°C, R_t = ?

Solution : $R_t = R_o\,(1 + \alpha t)$

$= 10\,(1 + (0.004 \times 100))$

$R_t = 14\ \Omega$

As temperature increases the resistance of wire also increases.

5.

Two wires of same material and length have resistances 5 Ω and 10 Ω respectively. Find the ratio of radii of the two wires.

Data : Resistance of first wire R_1 = 5 Ω ;

Radius of first wire = r_1

Resistance of second wire R_2 = 10 Ω

Radius of second wire = r_2

Length of the wires = l

Specific resistance of the material of the wires = ρ

Solution : $R = \frac{\rho l}{A}; A = \pi r^2$

$\therefore$ $R_1 = \frac{\rho l}{\pi r_1^{\ 2}}$; $R_2 = \frac{\rho l}{\pi r_2^{\ 2}}$

$\frac{R_2}{R_1} = \frac{r_1^2}{r_2^{\ 2}}$ or $\frac{r_1}{r_2} = \sqrt{\frac{R_2}{R_1}} = \sqrt{\frac{10}{5}} = \frac{\sqrt{2}}{1}$

$r_1 : r_2 = \sqrt{2} : 1$

6.

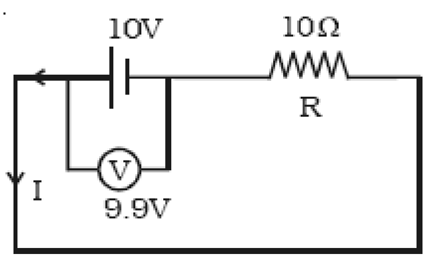
A 10 Ω resistance is connected in series with a cell of emf 10V. A voltmeter is connected in parallel to a cell, and it reads. 9.9 V. Find internal resistance of the cell.

Data : R = 10 Ω ; E = 10 V ; V = 9.9 V ; r = ?

Solution : $r = \left(\frac{E-V}{V}\right)R$

$= \left(\frac{10-9.9}{9.9}\right) \times 10$

$= 0.101\ \Omega$



7.

If a copper wire is stretched to make it 0.1% longer, what is the percentage change in resistance?

Data : Initial length of copper wire $l_1 = l$

Final length of copper wire after stretching

$l_2 = l + 0.1\%$ of l

$$= l + \frac{0.1}{100} l$$

$$= l\,(1 + 0.001)$$

$$l_2 = 1.001\ l$$

During stretching, if length increases, area of cross section decreases.

Initial volume $= A_1 l_1 = A_1 l$

Final volume $= A_2 l_2 = 1.001\ A_2 l$

Resistance of wire before stretching $= R_1$.

Resistance after stretching $= R_2$

Solution : Equating the volumes

$$A_1 l = 1.001\ A_2 l$$

(or) $A_1 = 1.001 A_2$

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

$$R_1 = \frac{\rho l_1}{A_1} \text{ and } R_2 = \frac{\rho l_2}{A_2}$$

$$R_1 = \frac{\rho l}{1.001 A_2} \text{ and } R_2 = \frac{\rho 1.001 l}{A_2}$$

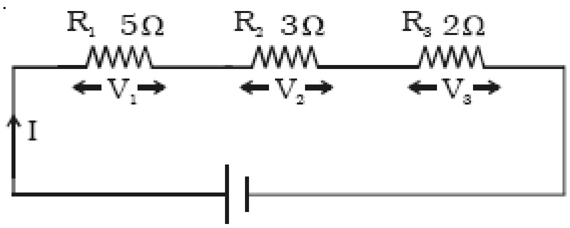
$$\frac{R_2}{R_1} = (1.001)^2 = 1.002$$

Change in resistance = (1.002 – 1) = 0.002

Change in resistance in percentage = 0.002 × 100 = 0.2%

8.

Three resistors are connected in series with 10 V supply as shown in the figure. Find the voltage drop across each resistor.



Data : $R_1 = 5\Omega$, $R_2 = 3\Omega$, $R_3 = 2\Omega$; $V = 10$ volt

Effective resistance of series combination,

$$R_s = R_1 + R_2 + R_3 = 10\Omega$$

Solution : Current in circuit $I = \frac{V}{R_s} = \frac{10}{10} = 1A$

Voltage drop across R_1, $V_1 = IR_1 = 1 \times 5 = 5V$

Voltage drop across R_2, $V_2 = IR_2 = 1 \times 3 = 3V$

Voltage drop across R_3, $V_3 = IR_3 = 1 \times 2 = 2V$

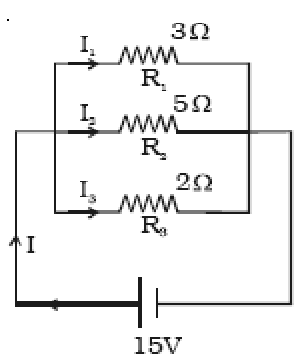
9.

Find the current flowing across three resistors 3Ω, 5Ω and 2Ω connected in parallel to a 15 V supply. Also find the effective resistance and total current drawn from the supply.

Data : $R_1 = 3\Omega$, $R_2 = 5\Omega$, $R_3 = 2\Omega$; Supply voltage $V = 15$ volt

Solution :

Effective resistance of parallel combination



$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{3} + \frac{1}{5} + \frac{1}{2}$$

$R_P = 0.9677\ \Omega$

Current through R_1, $I_1 = \frac{V}{R_1} = \frac{15}{3} = 5A$

Current through R_2, $I_2 = \frac{V}{R_2} = \frac{15}{5} = 3A$

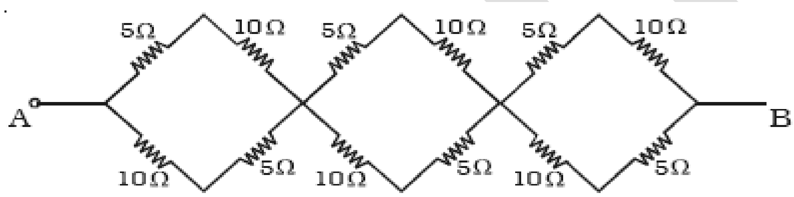
Current through R_3, $I_3 = \frac{V}{R_3} = \frac{15}{2} = 7.5A$

Total current $I = \frac{V}{R_p} = \frac{15}{0.9677} = 15.5$ A

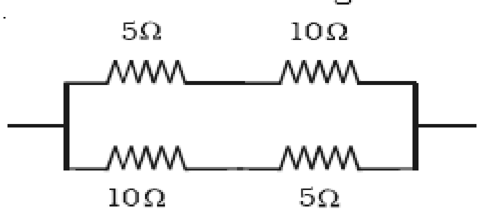
10.

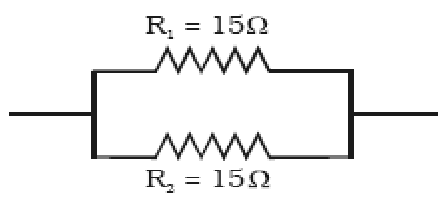
In the given network, calculate the effective resistance between points A and B

(i)



Solution : The network has three identical units. The simplified form of one unit is given below :

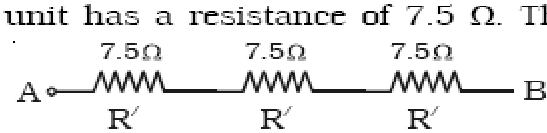




The equivalent resistance of one unit is

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{15} + \frac{1}{15} \text{ or } R_P = 7.5\ \Omega$$

Each unit has a resistance of 7.5 Ω. The total network reduces to



The combined resistance between points A and B is

$R = R' + R' + R'$ $(\because R_s = R_1 + R_2 + R_3)$

$R = 7.5 + 7.5 + 7.5 = 22.5\ \Omega$

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