CHAPTER – 3

CURRENT ELECTRICITY

"The flow of charge in a definite direction constitutes the electric current and the time rate of flow of charge through any cross-section of a conductor is the measure of current".

The electric current in measured by the 'rate of flow of charge'.

Charge flowing per second from any cross-section of the conductor is called electric current,

Current i = $\frac{Charge}{Time} = \frac{dq}{dt}$, if flow is uniform = $\frac{q}{t}$

Unit: Ampere (A)

1 ampere = 1 coulomb/second.

i.e., if 1 coulomb of charge flows per second then 1 ampere of current is said to be flowing.

Dimension: $(M^0L^0T^0A^1)$

If n electrons pass through any cross section in every t second then i = $\frac{ne}{t}$, where e = 1.6×10^{-19} coulomb.

1 ampere of current means the flow of 6.25×10^{18} electrons per second through any cross-section of the conductor

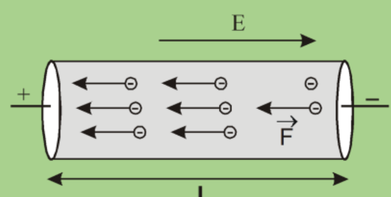
Direction of the flow of current is taken to be opposite to the direction of the flow of electrons.

Value of the current is same throughout the conductor, irrespective of the cross-section of conductor at different points.

Net charge in a current-carrying conductor is zero at any instant of time.

Note

A current-carrying conductor cannot have said to be charged, because in conductor the current is caused by electron (free electron). The no. of electron (negative charge) and proton (positive charge) in a conductor is same. Hence the net charge in a current carrying conductor is zero.



(k) Electric field outside a current carrying conductor is zero, but it is non zero inside the conductor and is given by e = $-\frac{v}{l}$

Note

The electric field inside charged conductor is zero, but it is non zero inside a current carrying conductor

Electric current is a scalar quality Although in diagrams, we represent current in a wire by an arrow but the arrow simply indicates the direction of flow of positive charges in the wire

Note

Though electric current needs direction for its representation, yet it is scalar quantity. It is because, the current can be added algebraically. Only scalar quantities can be added algebraically not the vector quantities

Did YOU KNOW?

Electricity travels at the speed of light! That is more than 186000 miles per second!

Q. How much current is present when 107 electrons per second run through a conducting wire?

Sol. Flow of electrons, $\frac{n}{t} = 10^7$/second

Therefore, current$(I) = \frac{q}{t} = \frac{ne}{t} = \frac{n}{t} \times e$

$= 10^7 \times (1.6 \times 10^{-19}) = 1.6 \times 10^{-12}$ A

Current density

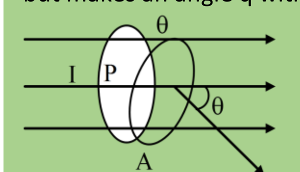
The current density at a point in a conductor is the ratio of the current at that point in the conductor to the area of cross–section of the conductor of that point.

It is denoted by j i.e., j = $\frac{i}{A}$

i = Electric current A = Area of cross-section.

Note

Area 'A' is normal to current 'I'. If A is not normal to I, but makes an angle q with the normal to current, then



$j = \frac{I}{A_{normal}} = \frac{I}{A\cos\theta}$

$\Rightarrow$ I = j A cos q = $\vec{j} \cdot \vec{A}$

$J = \dfrac{6.25}{\frac{\pi}{4} \times 2^2 \times 10^{-6}}$

≅ 2 × 106 A/m2 ≅ 200 A/cm^2

It is a VECTOR quantity Its direction is the direction of motion of the positive charges at that point.

Units: ampere / meter^2 (A/m^2)

Dimension: [$M^0L^{-2}T^0A$]

If, n = number of free electrons per unit volume of conductor.

A = cross sectional area of conductor

v_d = Drift velocity. then

I = neA v_d and J = ne v_d

Drift velocity: An applied potential difference does not give an accelerated motion to electrons but simply gives them a small constant velocity (» 10^{-4} m/s) along the length of wire towards the end at higher potential. This is called Drift velocity of the electrons.

Note

The speed of random motion of electrons is determined by temperature and is given by

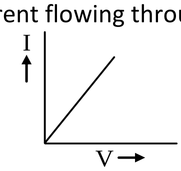
$\frac{1}{2}mv^2 = \frac{3}{2}kT \Rightarrow v = \sqrt{\frac{3kT}{m}}$

where m is mass of electron, T is absolute temp. and k is Boltzmann's constant.

(h) Electrons collide with the ions of metal while moving. The average time–interval between two successive collisions is called relaxation–time, denoted by t.
The relations between relaxation time (t) and drift velocity (v_d) are given $\vec{V}_d = -\frac{e\vec{E}\tau}{m}$

Ohm's law

If there is no change in the physical state of a conductor (Such as temperature) then the ratio of the potential difference applied at its ends and the current flowing through it is constant i.e.

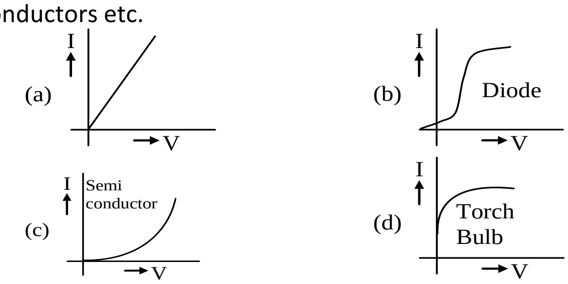


V ∝ I or V = I R;

where, R is a constant. This is called 'Electrical resistance' of the conductor.

This is true for metallic conductors only which have free electrons.

The law is not applicable for ionized gases, transistors, semi–conductors etc.



Units of resistance: ohm (Ω)

1 ohm = 1 volt / 1 ampere.

Dimensions of resistance: $[M^1L^2T^{-3}A^{-2}]$

If, L = length of conductor

R = resistance of the conductor

A = cross-sectional area of conductor perpendicular to current

Then, $R \propto L$, $R \propto \frac{1}{A}$

$\Rightarrow$ $R = \rho\frac{L}{A}$

This constant of proportionality r is called 'Resistivity' or 'Specific resistance'.

Significance of Ohm's Law:

Ohm's law is obeyed by many substances, but it is not a fundamental law of nature. It fails if

(a) V depends on I non- linearly. An example is when ρ increases with I (even if the temperature is kept fixed).

(b) The relation between V and I depend on the sign of V for the same absolute value of V.

(c) The relation between V and I is non-unique. For e.g., GaAs An example of (a) & (b) is a rectifier

When a source of emf (ε) is connected to an external resistance R, the voltage V_{ext} across R is given by

$$V_{ext} = IR = \frac{\varepsilon}{R+r}R$$

Where r is the internal resistance of the source.

Effect of stretching a wire on its resistance

If the length of wire is changed, then $\frac{R_1}{R_2} = \frac{\ell_1^2}{\ell_2^2}$

If the radius of wire is changed, then $\frac{R_1}{R_2} = \left(\frac{r_2}{r_1}\right)^4$

Units of ρ = Ohm–meter

Dimensions of $\rho = [M^1 L^3 T^{-3} A^2]$

If T = Temperature in kelvin $R = R_0 (1 + \alpha (T - T_0)$ where R_0 = Resistance at temp. T_0 and a = thermal coefficient of resistance so, as T increases $\rightarrow$ R increases.

Resistivity is also defined as the ratio of the intensity of the electric field E at any point within the conductor and the current density j at that point $\rho = \frac{E}{j}$ or $j \propto E$

Resistivity is' characteristic property of the material of the conductor. It does not depend upon length area etc. of the conductor. Although it depends on temperature. It increases with increase in temperature

Value of resistivity is least for conductors and most for insulators.

Inverse of resistivity is called conductivity of wire denoted by (σ) $\sigma = \frac{1}{\rho}$

Conductance: Inverse of resistance is known as conductance (Mho)

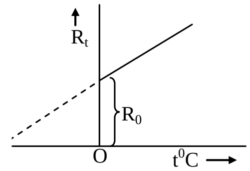
Note

(a) If a conductor is stretched to n times of its original length, it's new resistance will be n2 times the original

(b) if x% of change is brought in length of a wire, it's resistance will change by 2x%. This is true for x < 5 only.

(c) If a conductor is stretched such that it's radius is reduced to 1/nth of its original values, then resistance will increase n4 times similarly resistance will decrease n4 times if radius is increased n times by compression –

Effect of temperature on resistance:



$R_t = R_0 (1 + a Dt)$

where, R_t = Resistance at t^0 C.

R_0 = Resistance at 0^0 C

Δt = change in temperature.

a = Temperature coefficient of resistance at 0º C

= +ve for metals.

= –ve for semiconductors and insulators.

= 0 for alloys.

(b) $R_2 = R_1 [1 + a (t_2 - t_1)]$. This formula gives an approximate value.

(c) Resistance of the conductor decreases linearly with temperature and becomes zero at a specific temperature. This temperature is called critical or transition temperature, conductor becomes a super conductor at this temperature.

(d) There is no loss of energy in a circuit formed by super conductors. Current passed in loop formed by superconductor will continue flowing for infinite time if there is no resistance in the loop.

DO YOU KNOW?

Just 50mA across your heart can kill you. That's equivalent to 9V battery.

Q. A 6-volt battery is connected to the terminals of a three-meter-long wire of uniform thickness and resistance of 100 ohm. Then find the difference of potential between two points on the wire separated by a distance of 50 cm

Sol. According to given parameters in question $R = \rho\frac{l}{A} \Rightarrow 100\ \Omega = \rho\frac{3}{A} \Rightarrow \frac{\rho}{A} = \frac{100}{3}$

Thus, total resistance of 50 cm wire is $R_1 = \frac{\rho}{A}l = \frac{100}{3} \times 0.5 = \frac{50}{3}\ \Omega.$

The total current in the wire is $I = \frac{6}{100}$ A.

Therefore, potential difference across the two points on the wire separated by a distance of 50 m is

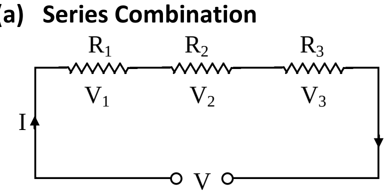
$V = IR_1 = \frac{50}{3} \times \frac{6}{100} = 1$ V

Q. A wire 50 cm long and 1 mm^2 in cross-section carries a current of 4 A when connected to a 2 V battery. Find the resistivity of the wire.

Sol. Length $(l) = 50 \text{ cm} = 0.5 \text{ m}$;
Area $(A) = 1 \text{ mm}^2 = 1 \times 10^{-6} \text{ m}^2$;
Current $(I) = 4A$ and voltage $(V) = 2$ volts.
Resistance$(R) = \frac{V}{I} = \frac{2}{4} = 0.5\ \Omega$
Resistivity$(\rho) = R \times \frac{A}{l} = 0.5 \times \frac{1\times10^{-6}}{0.5} = 1 \times 10^{-6}\ \Omega \text{ m}$

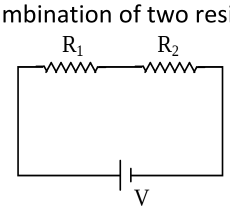
Combinations of Resistance

(a) Series Combination



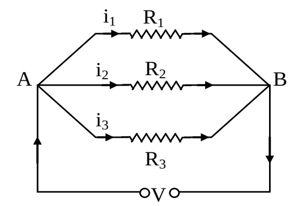
Same current passes through each resistance.
Voltage across each resistance is directly proportional to its value.
$V_1 = IR_1, V_2 = IR_2$
Sum of the voltages across resistances is equal to the voltage applied across the circuit i.e.,
$V = V_1 + V_2 + V_3 + ...$
$V = IR_1 + IR_2 + IR_3 + ...$
$\frac{V}{I} = R_1 + R_2 + R_3 + ...$
$= R$ Where, R = equivalent resistance.

For a series combination of two resistances



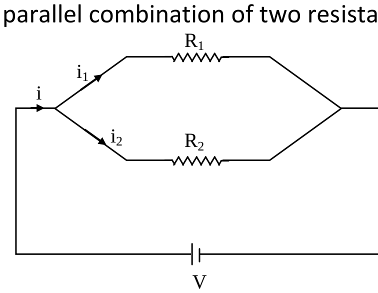
(A) equivalent resistance $R = R_1 + R_2$
(B) $I = V / (R_1 + R_2)$
(C) V_1 (voltage across R_1) $= IR_1 = \frac{R_1 V}{R_1+R_2}$
(D) V_2 (voltage across R_2) $= IR_2 = \frac{R_2 V}{R_1+R_2}$

(b) Parallel combination:



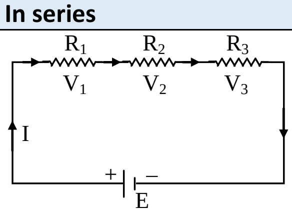
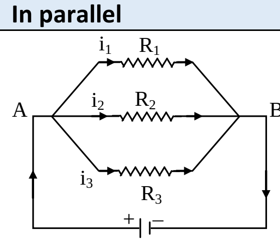
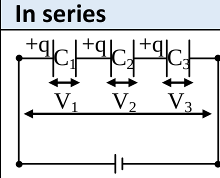
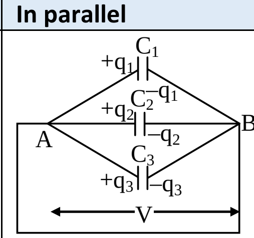
There is same drop of potential across each resistance.
Current in each resistance is inversely proportional to the value of resistance i.e.
$i_1 = \frac{V}{R_1}, i_2 = \frac{V}{R_2}, i_3 = \frac{V}{R_3}$ etc.
Current flowing in the circuit is sum of the currents in individual resistances i.e.
$i = i_1 + i_2 + i_3,$
$i = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} + ...$
$\Rightarrow \frac{i}{V} = \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ...$
where R = equivalent resistance.
The equivalent resistance of parallel combination is lower than the value of lowest resistance in the combination.

For a parallel combination of two resistances....



(i) $i = i_1 + i_2 = \frac{V(R_1+R_2)}{R_1 R_2}$

Comparative study of combination of resistor and capacitor-

Sr.No	Resistor		Capacitor	
	In series	In parallel	In series	In parallel
(i) (ii) (iii) (iv) (v) (vi)	 $R = R_1 + R_2 + R_3$ $V = V_1 + V_2 + V_3$ Current is same in all the resistances If n resistances,	 $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ $V_1 = V_2 = V_3 = V$ Currents through different but p.d. across	 $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$ $V = V_1 + V_2 + V_3$ Charge is equal in all capacitors If n cap. is in series then C' = C/n	 $C = C_1 + C_2 + C_3$ $V_1 = V_2 = V$ Different capacitor diff. charge.

	each of value R are connected in series then R' = nR Effective resistance is greater than the highest resistance in the combination	all of them is the same If n resistances each of value R are connected in parallel, then R' = R/n Effective resistance is less than the smallest resistance in the combination	Effective capacitance is less than smallest capacitor in the combination	If n capacitor is connected in parallel C' = nC Effective capacitance is greater than the largest capacitor in the combination

Kirchhoff law

Kirchhoff in 1842 gave two laws for solving complicated electrical circuits. These laws are as follows–

(a) First law:

In an electrical circuit, the algebraic sum of the current meeting at any junction in the circuit is zero.

OR

Sum of the currents entering the junction is equal to sum of the currents leaving the junction

Si = 0

$i_1 - i_2 - i_3 - i_4 + i_5 = 0$

or $i_1 + i_5 = i_2 + i_3 + i_4$

Note

This law is based on law of conservation of charge. In other words, when a steady current flows in a circuit then there is neither accumulation of charge at point in the circuit nor any charge is removed from there.

(b) Second law: In a 'closed' mesh of a circuit the algebraic sum of the products of the current and the resistance in each part of the mesh is equal to the algebraic sum of the e.m.f.'s in that mesh. i.e.

SiR = SE

In applying this law, when we traverse in the direction of current then the product of the current and the corresponding resistance is taken as positive, and the emf is taken as positive when we traverse from the negative to the positive electrode of the cell through the electrolyte.

This law is based on 'law of conservation of energy'.

Electric Cell

(a) Electro Motive Force (EMF): The potential difference across the terminals of a cell when it is not giving any current is called EMF of the cell.

or

The energy given by the cell in the flow of unit charge in the whole circuit (including the cell) is called the EMF of the cell.

$$E = \frac{W}{Q}$$

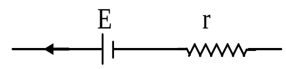
(b) Terminal voltage:

(i) The resistance offered by the electrolyte of the cell to the flow of current through it is called internal resistance of the cell.

(ii) When current is drawn through the cell or current is supplied to cell then, the potential difference across its terminals is called terminal voltage.

(iii) When i current is drawn from cell, then terminal voltage is less than it's emf E.

V = E – i r

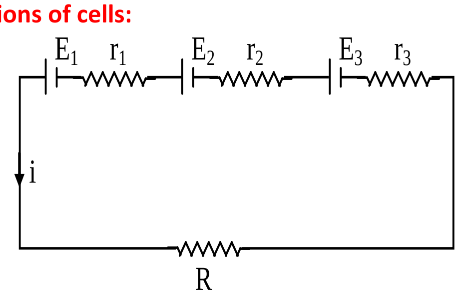


Where V = terminal voltage, r = internal resistance of battery

(iv) When current is supplied to the cell, the terminal voltage is greater than the emf E i.e., V = E + i r

(v) Units of both emf and terminal voltage are volt.

Combinations of cells:



(a) Series Combination:

Equivalent emf $E = E_1 + E_2 + E_3$ ....

Direction of emf is taken into consideration.

Equivalent internal resistance r is given by

$r = r_1 + r_2 + r_3$ ....

Current, $i = \frac{E}{r+R} = \frac{\Sigma E_i}{\Sigma r_i + R}$

For maximum current, R = Sr

i.e. The load resistance must be equal to the equivalent internal resistance.

If all emf are equal (E), then for series combinations of n such cells, $I = \frac{nE}{R+nr}$

Cases: (a) if nr >> R, $I = \frac{E}{r}$

(b) If nr << R, $I = \frac{nE}{R}$

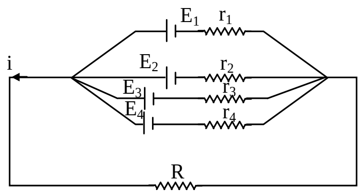
(c) Cells are employed in series only when internal resistance is less than the load resistance.

(b) Parallel Combination:

Equivalent internal resistance,

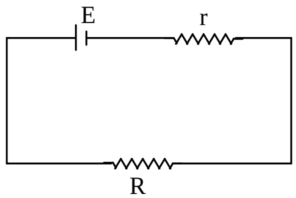
r is $\frac{1}{r} + \frac{1}{r_2} + \frac{1}{r_2} +$.......

Equivalent emf



$$E=\frac{\frac{E_1}{r_1}+\frac{E_2}{r_2}+\frac{E_3}{r_3}+........}{\frac{1}{r_1}+\frac{1}{r_2}+\frac{1}{r_3}+........}=\frac{\Sigma\frac{E_i}{r_i}}{\Sigma\frac{1}{r_i}}$$

Current, $i=\frac{E}{R+r}$



When all 'n' cells with emf E and internal resistance r each, are connected in parallel,

then equivalent emf = E,

equivalent internal resistance = $\frac{r}{n}$

In this (5) case $I=\frac{E}{R+\frac{r}{n}}=\frac{nE}{nR+r}$

Cases:

(a) If r << nR, $I=\frac{E}{R}$

(b) If r >> nR, $I=\frac{nE}{r}$

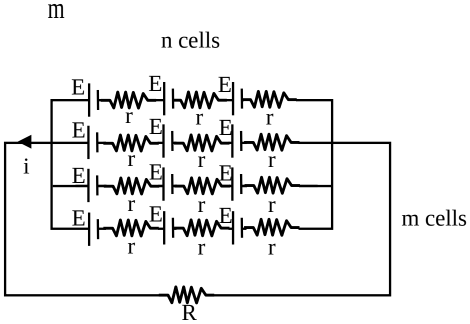
(c) This combination is used only when load resistance is lower than internal resistance.

(c) Mixed combination:

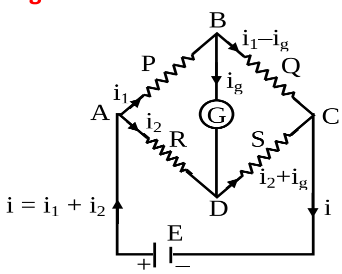
$i=\frac{mnE}{mR+nr}$, For maximum current

Internal resistance = External resistance

i.e. $R=\frac{nr}{m}$



Wheat-stone bridge



The configuration in the adjacent figure is called wheat stone bridge.

If $i_g = 0$ i.e., current in galvanometer is zero, then bridge is said to be balanced.

For $i_g = 0$ (i) $V_D = V_B$ (ii) $\frac{P}{Q}=\frac{R}{S}$

Equivalent resistance in balanced condition

$=\frac{(P+Q)(R+S)}{P+Q+R+S}$

If $\frac{P}{Q}<\frac{R}{S}$ then $V_B > V_D$ and current will flow from B to D.

If $\frac{P}{Q}>\frac{R}{S}$, the $V_B < V_D$ and current will flow from D to B.

Meter bridge and post office box work on this principle.

Electric energy and power

Electric energy:

When a potential difference is applied across a wire, current starts flowing in it. The free electrons collide with the positive ions of the metal and lose energy. Thus, energy taken from the battery is dissipated. The battery constantly provide energy to continue the motion of electron and hence electric current in the circuit. This energy is given to ions of the metal during collision and thus temperature of wire rises. Thus, energy taken from the battery gets transferred in to heat. This energy is called electrical energy. This effect is also called 'Heating Effect of Current'.

R = Resistance of wire

I = Current in wire

V = Potential difference across wire.

Flow of charge in 'dt' time = Idt.

Energy dissipated dW = Vdq = VIdt,

Q V = IR,

$dW = VIdt = I^2Rdt = \frac{V^2}{R}dt = Vdq$ this energy is equal to work done by battery or heat produced in the wire.

If energy is to be written in calorie–

Then $dW=\frac{dW}{4.2}$ cal = 24 dW cal

When dW is energy in Joules.

Electrical power:

The rate of loss of energy in an electrical circuit is called electrical power. It is denoted by 'P'

$P=\frac{dW}{dt}=I^2R=IV=\frac{V^2}{R}$

units of power = joule/sec, watt, horse power

1 watt = 1 joule/sec, 1 HP = 746 watt

unit of electrical energy = watt second, kilowatt hour

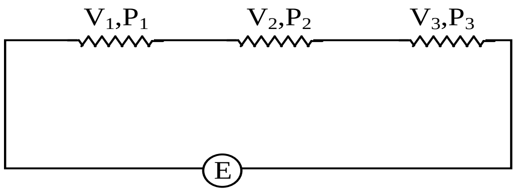
1 kilowatt hour (kwh) = 36×10^5 Joule

Combination of electrical instruments–

If 220V and 40W is written on an electrical instrument then this is called its standard Ratings. It means that if 220V is applied across this instrument then 40W of power will be generated.

Thus, the resistance will be given by $R=\frac{V^2}{P}=\frac{(220)}{40}ohm$

Series combination



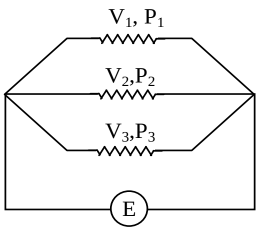
If total power dissipated if P,

then, $\frac{1}{P} = \frac{1}{P_1} + \frac{1}{P_2} + \frac{1}{P_3}$,

Where P'_1 are standard powers of instrument

In this combination, the bulb with least power will glow most and bulb with highest power will glow least or we can say that bulb with highest R will glow brightest and bulb with least R will glow least.

Parallel combination



Net power dissipation P = $P_1 + P_2 + P_3$

Bulb with least power will glow least or the bulb in which maximum current is flowing will glow brightest and vice–versa.

Note

(a) These formulae are applicable only if the voltage ratings of all the instruments are equal along with the power source. If voltage ratings are different then circuit is solved by considering equivalent resistances of the instruments as follows

(b) Replace the instrument by its's equivalent resistance. If standard rating is (V/P) then its resistance is

$R = V^2/P$

(c) Find the currents and voltages in different branches using Kirchhoff's first and second laws.

(a) If rating of a bulb is changed from V_1/P_1 to V_2/P_2 then

$\frac{V_1^2}{P_1} = \frac{V_2^2}{P_2} = R$ or $P_2 = \frac{V_2^2}{V_1^2} P_1$

Q. Two cities are 150 km apart. Electric power is sent from one city to another city through copper wires. The fall of potential per km is 8 volt and the average resistance per km is 0.5 Ω. Find the power loss in the wire.

Sol. Here,

Distance between two cities = 150 km

Resistance of the wire,

$R = (0.5\ \Omega\ \text{km}^{-1})(150\ \text{km}) = 75\ \Omega$

Voltage drops across the wire,

$V = (8\ \text{V km}^{-1})(150\ \text{km}) = 1200\ \text{V}$

Power loss in the wire is

$P = \frac{V^2}{R} = \frac{(1200\ V)^2}{75\ \Omega} = 19200\ \text{W} = 19.2\ \text{kW}$

Q. A 4 μF capacitor is charged to 400 V. If its plates are joined through a resistance of 2 kΩ, then find the amount of heat produced in the resistance.

Sol. Capacitance $(C) = 4\ \mu\text{F} = 4 \times 10^{-6}$ F; Voltage (V) = 400 volts and resistance $(R) = 2\ \text{k}\Omega = 2 \times 10^3\ \Omega$

Heat produced = Electrical energy stored = $\frac{1}{2}CV^2$

$= \frac{1}{2} \times (4 \times 10^{-6}) \times (400)^2 = 0.32$ J.

SUMMARY

- **Electrical Conductivity:**
  It is the inverse of specific resistance for a conductor whereas the specific resistance is the resistance of unit cube of the material of the conductor.

$$\sigma = \frac{1}{\rho} = \frac{ne^2\tau}{m}$$

  Where σ is the conductivity and ρ is resistivity.
- **SI Unit of Conductivity:**
  The SI unit of conductivity is mho m^{-1}.
- **Current through a given area of a conductor:**
  It is the net charge passing per unit time through the area.
- **Current Density Vector:**
  The current density vector $\vec{j}$ gives current per unit area flowing through area ΔA when it is held normal to the direction of charge flow. Note that the direction of $\vec{j}$ is in the direction of current flow.
- **Current Density:**
  Current density j gives the amount of charge flowing per second per unit area normal to the flow.
  $J = nqV_q$
  where n is the number density (number per unit volume) of charge carriers each of charge q and vd is the drift velocity of the charge carriers. For electrons q = –e. If j is normal to a cross – sectional area A and is constant over the area, the magnitude of the current I through the area is d neV_dA.
- **Mobility:**
  Mobility **μ** is defined to be the magnitude of drift velocity per unit electric field.
  $\mu = \left(\frac{V_d}{E}\right)$
  Now, $V_d = \frac{q\tau E}{m_q}$
  where q is the electric charge of the current carrier and mq is its mass.

$$\therefore \mu = \left(\frac{q_\tau}{m_q}\right)$$

  Thus, mobility is a measure of response of a charge carrier to a given external electric field.
- **Resistivity:**
  Resistivity ρ is defined to be reciprocal of conductivity.

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

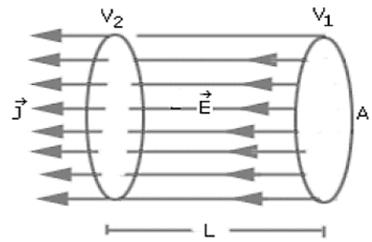
  It is measured in ohm-metre (Qm).
- **Resistivity as a function of temperature:**
  It is given as,

$$\rho_T = \rho_0 [1 + \alpha(T - T_0)]$$

  Where α is the temperature coefficient of resistivity and ρ_T is the resistivity of the material at temperature T.
- **Ranges of Resistivity:**
  (a) Metals have low resistivity: Range of ρ varies from 10^{-8} Ω m to 10^{-6} Ω m.
  (b) Insulators like glass and rubber have high resistivity: Range of ρ varies from 10^{22} to 10^{24} times greater than that of metals.
  (c) Semiconductors like Si and Ge lie roughly in the middle range of resistivity on a logarithmic scale.
- **Total resistance in Series and in Parallel**
  (a) Total resistance R of n resistors connected in series is given by R = R1 + R2 + … + Rn
  (b) Total resistance R of n resistors connected in parallel is given by

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

- If the mass of a charge carrier is large, then for a given field $\vec{E}$, its acceleration will be small and will contribute very little to the electric current.
- **Electrical Conductivity:**
  When a conducting substance is brought under the influence of an electric field $\vec{E}$, free charges (e.g. free electrons in metals) move under the influence of this field in such a manner, that the current density $\vec{j}$ due to their motion is proportional to the applied electric field.
  $\vec{j} = \sigma \vec{E}$



  where σ is a constant of proportionality called electrical conductivity. This statement is one possible form of Ohm's law.
- Consider a cylindrical material with cross sectional area A and length L through which a current is passing along the length and normal to the area A, then, since $\vec{j}$ and $\vec{E}$ are in the same direction,

$$J = \sigma E$$
$$JAL = \sigma ELA$$

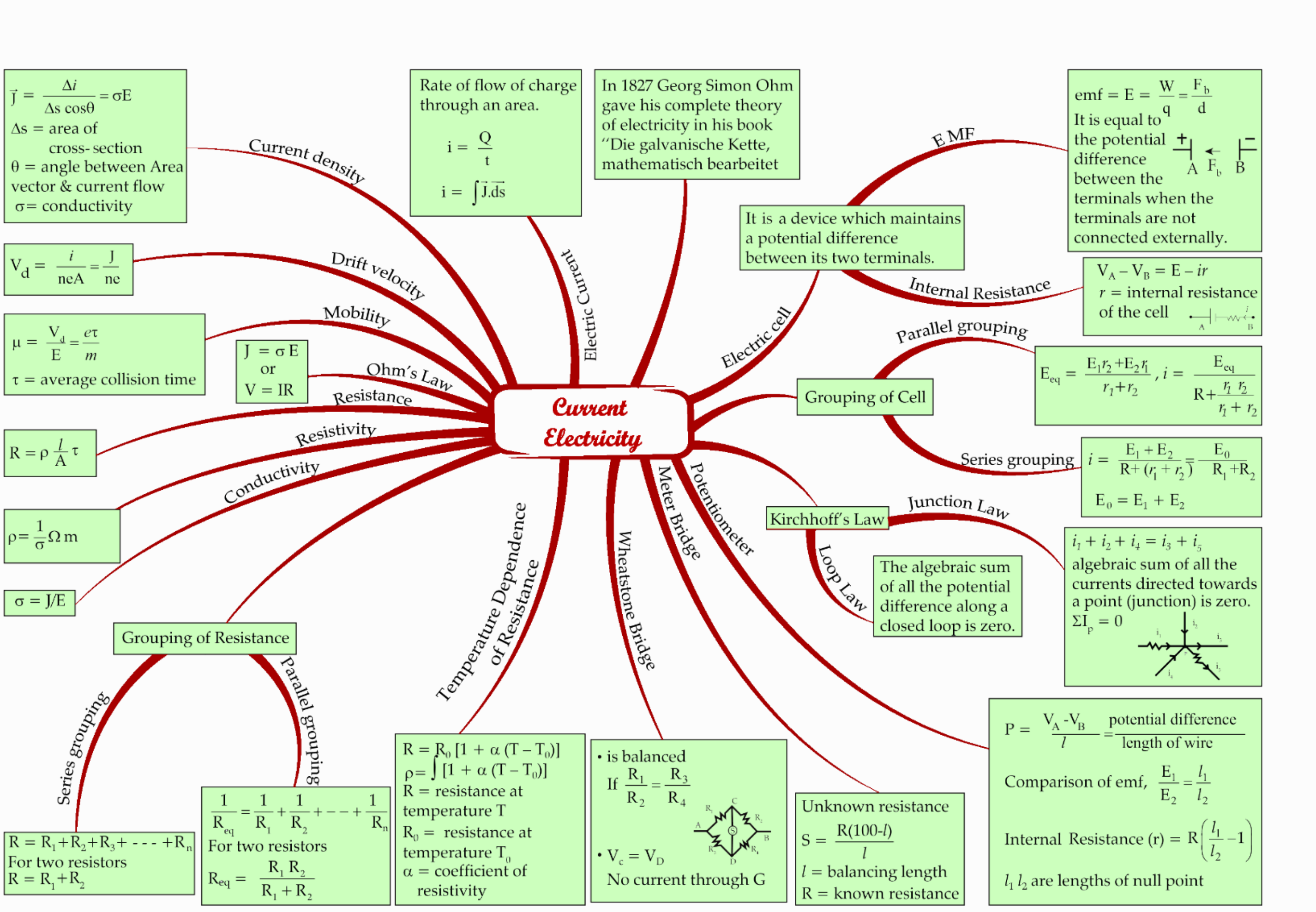
  Where A is cross sectional area and L is length of the material through which a current is passing along the length, normal to the area A. But, JA = I, the current through the area A and EL = V_1 - V_2, the potential difference across the ends of the cylinder denoting V_1-V_2 as V,

$$V = \frac{IL}{\sigma A} = RI$$

  Where $R = \frac{L}{\sigma A}$ is called resistance of the material. In this form, Ohm's law can be stated as a linear relationship between the potential drop across a substance and the current passing through it.
- **Measuring resistance:**
  R is measured in ohm ((Ω)), where $1\Omega = \frac{1V}{A}$

- **EMF:**
  Emf (Electromotive force) is the name given to a non-electrostatic agency. Typically, it is a battery, in which a chemical process achieves this task of doing work in driving the positive charge from a low potential to a high potential. The effect of such a source is measured in terms of work done per unit charge in moving a charge once around the circuit. This is denoted by $\in$.
- **Kirchhoff's First Rule:**
  At any junction of several circuit elements, the sum of currents entering the junction must equal the sum of currents leaving it.
  In the above junction, current I enters it and currents I_1 and I_2 leave it. Then,
  $$I = I_1 + I_2$$
  This is a consequence of charge conservation and assumption that currents are steady, that is no charge piles up at the junction.
- **Kirchhoff's Second Rule:**
  The algebraic sum of changes in potential around any closed resistor loop must be zero. This is based on the principle that electrostatic forces alone cannot do any work in a closed loop, since this work is equal to potential difference, which is zero, if we start at one point of the loop and come back to it.
- **Wheatstone Bridge:**
  Wheatstone bridge is an arrangement of four resistances R_1, R_2, R_3, R_4. The null point condition is given by,
  $$\therefore \frac{R_1}{R_2} = \frac{R_3}{R_4}$$
  This is also known as the balanced condition. If R_1, R_2, R_3 are known, R_4 can be determined.
  $$R_4 = \left(\frac{R_2}{R_1}\right) R_3$$
- In a balanced condition of the meter bridge,
  $$\frac{R}{S} = \frac{P}{Q} = \frac{\sigma l_1}{100-l_1}$$
  $$\therefore R = \frac{S l_1}{(100-l_1)}$$
  Where σ is the resistance per unit length of wire and l_1 is the length of wire from one end where null point is obtained.
- **Potentiometer:**
  The potentiometer is a device to compare potential differences. Since the method involves a condition of no current flow, the device can be used to measure potential differences; internal resistance of a cell and compare emf's of two sources.
- **Potential Gradient:**
  The potential gradient of the wire in a potentiometer depends on the current in the wire.
- If an emf $\in_1$ is balanced against length l_1, then $\in = \rho l_1$
  Similarly, if $\in_2$ is balanced against l_2, then $\in_2 = \rho l_2$
  The comparison of emf's of the two cells is given by,
  $$\therefore \frac{\in_1}{\in_2} = \frac{l_1}{l_2}$$

MIND MAP


Current Electricity
Current density
$\vec{j} = \frac{\Delta i}{\Delta s \cos\theta} = \sigma E$
Δs = area of cross-section
θ = angle between Area vector & current flow
σ = conductivity
Drift velocity
$V_d = \frac{i}{neA} = \frac{J}{ne}$
Mobility
$\mu = \frac{V_d}{E} = \frac{e\tau}{m}$
τ = average collision time
Ohm's Law
$J = \sigma E$ or $V = IR$
Resistance
$R = \rho \frac{l}{A} \tau$
Resistivity
$\rho = \frac{1}{\sigma} \Omega m$
Conductivity
$\sigma = J/E$
Grouping of Resistance
Series grouping
$R = R_1 + R_2 + R_3 + \text{- - -} + R_n$
For two resistors
$R = R_1 + R_2$
Parallel grouping
$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \text{- - -} + \frac{1}{R_n}$
For two resistors
$R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$
Electric Current
Rate of flow of charge through an area.
$i = \frac{Q}{t}$
$i = \int \vec{J}.\vec{ds}$
In 1827 Georg Simon Ohm gave his complete theory of electricity in his book "Die galvanische Kette, mathematisch bearbeitet
Temperature Dependence of Resistance
$R = R_0 [1 + \alpha (T - T_0)]$
$\rho = \int [1 + \alpha (T - T_0)]$
R = resistance at temperature T
R_0 = resistance at temperature T_0
α = coefficient of resistivity
Wheatstone Bridge
• is balanced
If $\frac{R_1}{R_2} = \frac{R_3}{R_4}$
• $V_c = V_D$
No current through G
Meter Bridge
Unknown resistance
$S = \frac{R(100-l)}{l}$
l = balancing length
R = known resistance
Potentiometer
$P = \frac{V_A - V_B}{l} = \frac{\text{potential difference}}{\text{length of wire}}$
Comparison of emf, $\frac{E_1}{E_2} = \frac{l_1}{l_2}$
Internal Resistance (r) = $R\left(\frac{l_1}{l_2} - 1\right)$
$l_1\ l_2$ are lengths of null point
Electric cell
It is a device which maintains a potential difference between its two terminals.
E MF
emf = $E = \frac{W}{q} = \frac{F_b}{d}$
It is equal to the potential difference between the terminals when the terminals are not connected externally.
A F_b B
Internal Resistance
$V_A - V_B = E - ir$
r = internal resistance of the cell
Grouping of Cell
Parallel grouping
$E_{eq} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$, $i = \frac{E_{eq}}{R + \frac{r_1 r_2}{r_1 + r_2}}$
Series grouping
$i = \frac{E_1 + E_2}{R + (r_1 + r_2)} = \frac{E_0}{R_1 + R_2}$
$E_0 = E_1 + E_2$
Kirchhoff's Law
Junction Law
$i_1 + i_2 + i_4 = i_3 + i_5$
algebraic sum of all the currents directed towards a point (junction) is zero.
$\Sigma I_p = 0$
Loop Law
The algebraic sum of all the potential difference along a closed loop is zero.

PRACTICE EXERCISE

MCQ

Q1. When 5V potential difference is applied across a wire of length 0.1 m, the drift speed of electrons is 2.5×10^{-4} ms^{-1}. If the electron density in the wire is 8×10^{28} m^{-3}, the resistivity of the material is close to:

(a) $1.6 \times 10^{-6}\,\Omega m$ (b) $1.6 \times 10^{-5}\,\Omega m$
(c) $1.6 \times 10^{-8}\,\Omega m$ (d) $1.6 \times 10^{-7}\,\Omega m$

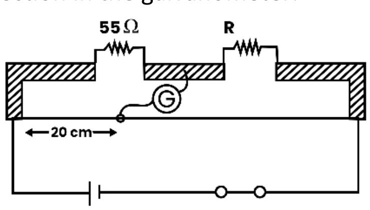
Q2. The length of a wire of a potentiometer is 100 cm, and the e.m.f. of its standard cell is E volt. It is employed to measure the e.m.f. of a battery whose internal resistance is 0.5Ω. If the balance point is obtained at ℓ = 30 cm from the positive end, the e.m.f. of the battery is

(a) $\frac{30E}{100.5}$ (b) $\frac{30E}{(100-0.5)}$
(c) $\frac{30(E-0.5i)}{100}$ (d) $\frac{30E}{100}$

Q3. n equal resistors are first connected in series and then connected in parallel. What is the ratio of the maximum to the minimum resistance?

(a) n (b) $1/n^2$
(c) n^2 (d) 1/n

Q4. Shown in the figure below is a meter-bridge set up with null deflection in the galvanometer.



The value of the unknown resistor *R* is

(a) 13.75Ω (b) 220Ω
(c) 110Ω (d) 55Ω

Q5. In the equation AB = C, A is the current density, C is the electric field, Then B is

(a) resistivity (b) conductivity
(c) potential difference (d) resistance

Q6. You are given a resistance coil and battery. In which of the following cases the largest amount of heat generated?

(a) When the coil is connected to the battery directly
(b) When the coil is divided into two equal parts and both the parts are connected to the battery in parallel
(c) When the coil id divided into four equal parts and all the four parts are connected to the battery in parallel
(d) When only half the coil is connected to the battery

Q7. On increasing the temperature of a conductor, its resistance increases because the

(a) relaxation time increases
(b) mass of electron increases
(c) electron density decreases
(d) relaxation time decreases

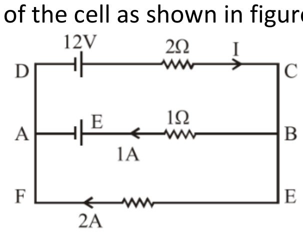
Q8. An electric current is passed through a circuit containing two wires of the same material, connected in parallel. If the lengths and radii are in the ratio of $\frac{4}{2}$ and $\frac{2}{3}$, then the ratio of the current passing through the wires will be

(a) 8/9 (b) 1/3
(c) 3 (d) 2

Q9. In a meter bridge experiment null point is obtained at 20 cm. from one end of the wire when resistance, *X* is balanced against another resistance *Y*. If *X* < *Y*, then where will be the new position of the null point from the same end, if one decides to balance a resistance of 4 *X* against *Y*

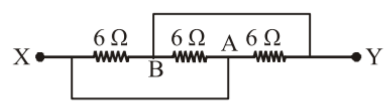
(a) 40 cm (b) 80 cm
(c) 50 cm (d) 70 cm

Q10. Find emf E of the cell as shown in figure.



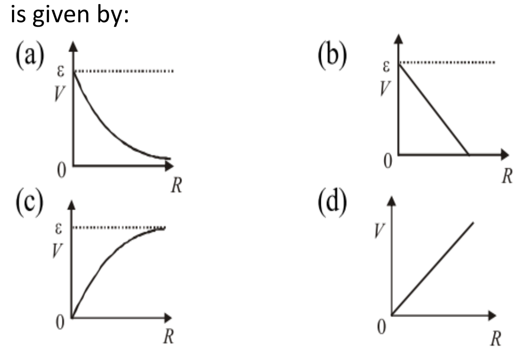
(a) 15V (b) 10V
(c) 12V (d) 5V

Q11. In a given network, each resistance has value of 6Ω. The point X is connected to point A by a copper wire of negligible resistance and point Y is connected to point B by the same wire. The effective resistance between X and Y will be



(a) 18 Ω (b) 6 Ω
(c) 3 Ω (d) 2 Ω

Q12. Cell having an emf ε 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:



Q13. If voltage across a bulb rated 220 Volt-100 Watt drops by 2.5% of its rated value, the percentage of the rated value by which the power would decrease is:

(a) 20% (b) 2.5%
(c) 5% (d) 10%

Q14. Two resistance R_1 and R_2 are made of different materials. The temperature coefficient of the material of R_1 is α and that of material of R_2 is – β. The resistance of the series combination of R1 and R_2 will not change with temperature if $\frac{R_1}{R_2}$ equal to

(a) $\frac{\alpha}{\beta}$ (b) $\frac{\alpha+\beta}{\alpha-\beta}$

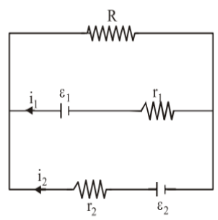
(c) $\frac{\alpha^2+\beta^2}{2\alpha\beta}$ (d) $\frac{\beta}{\alpha}$

Q15. Potentiometer wire of length 1 m is connected in series with 490Ω resistance and 2 V battery. If 0.2 mV/cm is the potential gradient, then resistance of the potentiometer wire is

(a) 4.9Ω (b) 7.9Ω

(c) 6.9Ω (d) 6.9Ω

Q16. See the electric circuit shown in the figure Which of the following equations is a correct equation for it?



(a) $\varepsilon_2 - i_2 r_2 - \varepsilon_1 - i_1 r_1 = 0$

(b) $-\varepsilon_2 - (i_1 + i_2)R + i_2 r_2 = 0$

(c) $\varepsilon_1 - (i_1 + i_2)R + i_1 r_1 = 0$

(d) $\varepsilon_1 - (i_1 + i_2)R - i_1 r_1 = 0$

Q17. If an ammeter is to be used in place of a voltmeter, then we must connect with the ammeter a

(a) low resistance in parallel

(b) high resistance in parallel

(c) high resistance in series

(d) low resistance in series.

Q18. A d.c. main supply of e.m.f. 220 V is connected across a storage battery of e.m.f. 200 V through a resistance of 1Ω. The battery terminals are connected to an external resistance 'R'. The minimum value of 'R', so that a current passes through the battery to charge it is:

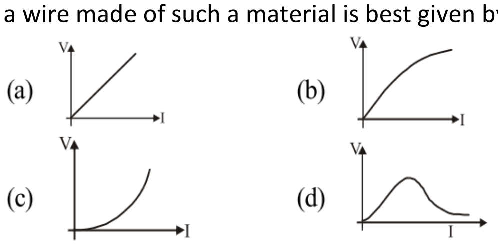
(a) 7Ω

(b) 9Ω

(c) 11Ω

(d) zero

Q19. Suppose the drift velocity v_d in a material varied with the applied electric field E as $v_d \propto \sqrt{E}$. Then V – I graph for a wire made of such a material is best given by:



Q20. An energy source will supply a constant current into the load if its internal resistance is

(a) very large as compared to the load resistance

(b) equal to the resistance of the load

(c) non-zero but less than the resistance of the load

(d) zero

Q21. A potentiometer is an accurate and versatile device to make electrical measurement 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 resistance

(d) cells

Q22. Which of the following characteristics of electrons determines the current in a conductor?

(a) Drift velocity alone

(b) Thermal velocity alone

(c) Both drift velocity and thermal velocity

(d) Neither drift nor thermal velocity

Q23. Temperature dependence of resistivity ρ(T) of semiconductors insulators and metals is significantly based on the following factors

(a) Number of charge carriers can change with temperature T.

(b) Time interval between two successive collisions can depend on T.

(c) Length of material can be a function of T.

(d) Option (a) and (b)

Q24. Kirchhoff's junction rule is a reflection of

(a) conservation of current density vector.

(b) conservation of charge and the fact that there is no accumulation of charged at a junction.

(c) the fact that the momentum with which a charged particle approaches a junction is unchanged (as a vector) as the charged particle leaves the junction.

(d) none of the above

Q25. What is the order of magnitude of the resistance of a dry human body?

(a) 10 Ω

(b) 10^4 Ω

(c) 10 MΩ

(d) 10 μΩ

ASSERTION AND REASONING

Directions: These questions consist of two statements, each printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following four responses.

(a) If both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) If the Assertion is correct but Reason is incorrect.

(d) If both the Assertion and Reason are incorrect.

Q1. Assertion: A larger dry cell has higher emf.
Reason: The emf of a dry cell is proportional to its size.

Q2. Assertion: A current continues to flow in superconducting coil even after switch is off.

Reason: Superconducting coils show Meissner effect.

Q3. Assertion: Voltmeter is connected in parallel with the circuit.
Reason: Resistance of a voltmeter is very large.

Q4. Assertion: Ohm's law is applicable for all conducting elements.
Reason: Ohm's law is a fundamental law.

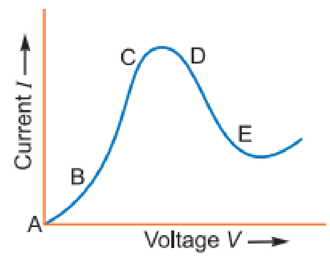
Q5. Assertion: An electric bulb becomes dim, when the electric heater in parallel circuit is switched on.
Reason: Dimness decreases after sometime.

VERY SHORT ANSWER QUESTIONS

Q1. Define electrical conductivity of a conductor and give its SI unit. On what factors does it depend?

Q2. Plot a graph showing variation of current versus voltage for the material GaAs.

Q3. 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 law is obeyed.

Q4. The emf of a cell is always greater than its terminal voltage. Why? Give reason.

Q5. Two materials Si and Cu, are cooled from 300 K to 60 K. What will be the effect on their resistivity?

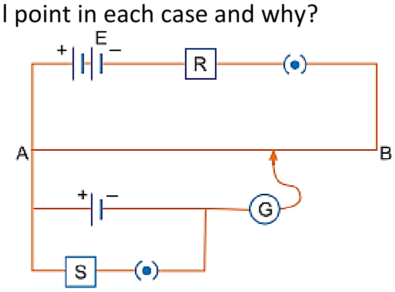
SHORT ANSWER QUESTIONS

Q1. Define the terms (i) drift velocity, (ii) relaxation time.

Q2. (a) You are required to select a carbon resistor of resistance 47 kΩ ± 10% from a large collection. What should be the sequence of color bands used to code it?
(b) Write the characteristics of manganin which make it suitable for making standard resistance.

Q3. Answer the following:
(a) Why are the connections between the resistors in a meter bridge made of thick copper strips?
(b) Why is it generally preferred to obtain the balance point in the middle of the meter bridge wire?
(c) Which material is used for the meter bridge wire and why?

Q4. Two students X and Y perform an experiment on potentiometer separately using the circuit diagram shown here. Keeping other things unchanged.
(i) X increases the value of resistance R.
(ii) (ii) Y decreases the value of resistance S in the set up. How would these changes affect the position of the null point in each case and why?



Q5. Show, on a plot, variation of resistivity of (i) a conductor, and (ii) a typical semiconductor as a function of temperature. Using the expression for the resistivity in terms of number density and relaxation time between the collisions, explain how resistivity in the case of a conductor increases while it decreases in a semiconductor, with the rise of temperature.

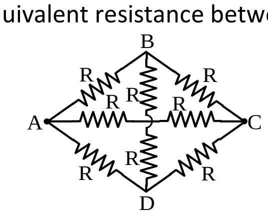
LONG ANSWER QUESTIONS

Q1. Draw a circuit diagram showing balancing of Wheatstone bridge. Use Kirchhoff's rules to obtain the balance condition in terms of the resistances of four arms of Wheatstone Bridge.

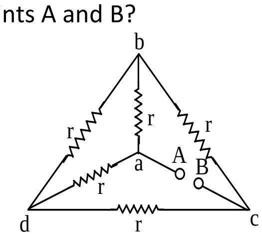
Q2. Using the principle of Wheatstone Bridge, describe the method to determine the specific resistance of a wire in the laboratory. Draw the circuit diagram and write the formula used. Write any two important precautions you would observe while performing the experiment.

NUMERICAL TYPE QUESTIONS

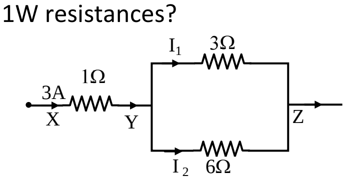
Q1. Find the equivalent resistance between A and C.



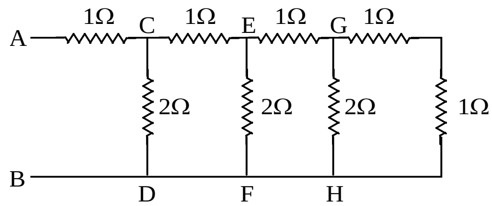
Q2. In the adjoining network of resistors, each is of resistance r ohm, then what will be the equivalent resistance between points A and B?



Q3. observe the following fig. ans find the ratio of current in 3W and 1W resistances?

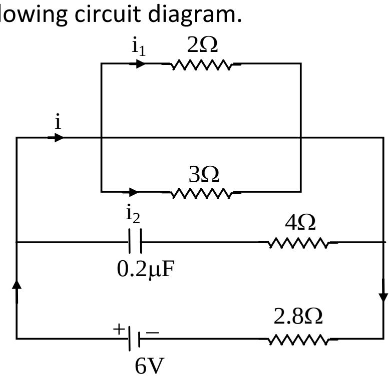


Q4. Determine the resultant resistance between the points A and B in the following diagram.

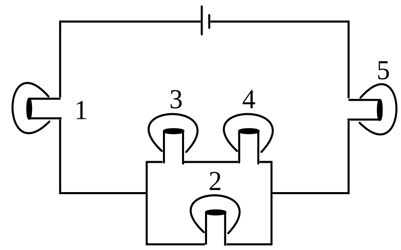


Q5. A galvanometer together with an unknown resistance in series is connected across two identical batteries of each 1.5 V. When the batteries are connected in series, the galvanometer records a current of 1 A and when the batteries are connected in parallel, the current is 0.6 A. Find the internal resistance of the battery.

Q6. What is the value of steady current in 2W resistance in the following circuit diagram.



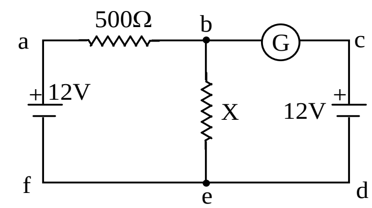
Q7. In the fig below the bulbs are identical, which bulb(s), light(s) most brightly?



Q8. A heating–coil of 2000 watt is immersed in an electric kettle. Find the time taken in raising the temperature of 1 liter of water from 4°C to 100°C. (Only 80% part of the thermal energy produced is used in raising the temperature of water.)

Q9. A 10 m long nichrome wire having 80W resistance, has current carrying capacity of 5 A. What is the power which can be obtained as heat by the wire from a 200 V mains supply? If the wires are cut in two equal parts and connected in such a way that it gives maximum power. What is the arrangement to obtain maximum power?

Q10. In a circuit shown, the galvanometer G reads zero. If batteries have negligible internal resistances, find the value of resistance X.



HOMEWORK QUESTIONS

MCQ

Q1. The rate of flow of electric charge through any cross-section of a conductor is known as __________.
(a) Electric flux (b) Electric potential
(c) Electric current (d) Electric field

Q2. Mobility is denoted by __________.
(a) μ (b) σ
(c) ρ (d) γ

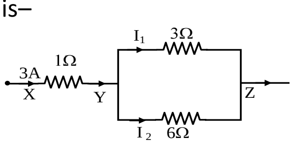
Q3. Which of the following is non-ohmic resistance?
(a) Lamp filament (b) Copper wire
(c) Carbon resistor (d) Diode

Q4. Current density is a __________.
(a) scalar quantity. (b) vector quantity.
(c) dimensionless quantity. (d) none of these options

Q5. The opposition offered by the electrolyte of the cell to the flow of current through itself is known as __________.
(a) External resistance (b) Internal resistance
(c) Non-resistance (d) None of these options

Q6. The resistivity of certain metals or alloys drops to zero when they are cooled below a certain temperature, this phenomenon is known as __________.
(a) Conductivity (b) Partial conductivity
(c) Superconductivity (d) non-conductivity

Q7. In the following fig. the ratio of current in 3W and 1W resistances is–



(a) $\frac{1}{3}$ (b) $\frac{2}{3}$ (c) 1 (d) 2

Q8. A 220 volt 100-watt bulb is connected to a 110-volt source. The power consume by the bulb will be –
(a) 25 W (b) 20 W
(C) 484 W (d) 120 W

Q9. According to Ohm's law
(a) V is directly proportional to I
(b) V is inversely proportional to I
(c) V is directly proportional to R
(d) V is inversely proportional to R

Q10. A heating–coil of 2000 watt is immersed in an electric kettle. The time taken in raising the temperature of 1 liter of water from 4ºC to 100ºC will be– (Only 80% part of the thermal energy produced is used in raising the temperature of water.)
(a) 252 s (b) 250 s (c) 245 s (d) 247 s

ASSERTION AND REASONING

Directions: In the following questions, statement of assertion is followed by a statement of reason. While answering a question, you are required to choose the correct one out of the given four responses and mark it as: -
(a) if both assertion and reason are true and reason is the correct explanation of the assertion.
(b) if both assertion and reason are true but reason is not correct explanation of the assertion.
(c) if assertion is true, but reason is false.
(d) if both assertion and reason are false.

Q1. Assertion: Electric current and velocity of light both have direction as well as the magnitude but still they are not considered as vectors.
Reason: Electric current and velocity of light do not follow the laws of vector addition.

Q2. Assertion: Drift velocity of electrons is independent of time
Reason: Electrons are accelerated in the presence of electric field

Q3. Assertion: Insulators do not allow flow of current through themselves.
Reason: They have no free charge carriers

Q4. Assertion: The tyres of aircraft are slightly conducting.
Reason: If a conductor is connected to ground, the extra charge induced on conductor will flow to ground

Q5. Assertion: The coulomb force is the dominating force in the universe.
Reason: The coulomb force is weaker than the gravitational force.

VERY SHORT ANSWER QUESTIONS

Q1. Distinguish between emf and terminal voltage of a cell.

Q2. Two wires one of manganin and the other of copper have equal length and equal resistance. Which one of these wires will be thicker?

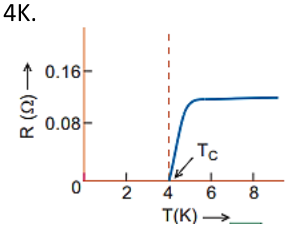
Q3. Why are alloys used for making standard resistance coils?

Q4. Why do we prefer a potentiometer to measure the emf of a cell rather than a voltmeter?

Q5. What is the advantage of using thick metallic strips to join wires in a potentiometer?

SHORT ANSWER QUESTIONS

Q1. (a) Draw a graph showing the variation of current versus voltage in an electrolyte when an external resistance is also connected.
(b) The graph between resistance (R) and temperature (T) for Hg is shown in the figure. Explain the behavior of Hg near 4K.



Q2. (a) State the principle of working a potentiometer.
(b) Write two possible causes for one sided deflection in the potentiometer experiment.

Q3. State the underlying principle of a potentiometer. Write two factors by which current sensitivity of a potentiometer can be increased. Why is a potentiometer preferred over a voltmeter for measuring the emf of a cell?

LONG ANSWER QUESTIONS

Q1. Draw the circuit diagram of a potentiometer which can be used to determine the internal resistance of a given cell of emf (E). Describe a method to find the internal resistance of a primary cell.

NUMERICAL TYPE QUESTIONS

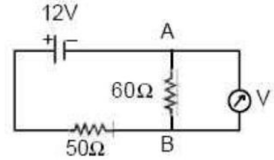
Q1. Three equal resistors connected in series across a source of emf together dissipate 10 watts of power. What would be the power dissipated if the same resistors are connected in parallel across the same source of emf

Q2. An electric motor whose resistance is 2 ohms is started with a supply of 110 volt. It takes 10 ampere current at its full speed. Find the electric power consumed and part of the power used in mechanical work.

Q3. Three 4V batteries, internal resistances 0.1, 0.2 and 0.3 are connected in parallel and in series with a 2.045-ohm resistor. Find
(a) equivalent resistance of the circuit
(b) equivalent voltage.

Q4. There are 8.4×10^{22} free electrons per cm^3 in copper. The current in the wire is 0.21 A ($e = 1.6 \times 10^{-19}$ C). Then find the drifts velocity of electrons in a copper wire of 1 mm^2 cross section.

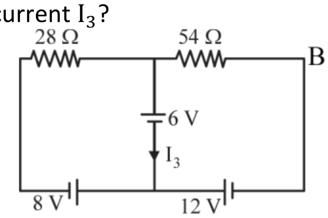
Q5. The voltmeter shown in fig, reads 6V across the 60 Ω resistor. Then find the resistance of the voltmeter.



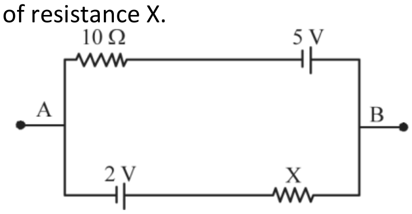
Q6. Find the value of shunt required for 10% of main current to be sent through the moving coil galvanometer of resistance 99Ω.

Q7. A voltmeter can measure upto 25 volt and its resistance is 1000 Ω. Then find the value of resistance required to add with voltmeter to measure upto 250 volt.

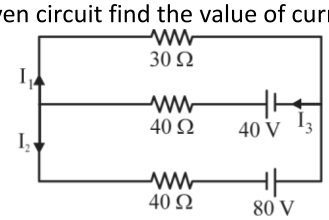
Q8. Consider the circuit shown in the figure. Then what is the value of current I_3?



Q9. If $V_B - V_A = 4$ V in the given figure, then determine the value of resistance X.



Q10. In the given circuit find the value of current I_1 .



PRACTICE EXERCISE SOLUTIONS

MCQ

S1. (b) $V = IR = (neAv_d)\rho\frac{\ell}{A}$

$\therefore \quad \rho = \frac{V}{V_d 1ne}$

Here V = potential difference

l = length of wire

n = no. of electrons per unit volume of conductor.

e = no. of electrons

Placing the value of above parameters, we get resistivity

$$\rho = \frac{5}{8\times10^{28}\times1.6\times10^{-19}\times2.5\times10^{-4}\times0.1}$$

$$=1.6\times10^{-5}\Omega\text{m}$$

S2. (d) let us consider, V is the potential across balance point and one end of wire,

From the principle of potentiometer, V ∝l

Also, if a cell of emf E is employed in the circuit between the ends of potentiometer wire of length L then E∝L.

$\Rightarrow \frac{V}{E} = \frac{l}{L}$;

Were

V = emf of battery, E = emf of standard cell.

L = Length of potentiometer wire

$$V = \frac{El}{L} = \frac{30E}{100}$$

S3. (c) In series (maximum), $R_s = nR$

Where R= resistance of each resistor

In parallel (minimum), $\frac{1}{R_p} = \frac{1}{R} + \frac{1}{R} + \ldots n$ terms

The ratio of maximum to minimum resistance is,

$$\frac{Rs}{Rp} = \frac{n^2}{1} = n^2$$

S4. (b) According to the condition of balancing

$$\frac{55}{20} = \frac{R}{80} \Rightarrow R = 220\Omega$$

S5. (a) J = σE ⇒Jρ= E J is current density; E is electric field so B = ρ = resistivity.

S6. (c) Let resistance of coil = R and voltage of battery = V

here resistance of each part = $\frac{R}{2}$ and equivalent resistance

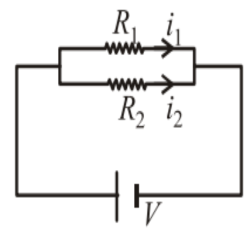
$$R_C = \left(\frac{4}{R} + \frac{4}{R} + \frac{4}{R} + \frac{4}{R}\right)^{-1} = \frac{R}{16}$$

Thus, $H_C = (16\,V^2/R)t$

S7. (d) Resistance of a conductor, $R = \frac{m}{ne^2\tau}\frac{l}{A}$

As the temperature increases, the relaxation time τ decreases because the number of collisions of electrons per second increases due to increase in thermal energy of electrons.

S8. (b)



$$R_1 = \frac{\rho\ell_1}{\pi r^2}; R_2 = \frac{\rho\ell_2}{\pi r_2}$$

$i_1R_1 = i_2R_2$ (same potential difference)

$$\therefore \frac{i_1}{i_2} = \frac{R_2}{R_1} = \frac{\ell_2}{\ell_1}\times\frac{r_1^2}{r_2^2} = \frac{3}{4}\times\frac{4}{9} = \frac{1}{3}$$

S9. (c) $\frac{R_1}{R_2} = \frac{\ell_1}{\ell_2}$ where $\ell_2 = 100 - \ell_1$

In the first case $\frac{X}{Y} = \frac{20}{80}$

In the second case

$$\frac{4X}{Y} = \frac{\ell}{100-\ell} \Rightarrow \ell = 50$$

S10. (d) By junction rule at point B

–I + 1A + 2A = 0

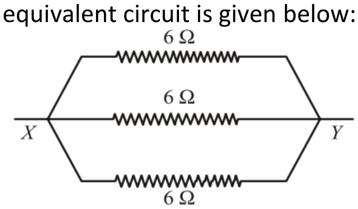
So, I = 3A

By Loop rule,

– 3 × 2 – 1 × 1 – E + 12 = 0

E = 5V

S11. (d) The equivalent circuit is given below:



The equivalent resistance is given by

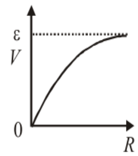
$$\frac{1}{R} = \frac{1}{6} + \frac{1}{6} + \frac{1}{6} = \frac{3}{6} = \frac{1}{2}$$

$$\Rightarrow R_{eq} = 2\Omega$$

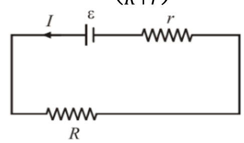
S12. (c) The current through the resistance R

$$I=\left(\frac{\varepsilon}{R+r}\right)R$$

The potential difference across R



$$V=IR=\left(\frac{\varepsilon}{R+r}\right)R$$



$$V=\frac{\varepsilon}{\left(1+\frac{r}{R}\right)}$$

when R = 0, V = 0, $R = \infty$, v = $\mathcal{E}$

Thus, V increases as R increases up to certain limit, but it does not increase further.

S13. (c) Resistance of bulb is constant

$$P=\frac{V^2}{R}\Rightarrow\frac{\Delta p}{p}=\frac{2\Delta V}{V}+\frac{\Delta R}{R}$$

$$\frac{\Delta p}{p}=2\times 2.5+0=5\%$$

S14. **(d)** $R_1 + R_2$ = Constant R_1 will increases, R_2 will decrease.

$$\mathrm{R_1\alpha\Delta T-R\beta\Delta T=0\Rightarrow R_1\alpha\Delta T=R_2\beta\Delta T}$$

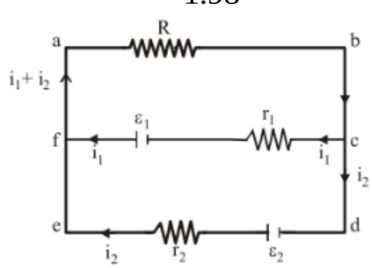
$$\therefore\frac{R_1}{R_2}=\frac{\beta}{\alpha}$$

S15. **(a)** Pot. gradient = 0.2mV/cm

$$=\frac{0.2\times10^{-3}}{10^{-2}}=2\times10^{-2}V/m$$

Emf of cell = 2 $\times 10^{-2} \times$ 1m = 2 $\times$ 10^{-2} V = 0.02V As per the condition of potentiometer 0.02(R + 490) = 2 (R) or 1.98 R = 9.8

$$\Rightarrow\ R=\frac{9.8}{1.98}=4.9\Omega$$



S16. **(d)** Applying Kirchhoff's rule in loop abcfa

$$\varepsilon_1-\left(i_1+i_2\right)R-i_1r_1=0.$$

S17. **(c)** To convert a galvanometer into a voltmeter we connect a high resistance in series with the galvanometer. The same procedure needs to be done if ammeter is to be used as a voltmeter.

S18. **(c)** Given, emf of cell E 200 V Internal resistance of cells = 1 Ω D.C. main supply voltage V = 220 V External resistance R =?

$$\mathrm{r}=\left(\frac{\mathrm{E\text{-}V}}{\mathrm{V}}\right)\mathrm{R}$$

$$1=\left(\frac{20}{220}\right)\times\mathrm{R}$$

$$\therefore\quad \mathrm{R}=11\Omega.$$

S19. **(c)** $i = neAV_d$ and $V_d \propto \sqrt{E}$ (Given)

or, $i \propto \sqrt{E}$

$i^2 \propto E$

$i^2 \propto V$

Hence graph (c) correctly depicts the *V-I* graph for a wire made of such type of material.

S20. **(d)** $I=\dfrac{E}{R+r}$, Internal resistance (r) is zero, $I=\dfrac{E}{R}$ = constant.

S21. (b) a condition of no current flow through the galvanometer 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, the device can be used to measure potential difference, internal resistance of a cell and compare emf's of two sources.

S22. (a) Drift velocity alone as we know drift velocity is the average uniform velocity acquired by the free electrons inside a metal by the application of electric field which is responsible for the current through it.

Relation between drift velocity (v_d) and current (I)is given by,

I = ne A V_d

Thus, only drift velocity determines the current in a conductor.

S23. (d) Option (a) and (b) Resistivity is a function of relaxation time(τ) and mass of charge carrier (m). Mass of charge carrier is independent of temperature, whereas length also does not fluctuate significantly over a temperature range.

S24. (b) conservation of charge and the fact that there is no accumulation of charged at a junction.

According to junction rule, the algebraic sum of current or charge flowing per unit time towards a junction in an electric network is zero, i.e., the law of conservation of charge verifies answer (b) and no any charges accumulate at junction as the sum of entering and outgoing charge are equal, at any time interval. It verifies answer (d).

S25. (b) $10^4\ \Omega$

It is known that the resistance of a dry human body is $10\ k\Omega = 10^4\ \Omega$.

ASSERTION AND REASONING

S1. (d) The e.m.f. of a dry cell is dependent upon the electrode potential of cathode and anode which in turn is dependent upon the reaction involved as well as the concentration of the electrolyte. It has nothing to do with the size of the cell. So, both assertion & reason are wrong.

S2. (b) Current continues to flow in a super conducting coil even after switch off because at critical temperature, its resistance is zero so there is no hindrance to current flow. Meissner effect says that at critical temperature magnetic field inside the conductor is zero i.e., B=0 but this does not explain assertion.

S3. (a) A voltmeter is always connected in parallel. This has of course a large resistance.

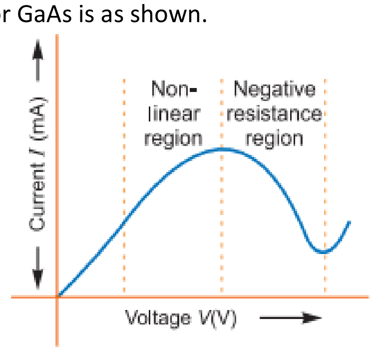
S4. (d) Ohm's law is obeyed by metals for a certain range of temperature, not obeyed by superconductors, valves, diodes and semiconductors. It is not a universal law but it is purely empirical.

S5. (b) The electric power of a heater is more than that of the bulb. As $P \propto 1/R$, the resistance of heater connected in parallel to the bulb is switched on, it draws more current due to its lesser resistance, consequently, the current through the bulb decreases and so it becomes dim. When the heater coil becomes sufficient hot, its resistance becomes more and hence it draws a little lesser current. Consequently, the current through the electric bulb recovers.

VERY SHORT ANSWER QUESTIONS

S1. The conductivity of a material equals the reciprocal of the resistance of its wire of unit length and unit area of cross-section. Its SI unit is $\left(\frac{1}{ohm} - meter\right)$ or ohm^{-1} m^{-1} or (mho m^{-1}) or Siemen m^{-1}

S2. The variation of electric current with applied voltage for GaAs is as shown.

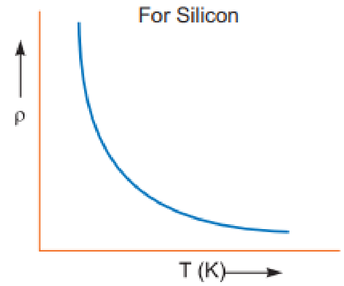


S3. (i) In region DE, material GaAs (Gallium Arsenide) offers negative resistance, because slope $\frac{\Delta V}{\Delta I} < 0$

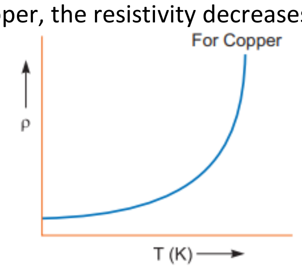
(ii) The region BC approximately passes through the origin, (or current also increases with the increase of voltage). Hence, it follows Ohm's law and, in this region, $\frac{\Delta V}{\Delta I} > 0$

S4. (i) In an open circuit, the emf of a cell and terminal voltage are same. (ii) In closed circuit, a current is drawn from the source, so, $V = E - Ir$, it is true/valid, because each cell has some finite internal resistance

S5. In silicon, the resistivity increases.



In copper, the resistivity decreases



SHORT ANSWER QUESTIONS

S1. (i) Drift Velocity: The average velocity acquired by the free electrons of a conductor in a direction opposite to the externally applied electric field is called drift velocity. The drift velocity will remain the same with lattice ions/atoms.

(ii) Relaxation Time: The average time of free travel of free electrons between two successive collisions is called the relaxation time.

S2. Resistance= 47 kΩ ± 10% = $47 \pm 10^3\Omega \pm 10\%$ Sequence of color should be: Yellow, Violet, Orange and Silver

(i) Very low temperature coefficient of resistance.

(ii) High resistivity

S3. (a) A thick copper strip offers a negligible resistance, so it does not alter the value of resistances used in the meter bridge.

(b) If the balance point is taken in the middle, it is done to minimise the percentage error in calculating the value of unknown resistance.

(c) Generally, alloys magainin/constantan/nichrome are used in meter bridge, because these materials have low temperature coefficient of resistivity.

S4. (i) By increasing resistance R, the current in main circuit decreases, so potential gradient decreases. Hence a greater length of wire would be needed for balancing the same potential difference. So, the null point would shift towards right (i.e., towards B).

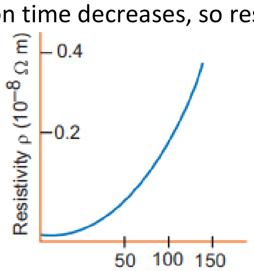
(ii) By decreasing resistance S, the terminal potential difference V= $\varepsilon - Ir$, were,$I = \frac{\varepsilon}{r+S}$

$V = \frac{\varepsilon}{1+\frac{r}{S}}$ across cell decreases, so balance is obtained at small length i.e., point will be obtained at smaller length. So, the null point would shift towards left (i.e., towards A).

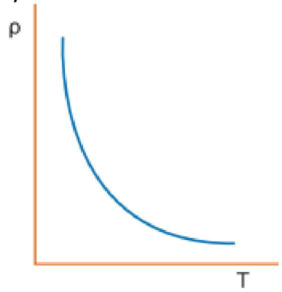
S5. We know that$\rho = \frac{m}{ne^2\tau}$,

where m is mass of electron,ρ = charge density, τ = relaxation time e = charge on the electron.

(i) In case of conductors with increase in temperature, relaxation time decreases, so resistivity increases.

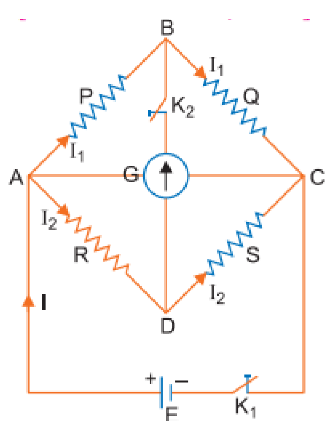


(ii) In case of semiconductors with increase in temperature number density (n) of free electrons increases, hence resistivity decreases



LONG QUESTIONS ANSWERS

S1.



Condition of balance of a Wheatstone bridge: The circuit diagram of Wheatstone bridge is shown in fig. P, Q, R and S are four resistances forming a closed bridge, called Wheatstone bridge. A battery is connected across A and C, while a galvanometer is connected between B and D. When the bridge is balanced, there is no current in galvanometer.

Derivation of Formula: Let the current flowing in the circuit in the balanced condition be I. This current on reaching point A is divided into two parts I_1 and I_2. As there is no current in galvanometer in balanced condition, current in resistances P and Q is I_1 and in resistances R and S it is I_2. Applying Kirchhoff 's I law at point A

$$I - I_1 - I_2 = 0 \; or \; I = I_1 + I_2$$

Applying Kirchhoff 's II law to closed mesh ABDA

$-I_1P + I_2R = 0 \; or \; I_1P = I_2R$ ...eq(1)

Applying Kirchhoff 's II law to mesh BCDB

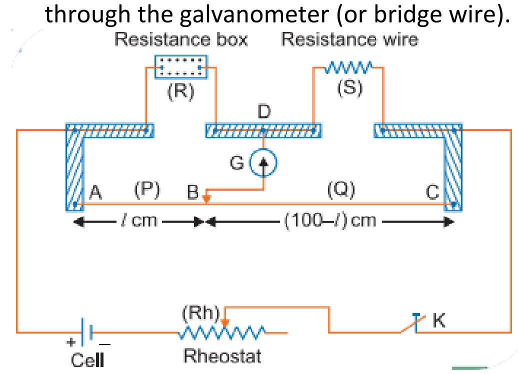
$-I_1Q + I_2S = 0 \; or \; I_1Q = I_2S$ ....eq(2)

Dividing equation (1) by (2), we get

$\frac{I_1P}{I_1Q} = \frac{I_2R}{I_2S} \; or \; \frac{P}{Q} = \frac{R}{S}$

This is the condition of balance of Wheatstone bridge.

S2. **Meter Bridge:** Special Case of Wheatstone Bridge It is a practical device based on the principle of Wheatstone bridge to determine the unknown resistance of a wire. If ratio of arms resistors in Wheatstone bridge is constant, then no current flows through the galvanometer (or bridge wire).



Construction: It consists of a uniform 1-metre-long wire AC of constantan or manganin fixed along a scale on a wooden base (fig.) The ends A and C of wire are joined to two L-shaped copper strips carrying connecting screws as shown. In between these copper strips, there is a third straight copper strip having three connecting screws. The middle screw D is connected to a sensitive galvanometer. The other terminal of galvanometer is connected to a sliding jockey B. The jockey can be made to move anywhere parallel to wire AC.

Circuit diagram: To find the unknown resistance S, the circuit is complete as shown in fig. The unknown resistance wire of resistance S is connected across the gap between points C and D and a resistance box is connected across the gap between the points A and D. A cell, a rheostat and a key (K) is connected between the points A and C by means of connecting screws. In the experiment when the sliding jockey touches the wire AC at any point, then the wire is divided into two parts. These two parts AB and BC act as the resistances P and Q of the Wheatstone bridge. In this way the resistances of arms AB, BC, AD and DC form the resistances P, Q, R and S of Wheatstone bridge. Thus, the circuit of meter bridge is the same as that of Wheatstone bridge.

Method: To determine the unknown resistance, first of all key K is closed and a resistance R is taken out from resistance box in such a way that on pressing jockey B at end points A and C, the deflection in galvanometer is on both the sides. Now jockey is slide on wire at such a position that on pressing the jockey on the wire at that point, there is no deflection in the galvanometer G. In this position, the points B and D are at the same potential; therefore, the bridge is balanced. The point B is called the null point. The length of both parts AB and BC of the wire are read on the scale. The condition of balance of Wheatstone bridge is

$\frac{P}{Q} = \frac{R}{S}$

⇒ Unknown resistance, S= $\left(\frac{Q}{P}\right) R$

If r is the resistance per cm length of wire AC and l cm is the length of wire AB, then length of wire BC will be (100 – l) cm

P = resistance of wire AB=lr

Q = resistance of wire BC= (100 – l) r

Substituting these values in equation S= $\left(\frac{Q}{P}\right) R$, we get

$$S = \frac{(100 - l)r}{lr} \times R \; or \; S = \frac{100 - l}{l} R$$

As the resistance (R) of wire (AB) is known, the resistance S may be calculated. A number of observations are taken for different resistances taken in resistance box and S is calculated each time and the mean value of S is found.

Specific resistance ρ$\frac{SA}{l} = \frac{S\pi r^2}{L}$

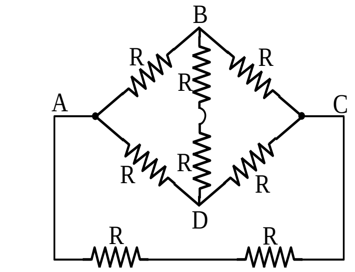
Knowing resistance S, radius r by screw gauge and length of wire L by meter scale, the value of r may be calculated. If a small resistance is to be measured, all other resistances used in the circuit, including the galvanometer, should be low to ensure sensitivity of the bridge. Also, the resistance of thick copper strips and connecting wires (end resistances) become comparable to the resistance to be measured. This results in large error in measurement.

Precautions: (i) In this experiment the resistances of the copper strips and connecting screws have not been taken into account. These resistances are called end-resistances. Therefore, very small resistances cannot be found accurately by meter bridge. The resistance S should not be very small.

(ii) The current should not flow in the metro bridge wire for a long time, otherwise the wire will become hot and its resistance will be changed.

NUMERICAL TYPE QUESTIONS

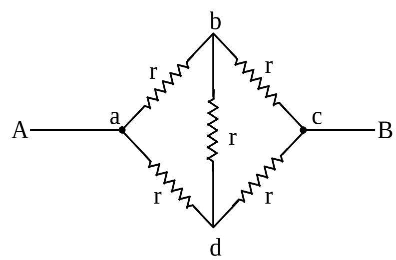
S1. The circuit is equivalent to Fig. It is a balanced Wheatstone bridge between abcd, and then in parallel (2R) resistances. Thus, ignoring resistance between bd arm. The circuit is equivalent to three (2R) resistances in parallel



i.e. $\frac{1}{R_{eq}} = \frac{1}{2R} + \frac{1}{2R} + \frac{1}{2R} = \frac{3}{2R}$

$R_{eq} = \frac{2}{3} R$

S2.



Imagine, A being pulled on the left side, then abcd becomes a balanced Wheatstone bridge Fig. The arm bd can be ignored. Then resistance between A, B becomes = r.

i.e. $\frac{1}{R_{eq}} = \frac{1}{2r} + \frac{1}{2r} = \frac{1}{r}$

Req = r

S3. The current in 1W resistance is 3A. The current in 3W resistance is $I_1 = \frac{R_2}{R_1 + R_2} I$

$= \frac{6}{3+6} \times 3 = 2A.$

Therefore, the ratio is $\frac{2}{3}$

S4. R_{eq} about GH $R_{GH} = \frac{2 \times 2}{2+4}$ = 1W

R_{eq} about EF $R_{EF} = \frac{2 \times 2}{2+2}$ = 1W

R_{eq} about CD $\frac{2 \times 2}{2+2}$ = 1W

R_{eq} about AB 1 + 1 = 2W.

S5. Let R be the combined resistance of galvanometer and an unknown resistance and r the internal resistance of each battery. When the batteries, each of e.m.f. E are connected in series, the net e.m.f. = 2E and net internal resistance = 2r

Current $i_1 = \frac{2E}{R+2r}$ or $1.0 = \frac{2\times 15}{R+2r}$

$R + 2r = 3.0$ ... eq (1)

When the batteries are connected in parallel, the e.m.f. remains E and net internal resistance becomes r/2. Therefore

Current $i_2 = \frac{E}{R+\frac{r}{2}} = \frac{2E}{2R+r}$

$2R + r = \frac{2E}{i_2} = \frac{2\times 1.5}{0.6} = 5.0$ ..eq (2)

Solving eq (1) and (2), we get r = 1 /3 W.

S6. When capacitor is fully charged no current flow in capacitor

Current from Battery

$I = \frac{E}{R+R'} = \frac{6}{2.8+\left(\frac{2\times 3}{2+3}\right)} = \frac{6}{2.8+1.2} = 1.5\text{ A}$

Current in 2W Branch

$I_{(2W)} = \frac{I\times 3}{3+2} = \frac{I\times 3}{5} = \frac{1.5\times 3}{5} = 0.9\text{A}$

S7. Since all bulbs are identical, they have the same resistances. The current I flowing through 1 branch at A. So current in 2 and 3, as well as in 4 will be less than I. The current through 5 is also I. Thus and 5 glow equally brightly and more than 2, 3 or 4.

S8. We know that the relation between work and heat produced is

W = JH

P.t = J. msDq

$\frac{80}{100} \times 2000.\ t = 4.2 \times 1000 \times 1 \times\times (100–4)$

$t = \frac{42\times 1000\times 96\times 1000}{2000\times 80} = 252$ sec.

S9. If the wire is connected as such across the battery, then current in wire,

$I = \frac{V}{R} = \frac{200}{80} = 2.5$ A and power obtained,

$P = \frac{V^2}{R} = \frac{200\times 200}{80} = 500$ watts.

The wire can carry maximum current of 5 A, therefore to double the current, the resistance should be halved. Thus, if we divide the wire in two parts and the two parts are connected in parallel across 200 V mains supply, the resistance of each part = 40W, therefore current in each wire = $\frac{200}{40}$ = 5A.

Net resistance, $R' = \frac{R_1 R_2}{R_1+R_2} = \frac{40\times 40}{40+40} = 20$W

and new power obtained, $P_{max} = \frac{V^2}{R'}$

$= \frac{200\times 200}{20} = 2000$ Watts.

Thus, maximum power is 2000 watts and this is obtained when wire is cut in two halves and they are connected in parallel across the given supply.

S10. Since there is no current in edcb part, the p.d. across b, e should be 2V. Let current in 500 W is I, then same current flows through X (think).

$\frac{12x}{500+x} = 2$

12x = 1000 + 2x

x = 100W

HOMEWORK EXERCISE SOLUTIONS

MCQ

S1. (c) Electric current
The rate of flow of electric charge through any cross-section of a conductor is known as electric current.

S2. (a) μ
Mobility is denoted by μ.

S3. (d) Diode
A non-ohmic resistance is a resistance that does not obey ohm's law. Among the given options, a diode is a non-ohmic resistance.

S4. (b) vector quantity.
Current density is a vector quantity

S5. (b) Internal resistance the opposition offered by the electrolyte of the cell to the flow of current through itself is known as internal resistance.

S6. (c) Superconductivity
The resistivity of certain metals or alloys drops to zero when they are cooled below a certain temperature, this phenomenon is known as superconductivity.

S7. (b) The current in 1W resistance is 3A. The current in 3W resistance is $I_1 = \frac{R_2}{R_1+R_2} I$
$= \frac{6}{3+6} \times 3 = 2A$.
Therefore, the ratio is $\frac{2}{3}$

S8. (a) Resistance of the bulb $R = \frac{V^2}{P} = \frac{220\times220}{100}$
The new power for the voltage of 110 volt is
$P' = \frac{V'^2}{R} = \frac{110\times110}{484} = 25$ watt.

S9. (a) V is directly proportional to I
By ohm's law, voltage is directly proportional to current only and not resistance, and the R in the equation is the proportionality constant, whose value depends on the circuit.

S10. (a) We know that the relation between work and heat produced is
W = JH
P.t = J. msDq
$\frac{80}{100} \times 2000.\ t = 4.2 \times 1000 \times 1 \times (100-4)$
$t = \frac{42\times1000\times96\times1000}{2000\times80} = 252$ sec

ASSERTION AND REASONING

S1. (a) Electric current and velocity of light are both scalar quantities. In the case of electric current, when two different electric currents meet at a junction, the net sum of the two currents will not be due to vector addition but will be rather due to the algebraic sum of the two currents. Hence electric current is not a vector quantity.
Similarly, when two light rays combine, they also do not follow the laws of vector addition so it is also not a vector quantity

S2. (b) Drift velocity is the average velocity of electrons in presence of electric field, which is independent of time.

S3. (a) In an insulator, the valence band is completely filled and the conduction band is completely empty. There are no charge carriers at all in the conduction hand. Moreover, as the energy gap $E_g >> K_BT$ where T is the room temperature, so no electron can jump from the valence band to the conduction band at low, temperatures and even at higher temperatures.

S4. (b) During take-off and landing, the friction between tyres and the run way may cause electrification of tyres. Due to conducting nature of tyre, the charge so collected is conducted to a ground and electrical sparking is avoided.

S5. (b) Gravitational force is the dominating force in nature and not coulomb's force. Gravitational force is the weakest force. Also, Coulomb's force>> gravitational force.

VERY SHORT ANSWER QUESTIONS

S1. The emf of a cell is equal to the terminal voltage, when the circuit is open. The emf of a cell is less than the terminal voltage, when the cell is being charged, i.e., V = E + ir

S2. Resistance
$$\boldsymbol{R = \frac{\rho l}{A} = \frac{\rho l}{\pi r^2} ss}$$
Resistivity ρ of manganin is much greater than that of copper, therefore to keep same resistance for same length of wire, the manganin wire must be thicker.

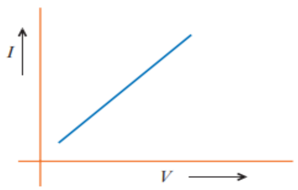
S3. Alloys have
(i)low value of temperature coefficient and the resistance of the alloy does not vary much with rise in temperature.
(ii)high resistivity, so even a smaller length of the material is sufficient to design high standard resistance.

S4. A voltmeter has a finite resistance and draws current from a cell, therefore voltmeter measures terminal potential difference rather than emf, while a potentiometer at balance condition, does not draw any current from the cell; so the cell remains in open circuit. Hence potentiometer reads the actual value of emf.

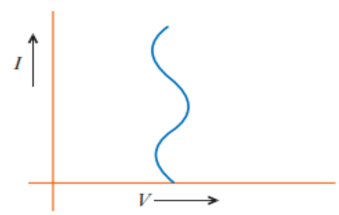
S5. The metal strips have low resistance and need not be counted in the potentiometer length l of the null point. One measures only their lengths along the straight segments (of length l meter each). This is easily done with the help of centimeter rulings or meter ruler and leads to accurate measurements.

SHORT ANSWER QUESTIONS

S1. **(a)**



OR



(b) At a temperature of 4 K, the resistance of Hg becomes zero.

S2. (a) Principle of Potentiometer: When a constant current flows through a wire of uniform area of cross-section, the potential drop across any length of the wire is directly proportional to the length.

(b) Possible causes for one side deflection:

(i) The emf ε_1 (or ε_2) is more than the emf of driver cell (auxiliary battery).

(ii) The end of the potentiometer wire connected to +ve of auxiliary battery is connected to negative terminal of the cell whose emf is to be determined.

S3. Principle: The potential drop across a part of the potentiometer wire is directly proportional to the length of that part of the wire of uniform cross section. V = k l

where k is potential gradient. Current sensitivity of potentiometer wire is also known as potential gradient, and it can be increased.

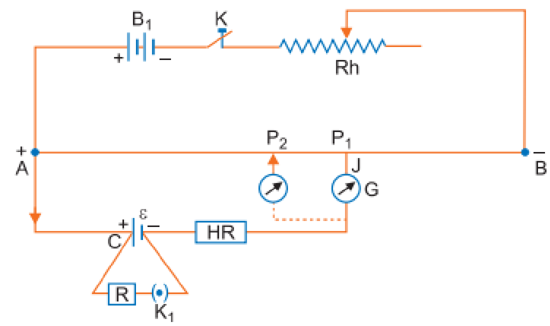
(i) By increasing the total length of the wire, keeping terminal voltage constant.

(ii) By connecting a suitable extra resistance R in series with the potentiometer. So, less amount of the current flows through the potentiometer wire. Reasons: At the balance point, there is no net current drawn from the cell, and cell is in open circuit condition. Voltmeter has some resistance, when connected across the cell. Some current is drawn, as a result emf of the cell decreases. Hence, emf of the cell cannot be measured by the voltmeter.

LONG ANSWER QUESTIONS

S1. **Determination of Internal Resistance of Potentiometer.**

Circuit: A battery B_1 a rheostat (Rh) and a key K is connected across the ends A and B of the potentiometer wire such that positive terminal of battery is connected to point A. This completes the primary circuit. Now the given cell C is connected such that its positive terminal is connected to A and negative terminal to jockey J through a galvanometer. A resistance box (R) and a key K_1 are connected across the cell. This completes the secondary circuit.



Method:

(i) Initially key K is closed and a potential difference is applied across the wire AB. Now rheostat Rh is so adjusted that on touching the jockey J at ends A and B of potentiometer wire, the deflection in the galvanometer is on both sides. Suppose that in this position the potential gradient on the wire is k.

(ii) Now key K_1 is kept open and the position of null deflection is obtained by sliding and pressing the jockey on the wire. Let this position be P_1 and $AP_1 = l_1$
In this situation the cell is in open circuit, therefore the terminal potential difference will be equal to the emf of cell, i.e.,
Emf $\varepsilon = kl_1$

(iii) Now a suitable resistance R is taken in the resistance box and key K_1 is closed. Again, the position of null point is obtained on the wire by using jockey J. Let this position on wire be P_2 and $AP_2 = l_2$.
In this situation the cell is in closed circuit, therefore the terminal potential difference (V) of cell will be equal to the potential difference across external resistance R, i.e.,
$\mathrm{V} = \mathrm{kl}_2$
Dividing Emf $\varepsilon = kl_1$ By $\mathrm{V} = \mathrm{kl}_2$ we get
$\frac{\varepsilon}{V} = \frac{l_1}{l_2}$
∴ Internal resistance of cell, r= $\left(\frac{\varepsilon}{V} - 1\right) R = \left(\frac{l_1}{l_2} - 1\right) R$
From this formula r may be calculated.

NUMERICAL TYPE QUESTIONS

S1. Let R be the resistance of each resistor.
When they are connected in series, the total resistance = R + R + R = 3R ohm.

Power dissipated $W_1 = E^2/3R$, where E = emf of the source.

When the resistors are connected in parallel, their effective resistance is given by

$$\frac{1}{R'} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} = \frac{3}{R}$$

or $R' = \frac{R}{3}$

Power dissipated $W_2 = \frac{E^2}{R/3} = \frac{3E^2}{R}$

Now $\frac{W_1}{W_2} = \frac{3E^2}{R} \times \frac{3R}{E^2} = 9$

or $W_2 = 9W_1 = 9 \times 10 = 90$ watt

(QW_1 = 10 watt).

S2. Power of the motor = VI= 110 ×10= 1100 watt

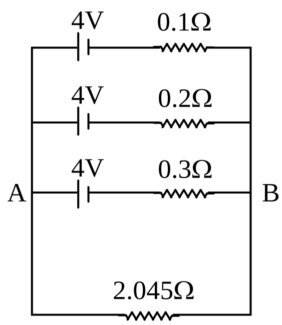
Heat loss in the motor = $i^2R = (10)^2 \times 2 = 200$ watt

Power converted to mechanical work

= (1100 – 200) watt = 900 watt

Percentage of total power consumed in mechanical work = (900/1100) × 100 = 82% (approximate).

S3.



The circuit arrangement is shown in fig. As the batteries are connected in parallel, hence total emf of the circuit = 4V.

The effective resistance R_{AB} between A and B is given by

$$\frac{1}{R_{AB}} = \frac{1}{0.1} + \frac{1}{0.2} + \frac{1}{0.3} = \frac{110}{6}$$

$R_{AB} = \frac{6}{110} = 0.055$ ohm.

(a) Equivalent resistance of the circuit $R = R_{AB} + 2.045 = 0.055 + 2.045 = 2.1$ ohm.

(b) Equivalent voltage = 4 volt.

S4. Number of free electrons $n = 8.4\times10^{22} \times 10^{6}$ per m^3 $= 8.4\times10^{28}$ per m^3

Current in the wire I = 0.21 A

Cross-section of the wire $A = 1 mm^2 = 10^{-6}\ m^2$

Thus, drift velocity of electrons, $v = \frac{I}{neA}$

$= \frac{0.21}{8.4\times10^{28}\times(1.6\times10^{-19})\times(10^{-6})} = 1.56 \times 10^{-5}$ m/s

S5. Let R is resistance of the voltmeter. The effective resistance across points A, B is

$r = \frac{60\times R}{60+R}$ ... (1)

The current in the circuit is $I = 12/(50+r)$

The p.d. across AB points is $V = Ir$

or $6 = \frac{12}{50+r} \times r$ or $50 + r = 2r$

or $r = 50\ \Omega$ ... (2)

using it in (1),

we get $50 = \frac{60}{60+R}$

$300 + 5R = 6R$

or $R = 300\ \Omega$

S6. We know,

$S = \frac{G}{n-1}$

$= \frac{G}{100-1} = \frac{G}{99}\Omega$

S7. $\therefore\ i = \frac{V}{R} = \frac{25}{1000}A$

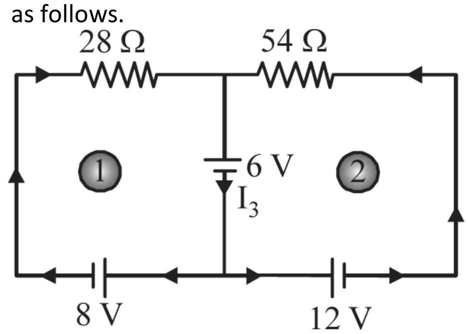
Let R′ be the required resistance to be connected in series with voltmeter.

So $i = \frac{V'}{R+R'}$

Here $V' = 250, R = 1000\ \Omega$ and $i = \frac{25}{1000}A$

$\therefore\ \frac{25}{1000} = \frac{250}{1000+R'} \Rightarrow R' = 9000\ \Omega.$

S8. Suppose current through different paths of the circuit is as follows.



After applying KVL of loop (1) and loop (2)

We get $28i_1 = -6 - 8 \Rightarrow i_1 = -\frac{1}{2}A$

and $54i_2 = -6 - 12 \Rightarrow i_2 = -\frac{1}{3}A$

Hence $i_3 = i_1 + i_2 = -\frac{5}{6}A$

S9. The given circuit can be visualized as a combination of two batteries in parallel.

The emf & internal resistance of batteries are,

$E_1 = 5$ V, $r_1 = 10\ \Omega$, $E_2 = 2$ V, $r_2 = x\ \Omega$

Since, both batteries are in parallel combination with same polarity, so net emf will be

$E_{eq} = \frac{E_1r_2+E_2r_2}{r_1+r_2}$

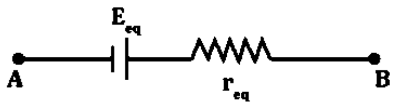
$E_{eq} = \frac{5X+2\times10}{X+10}$

Equivalent internal resistance,

$r_{eq} = \frac{r_1r_2}{r_1+r_2}$

$r_{eq} = \frac{10\times X}{10+X}$

The equivalent circuit can be drawn as:



Apply KVL between points A and B, $V_A + E_{eq} - i\, r_{eq} = V_B$

since, circuit is open, so current, i = 0

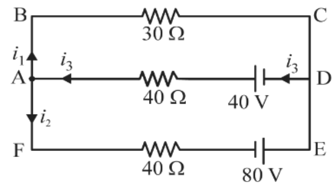
⇒ $E_{eq} = V_B - V_A$ Given that $V_B - V_A = 4$ V

⇒$\frac{5X+2\times10}{X+10}=4$

⇒40+4x=5x+20

⇒ $X = 20\,\Omega$

S10. The circuit can be simplified as follows



Applying KCL at junction A

$i_3 = i_1 + i_2$ ...(i)

Applying Kirchhoff's voltage law for the loop ABCDA

$-30i_1 - 40i_3 + 40 = 0$

⇒ $-30i_1 - 40(i_1 + i_2) + 40 = 0$

⇒ $7i + 4i_2 = 0$ ...(ii)

Applying Kirchhoff's voltage law for the loop ADEFA.

$-40i_2 - 40i_3 + 80 + 4 = 0$

⇒ $-40i_2 - 40(i_1 + i_2) = -120$

⇒ $i_2 + 2i_2 = 3$ ...(iii)

On solving equation (ii) and (iii) $i_1 = -0.4$ A

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