CURRENT AND ELECTRICITY

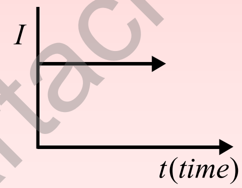
CHAPTER 03

Electric Current

- It arises due to the continuous flow of electric charge.
  In metallic conductors this is the flow of free electrons.
  In electrolytes and gases ions constitutes the electric current.
  In semi-conductor, both positive and negative charges, which are called holes and electrons respectively constitutes electric current.
  "Strength of the electric current flowing through a conductor is defined as the rate of flow of electric charge through cross section of conductor".

• **Types of Current**

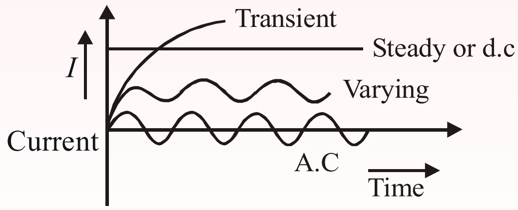
- **Direct or steady current:** If charge q cross any section of conductor in time t the electric current is given by $I = \frac{q}{t}$



Direct current

- **Varying current:** If the rate of flow of charge varies with time, then current is given by $I = \frac{dq}{dt}$
- **Transient current:** This current flows for very short interval of time.
- **Example:** Current flowing in the circuit when capacitor is charged or discharged is called transient current.
- **Alternating Current:** The current whose magnitude and direction is changing continuously at regular intervals of time.

• **Graphical representation of different types of current:**



Example-1: **In hydrogen atom, electron moves $6.6\times10^{15}\,rev/\sec$ around the nucleus in an orbit of radius $0.5\times10^{-10}\,\text{m}$. What is the equivalent current?**

Solution: Current $I =$ charge $\times$frequency

$=1.6\times10^{-19}\times6.6\times10^{15}$

$=10.56\times10^{-4}=1.056\times10^{-3}$ amp

Thermal velocity

- The free electrons in a conductor are filled just like gas molecules and moves randomly in all direction with velocity $(10^5\ to\ 10^6\ m/\sec)$ in absence of electric field.

  Note: Average thermal velocity is zero.

Drift velocity

- It is defined as the average velocity with which free electrons in a conductor get drifted in a direction opposite to the direction of applied electric field.

  Electron in a conductor experience force, which is given by $\vec{F}=-e\vec{E}$

  The average velocity of free electrons is called drift velocity which is given as

$$v_d=\frac{eE}{m}\tau=\frac{eV}{ml}\tau \qquad \left[E=\frac{V}{l}\right]$$

where τ is the time between two successive collisions known as average relaxation time.

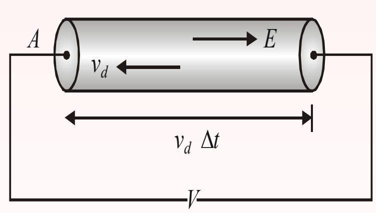
In vector form, $\vec{v}_d=-\left(\frac{e\vec{E}}{m}\right)\tau$

Note: (i) Order of relaxation time is 10^{-14} sec.

(ii) Order of drift velocity of electrons in a conductor is from 10^{-4} to $10^{-5}\ m/s$.

(iii)As temperature increases the average relaxation time and average drift velocity both decreases.

- **Relation between Current and drift velocity:**



Consider a cylindrical conductor of cross-section area A in which an electric field E exist. Let a length $v_d\Delta t$ of the conductor. The volume of this position is $Av_d\Delta t$. If there are n free electrons per unit volume of the wire. The number of free electrons in this portion is $= nAv_d\Delta t$

thus, charge crossing this area in time Δt is

$$\Delta Q = neAv_d\Delta t$$

or, current $\quad I = \frac{\Delta Q}{\Delta t} = neAv_d$

and current density $\quad J = \frac{I}{A} = nev_d$

Note:

(i) Randomly moving free electrons inside the metal collides with lattice and follow a zig - zag path.

(ii) In presence of electric-field path of electrons, on the average becomes curved (parabolic) instead of straight-line path.

Current Density

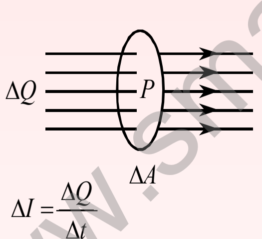
- Current is a scalar quantity but current density is a vector quantity.

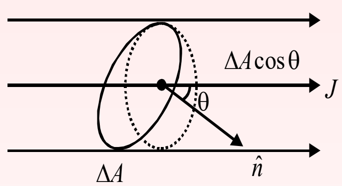
To define current density at a point P, we draw a small area ΔA through point P perpendicular to the flow of charges. If ΔI be current through area ΔA, the average current density $J = \frac{\Delta I}{\Delta A}$

the current density at point P

$$J = \lim_{\Delta A \to 0} \frac{\Delta I}{\Delta A} = \frac{dI}{dA}$$

If a current I is uniformly distributed over an area A and is perpendicular to it, then





$$J = \frac{\Delta I}{\Delta A}$$

Now, let us consider an area ΔA, which is not necessarily perpendicular to the current, then current density

$$J = \frac{\Delta I}{\Delta A \cos\theta}$$

or $\quad \Delta I = J\ \Delta A \cos\theta$

or $\quad \Delta I = \vec{J} . \Delta\vec{A} \quad$ (in vector form)

For a finite area

$$I = \int \vec{J} \cdot \vec{ds}$$

- **Unit of current:**

(i) S. I. Unit – Ampere
(ii) C G S unit (in e s u) – Stat Amp
(iii) CGS unit (in emu) – Ab ampere

Note: [1 $Amp = \left(\frac{1}{10}\right)$ emu of current]

Example-2: **If potential difference across a given conductor is kept constant then what is change in drift velocity when the area of cross-section changes by 10%?**

Solution: Current is related to drift velocity as,

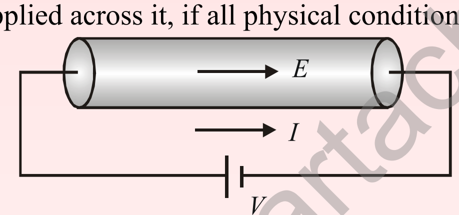
$$I = neAv_d$$

and $V = IR = R\, ne\, Av_d = \frac{\rho l}{A} ne\, Av_d = \rho l\, n e v_d$

So, the drift velocity does not change.

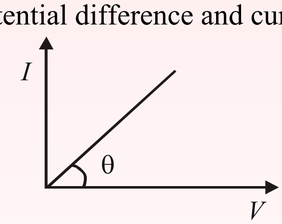
OHM'S LAW

"It states that current passing through a conductor is directly proportional to the potential difference applied across it, if all physical conditions remain constant".



$I \propto V$ $\qquad$ $I = \frac{1}{R} V$ or $\boxed{V = IR}$

Therefore, the graph between potential difference and current is a straight line.



Note:

(1) Resistance of conductor $\boxed{R = \frac{1}{\tan\theta}}$, if angle θ is taken from the axis of potential difference.

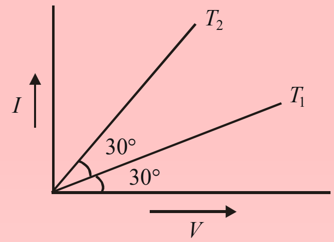
(2) If conductor is bent at one or more places, then its resistance remains unchanged.

- **Electrical Conductance:** "G". It is defined as reciprocal of resistance.

Its unit is mho or ohm^{-1}.

Dimensional formulae of 'G' = $[M^{-1}L^{-2}T^{3}A^{2}]$.

Example-3: **What is ratio of resistance of a given conductor at temperature T_1 and T_2 with help of following graph?**



Solution: $R_1 = \frac{1}{\tan 30°}$ and $R_2 = \frac{1}{\tan 60°}$. Therefore $\frac{R_1}{R_2} = \frac{\tan 60°}{\tan 30°} = \frac{3}{1}$

- **Specific resistance:** The resistance of a conductor of unit length and unit cross-section area is defined as specific resistance.

  Resistance of a given conductor is

  (1) directly proportional to its length $R \propto l$

  (2) inversely proportional to area of cross-section $R \propto A$

  from both equation (1) and (2)

  $$R \propto \frac{l}{A} \quad \text{or} \quad \boxed{R = \frac{\rho\, l}{A}}$$

  where, ρ is called specific resistance

  Unit of ρ is ohm. metre in S.I. system.

  Resistivity of conductor depends on nature of metal and its temperature.

- **Electrical conductivity:** It is defined as reciprocal of resistivity $\sigma = \frac{1}{\rho}$

  Unit of σ is $ohm^{-1}\ m^{-1}$ **or** $mho\ m^{-1}$

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

- **Stretching of wire:** Resistance of a wire of length l_1 and area of A_1

  $$R_1 = \frac{\rho\, l_1}{A_1} \quad \ldots \text{(i)}$$

  and on stretching the new resistance

  $$R_2 = \frac{\rho\, l_2}{A_2} \quad \ldots. \text{(ii)}$$

  on stretching, volume remains constant then, $A_1 l_1 = A_2 l_2$

  From (i) and (ii)

  $$\frac{R_2}{R_1} = \left(\frac{l_2}{l_1}\right)\left(\frac{A_1}{A_2}\right) \text{ or } \left(\frac{l_2}{l_1}\right)^2 \text{ or } \left(\frac{A_1}{A_2}\right)^2 \text{ or } \left(\frac{r_1}{r_2}\right)^4$$

Note:

(1) Resistance of a wire

$$R \propto \frac{l^2}{m}$$, where m = mass of the wire and $l =$ length of the wire

(2) Relation between current density, electrical conductivity and electric field $\boxed{J = \sigma E}$.

Example-4: **What is the electrical conductivity of a material of length 3m, area of cross-section 0.01mm^2 having a resistance of 4Ω?**

Solution: As $R = \frac{\rho l}{A}$, and electrical conductivity

$\sigma = \frac{l}{\rho}$, we have

$$\sigma = \frac{l}{RA} = \frac{3}{4 \times 0.01 \times 10^{-6}} = 7.5 \times 10^{7}\ ohm^{-1}\ m^{-1}$$

Example-5: **A given wire is stretched to reduce its diameter to half its original value. What will be its new resistance?**

Solution: Let l_1 = Original length

d_1 = Original diameter

l_2 = New length

d_2 = New diameter

Step- 1: After stretching the wire, volume (or density) of the wire remains the same

i.e., $A_1 l_1 = A_2 l_2$ or, $\frac{\pi d_1^2}{4} l_1 = \frac{\pi d_2^2}{4} l_2$ or, $l_2 = \left(\frac{d_1}{d_2}\right)^2 l_1$

Since, $d_2 = \frac{d_1}{2}$

New length, $l_2 = 4 l_1$

Step- 2: We know

$$R = \rho \frac{l}{A} = \rho \frac{4l}{\pi d^2}$$

$$\therefore\ R_1 = \frac{4 l_1 \rho}{\pi d_1^2} \text{ and } R_2 = \frac{4 l_2 \rho}{\pi d_2^2}$$

$$\therefore\ \frac{R_2}{R_1} = \frac{l_2 d_1^2}{l_1 d_2^2} = \frac{4 l_1 d_2^2 \times 4}{l_1 \times d_1^2} = 16$$

New resistance, $R_2 = 16\ R_1$

Hence, the new resistance of the wire will be 16 times of the original resistance.

Effect of temperature on Resistivity

- **Conductor:** Conductivity decreases and resistivity increase with increase in temperature for small temperature variations. We can write for most of the materials.

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

Note: $R(T) = R(T_0)[1 + \alpha(T - T_0)]$

$$\alpha = \frac{R(T) - R(T_0)}{R_0(T - T_o)}$$

Also, $\alpha = \dfrac{R_2 - R_1}{R_1(T_2 - T_1)}$, where R_1, R_2 are resistances at temperature T_1 and T_2 respectively.

- **Semiconductor and Insulator:** Number of free electrons per unit volume increases exponentially with the rise in temperature according to the relation.

$$n = n_0 e^{-E_g/kT}$$

Since, electrical conductivity is directly proportional to number density of electrons, so

$$\sigma = \sigma_0 e^{-E_g/kT}$$

Hence, electrical conductivity will also increase exponentially.

Note:

(i) At high temperature semi-conductor behaves as conductor $R = R_0(1 + \alpha\Delta T)$ and α is negative for semiconductor and insulator.

(ii) Conductivity of electrolytes and liquids will increase with the rise in temperature.

Example-6: **A copper coil has a resistance of 20.0Ω at 0°C and a resistance of 26.4Ω at 80°C. Find out the temperature coefficient of resistance of copper.**

Solution: $R_{80°C} = R_{0°C}[1 + \alpha\,\Delta T]$

$$26.4\Omega = 20.0\Omega\,[1 + \alpha(80 - 0)]$$

$$\frac{26.4 - 20}{20 \times 80} = \alpha$$

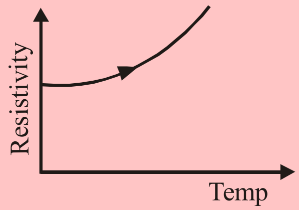
or $\alpha = \dfrac{6.4}{20 \times 80} = 4 \times 10^{-3}(°C)^{-1}$

Superconductivity

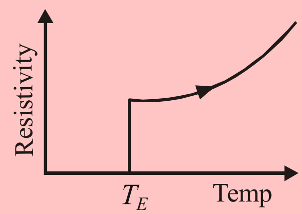
- As the temperature of certain metals and alloys decreases, their resistance also decreases. When the temperature reaches a certain critical value (called transition temperature or critical temperature). The resistance of material completely disappears. The material behaves like a super conductor and this phenomenon is called superconductivity.

  The critical temperature for mercury is $4.2\ K$.

  The reason for superconductivity is the coherent flow of electrons without any collisions within the ions.



Normal metal



Super conductor

- **Applications**
  - (i) In making strong electro-magnet
  - (ii) In producing very high-speed computers
  - (iii) High energy transmission

Thermistors

➤ It is a heat sensitive device whose resistivity changes rapidly with the change of temperature. It is temperature coefficients is very high and negative. It is made of semi-conductor.

- **Uses:**
  - (i) Used as non-linear resistances in various automatic applications.
  - (ii) Used as a safeguard of picture tube of T.V.

Grouping of Resistances

- **Series combination:** The electric current in all parts is same but potential difference set up in the ratio of the resistance. If R_1 and R_2 are connected in series with a source of potential difference V, then potential difference V_1 and V_2 across two resistors of resistance R_1 and R_2 respectively, be given as

$$\frac{V_1}{V_2} = \frac{R_1}{R_2} \quad \text{.... (i)}$$

and $V = V_1 + V_2$ ... (ii)

From eqn. (i) and (ii), we get

$$\boxed{V_1 = \frac{VR_1}{R_1 + R_2}}, \quad \boxed{V_2 = \frac{VR_2}{R_1 + R_2}}$$

Equivalent resistance, $R = R_1 + R_2$

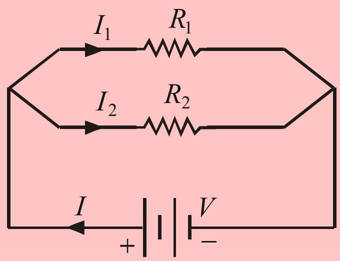
If G_1, G_2 are conductance, then equivalent conductance is given by

$$\frac{1}{G} = \frac{1}{G_1} + \frac{1}{G_2}$$

- **Parallel Combination:**

  In parallel combination the potential difference across all resistors remains same and current distribution is inverse ratio of resistances.

  If two resistors of resistance R_1 and R_2 are connected in parallel, then current I_1, I_2 through R_1 and R_2 respectively then,



Current supplied by cell $I = I_1 + I_2$ …(i)

$$\frac{I_1}{I_2} = \frac{R_2}{R_1} \quad ...(ii)$$

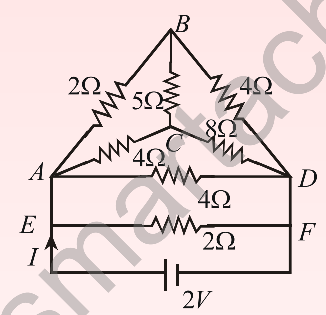
From eqn. (i) and (ii), we get

$$\boxed{I_1 = \frac{IR_2}{R_1 + R_2}}, \quad \boxed{I_2 = \frac{IR_1}{R_1 + R_2}}$$

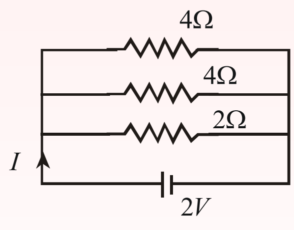
In parallel combination, the equivalent resistance is less than the lowest resistance in the combination.

- Effective resistance, $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$
- Effective conductance, $G = G_1 + G_2$

Example-7: **Find the current I drawn from the cell**

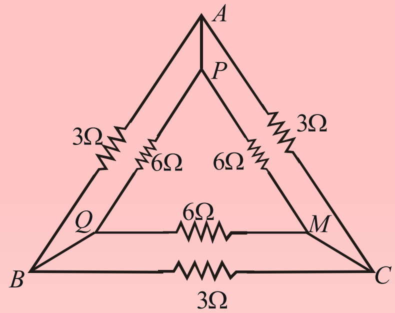


Solution: Ratio of resistances in arm AB and BD is equal to ratio of resistances in arm AC and CD, therefore resistance between B and C is neglected and hence resistance between AD is 4Ω (excluding resistance 4Ω between A and D.

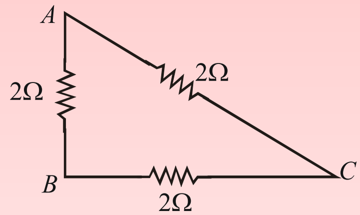


The equivalent resistance of the circuit is 1Ω, so current drawn from the cell is 2 amp.

Example-8: In the circuit shown what is the effective resistance between B and C?



Solution: As resistances AB & PQ, AC & PM and QM & BC are in parallel, therefore, the equivalent circuit diagram becomes as



The equivalent resistance between B and C is $\frac{4}{3}\Omega$.

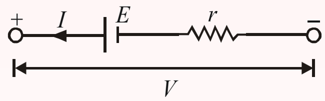
EMF of Cell

- EMF is the amount of work-done by the cell in circulating a unit positive charge throughout the circuit including cell.
- It is also the potential difference across electrodes of a cell when no current is drawn from the cell.
- S.I unit of emf is Joule/coulomb, called volt.
- EMF of a cell depends only upon the material of the electrode of the cell and electrolytes and it is constant for a given type of a cell.
- EMF is taken positive if current flows from -VE to + VE terminal inside the cell for such case cell is in discharging process. Otherwise, emf is taken –VE.

- **Terminal potential difference:**

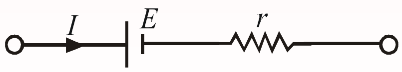
  It is defined as potential difference between the terminals in a closed circuit.

  Terminal potential difference is less than emf of the cell when the cell is getting discharge.



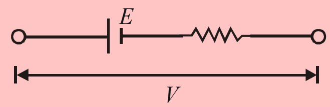
$$V = E - Ir$$

Terminal potential difference is greater than the emf of the cell when the cell is getting charged,



$$V = E + Ir$$

Terminal potential difference is equal to emf of the cell when no current flows out of the cell.



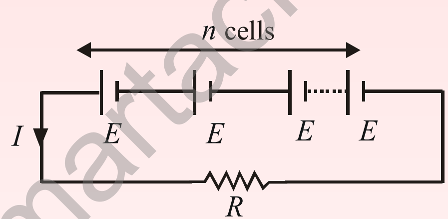
$$\boxed{V = E}$$

- **Internal resistance of the cell**
- The opposition of electrolyte to the flow of current through it is called internal resistance of the cell.
- The internal resistance of a cell depends upon
- (i) Material of the electrode
- (ii) Separation between electrodes $(r \propto d)$
- (iii) Temperature of electrolytes $\left(r \propto \frac{1}{temp}\right)$
- (iv) Area of electrodes $\left(r \propto \frac{1}{A}\right)$

Combination of cells

(i) Series Combination:

In this combination negative terminal of each cell is connected with positive terminal of the next cell and so on.



Let, n = no. of cell

r = internal resistance of each cell

R = external resistance

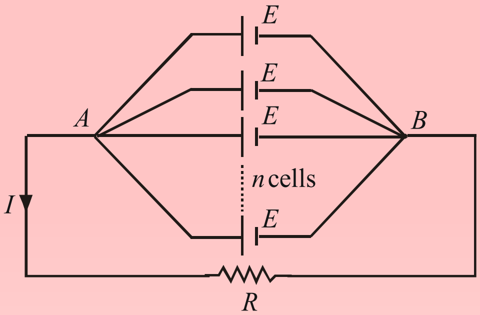
nE = total emf of the combination

$nr + R$ = total resistance of the circuit

So, current from combination of cells,

$$\boxed{I = \frac{nE}{nr + R}}$$

(ii) Parallel combination:



Let us assume all the cells have same emf then current from combination of cells

$$I = \frac{E}{\frac{r}{n} + R} = \frac{nE}{r + nR}$$

(iii) Mixed combination:

Let there be 'n' rows of m cells in each row

Total resistance in each row = mr

Total resistance of the circuit $= \frac{mr}{n} + R$

Total emf of the combination = ME

Net current, $I = \frac{mnE}{mr + nR}$

Note: When $mr = nR$, then current drawn from the cell is maximum.

Example-9: **Find the minimum number of cells required to produce an electric current of 1.5 A through a resistance of 30 ohm. Given that the a.m.f of each cell is 1.5 volt and internal resistance of each cell is 1.0 ohm.**

Solution: Let $(m \times n)$ be the minimum number of cells arranged in m rows and each row contains n cells.

Step-1: We know, Current in the mixed grouping of cells is $I = \frac{mnE}{mR + nr}$

Here, $I = 1.5\ A,\ E = 1.5\ V$

$R = 30\ \Omega,\ r = 1.0\ \Omega$

$\therefore\ 1.5 = \frac{mn \times 1.5}{30m + n \times 1}$

or $45m + 1.5n = 1.5\ mn$ ... (i)

Step-2: To have maximum current

$R = \frac{nr}{m}$ or $30 = \frac{n}{m}$

or n = 30 m ... (ii)

By solving eqn. (i) and (ii), we get $n = 30 \times 2 = 60$

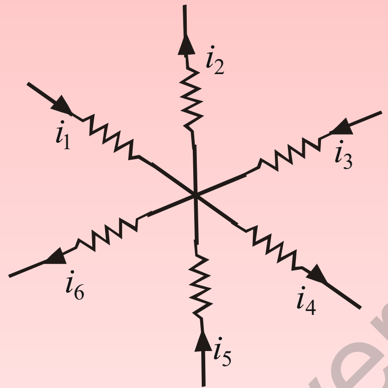
Step 3: Minimum number of cells required $= mn = 2 \times 60 = 120$

Kirchhoff's rules of electricity

➢ To analyse a complex D.C circuit's **Gustav Kirchhoff's** gave two laws

- **Junction rule or Current law**

"The algebraic sum of current meeting at a junction in an electrical circuit is zero".



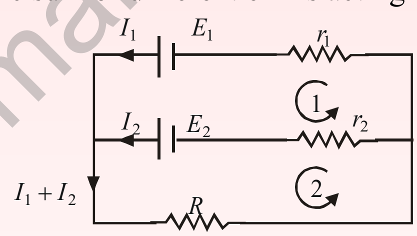
$$i_1 - i_2 + i_3 - i_4 + i_5 - i_6 = 0$$

Current is taken with positive sign if it is reaching the junction and negative when it is leaving the junction.

Current law is based on principle of conservation of charge.

- **Loop rule or Potential law**

"Algebraic sum of the product of currents and resistances of different parts of the loop is always equal to the algebraic sum of different emf's acting in that loop".



Applying Kirchhoff's second law to loop 1 and 2, we get

$$I_1 r_1 - I_2 r_2 = E_1 - E_2 \quad \dots \text{(i)}$$

$$I_2 r_2 + (I_1 + I_2)R = E_2 \quad \dots \text{(ii)}$$

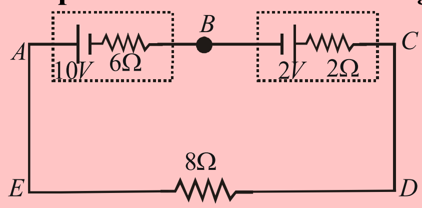
- **Sign convention:**

(i) If we traverse in direction of current in a loop then product $I.R$ is taken positive otherwise negative

(ii) If we traverse from negative to positive terminal of cell then emf is taken positive otherwise negative.

(iii)Loop rule is based on principle of conservation of energy.

Example-10: **Find the terminal potential difference in the given circuit.**



Solution: Using loop rule in mesh ACDEA

$I \times 6 + I \times 2 + I \times 8 = 10 - 2$

$16I = 8$, So, $I = \frac{1}{2}$

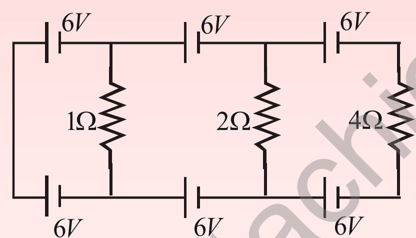
Terminal potential difference of 10 V cell

$$V = E - Ir = 10 - \frac{1}{2} \times 6 = 7 \text{ volt}$$

Terminal potential difference of 2V cell

$$V = E + Ir = 2 + \frac{1}{2} \times 2 = 3 \text{ volt}$$

Example-11: **Find the current in the resistances in the given circuit**

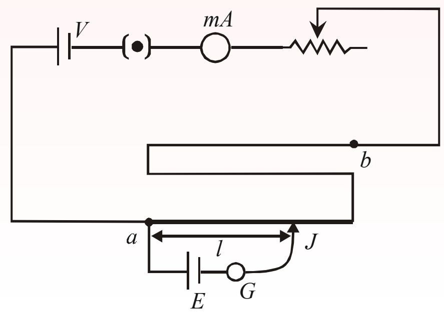


Solution: When loop rule is applied to any mesh, the net emf comes out to be zero. This means current in the given resistance is zero. It is an accurate device for measuring emf of a cell or potential difference between two points of an electric circuit.

Potentiometer

Principle:

The fall of potential across any portion of the wire is directly proportional to the length of that portion provided the wire is of uniform cross-section and a constant current is flowing through it.



If current flowing through potentiometer wire a, b is $'I'$, then using ohm's law

$$V = IR = I\frac{\rho l}{A} = Kl$$

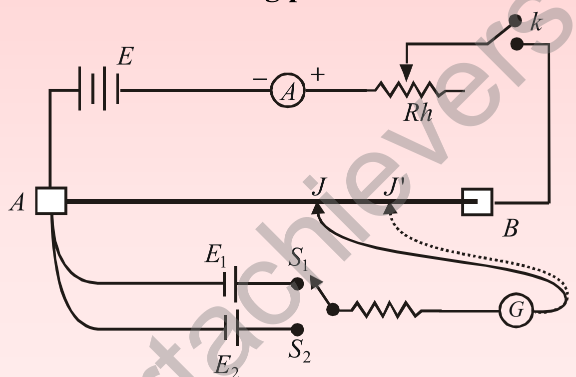
where $K = \frac{\rho I}{A}$, which is called potential gradient along the length of the wire.

i.e., $\boxed{V \propto l}$

- If there is no deflection in galvanometer G, then potential drop across portion aJ is balanced by emf of cell (E).
  Thus $\boxed{E = K\,l}$
- Sensitivity of potentiometer wire is increased by taking number of wires in potentiometer or by decreasing potential gradient along length of potentiometer wires.

APPLICATION OF POTENTIOMETER:

1. Comparison of emf's of two cells using potentiometer



Let E_1 and E_2 be the emf's of two cells which are to be compared.

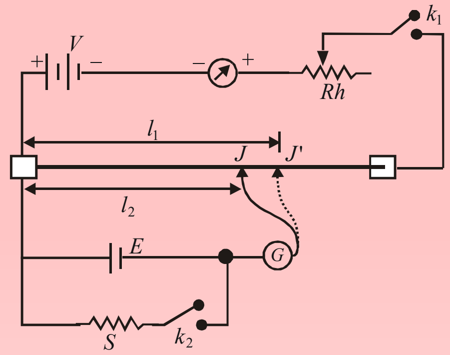
Close the switches and move Jockey J to different points on wire and let for l_1 of potentiometer, there is no deflection in galvanometer (G). So

$$\boxed{E_1 = K\,l_1}$$

Now close switch S_2 and repeat the process for zero deflection in galvanometer and let balancing length is l_2, then $\boxed{E_2 = K\,l_2}$ So, $\boxed{\frac{E_1}{E_2} = \frac{l_1}{l_2}}$

Note: emf of driver cell should be greater than emf of cells E_1 and E_2, otherwise null point cannot be obtained.

2. Determination of internal resistance of a cell using potentiometer



Close Key K_1, but key K_2 must be open. Find point on the wire at which galvanometer gives no deflection. At this stage potentiometer wire balances emf of cell

So, $E = Kl_1$ … (i)

Now close key K_2, so that unknown resistance S is connected across the cell. Let at this stage balancing length is l_2, then it will balance terminal potential difference of cell

$V = Kl_2$ … (ii)

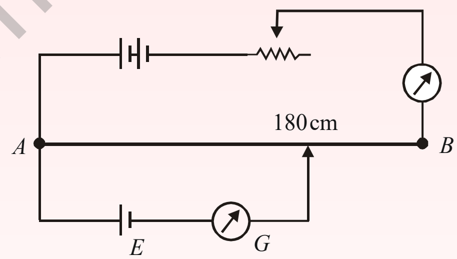
Dividing (i) by (ii), we get

$$\frac{E}{V} = \frac{l_1}{l_2} \quad \text{… (iii)}$$

Since, internal resistance $r = \left(\frac{E}{V} - 1\right)S = \left(\frac{l_1}{l_2} - 1\right)S$

Example-12: **Find the emf of a cell, which balances against a length of 180 cm of a potentiometer wire. Given potential difference per cm of wire as 0.006 volt.**

Solution: **Step-1:** The circuit diagram of the potentiometer along with the cell is shown in figure given below



Step-2: Let $E =$ emf of the given cell which balance against 180 cm of wire

Potential difference per cm of wire = 0.006 volt.

∴ Potential difference across 180 cm of wire,

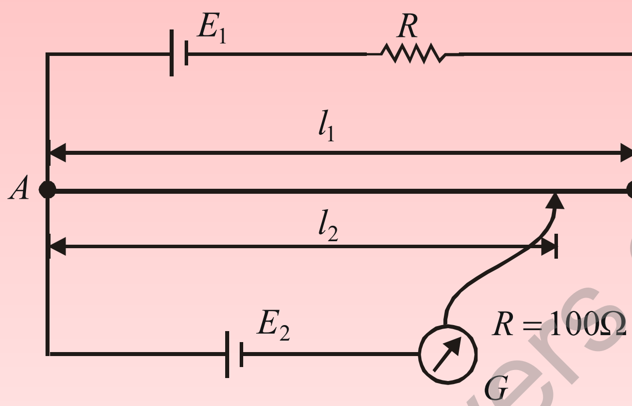
$$V = 0.006 \times 180 = 1.08\ volt$$

Since this potential difference is balanced by the e.m.f of the cell

∴ E.M.F. of the cell,

$$E = V = 1.08\ V$$

Example-13: **In the given circuit, AB is a uniform wire of $10\,\Omega$ and length 1 m. It is connected to series arrangement of cell E_1 of e.m.f 2V and negligible internal resistance and a resistor of resistance R. Terminal A is also connected to an electrochemical cell l_1 of e.m.f 100 mV and a galvanometer G. In this set up a balancing point is obtained at 40 cm mark from A. Calculate the resistance R. If l_1 were to have an e.m.f of 300 mV, where will you expect the balancing point to be?**



Solution: Potential gradient, $K = \dfrac{E_2}{l_2} = \dfrac{E_1}{l_1}\left(\dfrac{r}{R+r}\right)$

Putting the values $\dfrac{100\times10^{-3}}{40} = \dfrac{2}{100}\times\dfrac{10}{(R+10)}$

or $2.5\times10^{-3} = \dfrac{1}{5(R+10)}$

or $R+10 = \dfrac{1}{(2.5\times10^{-3})\times5} = 80$

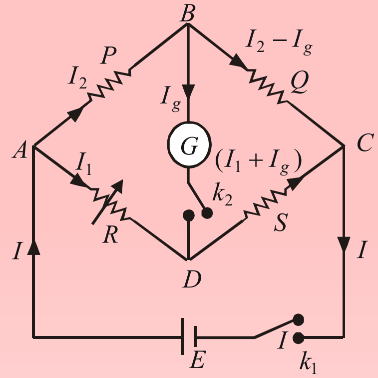
or $R = 80-10 = 70\ \Omega$ again $\dfrac{E_2}{E_1} = \dfrac{l_2}{l_1}$

or $l_2 = \dfrac{E_2}{E_1}\times l_1 = \dfrac{300}{100}\times40 = 120$ cm

Wheat-stone Bridge

- It is an arrangement of four resistances used for measuring unknown resistance in terms of other three known resistances.

Construction:



It consists of four resistances P, Q, R and S arranged in form of bridge. A source of emf E is connected between A and C and galvanometer is connected between B and D. Usually unknown resistance is put in place S.

Principle:

If there is no deflection in galvanometer on pressing key K_1 and $E=Kl_1$, then Wheatstone Bridge is said to be balanced and ratio of P and Q is equal to the ratio of R and S

i.e., $\boxed{\dfrac{P}{Q}=\dfrac{R}{S}}$

Knowing, P, Q and R, the value of S can be calculated.

Proof:

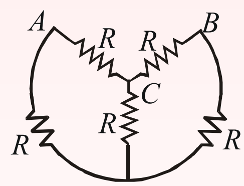
Applying K.V.L in loop BDCB, we get $I_1.R - I_gG - I_2P = 0$ … (i)

Applying K.V.L in loop ADBA, we get $I_gG + (I_1 + I_g)S - (I_2 - I_g)Q = 0$ … (ii)

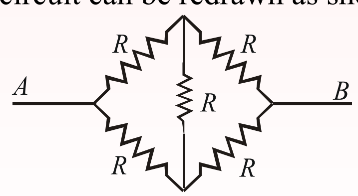
If bridge is balanced, then $I_g = 0$

Hence, equation (i) and (ii) becomes $I_1.R = I_2.P$ and $I_1.S = I_2.Q$ or $\boxed{\dfrac{P}{Q}=\dfrac{R}{S}}$

Example-14: **Find the equivalent resistance between A and B in the given circuit.**



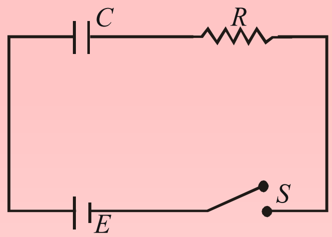
Solution: The given circuit can be redrawn as shown in figure.



It is balanced Wheatstone Bridge. So, equivalent resistance $=R$.

Charging of Capacitor

➢ Consider a capacitor of capacitance C and resistor of resistance R is connected in series with a cell of emf E as shown in circuit diagram.



Key is closed at time t = 0, q = 0 (In initial state)

At time, $t=\infty$, $q=q_0$ (maximum) (In steady state)

So,

$$I=0$$

By using K.V.L at any instant of time t

$$E=V_C+V_R$$

$$E=\frac{q}{C}+IR \qquad (I=\frac{dq}{dt})$$

$$E=\frac{q}{C}+R\frac{dq}{dt}$$

$$\frac{E}{R}=\frac{q}{RC}+\frac{dq}{dt}$$

$$\frac{dq}{dt}=\frac{E}{R}-\frac{q}{RC}$$

$$\frac{dq}{dt}=\frac{CE-q}{RC}$$

$$\frac{dq}{CE-q}=\frac{dt}{RC}$$

On integrating both sides,

$$\int_0^q\frac{dq}{CE-q}=\int_0^t\frac{dt}{RC}$$

$$(-1)[\log_e(CE-q)]_0^q=\frac{1}{RC}(t-0)$$

$$\log_e(CE-q)-\log_e(CE-O)=-\frac{t}{RC}$$

$$\log_e\frac{CE-q}{CE}=-\frac{t}{RC}$$

$$\frac{CE-q}{CE}=e^{-\frac{t}{RC}} \qquad [\log_x y=Z, then\ y=x^z]$$

$$1-\frac{q}{CE}=e^{-\frac{t}{RC}} \qquad q=CE\left(1-e^{-\frac{t}{RC}}\right)$$

At $t \to \infty$, charge is maximum, then $\frac{dq}{dt} = 0$

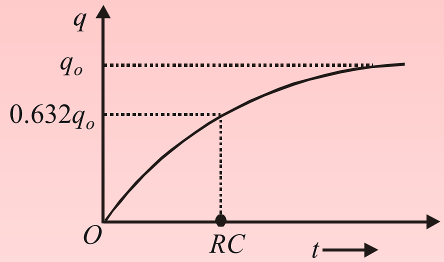
Therefore, $V = IR = 0$ (since, $I = 0$)

Hence, $E = V_C + 0$

$$E = \frac{q_0}{C}$$

So, $q_0 = CE$

$$\boxed{q = q_0\left(1 - e^{-\frac{t}{RC}}\right)}$$



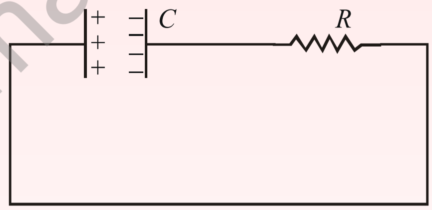
At, t = 0, $q = q_0(1 - e^{-0}) = 0$

At, t = RC $q = q_0\left(1 - \frac{1}{e}\right) = q_0(1 - 0.368) = q_0(0.632)$

At, $t = \infty$ $q = q_0(1 - e^{-\infty}) = q_0\left(1 - \frac{1}{\infty}\right) = q_0$

Discharging of Capacitor

❖ DECAY OF CHARGE ON CAPACITOR (DISCHARGING OF CAPACITOR):



When capacitor charged to attain its maximum value, then cell disconnected to the arrangement of CR circuit. Because of removal of source, capacitor will start discharging

In this case, at $t = 0$, $q = q_0$ (max.) and in steady state, $t = \infty$, $q = 0$.

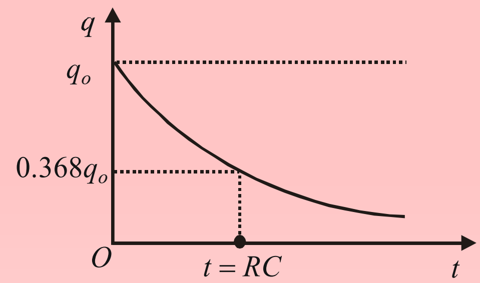
Applying K.V.L at any instant of time t

$V_C + V_R = 0$ or $\frac{q}{C} + IR = 0$ or, $q + IRC = 0$

or $\frac{dq}{dt}(RC) = -q$ (were, $I = \frac{dq}{dt}$) or $\frac{dq}{q} = -\frac{1}{RC}dt$

Integrating both sides, we get $\int_{q_0}^{q} \frac{dq}{q} = -\frac{1}{RC}\int_0^t dt$

or $\ln\left|\frac{q}{q_0}\right| = -\frac{1}{RC}.t$ or, $\frac{q}{q_0} = e^{-\frac{t}{RC}}$ or, $\boxed{q = q_0 e^{-\frac{t}{RC}}}$



Assume $RC = \tau$ (time constant)

At $t = \tau$, $q = q_0 e^{-1} = \frac{q_0}{e} = 0.368\ q_0 = 36.8\%\ q_0$ and

At $t = \infty$, $q = q_0 e^{-\infty} = 0$

Example-15: **A capacitor of capacity $0.5\mu F$ is discharged through resistance 10 Megaohm. Find the time taken for half the charge on the capacitor to be escape. Take $\log_e 2 = 0.693$.**

Solution: Here, $R = 10\,\text{megohm} = 10 \times 10^6 \Omega = 10^7 \Omega$

$T = ?$, $q = \frac{1}{2} q_O$

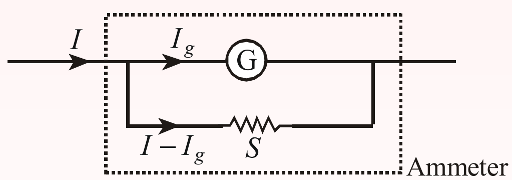
As, $q = q_o e^{-t/RC}$

$\frac{q_o}{2} = q_o e^{-t/RC}$ or $e^{t/RC} = 2$ $\frac{t}{RC} = \log_e 2 = 0.693$

$\therefore\ t = RC \times 0.693$ $= 10^7 \times 0.5 \times 10^{-6} \times 0.693$ $\boxed{t = 3.465\ \text{sec}}$

❖ **CONVERSION OF GALVANOMETER INTO AMMETER:**

(i) Galvanometer has moderate resistance
(ii) Ammeter is a galvanometer of low resistance
(iii) Ideal ammeter has zero resistance
(iv) Ammeter is always connected in series with the given resistance or the circuit through which current is to be measured.
(v) To convert galvanometer in to ammeter a small resistance (shunt) is connected in parallel to the galvanometer as shown in diagram.



Since G and S both are parallel, therefore $I_g G = (I - I_g)S$ or,

$$S = \frac{I_g G}{I - I_g}$$

Note: If $I = n\,Ig$ then $\boxed{S = \frac{G}{\ }}$.

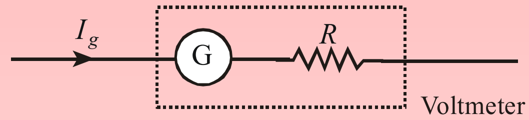
❖ CONVERSION OF GALVANOMETER IN TO VOLTMETER:

(i) Voltmeter has high resistance

(ii) Ideal voltmeter has infinite resistance.

(iii) Voltmeter is always connected in parallel with the resistance across which potential difference has to be measured.

(iv) To convert galvanometer into voltmeter a very high resistance R is connected is series with it.



Potential difference across galvanometer and resistance R is

$V = I_g(G+R)$ $\boxed{R = \frac{V}{I_g} - G}$

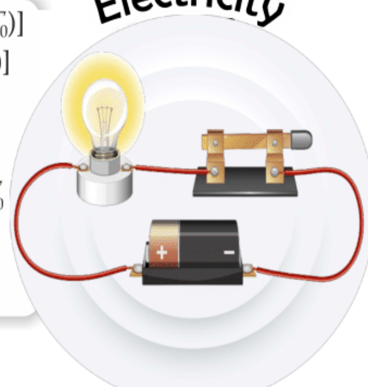
Example-16: **The resistance of galvanometer is 2.5Ω and it requires 50 mA current for full scale deflection. What is the value of the resistance required to convert into a V.M of 125 volts.**

Solution: $R = G(n-1)$

Were, $n = \frac{\text{final range of V.M}}{\text{initial range of galvanometer to measure voltage}}$

$= \frac{125}{2.5 \times 0.05} = 1000$ so, $R = 2497.5\Omega$.

Current Electricity



Electric Current
Rate of flow of charge through an area,

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

$$i = \int \vec{J}.d\vec{S}$$

Current density
$\vec{J} = \frac{\Delta i}{\Delta s \cos\theta} = \sigma E$

ΔS = Area of cross-section

θ = Angle between Area vector and 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 $V = IR$

Resistivity
$$\rho = \frac{1}{\sigma} \Omega\, m$$

Conductivity
$$\sigma = J/E$$

Grouping of Resistors
In series combination

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

For two resistors,

$R_{eq} = R_1 + R_2$

In parallel combination

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \text{- - -} + \frac{1}{R_n}$$

For two resistors

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$$

Temperature Dependence of Resistance
$R = R_0 [1 + \alpha (T - T_0)]$

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

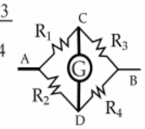
R = Resistance at temperature T

R_0 = Resistance at temperature T_0

α = Temperature coefficient of resistance

Wheatstone Bridge
- Condition for balanced wheatstone bridge

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



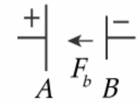
- $V_c = V_D$

  No current through G i.e., Ig > 0

Electric cell
It is a device which maintains a potential difference between its two terminals.

EMF
emf $= E = \frac{W}{q}$

It is equal to the potential difference between the terminals when the they are not connected externally.



Internal Resistance
$V_A - V_B = E - ir$

r = Internal resistance of the cell

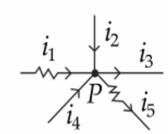
Grouping of Cell
Parallel grouping
$$E_{eq} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}, \quad i = \frac{E_{eq}}{R + \frac{r_1 r_2}{r_1 + r_2}}$$

Series grouping
$$i = \frac{E_1 + E_2}{R_1 + (r_1 + r_2)} = \frac{E_0}{R_1 + R_2}$$

$E_0 = E_1 + E_2, \quad R_2 = r_1 + r_2$

Kirchhoff's Rules
Junction Rule
$i_1 + i_2 + i_4 = i_3 + i_5$

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



Loop Rule
The algebraic sum of all the potential difference along a closed loop is zero.

$\Sigma E = 0$

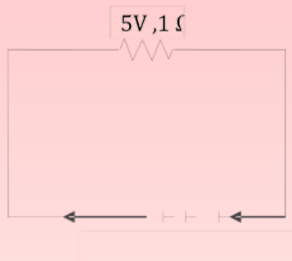
Trace the Mind Map

- First Level
- Second Level
- Third Level

PRACTICE QUESTIONS

1. A wire has an area of cross section 0.1 m^2 having 62.5×10^{18} electrons flowing per second through it. Find the value of current.
   a) 0.1 A b) 1 A c) 10 A d) 0.11 A

2. In the given electric circuit, each cell has an electromotive force (emf) of 5V and an internal resistance of 1Ω. The external resistance in the circuit is 3Ω. Determine the value of the current (I) flowing through the circuit, expressed in amperes.



   a) 1 A b) 1.5 A c) 2 A d) 2.5 A

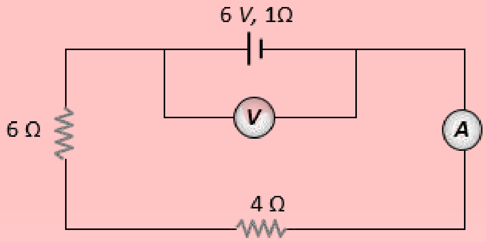
3. The resistance of 2 A ammeter is 0.1Ω. To convert it into 10 A ammeter, the shunt resistance required will be
   a)0.18 Ω b) 0.00125 Ω c) 0.002 Ω d) 0.125 Ω

4. Consider a straight conductor with a uniform cross-section that carries a current (I). Let's denote the specific charge on an electron as (S). The momentum per unit length of the conductor, contributed by the drift velocity of the free electrons only, can be calculated as follows.
   a) IS b) I/S c)$\sqrt{(\frac{I}{s})}$ d) $(I/S)^2$

5. To electroplate a piece of metal weighing 400 g with 5% of its weight in gold, we need to determine how long it will take to deposit the required amount of gold using a current strength of 5 A.
   (Given, electrochemical equivalent of H $= 0.0104 \times 10^{-4}$ gC^{-1} , atomic weight of gold = 197.1, atomic weight of hydrogen = 1.008)

   a)7347.9 s b) 14695.8 s c) 7151.7 s d) 14000 s

6. In the circuit shown here, the readings of the ammeter and voltmeter are



a) $6\ A, 60\ V$
b) $0.6\ A, 6\ V$
c) $6/11\ A, 60/11\ V$
d) $11/6\ A, 11/60\ V$

7. In a closed box, there is a series connection of twelve cells, each with an electromotive force (emf) of E volts. However, some of these cells are wrongly connected with their positive and negative terminals reversed. The circuit includes an ammeter, an external resistance of R ohms, and a two-cell battery (consisting of cells of the same type as the previous ones) connected perfectly in series. When the 12-cell battery and the 2-cell battery are aiding each other, the current in the circuit is measured as 3A. Conversely, when they oppose each other, the current is measured as 2A. Determine the number of cells in the 12-cell battery that are connected incorrectly.

a) 4 b) 3 c) 2 d) 1

8. An ammeter gives full scale deflection when current 2.0 A is passed in it. To convert it into 10 A range ammeter, the ratio of its resistance and the shunt resistance will be.

a) 1: 8 b) 1: 10 c) 4: 1 d) 2: 1

9. In a metallic conductor with a non-uniform cross-section, which of the following quantity or quantities remain constant along the length of the conductor as the current flows steadily

a) current, electric field, drift speed
b) drift speed only
c) current and drift speed
d) current only

10. The relation between Electric field (E) and current density (J) is

a) $E \propto J^{-1}$ b) $E \propto J$ c) $E \propto \frac{1}{J^2}$ d) $E^2 \propto \frac{1}{J}$

11. A wire 150cm long and 1.0 mm diameter has a resistance of 0.9 ohm, the electrical resistivity of the material is

a) 6.36×10^{-6} ohm × m
b) 2.23×10^{-6}ohm × m
c) 1.17×10^{-6} ohm × m
d) 3.18×10^{-6} ohm × m

12. A brass rectangular plate 15cm × 5cm is to be electroplated with copper. If we wish to coat it with a layer of 0.02 mm thick both sides, how much time will it take with a constant current of 2A? Given ECE of copper is 33×10^{-5}g C^{-1} and density of copper is 8.9 g cm^{-3}.

a)2025 s
b)4060 s
c)4000 s
d)8000 s

13. The specific resistance of manganin is 20×10^{-8} ohm × m. The resistance of a cube of length 100cm will be

a) 10^{-6} ohm
b) 0.2×10^{-6} ohm
c) 10^{-8} ohm
d) 5×10^{-4} ohm

14. Conductors have fairly large currents because

a) The electron drift speed is usually very large
b) The number density of free electrons is very high and this can compensate for the low values of the electron drift speed and the very small magnitude of the electron charge
c) The number density of free electrons as well as the electron drift speeds are very large and these compensate for the very small magnitude of the electron charge
d) The very small magnitude of the electron charge has to be divided by the still smaller product of the number density and drift speed to get the electric current

15. The expression for the current in a conductor as a function of time is given by I = 5t + 3t^2, where I is measured in amperes (A) and t is measured in seconds (s). Determine the electric charge that flows through a section of the conductor between t = 1s and t = 3s.

a) 10 C
b) 39 C
c) 33 C
d) 44 C

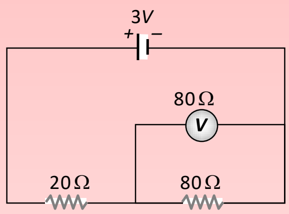
16. A silver voltameter of resistance 5 ohm and a 6 ohm resistor is connected in series across a cell. If a resistance of 2 ohm is connected in parallel with the voltameter, then the rate of deposition of silver

a) Decreases by 25%
b) Increases by 25%
c) Increases by 37.5%
d) Decreases by 37.5%

17. The V − i graph for a good conductor makes angle 60° with V −axis. Here V denotes voltage and i denotes current. The resistance of the conductor will be

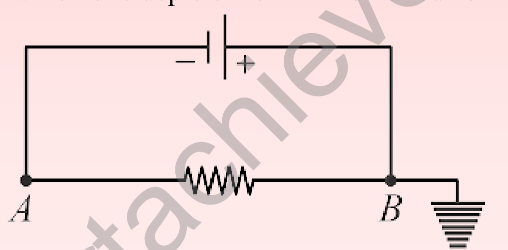
a) sin 40° b) cot 60° c) tan 40° d) cos 60°

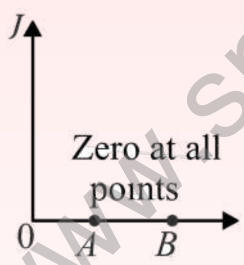
18. The e m f of the cell is 3 volt and the internal resistance is negligible. The resistance of the voltmeter is 80 ohm. The reading of the voltmeter will be

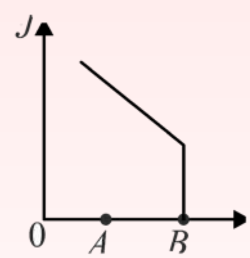


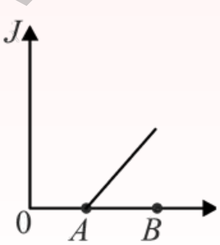
a) 0.80 $volt$ b) 1.60 $volt$ c) 1.33 $volt$ d) 2.00 $volt$

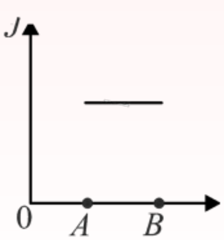
19. A uniform resistance wire AB is connected to a battery, and point B is earthed. We are given a set of graphs, determine which one depicts the variation of current density J along AB.



a)


c)


b)


d)


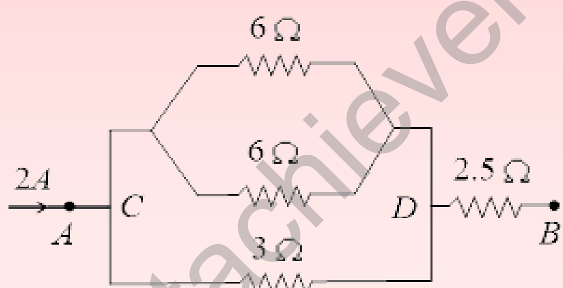
20. In an ionization chamber with parallel conducting plates serving as the anode and cathode, there are 2×10^7 electrons and an equal number of singly charged positive ions cm^3. The electrons are moving towards the anode at a velocity of 0.4 m/s. The current density from the anode to the cathode is $7\mu A/m^2$. Determine the velocity of the positive ions moving towards the cathode

a) 0.4 m/s b) 0.9 m/s c) 0.8 m/s d) 1 m/s

21. Two resistors are connected (a) in series (b) in parallel. The equivalent resistance in the two cases is 10 ohm and 8 ohm respectively. Then the resistance of the component resistors is

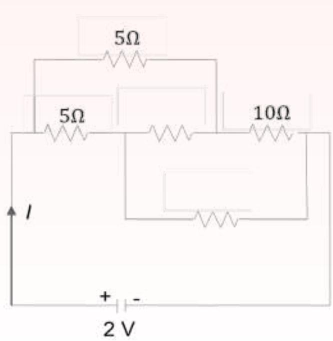
a) 2 ohm and 7 ohm b) 8 ohm and 10 ohm c) 3 ohm and 9 ohm d) 5 ohm and 4 ohm

22. What is the equivalent resistance and potential difference across the points A and B respectively?



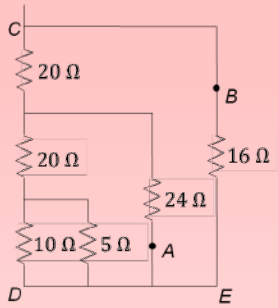
a) 4 Ω, 8 V b) 8 Ω, 4 V c) 2 Ω, 2 V d) 16Ω, 18V

23. The current I drawn from the 2 V source will be



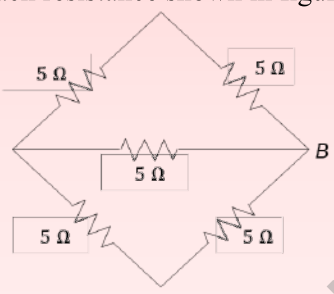
a) 0.83A b) 0.5A c) 0.67A d) 0.17A

24. What is the equivalent resistance across the points *A* and *B* in the circuit given below?



a) 8 Ω b) 12 Ω c) 16 Ω d) 32 Ω

25. Each resistance shown in figure is 5 Ω. The equivalent resistance between *A* and *B* is



a) 5 Ω b) 4 Ω c) 10 Ω d) 1Ω

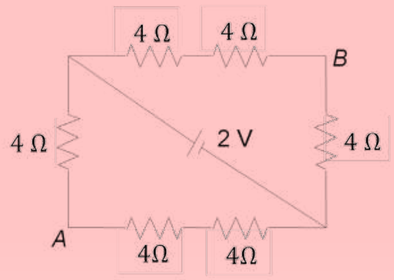
26. We have two resistances, R1 and R2, which are composed of different materials. The material of R1 has a temperature coefficient of α, while the material of R2 has a temperature coefficient of -β. To ensure that the resistance of the series combination of R1 and R2 remains constant regardless of temperature, the ratio R1/R2 is

a) $\frac{\alpha}{\beta}$ b) $\frac{\alpha+\beta}{\alpha-\beta}$ c) $\frac{\alpha^2+\beta^2}{\alpha\beta}$ d) $\frac{\beta}{\alpha}$

27. The thermo-electromotive force (EMF) in a thermocouple is expressed by the equation $E = 5\theta - \frac{\theta^2}{20}$, where θ represents the temperature difference between the two junctions. To determine the neutral temperature in this context, what is the value of θ at which the EMF is zero.

a) 100℃ b) 200℃ c) 50℃ d) 10℃

29. The potential difference between the points A and B will be



a) $\frac{2}{3}$V b) $\frac{8}{9}$V c) $\frac{4}{3}$V d) 2V

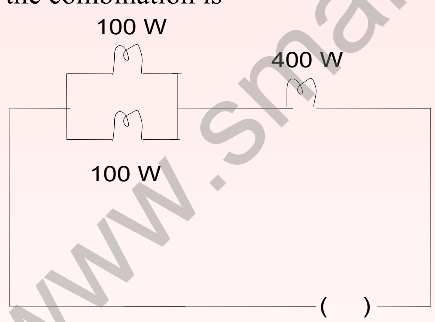
30. In a thermoelectric couple, one junction is maintained at a constant temperature Tr, while the temperature of the other junction is denoted as T. The thermo-electromotive force for this couple is expressed as $E = K(T - T_r)[\, T_0 + \frac{1}{2}(T^2 + T_r^2)\,]$
What is the value of the thermoelectric power, when T is equal to 2T1.

a) $\frac{1}{2}\, K\, T_0$ b) $\frac{3}{2}\, K\, T_0$ c) $\frac{1}{2}\, K\, T_0^2$ d) $\frac{1}{2} K\, (T_0 - T_r)^2$

31. Two cells connected in parallel, with internal resistances of 0.6 Ω and 0.4 Ω. The voltage across the combination of cells is measured to be 1.5 V. If the electromotive force (emf) of one cell is 1.2 V, determine the emf of the second cell

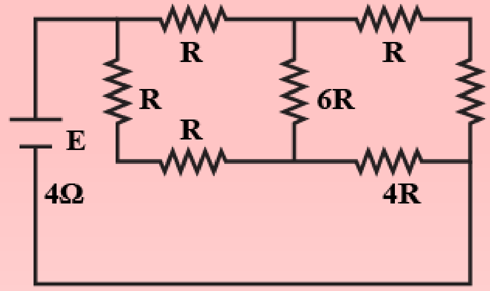
a) 2.7 V b) 2.1 V c) 3 V d) 4.2V

32. Three electric bulbs of 100 W, 100 W and 400 W are shown in figure. The resultant power of the combination is



a) 133W b) 155 W c) 200 W d) 399W

33. A network of resistors is connected to a battery with an internal resistance of 2 Ω. In order to achieve maximum power delivery to the network, determine the optimal value of R *(in Ω)*

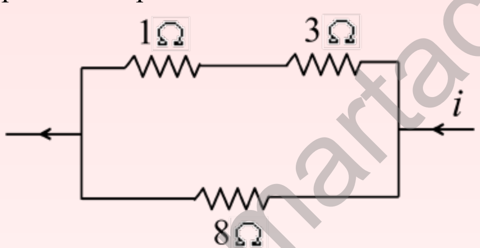


a) 4/9 b) 2 c) 1 d) 18

34. A heating coil can raise the temperature of a given amount of water from 20°C to 100°C within 60 minutes. Now, if two identical heating coils are connected in series and used to heat the same amount of water through the same temperature range, find the new time it will take (denoted as r), assuming there is no significant thermal capacity effect from the coils.

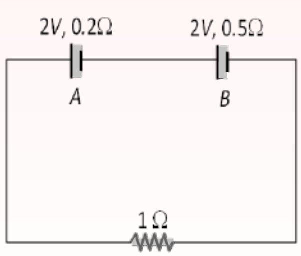
a) 60 minutes b) 30 minutes c) 150 minutes d) 120minutes

35. The circuit shown contains an 8Ω resistor where 2W of power is dissipated. Calculate the power dissipated in watts across the 3Ω resistor in the same circuit.



a) 1 ohm b) 2 ohm c) 0.43 ohm d) 0.34 ohm

36. The internal resistances of two cells shown are 0.2 Ω and 0.5 Ω. If $R = 1\ \Omega$, the potential difference across the cell



a) B will be zero
b) A will be zero
c) A and B will be 2V
d) A and B will be > 2V

37. The Wheatstone bridge configuration consists of three resistances, namely P, Q, and R, connected in three arms. The fourth arm is formed by two resistances, S1 and S2, connected in parallel. To achieve a balanced condition in the Wheatstone bridge, identify the specific condition that must be satisfied.

a) $\frac{P}{Q}=\frac{2R}{S_1+S_2}$
b) $\frac{P}{Q}=\frac{R(S_1+S_2)}{S_1S_2}$
c) $\frac{P}{Q}=\frac{R(S_1+S_2)}{2S_1S_2}$
d) $\frac{P}{Q}=\frac{R}{S_1+S_2}$

38. A galvanometer with a resistance of 30 ohms has a maximum current reading capacity of 6mA. By connecting the galvanometer appropriately, it can be used as a voltmeter to measure a maximum potential difference of 6V. Select the correct choice from the options provided.

a) 1025 Ω in series
b) 1025 Ω in parallel
c) 970 Ω in series
d) 970 Ω in parallel

39. A resistor has a colour code of green, blue, brown and silver. What is its resistance?

a) $5600\Omega \pm 10\%$
b) $560\Omega \pm 5\%$
c) $560\Omega \pm 10\%$
d) $56\Omega \pm 5\%$

40. A galvanometer, having a resistance of 30 Ω, gives a full-scale deflection for a current of 0.02A. The length in meter of a resistance wire of area of cross-section $4 \times 10^{-2} cm^2$ that can be used to convert the galvanometer into an ammeter which can read a maximum of 3 A current is
(Specific resistance of the wire $= 5 \times 10^{-7}\ \Omega m$)

a) 9
b) 6
c) 3
d) 1.5

-----------------------------------ANSWER KEY-------------------------------------

1)	c	2)	d	3)	b	4)	b
5)	b	6)	c	7)	d	8)	c
9)	d	10)	b	11)	a	12)	a
13)	b	14)	b	15)	b	16)	c
17)	b	18)	d	19)	b	20)	c
21)	d	22)	a	23)	a	24)	a
25)	a	26)	d	27)	c	28)	b
29)	b	30)	b	31)	a	32)	a
33)	c	34)	d	35)	d	36)	d
37)	d	38)	c	39)	c	40)	c

HINTS AND SOLUTIONS

1. c)

As we know,

$$I = Q/t$$

where Q = ne (number of electrons × charge on each electron which is 1.6×10^{-19})

Therefore,

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

$$= 62.5 \times 1018 \times 1.6 \times 10 - 19 / 1$$
$$= 10\,A$$

2. d)

Value of current,

$$\text{Current} = \frac{\text{net emf}}{\text{net resistance}}$$

or $I = \frac{5+5+5}{1+1+1+3} = \frac{15}{6} = 2.5A$

3. b)

$$S = \frac{i_g G}{(i - i_g)} = \frac{1 \times 0.1}{10 - 2} = \frac{0.01}{8}$$
$$= 0.00125\Omega$$

4. b)

In mechanics momentum is,

$$p = mv$$

Similarly, here for electrons in conductor momentum pc(say) is

$$pc = m\,N\,vd \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where, m is mass of electrons, N is number of free electrons per unit length

of conductor and v_d is the drift velocity.

Number of free electrons per unit length of conductor is

$$N = l\,n\frac{A}{l}$$
$$= nA$$

$$vd = \frac{i}{ne}A$$

where, variables have their usual meanings.

Using above values, equation (1) becomes

$$pc = m\left(\frac{\boldsymbol{i}}{neA}\right)(nA)$$

$$pc = \frac{i}{me}$$

$$pc = \frac{i}{S}$$

where, S=me, specific charge on an electron.

5. b)

Chemical equivalent of gold $= \frac{197.1}{3} = 65.7$

Gold to be deposited $= \frac{400\times5}{100}$ =20g

Electrochemical equivalent of gold

$$z_2 = \frac{W_2}{W_1} z_1\, z_2$$
$$= \frac{65.7}{1.008} \times 0.1044 \times 10^{-4} \text{gC}^{-1}$$

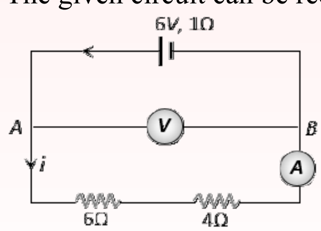
Also $m = zlt, t = \frac{m}{zl}$

$$\Rightarrow = \frac{20}{\left(\frac{65.7}{1.008} \times 0.1044 \times 10^{-4} \times 2\right)}$$

= 14695.8s

6. c)

The given circuit can be redrawn as follows



Current $i = \frac{6}{6+4+1} = \frac{6}{11}A$

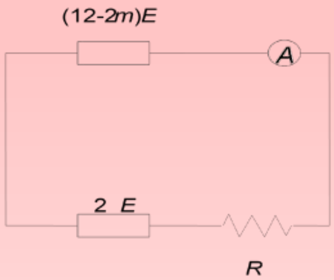
P.D. between A and B,

$$V = \frac{6}{11} \times 10 = \frac{60}{11}V$$

7. d)

Let polarity of m cells in a 12 cells battery is reversed, then equivalent emf of the battery = $(12-2m)E$

Now the circuit can be drawn as



When 12-cell battery and 2-cell battery aid each other, then current through the circuit

$$i_1 = \frac{(12-2m)E + 2E}{R}$$

or $3 = \dfrac{(14-2m)E}{R}$ .... (i)

When they oppose each other, the current through the circuit.

$$i_2 = \frac{(12-2m)E - 2E}{R}$$

or $2 = \dfrac{(10-2m)E}{R}$ ... (ii)

Dividing Eq. (i) by Eq. (ii), we have

$$\frac{3}{2} = \frac{14-2m}{10-2m}$$

or $30 - 6m = 28 - 4m$

or $2m = 2$

or $m = 1$

8. c)

$$S = \frac{i_g G}{(i - i_g)} \Rightarrow \frac{G}{S} = \frac{i = i_g}{i_g} = \frac{10-2}{2} = \frac{8}{2}$$

9. d)

When a steady current flows in a metallic conductor of non-uniform cross-section, the current flowing through the conductor is constant. Current density, electric field, and drift speed is inversely proportional to the area of cross-section. Therefore, they are not constant.

10. b)

Theory

11. a)

$$R = \frac{\rho L}{A} \Rightarrow 0.9 = \frac{\rho \times 1}{\frac{22}{7}(1.5 \times 10^{-3})^2}$$

$$\rho = 6.36 \times 10^{-6} ohm - m$$

12. a)

Mass of copper deposited,

m = volume × density

= (area × thickness) × density

= [(75) × 0.002] × 8.9 g

$$t = \frac{m}{zI} = \frac{[(75)\times 0.002 \times 8.91]}{33\times 10^{-5} \times 2} = 2025\text{s}.$$

13. b)

R=ρl/A

$=20\times10^{-8}\times100\times10^{-2}/(100\times10^{-2})^2$

=0.2 μ Ω

14. b)

We are able to obtain fairly currents in a conductor because the number density of free electrons is very high and this can compensate for the low values of the electrons drift speed and the very small magnitude of the electrons charge.

15. b)

$$dQ = Idt \Rightarrow Q = \int_{t=1}^{t=3} Idt$$

$$= \left[5\int_1^3 tdt + 3\int_1^3 t^2 dt\right]$$

$$= [5t^2/2]_1^3 + [t^3]_1^3$$

$$= (45-5)/2 + (27-8) = 20 + 19$$

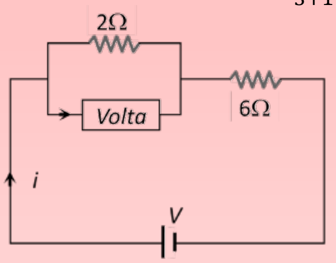
$$= 39C$$

16. c)

Initially current through the voltmeter

$i_1 = \frac{V}{(5+6)} = \frac{V}{11}$

Finally main current $i = \frac{V}{3+1} = \frac{V}{4}$



Hence current through voltameter $i_2 = \frac{V}{8}$

$\because$ Rate of deposition $(R) = \frac{m}{t} = Zi \Rightarrow R \propto i$

$\therefore$ % drop in rate $= \frac{R_2 - R_1}{R_1} \times 100 = \frac{i_2 - i_1}{i_1} \times 100$

$$= \frac{\left(\frac{V}{8} - \frac{V}{11}\right)}{\frac{V}{11}} \times 100 = +37.5\%$$

17. b)

Resistance, $R = \frac{V}{i} = \cot 60°$

18. d)

Total resistance of the circuit $= \frac{80}{2} + 20 = 60\ \Omega$

$\Rightarrow$ Main current $i = \frac{3}{60} = \frac{1}{20} A$

Combination of voltmeter and 80Ω resistance is connected in series with 20Ω, so current through 20Ω and this combination will be same $= \frac{1}{20}\ A$

Since the resistance of voltmeter is also 80Ω, so this current is equally distributed in 80Ω resistance and voltmeter [$i.e. \frac{1}{40} A$ through each]

P.D. across 80Ω resistance $= \frac{1}{40} \times 80 = 2V$

19. d)

Wire AB is uniform so current through wire AB at every across section will be same. Hence current density, $J (= i/A)$ at every point of the wire will be same

20. c)

Current density of drinking electrons

$j = nev$

$n = 2 \times 10^7\ cm^{-3} = 2 \times 10^7 \times 10^6 m^{-3}$

$v = 0.4\ ms^{-1}, e = 1.6 \times 10^{-19} C \Rightarrow j$

$= 3.2 \times 10^{-6}\ Am^{-2}$

Current density of ions $= (7 - 3.2) \times 10^{-6} = 3.8 \times 10^{-6} \frac{A}{m^2}$

This gives v for ions $= 0.8\ ms^{-1}$

21. b)

$R_1 + R_2 = 18$ and $\frac{R_1 R_2}{R_1 + R_2} = 4.44 \Rightarrow$

$R_1 R_2 = 80$

$R_1 - R_2 = \sqrt{(R_1 + R_2)^2 - 4R_1 R_2}$

$= \sqrt{324 - 320} = 2$

$R_1 = 8\Omega, R_2 = 10\Omega$

22. a)

The equivalent resistance between C and D is

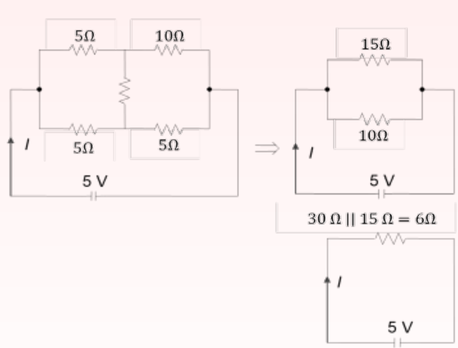
$\frac{1}{R'} = \frac{1}{6} + \frac{1}{6} + \frac{1}{3} = \frac{2}{3}$ or $R' = \frac{3}{2} = 1.5\Omega$

Now the equivalent resistance between A and B as $R' = 1.5\Omega$ and 2.5Ω are connected in series, $= 1.5 + 2.5 = 4\Omega$

Now by ohm's law, potential difference between A and B is given by $V_A - V_B = iR = 2 \times 4.0 = 8\ volt$

23. a)

Which is a balanced Wheatstone's bridge and hence, no current flows in the Centre resistor, so equivalent circuit would be as shown below.



So, $I = \frac{V}{R} = \frac{5}{6} = 0.83A$

24. a)

$$\frac{1}{R_1} = \frac{1}{10} + \frac{1}{2.5} = \frac{5}{10} = \frac{1}{2} \Rightarrow R_1 = 2\Omega$$

Now 2Ω and 10 Ω are in series

$R_2 = 10 + 2 = 12\Omega$

R_2 and 12Ω are in parallel

$$\frac{1}{R_3} = \frac{1}{12} + \frac{1}{12} \Rightarrow R_3 = 6\Omega$$

Now $R_3$and 6Ω are in series

$R_4 = 10 + 6 = 16\Omega$

Now, $R_4$and 16 Ω are in parallel

$$\therefore \frac{1}{R} = \frac{1}{16} + \frac{1}{16}$$

$$\Rightarrow R = 3\Omega$$

25. a)

Given circuit is a balanced Wheatstone bridge.

So, diagonal resistance of 5Ω will be ineffective.

Equivalent resistance of upper arms

=5+5=10 Ω

Equivalent resistance of lower arms

=5+5=10 Ω

$$R_{AB} = (10 * 10)/10 + 10 = 5\Omega$$

26. d)

$R_1 + R_2 = R_1(1 + \alpha t) + R_2(1 - \beta t)$

$$\Rightarrow R_1 + R_2 = R_1 + R_2 + R_1\alpha t - R_2\beta t$$

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

27. c)

Comparing the given equation with standard equation

$$E = \alpha t + \frac{1}{2}\beta t^2$$

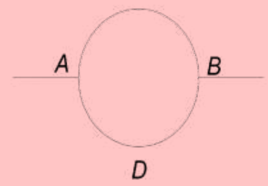
$$\alpha = 5 \text{ and} \frac{1}{2}\beta = -\frac{1}{20} \Rightarrow \beta = -\frac{1}{10}$$

Hence neutral temperature $t_n = -\frac{\alpha}{\beta} = \frac{-5}{-1/10}$

$\Rightarrow t_n = 50°C$

28. b)

Given that the resistance of the total wire is 2Ω.



Here, ACB (1Ω) and ADB (1Ω) are in parallel.

So, the resistance across any diameter is

$$\Longrightarrow \frac{1}{R} = \frac{1}{1} + \frac{1}{1} = 2$$

$$\Longrightarrow \text{R} = 2\Omega$$

29. b)

The circuit diagram may be redrawn as shown here.

Obviously, $I_{\text{CAD}} = I_{\text{CBD}} = \frac{2}{12}\text{A}$

$$\therefore V_C - V_A = \frac{2}{15}\text{A} \times 5\Omega = \frac{2}{3}\text{V}$$

and $V_c - V_B = \frac{2}{15}\text{A} \times 10\Omega = \frac{4}{3}\text{V}$

$$\therefore V_A - V_B = (V_C - V_B) - (V_c - V_A)$$

$$= \frac{4}{3}\text{V} - \frac{2}{3}\text{V} = \frac{2}{3}\text{V}$$

30. b)

$$E = K(T - T_r)T_0 + \frac{1}{2}K(T^2 - T_r^2)$$

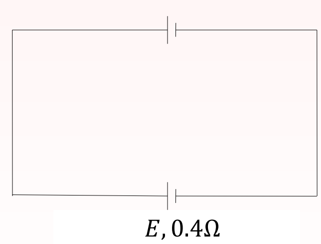
$$\frac{dE}{dT} = KT_0 + \frac{1}{2}K \times 2T = KT_0 + KT$$

At temperature $T = T_0/2$,

Thermo-electric power is $\frac{dE}{dT} = KT_0 + K\frac{T_0}{2} = \frac{3}{2}K\,T_0$.

31. a)

Given that, the resultant voltage across the battery terminal=1.5V

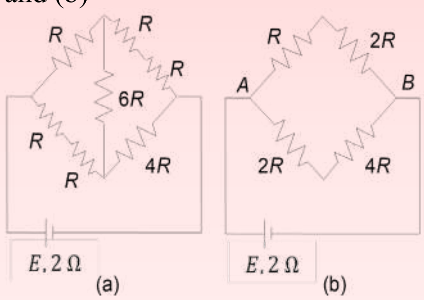


Let I be the current in the circuit then total resistance =1Ω
Hence, $V = IR$
$\Rightarrow 1.5 = I \times 1 \Rightarrow I = 1.5A$
Now, applying Kirchhoff's second law in the circuit
$0.4I + 0.6I + 1.2 - E = 0$
$1.5 + 1.2 = E$

32. a)
$P' = P_A + P_B = 100 + 100$
$= 200$ W
Now P' and bulb C are in series. So, the resultant power of the combination is

$$P'' = \frac{200 \times 400}{200 + 400} = 133.3 \text{ W}$$

33. c)
The equivalent circuit is as shown in figure (a) and (b)



Since, the network of resistances is a balanced Wheat stone bridge, so resistance between points A and B of network figure (b) is given by
$\frac{1}{R'} = \frac{1}{3R} + \frac{1}{6R} = \frac{2+1}{6R} = \frac{1}{2R}$ or $R' = 2R$
For maximum power to the network, R' should be equal to internal resistance of the battery. So
$$R' = 2R = 2 \text{ or } R = 2/2 = 1\Omega$$

34. d)
$$H_1 = H_2 \Rightarrow \frac{v^2}{R} t_1 = \frac{v^2}{2R} t_2 \Rightarrow$$
$$t_2 = 2t_1 \Rightarrow t_1 = 30 \text{ min}$$
$$\therefore t_2 = 120 \text{ min}$$

35. d)
$$i = \frac{V}{R} \Rightarrow 2 = \frac{6}{\frac{4 \times 8}{4 + 8} + R} = \frac{6}{2.6 + R}$$
$$\Rightarrow R = 0.34\ \Omega$$

36. d)
Applying Kirchhoff's law
$(2 + 2) = (0.2 + 0.5 + 1)i \Rightarrow$
$$i = \frac{4}{1.7} A$$
Hence potential difference across A
$= 2 - 0.23 = 1.52V$ [less than $2V$]
Potential difference across $B = 2 - 1.17 = 0.82V$

37. b)
Here S consist of S_1 and S_2 arranged in parallel, hence
$$S = \frac{S_1 S_2}{S_1 + S_2}$$
So, the balance condition will be $\frac{P}{Q} = \frac{R}{S} = \frac{R(S_1+S_2)}{S_1 S_2}$

38. c)
$R = \frac{V}{i_g} - G = \frac{6}{6 \times 10^{-3}} - 30 = 970\Omega$ [In series]

39. c)
$R = 56 \times 10 \pm 10\% = 560 + 10\%$

40. c)
Resistance of galvanometer
$G = 30\Omega$
Full scale current $i_g = 0.02$
$A = 4 \times 10^{-2} \text{cm}^2$
$= 4 \times 10^{-2} \times 10^{-4} \text{m}^2$
$= 4 \times 10^{-6} \text{m}^2$
$i = 3A$
$\rho = 5 \times 10^{-7} \Omega\text{m}$
Required resistance to convert the galvanometer into ammeter.
$R = \frac{i_g G}{i - i_g} = \frac{0.02 \times 30}{3 - 0.02} = \frac{0.6}{2.98}$
$\rho \frac{l}{A} = 15/40$
$$l = 0.375 \frac{A}{\rho} = 0.375 \frac{4 \times 10^{-6}}{5 \times 10^{-7}}$$
$$= 0.375 \times 8 = 3\text{m}$$