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Current Electricity

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The directional flow of charge in a conductor under a potential difference maintained between the ends of the conductor constitutes an electric current.

Electric Current

It is defined as the amount of charge flowing across any section of wire per unit time. If charge Δq passes through the area in time interval Δt at uniform rate, then current i is defined as

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

If rate of flow of charge is not steady, then instantaneous current is given by

$$i = \lim_{\Delta t \to 0} \frac{\Delta q}{\Delta t} = \frac{dq}{dt}$$

The SI unit of current is ampere (A). Smaller currents are more conveniently expressed in milliampere (mA) or microampere (μA).

$$1 \text{ mA} = 10^{-3} \text{ A and } 1\,\mu\text{A} = 10^{-6} \text{ A}$$

Note Total charge in time interval t_1 and t_2 is given as

$$q = \int_{t_1}^{t_2} i \cdot dt = \text{Area under the graph } i \text{ versus } t \text{ in interval } t_1 \text{ to } t_2.$$

Current Density

Current density at any point inside a conductor is defined as "the amount of charge flowing per second through a unit area held normal to the direction of the flow of charge at that point."

Current density is a vector quantity and its direction is along the motion of the positive charge.

Current density, $\mathbf{J} = \frac{q/t}{\mathbf{A}} = \frac{i}{\mathbf{A}}$

The SI unit of current density is ampere per square metre, *i.e.* Am^{-2} and its dimensional formula is $[\text{AL}^{-2}]$.

Drift Velocity

It is defined as "the average velocity with which the free electrons in a conductor get drifted towards the positive end of the conductor under the influence of an electric field applied across the conductor."

It is given by, $v_d = \frac{eE}{m}\tau$

where, e = charge on electron, E = electric field, m = mass of the electron and τ = relaxation time.

The electric current relates with drift velocity as

$$i = neAv_d$$

Hence, current density is also given by, $J = \frac{i}{A} = nev_d$.

The direction of drift velocity for electrons in a metal is opposite to that of applied electric field.

The drift velocity of electron is very small of the order of $10^{-4}\,\text{ms}^{-1}$ as compared to thermal speed ($\approx 10^5$ m/s) of electron at room temperature.

Relaxation Time (τ)

As free electrons move in a conductor, they continuously collide with positive ions. The time interval between two successive collisions of electrons with the positive ions in the metallic lattice is defined as relaxation time.

$$\tau = \frac{\text{mean free path}}{\text{rms velocity of electrons}} = \frac{\lambda}{v_{\text{rms}}}$$

With rise in temperature v_{rms} increases, consequently τ decreases.

Mobility (μ)

Drift velocity per unit electric field is called mobility of electron, *i.e.* $\mu = \frac{v_d}{E} = \frac{e\tau}{m}$.

Its unit is $\text{m}^2/\text{V-s}$.

Mobility of free electrons is independent of electric field.

Example 1. *The current in a wire varies with time according to the equation $i = 4 + 2t$, where i is in ampere and t is in second. The quantity of charge which has to be passes through a cross-section of the wire during the time $t = 2$ s to $t = 6$ s is*

(a) 40 C (b) 48 C
(c) 38 C (d) 43 C

Sol. (b) Let dq be the charge which passes in a small interval of time dt. Then, $dq = idt = (4 + 2t)dt$

$\Rightarrow$ $q = \int_2^6 (4 + 2t)dt = [4t + t^2]_2^6 = 48$ C

Example 2. *Drift speed of electrons, when 1.5 A of current flows in a copper wire of cross-section 5 mm^2 is v. If the electron density in copper is 9×10^{28} / m^3, the value of v (in mm/s) is close to (Take, charge of electron to be $= 1.6 \times 10^{-19}$ C)* **[JEE Main 2019]**

(a) 0.02 (b) 0.2 (c) 2 (d) 3

Sol. (a) Relation between current (i) flowing through a conducting wire and drift velocity of electrons (v_d) is given as $i = neAv_d$

where, n is the electron density and A is the area of cross-section of wire.

$\Rightarrow$ $v_d = \frac{i}{neA}$

Substituting the given values, we get

$$v = \frac{1.5}{9 \times 10^{28} \times 1.6 \times 10^{-19} \times 5 \times 10^{-6}}$$

$$v = \frac{1.5 \times 10^{-3}}{72}\ \text{m/s} = 0.2 \times 10^{-4}\ \text{m/s}$$

or $v = 0.02$ mm/s

Ohm's Law

It states that, "the current i flowing through a conductor is always directly proportional to the potential difference V applied across the ends of the conductor", provided that the physical conditions (temperature, mechanical strain, etc.) are kept constant.

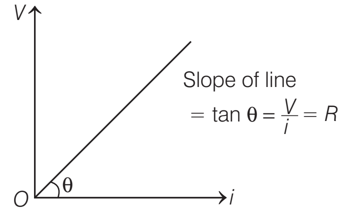
i.e. $i \propto V$ or $V \propto i$ or $V = Ri$

or $\frac{V}{i} = R$ = a constant

where, R = electrical resistance of the conductor.

The SI unit of R is Ω (ohm) and its dimensions are $[\text{ML}^2\text{T}^{-3}\text{A}^{-2}]$.

Graph between V and i for a metallic conductor is a straight line as shown below



Limitations of Ohm's Law

There are some materials and devices used in electric circuits, where the proportionality of V and i does not hold. The deviations broadly are one or more of the following types:

(i) V ceases to be proportional to i.

(ii) If i is the current for a certain V, then reversing the direction of V keeping its magnitude fixed, does not produce a current of the same magnitude as i in the opposite direction. This happens in a diode.

Electrical Resistance and Resistivity

The property of a substance by virtue of which it opposes the flow of current through it is known as resistance.

It depends on the geometrical factors of the substance [length (l), cross-sectional area (A)] as well as on the nature of the substance from which the resistor is made.

$\therefore$ Electrical reistance, $$R = \frac{\rho l}{A} \quad \ldots\text{(iv)}$$

where, ρ is a constant of proportionality called *resistivity* or specific resistance of substance.

Resistivity depends only on the nature of the material of the resistor and its physical conditions such as temperature and pressure. Its unit is ohm-m (Ω-m).

Conductance and Conductivity

Conductance The reciprocal of resistance of a conductor is called its conductance. Thus, conductance (G) of a conductor having resistance R is given by

$$G = \frac{1}{R}$$

Unit of conductance is ohm^{-1}(Ω^{-1}), which is also called *mho*. The unit of conductance in SI system is *siemens* and is denoted by the symbol S.

Conductivity The reciprocal of resistivity of the material of a conductor is called its conductivity. It is denoted by σ. Thus,

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

Its SI unit is siemen metre^{-1} (Sm^{-1}).

Vector Form of Ohm's Law

Ohm's law in vector form is given as

$$\mathbf{E} = \rho\mathbf{J}$$

or $$\mathbf{J} = \sigma\mathbf{E}$$

$\therefore$ Current density, $J = \left(\frac{ne^2\tau}{m}\right)E$

Conductivity, $\sigma = \frac{ne^2\tau}{m}$

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

Example 3. *A copper wire is stretched to make it 0.5% longer. The percentage change in its electrical resistance, if its volume remains unchanged is* **[JEE Main 2019]**

(a) 2.0% (b) 1.0% (c) 0.5% (d) 2.5%

Sol. (*b*) Electrical resistance of wire of length l, area of cross-section A and resistivity ρ is given as

$$R = \rho\frac{l}{A} \quad \ldots\text{(i)}$$

Since we know, volume of the wire is $V = A \times l$ ...(ii)

$\therefore$ From Eqs. (i) and (ii), we get

$$R = \rho\frac{l^2}{V} \quad \ldots\text{(iii)}$$

As, the length has been increased to 0.5%.

$\therefore$ New length of the wire,

$$l' = l + 0.5\% \text{ of } l = l + 0.005\, l = 1.005\, l$$

But V and ρ remains unchanged.

So, new resistance, $R' = \frac{\rho[(1.005)\ l]^2}{V}$ ...(iv)

Dividing Eq. (iv) by Eq. (iii), we get

$$\frac{R'}{R} = (1.005)^2$$

$\Rightarrow$ % change in the resistance $= \left(\frac{R'}{R} - 1\right) \times 100$

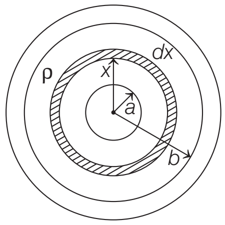
$$= [(1.005)^2 - 1] \times 100 = 1.0025\% \simeq 1\%$$

Example 4. *Space between two concentric conducting spheres of radii a and b (b > a) is filled with a medium of resistivity ρ. The resistance between the two spheres (in ohm) will be* **[JEE Main 2019]**

(a) $\frac{\rho}{2\pi}\left(\frac{1}{a} + \frac{1}{b}\right)$ (b) $\frac{\rho}{4\pi}\left(\frac{1}{a} - \frac{1}{b}\right)$

(c) $\frac{\rho}{2\pi}\left(\frac{1}{a} - \frac{1}{b}\right)$ (d) $\frac{\rho}{4\pi}\left(\frac{1}{a} + \frac{1}{b}\right)$

Sol. (*b*) For an elemental shell of radius x and thickness dx,



Resistance, $dR = \rho\frac{l}{A} \Rightarrow dR = \rho\frac{dx}{4\pi x^2}$

So, resistance of complete arrangement is

$$R = \int_a^b dR = \int_a^b \rho\frac{dx}{4\pi x^2} = \frac{\rho}{4\pi}\int_a^b x^{-2}dx$$

$$\Rightarrow \quad R = \frac{\rho}{4\pi}\left(\frac{x^{-1}}{-1}\right)_a^b = \frac{\rho}{4\pi}\left(-\frac{1}{x}\right)_a^b$$

$$= \frac{\rho}{4\pi}\left(-\frac{1}{b} - \left(-\frac{1}{a}\right)\right)$$

$$= \frac{\rho}{4\pi}\left(\frac{1}{a} - \frac{1}{b}\right) \text{ ohm}$$

Example 5. *In a conductor, if the number of conduction electrons per unit volume is 8.5×10^{28} m^{-3} and mean free time is 25 fs (femto second), it's approximate resistivity is (Take, $m_e = 9.1 \times 10^{-31}$ kg)* **[JEE Main 2019]**

(a) 10^{-7} Ω-m (b) 10^{-5} Ω-m

(c) 10^{-6} Ω-m (d) 10^{-8} Ω-m

Sol. *(d)* Resistivity of a conductor is $\rho = \dfrac{m_e}{ne^2\tau}$ ... (i)

where, m_e = mass of electron = 9.1×10^{-31} kg,

n = free charge density = 8.5×10^{28} m^{-3},

τ = mean free time = 25 fs = 25×10^{-15} s

and e = charge of electron = 1.6×10^{-19} C

Substituting the values in Eq. (i), we get

$$\rho = \frac{9.1 \times 10^{-31}}{8.5 \times 10^{28} \times (1.6 \times 10^{-19})^2 \times 25 \times 10^{-15}}$$

$$= \frac{9.1 \times 10^{-6}}{8.5 \times 2.56 \times 25} = 0.016 \times 10^{-6}$$

$$= 1.6 \times 10^{-8}\ \Omega\text{-m}$$

$$\simeq 10^{-8}\ \Omega\text{-m}$$

Temperature Dependence of Resistivity

Resistivity of a conductor varies approximately linearly with temperature as

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

Here, ρ is resistivity at temperature T and ρ_0 is resistivity at temperature T_0.

Also, α is temperature coefficient of resistivity which is given as $\alpha = \dfrac{\rho - \rho_0}{\rho_0 (T - T_0)}$

In terms of resistance, $R = R_0 [1 + \alpha (T - T_0)]$

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

Variation of resistance of some electrical material with temperature is as given in table

Material	Temperature coefficient of resistance	Effect of temperature rise on resistance
Metals	$\alpha > 0$	Increases
Solid non-metal	$\alpha \approx 0$	No effect
Semiconductors	$\alpha < 0$	Decreases
Electrolytes	$\alpha < 0$	Decreases
Alloys	$0 < \alpha < 1$	Nearly constant

Example 6. *A heating element using nichrome connected to a 230 V supply draws an initial current of 3.2 A in first 2 seconds, which settles, after a few seconds to a steady value of 2.8 A. What is the steady temperature of the heating element, if the room temperature is 27°C? Temperature coefficient of resistance of nichrome averaged over the temperature range involved is* 1.70×10^{-4} °C^{-1}.

(a) 678.35°C (b) 768.35°C

(c) 867.35°C (d) 976.35°C

Sol. (c) Here, $V = 230$ V, initial current, $i_1 = 3.2$ A, steady current, $i_2 = 2.8$ A

Therefore, resistance of wire at room temperature ($\theta_{12} = 27°$ C),

$$R_1 = \frac{V}{i_1} = \frac{230}{3.2} = 71.875\ \Omega$$

Resistance of wire at steady temperature θ_2° C,

$$R_2 = \frac{V}{i_2} = \frac{230}{2.8} = 82.143\ \Omega$$

Now, $$\alpha = \frac{R_2 - R_1}{R_1(\theta_2 - \theta_1)}$$

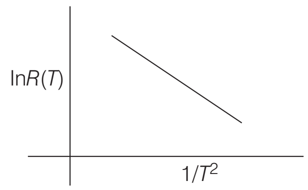
$$\therefore \quad 1.70 \times 10^{-4} = \frac{82.143 - 71.875}{71.875 \times (\theta_2 - 27)}$$

or $$\theta_2 = 27 + \frac{82.143 - 71.875}{71.875 \times 1.70 \times 10^{-4}}$$

$$= 27 + 840.35$$

$$= 867.35° \text{ C}$$

Example 7. *In an experiment, the resistance of a material is plotted as a function of temperature (in some range). As shown in the figure, it is a straight line.*



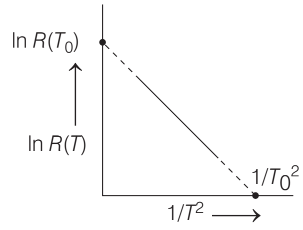
[JEE Main 2019]

One may conclude that

(a) $R(T) = R_0 e^{-T^2/T_0^2}$ (b) $R(T) = R_0 e^{T^2/T_0^2}$

(c) $R(T) = R_0 e^{-T_0^2/T^2}$ (d) $R(T) = \dfrac{R_0}{T^2}$

Sol. (c) From the given graph,



We can say that, $\ln R(T) \propto -\dfrac{1}{T^2}$

Negative sign implies that the slope of the graph is negative.

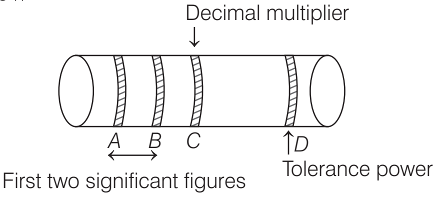
or $$\ln R(T) = \text{constant}\left(-\frac{1}{T^2}\right)$$

$$\Rightarrow \quad R(T) = \frac{\exp\text{ (const.)}}{\exp\left(\dfrac{1}{T^2}\right)}$$

$$\Rightarrow \quad R(T) = R_0 \exp\left(-\frac{T_0^2}{T^2}\right)$$

Colour Code for Carbon Resistors

The resistance of a carbon resistor can be calculated by the code given on it in the form of coloured strips as shown below



$\therefore$ The value of a carbon resistor is given as

$$R = AB \times C \pm D\%$$

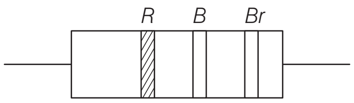
The table for colour code of carbon resistor is given below

Color codes	Values (*A*, *B*)	Multiplier (*C*)	Tolerance (*D*) (%)
Black	0	10^0	
Brown	1	10^1	
Red	2	10^2	
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Grey	8	10^8	
White	9	10^9	
Gold			$\pm 5\%$
Silver			$\pm 10\%$
No colour			$\pm 20\%$

Example 8. *A 200 Ω resistor has a certain colour code. If one replaces the red colour by green in the code, the new resistance will be* **[JEE Main 2019]**

(a) 100 Ω (b) 400 Ω (c) 300 Ω (d) 500 Ω

Sol. (*d*) Given, resistance is $200\ \Omega = 20 \times 10^1 \Omega$



So, colour scheme will be red, black and brown.

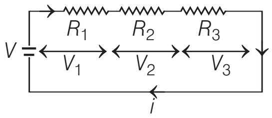
Significant figure of red band is 2 and for green is 5. When red (2) is replaced with green (5), new resistance will be

$$200 \text{ ohm} \longrightarrow 500 \text{ ohm}$$

Combination of Resistors

There are two types of combination of resistances, *i.e.* series and parallel combination.

Series Combination Combination of resistors in series is as shown below



Same current flows through each resistance but potential difference distributes in the ratio of their resistance, *i.e.*, $V \propto R$.

So, the total potential drop is equal to the sum of potential applied across the combination.

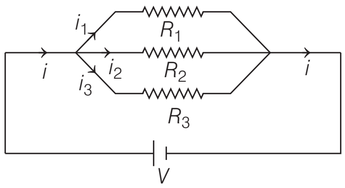
Equivalent resistance in series combination is given by

$$R_{eq} = R_1 + R_2 + R_3$$

i.e. Equivalent resistance is greater than the maximum value of resistance in the combination.

If n identical resistances are connected in series, then $R_{eq} = nR$ and potential difference across each resistance, is $V' = V/n$.

Parallel Combination Combination of resistors in parallel is as shown below



Same potential difference appears across each resistance but current distributes in the reverse ratio of their resistance, *i.e.* $I \propto \dfrac{V}{R}$. So, the total current is equal to the sum of currents through each resistance.

Equivalent resistance is given by, $\dfrac{1}{R_{eq}} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3}$

i.e. Equivalent resistance is less than the minimum value of resistance in the combination.

In n identical resistance are connected in parallel, then $R_{eq} = \dfrac{R}{n}$ and current through each resistance is, $I' = \dfrac{I}{n}$.

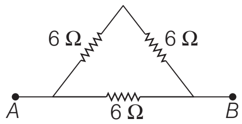
Example 9. *A uniform metallic wire has a resistance of 18 Ω and is bent into an equilateral triangle, then the resistance between any two vertices of the triangle is* **[JEE Main 2019]**

(a) 12 Ω (b) 8 Ω
(c) 2 Ω (d) 4 Ω

Sol. (*d*) Resistance of each arm of equilateral triangle will be

$$R = \frac{18}{3} = 6\ \Omega$$

So, we have following combination



Equivalent resistance,

$$R_{AB} = \frac{12 \times 6}{12 + 6} = \frac{12 \times 6}{18} = 4\ \Omega$$

Example 10. *A metal wire of resistance 3 Ω is elongated to make a uniform wire of double its previous length. This new wire is now bent and the ends joined to make a circle. If two points on this circle make an angle 60° at the centre, the equivalent resistance between these two points will be* **[JEE Main 2019]**

(a) $\frac{7}{2}\Omega$ (b) $\frac{5}{2}\Omega$ (c) $\frac{12}{5}\Omega$ (d) $\frac{5}{3}\Omega$

Sol. (*d*) Initial resistance of wire is 3 Ω. Let its length is l and area is A.

Then, $R_{\text{initial}} = \rho\frac{l}{A} = 3\ \Omega$ ... (i)

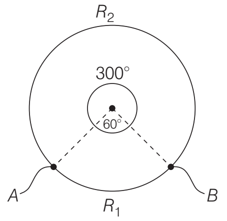
When wire is stretched twice its length, then its area becomes A', on equating volume, we have

$$Al = A'2l \Rightarrow A' = \frac{A}{2}$$

So, after stretching, resistance of wire will be

$$R' = R_{\text{final}} = \rho\frac{l'}{A'} = 4\rho\frac{l}{A} = 12\ \Omega \quad \text{[using Eq. (i)]}$$

Now, this wire is made into a circle and connected across two points A and B (making 60° angle at centre) as



Now, above arrangement is a combination of two resistances in parallel,

$$R_1 = \frac{60 \times R'}{360} = \frac{1}{6} \times 12 = 2\ \Omega$$

and $$R_2 = \frac{300}{360} \times R' = \frac{5}{6} \times 12 = 10\ \Omega$$

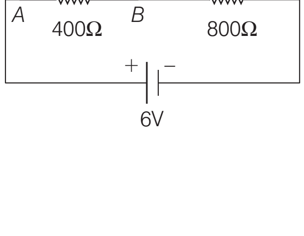
Since, R_1 and R_2 are connected in parallel.

So, $$R_{AB} = \frac{R_1R_2}{R_1 + R_2} = \frac{10 \times 2}{12} = \frac{5}{3}\ \Omega$$

Example 11. *Two resistors 400 Ω and 800 Ω are connected in series across a 6 V battery. The potential difference measured by a voltmeter of 10 kΩ across 400 Ω resistor is close to* **[JEE Main 2020]**

(a) 1.95 V (b) 2 V (c) 1.8 V (d) 2.05 V

Sol. (*a*) The circuit diagram is



The equivalent resistance across AB,

$$R_{AB} = \frac{10000 \times 400}{10000 + 400} = \frac{10000 \times 400}{10400} = \frac{40000}{104} = 384.6\ \Omega \approx 385\ \Omega$$

$\therefore$ Total circuit resistance = 385 + 800 = 1185 Ω

Hence, circuit current is $i = \frac{V}{R_{\text{eq}}} = \frac{6}{1185} = 5.06 \times 10^{-3}$ A

Now, potential drop across points A and B is

$$V_{AB} = i \cdot R_{AB} = 5.06 \times 10^{-3} \times 385 = 1.946\text{V} \simeq 1.95\text{V}$$

Electric Cell

It is a device which maintains a continuous flow of charge (or electric current) in a circuit by a chemical reaction. It converts chemical energy into electrical energy.

Electromotive Force (emf) of a Cell (ε) Electric cell has to do some work in maintaining the current through a circuit. The work done by the cell in moving unit positive charge through the whole circuit (including the cell) is called the *electromotive force* (emf) of the cell.

If during the flow of q coulomb of charge in an electric circuit, the work done by the cell is W, then

emf of the cell, $\varepsilon = \frac{W}{q}$

Its unit is joule/coulomb or volt.

Internal Resistance (r) Internal resistance of a cell is defined as the resistance offered by the electrolyte of the cell to the flow of current through it. It is denoted by r. Its unit is ohm.

Terminal Potential Difference (V) Terminal potential difference of a cell is defined as the potential difference between the two terminals of the cell in a closed circuit (*i.e.* when current is drawn from the cell). It is represented by V and its unit is volt.

Terminal potential difference of a cell is always less than the emf of the cell.

Relation between Terminal Potential Difference, emf of the Cell and Internal Resistance of a Cell

- If no current is drawn from the cell, *i.e.* the cell is in open circuit, so emf of the cell will be equal to the terminal potential difference of the cell.

$$i = 0 \quad \text{or} \quad V = \varepsilon$$

- Consider a cell of emf ε and internal resistance r is connected across an external resistance R.

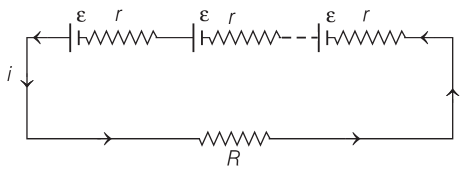
  Current drawn from the cell, $i = \frac{\varepsilon}{R + r}$

where, ε = emf of the cell, R = external resistance
and r = internal resistance of a cell;

and $r = \left(\dfrac{\varepsilon}{V} - 1\right)R$

Grouping of Cells

Series Grouping Suppose n cells each of emf ε and internal resistance r are connected in series as shown in figure, then net emf = $n\varepsilon$



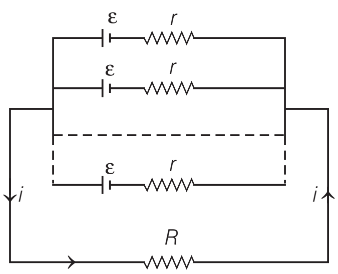
Total resistance = $nr + R$

$\therefore$ Current in the circuit = $\dfrac{\text{Net emf}}{\text{Total resistance}}$

or $$i = \frac{n\varepsilon}{nr + R}$$

Note If polarity of m cells is reversed, then equivalent emf $\varepsilon_{eq} = (n - 2m)\varepsilon$ while total resistance is still $nr + R$, so $i = \dfrac{(n-2m)\varepsilon}{nr + R}$.

Parallel Grouping Let n cells each of emf ε and internal resistance r are connected in parallel as shown in figure, then net emf = ε

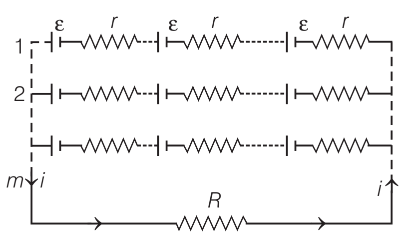


Total resistance = $\dfrac{r}{n} + R$

$\therefore$ Current in the circuit, $i = \dfrac{\text{Net emf}}{\text{Total resistance}}$

or $$i = \frac{\varepsilon}{R + r/n}$$

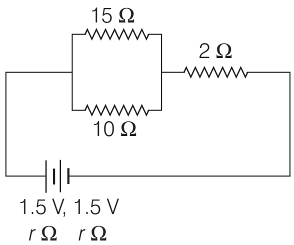
Mixed Grouping If n identical cells are in a row and such m rows are connected in parallel as shown, then net emf = $n\varepsilon$



Total resistance, $R_{eq} = R + \dfrac{nr}{m}$

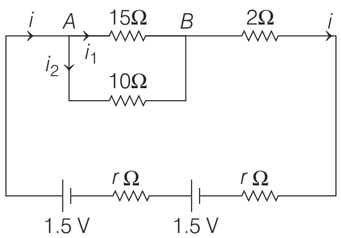
Hence, $$i = \frac{n\varepsilon}{R + \dfrac{nr}{m}}$$

Example 12. *In the given circuit, an ideal voltmeter connected across the 10 Ω resistance reads 2 V. The internal resistance r, of each cell is* **[JEE Main 2019]**



(a) 1.5 Ω (b) 0.5 Ω
(c) 1 Ω (d) 0 Ω

Sol. (b) For the given circuit,



Given, $V_{AB} = 2\text{V}$

Equivalent resistance between A and B is

$$\frac{1}{R_{AB}} = \frac{1}{10} + \frac{1}{15} = \frac{1}{6}$$

$\Rightarrow$ $R_{AB} = 6\,\Omega$

$\therefore$ Equivalent resistance of the entire circuit is,

$$R_{eq} = 6\,\Omega + 2\,\Omega + 2r = 8 + 2r$$

Now, current passing through the circuit is given as

$$i = \frac{\varepsilon_{net}}{R + r_{eq}} = \frac{\varepsilon_{net}}{R_{eq}}$$

where, R is external resistance, r_{eq} is net internal resistance and ε_{net} is the emf of the cells.

Here, $\varepsilon_{net} = 1.5 + 1.5 = 3\text{ V}$

$r_{eq} = r + r = 2r$

$\Rightarrow$ $i = \dfrac{3}{8 + 2r}$

Also, reading of the voltmeter,

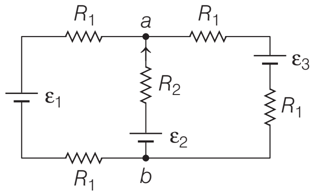
$$V = 2\text{V} = i \cdot R_{AB}$$

$$2 = \left(\frac{3}{8 + 2r}\right) \times 6$$

$\Rightarrow$ $8 + 2r = 9$

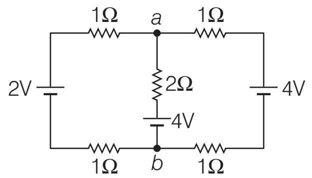
or $r = \dfrac{1}{2} = 0.5\,\Omega$

Example 13. *For the circuit shown with $R_1 = 1.0\ \Omega$, $R_2 = 2.0\ \Omega$, $\varepsilon_1 = 2$ V and $\varepsilon_2 = \varepsilon_3 = 4$ V, the potential difference between the points a and b is approximately (in volt)* **[JEE Main 2019]**

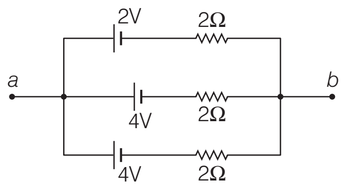


(a) 2.7 (b) 2.3 (c) 3.7 (d) 3.3

Sol. (d) Given circuit is



Above circuit can be viewed as



This is a parallel combination of three cells or in other words, a parallel grouping of three cells with internal resistances.

So, $$V_{ab} = \varepsilon_{eq} = \frac{i_{eq}}{r_{eq}} = \frac{\frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2} + \frac{\varepsilon_3}{r_3}}{\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}}$$

$$= \frac{\frac{2}{2} + \frac{4}{2} + \frac{4}{2}}{\frac{1}{2} + \frac{1}{2} + \frac{1}{2}}$$

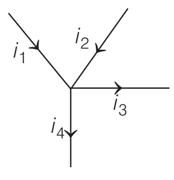
$$= \frac{10}{3}\text{ V} \approx 3.3\text{ V}$$

Kirchhoff's Laws

Many complex electrical circuits cannot be reduced to simple series or parallel combinations.

However, such circuits can be analysed by applying two rules, devised by Kirchhoff which are as follows

Junction Rule The sum of the currents meeting at any junction in a closed circuit is zero, *i.e.* $\sum_{\text{junction}} i = 0$



In figure, $$i_1 + i_2 = i_3 + i_4$$

This rule is based on *conservation of electric charge*.

Loop Rule The algebraic sum of the potential differences in any closed circuit is zero.

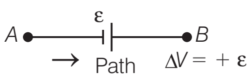
i.e. $$\sum_{\text{closed loop}} \Delta V = 0$$

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

Sign Convention in Kirchhoff's Laws

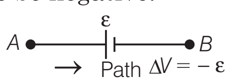
In applying the loop rule, we need sign convention as discussed below

(i) When we travel through a source in the direction from –ve to +ve, the emf is considered to be positive.



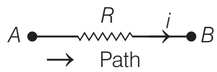
(a)

(ii) When we travel from +ve to –ve, the emf is considered to be negative.



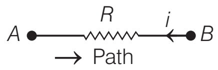
(b)

(iii) When we travel through a resistor in the same direction as the assumed current, the iR term is negative because the current goes in the direction of decreasing potential.



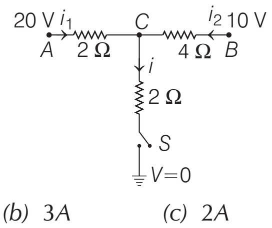
(c)

(iv) When we travel through a resistor in the direction opposite to the assumed current, the iR term is positive because this represents a rise of potential.



(d)

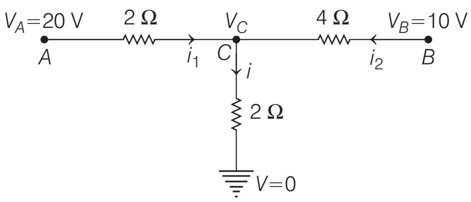
Example 14. *When the switch S in the circuit shown is closed, then the value of current i will be*



[JEE Main 2019]

(a) 4A (b) 3A (c) 2A (d) 5A

Sol. (d) When the switch S is closed, the circuit hence formed is given in the figure below



Then, according to Kirchhoff's current law, which states that the sum of all the currents directed towards a point in a circuit is equal to the sum of all the currents directed away from that point. Since, in the above circuit, that point is C.

$\therefore \quad i_1 + i_2 = i$

$$\Rightarrow \quad \frac{V_A - V_C}{2} + \frac{V_B - V_C}{4} = \frac{V_C - V}{2}$$

(∵ using Ohm's law, $V = iR$)

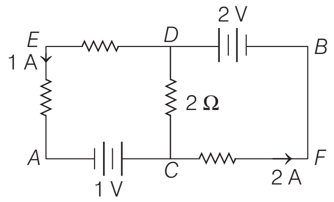
$$\text{or} \quad \frac{20 - V_C}{2} + \frac{10 - V_C}{4} = \frac{V_C - 0}{2}$$

$$\Rightarrow \quad 20 - V_C + (10 - V_C)2 = V_C \Rightarrow 40 = V_C + 3V_C$$

$$40 = 4V_C \text{ or } V_C = 10 \text{ V}$$

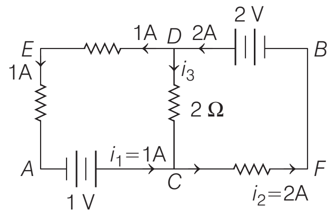
$$\therefore \quad \text{Current, } i = \frac{V_C}{2} = \frac{10}{2} = 5\text{A}$$

Example 15. *In the given circuit, currents in different branches and value of one resistor are shown. Then, potential at point B with respect to the point A is* ***[JEE Main 2020]***



(a) +2 V (b) −2 V
(c) −1V (d) +1V

Sol. (d) The given circuit can be drawn as



Current in branch DC (using KCL at point C),

$$i_1 + i_3 = i_2$$
$$2 - 1 - i_3 = 0$$
$$i_3 = 1\text{A}$$

Now, while moving from A to B via C and D, the potential along $ACDB$,

$$V_A + 1 + 2 \times i_3 - 2 = V_B \Rightarrow V_B - V_A = 1\text{V}$$

Electrical Energy

The total work done or energy supplied by the source in maintaining the current in electric circuit for a given time is called electric energy consumed in the circuit.

$$\text{Electric energy, } W = Vit = i^2Rt = \frac{V^2}{R}t$$

Its SI unit is joule (J).

where, 1 joule = 1 volt × 1 ampere × 1 second
= 1 watt × 1 second

Electrical Power

It is defined as the rate of electrical energy supplied per unit time to maintain flow of electric current through a conductor.

$$\text{Mathematically,} \quad P = Vi = i^2R = \frac{V^2}{R}$$

The SI unit of power is watt (W), where

1 watt = 1 volt × 1 ampere = 1 ampere-volt.

The bigger units of electrical power are kilowatt (kW) and megawatt (MW)

where, 1kW = 1000 W and 1 MW = 10^6 W

Commercial unit of electrical power is horse power (hp)

where, 1 hp = 74 6 watt.

Heating Effects of Current

When some potential difference V is applied across a resistance R and charge q to flow through the circuit in time t, the heat absorbed or produced, is given by

$$W = qV = Vit = i^2Rt = \frac{V^2t}{R} \text{ joule}$$

$$\text{or} \quad = \frac{Vit}{4.2} = \frac{i^2Rt}{4.2} = \frac{V^2t}{4.2R} \text{ cal}$$

where, J is the Joule's mechanical equivalent of heat (4.21 J/cal).

Electricity Consumption

To measure the electrical energy consumed commercially, joule is not sufficient. So, to express electrical energy consumed commercially a special unit *kilo-watt-hour* is used in place of joule. It is also called 1 unit of electrical energy.

1 kilowatt hour or 1 unit of electrical energy is the amount of energy dissipated in 1 hour in a circuit, when the electric power in the circuit is 1 kilowatt.

1 kilowatt hour (kWh) = 3.6× 10^6 joule (J)

Example 16. *A current of 2 mA was passed through an unknown resistor which dissipated a power of* 4.4 W. Dissipated power when an ideal power supply *of* 11 *V is connected across it is* ***[JEE Main 2019]***

(a) 11×10^{-4} W (b) 11×10^{-5} W
(c) 11×10^{5} W (d) 11×10^{-3} W

Sol. (b) Power dissipated by any resistor R,

when i current flows through it is, $P = i^2R$ ... (i)

Given, $i = 2 \text{ mA} = 2 \times 10^{-3}$ A and $P = 4.4$ W

Using Eq. (i), we get

$$4.4 = (2 \times 10^{-3})^2 \times R$$

$$\text{or} \quad R = \frac{4.4}{4 \times 10^{-6}} \quad \text{...(ii)}$$

When this resistance R is connected with 11 V supply, then power dissipated is,

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

or $$P = \frac{(11)^2}{4.4} \times 4 \times 10^{-6}$$

[$\because$ using Eq. (ii)]

$\Rightarrow$ $$P = \frac{11 \times 11 \times 4 \times 10^{-6}}{44 \times 10^{-1}} \text{ W}$$

or $$P = 11 \times 10^{-5} \text{ W}$$

Example 17. *In a building, there are 15 bulbs of 45 W, 15 bulbs of 100 W, 15 small fans of 10 W and 2 heaters of 1 kW. The voltage of electric main is 220 V. The minimum fuse capacity (rated value) of the building will be* **[JEE Main 2020]**

(a) 25 A (b) 10 A
(c) 20 A (d) 15 A

Sol. (c) Power of 15 bulbs (each of 45 W),

$$P_1 = 15 \times 45 = 675 \text{ W}$$

Power of 15 bulbs (each of 100 W),

$$P_2 = 15 \times 100 = 1500 \text{ W}$$

Power of 15 fans (each of 10 W),

$$P_3 = 15 \times 10 = 150 \text{ W}$$

Power of 2 heaters (each of 1 kW),

$$P_4 = 2 \times 1000 = 2000 \text{ W}$$

Total power usage of building,

$$P = P_1 + P_2 + P_3 + P_4 = 4325 \text{ W}$$

Using $P = V \cdot i$, current drawn from mains supply of 220 V,

$$i = \frac{P}{V} = \frac{4325}{220} = 19.66 \text{ A}$$

$\therefore$ Minimum fuse capacity required is 20 A.

Example 18. *A battery of 3.0 V is connected to a resistor dissipating 0.5 W of power. If the terminal voltage of the battery is 2.5 V, the power dissipated within the internal resistance is* **[JEE Main 2020]**

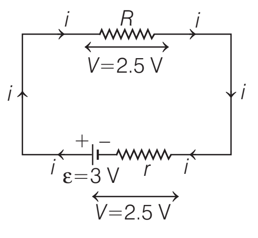
(a) 0.072 W (b) 0.125 W
(c) 0.50 W (d) 0.10 W

Sol. (d) Using Kirchhoff's loop law,

$$V = \varepsilon - ir$$

$$2.5 = 3 - ir$$

$\Rightarrow$ $$ir = 0.5 \quad \text{...(i)}$$



Now, from Ohm's law, $V = iR$

$$2.5 = iR$$

$$iR = 2.5 \quad \text{...(ii)}$$

and given that, $P_R = 0.5,\ i^2R = 0.5$ ...(iii)

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

$$\frac{ir}{iR} = \frac{0.5}{2.5} \Rightarrow \frac{r}{R} = \frac{1}{5} \quad \text{...(iv)}$$

Now, $$\frac{P_r}{P_R} = \frac{i^2r}{i^2R}$$

$\Rightarrow$ $$\frac{P_r}{0.5} = \frac{r}{R}$$

$\Rightarrow$ $$\frac{P_r}{0.5} = \frac{1}{5}$$

$\Rightarrow$ $$P_r = 0.10 \text{ W}$$

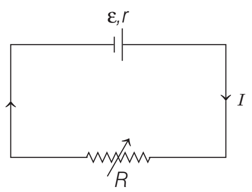
Maximum Power Transfer Theorem

It states that the power output across load due to a cell or or battery is maximum, if the load (external) resistance is equal to the effective internal resistance of cell of battery. It means, when the effective internal resistance of cell or a battery is equal to external load resistance in a circuit, the efficiency of battery or cell is maximum.

Example 19. *A cell of internal resistance r drives current through an external resistance R. The power delivered by the cell to the external resistance will be maximum when*

(a) $R = 2r$ (b) $R = r$ **[JEE Main 2019]**
(c) $R = 0.001r$ (d) $R = 1000\,r$

Sol. (b) Given circuit is shown in the figure below



Net current, $$I = \frac{\varepsilon}{R + r} \quad \text{...(i)}$$

Power across R is given as, $P = I^2R = \left(\frac{\varepsilon}{R + r}\right)^2 \cdot R$ [using Eq. (i)]

For the maximum power, $\frac{dP}{dR} = 0$

$\Rightarrow$ $$\frac{dP}{dR} = \frac{d}{dR}\left(\left(\frac{\varepsilon}{R + r}\right)^2 \cdot R\right) = \varepsilon^2 \frac{d}{dR}\left(\frac{R}{(R + r)^2}\right)$$

$$= \varepsilon^2\left[\frac{(R + r)^2 \times 1 - 2R \times (R + r)}{(R + r)^4}\right] = 0$$

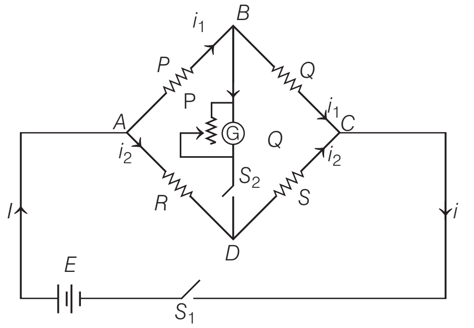
$\Rightarrow$ $$(R + r)^2 = 2R(R + r)$$

or $$R + r = 2R \Rightarrow r = R$$

$\therefore$ The power delivered by the cell to the external resistance is maximum when $R = r$.

Wheatstone Bridge

It is an arrangement of four resistances used to measure one of them in terms of other three.



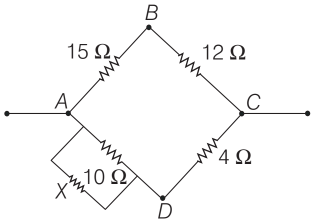
The bridge is said to be balanced when deflection in galvanometer is zero, *i.e.* $i_g = 0$. So, we have the balanced condition as

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

Example 20. *Four resistances of 15 Ω, 12 Ω, 4 Ω and 10 Ω respectively in cyclic order to form Wheatstone's network. The resistance that is to be connected in parallel with the resistance of 10 Ω to balance the network is* **[JEE Main 2020]**

(a) 4 Ω (b) 7 Ω
(c) 10 Ω (d) 12 Ω

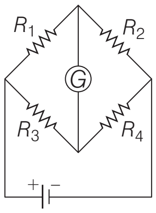
Sol. (c) Cyclic order and resistance X Ω which is connected to obtain balance condition is as shown in the figure.



For balance, $\dfrac{15}{12} = \dfrac{\left(\dfrac{10X}{10+X}\right)}{4} \Rightarrow \dfrac{10X}{10+X} = 5$

$\Rightarrow \quad X = 10\ \Omega$

Example 21. *The Wheatstone bridge shown in figure here, gets balanced when the carbon resistor is used as R_1 has the colour code (orange, red, brown). The resistors R_2 and R_4 are 80 Ω and 40 Ω, respectively.*



Assuming that the colour code for the carbon resistors gives their accurate values, the colour code for the carbon resistor used as R_3 would be **[JEE Main 2019]**

(a) brown, blue, black
(b) brown, blue, brown
(c) grey, black, brown
(d) red, green, brown

Sol. (b) The value of R_1 (orange, red, brown)

$$= 32 \times 10 = 320\ \Omega$$

Given, $R_2 = 80\ \Omega$ and $R_4 = 40\ \Omega$

In balanced Wheatstone bridge condition,

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

$$\Rightarrow \quad R_3 = R_4 \times \frac{R_1}{R_2}$$

$$\Rightarrow \quad R_3 = \frac{40 \times 320}{80}$$

or $\quad R_3 = 160\ \Omega$

$$= 16 \times 10^1$$

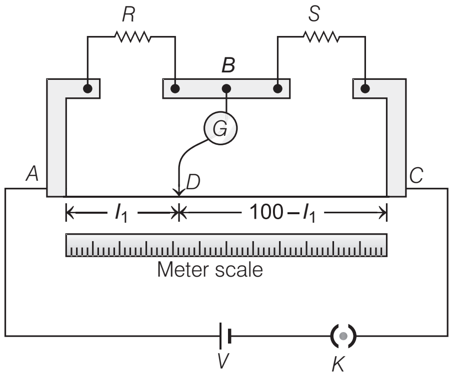
Comparing the value of R_3 with the colours assigned for the carbon resistor, we get

$$R_3 = \underset{\text{Brown}}{1}\underset{\text{Blue}}{6} \times 10^{\underset{\text{Brown}}{1}}$$

Meter Bridge

A meter bridge is **slide wire bridge** or Carey Foster **bridge**. It is an instrument which work on the principle of Wheatstone bridge.

It consists of a straight and uniform wire along a meter scale (AC) and by varying the taping point B as shown in figure, the bridge is balanced.

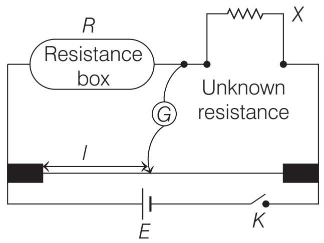


In balanced condition, $\dfrac{R}{S} = \dfrac{l_1}{(100 - l_1)}$

or $\quad R = S\,\dfrac{l_1}{100 - l_1}$

where, l_1 is the length of the wire from one end, where null point is obtained. The bridge is most sensitive, when null point is somewhere near the middle point of the wire.

Example 22. *In a meter bridge experiment, the circuit diagram and the corresponding observation table are shown in figure* ***[JEE Main 2019]***



S. No.	R (Ω)	l (cm)
1.	1000	60
2.	100	13
3.	10	1.5
4.	1	1.0

Which of the readings is inconsistent?

(a) 3 (b) 2

(c) 1 (d) 4

Sol. (*d*) Unknown resistance 'X' in meter bridge experiment is given by

$$X = \left(\frac{100 - l}{l}\right) R$$

***Case* I** When $R = 1000\ \Omega$ and $l = 60$ cm, then

$$X = \frac{(100-60)}{60} \times 1000 = \frac{40 \times 1000}{60}$$

$$\Rightarrow \qquad X = \frac{2000}{3}\ \Omega \approx 667\ \Omega$$

***Case* II** When $R = 100\ \Omega$ and $l = 13$ cm, then

$$X = \left(\frac{100 - 13}{13}\right) \times 100 = \frac{100 \times 87}{13}$$

$$= \frac{8700}{13}\ \Omega \approx 669\ \Omega$$

***Case* III** When $R = 10\ \Omega$ and $l = 1.5$ cm, then

$$X = \left(\frac{100 - 1.5}{1.5}\right) \times 10 = \frac{98.5}{1.5} \times 10$$

$$= \frac{9850}{15}\ \Omega \approx 656\ \Omega$$

***Case* IV** When $R = 1\ \Omega$ and $l = 1.0$ cm, then

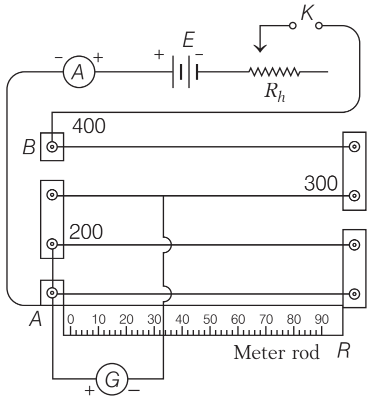
$$X = \left(\frac{100 - 1}{1}\right) \times 1$$

$$\therefore \qquad X = 99\ \Omega$$

Thus, from the above cases, it can be concluded that, value calculated in case (4) is inconsistent.

Potentiometer

It is an ideal device used to measure the potential difference between two points. It consists of a long resistance wire AB of uniform cross-section in which a steady direct current is set up by means of a battery.



The principle of potentiometer states that, when a constant amount of current flows through a wire of uniform cross-section, then the potential drop across the wire is directly proportional to its length,

i.e. $\qquad V \propto l$

$\Rightarrow \qquad V = kl$

where, k is known as *potential gradient.*

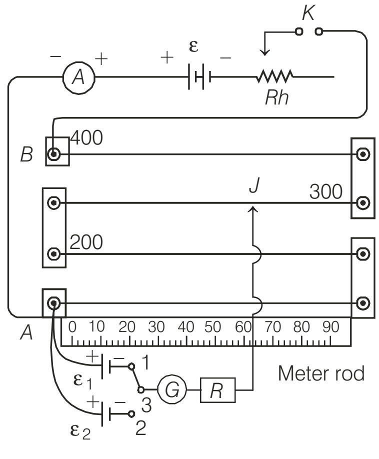
SI unit of k is Vm^{-1}.

Sensitivity of potentiometer is increased by increasing length of potentiometer wire.

Applications of Potentiometer

Potentiometer can be used for following purpose

- **To Compare the emf's of Two Cells using Potentiometer** The arrangement of two cells of emfs ε_1 and ε_2 which are to be compared is shown in the figure below



If the plug is put in the gap between 1 and 3, we get

$$\varepsilon_1 = (x\, l_1)\, i \qquad \text{...(i)}$$

where, x = resistance per unit length.

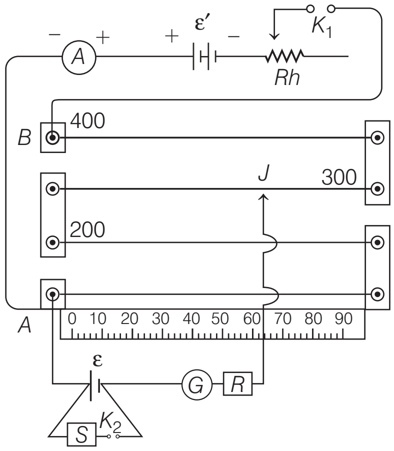
Similarly, when the plug is put in the gap between 2 and 3, we get

$$\varepsilon_2 = (x\, l_2)\, i \qquad \text{...(ii)}$$

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

or $\qquad \dfrac{\varepsilon_1}{\varepsilon_2} = \dfrac{l_1}{l_2}$

- **Determination of Internal Resistance of a Cell using Potentiometer** The arrangement is shown in figure

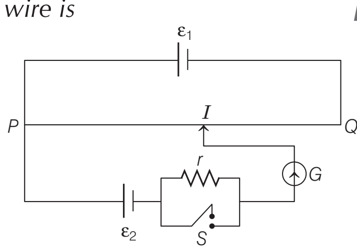


When K_2 is kept out, $\varepsilon = xl_1 i$

But if by inserting key K_2 and introducing some resistance S (say), then potential difference V is balanced by a length l_2, where $V = kl_2$

Internal resistance of cell, $r = \dfrac{\varepsilon - V}{V} R = \dfrac{l_1 - l_2}{l_2} R$

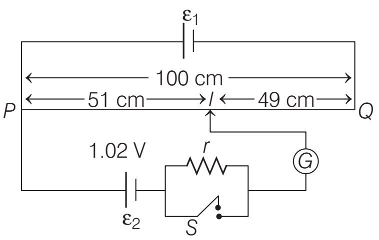
Example 23. *A potentiometer wire PQ of 1 m length is connected to a standard cell ε_1. Another cell ε_2 of emf 1.02 V is connected with a resistance r and switch S (as shown in figure). With switch S open, the null position is obtained at a distance of 49 cm from Q. The potential gradient in the potentiometer wire is* **[JEE Main 2020]**



(a) 0.02 V/cm
(b) 0.01 V/cm
(c) 0.03 V/cm
(d) 0.04 V/cm

Sol. *(a)* Resistance r limits current through ε_2 when there is no balance situation.

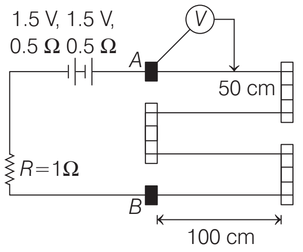
But at balance point, no current flows through galvanometer G and ε_2, so r does not affects the position of balance point as shown in figure.



Now, 1.02 V is balanced against 51 cm length, so potential gradient of wire PQ is;

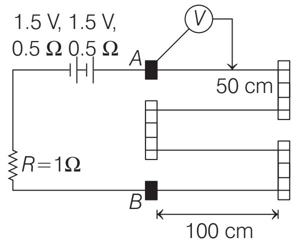
$$\text{Potential gradient} = \text{Fall of potential per unit length} = \frac{1.02}{51}\ \frac{\text{V}}{\text{cm}}$$
$$= 0.02 \text{ V/cm}$$

Example 24. *In the circuit shown, a four-wire potentiometer is made of a 400 cm long wire, which extends between A and B. The resistance per unit length of the potentiometer wire is $r = 0.01\,\Omega$/cm. If an ideal voltmeter is connected as shown with jockey J at 50 cm from end A, the expected reading of the voltmeter will be* **[JEE Main 2019]**



(a) 0.20 V
(b) 0.75 V
(c) 0.25 V
(d) 0.50 V

Sol. (c) In given potentiometer, resistance per unit length is $x = 0.01\,\Omega\text{cm}^{-1}$.



Length of potentiometer wire is $L = 400$ cm

Net resistance of the wire AB is

$$R_{AB} = \text{resistance per unit length} \times \text{length of } AB$$
$$= 0.01 \times 400$$
$$\Rightarrow \quad R_{AB} = 4\ \Omega$$

Net internal resistance of the cells connected in series,

$$r = 0.5 + 0.5 = 1\Omega$$

$\therefore$ Current in given potentiometer circuit is

$$I = \frac{\text{Net emf}}{\text{Total resistance}} = \frac{\text{Net emf}}{r + R + R_{AB}} = \frac{3}{1 + 1 + 4} = 0.5 \text{ A}$$

Reading of voltmeter when the jockey is at 50 cm (l') from one end A,

$$V = IR = I(xl')$$
$$= 0.5 \times 0.01 \times 50$$
$$= 0.25 \text{ V}$$

Practice Exercise

ROUND I Topically Divided Problems

Electric Current and Drift Velocity

1. The current flowing through a wire depends on time as $i = 3t^2 + 2t + 5$. The charge flowing the cross-section of the wire in time from $t = 0$ to $t = 2$ s is
(a) 21 C (b) 10 C (c) 22 C (d) 1 C

2. There is a current of 0.21 A in a copper wire whose area of cross-section is 10^{-6} m^2. If the number of free electrons per m^3 is 8.4×10^{28}, then find the drift velocity. (Take, $e = 1.6 \times 10^{-19}$ C)
(a) 2×10^{-5} ms^{-1} (b) 1.56×10^{-5} ms^{-1}
(c) 1×10^{-5} ms^{-1} (d) 0.64×10^{-5} ms^{-1}

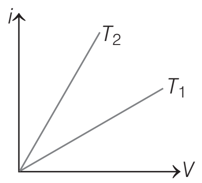
3. Two wires of the same material but of different diameters carry the same current i. If the ratio of their diameters is 2 : 1, then the corresponding ratio of their mean drift velocities will be
(a) 4 : 1 (b) 1 : 1 (c) 1 : 2 (d) 1 : 4

4. Every atom makes one free electron in copper. If 1.1 A current is flowing in the wire of copper having 1 mm diameter, then the drift velocity (approx.) will be (Take, density of copper $= 9 \times 10^3$ kg m^{-3} and atomic weight of copper = 63)
(a) 0.1 mms^{-1} (b) 0.2 mms^{-1}
(c) 0.3 mms^{-1} (d) 0.2 cms^{-1}

5. A straight conductor of uniform cross-section carries a current i. If s is the specific charge of an electron, the momentum of all the free electrons per unit length of the conductor, due to their drift velocity only is
(a) is (b) $\sqrt{i/s}$ (c) i/s (d) $(i/s)^2$

Resistance and Resistivity

6. The current i and voltage V graphs for a given metallic wire at two different temperatures T_1 and T_2 are shown in the figure. It is concluded that



(a) $T_1 > T_2$ (b) $T_1 < T_2$ (c) $T_1 = T_2$ (d) $T_1 = 2T_1$

7. The resistance of a 10 m long wire is 10Ω. Its length is increased by 25% by stretching the wire uniformly. The resistance of wire will change to (approximately)
(a) 12.5 Ω (b) 14.5 Ω (c) 15.6 Ω (d) 16.6 Ω

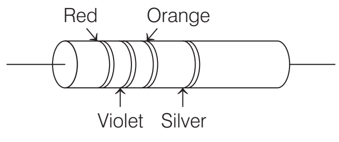
8. Masses of the three wires of same material are in the ratio of 1 : 2 : 3 and their lengths in the ratio of 3 : 2 : 1. Electrical resistance of these wires will be in the ratio of
(a) 1 : 1 : 1 (b) 1 : 2 : 3
(c) 9 : 4 : 1 (d) 27 : 6 : 1

9. Two conductors are made of the same material and have the same length. Conductor A is a solid wire of diameter 1 mm. Conductor B is a hollow tube of outer diameter 2 mm and inner diameter 1mm. What is the ratio of resistances R_A to R_B?
(a) 1 : 3 (b) 3 : 1
(c) 2 : 3 (d) 3 : 2

10. A metal rod of length 10 cm and a rectangular cross-section of 1 cm $\times \frac{1}{2}$ cm is connected to a battery across opposite faces. The resistance will be
(a) maximum when the battery is connected across 1 cm $\times \frac{1}{2}$ cm
(b) maximum when the battery is connected across 10 cm $\times$ 1 cm faces
(c) maximum when the battery is connected across 10 cm $\times \frac{1}{2}$ cm faces
(d) same irrespective of the three faces

11. Consider four conducting materials copper, tungsten, mercury and aluminium with resistivity ρ_C, ρ_T, ρ_M and ρ_A, respectively. Then, **[JEE Main 2020]**
(a) $\rho_A > \rho_T > \rho_C$ (b) $\rho_A > \rho_M > \rho_C$
(c) $\rho_C > \rho_A > \rho_T$ (d) $\rho_M > \rho_A > \rho_C$

12. A resistance is shown in the figure. Its value and tolerance are given respectively by **[JEE Main 2019]**



(a) 270 Ω, 5% (b) 27 k Ω, 20%
(c) 27 k Ω, 10% (d) 270 k Ω, 10%

13. Resistance of a resistor at temperature $t°$C is

$$R_t = R_0\,(1 + \alpha t + \beta t^2)$$

Here, R_0 is the resistance at 0°C. The temperature coefficient of resistance at temperature $t°$C is

(a) $\dfrac{(1 + \alpha t + \beta t^2)}{\alpha + 2\beta t}$ (b) $(\alpha + 2\beta t)$

(c) $\dfrac{\alpha + 2\beta t}{(1 + \alpha t + \beta t^2)}$ (d) $\dfrac{(\alpha + 2\beta t)}{2(1 + \alpha t + \beta t)}$

14. A silver wire has a resistance of 2.1 Ω at 27.5 °C and a resistance of 2.7 Ω at 100 °C. Determine the temperature coefficient of resistivity of silver.

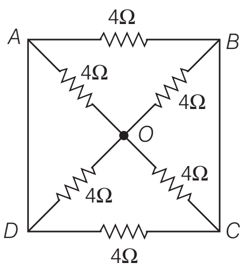
(a) 0.049/°C
(b) 0.0049/°C
(c) 0.0039/°C
(d) 0.039/°C

15. A copper wire of length 1 m and radius 1 mm is joined in series with an iron wire of length 2 m and radius 3 mm and a current is passed through the wires. The ratio of the current density in the copper and iron wires is

(a) 2 : 3 (b) 6 : 1
(c) 9 : 1 (d) 18 : 1

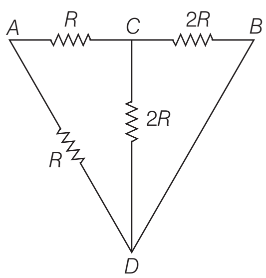
Grouping of Resistors

16. Six equal resistances each of 4Ω are connected to form a figure. The resistance between two corners A and B is



(a) 4 Ω (b) (4/3) Ω
(c) 12 Ω (d) 2 Ω

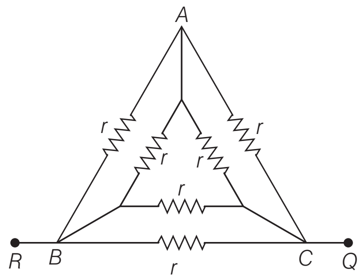
17. The effective resistance between points A and B is



(a) R (b) $\dfrac{R}{3}$

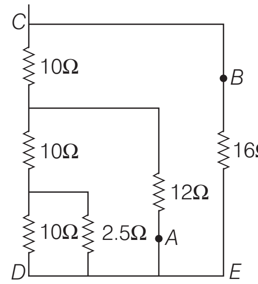
(c) $\dfrac{2R}{3}$ (d) $\dfrac{3R}{5}$

18. The resistance across R and Q in the figure.



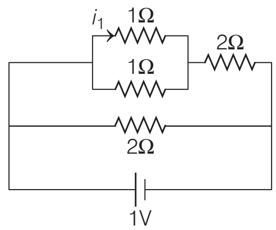
(a) $r/3$ (b) $r/2$ (c) $2r$ (d) $6r$

19. 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

20. The current i_1 (in ampere) flowing through 1Ω resistor in the following circuit is



[JEE Main 2020]

(a) 0.25 (b) 0.4
(c) 0.5 (d) 0.2

Grouping of Cells

21. The strength of current in a wire of resistance R will be the same for connection in series or in parallel of n identical cells each of the internal resistance r, when

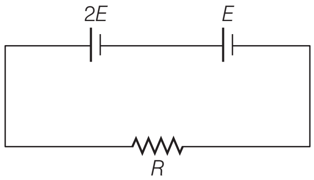
(a) $R = nr$ (b) $R = r/n$
(c) $R = r$ (d) $R \to \infty, r \to 0$

22. n identical cells, each of emf ε and internal resistance r, are connected in series, a cell A is joined with reverse polarity. The potential difference across each cell, except A is

(a) $\dfrac{2n\varepsilon}{n-2}$ (b) $\dfrac{(n-2)\varepsilon}{n}$

(c) $\dfrac{(n-1)\varepsilon}{n}$ (d) $\dfrac{2\varepsilon}{n}$

23. Two cells of emf $2E$ and E with internal resistances r_1 and r_2 respectively are connected in series to an external resistor R (see figure). The value of R, at which the potential difference across the terminals of the first cell becomes zero is **[JEE Main 2021]**



(a) $r_1 + r_2$ (b) $\frac{r_1}{2} - r_2$ (c) $\frac{r_1}{2} + r_2$ (d) $r_1 - r_2$

24. To get a maximum current through a resistance of $2.5\ \Omega$, one can use m rows of cells each row having n cells. The internal resistance of each cell is 0.5Ω. What are the values of m and n, if the total number of cells are 20?

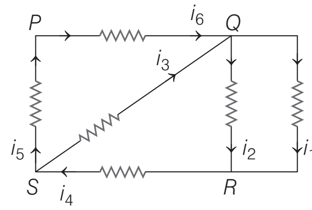
(a) $m = 2, n = 10$ (b) $m = 4, n = 5$
(c) $m = 5, n = 4$ (d) $n = 2, m = 10$

25. The series combination of two batteries, both of the same emf 10 V, but different internal resistance of $20\ \Omega$ and $5\ \Omega$, is connected to the parallel combination of two resistors $30\ \Omega$ and $R\ \Omega$. The voltage difference across the battery of internal resistance $20\ \Omega$ is zero, the value of R(in Ω) is **[JEE Main 2020]**

(a) 15 (b) 30 (c) 45 (d) 60

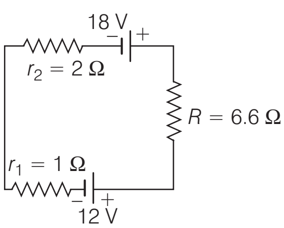
Kirchhoff's Law

26. In the given circuit diagram, the currents $i_1 = -0.3$ A, $i_4 = 0.8$ A and $i_5 = 0.4$ A, are flowing as shown. The currents i_2, i_3 and i_6 respectively are **[JEE Main 2019]**



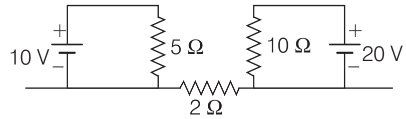
(a) 1.1 A, 0.4 A, 0.4 A (b) 1.1 A, – 0.4 A, 0.4 A
(c) 0.4 A, 1.1 A, 0.4 A (d) – 0.4 A, 0.4 A, 1.1 A

27. For the given circuit, terminal potential differences of cells are around



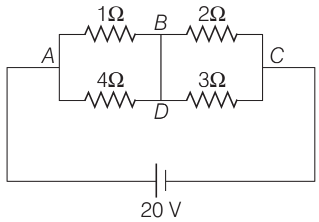
(a) 15 V, 10 V (b) 12 V, 15 V
(c) 6 V, 12 V (d) 17 V, 13 V

28. In the circuit shown the current through $2\ \Omega$ resistance is



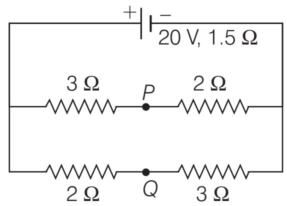
(a) 5 A (b) 2 A (c) 0 (d) 4 A

29. In the given circuit diagram, a wire is joining points B and D. The current in this wire is **[JEE Main 2020]**



(a) 0.4 A (b) zero (c) 2A (d) 4A

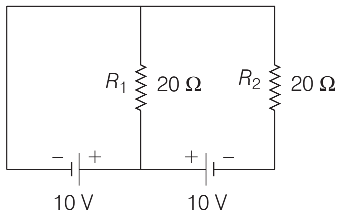
30. For the given circuit,



If internal resistance of cell is $1.5\ \Omega$, then

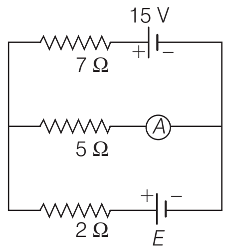
(a) $V_P - V_Q = 0$ (b) $V_P - V_Q = 4$ V
(c) $V_P - V_Q = -4$ V (d) $V_P - V_Q = -2.5$ V

31. In the given circuit, the cells have zero internal resistance. The currents (in ampere) passing through resistances R_1 and R_2 respectively are **[JEE Main 2019]**



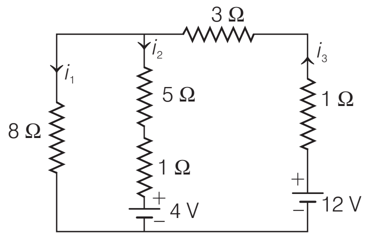
(a) 0.5, 0 (b) 1, 2 (c) 2, 2 (d) 0, 1

32. In the circuit shown in figure, if the ammeter reads 2 A. Then, i_1 and i_2 are



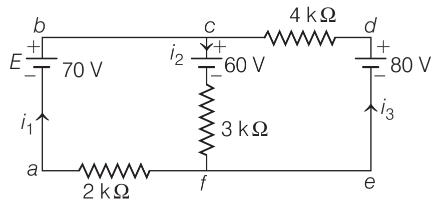
(a) $i_1 = 1.8$ A, $i_2 = 0.2$ A (b) $i_1 = 0.8$ A, $i_2 = 1.2$ A
(c) $i_1 = 0.75$ A, $i_2 = 1.25$ A (d) $i_1 = 0.714$ A, $i_2 = 1.29$ A

33. For the given network, mark the correct statement.



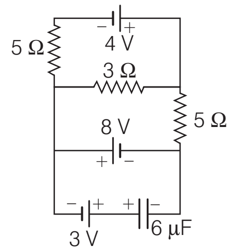
(a) Current through 8 Ω resistor is 846 mA.
(b) Current through 1 Ω resistor is 846 mA.
(c) Current through 1 Ω resistor is 400 mA.
(d) Current through 3 Ω resistor is 2 A.

34. For the given circuit, potential difference between points c and f is



(a) $V_c - V_f = 69.2$ V
(b) $V_c - V_f = -69.2$ V
(c) $V_c - V_f = 48.3$ V
(d) $V_c - V_f = -48.3$ V

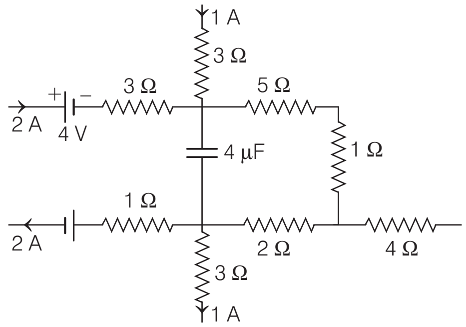
35. For the circuit given below, the charge on the capacitor is



(a) 45 μC
(b) 75 μC
(c) 66 μC
(d) 78 μC

Electrical Energy and Power

36. For the circuit shown, energy stored by the capacitor is



(a) around 0.3 mJ
(b) around 0.5 mJ
(c) around 0.8 mJ
(d) around 0.1 mJ

37. For two incandescent bulbs of rated power P_1 and P_2, if $P_1 > P_2$, then
(a) filament of bulb 1 is more thicker than filament of bulb 2
(b) filament of bulb 1 is thinner than the filament of bulb 2
(c) filament of both bulbs is of same thickness
(d) rated power of a bulb is independent of filament thickness

38. A heating filament of 500 W, 115 V is being operated at 110 V, percentage drop in output power (with comparison to rated output power) is
(a) 10.20% (b) 8.1% (c) 8.6% (d) 7.6%

39. Power of a heater is 500 W at 800°C. What will be its power at 200°C, if $\alpha = 4 \times 10^{-4}$ per°C?
(a) 484 W (b) 672 W (c) 526 W (d) 620 W

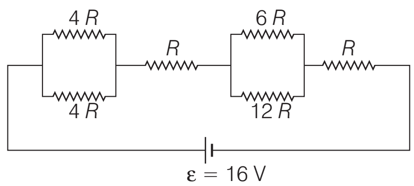
40. A wire when connected to 220 V mains supply has power dissipation P_1. Now, the wire is cut into two equal pieces which are connected in parallel to the same supply. Power dissipation in this case is P_2. Then, $P_2 : P_1$ is
(a) 1 : 1
(b) 4 : 1
(c) 2 : 1
(d) 3 : 1

41. In a large building, there are 15 bulbs of 40 W, 5 bulbs of 100 W, 5 fans of 80 W and 1 heater of 1 kW. The voltage of the electric mains is 220 V. The minimum capacity of the main fuse of the building will be **[JEE Main 2014]**
(a) 8 A
(b) 10 A
(c) 12 A
(d) 14 A

42. An electrical power line, having a total resistance of 2 Ω, delivers 1 kW at 220 V. The efficiency of the transmission line is approximately **[JEE Main 2020]**
(a) 91%
(b) 85%
(c) 96%
(d) 72%

43. Two electric bulbs rated at 25 W, 220 V and 100 W, 220 V are connected in series across a 220 V voltage source. If the 25 W and 100 W bulbs draw powers P_1 and P_2 respectively, then **[JEE Main 2019]**
(a) $P_1 = 16$ W, $P_2 = 4$W
(b) $P_1 = 4$ W, $P_2 = 16$W
(c) $P_1 = 9$ W, $P_2 = 16$W
(d) $P_1 = 16$ W, $P_2 = 9$W

44. The resistive network shown below is connected to a DC source of 16 V. The power consumed by the network is 4 W. The value of R is **[JEE Main 2019]**

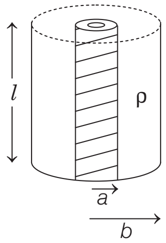


(a) 6 Ω
(b) 8 Ω
(c) 1 Ω
(d) 16 Ω

45. A resistor develops 500 J of thermal energy in 20s when a current of 1.5 A is passed through it. If the current is increased from 1.5 A to 3A, what will be the energy developed in 20 s? **[JEE Main 2021]**

(a) 1500 J (b) 1000 J (c) 500 J (d) 2000 J

46. A torch battery of length l is to be made up of a thin cylindrical bar of radius a and a concentric thin cylindrical shell of radius b is filled in between with an electrolyte of resistivity ρ (see figure). If the battery is connected to a resistance R, the maximum Joule's heating in R will takes place for



[JEE Main 2020]

(a) $R = \frac{\rho}{2\pi l}\left(\frac{b}{a}\right)$ (b) $R = \frac{\rho}{2\pi l}\ln\left(\frac{b}{a}\right)$

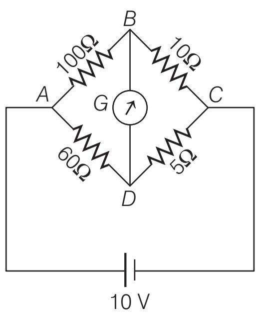
(c) $R = \frac{\rho}{\pi l}\ln\left(\frac{b}{a}\right)$ (d) $R = \frac{2\rho}{\pi l}\ln\left(\frac{b}{a}\right)$

Measuring Instruments

47. Which of the following statements is false? **[JEE Main 2017]**

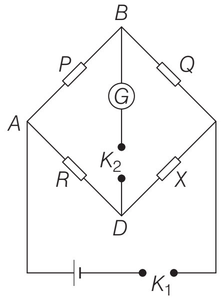
(a) In a balanced Wheatstone bridge, if the cell and the galvanometer are exchanged, the null point is disturbed.
(b) A rheostat can be used as a potential divider.
(c) Kirchhoff's second law represents energy conservation.
(d) Wheatstone bridge is the most sensitive when all the four resistances are of the same order of magnitude.

48. The four arms of a Wheatstone bridge have resistances as shown in the figure. A galvanometer of 15 Ω resistance is connected across BD. Calculate the current through the galvanometer when a potential difference of 10 V is maintained across AC. **[JEE Main 2021]**



(a) 2.44 μA (b) 2.44 mA (c) 4.87 mA (d) 4.87 μA

49. In a Wheatstone bridge (see figure), resistances P and Q are approximately equal. When $R = 400\,\Omega$, the bridge is balanced. On interchanging P and Q, the value of R for balance is $405\,\Omega$. The value of X is close to



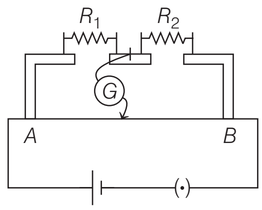
[JEE Main 2019]

(a) 404.5 Ω (b) 401.5 Ω (c) 402.5 Ω (d) 403.5 Ω

50. On interchanging the resistances, the balance point of a meter bridge shifts to the left by 10 cm. The resistance of their series combination is 1 kΩ. How much was the resistance on the left slot before interchanging the resistances? **[JEE Main 2018]**

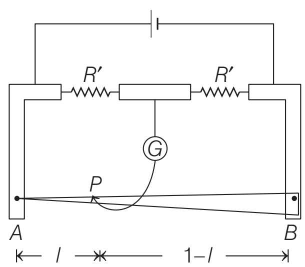
(a) 990 Ω (b) 505 Ω (c) 550 Ω (d) 910 Ω

51. In the experimental set up of meter bridge shown in the figure, the null point is obtained at a distance of 40 cm from A. If a 10 Ω resistor is connected in series with R_1, the null point shifts by 10 cm. The resistance that should be connected in parallel with $(R_1 + 10)\,\Omega$ such that the null point shifts back to its initial position is **[JEE Main 2019]**



(a) 60 Ω (b) 20 Ω (c) 30 Ω (d) 40 Ω

52. In a meter bridge, the wire of length 1m has a non-uniform cross-section such that the variation $\frac{dR}{dl}$ of its resistance R with length l is $\frac{dR}{dl} \propto \frac{1}{\sqrt{l}}$.
Two equal resistance are connected as shown in the figure. The galvanometer has zero deflection when the jockey is at point P. What is the length AP? **[JEE Main 2019]**



(a) 0.3 m (b) 0.25 m (c) 0.2 m (d) 0.35 m

53. The length of a wire of a potentiometer is 100 cm and the emf of its stand and cell is ε volt. It is employed to measure the emf of a battery whose internal resistance is 0.5 Ω. If the balance point is obtained at $l = 30$ cm from the positive end, the emf of the battery is

(a) $\frac{30\varepsilon}{100.5}$

(b) $\frac{30\varepsilon}{100 - 0.5}$

(c) $\frac{30\,(\varepsilon - 0.5\,i)}{100}$, where i is the current in the potentiometer wire

(d) $\frac{30\varepsilon}{100}$

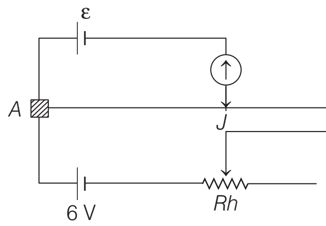
54. In a potentiometer experiment, the balancing with a cell is at length 240 cm. On shunting the cell with a resistance of 2 Ω, the balancing length becomes 120 cm. The internal resistance of the cell is

(a) 1 Ω (b) 0.5 Ω
(c) 4 Ω (d) 2 Ω

55. In a potentiometer experiment, it is found that no current passes through the galvanometer when the terminals of the cell are connected across 52 cm of the potentiometer wire. If the cell is shunted by a resistance of 5 Ω, a balance is found when the cell is connected across 40 cm of the wire. Find the internal resistance of the cell. **[JEE Main 2018]**

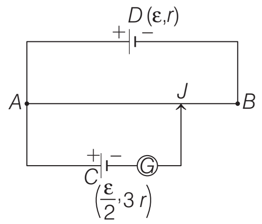
(a) 1 Ω (b) 1.5 Ω
(c) 2 Ω (d) 2.5 Ω

56. The resistance of the potentiometer wire AB in given figure is 4 Ω. With a cell of emf $\varepsilon = 0.5$ V and rheostat resistance $Rh = 2\,\Omega$. The null point is obtained at some point J. When the cell is replaced by another one of emf $\varepsilon = \varepsilon_2$, the same null point J is found for $Rh = 6\,\Omega$. The emf ε_2 is **[JEE Main 2019]**



(a) 0.6 V (b) 0.3 V (c) 0.5 V (d) 0.4 V

57. A potentiometer wire AB having length L and resistance $12\,r$ is joined to a cell D of emf ε and internal resistance r. A cell C having emf $\frac{\varepsilon}{2}$ and internal resistance $3\,r$ is connected. The length AJ at which the galvanometer as shown in figure shows no deflection is



(a) $\frac{5}{12}L$ (b) $\frac{11}{12}L$ (c) $\frac{13}{24}L$ (d) $\frac{11}{24}L$

ROUND II Mixed Bag

Only One Correct Option

1. The temperature dependence of resistances of Cu and undoped Si in the temperature range 300-400 K, is best described by **[JEE Main 2016]**

(a) linear increase for Cu, linear increase for Si
(b) linear increase for Cu, exponential increase for Si
(c) linear increase for Cu, exponential decrease for Si
(d) linear decrease for Cu, linear decrease for Si

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

(a) equal to the resistance of the load
(b) very large as compared to the load resistance
(c) zero
(d) non-zero but less than the resistance of the load

3. The length of a given cylindrical wire is increased by 100%. Due to the consequent decrease in diameter, the change in the resistance of the wire will be

(a) 200% (b) 100% (c) 50% (d) 300%

4. A conducting wire of length l, area of cross-section A and electric resistivity ρ is connected between the terminals of a battery. A potential difference V is developed between its ends, causing an electric current. If the length of the wire of the same material is doubled and the area of cross-section is halved, resultant current would be **[JEE Main 2021]**

(a) $\frac{1}{4}\frac{VA}{\rho l}$ (b) $\frac{3}{4}\frac{VA}{\rho l}$

(c) $\frac{1}{4}\frac{\rho l}{VA}$ (d) $4\frac{VA}{\rho l}$

5. The resistance of the series combination of two resistors is S. When they are joined in parallel, the total resistance is P. If $S = nP$, then the minimum possible value of n is

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

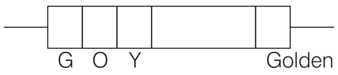
6. A current of 10 A exists in a wire of cross sectional area of 5 mm^2 with a drift velocity of 2×10^{-3} ms^{-1}. The number of free electrons in each cubic meter of the wire is **[JEE Main 2021]**

(a) 2×10^6 (b) 625×10^{25}
(c) 2×10^{25} (d) 1×10^{23}

7. A material B has twice the specific resistance of A. A circular wire made of B has twice the diameter of a wire made of A. Then, for the two wires to have the same resistance, the ratio l_B/l_A of their respective lengths must be

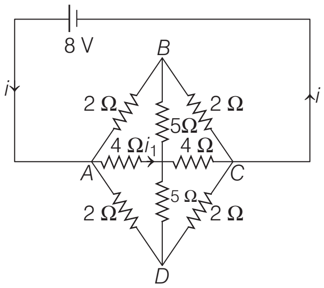
(a) 1 (b) 2/1
(c) 1/4 (d) 2

8. A carbon resistor has a following colour code. What is the value of the resistance? **[JEE Main 2019]**



(a) 5.3 MΩ ± 5% (b) 64 kΩ ± 10%
(c) 6.4 MΩ ± 5% (d) 530 kΩ ± 5%

9. The value of current i_1 flowing from A to C in the circuit diagram is **[JEE Main 2020]**



(a) 1 A (b) 5 A
(c) 2 A (d) 4 A

10. In a Wheatstone's bridge, three resistances P, Q and R are connected in the three arms and the fourth arm is formed by two resistances S_1 and S_2 connected in parallel. The condition for the bridge to be balanced will be

(a) $\dfrac{P}{Q} = \dfrac{2R}{S_1 + S_2}$

(b) $\dfrac{P}{Q} = \dfrac{R(S_1 + S_2)}{S_1 S_2}$

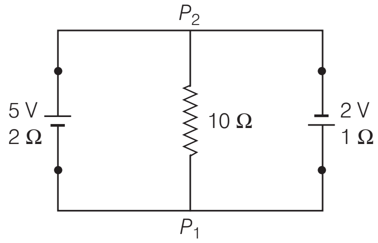
(c) $\dfrac{P}{Q} = \dfrac{R(S_1 + S_2)}{2 S_1 S_2}$

(d) $\dfrac{P}{Q} = \dfrac{R}{S_1 + S_2}$

11. A 2 W carbon resistor is colour coded with green, black, red and brown, respectively. The maximum current which can be passed through this resistor is **[JEE Main 2019]**

(a) 0.4 mA (b) 63 mA
(c) 20 mA (d) 100 mA

12. A 5 V battery with internal resistance 2 Ω and a 2 V battery with internal resistance 1 Ω are connected to a 10 Ω resistor as shown in the figure



The current in the 10 Ω resistor is

(a) 0.27 A, P_2 to P_1 (b) 0.03 A, P_1 to P_2
(c) 0.03 A, P_2 to P_1 (d) 0.27 A, P_1 to P_2

13. When 5V potential difference is applied across a wire of length 0.1m, the drift speed of electrons is $2.5 \times 10^{-4} ms^{-1}$. If the electron density in the wire is 8×10^{28} m^{-3} the resistivity of the material is close to **[JEE Main 2015]**

(a) 1.6×10^{-8} Ω-m (b) 1.6×10^{-7} Ω-m
(c) 1.6×10^{-6} Ω-m (d) 1.6×10^{-5} Ω-m

14. The supply voltage to room is 120 V. The resistance of the lead wires is 6 Ω. A 60 W bulb is already switched on. What is the decrease of voltage across the bulb, when a 240 W heater is switched on in parallel to the bulb? **[JEE Main 2013]**

(a) Zero (b) 2.9 V
(c) 13.3 V (d) 10.04 V

15. Two equal resistances when connected in series to a battery consume electric power of 60 W. If these resistances are now connected in parallel combination to the same battery, the electric power consumed will be **[JEE Main 2019]**

(a) 60 W (b) 30 W
(c) 240 W (d) 120 W

16. Two sources of equal emf are connected to an external resistance R. The internal resistances of the two sources are R_1 and $R_2 (R_2 > R_1)$. If the potential difference across the source having internal resistance R_2 is zero, then

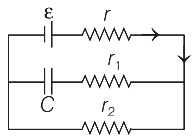
(a) $R = \dfrac{R_2 \times (R_1 + R_2)}{(R_2 - R_1)}$ (b) $R = R_2 - R_1$

(c) $R = \dfrac{R_1 R_2}{(R_1 + R_2)}$ (d) $R = \dfrac{R_1 R_2}{(R_2 - R_1)}$

17. An ideal battery of 4 V and resistance R are connected in series in the primary circuit of a potentiometer of length 1 m and resistance 5 Ω. The value of R to give a potential difference of 5 mV across 10 cm of potentiometer wire is **[JEE Main 2019]**

(a) 395 Ω (b) 495 Ω
(c) 490 Ω (d) 480 Ω

18. In the given circuit diagram, when the current reaches steady state in the circuit, the charge on the capacitor of capacitance C will be

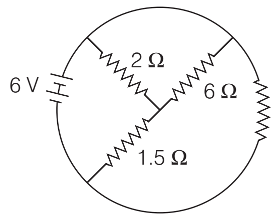


[JEE Main 2017]

(a) $C\varepsilon \dfrac{r_1}{(r_2 + r)}$ (b) $C\varepsilon \dfrac{r_2}{(r + r_2)}$

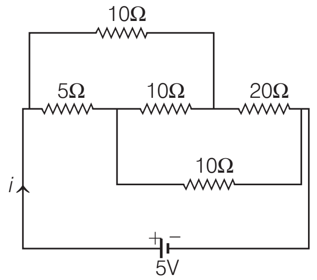
(c) $C\varepsilon \dfrac{r_1}{(r_1 + r)}$ (d) $C\varepsilon$

19. The total current supplied to the circuit by the battery is



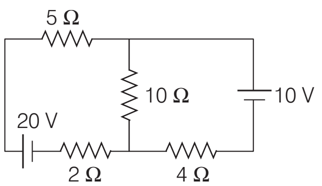
(a) 1 A (b) 2 A (c) 4 A (d) 6 A

20. The current i drawn from the 5 V source will be



(a) 0.33 A (b) 0.5 A (c) 0.67 A (d) 0.17 A

21. In above figure shown, the current in the 10 V battery is close to [JEE Main 2020]



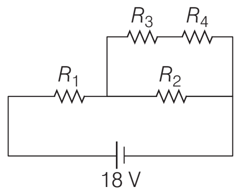
(a) 0.71 A from positive to negative terminal
(b) 0.42 A from positive to negative terminal
(c) 0.21 A from positive to negative terminal
(d) 0.36 A from negative to positive terminal

22. Two batteries with emf 12 V and 13 V are connected in parallel across a load resistor of 10 Ω. The internal resistances of the two batteries are 1 Ω and 2 Ω, respectively. The voltage across the load lies between [JEE Main 2018]

(a) 11.6 V and 11.7 V (b) 11.5 V and 11.6 V
(c) 11.4 V and 11.5 V (d) 11.7 V and 11.8 V

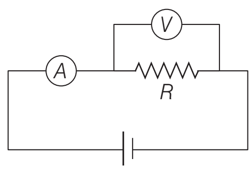
23. In the given circuit, the internal resistance of the 18 V cell is negligible. If R_1 = 400 Ω, R_3 = 100 Ω and R_4 = 500 Ω and the reading of an ideal voltmeter across R_4 is 5 V, then the value of R_2 will be

[JEE Main 2019]



(a) 550 Ω (b) 230 Ω
(c) 300 Ω (d) 450 Ω

24. The actual value of resistance R , shown in the figure is 30 Ω. This is measured in an experiment as shown using the standard formula $R = \dfrac{V}{i}$, where V and i are the readings of the voltmeter and ammeter, respectively. If the measured value of R is 5% less, then the internal resistance of the voltmeter is



[JEE Main 2019]

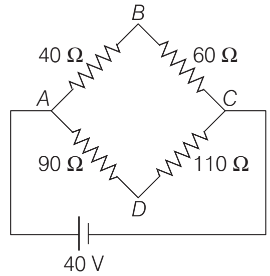
(a) 600 Ω (b) 570 Ω
(c) 350 Ω (d) 35 Ω

25. Two conductors have the same resistance at 0°C but their temperature coefficients of resistance are α_1 and α_2. The respective temperature coefficients of their series and parallel combinations are nearly

(a) $\dfrac{\alpha_1 + \alpha_2}{2}, \alpha_1 + \alpha_2$ (b) $\alpha_1 + \alpha_2, \dfrac{\alpha_1 + \alpha_2}{2}$

(c) $\alpha_1 + \alpha_2, \dfrac{\alpha_1 \alpha_2}{\alpha_1 + \alpha_2}$ (d) $\dfrac{\alpha_1 + \alpha_2}{2}, \dfrac{\alpha_1 + \alpha_2}{2}$

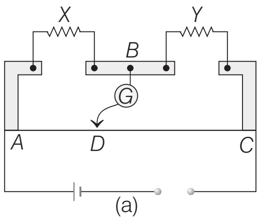
26. Four resistances 40 Ω, 60 Ω, 90 Ω and 110 Ω make the arms of a quadrilateral $ABCD$. Across AC is a battery of emf 40 V and internal resistance negligible. The potential difference across BD (in volt) is



[JEE Main 2020]

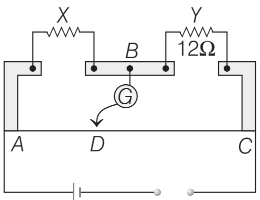
(a) 1 (b) 2
(c) 3 (d) 4

27. Fig. (a) shows a meter bridge (which is nothing but a practical Wheatstone bridge) consisting of two resistors X and Y together in parallel with one metre long constant wire of uniform cross-section.



(a)

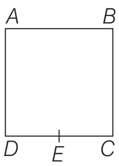
With the help of a movable contact D, one can change the ratio of the resistances of the two segments of the wire, until a sensitive galvanometer G connected across B and D shows to deflection. The null point is found to be at a distance of 33.7 cm from the end A. The resistance Y is shunted by a resistance Y' of 12.0 Ω [Fig. (b)] and the null point is found to shift by a distance of 18.2 cm. Determine the resistances of X and Y.



(b)

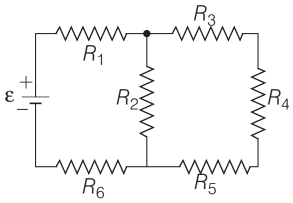
(a) $Y = 13.5\ \Omega$ and $X = 6.86\ \Omega$
(b) $Y = 13.5\ \Omega$ and $X = 5.86\ \Omega$
(c) $Y = 11.5\ \Omega$ and $X = 6.86\ \Omega$
(d) $Y = 12.5\ \Omega$ and $X = 6.86\ \Omega$

28. A wire of resistance R is bent to form a square $ABCD$ as shown in the figure. The effective resistance between E and C is [E is mid-point of arm CD] **[JEE Main 2019]**



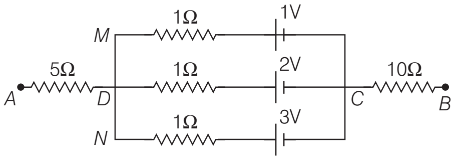
(a) $\frac{7}{64}R$ (b) $\frac{3}{4}R$ (c) R (d) $\frac{1}{16}R$

29. In the figure shown, what is the current (in ampere) drawn from the battery? You are given $R_1 = 15\ \Omega$, $R_2 = 10\ \Omega$, $R_3 = 20\ \Omega$, $R_4 = 5\ \Omega$, $R_5 = 25\ \Omega$, $R_6 = 30\ \Omega$, $\varepsilon = 15\ V$ **[JEE Main 2019]**



(a) 13/24 (b) 7/18 (c) 20/3 (d) 9/32

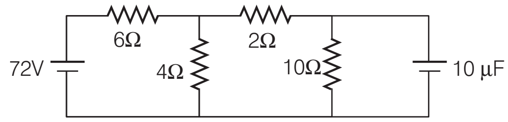
30. In the circuit shown, the potential difference between A and B is **[JEE Main 2019]**



(a) 3 V (b) 1 V (c) 6 V (d) 2 V

31. Two cells of emf's 2V and 1V and of internal resistances 1 Ω and 2Ω respectively, have their positive terminals connected by a wire of 10Ω resistance and their negative terminals by wire of 4Ω resistance. Another coil of 10Ω is connected between the middle points of these wires. The potential difference across the 10Ω coil is
(a) 1.07 V (b) 2.03 V (c) 3.45 V (d) 4.25 Vs

32. Determine the charge on the capacitor in the following circuit.



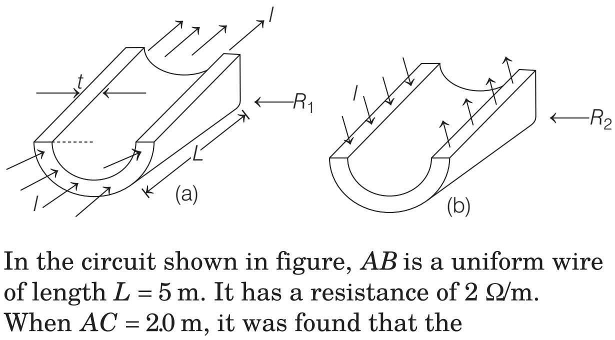
[JEE Main 2019]

(a) 2 μC (b) 200 μC (c) 10 μC (d) 60 μC

Numerical Value Questions

33. The number density of free electrons in a copper conductor is estimated as $8.5 \times 10^{28}\ m^{-3}$. How long does an electron take (in min) to drift from one end of a wire 3.0 m long to its other end? The area of cross-section of the wire is $2.0 \times 10^{-6}\ m^2$ and it is carrying a current of 3.0 A.

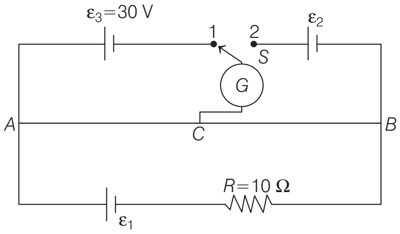
34. A conducting open pipe has shape of a half cylinder of length L. Its semi-circular cross-section has radius r and thickness of the conducting wall is $t(<< r)$. The resistance of the conductor when the current enters and leaves as shown in Fig. (a) is R_1 and its resistance is R_2 when the current is as shown in Fig. (b). Find the ratio of R_1 / R_2.
(Take, $L = 1$ m, $\pi^2 = 10$ and $r = 0.1$ m)



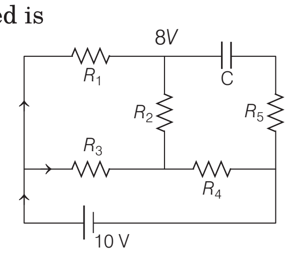
(a) (b)

35. In the circuit shown in figure, AB is a uniform wire of length $L = 5$ m. It has a resistance of 2 Ω/m. When $AC = 2.0$ m, it was found that the galvanometer shows zero reading when switch S is placed in either of the two positions 1 or 2.

Find the emf ε_1 (in volts).



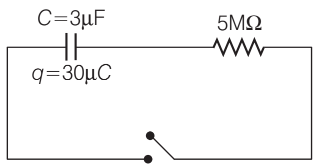
36. An ideal cell of emf 10 V is connected in circuit shown in figure. Each resistance is 2 Ω. The potential difference (in volt) across the capacitor when it is fully charged is



[JEE Main 2020]

37. Two wires of same length and thickness having specific resistance 6Ω cm and 3 Ω cm respectively are connected in parallel. The effective resistivity is ρ Ω cm. The value of ρ, to the nearest integer is .... [JEE Main 2021]

38. The circuit shown in the figure consists of a charged capacitor of capacity 3 μF and a charge of 30 μC. At time $t = 0$, when the key is closed, the value of current flowing through the 5 MΩ resistor is x μ-A. The value of x to the nearest integer is ....



[JEE Main 2021]

Answers

Round I

1. (c)	*2. (b)*	*3. (d)*	*4. (a)*	*5. (c)*	*6. (a)*	*7. (c)*	*8. (d)*	*9. (b)*	*10. (a)*
11. (d)	*12. (c)*	*13. (c)*	*14. (c)*	*15. (c)*	*16. (b)*	*17. (c)*	*18. (a)*	*19. (d)*	*20. (d)*
21. (c)	*22. (d)*	*23. (b)*	*24. (a)*	*25. (b)*	*26. (a)*	*27. (d)*	*28. (c)*	*29. (c)*	*30. (d)*
31. (a)	*32. (d)*	*33. (a)*	*34. (b)*	*35. (c)*	*36. (a)*	*37. (a)*	*38. (c)*	*39. (d)*	*40. (b)*
41. (c)	*42. (c)*	*43. (a)*	*44. (b)*	*45. (d)*	*46. (b)*	*47. (a)*	*48. (c)*	*49. (c)*	*50. (c)*
51. (a)	*52. (b)*	*53. (d)*	*54. (d)*	*55. (b)*	*56. (b)*	*57. (c)*			

Round II

1. (d)	*2. (c)*	*3. (d)*	*4. (a)*	*5. (a)*	*6. (b)*	*7. (b)*	*8. (d)*	*9. (a)*	*10. (b)*
11. (c)	*12. (c)*	*13. (d)*	*14. (d)*	*15. (c)*	*16. (b)*	*17. (a)*	*18. (b)*	*19. (c)*	*20. (b)*
21. (c)	*22. (b)*	*23. (c)*	*24. (b)*	*25. (d)*	*26. (b)*	*27. (a)*	*28. (a)*	*29. (d)*	*30. (d)*
31. (a)	*32. (b)*	*33. 453*	*34. 10*	*35. 150*	*36. 8*	*37. 4*	*38. 2*		

Solutions

Round I

1. We have, $i = \dfrac{dq}{dt} = 3t^2 + 2t + 5$

$\Rightarrow \quad dq = (3t^2 + 2t + 5)dt$

$\therefore \quad q = \int_0^2 (3t^2 + 2t + 5)\, dt$

$$= \left(\frac{3t^3}{3} + \frac{2t^2}{2} + 5t\right)\Bigg|_0^2 = \left[\frac{3(2)^3}{3} + 2\,\frac{(2)^2}{2} + 5\times 2\right]$$

$$= 8 + 4 + 10 = 22\text{C}$$

2. $\therefore \quad v_d = i/nAe = 0.21/(8.4\times10^{28}\times10^{-6}\times1.6\times10^{-19})$

$$= 1.56\times10^{-5}\ \text{ms}^{-1}$$

3. $\therefore \quad v_d = \dfrac{i}{nAe} = \dfrac{i\times4}{n\pi D^2 e} \Rightarrow v_d \propto \dfrac{1}{D^2}$

$\because \quad \dfrac{v_{d_1}}{v_{d_2}} = \dfrac{D_2^2}{D_1^2} = \left(\dfrac{1}{2}\right)^2 = \dfrac{1}{4}$

4. $\therefore \quad v_d = i/n\,Ae$

where, $\quad n = N\rho/M$

$$= 6.023\times10^{26}\times9\times10^3/63$$

$$= 0.860\times10^{29} = 8.6\times10^{28}$$

and $\quad A = \pi D^2/4 = \dfrac{22}{7}\times(10^{-3})^2/4\ \text{m}^2$

$$= \frac{11}{14}\times10^{-6}\,\text{m}^2$$

$$v_d = \frac{1.1}{8.6\times10^{28}\times\frac{11}{14}\times10^{-6}\times1.6\times10^{-19}}$$

$$= \frac{1}{9.6\times10^{+3}} = \frac{100\times10^{-4}}{96} = 0.1\ \text{mms}^{-1}$$

5. $\therefore i = nAev_d$

or $\quad v_d = \dfrac{i}{nAe}$

Total number of free electrons in the unit length of conductor,

$$N = nA\times1$$

Total linear momentum of all the free electrons per unit length

$$= (Nm)\,v_d = nAm\times\frac{i}{nAe} = \frac{i}{(e/m)} = \frac{i}{s}$$

6. Slope of the graph will give us reciprocal of resistance. Here, resistance at temperature T_1 is greater than that at T_2. Since, resistance of metallic wire is more at higher temperature, then at lower temperature, hence $T_1 > T_2$.

7. Given, $l_1 = l + \dfrac{25}{100}\,l = \dfrac{5\,l}{4}$. Since, volume of wire remains unchanged on increasing length, hence

$$Al = A_1\times5\,l/4$$

or $\quad A_1 = 4\,A/5$

Given, $\quad R = 10 = \rho l/A$

and $\quad R_1 = \dfrac{\rho l_1}{A_1} = \dfrac{\rho\,5l/4}{4A/5} = \dfrac{25}{16}\dfrac{\rho l}{A}$

or $\quad R_1 = \dfrac{25}{16}\times10 = \dfrac{250}{16} = 15.6\ \Omega$

8. Mass, M = Volume $\times$ Density = $Al\times d$

or $\quad A = M/ld$

Resistance, $R = \rho l/A = \rho l/(M/ld) = \dfrac{\rho l^2 d}{M}$

So, $\quad R \propto l^2/M$

Thus, $\quad R_1 : R_2 : R_3 = \dfrac{l_1^2}{M_1} : \dfrac{l_2^2}{M_2} : \dfrac{l_3^2}{M_3}$

$$= \frac{3^2}{1} : \frac{2^2}{2} : \frac{1^2}{3}$$

$$= 27 : 6 : 1$$

9. We have, $\quad R_A = \dfrac{\rho l'}{\pi\,(10^{-3}\times0.5)^2}$

$$R_B = \frac{\rho l}{\pi\,[(10^{-3})^2 - (0.5\times10^{-3})^2]}$$

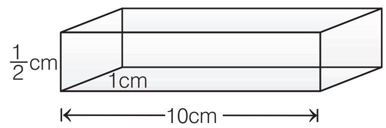
$\because \quad \dfrac{R_A}{R_B} = \dfrac{(10^{-3})^2 - (0.5\times10^{-3})^2}{(0.5\times10^{-3})^2} = 3$

$\therefore \quad R_A : R_B = 3 : 1$

10. We know that, $R = \dfrac{\rho l}{A}$

(a) When the battery is connected across 1 cm$\times$ 1/2 cm faces, then

$$l = 10\ \text{cm};\ A = 1\times1/2\ \text{cm}^2,\ R_1 = \frac{\rho\times10}{1\times1/2} = 20\rho\Omega$$



(b) When the battery is connected across 10 cm $\times$ 1 cm faces, then $l = \dfrac{1}{2}$ cm; $A = 10\times1\ \text{cm}^2$, $R_2 = \dfrac{\rho\times1/2}{10\times1} = \dfrac{\rho}{20}\ \Omega$

(c) When the battery is connected across $10\text{cm}\times\dfrac{1}{2}$ cm faces, then $l = 1$ cm;

$$A = 10\times1/2\ \text{cm}^2,\ R_3 = \frac{\rho\times1}{(10\times1/2)} = \frac{\rho}{5}\ \Omega$$

11. Aluminium is more resistive than copper and mercury is most resistive of all.

So, $\quad \rho_M > \rho_A > \rho_C$

12. Using colour code, resistance is

$$R = 27\times10^3\ \Omega,\ \pm\ 10\%$$

$$= 27\ \text{k}\,\Omega,\ \pm\ 10\%$$

13. Temperature coefficient of resistance $= \dfrac{1}{R_t}\dfrac{dR}{dt}$

$$= \frac{1}{R_0(1+\alpha t+\beta t^2)} \times \frac{d}{dt}\,[R_0(1+\alpha t+\beta t^2)]$$

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

14. Given, resistance of silver wire at 27.5 °C, $R_{27.5} = 2.1\ \Omega$

Resistance of silver wire at 100 °C, $R_{100} = 2.7\ \Omega$

Let the temperature coefficient of silver be α.

$$\alpha = \frac{R_{t_2} - R_{t_1}}{R_1\ (t_2 - t_1)}$$

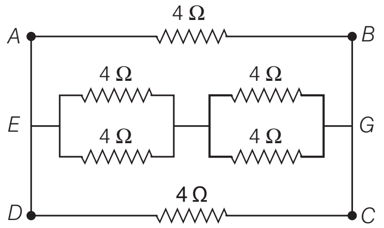
$$\alpha = \frac{R_{100} - R_{27.5}}{R_{27.5}\ (100-27.5)} = \frac{2.7-2.1}{2.1\times 72.5}$$

$$\alpha = 0.0039/\ °\mathrm{C}$$

15. The ratio, $\dfrac{J_1}{J_2} = \dfrac{i/\pi r_1^2}{i/\pi r_2^2} = \left(\dfrac{r_2}{r_1}\right)^2 = \left(\dfrac{3}{1}\right)^2 = \dfrac{9}{1}$

16. Equivalent circuit of this combination of resistances is as shown in figure. The effective resistance of arm

$$EG = 2\times\left[\frac{4\times4}{4+4}\right] = 4\ \Omega$$



Total resistance between A and B will be

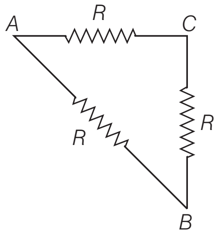
$$\frac{1}{R} = \frac{1}{4}+\frac{1}{4}+\frac{1}{4} = \frac{3}{4}$$

or $$R = \frac{4}{3}\ \Omega$$

17. Here, points B and D are common. So, $2R$ in arm DC and $2R$ in arm CB are in parallel between C and B.

Their effective resistance $= \dfrac{2R\times 2R}{2R+2R} = R$

The modified and simpler circuit will be as shown in figure. The effective resistance between A and B is



$$R_{\text{eff}} = \frac{R\times(R+R)}{R+(R+R)} = \frac{2}{3}R$$

18. Two resistances of each side of triangle are connected in parallel. Therefore, the effective resistance of each arm of the triangle would be $= \dfrac{r\times r}{r+r} = \dfrac{r}{2}$.

The two arms AB and AC are in series and they together are in parallel with third one.

$\therefore$ $$R' = (r/2) + (r/2) = r$$

Total resistance,

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

$\Rightarrow$ $$R = \frac{r}{3}$$

19. As, $\dfrac{1}{R_1} = \dfrac{1}{10}+\dfrac{1}{2.5} = \dfrac{5}{10} = \dfrac{1}{2} \Rightarrow R_1 = 2\ \Omega$

Now, 2 Ω and 10 Ω are in series,

$$R_2 = 10+2 = 12\ \Omega$$

R_2 and 12 Ω are in parallel, $\dfrac{1}{R_3} = \dfrac{1}{12}+\dfrac{1}{12} \Rightarrow R_3 = 6\ \Omega$

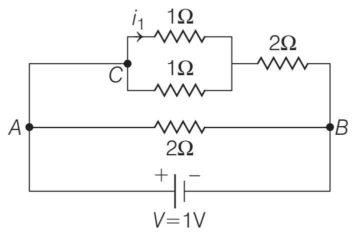
Now, R_3 and 6 Ω are in series, $R_4 = 10+6 = 16\ \Omega$

Now, R_4 and 16 Ω are in parallel.

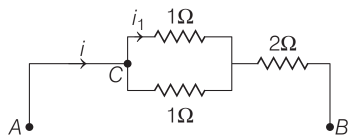
$\therefore$ $$\frac{1}{R} = \frac{1}{16}+\frac{1}{16}$$

$\Rightarrow$ $$R = 32\ \Omega$$

20. Given circuit is



In given circuit $V_{AB} = 1$ V, so upper branch of circuit is as shown in below figure.



Equivalent resistance of upper branch,

$$R_{\text{eq}} = (1\ \Omega\ ||\ 1\ \Omega) + 2\ \Omega = \frac{1}{2}+2 = \frac{5}{2}\ \Omega$$

So, current in upper branch,

$$i = \frac{V}{R} = \frac{V_{AB}}{R_{\text{eq}}} = \frac{1}{5/2} = \frac{2}{5}\ \mathrm{A}$$

At point C, this current is equally divided into two parts.

So, $$i_1 = \frac{1}{2}\left(\frac{2}{5}\right) = 0.2\ \mathrm{A}$$

21. In series combination of cells current, $i = \dfrac{n\varepsilon}{nr+R}$

In parallel combination of cells, $i' = \dfrac{\varepsilon}{(r/n)+R}$

If $i = i'$, then $\dfrac{n\varepsilon}{nr + R} = \dfrac{\varepsilon}{(r/n) + R} = \dfrac{n\varepsilon}{r + nR}$

It will be so if $r = R$.

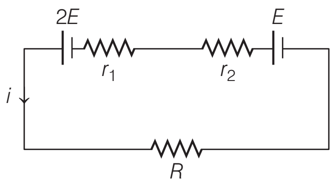
22. When one cell is wrongly connected in series, the emf of cells decreases by 2ε, but internal resistances of cells remains the same for all the cells.

Current in the circuit is $i = \dfrac{(n-2)\,\varepsilon}{nr} \times r$

Potential difference across each cell is

$$V = \varepsilon - ir = \varepsilon - \frac{(n-2)\,\varepsilon}{nr} \times r = \frac{2\,\varepsilon}{n}$$

23.



$$i = \frac{3E}{R + r_1 + r_2}$$

Total potential difference $= 2E - ir_1 = 0$

$$2E = ir_1$$

$$2E = \frac{3E \times r_1}{R + r_1 + r_2}$$

$$2R + 2r_1 + 2r_2 = 3r_1$$

$$R = \frac{r_1}{2} - r_2$$

24. Here, $mn = 20$

For maximum current, $R = nr/m$

or $\quad 2.5 = n \times 0.5/m$

or $\quad n = 5\,m$

From Eq. (i), we get

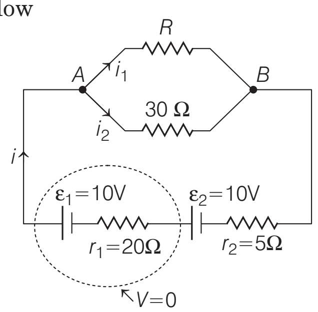
$$m \times 5\,m = 20$$

or $\quad m^2 = 4$

or $\quad m = 2$

Therefore, $\quad n = 5 \times 2 = 10$

25. Given arrangement of batteries and resistances is shown below



Let i = circuit current, then it is given that potential difference across battery of 10V and $20\,\Omega$ is zero.

i.e. $\quad \varepsilon_1 - ir_1 = 0$

$\Rightarrow \quad 10 - i(20) = 0 \;\Rightarrow\; i = \dfrac{1}{2} = 0.5\text{A}$

Now, potential drop across combination of resistors,

$$V_{AB} = (\varepsilon_1 + \varepsilon_2) - i(r_1 + r_2)$$
$$= 20 - 0.5 \times (25) = 7.5\text{ V}$$

Now, at junction B,

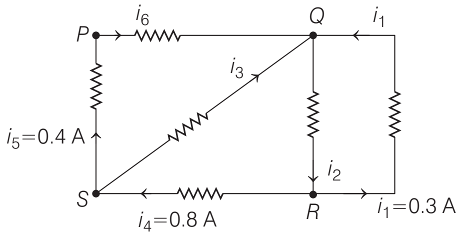
$$i = i_1 + i_2$$

$\Rightarrow \quad 0.5 = \dfrac{7.5}{R} + \dfrac{7.5}{30}$

On solving, we get

$$R = 30\,\Omega$$

26. Given circuit with currents is as shown in the figure below, [in the question $i_1 = 0.3$ A is given, due to it, we change the direction of i_1, in this figure]



From Kirchhoff's junction rule, $\Sigma i = 0$

At junction S, $\quad i_4 = i_5 + i_3$

$\Rightarrow \quad 0.8 = 0.4 + i_3$

$\Rightarrow \quad i_3 = 0.4\text{ A}$

At junction P, $\quad i_5 = i_6 \Rightarrow i_6 = 0.4\text{ A}$

At junction Q, $\quad i_2 = i_1 + i_3 + i_6 = 0.3 + 0.4 + 0.4 = 1.1\text{ A}$

27. From Kirchhoff's loop rule,

$$-i(2) + 18 - i(6.6) - 12 - i(1) = 0$$

$\Rightarrow \quad i = \dfrac{6}{9.6}\text{ A}$

Terminal voltage of 18 V battery,

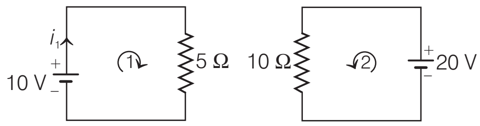
$$V = \varepsilon - ir_1$$
$$= 18 - i \times 2$$
$$= 18 - 0.625 \times 2$$
$$= 16.75 \approx 17\text{ V}$$

For 12 V battery,

$$V = \varepsilon + ir_2 = 12 + 1 \times 0.625$$
$$= 12.625 \approx 13\text{ V}$$

28. In loop 1,

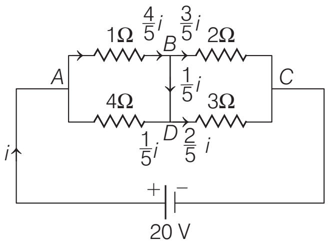
$$i_1 = \frac{5}{10} = \frac{1}{2}\text{ A}$$



In loop 2, $\quad i_2 = \dfrac{20}{10} = 2\text{ A}$

But both currents are confined to separate loops and so current through $2\,\Omega$ resistor is zero.

29. In given circuit, current distribution following Kirchhoff's law will be as shown in the figure.



Since, the current flows in inverse ratio of the resistance of branch.

Now, total circuit resistance,

$$R_{eq} = (1\Omega \,||\, 4\Omega) + (2\Omega \,||\, 3\Omega)$$
$$= \left(\frac{1\times 4}{1+4}\right) + \left(\frac{2\times 3}{2+3}\right)$$
$$= \frac{4}{5} + \frac{6}{5}$$
$$= \frac{10}{5}\,\Omega = 2\Omega$$

So, current drawn from cell,

$$i = \frac{V}{R_{eq}} = \frac{20\text{V}}{2\Omega} = 10\text{ A}$$

Hence, current through BD arm is (refer to circuit diagram),

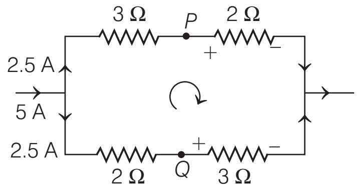
$$i_{BD} = \frac{i}{5} = \frac{10}{5} = 2\text{ A}$$

30. $R_{eq} = \frac{5}{2} + 1.5 = 4$ A

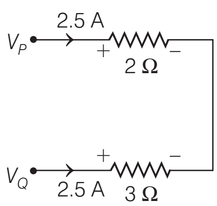
Current through cell $= \frac{V}{R} = \frac{20}{4} = 5$ A

So, current through each branch $= \frac{i}{2} = 2.5$ A

Now, considering loop

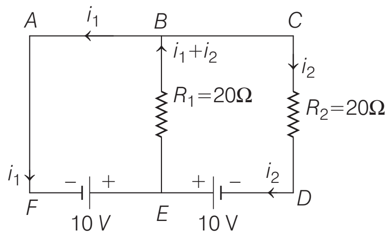


Now, applying Kirchhoff's rule to part loop P to Q,



$$V_P - 2\times 2.5 + 3\times 2.5 - V_Q = 0$$
$$\Rightarrow \qquad V_P - V_Q = -2.5\text{ V}$$

31. By Kirchhoff's loop rule in the given loop $ABEFA$, we get



$$10 - (i_1 + i_2)R_1 = 0$$
$$\Rightarrow \qquad 10 - (i_1 + i_2)\,20 = 0$$
$$\text{or} \qquad i_1 + i_2 = \frac{1}{2} \qquad \text{...(i)}$$

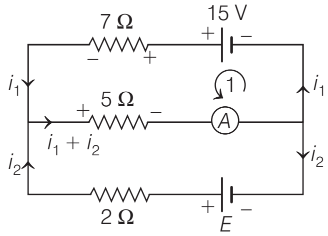
and from loop $BCDEB$, we get

$$10 - (i_1 + i_2)R_1 - i_2R_2 = 0$$
$$\Rightarrow \qquad 10 - (i_1 + i_2 + i_2)\,20 = 0$$
$$\Rightarrow \qquad i_1 + 2i_2 = \frac{1}{2} \qquad \text{...(ii)}$$

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

$$i_2 = 0$$
$$\text{and} \qquad i_1 = 0.5\text{ A}$$

32. Given,

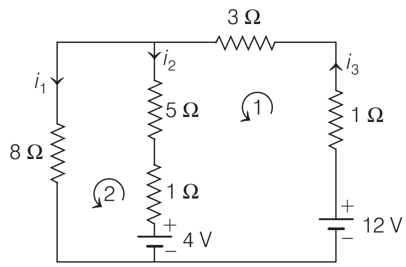


$$\text{Given,} \qquad i_1 + i_2 = 2\text{ A}$$

In loop 1, by Kirchhoff's rule, $\Sigma V = 0$

$$15 - 7i_1 - 2\times 5 = 0$$
$$\Rightarrow \qquad i_1 = \frac{5}{7}\text{ A}$$
$$\Rightarrow \qquad i_1 = 0.714\text{ A}$$
$$\text{Also,} \qquad i_1 + i_2 = 2\text{ A}$$
$$\Rightarrow \qquad i_2 = 2 - \frac{5}{7} = \frac{9}{7}\text{ A}$$
$$\Rightarrow \qquad i_2 = 1.29\text{ A}$$

33. By Kirchhoff's rule for loop 1,



$$12 - 4\,i_3 - 6\,i_2 - 4 = 0$$
$$\Rightarrow \qquad 8 = 4i_3 + 6i_2$$

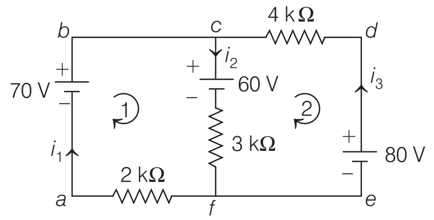
and from loop 2, $-6\,i_2 - 4 + 8\,i_1 = 0$

On solving, we get $\quad i_1 = 846\text{ mA}$

and $\quad i_2 = 462\text{ mA}$

Hence, current through 8 Ω resistor is 846 mA.

34. Let currents in branches are i_1, i_2 and i_3.



Then, from loops 1 and 2, we have

$$70 - 60 - i_2 \times 3 - i_1 \times 2 = 0 \qquad \text{...(i)}$$

$$80 - i_3 \times 4 - 60 - i_2 \times 3 = 0 \qquad \text{...(ii)}$$

and $$i_2 = i_1 + i_3 \qquad \text{...(iii)}$$

On solving Eqs. (i), (ii) and (iii), we get

$$i_1 = 0.385\text{ mA}$$

$$i_2 = 3.08\text{ mA}$$

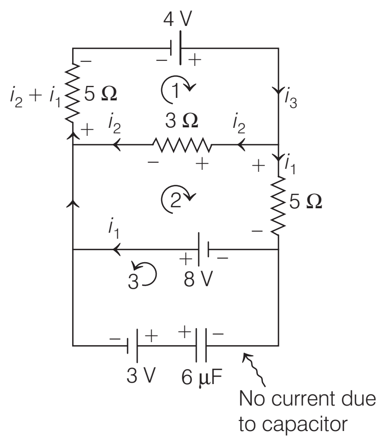
$$i_3 = 2.69\text{ mA}$$

and $$V_{cf} = -60 - 3.08 \times 3$$

i.e. $$V_c - V_f = -69.2\text{ V}$$

Point c is at higher potential.

35. Current distribution in the given circuit is taken as



Using equations of Kirchhoff's law as given below

$$i_1 + i_2 = i_3$$

$$4 - 3i_2 - 5i_3 = 0 \qquad \text{(loop 1)}$$

$$3i_2 - 5i_1 + 8 = 0 \qquad \text{(loop 2)}$$

On solving these equations, we get

$$i_2 = -0.364\text{ A}$$

$$i_1 = 1.38\text{ A}$$

$$i_3 = 1.02\text{ A}$$

Now, going anti-clockwise in loop 3,

$$\Sigma V = 0$$

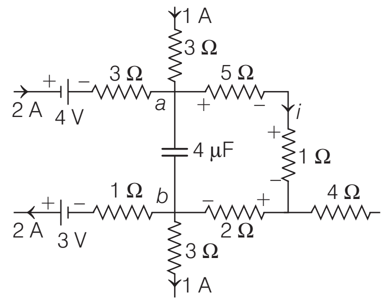
$$\Rightarrow \quad 8 + 3 - \Delta V_{\text{capacitor}} = 0$$

$$\Rightarrow \quad \Delta V_{\text{capacitor}} = 11\text{ V}$$

So, charge on a capacitor,

$$C = Q\Delta V = 6\,\mu\text{F} \times 11\text{ V} = 66\,\mu\text{C}$$

36. By Kirchhoff's laws,



At junction a and b,

$$i = 2\text{A} + 1\text{ A} = 3\text{ A}$$

and also current through corner 4 Ω resistor is zero.

Now, for path ab,

$$-3 \times 5 - 3 \times 1 + 3 \times 2 = V_{ab} = V_b - V_a$$

$$\Rightarrow \quad V_{ab} = V_b - V_a = -12\text{ V}$$

So, potential drop across capacitor = 12 V

Hence, energy stored $= \frac{1}{2}CV^2 = \frac{1}{2} \times 4 \times 10^{-6} \times 12^2$ J

$$= 0.288\text{ mJ} \approx 0.3\text{ mJ}$$

37. As, bulbs can be compared only when they are to be used with same source, so we take V = constant for both.

Now, $$P_1 > P_2$$

$$\frac{V^2}{R_1} > \frac{V^2}{R_2} \Rightarrow R_1 < R_2 \qquad \left(\text{as, } R = \frac{\rho l}{A}\right)$$

$$\Rightarrow \quad \frac{\rho l}{A_1} < \frac{\rho l}{A_2} \Rightarrow A_1 > A_2$$

Filament of first bulb is thicker.

38. Power consumed $= \left(\frac{\text{Supply voltage}}{\text{Rate voltage}}\right)^2 \times$ Rated power

$$= \left(\frac{110}{115}\right)^2 \times 500 = 456.6\text{ W}$$

$\therefore$ % drop in heat output $= \frac{P_{\text{actual}} - P_{\text{consumed}}}{P_{\text{actual}}} \times 100$

$$= \left(\frac{500 - 456.6}{500}\right) \times 100 = 8.6\%$$

39. $\therefore \quad P = \frac{V^2}{R}$

$$\because \quad \frac{P_{200}}{P_{800}} = \frac{V^2/R_{200}}{V^2/R_{800}} = \frac{R_{800}}{R_{200}}$$

$$= \frac{R_{200}(1 + \alpha\,\Delta T)}{R_{200}}$$

$$\Rightarrow \quad P_{200} = P_{800} \times (1 + 4 \times 10^{-4} \times 600)$$

$$= 500\ (1 + 4 \times 10^{-4} \times 600) = 620\text{ W}$$

40. ***Case* I** Using the formula, $P = \frac{V^2}{R}$ ...(i)

where, R is resistance of wire, V is voltage across wire and P is power dissipation in wire

and $$R = \frac{\rho l}{A} \quad \text{...(ii)}$$

From Eqs. (i) and (ii), we have

$$P_1 = \frac{V^2}{\rho l / A}$$

or $$P_1 = \frac{V^2}{\rho l} \cdot A \quad \text{...(iii)}$$

***Case* II** Let R_2 be net resistance of two wires in parallel, then

$$R_2 = \frac{R \times R}{R + R} = \frac{R}{2}$$

where, R is the resistance of half wire

$$\Rightarrow \quad R_2 = \frac{\rho \cdot \left(\frac{l}{2}\right)}{A \cdot 2} = \frac{\rho l}{4A}$$

or $$P_2 = \frac{V^2}{\rho l} \cdot 4A \quad \text{...(iv)}$$

On dividing Eq. (iii) by Eq. (iv), we get

$$\frac{P_1}{P_2} = \frac{1}{4} \Rightarrow \frac{P_2}{P_1} = \frac{4}{1}$$

41. Total power (P) consumed

$$= (15 \times 40) + (5 \times 100) + (5 \times 80) + (1 \times 1000)$$
$$= 2500 \text{ W}$$

As we know power, *i.e.* $P = Vi$

$$\Rightarrow \quad i = \frac{2500}{220} \text{ A} = \frac{125}{11} = 11.3 \text{ A}$$

Hence, minimum capacity should be 12 A.

42. Given, $P = 1 \text{ kW} = 1000 \text{ W}$,

$V = 220 \text{ V}, \; R = 2 \, \Omega$

Current, $$i = \frac{P}{V} = \frac{1000}{220} \text{ A}$$

Power loss, $$P_{\text{loss}} = i^2 R = \left(\frac{1000}{220}\right)^2 \times 2 = 41.32 \text{ W}$$

Now, the efficiency of transmission line,

$$\eta = \left(\frac{P}{P + P_{\text{loss}}}\right) \times 100 = \left(\frac{1000}{1000 + 41.32}\right) \times 100$$

$$\eta = 96.03\% \approx 96\%$$

43. Resistance of a bulb of power P and with a voltage source V is given by

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

Resistance of the given two bulbs are

$$R_1 = \frac{V^2}{P_1} = \frac{(220)^2}{25} \text{ and } R_2 = \frac{V^2}{P_2} = \frac{(220)^2}{100}$$

Since, bulbs are connected in series. This means same amount of current flows through them.

$\therefore$ Current in circuit is

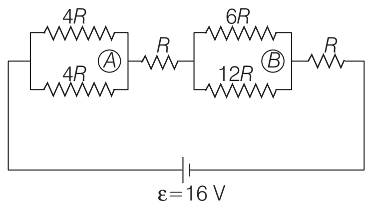
$$i = \frac{V}{R_{\text{total}}} = \frac{220}{\frac{(220)^2}{25} + \frac{(220)^2}{100}} = \frac{1}{11} \text{ A}$$

Power drawn by bulbs are respectively,

$$P_1 = i^2 R_1 = \left(\frac{1}{11}\right)^2 \times \frac{220 \times 220}{25} = 16 \text{ W}$$

and $$P_2 = i^2 R_2 = \left(\frac{1}{11}\right)^2 \times \frac{220 \times 220}{100} = 4 \text{ W}$$

44. Given circuit is



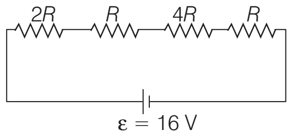
Equivalent resistance of part A,

$$R_A = \frac{4R \times 4R}{4R + 4R} = 2R$$

Equivalent resistance of part B,

$$R_B = \frac{6R \times 12R}{6R + 12R}$$
$$= \frac{72}{18} R = 4R$$

$\therefore$ Equivalent circuit is

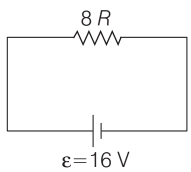


$\therefore$ Total resistance of the given network is

$$R_s = 2R + R + 4R + R = 8R$$

As we know, power of the circuit,

$$P = \frac{\varepsilon^2}{R_s} = \frac{(16)^2}{8R} = \frac{16 \times 16}{8R} \quad \text{...(i)}$$



According to question, power consumed by the network, $P = 4$ W

From Eq. (i), we get

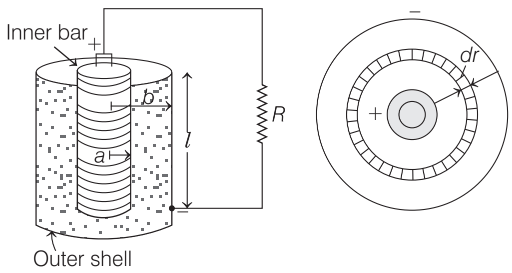
$$\therefore \quad \frac{16 \times 16}{8R} = 4$$

$$\Rightarrow \quad R = \frac{16 \times 16}{8 \times 4} = 8 \Omega$$

45. We have, $H = i^2Rt \Rightarrow 500 = (1.5)^2 \times R \times 20$

$$E = (3)^2 \times R \times 20$$
$$E = 2000\text{ J}$$

46. By maximum power theorem, maximum Joule's heating in external resistance R takes place when internal resistance of battery is equal to external resistance R.



Now, resistance of an elemental cylinder of radius r and thickness dr is

$$(dR)_{\text{internal}} = \frac{\rho \cdot dr}{2\pi r l}$$

$$\Rightarrow \quad R_{\text{internal}} = \int (dR)_{\text{internal}}$$

$$= \int_{r=a}^{r=b} \frac{\rho dr}{2\pi r l} = \frac{\rho}{2\pi l}\int_a^b \frac{dr}{r} = \frac{\rho}{2\pi l}[\ln r]_a^b$$

$$= \frac{\rho}{2\pi l}(\ln b - \ln a)$$

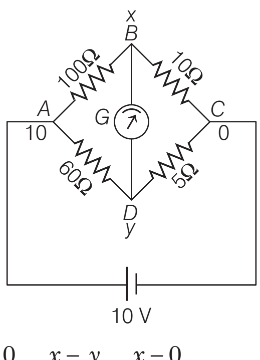
$$= \frac{\rho}{2\pi l} \cdot \ln\left(\frac{b}{a}\right)$$

So, the maximum Joule's heating in R will takes place when its value is

$$= R_{\text{internal}} = \frac{\rho}{2\pi l} \cdot \ln\left(\frac{b}{a}\right)$$

47. In a balanced Wheatstone bridge, there is no effect on position of null point, if we exchange the battery and galvanometer. So, option (a) is incorrect.

48.



$$\frac{x-10}{100} + \frac{x-y}{15} + \frac{x-0}{10} = 0$$

$$53x - 20y = 30 \quad \ldots\text{(i)}$$

$$\frac{y-10}{60} + \frac{y-x}{15} + \frac{y-0}{5} = 0$$

$$17y - 4x = 10 \quad \ldots\text{(ii)}$$

On solving Eqs. (i) and (ii), we get

$$x = 0.865 \Rightarrow y = 0.792$$
$$\Delta V = x - y = 0.073 \text{ and } R = 15\ \Omega$$
$$i = \frac{\Delta V}{R} = 4.87\text{ mA}$$

49. For a balanced Wheatstone bridge,

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

In first case when $R = 400\ \Omega$, the balancing equation will be

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

$$\Rightarrow \quad \frac{P}{400\ \Omega} = \frac{Q}{X}$$

$$\Rightarrow \quad P = \frac{400 \times Q}{X} \quad \ldots\text{(i)}$$

In second case, P and Q are interchanged and $R = 405\ \Omega$

$$\therefore \quad \frac{Q}{R} = \frac{P}{X} \Rightarrow \frac{Q}{405} = \frac{P}{X} \quad \ldots\text{(ii)}$$

Substituting the value of P from Eq. (i) in Eq. (ii), we get

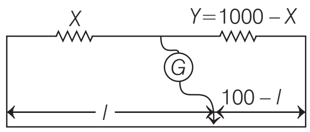
$$\frac{Q}{405} = \frac{Q \times 400}{X^2}$$

$$\Rightarrow \quad X^2 = 400 \times 405$$

$$\Rightarrow \quad X = \sqrt{400 \times 405} = 402.5$$

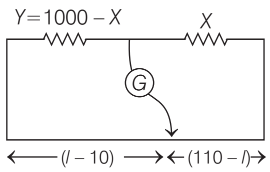
The value of X is close to $402.5\ \Omega$.

50. We have, $X + Y = 1000\ \Omega$



Initially, $$\frac{X}{l} = \frac{1000 - X}{100 - l} \quad \ldots\text{(i)}$$

When X and Y are interchanged, then



$$\frac{1000 - X}{l - 10} = \frac{X}{100 - (l - 10)}$$

or $$\frac{1000 - X}{l - 10} = \frac{X}{110 - l} \quad \ldots\text{(ii)}$$

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

$$\frac{100 - l}{l} = \frac{l - 10}{110 - l}$$

$$(100 - l)\ (110 - l) = (l - 10)\, l$$

$$11000 - 100\, l - 110\, l + l^2 = l^2 - 10\, l$$

$$\Rightarrow \quad 11000 = 200\, l$$

$$\therefore \quad l = 55 \text{ cm}$$

Substituting the value of l in Eq. (i), we get

$$\frac{X}{55} = \frac{1000 - 55}{100 - 55}$$

$$\Rightarrow \quad 20X = 11000$$

$$\therefore \quad X = 550\ \Omega$$

51. For meter bridge, if balancing length is l cm, then in first case, $\frac{R_1}{R_2} = \frac{l}{(100 - l)}$

It is given that, $l = 40$ cm

So, $$\frac{R_1}{40} = \frac{R_2}{100 - 40} \text{ or } \frac{R_1}{R_2} = \frac{2}{3} \quad \ldots\text{(i)}$$

In second case, $R_1' = R_1 + 10$, and balancing length is now 50 cm, then

$$\frac{R_1 + 10}{50} = \frac{R_2}{(100 - 50)}$$

or $$R_1 + 10 = R_2 \quad \ldots\text{(ii)}$$

Substituting the value of R_2 from Eq. (ii) in Eq. (i), we get

or $$\frac{R_1}{10 + R_1} = \frac{2}{3}$$

$$\Rightarrow \quad 3R_1 = 20 + 2R_1$$

or $$R_1 = 20\Omega$$

$$\Rightarrow \quad R_2 = 30\Omega$$

Let us assume the parallel connected resistance is x.

Then, equivalent resistance is $\frac{x\,(R_1 + 10)}{x + R_1 + 100}$.

So, this combination should be again equal to R_1.

$$\frac{(R_1 + 10)x}{R_1 + 10 + x} = R_1$$

$$\Rightarrow \quad \frac{30x}{30 + x} = 20$$

or $$30x = 600 + 20x$$

or $$x = 60\Omega$$

52. As, galvanometer shows zero deflection.

This means, the meter bridge is balanced.

$$\frac{R'}{R_{AP}} = \frac{R'}{R_{PB}}$$

$$\Rightarrow \quad R_{AP} = R_{PB} \quad \ldots\text{(i)}$$

Now, for meter bridge wire, $\frac{dR}{dl} = \frac{k}{\sqrt{l}}$

where, k is the constant of proportionality.

$$\Rightarrow \quad dR = \frac{k}{\sqrt{l}}\, dl$$

Integrating both sides, we get

$$\Rightarrow \quad R = \int \frac{k}{\sqrt{l}}\, dl$$

So, $$R_{AP} = \int_0^l \frac{k}{\sqrt{l}}\, dl = k(2\sqrt{l})\Big|_0^l = 2k\sqrt{l}$$

and $$R_{PB} = \int_l^1 \frac{k}{\sqrt{l}}\, dl = 2k(\sqrt{l})\Big|_l^1$$

$$= 2k\,(\sqrt{1} - \sqrt{l})$$

$$= 2k\,(1 - \sqrt{l})$$

Substituting the values of R_{AP} and R_{PB} in Eq. (i), we get

$$R_{AP} = R_{PB}$$

$$\Rightarrow \quad 2k\sqrt{l} = 2k(1 - \sqrt{l})$$

$$\Rightarrow \quad \sqrt{l} = \frac{1}{2} \quad \text{or} \quad l = \frac{1}{4} = 0.25 \text{ m}$$

53. $\because \quad V \propto l$

$$\therefore \quad \frac{V}{\varepsilon} = \frac{l}{L}$$

where, l = balance point distance

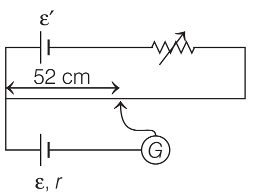
and L = length of potentiometer wire.

or $$V = \frac{l}{L}\,\varepsilon \text{ or } V = \frac{30 \times \varepsilon}{100} = \frac{30}{100}\,\varepsilon$$

54. The internal resistance of the cell,

$$r = \left(\frac{l_1 - l_2}{l_2}\right) R = \left(\frac{240 - 120}{120}\right) \times 2 = 2\ \Omega$$

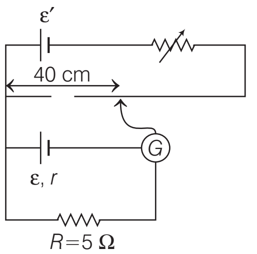
55. With only the cell,



On balancing, $\varepsilon = 52 \times x \quad \ldots\text{(i)}$

where, x is the potential gradient of the wire.

When the cell is shunted,



Similarly, on balancing,

$$V = \varepsilon - \frac{\varepsilon r}{(R + r)} = 40 \times x \quad \ldots\text{(ii)}$$

Solving Eqs. (i) and (ii), we get

$$\frac{\varepsilon}{V} = \frac{1}{1 - \frac{r}{R + r}} = \frac{52}{40}$$

$$\Rightarrow \quad \frac{\varepsilon}{V} = \frac{R+r}{R} = \frac{52}{40} \Rightarrow \frac{5+r}{5} = \frac{52}{40}$$

$$\Rightarrow \quad r = \frac{3}{2}\,\Omega \Rightarrow r = 1.5\,\Omega$$

56. Let length of null point J be x and length of the potentiometer wire be L.

In first case, current in the circuit, $i_1 = \frac{6}{4+2} = 1$ A

$\therefore$ Potential gradient $= i \times R = \frac{1 \times 4}{L}$

$\Rightarrow$ Potential difference in part 'AJ' $= \frac{1\times 4}{L} \times x = \varepsilon_1$

Given, $\varepsilon_1 = 0.5 = \frac{4x}{L}$ or $\frac{x}{L} = \frac{1}{8}$ ...(i)

In second case, current in the circuit, $i_2 = \frac{6}{4+6} = 0.6$ A

$\therefore$ Potential gradient $= \frac{0.6 \times 4}{L}$

$\Rightarrow$ Potential difference in part 'AJ'

$$= \frac{0.6\times 4}{L} \times x = \varepsilon_2$$

$$\Rightarrow \quad \varepsilon_2 = \frac{0.6 \times 4}{L} \times \frac{L}{8} \quad \text{[using Eq. (i)]}$$

$$\Rightarrow \quad \varepsilon_2 = 0.3\text{ V}$$

57. Given, length of potentiometer wire $(AB) = L$

Resistance of potentiometer wire $(AB) = 12\,r$

emf of cell D of potentiometer $= \varepsilon$

Internal resistance of cell $D = r$

emf of cell $C = \frac{\varepsilon}{2}$

Internal resistance of cell $C = 3r$

Current in potentiometer wire

$$i = \frac{\text{emf of cell of potentiometer}}{\text{total resistance of potentiometer circuit}}$$

$$\Rightarrow \quad i = \frac{\varepsilon}{r + 12r} = \frac{\varepsilon}{13r}$$

Potential drop across the balance length AJ of potentiometer wire is $V_{AJ} = i \times R_{AJ}$

$\Rightarrow$ $V_{AJ} = i$ (Resistance per unit length of potentiometer wire $\times$ length AJ)

$$\Rightarrow \quad V_{AJ} = i\left(\frac{12r}{L} \times x\right)$$

where, $x =$ balance length AJ.

As null point occurs at J, so potential drop across balance length $AJ =$ emf of the cell C.

$$\Rightarrow \quad V_{AJ} = \frac{\varepsilon}{2} \Rightarrow i\left(\frac{12r}{L} \times x\right) = \frac{\varepsilon}{2}$$

$$\Rightarrow \quad \frac{\varepsilon}{13r} \times \frac{12r}{L} \times x = \frac{\varepsilon}{2}$$

$$\Rightarrow \quad x = \frac{13}{24} L$$

Round II

1. As, we know Cu is a conductor, so when there is increase in temperature, resistance will increase linearly. Then, Si is semiconductor, so with increase in temperature, resistance will decrease linearly.

2. $$i = \frac{\varepsilon}{R+r}$$

$$\Rightarrow \quad i = \frac{\varepsilon}{R} = \text{constant}$$

where, $R =$ external resistance

$r =$ internal resistance $= 0$

3. Given, $l' = l + 100\%\, l = 2\,l$

Initial volume $=$ Final volume

i.e. $\pi r^2 l = \pi r'^2 l'$

or $$r'^2 = \frac{r^2 l}{l'} = r^2 \times \frac{l}{2\,l}$$

or $$r'^2 = \frac{r^2}{2}$$

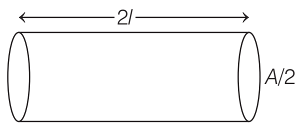
$$\therefore \quad R' = \rho\,\frac{l'}{A'} = \rho\,\frac{2l}{\pi r'^2} \quad \left(\because\ R = \frac{\rho l}{A}\right)$$

$$= \frac{\rho \cdot 4l}{\pi r^2} = 4R$$

Thus, $\Delta R = R' - R = 4R - R = 3\,R$

$$\therefore \quad \%\,\Delta R = \frac{3R}{R} \times 100\% = 300\%$$

4. As per the question,



$$\text{Resistance} = \frac{\rho(2l)}{(A/2)} = \frac{4\rho l}{A}$$

$$\Rightarrow \quad \text{Current} = \frac{V}{R} = \frac{VA}{4\rho l}$$

5. Let resistances be R_1 and R_2, then

$$S = R_1 + R_2 \text{ and } P = \frac{R_1 R_2}{R_1 + R_2}$$

$$\therefore \quad (R_1 + R_2) = \frac{n \times R_1 R_2}{R_1 + R_2} \quad (\because\ S = nP)$$

or $(R_1 + R_2)^2 = n R_1 R_2$

$$\Rightarrow \quad n = \left[\frac{R_1^2 + R_2^2 + 2\,R_1 R_2}{R_1 R_2}\right] = \left[\frac{R_1}{R_2} + \frac{R_2}{R_1} + 2\right]$$

We know, Arithmetic Mean $\geq$ Geometric Mean

$$\frac{\frac{R_1}{R_2} + \frac{R_2}{R_1}}{2} \geq \sqrt{\frac{R_1}{R_2} \times \frac{R_2}{R_1}} \Rightarrow \frac{R_1}{R_2} + \frac{R_2}{R_1} \geq 2$$

So, n (minimum value) $= 2 + 2 = 4$

6. Given, $i = 10\text{ A}, A = 5\text{ mm}^2 = 5 \times 10^{-6}\text{ m}^2$

and $v_d = 2 \times 10^{-3}$ m/s

We know that, $i = neAv_d$

$\therefore$ $10 = n \times 1.6 \times 10^{-19} \times 5 \times 10^{-6} \times 2 \times 10^{-3}$

$\Rightarrow$ $n = 0.625 \times 10^{28} = 625 \times 10^{25}$

7. Let (ρ_A, l_A, r_A, A_A) and (ρ_B, l_B, r_B, A_B) be specific resistances, lengths, radii and areas of wires A and B, respectively.

Resistance of A, $R_A = \dfrac{\rho_A l_A}{A_A} = \dfrac{\rho_A l_A}{\pi r_A^2}$

Resistance of B, $R_B = \dfrac{\rho_B l_B}{A_B} = \dfrac{\rho_B l_B}{\pi r_B^2}$

From given information,

$$\rho_B = 2\rho_A$$

$$r_B = 2\, r_A$$

and $R_A = R_B$

$\therefore$ $\dfrac{\rho_A l_A}{\pi r_A^2} = \dfrac{\rho_B l_B}{\pi r_B^2}$

or $\dfrac{\rho_A l_A}{\pi r_A^2} = \dfrac{2\rho_A \times l_B}{\pi (2\, r_A)^2}$

or $\dfrac{l_B}{l_A} = \dfrac{2}{1} = 2:1$

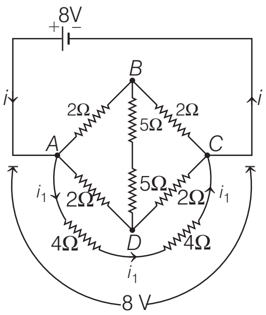
8. Using colour code, we have

$$R = 53 \times 10^4 \pm 5\%\ \Omega$$

or $R = 530 \times 10^3\ \Omega \pm 5\%$

or $R = 530\text{ k}\Omega \pm 5\%$

9.



From the given circuit diagram,

Potential drop across $AC, V = 8$ V

Resistance of mentioned wire,

$$R = 4 + 4 = 8\,\Omega$$

So, the current flowing from A to C,

$$i_1 = \frac{V}{R} = \frac{8\text{V}}{8\Omega} = 1\text{ A}$$

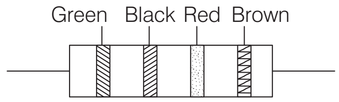
10. For balanced Wheatstone's bridge,

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

Here, $S = S_1 \,||\, S_2 = \dfrac{S_1 S_2}{S_1 + S_2}$

$\Rightarrow$ $\dfrac{P}{Q} = \dfrac{R(S_1 + S_2)}{S_1 S_2}$

11. Colour code of carbon resistor is shown in the figure below



So, resistance value of resistor using colour code is

$$R = 502 \times 10 = 50.2 \times 10^2\ \Omega$$

Here, we must know that for given carbon resistor first three colours give value of resistance and fourth colour gives multiplier value.

Now using power, $P = i^2 R$, we get

$\Rightarrow$ $i = \sqrt{\dfrac{P}{R}} = \sqrt{\dfrac{2}{50.2 \times 10^2}}$

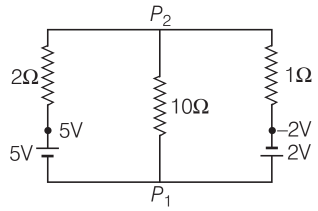
$$\simeq 20 \times 10^{-3}\text{ A}$$

$$= 20\text{ mA}$$

12. Let potential at P_1 be 0 V and potential at P_2 be V_0.

Now, apply KCL at P_2,

$$\Sigma\, i = 0$$

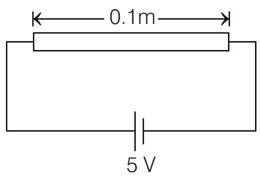


$$\frac{V_0 - 5}{2} + \frac{V_0 - 0}{10} + \frac{V_0 - (-2)}{1} = 0$$

or $V_0 = \dfrac{5}{16}$

So, current through 10 Ω resistor is $\dfrac{V_0}{10}$ ($\simeq 0.03$ A) from P_2 to P_1.

13. According to the question,



$$v_d = 2.5 \times 10^{-4}\text{ m/s},$$

$$n = 8 \times 10^{28}/\text{m}^3$$

We know that,

$$J = nev_d \text{ or } i = nev_d A$$

where, symbols have their usual meanings.

$\Rightarrow$ $\dfrac{V}{R} = nev_d A$

or $\dfrac{V}{\dfrac{\rho L}{A}} = nev_d A$

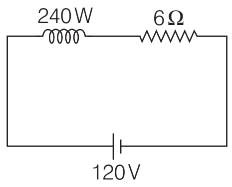
or $$\frac{V}{\rho L} = nev_d$$

or $$\rho = \frac{V}{nev_d\, L}$$

$$= \frac{5}{8 \times 10^{28} \times 1.6 \times 10^{-19} \times 2.5 \times 10^{-4} \times 0.1}$$

or $\rho = 1.6 \times 10^{-5}\ \Omega\text{-m}$

14. $$P = \frac{V^2}{R}$$



Resistance of the bulb,

$$R = \frac{120 \times 120}{60} = 240\ \Omega$$

$$R_{eq} = 240 + 6 = 246\ \Omega$$

$$\Rightarrow \quad i_1 = \frac{V}{R_{eq}} = \frac{120}{246}$$

$$\because \quad V_1 = i_1 R_1 = \frac{120}{246} \times 240 = 117.073\ \text{V}$$

Resistance of the heater $= \dfrac{V^2}{P} = \dfrac{120 \times 120}{240} = 60\ \Omega$

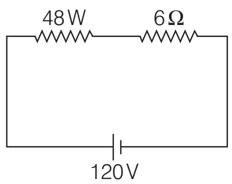
As bulb and heater are connected in parallel.

Net resistance $= \dfrac{240 \times 60}{300} = 48\ \Omega$

Total resistance, $R_2 = 48 + 6 = 54\ \Omega$

Total current, $i_2 = V/R_2 = 120/54$

Potential across heater = Potential across bulb



$$V_2 = \frac{120}{54} \times 48 = 106.66\ \text{V}$$

$$\because \quad V_1 - V_2 = 117.073 - 106.66 = 10.04\ \text{V}$$

15. Let P_1 and P_2 be the individual electric powers of the two resistances, respectively.

In series combination, power is

$$P_0 = \frac{P_1 P_2}{P_1 + P_2} = 60\text{W}$$

Since, the resistances are equal and the current through each resistor in series combination is also same. Then,

$$P_1 = P_2 = 120\ \text{W}$$

In parallel combination, power is

$$P = P_1 + P_2 = 120 + 120 = 240\ \text{W}$$

Alternate Solution

Let R be the resistance.

$\therefore$ Net resistance in series $= R + R = 2R$

$$P = \frac{V^2}{2R} = 60\ \text{W} \Rightarrow \frac{V^2}{R} = 120\ \text{W}$$

New resistance in parallel $= \dfrac{R \times R}{R + R} = R/2$

$$P' = \frac{V^2}{R/2} = 2\left(\frac{V^2}{R}\right) = 240\ \text{W}$$

16. As R_1, R_2 and R in series.

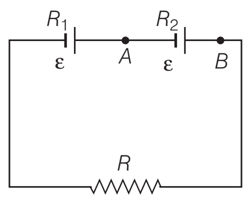
$$R_{eq} = R_1 + R_2 + R$$

$\therefore$ Net current, $i = \dfrac{2\varepsilon}{R_1 + R_2 + R}$

According to the question,

$$-(V_A - V_B) = \varepsilon - iR_2$$

$$\therefore \quad 0 = \varepsilon - iR_2$$



or $$\varepsilon E = iR_2$$

or $$\varepsilon = \frac{2\varepsilon}{R_1 + R_2 + R} R_2$$

or $$R_1 + R_2 + R = 2R_2$$

or $$R = R_2 - R_1$$

17. Given, potential difference of 5 mV is across 10 cm length of potentiometer wire. So, potential drop per unit length is

$$= \frac{5 \times 10^{-3}}{10 \times 10^{-2}} = 5 \times 10^{-2}\left(\frac{\text{V}}{\text{m}}\right)$$

Hence, potential drop across 1 m length of potentiometer wire is

$$V_{AB} = 5 \times 10^{-2}\left(\frac{\text{V}}{\text{m}}\right) \times 1 = 5 \times 10^{-2}\ \text{V}$$

Now, potential drop that must occurs across resistance R is

$$V_R = 4 - 5 \times 10^{-2} = \frac{395}{100}\ \text{V}$$

Now, circuit current is $i = \dfrac{V}{R_{\text{total}}} = \dfrac{4}{R + 5}$

Hence, for resistance R, using $V_R = iR$, we get

$$\frac{395}{100} = \frac{4}{R + 5} \times R$$

$$\Rightarrow \quad 395\,(R + 5) = 400R$$

$$\Rightarrow \quad 395 \times 5 = (400 - 395)R \Rightarrow R = 395\ \Omega$$

18. In steady state, no current flows through the capacitor. So, resistance r_p becomes ineffective.

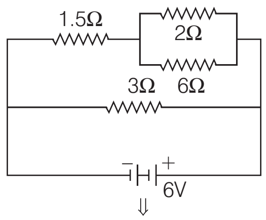
So, the current in circuit, $i = \dfrac{\varepsilon}{r + r_2}$

$\because$ Potential drop across capacitor = Potential drop across $r_2 = ir_2 = \dfrac{\varepsilon r_2}{r + r_2}$

$\therefore$ Stored charge of capacitor, $Q = CV = C\varepsilon \dfrac{r_2}{r + r_2}$

19. The equivalent circuit can be drawn as 6 Ω and 2 Ω are in parallel.

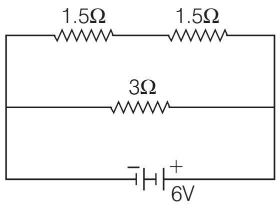
$$R' = \frac{2 \times 6}{8} = 1.5\ \Omega$$



$\Downarrow$

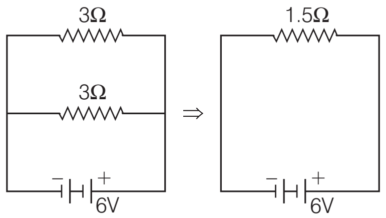
As, 1.5 Ω and 1.5 Ω are in series. (as shown in above circuit)

$$R'' = 1.5 + 1.5 = 3\ \Omega$$



Now, 3 Ω and 3 Ω are in parallel.

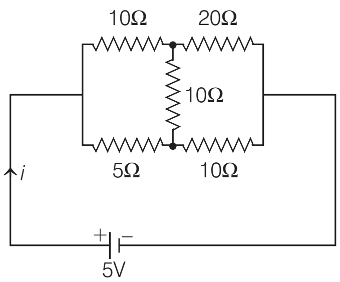
$$R_{eq} = \frac{3 \times 3}{6} = 1.5\ \Omega$$



Hence, current supplied by the battery is

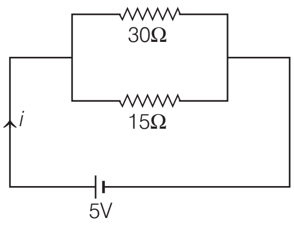
$$i = \frac{V}{R_{eq}} = \frac{6}{1.5} = 4\text{ A}$$

20. The given circuit can be redrawn as

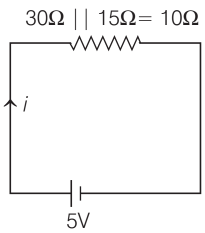


which is a balanced Wheatstone's bridge and hence, no current flows in the middle resistor, so equivalent circuit would be as shown below

$\Rightarrow$

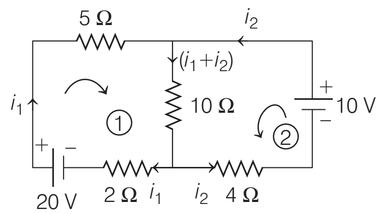


$\Rightarrow$



$$i = \frac{V}{R} = \frac{5}{10} = 0.5\text{ A}$$

21. Assume the current in branches as shown in figure



Applying KVL in loop 1,

$$+20 - 5i_1 - 10(i_1 + i_2) - 2i_1 = 0$$

$$17i_1 + 10i_2 = 20 \qquad \ldots\text{(i)}$$

Applying KVL in loop 2,

$$+10 - 10(i_1 + i_2) - 4i_2 = 0$$

$$5i_1 + 7i_2 = 5 \qquad \ldots\text{(ii)}$$

On solving Eqs. (i) and (ii), we get

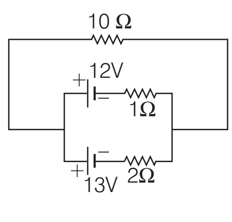
$$i_2 = -0.214\text{ A}$$

or $\qquad i_2 \simeq -0.21$ A

It means the direction of current is from positive to negative terminal of battery inside it.

22. For parallel combination of cells,

$$\varepsilon_{eq} = \frac{\dfrac{\varepsilon_1}{r_1} + \dfrac{\varepsilon_2}{r_2}}{\dfrac{1}{r_1} + \dfrac{1}{r_2}}$$



$$\therefore \qquad \varepsilon_{eq} = \frac{\frac{12}{1} + \frac{13}{2}}{\frac{1}{1} + \frac{1}{2}} = \frac{37}{3}\text{ V}$$

Potential drop across 10 Ω resistance,

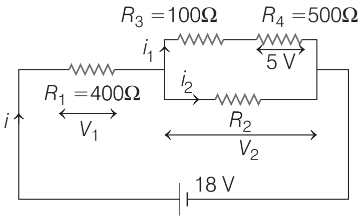
$$V = \left(\frac{\varepsilon}{R_{\text{total}}}\right) \times 10$$

$$= \frac{37/3}{\left(10 + \frac{2}{3}\right)} \times 10$$

$$= 11.56\text{ V}$$

$$\therefore \qquad V = 11.56\text{ V}$$

23. According to question, the voltage across R_4 is 5 V, then the current across it



According to Ohm's law,

$$V = iR$$

$$\Rightarrow \qquad 5 = i_1 \times R_4$$

$$\Rightarrow \qquad 5 = i_1 \times 500$$

$$\Rightarrow \qquad i_1 = \frac{5}{500} = \frac{1}{100}\text{ A}$$

The potential difference across series combination of R_3 and R_4,

$$V_2 = (R_3 + R_4)i = 600 \times \frac{1}{100} = 6\text{ V}$$

So, potential difference (across R_1),

$$V_1 = 18 - 6 = 12\text{ V}$$

Current through R_1,

$$i = \frac{V_1}{R_1} = \frac{12}{400} = \frac{3}{100}\text{ A}$$

So current through R_2,

$$i_2 = i - i_1 = \frac{3}{100} - \frac{1}{100}\text{ A} = \frac{2}{100}\text{ A}$$

Now, from $V = IR$, we have

$$R_2 = \frac{V_2}{i_2} = \frac{6}{(2/100)} = 300\ \Omega$$

24. Measured value of $R = 5\%$ less than actual value of R.

Actual values of $R = 30\ \Omega$

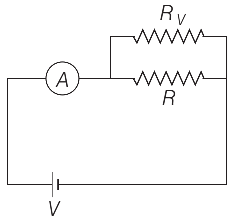
So, measured value of R is

$$R' = 30 - (5\% \text{ of } 30)$$

$$= 30 - \frac{5}{100} \times 30$$

$$\Rightarrow \qquad R' = 28.5\ \Omega \qquad \ldots\text{(i)}$$

Now, let us assume that internal resistance of voltmeter R_V. Replacing voltmeter with its internal resistance, we get following circuit.



It is clear that the measured value, R' should be equal to parallel combination of R and R_V. Mathematically,

$$R' = \frac{RR_V}{R + R_V} = 28.5\ \Omega$$

Given, $\qquad R = 30\ \Omega$

$$\Rightarrow \qquad \frac{30R_V}{30 + R_V} = 28.5$$

$$\Rightarrow \qquad 30R_V = (28.5 \times 30) + 28.5\,R_V$$

$$\Rightarrow \qquad 1.5R_V = 28.5 \times 30$$

$$\Rightarrow \qquad R_V = \frac{28.5 \times 30}{1.5} = 19 \times 30 \text{ or } R_V = 570\ \Omega$$

25. Let R_0 be the initial resistance of both conductors.

$\therefore$ At temperature θ, their resistances will be

$$R_1 = R_0(1 + \alpha_1\theta)$$

and $\qquad R_2 = R_0(1 + \alpha_2\theta)$

For series combination,

$$R_s = R_1 + R_2$$

$$R_{s0}(1 + \alpha_s\theta) = R_0(1 + \alpha_1\theta) + R_0(1 + \alpha_2\theta)$$

where, $\qquad R_{s0} = R_0 + R_0 = 2R_0$

$$\therefore \qquad 2R_0(1 + \alpha_s\theta) = 2R_0 + R_0\theta(\alpha_1 + \alpha_2)$$

or $\qquad \alpha_s = \dfrac{\alpha_1 + \alpha_2}{2}$

For parallel combination,

$$R_p = \frac{R_1R_2}{R_1 + R_2}$$

$$R_{p0}(1 + \alpha_p\theta) = \frac{R_0(1 + \alpha_1\theta)R_0(1 + \alpha_2\theta)}{R_0(1 + \alpha_1\theta) + R_0(1 + \alpha_2\theta)}$$

where, $\qquad R_{p0} = \dfrac{R_0R_0}{R_0 + R_0} = \dfrac{R_0}{2}$

$$\therefore \qquad \frac{R_0}{2}(1 + \alpha_p\theta) = \frac{R_0^2(1 + \alpha_1\theta + \alpha_2\theta + \alpha_1\alpha_2\theta^2)}{R_0(2 + \alpha_1\theta + \alpha_2\theta)}$$

As, α_1 and α_2 are small quantities.

$\therefore$ $\alpha_1\alpha_2$ is negligible.

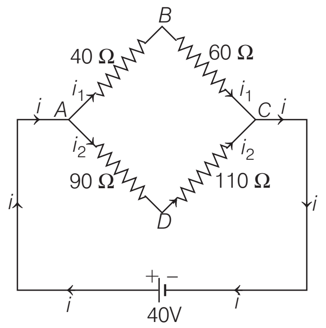
or $\qquad \alpha_p = \dfrac{\alpha_1 + \alpha_2}{2 + (\alpha_1 + \alpha_2)\theta}$

$$= \frac{\alpha_1 + \alpha_2}{2}\left[1 - \left(\frac{\alpha_1 + \alpha_2}{2}\right)\theta\right]$$

As, $(\alpha_1 + \alpha_2)^2$ is negligible.

$$\therefore \qquad \alpha_p = \frac{\alpha_1 + \alpha_2}{2}$$

26. The resistors 40 Ω and 60 Ω are connected in series combination. Similarly, the resistors 90 Ω and 110 Ω are also connected in series combination.



So, $$i_1 = \frac{V_{AC}}{R_{AB} + R_{BC}} = \frac{40}{40+60} = \frac{40}{100} = \frac{2}{5}\text{ A}$$

and $$i_2 = \frac{V_{AC}}{R_{AD} + R_{DC}} = \frac{40}{90+110} = \frac{40}{200} = \frac{1}{5}\text{ A}$$

For path BAD, using KVL (Kirchhoff's voltage law),

$$V_B + i_1 \times 40 - i_2 \times 90 = V_D$$

$$\Rightarrow \quad V_B + \frac{2}{5} \times 40 - \frac{1}{5} \times 90 = V_D$$

$$\Rightarrow \quad V_B + 16 - 18 = V_D$$

$$\Rightarrow \quad V_B - 2 = V_D$$

$$\Rightarrow \quad V_B - V_D = 2\text{ V}$$

So, the potential difference across BD (in volt) is 2.

27. Since, the wire is of uniform cross-section, the resistances of the two segments of the wire AD and DC are in the ratio of the lengths of AD and DC. Using the null point conditions of a Wheatstone bridge, we have

$$\left(\frac{X}{Y}\right) = \left(\frac{33.7}{66.3}\right) \quad \text{...(i)}$$

When Y is shunted by a resistance of 12.0 Ω, net resistance changes,

$$Y' = 12Y/(Y+12)$$

Since, Y' is less than Y, the ratio X/Y' is greater than $\frac{X}{Y}$. Thus, the null point must shift towards the end C, *i.e.*

$$\left(\frac{X}{Y'}\right) = \left(\frac{51.9}{48.1}\right)$$

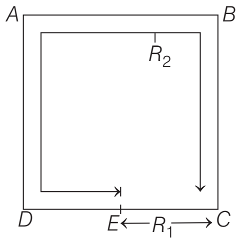
or $$X(Y+12)/12Y = (51.9/48.1)$$

i.e. $$\frac{Y+12}{12} = \left(\frac{51.9}{48.1}\right) \times \frac{66.3}{33.7}$$

which give $Y = 13.5$ Ω and $X = 6.86$ Ω using Eq. (i)

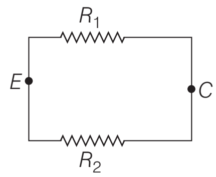
28. Let the length of each side of square $ABCD$ is a.

$\therefore$ Resistance per unit length of each side $= \frac{R}{4a}$



Now, $$R_1 = \frac{R}{4a}(EC) = \frac{R}{4a} \times \frac{a}{2} = \frac{R}{8}$$

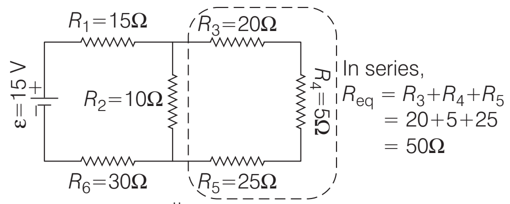
Similarly, $$R_2 = \frac{R}{4a}(EDABC) = \frac{R}{4a} \times \frac{7a}{2} = \frac{7R}{8}$$



Now, effective resistance between E and C is the equivalent resistance of R_1 and R_2 that are connected in parallel as shown below.

$$R_{EC} = \frac{R_1 R_2}{R_1 + R_2} = \frac{(R/8) \times (7R/8)}{(R/8) + (7R/8)} = \frac{7R^2}{64} \times \frac{8}{8R} = \frac{7}{64}R$$

29. Given circuit is redrawn and can be simplified as



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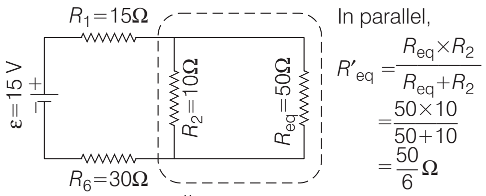

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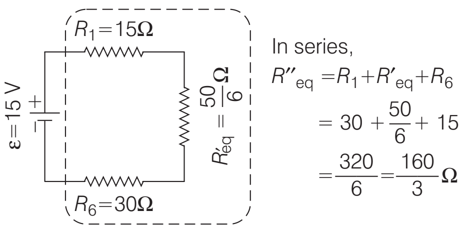
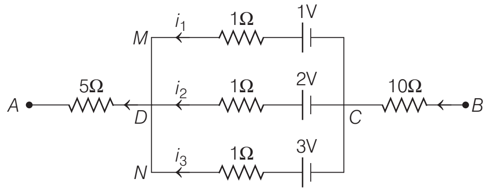


So, current drawn through cell is

$$i = \frac{\text{Voltage}}{\text{Net resistance of the circuit}} = \frac{V}{R''_{eq}} = \frac{15}{(160/3)} = \frac{9}{32}\text{ A}$$

30. In the given circuit, let's assume currents in the arms are i_1, i_2 and i_3, respectively.



Now, $i_1 = \frac{V_1}{R_1} = \frac{1}{1} = 1\text{ A}$

Similarly, $i_2 = \frac{2}{1} = 2\text{ A}$ and $i_3 = \frac{3}{1} = 3\text{ A}$

Total current in the arm DA,

$$i = i_1 + i_2 + i_3 = 6\text{ A}$$

As all three resistors between D and C are in parallel.

$\therefore$ Equivalent resistance between terminals D and C,

$$\frac{1}{R_{DC}} = \left(\frac{1}{1} + \frac{1}{1} + \frac{1}{1}\right)$$

$\therefore$ $R_{DC} = \frac{1}{3}\,\Omega$

So, potential difference across D and C,

$$V_{DC} = iR_{DC} = 6 \times \frac{1}{3} \Rightarrow V_{DC} = 2\text{ V}$$

Now, V_{AD} and $V_{CB} = 0$ (in case of open circuits, $i = 0$)

So, $V_{AB} = V_{AD} + V_{DC} + V_{CB} = V_{DC}$

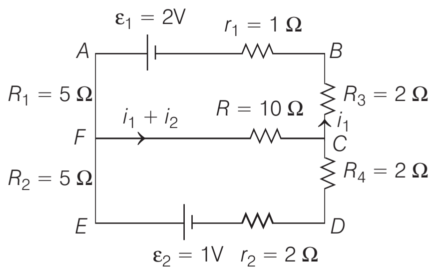
So, $V_{AB} = 2\text{V}$

31. The positive terminals of the cells ε_1 and ε_2 are connected to the wire AE of resistance 10Ω and negative terminals to the wire BD of resistance 4Ω. The resistance of 10Ω is connected between the middle points F and C of the wires AE and BD, respectively. Therefore,

$$R_1 = R_2 = \frac{10}{2} = 5\Omega$$

$$R_3 = R_4 = \frac{4}{2} = 2\Omega$$

The distribution of currents in various branches is shown in the figure



In closed part $ABCFA$ of the circuit,

$$i_1 \times r_1 + i_1 \times R_1 + (i_1 + i_2)R + i_1 \times R_3 = \varepsilon_1$$

$$i_1 \times 1 + i_1 \times 5 + (i_1 + i_2) \times 10 + i_1 \times 2 = 2$$

or $9i_1 + 5i_2 = i$ ...(i)

In closed part $CDEFC$ of the circuit,

$$i_2 \times r_2 + i_2 \times R_2 + (i_1 + i_2) \times R + i_2 \times R_4 = \varepsilon_2$$

or $i_2 \times 2 + i_2 \times 5 + (i_1 + i_2) \times 10 + i_2 \times 2 = 1$

or $10i_1 + 19i_2 = 1$ ...(ii)

Solving Eqs. (i) and (ii), we have

$$i_1 = \frac{14}{121}\text{ A} \text{ and } i_2 = -\frac{1}{121}\text{ A}$$

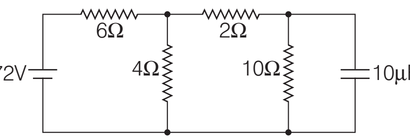
Therefore, current through resistance R,

$$i_1 + i_2 = \frac{14}{121} + \left(-\frac{1}{121}\right) = \frac{13}{121}\text{ A}$$

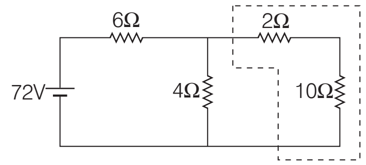
Potential difference across the resistance,

$$R = (i_1 + i_2)R = \frac{13}{121} \times 10 = 1.07\text{ V}$$

32. Given circuit is

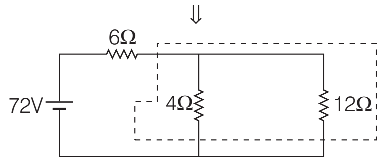


To find charge on capacitor, we need to determine voltage across it. In steady state, capacitor will acts as open circuit and circuit can be reduced as

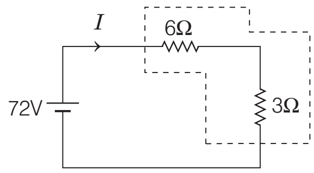


In series, $R_{\text{eq}} = 2\,\Omega + 10\,\Omega = 12\,\Omega$

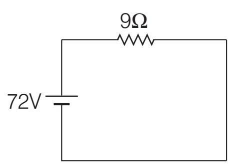
$\Downarrow$



In parallel, $R_{\text{eq}} = \frac{4 \times 12}{4 + 12} = 3\,\Omega$



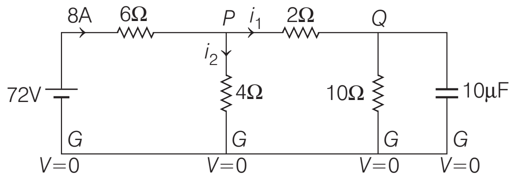
In series, $R_{\text{eq}} = 6\,\Omega + 3\,\Omega = 9\,\Omega$



So, current in steady state, $i = \frac{V}{R} = \frac{72}{9} = 8\text{ A}$

Now, by using current division at point P, current in 6 Ω branch is

$$\frac{72 - V_P}{6\,\Omega} = 8\text{ A} \Rightarrow V_P = 72 - 48 = 24\text{ V}$$



Current in 4 Ω branch,

$$i_2 = \frac{V_P - 0}{4} = \frac{24 - 0}{4} = 6\text{ A}$$

So, current in 2 Ω resistance,

$$i_1 = 8 - i_2 \qquad (\because i = i_1 + i_2)$$
$$= 8 - 6 = 2\text{A}$$

∴ Potential difference across 10 Ω resistor,

$$V_{QG} = 2\text{A} \times 10\ \Omega = 20\text{ V}$$

Same potential difference will be applicable over the capacitor (parallel combination).

So, charge stored in the capacitor will be

$$Q = CV = 10 \times 10^{-6} \times 20$$
$$\Rightarrow \quad Q = 2 \times 10^{-4}\text{ C} = 200\ \mu\text{C}$$

33. Given, number density of electrons, $n = 8.5 \times 10^{28}/\text{m}^3$

Length of wire, $l = 3$ m

Area of cross-section of wire, $A = 2 \times 10^{-6}\text{m}^2$

Current, $i = 3$ A and charge on electron,

$$e = 1.6 \times 10^{-19}\text{ C}$$

Time taken by electron to drift from one end to another of the wire,

$$t = \frac{\text{Length of the wire}}{\text{Drift velocity}} = \frac{l}{v_d} \qquad \ldots\text{(i)}$$

Using the relation, $i = ne\,A\,v_d$

or
$$v_d = \frac{i}{ne\,A} \qquad \ldots\text{(ii)}$$

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

$$t = \frac{l\,ne\,A}{i} = \frac{3 \times 8.5 \times 10^{28} \times 1.6 \times 10^{-19} \times 2 \times 10^{-6}}{3}$$

or $\quad t = 2.72 \times 10^4\text{ s} = 7\text{ h }33\text{ min}$

Thus, the time taken by an electron to drift from one end to another end is 7 h 33 min = 453 min.

34.
$$R_1 = \frac{\rho L}{\pi r \cdot t} \qquad [\because A_1 = \pi r t] \ldots\text{(i)}$$
$$R_2 = \frac{\rho \pi r}{tL} \qquad [\because A_2 = tL] \ldots\text{(ii)}$$

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

$$\frac{R_1}{R_2} = \frac{L^2}{\pi^2 r^2} = \frac{1^2}{10 \times 0.1 \times 0.1} = 10$$

35. $V_{AC} = \varepsilon_3 = 30\text{ V} \qquad \ldots\text{(i)}$

$$V_{CB} = \varepsilon_2 \qquad \ldots\text{(ii)}$$

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

$$\frac{\varepsilon_2}{30} = \frac{V_{CB}}{V_{AC}}$$

$$\Rightarrow \quad \frac{\varepsilon_2}{30} = \frac{3}{2} \qquad \left(\because \frac{V_{CB}}{V_{AC}} = \frac{l_{CB}}{l_{AC}} = \frac{3}{2}\right)$$

$$\Rightarrow \quad \varepsilon_2 = 45\text{ V}$$

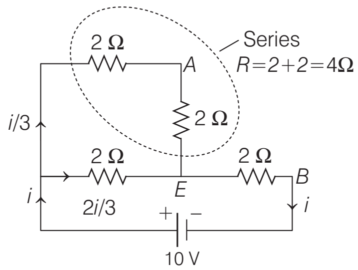
$$\therefore \quad V_{AB} = 30 + 45 = 75\text{ V}$$

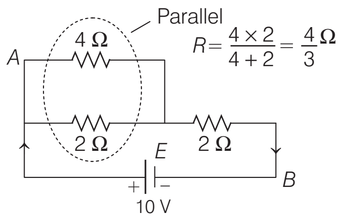
$$\because \quad R_{AB} = 2 \times 5 = 10\ \Omega$$

∴ Current through AB is $\frac{75}{10} = 7.5$ A

$$\therefore \quad \varepsilon_1 = 7.5 \times (R_{AB} + R) = 150\text{ V}$$

36. When capacitor is fully charged, circuit is reduced to as shown below





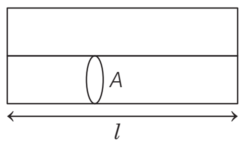
So, total resistance, $R_{\text{eq}} = \frac{4}{3} + 2 = \frac{10}{3}\ \Omega$

Current in circuit, $i = \frac{V}{R_{\text{eq}}} = \frac{10}{10/3} = 3$ A

Hence, potential difference across capacitor

$$= \text{potential difference across } AEB$$
$$= 2\,i/3 + 2 \times i = 2 \times \frac{3}{3} + 2 \times 3 = 8\text{ V}$$

37. ∵ In parallel, $\quad R_{\text{net}} = \frac{R_1 R_2}{R_1 + R_2}$



$$\frac{\rho l}{2A} = \frac{\rho_1 \frac{l}{A} \times \rho_2 \frac{l}{A}}{\rho_1 \frac{l}{A} + \rho_2 \frac{l}{A}}$$

$$\frac{\rho}{2} = \frac{6 \times 3}{6 + 3} = 2$$

$$\rho = 4$$

38. $\because \quad i_0 = \frac{V}{R} = \frac{30/3}{5 \times 10^6} = 2 \times 10^{-6}\text{ A} = 2\,\mu\text{A}$

$\therefore \quad x = 2$