3

Current Electricity

Multiple Choice Questions (MCQs)

Q. 1 Consider a current carrying wire (current I) in the shape of a circle.

(a) source of emf
(b) electric field produced by charges accumulated on the surface of wire
(c) the charges just behind a given segment of wire which push them just the right way by repulsion
(d) the charges ahead

Ans. *(b)* Current per unit area (taken normal to the current), I/A, is called current density and is denoted by j. The SI units of the current density are A/m^2. The current density is also directed along E and is also a vector and the relationship is given by

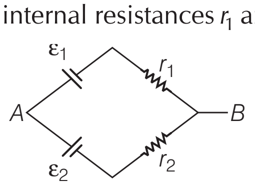
$$j = sE$$

The j changes due to electric field produced by charges accumulated on the surface of wire.

Note *That as the currrent progresses along the wire, the direction of j (current density) changes in an exact manner, while the current I remain unaffected. The agent that is essentially responsible for this.*

Q. 2 Two batteries of emf ε_1 and $\varepsilon_2 (\varepsilon_2 > \varepsilon_1)$ and internal resistances r_1 and r_2 respectively are connected in parallel as shown in figure.

(a) Two equivalent emf ε_{eq} of the two cells is between ε_1 and ε_2, *i.e.,* $\varepsilon_1 < \varepsilon_{eq} < \varepsilon_2$
(b) The equivalent emf ε_{eq} is smaller than ε_1
(c) The ε_{eq} is given by $\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2$ always
(d) ε_{eq} is independent of internal resistances r_1 and r_2



Ans. *(a)* The equivalent emf of this combination is given by

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

This suggest that the equivalent emf ε_{eq} of the two cells is given by

$$\varepsilon_1 < \varepsilon_{eq} < \varepsilon_2$$

Q. 3 A resistance R is to be measured using a meter bridge, student chooses the standard resistance S to be 100Ω. He finds the null point at $I_1 = 2.9$ cm. He is told to attempt to improve the accuracy. Which of the following is a useful way?

(a) He should measure I_1 more accurately
(b) He should change S to 1000Ω and repeat the experiment
(c) He should change S to 3Ω and repeat the experiment
(d) He should given up hope of a more accurate measurement with a meter bridge

K Thinking Process

Here, the concept of accurate balanced Wheatstone bridge is to be used.

Ans. *(c)* The percentage error in R can be minimised by adjusting the balance point near the middle of the bridge, *i.e.*, when I_1 is close to 50 cm. This requires a suitable choice of S.

Since,
$$\frac{R}{S} = \frac{R\, l_1}{R\,(100 - l_1)} = \frac{l_1}{100 - l_1}$$

Since here, $R : S :: 2.9 : 97.1$ imply that the S is nearly 33 times to that of R. In orded to make this ratio 1:1, it is necessary to reduce the value of S nearly $\frac{1}{33}$ times *i.e.*, nearly 3Ω.

Q. 4 Two cells of emfs approximately 5 V and 10 V are to be accurately compared using a potentiometer of length 400 cm.

(a) The battery that runs the potentiometer should have voltage of 8V
(b) The battery of potentiometer can have a voltage of 15 V and R adjusted so that the potential drop across the wire slightly exceeds 10 V
(c) The first portion of 50 cm of wire itself should have a potential drop of 10 V
(d) Potentiometer is usually used for comparing resistances and not voltages

K Thinking Process

The potential drop across wires of potentiometer should be greater than emfs of primary cells.

Ans. *(b)* In a potentiometer experiment, the emf of a cell can be measured, if the potential drop along the potentiometer wire is more than the emf of the cell to be determined. Here, values of emfs of two cells are given as 5V and 10V, therefore, the potential drop along the potentiometer wire must be more than 10V.

Q. 5 A metal rod of length 10 cm and a rectangular cross-section of 1cm x $\frac{1}{2}$ cm is connected to a battery across opposite faces. The resistance will be

(a) maximum when the battery is connected across 1 cm x $\frac{1}{2}$ cm faces
(b) maximum when the battery is connected across 10 cm x 1 cm faces
(c) maximum when the battery is connected across 10 cm x $\frac{1}{2}$ cm faces
(d) same irrespective of the three faces

K Thinking Process

The resistance of wire depends on its geometry l (length of the rod). Here, the metallic rod behaves as a wire.

Ans. ***(a)*** The resistance of wire is given by

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

For greater value of R, l must be higher and A should be lower and it is possible only when the battery is connected across 1 cm x $\left(\frac{1}{2}\right)$ cm (area of cross-section A).

Q. 6 Which of the following characteristics of electrons determines the current in a conductor?

(a) Drift velocity alone

(b) Thermal velocity alone

(c) Both drift velocity and thermal velocity

(d) Neither drift nor thermal velocity

Ans. ***(a)*** The relationship between current and drift speed is given by

$$I = neAv_d$$

Here, I is the current and v_d is the drift velocity.

So, $$I \propto v_d$$

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

Multiply Choice Questions (More Than One Options)

Q. 7 Kirchhoff's junction rule is a reflection of

(a) conservation of current density vector

(b) conservation of charge

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

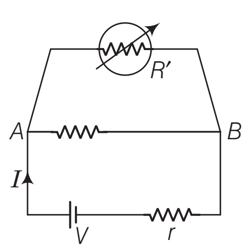
(d) the fact that there is no accumulation of charges at a junction

Ans. ***(b, d)***

Kirchhoff's junction rule is also known as Kirchhoff's current law which states that the algebraic sum of the currents flowing towards any point in an electric network is zero. *i.e.,* charges are conserved in an electric network.

So, Kirchhoff's junction rule is the reflection of conservation of charge

Q. 8 Consider a simple circuit shown in figure stands for a variable resistance R'.R' can vary from R_0 to infinity. r is internal resistance of the battery $(r<<R<<R,)$.



(a) Potential drop across AB is nearly constant as R' is varied

(b) Current through $R'$is nearly a constant as R' is varied

(c) Current I depends sensitively on R'

(d) $I \geq \frac{V}{r+R}$ always

Ans. ***(a, d)***

Here, the potential drop is taking place across AB and r. Since the equivalent resistance of parallel combination of R and R' is always less than R, therefore $I \geq \frac{V}{r+R}$ always.

Note *In parallel combination of resistances, the equivalent resistance is smaller than smallest resistance present in combination.*

Q. 9 Temperature dependence of resistivity $\rho(T)$ of semiconductors, insulators and metals is significantly based on the following factors

(a) number of charge carriers can change with temperature T

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

(c) length of material can be a function of T

(d) mass of carriers is a function of T

Ans. ***(a, b)***

The resistivity of a metallic conductor is given by,

$$e = \frac{m}{ne^2\tau}$$

where n is number of charge carriers per unit volume which can change with temperature T and τ is time interval between two successive collisions which decreases with the increase of temperature.

Q. 10 The measurement of an unknown resistance R is to be carried out using Wheatstones bridge as given in the figure below. Two students perform an experiment in two ways. The first students takes $R_2 = 10\Omega$ and $R_1 = 5\Omega$. The other student takes $R_2 = 1000\Omega$ and $R_1 = 500\Omega$. In the standard arm, both take $R_3 = 5\Omega$.

Both find $R = \frac{R_2}{R_1}$, $R_3 = 10\Omega$ within errors.

(a) The errors of measurement of the two students are the same

(b) Errors of measurement do depend on the accuracy with which R_2 and R_1 can be measured

(c) If the student uses large values of R_2 and R_1 the currents through the arms will be feeble. This will make determination of null point accurately more difficult

(d) Wheatstone bridge is a very accurate instrument and has no errors of measurement

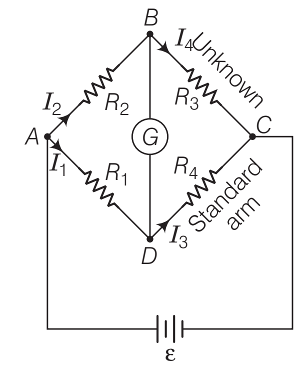
Ans. ***(b, c)***

Given, for first student, $R_2 = 10\ \Omega$, $R_1 = 5\ \Omega$, $R_3 = 5\ \Omega$

For second student, $R_1 = 500\ \Omega$, $R_3 = 5\ \Omega$

Now, according to Wheatstone bridge rule,

$$\frac{R_2}{R} = \frac{R_1}{R_3} \Rightarrow R = R_3 \times \frac{R_2}{R_1} \qquad ...(i)$$



Now putting all the values in Eq. (i), we get $R = 10\,\Omega$ for both students. Thus, we can analyse that the Wheatstone bridge is most sensitive and accurate if resistances are of same value.

Thus, the errors of measurement of the two students depend on the accuracy and sensitivity of the bridge, which inturn depends on the accuracy with which R_2 and R_1 can be measured.

When R_2 and R_1 are larger, the currents through the arms of bridge is very weak. This can make the determination of null point accurately more difficult.

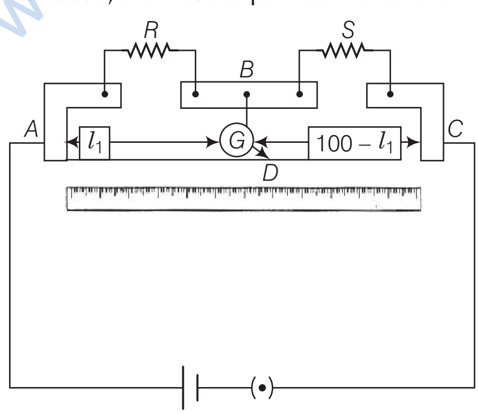
Q. 11 In a meter bridge, the point *D* is a neutral point (figure).

(a) The meter bridge can have no other neutral. A point for this set of resistances

(b) When the jockey contacts a point on meter wire left of *D*, current flows to *B* from the wire

(c) When the jockey contacts a point on the meter wire to the right of *D*, current flows from *B* to the wire through galvanometer

(d) When *R* is increased, the neutral point shifts to left



Ans. ***(a, c)***

At neutral point, potential at *B* and neutral point are same. When jockey is placed at to the right of *D*, the potential drop across *AD* is more than potential drop across *AB*, which brings the potential of point *D* less than that of *B*, hence current flows from *B* to *D*.

Very Short Answer Type Questions

Q. 12 Is the motion of a charge across junction momentum conserving? Why or why not?

Ans. When an electron approaches a junction, in addition to the uniform electric field **E** facing it normally. It keep the drift velocity fixed as drift velocity depend on E by the relation drift velocity

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

This result into accumulation of charges on the surface of wires at the junction. These produce additional electric field. These fields change the direction of momentum.

Thus, the motion of a charge across junction is not momentum conserving.

Q. 13 The relaxation time τ is nearly independent of applied E field whereas it changes significantly with temperature T. First fact is (in part) responsible for Ohm's law whereas the second fact leads to variation of p with temperature. Elaborate why?

K **Thinking Process**

The higher drift velocities of electrons make collisions more frequent which in turn decreases the time interval between two successive collision.

Ans. Relaxation time is inversely proportional to the velocities of electrons and ions. The applied electric field produces the insignificant change in velocities of electrons at the order of 1mm/s, whereas the change in temperature (T), affects velocities at the order of 10^2 m/s.

This decreases the relaxation time considerably in metals and consequently resistivity of metal or conductor increases as .

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

Q. 14 What are the advantages of the null-point method in a Wheatstone bridge? What additional measurements would be required to calculate $R_{unknown}$ by any other method?

Ans. The advantage of null point method in a Wheatstone bridge is that the resistance of galvanometer does not affect the balance point, there is no need to determine current in resistances and the internal resistance of a galvanometer.

It is easy and convenient method for observer.

The $R_{unknown}$ can be calculated applying Kirchhoff's rules to the circuit. We would need additional accurate measurement of all the currents in resistances and galvanometer and internal resistance of the galvanometer.

Note *The necessary and sufficient condition for balanced Wheatstone bridge is*

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

where P and Q are ratio arms and R is known resistance and S is unknown resistance.

Q. 15 What is the advantage of using thick metallic strips to join wires in a potentiometer?

Ans. In potentiometer, the thick metallic strips are used as they have negligible resistance and need not to be counted in the length l_1 of the null point of potentiometer. It is for the convenience of experimenter as he measures only their lengths along the straight wires each of lengths 1 m.

This measurements is done with the help of centimetre scale or metre scale with accuracy.

Q. 16 For wiring in the home, one uses Cu wires or Al wires. What considerations are involved in this?

K **Thinking Process**

The availability, conductivity and the cost of the metal are main criterion for the selection of metal for wiring in home.

Ans. The Cu wires or Al wires are used for wiring in the home.

The main considerations are involved in this process are cost of metal, and good conductivity of metal.

Q. 17 Why are alloys used for making standard resistance coils?

Ans. Alloys have small value of temperature coefficient of resistance with less temperature sensitivity.

This keeps the resistance of the wire almost constant even in small temperature change. The alloy also has high resistivity and hence high resistance, because for given length and cross-section area of conductor. (L and A are constant)

$$R \propto \rho$$

Q. 18 Power P is to be delivered to a device *via* transmission cables having resistance R_c. If V is the voltage across R and I the current through it, find the power wasted and how can it be reduced.

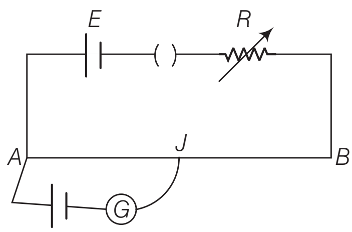
Ans. The power consumption in transmission lines is given by $P = i^2 R_c$, where R_c is the resistance of transmission lines. The power is given by

$$P = VI$$

The given power can be transmitted in two ways namely (i) at low voltage and high current or (ii) high voltage and low current. In power transmission at low voltage and high current more power is wasted as $P \propto i^2$ whereas power transmission at high voltage and low current facilitates the power transmission with minimal power wastage.

The power wastage can be reduced by transmitting power at high voltage.

Q. 19 *AB* is a potentiometer wire (figure). If the value of *R* is increased, in which direction will the balance point *J* shift?



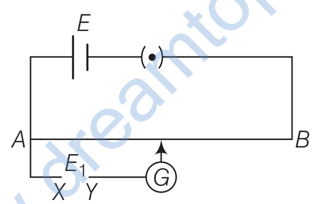
Ans. With the increase of *R*, the current in main circuit decreases which in turn , decreases the potential difference across *AB* and hence potential gradient(*k*) across *AB* decreases.

Since, at neutral point, for given emf of cell, I increases as potential gradient (*k*) across *AB* has decreased because

$$E = kI$$

Thus, with the increase of I, the balance point neutral point will shift towards *B*.

Q. 20 While doing an experiment with potentiometer (figure) it was found that the deflection is one sided and (i) the deflection decreased while moving from one and *A* of the wire, to the end *R;* (ii) the deflection increased, while the jockey was moved towards the end *D*.



(i) Which terminal positive or negative of the cell E_1 is connected at *X* in case (i) and how is E_1, related to *E*?

(ii) Which terminal of the cell E_1 is connected at *X* in case (1 in 1)?

Ans. **(i)** The deflection in galvanometer is one sided and the deflection decreased, while moving from one end '*A*' of the wire to the end '*B*', thus imply that current in auxiliary circuit (lower circuit containing primary cell) decreases, while potential difference across *A* and jockey increases.

This is possible only when positive terminal of the cell E_1, is connected at *X* and $E_1 > E$.

(ii) The deflection in galvanometer is one sided and the deflection increased, while moving from one end *A* of the wire to the end *B*, this imply that current in auxiliary circuit (lower circuit containing primary cell) increases, while potential difference across *A* and jockey increases.

This is possible only when negative terminal of the cell E_1, is connected at *X*.

Q. 21 A cell of emf E and internal resistance r is connected across an external resistance R. Plot a graph showing the variation of potential differential across R, *versus* R.

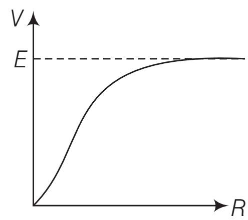
K Thinking Process

When the cell of emf E and internal resistance r is connected across an external resistance R, the relationship between the voltage across R is given by

$$V = \frac{E}{1+\frac{r}{R}}$$

With the increase of R, V approaches closer to E and when E is infinite, V reduces to 0.

Ans. *The graphical relationship between voltage across R and the resistance R is given below*



Short Answer Type Questions

Q. 22 First a set of n equal resistors of R each are connected in series to a battery of emf E and internal resistance R, A current I is observed to flow. Then, the n resistors are connected in parallel to the same battery. It is observed that the current is increased 10 times. What is 'n' ?

K Thinking Process

Here, in series combination of resistors, the equivalent resistance of series combination is in series with the internal resistance R of battery resistors whereas in parallel combination of resistors, the equivalent resistance of parallel combination is in series with the internal resistance of battery.

Ans. In series combination of resistors, current I is given by $I = \frac{E}{R + nR'}$

whereas in parallel combination current 10 I is given by

$$\frac{E}{R + \frac{R}{n}} = 10I$$

Now, according to problem,

$$\frac{1+n}{1+\frac{1}{n}} \Rightarrow 10 = \left(\frac{1+n}{n+1}\right)n \Rightarrow n = 10$$

Q. 23 Let there be n resistors $R_1 .... R_n$ with $R_{max} = \max(R_1 .... R_n)$ and $R_{min} = \min\{R_1 ...... R_n\}$. Show that when they are connected in parallel, the resultant resistance $R_p = R_{min}$ and when they are connected in series, the resultant resistance $R_s > R_{max}$. Interpret the result physically.

Ans. When all resistances are connected in parallel, the resultant resistance R_p is given by

$$\frac{1}{R_p} = \frac{1}{R_1} + ... + \frac{1}{R_n}$$

On multiplying both sides by R_{min} we have

$$\frac{R_{min}}{R_p} = \frac{R_{min}}{R_1} + \frac{R_{min}}{R_2} + ... + \frac{R_{min}}{R_n}$$

Here, in RHS, there exist one term $\frac{R_{min}}{R_{min}} = 1$ and other terms are positive, so we have

$$\frac{R_{min}}{R_p} = \frac{R_{min}}{R_1} + \frac{R_{min}}{R_2} + ... + \frac{R_{min}}{R_n} > 1$$

This shows that the resultant resistance $R_p < R_{min}$.

Thus, in parallel combination, the equivalent resistance of resistors is less than the minimum resistance available in combination of resistors . Now, in series combination, the equivalent resistant is given by

$$R_s = R_1 + ... + R_n$$

Here, in RHS, there exist one term having resistance R_{max}.

So, we have

$$R_s = R_1 + ... + R_{max} + .. + ..+ R_n$$

or

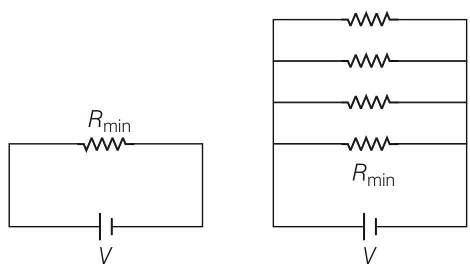
$$R_s = R_1 + ... + R_{max} ... + R_n = R_{max} + ... (R_1 + ...+) R_n$$

or

$$R_s \geq R_{max}$$

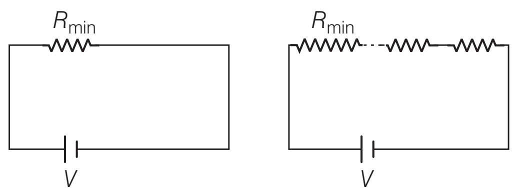
$$R_s = R_{max}\ (R_1 + \ ... + R_n)$$

Thus, in series combination, the equivalent resistance of resistors is greater than the maximum resistance available in combination of resistors. Physical interpretation



(a) (b)

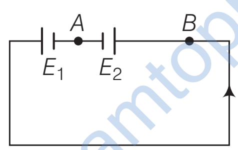
In Fig. (b), R_{min} provides an equivalent route as in Fig. (a) for current. But in addition there are (n–1) routes by the remaining (n –1) resistors. Current in Fig. (b) is greater than current in Fig. (a). Effective resistance in Fig. (b) < R_{min}. Second circuit evidently affords a greater resistance.



(c) (d)

In Fig. (d), R_{max} provides an equivalent route as in Fig. (c) for current. Current in Fig. (d) < current in Fig. (c). Effective resistance in Fig. (d) > R_{max}. Second circuit evidently affords a greater resistance.

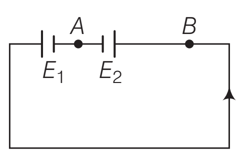
Q. 24 The circuit in figure shows two cells connected in opposition to each other. Cell E_1 is of emf 6V and internal resistance 2Ω the cell E_2 is of emf 4V and internal resistance 8Ω. Find the potential difference between the points A and B.



K **Thinking Process**

Here, after finding the electric current flow in the circuit by using Kirchhoff's law or Ohm's law, the potential difference across AB can be obtained.

Ans. Applying Ohm's law.



Effective resistance $= 2\,\Omega + 8\Omega = 10\Omega$ and effective emf of two cells $= 6 - 4 = 2$V, so the electric current is given by

$$I = \frac{6-4}{2+8} = 0.2\text{A}$$

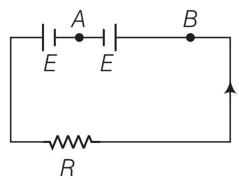
along anti-clockwise direction, since $E_1 > E_2$.

The direction of flow of current is always from high potential to low potential. Therefore $V_B > V_A$.

$\Rightarrow$ $$V_B - 4V - (0.2) \times 8 = V_A$$

Therefore, $$V_B - V_A = 3.6\text{V}$$

Q. 25 Two cells of same emf E but internal resistance r_1 and r_2 are connected in series to an external resistor R (figure). What should be the value of R so that the potential difference across the terminals of the first cell becomes zero?



Thinking Process

Here, after finding the electric current flow in the circuit by using Kirchhoff 's law or Ohm's law, the potential difference across first cell can be obtained.

Ans. Applying Ohm's law,

Effective resistance = $R + r_1 + r_2$ and effective emf of two cells = $E + E = 2E$, so the electric current is given by

$$I = \frac{E + E}{R + r_1 + r_2}$$

The potential difference across the terminals of the first cell and putting it equal to zero.

$$V_1 = E - Ir_1 = E - \frac{2E}{r_1 + r_2 + R} r_1 = 0$$

or

$$E = \frac{2Er_1}{r_1 + r_2 + R} \Rightarrow 1 = \frac{2r_1}{r_1 + r_2 + R}$$

$$r_1 + r_2 + R = 2r_1 \Rightarrow R = r_1 - r_2$$

This is the required relation.

Q. 26 Two conductors are made of the same material and have the same length. Conductor A is a solid wire of diameter 1mm. Conductor B is a hollow tube of outer diameter 2mm and inner diameter 1mm.

Find the ratio of resistance R_A to R_B.

Thinking Process

The resistance of wire is given by $R = \rho \frac{l}{A}$

where A is cross-sectional area of conductor.

Ans. The resistance of first conductor

$$R_A = \frac{\rho l}{\pi(10^{-3} \times 0.5)^2}$$

The resistance of second conductor,

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

Now, the ratio of two resistors is given by

$$\frac{R_A}{R_B} = \frac{(10^{-3})^2 - (0.5 \times 10^{-3})^2}{(0.5 \times 10^{-3})^2} = 3 : 1$$

Q. 27 Suppose there is a circuit consisting of only resistances and batteries. Suppose one is to double (or increase it to n-times) all voltages and all resistances. Show that currents are unaltered. Do this for circuit of Examples 3,7 in the NCERT Text Book for Class XII.

Thinking Process

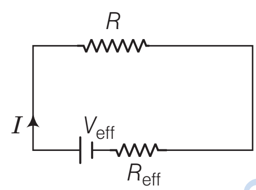
The electric current in two cases is obtained and then shown equal to each other

Ans. Let the effective internal resistance of the battery is R_{eff}, the effective external resistance R and the effective voltage of the battery is V_{eff}.

Applying Ohm's law,

Then current through R is given by

$$I = \frac{V_{eff}}{R_{eff} + R}$$



If all the resistances and the effective voltage are increased n-times, then we have

$$V_{eff}^{new} = nV_{eff}, R_{eff}^{new} = nR_{eff}$$

and $$R^{new} = nR$$

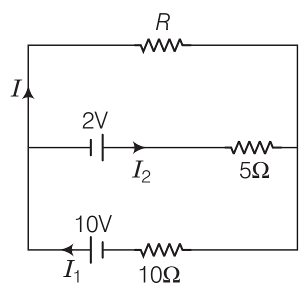
Then, the new current is given by

$$I' = \frac{nV_{eff}}{nR_{eff} + nR} = \frac{n(V_{eff})}{n(R_{eff} + R)} = \frac{(V_{eff})}{(R_{eff} + R)} = I$$

Thus, current remains the same.

Long Answer Type Questions

Q. 28 Two cells of voltage 10V and 2V and 10Ω internal resistances 10Ω and 5Ω respectively, are connected in parallel with the positive end of 10V battery connected to negative pole of 2V battery (figure). Find the effective voltage and effective resistance of the combination.



Thinking Process

The question can be solved by using Kirchhoff's voltage rule/ loop rule.

Ans. Applying Kirchhoff's junction rule, $I_1 = I + I_2$

Applying Kirchhoff's II law / loop rule applied in outer loop containing 10V cell and resistance R, we have

$$10 = IR + 10I_1 \qquad \ldots(i)$$

Applying Kirchhoff II law / loop rule applied in outer loop containing 2V cell and resistance R, we have

$$2 = 5I_2 - RI = 5(I_1 - I) - RI$$

or $$4 = 10I_1 - 10I - 2RI \qquad \ldots(ii)$$

Solving Eqs. (i) and (ii), gives

$\Rightarrow$ $$6 = 3RI + 10I$$

$$2 = I\left(R + \frac{10}{3}\right)$$

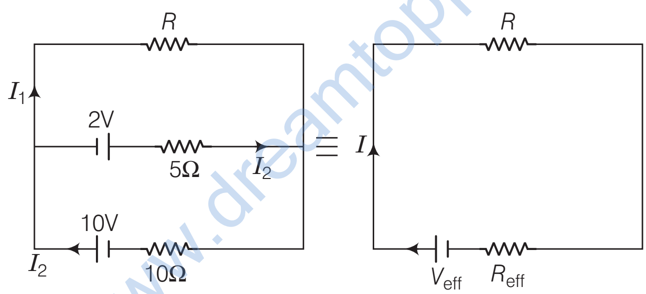
Also, the external resistance is R . The Ohm's law states that

$$V = I(R + R_{eff})$$

On comparing, we have $V = 2V$ and effective internal resistance

$$(R_{eff}) = \left(\frac{10}{3}\right)\Omega$$

Since, the effective internal resistance (R_{eff}) of two cells is $\left(\frac{10}{3}\right)\Omega$, being the parallel combination of 5Ω and 10Ω. *The equivalent circuit is given below*



Q. 29 A room has AC run for 5 a day at a voltage of 220V. The wiring of the room consists of Cu of 1 mm radius and a length of 10m. Power consumption per day is 10 commercial units. What fraction of it goes in the joule heating in wires? What would happen if the wiring is made of aluminium of the same dimensions?

$$[\rho_{Cu} = 11.7 \times 10^{-8}\ \Omega m,\ \rho_{Al} = 2.7 \times 10^{-8}\ \Omega m]$$

K **Thinking Process**

The power consumption in a current carrying resistor is given by $P = I^2R$

Ans. Power consumption in a day *i.e.,* in 5 = 10 units

Or power consumption per hour = 2units

Or power consumption = 2units = 2kW = 2000J/s

Also, we know that power consumption in resistor,

$$P = V \times l$$

$\Rightarrow$ $$2000\text{W} = 220\text{V} \times l \text{ or } l \approx 9\text{ A}$$

Now, the resistance of wire is given by $R = \rho\frac{l}{A}$

where, A is cross-sectional area of conductor.

Power consumption in first current carrying wire is given by

$$P = I^2R$$

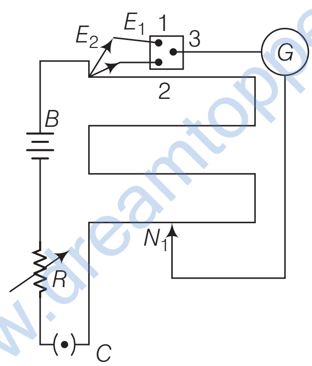
$$\rho\frac{l}{A}I^2 = 1.7\times10^{-8}\times\frac{10}{\pi\times10^{-6}}\times81 \text{ J/s} \approx 4 \text{ J/s}$$

The fractional loss due to the joule heating in first wire $= \frac{4}{2000}\times100 = 0.2\%$

Power loss in Al wire $= 4\frac{\rho_{Al}}{\rho_{Cu}} = 1.6\times4 = 6.4 \text{J/s}$

The fractional loss due to the joule heating in second wire $= \frac{6.4}{2000}\times100 = 0.32\%$

Q. 30 In an experiment with a potentiometer, $V_B = 10$V. R is adjusted to be 50Ω (figure). A student wanting to measure voltage E_1 of a battery (approx. 8V) finds no null point possible. He then diminishes R to 10Ω and is able to locate the null point on the last (4th) segment of the potentiometer. Find the resistance of the potentiometer wire and potential drop per unit length across the wire in the second case.



K **Thinking Process**

The null point is obtained only when emf of primary cell is less than the potential difference across the wires of potentiometer.

Ans. Let R' be the resistance of the potentiometer wire.

Effective resistance of potentiometer and variable resistor ($R = 50\Omega$) is given by $= 50\Omega + R'$

Effective voltage applied across potentiometer = 10V.

The current through the main circuit,

$$I = \frac{V}{50\Omega + R} = \frac{10}{50\Omega + R}$$

Potential difference across wire of potentiometer,

$$IR' = \frac{10R'}{50\Omega + R}$$

Since with 50Ω resistor, null point is not obtained it's possible only when

$$\frac{10\times R'}{50 + R} < 8$$

$\Rightarrow$ $$10R' < 400 + 8R'$$

$$2R' < 400 \text{ or } R' < 200\Omega.$$

Similarly with 10Ω resistor , null point is obtained its possible only when

$$\frac{10 \times R'}{10 + R'} > 8$$

$\Rightarrow$ $$2R' > 80$$

$\Rightarrow$ $$R' > 40$$

$$\frac{10 \times \frac{3}{4} R'}{10 + R'} < 8$$

$\Rightarrow$ $$7.5R' < 80 + 8R'$$

$$R' > 160$$

$\Rightarrow$ $$160 < R' < 200.$$

Any R' between 160Ω and 200 Ω wlll achieve.

Since, the null point on the last (4th) segment of the potentiometer, therefore potential drop across 400 cm of wire > 8V.

This imply that potential gradient

$$k \times 400\,\text{cm} > 8\text{V}$$

or $$k \times 4\,\text{m} > 8\text{V}$$

$$k > 2\,\text{V/m}$$

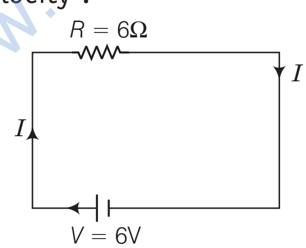
Similarly, potential drop across 300 cm wire < 8V.

$$k \times 300\text{cm} < 8\text{V}$$

or $$k \times 3\text{m} < 8\text{V}, \quad k < 2\frac{2}{3}\,\text{V/m}$$

Thus, $$2\frac{2}{3}\,\text{V/m} > k > 2\text{V/m}$$

Q. 31 (a) Consider circuit in figure. How much energy is absorbed by electrons from the initial state of no current (Ignore thermal motion) to the state of drift velocity ?



(b) Electrons give up energy at the rate of RI^2 per second to the thermal energy. What time scale would number associate with energy in problem (a)? n = number of electron/volume = $10^{29}\,/\,\text{m}^3$. Length of circuit = 10 cm, cross-section= $A = (1\text{ mm})^2$.

Thinking Process

The current in a conductor and drift velocity of electrons are related as $i = neAv_d$, where v_d is drift speed of electrons and n is number density of electrons.

Ans. (a) By Ohm's law, current I is given by

$$I = 6\text{V} / 6\Omega = 1\text{A}$$

But, $$I = net\, A\, v_d \text{ or } v_d = \frac{i}{neA}$$

On substituting the values

For, n = number of electron/volume = $10^{29}/\text{m}^3$

length of circuit = 10cm, cross-section $= A = (1\text{mm})^2$

$$v_d = \frac{1}{10^{29} \times 1.6 \times 10^{-19} \times 10^{-6}}$$

$$= \frac{1}{1.6} \times 10^{-4} \text{ m/s}$$

Therefore, the energy absorbed in the form of KE is given by

$$\text{KE} = \frac{1}{2} m_e \, v_d{}^2 \times nAI$$

$$= \frac{1}{2} \times 9.1 \times 10^{31} \times \frac{1}{2.56} \times 10^{20} \times 10^{8} \times 10^{6} \times 10^{1}$$

$$= 2 \times 10^{-17} \text{J}$$

(b) Power loss is given by $P = I^2 R = 6 \times 1^2 = 6\text{W} = 6\text{J/s}$

Since, $P = \frac{E}{t}$

Therefore, $E = P \times t$

or $t = \frac{E}{P} = \frac{2 \times 10^{-17}}{6} \approx 10^{-17}$ s