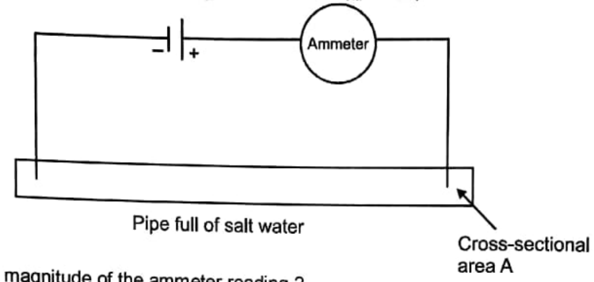
F-11. Salt water contains n sodium ions (Na+) per cubic meter and n chloride ions (Cl^-) per cubic meter. A battery is connected to metal rods that dip into a narrow pipe full of salt water. The cross sectional area of the pipe is A. The magnitude of the drift velocity of the sodium ions is V_{Na} and the magnitude of the drift velocity of the chloride ions is V_{Cl}. Assume that $V_{Na} > V_{Cl}$ (+e is the charge of a proton).



What is the magnitude of the ammeter reading ?

(A) $enAV_{Na} - enAV_{Cl}$ (B) $enAV_{Na} + enAV_{Cl}$ (C) $enAV_{Na}$ (D) $enAV_{Cl}$

PART - III : MATCH THE COLUMN

1. **Match the following :**

The following table gives the lengths of four copper rods at the same temperature, their diameters, and the potential differences between their ends.

Rod	Length	Diameter	Potential Difference
1	L	3d	V
2	2L	d	3V
3	3L	2d	2V
4	3L	d	V

Correctly match the physical quantities mentioned in the left column with the rods as marked.

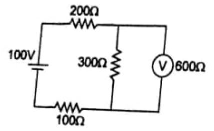
Column-I	Column-II
(A) Greatest Drift speed of the electrons.	(p) Rod 1
(B) Greatest Current	(q) Rod 2
(C) Greatest rate of thermal energy produced	(r) Rod 3
(D) Greatest Electric field	(s) Rod 4

2. Match the statements in Column I with the current element in Column II

Column-I	Column-II
(A) Current always flows from higher potential to lower potential	(p) A Resistor
(B) Energy dissipated in an element is always zero	(q) Ideal cell/Battery
(C) Current flow through the element is always zero	(r) Non-Ideal cell/Battery
(D) Potential difference may/will be zero	(s) Short-circuited resistor

Section (F) : Instrument

F-1. The reading of voltmeter is



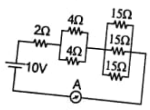
(A) 50V (B) 60 V (C) 40V (D) 80 V

F-2. The length of a wire of a potentiometer is 100 cm, and the emf of its standard cell is E volt. It is employed to measure the emf of a battery whose internal resistance is 0.5 ohm. If the balance point is obtained at 30 cm from the positive end, the emf of the battery is [AIEEE 2003, 4/300]

(A) $\frac{30E}{100}$ (B) $\frac{30E}{100.5}$ (C) $\frac{30E}{(100-0.5)}$

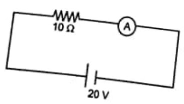
(D) $\frac{30(E-0.5i)}{100}$, $\frac{30(E-0.5i)}{100}$, where i is the current in the potentiometer

F-3. The current through the ammeter shown in figure is 1 A. If each of the 4Ω resistor is replaced by 2Ω resistor, the current in circuit will become nearly :



(A) $\frac{10}{9}$ A (B) $\frac{5}{4}$ (C) $\frac{9}{8}$ A (D) $\frac{5}{8}$ A

F-4. The ammeter shown in figure consists of a 480 Ω coil connected in parallel to a 20 Ω shunt. Find the reading of the ammeter.



(A) $\frac{50}{73}$ A (B) $\frac{40}{53}$ A (C) $\frac{50}{93}$ A (D) $\frac{73}{50}$ A

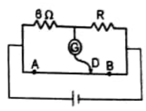
F-5. A galvanometer together with an unknown resistance in series is connected to two identical batteries each of 1.5 V. When the batteries are connected in series, the galvanometer records a current of 1A, and when the batteries are in parallel the current is 0.6 A. What is the internal resistance of the battery? [JEE - 1973]

(A) $r = \frac{2}{3}\Omega$ (B) $r = \frac{2}{5}\Omega$ (C) $r = \frac{1}{3}\Omega$ (D) $r = \frac{3}{2}\Omega$

F-6. A potentiometer wire of length 100 cm has a resistance of 10 ohm. It is connected in series with a resistance and an accumulator of emf 2V and of negligible internal resistance. A source of emf of 10 mV is balanced against a length of 40 cm of the potentiometer wire. What is the value of external resistance ? [JEE - 1976]

(A) 890 Ω (B) 600 Ω (C) 650 Ω (D) 790 Ω

F-7. The meter-bridge wire AB shown in figure is 50 cm long. When AD = 30 cm, no deflection occurs in the galvanometer. Find R.

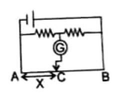


(A) 1 Ω (B) 2 Ω (C) 3 Ω (D) 4 Ω

F-8. The current in a conductor and the potential difference across its ends are measured by an ammeter and a voltmeter. The meters draw negligible currents. The ammeter is accurate but the voltmeter has a zero error (that is, it does not read zero when no potential difference is applied). Then the zero error is (if the readings for two different conditions are 1.75 A, 14.4 V and 2.75 A, 22.4 V.)

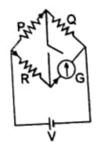
(A) 0.4 volt (B) 0.8 volt (C) –0.4 volt (D) –0.8 volt

F-9. In the given circuit, no current is passing through the galvanometer. If the cross-sectional diameter of the wire AB is doubled, then for null point of galvanometer, the value of AC would be: [IIT-JEE(Scr.) - 2003, 3/84]



(A) 2 X (B) X (C) $\frac{X}{2}$ (D) None

F-10. In the circuit shown, P ≠ R, the reading of the galvanometer is same with switch S open or closed. Then [IIT-JEE 1999, 2/200]



(A) $I_R = I_G$ (B) $I_P = I_G$ (C) $I_Q = I_G$ (D) $I_Q = I_R$

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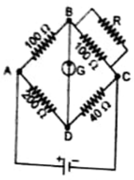
D-9. Three equal resistors connected in series across a source of emf together dissipate 10 watts of power. What would be the power dissipated if the same resistors are connected in parallel across the same source of emf ? [JEE 1972]

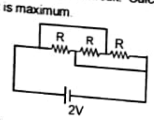
(A) 60 watt (B) 90 watt (C) 100 watt (D) 30 watt

D-10. The given Wheatstone bridge is showing no deflection in the galvanometer joined between the points B and D (Figure). Calculate the value of R.



(A) 25 Ω (B) 50 Ω (C) 40 Ω (D) 100 Ω

D-11. Three equal resistance each of R ohm are connected as shown in figure. A battery of 2 volts of internal resistance 0.1 ohm is connected across the circuit. Calculate the value of R for which the heat generated in the exeternal circuit is maximum. [REE 1990]

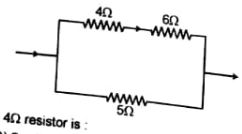


(A) 0.1 Ω (B) 0.2 Ω (C) 0.3 Ω (D) 0.4 Ω

D-12. A wire of resistance 0.1 ohm cm^{-1} bent to form a square ABCD of side 10 cm. A similar wire is connected between the corners B and D to form the diagonal BD. Find the effective resistance of this combination between corners A and C. If a 2V battery of negligible internal resistance is connected across A and C calculate the total power dissipated. [JEE - 1971]

(A) 1 Ω, 3 W (B) 1 Ω, 4 W (C) 2 Ω, 3 W (D) 2 Ω, 4 W

D-13. In the circuit shown in figure the heat produced in the 5Ω resistor due to the current flowing through it is 10 calories per second. [JEE' 1981; 2M]



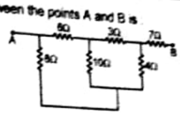
The heat generated in the 4Ω resistor is :

(A) 1 cal/s (B) 2 cal/s (C) 3 cal/s (D) 4 cal/s

D-14. A 50 W bulb is in series with a room heater and the combination is connected across the mains. To get max. heater output, the 50 W bulb should be replaced by :

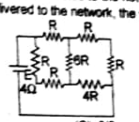
(A) 25 W (B) 10 W (C) 100 W (D) 200 W

D-15. The equivalent resistance between the points A and B is



(A) $\frac{36}{7}$ Ω (B) 10 Ω (C) $\frac{85}{7}$ Ω (D) none of these

D-16. A battery of internal resistance 4 ohm is connected to the network of resistance as shown. In the order that the maximum power can be delivered to the network, the value of R in ohm should be : [JEE - 1995]



(A) 4/9 (B) 2 (C) 8/3 (D) 18

Section (E) : Combination of Cells

E-1. Two nonideal batteries are connected in parallel. Consider the following statements

(I) The equivalent emf is smaller than either of the two emfs.

(II) The equivalent internal resistance is smaller than either of the two internal resistance.

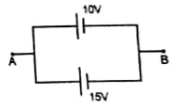
(A) Both I and II are correct (B) I is correct but II is wrong

(C) II is correct but I is wrong (D) Each of I and II is wrong.

E-2. 12 cells each having the same emf are connected in series and are kept in a closed box. Some of the cells are wrongly connected. This battery is connected in series with an ammeter and two cells identical with each other and also identical with the previous cells. The current is 3 A when the external cells support this battery and is 2 A when the cells oppose the battery. How many cells in the battery are wrongly connected?

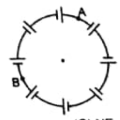
(A) one (B) two (C) three (D) none

E-3. Two cells of e.m.f. 10 V & 15 V are connected in parallel to each other between points A & B. The cell of e.m.f. 10 V is ideal but the cell of e.m.f. 15 V has internal resistance 1 Ω. The equivalent e.m.f. between A and B is :



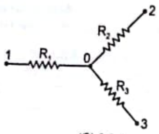
(A) $\frac{25}{2}$ V (B) not defined (C) 15 V (D) 10 V

E-4. N sources of current with different emf's are connected as shown in figure. The emf's of the sources are proportional to their internal resistances, i.e. E = αR, where α is an assigned constant. The connecting wire resistance is negligible. The potential difference between points A and B dividing the circuit in n and N – n links



(A) 0 (B) nE/2 (C) NE (D) (N – n)E

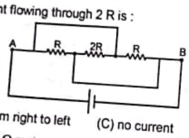
C-6. (i) Find the current flowing through the resistance R_1 of the circuit shown in figure if the resistances are equal to $R_1 = 10\ \Omega$, $R_2 = 20\ \Omega$, and $R_3 = 30\ \Omega$, and the potentials of points 1, 2 and 3 are equal to $\varphi_1 = 10$ V, $\varphi_2 = 6$ V, and $\varphi_3 = 5$ V.



(A) 0.1 A (B) 0.2 A (C) 0.3 A (D) 0.4 A

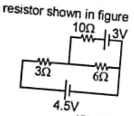
(ii) In the previous question potential at point 0 is
(A) 15 V (B) 20 V (C) 25 V (D) 8 V

C-7. In the figure shown the current flowing through 2 R is :



(A) from left to right (B) from right to left (C) no current (D) None of these

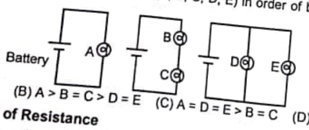
C-8. Find the current through the $10\ \Omega$ resistor shown in figure



(A) zero (B) 1 A (C) 2A (D) 5 A

C-9. The efficiency of a cell when connected to a resistance R is 60%. What will be its efficiency if the external resistance is increased to six times.
(A) 80 % (B) 90% (C) 55% (D) 95%

C-10. In these three circuits all the batteries are identical and have negligible internal resistance, and all the light bulbs are identical. Rank all 5 light bulbs (A, B, C, D, E) in order of brightness from brightness to dimmest.



(A) A = B = C > D = E (B) A > B = C > D = E (C) A = D = E > B = C (D) A = D = E > B > C

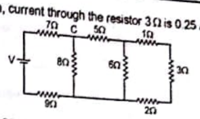
Section (D) : Combination of Resistance

D-1. Two coils connected in series have resistances 600 Ω and 300 Ω at 20°C and temperature coefficient of resistivity 0.001 K^{-1} and 0.004 K^{-1} respectively.

(a) The resistance of the combination at temperature 50°C is
(A) 426 Ω (B) 954 Ω (C) 1806 Ω (D) 214 Ω

(b) The effective temperature coefficient of the combination is
(A) $\frac{1}{1000}$ degree^{-1} (B) $\frac{1}{250}$ degree^{-1} (C) $\frac{1}{500}$ degree^{-1} (D) $\frac{3}{1000}$ degree^{-1}

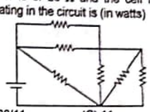
D-2. In the ladder network shown, current through the resistor 3 Ω is 0.25 A. The input voltage 'V' is equal to



(A) 10 V (B) 20 V (C) 5 V (D) $\frac{15}{2}$ V

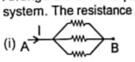
D-3. If 2 bulbs rated 2.5 W – 110 V and 100 W – 110 V are connected in series to a 220 V supply then
(A) 2.5 W bulb will fuse (B) 100 W bulb will fuse (C) both will fuse (D) both will not fuse

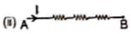
D-4. In the figure shown each resistor is of 20 Ω and the cell has emf 10 volt with negligible internal resistance. Then rate of joule heating in the circuit is (in watts)

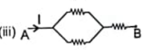


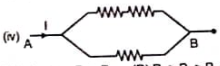
(A) 100/11 (B) 10000/11 (C) 11 (D) None of these

D-5. Arrange the order of power dissipated in the given circuits, if the same current is passing through the system. The resistance of each resistor is 'r'. [IIT-JEE(Scr.) 2003, 3/84]

(i) 

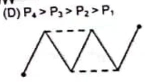
(ii) 

(iii) 

(iv) 

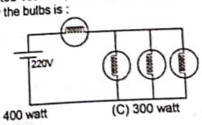
(A) $P_2 > P_3 > P_4 > P_1$ (B) $P_1 > P_4 > P_3 > P_2$ (C) $P_1 > P_2 > P_3 > P_4$ (D) $P_4 > P_3 > P_2 > P_1$

D-6. Five identical resistors each of resistance 1Ω are initially arranged as shown in the figure by clear lines. If two similar resistances are added as shown by the dashed lines then change in resistance in final and initial arrangement is



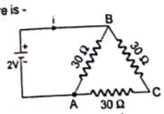
(A) 2 Ω (B) 1 Ω (C) 3 Ω (D) 4 Ω

D-7. Four identical bulbs each rated 100 watt, 220 volts are connected across a battery as shown. The total electric power consumed by the bulbs is :



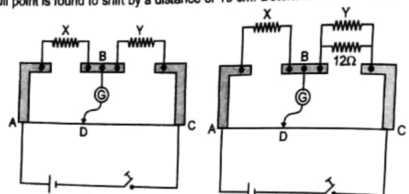
(A) 75 watt (B) 400 watt (C) 300 watt (D) 400/3 watt

D-8. The current i in the circuit of figure is - [JEE 1983]



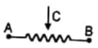
(A) $\frac{1}{45}$ amp. (B) $\frac{1}{15}$ amp. (C) $\frac{1}{10}$ amp. (D) $\frac{1}{5}$ amp.

F-8. Figure shows a metre bridge (which is nothing but a practical Wheatstone Bridge) consisting of two resistors X and Y together in parallel with a metre long constantan wire of uniform cross-section. 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 no deflection. The null point is found to be at a distance of 30 cm from the end A. The resistor Y is shunted by a resistance of 12.0 Ω and the null point is found to shift by a distance of 10 cm. Determine the resistance of X and Y.



(a) (b)

F-9. Connect a battery to the terminals and complete the circuit diagram so that it works as a potential divider meter. Indicate the output terminals also. [IIT-JEE(Main) 2003, 2/60]



PART - II : ONLY ONE OPTION CORRECT TYPE

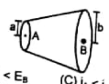
Section (A) : Definition of current, Current densities, Drift

A-1. The drift velocity of electrons in a conducting wire is of the order of 1mm/s, yet the bulb glows very quickly after the switch is put on because
(A) The random speed of electrons is very high, of the order of 10^6 m/s
(B) The electrons transfer their energy very quickly through collisions
(C) Electric field is set up in the wire very quickly, producing a current through each cross section, almost instantaneously
(D) All of above

A-2. In the presence of an applied electric field ($\vec{E}$) in a metallic conductor.
(A) The electrons move in the direction of $\vec{E}$
(B) The electrons move in a direction opposite to $\vec{E}$
(C) The electrons may move in any direction randomly, but slowly drift in the direction of $\vec{E}$.
(D) The electrons move randomly but slowly drift in a direction opposite to $\vec{E}$.

A-3. The potential difference applied to an X-ray tube is 5 kV and the current through it is 3.2 mA. Then the number of electrons striking the target per second is [IIT-JEE(Scr.) 2002,3/105]
(A) 2×10^{16} (B) 5×10^{16} (C) 1×10^{17} (D) 4×10^{15}

A-4 An electric current passes through non uniform cross-section wire made of homogeneous and isotropic material. If the j_A and j_B be the current densities and E_A and E_B be the electric field intensities at A and B respectively, then

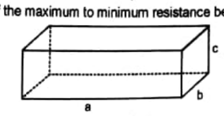


(A) $j_A > j_B$; $E_A > E_B$ (B) $j_A > j_B$; $E_A < E_B$ (C) $j_A < j_B$; $E_A > E_B$ (D) $j_A < j_B$; $E_A < E_B$

Section (B) : Resistance

B-1. A piece of copper and another of germanium are cooled from room temperature to 80 K. The resistance of :
(A) each of the them increases (B) each of them decreases
(C) copper increases and germanium decreases (D) copper decreases and germanium increases

B-2. All the edges of a block in cuboidal shape with parallel faces are equal. Its longest edge is twice its shortest edge. The ratio of the maximum to minimum resistance between parallel faces is:

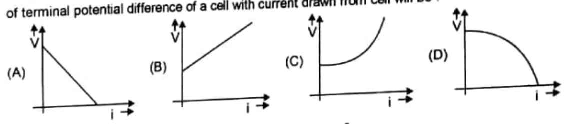


(A) 2 (B) 4 (C) 8
(D) indeterminate unless the length of the third edge is specified

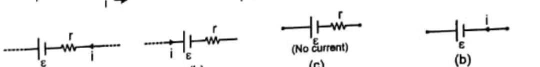
Section (C) : Power, Energy, Battery, EMF and Terminal voltage

C-1. In an electric circuit containing battery, the positive charge inside the battery
(A) always goes from the positive terminal to the negative terminal
(B) may go from the positive terminal to the negative terminal
(C) always goes from the negative terminal to the positive terminal
(D) does not move.

C-2. If internal resistance of a cell is proportional to current drawn from the cell. Then the best representation of terminal potential difference of a cell with current drawn from cell will be :



C-3.

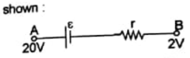


(a) (b) (c) (b)

In which of the above cells, the potential difference between the terminals of a cell exceeds its emf.
(A) a (B) b (C) c (D) d

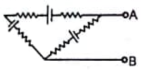
C-4. A resistor of resistance R is connected to a cell of internal resistance 5 Ω. The value of R is varied from 1 Ω to 5 Ω. The power consumed by R:
(A) increases continuously (B) decreases continuously
(C) first decreases then increases (D) first increases then decreases.

C-5. In the figure a part of circuit is shown :

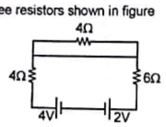


(A) current will flow from A to B (B) current may flow from A to B
(C) current will flow from B to A (D) the direction of current will depend on r.

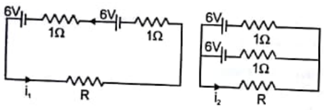
E-3. In the circuit shown all five resistors have the same value 200 ohms and each cell has an emf 3 volts. Find the open circuit voltage and the short circuit current for the terminals A and B.



E-4. Find the currents through the three resistors shown in figure



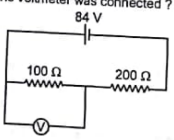
E-5. Find the value of i_1/i_2 in figure if (a) R = 0.1 Ω, (b) R = 1Ω (c) R = 10 Ω. Note from your answer that in order to get more current from a combination of two batteries they should be joined in parallel if the external resistance is small and in series if the external resistance is large as compared to the internal resistances.



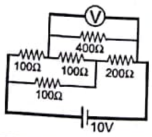
Section (F) : Instrument

F-1. A galvanometer has a resistance of 30 ohm and a current of 2 mA is needed to give a full scale deflection. What is the resistance needed and how is it to be connected to convert the galvanometer. **[REE 1986]**
(a) Into an ammeter of 0.3 ampere range ? (b) Into a voltmeter of 0.2 volt range ?

F-2. A voltmeter of resistance 400Ω is used to measure the potential difference across the 100Ω resistor in the circuit shown in the figure. (a) What will be the reading of the voltmeter ? (b) What was the potential difference across 100 Ω before the voltmeter was connected ?

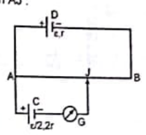


F-3. An electrical circuit is shown in the figure. Calculate the potential difference across the resistance of 400 ohm, as will be measured by the voltmeter V of resistance 400 ohm, either by applying Kirchhoff's rules or otherwise. **[JEE 1996, 5]**

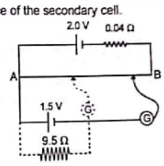


F-4. A battery of emf 1.4 V and internal resistance 2 Ω is connected to a resistor of 100 Ω through an ammeter. The resistance of the ammeter is 4/3 Ω. A voltmeter has also been connected to find the potential difference across the resistor.
(i) Draw the circuit diagram.
(ii) The ammeter reads 0.02 A. What is the resistance of the voltmeter ?
(iii) The voltmeter reads 1.10 V, what is the zero error in the voltmeter ?
(Hint : zero error = observed reading – actual reading)

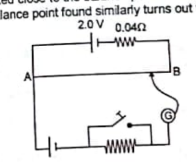
F-5. In the fig. the potentiometer wire AB of length L & resistance 9 r is joined to the cell D of e.m.f. ε and internal resistance r. The cell C's e.m.f. is ε/2 and its internal resistance is 2 r. The galvanometer G will show no deflection then find length AJ :



F-6. Figure shows a 2.0 V potentiometer used for the determination of internal resistance of 1.5 V cell. The balance point of the cell without 9.5 Ω in the external circuit is 70 cm. When a resistor of 9.5 Ω is used in the external circuit of the cell, the balance point shifts to 60 cm length of the potentiometer wire. Determine the internal resistance of the secondary cell.

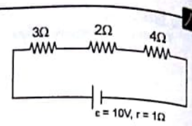


F-7. Figure shows a potentiometer with a cell of emf 2.0 V and internal resistance 0.04 Ω maintaining a potential drop across the potentiometer wire AB. A standard cell which maintains a constant emf of 1.02 V (for very moderate currents up to a few ampere) gives a balance point of 67.3 cm length of the wire. To ensure very low currents drawn from the standard cell, a very high resistance of 600 kΩ is put in series with it which is shorted close to the balance point. The standard cell is then replaced by a cell of unknown emf E and the balance point found similarly turns out to be at 82.3 cm length of the wire.

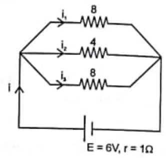


(a) What is the value of E ?
(b) What purpose does the high resistance of 600 kΩ have ?
(c) Is the balance point affected by this high resistance?
(d) Is the balance point affected by the internal resistance of the driver cell?
(e) Would the method work in the above situation if the driver cell of the potentiometer had an emf of 1.0 V instead of 2.0 V?
(f) Would the circuit work well for determining extremely small emf, say, of the order of few mV (such typical emf of thermocouple)?

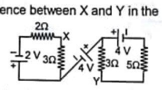
D-4. In the given circuit determine
(a) Equivalent resistance (Including internal resistance).
(b) Current in each resistance
(c) Potential difference across each resistance
(d) The rate at which the chemical energy of the cell is consumed
(e) The rate at which heat is generated inside the battery
(f) Electric power output
(g) Potential difference across battery
(h) Which resistance consumes maximum power
(i) Power dissipated in 3 Ω resistance.



D-5. In given circuit determine
(a) Equivalent resistance (Including internal resistance).
(b) Current i, i_1, i_2 and i_3
(c) Potential difference across battery and each resistance
(d) The rate at which the chemical energy of the cell is consumed
(e) The rate at which heat is generated inside the battery
(f) Electric power output
(g) Which resistance consumes maximum power ?
(h) Power dissipated across 4Ω resistance

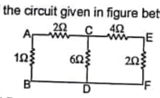


D-6. (a) Determine the potential difference between X and Y in the circuit shown in Figure.



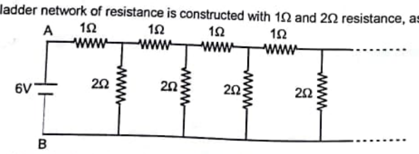
(b) If intermediate cell has internal resistance r = 1Ω then determine the potential difference between X and Y.

D-7. Find the equivalent resistance of the circuit given in figure between the following point:



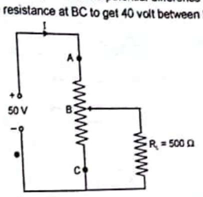
(i) A and B (ii) C and D (iii) E and F (iv) A and F
(v) A and C

D-8. An infinite ladder network of resistance is constructed with 1Ω and 2Ω resistance, as shown in figure.



(i) Show that the effective resistance between A and B is 2Ω.
(ii) What is the current that passes through the 2Ω resistance nearest to the battery ?

D-9. As shown in figure a variable rheostat of 2 kΩ is used to control the potential difference across 500 ohm load. (i) If the resistance AB is 500 Ω, what is the potential difference across the load ? (ii) If the load is removed, what should be the resistance at BC to get 40 volt between B and C ?

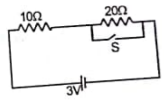


D-10. ABCD is a square where each side is uniform wire of resistance 1 Ω. Find a point E on CD such that if a uniform wire of resistance 1 Ω is connected across AE and a potential difference is applied across A and C, the points B and E will be equipotential.

D-11. Suppose you have three resistors of 20 Ω, 50 Ω and 100 Ω. What minimum and maximum resistances can you obtain from these resistors ?

D-12. Three bulbs, each having a resistance of 180 Ω, are connected in parallel to an ideal battery of emf 60 V. Find the current delivered by the battery when
(a) all the bulbs are switched on, (b) two of the bulbs are switched on and
(c) only one bulb is switched on.

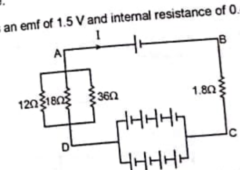
D-13. Consider the circuit shown in figure. Find the current through the 10Ω resistor when the switch S is (a) opened (b) closed.



Section (E) : Combination of Cells

E-1. Six lead-acid type of secondary cells, each of emf 2.0 V and internal resistance 0.015 Ω, are joined in series to provide a supply to a resistance of 8.5 Ω. Determine : (i) the current drawn from the supply and (ii) its terminal voltage.

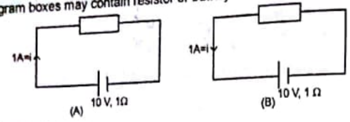
E-2. In the figure each cell has an emf of 1.5 V and internal resistance of 0.40 Ω. Calculate:



(i) current I (ii) current in the 36 Ω resistor
(iii) potential difference across A and B.

Section (C) : Power, Energy, Battery, EMF, Terminal voltage & Kirchoff's laws

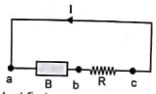
C-1. In following diagram boxes may contain resistor or battery or any other element



then determine in each case
(a) E.m.f. of battery
(b) Battery is acting as a source or load
(c) Potential difference across each battery
(d) Power input to the battery or output by the battery.
(e) The rate at which heat is generated inside the battery.
(f) The rate at which the chemical energy of the cell is consumed or increased.
(g) Potential difference across box
(h) Electric power output across box.

C-2. A resistor with a current of 3 A through it converts 500 J of electrical energy to heat energy in 12 s. What is the voltage across the resistor?

C-3. The figure shows the current I in a single-loop circuit with a battery B and resistance R (and wires of negligible resistance). Then find the order of following at the point a, b and c

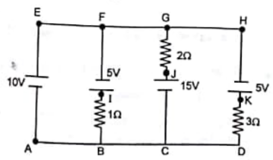


(a) The magnitude of the current,
(b) The electric potential, and
(c) The electric potential energy of the charge carriers (electron), greatest first.

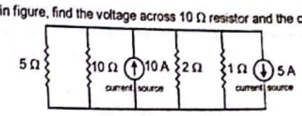
C-4. (a) A car has a fresh storage battery of emf 12 V and internal resistance $5.0 \times 10^{-2}\ \Omega$. If the starter draws a current of 90 A, what is the terminal voltage of the battery when the starter is on?
(b) After long use, the internal resistance of the storage battery increases to 500 Ω. What maximum current can be drawn from the battery? Assume the emf of the battery to remain unchanged.
(c) If the discharged battery is charged by an external emf source, is the terminal voltage of the battery during charging greater or less than its emf 12 V?

C-5. 1 kW, 220 V electric heater is to be used with 220 V D.C. supply.
(a) What is the current in the heater.
(b) What is its resistance.
(c) What is the power dissipated in the heater.
(d) How much heat in calories is produced per second.
(e) How many grams of water at 100° C will be converted per minute into steam at 100° C with the heater. (latent heat of vaporisation of water = 540 cal/g)] [J = 4.2 J/cal]

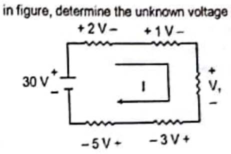
C-6. In following circuit potential at point 'A' is zero then determine
(a) Potential at each point
(b) Potential difference across each resistance
(c) Identify the batteries which act as a source
(d) Current in each battery
(e) Which resistance consumes maximum power
(f) Which battery consume or gives maximum power.



C-7. For the circuit shown in figure, find the voltage across 10 Ω resistor and the current passing through it.

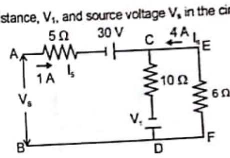


C-8. For the circuit shown in figure, determine the unknown voltage drop V_1.



C-9. A resistor develops 400 J of thermal energy in 10 s when a current of 2 A is passed through it.
(a) Find its resistance.
(b) If the current is increased to 4 A, what will be the energy developed in 20 s.

C-10. Find the current in 10 Ω resistance, V_1, and source voltage V_s in the circuit shown in figure ($V_s = V_A - V_B$)

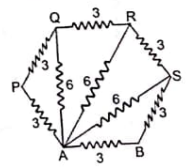


Section : (D) Combination of Resistance

D-1. Two electric bulbs, each designed to operate with a power of 500 watts in 220 volt line, are connected in series with a 110 volt line. What will be the power generated by each bulb? [JEE 1977]

D-2. Two (non-physics) students, A and B living in neighboring hostel rooms, decided to economies by connecting their bulbs in series. They agreed that each would install a 100 W bulb in their own rooms and that they would pay equal shares of the electricity bill. However, both decided to try to get better lighting at the other's expense; A installed a 200 W bulb and B installed a 50 W bulb. Which student is more likely to fail the end-of-term examinations?

D-3. All resistance in diagram (fig.) are in ohms. Find the effective resistance between the points A and B. [JEE 1979]



Exercise-1

✍ Marked Questions can be used as Revision Questions.

PART - I : SUBJECTIVE QUESTIONS

Section (A) : Definition of Current, Current densities & Drift velocities

A-1. The current through a wire depends on time as $i = i_0 + \alpha \sin \pi t$, where $i_0 = 10$ A and $\alpha = \frac{\pi}{2}$ A. Find the charge crossed through a section of the wire in 3 seconds, and average current for that interval.

A-2.✍ Estimate the average drift speed of conduction electrons in a copper wire of cross-sectional area 1.0×10^{-7} m^2 carrying a current of 1.5 A. Assume that each copper atom contributes roughly one conduction electron. The density of copper is 9.0×10^3 kg m^{-3} and its atomic mass is 63.5 amu.

A-3. A current of 5 A exists in a 10 Ω resistance for 4 minutes.
(i) How many coulombs and
(ii) How many electrons pass through any cross section of the resistor in this time?
Charge of the electron = 1.6×10^{-19} C.

Section (B) : Resistance

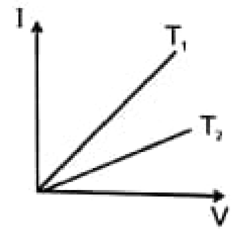
B-1. A cyllindrical conducting wire of radius 0.2 mm is carrying a current of 20 mA. (a) How many electrons are transferred per second between the supply and the wire at one end? (b) Write down the current density in the wire.

B-2.✍ A battery sets up an electric field of 25 N/C inside a uniform wire of length 2 m and a resistance of 5 Ω. Find current through the wire.

B-3. **(i)** A potential difference of 200 volt is applied to a coil at a temperature of 15°C and the current is 10 A. What will be the temperature of the coil when the current has fallen to 9 A, the applied voltage being the same as before? temperature coefficient of resistance $(\alpha) = \frac{1}{234}$ °C^{-1}.

(ii) A platinum wire has resistance of 10 ohm at 0°C and 20 ohm at 273°C. Find the value of temperature coefficient of resistance.

B-4. The current-voltage graphs for a given metallic wire at two different temperature T_1 and T_2 are shown in the figure. Which one is higher, T_1 or T_2



B-5. If a copper wire is stretched to make it 0.1% longer, what is the percentage change in its resistance ?

B-6 A rectangular carbon block has dimensions 1.0 cm × 1.0 cm × 50 cm.
(i) What is the resistance measured between the two square ends?
(ii) Between two opposing rectangular faces?
Resistivity of carbon at 20° C is 3.5×10^{-5} Ωm.

Solved Examples

Example 50. The post office box works on the principle of :
(A) Potentiometer (B) Wheatstone bridge (C) Matter waves (D) Ampere's law

Answer : (B)

Example 51. While using a post office box the keys should be switched on in the following order :
(A) first cell key the and then galvanometer key.
(B) first the galvanometer key and then cell key.
(C) both the keys simultaneously.
(D) any key first and then the other key.

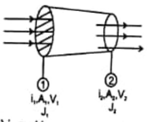
Answer : (A)

Example 52. In a post office box if the position of the cell and the galvanometer are interchanged, then the :
(A) null point will not change (B) null point will change
(C) post office box will not work (D) Nothing can be said.

Answer : (A)

Solved Miscellaneous Problems

Problem 1. Current is flowing from a conductor of non-uniform cross section area if $A_1 > A_2$ then find relation between



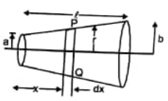
(a) i_1 and i_2 (b) j_1 and j_2 (c) v_1 and v_2 (drift velocity)
where i is current, j is current density and V is drift velocity.

Answer : $i_1 = i_2$, $V_1 < V_2$, $J_1 < J_2$

Solution :
(a) i = charge flowing through a cross-section per unit time.
$\therefore i_1 = i_2$
(b) $j = \frac{i}{A}$ as $A_1 > A_2$ then $j_1 < j_2$
(c) $j = nev_d$
$v_d = \frac{j}{ne}$ as $j_1 < j_2$ then, $v_1 < v_2$

Problem 2. Figure shows a conductor of length ℓ having a circular cross-section. The radius of cross-section varies linearly from a to b. The resistivity of the material is ρ. Find the resistance of the conductor

Solution : In this problem cross–section area is variable so we can't apply formula $\left(R = \frac{\rho\ell}{A}\right)$ directly.



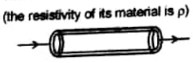
So we assume elementary strip 'PQ' of thickness dx and radius r resistance of this strip is :

$dR = \frac{\rho dx}{\pi r^2}$

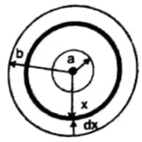
By geometry $= \frac{r-a}{x} = \frac{b-a}{\ell} \Rightarrow r = \frac{b-a}{\ell}x + a$

resistance of conductor is $R = \int_0^{\ell} \frac{\rho dx}{\pi\left\{\frac{b-a}{\ell}x + a\right\}^2} \Rightarrow R = \frac{\rho\ell}{\pi ab}$ **Ans.**

Problem 3. A cylindrical tube of length ℓ has inner radius a while outer radius b. What is the resistance of the tube between (a) its ends (b) its inner and outer surfaces ? (the resistivity of its material is ρ)

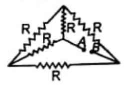


Solution :
(a) $A = \pi(b^2 - a^2)$
$R = \frac{\rho\ell}{\pi(b^2 - a^2)}$
(b) $d_R = \frac{\rho dx}{2\pi x\ell}$



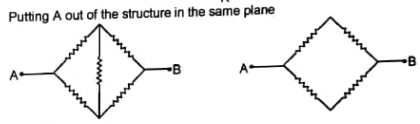
for a section taken at distance x from centre.
$d_R = \frac{\rho}{2\pi\ell} \cdot \frac{dx}{x}$
$\Rightarrow R = \int dR = \frac{\rho}{2\pi\ell}\int_a^b \frac{dx}{x} = \ell n\frac{b}{a}$

Problem 4. Find the equivalent Resistance between A and B



Solution :

Putting A out of the structure in the same plane



$R_{eq} = \frac{2R \times 2R}{2R + 2R} = R$ **Ans. :** $R_{eq} = R$

Problem 5. What shunt resistance is required to convert the 1.0 mA, 20Ω galvanometer into an ammeter with a range of 0 to 50 mA ?

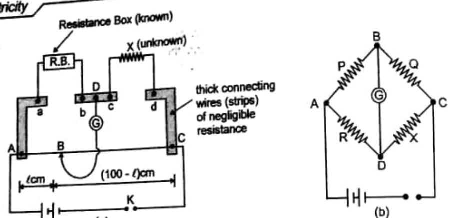
Answer : $S = \frac{20}{49} = 0.408\ \Omega$

Solution :
$i_g R_g = (i - i_g)S$
$i_g = 1.0 \times 10^{-3}$ A , G = 20Ω
$i = 50 \times 10^{-3}$ A
$S = \frac{i_g R_g}{i - v_g} = \frac{1 \times 10^{-3} \times 20}{49 \times 10^{-3}} = 0.408\ \Omega$

Problem 6. How can we convert a galvanometer with $R_g = 20\ \Omega$ and $i_g = 1.0$ mA into a voltmeter with a maximum range of 10 V ?

Answer : A resistance of 9980 Ω is to be connected in series with the galvanometer.

Solution :
$v = i_g R_S + i_g R_g$
$10 = 1 \times 10^{-3} \times R_s + 1 \times 10^{-3} \times 20$
$R_S = \frac{10 - 0.02}{1 \times 10^{-3}} = \frac{9.98}{10^{-3}} =$ **9980 Ω**



(a) (b)

Similarly, if Q is resistance of the wire between B and C, then

$Q \propto 100 - \ell$

$\therefore \quad Q = \sigma(100 - \ell)$ ....(2)

Dividing (1) by (2), $\frac{P}{Q} = \frac{\ell}{100-\ell}$

Applying the condition for balanced Wheatstone bridge, we get

$R\ Q = P\ X$

$\therefore \quad x = R\frac{Q}{P} \quad$ or $\quad X = \frac{100-\ell}{\ell}R$

Since R and ℓ are known, therefore, the value of X can be calculated.

Note : For better accuracy, R is so adjusted that ℓ lies between 40 cm and 60 cm.

Solved Example

Example 49. In a meter bridge experiment, the value of unknown resistance is 2Ω. To get the balancing point at 40cm distance from the same end, the resistance in the resistance box will be :

(A) 0.5 Ω (B) 3 Ω (C) 20 Ω (D) 80 Ω

Solution : Apply condition for balance wheat stone bridge,

$\frac{P}{Q} = \frac{\ell}{100-\ell} = \frac{P}{2} = \frac{100-40}{40}$

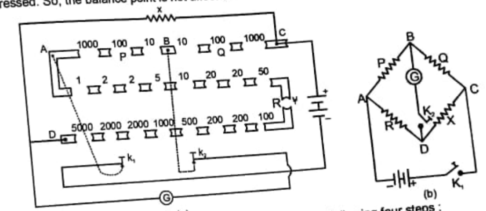
Ans. : P = 3Ω.

22. POST-OFFICE BOX

Introduction : It is so named because its shape is like a box and it was originally designed to determine the resistances of electric cables and telegraph wires. It was used in post offices to determine the resistance of transmission lines.

Construction : A post office box is a compact form of Wheatstone bridge with the help of which we can measure the value of the unknown resistance correctly up to 2nd decimal place, i.e., up to 1/100th of an ohm correctly. Two types of post office box are available - plug type and dial type. In the plug-type instrument shown in figure (a), each of the arms AB and BC contains three resistances of 10, 100 and 1000 ohm. These arms are called the ratio arms. While the resistance P can be introduced in the arm AB, the resistance Q can be introduced in the arm BC. The third arm AD, called the resistance arm, is a complete resistance box containing resistances from 1 Ω to 5,000 Ω. In this arm, the resistance R is introduced by taking out plugs of suitable values. The unknown resistance X constitutes the fourth arm CD. Thus, the four arms AB, BC, CD and AD are infect the four arms of the Wheatstone bridge (figure (b)). Two tap keys K_1 and K_2 are also provided. While K_1 is connected internally to the terminal A, K_2 is connected internally to B. These internal connections are shown by dotted lines in figure (a).

A battery is connected between C and key K_1 (battery key). A galvanometer is connected between D and key K_2 (galvanometer key). Thus, the circuit is exactly the same as that shown in figure (b). It is always the battery key which is pressed first and then the galvanometer key. This is because a self-induced current is always set up in the circuit whenever the battery key is pressed or released. If we first press the galvanometer key, the balance point will be disturbed on account of induced current. If the battery key is pressed first, then the induced current becomes zero by the time the galvanometer key is pressed. So, the balance point is not affected.



(a) (b)

Working : The working of the post office box involves broadly the following four steps :

I. Keeping R zero, each of the resistances P and Q are made equal to 10 ohm by taking out suitable plugs from the arms AB and BC respectively. After pressing the battery key first and then the galvanometer key, the direction of deflection of the galvanometer coil is noted. Now, making R infinity, the direction of deflection is again noted. If the direction is opposite to that in the first case, then the connections are correct.

II. Keeping both P and Q equal to 10Ω, the value of R is adjusted, beginning from 1Ω, till 1 Ω increase reverses the direction of deflection. The 'unknown' resistance clearly lies somewhere between the two final values of R.

$$\left[X = R\frac{Q}{P} = R\frac{10}{10} = R\right]$$

As an illustration, suppose with 3Ω resistance in the arm AD, the deflection is towards left and with 4Ω, it is towards right. The unknown resistance lies between 3Ω and 4Ω.

III. Making P 100 Ω and keeping Q 10 Ω, we again find those values of R between which direction of deflection is reversed. Clearly, the resistance in the arm AD will be 10 times the resistance X of the wire.

$$\left[X = R\frac{Q}{P} = R\frac{10}{100} = \frac{R}{10}\right]$$

In the illustration considered in step II, the resistance in the arm AD will now lie between 30 Ω, and 40 Ω. So, in this step, we have to start adjusting R from 30 Ω onwards. If 32 Ω and 33 Ω are the two values of R which give opposite deflections, then the unknown resistance lies between 3.2 Ω and 3.3 Ω.

IV. Now, P is made 1000 Ω and Q is kept at 10 Ω. The resistance in the arm AD will now be 100 times the 'unknown' resistance.

$$\left[X = R\frac{10}{1000} = \frac{R}{100}\right]$$

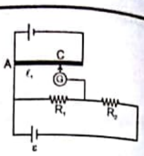
In the illustration under consideration, the resistance in the arm AD will lie between 320 Ω and 330Ω. Suppose the deflection is to the right for 326 ohm, towards left for 324 ohm and zero deflection for 325Ω then, the unknown resistance is 3.25 Ω.

The post office box method is a less accurate method for the determination of unknown resistance as compared to a metre bridge. This is due to the fact that it is not always possible to arrange resistance in the four arms to be of the same order. When the arms ratio is large, large resistance are required to be introduced in the arm R.

(b) To find current if resistance is known

$V_A - V_C = x\ell_1$

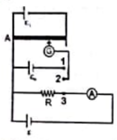
$IR_1 = x\ell_1$; $I = \frac{x\ell_1}{R_1}$



Similarly, we can find the value of R_2 also.
Potentiometer is ideal voltmeter because it does not draw any current from circuit, at the balance point.

Solved Examples

Example 47. A standard cell of emf $\varepsilon_0 = 1.11$ V is balanced against 72 cm length of a potentiometer. The same potentiometer is used to measure the potential difference across the standard resistance R = 120 Ω. When the ammeter shows a current of 7.8 mA, a balanced length of 60 cm is obtained on the potentiometer.



(i) Determine the current flowing through the resistor.
(ii) Estimate the error in measurement of the ammeter.

Solution : Here, $\ell_0 = 72$ cm ; $\ell = 60$ cm ; R = 120 Ω and $\varepsilon_0 = 1.11$ V

(i) By using equation $\varepsilon_0 = x\,\ell_0$ .....(i)

$V = IR = x\,\ell$ .....(ii)

From equation (i) and (ii)

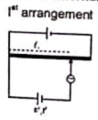
$I = \frac{\varepsilon_0}{R}\left(\frac{\ell}{\ell_0}\right)$ $\quad\therefore\; I = \frac{1.11}{120}\left(\frac{60}{72}\right) = 7.7$ mA

(ii) Since the measured reading 7.8 mA (> 7.7 mA) therefore, the instrument has a positive error.

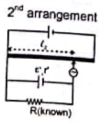
$\Delta I = 7.8 - 7.7 = 0.1$ mA, $\quad \frac{\Delta I}{I} = \frac{0.1}{7.7} \times 100 = 1.3$ %

(c) **To find the internal resistance of cell.**

I^{st} arrangement



2^{nd} arrangement



by first arrangement $\varepsilon' = x\ell_1$ .....(1)

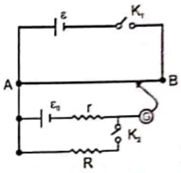
by second arrangement $IR = x\ell_2$

$I = \frac{x\ell_2}{R}$, also $I = \frac{\varepsilon'}{r'+R}$ $\quad\Rightarrow\quad \frac{\varepsilon'}{r'+R} = \frac{x\ell_2}{R}$

$\Rightarrow \frac{x\ell_1}{r'+R} = \frac{x\ell_2}{R}$ $\quad\Rightarrow\quad r' = \left[\frac{\ell_1 - \ell_2}{\ell_2}\right]R$

Solved Example

Example 48. The internal resistance of a cell is determined by using a potentiometer. In an experiment, an external resistance of 60Ω is used across the given cell. When the key is closed, the balance length on the potentiometer decreases from 72 cm to 60 cm. calculate the internal resistance of the cell.



Solution : According to equation $\varepsilon_0 = x\ell_0$ ....(i)

$V = IR = x\ell$ ....(ii)

$I = \frac{\varepsilon_0}{R+r}$ ....(iii)

From equation (i), (ii) and (iii) we get

$r = R\left(\frac{\ell_0}{\ell} - 1\right)$

here $\ell_0 = 72$ cm ; $\ell = 60$ cm ; R = 60 Ω

$\therefore\; r = (60)\left(\frac{72}{60} - 1\right)$ or $r = 12\,\Omega$

21. METRE BRIDGE (USE TO MEASURE UNKNOWN RESISTANCE)

If AB = ℓ cm, then BC = $(100 - \ell)$ cm.

Resistance of the wire between A and B $\quad R \propto \ell$

[$\because$ Specific resistance ρ and cross-sectional area A are same for whole of the wire]

or $R = \sigma\ell$ .....(1)

where σ is resistance per cm of wire.

Full scale deflection voltage $V_g = \frac{\theta}{vs}$

$= mv = 50\ mv$

So galvanometer resistance $G = \frac{V_g}{i_g} = \frac{50mV}{10mA} = 5\ \Omega$

(a) to convert the galvanometer into an ammeter of range 5A, a resistance of value $S\Omega$ is connected in parallel with it such that

$(I - i_g)\ S = i_g\ G$

$(5 - 0.01)\ S = 0.01 \times 5$

$S = \frac{5}{499} \cong 0.01\ \Omega$ **Ans.**

(b) To convert the galvanometer into a voltmeter which reads 1 division per volt, i.e. of range 100 V,

$V = i_g\ (R + G)$

$100 = 10 \times 10^{-3}\ (R + 5)$

$R = 10000 - 5$

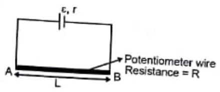
$R = 9995\ \Omega \cong 9.995\ k\Omega$ **Ans.**

20. POTENTIOMETER

A potentiometer is a linear conductor of uniform cross-section with a steady current set up in it. This maintains a uniform potential gradient along the length of the wire. Any potential difference which is less than the potential difference maintained across the potentiometer wire can be measured using this. The wire should have high resistivity and low expansion coefficient. For example : Manganin or, Constantine wire etc.

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

$V_A - V_B = \frac{\varepsilon}{R + r}.R$



Potential gradient (x) → Potential difference per unit length of wire

$x = \frac{V_A - V_B}{L} = \frac{\varepsilon}{R + r} \cdot \frac{R}{L}$

Solved Examples

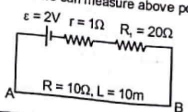
Example 44. Primary circuit of potentiometer is shown in figure determine :

(A) current in primary circuit

(B) potential drop across potentiometer wire AB

(C) potential gradient (means potential drop per unit length of potentiometer wire)

(D) maximum potential which we can measure above potentiometer



Solution : (a) $i = \frac{\varepsilon}{r + R_1 + R} = \frac{2}{1 + 20 + 10} \Rightarrow \quad i = \frac{2}{31} A$ **Ans.**

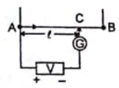
(b) $V_{AB} = iR = \frac{2}{31} \times 10 \quad \Rightarrow \quad V_{AB} = \frac{20}{31}$ volt **Ans.**

(c) $x = \frac{V_{AB}}{L} = \frac{2}{31}$ volt/m **Ans.**

(d) Maximum potential which we can measure by it = potential drop across wire AB = $\frac{20}{31}$ volt

Example 45. How to measure an unknown voltage using potentiometer.

Solution : The unknown voltage V is connected across the potentiometer wire as shown in figure. The positive terminal of the unknown voltage is kept on the same side as of the source of the top most battery. When reading of galvanometer is zero then we say that the meter is balanced. In that condition $V = x\ell$.



20.1 Application of potentiometer

(a) To find emf of unknown cell and compare emf of two cells.

In case I, In figure, (2) is joint to (1) then balance length = ℓ_1

$\varepsilon_1 = x\ell_1$ ....(1)

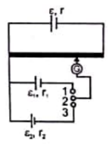
in case II, In figure, (3) is joint to (2)

then balance length = ℓ_2

$\varepsilon_2 = x\ell_2$ ....(2)

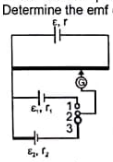
$\frac{\varepsilon_1}{\varepsilon_2} = \frac{\ell_1}{\ell_2}$

If any one of ε_1 or ε_2 is known the other can be found. If x is known then both ε_1 and ε_2 can be found



Solved Examples

Example 46. In an experiment to determine the emf of an unknown cell, its emf is compared with a standard cell of known emf ε_1 = 1.12 V. The balance point is obtained at 56cm with standard cell and 80 cm with the unknown cell. Determine the emf of the unknown cell.



Solution : Here, $\varepsilon_1 = 1.12\ V$; $\ell_1 = 56$ cm ; $\ell_2 = 80$ cm

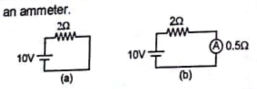
Using equation

$\varepsilon_1 = x\ell_1$ .....(1)

$\varepsilon_2 = x\ell_2$ .....(2)

we get $\frac{\varepsilon_1}{\varepsilon_2} = \frac{\ell_1}{\ell_2} \Rightarrow \varepsilon_2 = \varepsilon_1\left(\frac{\ell_2}{\ell_1}\right)$ or $\varepsilon_2 = 1.12\left(\frac{80}{56}\right) = 1.6$ V Ans

Example 39. Find the current in the circuit (a) & (b) and also determine percentage error in measuring the current through an ammeter.



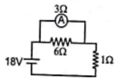
Solution : In A $I = \frac{10}{2} = 5A$

In B $I = \frac{10}{2.5} = 4A$

Percentage error is $= \frac{i - i'}{i} \times 100 = 20\%$ **Ans.**

Here we see that due to ammeter the current has reduced. A good ammeter has very low resistance as compared with other resistors, so that due to its presence in the circuit the current is not affected.

Example 40. Find the reading of ammeter ? Is this the current through 6 Ω ?



Solution : $R_{eq} = \frac{3 \times 6}{3+6} + 1 = 3\ \Omega$

Current through battery $I = \frac{18}{3} = 6$ A

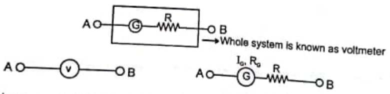
So, current through ammeter $= 6 \times \frac{6}{9} = 4$ A

No, it is not the current through the 6 Ω resistor.

Note: Ideal ammeter is equivalent to zero resistance wire for calculation potential difference across it is zero.

19. VOLTMETER

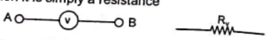
A high resistance is put in series with galvanometer. It is used to measure potential difference across a resistor in a circuit.



For maximum potential difference $V = I_G \cdot R + I_G R_G$ $R = \frac{V}{I_G} - R_G$

If $R_G << R \Rightarrow R_S \approx \frac{V}{I_G}$

For measuring the potential difference a voltmeter is connected across that element. (parallel to that element it measures the potential difference that appears between terminals 'A' and 'B'.)
For calculation it is simply a resistance



Resistance of voltmeter $R_V = R_G + R \approx R$

$I_g = \frac{V_o}{R_g + R}$. $R \to \infty \Rightarrow$ Ideal voltmeter.

A good voltmeter has high value of resistance.
Ideal voltmeter → which has high value of resistance.

Note :
- For calculation purposes the current through the ideal voltmeter is zero.
- Percentage error in measuring the potential difference by a voltmeter is $= \frac{V - V'}{V} \times 100$

Solved Example

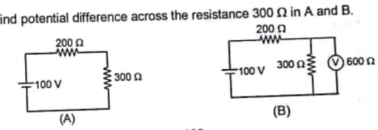
Example 41. A galvanometer has a resistance of G ohm and range of V volt. Calculate the resistance to be used in series with it to extend its range to nV volt.

Solution : Full scale current $i_g = \frac{V}{G}$

to change its range

$V_1 = (G + R_s)i_g \Rightarrow nV = (G + R_s)\frac{V}{G} \Rightarrow R_s = G(n-1)$ **Ans.**

Example 42. Find potential difference across the resistance 300 Ω in A and B.



Solution : In (A) : Potential difference $= \frac{100}{200+300} \times 300 = 60$ volt

In (B) : Potential difference $= \frac{100}{200 + \frac{300 \times 600}{300 + 600}} \times \frac{300 \times 600}{300 + 600} = 50$ volt

We see that by connecting voltmeter the voltage which was to be measured has changed. Such voltmeters are not good. If its resistance had been very large than 300 Ω then it would not have affected the voltage by much amount.

Current sensitivity

The ratio of deflection to the current i.e. deflection per unit current is called current sensitivity (C.S.) of the galvanometer $CS = \frac{\theta}{I}$

Note : Shunting a galvanometer decreases its current sensitivity.

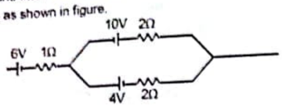
Solved Examples

Example 43. A galvanometer with a scale divided into 100 equal divisions, has a current sensitivity of 10 division per mA and voltage sensitivity of 2 division per mV. What adoptions are required to use it (a) to read 5A full scale and (b) 1 division per volt ?

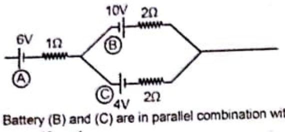
Solution : Full scale deflection current $i_g = \frac{\theta}{CS} = \frac{100}{10}$ mA = 10 mA

Solved Examples

Example 37. Find the emf and internal resistance of a single battery which is equivalent to a combination of three batteries as shown in figure.

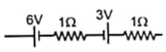


Solution :



Battery (B) and (C) are in parallel combination with opposite polarity. So, their equivalent

$\varepsilon_{BC} = \dfrac{\frac{10}{2} + \frac{-4}{2}}{\frac{1}{2} + \frac{1}{2}} = \dfrac{5-2}{1} = 3V \quad \Rightarrow r_{BC} = 1\Omega.$

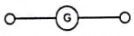


Now, $\varepsilon_{ABC} = 6 - 3 = 3V$

$r_{ABC} = 2\Omega$. **Ans.**

17. GALVANOMETER

Galvanometer is represented as follow :



It consists of a pivoted coil placed in the magnetic field of a permanent magnet. Attached to the coil is a spring. In the equilibrium position, with no current in the coil, the pointer is at zero and spring is relaxed. When there is a current in the coil, the magnetic field exerts a torque on the coil that is proportional to current. As the coil turns, the spring exerts a restoring torque that is proportional to the angular displacement. Thus, the angular deflection of the coil and pointer is directly proportional to the coil current and the device can be calibrated to measure current.

When coil rotates the spring is twisted and it exerts an opposing torque on the coil.

There is a resistive torque also against motion to damp the motion. Finally in equilibrium

$\tau_{magnetic} = \tau_{spring} \Rightarrow$ BINA $\sin\theta = C\phi$

But by making the magnetic field radial $\theta = 90°$.

$\therefore$ BINA $= C\phi$

$I \propto \phi$

here B = magnetic field   A = Area of the coil

I = Current   C = torsional constant

N = Number of turns ϕ = angle rotate by coil.

- **Current sensitivity**

The ratio of deflection to the current i.e. deflection per unit current is called current sensitivity (C.S.) of the galvanometer CS $= \dfrac{\phi}{I} = \dfrac{BNA}{C}$

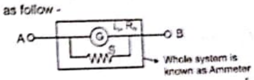
Note: Shunting a galvanometer decreases its current sensitivity. A linear scale is obtained. The marking on the galvanometer are proportionate.

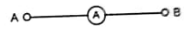
The galvanometer coil has some resistance represented by R_g. It is of the order of few ohms. It also has a maximum capacity to carry a current known as I_g. I_g is also the current required for full scale deflection. This galvanometer is called moving coil galvanometer.

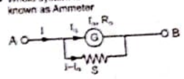
18. AMMETER

A shunt (small resistance) is connected in parallel with galvanometer to convert it into ammeter; An ideal ammeter has zero resistance

Ammeter is represented as follow -







If maximum value of current to be measured by ammeter is I then

$I_G \cdot R_G = (I - I_G)S$

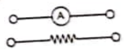
$S = \dfrac{I_G R_G}{I - I_G}$

$S = \dfrac{I_G \times R_G}{I}$ when $I >> I_G$.

where I = Maximum current that can be measured using the given ammeter.

For measuring the current the ammeter is connected is series.

In calculation it is simply a resistance



Resistance of ammeter $R_A = \dfrac{R_G S}{R_G + S}$

for $S << R_G \Rightarrow R_A = S$

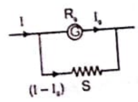
Solved Examples

Example 38. What is the value of shunt which passes 10% of the main current through a galvanometer of 99 ohm ?

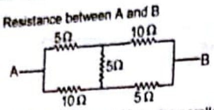
Solution : As in figure $R_g I_g = (I - I_g)S$

$\Rightarrow 99 \times \dfrac{I}{10} = \left(I - \dfrac{I}{10}\right) \times S$

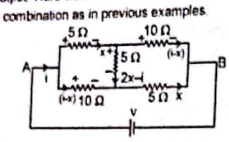
$\Rightarrow S = 11\,\Omega$



Example 35. Find the equivalent Resistance between A and B



Solution : It is wheat stone bridge but not balanced. No series parallel connections. But similar values on input side and output. Here we see that even after using symmetry the circuit does not reduce to series parallel combination as in previous examples.



∴ Applying kirchoff voltage law $v - 10(i - x) - 5x = 0$

$v - 10i + 5x = 0$ ......(1)

$10(i - x) - 5(2x - i) - 5x = 0$

$10i - 10x - 10x + 5i - 5x = 0$

$15i - 25x = 0$

$x = \frac{15}{25} i \qquad 5x = 3i$ ......(2)

Using (2) and (1)

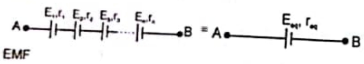
∴ $v - 10i + 3i = 0$

$\frac{v}{i} = 7\Omega$

$R_{eq} = 7\Omega$ **Ans.**

16. GROUPING OF CELLS

16.1 Cells in Series :

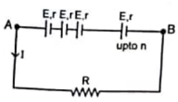


Equivalent EMF

$E_{eq} = E_1 + E_2 + ... + E_n$ [write EMF's with polarity]

Equivalent internal resistance $r_{eq} = r_1 + r_2 + r_3 + r_4 + ... + r_n$

If n cells each of emf E, arranged in series and if r is internal resistance of each cell, then total emf = n E so current in the circuit



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

If $nr << R$ then $I = \frac{nE}{R}$ ⟶ Series combination is advantageous.

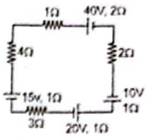
If $nr >> R$ then $I = \frac{E}{r}$ ⟶ Series combination is not advantageous.

Note : If polarity of m cells is reversed, then equivalent emf = (n-2m)E while the equivalent resistance is still nr + R, so current in R will be

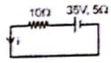
$i = \frac{(n-2m)E}{nr + R}$

Solved Examples

Example 36. Find the current in the loop

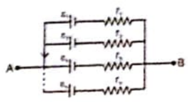


Solution : The given circuit can be simplified as



$i = \frac{35}{10+5} = \frac{35}{15} = \frac{7}{3} A \Rightarrow I = \frac{7}{3} A$

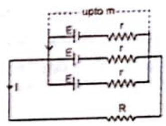
16.2 Cells in Parallel :



$E_{eq} = \frac{\frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2} + ... + \frac{\varepsilon_n}{r_n}}{\frac{1}{r_1} + \frac{1}{r_2} + ... + \frac{1}{r_n}}$ [Use emf's with polarity]

$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} + ... + \frac{1}{r_n}$

If m cells each of emf E and internal resistance r be connected in parallel and if this combination is connected to an external resistance then equivalent emf of the circuit = E.



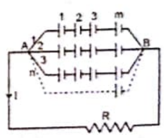
Internal resistance of the circuit = $\frac{r}{m}$.

and $I = \frac{E}{R + \frac{r}{m}} = \frac{mE}{mR + r}$.

If $mR << r$; $I = \frac{mE}{r}$ ⟶ Parallel combination is advantageous.

If $mR >> r$; $I = \frac{E}{R}$ ⟶ Parallel combination is not advantageous.

16.3 Cells in Multiple Arc :



mn = number of identical cells.

n = number of rows

m = number of cells in each row.

The combination of cells is equivalent to single cell of

emf = mE

and internal resistance = $\frac{mr}{n}$

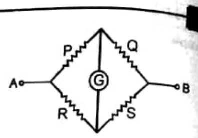
Current $I = \frac{mE}{R + \frac{mr}{n}}$

For maximum current nR = mr

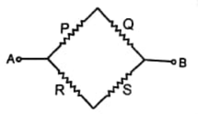
or $R = \frac{mr}{n}$ = internal resistance of the equivalent battery.

$I_{max} = \frac{nE}{2r} = \frac{mE}{2R}$.

The arrangement as shown in figure, is known as Wheat stone bridge



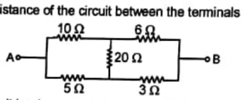
or



Here there are four terminals in which except two all are connected to each other through resistive elements.
In this circuit if $R_1 R_3 = R_2 R_4$ then $V_C = V_D$ and current in $R_5 = 0$ this is called balance point or null point
When current through the galvanometer is zero (null point or balance point) $\frac{P}{Q} = \frac{R}{S}$, then PS = QR ⇒ Here in this case products of opposite arms are equal. Potential difference between C and D at null point is zero. The null point is not affected by resistance R_5, E and R. **It is not affected even if the positions of Galvanometer and battery (E) are interchanged.**
hence, here the circuit can be assumed to be following,

Solved Examples

Example 28. Find equivalent resistance of the circuit between the terminals A and B.

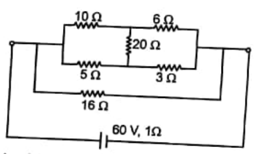


Solution : Since the given circuit is wheat stone bridge and it is in balance condition.

$\because$ 10 × 3 = 30 = 6 × 5

hence this is equivalent to $R_{eq} = \frac{16 \times 8}{16+8} = \frac{16}{3} \Omega$

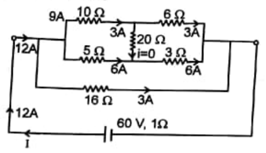
Example 29.



Find (a) Equivalent resistance (b) and current in each resistance

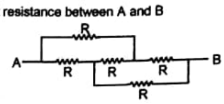
Solution : (a) $R_{eq} = \left(\frac{1}{16}+\frac{1}{8}+\frac{1}{16}\right)^{-1} + 1 = 5\ \Omega$

(b) $i = \frac{60}{4+1} = 12$ A

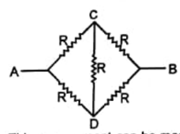


Hence 12 A will flow through the cell.
By using current distribution law.
Current in resistance 10Ω and 6Ω = 3A
Current in resistance 5Ω and 3Ω = 6A
Current in resistance 20Ω = 0
Current in resistance 16Ω = 3A

Example 30. Find the equivalent resistance between A and B



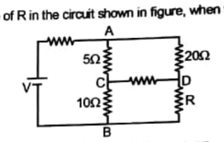
Solution :



This arrangement can be modified as shown in figure since it is balanced wheat stone bridge

$R_{eq} = \frac{2R \times 2R}{2R + 2R} = R$

Example 31. Determine the value of R in the circuit shown in figure, when the current is zero in the branch CD.



Solution : The current in the branch CD is zero, if the potential difference across CD is zero.
That means, voltage at point C = voltage at point D.
Since no current is flowing, the branch CD is open circuited. So the same voltage is applied across ACB and ADB

$V_{10} = V \times \frac{10}{15}$ ⇒ $V_R = V \times \frac{R}{20+R}$

$\therefore$ $V_{10} = V_R$ and $V \times \frac{10}{15} = V \times \frac{R}{20+R}$

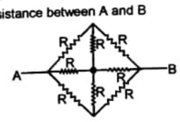
$\therefore$ $R = 40\ \Omega$ **Ans.**

15. SYMMETRICAL CIRCUITS :

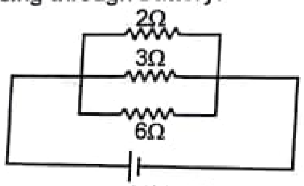
Some circuits can be modified to have simpler solution by using symmetry if they are solved by traditional method of KVL and KCL then it would take much time.

Solved Examples

Example 32. Find the equivalent Resistance between A and B



Exercise 24. Find current which is passing through battery.

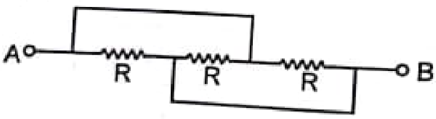


Solution : Here potential difference across each resistor is not 30 V

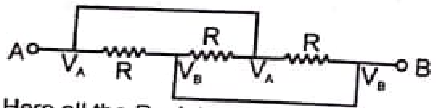
$\because$ battery has internal resistance. Here the concept of combination of resistors is useful.

$R_{eq} = 1 + 1 = 2\,\Omega$; $i = \dfrac{30}{2} = 15$ A.

Example 25. Find equivalent Resistance

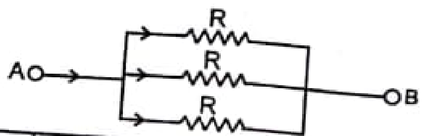


Solution :



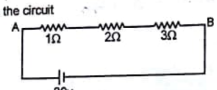
Here all the Resistance are connected between the terminals A and B
Modified circuit is

So $R_{eq} = \dfrac{R}{3}$



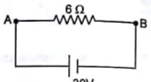
Solved Examples

Example 20. Find the current in the circuit



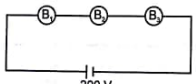
Solution : $R_{eq} = 1 + 2 + 3 = 6\,\Omega$

the given circuit is equivalent to



current $i = \frac{V}{R_{eq}} = \frac{30}{6} = 5\,A$ **Ans.**

Example 21. In the figure shown B_1, B_2 and B_3 are three bulbs rated as (200V, 50 W), (200V, 100W) and (200 V, 25W) respectively. Find the current through each bulb and which bulb will give more light?



Solution : $R_1 = \frac{(200)^2}{50}$; $R_2 = \frac{(200)^2}{100}$; $R_3 = \frac{(200)^2}{25}$

the current following through each bulb is

$$= \frac{200}{R_1 + R_2 + R_3} = \frac{200}{(200)^2\left[\frac{2+1+4}{100}\right]} = \frac{100}{200 \times 7} = \frac{1}{14}A$$

Since $R_3 > R_1 > R_2$

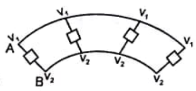
$\therefore$ Power consumed by bulb = i^2R

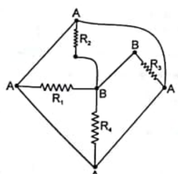
$\therefore$ if the resistance is of higher value then it will give more light.

$\therefore$ Here Bulb B_3 will give more light.

13.2 Resistances in Parallel :

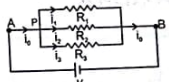
A parallel circuit of resistors is one in which the same voltage is applied across all the components in a parallel grouping of resistors R_1, R_2, R_3,........, R_n.





In the figure (a) and (b) all the resistors are connected between points A and B so they are in parallel.

Equivalent resistance :



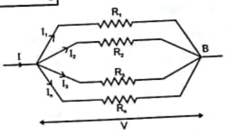
Applying kirchhoff's junction law at point P

$i_0 = i_1 + i_2 + i_3$

Therefore, $\frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$ $\boxed{\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$

in general,

$$\boxed{\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots\dots\dots + \frac{1}{R_n}}$$



Conclusions: (about parallel combination)

(a) Potential difference across each resistor is same.

(b) $I = I_1 + I_2 + I_3 + \dots\dots\dots I_n$.

(c) Effective resistance (R) then $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots\dots + \frac{1}{R_n}$. (R is less than each resistor).

(d) Current in different resistors is inversely proportional to the resistance.

$I_1 : I_2 : \dots\dots\dots I_n = \frac{1}{R_1} : \frac{1}{R_2} : \frac{1}{R_3} : \dots\dots : \frac{1}{R_n}$.

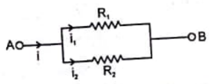
$I_1 = \frac{G_1}{G_1 + G_2 + \dots\dots + G_n} I$, $I_2 = \frac{G_2}{G_1 + G_2 + \dots\dots + G_n} I$, etc.

where $G = \frac{1}{R}$ = Conductance of a resistor. [Its unit is Ω^{-1} or ℧ (mho)]

Solved Example

Example 22. When two resistors are in parallel combination then determine i_1 and i_2, if the combination carries a current i ?

Solution : $\therefore$ $i_1R_1 = i_2R_2$ or $\frac{i_1}{i_2} = \frac{R_2}{R_1}$



$i_1 = \frac{R_2\, i}{R_1 + R_2}$ $\Rightarrow$ $i_2 = \frac{R_1\, i}{R_1 + R_2}$.

Note : Remember this law of $i \propto \frac{1}{R}$ in the resistors connected in parallel. It can be used in problems.

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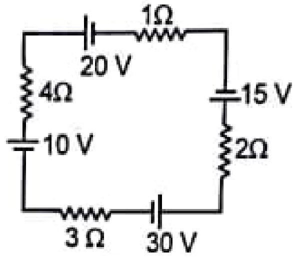
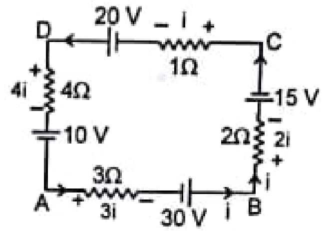
Example 17. Find current in the circuit



Solution : $\because$ all the elements are connected in series current is all of them will be same let current = i



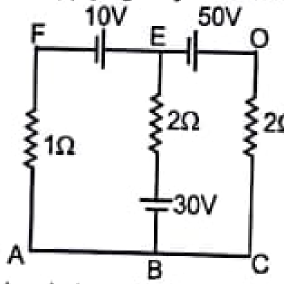
Applying kirchhoff voltage law in ABCDA loop

$10 + 4i - 20 + i + 15 + 2i - 30 + 3i = 0$

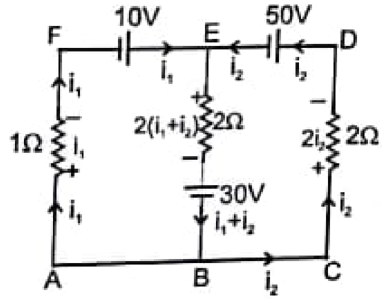
$10i = 25$

$\Rightarrow \; i = 2.5$ A

Example 18. Find the current in each wire applying only kirchhoff voltage law



Solution : Applying kirchhoff voltage law in loop ABEFA



$i_1 + 30 + 2\,(i_1 + i_2) - 10 = 0$

$3I_1 + 2I_2 + 20 = 0$ .....(i)

Applying kirchoff voltage law in BEDCB

$+ 30 + 2(i_1 + i_2) + 50 + 2i_2 = 0$

$4i_2 + 2i_1 + 80 = 0$

$2i_2 + i_1 + 40 = 0$ .....(ii)

Solving (i) and (ii)

$3\left[-40 \;\; -2i_2\right] + 2i_2 + 20 = 0$

$-120 - 4i_2 + 20 = 0$

$i_2 = -25$ A and $i_1 = 10$ A $\quad \therefore \; i_1 + i_2 = -15$ A

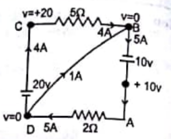
current in wire AF = 10 A from A to F

current in wire EB = 15 A from B to E

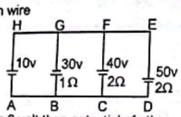
current in wire DE = 25 A from E to D.

Solution : Let at point D potential = 0 and write the potential of other points then current in wire AD = $\frac{10}{2}$ = 5 A from A to D current in wire CB = $\frac{20}{5}$ = 4A from C to F

$\therefore$ current in wire BD = 1 A from D to B



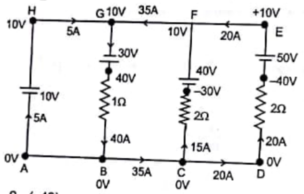
Example 13. Find the current in each wire



Solution : Let potential at point A is 0 volt then potential of other points is shown in figure.

current in BG = $\frac{40-0}{1}$ = 40 A from G to B

current in FC = $\frac{0-(-30)}{2}$ = 15 A from C to F



current in DE = $\frac{0-(-40)}{2}$ = 20 A from D to E

current in wire AH = 40 – 35 = 5 A from A to H

12. KIRCHHOFF'S LAWS

12.1 Kirchhoff's Current Law (Junction law)

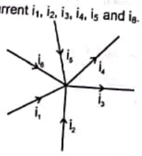
This law is based on law of conservation of charge. It states that "The algebraic sum of the currents meeting at a point of the circuit is zero" or total currents entering a junction equals total current leaving the junction.

$\Sigma I_{in} = \Sigma I_{out}$.

It is also known as KCL (Kirchhoff's current law).

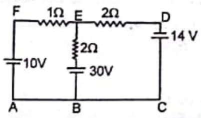
Solved Examples

Example 14. Find relation in between current i_1, i_2, i_3, i_4, i_5 and i_6.

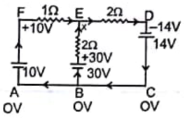


Solution : $i_1 + i_2 - i_3 - i_4 + i_5 + i_6 = 0$

Example 15. Find the current in each wire



Solution :



Let potential at point B = 0. Then potential at other points are mentioned.

$\therefore$ Potential at E is not known numerically.

Let potential at E = x

Now applying kirchhoff's current law at junction E. (This can be applied at any other junction also).

$$\frac{x-10}{1}+\frac{x-30}{2}+\frac{x+14}{2}=0$$

$4x = 36 \Rightarrow x = 9$

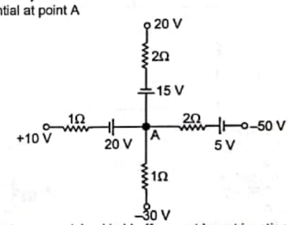
Current in EF = $\frac{10-9}{1}$ = 1A from F to E

Current in BE = $\frac{30-9}{2}$ = 10.5A from B to E

Current in DE = $\frac{9-(-14)}{2}$ = 11.5A from E to D

Solved Example

Example 16. Find the potential at point A



Solution : Let potential at A = x, applying kirchhoff current law at junction A

$$\frac{x-20-10}{1}+\frac{x-15-20}{2}+\frac{x+45}{2}+\frac{x+30}{1}=0$$

$$\Rightarrow \frac{2x-\ 60+x-35+x+45+2x+60}{2}=0$$

$\Rightarrow 6x + 10 = 0 \quad \Rightarrow \quad x = -5/3$

Potential at A = $\frac{-5}{3}$ V

Case I : Battery acting as a source (or battery is discharging)

$V_A - V_B = \varepsilon - ir$

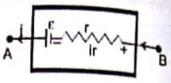
$V_A - V_B$

$\Rightarrow$ it is also called terminal voltage.

The rate at which the chemical energy of the cell is consumed = εi

The rate at which heat is generated inside the battery or cell = i^2r

electric power output = $\varepsilon i - i^2r = (\varepsilon - ir)\,i$



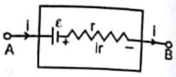
Case II : Battery acting as a load (or battery charging)

$V_A - V_B = \varepsilon + ir$

the rate at which chemical energy stored in the cell = εi

thermal power inside the cell = i^2r

electric power input = $\varepsilon i + i^2r = (\varepsilon + ir)\,i = (V_A - V_B)\,i$



Definition III :

Electromotive force of a cell is equal to potential difference between its terminals when no current is passing through the circuit.

Case III : When cell is in open circuit

i = 0 as resistance of open circuit is infinite (∞).

So V = ε, so open circuit terminal voltage difference is equal to emf of the cell.

Case IV :

Short circuiting : Two points in an electric circuit directly connected by a conducting wire are called short circuited, under such condition both points are at same potential.

When cell is short circuited

$i = \frac{\varepsilon}{r}$ and V = 0, short circuit current of a cell is maximum.

Note :

- The potential at all points of a wire of zero resistance will be same.

* **Earthing :** If some point of circuit is earthed then its potential is assumed to be zero.

11 RELATIVE POTENTIAL

While solving an electric circuit it is convenient to chose a reference point and assigning its voltage as zero, then all other potentials are measured with respect to this point. This point is also called the common point.

Solved Examples

Example 11. In the given electric circuit find

(a) current

(b) power output

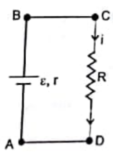
(c) relation between r and R so that the electric power output (that means power given to R) is maximum.

(d) value of maximum power output.

(e) plot graph between power and resistance of load

(f) From graph we see that for a given power output there exists two values of external resistance, prove that the product of these resistances equals r^2.

(g) what is the efficiency of the cell when it is used to supply maximum power.



Solution : (a) In the circuit shown if we assume that potential at A is zero then potential at B is $\varepsilon - ir$. Now since the connecting wires are of zero resistance

$\therefore\ V_D = V_A = 0 \quad \Rightarrow \quad V_C = V_B = \varepsilon - ir$

Now current through CD is also i ($\because$ it's in series with the cell).

$\therefore\ i = \frac{V_C - V_D}{R} = \frac{(\varepsilon - i\,r) - 0}{R}$ Current $i = \frac{\varepsilon}{r + R}$

Note : After learning the concept of series combination we will be able to calculate the current directly

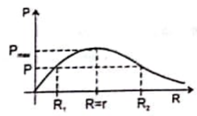
(b) Power output $P = i^2R = \frac{\varepsilon^2}{(r+R)^2}\cdot R$

(c) $\frac{dP}{dR} = \frac{\varepsilon^2}{(r+R)^2} - \frac{2\varepsilon^2R}{(r+R)^3} = \frac{\varepsilon^2}{(R+r)^3}[R + r - 2R]$

for maximum power supply $\frac{dP}{dR} = 0$

$\Rightarrow r + R - 2R = 0 \Rightarrow$ **r = R**

Here for maximum power output outer resistance should be equal to internal resistance



(d) $P_{max} = \frac{\varepsilon^2}{4r}$

(e) Graph between 'P' and R maximum power output at R = r

$P_{max} = \frac{\varepsilon^2}{4r} \quad \Rightarrow \quad i = \frac{\varepsilon}{r + R}$

(f) Power output $P = \frac{\varepsilon^2R}{(r+R)^2}$

$P(r^2 + 2rR + R^2) = \varepsilon^2R$

$R^2 + (2r - \frac{\varepsilon^2}{P})R + r^2 = 0$

above quadratic equation in R has two roots R_1 and R_2 for given values of ε, P and r such that

$\therefore\ R_1R_2 = r^2$ (product of roots)

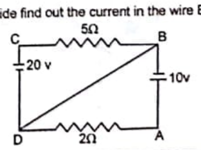
$r^2 = R_1R_2$

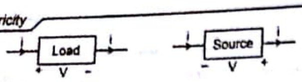
(g) Power of battery spent = $\frac{\varepsilon^2}{(r+r)^2}\cdot 2r = \frac{\varepsilon^2}{2r}$

power (output) = $\left(\frac{\varepsilon}{r+r}\right)^2 \times r = \frac{\varepsilon^2}{4r}$

Efficiency = $\frac{\text{power output}}{\text{total power spent by cell}} = \frac{\frac{\varepsilon^2}{4r}\times 100}{\frac{\varepsilon^2}{2r}} = \frac{1}{2}\times 100 = 50\%$

Example 12. In the figure given beside find out the current in the wire BD





Power $= \frac{V.dq}{dt} = V\,I$

P = V I

If power is constant then energy = P t

If power is variable then Energy = $\int p dt$

Power consumed by a resistor $P = I^2R = VI = \frac{V^2}{R}$.

When a current is passed through a resistor energy is wasted in overcoming the resistance of the wire. This energy is converted into heat.

$$W = VIt = I^2Rt = \frac{V^2}{R}t$$

The heat generated (in joules) when a current of I ampere flows through a resistance of R ohm for t second is given by:

$$H = I^2Rt \text{ Joule} = \frac{I^2Rt}{4.2} \text{ Calorie}$$

1 unit of electrical energy = 1 Kilowatt hour = 1 KWh = 3.6×10^6 Joule.

Solved Examples

Example 9. If bulb rating is 100 watt and 220 V then determine
(a) Resistance of filament
(b) Current through filament
(c) If bulb operate at 110 volt power supply then find power consumed by bulb.

Solution : Bulb rating is 100 W and 220 V bulb means when 220 V potential difference is applied between the two ends then the power consumed is 100 W

Here V = 220 Volt

P = 100 W

$\frac{V^2}{R} = 100$ So $R = 484\ \Omega$

Since Resistance depends only on material hence it is constant for bulb

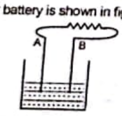
$I = \frac{V}{R} = \frac{220}{22 \times 22} = \frac{5}{11}$ Amp.

power consumed at 110 V

$\therefore$ power consumed $= \frac{110 \times 110}{484} = 25$ W

BATTERY (CELL)

A battery is a device which maintains a potential difference across its two terminals A and B. Dry cells, secondary cells, generator and thermocouple are the devices used for producing potential difference in an electric circuit. Arrangement of cell or battery is shown in figure. Electrolyte provides continuity for current.



It is often prepared by putting two rods or plates of different metals in a chemical solution. Some internal mechanism exerts force ($\vec{F}_n$) on the ions (positive and negative) of the solution. This force drives positive ions towards positive terminal and negative ions towards negative terminal. As positive charge accumulates on anode and negative charge on cathode a potential difference and hence an electric field $\vec{E}$ is developed from anode to cathode. This electric field exerts an electrostatic force $\vec{F} = q\vec{E}$ on the ions. This force $\vec{E}$ is opposite to that of $\vec{F}_n$. In equilibrium (steady state)

$F_n = F_e$ and no further accumulation of charge takes place.

When the terminals of the battery are connected by a conducting wire, an electric field is developed in the wire. The free electrons in the wire move in the opposite direction and enter the battery at positive terminal. Some electrons are withdrawn from the negative terminal. Thus, potential difference and hence, F_e decreases in magnitude while F_n remains the same. Thus, there is a net force on the positive charge towards the positive terminal. With this the positive charge rush towards positive terminal and negative charge rush towards negative terminal. Thus, the potential difference between positive and negative terminal is maintained.

Internal resistance (r) :

The potential difference across a real source in a circuit is not equal to the emf of the cell. The reason is that charge moving through the electrolyte of the cell encounters resistance. We call this the internal resistance of the source.

• The internal resistance of a cell depends on the distance between electrodes ($r \propto d$), area of electrodes ($r \propto \frac{1}{s}$) and nature, concentration ($r \propto c$) and temperature of electrolyte ($r \propto \frac{1}{\text{Temp.}}$).

Solved Example

Example 10. What is the meaning of 10 Amp. hr ?

Solution : It means if the 10 A current is withdrawn then the battery will work for 1 hour.

10 Amp $\longrightarrow$ 1 hr

1 Amp $\longrightarrow$ 10 hr

½ Amp $\longrightarrow$ 20 hr

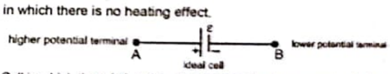
10. ELECTROMOTIVE FORCE : (E.M.F.)

Definition I : Electromotive force is the capability of the system to make the charge flow.

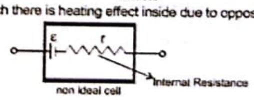
Definition II : It is the work done by the battery for the flow of 1 coloumb charge from lower potential terminal to higher potential terminal inside the battery.

10.1 Representation for battery :

Ideal cell : Cell in which there is no heating effect.



Non ideal cell : Cell in which there is heating effect inside due to opposition to the current flow internally



Example 5. The wire is stretched to increase the length by 1% find the percentage change in the Resistance.

Solution : As we known that $\therefore\ R = \frac{\rho \ell}{A}$

$$\frac{\Delta R}{R} = \frac{\Delta \rho}{\rho} + \frac{\Delta \ell}{\ell} - \frac{\Delta A}{A} \text{ and } \frac{\Delta \ell}{\ell} = -\frac{\Delta A}{A}$$

$$\frac{\Delta R}{R} = 0 + 1 + 1 = 2$$

Hence percentage increase in the Resistance = 2%

Note :

- Above method is applicable when % change is very small.

Temperature Dependence of Resistivity and Resistance :

The resistivity of a metallic conductor nearly increases with increasing temperature. This is because, with the increase in temperature the ions of the conductor vibrate with greater amplitude, and the collision between electrons and ions become more frequent. Over a small temperature range (upto 100°C), the resistivity of a metal can be represented approximately by the equation,

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

where, ρ_0 is the resistivity at a reference temperature T_0 (often taken as 0°C or 20°C) and $\rho(T)$ is the resistivity at temperature T, which may be higher or lower than T_0. The factor α is called the temperature coefficient of resistivity.

The resistance of a given conductor depends on its length and area of cross-section besides the resistivity. As temperature changes, the length and area also change. But these changes are quite small and the factor ℓ/A may be treated as constant.

Then, $R \propto \rho$

and hence, $R(T) = R_0 [1 + \alpha(T - T_0)]$ .....(ii)

In this equation R(T) is the resistance at temperature T and R_0 is the resistance at temperature T_0, often taken to be 0°C or 20°C. The temperature coefficient of resistance α is the same constant that appears.

Note :

- The ρ-T equation written above can be derived from the relation,
  α = fractional change in resistivity per unit change in temperature
  $= \frac{d\rho}{\rho dT} = \alpha$ or, $\frac{d\rho}{dT} = \alpha\rho$

$\therefore\ \frac{d\rho}{\rho} = \alpha dT$ (α can be assumed constant for small temperature variation)

$$\therefore\ \int_{\rho_0}^{\rho} \frac{d\rho}{\rho} = \alpha \int_{T_0}^{T} dT \quad .....(iii)$$

$$\therefore\ \ln\left(\frac{\rho}{\rho_0}\right) = \alpha (T - T_0)$$

$$\therefore\ \rho = \rho_0 e^{\alpha(T-T_0)}$$

if $\alpha (T - T_0) << 1$ then

$e^{\alpha(T-T_0)}$ can approximately be written as $1 + \alpha(T - T_0)$. Hence,

In the above discussion we have assumed α to be constant. If it is a function of temperature it will come inside the integration in Eq. (iii).

Solved Examples

Example 6. The resistance of a thin silver wire is 1.0 Ω at 20°C. The wire is placed in liquid bath and its resistance rises to 1.2 Ω. What is the temperature of the bath ? (Here $\alpha = 10^{-2}$ /°C)

Solution : Here change in resistance is small so we can apply

$R = R_0(1 + \alpha\Delta\theta)$

$\Rightarrow 1.2 = 1 \times (1 + 10^{-2}\Delta\theta) \quad \Rightarrow \quad \Delta\theta = 20°C$

$\Rightarrow \theta - 20 = 20 \quad \Rightarrow \quad \theta = 40°\ C$ **Ans.**

Example 7. A conductive wire has resistance of 10 ohm at 0°C, and α is $\frac{1}{273}$/°C, then determine its resistance at 273°C.

Solution : In such a problem, term $\alpha\ \Delta\ T$ will have a larger value so could not be used directly in $R = R_0 (1 + \alpha\ \Delta\ T)$. We need to go for basics as

As we know that $\alpha = \frac{dR}{RdT}$

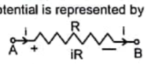
$\Rightarrow \int \frac{dR}{R} = \int \alpha dT \quad \Rightarrow \quad \ell n\frac{R_2}{R_1} = \alpha(T_2 - T_1)$

$\Rightarrow R_2 = R_1 e^{\alpha(T_2-T_1)} \quad \Rightarrow \quad R_2 = 10e^1$

$\Rightarrow R_2 = 10\ e\ \Omega$ **Ans.**

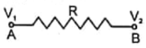
<u>**Electric current in resistance**</u>

In a resistor current flows from high potential to low potential High potential is represented by positive (+) sign and low potential is represented by negative (–) sign.



$V_A - V_B = iR$

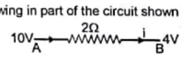
If $V_1 > V_2$ then current will flow from A to B



and $i = \frac{V_1 - V_2}{R}$

If $V_1 < V_2$ then current will go from B to A and $i = \frac{V_2 - V_1}{R}$

Example 8. Calculate current (i) flowing in part of the circuit shown in figure?



Solution : $V_A - V_B = i \times R \quad \Rightarrow \quad i = \frac{6}{2} = 3A$ **Ans.**

8. ELECTRICAL POWER :

Energy liberated per second in a device is called its power. The electrical power P delivered or consumed by an electrical device is given by P = VI, where V = Potential difference across the device and

I = Current.

If the current enters the higher potential point of the device then electric power is consumed by it (i.e. acts as load). If the current enters the lower potential point then the device supplies power (i.e. acts as source).

Solved Examples

Example 2. Find the approximate total distance travelled by an electron in the time-interval in which its displacement is one meter along the wire.

Solution : time = $\frac{\text{displacement}}{\text{drift velocity}} = \frac{S}{V_d}$

$\therefore$ $V_d = 1$ mm/s $= 10^{-3}$ m/s (normally the value of drift velocity is 1 mm/s)

S = 1 m

time = $\frac{1}{10^{-3}} = 10^3$ s

$\therefore$ speed = 10^6 m/s

distance travelled = speed × time

So required distance = $10^6 \times 10^3$ m = 10^9 m

6. RELATION BETWEEN I & V IN A CONDUCTOR

In absence of potential difference across a conductor no net current flows through a cross section. When a potential difference is applied across a conductor the charge carriers (electrons in case of metallic conductors) start drifting in a direction opposite to electric field with average drift velocity. If electrons are moving with velocity v_d. A is area of cross section and n is number of free electrons per unit volume then,

$I = nAev_d \Rightarrow v_d = \frac{\lambda}{\tau}$

$\lambda \rightarrow$ average displacement of electron along the wire between two successive collisions. It is also called **mean free path**.

$\tau \rightarrow$ the time in which the particle does not collide with any other particle and is called as **relaxation time.**

$$\lambda = \frac{1}{2}\left(\frac{eE}{m}\right)\tau^2 = \frac{1}{2}\frac{e\tau^2}{m}E = \frac{1}{2}\frac{e\tau^2}{m} \times \frac{V}{\ell}$$

$$i = nAe \cdot \frac{1}{2}\frac{e\tau^2}{m} \times \frac{V}{\ell} \times \frac{1}{\tau} = \left(\frac{nAe^2\tau}{2m\ell}\right)V \Rightarrow i = \frac{nAe^2\tau}{2m\ell}V$$

As temperature (T) $\uparrow$, $\tau \downarrow$

7. ELECTRICAL RESISTANCE

The property of a substance by virtue of which it opposes the flow of electric current through it is termed as electrical resistance. Electrical resistance depends on the size, geometry, temperature and internal structure of the conductor.

We have $i = \frac{nAe^2\tau}{2m\ell}V$

Here $i \propto V$

it is known as Ohm's law

$i = \frac{V}{R} \Rightarrow R = \frac{2m\ell}{nAe^2\tau} \Rightarrow V = IR$

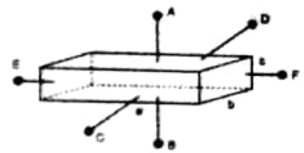
hence $R = \frac{2m\ell}{nAe^2\tau} \cdot \frac{\ell}{A}$ so Here $R = \frac{\rho\ell}{A} \Rightarrow V = I \times \frac{\rho\ell}{A}$

$\Rightarrow \frac{V}{\ell} = \frac{I}{A}\rho \Rightarrow E = J\rho \Rightarrow J = \frac{I}{A}$ = current density

ρ is called resistivity (it is also called specific resistance), and $\rho = \frac{2m}{ne^2\tau} = \frac{1}{\sigma}$, σ is called conductivity. Therefore current in conductors is proportional to potential difference applied across its ends. This is **Ohm's Law**. Units: $R \rightarrow$ ohm(Ω), $\rho \rightarrow$ ohm – meter(Ω – m) also called siemens, $\sigma \rightarrow \Omega^{-1}m^{-1}$

Solved Examples

Example 3. The dimensions of a conductor of specific resistance ρ are shown below. Find the resistance of the conductor across AB, CD and EF.



Answer : $R_{AB} = \frac{\rho c}{ab}$, $R_{CD} = \frac{\rho b}{ac}$, $R_{EF} = \frac{\rho a}{bc}$

Solution : For a condition

$R = \frac{\rho\ell}{A} = \frac{\text{Resistivity} \times \text{length}}{\text{Area of cross section}}$

$R_{AB} = \frac{\rho c}{ab}$, $R_{CD} = \frac{\rho b}{ac}$, $R_{EF} = \frac{\rho a}{bc}$

7.1 Dependence of Resistance on various factors

$$R = \rho\frac{\ell}{A} = \frac{2m}{ne^2\tau} \cdot \frac{\ell}{A}$$

Therefore R depends as

(1) $\propto \ell$ (2) $\propto \frac{1}{A}$ (3) $\propto \frac{1}{n} \propto \frac{1}{\tau}$

(4) and in metals τ decreases as T increases $\Rightarrow$ R also increases.

Results

(a) On stretching a wire (volume constant)

If length of wire is taken into account then $\frac{R_1}{R_2} = \frac{\ell_1^2}{\ell_2^2}$

If radius of cross section is taken into account then, where R_1 and R_2 are initial and final resistances and ℓ_1, ℓ_2 are initial and final lengths and r_1 and r_2 initial and final radii respectively. (If elasticity of the material is taken into consideration, the variation of area of cross-section is calculated with the help of Young's modulus and Poison's ratio)

(b) Effect of percentage change in length of wire

$$\frac{R_2}{R_1} = \frac{\ell^2\left[1 + \frac{x}{100}\right]^2}{\ell^2}$$ where ℓ – original length and x - % increment

if x is quite small (say < 5%) then % change in R is

$$\frac{R_2 - R_1}{R_1} \times 100 = \left(\frac{\left(1 + \frac{x}{100}\right)^2 - 1}{1}\right) \times 100 \cong 2x\%$$

Solved Examples

Example 4. If a wire is stretched to double its length, find the new resistance if original resistance of the wire was R.

Solution : As we know that $R = \frac{\rho\ell}{A}$

in case $R' = \frac{\rho\ell'}{A'}$

$\ell' = 2\ell$ (volume of the wire remains constant)

$A' = \frac{A}{2} \Rightarrow R' = \frac{\rho \times 2\ell}{A/2} = 4\frac{\rho\ell}{A} = 4R$

CURRENT ELECTRICITY

1. ELECTRIC CURRENT

(a) Time rate of flow of charge through a cross sectional area is called current.
if Δq charge flows in time interval Δt then average current is given by

$I_{av} = \frac{\Delta q}{\Delta t}$ and Instantaneous current $i = \lim_{\Delta t \to 0} \frac{\Delta q}{\Delta t} = \frac{dq}{dt}$.

(b) Direction of current is along the direction of flow of positive charge or opposite to the direction of flow of negative charge. But the current is a scalar quantity.

$q\oplus \longrightarrow$ velocity, $\overrightarrow{i}$ $\quad q\ominus \longrightarrow$ velocity, $\overleftarrow{i}$

SI unit of current is ampere and
1 Ampere = 1 coulomb/sec
1 coulomb/sec = 1A

2. CONDUCTOR

In some materials, the outer electrons of each atom or molecule are only weakly bound to it. These electrons are almost free to move throughout the body of the material and are called free electrons. They are also known as conduction electrons. When such a material is placed in an electric field, the free electrons drift in a direction opposite to the field. Such materials are called conductors.

3. INSULATOR

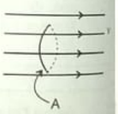
Another class of materials is called insulators in which all the electrons are tightly bound to their respective atoms or molecules. Effectively, there are no free electrons. When such a material is placed in an electric field, the electrons may slightly shift opposite to the field but they can't leave their parent atoms or molecules and hence can't move through long distances. Such materials are also called dielectrics.

4. SEMICONDUCTOR

In semiconductors, the behavior is like an insulator at low levels of temperature. But at higher temperatures, a small number of electrons are able to free themselves and they respond to the applied electric field. As the number of free electrons in a semiconductor is much smaller than that in a conductor, its behavior is in between a conductor and an insulator and hence, the name semiconductor. A free electron in a semiconductor leaves a vacancy in its normal bound position. These vacancies also help in conduction.

Current, velocity and current density

$n \to$ no. of free charge particles per unit volume
$q \to$ charge of each free particle
$i \to$ charge flow per unit time
$i = nqvA$



Current density, a vector, at a point have magnitude equal to current per unit normal area at that point and direction is along the direction of the current at that point

$\vec{j} = \frac{di}{ds}\hat{n}$ so $di = \vec{j}\cdot d\vec{s}$

Current is flux of current density.

Due to principle of conservation of charge :

Charge entering at one end of a conductor = charge leaving at the other end, so current does not change with change in cross section and conductor remains uncharged when current flows through it.

Solved Examples

Example 1. Find free electrons per unit volume in a metallic wire of density 10^4 kg/m^3, atomic mass number 100 and number of free electron per atom is one.

Solution : Number of free charge particle per unit volume

$$(n) = \frac{\text{total free charge particle}}{\text{total volume}}$$

$\therefore$ Number of free electron per atom means total free electrons = total number of atoms.

$$= \frac{N_A}{M_W} \times M$$

$$\text{So } n = \frac{\frac{N_A}{M_W} \times M}{V} = \frac{N_A}{M_W} \times d = \frac{6.023 \times 10^{23} \times 10^4}{100 \times 10^{-3}}$$

$$n = 6.023 \times 10^{28}\ m^{-3}$$

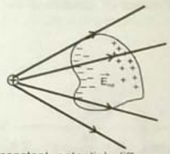
5. MOVEMENT OF ELECTRONS INSIDE CONDUCTOR

All the free electrons are in random motion due to the thermal energy and relationship in given by $\frac{3}{2}KT = \frac{1}{2}mv^2$

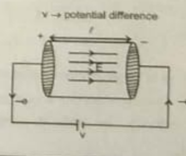
At room temperature its speed is around 10^6 m/sec or 10^3 km/sec

but the average velocity is zero so current in any direction is zero.

When a conductor is placed in an electric field. Then for a small duration electrons, do have an average velocity but its average velocity becomes zero within short interval of time.



When by some means a constant potential difference is applied across the conductor, then the electrons start moving with an acceleration and due to collision with other atoms & electrons, its average velocity becomes nearly constant and is called as drift velocity.



$E = \frac{V}{\ell}$

the electric field between the plate $= E = \frac{V}{\ell}$

V_d = drift velocity = average velocity along the wire
hence $i = nAeV_d$ $\quad V_d$ is of the order 10^{-3} m/s