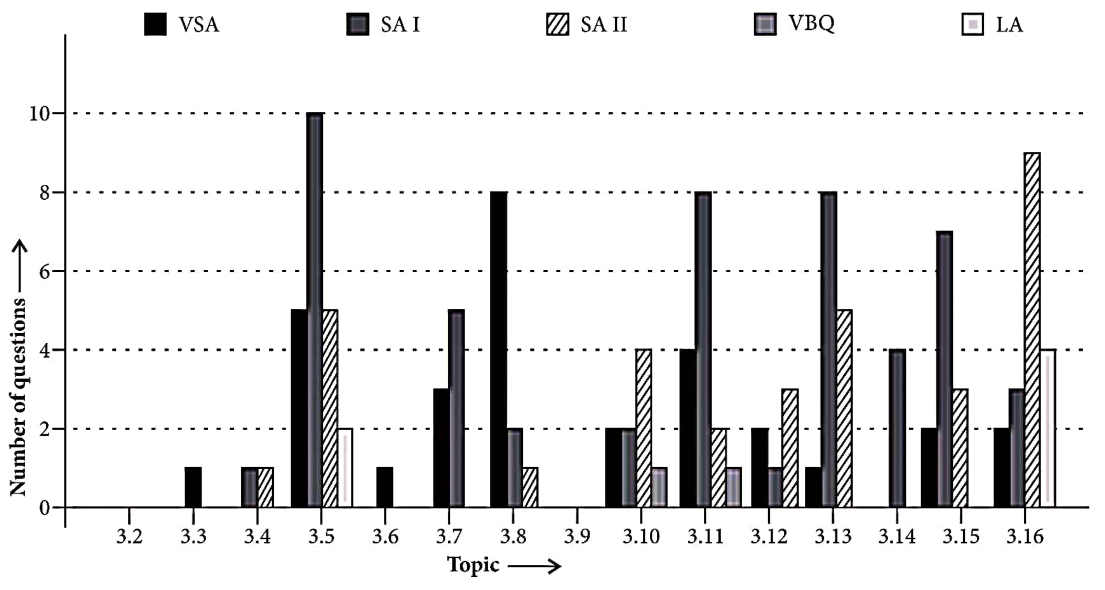
03 Current Electricity

Topicwise Analysis of Last 10 Years' CBSE Board Questions



- Maximum weightage is of *Drift of Electrons and the Origin of Resistivity.*
- Maximum VSA type questions were asked from *Temperature Dependence of Resistivity.*
- Maximum SA II and LA type questions were asked from *Drift of Electrons and the Origin of Resistivity and Potentiometer.*
- No VBQ type questions were asked till now.

QUICK RECAP

- **Electric current :** It is defined as the rate of flow of electric charge through a cross-section of the conductor. $I = \dfrac{dq}{dt}$

If the current is steady *i.e.* it does not change with time, then

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

where q is the charge that flows across the cross-sectional area in time t.

- Current is a scalar quantity. It is not a vector quantity as it does not follow the laws of vector addition.
- SI unit and Dimension :
  - The dimensional formula of current is $[M^0L^0T^0A]$.
  - The SI unit of current is ampere. It is denoted by symbol A. It is also a practical unit of current.

$$1\,A = \frac{1\,C}{1\,s} = 6.25 \times 10^{18} \text{ electrons/s}$$

- Conventionally, the direction of current is taken to be the direction of flow of positive charges. Since electrons are negatively charged, hence their direction will be opposite to that of the conventional current flow.
- If n particles, each having a charge q cross through a given area in time t, then

$$I = \frac{nq}{t}.$$

- The current is the same for all cross-section of a conductor of non-uniform cross-section.
- Current in different situations is due to motion of different charge carriers.
  - Current in conductors and vacuum tubes is due to motion of electrons.
  - In electrolytes due to motion of both positive and negative ions.
  - In semiconductors due to motion of electrons and holes.
  - In discharge tube (containing atomic gases) due to motion of positive ions and negative electrons.

Current density : Current density at a point inside the conductor is defined as the amount of current flowing per unit area around that point of the conductor, provided the area is held in a direction normal to the current. It is denoted by symbol j.

$$j = \frac{I}{A}$$

If area A is not normal to the current but makes an angle θ with the direction of current, then

$$j = \frac{I}{A\cos\theta} \quad \text{or} \quad I = jA\cos\theta = \vec{j}\cdot\vec{A}$$

- Current density is a vector quantity.
- SI unit is A m^{-2}.

  Dimensional formula is $[M^0L^{-2}T^0A]$.

Drift velocity : It is defined as the average velocity with which free electrons get drifted towards the positive end of the conductor under the influence of an external electric field.

- Drift velocity of electrons is given by

$$\vec{v}_d = -\frac{e\vec{E}}{m}\tau$$

where e is the charge on electron, m is the mass of the electron, $\vec{E}$ is the electric field applied and τ is the time of relaxation.

–ve sign shows that drift velocity of electrons is in a direction opposite to that of the external electric field.

- Drift velocity depends on electric field as $v_d \propto E$. So greater the electric field, larger will be the drift velocity.
- Unit of drift velocity is m s^{-1} and its dimensions is $[M^0\,L\,T^{-1}]$.
- Relationship between current and drift velocity $I = nAe\,v_d$ where n is the number density of electrons or number of electrons per unit volume of the conductor and A is the area of cross-section of the conductor.
- Relationship between current density and drift velocity $j = nev_d$ where symbols have their usual meaning.

Mobility : It is defined as the magnitude of drift velocity per unit electric field. It is denoted by symbol μ.

$$\mu = \frac{|v_d|}{E} = \frac{qE\tau/m}{E} = \frac{q\tau}{m}$$

where q, τ and m are charge, relaxation time and mass of a charge carrier respectively.

- The SI unit of mobility is $m^2\,V^{-1}\,s^{-1}$ and its dimensional formula is $[M^{-1}L^0T^2A]$.

Ohm's law : It states that the current (I) flowing through a conductor is directly proportional to the potential difference (V) across the ends of the conductor, provided physical conditions of the conductor such as temperature, mechanical strain etc. are kept constant.

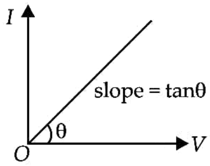
$V \propto I$ or $V = RI$

where the constant of proportionality R is called resistance of the conductor.

- The graph between potential difference (V) and current (I) through a metallic conductor is a straight line passing through the origin as shown in figure.

The reciprocal of slope of line gives resistance.

$$R = \frac{V}{I} = \frac{1}{\tan\theta \text{ (slope of } I\text{-}V)}$$



- The resistance of a conductor is obstruction posed by the conductor to the flow of current through it.
- The SI unit of resistance is ohm (Ω) and its dimensional formula is $[ML^2T^{-3}A^{-2}]$.
- The resistance of a conductor is

$$R = \frac{m}{ne^2\tau}\frac{l}{A} = \rho\frac{l}{A} \text{ where } \rho = \frac{m}{ne^2\tau}$$

where m is the mass of electron, e is charge of electron, n is the number density of electrons, τ is the relaxation time, l is the length of conductor and A is its area of cross section, ρ is the specific resistance or resistivity of the conductor.

- **Resistivity :** The specific resistance offered by the conductor of unit length and unit cross-section area. It is denoted by ρ.
  - The SI unit of resistivity is Ω m and its dimensional formula is $[ML^3T^{-3}A^{-2}]$.
- If the conductor is in the form of wire of length l and a radius r, then its resistance is

$$R = \frac{\rho l}{\pi r^2}$$

- If a conductor has mass m, volume V and density d, then its resistance R is

$$R = \frac{\rho l}{A} = \frac{\rho l^2}{Al} = \frac{\rho l^2}{V} = \frac{\rho l^2 d}{m}$$

- If length of a given metallic wire of resistance R is stretched to n times, its resistance becomes n^2R but its resistivity remains unchanged.
- If radius of the given metallic wire of resistance R becomes n times, its resistance becomes $(1/n^4)R$.
- If the area of cross-section of the given metallic wire of resistance R becomes n times, then its resistance becomes $(1/n^2)R$.
- **Conductivity :** The reciprocal of resistivity is known as conductivity or specific conductance. It is denoted by symbol σ.

$$\sigma = \frac{1}{\rho} = \frac{ne^2\tau}{m} = ne\mu \quad \left[\text{As } \mu = \frac{v_d}{E} = \frac{e\tau}{m}\right]$$

  - The SI unit of conductivity is $\Omega^{-1}m^{-1}$ or S m^{-1} or mho m^{-1} and its dimensional formula is $[M^{-1}L^{-3}T^3A^2]$.

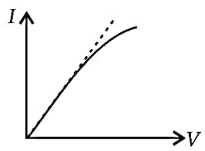
Relationship between j, σ and E

$j = \sigma E$

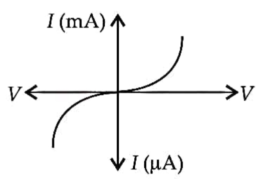
It is a microscopic form of Ohm's law.

Ohmic and non-ohmic conductors

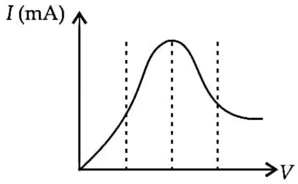
- **Ohmic conductors :** Those conductors which obey Ohm's law are known as ohmic conductors, *e.g.* metals. For ohmic conductors, the graph between current and potential difference is a straight line passing through the origin.
- **Non-ohmic conductors :** Those conductors which do not obey Ohm's law are known as non-ohmic conductors *e.g.* diode valve, junction diode.
- For non-ohmic conductors, the graph between the current (I) and potential difference (V) has one or more of the following characteristics:
  - The relation between V and I is non-linear.



  - The relation between V and I depends on the sign of V.



  - The relation between V and I is not unique, *i.e.*, there is more than one value of V for the same current I.

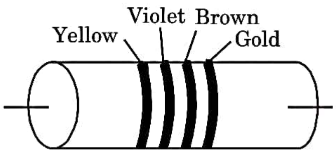


Colour code of carbon resistors : A colour code is used to indicate the resistance value and its percentage accuracy. Every resistor has a set of coloured rings on it. The first two coloured rings from the left end indicate the first two significant figures of the resistance in ohms. The third colour ring indicates the decimal multiplier and the last colour ring stands for the tolerence in percent.

- The colour code of a resistor is as shown in the table.

Colour	Number	Multiplier	Tolerance (%)
Black	0	10^0	
Brown	1	10^1	
Red	2	10^2	
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Gray	8	10^8	
White	9	10^9	
Gold		10^{-1}	5
Silver		10^{-2}	10
No colour			20

- Suppose a resistor has yellow, violet, brown and gold rings as shown in the figure below. The resistance of the resistor is $(47 \times 10\ \Omega) \pm 5\%$.



Effect of temperature on resistance and restistivity

- The resistance of a metallic conductor increases with increase in temperature.
- The resistance of a conductor at temperature t°C is given by

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

where R_t is the resistance at t °C, R_0 is the resistance at 0°C and α is the characteristics constants of the material of the conductor.

  - Over a limited range of temperatures, that is not too large. The resistivity of a metallic conductor is approximately given by $\rho_t = \rho_0(1 + \alpha t)$.

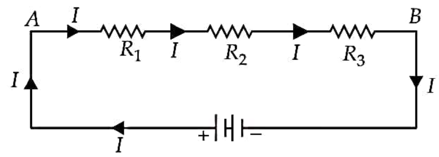
where α is the temperature coefficient of resistivity. Its unit is K^{-1} or °C^{-1}.

  - In the temperature range in which resistivity increases linearly with temperature, the *temperature coefficient of resistivity* α is defined as the fractional increase in resistivity per unit increase in temperature.

- For metals, α is positive *i.e.*, resistance increases with rise in temperature.
- For insulators and semiconductors, α is negative *i.e.*, resistance decreases with rise in temperature.

Resistors in series and parallel

- **Resistors in series :** The various resistors are said to be connected in series if they are connected as shown in the figure.

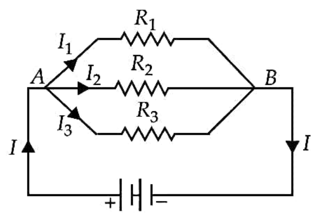


  - The equivalent resistance of the combination of resistors is

$$R_s = R_1 + R_2 + R_3$$

  - The current through each resistor is the same.

- **Resistors in parallel :** The various resistors are said to be connected in parallel if they are connected as shown in figure.



  - The equivalent resistance of the combination of resistors is

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}.$$

- The potential difference is same across each resistor.
- If a wire of resistance R is cut into n equal parts, then resistance of each part = R/n.

Cells, emf, internal resistance

- **Electrochemical cell :** It is a device which, converts chemical energy into electrical energy, maintains the flow of charge in a circuit.
- **Electromotive force (emf) of a cell**
  - It is defined as the potential difference between the two terminals of a cell in an open circuit *i.e.*, when no current flows through the cell. It is denoted by symbol ε.
  - The SI unit of emf is joule/coulomb or volt and its dimensional formula is $[ML^2T^{-3}A^{-1}]$.
  - The emf of a cell depends upon the nature of electrodes, nature and the concentration of electrolyte used in the cell and its temperature.
- **Terminal potential difference :** It is defined as the potential difference between two terminals of a cell in a closed circuit *i.e.*, when current is flowing through the cell.
- **Internal resistance of a cell**
  - It is defined as the resistance offered by the electrolyte and electrodes of a cell when the current flows through it.
  - Internal resistance of a cell depends upon the following factors:

Distance between the electrodes
The nature of the electrolyte
The nature of electrodes
Area of the electrodes, immersed in the electrolyte.

- **Relationship between ε, V and r :** When a cell of emf ε and internal resistance r is connected to an external resistance R as shown in the figure.

The voltage across R is

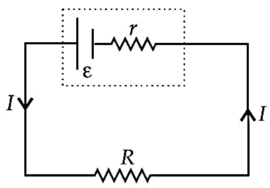
$$V = IR = \frac{\varepsilon}{R+r}R$$

or $\varepsilon = IR + Ir$

or $V = \varepsilon - Ir$

or $\varepsilon = V + Ir$

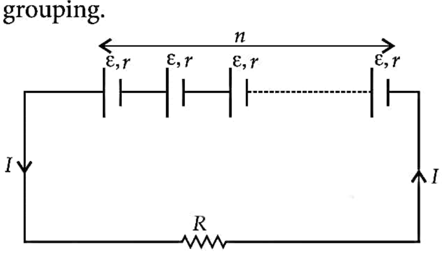
or $r = R\left(\frac{\varepsilon}{V} - 1\right)$



- During discharging of a cell, terminal potential difference = emf of a cell – voltage drop across the internal resistance of a cell. *i.e.*, terminal potential difference across it is less than emf of the cell. The direction of current inside the cell is from negative terminal to positive terminal.
- During charging of a cell, terminal potential difference = emf of a cell + voltage drop across internal resistance of a cell *i.e.*, terminal potential difference becomes greater than the emf of the cell. The direction of current inside the cell is from positive terminal to negative terminal.

Grouping of cells : Cells can be grouped in the following three ways:
Series grouping
Parallel grouping
Mixed grouping

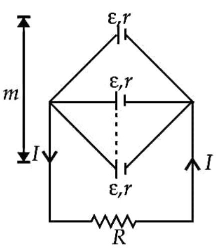
- **Series grouping :** If n identical cells each of emf ε and internal resistance r are connected to the external resistor of resistance R as shown in the figure, they are said to be connected in series grouping.



$\varepsilon_{eq} = n\varepsilon$ and $r_{eq} = nr$

$\therefore$ Current in the circuit, $I = \frac{n\varepsilon}{R+nr}$

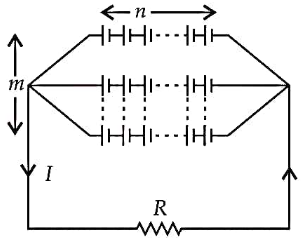
- **Special cases :**
  - If $R << nr$, then $I = \frac{n\varepsilon}{nr} = \frac{\varepsilon}{r}$.
  - If $R >> nr$, then $I = \frac{n\varepsilon}{R}$.
- **Parallel grouping :** If m identical cells each of emf ε and internal resistance r are connected to the external resistor of resistance R as shown in figure, they are said to be connected in parallel grouping.



$\varepsilon_{eq} = \varepsilon$ and $r_{eq} = \frac{r}{m}$.

$\therefore$ The current in the circuit, $I = \frac{\varepsilon}{R + \left(\frac{r}{m}\right)}$.

- **Special cases :**
  - If $\frac{r}{m} << R$, then $I = \frac{\varepsilon}{R}$.
  - If $\frac{r}{m} >> R$, then $I = m\frac{\varepsilon}{r}$.
- **Mixed grouping :** If the cells are connected as shown in figure they are said to be connected in mixed grouping. Let there be n cells in series in one row and m such rows of cells in parallel. Suppose all the cells are identical. Let each cell be of emf ε and internal resistance r.



$\varepsilon_{eq} = n\varepsilon$ and $r_{eq} = \frac{nr}{m}$ $\quad \therefore I = \frac{n\varepsilon}{R + \left(\frac{nr}{m}\right)}$

In case of mixed grouping of cells, current in the circuit will be maximum, when

$$R = \frac{nr}{m}$$

i.e., external resistance = total internal resistance of all cells

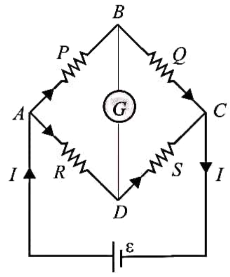
Kirchhoff's laws : Kirchhoff in 1942 put forward the following two laws to solve the complicated circuits. These two laws are stated as follows :

- Kirchhoff's first law or Kirchhoff's junction rule or Kirchhoff's current law : It states that the algebraic sum of the currents meeting at a junction is zero.
  - Kirchhoff's first law supports the law of conservation of charge.
  - According to sign convention the current flowing towards a junction is taken as positive and the current flowing away from the junction is taken as negative.
- Kirchhoff's second law or Kirchhoff's loop law or Kirchhoff's voltage law : It states that in a closed loop, the algebraic sum of the emfs is equal to the algebraic sum of the products of the resistance and the respective currents flowing through them.

$$\sum \varepsilon = \sum IR$$

  - Kirchhoff's second law supports the law of conservation of energy.
  - According to sign convention while traversing a closed loop (in clockwise or anti-clockwise direction), if negative pole of the cell is encountered first then its emf is positive, otherwise negative. The product of resistance and current in an arm of the circuit is taken positive if the direction of current in that arm is in the same sense as one moves in a closed loop and is taken negative if the direction of current in that arm is opposite to the sense as one moves in the closed loop.

Wheatstone's bridge : It is an arrangement of four resistances P, Q, R and S connected as shown in the figure.



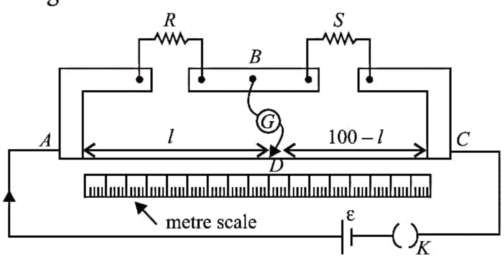
Their values are so adjusted that the galvanometer G shows no deflection. The bridge is then said to be balanced. When this happens, the points B and D are at the same potential and it can be shown that

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

This is called the balancing condition. If any three resistances are known, the fourth can be found.

Metre bridge or slide wire bridge

- It is based on the principle of Wheatstone's bridge.

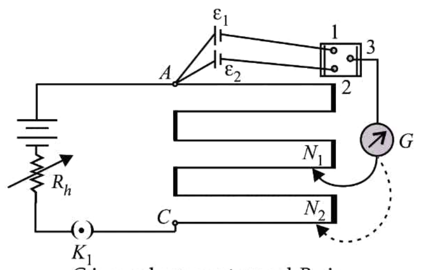


Wire AC is 1 m long. R is a resistance to be measured and S is a standard resistance of known value.

- The unknown resistance, $R = \frac{Sl}{100 - l}$, where l is the balancing length of metre bridge.

Potentiometer

- **Principle of potentiometer :** It is based on the fact that the fall of potential across any portion of the wire is directly proportional to the length of that portion provided the wire is of uniform area of cross-section and a constant current is flowing through it.
  i.e., $V \propto l$ (If I and A are constant)
  or $V = Kl$
  where K is known as potential gradient *i.e.*, fall of potential per unit length of the given wire.
- **Comparison of emfs of two cells by using potentiometer**

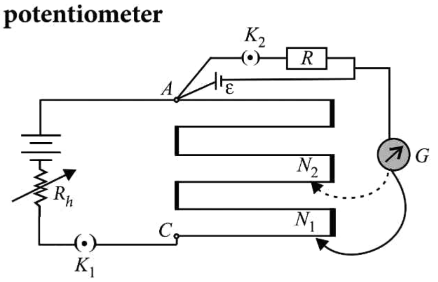


G is a galvanometer and R_h is rheostat. 1, 2, 3, are terminals of a two way key

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{l_1}{l_2}$$

where l_1, l_2 are the balancing lengths of potentiometer wire for the emfs ε_1 and ε_2 of two cells respectively.

- **Determination of internal resistance of a cell by potentiometer**



$$r = \left(\frac{l_1 - l_2}{l_2}\right)R$$

where l_1 = balancing length of potentiometer wire corresponding to emf of the cell, l_2 = balancing length of potentiometer wire corresponding to terminal potential difference of the cell when a resistance R is connected in series with the cell whose internal resistance is to be determined.

Joule's Law of Heating : According to Joule's heating effect of current, the amount of heat produced (H) in a conductor of resistance R, carrying current I for time t is

$H = I^2Rt$ (in joule)

or $H = \frac{I^2Rt}{J}$ (in calorie)

where J is Joule's mechanical equivalent of heat (= 4.2 J/cal).

Electric power : It is defined as the rate at which work is done by the source of emf in maintaining the current in the electric circuit.

Electric power $P = \frac{\text{electric work done}}{\text{time taken}}$

$P = VI = I^2R = \frac{V^2}{R}$.

- SI unit and Dimensions :
  - The SI unit of power is watt (W).
  - The practical unit of power is kilowatt (kW) and horse power (hp).
  - Dimension of power $[ML^2T^{-3}A^2]$
- Power dissipated in connecting wires, which is wasted is P_c given by
  $P_c = I_2R_c = \frac{P^2R_c}{V^2}$
- If P_1, P_2, P_3 .... are the powers of electric appliances in series with source of rated voltage V, the effective power consumed is
  $\frac{1}{P_S} = \frac{1}{P_1} + \frac{1}{P_2} + \frac{1}{P_3} + ...$
- If P_1, P_2, P_3 are the powers of electric appliances in parallel with a source of rated voltage V, the effective power consumed is
  $P_P = P_1 + P_2 + P_3 + ...$

Electric energy : It is defined as the total electric workdone or energy supplied by the source of emf in maintaining the current in an electric circuit for a given time.

Electric energy = electric power × time = $P \times t$.

- The SI unit of electrical energy is joule (J).
- The commercial unit of electric energy is kilowatt-hour (kWh),
  1 kWh = 1000 Wh = 3.6×10^6 J = one unit of electricity consumed.
- The number of units of electricity consumed is n = (total wattage × time in hour)/1000.

Previous Years' CBSE Board Questions

3.3 Electric Currents in Conductors

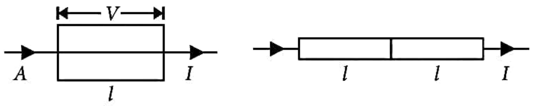
VSA (1 mark)

1. How does the random motion of free electrons in a conductor get affected when a potential difference is applied across its ends ? *(Delhi 2014C)*

3.4 Ohm's Law

SA I (2 marks)

2. A metal rod of square cross-sectional area A having length l has current I flowing through it when a potential difference of V volt is applied across its ends (figure I). Now the rod is cut parallel to its length into two identical pieces and joined as shown in figure II. What potential difference must be maintained across the length of $2l$ so that the current in the rod is still I ?

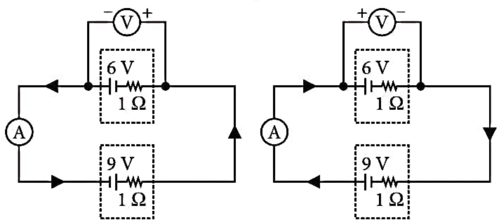


(I) (II)

(Foreign 2016)

SA II (3 marks)

3. In the two electric circuits shown in the figure, determine the readings of ideal ammeter (A) and the ideal voltmeter (V).



(a) (b)

(Delhi 2015C)

3.5 Drift of Electrons and the Origin of Resistivity

VSA (1 mark)

4. Define the term 'electrical conductivity' of a metallic wire. Write its S.I. unit. *(Delhi 2014)*

5. Define the term drift velocity of charge carriers in a conductor and write its relationship with the current flowing through it. *(Delhi 2014)*

6. Write the expression for the drift velocity of charge carriers in a conductor of length 'l' across which a potential difference 'V' is applied. *(AI 2014C)*

7. When electrons drift in a metal from lower to higher potential, does it mean that all the free electrons of the metal are moving in the same direction? *(Delhi 2012)*

8. Two conducting wires X and Y of same diameter but different materials are joined in series across a battery. If the number density of electrons in X is twice that in Y, find the ratio of drift velocity of electrons in the two wires. *(AI 2010)*

SA I (2 marks)

9. Using the concept of drift velocity of charge carriers in a conductor, deduce the relationship between current density and resistivity of the conductor. *(Delhi 2015C)*

10. 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 the density of conduction electrons to be 9×10^{28} m^{-3}. *(AI 2014)*

11. Explain the term 'drift velocity' of electrons in a conductor. Hence obtain the expression for the current through a conductor in terms of 'drift velocity'. *(AI 2013)*

12. Write a relation between current and drift velocity of electrons in a conductor. Use this relation to explain how the resistance of a conductor changes with the rise in temperature. *(Delhi 2013C)*

13. Define mobility of a charge carrier. Write the relation expressing mobility in terms of relaxation time. Give its SI unit. *(AI 2013C)*

14. A conductor of length 'l' is connected to a dc source of potential 'V'. If the length of the conductor is tripled by gradually stretching it keeping 'V' constant, how will (i) drift speed of electrons and (ii) resistance of the conductor be affected. Justify your answer. *(Foreign 2012)*

15. Define drift velocity. Write its relationship with relaxation time in terms of the electric field $\vec{E}$ applied to a conductor.
A potential difference V is applied to a conductor of length l. How is the drift velocity affected when V is doubled and l is halved ? *(Foreign 2010)*

16. Derive an expression for drift velocity of free electrons in a conductor in terms of relaxation time. *(Delhi 2009)*

17. Two metallic wires of the same material have the same length but cross-sectional area is in the ratio 1 : 2. They are connected (i) in series and (ii) in parallel. Compare the drift velocities of electrons in the two wires in both the cases (i) and (ii). *(Delhi 2008)*

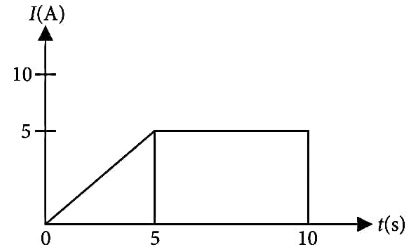
18. Derive an expression for the resistivity of a good conductor, in terms of the relaxation time of electrons. *(AI 2008)*

SA II (3 marks)

19. (a) Find the relation between drift velocity and relaxation time of charge carriers in a conductor.
(b) A conductor of length L is connected to a d.c. source of e.m.f. V. If the length of the conductor is tripled by stretching it, keeping V constant. Explain how drift velocity would be affected. *(AI 2015)*

20. A steady current flows in a metallic conductor of non-uniform cross-section. Which of these quantities is constant along the conductor : current, current density, electric field, drift speed ? *(1/3, Delhi 2015C)*

21. (a) Deduce the relation between current I flowing through a conductor and drift velocity $\vec{v}_d$ of the electrons.
(b) Figure shows a plot of current 'I' flowing through the cross-section of a wire versus the time 't'. Use the plot to find the charge flowing in 10 sec through the wire.



(AI 2015C)

22. Define relaxation time of the free electrons drifting in a conductor. How is it related to the drift velocity of free electrons? Use this relation to deduce the expression for the electrical resistivity of the material. *(AI 2012)*

23. A conductor of length L is connected to a dc source of emf ε. If this conductor is replaced by another conductor of same material and same area of cross-section but of length $3L$, how will the drift velocity change? *(1/3, Delhi 2011)*

LA (5 marks)

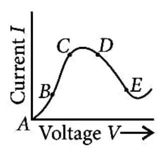
24. Define the term 'drift velocity' of charge carriers in a conductor. Obtain the expression for the current density in terms of relaxation time. *(2/5, Foreign 2014)*

25. (a) Derive the relation between current density '$\vec{j}$' and potential difference 'V' across a current carrying conductor of length 'l', area of cross-section 'A' and the number density 'n' of free electrons.
(b) 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 the number density of conduction electrons is 9×10^{28} m^{-3}.] *(Delhi 2012C)*

3.6 Limitations of Ohm's Law

VSA (1 mark)

26. Graph showing the variation of current versus voltage for a material GaAs is shown in the figure. Identify the region of



(i) negative resistance
(ii) where Ohm's law is obeyed. *(Delhi 2015)*

3.7 Resistivity of Various Materials

VSA (1 mark)

27. Two wires of equal length, one of copper and the other of manganin have the same resistance. Which wire is thicker ? *(AI 2012)*

28. Carbon and silicon both have four valence electrons each. How then are they distinguished ? *(Delhi 2011C)*

29. Define resistivity of a conductor. Write its S.I. unit. *(AI 2011C)*

SA I (2 marks)

30. (a) You are required to select a carbon resistor of resistance 47 kΩ ± 10% from a large collection. What should be the sequence of colour bands used to code it ?
(b) Write the characteristics of manganin which make it suitable for making standard resistance. *(Foreign 2011)*

31. Define ionic mobility. Write its relationship with relaxation time. How does one understand the temperature dependence of resistivity of a semiconductor ? *(Foreign 2010)*

32. The sequence of coloured bands in two carbon resistors R_1 and R_2 is
(i) brown, green, blue
(ii) orange, black, green
Find the ratio of their resistances. *(AI 2010C)*

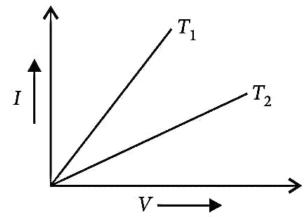
33. A voltage of 30 V is applied across a carbon resistor with first, second and third rings of blue, black and yellow colours respectively. Calculate the value of current, in mA, through the resistor. *(AI 2007)*

34. A cylindrical metallic wire is stretched to increase its length by 5%. Calculate the percentage change in its resistance. *(Delhi 2007)*

3.8 Temperature Dependence of Resistivity

VSA (1 mark)

35. *I-V* graph for a metallic wire at two different temperatures, T_1 and T_2 is as shown in the figure. Which of the two temperatures is lower and why?



(AI 2015)

36. Plot a graph showing the variation of resistivity of a conductor with temperature. *(Foreign 2015)*

37. Show variation of resistivity of copper as a function of temperature in a graph. *(Delhi 2014)*

38. Plot a graph showing variation of current versus voltage for the material GaAs. *(Delhi 2014)*

39. How does one explain increase in resistivity of a metal with increase of temperature ? *(AI 2014C)*

40. Plot a graph showing the variation of resistance of a conducting wire as a function of its radius. Keeping the length of the wire and its temperature as constant. *(Foreign 2013)*

41. Two materials Si and Cu, are cooled from 300 K to 60 K. What will be the effect on their resistivity ? *(Foreign 2013)*

42. Show on a graph, the variation of resistivity with temperature for a typical semiconductor. *(Delhi 2012)*

SA I (2 marks)

43. Draw a graph showing variation of resistivity with temperature for nichrome. Which property of nichrome is used to make standard resistance coils ? *(AI 2013C)*

44. Plot a graph showing temperature dependence of resistivity for a typical semiconductor. How is this behaviour explained ? *(Foreign 2011)*

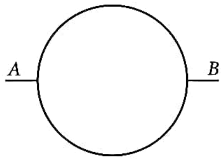
SA II (3 marks)

45. Write the mathematical relation for the resistivity of a material in terms of relaxation time, number density and mass and charge of charge carriers in it. Explain, using this relation, why the resistivity of a metal increases and that of a semiconductor decreases with rise in temperature. *(Delhi 2007)*

3.10 Combination of Resistors- Series and Parallel

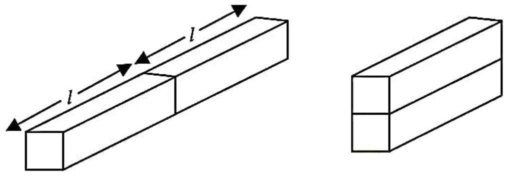
VSA (1 mark)

46. A wire of resistance $8R$ is bent in the form of a circle. What is the effective resistance between the ends of a diameter AB ?



(Delhi 2010)

47. Two identical slabs, of a given metal, are joined together, in two different ways, as shown in figures (i) and (ii). What is the ratio of the resistances of these two combinations ?



(i) (ii)

(Delhi 2010C)

SA I (2 marks)

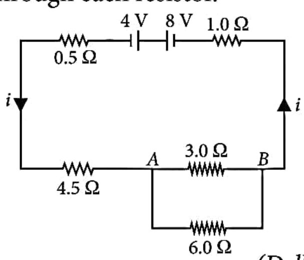
48. Given the resistances of 1 Ω, 2 Ω and 3 Ω how will you combine them to get an equivalent resistance of (i) $\frac{11}{3}$ Ω and (ii) $\frac{11}{5}$ Ω ?

(Foreign 2015)

49. A wire of 15 Ω resistance is gradually stretched to double its original length. It is then cut into two equal parts. These parts are then connected in parallel across a 3.0 volt battery. Find the current drawn from the battery. *(AI 2009)*

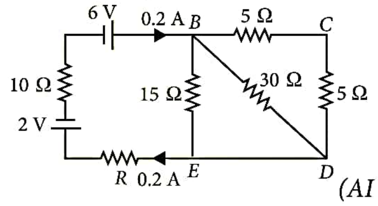
SA II (3 marks)

50. In the circuit shown in the figure, find the current through each resistor.



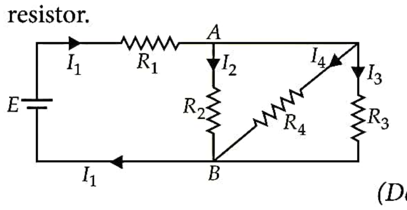
(Delhi 2015C)

51. Calculate the value of the resistance R in the circuit shown in the figure so that the current in the circuit is 0.2 A. What would be the potential difference between points B and E?



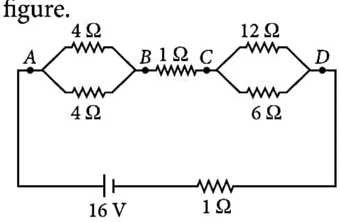
(AI 2012)

52. In the circuit shown, $R_1 = 4$ Ω, $R_2 = R_3 = 15$ Ω, $R_4 = 30$ Ω and $E = 10$ V. Calculate the equivalent resistance of the circuit and the current in each resistor.



(Delhi 2011)

53. A network of resistors is connected to a 16 V battery of internal resistance of 1 Ω as shown in the figure.



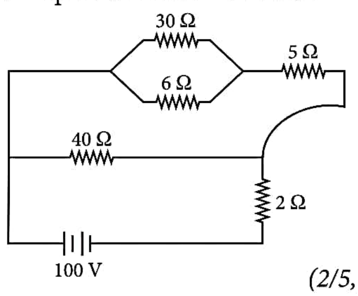
(a) Compute the equivalent resistance of the network.

(b) Obtain the voltage drops V_{AB} and V_{CD}.

(Foreign 2010)

LA (5 marks)

54. A 100 V battery is connected to the electric network as shown. If the power consumed in the 2 Ω resistor is 200 W, determine the power dissipated in the 5 Ω resistor.

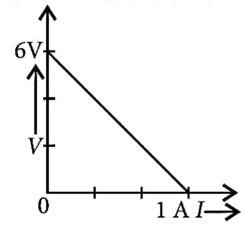


(2/5, Foreign 2014)

3.11 Cells, emf, Internal Resistance

VSA (1 mark)

55. The plot of the variation of potential difference across a combination of three identical cells in series versus current is shown below. What is the emf and internal resistance of each cell?

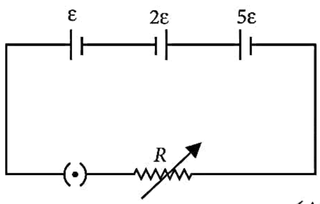


(AI 2016, Delhi 2008)

56. The emf of a cell is always greater than its terminal voltage. Why? Give reason. (Delhi 2013)

57. Why is the terminal voltage of a cell less than its emf ? (AI 2013C)

58. Three cells of emf ε, 2ε and 5ε having internal resistances r, $2r$ and $3r$ respectively are connected across a variable resistance R as shown in the figure. Find the expression for the current. Plot a graph for variation of current with R.



(AI 2010C)

SA I (2 marks)

59. A cell of emf 'E' and internal resistance 'r' is connected across a variable resistor 'R'. Plot a graph showing variation of terminal voltage 'V' of the cell versus the current 'I'. Using the plot, show how the emf of the cell and its internal resistance can be determined. (AI 2014)

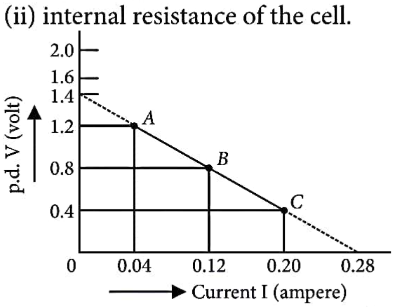
60. (a) Distinguish between emf (ε) and terminal voltage (V) of a cell having internal resistance 'r'.
(b) Draw a plot showing the variation of terminal voltage (V) vs the current (I) drawn from the cell. Using this plot, how does one determine the internal resistance of the cell ? (AI 2014C)

61. A battery of emf E and internal resistance r when connected across an external resistance of 12 Ω, produces a current of 0.5 A. When connected across a resistance of 25 Ω, it produces a current of 0.25 A. Determine (i) the emf and (ii) the internal resistance of the cell. (AI 2013C)

62. A cell of emf E and internal resistance r is connected to two external resistances R_1 and R_2 and a perfect ammeter. The current in the circuit is measured in four different situations :
(i) without any external resistance in the circuit
(ii) with resistance R_1 only
(iii) with R_1 and R_2 in series combination
(iv) with R_1 and R_2 in parallel combination
The currents measured in the four cases are 0.42 A, 1.05 A, 1.4 A and 4.2 A, but not necessarily in that order. Identify the currents corresponding to the four cases mentioned above. (Delhi 2012)

63. A battery of emf 10 V and internal resistance 3 Ω is connected to a resistor. If the current in the circuit is 0.5 A, find
(i) The resistance of the resistor;
(ii) The terminal voltage of the battery (Delhi 2012C)

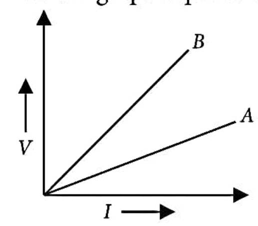
64. A straight line plot showing the terminal potential difference (V) of a cell as a function of current (I) drawn from it is shown in the figure. Using this plot, determine (i) the emf and (ii) internal resistance of the cell.



(Delhi 2011C)

65. A cell of emf 'E' and internal resistance 'r' is connected across a variable resistor 'R'. Plot a graph showing the variation of terminal potential 'V' with resistance R.
Predict from the graph the condition under which 'V' becomes equal to 'E'. (Delhi 2009)

66. *V-I* graphs for parallel and series combination of two metallic resistors are shown below. Which graph represents parallel combination ?

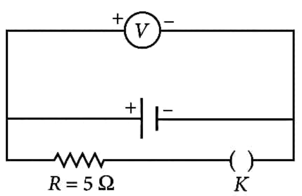


(Delhi 2009)

SA II (3 marks)

67. A cell of emf 'E' and internal resistance 'r' is connected across a variable load resistor R. Draw the plots of the terminal voltage V versus (i) R and (ii) the current I.
It is found that when $R = 4\ \Omega$, the current is 1 A and when R is increased to 9 Ω, the current reduces to 0.5 A. Find the values of the emf E and internal resistance r. *(Delhi 2015)*

68. Write any two factors on which internal resistance of a cell depends. The reading on a high resistance voltmeter, when a cell is connected across it, is 2.2 V. When the terminals of the cell are also connected to a resistance of 5 Ω as shown in the circuit, the voltmeter reading drops to 1.8 V. Find the internal resistance of the cell.



(AI 2010)

LA (5 marks)

69. A cell, with a finite internal resistance r, is connected across two external resistances R_1 and R_2 ($R_1 > R_2$), one by one. In which case would the terminal potential difference of the cell be more ? *(2/5, Delhi 2010C)*

3.12 Cells in Series and in Parallel

VSA (1 mark)

70. Two identical cells, each of emf E, having negligible internal resistance, are connected in parallel with each other across an external resistance R. What is the current through this resistance? *(AI 2013)*

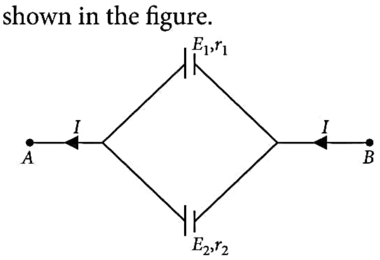
71. Two cells, of emf 2ε and ε, and internal resistance $2r$ and r respectively, are connected in parallel. Obtain the expression for the equivalent emf and the internal resistance of the combination. *(AI 2010C)*

SA I (2 marks)

72. Two cells of emfs 1.5 V and 2.0 V having internal resistances 0.2 Ω and 0.3 Ω respectively are connected in parallel. Calculate the emf and internal resistance of the equivalent cell. *(Delhi 2016)*

SA II (3 marks)

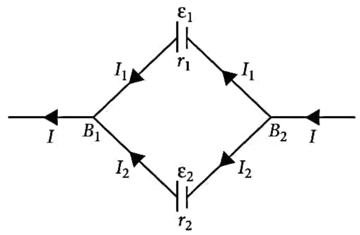
73. Two cells of emf E_1, E_2 and internal resistance r_1 and r_2 respectively are connected in parallel as shown in the figure.



Deduct the expression for
(i) The equivalent emf of the combination
(ii) The equivalent resistance of the combination
(iii) The potential difference between the points A and B. *(Foreign 2012)*

74. Two cells of emfs E_1 and E_2 and internal resistance r_1 and r_2 are connected in parallel. Obtain the expression for the emf and internal resistance of a single equivalent cell that can replace this combination ? *(2/5, Foreign 2016)*

75. Two cells of emf ε_1 and ε_2 having internal resistances r_1 and r_2 respectively are connected in parallel as shown. Deduce the expressions of the equivalent emf a cell which can replace the combination between the points B_1 and B_2.

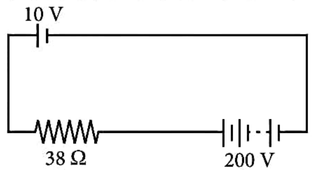


(AI 2011C)

3.13 Kirchhoff's Laws

VSA (1 mark)

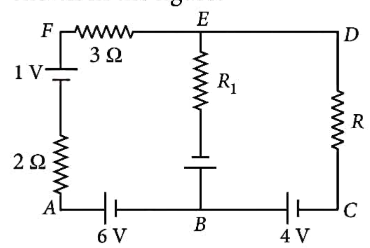
76. A 10 V battery of negligible internal resistance is connected across a 200 V battery and a resistance of 38 Ω as shown in the figure. Find the value of the current in circuit.



(Delhi 2013)

SA I (2 marks)

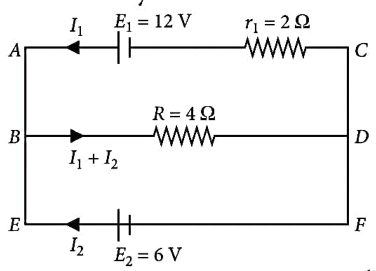
77. Use Kirchhoff's rules to determine the potential difference between the points *A* and *D* when no current flows in the *BE* of the electric network shown in the figure.



(AI 2015)

78. State Kirchhoff's rules. Explains briefly how these rules are justified. *(Delhi 2014)*

79. In the electric network shown in the figure, use Kirchhoff's rules to calculate the power consumed by the resistance $R = 4\ \Omega$.



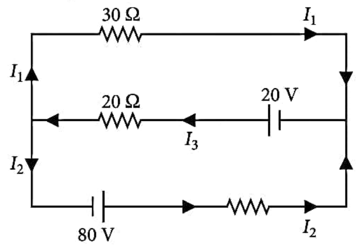
(Delhi 2014C)

80. An ammeter of resistance 0.80 Ω can measure current up to 1.0 A.

(i) What must be the value of shunt resistance to enable the ammeter to measure current up to 5.0 A?

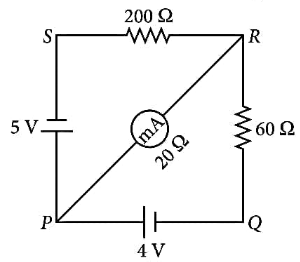
(ii) What is the combined resistance of the ammeter and the shunt? *(Delhi 2013)*

81. Use Kirchhoff's rules to determine the value of the current I_1 flowing in the circuit shown in the figure.



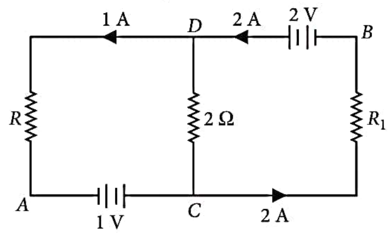
(Delhi 2013C)

82. The network *PQRS*, shown in the circuit diagram, has the batteries of 4 V and 5 V and negligible internal resistance. A milliammeter of 20 Ω resistance is connected between *P* and *R*. Calculate the reading in the milliammeter.



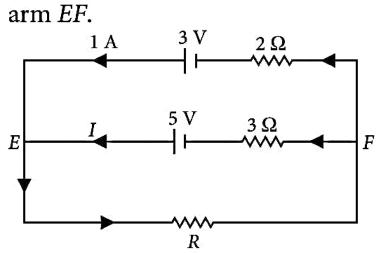
(AI 2012C)

83. In the given circuit, assuming point *A* to be at zero potential, use Kirchhoff's rules to determine the potential at point *B*.



(AI 2011)

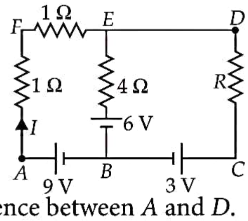
84. Using Kirchhoff's rules in the given circuit, determine (i) the voltage drop across the unknown resistor *R* and (ii) the current *I* in the arm *EF*.



(AI 2011C)

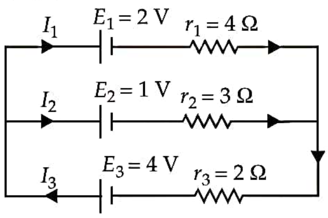
SA II (3 marks)

85. Using Kirchhoff's rulesdetermine the value of unknown resistance R in the circuit so that no current flows through 4 Ω resistance. Also find the potential difference between A and D.



(Delhi 2012)

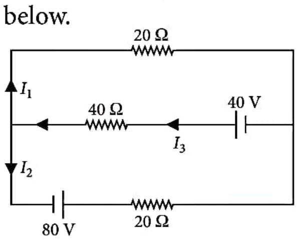
86. (a) State Kirchhoff's rules.
(b) Use these rules to write the expressions for the currents I_1, I_2 and I_3 in the circuit diagram shown.



(AI 2010)

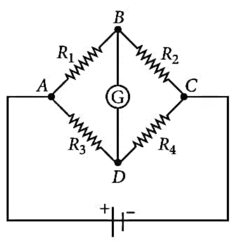
87. (a) State Kirchhoff's rules.
(b) A battery of 10 V and negligible internal resistance is connected across the diagonally opposite corners of a cubical network consisting of 12 resistors each of 1 Ω resistance. Use Kirchhoff's rules to determine (i) the equivalent resistance of the network, and (ii) the total current in the network. *(AI 2010C)*

88. (a) State Kirchhoff's rules of current distribution in an electrical network.
(b) Using these rules determine the value of the current I_1 in the electric circuit given below.



(Delhi 2007)

89. The given figure shows a network of resistances R_1, R_2, R_3 and R_4.
Using Kirchhoff's laws, establish the balance condition for the network.



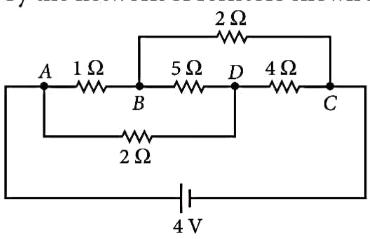
(AI 2007)

3.14 Wheatstone Bridge

SA I (2 marks)

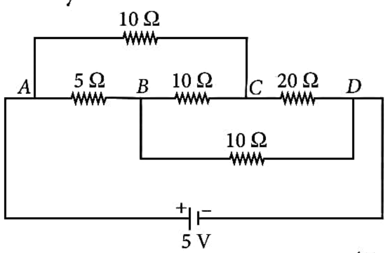
90. Use Kirchhoff's rules to obtain conditions for the balance condition in a Wheatstone bridge. *(Delhi 2015)*

91. Calculate the current drawn from the battery by the network of resistors shown in the figure.



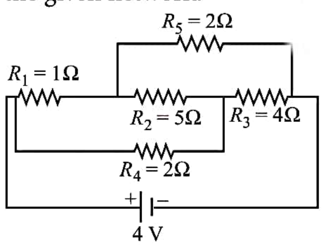
(AI 2015C)

92. Calculate the value of current drawn form a 5 V battery in the circuit as shown.



(Foreign 2013)

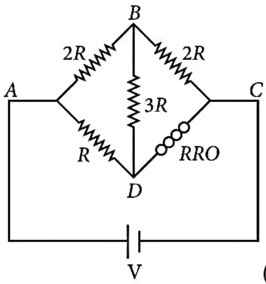
93. Calculate the current drawn from the battery in the given network.



(AI 2009)

LA (5 marks)

94. Use Krichhoff's rules to obtain the balance condition in a Wheatstone bridge.
Calculate the value of R in the balance conditionof the Wheatstone bridge, if the carbon resistor connected across the arm CD has the colour sequence red, red and orange, as is shown in the figure.
If now the resistances of the arms BC and CD are interchanged, to obtain the balance condition, another carbon resistor is connected in place of R. What would now be the sequence of colour bands of the carbon resistor ?



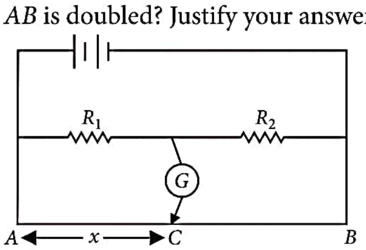
(Delhi 2012C)

95. (a) State Kirchhoff's rules for an electric network.
(b) Using Kirchhoff's rules, obtain the balance condition in terms of the resistances of four arms of Wheatstone bridge.
(3/5, Delhi 2013, 2010C)

3.15 Meter Bridge

VSA (1 mark)

96. In an experiment on meter bridge, if the balancing length AC is 'x', what would be its value, when the radius of the meter bridge wire AB is doubled? Justify your answer.



(AI 2011C)

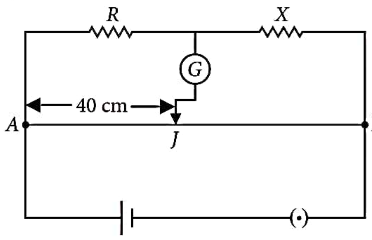
97. In a meter bridge, two unknown resistances R and S when connected in the two gaps, give a null point at 40 cm from one end. What is the ratio of R and S? *(Delhi 2010C)*

SA II (3 marks)

98. With the help of the circuit diagram, explain the working principle of meter bridge. How is it used to determine the unknown resistance of a given wire ? Write the necessary precautions to minimize to error in the result. *(AI 2015C)*

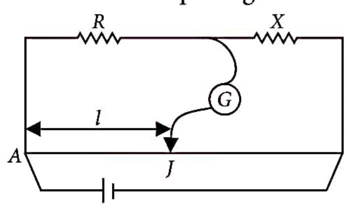
99. Answer the following :
(a) Why are the connections between the resistors in a meter bridge made of thick copper strips?
(b) Why is it generally preferred to obtain the balance point in the middle of the metre bridge wire?
(c) Which material is used for the meter bridge wire and why? *(AI 2014)*

100. Write the principle on which the working of a meter bridge is based. In an experiment of meter bridge, a student obtains the balance point at the point J such that AJ = 40 cm as shown in the figure. The values of 'R' and 'X' are both doubled and then interchanged. Find the new position of the balance point. If the galvanometer and battery are also interchanged, how will the position of balance point be affected ?



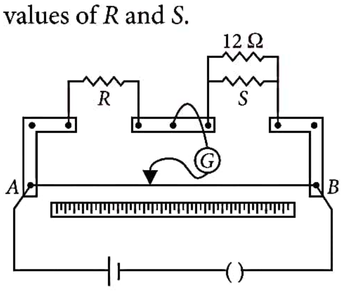
(AI 2012C)

101. In the meter bridge experiment, balance point was observed at J with $AJ = l$.
(i) The value of R and X were doubled and then interchanged. What would be the new position of balance point ?
(ii) If the galvanometer and battery are interchanged at the balance position, how will the balance point get affected ?



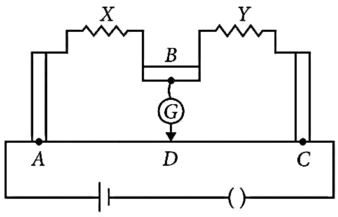
(AI 2011)

102. In a meter bridge, the null points is found at a distance of 40 cm from A. If a resistance of 12 Ω is connected in parallel with S, the null point occurs at 50.0 cm from A. Determine the values of R and S.



(Delhi 2010)

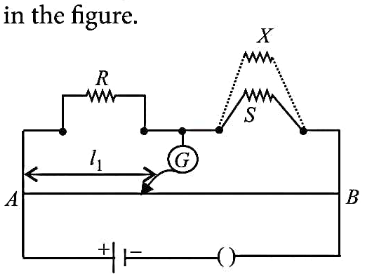
103.



The figure shows experimental set up of a meter bridge. When the two unknown resistances X and Y are inserted, the null point D is obtained 40 cm from the end A. When a resistance of 10 Ω is connected in series with X, the null point shifts by 10 cm. Find the position of the null point when the 10 Ω resistance is connected in series with resistance 'Y'. Determine the values of the resistance X and Y. *(Delhi 2009)*

104. (i) State the principle of working of a meter bridge.

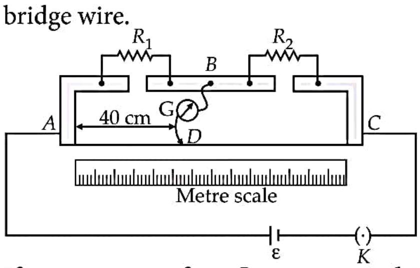
(ii) In a meter bridge balance point is found at a distance l_1 with resistances R and S as shown in the figure.



When an unknown resistance X is connected in parallel with the resistance S, the balance point shifts to a distance l_2. Find the expression for X in terms of l_1, l_2 and S. *(AI 2009)*

LA (5 marks)

105. In the meter bridge experimental set up, shown in the figure, the null point 'D' is obtained at a distance of 40 cm from end A of the meter bridge wire.



If a resistance of 10 Ω is connected in series with R_1, null point is obtained at AD = 60 cm. Calculate the values of R_1 and R_2.

(2/5, Delhi 2013)

106. (a) State, with the help of a circuit diagram, the working principle of a meter bridge. Obtain the expression used for determining the unknown resistance.

(b) What happens if the galvanometer and cell are interchanged at the balance point of the bridge ?

(c) Why is it considered important to obtain the balance point near the mid-point of the wire ? *(Delhi 2011C)*

107. Draw a circuit diagram for determining the unknown resistance R using meter bridge. Explain briefly its working giving the necessary formula used. *(2/5, Delhi 2010C)*

3.16 Potentiometer

VSA (1 mark)

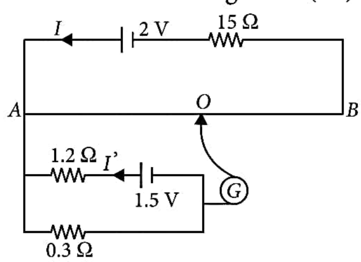
108. State the underlying principle of a potentiometer. *(Delhi 2014C)*

109. A resistance R is connected across a cell of emf ε and internal resistance r. A potentiometer now measures the potential difference between the terminals of the cell as V. Write the expression for r in terms of ε, V and R. *(Delhi 2011)*

SA I (2 marks)

110. (i) State the principle of working of a potentiometer.

(ii) In the following potentiometer circuit AB is a uniform wire of length 1 m and resistance 10 Ω. Calculate the potential gradient along the wire and balance length AO (= l).

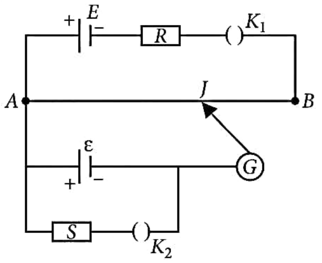


(Delhi 2016)

111. Describe briefly, with the help of a circuit diagram, how a potentiometer is used to determine the internal resistance of a cell.

(AI 2013)

112. Two students '*X*' and '*Y*' preform an experiment on potentiometer separately using the circuit given : Keeping other parameters unchanged, how will the position of the null point be affected if



(i) '*X*' increases the value of resistance *R* in the set-up by keeping the key K_1 closed and the key K_2 open ?

(ii) '*Y*' decreases the value of resistance *S* in the set-up, while the key K_2 remains open and the key K_1 closed ? *(Foreign 2012)*

SA II (3 marks)

113. Draw a circuit diagram of a potentiometer. State its working principle. Drive the necessary formula to describe how it is used to compare the emfs of the two cells. *(2012C)*

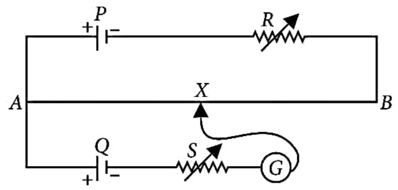
114. A potentiometer wire of length 1 m has a resistance of 10 Ω. It is connected to a 6 V battery in series with a resistance of 5 Ω. Determine the emf of the primary cell which gives a balance point at 40 cm. *(Delhi 2014)*

115. A potentiometer wire of length 1.0 m has a resistance of 15 Ω. It is connected to a 5 V battery in series with a resistance of 5 Ω. Determine the emf of the primary cell which gives a balance point at 60 cm. *(Delhi 2014)*

116. (a) State the underlying principle of a potentiometer. Why is it necessary to (i) use a long wire, (ii) have uniform area of cross-section of the wire and (iii) use a driving cell whose emf is taken to be greater than the emfs of the primary cells ?

(b) In a potentiometer experiment, if the area of the cross-section of the wire increases uniformly from one end to the other, draw a graph showing how potential gradient would vary as the length of the wire increases from one end. *(AI 2014C)*

117. State the underlying principle of a potentiometer. Write two factors on which the sensitivity of a potentiometer depends.

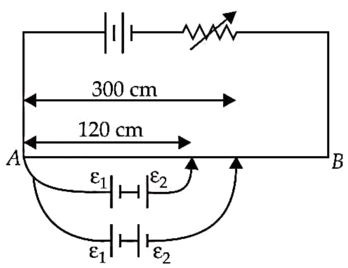


In the potentiometer circuit shown in the figure, the balance point is at *X*. State, giving reason, how the balance point is shifted when

(i) Resistance *R* is increased ?

(ii) Resistance *S* is increased, keeping *R* constant ? *(2/3, Delhi 2013C)*

118. In the figure a long uniform potentiometer wire *AB* is having a constant potential gradient along its length. The null points for the two primary cells of emfs ε_1 and ε_2 connected in the manner shown are obtained at a distance of 120 cm and 300 cm from the end *A*. Find (i) $\varepsilon_1/\varepsilon_2$ and (ii) position of null point for the cell ε_1. How is the sensitivity of a potentiometer increased?

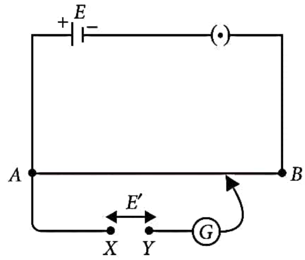


119. (a) State the underlying principal of potentiometer.

(b) Describe briefly, giving the necessary circuit diagram, how a potentiometer is used to measure the internal resistance of a given cell. *(Foreign 2011)*

120. Write the principle of working of a potentiometer. Describe briefly, with the help of a circuit diagram, how a potentiometer is used to determine the internal resistance of a given cell. *(Delhi 2010)*

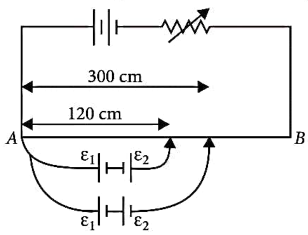
121. For the potentiometer circuit shown in the given figure, points *X* and *Y* represent the two terminals of an unknown emf *E*′. A student observed that when the jockey is moved form the end A to the end B of the potentiometer wire, the deflection in the galvanometer remains in the same direction. What may be the two possible faults in the circuit that could result in this observation ?



If the galvanometer deflection at the end B is (i) more, (ii) less, than that at the end A, which of the two faults, listed above, would be there in the circuit ?
Give reasons in support of your answer in each case. *(AI 2007)*

LA (5 marks)

122. (a) State the principle of a potentiometer. Define potential gradient. Obtain an expression of potential gradient in terms of resistivity of the potentiometer wire.
(b) Figure shows a long potentiometer wire AB having a constant potential gradient. The null points for the two primary cells of emfs ε_1 and ε_2 connected in the manner shown are obtained at a distance of l_1 = 120 cm and l_2 = 300 cm from the end A. Determine (i) $\varepsilon_1/\varepsilon_2$ and (ii) position of null point for the cell ε_1 only.



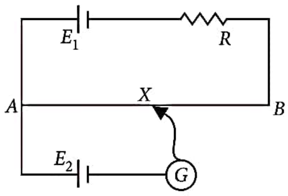
(Foreign 2014)

123. (a) State the working principle of a potentiometer. With the help of the circuit diagram, explain how a potentiometer is used to compare the emf's of two primary cells. Obtain the required expression used for comparing the emfs.
(b) Write two possible causes for one sided deflection in a potentiometer experiment. *(Delhi 2013)*

124. (a) State the working principle of a potentiometer. Draw a circuit diagram to compare emf of two primary cells. Drive the formula used.
(b) Which material is used for potentiometer wire and why ?
(c) How can the sensitivity of a potentiometer be increased ? *(Delhi 2011C)*

125. (a) Write the underlying principle of a potentiometer.
(b) Draw the circuit diagram of the experimental set-up used for determining the internal resistance of a cell by potentiometer. Write the necessary formula used. *(3/5, Delhi 2010C)*

126. (i) In the circuit diagram given below, AB is a uniform wire of resistance 15 Ω and length 1 m. It is connected to a cell E_1 of emf 2V and negligible internal resistance and a resistance R. The balance point with another cell E_2 of emf 75 mV is found at 30 cm from end A. Calculate the value of R.



(ii) Why is potentiometer preferred over a voltmeter for comparison of emf of cells ?
(iii) Draw a circuit diagram to determine internal resistance of a cell in the laboratory. *(Foreign 2016)*

Detailed Solutions

1. Conductors contain free electrons. In the absence of any external electric field, the free electrons are in random motion just like the molecules of gas in a container and the net current through wire is zero. If the ends of the wire are connected to a battery, an electric field (E) will setup at every point within the wire. Due to electric effect of the battery, the electrons will experience a force in the direction opposite to E.

2. From Ohm's law, we have
$V = IR$

$$\Rightarrow \quad V = I\rho\frac{l}{A} \qquad ...(i)$$

When the rod is cut parallel, and rejoined by length, the length of the conductor becomes $2l$, whereas the area decrease to $\frac{A}{2}$. If the current remains the same the potential changes as

$$V = I\rho\frac{2l}{A/2} = 4\times I\rho\frac{l}{A} = 4V \quad \text{[Using (i)]}$$

The new potential applied across the metal rod will be four times the original potential (V).

3. In First Circuit
Reading of ideal voltmeter = 6 V
Net potential difference = 9 + 6 = 15 V
Total resistance = 1 + 1 = 2 Ω

Current in ammeter $= \frac{V}{R} = \frac{15}{2} = 7.5$ A

In Second Circuit
Reading of ideal volt meter = 6 V
Net potential difference = 9 – 6 = 3 V
Total resistance = 1 + 1 = 2 Ω

Current in ammeter $= \frac{V}{R} = \frac{3}{2} = 1.5$ A

4. The electrical conductivity of a metallic wire is defined as the ratio of the current density to the electric field it creates.
It is reciprocal of resistivity (ρ).

Electrical conductivity, $(\sigma) = \frac{1}{\rho} = \frac{j}{E}$

S.I. unit = mho m^{-1} or (ohm m)$^{-1}$ or S m^{-1}

5. When an electric field is applied across a conductor then the charge carriers inside the conductor move with an average velocity which is independent of time. This velocity is known as drift velocity (v_d).

Relationship between current (I) and drift velocity (v_d)
$I = neAv_d$
where ne = amount of charge inside the conductor
A = area of cross-section of conductor

6. $\because \quad I = neAv_d$

$$\therefore \quad v_d = \frac{V}{ne\rho l} \quad \left\{\text{Using } A = \frac{\rho l}{R}\right\}$$

7. Yes, all the electrons will move in same direction during drift due to external electric field.

8. Since the wires are connected in series, current I through both is same. Therefore ratio of drift velocities

$$\frac{v_X}{v_Y} = \frac{I/n_XeA_X}{I/n_YeA_Y}$$

where, n_X, n_Y = respective electron densities
A_X, A_Y = cross-sectional areas

$$\Rightarrow \quad \frac{v_X}{v_Y} = \frac{n_Y}{n_X} = \frac{1}{2} \quad (\text{Given } A_X = A_Y,\ n_X = 2n_Y)$$

$$\Rightarrow \quad v_X : v_Y = 1 : 2$$

9. As we know that
$I = neAv_d$

Also current density j is given by $j = \frac{I}{A}$

$$\therefore \quad |\vec{j}| = \frac{ne^2}{m}\tau|\vec{E}| \qquad \left(\because v_d = \frac{e\tau E}{m}\right)$$

$\because \quad \vec{j}$ is parallel to $\vec{E}$,

$$\therefore \quad \vec{j} = \frac{ne^2}{m}\tau\vec{E}$$

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

$$\therefore \quad \vec{j} = \frac{\vec{E}}{\rho}$$

10. $I = neAv_d$

$$v_d = \frac{I}{neA} = \frac{1.5}{9\times10^{28}\times1.6\times10^{-19}\times1.0\times10^{-7}} \text{ m s}^{-1}$$

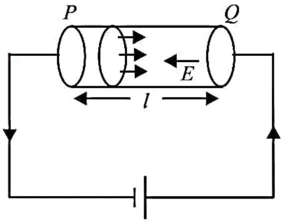
$= 1.042 \times 10^{-3}$ m $s^{-1} \approx 1$ mm s^{-1}

11. *Refer to answer 5.*

Total number of free electrons in a conductor PQ of length l, cross-sectional area A having n free electrons per unit volume is

$N = n \times$ volume of conductor PQ

or $N = nAl$



Time 't' in which an electron moves from P to Q, all N free electrons pass through cross section Q.

$$t = \frac{l}{v_d}$$

where v_d is the drift velocity of electrons in the conductor.

So electric current flowing through conductor is given by

$$I = \frac{q}{t} = \frac{Ne}{t} = \frac{nAle}{l/v_d} \text{ or } I = neAv_d$$

This gives the relation between electric current and drift velocity.

12. Drift velocity $v_d = \frac{e\vec{E}}{m}\tau$, where E is electric field strength. And the relation between current and drift velocity is $I = neAv_d$.

$$\therefore \quad \frac{I}{A} = \frac{ne^2\tau}{m}E \Rightarrow j = \sigma AE$$

$$\sigma = \frac{ne^2\tau}{m} = \frac{1}{\rho} \quad \text{or,} \quad \rho = \frac{m}{ne^2\tau}$$

With rise of temperature, the rate of collision of electrons with ions of lattice increases, so relaxation time decreases. As a result resistivity of the material increases with the rise of temperature, hence the resistance.

13. Mobility of a charge carrier is defined as t[illegible]ft velocity of the charge carrier per unit electric[illegible]

It is generally denote by μ.

$$\mu = \frac{v_d}{E}$$

The SI. unit of mobility is $m^2 V^{-1} s^{-1}$.

Mobility in term of relaxation time :

$$\vec{v}_d = \frac{-e\vec{E}}{m}\tau$$

In magnitude,

$$v_d = \frac{eE}{m}\tau \text{ or } \frac{v_d}{E} = \frac{e\tau}{m}$$

$$\mu = \frac{e\tau}{m}$$

14. (i) We know that $v_d = \frac{eV\tau}{ml} \Rightarrow v_d \propto \frac{1}{l}$

When length is tripled, the drift velocity becomes one-third.

(ii) $R = \rho\frac{l}{A} = \rho\frac{l \times l}{A \times L} = \rho\frac{l^2}{V}$, $l' = 3l$

New resistance

$$R' = \rho\frac{l'}{V'} = \rho \times \frac{(3l)^2}{V} = 9R$$

$R' = 9R$

Hence, the new resistance will be 9 times the original.

15. Drift velocity is defined as the average velocity with which the free electrons get drifted towards the positive end of the conductor under the influence of an external electric field applied. It is given by

$$\vec{v}_d = \frac{e\vec{E}}{m}\tau; v_d = \frac{eV}{ml}\tau$$

where m = mass of electron, e = charge of electron

E = electric field applied

If $V' = 2V$ and $l' = 2l$, then

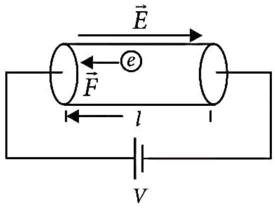
$$v_d' = \frac{e(2V)}{m \times l/2} = \frac{4eV}{ml} = 4v_d$$

Becomes 4 times.

16. Expression for drift velocity :

Let V be the potential difference applied across the ends of the conductor of length l, then magnitude of electric field E is

$\vec{F} = -e\vec{E}$



If m be the mass of an electron, the acceleration of each electron is

$\vec{a} = \frac{-e\vec{E}}{m}$ $[\because F = m\vec{a}]$

Due to this acceleration, the free electron apart from this thermal velocity, acquires additional velocity component in a direction opposite to the direction of electric field. At any instant of time, the velocity acquired by electron having thermal velocity $\vec{u}_1$ is

$\vec{v}_1 = \vec{u}_1 + \vec{a}\tau_1$

where τ_1 is the time elapsed. Similarly, the velocities acquired by other electrons in the conductor is

$\vec{v}_2 = \vec{u}_2 + \vec{a}\tau_2$ and so on

$\therefore \quad \vec{v}_n = \vec{u}_n + \vec{a}\tau_n$

The average velocity of all the free electrons in the conductor is the drift velocity $\vec{v}_d$ of free electrons.

$$\therefore \quad \vec{v}_d = \frac{\vec{v}_1 + \vec{v}_2 + \text{.........} + \vec{v}_n}{n}$$

$$= \frac{(\vec{u}_1 + \vec{a}\tau_1) + (\vec{u}_2 + \vec{a}\tau_2) + \text{.........} + (\vec{u}_n + \vec{a}\tau_n)}{n}$$

$$= \left(\frac{\vec{u}_1 + \vec{u}_2 + \text{.....} + \vec{u}_n}{n}\right) + \vec{a}\left(\frac{\tau_1 + \tau_2 + \text{........} + \tau_n}{n}\right)$$

$= 0 + \vec{a}\,\tau = \vec{a}\,\tau$

[Since average thermal velocity of electrons is zero]

where $\tau = \frac{\tau_1 + \tau_2 + \text{.......} + \tau_n}{n}$

is called relaxation time. Its value is of the order of 10^{-14} seconds.

Putting the value of a in (3), we get

$\vec{v}_d = \frac{-e\vec{E}}{m}\tau$

Hence average drift speed, $v_d = \frac{eE}{m}\tau$.

17. We have given $A_1 : A_2 = 1 : 2 \Rightarrow \frac{A_1}{A_2} = \frac{1}{2}$

(i) When two wires are connected in series, the current in both wires A and B will be same,

$\therefore \quad I_A = I_B$

$ne A_1 v_{d_1} = ne A_2 v_{d_2}$

$\therefore \quad \frac{v_{d_1}}{v_{d_2}} = \frac{2}{1} \Rightarrow v_{d_1} : v_{d_2} = 2 : 1$

(ii) When two wires are connected in parallel, then the potential difference across the wire A and B will be same; $V_A = V_B$

$\because V = IR$

$V = ne A\, v_d \rho \frac{l}{A} \Rightarrow \therefore V = ne\rho l\, v_d$

$\therefore \quad ne\rho l v_{d_1} = ne\rho l v_{d_2}$

$\Rightarrow v_{d_1} = v_{d_2}$

$\therefore \quad \frac{v_{d_1}}{v_{d_2}} = \frac{1}{1} \Rightarrow v_{d_1} : v_{d_2} = 1 : 1$

18. Relation between the resistivity and relaxation time :

We know that drift velocity of electron is given by

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

but $E = \frac{V}{l}$

$\therefore \quad v_d = \frac{e}{m} \cdot \frac{V}{l} \cdot \tau \Rightarrow V = \frac{v_d \cdot ml}{e\tau}$

$\therefore$ According to ohm's law

$R = \frac{V}{I} = \frac{v_d\, ml / e\tau}{I} = \frac{v_d ml / e.\tau}{neAv_d}$

$R = \frac{v_d\, ml}{e\tau.neAv_d} = \frac{m}{ne^2\tau} \cdot \frac{l}{A}$ ...(i)

But the resistivity is given by

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

Comparing (i) and (ii), we get

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

which is the required relationship between resistivity and relaxation time of electrons.

19. (a) *Refer to answer 16.*

(b) In terms of potential difference, $v_d = \frac{eV}{Lm_e}\tau$

So, tripling the length of the conductor $l' = 3L$ and keeping V constant, the drift velocity will reduce to one third of initial value.

$v_d' = \frac{v_d}{3}$

20. Current is constant in non-uniform cross-section.

21. (a) *Refer to answer 11.*

(b) Area under I-t curve on t-axis is charge flowing through the conductor

$Q = \frac{1}{2} \times 5 \times 5 + (10 + 5) \times 5 = 37.5C$

22. The average time interval between two successive collisions. For the free electrons drifting within a conductor due to the action of the applied electric field is called relaxation time.

Relation between relaxation time and drift velocity,

$$v_d = \left(\frac{-eE\tau}{m}\right)$$

Since $i = -ne\,Av_d$

$$i = ne^2 A\,\tau V/ml$$

$$\therefore \quad \frac{V}{i} = \frac{ml}{ne^2 A\tau} = \frac{\rho l}{A}$$

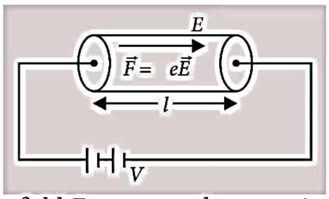
$$\therefore \quad \rho = \frac{m}{(ne^2\tau)}$$

23. *Refer to answer 19(b).*

24. Drift velocity : It is the velocity with which free electrons get drifted towards the positive terminal under the effect of the applied electric field. Free electrons are in continuous random motion. They undergo change in direction at each collision and the thermal velocities are randomly distributed in all directions.

$\therefore$ Average thermal velocity,

$$u = \frac{u_1 + u_2 + \ldots + u_n}{n} = 0 \quad \ldots\text{(i)}$$



The electric field E exerts an electrostatics force $-Ee$

Acceleration of each electron, $\vec{a} = \dfrac{-e\vec{E}}{m}$ ...(ii)

where,

m = mass of an electron

e = charge on an electron

$$\vec{v}_d = \frac{\vec{v}_1 + \vec{v}_2 + \ldots\ldots\ldots + \vec{v}_n}{n}$$

$$\vec{v}_d = \frac{(\vec{u}_1 + \vec{a}\tau_1) + (\vec{u}_2 + \vec{a}\tau_2) + \ldots\ldots\ldots + (\vec{u}_n + \vec{a}\tau_n)}{n}$$

where,

$\vec{u}_1, \vec{u}_2 \rightarrow$ thermal velocities of the electrons

$\vec{a}\tau_1, \vec{a}\tau_2 \rightarrow$ velocities acquired by electrons

$T_1, T_2 \rightarrow$ time elapsed after the collision

$$\vec{v}_d = \frac{(\vec{u}_1 + \vec{u}_2 + \vec{u}_n)}{n} + \frac{\vec{a}(\tau_1 + \tau_2 + \ldots + \tau_n)}{n}$$

Since $\dfrac{\vec{u}_1 + \vec{u}_2 + \vec{u}_n}{n} = 0$, we get

$\therefore \quad v_d = a\tau$, where, $\tau = \dfrac{\tau_1 + \tau_2 + \tau_3 + \ldots\ldots + \tau_n}{n}$ ...(iii)

is the average time elapsed.

Substituting the value of a in equation (iii) from equation (ii), we have

$$\vec{v}_d = \frac{-e\vec{E}}{m}\tau \quad \ldots\text{(iv)}$$

$$I = -neAv_d = \frac{ne^2 A\tau}{m}E$$

$$\Rightarrow \quad j = \frac{I}{A} = \left(\frac{ne^2\tau}{m}\right)E$$

25. (a) Consider a conductor of length l and cross-sectional area A. When a potential difference V is applied across its ends, the current produced is I. If n is the number of electron per unit volume in the conductor and v_d the drift velocity of electrons then the relation between current and drift velocity is

$I = -\,ne\,Av_d$ ...(i)

Where $-e$ is the charge on electron

$(e = 1.6 \times 10^{-19}\text{C})$

Electric field produced at each point of wire,

$E = \dfrac{V}{l}$ ...(ii)

If τ is relaxation time and E is electric field strength, then drift velocity.

$v_d = -\dfrac{e\tau E}{m}$ ...(iii)

Putting this value of v_d in eqn (i)

$$I = -n\,eA\left(-\frac{e\tau}{m}E\right)$$

$I = \dfrac{ne^2\tau}{m}AE$ ...(iv)

As $E = \dfrac{V}{l}$ (from (ii))

$$I = \frac{ne^2\tau A}{m}\frac{V}{l}$$

$$\frac{V}{I} = \frac{m}{ne^2\tau}\cdot\frac{l}{A} \Rightarrow V = \frac{ml}{ne^2\tau}\cdot\frac{I}{A}$$

$$V = \frac{ml}{ne^2\tau}j \qquad \left[\because \frac{I}{A} = j\right]$$

(b) *Refer to answer 10.*

26. (i) Region DE has negative resistance property because current decreases with increase in voltage or slope of DE is negative.
(ii) Region BC obeys Ohm's law because current varies linearly with the voltage.

27. $R_{Cu} = R_m$

$$\rho_{Cu}\frac{l_{Cu}}{A_{Cu}} = \rho_m\frac{l_m}{A_m}$$

Here $l_{Cu} = l_m$

as $\rho_m > \rho_{Cu}$

$$\frac{\rho_{Cu}}{A_{Cu}} = \frac{\rho_m}{A_m} \Rightarrow \frac{\rho_m}{\rho_{Cu}} = \frac{A_m}{A_{Cu}}$$

As, $\rho_m > \rho_{Cu}$
So, $A_m > A_{Cu}$
Manganin wire is thicker than copper wire.

28. For both, valence electrons are same. The energy gap of Si is 1.1eV while C is 5.44 eV. Carbon behaves as an insulator while si is as Semi-conductor.

29. The specific resistance of a conductor of unit length and unit cros-sectional area is called resistivity of the conductor.

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

For $l = 1$ m, $A = 1$ m^2
$R = \rho$
Its SI unit is Ω m.

30. (a) Resistance = 47 KΩ ± 10%
= 47×10^3 Ω ± 10%
Sequence of colour should be :
Yellow, Violet, Orange and Silver
(b) (i) Very low temperature coefficient of resistance.
(ii) High resistivity.

31. Mobility of an ion is defined as the drift velocity per unit electric field *i.e.*,

$$\mu = \frac{v_d}{E} = \frac{e\tau}{m}$$

Its unit is m^2/Vs.

When temperature increases, covalent bonds of neighbouring atoms break and charge carriers become free to cause conductive, so resistivity of semi-conductor decreases with rise of temperature.

32. (i) We know that the numbers for brown, green and blue are 1, 5 and 6 respectively
$\therefore \quad R_1 = 15 \times 10^6$ Ω

(ii) We know that the numbers for orange, black and green are 3, 0 and 5 respectively.
$R_2 = 30 \times 10^5$ Ω
$\therefore$ Ratio of their resistances is

$$\frac{R_1}{R_2} = \frac{15\times10^6}{30\times10^5} = \frac{10}{2} = \frac{5}{1} = 5:1$$

33. We know that the numbers for blue, black and yellow are 6, 0 and 4 respectively.
$\therefore \quad R = 60 \times 10^4$Ω; $V = 30$ V

$$I = \frac{30}{60\times10^4} = 0.05 \text{ mA}$$

34. Resistance, $R = \rho\frac{l}{A}$

$$\frac{l_f - l_i}{l_i} = \frac{5}{100}$$

$$\frac{l_f}{l_i} = \frac{21}{20}$$

On stretching volume remains same *i.e.*, $\frac{l_f}{l_i} = \frac{A_i}{A_f}$.

From the relation $R = \rho\frac{l}{A}$, we have

$$\frac{R_f}{R_i} = \frac{l_f}{l_i} \times \frac{A_i}{A_f} = \left(\frac{21}{20}\right)^2$$

$$\frac{R_f - R_i}{R_i} = \left(\frac{21}{20}\right)^2 - 1 = 0.1025$$

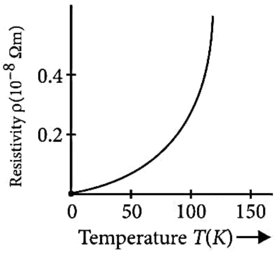
Thus change in resistance is 10.25%.

35. As $R = \frac{\Delta V}{\Delta I}$

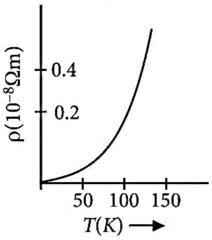
so in I-V graph, $R \propto \frac{1}{(\text{Slope of } I - V \text{ grpah})}$

$\therefore \quad R_1 < R_2$
Resistance of metalic wire increases with temperature. Hence, $T_1 < T_2$.

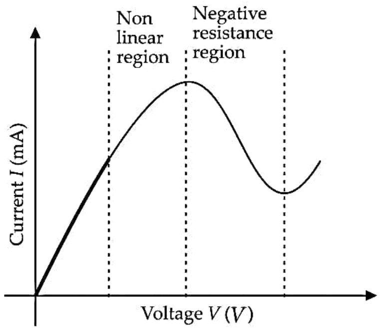
36. The resistivity of a metallic conductor is given by
$\rho = \rho_0[1 + \alpha(T - T_0)]$
where
ρ_0 = Resistivity at reference temperature
T_0 = Reference temperature
α = Coefficient of resistivity
From the above relation, we can say that the graph between resistivity of a conductor with temperature is straight line. But, at temperatures much lower than 273 K (*i.e.*, 0 °C), the graph deviates considerably from a straight line as shown in the figure.



37. The variation of resistivity of copper with temperature as shown in figure.



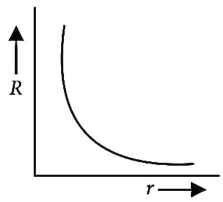
38. Variation of current versus voltage for GaAs.



39. Increasing temperature causes greater electron scattering due to increased thermal vibrations of atoms and hence, resistivity ρ (reciprocal of conductivity) of metals increases linearly with temperature.

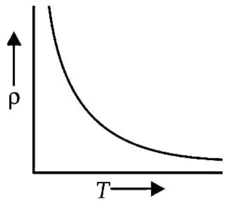
40. Resistance of a conductor of length l, and radius r is given by

$$R = \rho \frac{l}{\pi r^2}$$

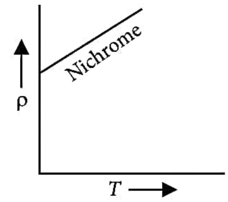


41. In silicon, the resistivity increases with decrease in temperature.
In copper, the resistivity decreases with decrease in temperature.

42. The variation of resistivity with temperature for a typical semiconductor is as shown in figure.

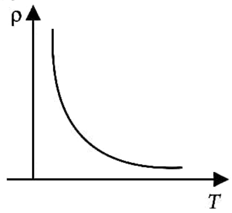


43. Variation of resistivity with temperature for nichrome



Nichrome is used to make standard resistance coils because the temperature coefficient of resistivity of nichrome is negligible.

44. Variation of resistivity (ρ) with temperature (T) is shown below :



In semiconductor the number density of free electrons (n) increases with increase in temperature (T) and consequently the relaxation period decreases. But the effect of increase in n has higher impact than decrease of τ. So, resistivity decreases with increase in temperature.

45. $\rho = \dfrac{m}{ne^2\tau}$

Resistivity of a metal increases with rise in temperature.

With the rise in temperature, relaxation time decreases as number of collisions increases. Although number density of electrons also increases, it further reduces the relaxation time because probability of collisions further increases.
In case of semiconductors with increase in number density of electrons, probability of collisions does not increases as this density is too low to effect it. On the other hand, it increases the conductivity *i.e.*, resistivity is reduced.

46. Resistance of each semi-circular part of circle is $4R$.

$\therefore \quad R_1 = R_2 = 4R$

Since two resistors are in parallel,

$\therefore$ Effective resistance (R_e) is

$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{4R} + \frac{1}{4R} = \frac{2}{4R} = \frac{1}{2R}$$

$\therefore \quad R_e = 2R$

47. Let R be the resistance of one slab.

$\therefore$ Total resistance in figure (i) is

$R_1 = 2R$

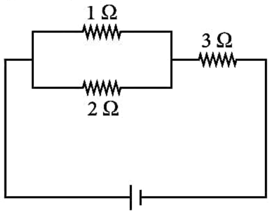
Total resistance in figure (ii) is

$R_2 = R/2$

Required ratio of the resistances = $R_1 : R_2$

$$= \frac{2R}{R/2} = 4:1$$

48. (i) To get the equivalent resistance of $\frac{11}{3}\,\Omega$, the resistance of 1 Ω and 2 Ω must be in parallel and resistance of 3 Ω should be connected in series with the resulting resistance.



Equivalent resistance of the parallel combination of 1 Ω and 2 Ω is given by

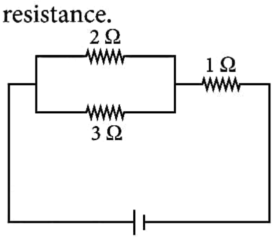
$$\frac{1}{R} = \frac{1}{1} + \frac{1}{2} \Rightarrow \frac{1}{R} = \frac{3}{2} \Rightarrow R = \frac{2}{3}$$

Now, resistance 3 Ω is connected in series to the resultant resistance. Here, the equivalent resistance is given by

$$R' = R + 3 \Rightarrow R' = \frac{2}{3} + 3$$

$\Rightarrow R' = \frac{11}{3}\,\Omega$ (The required value of equivalent resistance)

(ii) To get the equivalent resistance of $\frac{11}{5}\,\Omega$, the resistance of 2 Ω and 3 Ω must be in parallel and resistance of 1 Ω should be connected in series with the resulting resistance.



Equivalent resistance of the parallel combination of 2 Ω and 3 Ω is

$$\frac{1}{R} = \frac{1}{2} + \frac{1}{3} \Rightarrow \frac{1}{R} = \frac{5}{6} \Rightarrow R = \frac{6}{5}$$

Now, resistance 1 Ω is connected in series to the resultant resistance.

Here, the equivalent resistance is given by

$R' = R + 1$

$$\Rightarrow R = \frac{6}{5} + 1 \Rightarrow R = \frac{11}{5}\,\Omega$$

(The required value of equivalent resistance).

49. When the wire of 15 Ω resistance is stretched to double its original length, then its resistance becomes

$R' = n^2 \times 15 = 2^2 \times 15 = 60\ \Omega$

When it cut into two equal parts, then resistance of each part becomes

$$R'' = \frac{R'}{2} = \frac{60}{2} = 30\ \Omega$$

These parts are connected in parallel, then net resistance of their combination is

$$R = \frac{R''}{2} = \frac{30}{2} = 15\ \Omega$$

So, the current drawn from the battery

$$I = \frac{V}{R} = \frac{3}{15} = \frac{1}{5}\ \text{A or } I = 0.2\ \text{A.}$$

50. $E_2 - E_1 = 8 - 4 = 4$ volt

Total resistance = $0.5 + 1 + 4.5 + \frac{6 \times 3}{6+3} = 8\ \Omega$

$$I = \frac{4}{8} = 0.5\ \text{A}$$

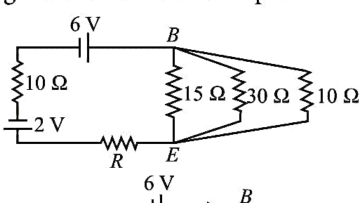
Current through 3 Ω resistor

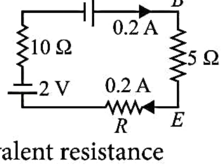
$$= \frac{6 \times 0.5}{6+3} = 0.33\ \text{A}$$

Current through 6 Ω resistor

$$= \frac{3 \times 0.5}{6+3} = \frac{1.5}{9} = 0.16\ \text{A}$$

51. The given circuit can be simplified





For BCD, equivalent resistance

$R_1 = 5\ \Omega + 5\ \Omega = 10\ \Omega$

Across BE equivalent resistance R_2

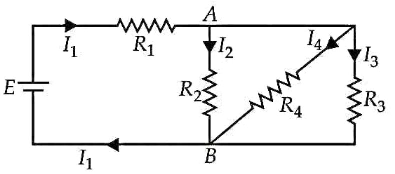
$$\frac{1}{R_2} = \frac{1}{10} + \frac{1}{30} + \frac{1}{15} = \frac{3+1+2}{30} = \frac{6}{30} = \frac{1}{5}$$

$\Rightarrow \quad R_2 = 5\ \Omega$

Potential difference $V_{BE} = I \times R_2 = 0.2 \times 5$

$\Rightarrow V_{BE} = 1$ V

52.



From figure, R_2, R_3 and R_4 are connected in parallel.

$\therefore$ Effective resistance R_p

$$\frac{1}{R_p} = \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} = \frac{1}{15} + \frac{1}{15} + \frac{1}{30} = \frac{5}{30}$$

$\Rightarrow \quad R_p = 6\ \Omega.$

Now, equivalent resistance of circuit,

$R = R_1 + R_p = 4 + 6 = 10\ \Omega$

Current $I_1 = \frac{10}{10} = 1$ A

Potential drop across $R_1 = I_1 R_1 = 1 \times 4 = 4$ V

Potential drop across all other resistances = 10 – 4 = 6 V

Current through R_2 or R_3;

$$I_2 = \frac{6}{15}\text{A},\ I_3 = \frac{6}{15}\ \text{A} \Rightarrow I_2 = \frac{2}{5}\text{A},\ I_3 = \frac{2}{5}\text{A}$$

Current through R_4, $I_4 = \frac{6}{30}$ A $\Rightarrow I_4 = \frac{1}{5}$A

53. (a) $R_{AB} = \frac{4 \times 4}{4+4} = 2\ \Omega,$

$R_{BC} = 1\ \Omega,\ R_{CD} = \frac{12 \times 6}{12+6} = 4\ \Omega$

Equivalent resistance of network

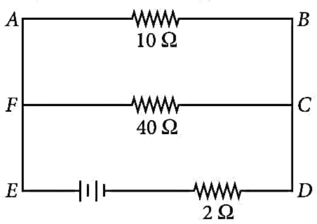
$R_{AD} = R_{AB} + R_{BC} + R_{CD} = 2 + 1 + 4 = 7\ \Omega$

(b) Current in circuit $I = \frac{E}{R+r} = \frac{16}{7+1} = 2$ A

$V_{AB} = R_{AB} I = 2 \times 2 = 4$ V

$V_{CD} = R_{CD} I = 4 \times 2 = 8$ V

54. Here simplified circuit is given as



Current delivered by the battery is

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

($\because$ Given power dissipated across 2 Ω is 200 W)

$I^2 = \frac{200}{2}$; $I^2 = 100 \Rightarrow I = 10$ A

$\therefore$ Current in branch AB is

$$I_{AB} = \frac{40 \times 10}{40+10} = 8\text{ A}$$

$\therefore$ Power dissipated across 5 Ω will be

$P = I_{AB}^2 \times 5\ \Omega = 8^2 \times 5 \Rightarrow P = 320$ W

55. Potential difference across a cell with internal resistance, r is $V = \varepsilon - Ir$.

As three cells are in series, so emf = 3ε and internal resistance = $3r$

$\therefore \quad V = 3\varepsilon - 3rI$

When $I = 0$ then $V = 6$ V, so $6 = 3\varepsilon - 0$ or $\varepsilon = 2$ V

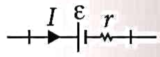
When $V = 0$ then $I = 1$ A, so $0 = 6 - 1 \times 3r$

or $\quad 3r = 6 \quad$ or $\quad r = 2\ \Omega$

56. We know the relation $V = \varepsilon - Ir$. The emf of a cell is greater than its terminal voltage because there may be some potential drop within the cell due to its small internal resistance offered by the electrolyte.

57. *Refer to answer 56.*

Note : When cell is charged the current goes into the positive terminal as shown in the figure. So potential difference across a cell, $V = \varepsilon + Ir$.



58. Here $\varepsilon_1 = \varepsilon$, $\varepsilon_2 = -2\varepsilon$ and $\varepsilon_3 = 5\varepsilon$,

$r_1 = r$, $r_2 = 2r$ and $r_3 = 3r$

Equivalent emf of the cell is

$\varepsilon = \varepsilon_1 + \varepsilon_2 + \varepsilon_3$

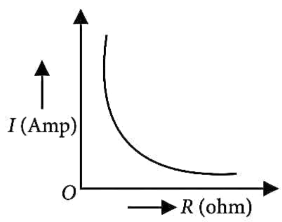
$= \varepsilon - 2\varepsilon + 5\varepsilon = 4\varepsilon$

Equivalent resistance = $r_1 + r_2 + r_3 + R$

$= r + 2r + 3r + R = 6r + R$

$\therefore \quad$ Current $I = \frac{4\varepsilon}{6r+R}$

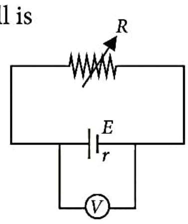
The graph for variation of current I with resistance R is shown below :



59. Terminal voltage 'V' of the cell is

$V = E - Ir$

E is the emf of the cell, r is the internal resistance of the cell and I is the current through the circuit.

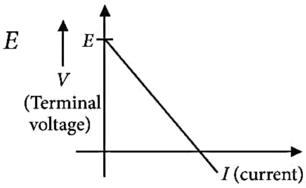


So, $V = -Ir + E$

Comparing with the equation of a straight line $y = mx + c$, we get,

$y = V; x = I; m = -r; c = E$

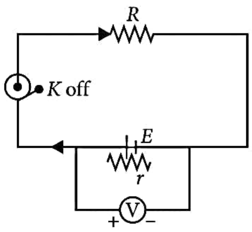
Graph showing variation of terminal voltage 'V' of the cell versus the current 'I'.



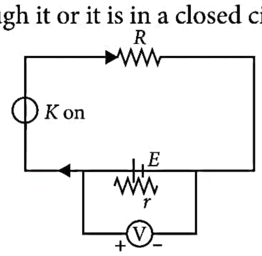
Emf of the cell = Intercept on V axis

Internal resistance = slope of line.

60. (a) Electromotive force of emf 'ε' of a cell is the potential difference across its terminals when no electric current is flowing through it or it is in an open circuit.



Terminal voltage V of a cell is the potential difference across its terminals when some electric current is flowing through it or it is in a closed circuit.



(b) *Refer to answer 59.*

61. $R_1 = 12\ \Omega$, $R_2 = 25\ \Omega$

$I_1 = 0.5$ A, $I_2 = 0.25$ A

For the 1st case

$$r = \frac{\varepsilon}{I_1} - R_1 = \frac{\varepsilon}{0.5} - 12$$

$$r = \frac{\varepsilon - 6}{0.5} \quad \text{...(i)}$$

Now, for the 2nd case

$$r = \frac{\varepsilon}{0.25} - 25;\ r = \frac{\varepsilon - 6.25}{0.25} \quad \text{...(ii)}$$

Compare the equation (i) and (ii), we get

$$\frac{\varepsilon - 6}{0.5} = \frac{\varepsilon - 6.25}{0.25}$$

$0.25\,\varepsilon - 1.5 = 0.5\,\varepsilon - 3.125$

$-0.25\,\varepsilon = -1.625$

$$\varepsilon = \frac{1.625}{0.25};\ \varepsilon = 6.5\ V$$

Putting the value of ε, $r = \frac{6.5 - 6}{0.5} = \frac{0.5}{0.5}$

$r = 1\ \Omega$

62. The current relating to corresponding situations are as follows :

(i) Without any external resistance

$$I_1 = \frac{E}{r}$$

In this case, effective resistance of circuit is minimum so current is maximum.

Hence $I_1 = 4.2$ A.

(ii) With resistance R_1 only

$$I_2 = \frac{E}{r + R_1}$$

In this case, effective resistance of circuit is more than situations (i) and (iv) but less than (iii). So $I_2 = 1.05$ A.

(iii) With R_1 and R_2 in series combination

$$I_3 = \frac{E}{r + R_1 + R_2}$$

In this case, effective resistance of circuit is maximum so current is minimum. Hence $I_3 = 0.42$ A.

(iv) $$I_4 = \frac{E}{r + \frac{R_1 R_2}{R_1 + R_2}}$$

In this case, the effective resistance is more than (i) but less than (ii) and (iii). So $I_4 = 1.4$ A.

63. Given $E = 10$ V, $r = 3\ \Omega$, $I = 0.5$ A

Total resistance of circuit

$$R + r = \frac{E}{I} = \frac{10}{0.5} = 20\ \Omega$$

(i) External resistance $R = 20 - r = 20 - 3 = 17\ \Omega$

(ii) Terminal voltage $V = IR = 0.5 \times 17 = 8.5$ V

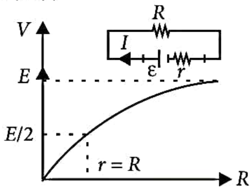
64. (i) The value of potential difference corresponding to zero current gives the emf of cell. This value is 1.4 Volt.

(ii) Maximum current is drawn form the cell when the terminal potential difference is zero. The current corresponding to zero value of terminal potential difference is 0.28 A. This is maximum value of current.

$r = \frac{E}{I} = \frac{1.4}{0.28}\ \Omega\,;\ r = 5\ \Omega.$

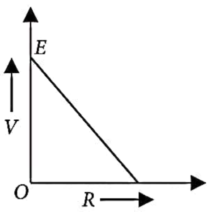
65. Terminal potential difference

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



When R $\to \infty$, $V = E$

The graph between V and R is shown



If no current is drawn from the cell then

$V = E$ $\quad [\because V = E - Ir, I = 0]$

66. Since $V = IR$

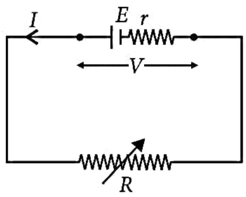
$R = \frac{V}{I}$

The slope of combination of metallic wire A is smaller than that of B.

$\therefore$ Resistance of combination A is less. Hence A represents parallel combination.

67. Given situation is shown in figure

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

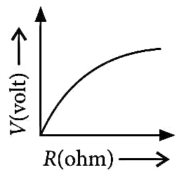


Terminal voltage,

$V = E - Ir$

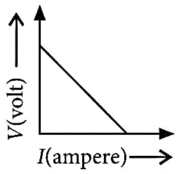
$V = E - Ir = E - \frac{E}{r+R}r = \frac{ER}{r+R}$

(i) V versus R,



(ii) V versus I,

$V = E - Ir$



When $R = 4\ \Omega$, then $I_1 = 1$ A

$\therefore \quad 1 = \frac{E}{r+4}\,;\ r + 4 = E \quad ...(i)$

When $R = 9\ \Omega$, then $I = 0.5\text{ A} = \frac{1}{2}\text{ A}$

$\therefore \quad \frac{1}{2} = \frac{E}{r+9} = \frac{r+4}{r+9}$ $\quad$ [Using eqn. (i)]

$r + 9 = 2r + 8,\ r = 1\ \Omega$

From eqn. (i)

emf, $E = 1 + 4 = 5$ V

68. Internal resistance of a cell depends upon

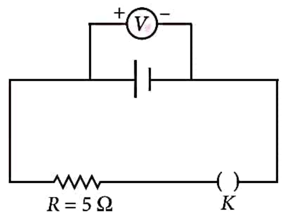
(i) surface area of each electrode.

(ii) distance between the two electrodes.

(iii) nature, temperature and concentration of electrolyte.

Let internal resistance of cell be r.

The circuit given in question can be redrawn as



Initially when K is open, voltmeter reads 2.2 V.

i.e., emf of the cell, $\varepsilon = 2.2$ V

Later when K is closed, voltmeter reads 1.8 V which is actually the terminal potential difference, V.

i.e., if I is the current flowing, then

$\varepsilon = I(R + r)$

$\Rightarrow \quad 2.2 = I(5 + r)$ $\quad ...(i)$

and $\quad V = \varepsilon - Ir$

$1.8 = 2.2 - Ir$ $\quad ...(ii)$

Solving (i) and (ii),

$I = 0.36$ A

Substituting in (ii)

$r = \frac{0.4}{0.36} \Rightarrow r = \frac{10}{9}\ \Omega$

69. The terminal potential difference of a cell is given by

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

Where ε is emf of the cell, r is internal resistance and R is an external resistance.

$V = \frac{\varepsilon}{r/R+1}$

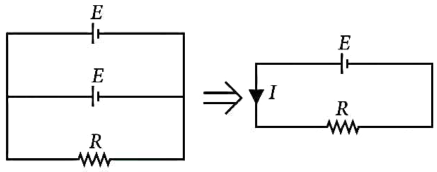
For resistance R_1, $V_1 = \frac{\varepsilon}{r/R_1+1}$

For resistance R_2, $V_2 = \frac{\varepsilon}{r/R_2+1}$

Since $R_1 > R_2 \ \therefore\ V_1 > V_2$

Hence terminal potential difference of the cell will be more when external resistor R_1 is connected to the cell.

70.



So, current $I = \frac{E}{R}$

71. Equivalent emf and internal resistance of the combination of two cells connected in parallel combination is given as

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

Here $\varepsilon_1 = 2\varepsilon$, $\varepsilon_2 = \varepsilon$, $r_1 = 2r$ and $r_2 = r$

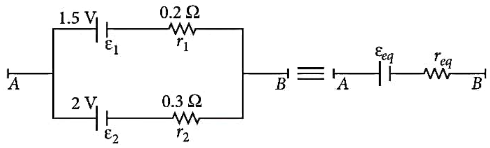
$$\therefore \quad \varepsilon_{eq} = \frac{2\varepsilon.r + \varepsilon.2r}{2r + r}, r_{eq} = \frac{2r.r}{2r + r}$$

$$\varepsilon_{eq} = \frac{2\varepsilon r + 2\varepsilon r}{3r}, r_{eq} = \frac{2r^2}{3r}$$

$$\varepsilon_{eq} = \frac{4\varepsilon r}{3r}, r_{eq} = \frac{2}{3}r$$

Therefore, $\varepsilon_{eq} = \frac{4}{3}\varepsilon$ and $r_{eq} = \frac{2}{3}r.$

72.



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

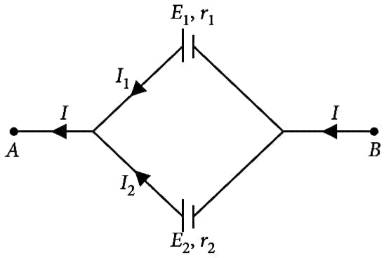
$$\therefore \quad \varepsilon_{eq} = \frac{1.5 \times 0.3 + 2 \times 0.2}{0.3 + 0.2}$$

$$= \frac{0.45 + 0.4}{0.5} = \frac{0.85}{0.5} = 1.7 \text{ V}$$

$$r_{eq} = \frac{0.2 \times 0.3}{0.2 + 0.3} = \frac{0.06}{0.5} = 0.12\,\Omega$$

73. Here, $I = I_1 + I_2$ ...(i)

Let V = Potential difference between A and B



For cell E_1,

$$V = E_1 - I_1 r_1 \Rightarrow I_1 = \frac{E_1 - V}{r_1}$$

Similarly, for cell E_2, $I_2 = \frac{E_2 - V}{r_2}$

Putting these values in equation (i)

$$I = \frac{E_1 - V}{r_1} + \frac{E_2 - V}{r_2}$$

or $$I = \left(\frac{E_1}{r_1} + \frac{E_2}{r_2}\right) - V\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

or $$V = \left(\frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}\right) - I\left(\frac{r_1 r_2}{r_1 + r_2}\right) \quad \text{...(ii)}$$

Comparing the above equation with the equivalent circuit of emf 'E_{eq}' and internal resistance 'r_{eq}' then,

$V = E_{eq} - Ir_{eq}$ ...(iii)

Then

(i) $E_{eq} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$ (ii) $r_{eq} = \frac{r_1 r_2}{r_1 + r_2}$

(iii) The potential difference between A and B

$V = E_{eq} - Ir_{eq}$

74. *Refer to answer 73.*

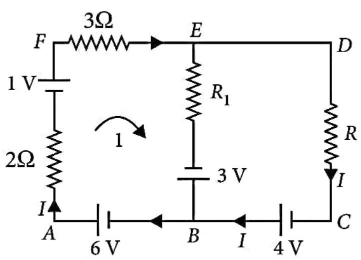
75. *Refer to answer 73.*

76. Since, the positive terminal of the batteries are connected together, so the equivalent emf of the batteries is given by ε = 200 V – 10 V = 190 V.

Hence, the current in the circuit is given by

$$I = \frac{\varepsilon}{R} = \frac{190 \text{ V}}{38\,\Omega} = 5 \text{A}.$$

77. First we need to calculate R for no current through R_1.



By Kirchhoff' law,

$3I + RI + 2I = 1 + 4 + 6$

$5I + RI = 11$ ... (i)

Also, in loop (1),

$3I + 2I = 3 + 6 + 1$

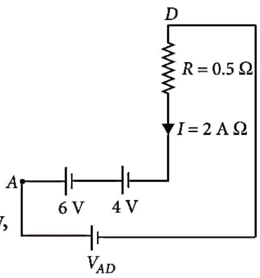
$5I = 10$ or $I = 2$ amp ... (ii)

Using in eqn. (i),

$10 + R \times 2 = 11$

$2R = 1$ or $R = 0.5\ \Omega$ ... (iii)

Now to determine the potential difference between A and D, we can assume a cell of required potential V_{AD} between two points.



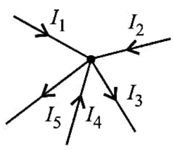
On applying Kirchhoff's law,

$V_{AD} - 6 - 4 = -2 \times 0.5$

$V_{AD} - 10 = -1$

$V_{AD} = 9$ volt

78. Kirchhoff's first rule : The algebraic sum of all the current passing through a junction of an electric circuit is zero.



Here, I_1, I_2, I_3, I_4 and I_5 are current in different branches of a circuit which meet at a junction.

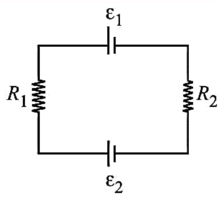
$I_1 + I_2 - I_3 + I_4 - I_5 = 0$

This rule is based on the principle of conservation of charge.

Kirchhoff's second rule : The algebraic sum of the applied emf's of an electrical circuit is equal to the algebraic sum of potential drops across the resistors of the loop.

Mathematically,

$\Sigma \varepsilon = \Sigma IR$



This is based on energy conservation principle

Using this rule,

$\varepsilon_1 - \varepsilon_2 = IR_1 + IR_2$

79. In closed mesh *ABCD*

$I_1 r_1 + (I_1 + I_2) R = 12$

$2I_1 + 4(I_1 + I_2) = 12$

$2I_1 + 4I_1 + 4I_2 = 12$

$6I_1 + 4I_2 = 12$

$3I_1 + 2I_2 = 6$ ...(i)

In closed mesh *BDEF*

$(I_1 + I_2) R = 6$

$(I_1 + I_2) 4 = 6$

$2I_1 + 2I_2 = 3$ ...(ii)

On solving equations (i) and (ii), we get

$I_1 = 3$

Putting the value of I_1 in equation (i)

$3I_1 + 2I_2 = 6$

$3 \times 3 + 2I_2 = 6$

$I_2 = -1.5$

Now, $I_1 + I_2 = 3 + (-1.5)$

$= 1.5$ Amp.

$P = (I_1 + I_2)^2 R = (1.5)^2 \times 4$

$= 2.25 \times 4 = 9$ watt.

80. (i) To measure current upto 5 *A*, the shunt *S* should have a value, such that for 5 A input current through system , 4 A should pass through shunt *S* and 1 A should pass through given ammeter.

$1 \times R_A = 4S$

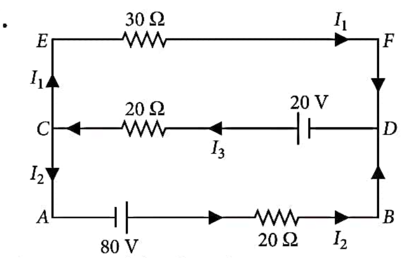
$1 \times 0.8 = 4S$; $S = 0.2\ \Omega$

Thus, the shunt resistance is $0.2\ \Omega$.

(ii) Combined resistance of the ammeter and the shunt,

$$R = \frac{0.8S}{0.8+S} = \frac{0.8 \times 0.2}{0.8+0.2} = \frac{0.16}{1} = 0.16\ \Omega$$

81.



Applying Kirchhoff 1st law.

$I_3 = I_1 + I_2$ (at *C*) ...(i)

Applying Kirchhoff's loop rule to *CDFEC*

$-30I_1 + 20 - 20I_3 = 0$

$3I_1 + 2I_3 = 2$ ...(ii)

For loop *ABFEA*

$-30I_1 + 20I_2 - 80 = 0$

$-3I_1 + 2I_2 = 8$ ...(iii)

from eq. (i) put the value of I_3 in eq. (ii)

$3I_1 + 2I_1 + 2I_2 = 2$

$5I_1 + 2I_2 = 2$ ...(iv)

$-3I_1 + 2I_2 = 8$

$8I_1 = -6$

$I_1 = -3/4$ A

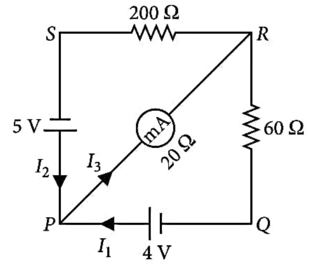
Put I_1 in eq. (iv)

$$-5 \times 3/4 + 2I_2 = 2 \Rightarrow I_2 = \frac{23}{8}\ \text{A}$$

from eq. (i)

$$I_3 = \frac{-3}{4} + \frac{23}{8} = \frac{-6+23}{8} = \frac{17}{8}\ \text{A}$$

82.



Applying Kirchhoff's 2nd law to the loop $PRSP$

$-I_3 \times 20 - I_2 \times 200 + 5 = 0$

$4I_3 + 40I_2 = 1$ ...(i)

for loop $PRQP$,

$-20I_3 - 60I_1 + 4 = 0$

$5I_3 + 15I_1 = 1$ ...(ii)

Applying Kirchhoff's 1st law

$I_3 = I_1 + I_2$ ...(iii)

from eq. (i) and (iii) we have,

$4I_1 + 44I_2 = 1$

from eq. (ii) and (iii)

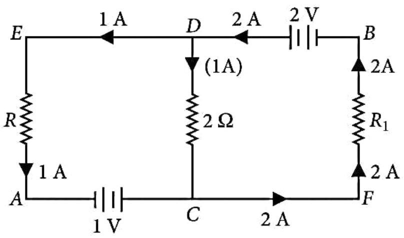
$20I_1 + 5I_2 = 1$

On solving we get

$$I_3 = \frac{11}{172}\text{A} = \frac{11000}{172}\text{mA}$$

$$I_2 = \frac{4000}{215}\text{ mA}, I_1 = \frac{39000}{860}\text{ mA}$$

83.



Using KCL at point D

$I_{DC} + 1 = 2$

$I_{DC} = 1\text{A}$

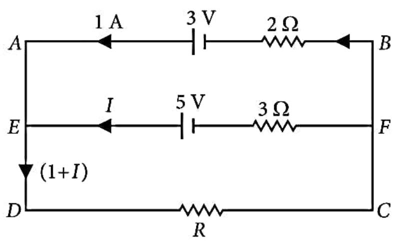
Along $ACDB$

$V_A + 1 + 1 \times 2 - 2 = V_B$

But $V_A = 0$

$V_B = 1 + 2 - 2 = 1\text{ V}$

84.

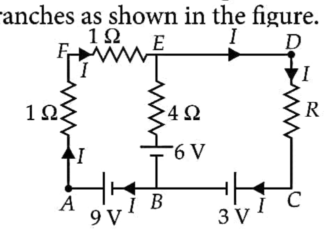


Here, $V_{AB} = V_{CD} = V_{EF}$

$V_{AB} = V_{CD} \Rightarrow$ Voltage drop across $R = 3 - 1 \times 2 = 1V$

Now, $V_{EF} - V_{CD} \Rightarrow 5 - 3I = 1 \Rightarrow I = \frac{4}{3}A$.

85. As no current flows through 4 Ω, the current in various branches as shown in the figure.



Applying Kirchhoff's loop rule to the closed loop $AFEBA$, we get

$-I - I - 4 \times 0 - 6 + 9 = 0$

or $9 - 6 - 2I = 0$ or $2I = 3$

or $I = \frac{3}{2}\text{A}$ ...(i)

Again, applying Kirchhoff's loop rule to the closed loop $BEDCB$, we get

$6 + 4 \times 0 - IR - 3 = 0$ or $IR = 3$

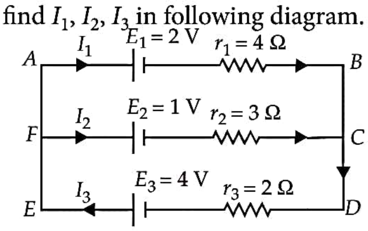
$R = \frac{3}{I} = 3 \times \frac{2}{3} = 2\,\Omega$ (Using (i))

Potential difference between A and D = Potential difference A and E

$\therefore \quad V_{AD} = 2I = 2 \times \frac{3}{2} = 3\text{ V}$

86. (a) *Refer to answer 78.*

(b) To find I_1, I_2, I_3 in following diagram.



For loop $ABCFA$

$E_1 + I_1r_1 - I_2r_2 - E_2 = 0$

$\Rightarrow \quad 2 + 4I_1 - 3I_2 - 1 = 0$

$\Rightarrow \quad 4I_1 - 3I_2 + 1 = 0$ ...(i)

Using loop $FCDEF$

$E_2 + I_2r_2 + I_3r_3 - E_3 = 0$

$\Rightarrow \quad 1 + 3I_2 + 2I_3 - 4 = 0$

$\Rightarrow \quad 3I_2 + 2I_3 - 3 = 0$ ...(ii)

Also using junction rule $I_3 = I_1 + I_2$ ...(iii)

Using (ii) and (iii)

$3I_2 + 2I_1 + 2I_2 - 3 = 0$

$\Rightarrow \quad 2I_1 + 5I_2 - 3 = 0$ ...(iv)

Solving (i) and (iv)

$$\begin{array}{r} 4I_1 - 3I_2 + 1 = 0 \\ -2\times(2I_1 + 5I_2 - 3) = 0 \\ \hline 0 - 13I_2 + 7 = 0 \\ \hline \end{array}$$

$\Rightarrow \; I_2 = \dfrac{7}{13}$ A

Substituting in (i)

$4I_1 - 3\times\dfrac{7}{13} + 1 = 0$

$4I_1 = \dfrac{8}{13} \;\Rightarrow\; I_1 = \dfrac{2}{13}$ A

$\Rightarrow \; I_3 = I_1 + I_2 \Rightarrow \; = \dfrac{9}{13}$ A

87. (a) *Refer to answer 78.*

(b) The network is not reducible to a simple series and parallel combinations of resistors. There is however, a clear symmetry in the problem which we can exploit to obtain the equivalent resistance of the network. The paths AA', AD and AB are obviously symmetrically placed in the network. Thus, the current in each must be the same, say, I. Further at the corners A', B and D, the incoming current I must split equally into the two outgoing branches. In this manner, the current, in all the 12 edges of the cube are easily written down in terms of I, using Kirchhoff's first rule and the symmetry in the problem. Next take a closed loop, say, $ABCC'EA$, and apply Kirchhoff's second rule :

$-IR - (1/2)\,IR - IR + \varepsilon = 0$

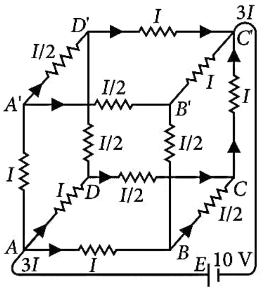
Where R is the resistance of each edge and ε the emf of battery. Thus, $\varepsilon = \dfrac{5}{2}IR$

The equivalent resistance R_{eq} of the network is

$R_{eq} = \dfrac{\varepsilon}{3I} = \dfrac{5}{6}R$

For $R = 1\ \Omega$, $R_{eq} = (5/6)/\Omega$ and for $\varepsilon = 10$ V, the total current (= $3I$) in the network is $3I = 10$ V/(5/6) Ω = 12 A. *i.e.*, $I = 4$ A

The current flowing in each edge can now be read off from the figure.



(i) The equivalent resistance of the network is $\dfrac{5}{6}\ \Omega$.

(ii) The total current is the network is 12 A.

88. (a) *Refer to answer 78.*

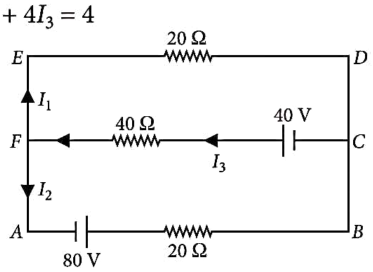
(b) $I_3 = I_1 + I_2$ ...(i)

Taking loop *FEDCF*

$20I_1 + 40I_3 = 40$

$\Rightarrow \; I_1 + 2I_3 = 2$

$\Rightarrow \; 2I_1 + 4I_3 = 4$ ...(ii)



Taking loop *FCBAF*

$-40I_3 - 20I_2 = -40 - 80$

$\Rightarrow \; 4I_3 + 2I_2 = 12$

$\Rightarrow \; 2I_3 + I_2 = 6$ ...(iii)

Substituting value of I_2 from equation (i) in equation (iii)

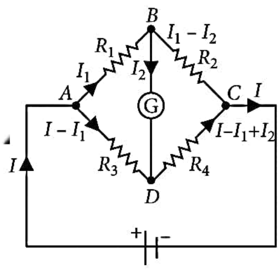
$2I_3 + (I_3 - I_1) = 6$

$\Rightarrow \; 3I_3 - I_1 = 6$ ...(iv)

On solving equations (ii) and (iv), we get

$I_1 = -1.2$ A

89.



Consider loop *ABDA*

$I_1R_1 + I_2G - (I - I_1)\,R_3 = 0$

$I_1(R_1 + R_3) + I_2G - IR_3 = 0$ ...(i)

Consider loop *BCDB*

$(I_1 - I_2)R_2 - (I - I_1 + I_2)R_4 - I_2G = 0$

$I_1(R_2 + R_4) - I_2(R_2 + R_4 + G) - IR_4 = 0$ ...(ii)

When bridge is balanced, B and D are at same potential *i.e.*, $I_2 = 0$. From equations (i) and (ii), we get

$\dfrac{R_1 + R_3}{R_2 + R_4} = \dfrac{R_3}{R_4}$

$R_1R_4 + R_3R_4 = R_3R_4 + R_2R_3$

$R_1R_4 = R_2R_3$

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

90. *Refer to answer 89.*

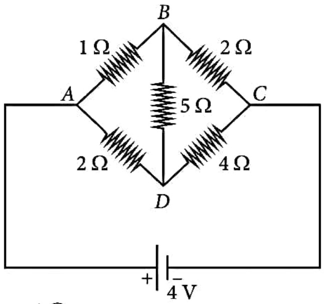
91. Since the condition $\frac{P}{Q} = \frac{R}{S}$ is satisfied, it is a balanced bridge.

The equivalent Wheatstone bridge for the given combination is shown in figure.

The resistance of arm *ABC*,

$R_{S_1} = 2 + 1 = 3\ \Omega$

Also, the resistance of arm *ADC*,



$R_{S_2} = 4 + 2 = 6\ \Omega$

Equivalent resistance

$$R_{eq} = \frac{R_{S_1} \times R_{S_2}}{R_{S_1} + R_{S_2}}$$

$$= \frac{3 \times 6}{3 + 6} = \frac{18}{9} = 2\ \Omega$$

Current drawn form the battery

$$I = \frac{V}{R_{eq}} = \frac{4}{2} \quad \therefore I = 2\ \text{A}.$$

92. In case of balanced Wheatstone bridge, no current flows through the resistor 10 Ω between points *B* and *C*.

The resistance of arm *ACD*, $R_{S_1} = 10 + 20 = 30\ \Omega$

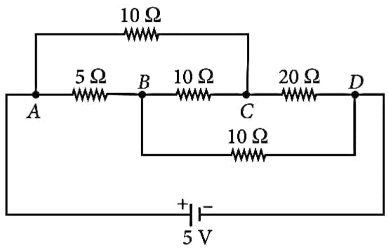
The resistance of arm *ABD*, $R_{S_2} = 5 + 10 = 15\ \Omega$

Equivalent resistance $R_{eq} = \frac{R_{S_1} \times R_{S_2}}{R_{S_1} + R_{S_2}}$

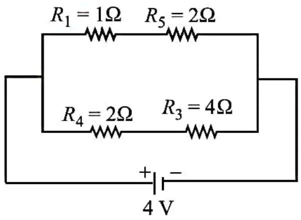
$$= \frac{30 \times 15}{30 + 15} = \frac{30 \times 15}{45} = 10\ \Omega$$

Current drawn form the source,

$$I = \frac{V}{R_{eq}} = \frac{5}{10} = \frac{1}{2}\ \text{A} = 0.5\ \text{A}$$



93. The given circuit is a balanced Wheatstone bridge, so it can be reduced as



As R_1 and R_5 are in series, so their equivalent resistance is $R' = R_1 + R_5 = 1 + 2 = 3\ \Omega$

As R_4 and R_3 are in series, so their equivalent resistance is $R'' = R_4 + R_3 = 2 + 4 = 6\ \Omega$

So, net resistance of the network is

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

or $R = 2\ \Omega$

So, current drawn from the battery is

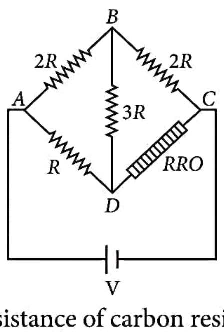
$$I = \frac{V}{R} = \frac{4}{2} \text{ or } I = 2\ \text{A}.$$

94. (i) *Refer to answer 89.*

(ii) Let the carbon resistor be *S* in the given wheatstone bridge, we have

$$\frac{2R}{R} = \frac{2R}{S}$$

$$\Rightarrow 1 = \frac{R}{S}$$

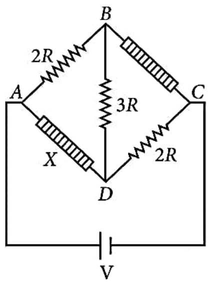


$\Rightarrow$ $R = S$ = resistance of carbon resistor

$\therefore$ $R = S = 22 \times 10^3\ \Omega = 22\ \text{k}\Omega$

(iii) When the resistance are interchanged, the bridge will be a balanced if

$$\frac{2R}{X} = \frac{22 \times 10^3}{2 \times 22 \times 10^3} = \frac{1}{2}$$



$\therefore \quad X = 4R = 4 \times 22\ k\Omega = 88\ k\Omega$

Thus, the sequence of colour will be grey, grey orange.

95. (a) *Refer to answer 78.*

(b) *Refer to answer 89.*

96. The value of balancing length would remain same, there will be no effect of changing the radius of the wire. Because balancing length is independent of radius of the wire, it only depends on the length ratio.

$$\frac{R_1}{R_2} = \frac{x}{100 - x}$$

97. Here $l_1 = 40$ cm

$$\because \quad \frac{R}{S} = \frac{l_1}{100 - l_1} \Rightarrow \frac{R}{S} = \frac{40}{100 - 40}$$

$$\Rightarrow \quad \frac{R}{S} = \frac{40}{60} \Rightarrow \frac{R}{S} = \frac{2}{3} \quad \therefore \ R : S = 2 : 3.$$

98. Metre bridge : It is the simplest practical application of the Wheatstone bridge that is used to measure an unknown resistance.

Principle : Its working is based on the principle of Wheatstone bridge.

When the bridge is balanced,

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

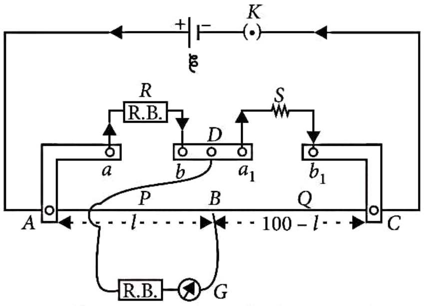


Fig. : Measurement of unknown resistance by a metre bridge.

Working : After taking out a suitable resistance R from the resistance box, the jockey is moved along the wire AC till there is no deflection in the galvanometer. This is the balanced condition of the Wheatstone bridge. If P and Q are the resistance of the parts AB and BC of the wire, then for the balanced condition of the bridge, we have

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

Let total length of wire AC = 100 cm and AB = l cm, then BC = (100 – l) cm. Since the bridge wire is of uniform cross-section, therefore,

resistance of wire $\propto$ length of wire

$$\text{or} \quad \frac{P}{Q} = \frac{\text{resistance of } AB}{\text{resistance of } BC} = \frac{\sigma l}{\sigma(100 - l)} = \frac{l}{100 - l}$$

where σ is the resistance per unit length of the wire.

$$\text{Hence, } \frac{R}{S} = \frac{l}{100 - l}$$

$$\text{or} \quad S = \frac{R(100 - l)}{l}$$

Knowing l and R, unknown resistance S can be determined.

(i) The current must be kept at low value. Otherwise, resistance of wire changes on getting heated and affected the values.

(ii) The current should not be passed continuously for a very long time.

(iii) The jockey should not be dragged along the wire.

99. (a) The resistivity of a copper wire is very low. Also, the connections are thick, so that the area is quite large and hence the resistance of the wires is almost negligible.

(b) It is preferred to obtain the balance point in the middle of the meter bridge wire because it improves the sensitivity of the meter bridge and minimum error due to resistance of copper strips.

(c) Constantan is used for meter bridge wire because its temperature coefficient of resistance is almost negligible due to which the resistance of the wire does not change with increase in temperature of the wire due to flow of current.

100. Working principle of a meter bridge is the wheatstone bridge condition. The value of R and X were doubled and then interchanged. Hence the new position of balance point remain same.

$AJ = 40$

From the principle of Wheatstone bridge,

$$\frac{R}{X}=\frac{40}{100-40}$$

$$X=R\frac{60}{40}=\frac{3R}{2}$$

When, the galvanometer and cell are interchanged, the condition for a balance bridge is still satisfied. Therefore the galvanometer will not show any deflection.

101. *Refer to answer 100.*

102. When resistances R and S are connected then balance point is found at a distance 40 cm form the zero

$$\frac{R}{S}=\frac{40}{100-40}$$

$$\frac{R}{S}=\frac{40}{60}\Rightarrow\frac{R}{S}=\frac{2}{3} \quad \text{....(i)}$$

When a resistance of 12 Ω is connected in parallel with S then total resistance in the right hand gap is

$$S_1=\frac{12S}{S+12} \quad \text{...(ii)}$$

$$\left[\because \frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}\Rightarrow R=\frac{R_1R_2}{R_1+R_2}\right]$$

Since balance point is obtained at a distance 50 cm form the zero.

$$\therefore \quad \frac{R}{S_1}=\frac{50}{100-50}\Rightarrow\frac{R}{S_1}=\frac{50}{50}$$

$$\therefore \quad \frac{R}{S_1}=1 \quad \text{...(iii)}$$

Dividing (i) by (iii), we get

$$\frac{\frac{R}{S}}{\frac{R}{S_1}}=\frac{\frac{2}{3}}{1}\Rightarrow\frac{R}{S}\cdot\frac{S_1}{R}=\frac{2}{3}$$

$$\Rightarrow \quad \frac{S_1}{S}=\frac{2}{3}\Rightarrow S_1=\frac{2}{3}S$$

Putting the value of S_1 in (ii), we get

$$\frac{2}{3}S=\frac{12S}{S+12}\Rightarrow\frac{2}{3}=\frac{12}{S+12}$$

$\Rightarrow \quad 2S + 24 = 36 \Rightarrow 2S = 12 \ \therefore \ S = 6\,\Omega$

Putting the value of S in (i), we get

$$\frac{R}{6}=\frac{2}{3}\Rightarrow R=\frac{2}{3}\times 6=4\,\Omega$$

$\therefore \quad R = 4\,\Omega$ and $S = 6\,\Omega$

103. (a) When X and Y are connected in left and right gaps of meter bridge respectively, then

$$\frac{X}{Y}=\frac{l}{100-l}=\frac{40}{100-40}=\frac{40}{60}=\frac{2}{3}$$

$$\text{or} \quad X=\frac{2}{3}Y \quad \text{...(i)}$$

(ii) When 10 Ω is connected in series with X in left gap, then its effective resistance becomes $X' = (X + 10)\,\Omega$ and the balance point shifts by 10 cm towards right side, So, new balancing length becomes $l' = 1 + 10 = 40 + 10 = 50$ cm

$$\text{Hence} \quad \frac{X'}{Y}=\frac{l'}{100-l'}$$

$$\text{or} \quad \frac{X+10}{Y}=\frac{50}{100-50}=\frac{50}{50}=1$$

$$\text{or} \quad X+10=Y \ \text{or} \ \frac{2}{3}Y+10=Y$$

$$\text{or} \quad 10=Y-\frac{2}{3}Y=\frac{1}{3}Y$$

$$\text{or} \quad Y=30\,\Omega \quad \text{...(ii)}$$

$$\text{and} \quad X=\frac{2}{3}Y=\frac{2}{3}\times 30$$

$$\text{or} \quad X=20\,\Omega \quad \text{...(iii)}$$

(iii) When 10 Ω resistance is instead connected in series with Y in right gap, then

$$\frac{X}{Y+10}=\frac{l_1}{100-l_1} \quad \text{or} \quad \frac{20}{30+10}=\frac{l_1}{100-l_1}$$

$$\text{or} \quad \frac{1}{2}=\frac{l_1}{100-l_1}$$

$$\text{or} \quad 100-l_1=2l_1 \quad \text{or} \quad 100=3l_1$$

$$\text{or} \quad l_1=\frac{100}{3}=33.33\text{ cm}$$

So, then null point will be obtained at 33.33 cm on the wire from left end A.

104. (i) Meter bridge works on the principle of Wheatstone bridge.

(ii) In first case, $\frac{R}{S}=\frac{l_1}{100-l_1}$

$$\text{or} \quad R=\frac{S\,l_1}{100-l_1} \quad \text{...(i)}$$

In second case,

$$\frac{R}{\left(\frac{XS}{X+S}\right)}=\frac{l_2}{100-l_2}$$

or $R = \dfrac{l_2 \times XS}{(100 - l_2)(X+S)}$ ...(ii)

From equations (i) and (ii), we get

$\dfrac{S\,l_1}{100 - l_1} = \dfrac{l_2 \times XS}{(100-l_2)(X+S)}$

or $l_1 (100 - l_2)(X + S) = Xl_2 (100 - l_1)$

or $(100l_1 - l_1l_2)(X + S) = 100\,Xl_2 - Xl_1l_2$

or $100\,Xl_1 - Xl_1l_2 + 100\,Sl_1 - Sl_1l_2 = 100Xl_2 - Xl_1l_2$

or $100\,Xl_1 - 100\,Xl_2 = Sl_1l_2 - 100\,Sl_1$

or $100\,X(l_1 - l_2) = Sl_1(l_2 - 100)$

or $X = \dfrac{S\,l_1\,(l_2 - 100)}{100\,(l_1 - l_2)}$

105. Case - I : $\dfrac{R_1}{R_2} = \dfrac{40}{(100-40)} = \dfrac{40}{60} = \dfrac{2}{3}$

$\dfrac{R_1}{R_2} = \dfrac{2}{3}$ ...(i)

Case - II : $\dfrac{R_1 + 10}{R_2} = \dfrac{60}{(100-60)} = \dfrac{60}{40} = \dfrac{3}{2}$

$\dfrac{R_1 + 10}{R_2} = \dfrac{3}{2}$ ...(ii)

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

$\dfrac{2}{3} + \dfrac{10}{R_2} = \dfrac{3}{2}$

$R_2 = 12\ \Omega$

From equation (i) $\dfrac{R_1}{12} = \dfrac{2}{3}$; $R_1 = 8\ \Omega$

106. (a) *Refer to answer 98.*

(b) *Refer to answer 100.*

(c) The bridge is most sensitive when null points, some where near the middle point of the wire. This is due to end resistance. Because of this reason it is important to obtain the balance point near the mid-point of the wire.

107. *Refer to answer 98.*

108. Working : When a constant current flows through a wire of uniform thickness, the potential difference between its two points is directly proportional to the length of the wire between these two points.

$V \propto l \Rightarrow V = Kl$, where K is potential gradient.

109. $\varepsilon = I(R + r)$ and $V = IR$

$\therefore \quad \dfrac{\varepsilon}{V} = \dfrac{R + r}{R}$

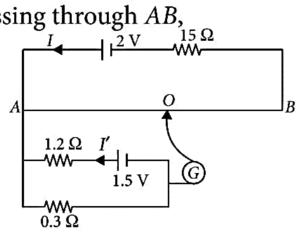
We get, $r = \left(\dfrac{\varepsilon}{V} - 1\right)R$

110. (i) *Refer to answer 108.*

(ii) Here $AB = 1$ m, $R_{AB} = 10\ \Omega$,

Potential gradient, $k = ?$, $AO = l = ?$

Current passing through AB,



$I = \dfrac{2}{15 + R_{AB}} = \dfrac{2}{15+10} = \dfrac{2}{25}$ A

$V_{AB} = I \times R_{AB} = \dfrac{2}{25} \times 10 = \dfrac{4}{5}$ V

$\therefore \quad k = \dfrac{V_{AB}}{AB} = \dfrac{4}{5}\ \mathrm{V\,m^{-1}}$

Current in the external circuit,

$I' = \dfrac{1.5}{1.2 + 0.3} = \dfrac{1.5}{1.5} = 1$ A

For no deflection in galvanometer,

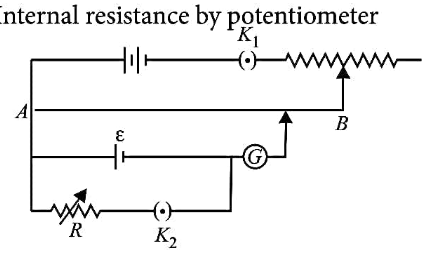
Potential difference across $AO = 1.5 - 1.2\,I'$

$\Rightarrow \quad k\,(l) = 1.5 - 1.2 \times I'$

$\Rightarrow \quad \dfrac{4}{5} l = 0.3$ or, $l = \dfrac{0.3 \times 5}{4} = 0.375$ m

$\therefore \quad l = 37.5$ cm

111. Internal resistance by potentiometer



Initially key K_2 is off

Then at balancing length l_1

$\varepsilon = Kl_1$ ...(i)

Now key K_2 is made on.

Then at balancing length l_2

$V = Kl_2$ ...(ii)

So, $\dfrac{\varepsilon}{V} = \dfrac{l_1}{l_2}$ ...(iii)

Also, $\dfrac{\varepsilon}{V} = \dfrac{\varepsilon}{\varepsilon - Ir} = \dfrac{\varepsilon}{\varepsilon - \dfrac{\varepsilon}{(R+r)}r} = \dfrac{R+r}{R} = 1 + \dfrac{r}{R}$

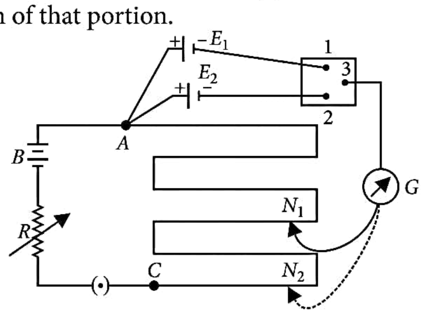
$r = \left(\dfrac{\varepsilon}{V} - 1\right)R$

So, $r = \left(\dfrac{l_1}{l_2} - 1\right)R$ [Using (iii)]

112. (i) By increasing resistance R, the current through AB decreases, so potential gradient decreases. Hence a greater length of wire would be needed for balancing the same potential difference. So the null point would shift towards B.

(ii) By decreasing resistance S, the current through AB remains the same, potential gradient does not change. As K_2 is open so there is no effect of S on null point.

113. Working principle of potentiometer : When a constant current is passed through a wire of uniform area of cross-section, the potential drop across any portion of the wire is directly proportional to the length of that portion.



Application of potentiometer for comparing emf's of two cells : The given figure shows an application of the potentiometer to compare the emf of two cells of emf E_1 and E_2. E_1, E_2 are the emfs of the two cells and 1, 2, 3 form a two way key.

When 1 and 3 are connected, E_1 is connected to the galvanometer (G).

Jokey is moved to N_1, which is at a distance l_1 from A, to find the balancing length.

Applying loop rule to $AN_1\ G31A$,

$\phi l_1 + 0 - E_1 = 0$ ...(i)

Where, ϕ is the potential drop per unit length.

Similarly, for E_2 balanced against $l_2(AN_2)$,

$\phi l_2 + 0 - E_2 = 0$ ...(ii)

From equation (i) and (ii)

$$\frac{E_1}{E_2} = \frac{l_1}{l_2} \quad \text{...(iii)}$$

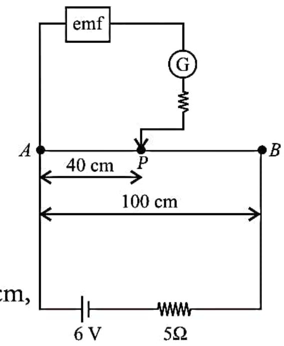
Thus we can compare the emfs of any two sources. Generally, one of the cells is chosen as a standard cell whose emf is known to a high degree of accuracy. The emf of the other cell is then calculated from equation (iii).

114. Net resistance of the circuit,

$R = (R_{AB} + 5) = 10 + 5 = 15\ \Omega$

Current flowing in the circuit,

$I = \frac{V}{R} = \frac{6}{15}\text{A}$



Potential drop across

$AB = IR_{AB}$

$= \frac{6}{15} \times 10 = 4\text{V}$

e.m.f. of primary cell,

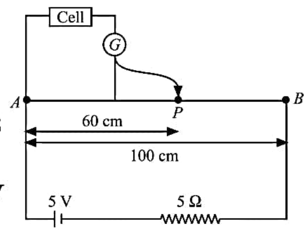
$\varepsilon = \frac{l}{L} V_{AB}$

Here, $l = 40$ cm, $L = 100$ cm,

$V_{AB} = 4$ V

So, $\varepsilon = \frac{40}{100} \times 4 = 1.6$ V

115. From the figure :



Total resistance of the circuit,

$R = (R_{AB} + 5)\ \Omega = 20\ \Omega$

Current in the circuit,

$I = V/R = 5/20 = 0.25$ V

$\therefore$ Voltage across AB,

$V_{AB} = I.R_{AB} = 3.75$ V

The emf of the cell connected as above is given by:

$\varepsilon = \frac{V_{AB}}{L} l$

Here, $l = 60$ cm (balance point)

$L = 1$ m $= 100$ cm (total length of the wire)

$\therefore \quad \varepsilon = \frac{3.75 \times 60}{100} = 2.25$ V

116. (a) Principle of potentiometer : The potential drop across the length of a steady current carrying wire of uniform cross-section is proportional to the length of the wire.

(i) We use a long wire to have a lower value of potential gradient *i.e.*, a lower "least count" or greater sensitivity of the potentiometer.

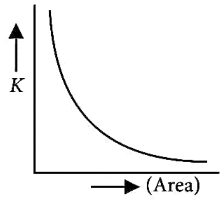
(ii) The area of cross section has to be uniform to get a uniform wire as per the principle of the potentiometer.

(iii) The emf of the driving cell has to be greater than the emf of the primary cells as otherwise, no balance point would be obtained.

(b) Potential gradient, $K = \frac{V}{L} = \frac{IR}{L} = \frac{IP}{A}$

KA = constant

$\therefore$ The required graph is shown in the figure



117. Principle of potentiometer : When a constant current is passed through a wire of uniform area of cross-section, the potential drop across any portion of the wire is directly proportional to the length of that portion.

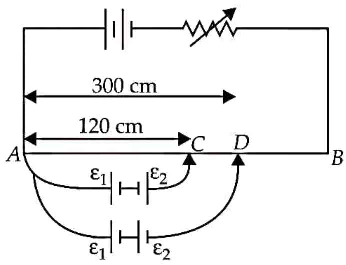
Factors on which sensitivity of potentiometer depends are :

(a) Resistance of the wire, (b) Number of the turns in the wire, and (c) Increasing the length of the wire.

(i) When resistance R is increased, the current through potentiometer wire AB will decrease, so potential difference across AX will decrease, so balance point X will shift towards B.

(ii) When resistance S is increased, keeping R constant there is no change in balance point because there is no current in the secondary circuit.

118. (i)



Let ϕ V cm^{-1} be potential gradient of the wire.

Applying Kirchhoff's loop rule to the closed loop ACA, we get

$\phi(120) = \varepsilon_1 - \varepsilon_2$ ...(i)

Again, applying Kirchhoff's loop rule to the closed loop ADA, we get

$\phi(300) = \varepsilon_1 + \varepsilon_2$ ...(ii)

Divide (i) by (ii), we get

$$\frac{\varepsilon_1 - \varepsilon_2}{\varepsilon_1 + \varepsilon_2} = \frac{120}{300} = \frac{2}{5}$$

$5\varepsilon_1 - 5\varepsilon_2 = 2\varepsilon_1 + 2\varepsilon_2$ or $3\varepsilon_1 = 7\varepsilon_2$

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{7}{3} \quad ...(iii)$$

(ii) Let the position of null point for the cell ε_1 is l_3.

$\therefore \quad \varepsilon_1 = \phi l_3$ ...(iv)

Divide (i) by (iv), we get

$$\frac{\varepsilon_1 - \varepsilon_2}{\varepsilon_1} = \frac{120}{l_3} \text{ or } 1 - \frac{\varepsilon_2}{\varepsilon_1} = \frac{120}{l_3}$$

$$1 - \frac{3}{7} = \frac{120}{l_3} \quad \text{(Using (iii))}$$

$$\frac{4}{7} = \frac{120}{l_3} \quad \text{or} \quad l_3 = 210 \text{ cm}$$

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

119. (a) *Refer to answer 108.*

(b) *Refer to answer 111.*

120. *Refer to answers 108 and 111.*

121. (a) Two possible faults are

(i) Negative terminal of the source of unknown emf is joined with end A of the wire.

(ii) The emf (E) is less than the unknown emf E'.

(b) The galvanometer deflection at the end B is more, means source of unknown emf have been joined with its –ve terminal to end A. Current gets divided at point A and combines at point B. The galvanometer deflection at the end B is less than at the end A, means the emf applied is less than the unknown emf used. Current gets combined at end A and divided at end B.

122. (a) Principle of a potentiometer : When a constant current is passed through a wire of uniform area of cross-section, the potential drop across any portion of the wire is directly proportional to the length of that portion.

Potential gradient : Fall of potential per unit length of the given wire is known as potential gradient.

$$K = \frac{V}{l}$$

where K is potential gradient, V is potential across any portion of length l of the wire.

Let V be the potential difference across certain portion of the wire, whose resistance is R. If I is the current through the wire then $V = IR$

We know that $R = \rho\frac{l}{A}$, where l, A and ρ are length, area of cross-section and resistivity of the material of the wire respectively.

$$\therefore \quad V = I\rho\frac{l}{A}$$

$$\Rightarrow \quad \frac{V}{l} = \frac{I\rho}{A} \Rightarrow K = \frac{I\rho}{A}$$

(b) *Refer to answer 118.*

123. (a) *Refer to answer 113.*

(b) (i) The emf of the cell connected in main circuit may not be more than the emf of the primary cells.

(ii) The positive ends of all cells are not connected to the same end of the wire.

124. (a) *Refer to answer 113.*

(b) The potentiometer wire is made of an alloy, such as constant or manganin. It is because, an alloy has high resistivity and a low value of temperature coefficient of resistance.

(c) The sensitivity of a potentiometer can be increased by increasing the length of potentiometers wire which is responsible for decreasing the value of potential gradient.

125. (a) *Refer to answer 108.*

(b) *Refer to answer 113.*

126. As per the figure,

Total current through the wire AB is given by

$$I = \frac{E}{R+r} = \frac{2}{R+15}$$

The potential gradient of the wire is given by

$$K = I \times \frac{15}{100} = \frac{2}{R+15} \times \frac{15}{100}$$

As, the balance point with cell E_2 of emf 75 mV is found at 30 cm from end A

$$\frac{2}{R+15} \times 0.15 \times 30 = 75 \times 10^{-3}$$

$$\left(\frac{2}{75 \times 10^{-3}} \times 0.15 \times 30\right) - 15 = R$$

$R = 105\ \Omega$

(ii) Potentiometer is preferred over a voltmeter for comparison of emf of cells because at null point, it does not draw any current from the cell and thus there is no potential drop due to the internal resistance of the cell. It measures the p.d. in an open circuit which is equal to the actual emf of the cell.

(iii)