CHAPTER 3

# Current Electricity

## Syllabus

- **Electric current and resistance:** Electric current; Flow of electric charges in a metallic conductor; Drift velocity; Relationship between electric current; Relationship between current density and drift velocity; Mobility of electron; Ohm's law; Electrical resistance; V-I characteristics; Electrical resistivity; Conductivity; Electrical Energy; Electrical Power; Carbon resistor, colour code for carbon resistor; Series and parallel combination of resistors; Temperature dependence of resistance.
- **Electric cell and bridges:** Electromotive force of a cell; Internal resistance; Potential difference; Combination of cells in series and parallel; Kirchhoff's law and its application; Wheatstone bridge; Meter bridge or slide-wire bridge; Potentiometer.

## MIND MAP

**CURRENT ELECTRICITY**

- Electric Current and Resistance
  - Electric current (Time rate of flow of charges through any conductor) $I = \frac{q}{t}$
  - Ohm's law (Current flowing through a conductor is directly proportional to potential difference across the ends of the conductor)
  - Electric resistance (Obstruction posed by conductor to flow of electric current through it) $R = \rho \frac{l}{A}$
  - Combination of resistances
    - In series $R_s = R_1 + R_2 + R_3 + \ldots + R_n$
    - In parallel $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_n}$
- Electric Cell and Bridges
  - Electric cell (Device used to generate electricity)
    - Combination of cell
      - In series
      - In parallel
      - In Mixed
    - Kirchhoff's law
      - Kirchhoff's first law $M = \frac{\mu N_1 N_2 A}{l}$
      - Kirchhoff's second law $\Sigma E = \Sigma IR$
  - Electric bridges
    - Wheatstone bridge (Condition for a balanced bridge) $\frac{P}{Q} = \frac{R}{S}$
    - Meter bridge (Balanced wheat stone bridge principle)
  - Potentiometer
    - Used to compare emfs
    - To find internal resistance of cell

**Mind Map:** Current Electricity at a Glance

# RECAP

## Electric Current and Resistance

### Electric Current

- The time rate of flow of charges through any conductor is called as **electric current.**

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

- If $\Delta Q$ be the net charge flowing across a cross-section of a conductor during the time interval $\Delta t$ [i.e., between times $t$ and $(t + \Delta t)$]. Then, the current at time $t$ across the cross-section of the conductor is defined as the value of the ratio of $\Delta Q$ to $\Delta t$ in the limit of $\Delta t$ tending to zero,

$$I(t) \equiv \lim_{\Delta t \to 0} \frac{\Delta Q}{\Delta t}$$

- Unit of electric current is ampere (A) in SI system and stat ampere in CGS system and its dimensional formula is $[M^0L^0T^0A^1]$.
- Electric current is a scalar quantity and is due to the flow of:
  - electrons in conductors.
  - electrons and holes in semiconductors.
  - coherent pairs of electrons in superconductor.
  - positive and negative ions in electrolyte.
  - positive ions and electrons in gases.
- Electric current is of two types:
  - **Alternating current (AC):** It is the current whose magnitude as well as direction varies with time.
  - **Direct current (DC):** It is the current whose magnitude varies with time while the direction remains unchanged (constant).

### Flow of Electric Charges in a Metallic Conductor

- In a metallic conductor, free electrons (having negative charge) act as the electric charge carriers. Examples: Silver, copper, aluminium etc.
- The free electrons in a conductor are always in a state of random motion with a velocity of the order of $10^4$ m/s. The net flow of an electric charge in a conductor without application of a potential difference is zero.
- The application of electric potential difference (or electric field) gives the flow of electric charges i.e., electric current through the conductor.
- The electric current flows from higher potential to lower potential. The direction of electric current is conventionally opposite to the direction of flow of electrons.
- The net charge in current carrying conductor is zero.

### Drift Velocity

- At any temperature, electrons in a metal move randomly in all directions like ideal gas particles. When an electric field is applied, each electron experiences an acceleration of $(eE/m)$ opposite to field direction. But the acceleration is momentary, because electrons loose the gained velocity due to collisions with vibrating atoms or ions or other free electrons.
- The average velocity with which electrons get drifted towards the positive end of the conductor under the influence of an external applied electric field is called drift velocity ($v_d$).

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

- Negative sign shows that the direction of drift velocity for electrons in a conductor is opposite to that of the applied 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 in SI system and cm/s in CGS system and its dimensional formula is $[M^0L^1T^{-1}]$.

## Relationship between Electric Current and Drift Velocity

$$I = nAev_d$$

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

- Current density $J$, at any point inside a conductor, is a vector quantity whose magnitude is equal to the current per unit area through an infinitesimal area at that point, the area being held perpendicular to the direction of flow of charge and its direction is along the direction of flow of positive charge.

$$J = nev_d$$

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

## Mobility of Electron

- The drift velocity acquired by the free electrons per unit strength of the electric field applied across the conductor is called as mobility of (free) electrons in a conductor.

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

- Mobility is positive for both electrons and holes whereas their drift velocities are in opposite direction to each other.
- The SI unit of mobility is $m^2V^{-1}s^{-1}$ and its dimensional formula is $[M^{-1}L^0T^2A]$.

## Ohm's Law

- The current ($I$) flowing through a conductor is directly proportional to the potential difference ($V$) across the ends of the conductor, provided that the physical conditions of the conductor (length, temperature, mechanical strain etc.) are kept constant.
  Mathematically,

$$V \propto I$$

$$\therefore \quad V = IR$$

  where,
  $R$ = constant of proportionality
- This constant of proportionality is known as electrical resistance of a conductor.

## Electrical Resistance

- The property of a conductor by virtue of which it opposes the flow of current through it is known as electrical resistance.
- The ratio of potential difference applied ($V$) across the ends of conductor to the current ($I$) flowing through it is called electrical resistance ($R$).

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

  - Resistance of a conductor changes with temperature.

    $R \propto T$

  - Resistance of a conductor is directly proportional to its length.

    $R \propto l$

  - Resistance of a conductor is inversely proportional to its area of cross-section.

    $$R \propto \frac{1}{A}$$

  - Volume of the conductor (or wire) remains unaffected by the stretching of conductor, $A_1 l_1 = A_2 l_2$ and resistance changes from $R_1$ (before stretching) to $R_2$ (after stretching)
    where,

$A_1, A_2$ = Areas of cross-section of a conductor before and after stretching
$l_1, l_2$ = lengths of conductor before and after stretching

- Ratio of resistances before and after stretching of a conductor is,

$$\frac{R_1}{R_2} = \frac{l_1}{l_2} \times \frac{A_2}{A_1}$$

- Unit is volt/ampere or ohm (Ω) in SI system and its dimensional formula is $[M^1L^2T^{-3}A^{-2}]$.
- The reciprocal of resistance is called conductance (G). Its unit is mho ($\Omega^{-1}$) or Siemens (S).

## V-I Characteristics

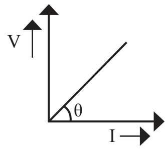


**Figure:** *V-I* characteristic for an ideal resistor

- The voltage-current characteristics (*V-I* curves) are linear for the substances obeying Ohm's law (ohmic substances).
  Example: Metallic conductors
  - Slope of the line,

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

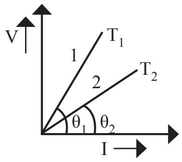


**Figure:** *V-I* Characteristic curve at different temperature

- The V-I curves are different at different temperatures.

$$\tan\theta_1 > \tan\theta_2$$

So, $R_1 > R_2$

i.e., $T_1 > T_2$

- Ohm's law is valid only for metallic conductors. So they are called ohmic substances.
- The V-I curves are non-linear for the substances not obeying Ohm's law (non-ohmic substances). Examples: Gases, crystal rectifiers, transistors etc.

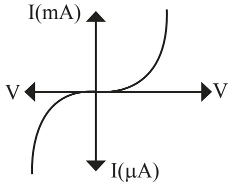


**Figure**: *V-I* characteristic curve of a diode

## Electrical Resistivity

- The opposition offered by the conductor to the flow of electric current or charge through it is called its resistance.
- The resistance offered by a conductor of unit length and unit area of cross-section is called the electrical resistivity or specific resistance of the material of the conductor.

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

where $\rho$ is the constant of material of conductor known as its 'resistivity' or 'specific resistance'.

- The resistivity is the intrinsic property of the material of a conductor. It is independent of the shape and size of the conductor.
- Resistivity of a conductor depends only on the material of conductor and not on its dimensions. When a potential difference $V$ is applied across a conductor of length $l$ and cross-section area $A$, then all the free electrons in conductor start moving with drift velocity $v_d$ given by,

$$v_d = \frac{eV\tau}{ml}$$

So electric current starts flowing through the conductor given by,

$$I = neAv_d = \frac{neAeV\tau}{ml} = \frac{ne^2\tau AV}{ml}$$

or, $$R = \frac{ml}{ne^2\tau A} = \frac{ml}{ne^2\tau A}$$

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

- The SI unit of resistivity is Ω m and its dimensional formula is $[ML^3T^{-3}A^{-2}]$.

## Conductivity

- The reciprocal of resistivity of the material of a conductor is called its conductivity.

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

- Unit of conductivity is $ohm^{-1}m^{-1}$ or mho $m^{-1}$ or $Sm^{-1}$ in SI system and its dimensional formula is $[M^{-1}L^{-3}T^{3}A^{2}]$.
- The relation between current density ($J$) and conductivity ($\sigma$),

$$\sigma = \frac{J}{E}$$

- Relation between mobility (μ) and conductivity ($\sigma$),

$$\sigma = ne\mu$$

- Relation between drift velocity ($v_d$) and conductivity ($\sigma$),

$$\sigma = ne\frac{v_d}{E}$$

- Materials are subdivided into conductors (metals), semiconductors and insulators according to their conductivity.
- Metals are good conductors, insulators are bad conductors while conductivity of semiconductor lies in between that of conductors and insulators.

**Table:** Resistivity of metal, semiconductor, and insulator

| Conductor | | Semiconductor | | Insulator | |
|---|---|---|---|---|---|
| Name of the substance | Resistivity in ohm meter | Name of the substance | Resistivity in ohm meter | Name of the substance | Resistivity in ohm meter |
| Silver | $1.47 \times 10^{-8}$ | Carbon | $3.5 \times 10^{-5}$ | Amber | $5 \times 10^{14}$ |
| Copper | $1.72 \times 10^{-8}$ | Germanium | 0.60 | Glass | $10^{-10}$ - $10^{14}$ |
| Aluminium | $2.63 \times 10^{-8}$ | Silicon | 2300 | Lucite | $> 10^{13}$ |
| Tungsten | $5.51 \times 10^{-8}$ | | | Mica | $10^{11}$ - $10^{15}$ |
| Iron | $10 \times 10^{-8}$ | | | Quartz (fused) | $75 \times 10^{16}$ |
| Platinum | $11 \times 10^{-8}$ | | | Sulphur | $10^{15}$ |
| Mercury | $98 \times 10^{-8}$ | | | Teflon | $> 10^{13}$ |
| | | | | Wood | $10^{8}$ - $10^{11}$ |
| | | | | Hard rubber | $10^{13}$ - $10^{16}$ |

## Electrical Energy

- The total work done (or energy supplied) by the source of an emf in maintaining the electric current in the circuit for the given time is called electric energy consumed in the circuit.

$$W = Vq = VIt; \text{ Electric energy } = \text{ Electric power } \times \text{time } = P \times t$$

- This work done produces heat ($H$) in the conductor,

$$H = I^2Rt$$

- The SI unit of electrical energy is joule (J) and erg in CGS and dimensional formula is $[M^{1}L^{2}T^{-2}]$.
- The commercial unit of electric energy is kilowatt-hour (kWh),
  1 kWh = 1000 Wh = $3.6 \times (10^6)$ = one unit of electricity consumed
- The number of units of electricity consumed is,

$$n = \frac{\text{total wattage} \times \text{time in hour}}{1000}$$

- Bill of electricity i.e., the cost of consumption of electricity in a house = no. of units of electricity consumed × amount for one unit of electricity.

## Electric Power

- The rate at which work is done by the source of emf in maintaining the electric current in a circuit is called electric power of the circuit.

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

- The SI unit of power is watt (W). The practical unit of power is kilowatt (kW) and horse power (hp) and its dimensional formula is $[M^1L^2T^{-3}]$.

  1 kilowatt = 1000 watt; 1 hp = 746 watt

- **Power-voltage rating**
  - The power-voltage rating of an electrical appliance is the electrical energy consumed per second by the appliance when connected across the marked voltage of the mains.
  - It determines the resistance of the device and the current it will draw (at constant voltage).

  Current, $I = \frac{P}{V}$; Resistance, $R = \frac{V^2}{P}$

## Carbon Resistors, Colour Code for Carbon Resistors

- The resistor made from carbon with a suitable binding material moulded into a cylinder is known as a carbon resistor.
- The resistor is encased in a plastic jacket or a ceramic jacket. It is connected to the circuit by means of two leads (wires).
- The values of (resistance of) carbon resistors are marked on them according to a colour code.
- These codes are printed on the jacket of resistors in the form of a set of rings (strips or bands) of different colours.
- Colour code i.e., colours of bands are different for different resistors.
- The carbon resistor has four coloured rings (or bands) as shown in the figure.

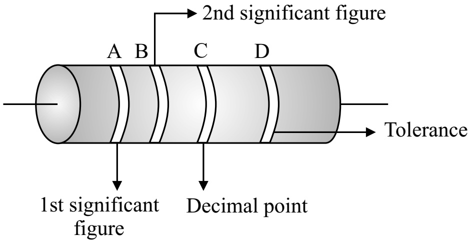



**Figure:** Carbon resistor with coloured rings

**Table:** Colour code for carbon resistor

| Colour | Letter as an aid to memory | Figure (A,B) | Multiplier (C) |
|---|---|---|---|
| Black | B | 0 | $10^0$ |
| Brown | B | 1 | $10^1$ |
| Red | R | 2 | $10^2$ |
| Orange | O | 3 | $10^3$ |
| Yellow | Y | 4 | $10^4$ |
| Green | G | 5 | $10^5$ |
| Blue | B | 6 | $10^6$ |
| Violet | V | 7 | $10^7$ |
| Grey | G | 8 | $10^8$ |
| White | W | 9 | $10^9$ |
| Gold | | | $10^{-1}$ |
| Silver | | | $10^{-2}$ |

**Table:** Tolerance in percent for carbon resistor

| Colour | Tolerance |
|---|---|
| Gold | ±5% |

| | |
|---|---|
| Silver | ±10% |
| No colour | ± 20% |

## Series and Parallel Combinations of Resistors

- **Series combination of resistors:** The number of resistors are said to be connected in series, if the same current is flowing through each resistor when some potential difference is applied across the combination.
- The current in the circuit is independent of the relative positions of various resistors connected in series.
- The voltage across any resistor is directly proportional to the resistance of that resistor,

  $V \propto R$

- The equivalent resistance ($R_s$) for series combination is given by, (including internal resistance of cell if any)

  $R_s = R_1 + R_2 + R_3 + \ldots + R_n$

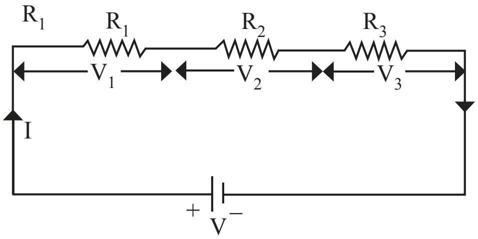



**Figure:** Series combination of resistors

- The equivalent (series) resistance is greater than the maximum value of the resistance in the combination.
- For $n$ identical resistances connected in series,

  $$R_s = nR; \text{ and, } V' = \frac{V}{n}$$

- **Parallel combination of resistors:** The number of resistors are said to be connected in parallel if potential difference across each of them is the same and is equal to the applied potential difference.
- Current through each resistor is inversely proportional to the resistance of that resistor.

  $$I \propto \frac{1}{R}$$

- Total current through a parallel combination is the sum of the individual currents through the various resistors.

  $I = I_1 + I_2 + I_3 + \ldots + I_n$

- The reciprocal of the equivalent resistance ($R_p$) for parallel combination is given by,

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

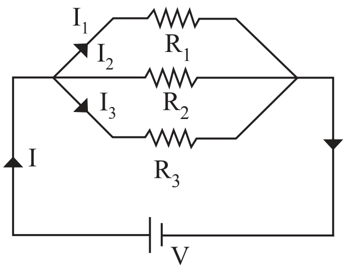



**Figure:** Parallel combination of resistors

- The equivalent resistance ($R_p$) of a parallel combination is less than the least resistance connected in the circuit.
- Current through any resistor (branch current) I′ is given by,

  $$I' = I\left(\frac{\text{Resistance of opposite branch}}{\text{Total resistance}}\right)$$

- For $n$ identical resistances connected in parallel combination,

  $$R_p = \frac{R}{n} \text{ and, } I' = \frac{I}{n}$$

  where,
  $I'$ = current through each resistance ($R$); $I$ = Total current or main current in the circuit

## Temperature Dependence of Resistance

- Effect of temperature on resistance of a material depends on the nature of the material.
- For metallic conductors, resistance is given by,

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

- As the temperature increases, the relaxation time ($\tau$) decreases and the resistance increases in the metallic conductor i.e.,

$$T \propto \frac{1}{\tau} \propto R$$

- Resistance $R_T$ for a metallic conductor at temperature $T$ °C (not sufficiently large) is given by,

$$R_T = R_0(1+\alpha T)$$

$$\therefore \quad \alpha = \frac{R_T - R_0}{R_0 T}$$

- The temperature coefficient of resistance is defined, as the increase in resistance per unit original resistance per degree rise of temperature. The unit of a is $K^{-1}$ or $^\circ C^{-1}$.
- **For metals:** The value of $\alpha$ is positive. The resistance of a metal increases with increase in temperature. The filament of electric bulb (tungsten) and element of heating devices (nichrome) have high resistivities and high melting points.
- **For insulators and semiconductors:** The value of $\alpha$ is negative. The resistance decreases with rise in temperature.
- **For alloys:** The value of a is very small as compared to that for metals. The resistance boxes (manganin, constantan, eureka) and fuse wire (tin lead) have moderate or high resistivities and low melting points.
- **For thermistor:** Value of a is very high (positive or negative). Resistance of thermistors changes very rapidly with change in temperature. Oxides of various metals (nickel, copper, cobalt, iron etc.) are used to prepare heat sensitive resistors.
- **For superconductors:** At very low temperatures, certain metals [mercury (4.2 K), niobium (9.2 K)] or alloys [plutonium, cobalt and gallium (below 18.5 K)] lose their resistances completely i.e., $R = 0$.

## Electric Cell and Bridges

### Electromotive Force (emf) of a Cell

- The potential difference between the two terminals (poles) of a cell in an open circuit (when no current is drawn from the cell) is called electromotive force (emf) of the cell. Or, the energy supplied by the cell to drive a unit charge round the complete circuit is known as electromotive force (emf) of the cell.

$$E = V + Ir$$

- Electromotive force is the work done per unit charge to drive the carriers of electricity.
- 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.

### Internal Resistance

- The resistance offered by the electrolyte and electrodes of a cell when the electric current flows through it is called as the internal resistance of cell.

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

- The internal resistance of a cell depends on:
  - The distance ($d$) between electrodes, $r \propto d$
  - The area ($A$) of electrodes, $r \propto \frac{1}{A}$
  - The nature of the material of electrodes.
  - The concentration ($C$) of electrolytes, $r \propto C$
  - The temperature ($T$) of electrolyte, $r \propto \frac{1}{T}$
- The value of internal resistance is very low for freshly prepared cells and it increases with the use of the cell.
- If the internal resistance of a cell is zero, then the cell is known as an ideal cell.

## Potential Difference

- The potential difference between the two poles of a cell in a closed circuit (when current is drawn from the cell) is called the potential difference or terminal voltage.

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

- Unit of potential difference is volt (V) in SI system and stat-volt in CGS system.
- The potential difference across the internal resistance of the cell falls (or drops) due to the flow of current through it $(V = Ir)$.
- In a closed circuit, the terminal potential difference is less than emf of the cell.

$$(V < E);\ I = \frac{E}{R+r}$$

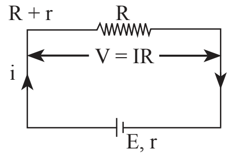



**Figure:** Closed circuit

- In an open circuit, $V = E,\ I = 0$

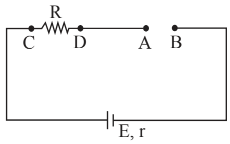



**Figure:** Open circuit

- In short circuit condition, $V = 0,\ I_{sc} = \frac{E}{r}$
- During the charging of a cell, current is given to the cell thus, $E = V - Ir$ and $E < V$.
- Power dissipated in the external resistance (load),

$$P = VI = I^2R = \left(\frac{E}{R+r}\right)^2 R$$

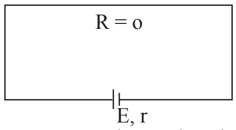



**Figure:** Short circuit

- Power delivered will be maximum if $R = r$

$$\therefore\ P_{max} = \frac{E^2}{4r}$$

## Combination of Cells in Series and Parallel

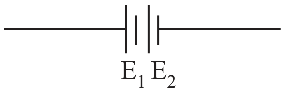



**Figure:** Series combination of cells

- **Series combination of cells:** In series combination of cells, the anode of one cell is connected to the cathode of other cell and soon.
  - The equivalent emf here is sum of emfs of individual cells.

$$E_{nett} = E_1 + E_2$$

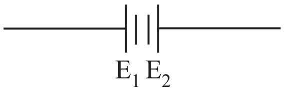



**Figure:** Series combination but oppose each other

  - If the cells oppose each other then,

$$E_{net} = E_1 - E_2$$

  - **For *n* identical cells in series:**
    - Equivalent emf of the series combination,

$$E_s = nE$$

    - Equivalent internal resistance,

$$r_s = nr$$

    - Main current is equal to the current from each cell,

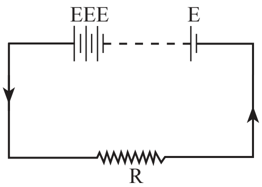



**Figure:** *n* identical cells in series

Main current = Current from each cell $I = \frac{nE}{R+nr}$

When $R < nr,\ I_{min} = \frac{nE}{nr} = \frac{E}{r}$ = the current due to single cell

When $R >> nr,\ I_{max} = \frac{nE}{R} = n$ times the current due to a single cell

- Potential difference across each cell,

$$V' = \frac{V}{n}$$

- Power dissipated in the external circuit,

$$= \left(\frac{nE}{R+nr}\right)^2 R$$

- Condition for maximum power,

$R = nr$ and, $p_{max} = n\left(\frac{E^2}{4r}\right)$

- The series combination of cells is used when $R >> nr$ to obtain maximum current.

**Parallel combination of cells:** In parallel combination of cells, all anodes are connected at one point and all cathode are connected together at other point.

- Here, potential difference ($V$) across the terminals of first cell equals potential difference across the terminals of second cell. It is given as,

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

$$\therefore \quad E_{eq} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}; r_{eq} = \frac{r_1 r_2}{r_1 + r_2}$$

and, $I = I_1 + I_2$

where, $I_1 = \frac{E_1 - V}{r_1}$ and, $I_2 = \frac{E_2 - V}{r_2}$

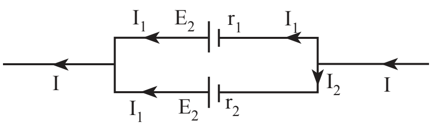



**Figure:** Parallel combination of cells

- **For *n* identical parallel cell:**
  - Equivalent emf of parallel combination,

$$E_p = E$$

  - Equivalent internal resistance,

$$r_p = \frac{r}{n}$$

  - Main current,

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

When $R >> \frac{r}{n}, I_{min} = \frac{E}{R} =$ the current due to a single cell

When $R << \frac{r}{n}, I_{max} = \frac{E}{r/n} = n\frac{E}{r} = n$ times the current due to a single cell

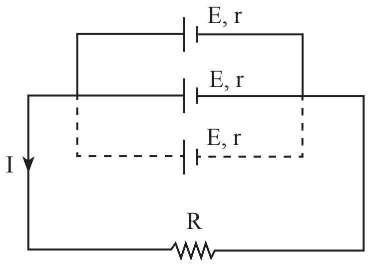



**Figure:** *n* identical cells connected in parallel combination

  - Potential difference across external resistance is equal to potential difference across each cell.

$V = IR$

  - Current from each cell,

$$I' = \frac{I}{n}$$

  - Power dissipated in the circuit,

$$P = \left(\frac{E}{R + \frac{r}{n}}\right)^2 \cdot R$$

- Condition for maximum power is,

$$R = \frac{r}{n}; \text{ and } P_{max} = n\left(\frac{E^2}{4r}\right)$$

- The parallel combination of cells is used when $R << nr$ to obtain maximum current.

- **Mixed combination of cells:** $n$ identical cells are connected in row (in series) and $m$ rows are connected in parallel.
  - Total number of cells is $mn$.
  - Equivalent emf of the combination.

$$E_{sp} = nE$$

  - Equivalent internal resistance of the combination,

$$r_{sp} = \frac{nr}{m}$$

  - Main current flowing through the load,

$$I = \frac{nE}{R + \frac{nr}{m}} = \frac{mnE}{mR + nr}$$

  - Potential difference across load,

$V = IR$

  - Potential difference across each cell,

$$V' = \frac{V}{n}$$

  - Current from each cell,

$$I' = \frac{I}{n}$$

  - Condition for maximum power,

$$R = \frac{nr}{m}; \text{ and; } P_{max} = (mn)\frac{E^2}{4r}$$

  - The mixed combination of cells is used when $R = r$ to obtain maximum current.

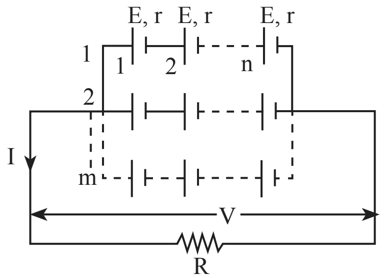


**Figure:** Mixed combination of cells

## Kirchhoff's Law and its Application

- **Kirchhoff's law:** Kirchhoff in 1942 put forward the following two laws to solve the complicated circuits.
  - **Junction rule or Kirchhoff's first law or Kirchhoff's current law (KCL):** The algebraic sum of the currents meeting at a junction (point) in an electrical circuit is always zero. Or, the sum of currents flowing towards the junction is equal to sum of currents leaving the junction.
    $\Sigma I = 0; I_1 + I_3 = I_2 + I_4$
    - It is the statement of conservation of charge.
    - Sign convention:
      - The current flowing (through a conductor) towards the junction is taken as positive.
      - The current flowing away from the junction is taken as negative.
  - **Loop rule or Kirchhoff's second law or Kirchhoff's voltage law (KVL):** In any closed part (loop) of an electrical circuit, the algebraic sum of emfs is equal to the algebraic sum of product of the resistances and currents flowing through them.

    $\Sigma E = \Sigma IR$
    - This law represents conservation of energy.
    - Sign convention:
      - Current flowing in anticlockwise direction is positive and that in clockwise direction is taken as negative.

- emf sending current in circuit in anticlockwise direction is positive and one sending current in clockwise direction is negative.

- **Applications of Kirchhoff's Laws**
  - If a skeleton cube formed by using 12 wires each of resistance $R$ ohm, then the total resistance between two diagonally opposite comers of the cube = $5R/6$ ohm.
  - If a skeleton cube formed by using 12 wires each of resistance $R$ ohm, then the total resistance between the comers of the same edge of cube = $7R/12$ ohm.
  - If a skeleton cube formed by using 11 wires each of resistance $R$ ohm, then the total resistance from one end of vacant edge to the other end is = $7R/5$ ohm.

## Wheatstone Bridge

- It is arrangement of four resistances, measure one (unknown) of them in terms of rest of them. Arms AB and BC are ratio arms and AC and BD are conjugate arms.
- Measurement of unknown resistance is not affected by internal resistance of the battery, current and potential difference (i.e., ammeter and voltmeter).
- The value of unknown resistance can be measured to a very high degree of accuracy by increasing the ratio of the resistances ($P$ and $Q$) in arms AB and BC.
- Practical applications are 'meterbridge', 'post office box' and 'Carey Foster's bridge'.

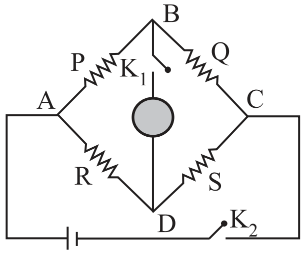


**Figure:** Wheatstone bridge

- **Balanced bridge:**
  - It is balanced when in closed circuit, deflection in galvanometer is zero i.e., no current flows through the galvanometer. The condition for a balanced bridge is,

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

  - In the balanced position of bridge, $V_B = V_D$. The condition for balanced bridge remains unchanged on mutual interchange in the positions of cell and galvanometer in the circuit.
  - The wheatstone bridge is the most sensitive if the resistances of all the four arms are same i.e., $P=Q=R=S$
  - The condition for a balanced bridge can be obtained by using Kirchhoff's laws.
- **Unbalanced bridge:**
  - It is unbalanced if in closed circuit galvanometer shows deflection.
  - If $R > \frac{QS}{P}$ then current flows from B to D.
  - If $R < \frac{QS}{P}$ then current flows from D to B.
  - If $V_D > V_B$,

    $(V_A - V_D) < (V_A - V_B)$ then $PS > RQ$

## Meter Bridge or Slide-Wire Bridge

- Meter bridge is a simple practical form of a wheat stone bridge. It is constructed on the principle of balanced wheat stone bridge. The balancing condition is, $\frac{P}{Q}=\frac{R}{S}$
- The resistances $R$ and $S$ (unknown resistance) are connected in the left and right gaps of the meter bridge.
- Resistances $P$ and $Q$ are considered along conducting wire AC (L = 100 cm) wrt balancing point B such that $P \propto$ AB and $Q \propto$ BC.
- **Applications of meter bridge:**
  - Measurement of unknown resistance ($s$):
    - If in balance position of bridge,

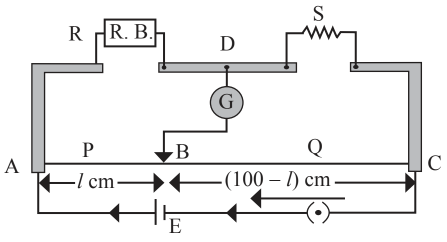


**Figure:** Meter bridge

$AB = l,\ BC = (100 - l)$ so, $\dfrac{Q}{P} = \dfrac{(100-l)}{l}$

Also, $\dfrac{P}{Q} = \dfrac{R}{S}$

$$\Rightarrow\ S = \frac{(100-l)}{l}R$$

- The meter bridge cannot be used to measure very low (< 1 Ω) or very high (> 10000 Ω) resistances.

- Comparison of two unknown resistances:
  - The values of $P$ and $Q$ are obtained for both the unknown resistances ($R_1$ and $R_2$) by connecting them in the right gap of the meter bridge(s) one by one.

$$\frac{P}{Q} = \frac{l_1}{(100-l_1)}$$

$$\Rightarrow \frac{P}{Q} = \frac{R}{R_1}$$

$$\Rightarrow R_1 = \frac{R(100-l_1)}{l_1}$$

  - Similarly,

$$R_2 = \frac{R(100-l_2)}{l_2}$$

$$\Rightarrow \frac{R_1}{R_2} = \frac{l_2}{l_1} \times \frac{(100-l_1)}{(100-l_2)}$$

  - Knowing the values of $l_1$ and $l_2$, the ratio of $R_1$ and $R_2$ can be found.

- **Measurement of unknown temperature:**
  - The unknown temperature ($T$ °C) of an unknown resistance $X$ (in the form of metallic wire) is measured by connecting it in the right gap of the meter bridge.
  - The value of $R_T$ at unknown temperature $T$ °C is found by knowing the values of $R_0$ at 0 °C (in ice) and $R_{100}$ at 100 °C (in steam) and using formula,

$$T^{\circ}\text{C} = \frac{R - R_0}{R_{100} - R_0} \times 100$$

  - The balanced position of meter bridge is not affected on inter changing the position of battery and galvanometer. The balance point of the meter bridge is constant even if the emf of a cell is not constant.

## Potentiometer

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

$$V \propto L;\ V = xL$$

- The potential gradient can be written in different forms as,

$$x = \frac{V}{L} = \frac{IR}{L} = \frac{I\rho}{A} = \left(\frac{Ea}{R + R_h + r}\right)\frac{R}{L}$$

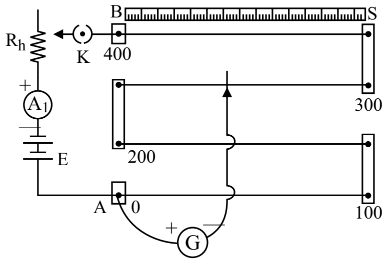



**Figure:** Potentiometer

- Potentiometer is balanced when no current flows through galvanometer circuit while sliding jockey on wire i.e., $V = E$. This is null deflection position, (point J on wire AB and AJ is balancing length). In balanced condition, $E - xl$

If $V$ is constant then,

$$L \propto l$$

$$\Rightarrow \frac{x_1}{x_2} = \frac{L_1}{L_2} = \frac{l_1}{l_2}$$

- The potentiometer is sensitive as it measures small potential differences more accurately.
- The sensitivity of a potentiometer is directly proportional to the potential gradient.
- **Applications of potentiometer**
  - **Determination of potential difference using potentiometer:** The circuit diagram to determine potential difference using potentiometer is shown in figure.
    - To determine potential difference across points C and D, first standard cell of known emf $E$ is connected instead of resistance $R$. Using jockey, null deflection position is determined to obtain potential gradient $x$.

$$x = \frac{E}{L}$$

    - Standard cell is replaced by resistance $R$ and null deflection position is obtained to find balancing length AJ i.e., $l$ thus,

$$V = xl = \frac{E}{L}l$$

  - **Comparison of emfs of two cells using potentiometer:** The circuit diagram is shown in figure.
    - The secondary circuit of potentiometer is closed using two way key K (between 1 and 3).
    - Null deflection position is obtained at point J for cell $E_1$ (emf $E_1$). The balancing length is AJ = $l_1$. According to principle of potentiometer,

$E_1 = xl_1$ ...(i)

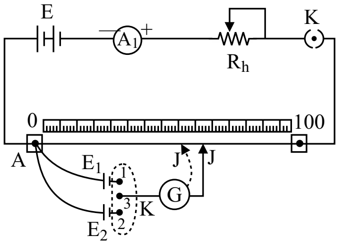


**Figure:** Comparison of emfs of two cells using potentiometer

    - Now, the secondary circuit is closed using two way key K′ (between 2 and 3 closed and 1 and 3 open). The null deflection position is obtained at point J′ for cell $E_2$ (emf $E_2$). The balancing length is AJ′ = $l_2$
    - According to principle of potentiometer,

$E_2 = xl_2$ ...(ii)

From equations (i) and (ii),

$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$

  - **Determination of internal resistance of a cell using potentiometer:** The circuit diagram is shown in figure.
    - Primary circuit of potentiometer is closed using key K and null deflection position (null point) is obtained using jockey to balance emf ($E$) of the cell $E'$ (whose internal resistance ($r$) is to be found). The balancing point is obtained at point J on wire AB such that AJ = $l_1$ then,

$E = xl_1$...(i)

    - The secondary circuit with battery $E'$ is closed with key $K'$ and null deflection position is obtained using jockey to balance terminal potential difference ($V$) between two poles of cell $E'$.
    - Balancing point is obtained at J′ on wire AB such that $AJ' = l_2$ then,

$V = xl_2$ ...(ii)

from eq. (i) and (ii),

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

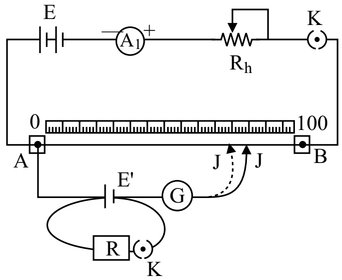


**Figure:** Determination of potential difference using potentiometer

    - The internal resistance ($r$) of a cell is given by,

$$r' = \left(\frac{E}{V} - 1\right)R$$

from eq.(iii),

$$r = \left(\frac{l_1}{l_2} - 1\right)R = \left(\frac{l_1 - l_2}{l_2}\right)R$$

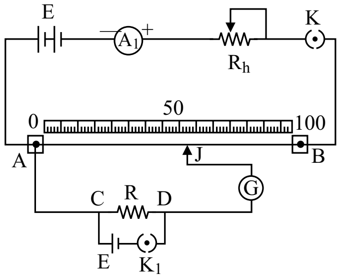


**Figure:** Determination of potential difference using potentiometer

- **Advantages of potentiometer**
  - It measures emf of a cell very accurately, it does not draw any current from the source of known emf and the resistance of potentiometer becomes infinite.
  - Its sensitivity is high and is based on the null deflection method.

# PRACTICE TIME

## Electric Current and Resistance

**1.** The carriers of electricity in a metallic conductor are ______

(a) holes (b) negative ions
(c) positive ions (d) electrons

**2.** The time rate of flow of charge through any cross-section of a conductor is ______

(a) electric potential (b) electric current
(c) electric intensity (d) electric charge

**3.** When no current is passed through a conductor:

(a) the free electrons do not move
(b) the average speed of a free electron over a large period of time is not zero
(c) the average velocity of a free electron over a large period of time is zero
(d) the average of the velocities of all the free electrons at an instant is non-zero

**4.** A steady current is flowing through a conductor of non-uniform cross-section. The charge passing through any cross-section of it per unit time is:

(a) directly proportional to the area of cross-section
(b) inversely proportional to the area of cross-section
(c) proportional to square of the area of cross-section
(d) independent of the area of cross-section

**5.** Drift velocity of electrons is due to:

(a) motion of conduction electrons due to random collisions.
(b) motion of conduction electrons due to electric field *E*.
(c) repulsion to the conduction electrons due to inner electrons of ions.
(d) collision of conduction electrons with each other.

**6.** Match the Column I and Column II.

| | Column I | | Column II |
|---|---|---|---|
| A | Smaller the resistance greater the current | (i) | If the same voltage is and resistance are in series applied |
| B | Greater or smaller the resistance the current is same | (ii) | If the same current is passed |
| C | Greater the resistance smaller the power | (iii) | When resistances are connected in series |
| D | Greater the resistance greater the power | (iv) | When resistances are connected in parallel |

(a) A-(iii), B-(i), C-(ii), D-(iv)
(b) A-(i), B-(iii), C-(ii), D-(iv)
(c) A-(ii), B-(i), C-(iv), D-(ii)
(d) A-(iv), B-(iii), C-(i), D-(ii)

**7.** Given a current carrying wire of non-uniform cross-section. Which of the following is constant throughout the length of the wire?

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

**8.** A current passes through a wire of non-uniform cross-section. Which of the following quantities are independent of the cross-section?

(a) the charge crossing
(b) drift velocity
(c) current density
(d) free electron density

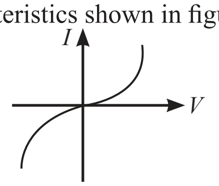
**9.** A cross metallic conductor of non-uniform cross-section a constant potential difference is applied. The quantity which remains constant along the conductor ______:

(a) current density (b) current
(c) drift velocity (d) electric field

**10.** Identify the set in which all the three materials are good conductors of electricity:

(a) Cu, Ag and Au (b) Cu, Si and diamond
(c) Cu, Hg and NaCl (d) Cu, Ge and Hg

**11.** The *I*-*V* characteristics shown in figure represents:




(a) ohmic conductors
(b) non-ohmic conductors
(c) insulators
(d) superconductors

**12.** In the equation $AB = C$, $A$ is the current density, $C$ is the electric field, Then $B$ is:
(a) resistivity (b) conductivity
(c) potential difference (d) resistance

**13.** If a current of 0.5 A flows in a 60 W lamp, then the total charge passing through it in two hours will be:
(a) 1800 C (b) 2400 C
(c) 3000 C (d) 3600 C

**14.** The relaxation time in conductors:
(a) increases with the increases of temperature
(b) decreases with the increases of temperature
(c) it does not depend on temperature
(d) all of sudden changes at 400 K

**15.** A steady current of 1 A is flowing through the conductor. The number of electrons flowing through the cross-section of the conductor in 1 sec is:
(a) $6.25 \times 10^{15}$ (b) $6.25 \times 10^{17}$
(c) $6.25 \times 10^{19}$ (d) $6.25 \times 10^{18}$

**16.** A metal wire is subjected to a constant potential difference. When the temperature of the metal wire increases, the drift velocity of the electron in it:
(a) increases, thermal velocity of electron increases
(b) decreases, thermal velocity of electron increases
(c) increases, thermal velocity of electron decreases
(d) decreases, thermal velocity of electron decreases

**17.** Current of 4.8 amperes is flowing through a conductor. The number of electrons crossing any cross-section per second will be:
(a) $3 \times 10^{19}$ (b) $7.68 \times 10^{21}$
(c) $7.68 \times 10^{20}$ (d) $3 \times 10^{20}$

**18.** If $N$, e, $\tau$ and $m$ are representing electron density, charge, relaxation time and mass of an electron respectively, then the resistance of wire of length $l$ and cross-sectional area $A$ is given by:
(a) $\frac{m\ell}{Ne^2A^2\tau}$ (b) $\frac{2m\tau A}{Ne^2\ell}$
(c) $\frac{Ne^2\tau A}{2m\ell}$ (d) $\frac{Ne^2A}{2m\tau\ell}$

**19.** $10^6$ electrons are moving through a wire per second, the current developed is:
(a) $1.6 \times 10^{19}$ A (b) 1 A
(c) $1.6 \times 10^{13}$ (d) $10^6$ A

**20.** The electric resistance of a certain wire of iron is $R$. If its length and radius are both doubled, then:
(a) the resistance and the specific resistance will both remain unchanged
(b) the resistance will be doubled, and the specific resistance will be halved
(c) the resistance will be halved, and the specific resistance will remain unchanged
(d) the resistance will be halved, and the specific resistance will be doubled

**21.** The direction of drift velocity in a conductor is:
(a) opposite to that of applied electric field
(b) opposite to the flow of positive charge
(c) in the direction of the flow of electrons
(d) All of these

**22.** Two wires A and B of the same material, having radii in the ratio 1:2 and carry currents in the ratio 4:1. The ratio of drift speed of electrons in A and B is:
(a) 16:1 (b) 1:16
(c) 1:4 (d) 4:1

**23.** The quantity of a charge that will be transferred by a current flow of 20 A over 1 hour 30 minutes period is:
(a) $10.8 \times 10^3$ C (b) $10.8 \times 10^4$ C
(c) $5.4 \times 10^3$ C (d) $1.8 \times 10^4$ C

**24.** When a current $I$ is set up in a wire of radius $r$, the drift velocity is $v_d$. If the same current is set up through a wire of radius $2r$, the drift velocity will be:
(a) $4v_d$ (b) $2v_d$
(c) $v_d/2$ (d) $v_d/4$

**25.** Drift velocity of a free electron inside a conductor is:
(a) the thermal speed of the free electron
(b) the speed with which a free electron emerges out of the conductor
(c) the average speed acquired by the electron in any direction
(d) the average speed of the electron between successive collisions in the direction opposite to the applied electric field

**26.** If the resistance of a conductor is 5Ω at 50° C and 7Ω at 100° C, then mean temperature coefficient of resistance (of material) is:
(a) 0.013/°C (b) 0.004/°C
(c) 0.006/°C (d) 0.008/°C

[***Hint:*** $R_t = R_o(1 + \alpha t.$]

**27.** When a long straight uniform rod is connected across an ideal cell, the drift velocity of electrons in it is $v$. If a uniform hole is made along the axis of the rod and the same battery is used, then the drift velocity of electron becomes:
(a) $v$ (b) $>v$
(c) $<v$ (d) 0

**28.** A potential difference $V$ is applied to a copper wire. If the potential difference is increased to $2V$, then the drift velocity of electrons will:

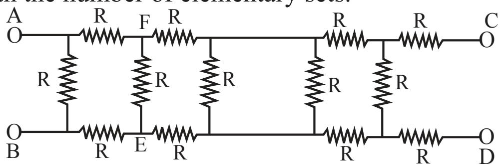
(a) be double the initial velocity
(b) remain same
(c) be $\sqrt{2}$ times the initial velocity
(d) be half the initial velocity

**29.** A wire has a non-uniform cross-section as shown in the figure. If a steady current is flowing through it, then the drift speed of the electrons:


(a) is constant throughout the wire
(b) decreases from A to B
(c) increases from A to B
(d) varies randomly

**30.** Choose the incorrect statement:
In gallium-arsenide compound,
(a) the ratio of effective mass of holes to electrons is less than one.
(b) different relaxation time of electrons and holes contribute to their different mobility.
(c) $[\mu]=[M^{-1}L^0T^2A^1]$
(d) mobility is positive for positive current carriers and negative for negative current carriers because their drift velocities are opposite to each other.

**31.** In the given figure, find out the value of resistor to be connected between C and D, so that the resistance of the entire circuit between A and B does not change with the number of elementary sets.




(a) $R$
(b) $R(\sqrt{3}-1)$
(c) $3R$
(d) $R(\sqrt{3}+1)$

**32.** A copper wire of length 1 m and radius 1 mm is joined in series with an iron wire of length 2 m and radius 3 mm and a current is passed through the wires. The ratio of current densities in the copper and iron wires is:
(a) 18:1
(b) 9:1
(c) 6:1
(d) 2:3

**33.** A potential difference of 10 V is applied across a conductor of length 0.1 m. If the drift velocity of electrons is $2 \times 10^{-4}$ m/s, the electron mobility is _____ $m^2V^{-1}s^{-1}$.
(a) $1 \times 10^{-6}$
(b) $2 \times 10^{-6}$
(c) $3 \times 10^{-6}$
(d) $4 \times 10^{-6}$

**34.** The mean free path of electrons in a metal is $5 \times 10^{-8}$ m. The electric field which can give on an average 2 eV energy to an electron in the metal will be (in V/m):
(a) $4 \times 10^{-11}$
(b) $8 \times 10^{-11}$
(c) $4 \times 10^{7}$
(d) $8 \times 10^{7}$

**35.** Ohm's law deals with the relation between:
(a) current and potential difference
(b) capacity and charge
(c) capacity and potential
(d) charge and potential difference

**36.** Ohm's law is valid when the temperature of the conductor is _____:
(a) constant
(b) very high
(c) very low
(d) varying

**37.** Ten identical cells connected in series are needed to heat a wire of length one meter and radius $r$ by 10° C in time $t$. How many cells will be required to heat the wire of length two meter of the same radius by the same temperature in time $t$?
(a) 10
(b) 20
(c) 30
(d) 40

**38.** Ohm's law is valid for:
(a) metallic conductors at low temperature
(b) metallic conductors at high temperature
(c) electrolytes when current passes through them
(d) diode when current flows

**39.** In gallium-arsenide material, Ohm's law does not hold good because:
(a) current remains constant for any value of voltage
(b) resistance is infinite
(c) negative resistance exists in the voltage-current variation
(d) current goes to infinite at very low voltages

**40.** When the length and area of cross-section both are doubled, then its resistance:
(a) will become half
(b) will be doubled
(c) will remain the same
(d) will become four times

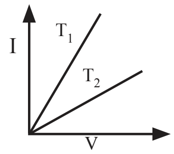
**41.** For a metallic wire, the ratio $V/I$ ($V$ = the applied potential difference, $I$ = current flowing):
(a) is independent of temperature.
(b) increases as the temperature rises.
(c) decreases as the temperature rises.
(d) increases or decreases as temperature rises, depending upon the metal.

**42.** The current density varies with radial distance $r$ as $J = ar^2$, in a cylindrical wire of radius $R$. The current passing through the wire between radial distance $R/3$ and $R/2$ is:

(a) $\dfrac{65\neq aR^4}{2592}$ (b) $\dfrac{25\neq aR^4}{72}$

(c) $\dfrac{65\neq a^2R^3}{2938}$ (d) $\dfrac{81\neq a^2R^4}{144}$

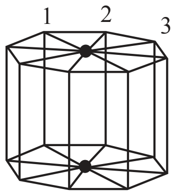
**43.** The current-voltage ($I$-$V$) graph for a given metallic wire at two different temperatures $T_1$ and $T_2$ are shown in figure. It follows from the graph that:




(a) $T_1 > T_2$
(b) $T_1 < T_2$
(c) $T_1 = T_2$
(d) $T_1$ is greater or less than $T_2$ depending on whether the resistance $R$ of the wire is greater or less than the ratio $V/I$.

**44.** The resistivity of a wire:
(a) increases with the length of the wire.
(b) decreases with the area of cross-section.
(c) decreases with the length and increases with the cross-section of wire.
(d) is unaffected by change in its length and area of cross-section.

**45.** In the diagram shown, all the wires have resistance $R$. The equivalent resistance between the upper and lower dots shown in the diagram is:




(a) $R/8$ (b) $R$
(c) $2R/5$ (d) $3R/8$

**46.** Which of the following wires of the same material will have higher resistance?
(a) radius is 1 mm and the length is 40 m
(b) radius is 2 mm and the length is 40 m
(c) radius is 1mm and the length is 80 m
(d) radius is 2 mm and the length is 80 m

**47.** The resistance of a straight conductor does not depend upon its:
(a) temperature
(b) length
(c) material
(d) shape of cross-section

**48.** A certain wire has a resistance $R$. The resistance of another wire identical with the first except having twice its diameter is:
(a) $2R$ (b) $0.25R$
(c) $4R$ (d) $0.5R$

**49.** An electrical cable of copper has just one wire of radius 9 mm. Its resistance is 5 Ω. This single copper wire of the cable is replaced by 6 different well insulated copper wires each of radius 3 mm. The total resistance of the cable will now be equal to
(a) 7.5 Ω (b) 45 Ω
(c) 90 Ω (d) 270 Ω

**50.** The reciprocal of resistance is:
(a) conductance (b) voltage
(c) resistivity (d) reactance

**51.** A carbon resistor of (47 ± 4.7) kΩ is to be marked with rings of different colours for its identification. The colour code sequence will be:
(a) Violet - Yellow - Orange - Silver
(b) Yellow - Violet - Orange - Silver
(c) Green - Orange - Violet - Gold
(d) Yellow - Green - Violet - Gold

**52.** A wire of resistance 4 Ω is stretched to twice its original length. The resistance of stretched wire would be:
(a) 2 Ω (b) 4 Ω
(c) 8 Ω (d) 16 Ω

**53.** A hank of uninsulated wire consisting of seven and a half turns is stretched between two nails hammered into a board to which the ends of the wire are fixed. The resistance of the circuit between the nails is determined with the help of electrical measuring instruments. Determine the proportion in which the resistance will change if the wire is unwound so that the ends remain to be fixed to the nails.
(a) 225 (b) 15
(c) 240 (d) 250

**54.** If there is a 0.1% increase in the length of a conductor due to stretching, then the percentage increase in its resistance will be:
(a) 0.2% (b) 2.0%
(c) 1.0% (d) 0.1%

**55.** Two different conductors have same resistance at 0° C. It is found that the resistance of the first conductor at $t_1$° C is equal to the resistance of the second conductor at $t_2$° C. The ratio of the temperature coefficients of resistance of the conductors, $\dfrac{\alpha_1}{\alpha_2}$ is:

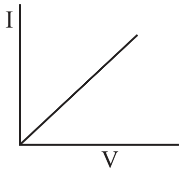
(a) $\dfrac{t_1}{t_2}$ (b) $\dfrac{t_2 - t_1}{t_2}$

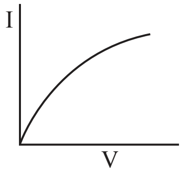
(c) $\dfrac{t_2 - t_1}{t_1}$ (d) $\dfrac{t_2}{t_1}$

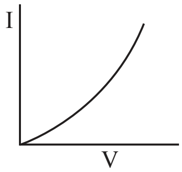
**56.** A wire of length 5 m and radius 1 mm has a resistance of 1 ohm. What length of the wire of the same material at the same temperature and of radius 2 mm will also have a resistance of 1 ohm?

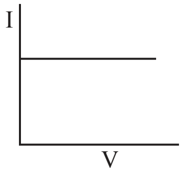
(a) 1.25 m (b) 2.5 m
(c) 10 m (d) 20 m

**57.** The *V-I* characteristics of four circuit elements are shown. Which of these is ohmic?

(a)



(b)



(c)



(d)



**58.** A potentiometer wire, 10 m long, has a resistance of 40 Ω. It is connected in series with a resistance box and a 2V storage cell. If the potential gradient along the wire is 0.1 mV/cm, the resistance unplugged in the box is:

(a) 260 Ω (b) 760 Ω
(c) 960 Ω (d) 1060 Ω

**59.** You are given several identical resistances each of value $R = 10\ \Omega$ and each capable of carrying a maximum current of one ampere. It is required to make a suitable combination of these resistances of 5 Ω which can carry a current of 4 ampere. The minimum number of resistances of the type *R* that will be required for this job is:

(a) 4 (b) 10
(c) 8 (d) 20

## Electric Cell and Bridges

**60.** In a closed circuit, the vector sum of total emf is equal to the sum of the _____:

(a) currents
(b) resistances
(c) products of currents and the resistances
(d) products of potential differences

**61.** Kirchhoff's first law i.e., $\Sigma i = 0$ at a junction is based on the law of conservation of:

(a) charge
(b) energy
(c) momentum
(d) angular momentum

**62.** At a point I, $i = 0$ in a circuit with one emf source, then:

(a) the resistance of the circuit is zero
(b) that point is a junction point
(c) the emf of the source is infinity
(d) this is not possible

**63.** According the Kirchhoff's law, in any analytic circuit, if the direction of current is assumed opposite, then the value of current will be:

(a) $i$ (b) $2i$
(c) $-i$ (d) 0

**64.** In a wheatstone bridge in the battery and galvanometer are interchanged then the deflection in galvanometer will:

(a) change in previous direction
(b) not change
(c) change in opposite direction
(d) None of these

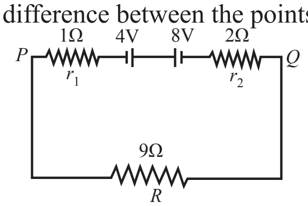
**65.** A capacitor is connected to a cell of emf *E* having some internal resistance *r*. The potential difference across the:

(a) Cell is < E (b) Cell is E
(c) Capacitor is > E (d) Capacitor is < E

**66.** If an electron is placed in a non-uniform electric field, then the force experienced by electron is in the direction:

(a) of the electric field.
(b) opposite to the electric field.
(c) perpendicular to the field.
(d) making some angle to field, which depends on strength of field.

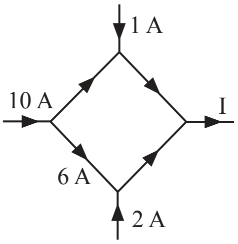
**67.** Two batteries of emf 4 V and 8 V with internal resistance 1 ohm and 2 ohm are connected in a circuit with a resistance of 9 as shown in figure. The current and potential difference between the points P and Q are:



(a) $\frac{1}{3}$ A and 3 V (b) $\frac{1}{6}$ A and 4 V

(c) $\frac{1}{9}$ A and 9 V (d) $\frac{1}{12}$ A and 12 V

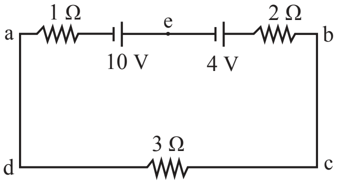
**68.** The figure shows a network of currents. The magnitude of currents is shown here. The current $I$ will be:




(a) 3 A (b) 9 A
(c) 13 A (d) 19 A

**69.** Kirchhoff's second law is based on the law of conservation of:
(a) charge
(b) energy
(c) momentum
(d) sum of mass and energy

**70.** The magnitude and direction of the current in the circuit shown will be:



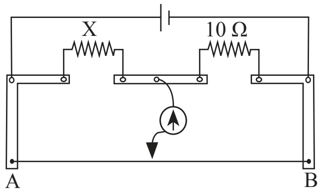

(a) 7/3 A from a to b through e
(b) 7/3 A from b to a through e
(c) 1 A from b to a through e
(d) 1 A from a to b through e

**71.** Match the entries of column I with their correct mathematical expressions in column II:

| | Column I | | Column II |
|---|---|---|---|
| A | Balanced condition of wheatstone bridge | (i) | $\frac{R_1}{R_2} = \frac{R_3}{R_4}$ |
| B | Comparison of emf of two cells held | (ii) | $\frac{R}{S} = \frac{l_1}{100 - l_1}$ |
| C | Determination of internal resistance of a cell | (iii) | $\frac{E_1}{E_2} = \frac{l_1}{l_2}$ |
| D | Determination of unknown resistance by meter bridge | (iv) | $r = R\left(\frac{l_1}{l_2} - 1\right)$ |

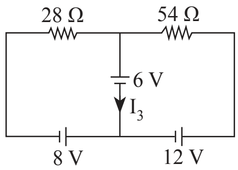
(a) A-(iv), B-(ii), C-(iii), D-(i)
(b) A-(i), B-(iii), C-(iv), D-(ii)
(c) A-(iii), B-(iv), C-(ii), D-(i)
(d) A-(iv), B-(iii), C-(ii), D-(i)

**72.** A meter bridge is setup as shown to determine an unknown resistance X using a standard 10 ohm resistor. The galvanometer shows null point when tapping-key is at 52 cm mark. The end-corrections are 1 cm and 2 cm respectively for the ends A and B. The determined value of $X$ is:



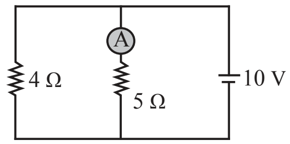

(a) 10.2 ohm (b) 10.6 ohm
(c) 10.8 ohm (d) 11.1 ohm

**73.** Consider the circuit shown in the figure. The current $I_3$ is equal to:




(a) 5 A (b) 3 A
(c) –3 A (d) –5/6 A

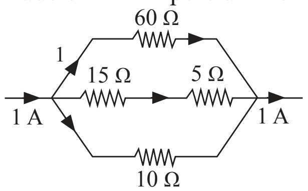
**74.** In the given circuit, the reading of the ammeter is (assume internal resistance of the battery to be zero)




(a) 40/29 A (b) 10/9 A
(c) 5/3 A (d) 2 A

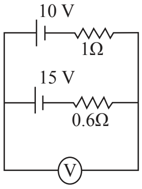
**75.** In meter bridge or Wheatstone bridge for measurement of resistance, the known and the unknown resistance are interchanged. The error so removed is:
(a) end correction
(b) index error
(c) due to temperature effect
(d) random error

**76.** The magnitude of I in ampere unit is:



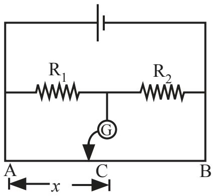

(a) 0.1 (b) 0.3
(c) 0.6 (d) 0.5

**77.** A 10 V battery with internal resistance 1 ohm and a 15 V battery with internal resistance 0.6 ohm are connected in parallel to a voltmeter (see figure). The reading in the voltmeter will be close to:




(a) 12.5 V (b) 24.5 V
(c) 13.1 V (d) 11.9 V

**78.** In the meter bridge experiment shown in the figure, the balance length AC corresponding to null deflection of the galvanometer is $x$. What would be the balance length if the radius of the wire AB is doubled?

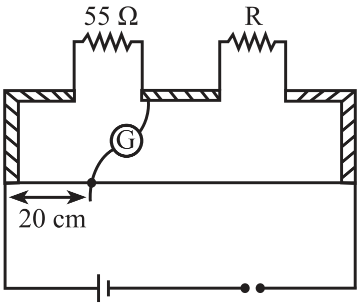



(a) $4x$ (b) $2x$
(c) $x$ (d) $x/2$

**79.** In a potentiometer experiment. It is found that no current passes through the galvanometer when the terminals of the cell are connected across 52 cm of the potentiometer wire. If the cell is shunted by a resistance of 5 ohm, a balance is found when the cell is connected across 40 cm of the wire. Find the internal resistance of the cell.

(a) 1 Ω (b) 1.5 Ω
(c) 2 Ω (d) 2.5 Ω

**80.** Shown in the figure below is a meter bridge set up with null deflection in the galvanometer. The value of the unknown resistance $R$ is:

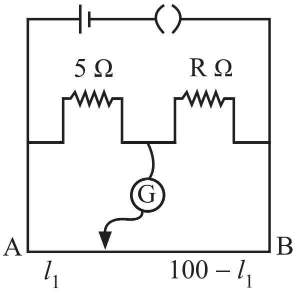



(a) 55 Ω (b) 1375 Ω
(c) 220 Ω (d) 110 Ω

**81.** A resistance of 5 ohm is connected in the left gap of a meter bridge and 15 ohm in the other gap. The position of the balancing point is:

(a) 10 cm (b) 20 cm
(c) 25 cm (d) 75 cm

**82.** The resistances in the two arms of the meter bridge are 5 ohm and $R$ ohm, respectively. When the resistance $R$ is shunted with an equal resistance, the new balance point is at $1.6l_1$. The resistance $R$, is:

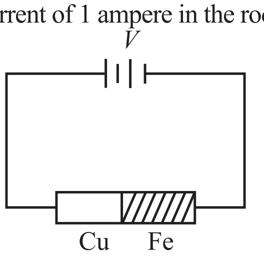



**(a)** 10 ohm (b) 15 ohm
**(c)** 20 ohm (d) 25 ohm

**83.** The instrument among the following which measures the emf of a cell most accurately is:

(a) a voltmeter (b) an ammeter
(c) potentiometer (d) post office box

**84.** Two rods are joined end to end, as shown. Both have a cross-sectional area of 0.01 $cm^2$. Each is 1 meter long. One rod is of copper with a resistivity of $1.7 \times 10^{-6}$ ohm-cm, the other is of iron with a resistivity of $10^{-5}$ ohm-cm. How much voltage is required to produce a current of 1 ampere in the rods?




(a) 0.117 V (b) 0.00145 V
(c) 0.0145 V (d) $1.7 \times 10^{-6}$ V

**85.** In a meter bridge experiment, the ratio of the left gap resistance to right gap resistance is 2:3. The balance point from the left is:

(a) 60 cm (b) 50 cm
(c) 40 cm (d) 20 cm

**86.** In a balanced Wheatstone network, the resistances in the arms Q and S are interchanged. As a result of this:

(a) network is not balanced.
(b) network is still balanced.
(c) galvanometer shows zero deflection.
(d) galvanometer and the cell must be interchanged to balance.

**87.** In Wheatstone's bridge, three resistors P, Q, R are connected in three arms in order and 4th arm S is formed by two resistors $S_1$ and $S_2$ connected in parallel. The condition for bridge to be balanced is $\frac{P}{Q} =$

(a) $\frac{R(S_1+S_2)}{S_1S_2}$ (b) $\frac{S_1S_2}{R(S_1+S_2)}$

(c) $\frac{RS_1S_2}{(S_1+S_2)}$ (d) $\frac{(S_1+S_2)}{RS_1S_2}$

**88.** To get maximum current in a resistance of 3 ohms, one can use $n$ rows of $m$ cells (connected in series) connected in parallel. If the total number of cells is 24 and the internal resistance of a cell is 0.5 ohms then:

(a) $m = 12, n = 2$ (b) $m = 8, n = 3$
(c) $m = 2, n = 12$ (d) $m = 6, n = 4$

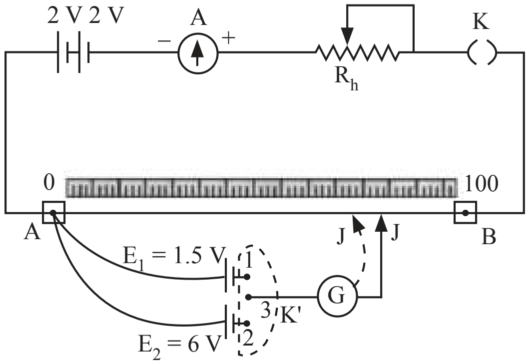
**89.** In balanced meter bridge, the resistance of bridge wire is 0.1 ohm/cm. Unknown resistance $X$ is connected in left gap and 6 ohm in right gap, null point divides the wire in the ratio 2:3. Find the current drawn from the battery of 5 V having negligible resistance.

(a) 1 A (b) 1.5
(c) 2 A (d) 5 A

**90.** Select the WRONG statement.

(a) A potentiometer is a constant voltage device.
(b) A potentiometer is a constant current device.
(c) A potentiometer is used to measure emf of a cell.
(d) A potentiometer is used to measure potential drop between two points in an electric circuit.

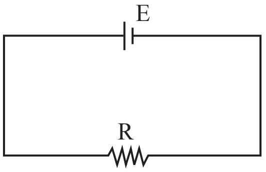
**91.** Kiran while performing the potentiometer experiment to compare emf's of two cells, first connected cell $E_1$ and found balancing length as 58.4 cm. Then, he connected cell $E_2$ and continuously worked with apparatus for 1 hr 20 minutes to get balancing length for $E_2$. But, he could not get balancing length. If he had connected the circuit with tight connections of wire exactly as shown below,




then number of errors occurred are:

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

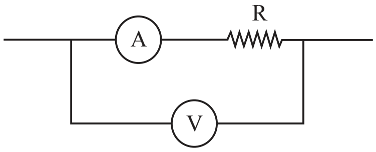
**92.** Consider the circuit given here with the following parameters:
EMF of the cell = 12 V, internal resistance of the cell = 2 ohm, resistance $R$ = 4 ohm




Which one of the following statements in true?

(a) Rate of energy loss in the source is 8 W.
(b) Rate of energy loss in the source is 16 W.
(c) Power output is 8 W.
(d) Potential drop across $R$ is 16 V.

**93.** In the circuit shown below, the ammeter and the voltmeter readings are 3 A and 6 V respectively. Then the value of the resistance $R$ is:

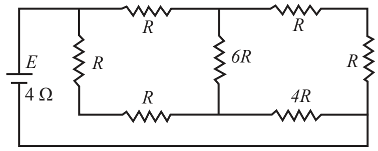



(a) $< 2\ \Omega$ (b) 2 |
(c) $\geq 2\ \Omega$ (d) $> 2\ \Omega$

**94.** Which is a wrong statement?

(a) The Wheatstone bridge is the most sensitive when all the four resistances are of the same order.
(b) In a balanced Wheatstone bridge, interchanging the positions of galvanometer and cell affects the balance of the bridge.
(c) Kirchhoff's first law (for currents meeting at a junction in an electric circuit) expresses the conservation of chaise.
(d) The rheostat can be used as a potential divider.

**95.** A battery of internal resistance 4 ohm is connected to the network of resistances as shown. In order that the maximum power can be delivered to the network, the value of $R$ in ohm should be:

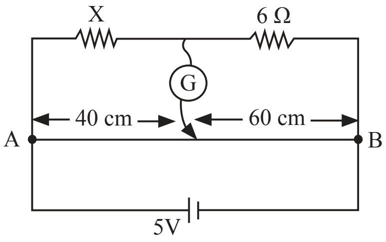



(a) 4/9
(b) 2
(c) 8/3
(d) 18

**96.** In a potentiometer experiment, when the galvanometer shows no deflection, then no current flows through _____

(a) potentiometer wire
(b) galvanometer circuit
(c) main circuit
(d) battery

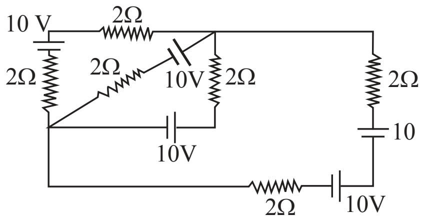
**97.** In the circuit shown, a meter bridge is in its balanced state. The meter bridge wire has a resistance 0.1 ohm/cm. The value of unknown resistance $X$ and the current drawn from the battery of negligible resistance are:




(a) 6 Ω, 5 A (b) 10 Ω, 0.1 A
(c) 4 Ω, 1.0 A (d) 12 Ω, 0.5 A

**98.** A potentiometer is an ideal device for measuring potential difference because:
(a) it uses a sensitive galvanometer.
(b) it does not disturb the potential difference it measures.
(c) it is an elaborate arrangement.
(d) it has a long wire hence heat developed is quickly radiated.

**99.** All batteries are having emf 10 volt and internal resistance negligible. All resistors are in ohms. Calculate the current in the right most 2 ohm resistor:

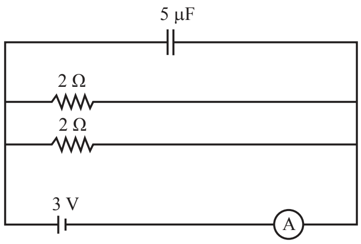



(a) $\frac{25}{12}$ A (b) $\frac{25}{6}$ A
(c) $\frac{12}{25}$ A (d) $\frac{6}{25}$ A

**100.** The resistances of the four arms P, Q, R and S in a wheatstone's bridge are 10 ohm, 30 ohm, 30 ohm and 90 ohm, respectively. The emf and internal resistance of the cell are 7 volt and 5 ohm respectively. If the galvanometer resistance is 50 ohm, the current drawn from the cell will be:
(a) A (b) 0.2 A
(c) 0.1 A (d) A

**101.** When an unknown resistance is placed in the left gap of a meter bridge and resistance of 60 ohm in the right gap, null point is obtained at a certain point. If unknown resistance is shunted by one-ninth of its value, then the value of resistance in the right gap, to obtain the null point at the same point, will be:
(a) 6 ohm
(b) 9 ohm
(c) 15 ohm
(d) 45 ohm

**102.** What is the reading of ammeter shown in the figure below?




(a) 3 A (b) 4 A
(c) 1.5 A (d) 6 A

# HIGH-ORDER THINKING SKILL

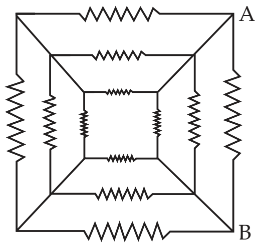
## Electric Current and Resistance

**1.** When 5 V potential difference is applied across a wire of length 0.1 m, the drift speed of electrons is $2.5 \times 10^{-4}$ m/s. If the electron density in the wire is $8 \times 10^{28}$ m$^3$, the resistivity of the material is close to:
(a) $1.6\times10^{-6}\,\Omega$m (b) $1.6\times10^{-5}\,\Omega$m
(c) $1.6\times10^{-8}\,\Omega$m (d) $1.6\times10^{-7}\,\Omega$m

**2.** A constant voltage is applied between the two ends of a uniform metallic wire. Some heat is developed in it. The heat developed is doubled if:
(a) both the length and the radius of the wire are halved.
(b) both the length and the radius of the wire are doubled.
(c) the radius of the wire is doubled.
(d) the length of the wire is doubled.

**3.** A current source drives a current in a coil of resistance $R_1$ for a time $t$. The same source drives current in another coil of resistance $R_2$ for same time. If heat generated is same, find internal resistance of source.
(a) $\frac{R_1R_2}{R_1+R_2}$ (b) $R_1+R_2$
(c) 0 (d) $\sqrt{R_1R_2}$

4. Twelve resistors each of resistance 16 Ω are connected in the circuit as shown. The net resistance between AB is:




(a) 1 Ω (b) 2 Ω
(c) 3 Ω (d) 4 Ω

5. An electric heating element in vacuum is surrounded by a cavity at constant temperature of 227 °C; it consumes 60 W of power to maintain a temperature of 727 °C. What is the power consumed by the element to maintain a temperature of 1227 °C?
(a) 101 W (b) 304 W
(c) 90 W (d) 320 W

6. The resistance of an electrical toaster has a temperature dependence given by $R(T) = R_0\left[1+\alpha\left(T-T_0\right)\right]$

in its range of operation. At $T_0$ =300K, R = 100 Ω and at $T$ = 500 K, $R$= 120 Ω. The toaster is connected to a voltage source at 200 V and its temperature is raised at a constant rate from 300 to 500 K in 30 s. The total work done in raising the temperature is:
(a) $400\ln\frac{5}{6}$ kJ (b) $200\ln\frac{2}{3}$ kJ
(c) $60\ln\left(\frac{6}{5}\right)$ kJ (d) $400\ln\left(\frac{1.5}{1.3}\right)$ kJ

## Electric Cell and Bridges

7. In an experiment to measure the internal resistance of a cell, by a potentiometer, it is found that the balance point is at a length of 2 m, when the cell is shunted by a 5 Ω resistance and is at a length of 3 m when the cell is shunted by a 10 Ω resistance. The internal resistance of the cell is:
(a) 1.5 Ω (b) 10 Ω
(c) 15 Ω (d) 1 Ω

8. On interchanging the resistances, the balance point of a meter bridge shifts to the left by 10 cm. The resistance of their series combination is 1 kΩ. How much was the resistance on the left slot before interchanging the resistances?
(a) 990 Ω (b) 505 Ω
(c) 550 Ω (d) 910 Ω

# NCERT EXEMPLAR PROBLEMS

## Electric Current and Resistance

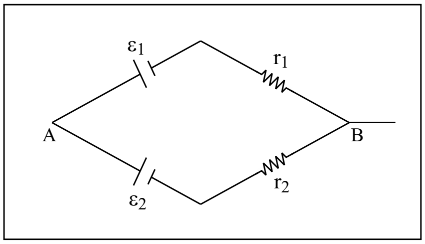
1. Consider a current carrying wire (current $I$) in the shape of a circle. Note that as the current progresses along the wire, the direction of $j$ (current density) changes in an exact manner, while the current $I$ remain unaffected. The agent that is essentially responsible for is:
(a) source of emf
(b) electric field produced by charges accumulated on the surface of wire.
(c) the charges just behind a given segment of wire which push them just the right way by repulsion.
(d) the charges ahead

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

3. Which of the following characteristics of electrons determines the current in a conductor?
(a) Drift velocity alone
(b) Thermal velocity alone
(c) Both drift velocity and thermal velocity
(d) Neither drift nor thermal velocity

## Electric Cell and Bridges

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



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

**5.** A resistance $R$ is to be measured using a meter bridge. Student chooses the standard resistance $S$ to be 100 Ω. He finds the null point at $l_1 = 2.9$ cm. He is told to attempt to improve the accuracy. Which of the following is a useful way?
(a) He should measure $l_1$ more accurately.
(b) He should change $S$ to 1000 Ω and repeat the experiment.
(c) He should change $S$ to 3 Ω and repeat the experiment.
(d) He should give up hope of a more accurate measurement with a meter bridge.

**6.** Two cells of emf's approximately 5V and 10V are to be accurately compared using a potentiometer of length 400 cm:
(a) The battery that runs the potentiometer should have voltage of 8V
(b) The battery of potentiometer can have a voltage of 15 V and $R$ adjusted so that the potential drop across the wire slightly exceeds 10 V
(c) The first portion of 50 cm of wire itself should have a potential drop of 10 V
(d) Potentiometer is usually used for comparing resistances and not voltages

## ASSERTION AND REASONS

**Directions:** In the following questions, a statement of assertion is followed by a statement of reason. Mark the correct choice as:
(a) If both assertion and reason are true and reason is the correct explanation of assertion.
(b) If both assertion and reason are true but reason is not the correct explanation of assertion.
(c) If assertion is true but reason is false.
(d) If both assertion and reason are false.

### Electric Current and Resistance

**1. Assertion:** The current density $\vec{j}$ at any point in ohmic resistor is in direction of electric field $\vec{E}$ at that point.

Reason: A point charge when released from rest in a region having only electrostatic field always moves along electric lines of force.

**2. Assertion:** The 200 W bulbs glows with more brightness then 100 W bulbs.

Reason: A 100 W bulb has more resistance than a 200 W bulb.

**3. Assertion:** Bending a wire does not effect electrical resistance.

Reason: Resistance of wire is proportional or resistivity of material.

**4. Assertion:** Fuse wire must have high resistance and low melting point.

Reason: Fuse is used for small current flow only.

**5. Assertion:** Drift speed $v_d$ is the average speed between two successive collisions.

Reason: If $\Delta l$ is the average distance moved between two collision and $\Delta t$ is the corresponding time, then

$$v_d = \lim_{\Delta t \to 0} \frac{\Delta \ell}{\Delta t}.$$

**6. Assertion:** Two electric bulbs of 50 W and 100 W are given. When connected in series 50 W bulb glows more but when connected parallel 100 W bulb glows more.

Reason: In series combination, power is directly proportional to the resistance of circuit. But in parallel combination, power is inversely proportional to the resistance of the circuit.

**7. Assertion:** When current through a bulb decreases by 0.5%, the glow of bulb decreases by 1%.

Reason: Glow (Power) which is directly proportional to square of current.

**8. Assertion:** For a conductor resistivity increases with increase in temperature.

Reason: Since $\rho = \frac{m}{ne^2\tau}$ when temperature increases the random motion of free electrons increases and vibration of ions increases which decreases $\tau$.

**9. Assertion:** Two bulbs of same wattage, one having a carbon filament and the other having a metallic filament are connected in series. Metallic bulbs will glow more brightly than carbon filament bulb.

Reason: Carbon is a semiconductor.

**10. Assertion:** A current flows in a conductor only when there is an electric field within the conductor.

Reason: The drift velocity of electron in presence of electric field decreases.

**11. Assertion:** In practical application, power rating of resistance is not important.

Reason: Property of resistance remain same even at high temperature.

## Electric Cell and Bridges

**12. Assertion:** Kirchhoff's junction rule can be applied to a junction of several lines or a point in a line.

Reason: When steady current is flowing, there is no accumulation of charges at any junction or at any point in a line.

**13. Assertion:** In meter bridge experiment, a high resistance is always connected in series with a galvanometer.

Reason: As resistance increase current more accurately then ammeter.

**14. Assertion:** The emf of driver cell in potentiometer experiment should be greater that emf of cell to be determined.

Reason: The fall of potential across the potentiometer wire should not be less than emf of cell to be determined.

**15. Assertion:** Kirchhoff's junction rule follows from conservation of charge.

Reason: Kirchhoff's loop rule follows from conservation of momentum.

# ANSWER KEY

## Practice Time

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | (d) | 2 | (b) | 3 | (d) | 4 | (d) | 5 | (b) | 6 | (c) | 7 | (d) | 8 | (d) | 9 | (b) | 10 | (a) |
| 11 | (b) | 12 | (a) | 13 | (d) | 14 | (b) | 15 | (d) | 16 | (b) | 17 | (a) | 18 | (a) | 19 | (c) | 20 | (c) |
| 21 | (d) | 22 | (a) | 23 | (b) | 24 | (d) | 25 | (d) | 26 | (a) | 27 | (a) | 28 | (a) | 29 | (b) | 30 | (d) |
| 31 | (b) | 32 | (b) | 33 | (b) | 34 | (c) | 35 | (a) | 36 | (a) | 37 | (b) | 38 | (a) | 39 | (c) | 40 | (c) |
| 41 | (b) | 42 | (a) | 43 | (b) | 44 | (d) | 45 | (d) | 46 | (c) | 47 | (d) | 48 | (b) | 49 | (a) | 50 | (a) |
| 51 | (b) | 52 | (d) | 53 | (a) | 54 | (a) | 55 | (d) | 56 | (d) | 57 | (a) | 58 | (b) | 59 | (c) | 60 | (c) |
| 61 | (a) | 62 | (b) | 63 | (c) | 64 | (b) | 65 | (b) | 66 | (b) | 67 | (a) | 68 | (c) | 69 | (b) | 70 | (d) |
| 71 | (b) | 72 | (b) | 73 | (d) | 74 | (d) | 75 | (a) | 76 | (a) | 77 | (c) | 78 | (c) | 79 | (b) | 80 | (b) |
| 81 | (c) | 82 | (b) | 83 | (c) | 84 | (a) | 85 | (c) | 86 | (a) | 87 | (a) | 88 | (a) | 89 | (a) | 90 | (a) |
| 91 | (b) | 92 | (a) | 93 | (a) | 94 | (b) | 95 | (b) | 96 | (b) | 97 | (c) | 98 | (b) | 99 | (a) | 100 | (b) |
| 101 | (a) | 102 | (a) | | | | | | | | | | | | | | | | |

## High-Order Thinking Skill

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | (b) | 2 | (b) | 3 | (d) | 4 | (d) | 5 | (d) | 6 | (c) | 7 | (b) | 8 | (c) |

## NCERT Exemplar Problems

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | (b) | 2 | (a) | 3 | (a) | 4 | (a) | 5 | (c) | 6 | (b) |

## Assertion and Reason

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | (c) | 2 | (a) | 3 | (a) | 4 | (c) | 5 | (c) | 6 | (a) | 7 | (a) | 8 | (a) | 9 | (d) | 10 | (c) |
| 11 | (d) | 12 | (a) | 13 | (c) | 14 | (a) | 15 | (c) | | | | | | | | | | |

# HINTS AND EXPLANATIONS

## Practice Time

**1 (d)** The carriers of electricity in a metallic conductor are electrons.

**2 (b)** The time rate of flow of charge through any cross-section of a conductor is electric current.

**3 (d)** Average of the velocities of all free electrons at an instant is non-zero, if not current is passed through a conductor.

**4 (d)** Since current is constant, charge crossing a given area per unit time is constant and is independent of area of cross-section. However, current density depends on area.

**5 (b)** Motion of conduction electrons due to random collisions has no preferred direction and average to zero. Drift velocity is caused due to motion of conduction electrons due to applied electric field.

**6 (c)** Smaller the resistance greater the current applied -If the same current is passed.
Greater or smaller the resistance the current is same - If the same voltage is and resistance are in series
Greater the resistance smaller the power - When resistances are connected in parallel
Greater the resistance greater the power - If the same current is passed

**7 (d)** As we know that,

$I =$ constant

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

It is clear that, as $A$ changes, current density $J$ changes.

$E = J\rho$

$\rho$ is constant

As $J$ changes, electric field $E$ changes.

$I = neAv_d$

$I$ is constant

So as $A$ changes, drift speed $v_d$ changes.

**8 (d)** If a current passes through a wire of non-uniform cross-section then free electron density is independent of the cross-section.

**9 (b)** A cross a metallic conductor of non-uniform cross-section the rate of flow of charge through every cross-section is constant hence, current is constant.

**10 (a)** Cu, Ag and Au are the good conductors of electricity.

**11 (b)** The figure is showing $I$-$V$ characteristics of non-ohmic or non-linear conductors.

**12 (a)** As we know that,

$$J = \sigma E$$

$$\Rightarrow J\rho = E$$

J is current density, E is electric field, So

$B = \rho$

$=$ resistivity

**13 (d)** As we know that,

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

$$q = It$$

$$= 0.5 \times 7200$$

$$= 3600 \text{ C}$$

**14 (b)** Because as temperature increases, the resistivity increases and hence the relaxation time decreases for conductors,

$$\tau \propto \frac{1}{\rho}$$

**15 (d)** As we know that,

$$q = It$$

$$\Rightarrow ne = It$$

$$\therefore n = \frac{It}{e}$$

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

$$= 6.25 \times 10^{18}$$

**16 (b)** When the temperature increases, resistance increases. As the emf applied is the same, the current density decreases the drift velocity decreases. But the rms velocity of the electron due to thermal motion is proportional to $\sqrt{T}$. Therefore, the thermal velocity increases.

**17 (a)** Number of electrons crossing any cross-section per second,

$$\frac{n}{t} = \frac{I}{e}$$

$$= \frac{4.8}{1.6 \times 10^{-19}}$$

$$= 3 \times 10^{19}$$

**18 (a)** If $N$, e, $\tau$ and $m$ are representing electron density, charge, relaxation time and mass of an electron respectively, then the resistance of wire of length $l$ and cross-sectional area $A$ is,

$$\frac{m\ell}{Ne^2A^2\tau}$$

**19 (c)** Given that,

$$q = ne$$

$$= 10^6 \times 1.6 \times 10^{-19}$$

$$\therefore q = 1.6 \times 10^{-13} \text{ C}$$

Now current flowing per second,

$$\frac{q}{t} = 1.6\times10^{-13}\text{ A}$$

**20 (c)** According to the given condition,

$$R = \frac{\rho\ell_1}{A_1}$$

now, $\ell_2 = 2\ell_1$

$$A_2 = \pi(r_2)^2$$

$$= \pi(2r_1)^2 = 4\pi r_1^2 = 4A_1$$

$$\therefore \quad R_2 = \frac{\rho(2\ell_1)}{4A_1} = \frac{\rho\ell}{2A} = \frac{R}{2}$$

Resistance is halved, but specific resistance remains the same.

**21 (d)** The direction of drift velocity in a conductor is - opposite to that of applied electric field, opposite to the flow of positive charge, and in the direction of the flow of electrons.

**22 (a)** Current flowing through the conductor, $I = n\,e\,v_d A$. Hence,

$$\frac{4}{1} = \frac{nev_{d_1}\pi(1)^2}{nev_{d_2}\pi(2)^2}$$

$$\Rightarrow \frac{v_{d_1}}{v_{d_2}} = \frac{4\times1}{1}$$

$$= \frac{16}{1}$$

**23 (b)** Given that,

$t = 1$ hour 30 min

$= 90$ min

$= 90\times60$ s

$q = It$

$= 20\times(90\times60)$

$= 108000$

$= 10.8\times10^4$ C

**24 (d)** As we know that,

$$I = nAev_d$$

or,

$$v_d \propto 1/\pi r^2$$

If $r \to 2r$ then,

$$v_d' \propto 1/\pi(2r)^2$$

$$v_d' = \frac{v_d}{4}$$

**25 (d)** When no emf is applied, the electrons move randomly inside the conductor. When emf is applied, electrons drift opposite to the applied emf and collide with each other. Between the collisions, average speed in the direction of field is $V_d$.

**26 (a)** According to the given condition,

$5\Omega = R_0(1+\alpha\times50)$ ...(i)

and,

$7\Omega = R_0(1+\alpha\times100)$ ...(ii)

Divide equation (i) by (ii)

$$\frac{5}{7} = \frac{1+50\alpha}{1+100\alpha}$$

$$\alpha = \frac{2}{150}$$

$$= 0.0133/°\text{C}$$

**27 (a)** Making a uniform hole along axis will change area of cross-section of conductor. As, drift velocity is independent of area of cross-section of conductor, it will remain the same.

**28 (a)** As we know that,

$$I = nev_d$$

$$\therefore \quad I \propto v_d$$

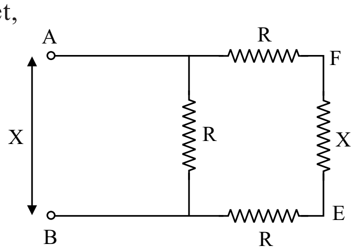
From Ohm's law, $V \propto I \propto v_d$

If the potential difference is doubled, drift velocity of electrons will also double.

**29 (b)** As area increases, $v_d$ decreases.

**30 (d)** Gallium-arsenide is a compound semiconductor. Hence, mobility of holes ($\mu_h$) equates to $\frac{e\tau_h}{m_h}$ and mobility of electrons ($\mu_e$) equates to $\frac{e\tau_e}{m_e}$. But value of mobility is positive for both charge carriers even though their drift velocities are opposite to each other.

**31 (b)** Let the resistor to be connected across CD be $x$. Then the equivalent resistance across EF should be $x$ and also across AB should be $x$. So we get,




$$\frac{(2R+x)R}{3R+x} = x$$

$$x = (\sqrt{3}-1)R$$

**32 (b)** As we know the current density,

$$J = \frac{I}{A} = \frac{I}{\pi r^2}$$

$$\therefore \quad \frac{J_1}{J_2} = \frac{I_1}{I_2} \times \frac{r_2^2}{r_1^2}$$

But the wires are in series, so they have the same current. So that,

$$I_1 = I_2$$

$$\therefore \quad \frac{J_1}{J_2} = \frac{r_2^2}{r_1^2} = 9:1$$

**33 (b)** As we know that,

$$E = \frac{V}{l} = \frac{10}{0.1} = 100 \text{ V/m}$$

$$\therefore \quad \mu = \frac{V_d}{E} = \frac{2\times10^{-4}}{100} = 2\times10^{-6}\,\text{m}^2\text{v}^{-1}\text{s}^{-1}$$

**34 (c)** Given that,
Energy = 2 eV
If electric field of E can give such energy, then

Energy = $eE\lambda$

where, $\lambda$ is mean free path

$$\therefore \quad E = \frac{2eV}{e\lambda} = \frac{2}{\lambda} = \frac{2}{5\times10^{-8}}$$

$$\therefore \quad = 4\times10^{7}\text{ V/m}$$

**35 (a)** Ohm's law deals with the relation between current and potential difference.

**36 (a)** Ohm's law is valid when the temperature of the conductor is constant.

**37 (b)** Resistance is directly proportional to length of the wire. As length is doubled so mass is doubled and resistance is doubled. We have,

$$\frac{(10E)^2}{R}t = mS\Delta T$$

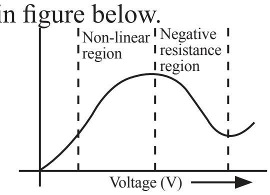
Now, $$\frac{(nE)^2 t}{2R} = (2m)S\Delta T$$

$$\Rightarrow \quad \frac{n^2E^2t}{2R} = 2\frac{10^2E^2t}{R}$$

$$\Rightarrow \quad n = 20$$

**38 (a)** Because with rise in temperature, resistance of conductor increases, so the graph between $V$ and $I$ then becomes non-linear.

**39 (c)** The voltage-current curve for GaAs material is as shown in figure below.




Thus, there exists a region where increase in voltage leads to decrease in current which is a non-ohmic behaviour and is attributed to negative resistance.

**40 (c)** As we know that,

$$R_1 \propto \frac{1}{A}$$

$$\Rightarrow \quad R_2 \propto \frac{2l}{2A}$$

$$\text{i.e.} \quad R_2 \propto \frac{l}{A}$$

$$\therefore \quad R_1 = R_2$$

**41 (b)** As we know that,

$$\frac{V}{I} = R \text{ and, } R \propto \text{ temperature}$$

**42 (a)** Given that,

$$J = ar^2$$

$$i = \int_1^2 J\times 2\pi r dr$$

$$= \int_{R/3}^{R/2} ar^2 \times 2\pi r dr$$

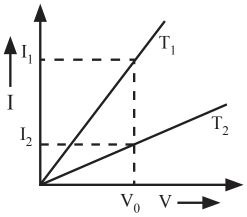
$$= 2\pi a\int_{R/3}^{R/2} r^3 dr$$

$$= 2\pi a\left|\frac{r^4}{4}\right|_{R/3}^{R/2}$$

$$= \frac{\pi a}{2}\left[\left(\frac{R}{2}\right)^4 - \left(\frac{R}{3}\right)^4\right]$$

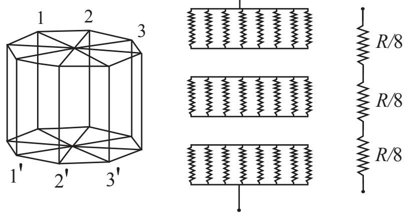
$$= \frac{\pi aR^4}{2}\times\frac{65}{81\times16} = \frac{65\pi aR^4}{2592}$$

**43 (b)** It is clear from figure that at a given voltage $V_0$, the current $I_1$ in the wire at temperature $T_1$ is greater than the current $I_2$ in the wire at temperature $T_2$. Therefore, the resistance of the wire at temperature $T_1$ is less than that at temperature $T_2$. This can happen if $T_1$ is less than $T_2$ because the resistance of a wire increases with increase in temperature.



**44 (d)** Resistivity is the properly of the material. It does not depend upon size and shape.

**45 (d)** Points 1,2,3,…… are equipotential




and 1′, 2′, 3′,.... are also equipotential.

**46 (c)** As we know that,

$$R \propto \frac{l}{r^2}$$

Hence, wire with maximum length and minimum radius will have highest resistance.

**47 (d)** As we know that,

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

So that, $R$ is independent of shape of cross-section.

**48 (b)** As we know that,

$$R \propto \frac{1}{A}$$

$$\Rightarrow \quad R \propto \frac{1}{r^2}$$

$$R \propto \frac{1}{d^2} \qquad (d = \text{ diameter of wire})$$

**49 (a)** Let the resistance of single copper wire be $R_1$. If $\rho$ is the specific resistance of copper wire, then,

$$R_1 = \frac{\rho \times \ell}{A_1}$$

$$= \frac{\rho \times l}{\pi r_1^2} \quad ...(i)$$

When the wire replaced by six wires, let the resistance of each wire be $R_2$. Then

$$R_2 = \frac{\rho \times \ell}{A_2}$$

$$= \frac{\rho \times l}{\pi r_2^2} \quad ...(ii)$$

from eq (i) and (ii), we get

$$\frac{R_1}{R_2} = \frac{r_2^2}{r_1^2}$$

$$\frac{5}{R_2} = \frac{(3 \times 10^{-3})^2}{(9 \times 10^{-3})^2}$$

$$R_2 = 45\ \Omega$$

These six wires are in parallel. Hence the resistance of the combination would be $R_2$ is 7.5 Ω.

**50 (a)** The reciprocal of resistance is called conductance.

**51 (b)** Colour code for carbon resistor,

| Colour | Figure (A, B) | Multiplier (C) |
|---|---|---|
| Black | 0 | $10^0$ |
| Brown | 1 | $10^1$ |
| Red | 2 | $10^2$ |
| Orange | 3 | $10^3$ |
| Yellow | 4 | $10^4$ |
| Green | 5 | $10^5$ |
| Blue | 6 | $10^6$ |
| Violet | 7 | $10^7$ |
| Grey | 8 | $10^8$ |
| White | 9 | $10^9$ |
| Gold | | $10^{-1}$ |
| Silver | | $10^{-2}$ |

Tolerance in percent for carbon resistor

| Colour | Tolerance |
|---|---|
| Gold | ±5% |
| Silver | ±10% |
| No colour | ± 20% |

$$(47 \pm 4.7)\ \text{k}\Omega = 47 \times 10^3 \pm 10\%$$

So that, Yellow - Violet - Orange - Silver

**52 (d)** Let $R$ be the resistance and $l$ be the original length. At constant volume, $R \propto l^2$

Resistance of stretched wire is,

$$R' = 4R$$

$$= 4(4)$$

$$= 16\ \Omega$$

**53 (a)** Let the resistance of half the turn be $R$. Then in the former case, we have fifteen resistors of resistance $R$ connected in parallel, the total resistance being $R/15$. In the latter case, we have the same fifteen resistors connected in series, the total resistance being $15R$. Therefore, as a result of unwinding, the resistance of the wire will increase by a factor of 225.

**54 (a)** As we know that,

$$R \propto l^2$$

$$\Rightarrow \quad \frac{\Delta R}{R} = \frac{2\Delta l}{l}$$

$$\therefore \quad \frac{\Delta R}{R}\% = 2 \times 0.1$$

$$= 0.2\%$$

**55 (d)** As we know that,

$$R_1 = R_1(1+\alpha_1 t_1)$$
$$R_2 = R_2(1+\alpha_2 t_2)$$

As,

$$R_1 = R_2$$

and

$$R_1 = R_2$$
$$\therefore\ 1+\alpha_1 t_1 = 1+\alpha_2 t_2$$
$$\alpha_1 t_1 = \alpha_2 t_2$$
$$\Rightarrow \frac{\alpha_1}{\alpha_2} = \frac{t_2}{t_1}$$

**56 (d)** As we know that,

$$R \propto \frac{l}{r^2}$$
$$\Rightarrow \frac{R_1}{R_2} = \frac{l_1}{l_2} \times \frac{r_2^2}{r_1^2}$$
$$\therefore \frac{1}{1} = \frac{5}{l_2} \times \left(\frac{2}{1}\right)^2$$
$$\therefore l_2 = 20 \text{ m}$$

**57 (a)** For ohmic circuit, $V \propto I$

Graph of such is a straight line through origin with positive slope.

**58 (b)** As we know that,

$$\text{Pot. gradient along wire} = \frac{\text{Pot. diff. along wire}}{\text{length of wire}}$$
$$0.1 \times 10^{-3} = \frac{I \times 40}{1000} \text{ V/cm}$$
$$\text{Current in wire, } I = \frac{1}{400} \text{A}$$

or, $$\frac{2}{40+R} = \frac{1}{400}$$

or, $$R = 800 - 40$$
$$R = 760\ \Omega$$

**59 (c)** To carry a current of 4 ampere, we need four paths, each carrying a current of one ampere. Let $r$ be the resistance of each path. These are connected in parallel. Hence, their equivalent resistance will be $r/4$. According to the given condition,

$$\frac{r}{4} = 5$$
$$r = 20\ \Omega$$

For this propose two resistances should be connected. There are four such combinations. Hence, Total number of resistance = 4 × 2 = 8.

**60 (c)** In a closed circuit, the vector sum of total emf is equal to the sum of the products of currents and the resistances.

**61 (a)** Kirchhoff's first law is based on the law of conservation of charge.

**62 (b)** At a point I, $i = 0$ in a circuit with one emf source, then that point is a junction point.

**63 (c)** According the Kirchhoff's law, in any analytic circuit, if the direction of current is assumed opposite, then the value of current will be $-i$.

**64 (b)** The deflection in galvanometer will not be changed due to interchange of battery and the galvanometer.

**65 (b)** In the given case, cell is in open circuit mode ($I$ = 0). So voltage across the cell is equal to its emf.

**66 (b)** Electron always moves from negative to positive potential, hence opposite to direction of electric field.

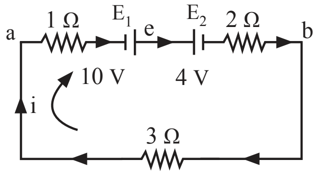
**67 (a)** From the given figure,

$$I = \frac{8-4}{1+2+9}$$
$$= \frac{4}{12}$$
$$= \frac{1}{3} \text{A}$$
$$V_P - V_Q = 4 - \frac{1}{3} \times 3$$
$$= 3 \text{ volt}$$

**68 (c)** On applying Kirchhoff's current law, $I$ = 13 A

**69 (b)** Kirchhoff's second law is based on the law of conservation of energy.

**70 (d)** Since, $E_1$(10V) > $E_2$(4V0)
So current in the circuit will be clockwise,




Applying Kirchhoff's voltage law,

$$-1 \times I + 10 - 4 - 2 \times I - 3I = 0$$
$$\Rightarrow I = 1 \text{ A} \quad \text{(a to b via e)}$$
$$\text{Current } = \frac{V}{R}$$
$$= \frac{E_1 - E_2}{R_s}$$
$$= \frac{10-4}{(1+2+3)}$$
$$= 1 \text{ A} \quad \text{(a to b via e)}$$

**71 (b)** Balanced condition of wheat stone bridge: $\frac{R_1}{R_2} = \frac{R_3}{R_4}$

Comparison of emf of two cells held: $\frac{E_1}{E_2} = \frac{l_1}{l_2}$

Determination of internal resistance of a cell: $r = R\left(\frac{l_1}{l_2} - 1\right)$

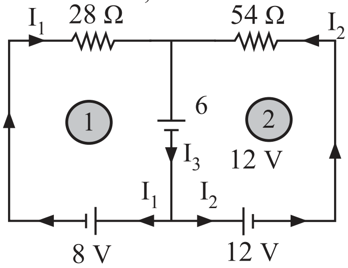
Determination of unknown resistance by meter bridge: $\frac{R}{S} = \frac{l_1}{100 - l_1}$

**72 (b)** According to the balance condition of meter bridge,

$$\frac{X}{10} = \frac{(52+1)}{(48+2)}$$

$$\therefore \quad X = 10.6\ \Omega$$

**73 (d)** Suppose currents through different paths of the circuit are as follows,




After applying KVL for loop (1) and loop (2),

$$28I_1 = -6 - 8$$

$$\Rightarrow \quad I_1 = -\frac{1}{2}\ \text{A}$$

and, $\quad 54I_2 = -6 - 12$

$$\Rightarrow \quad I_2 = -\frac{1}{3}\ \text{A}$$

Hence, $\quad I_3 = I_1 + I_2$

$$= -\frac{5}{6}\ \text{A}$$

**74 (d)** Applying Kirchhoff's law to the closed path containing the cell and 5 ohm resistor.

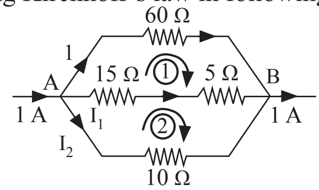
$$10 = 5 \times I$$

$$\Rightarrow \quad I = \frac{10}{5}$$

$$= 2A$$

**75 (a)** In meter bridge experiment, it is assumed that the resistance of the *L* shaped plate is negligible, but actually it is not so. The error created due to this is called end error. To remove this the resistance box and the unknown resistance must be interchanged and then the mean reading must be taken.

**76 (a)** Applying Kirchhoff's law in following figure,




At junction A,

$$I + I_1 + I_2 = 1 \qquad \text{...(i)}$$

For Loop (1),

$$-60I + (15+5)I_1 = 0$$

$$\Rightarrow \quad I_1 = 3I \qquad \text{...(ii)}$$

For Loop (2)

$$-(15+5)I1 + 10I_2 = 0$$

$$\Rightarrow \quad I_2 = 2I_1$$

$$= 2(3I)$$

$$= 6I \qquad \text{...(iii)}$$

On solving equation (i), (ii) and (iii),

$$I = 0.1\ \text{A}$$

**77 (c)** As the two cells oppose each other hence, the effective emf in closed circuit is 15 – 10 = 5 V and net resistance is 1 + 0.6 = 1.6 ohm (because in the closed circuit the internal resistance of two cells are in series.)

$$\text{Current in the circuit, } I = \frac{\text{effective emf}}{\text{total resistance}}$$

$$= \frac{5}{1.6}\text{A}$$

The potential difference across voltmeter will be same as the terminal voltage of either cell. Since the current is drawn from the cell of 15 V.

$$\therefore \quad V_1 = E_1 - Ir_1$$

$$= 15 - \frac{5}{1.6} \times 0.6$$

$$= 13.1\ \text{V}$$

**78 (c)** Balancing length is independent of cross-sectional area of wire.

**79 (b)** Using formula of internal resistance,

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

$$= \left(\frac{52-40}{40}\right) \times 5$$

$$= 1.5\ \Omega$$

**80 (b)** For balanced meter bridge,

$$\frac{55}{R}=\frac{20}{80}$$

$$\Rightarrow R=220\ \Omega$$

**81 (c)** According to the given condition,

$$\frac{l}{100-l}=\frac{5}{15}$$

$$\frac{l}{100-l}=\frac{1}{3}$$

$$3l = 100-x$$

$$\therefore \quad 4l=100$$

$$\therefore \quad l=25\text{ cm}$$

**82 (b)** Initially,

$$\frac{5}{l_1}=\frac{R}{100-l_1} \qquad ...(i)$$

Finally,

$$\frac{5}{1.6l_1}=\frac{R/2}{(100-1.6l_1)} \qquad ...(ii)$$

$$\therefore \frac{R}{1.6(100-l_1)}=\frac{R}{2(100-1.6l_1)}$$

$$\therefore \quad 100-1.6l_1=200-3.2l_1$$

$$\therefore \quad 1.6l_1=40$$

$$\therefore \quad l_1=25\text{ cm}$$

From equation (i),

$$\frac{5}{25}=\frac{R}{75}$$

$$\Rightarrow \quad R=15\ \Omega$$

**83 (c)** The instrument among the following which measures the emf of a cell most accurately is potentiometer.

**84 (a)** Copper rod and iron rod are joined in series.

$$\therefore \quad R=R_{Cu}+R_{Fe}$$

$$=(\rho_1+\rho_2)\frac{\ell}{A} \quad \left(\because R=\rho\frac{\ell}{A}\right)$$

From ohm's law, $V=RI$

$$=\frac{(1.7\times10^{-6}\times10^{-2}+10^{-5}\times10^{-2})}{0.01\times10^{-4}}$$

$$=0.117\text{ volt} \qquad (\because I=1\text{ A})$$

**85 (c)** According to the given condition,

$$\frac{2}{3}=\frac{1}{100-l}$$

$$\therefore \quad 2(100-l)=3l$$

$$\therefore \quad l=\frac{200}{5}$$

$$=40\text{ cm}$$

**86 (a)** In a balanced Wheatstone network, the resistances in the arms Q and S are interchanged. As a result of this network is not balanced

**87 (a)** For balancing the bridge,

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

$$\therefore \quad S=\frac{S_1S_2}{S_1+S_2} \quad (\because S_1, S_2 \text{ are in parallel})$$

$$\therefore \quad \frac{P}{Q}=\frac{R(S_1+S_2)}{S_1S_2}$$

**88 (a)** Let, we connect 24 cells in $n$ rows of $m$ cells, then if $I$ is the current in external circuit then

$$I=\frac{mE}{mr/n+R} \qquad ...(i)$$

For $I$ to be maximum, $(mr + nR)$ should be minimum. It is minimum for

$$R=\frac{mr}{n} \qquad ...(ii)$$

So maximum current in external circuit is

$$I=\frac{mE}{2R} \qquad ...(iii)$$

Where $R = 3$, $r = 0.5$
so equation (ii) becomes

$$\frac{m}{n}=6$$

so,

$$n=2,\ m=12$$

**89 (a)** Unknown resistance,

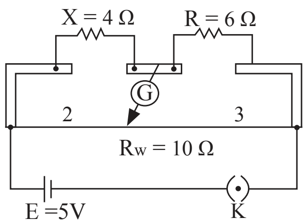
$$X=R\frac{l_1}{l_2}=6\times\frac{2}{3}$$

$$\therefore \ X=4\ \Omega$$

Resistance of bridge wire,

$$R_W=0.1\ \Omega/\text{cm}$$

$$=10\ \Omega$$




Equivalent resistance,

$$R_{eq}=(X+R)\,||\,R_W$$

$$=(10)\,||\,(10)$$

$$=5\ \Omega$$

Current drawn from the battery is,

$$I = \frac{E}{R_{eq}}$$
$$= \frac{5}{5}$$
$$= 1 \text{ A}$$

**90 (a)** The wrong statement is - potentiometer is a constant voltage device.

**91 (b)** Kiran overlooked following two things.

(i) Current in the potentiometer wire from driving cell should not be passed for long time as this causes heating effect and thus, changes resistance of wire.

(ii) A balanced point is obtained on potentiometer wire if fall of potentiometer wire, due to driving cell is greater than emf of cell to be balanced.

Here, $E_2(6\text{ V}) > E(4\text{ V})$

Hence, balancing length for cell $E_2$ cannot be obtained.

**92 (a)** According to the given condition,

$$I = \frac{12}{(4+2)}$$
$$= 2 \text{ A}$$

Energy loss inside the source $= I^2 r$

$$= (2)^2 \times 2$$
$$= 8 \text{ W}$$

**93 (a)** According to Ohm's law,

$$V = IR$$

$$\therefore \; R = \frac{6}{3}$$
$$= 2\ \Omega$$

But this is valid if ammeter and voltmeter are ideal.

In reality, ammeter and voltmeter both have their resistance values, contributed in the circuit.

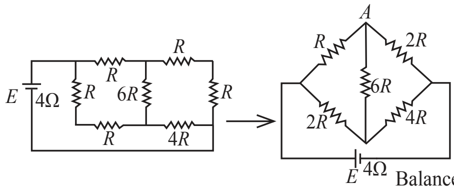
This means effective resistance of circuit in reality is,

$$\left[\frac{1}{R_V} + \frac{1}{R + R_A}\right]^{-1}$$

Where, $R_V$ and $R_A$ are resistances of voltmeter and ammeter respectively. As $R_V >> (R_A + R)$, net resistance is less than ideal resistance of circuit, i.e., < 2 ohm

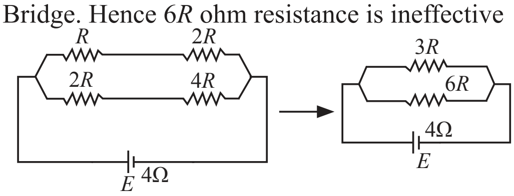
**94 (b)** In balanced Wheatstone bridge, the arms of galvanometer and cell can be interchanged without affecting the balance of the bridge.

**95 (b)** The equivalent circuits are shown in the figure.



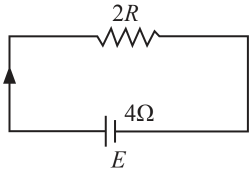

Balanced Wheat stone Bridge

The circuit represents balanced Wheatstone Bridge. Hence $6R$ ohm resistance is ineffective




$$\frac{1}{R_{eq}} = \frac{1}{3R} + \frac{1}{6R}$$

$$R_{eq} = \frac{(3R)(6R)}{(3R)+(6R)}$$
$$= 2R$$



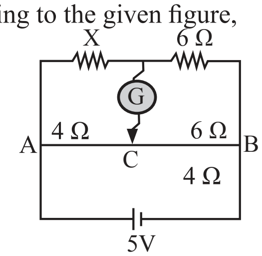

For Maximum Power

External Resistance = Internal Resistance

$$2R = 4\ \Omega$$
$$R = 2\ \Omega$$

**96 (b)** When the resistance in the main circuit is increased, the current through the wire due to auxiliary battery decreases. This decrease in potential gradient increases the balancing length. Hence balance point can be shifted from 6th to 8th wire.

**97 (c)** According to the given figure,




Resistance of the part AC,

$$R_{AC} = 0.1 \times 40$$
$$= 4\ \Omega$$

and,
$$R_{CB} = 0.1 \times 60$$
$$= 6\ \Omega$$

In balanced condition, $\frac{X}{6} = \frac{4}{6}$

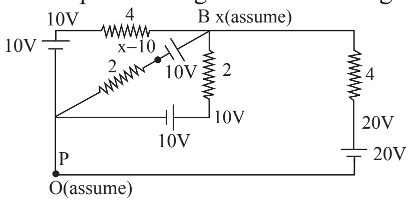
$$\Rightarrow \qquad X = 4\ \Omega$$

Equivalent resistance, $R_{eq} = 5\ \Omega$

so current drawn from battery, $I = \frac{5}{5} = 1$ A

**98 (b)** In balance condition, potentiometer doesn't draw any current from secondary circuit.

**99 (a)** Now simplified the given circuit. we get,




We have to find I. Let potential of point P be 0. Potential at other points are shown in the figure apply Kirchhoff's current law at B where potential is assume to be $x$ volt.

$$\frac{x-10}{4} + \frac{x-10}{2} + \frac{x-20}{4} + \frac{(x-10)-0}{2} = 0$$

$$\Rightarrow x - 10 + 2x - 20 + x - 20 + 2x - 20 = 0$$

$$\Rightarrow \qquad 6x = 70$$

$$\Rightarrow \qquad x = \frac{35}{3} \text{ volt}$$

$$I = \frac{20 - \frac{35}{3}}{4}$$

$$= \frac{25}{12} \text{A}$$

**100 (b)** For a Balanced Wheatstone's bridge,

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

As the bridge is balanced, no current will flow through galvanometer. Thus, equivalent resistance,

$$R_{eff} = \frac{(10+30)(30+90)}{(10+30+30+90)}$$

$$= \frac{40 \times 120}{160} = 30\ \Omega$$

Now, $R_{eff} = 30 + 5 = 35\ \Omega$

Now, $I = \frac{V}{R_{eff}}$

$$= \frac{7}{35}$$

$$= \frac{1}{5}$$

$$= 0.2 \text{ A}$$

**101 (a)** According to the given condition,

$$\frac{x}{60} = \frac{l}{100-l} \qquad \text{...(i)}$$

$$\frac{1}{X_p} = \frac{1}{X} + \frac{9}{X}$$

$$\frac{1}{X_p} = \frac{10}{X}$$

$$\Rightarrow \qquad X_p = \frac{X}{10}$$

$$\therefore \quad \frac{X/10}{R} = \frac{l}{100-l} \qquad \text{...(ii)}$$

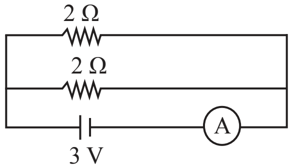
Equating equations (i) and (ii),

$$\frac{X}{60} = \frac{X}{10R}$$

$$\therefore \quad 10R = 60$$

$$\therefore \quad R = 6\ \Omega$$

**102 (a)** Capacitor acts as open circuit for dc. Hence, circuit reduces to,




$$R = \frac{2 \times 2}{2+2} = 1\ \Omega$$

$$I = \frac{E}{R} = \frac{3}{1} = 3 \text{ A}$$

## High-Order Thinking Skill

**1 (b)** As we know that,

$$V = IR = (neAv_d)\rho\frac{\ell}{A}$$

$$\Rightarrow \rho = \frac{V}{nelV_d} = \frac{5}{8 \times 10^{28} \times 1.6 \times 10^{-19} \times 2.5 \times 10^{-4} \times 0.1}$$

**2 (b)** The heat produced is given by,

$$H = \frac{V^2}{R} \text{ and, } R = \frac{\rho\ell}{\pi r^2}$$

$$\therefore \ H = V^2\left(\frac{\pi r^2}{\rho\ell}\right)$$

Thus, heat is doubled if both length ($l$) and radius ($r$) are doubled.

**3 (d)** Let internal resistance of source = $R$

Current in coil of resistance,

$$R_1 = I_1$$
$$= \frac{V}{R+R_1}$$

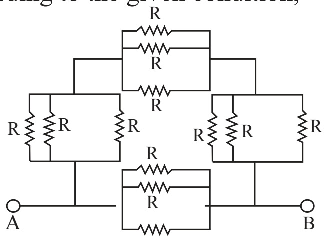
Current in coil of resistance,

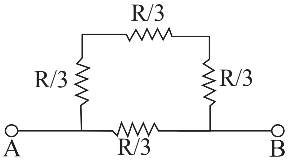
$$R_2 = I_2$$
$$= \frac{V}{R+R_2}$$

Further, as heat generated is same. So,

$$I_1^2 R_1 t = I_2^2 R_2 t$$
$$\left(\frac{V}{R+R_1}\right)^2 R_1 = \left(\frac{V}{R+R_2}\right)^2 R_2$$
$$\Rightarrow \quad R_1\left(R+R_2\right)^2 = R_2\left(R+R_1\right)^2$$
$$\Rightarrow \quad R^2R_1 + R_1R_2^2 + 2RR_1R_2 = R^2R_2 + R_1^2R_2 + 2RR_1R_2$$
$$\Rightarrow \quad R^2\left(R_1 - R_2\right) = R_1R_2\left(R_1 - R_2\right)$$
$$\Rightarrow \quad R = \sqrt{R_1R_2}$$

**4 (d)** According to the given condition,




$$R_{net} \text{ between AB} = \frac{\frac{3R}{3}\times\frac{R}{3}}{\frac{3R}{3}+\frac{R}{3}}$$
$$= \frac{R^2}{4R}$$
$$= 4\ \Omega$$

**5 (d)** Given that,

In first case,

$$T_1 = 727 + 273$$
$$= 1000 \text{ K}$$
$$T_2 = 227 + 273$$
$$= 500 \text{ K}$$
$$P = 60 \text{ watt}$$

As we know that,

$$P = \frac{H}{t}$$
$$= \sigma\left(T_1^4 - T_2^4\right)$$

In the second case,

$$T_1' = 1227 + 273 = 1500 \text{ K}$$
$$T_2' = 500 \text{ K}$$

$$\frac{P'}{P} = \frac{(1500)^4 - (500)^4}{(1000)^4 - (500)^4} = \frac{(500)^4\left(3^4 - 1\right)}{(500)^4\left(2^4 - 1\right)} = \frac{80}{15}$$

$$\Rightarrow \quad P' = 60 \times \frac{80}{15} = 320 \text{ watt}$$

**6 (c)** As we know that,

$$\text{W} = \int_0^{30} \frac{\text{V}^2}{\text{R}} dt$$
$$W = \int_0^{30} \frac{(200)^2}{100\left(1+\alpha\frac{20t}{3}\right)} dt$$
$$= \frac{(200)^2}{100}\int_0^{30} \frac{dt}{1+\frac{20\alpha}{3}t}$$
$$= \frac{400\times 3}{20\alpha} \ln\left(\frac{1+\frac{20\alpha}{3}\times 30}{1}\right)$$
$$= 60{,}000 \ln\left(\frac{6}{5}\right)$$
$$\because \quad 120 = 100\left[1+\alpha(200)\right]$$
$$\therefore \quad \alpha = \frac{1}{1000}$$

**7 (b)** In case of internal resistance measurement by potentiometer,

$$\frac{V_1}{V_2} = \frac{\ell_1}{\ell_2}$$
$$= \frac{\left[ER_1/\left(R_1+r\right)\right]}{\left[ER_2/\left(R_2+r\right)\right]}$$
$$= \frac{R_1\left(R_2+r\right)}{R_2\left(R_1+r\right)}$$

where,

$l_1 = 2$ m

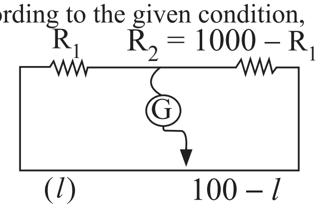
$l_2 = 3$ m

$R_1 = 5\ \Omega$

$R_2 = 10\ \Omega$

$$\therefore \quad \frac{2}{3} = \frac{5(10+r)}{10(5+r)}$$
$$20 + 4r = 30 + 3r$$
$$r = 10\ \Omega$$

**8 (c)** According to the given condition,



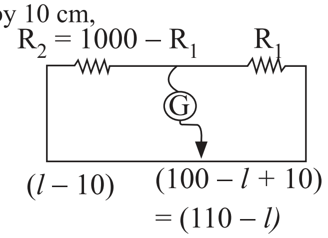

$$R_1 + R_2 = 100$$

$$\Rightarrow \quad R_2 = 100 - R_1 \quad ...(ii)$$

On balancing condition,

$$R_1(100 - l) = (1000 - R_1)l \quad ...(i)$$

on interchanging resistance balance point shifts left by 10 cm,




$$R_2 = 1000 - R_1$$

on balancing condition,

$$(1000 - R_1)(110 - l) = R_1(l - 10)$$

or,

$$R_1(l - 10) = (1000 - R_1)(110 - l) \ldots (ii)$$

Divide eq. (i) by (ii),

$$\frac{100 - 1}{l - 10} = \frac{l}{110 - l}$$

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

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

or, $\quad l = 55$

Putting the value of l in eqn (i),

$$R_1(100 - 55) = (1000 - R_1)55$$

$$\Rightarrow \quad R_1(45) = (1000 - R_1)55$$

$$\Rightarrow \quad 20R_1 = 11000$$

$$\therefore \quad R_1 = 550\ \text{K}\Omega$$

## NCERT Exemplar Problems

**1 (b)** As we know, electric current per unit area is called current density. The current density is also directed along E and is also a vector.

Conductivity is given by, $\sigma = \frac{1}{\rho} = \frac{1}{RA}$

Electric field is given by, $J = \sigma E$

So, current density changes due to electric field produced by charges accumulated on the surface of wire.

**2 (a)** According to the formula of resistance, $R = \rho(l/A)$ For maximum resistance, the value of $l$ should be maximum and A must be minimum.

So that, it is minimum when area of cross-section is 1 cm × ½ cm.

**3 (a)** We know that the relationship between current and drift speed is,

$$I = Anev_d$$

That means, $I \propto v_d$

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

**4 (a)** As we know the equivalent emf (equivalent) in the parallel combination is given by,

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

So that, the equivalent emf $\varepsilon_{eq}$ of the two cells is between $\varepsilon_1$ and $\varepsilon_2$, i.e. $\varepsilon_1 < \varepsilon_{eq} < \varepsilon_2$

**5 (c)** To improve accuracy, balance point should be obtained near the midpoint on the bridge. This means, l is approximately is equal to 50 cm. This need choosing of resistance S suitably.
For given value of $l_1$

$$\frac{R}{S} = \frac{l_1}{100 - l_1} = \frac{2.9}{97.1}$$

$$S \approx 33R$$

To make R/S ratio 1:1, value of S should be reduced by 33 times.
And S = 100 ohm
Hence required,

$$S = \frac{100}{33} \approx 3\Omega$$

**6 (b)** The potential drop across wires of potentiometer should be more than emf of primary cells. Here, values of emfs of two cells are given as 5 V and 10 V, so the potential drop along the potentiometer wire must be more than 10 V. So battery should be of 15 V and about 4 V potential is dropped by using variable resistance

## Assertion and Reasons

**1 (c)** From relation $\vec{J}=\sigma\vec{E}$ the current density $\vec{j}$ at any point in ohmic resistor is in direction of electric field $\vec{E}$ at that point. In space having non-uniform electric field, charges released from rest may not move along ELOF. Hence Assertion is correct while Reason is incorrect.

**2 (a)** As we know that,

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

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

$$\Rightarrow R\propto\frac{1}{P}$$

That means higher is the wattage of a bulb, lesser is the resistance and so it will glow bright.

**3 (a)** Resistance of wire $R=\rho\frac{l}{A}$

where $\rho$ is resistivity of material which does not depend on the geometry of wire. Since when wire is bent resistivity, length and area of cross-section do not change, therefore resistance of wire also remains same.

**4 (c)** Fuse wire must have high resistance because in series current remains same, therefore according to Joule's law,

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

Heat produced is high if $R$ is high. The melting point must be low so that wire may melt with increase in temperature. As the current equal to maximum safe value, flows through the fuse wire, it heats up, melts and break the circuit.

**5 (c)** Drift speed is the average speed between two successive collision.

**6 (a)** Resistance of 50 W bulb is two times the resistance of 100 W bulb. When bulbs are connected in series, 50 W bulb will glow more as $P=i^2R$ (current remains same in series). In parallel the 100 W bulb will glow more as $P=\frac{V^2}{R}$ (potential difference remains same in parallel).

**7 (a)** As we know that,

$$\text{Glow} = \text{Power }(P)=I^2R$$

$$\therefore\ \frac{dP}{P}=2\left(\frac{dI}{I}\right)=2\times0.5=1\%$$

**8 (a)** When temperature increases the random motion of electrons and vibration of ions increases which results in more frequent collisions of electrons with the ions. Due to this the average time between the successive collisions, denoted by $\tau$, decreases which increases $\rho$.

**9 (d)** When two bulbs are connected in series, the resistance of the circuit increases and so the voltage in each decreases, hence the brightness and the temperature also decreases. Due to decrease in temperature, the resistance of the carbon filament will slightly increase while that of metal filament will decrease. Hence, carbon filament bulb will glow more brightly $P=i^2R$ Also carbon is not a semiconductor.

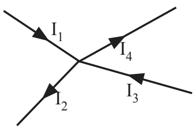
**10 (c)** Before the presence of electric field, the free electrons move randomly in the conductor, so their drift velocity is zero and therefore there is no current in the conductor. In the presence of electric field, each electron in the conductor experience a force in a direction opposite to the electric field. Now the free electrons are accelerated from negative and to the positive end of the conductor and hence a current starts to flow from the conductor.

**11 (d)** Because of heat production every resistance has a maximum power rating, the maximum power that can be dissipated without overheating the device. When this rating is exceeded, heat is produced, due to which resistance may change unpredictably.

**12 (a)** **Junction rule or Kirchhoff's first law or Kirchhoff's current law (KCL)** states that the algebraic sum of the currents meeting at a junction (point) in an electrical circuit is always zero. Or, the sum of currents flowing towards the junction is equal to sum of currents leaving the junction.

$$\Sigma I=0$$

$$I_1+I_3=I_2+I_4$$




**13 (c)** The resistance of the galvanometer is fixed. In meter bridge experiments, to protect the galvanometer from a high current, high resistance is connected to the galvanometer in order to protect it from damage.

**14 (a)** If either emf of the driver cell or potential difference across the whole potentiometer wire is lesser than the emf of then experimental cell, then balance point will not obtained.

**15 (c)** Kirchhoff's loop rule follows from conservation of energy.