CHAPTER 3

Current Electricity

Electricity conduction, Ohm's law and resistance

Electric Current: Net charge flowing across a given area of conductor per unit time is defined as electric current.

$I = \frac{q}{t}$, S.I. unit of current is Ampere (A).

A steady current is generated in a closed circuit where electric charge moves from higher to lower potential. ***Electromotive force*** or ***emf*** is the work done by the source in taking the charge from lower to higher potential energy.

Drift velocity: The free electrons drift with some velocity towards the positive terminal when a potential difference is applied across the ends. The average velocity with which the electrons move is termed as drift velocity.

Drift velocity, $v_d = \frac{eE\tau}{m} = \frac{eV\tau}{ml}$

Where e = charge on electron

E = Electric field intensity

V = Potential difference across the ends of the conductor

τ = Relaxation time

m = Mass of electron

Relation between current and drift velocity: Current is directly proportional to the drift velocity.

$I \propto v_d$

When the number of electrons are less, current is less so the drift velocity is small.

When the number of electrons are large, high current flows so the drift velocity is large.

Ohm's law: The voltage across the ends of the conductor is directly proportional to the electric current flowing through the conductor.

$V \propto I$

Or V = IR, where R is the electrical resistance of the conductor

Resistance: The property that resists the flow of current through any conductor is called the resistance of the conductor.

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

It varies directly with the length of the conductor while depends inversely on the area of cross section of the conductor.

$R = \frac{\rho l}{A}$, ρ being the resistivity of the material of the conductor.

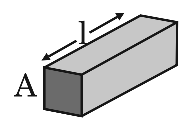


Fig.: Resistance in a conductor

Resistivity: It depends on the nature of the material and temperature. It is also termed as specific resistance.

$\rho = \frac{m}{ne^2\tau}$ gives the relation between resistivity and relaxation time.

There is an increasing order of resistivity as we go from metal to insulator.

$\rho_{metals} < \rho_{semiconductors} < \rho_{insulators}$

Conductivity and conductance: The reciprocal of resistivity is conductivity (σ).

$\sigma = \frac{1}{\rho}$ and its S.I. unit is $\Omega^{-1}m^{-1}$.

The reciprocal of resistance is the conductance of the conductor. Its S.I. unit is mho.

Current Density: The amount of charge flowing per unit area per second is called the current density.

$J = mqv_d$, where v_d is the drift velocity of the charge carriers, n is the number of charge carriers and q is the charge.

The relation between current density and conductivity is

$J = \sigma E$

Mobility: Mobility is the ratio of drift velocity to the applied electric field. Mobility is symbolized by μ.

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

Its S.I. unit is $m^2s^{-1}V^{-1}$.

Resistors: The objects which resist the flow of charge are called resistors which can be of two types, i.e. wire bound resistors and carbon resistors.

Resistors can combine in two different ways; either in series or in parallel.

- Consider n number of resistors connected in series, then the combined resistance will be as follows:

  $$R_{eqv} = R_1 + R_2 + R_3 + ... + R_n$$

Same amount of current will flow through each resistor connected in series while the potential difference would be different for every resistor.

- Consider n number of resistors connected in parallel, then the combined resistance will be as follows:

  $$R_{eqv} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ... + \frac{1}{R_n}$$

The current flowing through each resistor would be different in this case while the potential difference would be same for all the resistors.

Internal resistance: It is the resistance on the current offered by the electrolyte and the electrodes. It is symbolize by r.

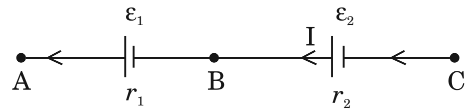
Let us assume a cell with 2 electrodes connected by an external resistance R. Then current is, $I = \frac{\varepsilon}{R + r}$

where ε = emf, r = Internal resistance

Kirchhoff's Laws, cells and their combinations

Cells in series and in parallel

- The equivalent emf of a series combination of n cells is just the sum of their individual emfs
- The equivalent internal resistance of a series combination of n cells is the sum of their internal resistances.

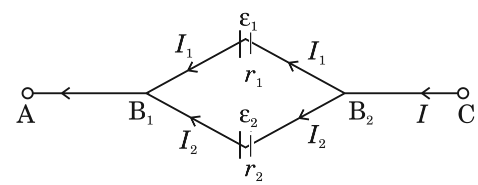


$\varepsilon = \varepsilon_1 + \varepsilon_2$

- In a parallel connection,

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

  $$\frac{\varepsilon_{eq}}{r_{eq}} = \frac{\varepsilon_1}{r_1} + ... + \frac{\varepsilon_n}{r_n}$$



Kirchhoff's law:

- **Junction Rule:** The sum of currents entering a junction would be equal to the sum of currents leaving the junction.
- **Loop Rule:** The sum of changes in potential around any loop that is closed should be zero.

  Wheatstone bridge: It is an arrangement of four resistors in a way so that a galvanometer is placed between the two opposite arms.

  There is a null-point condition in the wheat stone bridge where current is zero which can be represented as follows:

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

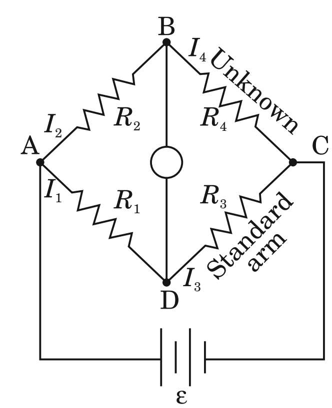


Fig.: Wheastone bridge

Electrical devices

Meter Bridge: Meter Bridge is the simplest form of the Wheatstone bridge which is used for accurate comparison of resistances.

In order to find out an unknown resistance R with the help of a standard known resistance S:

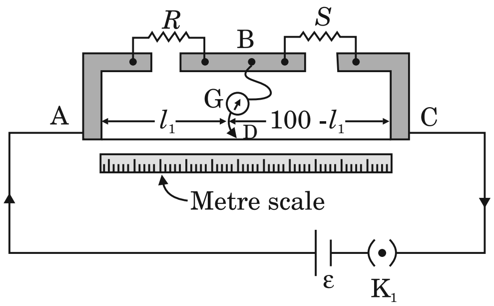


Fig.: Meter bridge

$R = S\frac{l_1}{100 - l_1}$, l_1 being the distance of the jockey from end A at the balance point.

Potentiometer: It is a device which is used to compare potential differences and emf"'s. It also measures the internal resistance of a cell.

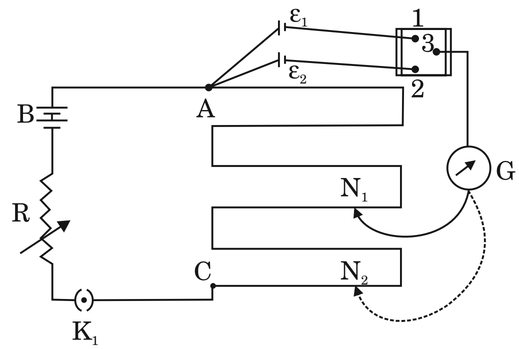


Fig.: Potentiometer

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

Potentiometer does not draw any current from the voltage source being measured. The internal resistance of a given cell can be measured by:

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

Exercise

1. Current of 4.8 ampere is flowing through a conductor. The number of electrons per second will be
   (*a*) 3×10^{19} (*b*) 7.68×10^{21}
   (*c*) 7.68×10^{20} (*d*) 3×10^{20}
2. When the current i is flowing through a conductor, the drift velocity is v. If 2i current is flowed through the same metal but having double the area of cross section then the drift velocity will be
   (*a*) $\frac{v}{4}$ (*b*) $\frac{v}{2}$
   (*c*) v (*d*) $4v$
3. If there is 0.1% increase in length due to stretching the percentage increase in its resistance will be
   (*a*) 0.2% (*b*) 2%
   (*c*) 1% (*d*) 0.1%
4. 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
5. The resistivity of a wire
   (*a*) Increase with the length of the wire
   (*b*) Decrease with the area of cross section
   (*c*) Decreases with the length and increases with the area of cross section of wire
   (*d*) None of the above
6. Ohm's law is true
   (*a*) For metallic conductors at low temperature
   (*b*) For metallic conductors at high temperature
   (*c*) For electrolytes when current passes through them
   (*d*) For diode when current flows

7. Drift velocity v_d varies with the intensity of electric field as per the relation

(*a*) $v_d \propto E$ (*b*) $v_d \propto \frac{1}{E}$

(*c*) v_d = constant (*d*) $v_d \propto E^2$

8. The specific resistance of a wire is P, its volume is $3m^3$ and its resistance is 3Ω, then its length will be

(*a*) $\sqrt{\frac{1}{\rho}}$ (*b*) $\frac{3}{\sqrt{\rho}}$

(*c*) $\frac{1}{\rho}\sqrt{3}$ (*d*) $\rho\sqrt{\frac{1}{3}}$

9. 5 ampere of current is passed through a metallic conductor. The charge flowing in one minute in coulomb will be

(*a*) 5 (*b*) 12

(*c*) $\frac{1}{12}$ (*d*) 300

10. The reciprocal of resistance is

(*a*) Conductance (*b*) Resistivity

(*c*) Voltage (*d*) None of these

11. A cell of e.m.f. 1.5 V having a finite internal resistance is connected to a load resistance of 2 Ω. For maximum power transfer the internal resistance of the cell should be

(*a*) 4 Ω (*b*) 0.5 Ω

(*c*) 2 Ω (*d*) None

12. The e.m.f. of a cell is E volt and internal resistance is r Ω. The resistance in external circuit is also r Ω. The potential difference across the cell will be

(*a*) $\frac{E}{2}$ (*b*) 2E

(*c*) 4E (*d*) $\frac{E}{4}$

13. A cell of e.m.f. E is connected with an external resistance R, then potential difference across cell is V. The internal resistance of cell will be

(*a*) $\frac{(E-V)R}{E}$ (*b*) $\frac{(E-V)R}{V}$

(*c*) $\frac{(V-E)R}{V}$ (*d*) $\frac{(V-E)R}{E}$

14. Two cells, each of e.m.f. E and internal resistance r are connected in parallel between the resistance R. The maximum energy given to the resistor will be, only when

(*a*) $R = \frac{r}{2}$ (*b*) R = r

(*c*) R = 2 r (*d*) R = 0

15. 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*) Angularmomentum

16. Kirchhoff's second law is based on the law of conservation of

(*a*) Charge

(*b*) Energy

(*c*) Momentum

(*d*) Sum of mass and energy

17. A new flashlight cell of e.m.f 1.5 volt gives a current of 15 amp, when connected directly to an ammeter of resistance 0.04 Ω. The internal resistance of cell is

(*a*) 0.04 Ω (*b*) 0.06 Ω

(*c*) 0.10 Ω (*d*) 10 Ω

18. When cells are connected in parallel, then

(*a*) The current decrease

(*b*) The current increase

(*c*) The e.m.f increases

(*d*) The e.m.f decrease

19. The internal resistance of a cell depends on

(*a*) The distance between the plates

(*b*) The area of the plates immersed

(*c*) The concentration of the electrolyte

(*d*) All the above

20. A cell of e.m.f 6 V and resistance 0.5 Ω is short circuited. The current in the cell is

(*a*) 3 amp (*b*) 12 amp

(*c*) 24 amp (*d*) 6 amp

21. Kirchhoff's I law and II law of current, prove the

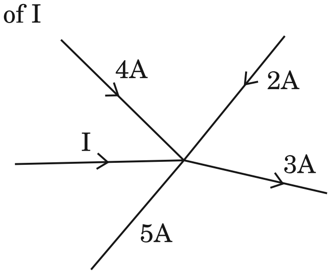
(*a*) Conservation of charge and energy

(*b*) Conservation of current and energy

(*c*) Conservation of mass and charge

(*d*) None of these

22. In the given current distribution what is the value of I



(*a*) 3 A (*b*) 8 A

(*c*) 2 A (*d*) 5 A

23. In meter bridge or wheatstone bridge for measurement of resistance, the known and the unknown resistances are interchanged. The error so removed is

(*a*) End correction

(*b*) Index error

(*c*) Due to temperature effect

(*d*) Random error

24. A galvanometer can be converted into an ammeter by connecting

(*a*) Low resistance in series

(*b*) High resistance in parallel

(*c*) Low resistance in parallel

(*d*) High resistance in series

25. By ammeter, Which of the following can be measured

(*a*) Electric potential (*b*) Potential Difference

(*c*) Current (*d*) Resistance

26. The resistance of 1 A ammeter is 0.018Ω. To convert it into 10 A ammeter, the shunt resistance required will be

(*a*) 0.18Ω (*b*) 0.0018Ω

(*c*) 0.002Ω (*d*) 0.12Ω

27. A galvanometer can be used as a voltmeter by connecting a

(*a*) High resistance in series

(*b*) Low resistance in series

(*c*) High resistance in parallel

(*d*) Low resistance in parallel

28. If the length of potentiometer wire is increased, then the length of the previously obtained balance point will

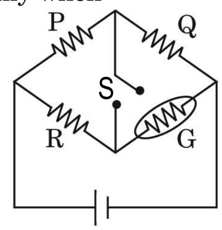
(*a*) Increase

(*b*) Decrease

(*c*) Remain unchanged

(*d*) Become two times

29. The figure shows a circuit diagram of a 'Wheat stone Bridge' to measure the resistance G of the galvanometer. The relation $\frac{P}{Q} = \frac{R}{G}$ will be satisfied only when



(*a*) The galvanometer shows a deflection when switch S is closed

(*b*) The galvanometer shows a deflection when switch S is open

(*c*) The galvanometer shows no change in deflection whether S is open or closed

(*d*) The galvanometer shows no deflection

30. The resistance of an ideal voltmeter is

(*a*) Zero (*b*) Very low

(*c*) Very large (*d*) Infinite

31. If an ammeter is connected in parallel to a circuit, it is likely to be damaged due to excess

(*a*) Current (*b*) Voltage

(*c*) Resistance (*d*) All the above

32. The resistance of an ideal ammeter is

(*a*) Infinite (*b*) Very high

(*c*) Small (*d*) Zero

33. The material of wire of potentiometer is

(*a*) Copper (*b*) Steel

(*c*) Manganin (*d*) Aluminium

34. To convert a galvanometer into a voltmeter, one should connect a

(*a*) High resistance in series with galvanometer

(*b*) Low resistance in series with galvanometer

(*c*) High resistance in parallel with galvanometer

(*d*) Low resistance in parallel with galvanometer

Answer Keys

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

Solutions

1. Number of electrons flowing per second

$\frac{n}{t} = \frac{i}{e} = \frac{4.8}{1.6\times10^{-19}} = 3\times10^{19}$

2. $\nu_d = \frac{J}{ne} \Rightarrow \nu_d \propto J$ (current density)

$J_1 = \frac{i}{A}$ and $J_2 = \frac{2i}{2A} = \frac{i}{A} = J_1$

$\therefore (\nu_d)_1 = (\nu_d)_2 = \nu$

3. $R \propto \ell^2 \Rightarrow \frac{\Delta R}{R} = \frac{2\Delta\ell}{\ell} \Rightarrow \frac{\Delta R}{R}\%$

$= 2 \times 0.1 = 0.2\%$

4. $R_1 \propto \frac{\ell}{A} \Rightarrow R_2 \propto \frac{2\ell}{2A} \Rightarrow R_2 \propto \frac{\ell}{A}$

$\therefore R_1 = R_2$

5. Resistivity is the property of the material. It does not depend upon size and shape.

6. Because with rise in temperature resistance of conductor increases, so graph between v and i become no linear.

7. $\nu_d = \frac{e}{m}\times\frac{\nu}{\ell}\tau$ or $\nu_d = \frac{e}{m}\frac{E\ell}{\ell}\tau$ (since $\nu = E\ell$)

$\therefore V_d \propto E$

8. Volume = $A\ell = 3$ $A = \frac{3}{\ell}$

Now $R = \rho\frac{\ell}{A} \Rightarrow 3 = \frac{\rho\times\ell}{\frac{3}{\ell}} = \frac{\rho\ell^2}{3}$

$\Rightarrow \ell^2 = \frac{9}{\rho} = \frac{3}{\sqrt{\rho}}$

9. charge = Current × Time

= 5 × 60 = 300 C

10. The reciprocal of resistance is called conductance

11. For maximum power, external resistance = internal resistance. Hence, the internal resistance should be 2 Ω.

12. Since, both the resistors are same, therefore potential difference = V + V = E $\Rightarrow V = \frac{E}{2}$

13. Let the current in the circuit = $i = \frac{V}{R}$

Across the cell, E = V + ir

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

14. For maximum energy, we have

External resistance of the circuit

= Equivalent internal resistance of the circuit

i.e. $R = \frac{r}{2}$

15. Kirchhoff's first law is based on the law of conservation of charge.

16. Kirchhoff's second law is based on the law of conservation of energy.

17. Let the internal resistance of cell be r, then

$i = \frac{E}{R+r} \Rightarrow 15 = \frac{15}{0.04+r} \Rightarrow r = 0.06\Omega$

18. In parallel, equivalent resistance is low

$i = \frac{E}{R+\frac{r}{n}}$

19. Internal resistance $\propto$ distance $\propto \frac{1}{\text{Area}} \propto$ concentration

20. $i = \frac{E}{r} = \frac{6}{0.5} = 12$ amp

21. Kirchhoff's I law and II law of current, prove the conservation of charge and energy.

22. From kirchhoff's junction law

$\Rightarrow 4 + 2 + i - 5 - 3 = 0$

$\Rightarrow i = 2$ amp

23. 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.

24. To convert a galvanometer into an ammeter a low value resistance called shunt is to be connected in parallel to it.

25. Ammeter is used to measure the current through the circuit.

26. $S = \frac{i_g G}{(i-i_g)} = \frac{1\times0.018}{10-1} = \frac{0.018}{9} = 0.002\Omega$

27. To convert a galvanometer into a voltmeter, a high value resistance is to be connected in series with it.

28. When the length of potentiometer wire is increased, the potential gradient decrease and the length of previous balance point is increased

29. In balance condition, no-current will flow through the branch containing S. Hence, the galvanometer shows no change is deflection whether S is open or closed.

30. The resistance of an ideal voltmeter is considered as infinite.

31. When ammeter is connected in parallel to the circuit, net resistance of the circuit decreases. Hence. more current is drawn from the battery. which damages the ammeter.

32. The resistance of an ideal ammeter is zero.

33. Manganin and constantan are used for making the potentiometer wire.

34. To convert a galvanometer into a voltmeter one should connect a high resistance in series with galvanometer.