3.1. ELECTRIC CURRENT:

1. Charges in motion constitute electric current. $I = \frac{q}{t}$ or $I = dq/dt$ or $q = \int I dt$.
2. The current is a scalar quantity because it does not follow triangle law of vector addition. It is also a scalar because it is the dot product of two vector quantities as $I = \vec{J} \cdot \vec{A}$ where J = current density and A = area of cross section.

Questions:

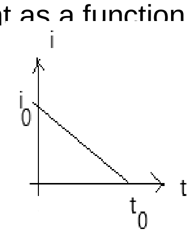
1) Calculate the current flows in a wire at time t = 2 s if charge flows in the wire as a function of time is given by $q = (t + 2)\ C$.
2) Calculate the charge flows in the wire between t = 1 s and t = 2 s if the current as a function of time is $I = (t + 2\ )\ A$.

For non-uniform cross-sectional area, (very small charge dq to flow for small time dt),current is given as:

$$i = \frac{dq}{dt}\ or, \qquad q = \int_{t_1}^{t_2} i dt$$

Here, we see that, charge and current both are a function of time.

For example, the current as a function of time graph is shown of a conductor of resistance R as:



Find the equation of current and charge flows in the conductor.

From the equation of straight line having two points coordinates (x_1, y_1) and (x_2, y_2), it is given as:

$$y - y_1 = \frac{y_2 - y_1}{x_2 - x_1}(x - x_1)$$

In this way, $(0, i_0)\ and\ (t_0, 0)$ are two points in the above graph between I and t. Hence, the **equation of current** is:

$$i - i_0 = \frac{(0 - i_0)}{t_0 - 0}(t - 0)\ or, i = i_0\left(1 - \frac{t}{t_0}\right) - -this\ is\ the\ required\ equation.$$

For **charge flows** in the conductor,

$$q = \int_{t_1}^{t_2} i dt\ \ or, q = \int_0^{t_0} i_0\left(1 - \frac{t}{t_0}\right) dt, or, q = i_0 t - \frac{i_0 t}{2}, or, q = i_0 t/2 - -required\ equation$$

For total heat to be dissipated across the conductor,

$$H = \int_0^{t_0} i^2 R\ dt = \int_0^{t_0} {i_0}^2 R\left(1 - \frac{t}{t_0}\right)^2 dt\ or, H =\ {i_0}^2 R t_0/3 - - - required\ equation.$$

3.2. CURRENT DENSITY:

1. It is defined as electric current per unit surface area. It is:$J = I/A$. In vector form, it $I = \vec{J} \cdot \vec{A} = JA\cos\theta$
2. Current density $(\vec{J})$, electric field $(\vec{E})$ and conductivity (σ) are related as $\vec{J} = \sigma\vec{E}$ or in magnitude form, $J = \sigma E$

Derivation:

$$\boldsymbol{Since, current\ density, J = \frac{I}{A}; \ resistivity, \rho = \frac{1}{conductivity, \sigma}; V = EL, Resistance\ , R = \frac{\rho L}{A}}$$

$$\boldsymbol{Now}, V = RI, or, EL = \left(\frac{\rho L}{A}\right)(I), Or, E = \left(\frac{I}{A}\right)(\rho) Or, \frac{I}{A} = \frac{E}{\rho} Or\ J = \sigma E - -Derived$$

3.3. DRIFT VELOCITY$\vec{v}_d$ AND RELAXATION TIME$(\boldsymbol{\tau})$:

3. It is defined as ''average velocity of free electrons in a conductor which moves in opposite direction of electric field'' applied. Drift velocity is given as:

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

Derivation:

From the equation of motion, v = u + at , so,

$$\vec{v} = \vec{u} + \vec{a}t$$

For 1 electron, 2nd electron, 3rd electron-------n^{th}electrons,

$\vec{v}_1 = \vec{u}_1 + \vec{a}t_1$

$\vec{v}_2 = \vec{u}_2 + \vec{a}t_2$

: : :

: : :

$\vec{v}_n = \vec{u}_n + \vec{a}t_n$

For N number of electrons in a conductor, adding the above expressions and dividing by N both sides, we get,

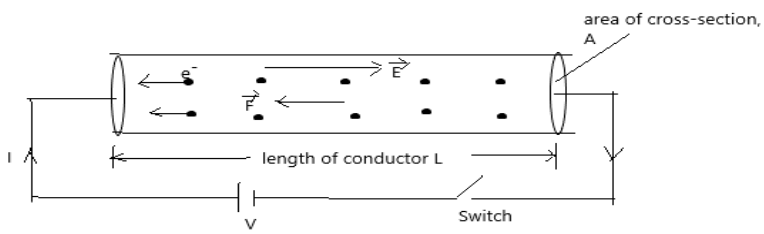
$$\frac{\vec{v}_1 + \vec{v}_2 \pm - - - - - - -}{N} = \frac{\vec{u}_1 + \vec{u}_2 \pm - - - -}{N} + \vec{a}\frac{t_1 + t_2 \pm - - - - -}{N}$$

$$Or, \vec{v}_d = 0 + \vec{a}\tau - - - -(i)$$

Since, $\vec{a} = \frac{\vec{F}}{m} or, \vec{a} = \frac{q\vec{E}}{m}, or, \vec{a} = -eE/m$, therefore,

$$\vec{v}_d = -\frac{e\vec{E}\tau}{m} - - - -(2) \quad Derived$$

The drift speed is given by , $v_d = |\vec{v}_d| = eE\tau/m$



Since, $E = \frac{V}{L}$, therefore, drift speed can be written as:

$$v_d = |\vec{v}_d| = \frac{eE\tau}{m} = \frac{eV\tau}{mL}$$

4. Drift speed is given as $v_d = \frac{eE\tau}{m}$. The drift speed can also be given as $v_d = \frac{eV\tau}{mL}$ where V = potential difference, L = length of the conductor, m = mass of an electron (=9.1 x 10^{-31} kg), τ = relaxation time and e = charge of one electron (= 1.6 x 10^{-16} C).
5. Relaxation time is defined as the average time taken between collisions of two successive electrons.
6. Increasing the temperature, the drift speed decreases.
7. Drift speed depends on (a) electric field, (b) potential difference, (c) relaxation time, (d) temperature, (e) length of conductor.
8. The electric current is related with drift speed as: $I = neAv_d \ \ (\boldsymbol{Derive\ it})$
   where n = electron density= number of free electrons per unit volume. Here A = area of cross-section of the wire
   Derivation:
   $$Since, I = \frac{q}{t} = \frac{Ne}{\tau} = \left(\frac{N}{Vol}\right)(e)\left(\frac{Vol}{\tau}\right) = (n)(e)\left(\frac{AL}{\tau}\right) = (n)(e)(A)(v_d) = neAv_d$$
9. The electrical resistivity is related with electron density and relaxation time as:
   $$\rho = \frac{m}{ne^2\tau} \ldots (\boldsymbol{Derive\ it})$$
   Derivation:
   $$Since, I = neAv_d, Or\frac{V}{R} = (neA)\left(\frac{eE\tau}{m}\right)Or, \frac{L}{R} = (neA)\left(\frac{e\tau}{m}\right), Or, \frac{RA}{L} = \frac{m}{ne^2\tau}, Or,$$
   $$\rho = \frac{m}{ne^2\tau} - - - Derived$$
10. The current density is related with drift speed as: $J = nev_d .. (\boldsymbol{Obtain\ it})$

3.4. MOBILITY (μ):

1. The drift speed is directly proportion to electric field. The proportionality constant is called mobility. So, it is defined as the magnitude of drift velocity per unit electric field.
   $$v_d \propto E \ or \ v_d = \ \mu E \ or \ \mu = \frac{v_d}{E}$$
2. The charge carriers are free electrons in a conductor.
3. The charge carriers in the electrolyte are positive ions and negative ions.
4. The charge carriers in ionized gas are electrons and positive ions.
5. The charge carriers in semiconductor are holes and electrons.
6. The unit of mobility is m^2/V-s and it is of the order of 10^4 cm^2/Vs.
7. The mobility is related with relaxation time as: $\mu = e\tau/m$ where τ = average collision time for electrons.

3.5. OHM'S LAW:

1. The potential difference across a conductor is directly proportional to current flows in the conductor provided that temperature remains constant. That is, $V \propto IorV = RIorR = \frac{V}{I} = constant$. Here R is the proportionality constant, called resistance. The SI unit of resistance

is Ohm (Ω). **The resistance R depends on (i) type of material of the conductor, (ii) dimensions of the conductor (L and A) and (iii) temperature**.

2. The resistance does not depend on V and I as V changes, I changes. But converse is true as (a) for constant I, $R \propto V$ (series combination of resistors) and (b) for V constant, $R \propto \frac{1}{I}$ (parallel combinations of resistors).
3. The graph between V and I for ohmic resistance is given below.

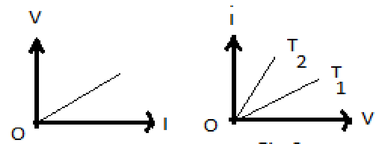


Fig-1 Fig-2

In Fig-2, explain which temperature T_1 or T_2 is greater?

3.6. RESISTIVITY:

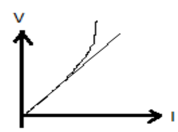
1. Since, $R \propto L and R \propto 1/A$ or, $R \propto L/A$ or $R = \rho\, L/A$, where L = length of the conductor, A = area of cross-section and ρ = resistivity of the material. The resistivity depends on (i) type of materials (conductor, semiconductor, insulators) and (ii) temperature. The SI unit of resistivity is Ωm(Ohm-metre).

3.7. CONDUCTIVITY:

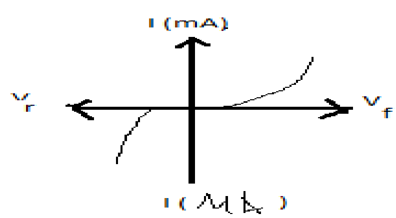
The reciprocal of resistivity is called conductivity (σ). Its SI unit is Siemen/m, or $\Omega^{-1}m^{-1}$. The higher the conductivity of the material, the lower will be its resistivity.

3.8. LIMITATIONS OF OHM'S LAW:

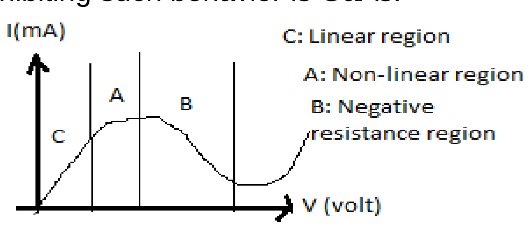
1. The proportionality of V and I does not hold good in the following cases.
   (a) V ceases to be proportional to I. The bend line is for good conductor and straight line holds good for ohmic resistance (linear Ohm's law).



   (b) The relation between V and I depends on the sign of V. If I is for certain V, then reversing the direction of V keeping its magnitude fixed, we will not get the same I in opposite direction. This is the case of semiconductor.



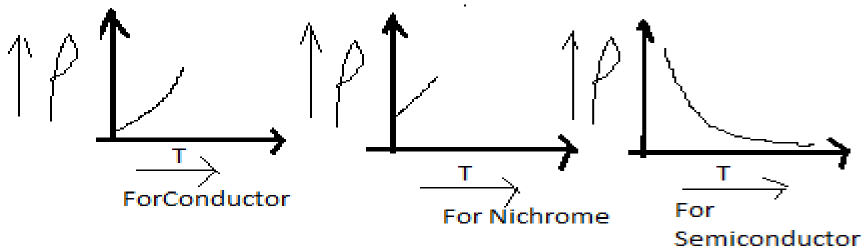
   (c) The relation between V and I is not unique. There is more than one value of V for same current. The material exhibiting such behavior is GaAs.



2. Materials and devices not obeying Ohm's law are actually widely used in electronic circuits.

3.9. TEMPERATURE DEPENDENCE OF RESISTIVITY:

1. A graph is plotted for resistivity $(\rho)$of each material like conductor, alloy (nichrome) and semiconductor which depends on temperature(T).



2. Nichrome is an alloy consists of Ni, Fe, Cr and it is weak dependence of resistivity with temperature.
3. Nichrome or Manganin are is widely used in wire-bound standard resistors (in Metre bridge etc.) because of their very weakly temperature dependent resistivity. These materials have high resistivity and low temperature coefficient. That is, these materials are insensitive to temperature.
4. Fractional increase in resistivity per unit increase in temperature is called temperature coefficient of resistivity.

3.10. RESISTANCE AND TEMPERATURE RELATION:

1. Suppose R_1 is the resistance at temperature t_1 and R_2 is the resistance at temperature t_2, if α = temperature coefficient of resistance, then the relation is

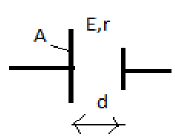
$$R_2 = R_1[1 + \alpha(t_2 - t_1)]$$

3.11. ELECTRICAL POWER AND HEAT DISSIPATED:

1. Electrical power (P) is the product of potential difference and current in the conductor. It $P = VI = I^2R = \frac{V^2}{R}$ and Heat dissipated is $H = VIt = I^2Rt$

3.12. CELL EMF AND INTERNAL RESISTANCE:

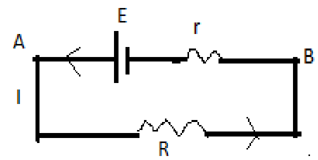
1. EMF (electromotive Force, E) of a cell is defined as the work done to move a unit positive charge from negative plate to positive plate against the electric force. So, $E = W/q$.
   Its unit is volt.
2. The internal resistance (r) is defined as the resistance offered by an electrolyte to the flow of current from negative to positive plate.
   The internal resistance (r) depends upon the following factors.
   a) Nature of electrolyte (dilute or concentrated), the value of r is greater concentrated electrolyte than that of dilute electrolyte.
   b) Separation between electrodes, $r \propto d$
   c) Area of plates, $r \propto 1/A$
   d) Temperature of the electrolyte solution, $r \propto 1/T$



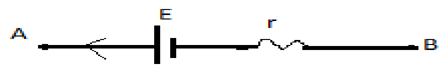
1.13. DISCHARGING OF A CELL:

1. A cell is fully charged and getting it discharged when connected with a load.
2. The relation between terminal potential difference (v) across A and B terminals, cell e.m.f and internal resistance (r) is given as in the following closed circuit diagram.

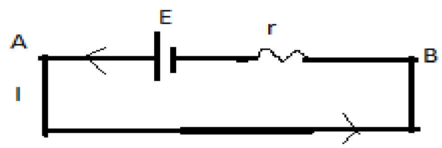
$$V = E - Ir$$



3. When the cell is in open circuit, T. P. D. is equal to V. $(V = E), I = 0$



4. When the cell is shorted in the circuit, $E = Ir, V = 0$



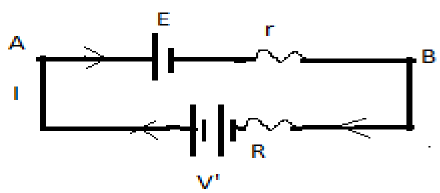
3.14. CHARGING OF A CELL:

1. When a cell is fully discharged and getting it charged by an external battery, then the circuit diagram and its circuit equation is given as-

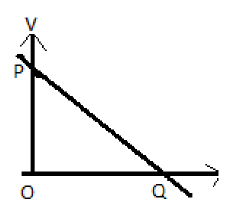
$$V = E + Ir$$

In the below circuit,

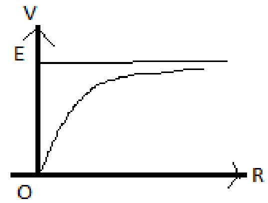
$$I = \frac{V' - E}{r + R}$$



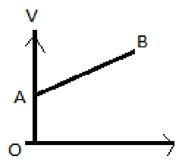
2. The internal resistance of a cell acts only in closed circuit and its function is to reduce the current in the circuit.
3. Graph between
   (i) Terminal potential difference (V) and current (I) when the cell is getting discharged, is given as below. Here, OP = E (equals to cell E. M. F.), OQ = E/r = I and its slope (slope of line PQ) = - r. The equation is $V = E - Ir$



(ii) Terminal potential difference (V) and load resistance R when the cell is getting discharged is given as below. When $= 0; V = 0\ and\ wnen\ R \rightarrow \infty. V = E$. The equation is $V = E/(1 + r/R)$.



4. Graph between V and I for charging a cell: Here in the below graph, OA = E, slope = r and the equation of charging a cell is $V = E + Ir$

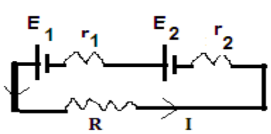


3.15. SERIES COMBINATION OF CELLS:

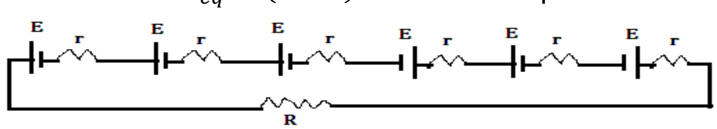
1. When cells E_1, E_2, E_3 --- and their internal resistance r_1, r_2, r_3 ---- are connected in series , then equivalent e. m. f. will be

$$E_{eqvt} = \sum_{i=1}^{n} E_i and r_{eqvt} = \sum_{i=1}^{n} r_i \quad (\boldsymbol{Derive\ it})$$

2. When two cells are in series the its equivalent e. m. f. is $E_{eq} = E_1 + E_2 and$ its internal resistance equivalent, $r_{eq} = r_1 + r_2$. The circuit is given below.



3. If n cells each capacity E and r, are connected in series having same polarity of each cell, then its equivalent emf is $E_{eq} = nE$ and its equivalent internal is $r_{eq} = nr$.
4. If n cells, each capacity E and r are connected in series, and m cells out of n cells have reversed polarities, then its equivalent emf will be $E_{eq} = (n - 2m)E$ and its equivalent internal resistance will be $r_{eq} = n$r.**For example**, in the below circuit, there are total 6 cells, so n = 6, out of six cells, two cells have reverse polarities, that is, m = 2; hence its equivalent emf will be $E_{eq} = (6 - 4)E = 2E$ and equivalent internal resistance $r_{eq} = 6r$.

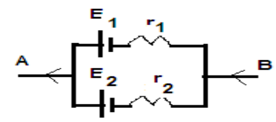


3.16. PARALLEL COMBINATIONS OF CELLS-

1. When cells E_1, E_2, E_3 --- and their internal resistance r_1, r_2, r_3 ---- are connected in parallel, then equivalent e. m. f. will be

$$\frac{E_{eq}}{r_{eq}} = \sum_{i=1}^{n} \frac{E_i}{r_i}\ and\ \frac{1}{r_{eq}} = \sum_{i=1}^{n} \frac{1}{r_i} \quad (\boldsymbol{Derive\ it})$$

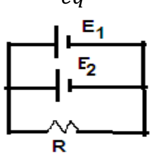
Derivation:



$$I = I_1 + I_2$$
$$I = \frac{E - V}{r}$$
$$\frac{E_{eqvt} - V}{r_{eqvt}} = \frac{E_1 - V}{r_1} + \frac{E_2 - V}{r_2} = \left(\frac{E_1}{r_1} + \frac{E_2}{r_2}\right) - V\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$
$$\frac{E_{eqvt}}{r_{eqvt}} = \frac{E_1}{r_1} + \frac{E_2}{r_2} \; and \; \frac{1}{r_{eqvt}} = \frac{1}{r_1} + \frac{1}{r_2}$$

Note:

1) If n cells of same emf and same internal resistance are connected in parallel, then $\sum \frac{E}{r} = \frac{nE}{r} \; and \; \sum \frac{1}{r} = \frac{n}{r}$ Therefore, $I = \frac{\frac{nE}{r}}{1+R\frac{n}{r}} = \frac{E}{R+\frac{r}{n}}$
2) In parallel grouping, E_{eqvt} = E if each cell equals to E and each resistance equals to r.
3) When positive terminals of few cells are connected to negative terminals of others.
4) Suppose there are three cells E1, E2 and E3 with internal resistance r1, r2 and r3 are connected in parallel. E2 is of opposite polarity and E1 and E3 are of same polarity, then
$$I = \frac{\frac{E_1}{r_1} - \frac{E_2}{r_2} + \frac{E_3}{r_3}}{1 + R\left(\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}\right)}$$
5) When two cells are in parallel, then its equivalent e. m. f. is $E_{eq} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2} \, and$ its internal resistance equivalent, $r_{eq} = \frac{r_1 r_2}{r_1 + r_2}$. The circuit is given below.
6) If n cells each capacity E and r, are connected in parallel having same polarity of each cell, then its equivalent emf is $E_{eq} = E$ and its equivalent internal is $r_{eq} = \frac{r}{n}$.
7) If two cells of different emf are connected in parallel and its internal resistances are not mentioned, take it r for both cells and calculate the average emf. Or, simply take the average of both given emfs and it will be its equivalent emf, incase r is not given. For example, if $E_1 = E_2 = E$ then its equivalent emf will be $E_{eq} = E$ and the current through R is $I = E/R$, but if $E_1 = 2$ E and $E_2 = 4$ E, then its equivalent emf will be $E_{eq} = averageof \; 2 \; Eand \; 4 \; E = 3 \; E$ and current through R is $I = 3E/R$.



3.17. KIRCHHOFF'S RULES: KIRCHHOFF'S JUNCTION RULE:

1. Kirchhoff's Junction Rule or Kirchhoff's current Law (LCL) states that the algebraic sum of electric current at the junction is equal to zero. That is, $\sum I = 0$. Also, it can be stated as the sum of entering current is equal to the sum of leaving current at the junction.
2. This junction rule is based on the principle of conservation of charge.

3.18. KIRCHHOFF'S RULES: KIRCHHOFF'S LOOP RULE:

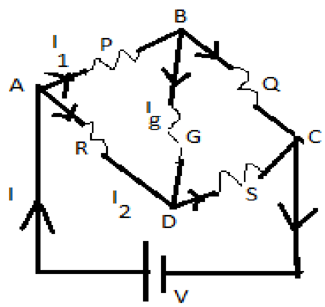
1. This rule is also known as Kirchhoff's voltage law (KVL). This states that sum of all voltages (voltage rise and voltage drop) in a closed loop is equal to zero. That is, $\sum V = 0$

2. This loop rule is based on the principle of conservation of energy.

3.19. WHEAT STONE BRIDGE CIRCUIT:

1. It is based on the principle that in balancing condition, there is no deflection in the galvanometer.
2. The circuit consists of four arm resistances in the shape of parallelogram. These four resistors are related in the balanced condition of Bridge circuit as when no current flows in the galvanometer branch. The circuit is also given below.

$$PS = QR \quad (\boldsymbol{Derive\ it})$$



Derivation:

$$V_A - V_B = V_A - V_D$$
$$I_1 P = I_2 R \Rightarrow \frac{I_1}{I_2} = \frac{R}{P}$$

Similarly,

$$V_B - V_C = V_D - V_C$$
$$I_1 Q = I_2 S \Rightarrow \frac{I_1}{I_2} = \frac{S}{Q}$$

Hence,

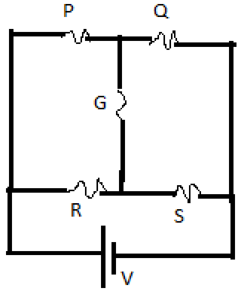
$$\frac{P}{Q} = \frac{R}{S}$$

One of the four resistances is unknown say, P and another one is variable, say Q. The value of Q is so adjusted so that deflection through galvanometer is zero and in this case, unknown resistance is

$$P = \left(\frac{R}{S}\right) Q$$

3. In the balanced condition, $I_g = 0$; $V_B = V_D$; $PS = QR$
4. In the unbalanced condition, when $PS > QR$; the current in the galvanometer branch flows from point D to C and $V_D > V_C$.
5. In the unbalanced condition, when $PS < QR$, the current in the galvanometer will flow from point B to point D in the galvanometer branch and then $V_B > V_D$.
6. When interchanging galvanometer with battery, there is no effect on balancing of Wheat Stone Bridge Circuit. Also, The bridge circuit will be most sensitive when all four resistances (P, Q, R and S) are of the same order.
7. The other forms of bridge circuits are given as below.

Fig-1



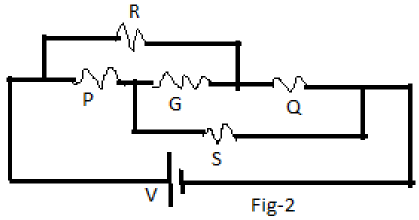


Fig-2

Ser. No.	Electromotive Force (EMF) (E)	Potential Difference (V)
1.	It is work done by a source in taking a unit charge once round the complete circuit.	It is the amount of work done in taking a unit charge from one point to another.
2.	It is equal to the maximum potential difference between the two terminals of a source when it is in an open circuit.	Potential difference may exist between any two points of a closed circuit.
3.	It exists even when circuit is not closed.	It exists only when circuit is closed.
4.	It has non-electrostatic origin	It originates from the electrostatic field
5.	It is a cause. When emf is applied in a circuit, potential difference is caused.	It is an effect.
6.	It is larger than PD	It is smaller than emf
7.	It is independent of external resistance in the circuit.	It depends upon it

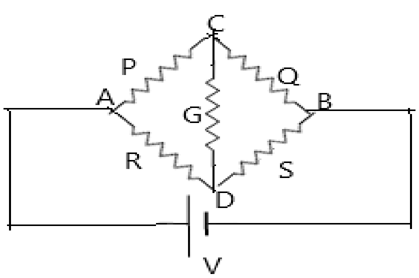


Figure-1: Wheatstone bridge circuit

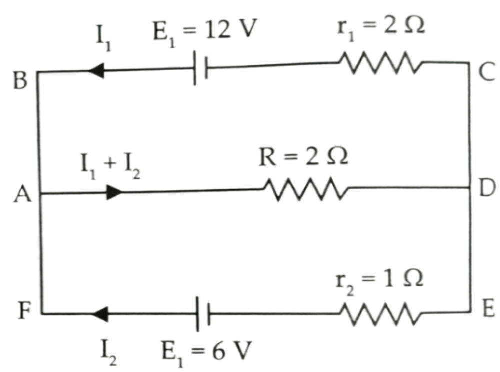
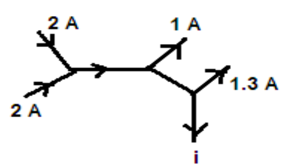


Figure-2:

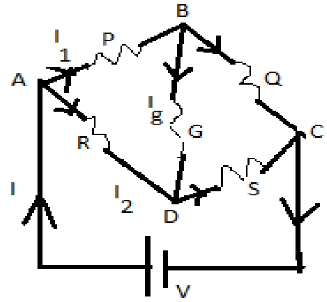
Note: Solve the questions on the above Figure-1 and 2: by using Kirchhoff's rules.
In Figure-1 of Wheatstone, P = S = 10 ohm, Q = R = 5 ohm, Resistance of galvanometer (G)= 15 ohm, battery voltage = 12 V.
In Figure-2, find current in resistance 2 ohm.

Ch-3 Questions for Practice:

1. Estimate the average drift speed of conduction electrons in a copper wire of cross-sectional area 1.0 x 10^{-7} m^2 carrying a current of 1.5 A. Assume that electron density of copper is 8.5 $\times$ 10^{28} /m^3. [Ans. 1.1 mm/s]
2. At room temperature (27.0 ^{0}C), the resistance of a heating element is 100 Ω. What is the temperature of the element if the resistance is found to be 117 Ω, given that the temperature coefficient of the material of the resistor is 1.70 x 10^{-4} ^{0}C^{-1}. [Ans. 1027 ^{0}C]
3. A silver wire has a resistance of 2.1 Ω at 27.5 ^{0}C and a resistance of 2.7 Ω at 100 ^{0}C. Determine the temperature coefficient of resistivity of the silver. [Ans. 0.0039 ^{0}C^{-1}]
4. The storage battery of a car has an emf of 12 V. If the internal resistance of the battery is 0.4 Ω, what is the maximum current that can be drawn from the battery? [Ans. 30 A]
5. A battery of emf 10 V and internal resistance 3 Ω is connected to a resistor. If the current in the circuit is 0.5 A, what is the resistance of the resistor? What is the terminal voltage of the battery when the circuit is closed? [Ans. 17 Ω, 8.5 V]
6. A storage battery of emf 8.0 V and internal resistance 0.5 Ω is being charged by a 120 V dc supply using a series resistor of 15.5 Ω. What is the terminal voltage of the battery during charging? What is the purpose of having a series resistor in the charging current? [Ans. 11.5 V, to limit the current, otherwise current will be dangerously high].
7. The figure below shows currents in a part of electric circuit. The current I is
   (a) 1.7 A (b) 3.7 A (c) 1.3 A (d) 1 A



8. Kirchhoff's junction rule is a reflection of
   (a) Conservation of current density vector
   (b) Conservation of charge
   (c) Conservation of energy
   (d) Conservation of momentum
9. Consider the circuit shown in the figure below. Find the current through 10 V battery.
10. As shown in the circuit diagram, th four arm of a Wheatstone bridge have the following resistances: P =100 Ω, Q = 10 Ω, S = 5 Ω, R = 60 Ω, G = 150 Ω. Calculate the current through the galvanometer when a potential difference of 10 V is maintained across AC. [Ans. 4.87 mA]



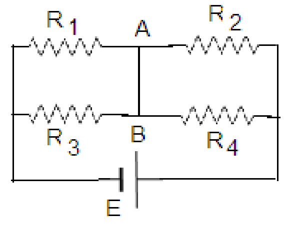
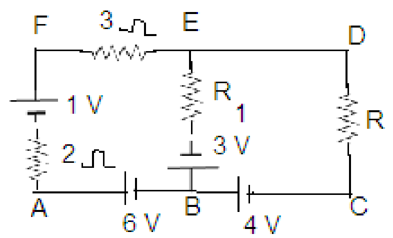
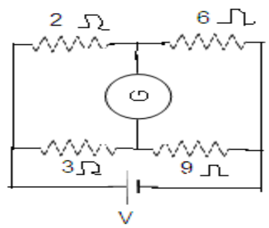


Figure-1

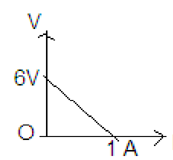
11. Find the current in the branch AB in the adjacent figure-1. Given $R_1 = R_2 = 3\ \Omega$, $R_3 = R_4 = 6\ \Omega$, $E = 12$ V
12. Use Kirchhoff's rules to determine the potential difference between the points A and D, when no current flows in the arm BE of the electric network shown in the figure below.



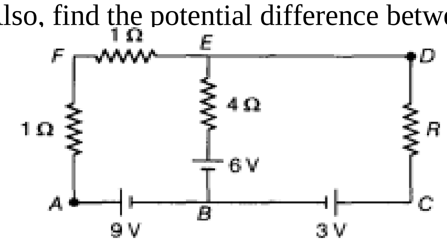
13. **Assertion (A):** The given figure shows a balanced Wheatstone bridge.



Reason (R): For a balanced bridge, no current should flow through the galvanometer.
   a) Both A and R are true and R is the correct explanation of A.
   b) Both A and R are true but R is not the correct explanation of A.
   c) A is true but R is false.
   d) A is false but R is true.
14. Drift speed of electrons does not depend upon
   a) electric field b) electric current
   c) length of conductor d) resistance of the conductor
15. How does the resistivity of (i) a conductor and (ii) a semiconductor vary with temperature? Give reason for each case.
16. The plot of variation of potential difference across a combination of three identical cells in series versus current shown in the adjoining figure. What is the emf and internal resistance of each cell?



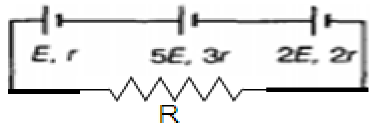
17. If a wire is stretched to make its length four times, then its specific resistance will be
   a) four times b) unchanged c) one-fourth d) two times
18. Using Kirchhoff's rules, determine the value of unknown resistance R in the circuit, so that no current flows through 4Ω resistance. Also, find the potential difference between points A and D.



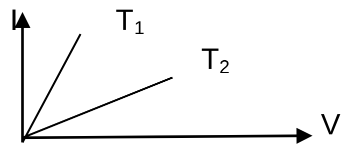
19. Six identical cells, each of emf of 6 V, are connected in parallel. The net emf across the battery is:

a) 6 V b) 36 V c) between 6 V and 36 V d) 0 V

20. Three cells of emf E, 2E and 5E having internal resistances r, 2r and 3r, variable resistance R as shown in the below figure. Find the expression for the current. Plot also a graph for variation of current I with R.



21. I-V graph for a metallic wire at two different temperatures are shown. Which of the two temperatures is lower?
[Delhi 2015]



22. Plot a graph showing variation of Current vs. Voltage for the material GaAs. [CBSE D 2014]
23. Show variation of resistivity of copper as a function of temperature in graph. [All India 2015]
24. Define drift velocity and write its relation with current [Delhi 2014]
25. Define the term electrical conductivity of a metallic wire. Write its SI unit. [D-2014]
26. Define the term mobility of charge carriers in a conductor. Write its SI unit. [D-2014]
27. When electrons drift in a metal from lower to higher potential, does it mean that all free electrons in the metal are moving in the same direction.
28. Draw a plot showing a variation of resistivity of a conductor and semiconductor, with increase in temperature.
29. How does one explain this behaviour in terms of number density of charge carriers and relaxation time?
30. Estimate the average drift speed of conduction electrons in a copper wire of cross sectional area 2.5 x 10^{-7} m^2 carrying a current of 2.7 A. Assume the density of conduction electrons to be 9 x 1028 m^{-3}. [Ans. 7.5 x 10^{-4} m/s] [All India 2014]
31. A wire of 15 Ω resistances is gradually stretched to double of its original length. It is then cut into two equal parts. These parts are then connected in parallel across a 3 V battery. Find the current drawn from the battery.[Ans. 0.2 A] [All India 2009]
32. Derive expression for drift velocity of free electrons in a conductor in terms of relaxation time. [D-2009]