CURRENT ELECTRICITY

The study of charge electric charge can be grouped into static electricity and current electricity. Current electricity deals with the movement of charges.

TERMS USED IN CURRENT ELECTRICITY

1. ELECTRIC CURRENT

This is defined as the rate at which charges travel. It is also defined as the rate of flow of charges. It is also defined as the rate at which charges are transported. It also is defined as the total amount of charge passing through a cross-sectional area A of a wire per unit time

$$I=\frac{\Delta Q}{\Delta t}$$

As $\Delta t \to 0$

$$I=\frac{dQ}{dt}$$

$$Q=\int I\,dt$$

In basic algebraic form,

$$Current=\frac{Charge}{time}$$

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

Therefore,

$$q=It$$

Current electricity exists in a region wherever electric charge is being transported from one point to another in that region.

Suppose there are n moving charged particles per unit volume in the conductor, we assume that all the particles move with the same drift velocity with magnitude v_d. In time interval of Δt, each charged particle moves a distance $d=v_d \Delta t$. The volume of the cylinder V = Ad, the number of particles within the cylinder N = nV. The total charge ΔQ that passes through an area, A in a time Δt (assuming each particle has a charge of e) is given as

$$q = Ne$$

$$q = nAde$$

$$q = enA v_d \Delta t$$

But,

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

$$I = \frac{Ne}{\Delta t}$$

Current Density. This is defined as the current per unit cross-sectional Area

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

2. CURRENT DIVISION PRINCIPLE

One useful formula in this topic will be the current division principle.

$$I_1 = \frac{I R_2}{R_1 + R_2}$$

3. ELECTRIC CIRCUIT

This is the path along which current flows

4. OHM'S LAW

This states that the potential difference across a **(metallic) conductor** is directly proportional to the magnitude of current flowing through it provided that temperature and all other physical factors remain constant

$$V \propto I$$

$$V = IR$$

R is called the resistance of the metallic conductor.

Modern definition of Ohm's law states that R is a constant independent on the values of the voltage (V) and the current (I).

5. RESISTANCE

This is the ability of a material to convert electrical energy to heat energy. It is also defined as the measure of opposition to the flow of current offered by an element.
Battery (or cell): A cell is a device used for harnessing electrical energy. A cell produces a voltage called the potential difference.

The resistance of a wire is defined as the opposition to the flow of current offered by the wire. The resistance of a wire or an object is a measure of the potential difference that must be impressed across one object to cause a unit current to flow through it.
From Ohm's law

$$V = IR$$

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

FACTORS THAT AFFECT THE RESISTANCE OF A CONDUCTOR

1. Length of the conductor: $R \propto l$
2. Area of the conductor: $R \propto \frac{1}{A}$
3. Nature of the objects: Some objects have higher resistances than others. Objects that don't allow current to pass through them are called insulators and they have very high resistances.
4. Temperature: Resistance of a metallic conductor has a positive temperature coefficient. That means that an increase in temperature will cause an increase in the resistance of a metal.

$$R_f = R_i\left(1 + \propto \Delta\theta\right)$$

$$R_f = R_i + R_i \propto \Delta\theta$$

$$R_f - R_i = R_i \propto \Delta\theta$$

$$R_i \propto \Delta\theta = R_f - R_i$$

$$\propto = \frac{R_f - R_i}{R_i \Delta\theta}$$

$$\propto = \frac{R_f - R_i}{R_i\left(\theta_f - \theta_i\right)}$$

$$\propto = \frac{\Delta R}{R_i \Delta\theta}$$

However, it should be noted that non-ohmic conductors and semiconductors have a negative temperature coefficient. Therefore, an increase in temperature will reduce the resistance (or resistivity) and increase the conductance (or conductivity).

$R_f = R_i(1 - \propto \Delta\theta)$

$R_f = R_i - R_i \propto \Delta\theta$

$R_i - R_f = R_i \propto \Delta\theta$

$R_i \propto \Delta\theta = R_i - R_f$

$\propto = \frac{R_i - R_f}{R_i \Delta\theta}$

$\propto = \frac{R_i - R_f}{R_i(\theta_f - \theta_i)}$

$\propto = \frac{-\Delta R}{R_i \Delta\theta}$

On combining

$R \propto l$

And

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

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

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

ρIs a constant called the resistivity of the material (metal)

6. CONDUCTANCE

This is defined mathematically as the inverse of the resistance

$G = \frac{1}{R}$

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

$G = \frac{1}{\left(\frac{V}{I}\right)}$

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

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

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

The unit of conductance is mhos (ohm spelled backward) or Siemens.

7. POTENTIAL DIFFERENCE (V)

This is defined as the work done in moving a unit charge from one part of the circuit to another. If there is no internal energy loss in the battery, the potential difference is equal to the electromotive force (emf) of the cell.

8. INTERNAL RESISTANCE OF A CELL

This is defined as the measure of opposition to the flow of current offered by the electrolyte of the cell.

9. LOST VOLT

If the cell has an internal energy loss (usually due to internal resistance), the potential difference won't be equal to the emf of the cell. The lost volt is defined as the potential drop across the cell. It is expressed as the product of the current in the circuit and the internal resistance of the cell. $L = Ir$

10. RESISTIVITY

This is defined as the resistance of a unit length of a material with a unit area

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

$$\rho l = RA$$

$$\rho = \frac{RA}{l}$$

Similarly,

$$\rho_f = \rho_i (1 + \propto \Delta\theta)$$

$$\rho_f = \rho_i + \rho_i \propto \Delta\theta$$

$$\rho_f - \rho_i = \rho_i \propto \Delta\theta$$

$$\rho_i \propto \Delta\theta = \rho_f - \rho_i$$

$$\propto = \frac{\rho_f - \rho_i}{\rho_i \Delta\theta}$$

$$\propto = \frac{\rho_f - \rho_i}{\rho_i (\theta_f - \theta_i)}$$

$$\propto = \frac{\Delta \rho}{\rho_i \Delta \theta}$$

11. CONDUCTIVITY

This is defined as the rate of flow of charges through a body. It is also defined as the reciprocal of resistivity.

$$Conductivity = \frac{1}{Resistivity}$$

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

$$\rho = \frac{RA}{l}$$

$$\sigma = \frac{1}{\left(\frac{RA}{l}\right)}$$

$$\sigma = \frac{l}{RA}$$

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

$$G = \frac{1}{\rho} \cdot \frac{A}{l}$$

$$G = \frac{\sigma A}{l}$$

12. CONDUCTORS

CAN BE CATEGORIZED INTO TWO TYPES

Ohmic Conductors: These are conductors that obey ohms law. The slope of the voltage (V) against current (I) graph is a linear function. Ohmic conductors include metals like silver, copper and aluminum etc.

In a current (I) against voltage (V) graph, the slope represents conductance. However, in a voltage (V) against current (I) graph, the slope gives resistance.

Non-Ohmic Conductors: These do not obey Ohm’s law. They do not have a linear (I) against (V) function.

They include diodes (rectifiers), transistors and pent-diodes etc.

TOOLS USED IN CURRENT ELECTRICITY

AMMETER

This is a device used to measure the magnitude (and maybe direction) of current. An ideal (or perfect) ammeter must have negligible (or zero) resistance. An ammeter must be connected in series with the circuit elements.

An ammeter can be sensitive, accurate or both.

A sensitive ammeter is one that can detect little changes in current. An accurate ammeter is one whose reading is the same as the exact amount of current passing through it.

VOLT METER

This is a device used for measuring voltages and potential differences. They must be connected in parallel with the circuit elements and must have an infinite resistance.

RESISTOR

ARRANGEMENT OF RESISTORS

Arrangement in series: Resistors in series have the same amount of current flowing through them. The voltage in the series circuit is the sum of the potential differences across each resistor.

$$V = \sum V_i$$

$$V = V_1 + V_2 + V_3 + \ldots + V_n$$

But

$$V = IR$$

$$IR = I R_1 + I R_2 + I R_3 + \ldots + I R_n$$

$$IR = I\left(R_1 + R_2 + R_3 + \ldots + R_n\right)$$

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

$$R = \sum R_i$$

Parallel Arrangement: If resistors are arranged in parallel

The resistors in parallel have equal amount of voltage

The total current in a parallel circuit is equal to the sum of the current passing through the resistor.

$$I=\sum I_i$$

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

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

$$\frac{V}{R}=\frac{V}{R_1}+\frac{V}{R_2}+\frac{V}{R_3}+\ldots+\frac{V}{R_n}$$

$$\frac{V}{R}=V\left(\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+\frac{1}{R_n}\right)$$

$$\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}$$

$$\frac{1}{R}=\sum \frac{1}{R_i}$$

WHEATSTONE BRIDGE

This consists of four resistors of which three are standard resistors and the fourth a resistor of unknown resistance all arranged in a rhombus like structure.

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

METER BRIDGE

This is another form of the wheatstone bridge. This is a device used for determining the resistance of an unknown resistor. The meter bridge consists of a standard resistor (a resistor whose resistance is known), a standard cell, a jockey (a galvanometer) and a metallic strip of length 100cm.

At balance point,

$$\frac{R_1}{R_2}=\frac{l_1}{l_2}$$

$$l_1+l_2=100\,cm$$

$$l_2=100-l_1$$

$$\frac{R_1}{R_2}=\frac{l_1}{100-l_1}$$

In science a device or cell or anything is said to be standard if its value is known. A standard resistor is one whose resistance is known. A standard cell is one whose emf is known.

POTENTIOMETER

A potentiometer is a device used for the accurate determination of the internal resistance of a cell.

It is also used for comparing the magnitudes of emfs of two (or more) cells.

Generally,

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

Here, l_1 and l_2 are the balance points obtained for the two cells respectively

MOVING COIL GALVANOMETER

A galvanometer is a device used for detecting the direction of the flow of current. It can also be employed for measuring small current and voltages

ESSENTIAL COMPONENTS OF A GALVANOMETER

Magnet: Usually a horseshoe magnet is used. His is a permanent magnet that provides a strong magnetic field

Soft Iron Cylinder: This provides a uniform radial field. It also prevents magnetic flux leakage

Control Springs (or hair springs): These provide opposing couples or control couples. They allow the movement of the pointer over the scale

Rectangular coil: This serves as the current carrying conductor.

SENSITIVITY OF A GALVANOMETER

A sensitive galvanometer is one that can detect little changes in current.

The sensitivity is defined mathematically as the angle of rotation per unit current.

$$Sensitivity=\frac{Angle\,moved}{Unit\ current}$$

$$S=\frac{\theta}{I}$$

HOW TO ENHANCE THE SENSITIVITY OF A GALVANOMETER

1. The use of weak control springs
2. The use of strong permanent magnets
3. The use of a large area of coil
4. The use of a higher number of turns

SHUNT

This is a Low resistance resistor connected in parallel with a galvanometer in order to convert it to an ammeter

$$pd\,across\,shunt=potential\,difference\,across\,the\,galvanometer$$

$$V_S=V_G$$

$$I_S R_S=I_G R_G$$

$$R_S = \frac{I_G R_G}{I_S}$$

$$I_S = I - I_G$$

$$R_S = \frac{I_G R_G}{I - I_G}$$

MULTIPLIER

This is a high resistance resistor connected in series with a galvanometer in order to convert to a volt meter

$$V = V_M + V_G$$

$$V = I_M R_M + I_G R_G$$

$$I_M = I_G = I$$

$$V = I R_M + I R_G$$

$$V = I\left(R_M + R_G\right)$$

$$R_M + R_G = \frac{V}{I}$$

$$R_M = \frac{V}{I} - R_G$$

EMF: The electromotive force of a circuit or cell is the work done in moving a unit charge round the entire circuit. It is also defined as the voltage across on an open circuit (i.e. when it is not delivering any current).

The emf can also be defined as the work done per unit charge.

$$Emf = \frac{Work\ done}{Charge}$$

$$E = \frac{W}{q}$$

$$W = Eq$$

It is seen above that the formula from electric fields has been repeated

$$W = qV$$

So it can be understood that the electric potential (V) is actually a potential difference (E)

The emf of a cell is mathematically the sum of the terminal voltage (V) and the lost volt (L)

$$E = V + L$$

$$E = IR + Ir$$

$$E = I\left(R + r\right)$$

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

If there is no energy loss in the circuit

The lost volt equals zero

Therefore, for an ideal circuit,

$$L = 0$$

$$E = V + L$$

$$E = V + 0$$

$$E = V$$

$$E = IR$$

EFFICIENCY OF A CELL

This is defined as the (percentage) ratio of the power output to the power input

$$Efficiency = \frac{Power\ output}{Power\ input} \times 100$$

$$Eff = \frac{VI}{(Emf) \times I} \times 100$$

$$Eff = \frac{V}{Emf} \times 100$$

$$Eff = \frac{IR}{I(R + r)} \times 100$$

$$Eff = \frac{R}{R + r} \times 100$$

The terminal potential difference (V) of a battery when it delivers a current (I) is related to its Emf as follows

When the battery is delivering current (on discharge)

$$E = V + L$$

$$V = E - L$$

When receiving current (Charging)

$$V = E + L$$

When the cell is doing no work (i.e. it is passive or in an open circuit),

$$V = E$$