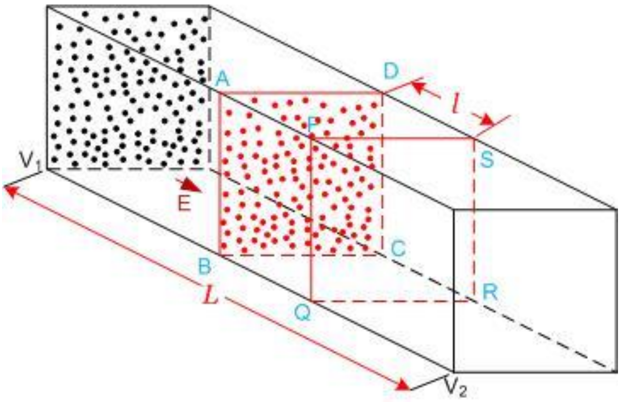
ELECTROMAGNETISM – Part I: Current Electricity

Study of Electrostatics has led to an understanding that – ***a)*** *every matter in nature, in its normal state has zero charge, i.e. quantity of (+)ve and (-ve) charges present in it are equal,* ***b)*** *when charges in a substance are separated an electric field is established between the separated charges,* ***c)****when an electric charge is held in an electric field is experiences a force such that that (-ve) charge is accelerated in the (+)ve direction of the electric field, and* ***d)*** *the acceleration can be determined with in accordance with the Newton's Second Law of Motion. This creates a scientific curiosity to know –* ***i)*** *Rate of movement of charges in an electric field,* ***ii)*** *Relationship between potential difference and rate of movement of charges,* ***iii)*** *Is it that the movement of only (-) charges constitute current, or there is possibility of movement of (+) charges,* ***iv)*** *Patterns of electric current fixed, periodic or any other,* ***v)*** *Are there any effects of movement of charges viz. thermal and magnetic and if so are they dependent on direction of current,* ***vi)*** *What are the types of electrical elements,* ***vii)*** *If magnetic field is created by flow of charges, is there any effect of movement of electric field or change of magnetic field on charges in the given space,* ***viii)*** *If there is dependence of electric current and magnetic field, is there a way to unify them?*
Lightning, a natural disaster in the pre-recorded history, was related to electricity in 1752 by Benjamin Franklin through his famous experiment in 1752. Nevertheless, the answers to the above questions were explored by different scientists independently. It is no exaggeration to admit that we are enjoying a legacy of their pains taking efforts in the form of technological developments.
In this section. a beginning is being made to elaborate concepts relating to each of the question which will lead to an integrated understanding of electromagnetism.

George Ohm in 1827, was first to experimentally define quantitative relationship between electric current and potential difference and is primitive to the understanding of current electricity. It states that "*When electric current (I) passes through two points of a conductor, is directly proportional to voltage drop (V) across the two points. The proportionality constant is called resistance (R).*" Accordingly, $\propto V$, or alternatively, $V \propto I$, or $V = KI/$ Here, constant of proportionality is $K = R$. Initially, based on value of R electrically materials were classified as ***conductor*** and ***insulator***. *Materials having low resistance are called* ***Conductor****; such materials are conducive for flow of electric current. While, materials which have extremely high resistance such that flow of current through it is negligible are called* ***Insulators***. Later increased understanding of atomic and crystalline structure materials and their electrical behaviour led to various types of electrical materials viz. *Linear resistors, Non-linear resistors, Super Conductors and Semiconductors*. Study of Semiconductors shall call a separate section as we take a forward path beyond Electromagnetism, which involves an understanding of atomic structure.

Mathematical derivation of Ohm's Law and quantification of resistance based on the properties of material was done later and is found to be in conformity. Prima facie, structure of solid materials is conglomeration of atoms and molecules, having nucleus embedded into its lattice. *Some of the electrons of atoms revolve around nucleus and are called* ***Bound Electrons****, while a few based on energy state matter move freely in the lattice and are called* ***Free Electrons****. In conductors. density of free electrons is large enough to constitute electric current, while in Insulators, density of Free Electrons is negligible and thus on application of potential difference across it current is negligible*. These free electrons in their continuous motion collide, change direction and continue motion restlessly performing ***Brownian Motion***, similar to that of gas molecules, elaborated in ***Kinetic Theory of Gases***. Each material in normal state is electrically neutral i.e. it has Zero Charge. Therefore, as per Guass's Law, $Q = 0 = \oint E.ds$, and also at any point on the surface of the solid, E is also Zero. But, when either the material is placed in an external Electric Field (***E***), or an electric field is applied across the material a *Potential Difference* $(V = V_1 - V_2)$ is established such that $V = \int E.dl$, here, $E = \frac{V}{L}$ and ***dl*** is incremental displacement between two ends of the material across which potential difference exists, as shown in the figure. Each, of the free electrons having (-)ve charge, under influence of external field will experience an acceleration ($\boldsymbol{a_e}$) i.e. in a direction opposite to that of the of the Electric Field such that $m_e a_e = q_e E$. Here, $\boldsymbol{m_e}$- is mass of electron and $\boldsymbol{q_e}$- is charge of electron. This is the point where, *Coulomb's Law* is being integrated with *Newton's Second Law of Motion, and integration of mechanics and electromagnetism starts*. Thus acceleration of electron shall be $a_e = \frac{q_e E}{m_e}$. The free electrons during motion in the lattice collide, loose energy and come to a state of rest ($v_e = 0$) and are again set to acceleration and the process continues. Distance travelled by an electron between two consecutive collisions is called free path (l) and time taken by an electron to traverse the free path is called relaxation time ($\boldsymbol{\tau}$). Since, it is not possible to determine these two parameters for motion of each electron, these are taken as ***Mean Free Path*** (***l***), and **Mean Relaxation Time** ($\boldsymbol{\tau}$) and analysis is carried out. Using *Galileo's First Equation of Motion*, $l = 0 + \frac{1}{2}a_e\tau^2$. Thus cloud of free electrons drift in the direction of Electric Field. Thus average velocity of drift (v_d) of electrons is $v_d = \frac{l}{\tau} = \frac{1}{2}a_e\tau = \frac{1}{2}\left(\frac{q_e E}{m_e}\right)\tau$.



Current (I) has been defined as rate of flow of charges $\left(I = \frac{Q}{t}\right)$ and this requires taking an holistic view of material of length (L), cross sectional area (A), density of free electron (n) per unit volume, drift of electrons cloud through the cross-section PQRS in time (τ) shall fill volume between ABCD and PQRS. Thus, current in the instant case shall be $I = \frac{n\cdot(A\cdot l)\cdot q_e}{\tau} = n\cdot A\cdot q_e\cdot v_d = n\cdot A\cdot q_e\cdot\left(\frac{l}{\tau}\right) = n\cdot A\cdot q_e\cdot\frac{1}{2}\left(\frac{q_e E}{m_e}\right)\tau$. Accordingly, current ($I$) in the conductor subjected to potential difference (V) is $I = \left(\frac{n\cdot q_e^2\cdot\tau}{2m_e}\right)\cdot\left(\frac{A}{L}\right).EL = \left(\frac{n\cdot q_e^2\cdot\tau}{2m_e}\right)\cdot\left(\frac{A}{L}\right).V = \sigma\cdot\left(\frac{A}{l}\right).V$. Here, σ is conductivity of material governed by the properties of material viz. charge density (n) and Mean Free Time (τ) and properties of electron viz its charge (q_e) and mass (m_e); while area (A) and length (L) are geometrical properties of the conductor. Alternatively, this relationship can be transformed into Ohm's Law where, $V = \frac{1}{\sigma}\cdot\frac{L}{A}.I = \rho\cdot\frac{L}{A}.I = R\cdot I$. Here, ρ is called ***Specific Resistance***. It is also called *Resistivity of conductor and mathematically it is reciprocal of* ***Conductivity*** $\left(\rho = \frac{1}{\sigma}\right)$. Thus, while mathematically establishing validity of experimentally determined Ohm's Law, Resistance of a conductor is also defined as $R = \rho\cdot\frac{L}{A}$.

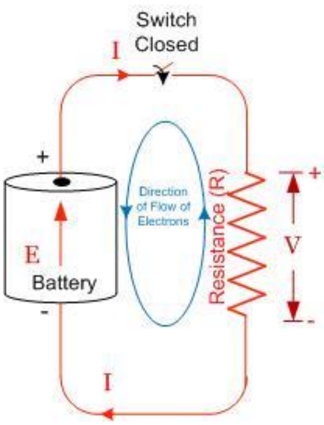
Dependence of Resistance of a Conductor: Experimentally it has been observed that resistance of conductor increases linearly with the increase in temperature, but over a small range and is expressed as $\rho_T = \rho_{T_0}(1 + \alpha(T - T_0))$. Here, α – is called ***Temperature Coefficient of Resistivity.*** Typical values of ρ and α of commonly used conductors are as under –

Property	Copper	Aluminium	Iron
Resistivity (Ohm/m)	1.72x10^{-8}	2.63x10^{-8}	9.71x10^{-8}
Temperature Coefficient of Resistivity (K^{-1})	0.0039	0.0039	0.0050

A close observation of the above relationship reveals that - **a)** Increase in charge density ($\boldsymbol{n}$) causes increase in number of charge carriers and thus initially reduces resistivity of the conductor, **b)** Excessive charge density since increases charge carriers reduces mean free path ($\boldsymbol{l}$) with a consequent reduction in relaxation time ($\boldsymbol{\tau}$) and thus mean drift velocity; this results in increase of Resistivity, **c)** Keeping the volume of conductor same, x% reduction in cross section increases length of the conductor by a proportion $\frac{1}{\left(1-\frac{x}{100}\right)} = \left(1 - \frac{x}{100}\right)^{-1}$ and in turn resistance of the new geometry by $\left(1-\frac{x}{100}\right)^{-2}$ [From Binomial Theorem: $(1-x)^{-2} = 1 + 2x + 3x^2 + 4x^3 \ldots (r+1)x^r \ldots$]. Accuracy of resistance for the variation in geometry, with this mathematical formulation, depends upon – a) order of variation and b) degree of precision desired. The first Two observations, of the above, substantiate thermal dependence of resistivity of conductor, while the third observation corroborates dependence of resistance of conductor on its geometry.

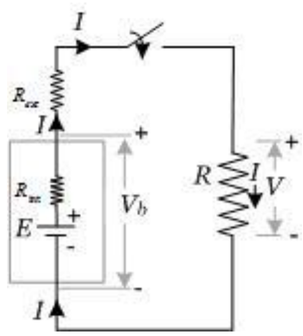
Summary: *It is seen that every conductor by virtue of its composition, experiences collision of free charges during flow current and losses its kinetic energy in each collision. This is similar to the phenomenon in Mechanics and this kind of obstruction to the flow of electrons in electrical circuits is called* ***Resistance****. Thus resistivity is an intrinsic property of every conductor and may vary with a difference of degree from material, while resistance of an element of circuit, together with the resistivity depends upon its geometry.*

Electromotive Force (EMF) and Voltage Difference: Initial study of current electricity started with chemical cell and a combination of such cells is called Battery and arrangement of a circuit is shown in the figure. Battery, with switch open i.e. when current is not flowing, it exhibits a potential difference E and is called ***Electromotive Force***; *it is the net potential of the battery to supply electric current.* But, when switch is closed current is supplied by the battery from its (+)ve terminal and this current returns back to it through (-)ve terminal. In current electricity, unlike Electrostatics, charge does not stay separated, and circuit is completed only when charges supplied in the form of current are returned to the point of supply, and thus, with battery electric current flows from its (-)ve terminal to (+)ve terminal. At this point, measurements of Voltage and Current are assumed to be available, since knowing about these instruments would require understanding of effects of electric current which are yet to be elaborated.



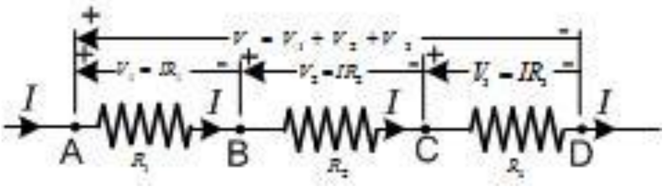
Here, there are two important concepts are surfaced: **a)** Potential Difference across battery when current is supplied by it and **b)** Direction of flow electrons within the battery. It is observed that when current is supplied by the battery, a voltage drop occurs in it and it is attributed to ***Internal Resistance (R_{int}) of the Battery***. The thin connecting wires including switch are , initially, taken to be negligible resistance. Thus, ***voltage (V) across battery*** or the resistance (R) is $V = E - IR_{int}$. The second question is direction of flow of electrons having (-) charge and as elaborated in Electrostatics, they shall be attracted towards (+)ve potential and notional direction of current is direction of flow of (+)ve charges. Accordingly, direction of flow of Electrons is opposite to the direction of current.

A closer look of the battery circuit, is shown in a separate figure where Internal Resistance of Battery (R_{int}) is shown distinctly and resistances of all conducting connections and switches are lumped into an External Resistance (R_{ext}) while any load or device is shown as Resistance (R). It will be seen that – **a)** all elements of the circuit are connected in series, **b)** direction of current in the circuit is same, c) Current through resistances is in (+)ve to (-)ve direction while current through battery is from (-) to (+)ve direction which replenishes charges supplied by it through its (+) terminal. Thus at any point of time balance in every element of the circuit (+)ve and (-)ve charges remains. Accordingly, as per Ohm's Law $E = I(R_{int} + R_{ext} + R)$, which consumes complete EMF of the battery in resistive elements in a cascaded manner as it encounters during flow of current. Thus, voltage across battery is $V_b = E - I \cdot R_{int}$ and voltage across resistance (R) is $V = E - I(R_{int} + R_{ext}) = I \cdot R$. This analysis foundation of Series-Parallel Combination of Resistances and Kirchhoff's Laws,



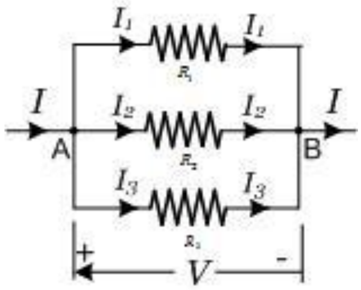
Combination Of Resistances: Every electrical circuit is a combination of electrical sources, connecting elements of conducting material, switches and resistances in the form of electrical devices. These element are connected in various formations. Analysis of voltage and currents across different elements of circuits can be carried out by decomposing an integrated and complex circuit into most generic combinations of resistances – **a)** *Series Combination* and **b)** Parallel Combination. The basic concepts involved in the analysis are- **i)** *Ohm's Law – which stipulates relationship between its Resistance (R), current (I) through it and voltage (V) across each resistive element, and* ***ii)*** *at any point of time, despite flow of current, balance of electrical charges remains unaltered. Thus in effect current entering an element at any instant is equal to current leaving the element.*

A typical **Series Combination** of Three **Resistances** is shown in the figure. In this current (I) enters at point A and leaves at point D. Since, in the circuit there is neither any diversion nor spillage, current leaving the combination (I) remains unaltered; and this true for all cascaded nodes forming the Series Combination. Let, equivalent resistance of the series combination be R_s. According to Ohms Law voltage across the Series Combination shall be $V = IR_s$.

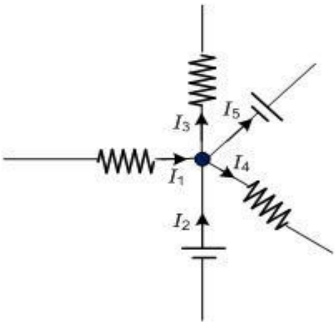


Likewise, for voltage drop across the three elements of the combination $V_1 = IR_1$, $V_2 = IR_2$ and $V_3 = IR_3$. Since, these voltages are cascading and hence $V = V_1 + V_2 + V_3$. Using the V,I and R relationships, as per Ohm's Law, it leads to $V = IR_s = IR_1 + IR_2 + IR_3$; alternatively $IR_s = I(R_1 + R_2 + R_3)$. It leads to $R_s = (R_1 + R_2 + R_3)$, or in its general form the ***equivalent resistance of series combination*** of ***n*** resistances is $R_s = \sum_{i=1}^{n} R_i$.

Similarly, a general expression of equivalent resistance of a parallel combination is developed using a typical connection as shown in the figure. The three resistances are lumped at Points A and B forming a parallel combination of resistances and hence potential difference (V) responsible for diving current in each of the resistances shall be same. Thus, as per Ohm's Law $V = I_1R_1 = I_2R_2 = I_3R_3$. Considering, equivalent resistance of the parallel combination to be R_p, as per Ohm's Law, $V = IR_p$. In current electricity, there is no accumulation of charge at any point of time, and therefore, balance of current shall be there at both the nodes A and B. Accordingly, $I = I_1 + I_2 + I_3$ and using equations evolved for the combination and individual resistances of the combination, $\frac{V}{R_p} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$. It leads to $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$, or in its general form the **equivalent resistance of a parallel combination** of ***n*** resistances is $\frac{1}{R_p} = \sum_{i=1}^{n} \frac{1}{R_i}$.

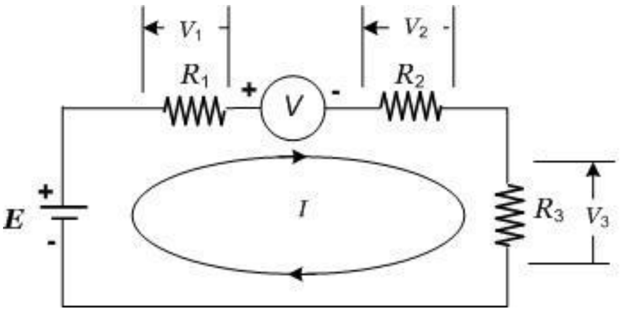


In 1845 **Gustav Kirchhoff** generalized the analysis of an electrical network which includes resistances and electrical and are known as Kirchhoff's Laws – **a)** *Kirchhoff's Current Law (KCL)* and **b)** *Kirchhoff's Voltage Law (KVL)*. These laws are extremely useful in solving an electrical network.



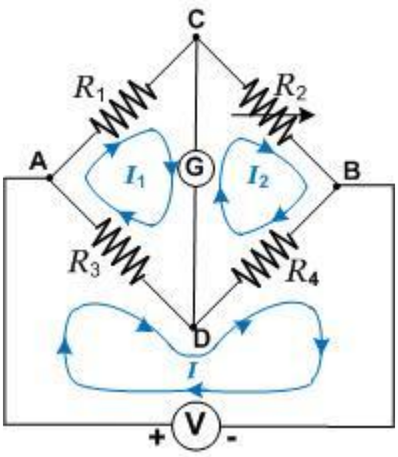
KCL states that ***algebraic sum of currents at any node is Zero,*** *i.e. mathematically* $\sum \boldsymbol{I_j} = \mathbf{0}$**.** Here, node is a point where various conductors of the network are joined, $\boldsymbol{I_j}$ is the current in j[th] branch joined at the node. Since, this law invokes algebraic value of current and hence sign convention is extremely important. Accordingly, ***sign convention*** stipulates that *currents entering a node have (+)ve value and currents leaving a node have (-)ve values, and vice-versa*. In this sequencing of current viz-a-viz branch with suffix j is not important and is purely for the convenience of the persons making network analysis. Thus KCL equation of the network comes to $I_1 + I_2 - I_3 - I_4 - I_5 = 0$. Similar equations shall be there for each node, and can be solved as simultaneous equations to determine unknown current.

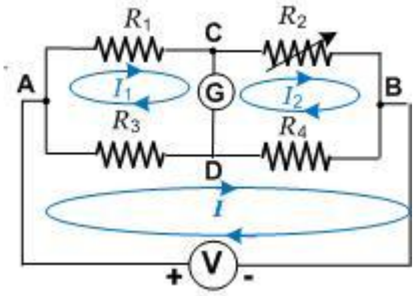
KVL states that ***algebraic sum of voltages in a electrical loop is Zero, i.e. sum of EMF and voltage drops in an electrical loop is Zero*** and is mathematically expressed as $\sum V_i = 0$. Here, V_i- is the algebraic voltage across **i**[th] element of the loop, also referred to as Mesh. In each loop, *a notional current (**I**$_j$) is considered in a hypothetical direction is considered and is independent of direction in adjoining loops*. Here, subscript j represents the **j**[th] loop Accordingly, ***sign convention*** stipulates that - *voltage rise, in case of Voltage sources* *viz. Battery is taken to be (+)ve, and voltage drop in the direction of current is taken to be (-)ve, which is invariably the case in resistances and voltage sources connected with polarity in a direction reverse to that of current*. Thus, in case of an electrical circuit having multiple loops, each loop is assigned different current and it analysis of the network using KVL involves solving simultaneous equations equal to number of loops . While doing so, consistency of KCL, is node. Elaboration of KVL is presently done with a single loop, and solution of complex networks shall be done taking a forward path and solving problems.



Applying the KVL in the loop shown in figure, it leads to $E - V_1 - V - V_2 - V - V_3 = 0$. Here, I - is the notional current in the loop, E- is the EMF of the battery, voltage source, *having its polarities which support the direction of notional current*, V - is the absolute value of the voltage of a ***voltage source connected*** such that *its polarities are in a direction which oppose the notional current*. It leads to a equation of the loop as $E - V - I(R_1 + R_2 + R_3) = 0$. Thus it is possible to determine loop current once Values of voltage sources and resistances in loop(s) are known.

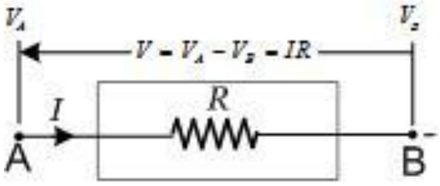
Wheatstone Bridge is a device, which is analysed using basic Ohm's Law, KCL and KVL. A typical Wheatstone bridge is shown in the figure which has four resistances R_1, R_2, R_3, and R_4 are connected across nodes A, B, C and D as shown in the figure. In some references this topology of circuit is also shown in rectangular formation, as also shown in the figure, which is conceptually and analytically the same. Out of these Four resistances three are fixed, while fourth is a variable resistance. Any of the four resistances can be variable, while in instant case R_2 is taken as variable. Across nodes A and B a voltage source (V) is connected, while across nodes C and D a galvanometer (G) is connected. Galvanometer is a very sensitive instrument to record small current. It forms base of the Ammeter and Voltmeter and shall be elaborated later. In this values of R_2 is so adjusted that galvanometer (G) shows no deflection, and the ***four resistances exhibit a definite relationship*** $\frac{R_1}{R_2} = \frac{R_3}{R_4}$. This is stated to be balanced condition of the circuit and is being verified analytically.





Let voltages at Four nodes be $V_A = V$, V_B, V_c and $V_D = 0$. And current in Three loops ABCA, CBDC and ACBA be I, I_1 and I_3, respectively. Direction of currents can be taken to be clockwise or anti-clockwise, but it is convenient to have a uniformity in direction-convention. Net, current in each element of the circuit is difference of currents in adjoining loops of which the element forms the branch of the circuit. Accordingly. $I_{AC} = I_1$, $I_{CB} = I_2$, $I_{AD} = I - I_1$, and $I_{DB} = I - I_2$ and $I_{CD} = I_1 - I_2$. Current $I_{CD} = 0$ under balanced condition this eventually leads to $I_1 = I_2$. Thus. as per Ohm's Law $V_{CD} = R_G \cdot [I_1 - I_2] = 0$, which implies both nodes V_c and V_D are it is at same potential (electrical level), this condition bring it a name Bridge and accordingly this circuit configuration is called **Wheatstone Bridge**. At node A validity of KCL is seen; $-I_1 - (I - I_1) = 0$, Applying, KVL to loop ACDA, $V_{AC} - V_{CD} - V_{DA} = 0 = I_1R_1 - 0 - (I - I_1)R_3$. It leads to $\frac{R_1}{R_3} = \frac{I - I_1}{I_1}$. Likewise, in loop CBDC we find that $\frac{R_2}{R_3} = \frac{I - I_1}{I_1}$. These two proportions, further, lead to , $\frac{R_1}{R_3} = \frac{R_2}{R_4}$, alternatively, using invertendo property of ratio-proportions, $\frac{R_1}{R_2} = \frac{R_3}{R_4}$. This is beautiful case of integration of basic laws of electrical circuits, and finds extensive application in analysis of electrical and electronic circuits with many variants.

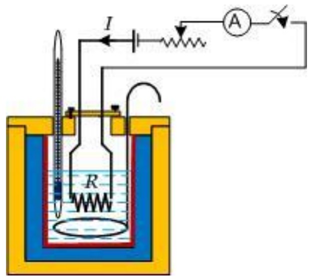
Electrical Power and Energy: Electrical Potential Difference between two points is the amount of work done on Jules (N-m) to move unit (+)ve charge from lower potential to higher potential. Likewise, when a unit (+)ve charge moves from (+)ve potential to (-)ve potential, it imparts that energy to the charge, in accordance with laws of conservation of energy. It is similar to potential energy gained by an object when moved above the ground level, which is get converted into kinetic energy when the object moves towards the ground. In electrostatics, it has been seen that when charge is moved from one point to other against electric field, it increases potential of the point. But, in current electricity, there is only replenishment of the charge in the form of drift current. but there is no accumulation of charge. Further, electric current $I = \frac{dQ}{dt}$, which implies that $Q = \int Idt$ charge has moved from higher potential to lower potential, as shown in the figure. Thus, ***power of a circuit (P)*** *having potential difference (V) is the rate of doing work in* ***Joules-s⁻¹*** *in moving charge at a rate* $\frac{dQ}{dt}$, *and is expressed as* $P = \boldsymbol{VI}$. Commonly used unit of electrical power is Watt and One Watt is equal to One Nm-s-1. Applying Ohm's Law to the circuit under consideration, $P = V\left(\frac{V}{R}\right) = \frac{V^2}{R}$, alternatively, $P = (IR)I = I^2R$. Further, energy consumed by the circuit = $\int_0^T Pdt = PT$ and **unit of electrical energy is Watt-sec**. In common use the unit of electrical energy is kWH, which implies 1 kW power consumed for one hour.



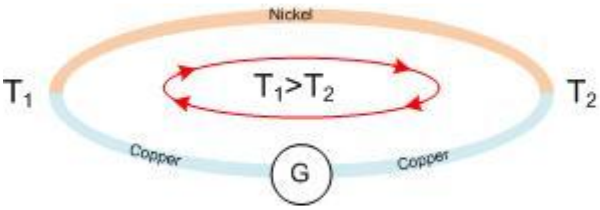
Effects of Current Electricity: Beauty of Current Electricity is that, on it everything happen but nothing can be seen. Realization of the happening is through close examination and correlation of effects with its basic laws. The current electricity does not assume importance by virtue of its existence, rather it is hysterically escalated due to usefulness of its effects which have found an important application through technology be it domestic life or interaction with the outside world. The effects are classified into – a) Thermal Effects, b) Chemical Effect and c) Magnetic Effects. While elaboration of Thermal and Chemical Effects follows in this part, ***Magnetic Effects will be elaborated in parts to follow.***

Thermal Effects of Electric Current: Thermal effect of current are of two types – a) Heating Effect, it is an irreversible phenomenon and b) Thermo-Electric Effect – a reversible phenomenon and are elaborated here.

Heating Effect: It is seen that when current is passed through a resistance it consumers electrical power. James Prescott Joule made a careful study of the phenomenon during 1840 and 1843 and demonstrated through an experiment that this electrical power is converted into heat such that $E = P \cdot t = (I^2R) \cdot t = W = JH$. This is known as Joule's Law of Heating. Here, $\boldsymbol{E}$ is the energy dissipated by resistance, when current $\boldsymbol{I}$ pass through it for time $\boldsymbol{t}$ seconds, $\boldsymbol{P}$ is the power in watts (rate of energy = $\boldsymbol{I^2R}$ consumed per second, $\boldsymbol{J}$ is the Joule's constant, and $\boldsymbol{H}$ is heat generated by the resistance in Calorie. Equivalence of units of energy to be noted are 1 W-sec=1 Joule= 1 Nm. This is in conformity with the *Law of Conservation of Energy*.



Thermo-electric Effect of Current: When electric current is passed through a joint of two dissimilar metals, heating or cooling at the joint takes place. Likewise in closed loop of Two dissimilar metals (Nickel-Copper), with one joint at higher temperature T_1 and the other at T_2, such that $T_1 > T_2$, an electric current is established in the loop. *This current is due to differential concentration of electrons in the Two metals at the Two joints, which produces an emf called* ***Thermo EMF*** *to cause a circulatory current, in accordance with the Ohm's Law, in the bimetallic loop*. This phenomenon is totally a different from the one occurring in bimetallic strip, as elaborated in Heat and Thermodynamics. This effect is known as ***Seebeck Effect***, discovered by **Thomas Johann Seebeck** in 1821. Direction of Thermo EMF is used to sequence metals such that at cold junction current is from metal occurring earlier in the sequence to the metal occurring later in the sequence, which is known as ***Thermoelectric Series***. This series of metals is



- Antimony, *Nichrome, Iron, Zinc, Copper, Gold, Silver, Lead, Aluminium, Mercury, Platinum-Rhodium, Platinum, Nickel, Bismuth, Constantan and Bismuth.*

This *Thermo EMF* E_{AB} *between two metals is seen to vary with temperature difference* θ. *Let, temperature of cool joint is* 0^0C *and* θ^0C *then* $E_{AB} = \alpha_{AB}\theta + \beta_{AB}\theta^2$. If E_{AB} is Thermo EMF between metal A and B, and E_{BC} is Thermo EMF between metal B and C, then Thermo EMF between metal A and C is and $E_{AC} = E_{AB} + E_{BC}$.

Jean Charles Athanase Peltier in 1834 discovered that, *if an electric current is flown through junction of two conductors heat may be generated or absorbed, which is just reverse of Seebeck Effect. This discovery is known as* ***Peltier Effect***.

In 1854, **William Thomson** discovered *that if a long metal has non-uniform temperature along its length, and a current is driven through it then heat is produced or absorbed in different sections of the metal in addition to Joule's Effect, and is known as* ***Thomson's Effect***. In fact Thomson Effect is combining the Seebeck and Peltier Effect.

Thermo-Chemical Effect of Electric Current: In liquids molecules break into (+)ve and (-)ve ions due high dielectric constant of the liquid medium, which weakens the electrostatic binding forces between the ions This is known as ***electrolytic solution***. This results into deposits of ions as free molecules when an electric current is passed through the electrolytic solution. This phenomenon is known as Electrolysis, which converts a dielectric-solution into a conductor. Michael Faraday in 1834 published quantitative relationship of electrolysis and is known as Faraday's Laws of Electrolysis. In the same year Carlo Matteucci has also discovered Laws of Electrolysis, independently. The Laws of Electrolysis are – a) Mass of a substance deposited or liberated at an electrode is proportional to the electric charge through it, b) Mass of substance deposited or liberated at an electrode is proportional to the chemical equivalent of the substance, and is mathematically represented as $\boldsymbol{m} = \left(\frac{\boldsymbol{Q}}{\boldsymbol{F}}\right)\left(\frac{\boldsymbol{M}}{\boldsymbol{z}}\right)$. Here, $\boldsymbol{m}$ is the mass of substance liberated in grams, $\boldsymbol{Q} = \int I dt$ is the total electric charge passed through the electrode in Coulomb, $\boldsymbol{M}$ is the molar mass of substance in grams per mol, $\boldsymbol{z}$ *is the valency of the ions of the substance and* $\boldsymbol{F}$ *is the Faraday's Constant. This is also written as* $m = \left(\frac{Q}{F}\right)E$, *where* $\boldsymbol{E} = \frac{\boldsymbol{M}}{\boldsymbol{z}}$, *is called* ***chemical equivalent of substance***.

Summary: *As one advances into journey into Physics, he finds increasing integration of Mathematics into Physics. The advent of current electricity has opened a new era of not only nature but transforming world through technological developments.*

Extending, Electrostatics, this Part on Current Electricity elaborates basics laws of electrical circuits and its Thermal and Chemical effects. In Part-I concepts of waves and in Part- II Sound Waves were elaborated. Understanding current electricity is slightly different from other topics, where one could observe the phenomenon. In this topic everything happen, but nothing is visible. But, verification of phenomenon of current electricity is through observations of its effects. At this point, some of the inter-related topics are referred to but their elaboration has been deferred, till related concepts are covered.Nevertheless, readers are welcome to raise their inquisitiveness, beyond the contents, through ***Contact Us***.

Solving of problems, is an integral part of a deeper journey to make integration and application of concepts intuitive. This is absolutely true for any real life situations, which requires multi-disciplinary knowledge, in skill for evolving solution. Thus, problem solving process is more a conditioning of the thought process, rather than just learning the subject. Practice with wide range of problems is the only pre-requisite to develop proficiency and speed of problem solving, and making formulations more intuitive rather than a burden on memory, as much as overall personality of a person. References cited below provide an excellent repository of problems. Readers are welcome to pose their difficulties to solve any-problem from anywhere, but only after two attempts to solve. It is our endeavour to stand by upcoming student in their journey to become a scientist, engineer and professional, whatever they choose to be.

Looking forward, these articles are being integrated into Mentors' Manual. After completion of series of such articles on Physics, representative problems from contemporary text books and Question papers from various competitive examinations shall be drawn and supported with necessary guidance to evolve solutions as a dynamic exercise which is contemplated to accelerate the conceptual thought process.

References:

1. *NCERT; PHYSICS, Text Book for Class XI (Part I and II), and Exemplar Problems.*
2. *भौतिक शास्त्र, कक्षा ११ एवं १२,, मध्य प्रदेश पाठ्यपुस्तक निगम, 2016*
3. *S.L.Loney; The Elements of Statistics and Dynamics: Part 1 – Statics and Part 2 – Dynamics.*
4. *H.C. Verma; Concepts of Physics, (Vol 1 & 2).*
3. *Resnick, Halliday, Resnick and Krane; Physics (Vol I and II).*
4. *Sears & Zemansky; University Physics with Modern Physics.*
5. *I.E. Irodov; Problems in General Physics*

Author is Coordinator of this initiative Gyan-Vigyan Sarita. ***e-Mail ID****: subhashjoshi2107@gmail.com*