BEEE

MODULE 1

BY MANKIRAN KAUR

contents

Electric current, flow of electric charges in a metallic conductor, drift velocity

Ohm's law, electrical resistance, V-I characteristics (linear and non-linea
r),
Law of resistance, electrical energy and power, electrical resistivity, and conductivity

What is electricity?

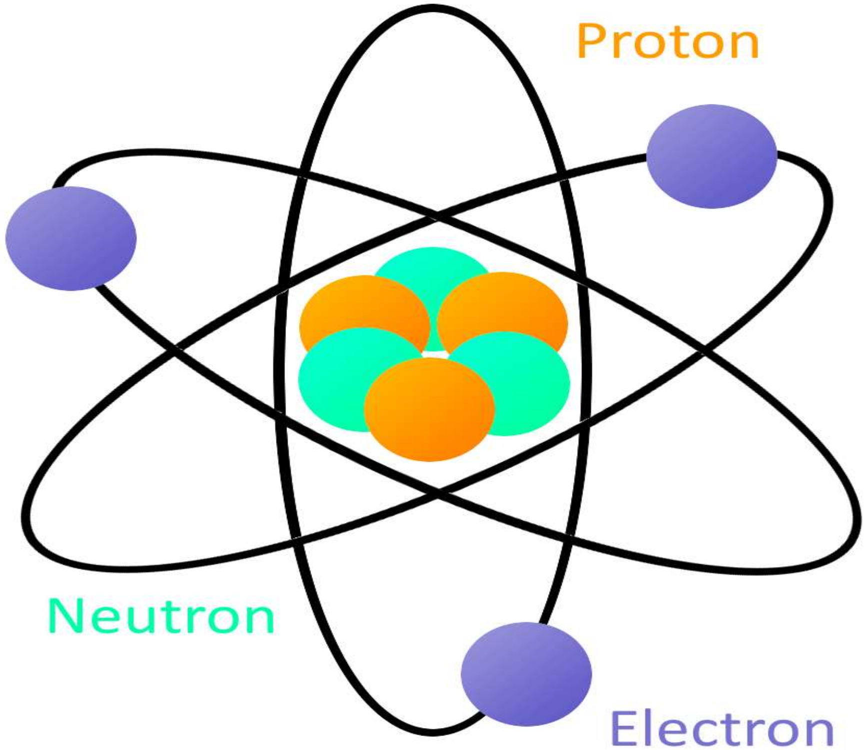
- Electricity is all around us--powering technology like our cell phones, computers, lights, soldering irons, and air conditioners. It's tough to escape it in our modern world
- Electricity is briefly defined as the **flow of electric charge**

Atoms

- To understand the fundamentals of electricity, we need to begin by focusing in on atoms, one of the basic building blocks of life and matter. Atoms exist in over a hundred different forms as chemical elements like hydrogen, carbon, oxygen, and copper.

Building Blocks of Atoms

- An atom is built with a combination of three distinct particles: electrons, protons, and neutrons



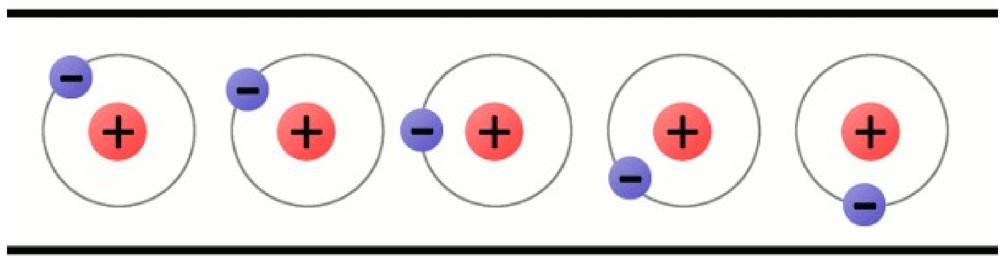
A very simple atom model. It's not to scale but helpful for understanding how an atom is built. A core nucleus of protons and neutrons is surrounded by orbiting electrons.

- Every atom must have at least one proton in it. The number of protons in an atom is important, because it defines what chemical element the atom represents. For example, an atom with just one proton is hydrogen, an atom with 29 protons is copper, and an atom with 94 protons is plutonium. This count of protons is called the atom's **atomic number**.

Flowing Charges

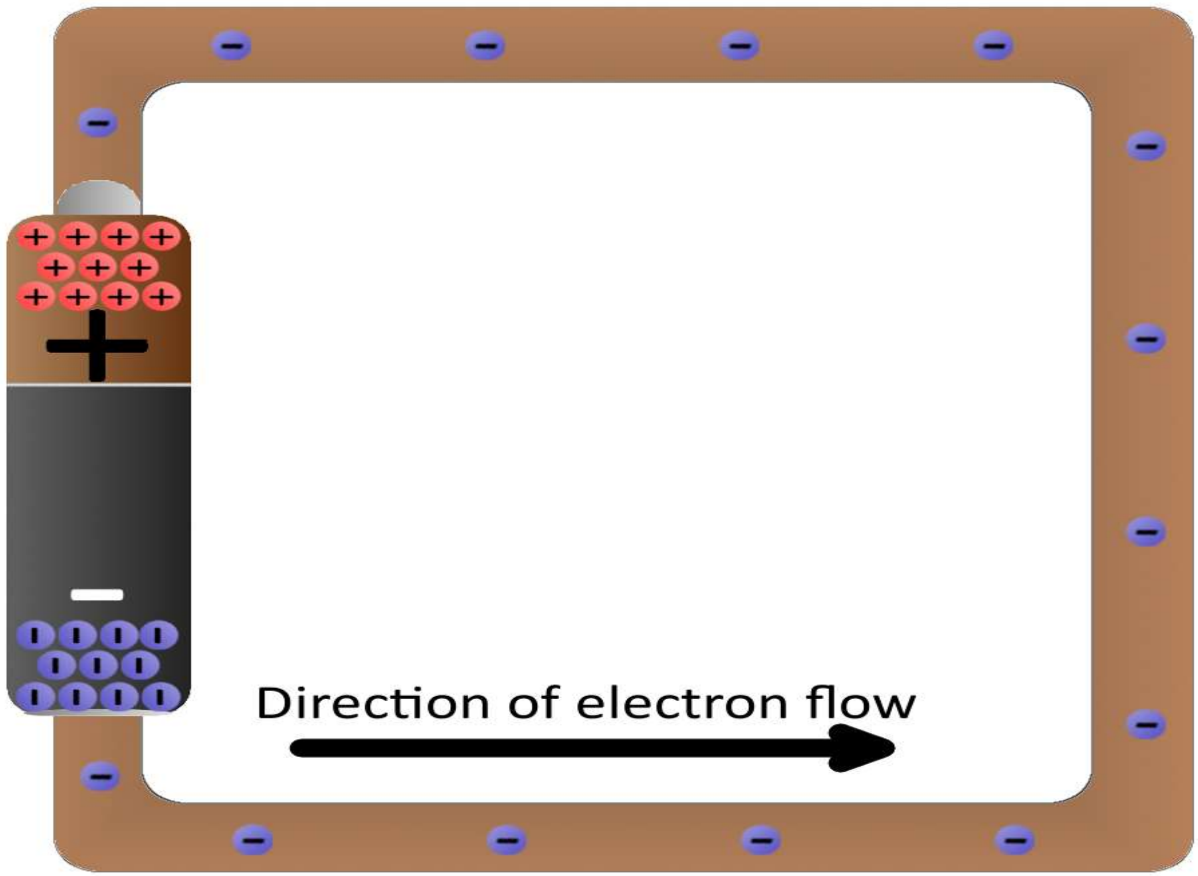
- **Charge** is a property of matter--just like mass, volume, or density. It is measurable
- The key concept with charge is that it can come in two types: **positive (+) or negative (-)**.
- In order to move charge we need **charge carriers**,
- Electrons always carry a negative charge, while protons are always positively charged. Neutrons (true to their name) are neutral, they have no charge. Both electrons and protons carry the same **amount** of charge, just a different type.

- **Electrons** in atoms can act as our **charge carrier**, because every electron carries a negative charge. If we can free an electron from an atom and force it to move, we can create electricity

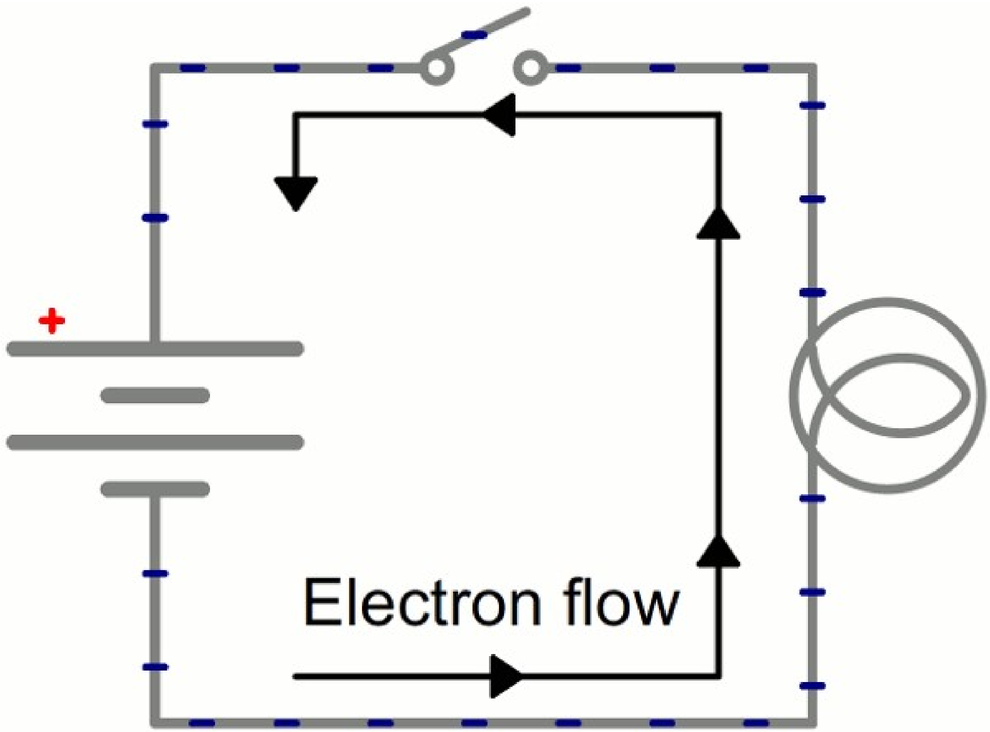


Electrostatic Force

- Electrostatic force (also called Coulomb's law) is a force that operates between charges. It states that charges of the same type repel each other, while charges of opposite types are attracted together. **Opposites attract, and likes repel**.


Direction of electron flow

Illuminating a Light Bulb



- *A battery (left) connecting to a lightbulb (right), the circuit is completed when the switch (top) closes. With the circuit closed, electrons can flow, pushed from the negative terminal of the battery through the lightbulb, to the positive terminal.*

Definition and Mechanism of Electric Current

- Electric current is a movement or flow of electrically charged particles and its unit of measurement is amperes. When an electric current flows in a conductor, it flows as a drift of free electrons in the metal.
- Electricity flows easily through a conductor because the electrons are free to move around in the object. Whenever there is a movement of electrons through a conductor, an electric current is created.

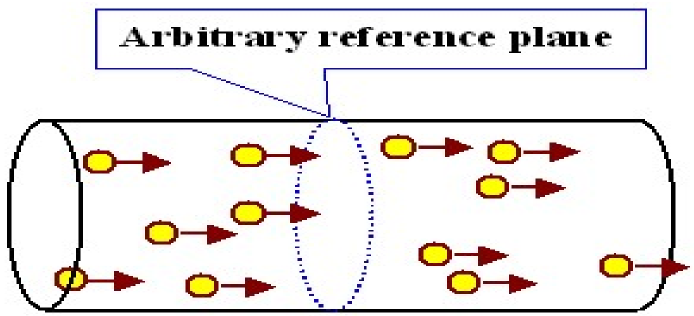
Current can also be divided into two types-.

- DC and AC
- **Dc or Direct Current**- As the name suggests, the current that always flows in one direction and does not move back and forth is called as the direct current. The most common example of DC is battery
- **AC or Alternating Current-** The current that flows back and forth and not in one direction is termed as the alternating current.

- Before we actually discuss the mechanism of current flow in a conductor we explain the concept of drift velocity as it will be required in its description.

- **Drift Velocity:** The average velocity achieved by some particle like the electron due to the existence of electric field is termed as drift velocity. The particles are actually assumed to be moving along some plane and hence the velocity may also be termed as axial drift velocity.

- NOTE *(The **velocity** of an object is the rate of change of its position with respect to a frame of reference, and is a function of time. **Velocity** is equivalent to a specification of an object's speed and direction of motion)



Ensemble with only the
drift velocity shown

Mechanism of Current Flow in a Conductor

- Flow of current in metals is due to preferential flow of free electrons. In the absence of any externally applied emf (by means of a battery), the free electrons move randomly through the metal from one point to another giving zero net current.
- When connected to a battery, the free electrons get accelerated due to the electric field (set up by the battery) and they gain velocity and energy.

Current, Voltage, and Resistance

Voltage

- **<u>Voltage:</u>** the charge (electron) "pusher." Voltage *causes* current to flow/move.
- Voltage sources:
  - Battery
  - Generator
  - Outlets
- **Symbol for voltage** = V
- **Unit for voltage** = Volts (V)

Alessandro Volta (1745 – 1827)

- Italian physicist
- known especially for the invention of the electrochemical cell, aka the battery in 1800.

Voltage at Home

- Power utilities use large generators to provide the 120V that is delivered to your home outlets.

- When you plug in something to the outlet (lamp, blow dryer, TV, etc) the voltage is applied *across the circuit*, allowing the charge to flow (electric current).

Current

- **<u>Current:</u>** flow of charge (electrons) within a conductor or how fast charge is moving.
- Charge will only flow if there is a voltage source (potential difference).
- **Symbol for Current** = I
- **Unit for Current** = Amps (A)

André Ampère (1775 – 1836)

- French physicist and mathematician.
- One of the main discoverers of electromagnetism.
- SI unit of measurement of electric current, the ampere, is named after him.

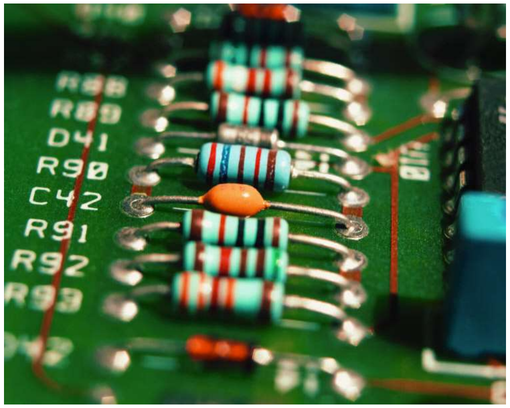
What level of current is dangerous to people?

Current in Amps	**Effect on A Person**
0.001 Amps	Can be felt
0.005 Amps	Painful
0.010 Amps	Involuntary muscle spasms
0.015 Amps	Loss of muscle control
0.070 Amps	If through heart, serious injury, likely fatal if it lasts more than 1 second

Resistance

- **Resistance:** opposes the push from the voltage source. Resistance affects the speed of the current.

- **Symbol for Resistance** = R
- **Unit for Resistance** = Ohms (ʹΩ)



Georg Ohm (1789 – 1854)

- German physicist
- Ohm determined that there is a direct proportionality between the voltage applied across a conductor and the electric current.
- This relationship is known as Ohm's law.

Voltage and Current

- If the voltage in a circuit increases, the current will increase.
- If the voltage in a circuit decreases, the current will decrease.
- This is a <u>***direct/proportional***</u> relationship.

Resistance and Current

- If the resistance in a circuit increases, the current will decrease.
- If the resistance in a circuit decreases, the current will increase.
- This is an ***<u>inversely proportional</u>*** relationship.

Ohm's Law

- State the relationship between current, voltage, and resistance.
- German physicist George Ohm had the law named after him, because of his extensive research.

Ohm's Law

Voltage is equal to the current multiplied by the resistance.

Voltage, measured in Volts, ***V***

Current, measured in Amps, ***A***

$$V=IR$$

Resistance, measured in Ohms, Ω

Ohm's Law Examples…

- **If you want to find <u>Voltage</u> in Volts:**

$$\mathbf{V = IR}$$

If I= 2 A and R = 5 Ohms

Then, V= (2A)(5Ω) = 10 V

Examples…

- **If you want to find <u>Resistance</u> in Ohm's:**

$$\mathbf{R = V / I}$$

If V = 9 Volts and I = 4 A

Then R = 9 V/ 4A = 2.25 Ω

Examples…

- **If you want to find <u>Current</u> in Amps:**

I = V / R

If V= 140 V and R = 2Ω

Then, I = 140V/ 2Ω = 70 A

V-I characteristics

- **V-I characteristics**
- **Explanation:**
- V-I characteristics denotes the voltage-current characteristics of a circuit.
- A **linear V-I characteristic** denotes **constant resistance**. When we plot this graph, the V-I curve will be a **straight line passing through the origin.** However, this is not ideal situation. An electronic component tends to exhibit linear characteristic only in a particular region. Example, a diode.

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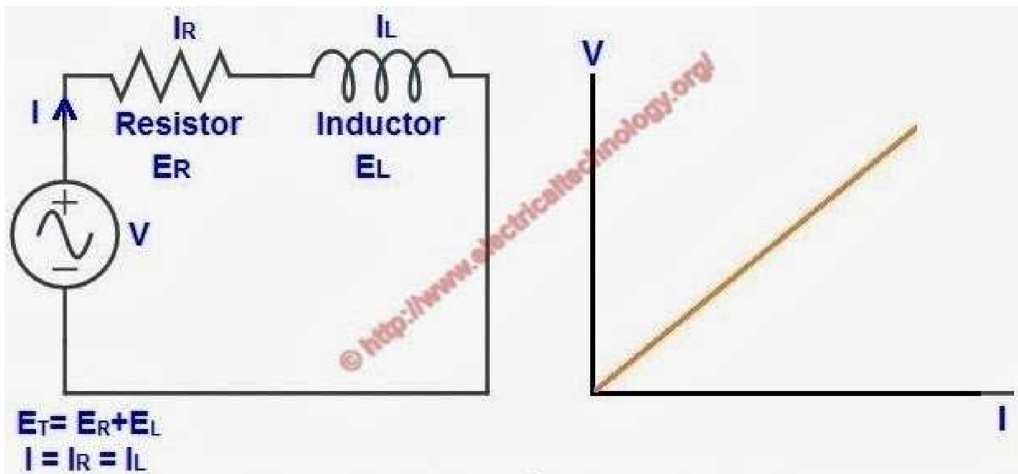
- In general, a circuit component tends to have **non-linear characteristic** as the **resistance is not constant** throughout. It will be a function of voltage (V) and current (i). The graph is **not a straight line** and hence it is called non-linear V-I characteristics.

Linear circuit

- In simple words, a linear circuit is an electric circuit in which circuit parameters (Resistance, inductance, capacitance, waveform, frequency etc) are constant. In other words, a circuit whose parameters are not changed with respect to Current and Voltage is called Linear Circuit.
- the word “linear” literally means “along with a straight line”. As the name tells everything, a linear circuit means linear characteristics in between Current and Voltage, which means, current flowing through a circuit is directly proportional to the applied Voltage.

- If we increase the applied voltage, then the current flowing through the circuit will also increase, and vice versa. If we draw the circuit output characteristic curve in between Current and Voltage, it will look like a straight line (Diagonal)

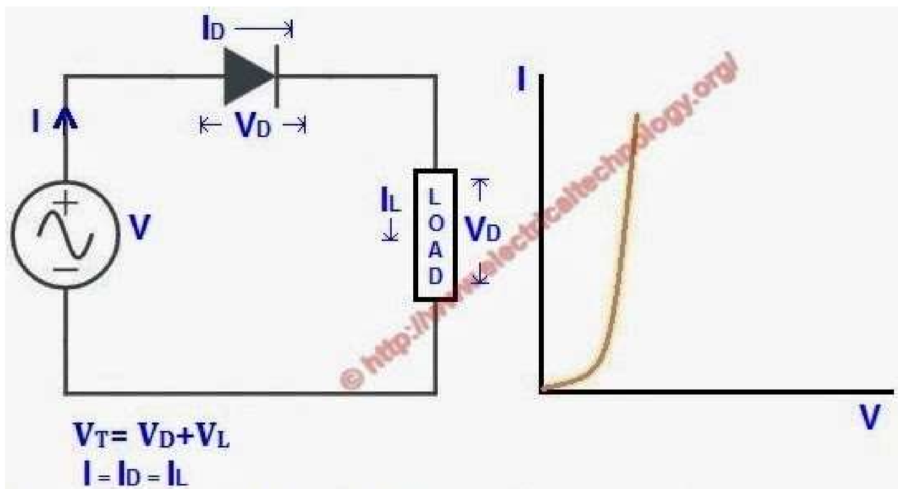


Linear Circuit & its characteristic curve

Non Linear Circuit

- A nonlinear circuit is an electric circuit whose parameters are varied with respect to Current and Voltage. In other words, an electric circuit in which circuit parameters (Resistance, inductance, capacitance, waveform, frequency etc) is not constant, is called Non Linear Circuit.

- If we draw the circuit output characteristic curve in between Current and Voltage, it will look like a curved or bending line as shown in fig



Non Linear Circuit & its characteristic curve

- **Examples of Non-Liner Circuits and Non Linear Elements**
- Diode
- Transistor
- Transformer
- Iron Core
- inductor (when the core is saturated)
- and any circuit composed exclusively of ideal Diode,
- Transistor
- Transformer
- and Iron Core inductor is called Non linear circuit.

- **Examples of Liner Circuits and Linear Elements**
- Resistance and Resistive Circuit
- Inductor and Inductive Circuits
- Capacitor and Capacitive Circuits

Law of resistance

- **Resistivity or Coefficient of Resistance**
- Resistivity or Coefficient of Resistance is a property of substance, due to which the substance offers opposition to the flow of current through it. Resistivity or Coefficient of Resistance of any substance can easily be calculated from the formula derived from **Laws of Resistance**.

$R \propto L$

Laws of Resistance

The resistance of any substance depends on the following factors,

- Length of the substance.
- Cross sectional area of the substance.
- The nature of material of the substance.
- Temperature of the substance.

- There are mainly four (4) **laws of resistance** from which the **resistivity** or **specific resistance** of any substance can easily be determined.

First Law of Resistance

The resistance of a substance is directly proportional to the length of the substance. electrical resistance R of a substance is

$$R \propto L$$

Where L is the length of the substance.

If the length of a substance is increased, the path traveled by the electrons is also increased. If electrons travel long, they collide more and consequently the number of electrons passing through the substance becomes less; hence current through the substance is reduced. In other words, the resistance of the substance increases with increasing length of the substance. This relation is also linear.

Second Law of Resistivity

- The resistance of a substance is inversely proportional to the cross-sectional area of the substance. Electrical resistance R of a substance is

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

- Where A is the cross-sectional area of the substance.

The current through any substance depends on the numbers of electrons pass through a cross-section of substance per unit time. So, if the cross section of any substance is larger then more electrons can cross the cross section. Passing of more electrons through a cross-section per unit time causes more current through the substance. For fixed voltage, more current means less electrical resistance and this relation is linear.

Resistivity

- Combining these two laws we get,

$$R \propto \frac{L}{A} \Rightarrow R = \rho \frac{L}{A}$$

- Where, ρ (rho) is the proportionality constant and known as **resistivity** or **specific resistance** of the material of the conductor or substance. Now if we put, L = 1 and A = 1 in the equation, we get, R = ρ. That means resistance of a material of unit length having unit cross – sectional area is equal to its **resistivity** or **specific resistance**. Resistivity of a material can alternatively be defined as the electrical resistance between opposite faces of a cube of unit volume of that material.

Third Law of Resistivity

- The resistance of a substance is directly proportional to the resistivity of the materials by which the substance is made. The resistivity of all materials is not the same. It depends on the number of free electrons, and size of the atoms of the materials, types of bonding in the materials and many other factors of the material structures. If the resistivity of a material is high, the resistance offered by the substance made by this material is high and vice versa. This relation is also linear.

$$R \propto \rho$$

Fourth Law of Resistivity

- The temperature of the substance also affects the resistance offered by the substance
- in metallic substance, resistance increases with increasing temperature.
- If the substance in nonmetallic, resistance is decreased with increase in temperature.

Unit of Resistivity

- The **unit of resistivity** can be easily determined form its equation

$$R = \rho \frac{L}{A} \Rightarrow \rho = \frac{RA}{L}$$

$$In\ SI\ System\ of\ Unit$$

$$\rho = \frac{R\,\Omega\ \times A\,m^2}{L\,m}$$

$$\Rightarrow \rho = \frac{RA}{L}\ \ \frac{\Omega - m^2}{m}\ or\ \Omega - m$$

Electrical Energy and Power

- Electrical Energy supplies the power required to produce work or an action within an electrical circuit and is given in joules per second
- **Electrical Energy** is the ability of an electrical circuit to produce work by creating an action. This action can take many forms, such as thermal, electromagnetic, mechanical, electrical, etc.
- *Electrical energy* can be both created from batteries, generators, dynamos, and photovoltaics, etc. or stored for future use using fuel cells, batteries, capacitors or magnetic fields, etc
- "*The Law of the Conservation of Energy*" states that energy cannot be created or destroyed, only converted

- But for energy to do any useful work it must be converted from one form into something else.
- For example, a motor converts electrical energy into mechanical or kinetic (rotational) energy, while a generator converts kinetic energy back into electrical energy to power a circuit.
- Another example is a lamp, light bulb or LED (light emitting diode) which convert electrical energy into light energy and heat (thermal) energy.

- For electrical energy to move electrons and produce a flow of current around a circuit, work must be done, that is the electrons must move by some distance through a wire or conductor. The work done is stored in the flow of electrons as energy. Thus “Work” is the name we give to the process of energy.

Electrical Energy: The Volt

- As we now know that energy is the capacity to do work, with the standard unit used for energy (and work) being the **Joule**. A joule of energy is defined as the energy expended by one ampere at one volt, moving in one second.

- Electric current results from the movement of electric charge (electrons) around a circuit, but to move charge from one node to another there needs to be a force to create the work to move the charge, and there is: *voltage*.
- voltage is important as it provides the work needed to move the charge from one point to another, either in a forward direction or a reverse direction. The voltage, or potential difference between two terminals or points is defined as having a value of one volt, when one joule of energy is used in moving one coulomb of electric charge between those two terminals.

- In other words, the *Voltage* difference between two points or terminals is the work required in *Joules* to move one *Coulomb* of charge from A to B. Therefore voltage can be expressed as being:

$$1\,\text{Volt} = \frac{1\,\text{Joule}}{1\,\text{Coulomb}} = \frac{\text{J}}{\text{C}}$$

ELECTRICAL POWER

- **Electrical Power** is the product of the two quantities, *Voltage* and *Current* and so can be defined as the rate at which work is performed in expending energy.

$$V = \frac{J}{C} \quad \text{and} \quad I = \frac{Q}{t}$$

As: $Q = 1C$

If: $P = V \times I = \frac{J}{C} \times \frac{Q}{t} = \frac{J}{C} \times \frac{C}{t}$

Then: $P = \frac{J}{\cancel{C}} \times \frac{\cancel{C}}{t} = \frac{J}{t}$

- So we can see that electrical power is also the rate at which work is performed during one second. That is, one joule of energy dissipated in one second. As electrical power is measured in Watts (W), therefore it must be also be measured in Joules per Second. So we can correctly say that: 1 watt = 1 joule per second (J/s)

ELECTRICAL ENERGY

- So electrical energy (the work done) is obtained by multiplying power by the time in seconds that the charge (in the form of a current) flows.
- Thus units of electrical energy depend on the units used for electric power and time.

EXAMPLE

- A 100 Watt light bulb is illuminated on for one hour only. How many joules of electrical energy have been used by the lamp.

$$\text{Electrical Energy} = \text{Power} \times \text{Time}$$

$$\text{Electrical Energy} = 100 \times (60 \times 60)$$

$$\text{Electrical Energy} = 100 \times 3600 = 360{,}000 \text{ joules}$$