Sheikh Hasina University, Netrokona

Department of Computer Science and Engineering

CSE-2205: Introduction to Mechatronics

Lec-5: Basic Electronics

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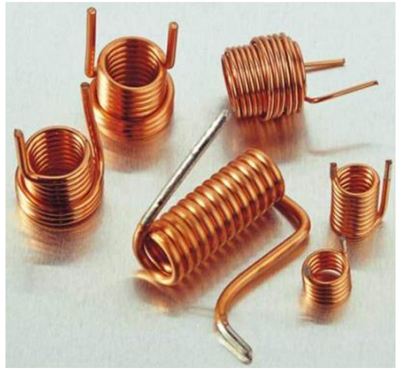
Inductor

According to the Faraday's law of Electromagnetic induction, When the current flowing through an inductor changes, the time-varying magnetic field induces a voltage in the conductor. According to lens law, the direction of induced EMF opposes the change in current that created it. Hence, **induced EMF is opposite to the voltage** applied across the coil. This is the property of an inductor.

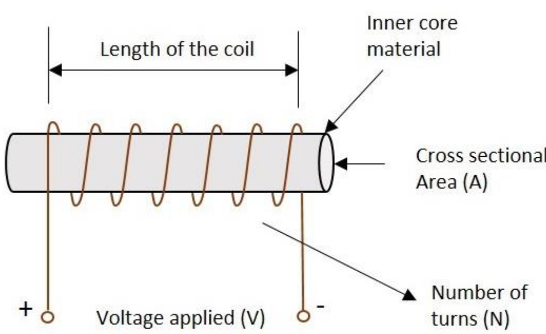
The following figure shows how an inductor looks like.



An inductor blocks any AC component present in a DC signal. The inductor is sometimes wrapped upon a core, for example a ferrite core. It then looks as in the figure below.

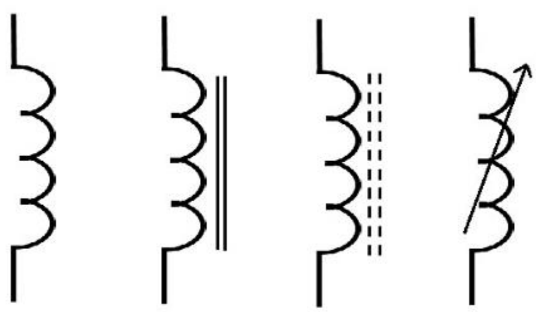
Core | Core wounded with wire | Inductors having different types of core

The following figure shows an inductor with various parts labelled.



Symbols

The symbols of various types of inductors are as given below.



Air Core Inductor | Iron Core Inductor | Ferrite Core Inductor | Variable Core Inductor

Storage of Energy

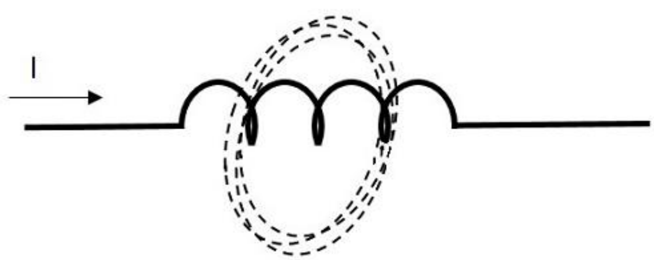
One of the Basic properties of electromagnetism is that the current when flows through an inductor, a magnetic field gets created perpendicular to the current flow. This keeps on building up. It gets stabilized at some point, which means that the inductance won't build up after that. When the current stops flowing, the magnetic field gets decreased.

This magnetic energy gets turned into electrical energy. Hence energy gets stored in this temporarily in the form of magnetic field.

Working of an Inductor

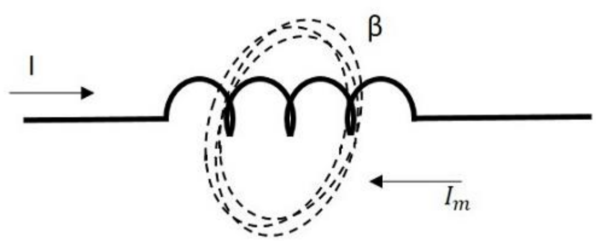
According to the theory of Electromagnetic Induction, any varying electric current, flowing in a conductor, produces a magnetic field around that, which is perpendicular to the current. Also, any varying magnetic field, produces current in the conductor present in that field, whereas the current is perpendicular to the magnetic field.

Now, if we consider an inductor which is made up of a conducting coil and when some current passes through the inductor, a magnetic field is created perpendicular to it. The following figure indicates an inductor with magnetic field around it.



Now, here we have a varying magnetic field, which creates some current through the conductor. But this current is produced such that it opposes the main current, which has produced the magnetic field.

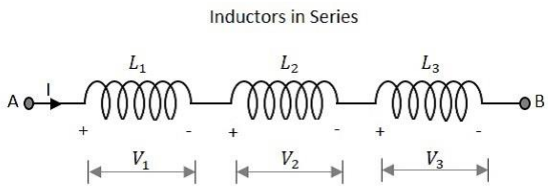
If this current is named as Im which means the current produced due to the magnetic field and the magnetic field is indicated by β, the following figure indicates it.



This opposing current gains strength with the varying magnetic field, which gains energy by the input supply frequency. Hence as the input current becomes more and more AC with high frequency, the resulting opposing current also gains its strength in opposite direction to the very cause producing it. Now, this opposing current, tries to stop the high frequency AC to pass through the inductor, which means "blocking of AC".

Inductors in Series

Let us observe what happens, when few inductors are connected in Series. Let us consider three resistors with different values, as shown in the figure below.



Inductance

The total inductance of a circuit having series inductors is equal to the sum of the individual inductances. Total inductance value of the network given above is

$$L_T = L_1 + L_2 + L_3$$

Where L_1 is the inductance of 1st resistor, L_2 is the inductance of 2nd resistor and L_3 is the inductance of 3rd resistor in the above network.

Voltage

The total voltage that appears across a series inductors network is the addition of voltage drops at each individual inductances.

Total voltage that appears across the circuit

$$V = V_1 + V_2 + V_3$$

Where V_1 is the voltage drop across 1st inductor, V_2 is the voltage drop across 2nd inductor and V_3 is the voltage drop across 3rd inductor in the above network.

Current

The total amount of Current that flows through a set of inductors connected in series is the same at all the points throughout the network.

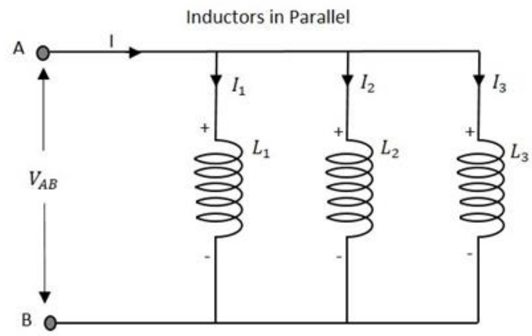
The Current through the network

$$I = I_1 = I_2 = I_3$$

Where I_1 is the current through the 1st inductor, I_2 is the current through the 2nd inductor and I_3 is the current through the 3rd inductor in the above network.

Inductors in Parallel

Let us observe what happens, when few resistors are connected in Parallel. Let us consider three resistors with different values, as shown in the figure below.



Inductance

The total inductance of a circuit having Parallel resistors is calculated differently from the series inductor network method. Here, the reciprocal 1/R value of individual inductances are added with the inverse of algebraic sum to get the total inductance value.

Total inductance value of the network is

$$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}$$

Where L_1 is the inductance of 1st inductor, L_2 is the inductance of 2nd inductor and L_3 is the inductance of 3rd inductor in the above network.

From the method we have for calculating parallel inductance, we can derive a simple equation for two-inductor parallel network. It is

$$L_T = \frac{L_1 \times L_2}{L_1 + L_2}$$

Voltage

The total voltage that appears across a Parallel inductors network is same as the voltage drops at each individual inductance.

The Voltage that appears across the circuit

$$V = V_1 = V_2 = V_3$$

Where V_1 is the voltage drop across 1st inductor, V_2 is the voltage drop across 2nd inductor and V_3 is the voltage drop across 3rd inductor in the above network. Hence the voltage is same at all the points of a parallel inductor network.

Current

The total amount of current entering a Parallel inductive network is the sum of all individual currents flowing in all the Parallel branches. The inductance value of each branch determines the value of current that flows through it.

The total Current through the network is

$$I = I_1 + I_2 + I_3$$

Where I_1 is the current through the 1^{st} inductor, I_2 is the current through the 2^{nd} inductor and I_3 is the current through the 3^{rd} inductor in the above network.

Hence the sum of individual currents in different branches obtain the total current in a parallel network.

Inductive Reactance

Inductive Reactance is the opposition offered by an inductor to the alternating current flow, or simply AC current. An inductor has the property of resisting the change in the flow of current and hence it shows some opposition which can be termed as **reactance**, as the frequency of the input current should also be considered along with the resistance it offers.

- Indication − **XL**
- Units − **Ohms**
- Symbol − **Ω**

In a purely inductive circuit, the current $\mathbf{I_L}$ **lags** the applied voltage by 90°. Inductive reactance is calculated by,

$$X_L = 2\pi f L$$

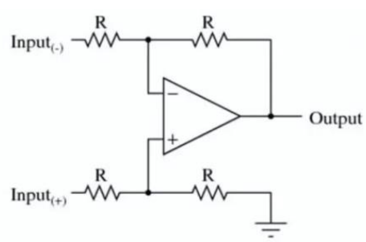
Where f is the frequency of the signal. Hence inductive reactance is a function of frequency and inductance.

Types of Electronic Circuits

Electronic circuits are categorized as Analog Circuits, Digital Circuit and Mixed-signal Circuit (*a combination of analog and digital*).

Now, let us understand each of these in detail:

1. Analog Electronic Circuits



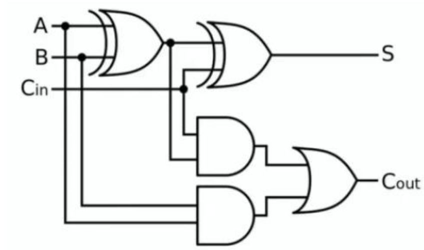
Simple Analog Circuit

Analog Electronic Circuits are those in which signals may vary continuously with time to correspond to the information being represented.

Electronic equipment like voltage amplifiers, power amplifiers, tuning circuits, radios, and televisions are mainly analog.

The basic units of analog circuits are passive (*resistors, capacitors, inductors, and memristors*) and active.

2. Digital Electronic Circuits

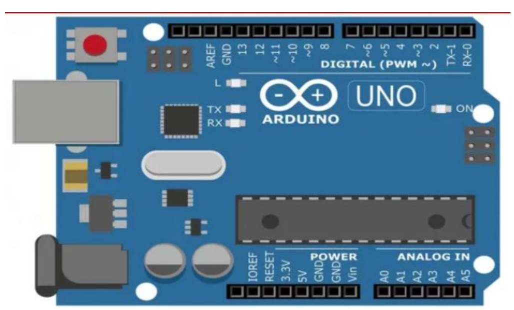


Simple Digital Circuit

In Digital Circuits, electric signals take on discrete values, which are not dependent upon time, to represent logical and numeric values. These values represent the information that is being processed.

The transistor is one of the primary components used in Digital Circuits.

3. Mixed-signal Circuit



Mixed-signal Circuits are also called hybrid circuits. They contain elements of both analog and digital circuits.

Examples of Mixed-Signal Circuits are – Comparators, Timers, PLLs, ADCs (*analog-to-digital converters*), and DACs (*digital-to-analog converters*).

Potential Difference

Potential difference can be simply defined as the difference of electrical potential between two points. When two positive charges when brought close to each other, they repel.

When two negative charges are brought close to each other, they also repel. But when a positive and a negative charge are brought close together, they attract each other. When these two opposite charges are combined, they can be used to work. This is why we need a positive (**+**) and a negative (**–**) to light a bulb or run any electrical tool, equipment, mobile phone or home appliance. This ability of charged particles to do work is called an ***electric potential***.

Therefore, two opposite charges have a ***difference of potential*** *or Potential Difference*. The unit of potential difference (*pd*) is **volt**.

Unit of Potential Difference

The unit of *Potential Difference (Volt)* is named after Alessandro Volta. The volt is a measure of electric potential. Electrical potential is a type of potential energy, and refers to the energy that could be released if electric current is allowed to flow.

One volt is defined as the difference in electric potential between two points of a conducting wire when an electric current of one ampere dissipates one watt of power between those points. It is also equal to the potential difference between two parallel, infinite planes spaced 1 meter apart that create an electric field of 1 newton per coulomb.

The SI unit of work is the ***joule*** (**J**). The SI unit of force is the ***newton*** (**N**). The SI unit of distance is the *meter* (**m**).

W (joules) = N (newtons) x m (meters)

Voltage

In the field of electronics, potential difference is commonly referred to as voltage and its symbol is **V**. In some cases, the symbol **U** or **E** for emf (*electromotive force*) is also used, but the standard symbol **V** represents any potential difference. This applies to the voltage generated by sources like battery or solar cell, and also to the voltage dropped across a passive electronic component such as a resistor.

The potential difference, also referred to as voltage difference between two given points is the work in joules required to move one coulomb of charge from one point to the other. The SI unit of voltage is the **volt**.

$$\mathrm{V(volts)} = \frac{\mathrm{W(joules)}}{\mathrm{Q(coulombs)}}$$

Types of Voltage

There are 2 types of voltage – DC or Direct Current and AC or Alternating Current.

DC – It is constant voltage. Here the electric charge (*current*) only flows in one direction. Sources of voltage like a mobile phone battery or solar cell supplies DC voltage. *Example – 12 VDC*

AC – It is Alternating Current. Here electric charge (current) changes direction periodically. Sources of voltage like an AC generator supplies AC voltage. *Example – 240 VAC.*

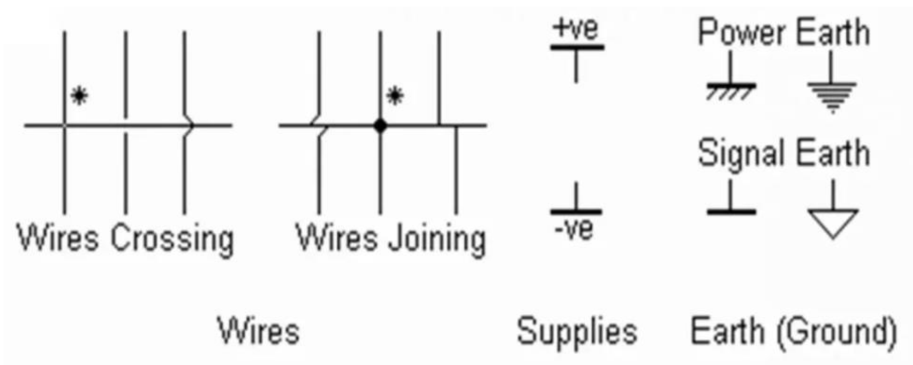
Voltage Polarity

Suppose there are 2 charged points – Point **A** is Positively Charged (+) and Point **B** is Negatively Charged (-). Now, if we move A (+) closed circuit from A to B or vice-verse, it requires work. The difference between the two points is the *voltage polarity.* This voltage polarity is indicated by a positive sign (+) at A and a negative sign (-) at Point B.

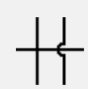
How to Calculate Electric Potential Difference by Ohm’s Law

1. Calculate the amount of current flowing through a circuit. This is measure in amperes (**I**)
2. Calculate the amount of resistance in the circuit. Resistance is measures in Ohms (**R**).
3. Multiply amount of current in the circuit with amount of resistance in the circuit – **V = IR (Ohm’s Law)**

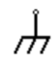
Electrical Wiring Symbols, Meanings and Drawings



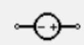
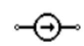
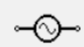
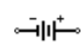
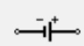
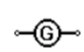
Electrical Wiring Symbols for Wire

Name	Meaning / Function	Symbol
Electrical Wire	Conduct Electricity	
Connected Wires	Wires are Connected	
Not Connected Wires	Wires are not Connected	

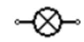
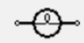
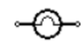
Electrical Wiring Symbols for Ground

Name	Meaning / Function	Symbol
Earth Ground	Protection against Electrical Shock	
Chassis Ground	Connected to Chassis of a Circuit	
Common Ground	For Analog and Digital Grounding	

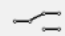
Power Supply Symbols

Name	Meaning / Function	Symbol
Voltage Source	Constant Voltage Source	
Current Source	Constant Current Source	
AC Voltage Source	Source of AC Voltage	
Battery	Constant Voltage Source	
Battery Cell	Constant Voltage Source	
Generator	Mechanical Voltage Source	

Lamp and Light Bulb Symbols

Name	Meaning / Function	Symbol
Lamp or Light Bulb	Generates Light with Flow of Current	
Lamp or Light Bulb	Generates Light with Flow of Current	
Lamp or Light Bulb	Generates Light with Flow of Current	

Switch and Relay Symbols

Name	Meaning / Function	Symbol
SPST Toggle Switch	Disconnect Current when Open	
SPDT Toggle Switch	Select Between 2 Connections	
Push Button Switch (N.O)	Switch Momentary – Generally Open	
Push Button Switch (N.C)	Switch Momentary – Generally Closed	
DIP Switch	Onboard Configuration	
SPST Relay	Single Pole Single Throw	
SPDT Relay	Single Pole Double Throw	
Jumper	Jumper to Close Connection	
Solder Bridge	Solder Connection	

What is Electric Current?

Electric current is the flow of charge (*charged particles*) through a conductor with respect to time. The process is similar to flowing of a river in one direction.

How is Electric Current Produced?

Electron flow is in the opposite direction from negative to positive. **Electric current** flows in the direction of positive charge i.e positive to negative.

In a circuit, flow of positive current is marked by an arrow. In a conductor metal like copper or aluminum, only negatively charged free electrons move to produce current.

Positively charged protons cannot move. But in a gas or liquid, both the protons (**+**) and electrons (**–**) move to produce a flow of current.

How is Electric Current Measured and What is its Unit?

Electric current is measured by the number of "*free electrons*" passing a particular point in a circuit per second. So we can conclude and define electric current as flow of charge per unit second.

The **SI unit** of charge (*not current*) is coulomb. 1 coulomb = quantity of electricity carried in 1 second by a current of 1 **ampere**.

The SI (*International System of Units*) unit of current is the ampere (**A**). A constant current has symbol "**I**". Time-varying current has a symbol "**i**".

What is Formula to Calculate Electric Current?

A current of one **ampere** = 1 coulomb of charge passing a given point per second. In general, charge **Q** is determined by steady current **I** flowing for a time **t** as **Q = It**.

$$\mathrm{I(amperes)} = \frac{\mathrm{Q(coulombs)}}{\mathrm{t(seconds)}}$$

Types of Electric Current

There are 2 types of Electric Current – AC (Alternating Current and DC (Direct Current.

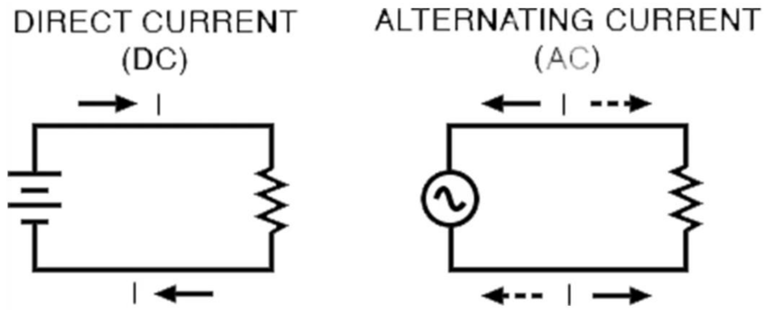
Electrical current is the flow of charged particles. It is similar to flow of water molecules in a river. AC and DC are ways of flow of current an electrical circuit.Electric charge or current can flow only in one direction (DC) or in the charge can change direction periodically (AC).

While AC Current is good for transmission over long distance, DC current is good for digital electronics.

So, Electric current is of two types:

1. Direct Current (DC)

2. Alternative Current (AC)

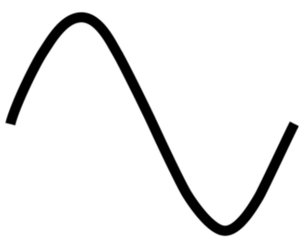


Direct Current: (DC)

In this type of electric current, direction is always same. The electric current generated from a cell or battery is DC. Due to the same direction of Direct Current, its frequency is ZERO. In DC Current one end is Positive (+) and the other end is Negative (-).

Alternative Current (AC)

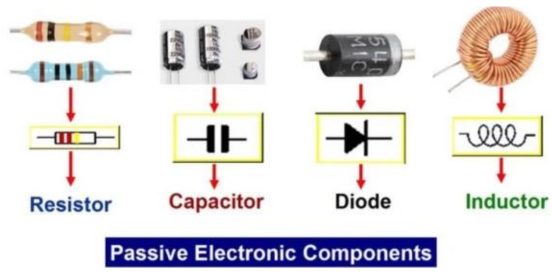
Electrical current whose direction and value keeps changing is known as Alternating Current (AC). The value of AC current in one direction increases from ZERO to Maximum and fall down to ZERO and then in opposite direction it increases from ZERO to Maximum again and come back to ZERO. Due to this increase in both directions, the graph of AC looks like a Wave. This is called sine wave. In Alternate Current or AC, 50 such cycles or waves come in ONE Second. One side of AC is PHASE and the other side is NEUTRAL.



Basic Electrical Units and Definition

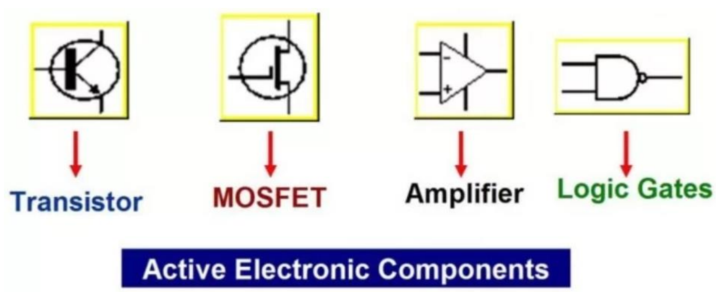
1. Passive

Capable of operating without an external power source. Typical passive components are resistors, capacitors, inductors and diodes (*although the latter are a special case*).



2. Active

Requiring a source of power to operate. Includes transistors (*all types*), integrated circuits *(all types*), TRIACs, SCRs, LEDs, etc.



3. DC

Direct Current. The electrons flow in one direction only. Current flow is from negative to positive, although it is often more convenient to think of it as from positive to negative. This is sometimes referred to as "*conventional*" current as opposed to electron flow.

4. AC

Alternating Current. The electrons flow in both directions in a cyclic manner – first one way, then the other. The rate of change of direction determines the frequency, measured in Hertz (*cycles per second*).

5. Frequency

Unit is Hertz, Symbol is Hz, old symbol was cps (*cycles per second*).

A complete cycle is completed when the AC signal has gone from zero volts to one extreme, back through zero volts to the opposite extreme, and returned to zero.

The accepted audio range is from 20 Hz to 20,000 Hz. The number of times the signal completes a complete cycle in one second is the frequency.

6. Voltage

Unit is Volts, Symbol is V or U, old symbol was E . Voltage is the "*pressure*" of electricity, or "*electromotive force*" (*hence the old term **E***).

A 9V battery has a voltage of 9V DC, and may be positive or negative depending on the terminal that is used as the reference.

The mains has a voltage of 220, 240 or 110V depending where you live – this is AC, and alternates between positive and negative values. Voltage is also commonly measured in millivolts (*mV*), and 1,000 mV is 1V. Microvolts (*uV*) and nanovolts (*nV*) are also used.

7. Current

Unit is Amperes (*Amps*), Symbol is I . Current is the flow of electricity (*electrons*). No current flows between the terminals of a battery or other voltage supply unless a load is connected.

The magnitude of the current is determined by the available voltage, and the resistance (*or impedance*) of the load and the power source.

Current can be AC or DC, positive or negative, depending upon the reference.

For electronics, current may also be measured in mA (*milliamps*) – 1,000 mA is 1A. Nanoamps (*nA*) are also used in some cases.

8. Resistance

Unit is Ohms, Symbol is R or Ω . Resistance is a measure of how easily (*or with what difficulty*) electrons will flow through the device.

Copper wire has a very low resistance, so a small voltage will allow a large current to flow.

Likewise, the plastic insulation has a very high resistance, and prevents current from flowing from one wire to those adjacent.

Resistors have a defined resistance, so the current can be calculated for any voltage. Resistance in passive devices is always positive (*i.e. > 0*)

9. Capacitance

Unit is Farads, Symbol is C. Capacitance is a measure of stored charge. Unlike a battery, a capacitor stores a charge electrostatically rather than chemically, and reacts much faster.

A capacitor passes AC, but will not pass DC (at least for all practical purposes). The reactance or AC resistance (*called impedance*) of a capacitor depends on its value and the frequency of the AC signal. Capacitance is always a positive value.

10. Inductance

Unit is Henrys, Symbol is H or L (*depending on context*). Inductance occurs in any piece of conducting material, but is wound into a coil to be useful.

An inductor stores a charge magnetically, and presents a low impedance to DC (*theoretically zero*), and a higher impedance to AC dependent on the value of inductance and the frequency.

In this respect it is the electrical opposite of a capacitor. Inductance is always a positive value. The symbol "*Hy*" is sometimes used in the US. There is no such symbol.

11. Impedance

Unit is Ohms, Symbol is Ω or Z. Unlike resistance, impedance is a frequency dependent value, and is specified for AC signals. Impedance is made up of a combination of resistance, capacitance, and/ or inductance.

In many cases, impedance and resistance are the same (*a resistor for example*). Impedance is most commonly positive (*like resistance*), but can be negative with some components or circuit arrangements.

12. Decibels

Unit is Bel, but because this is large, deci-Bels (*1/10th Bel*) are used), Symbol is dB.

Decibels are used in audio because they are a logarithmic measure of voltage, current or power, and correspond well to the response of the ear.

A 3dB change is half or double the power (*0.707 or 1.414 times voltage or current respectively*).

Basic Rules of Electrical Circuit

1. A voltage of 1V across a resistance of 1 Ohm will cause a current flow of 1 Amp, and the resistor will dissipate 1 Watt (*all as heat*).
2. The current entering any passive circuit equals the current leaving it, regardless of the component configuration.
3. The danger of electricity is current flowing through your body, not what is available from the source. A million volts at 1 microamp will make you jump, but 50V at 50mA can stop you dead.
4. An electric current flowing in a circuit does not cause vibrations at the physical level, unless the circuit is a vibrator, loudspeaker, motor or some other electro-mechanical device.
5. External vibrations do not affect the operation of 99.9% of electronic circuits, unless of a significant magnitude to cause physical damage, or the equipment is designed to detect such vibrations (*for example, a microphone*).
6. Power is measured in Watts, and PMPO does not exist except in the minds of advertising writers.
7. Large capacitors are not intrinsically "*slower*" than small ones (*of the same type*). Large values take longer to charge and discharge, but will pass AC just as well as small ones. They are better for low frequencies.
8. Electricity can still kill you!

Parallel Circuit Rules

1. Electronic Components in a parallel circuit share the same voltage.
2. Total resistance in a parallel circuit is less than any of the individual resistances.
3. Total current in a parallel circuit is equal to the sum of the individual branch currents.

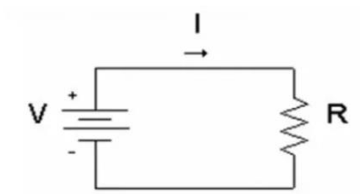
Series Circuit Rules

1. Electronic Components in a series circuit share the same current.
2. Total resistance in a series circuit is equal to the sum of the individual resistances. Thus total resistance in a series is greater than any of the individual resistances.
3. Total voltage in a series circuit is equal to the sum of the individual voltage drops.

Ohm's Law Definition, Formula, Example

Ohm's law describes the relationship between Voltage, Resistance and Current where **V**oltage (V) is trying to force charge to flow, **R**esistance (R) is resisting that flow, and the actual resulting **C**urrent (I).

Georg Simon Ohm



Basic Electrical Circuit

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

Ohm's Law

Ohm's Law Definition

1. **Ohm's Law** states that electric current is proportional to voltage and inversely proportional to resistance.
2. Mathematically, the law states that **V = IR**, where **V** is the voltage difference, **I** is the current in amperes, and **R** is the resistance in ohms.

Who Invented Ohm's Law?

Ohm's Law is Named after the Great German Physicist and Mathematician – Georg Simon Ohm. He was born on March 16, 1789 and died on July 6, 1854.

Georg Simon Ohm did a research on the Battery Invented by the Italian scientist Alessandro Volta.

He concluded his research with a Formula which states that the current flow through a conductor is directly proportional to the potential difference (*voltage*) and inversely proportional to the resistance. This relationship is known as Ohm's law.

Ohm's Law Formula

The Ohm's law formula helps to calculate voltage, current and resistance.

I = V / R; where

- **I** = Electrical Current Flowing through the Resistor
- **V** = Voltage Drop of the Resistor
- **R** = R is the resistance of the resistor, measured in Ohms (Ω)

Understanding Ohm's Law

As per the law, we can state that:

1. Large voltage and low resistances produces large current.
2. Large resistance limit current to low values.

Question: Almost every electric circuit is more complicated than just a basic circuit with a battery and a resistor. So which voltage does the formula refer to?

Answer: Well, it refers to the voltage across the resistor, the voltage between the two terminal wires.

Examples

Example-1: Find the current of an electrical circuit that has resistance of 100 Ohms and voltage supply of 10 Volts.

Solution:

- V = 10 V
- R = 100 Ω
- $I = V / R$ = 10V / 100Ω = 0.1A = 100mA

Example-2: Find the voltage applied across 100 kΩ resistors when 5 mA current flows through it

Solution: V = 100 kΩ * 5 mA = 500 V

Example-3: Find the value of a Resistor which drops 100 V when 50 mA current is flowing through it.

Solution: R = 100 V / 50mA = 200 Ω

What is Battery: Types of Battery & How Battery Works

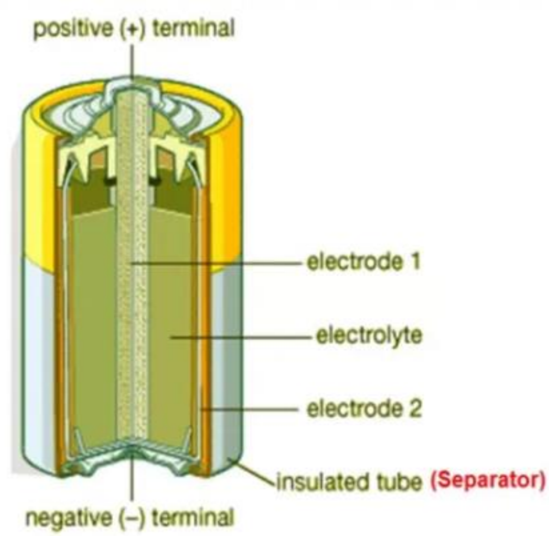
What is Battery?

A battery is a device with a collection of one or more cells that forces flow of electrons in a circuit through electrochemical reaction. It actually transforms stored chemical energy directly into electrical energy.

All types of batteries have: an anode (*Negative Terminal*), a cathode (*Positive Terminal*), and some chemical called electrolyte for chemical reaction.

What is a Battery Made of?

Most batteries consist of 3 components: Electrodes, Electrolyte and Separator.



Let us understand about these three components in Detail:

Electrode

All Batteries have two electrodes and Both play different roles.

One electrode is connected to the positive terminal and is called cathode (**+**). Electrical current leaves this end during discharge.

The other electrode is connected to the negative terminal and is called anode (**–**). Electrical current enters this end during discharge.

Electrolyte

Electrolyte is present between the two electrodes, as well as inside them. Electrolyte substances contain electrically charged particles called ions.

These ions react with the electrodes that produces electric current or electricity.

Separator

A Porous Cardboard Separator keeps the Anode and the Cathode Apart.

How Battery Works

Charge can be separated by several means to produce a voltage. A battery uses a chemical reaction to produce energy and separate opposite charges onto its two terminals.

As the charge is drawn off by an external circuit, doing work and finally returning to the opposite terminal, more chemicals react to restore the charge difference and the voltage.

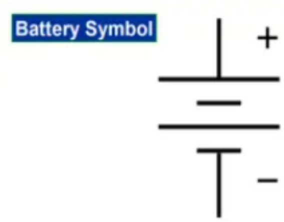
The type of chemical reaction used determines the voltage of the battery, but for most commercial batteries the voltage is about **1.5** V per chemical section or cell.

Batteries with higher voltages contain multiple cells inside connected together in series. Now you know why there are 3 V, 6 V, 9 V, and 12 V batteries, but no 4V or 7 V batteries.

The current batteries can supply depends on the speed of the chemical reaction supplying charge, which in turn often depends on the physical size of the cell and the surface area of the electrodes.

The size of batteries also limits the amount of chemical reactants stored. During use, the chemical reactants are depleted and eventually the voltage drops and the current stops.

Battery Symbol



Types of Batteries

Batteries can be classified into two major types –

1. Non-Rechargeable (Primary Batteries); and
2. Rechargeable (Secondary Batteries)

Non-Rechargeable Battery (Primary Batteries)

Non-Rechargeable or Primary batteries cannot be recharged once depleted. Their electrochemical reaction cannot be reversed. **Alkaline batteries** are the most popular type of primary battery. They are available in different cell sizes like **AA** or **AAA**.

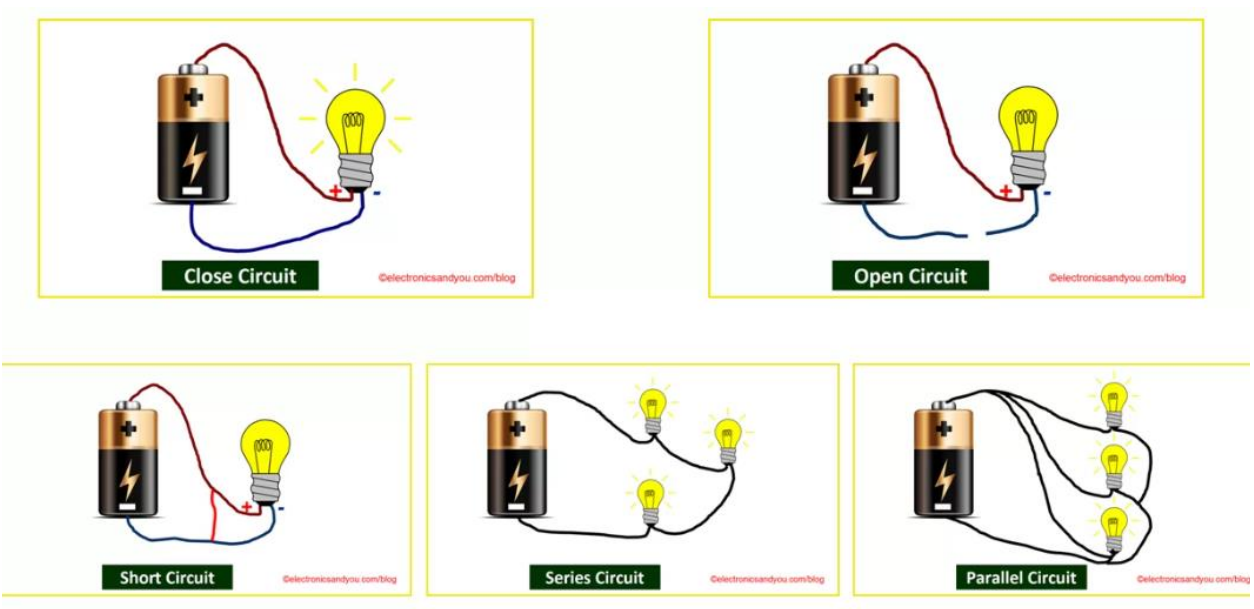
Rechargeable Battery (Secondary Batteries)

In these types of batteries the chemical reaction is reversible: applying an external voltage and forcing a current through the battery, which requires work, reverses the chemical reaction and restores most, but not all, the chemical reactants. This cycle can be repeated many times.

Examples: Lithium-ion(*Li-ion*) Battery of Mobile Phone, Nickel Cadmium(*Ni-Cd*), Nickel-Metal Hydride (*Ni-MH*), Lead-Acid Batteries.

Electric Circuit -Types of Electric Circuit

An **Electric Circuit** is the conductive path for flow of current or electricity is called electric circuit or electrical circuit. A conductive wire is used to establish relation among source of voltage and load. An ON / OFF switch and a fuse is also used in between the source and load.

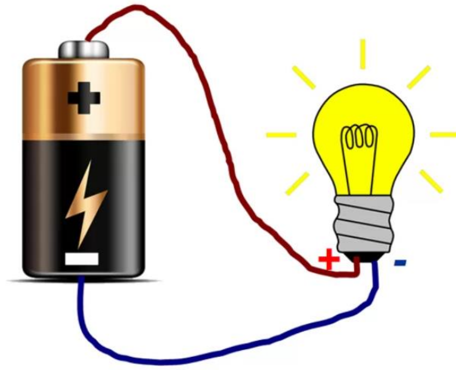


Types of Electric Circuit

There are following 5 main types of electric circuit:

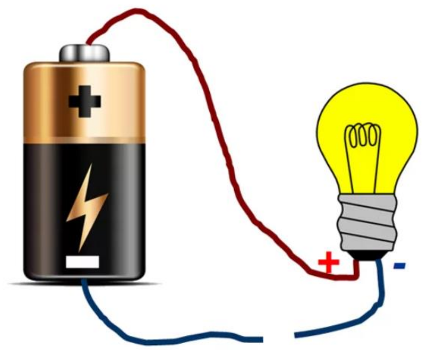
1. Close Circuit

When load works on its own in a circuit then it is called Close Circuit or Closed Circuit. Under this situation, the value of current flow depends on load.



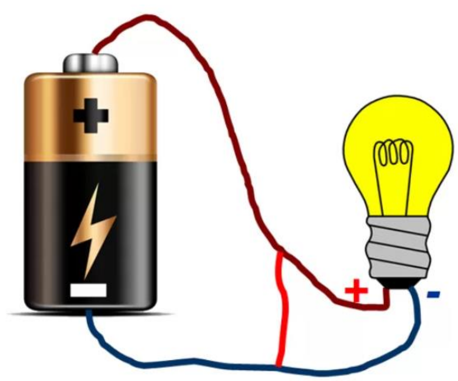
2. Open Circuit

When there is a faulty electrical wire or electronic component in a circuit or the switch is OFF, then it is called Open Circuit. In the below diagram you can see that the Bulb is Not glowing because either the switch is OFF or there is fault is the electrical wire.



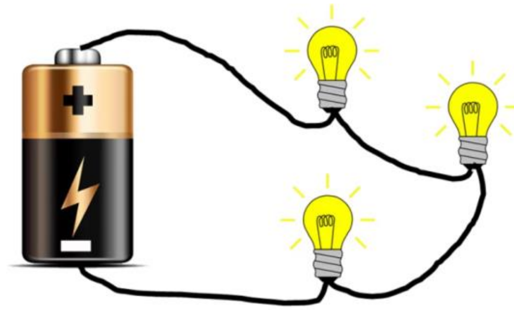
3. Short Circuit

When both points (**+** & **–**) of voltage source in a circuit gets joint with each other for some reason then it is called Short Circuit. Maximum current starts to flow under this situation. Short circuit generally happens when the conducting electrical wires get joint of even because of shorting in the load.



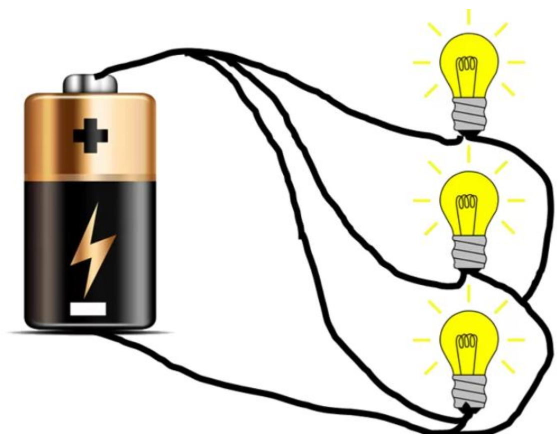
4. Series Circuit

When 2 or more loads (*Bulb, CFL, LED, Fan etc*) are connected to each other in a series, then it is called a Series Circuit. In a series circuit, if one load or bulb gets fuse, then rest of the bulbs will not get power supply and will not glow. *Look at the example below*.



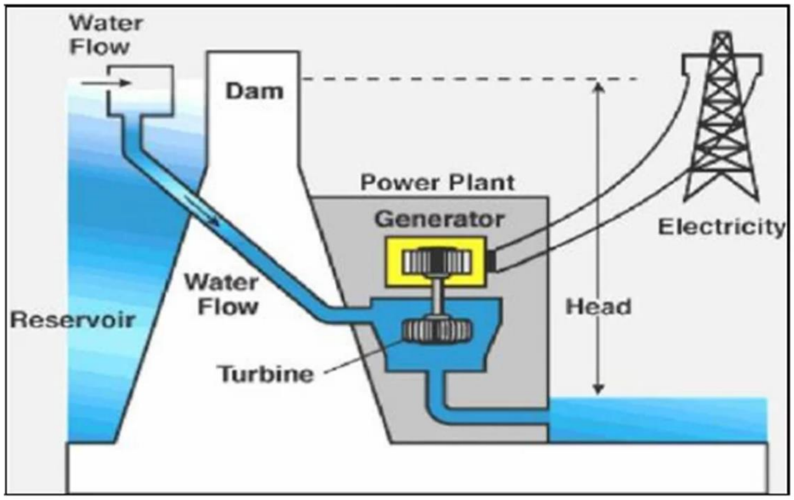
5. Parallel Circuit

When 2 or more loads (*Bulb, CFL, LED, Fan etc*) are connected to each other in parallel, then it is called Parallel Circuit. In this type of circuit, the voltage capacity of all loads must be equal to input supply. Power of "load" can be different. In a parallel circuit, if one load or bulb gets fuse, then rest of the bulbs will still get power supply and will glow. *Look at the example below*.



How is Electricity Generated, Transmitted and Distributed?

Electricity generation, transmission and distribution is a complex engineering process. The process requires huge investment and skilled manpower. The basics of **generating electricity** remains the same in all forms of electricity such as hydroelectricity, electricity generated using coal, nuclear electricity, renewable energy sources *etc*. Let us understand in detail.



How is Electricity Generated?

Electricity is generated or produced by turning or rotation of turbines. These turbines can be rotated by any means – coal, steam, nuclear energy, renewable energy such as solar energy *etc*. In most power plants, turbines are rotated by the pressure of steam. This steam is created by boiling water using burning coal in large boilers. The pressure of steam is such that is turns the turbines, which in turn generates electricity.

Hydroelectricity uses the force of running water downstream a man-made water reservoir dam. The great force of the running water turns the turbines. The motive is to turn the turbines by any means.

How is Electricity Transmitted?

After electricity is generated in power plant, it is time for transmission. This is done by using step-up transformers that increases the voltage. This high voltage electricity is transmitted through a network of electrically conductive wires of aluminum or copper. These lines are called high-voltage transmission lines that can transmit electricity over long distances.

How is Electricity Distributed?

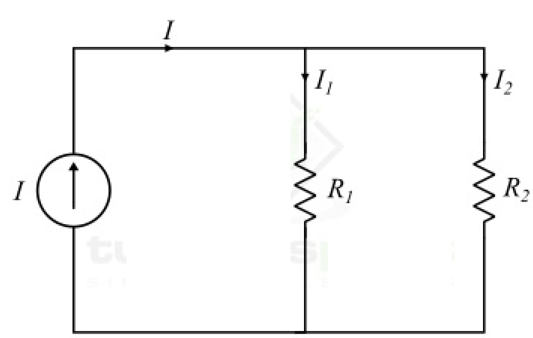
Electricity is distributed via electric distribution substation. At the substation, the high voltage electricity from the high-voltage transmission lines is passed through step-down transformers that lower the voltage. The electricity is then transmitted to network of local electric distribution lines. Before electricity enters a home, the voltage is again lowered using step-down transformers. In most countries the voltage is 220 V AC or 110 V DC. In a home, electricity is distributed to different outlets by network of wires through electrical wiring.

Current Divider Rule and Voltage Divider Rule

Electric circuits are classified into two main types namely **series circuit** and **parallel circuit** based on the arrangement of components in the circuit. A series circuit is one in which the components are chain connected, while a parallel circuit is one in which all the circuit components are connected between two common points. Series circuits and parallel circuits act as voltage divider circuits and current divider circuits, respectively.

Current Division Rule

A parallel circuit acts as a **current divider** as it divides the total circuit current in its all branches. Figure1 shows a current divider circuit in which the total circuit current I has been divided into currents I_1 and I_2 in two parallel branches with resistances R_1 and R_2. Although, we can notice that the voltage drop across both resistances is same, i.e., V.



According to Ohm's law,

$$\mathrm{I_1 = \frac{V}{R_1} \text{ and } I_2 = \frac{V}{R_2}}$$

Let R is the equivalent resistance of the circuit, and it is given by,

$$\mathrm{R = \frac{R_1R_2}{R_1 + R_2} \quad \cdots (1)}$$

Also, from the circuit, we get,

$$\mathrm{I = \frac{V}{R} = V \times \left(\frac{R_1 + R_2}{R_1R_2}\right) \quad \cdots (2)}$$

But, we know that the voltage across both resistances is same.

$$\mathrm{\therefore V = I_1R_1 = I_2R_2 \quad \cdots (3)}$$

Hence, from equations (2) & (3), we finally get,

$$\mathrm{I = I_1R_1 \left(\frac{R_1 + R_2}{R_1R_2}\right) = I_1 \left(\frac{R_1 + R_2}{R_2}\right)}$$

$$\mathrm{\therefore I_1 = \frac{IR_2}{R_1 + R_2} \quad \cdots (4)}$$

Similarly,

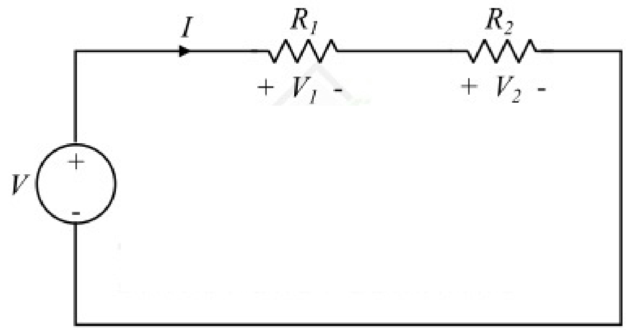
$$\mathrm{I = I_2R_2 \left(\frac{R_1 + R_2}{R_1R_2}\right) = I_2 \left(\frac{R_1 + R_2}{R_1}\right)}$$

$$\mathrm{\therefore I_2 = \frac{IR_1}{R_1 + R_2} \cdots (5)}$$

Equations (4) and (5) give the expressions of current division rule. From these equations, we may state that the current in any of the parallel branches is equal to the ratio of opposite branch resistance to the sum of all resistances, multiplied by the total circuit current.

Voltage Division Rule

A series circuit acts as a **voltage divider** as it divides the total supply voltage into different voltages across the circuit elements. Figure2 shows a voltage divider circuit in which the total supply voltage V has been divided into voltages V_1 and V_2 across two resistances R_1 and R_2. Although, the current through both resistances is same, i.e., I.



According to Ohm's law,

$$V_1 = IR_1 \text{ and } V_2 = IR_2$$

Let R is the total resistance of the circuit, and it is given by,

$$R = R_1 + R_2 \quad \cdots (1)$$

Also, from the circuit, we have,

$$V = IR = I\,(R_1 + R_2) \quad \cdots (2)$$

But

$$I = \frac{V_1}{R_1} = \frac{V_2}{R_2} \quad \cdots (3)$$

Therefore, from equations (2) & (3), we finally get,

$$V = \frac{V_1}{R_1}(R_1 + R_2)$$

$$\therefore V_1 = \frac{VR_1}{R_1 + R_2} \quad \cdots (4)$$

Similarly,

$$V = \frac{V_2}{R_2}(R_1 + R_2)$$

$$\therefore V_2 = \frac{VR_2}{R_1 + R_2} \quad \cdots (5)$$

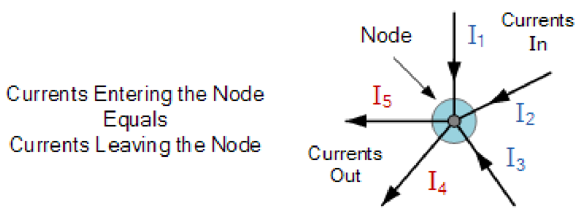
Hence, from equations of voltage division rule, it may be said that the voltage across a resistor in a series circuit is equal to the product of the value of that resistor and the total supply voltage, divided by the total resistance of the series resistors.

Kirchhoff's Law

Kirchhoffs First Law – The Current Law, (KCL)

Kirchhoffs Current Law or KCL, states that the "*total current or charge entering a junction or node is exactly equal to the charge leaving the node as it has no other place to go except to leave, as no charge is lost within the node*". In other words the algebraic sum of ALL the currents entering and leaving a node must be equal to zero, $I_{(exiting)} + I_{(entering)} = 0$. This idea by Kirchhoff is commonly known as the **Conservation of Charge**.

Kirchhoffs Current Law



$$I_1 + I_2 + I_3 + (-I_4 + -I_5) = 0$$

Here, the three currents entering the node, I_1, I_2, I_3 are all positive in value and the two currents leaving the node, I_4 and I_5 are negative in value. Then this means we can also rewrite the equation as;

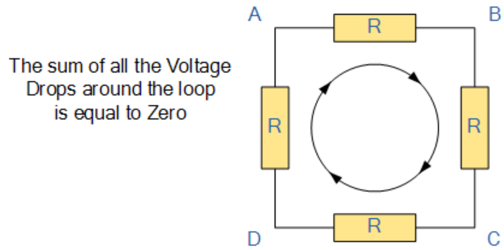
$I_1 + I_2 + I_3 – I_4 – I_5 = 0$

The term **Node** in an electrical circuit generally refers to a connection or junction of two or more current carrying paths or elements such as cables and components. Also for current to flow either in or out of a node a closed circuit path must exist. We can use Kirchhoff's current law when analysing parallel circuits.

Kirchhoffs Second Law – The Voltage Law, (KVL)

Kirchhoffs Voltage Law or KVL, states that "*in any closed loop network being driven by a voltage source, the total voltage around the loop is equal to the sum of all the voltage drops within the same loop*" which is equal to zero. In other words the algebraic sum of all voltage sources and voltage drops within a closed loop must be equal to zero since the algebraic sum of the voltage drops equals the algebraic sum of the voltage sources. This idea by Kirchhoff is known as the **Conservation of Energy**.

Kirchhoffs Voltage Law



$$V_{AB} + V_{BC} + V_{CD} + V_{DA} = 0$$

Starting at any point in the loop continue in the **same direction** noting the direction of all the voltage drops, either positive or negative, and returning back to the same starting point. It is important to maintain the same direction either clockwise or anti-clockwise or the final voltage sum will not be equal to zero. We can use Kirchhoff's voltage law when analysing series circuits.

When analysing either DC circuits or AC circuits using **Kirchhoffs Circuit Laws** a number of definitions and terminologies are used to describe the parts of the circuit being analysed such as: node, paths, branches, loops and meshes. These terms are used frequently in circuit analysis so it is important to understand them.

Common DC Circuit Theory Terms:

- Circuit – a circuit is a closed loop conducting path in which an electrical current flows.
- Path – a single line of connecting elements or sources.
- Node – a node is a junction, connection or terminal within a circuit were two or more circuit elements are connected or joined together giving a connection point between two or more branches. A node is indicated by a dot.
- Branch – a branch is a single or group of components such as resistors or a source which are connected between two nodes.
- Loop – a loop is a simple closed path in a circuit in which no circuit element or node is encountered more than once.
- Mesh – a mesh is a single closed loop series path that does not contain any other paths. There are no loops inside a mesh.