Circuit Elements

Electric Charge and Current

- The most basic quantity in an electric circuit is the electric charge.
- We all experience the effect of electric charge when we try to remove our wool sweater and have it stick to our body or walk across a carpet and receive a shock.

Charge is an electrical property of the atomic particles of which matter consists, measured in **coulombs** (C).

Circuit Elements

- The following points should be noted about electric charge:

1) The coulomb is a large unit for charges. In 1 C of charge, there are 6.24×10^{18} electrons. Thus realistic or laboratory values of charges are on the order of pC, nC, or μC.

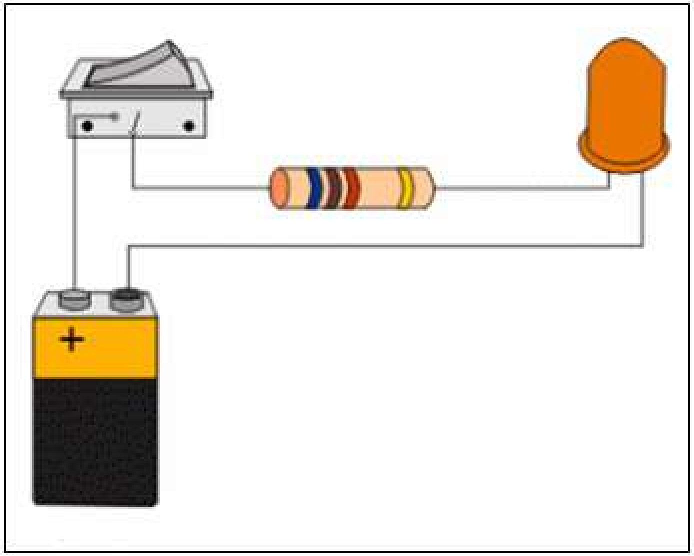
2) According to experimental observations, the only charges that occur in nature are integral multiples of the electronic charge $e = -1.602 \times 10^{-19}$ C.

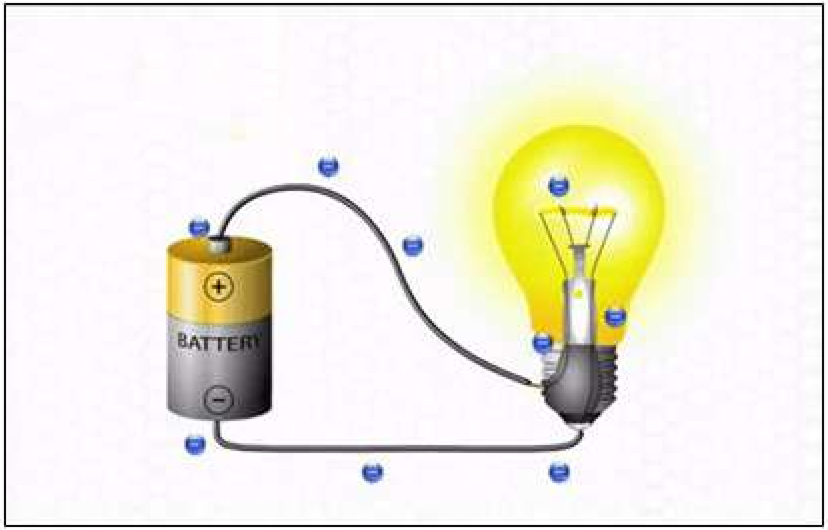
3) The *law of conservation of charge* states that charge can neither be created nor destroyed, only transferred. Thus the algebraic sum of the electric charges in a system does not change.

Circuit Elements

What is an electric circuit?

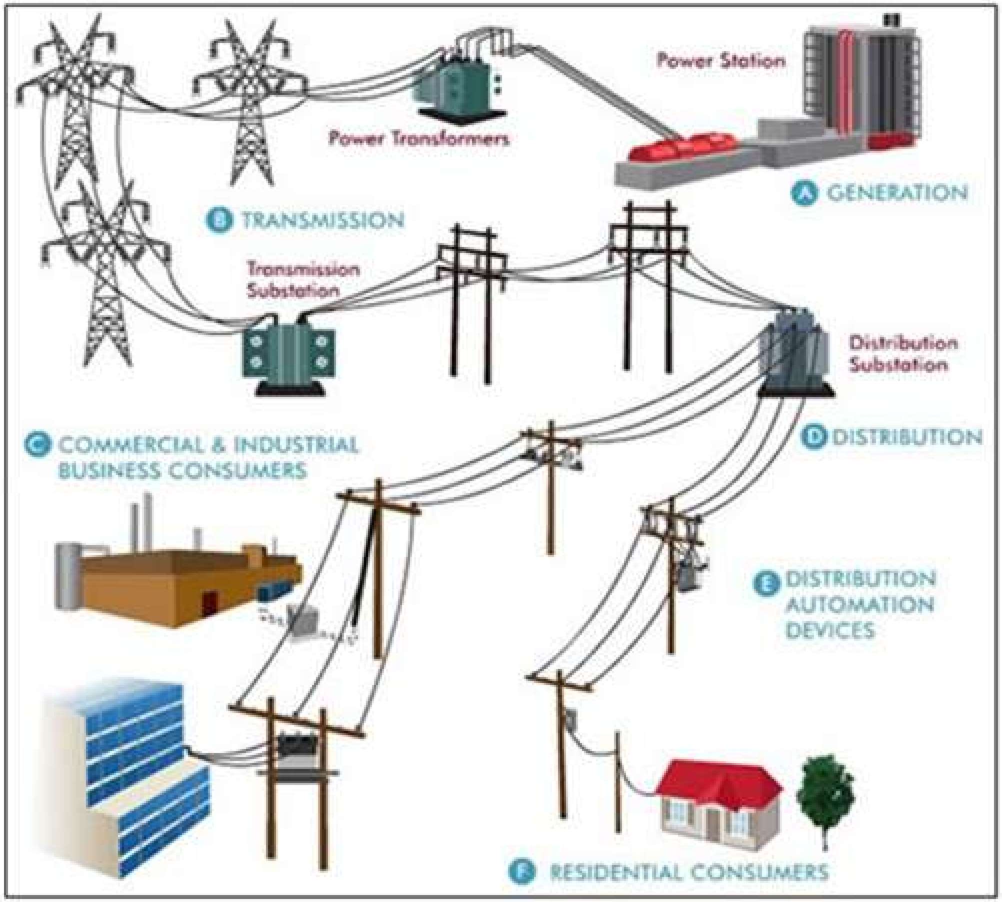
- It is a closed path for transmitting an electric current through the medium of electrical and magnetic fields.
- The flow of electrons across the loop constitutes the electric current.
- Electrons enter the circuit through the 'Source' which can be a battery or a generator.





Circuit Elements

Electrical Network: A combination of various electric elements (Resistor, Inductor, Capacitor, Voltage source, Current source) connected in any manner.



Circuit Elements

Circuit Elements

Active Elements

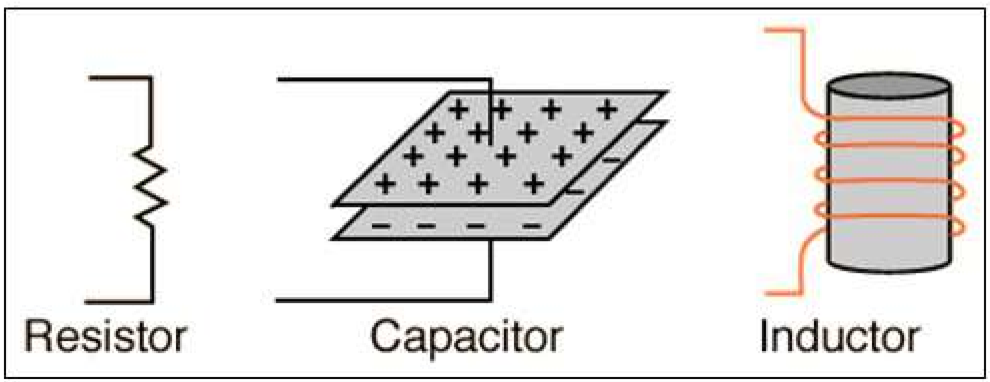
Passive Elements

- Active Elements are those which can generate energy.
- Batteries, generators, operational amplifiers and diodes.
- The source elements are the most significant active elements.

- Passive Elements can be defined as elements which can control the flow of electrons through them.
- Resistor, inductor, capacitor.
- They either increase or decrease the voltage.

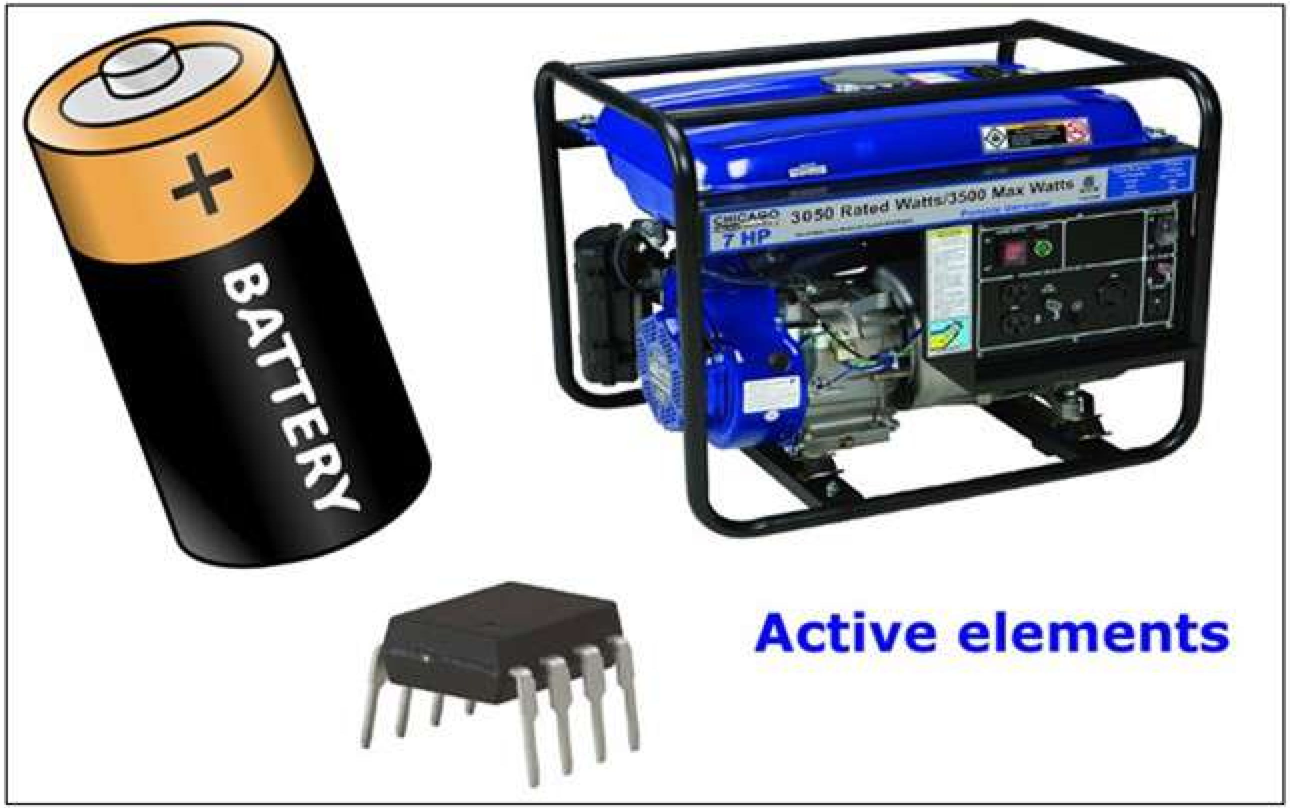
Circuit Elements

- Passive Element: The element which receives energy (or absorbs energy) and then either converts it into heat (R) or stored it in an electric (C) or magnetic (L) field is called passive element.



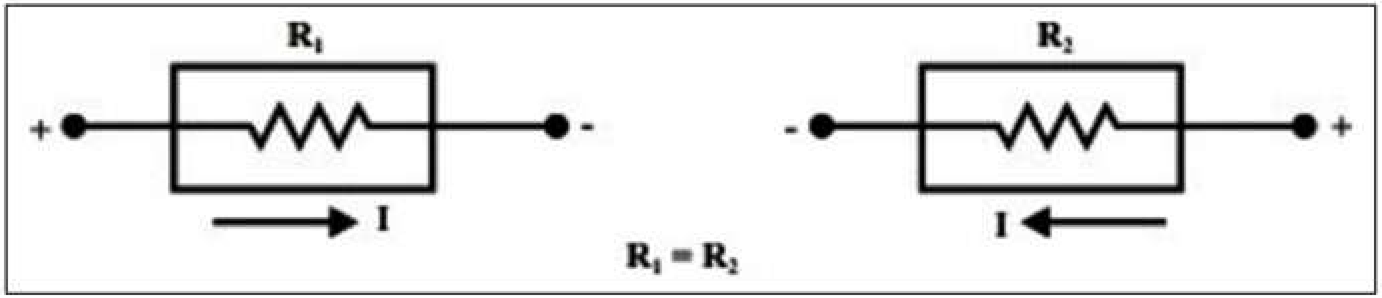
Circuit Elements

➤ **Active Element:** The elements that supply energy to the circuit is called active element. Examples of active elements include voltage and current sources, generators and electronic devices that require power supplies.

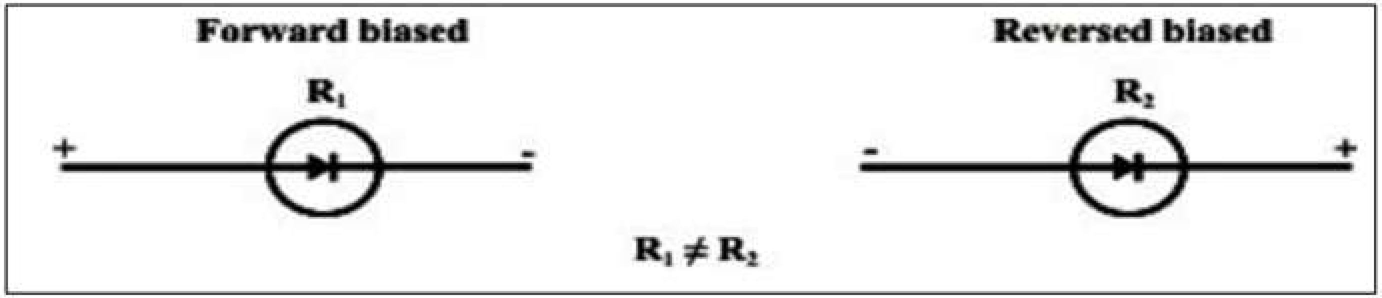


Circuit Elements

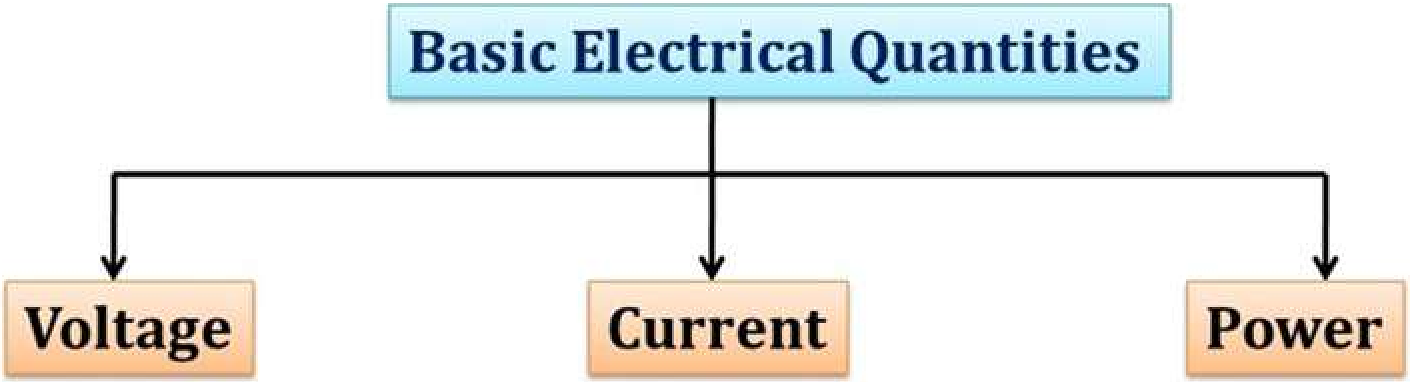
➢ Bilateral Element: Conduction of current in both directions in an element (example: Resistance; Inductance; Capacitance) with same magnitude is termed as bilateral element.

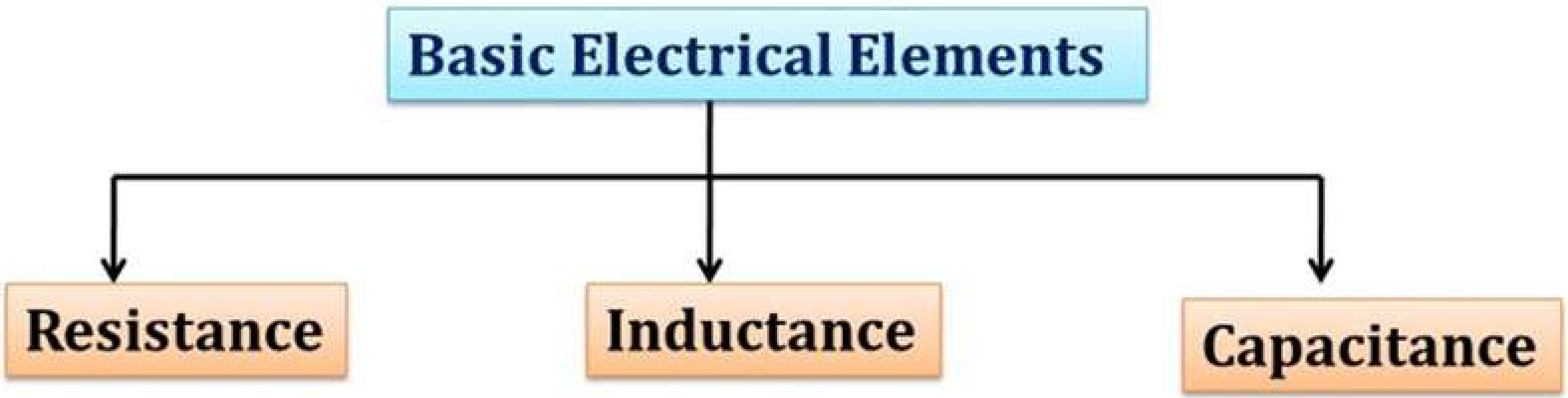


➢ Unilateral Element: Conduction of current in one direction is termed as unilateral (example: Diode, Transistor) element.



Circuit Elements





Circuit Elements: Voltage

- Voltage is the difference in electric potential between two points.

- Voltage is also called an electromotive force (e.m.f).
- When 1 J of work is required to move 1 C of charge from A to B, there is a voltage of 1 volt between A and B.

- Voltage (V or v) across an element requires both a magnitude and a polarity.

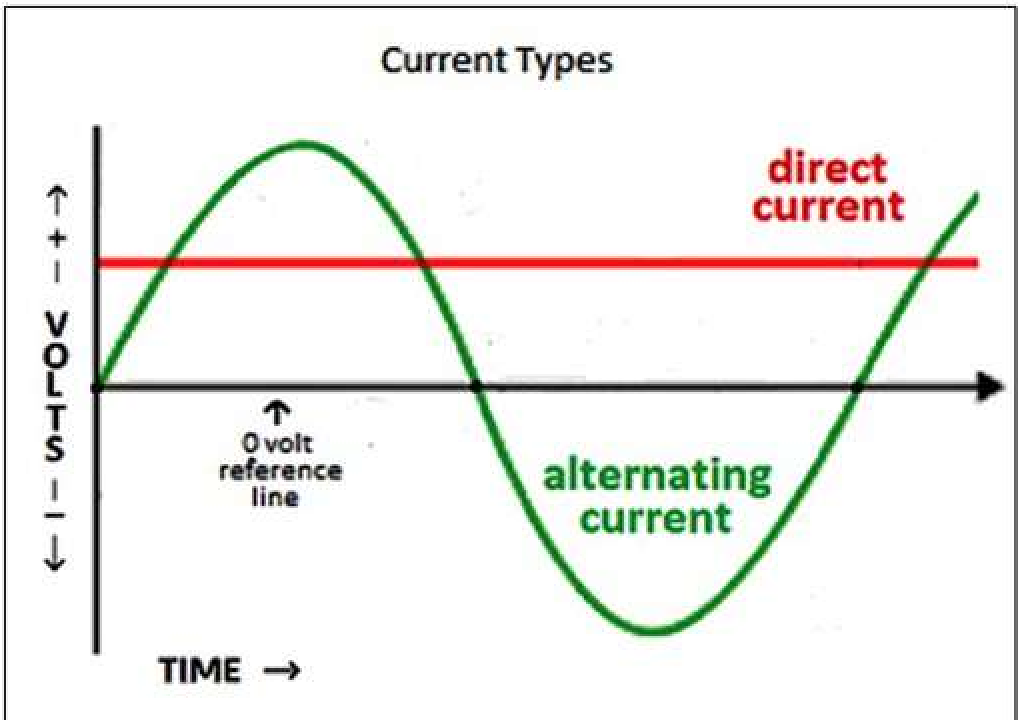
- It is measured in volts.

Alessandro Volta

1745 to 1827

Circuit Elements: Current

- The unit of current is the ampere (A).
- We note that, 1 ampere = 1 coulomb/second
- We normally refer to current as being either direct (DC) or alternating (AC).



1775-1836
Andre-Marie Ampere

Circuit Elements: Power

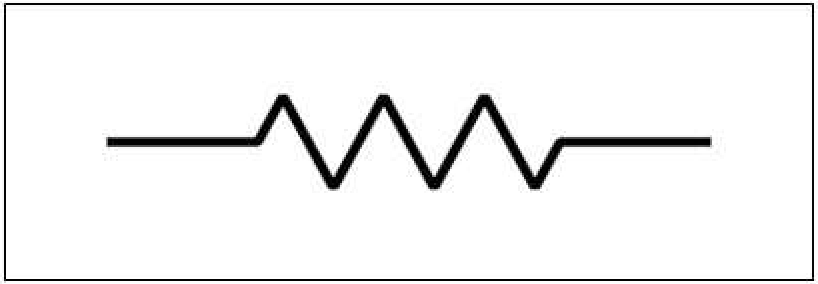
- Electric power is the rate at which electrical energy is transferred by an electric circuit.
- The SI unit of power is the watt, one joule per second.
- Electric power is usually produced by generators, but can also be supplied by sources such as batteries.
- Electric power is usually sold by the kilowatt-hour (3.6 MJ-1 unit).
- Electric utilities measure power using an electricity meter, which keeps a running total of the electric energy delivered to a customer.

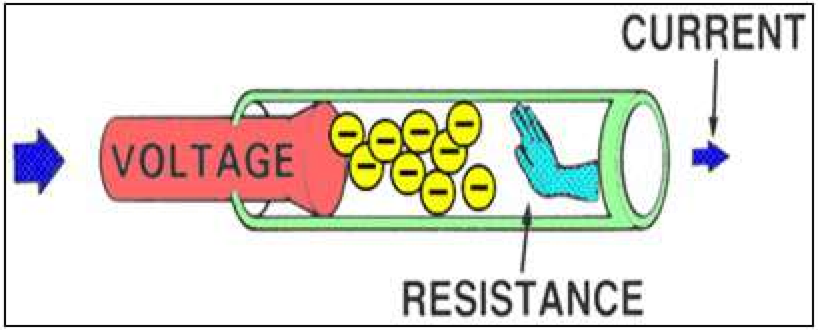
James Watt

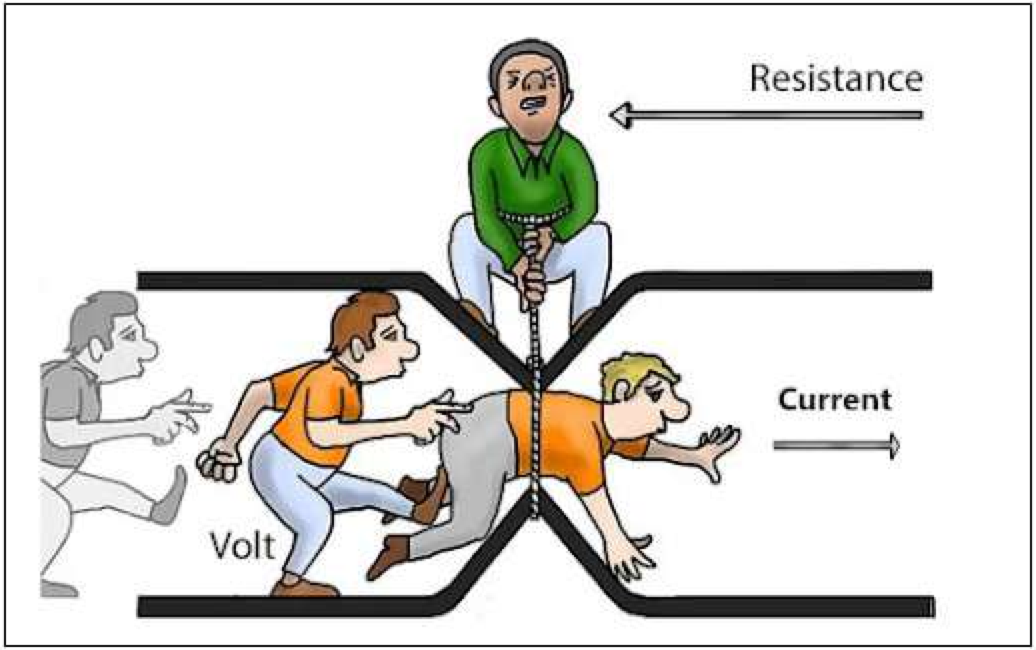
Circuit Elements: Resistor

Resistance (R)

➢ Resistance is a "property" of material which opposes the flow of electricity through it when potential is applied.

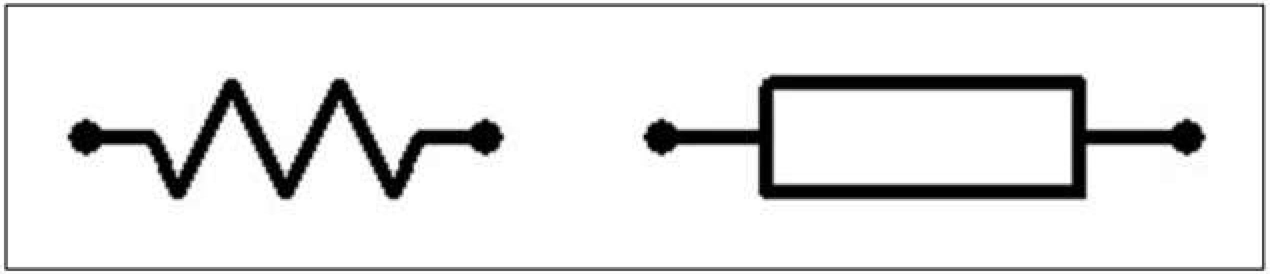


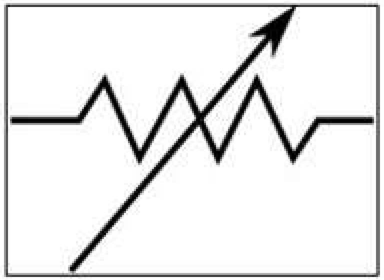




Circuit Elements: Resistor

- It opposes the flow of electrons (current).





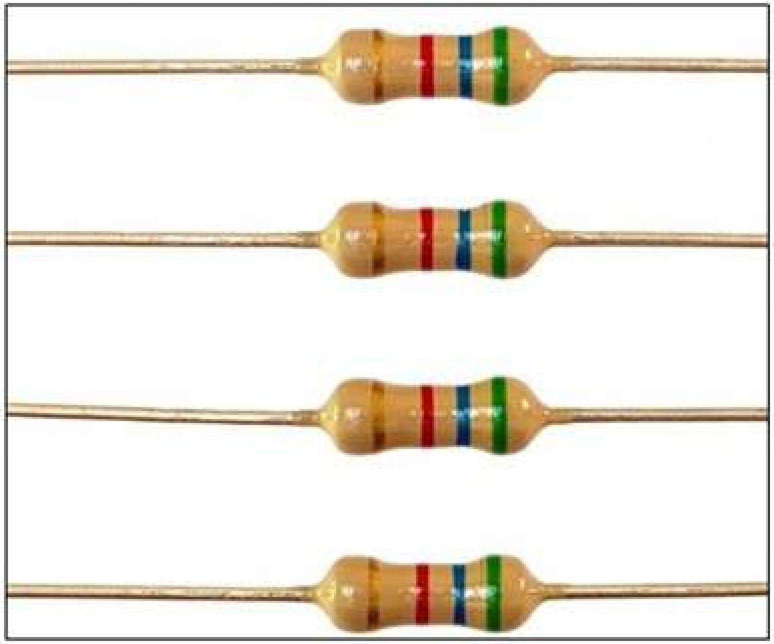
- Resistance is measured in units called "Ohm", symbol is Ω.

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

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

1789-1854
George-Simon Ohm

Circuit Elements: Resistor

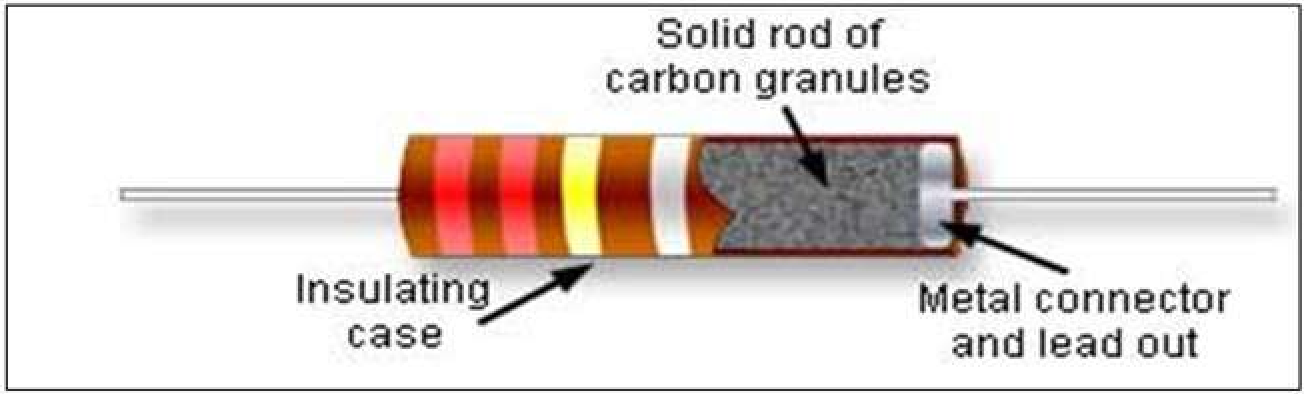


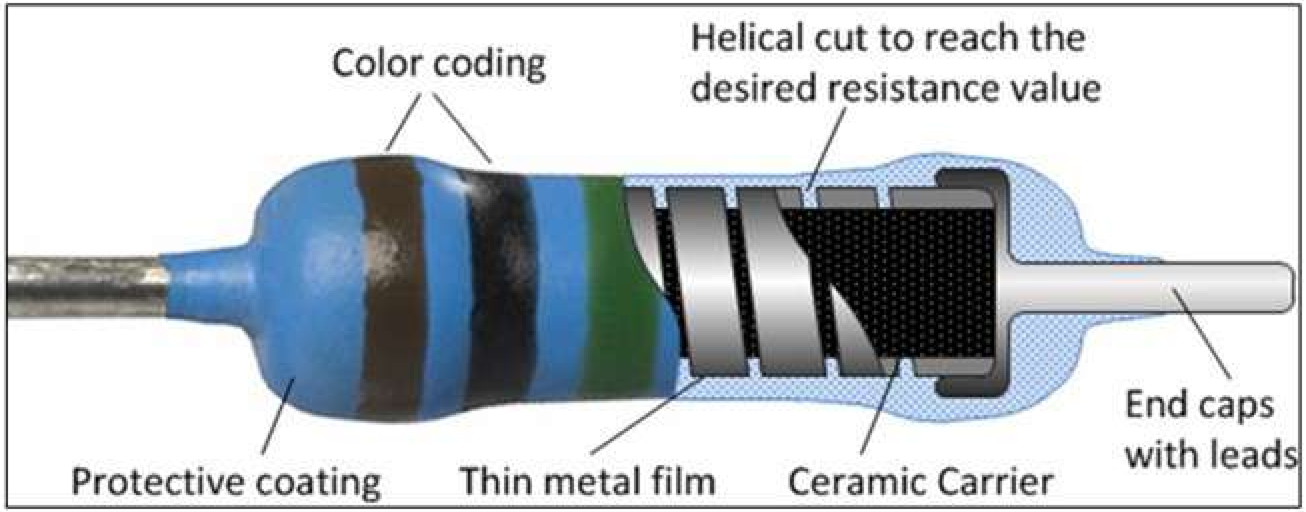
Fixed Resistor

Variable Resistor

Circuit Elements: Resistor

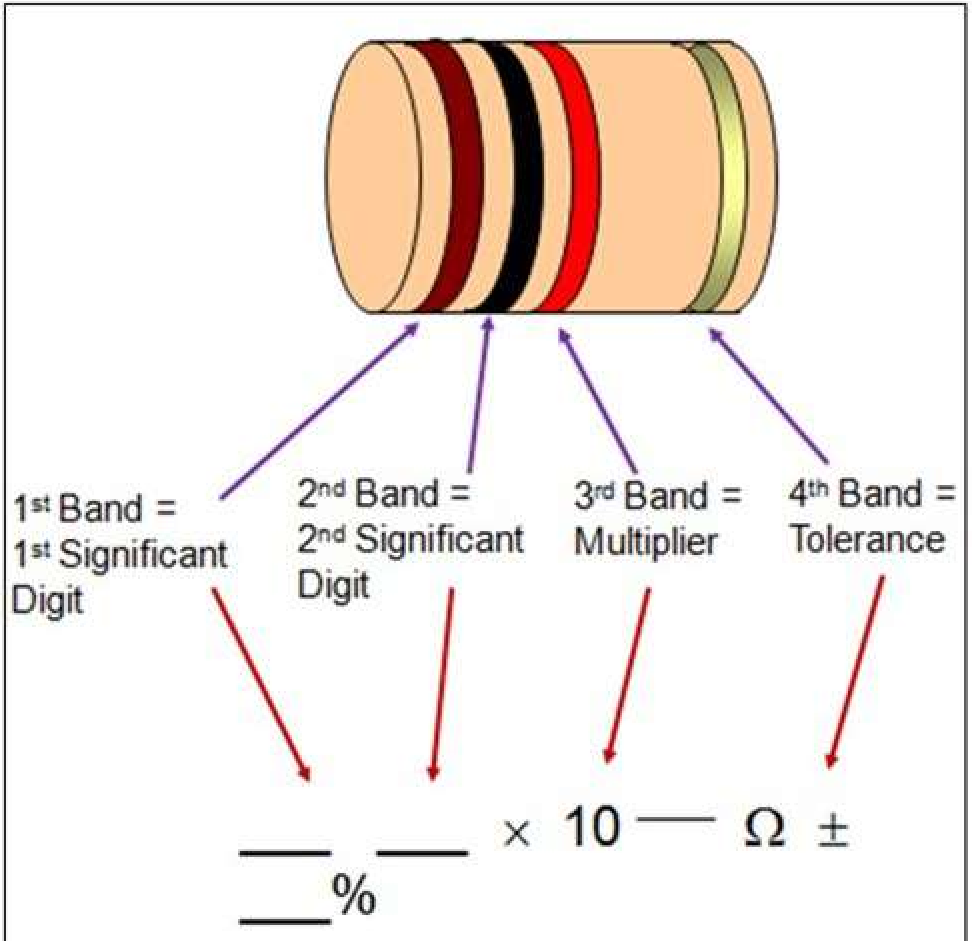
Common Fixed Resistors





Circuit Elements: Resistor

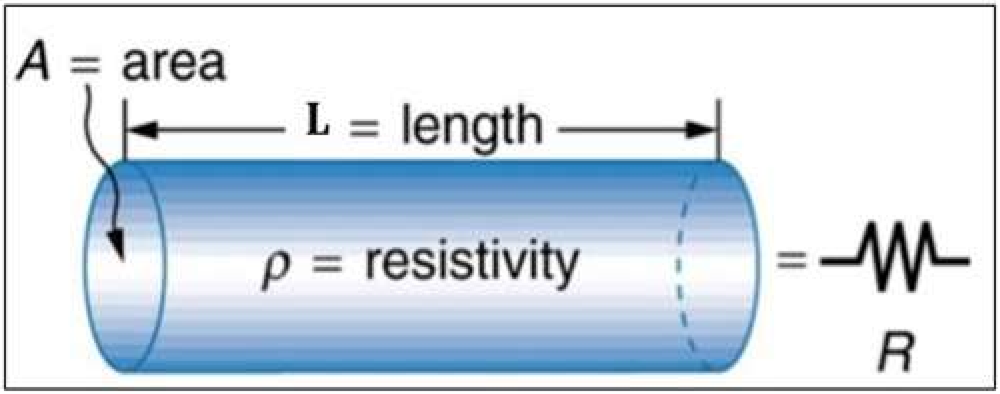
Color-code Bands on a Resistor



Number	Color
0	Black
1	Brown
2	Red
3	Orange
4	Yellow
5	Green
6	Blue
7	Violet
8	Gray
9	White
±5% (0.1 multiplier if 3rd band)	Gold
±10% (0.01 multiplier if 3rd band)	Silver

Circuit Elements: Resistor

- One way to calculate resistance is



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

ρ : Resistivity or specific resistance of the material

L: Length of the conductor

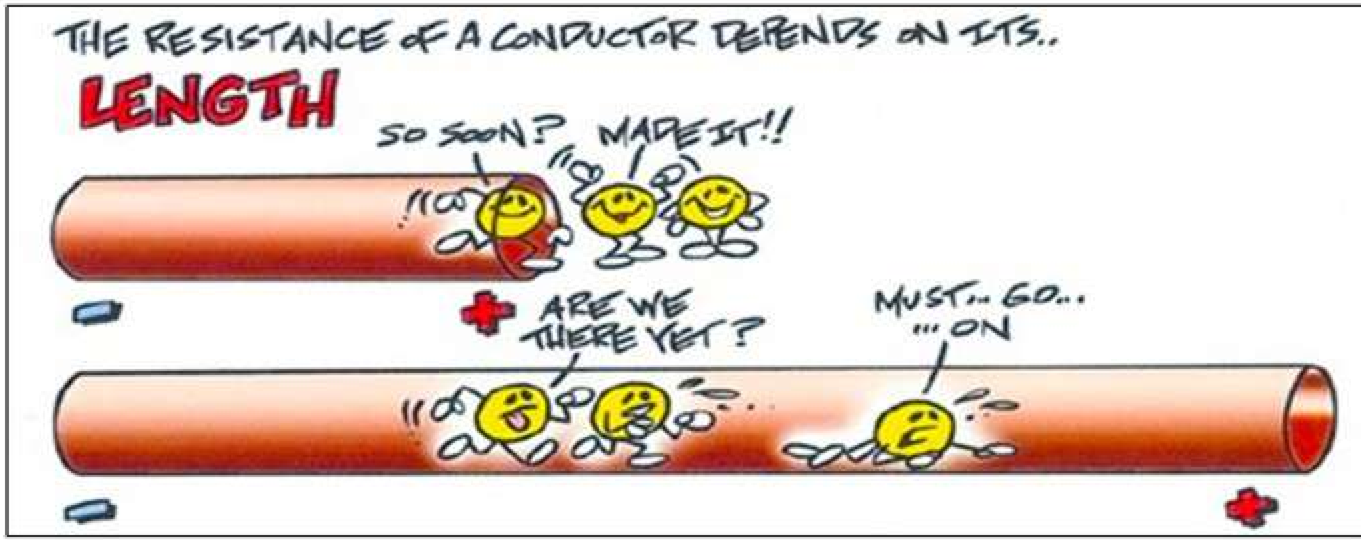
A: Area of the conductor

- Another form to calculate the resistance is applying Ohm's law.

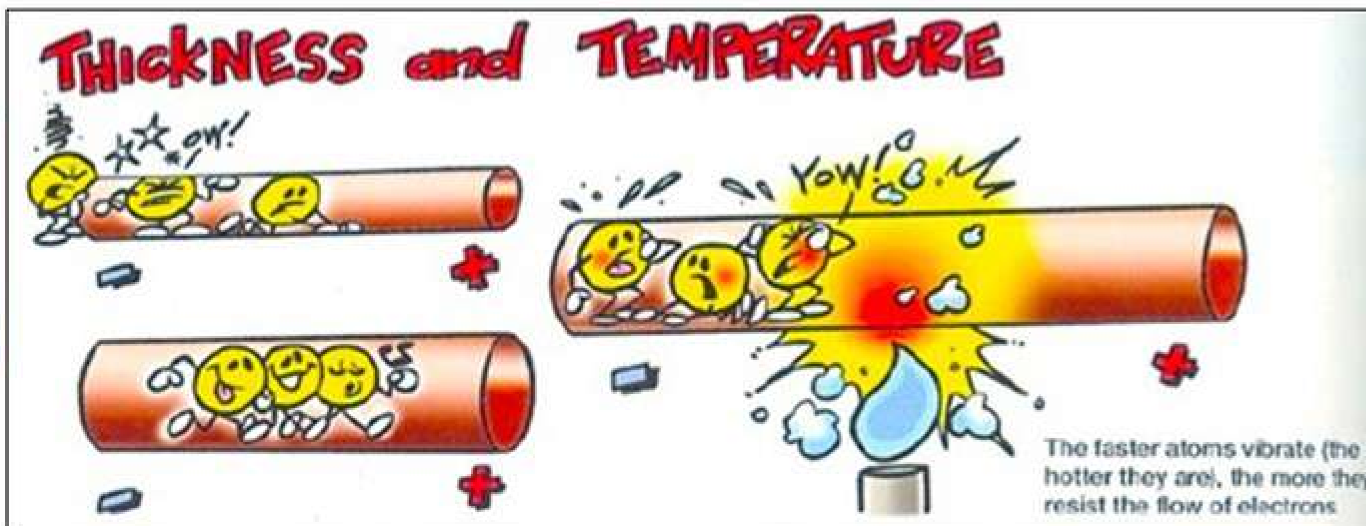
Circuit Elements: Resistor

➢ Factors that affect the resistance:

Length



Thickness
&
Temperature



Circuit Elements: Resistor

Ohm's Law

- **Georg Simon Ohm** (1787–1854), a German physicist, is credited with finding the relationship between current and voltage for a resistor.
- This relationship is known as **Ohm's law**.

Ohm's law states that the current flowing between two points of the circuit is directly proportional to the potential difference between the points.

$$\boxed{i \;\alpha\; v}$$

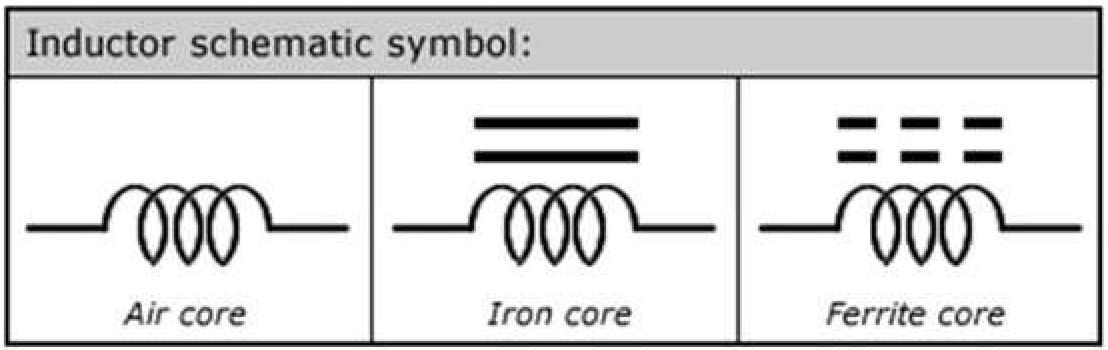
$$\boxed{i = \frac{1}{R}\, v} \Rightarrow \boxed{v = iR}$$

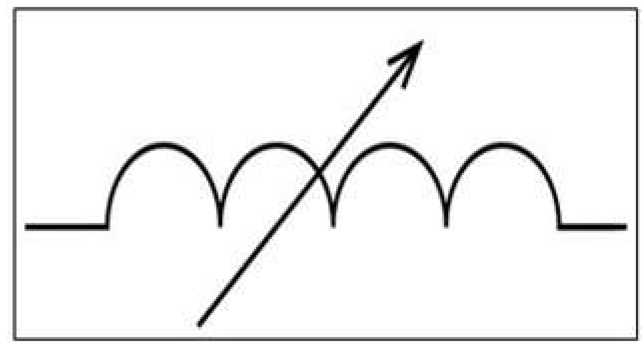
Ohm defined the constant of proportionality for a resistor to be the resistance, R.

Circuit Elements: Inductor

Inductance (L)

- An inductor is a passive electric component that stores energy in the form of a magnetic field.
- In its simplest form, an inductor consists of a wire loop or coil.





- The inductance is directly proportional to the number of turns in the coil.

- Inductance also depends on the radius of the coil and on the type of material around which the coil is wound.

Circuit Elements: Inductor

Circuit Elements: Inductor

- The standard unit of inductance is the henry, abbreviated H.

- More common units are the microhenry, abbreviated μH (1 μH $=10^{-6}$ H) and the millihenry, abbreviated mH (1 mH $=10^{-3}$ H).

- It is commonly used in
  - Choke,
  - Filter,
  - Buck/Boost Regulator,
  - Reactive Power Compensation, etc.

1797-1878
Joseph Henry

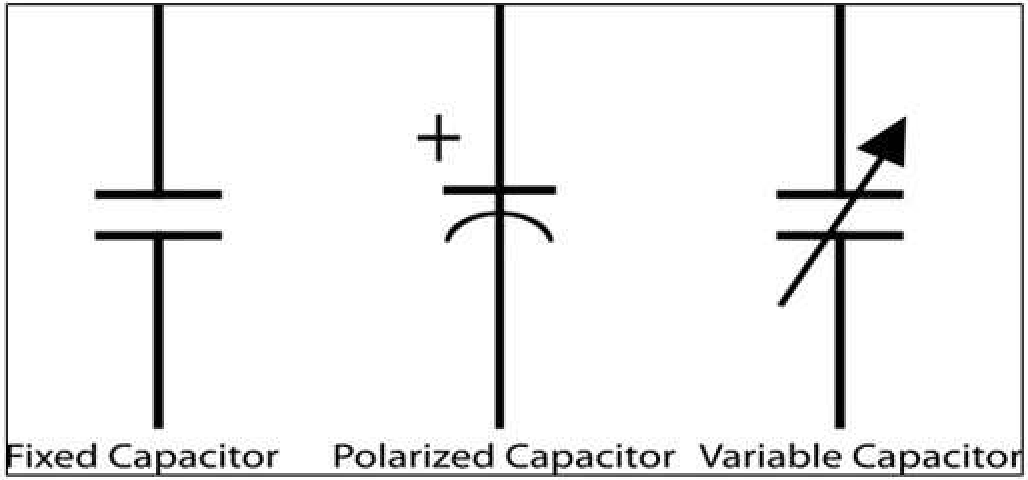
Circuit Elements: Capacitor

Capacitance (C)

- The function of the capacitor is to store electric charge or in effect electrical energy.
- It is also known as condenser.
- The forms of practical capacitors vary widely, but all contain at least two conducting plates separated by a dielectric material.

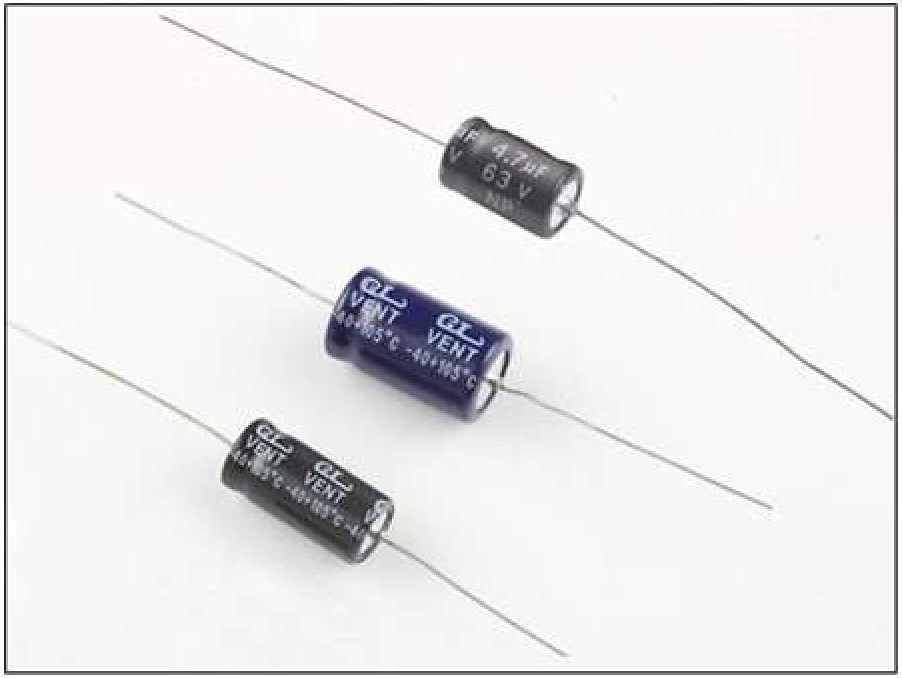
- A dielectric can be glass, ceramic, plastic film, air, vacuum, paper, mica, oxide layer etc.

$$C = \frac{Q}{V}$$



Circuit Elements: Capacitor

Ceramic Capacitor



Electrolytic Capacitor

Circuit Elements: Capacitor

- Capacitance is a measure of the capacity of storing electric charge for a given potential difference.

- The SI unit of capacitance is the farad (F).

  1 F = 1 farad = 1 coulomb/volt = 1 C/V

- A typical capacitance is in the picofarad (pF) to millifarad (mF) range.

- It is commonly used in

  - Storing energy,
  - Power factor correction,
  - Reactive power compensation,
  - Starting single phase motors, etc.

Michael Faraday
(1791-1867)

Voltage Source

- A **voltage source**, such as a **battery or generator**, provides a potential difference (voltage) between two points within an electrical circuit allowing current to flowing around it.

The voltage can exist without current.

- The types of voltage source:

1) Independent Voltage Source:
   i. Direct Voltage Source
   ii. Alternating Voltage Source

2) Dependent Voltage Source:
   i. Voltage Controlled Voltage Source
   ii. Current Controlled Voltage Source.

Voltage Source

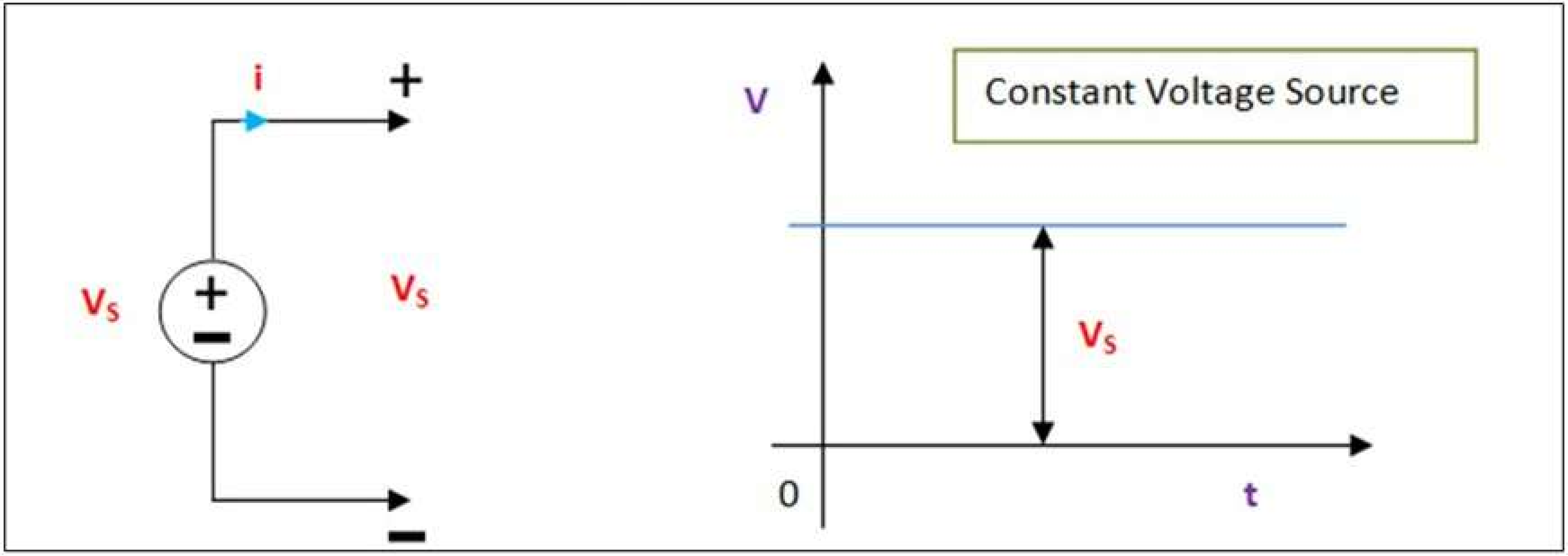
Independent Voltage Source

- The voltage source which can deliver steady voltage (fixed or variable with time) to the circuit and it does not depend on any other elements or quantity in the circuit.

Direct or Time Invariant Voltage Source

- The voltage source which can produce or deliver constant voltage as output is termed as direct voltage source.
- The flow of electrons will be in one direction that is polarity will be always same.
- The movement of electrons or current will be in one direction always. The value of voltage will not alter with time.
- Example: **DC Generator, Battery Cells**, etc.

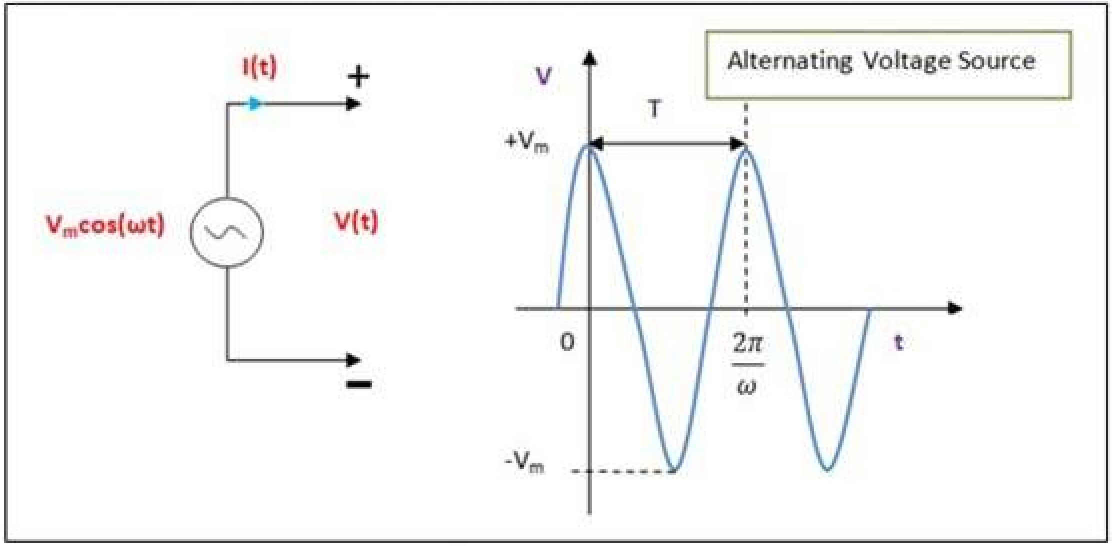
Voltage Source



Voltage Source

Alternating Voltage Source

- The voltage source which can produce or deliver alternating voltage as output is termed as alternating voltage source.
- Here, the polarity gets reversed at regular intervals.
- This voltage causes the current to flow in a direction for a time and after that in a different direction for another time.
- That means it is time varying.
- Example: **DC to AC converter, Alternator**, etc.



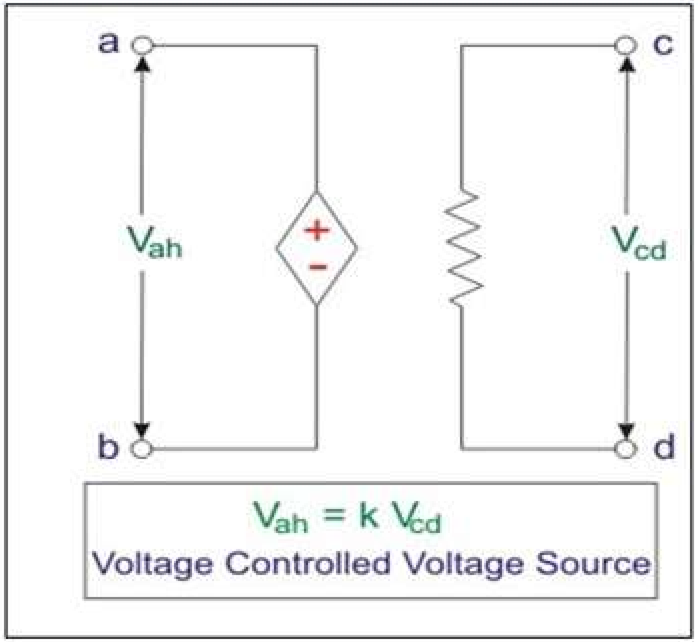
Voltage Source

Dependent Voltage Source

- The voltage source delivers an output voltage which is not steady or fixed and it always depends on other quantities such as voltage or current in any other part of the circuit.

Voltage Controlled Voltage Source (VCVS)

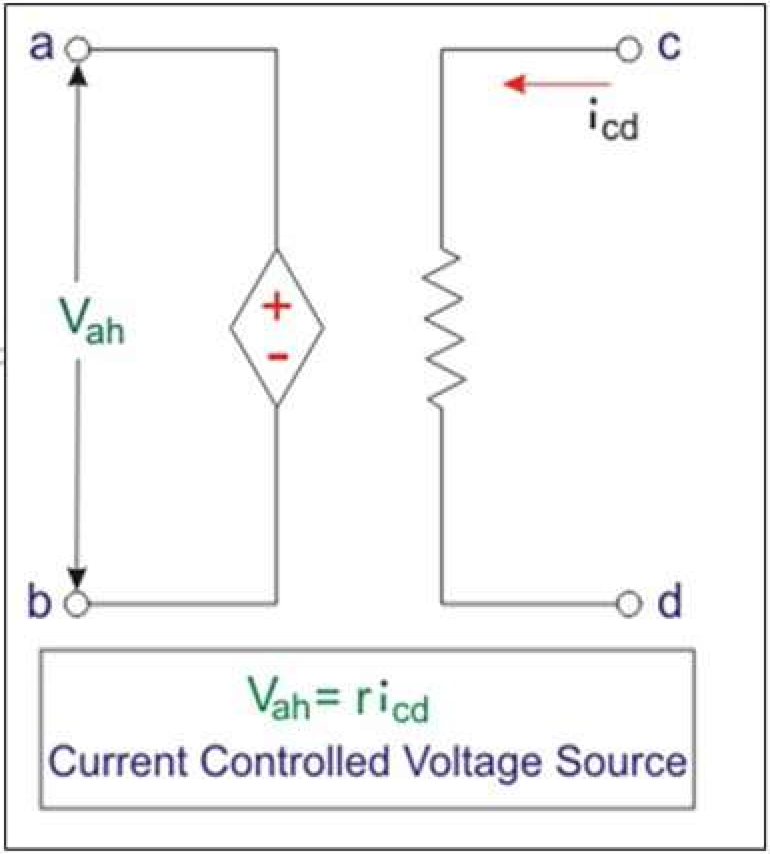
- When the voltage source depends on voltage in any other part of the circuit, then it is called **Voltage Controlled Voltage Source** (VCVS).



Voltage Source

Current Controlled Voltage Source (CCVS)

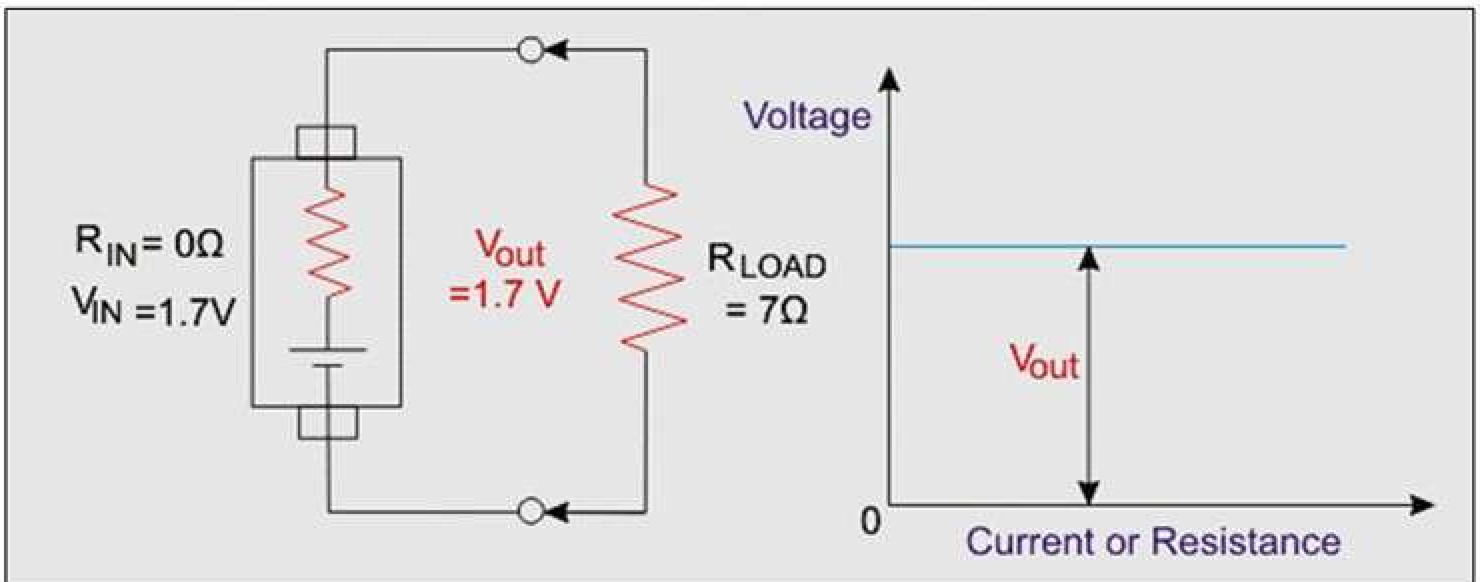
- When the voltage source depends on current in any other part of the circuit, then it is called **Current Controlled Voltage Source** (CCVS).



Voltage Source

Ideal Voltage Source

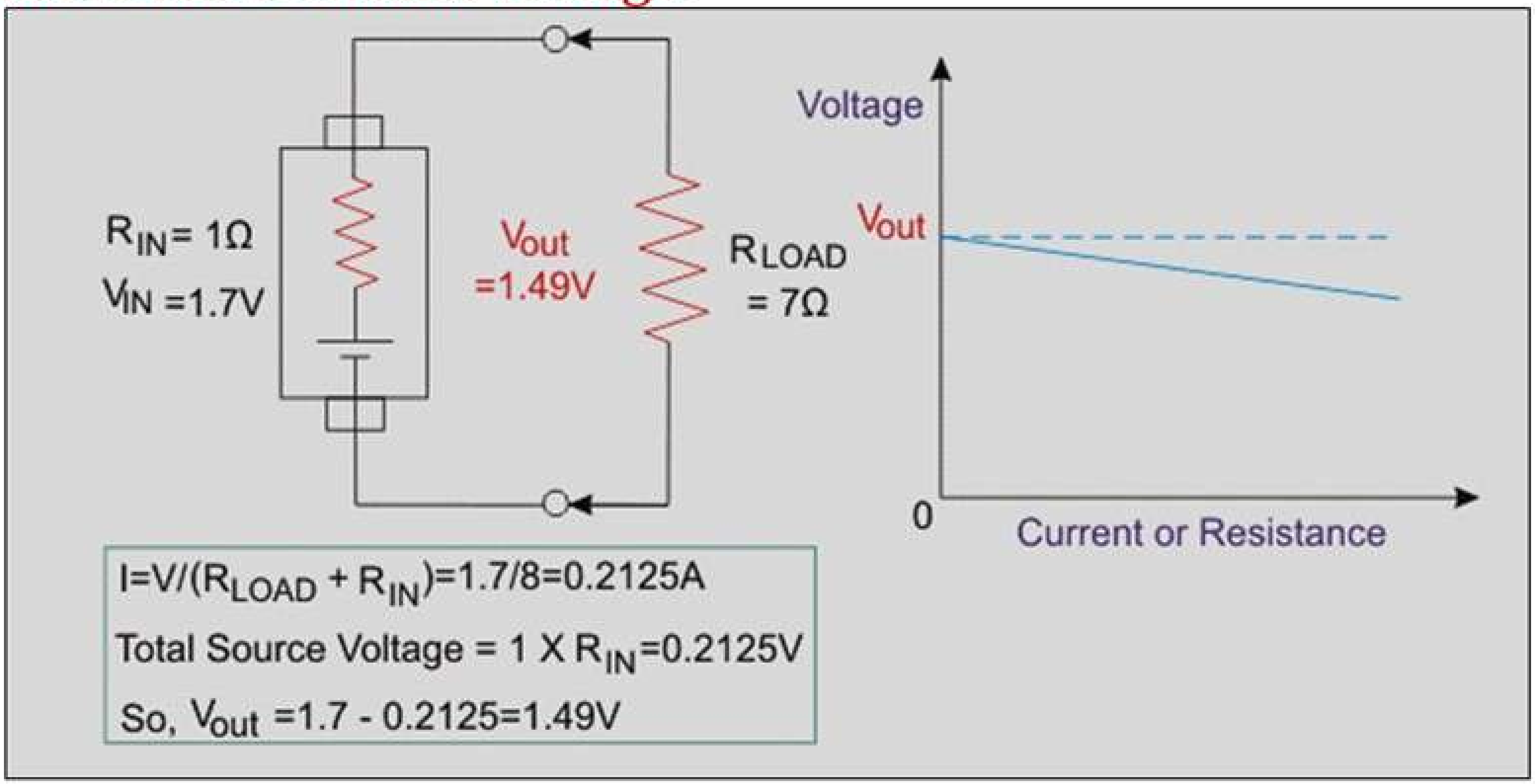
- The voltage source which can deliver constant voltage to the circuit which is independent of the current that the circuit draws.
- The value of internal resistance is zero so no power is wasted owing to internal resistance.
- It performs as a 100% efficient voltage source. All of its voltage of the ideal voltage source can drop perfectly to the load.



Voltage Source

Practical Voltage Source

- The voltage source having internal resistance is known as practical or real voltage source.
- Due to this internal resistance, voltage drop takes place which reduces the terminal voltage.



Current Source

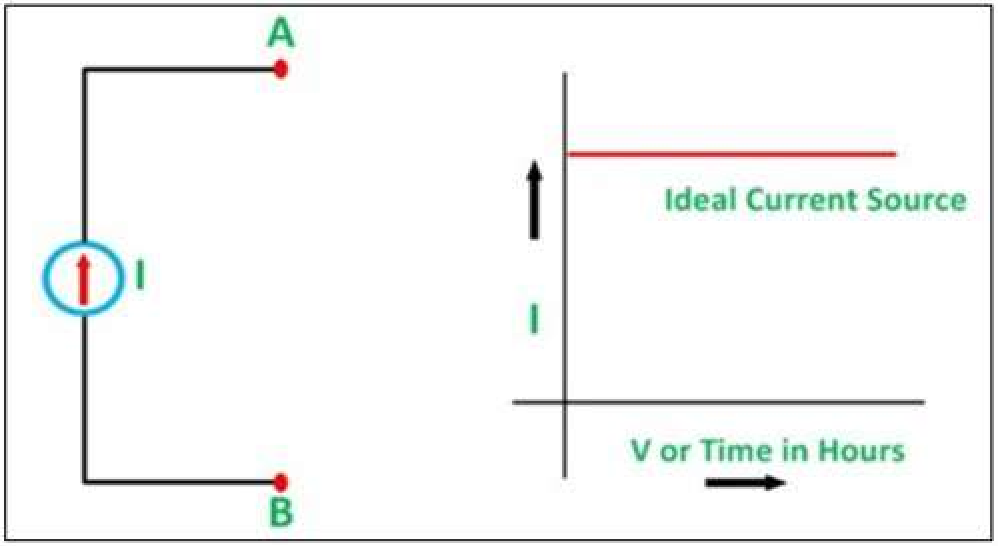
- A current source is a circuit element that maintains a constant current flow regardless of the voltage developed across its terminals as this voltage is determined by other circuit elements.

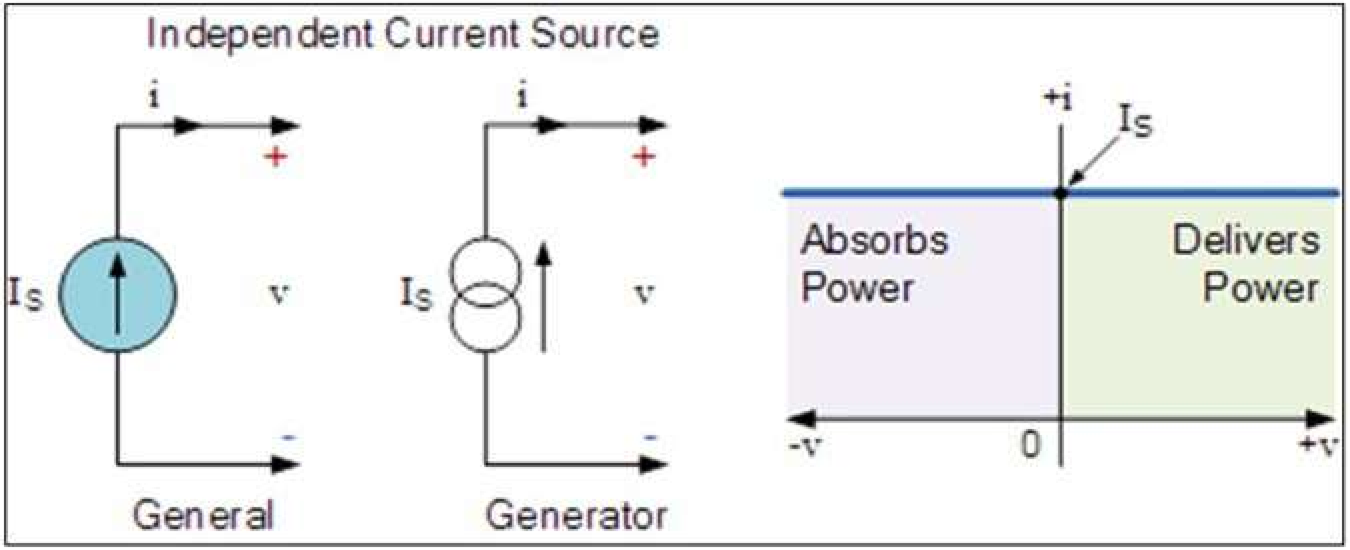
1) Ideal Current Source
2) Practical Current Source

Ideal Current Source

- An ideal current source is a two-terminal circuit element which supplies the same current to any load resistance connected across its terminals.
- It is important to keep in mind that the current supplied by the current source is independent of the voltage of source terminals.
- It has infinite resistance.

Current Source

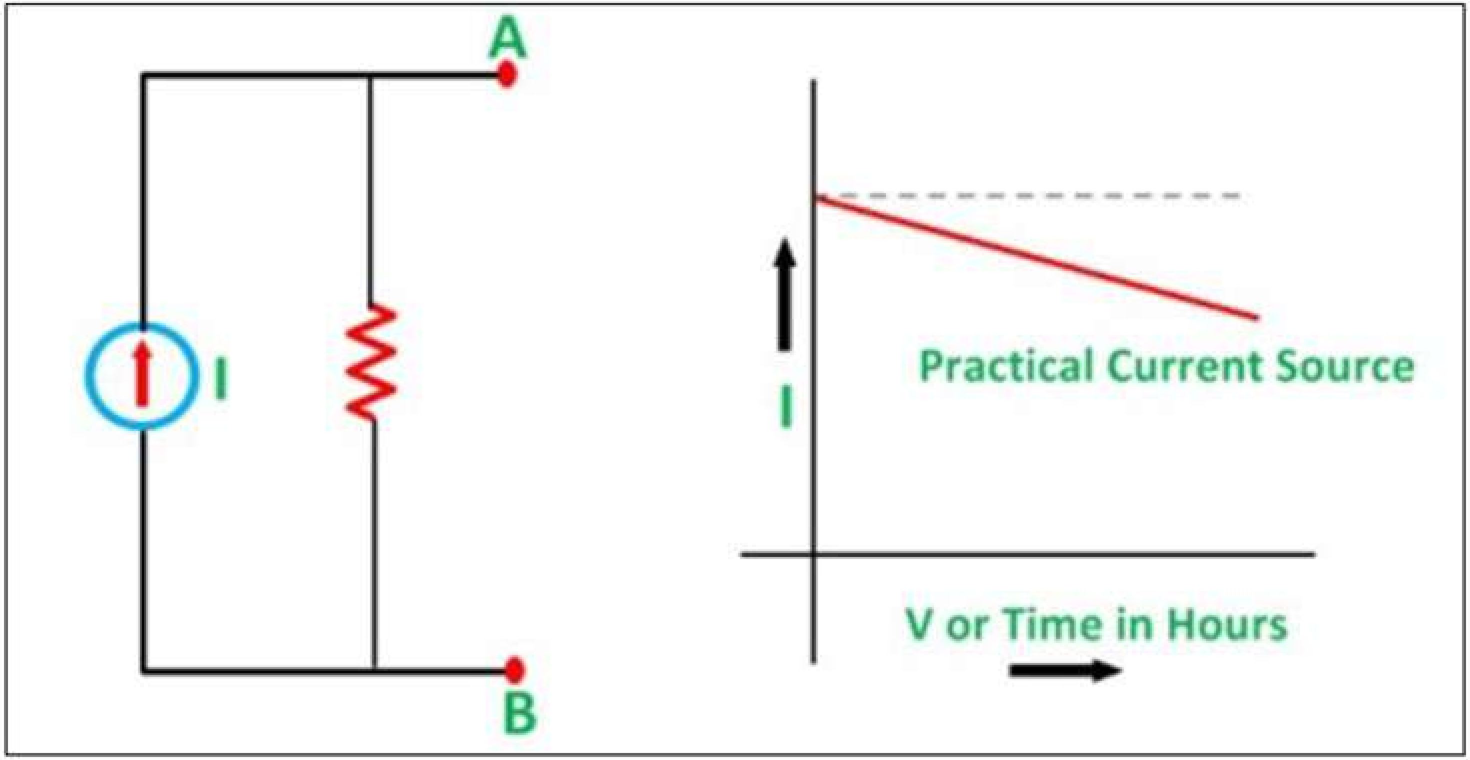




Current Source

Practical Current Source

- A practical current source is represented as an ideal current source connected with the resistance in parallel. The symbolic representation is shown below:

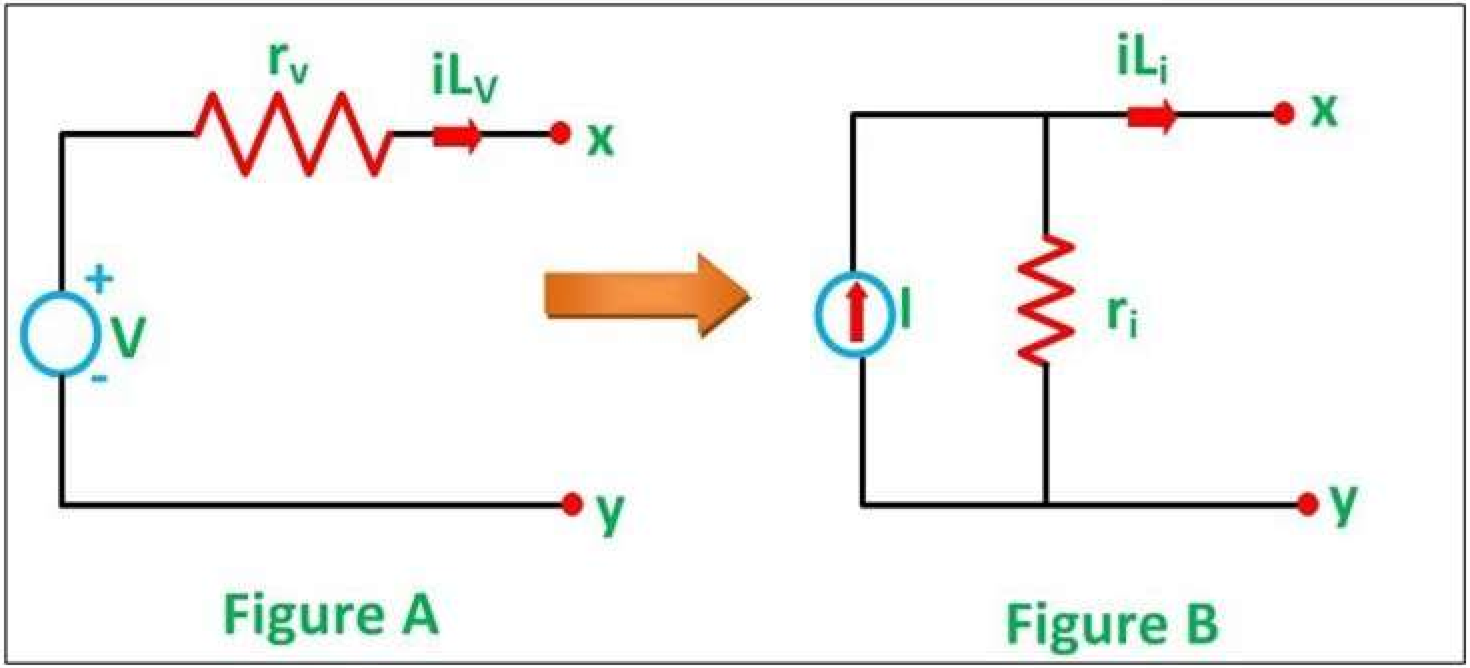


Source Transformation

- Source Transformation simply means replacing one source by an equivalent source.
- A practical voltage source can be transformed into an equivalent practical current source and similarly a practical current source into voltage source.
- Any practical voltage source consists of an ideal voltage source in series with an internal resistance or impedance (for an ideal source this impedance will be zero), the output voltage becomes independent of the load current.
- For any practical current source or simply current source, there is an ideal current source in parallel with the internal resistance or impedance, for ideal current source this parallel impedance is infinity.
- The voltage and current source are mutually transferable.

Source Transformation

- Consider a circuit given below:



- Figure A represents a practical voltage source in series with the internal resistance $\mathbf{r_v}$, while figure B represents a practical current source with parallel internal resistance $\mathbf{r_i}$.

Source Transformation

- For the practical voltage source the load current will be given by the equation:

$$\boxed{iL_v = \frac{V}{r_v + r_L} \quad \ldots\ldots\ldots.(1)}$$

Where,
iL_v is the load current for the practical voltage source
V is the voltage
r_v is the internal resistance of the voltage source
r_L is the load resistance

- It is assumed that the load resistance r_L is connected at the terminals x-y.

Source Transformation

- For the practical current source, the load current is given as:

$$iL_i = I \frac{r_i}{r_i + r_L} \quad \dots\dots\dots\dots (2)$$

Where,
iL_i is the load current for the practical current source is the current
r_i is the internal resistance of the current source
r_L is the load resistance connected across the terminal x-y

- Two sources become identical, when we will equate equation (1) and equation (2)

$$\frac{V}{r_v + r_L} = I \frac{r_i}{r_i + r_L}$$

Source Transformation

- However, for the current source, the terminal voltage at x-y would be Ir_i, x-y terminal are open. i.e.

$$\boxed{V = I \times r}$$

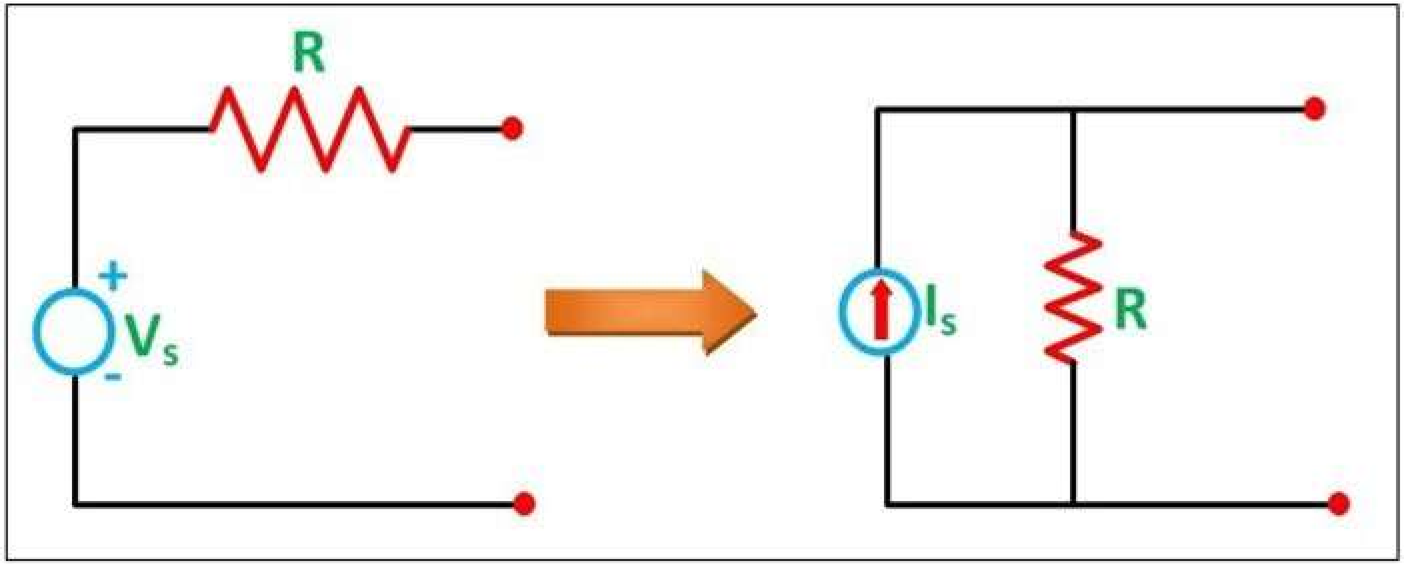
- Therefore

$$\boxed{\begin{gathered} r_v + r_L = r_i + r_L \\ r_v = r_i \end{gathered}}$$

- Therefore, for any practical voltage source, if the ideal voltage is V and internal resistance be r_v, the voltage source can be replaced by a current source I with the internal resistance in parallel with the current source.

Source Transformation

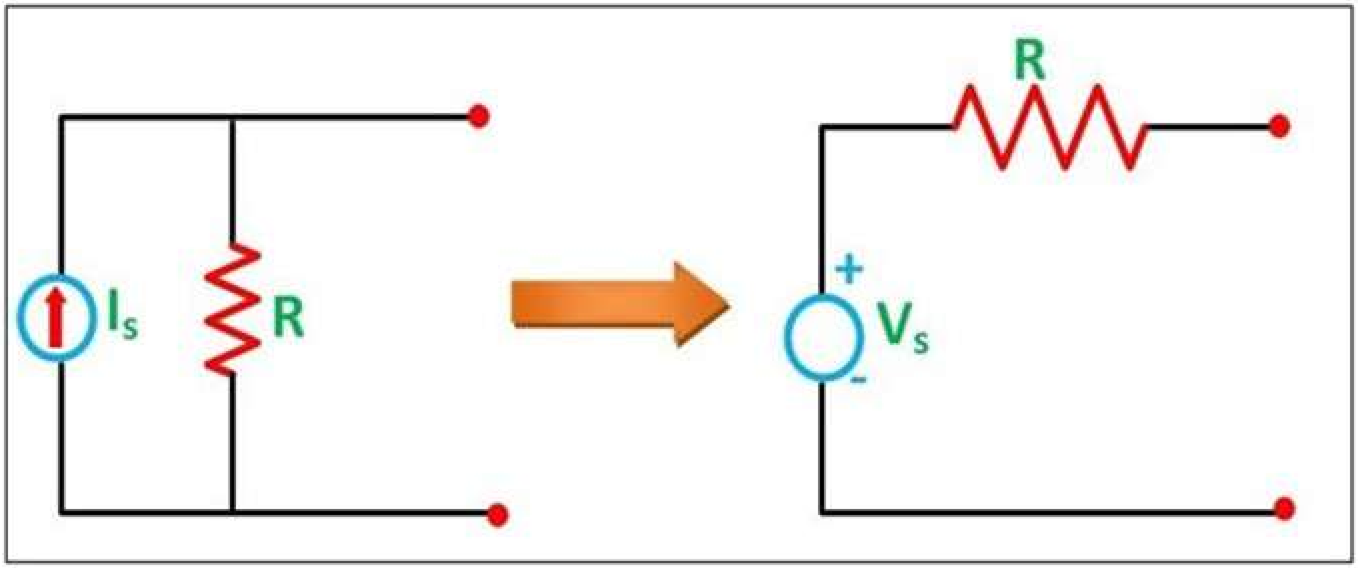
Conversion of Voltage Source into Current Source



- When the voltage source is connected with the resistance in series and it has to be converted into the current source than the resistance is connected in parallel with the current source as shown in the above figure.
- Where $$\boxed{I_s = V_s / R}$$

Source Transformation

Conversion of Current Source into Voltage Source



- In the above circuit diagram a current source which is connected in parallel with the resistance is transformed into a voltage source by placing the resistance in series with the voltage source.

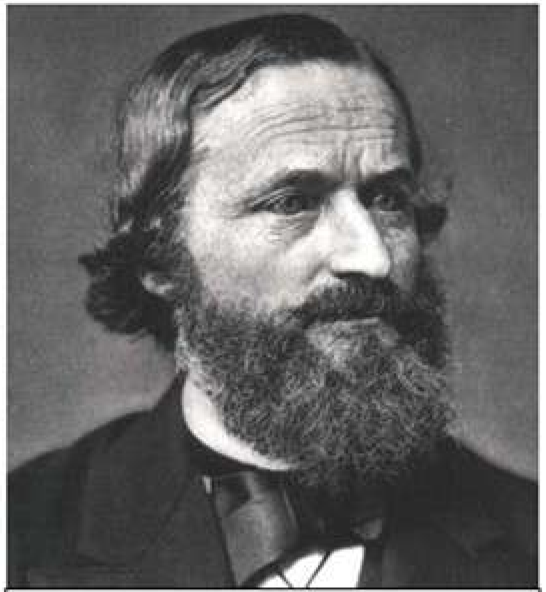
- Where $\boxed{V_s = I_s \ R}$

Kirchhoff's Laws

What are Kirchhoff's Laws?

- Kirchhoff's laws govern the conservation of charge and energy in electrical circuits.
- Kirchhoff's circuit laws allow us to solve complex circuit problems by defining a set of basic network laws and theorems for the voltages and currents around a circuit.

1) **Kirchhoff's Current Law (KCL)**
2) **Kirchhoff's Voltage Law (KVL).**



Gustav Kirchhoff

Kirchhoff's Laws

Kirchhoff's Current Law (KCL)

At any node (junction) in an electrical circuit, the sum of currents flowing into that node is equal to the sum of currents flowing out of that node.

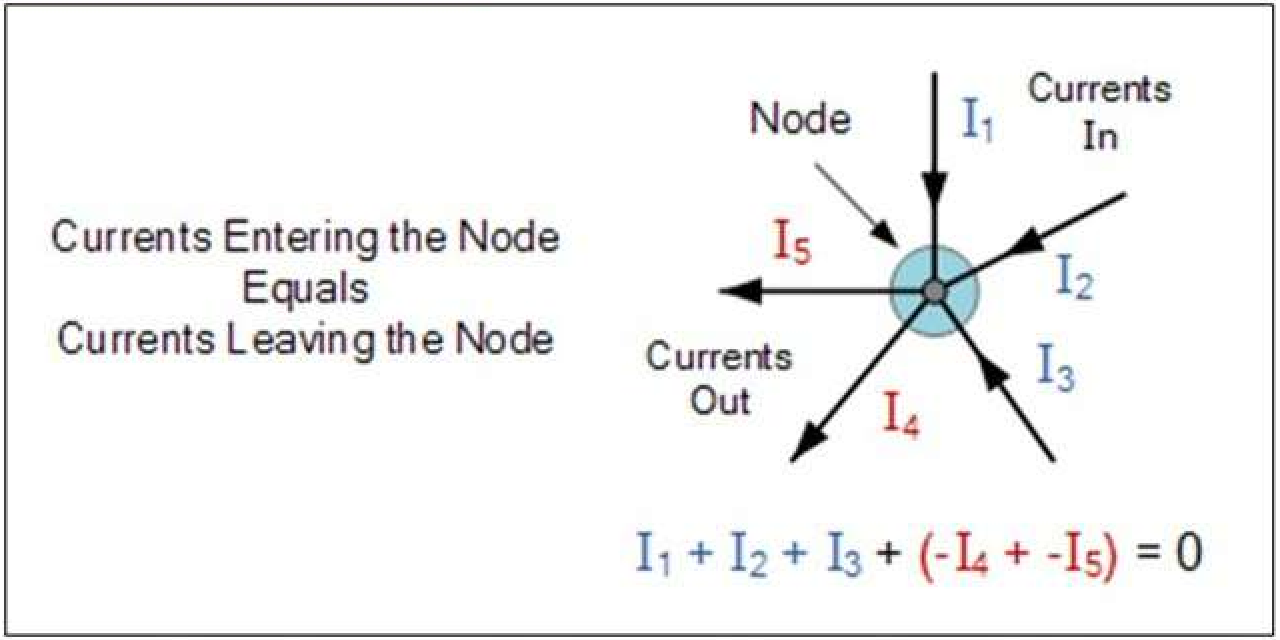
OR

The algebraic sum of currents in a network of conductors meeting at a point is zero.

$$\boxed{\sum I_{in} = \sum I_{out}}$$

- The sum of currents entering the junction are thus equal to the sum of currents leaving.
- This implies that the current is conserved (no loss of current).

Kirchhoff's Laws



- Current entering the node is considered positive and leaving the node is considered negative in value.

$$\boxed{\mathbf{I_1 + I_2 + I_3 - I_4 - I_5 = 0}}$$

$$\boxed{\therefore \mathbf{I_1 + I_2 + I_3 = I_4 + I_5}}$$

Kirchhoff's Laws

Kirchhoff's Voltage Law (KVL)

In any closed loop network, the total voltage around the loop is equal to the sum of all the voltage drops within the same loop.

OR

In other words the algebraic sum of all voltages within the loop must be equal to zero.

$$\boxed{\sum V - \sum (I \times R) = 0}$$

$$\boxed{\therefore \sum \Delta V_{\text{closed loop}} = 0}$$

- This idea by Kirchhoff is known as the Conservation of Energy.

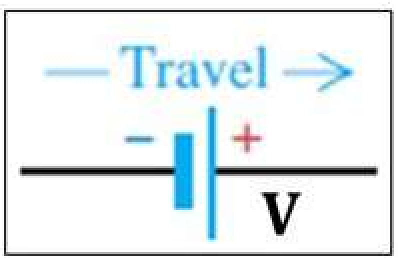
Kirchhoff's Laws

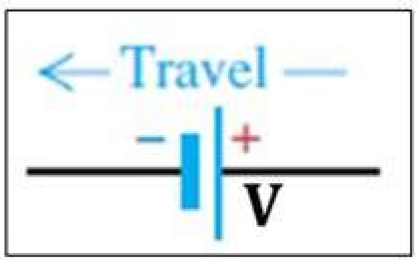
Sign Conventions for KVL

For emf (Voltage Source)

+V:
Travel direction from – to +

-V:
Travel direction from + to -

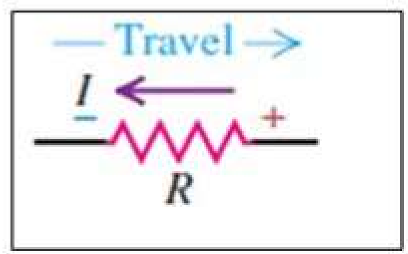


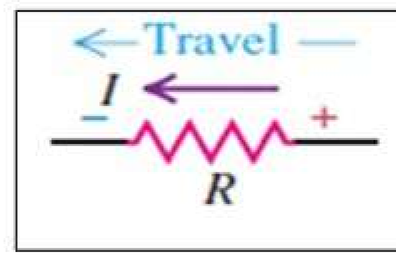


For Voltage Drop in Resistor

+IR:
Travel direction from – to +

-IR:
Travel direction from + to -





Kirchhoff's Laws

- Consider the closed path ABCDA in figure. As we travel around the mesh in the clockwise direction, different voltage drops will have the following signs:

I_1R_2 is −ve (fall in potential)

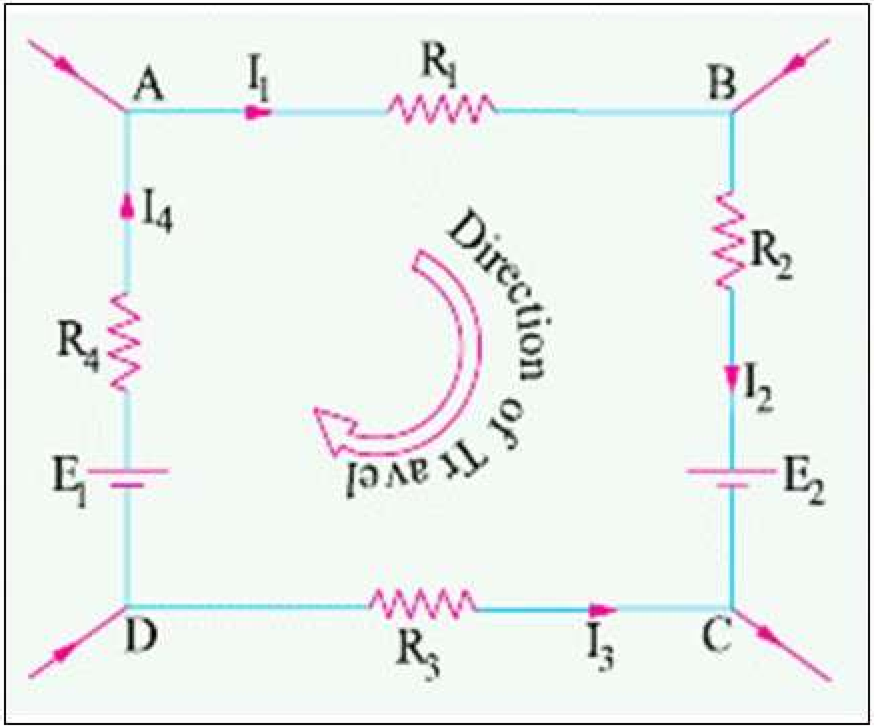
I_2R_2 is −ve (fall in potential)

I_3R_3 is +ve (rise in potential)

I_4R_4 is −ve (fall in potential)

E_2 is −ve (fall in potential)

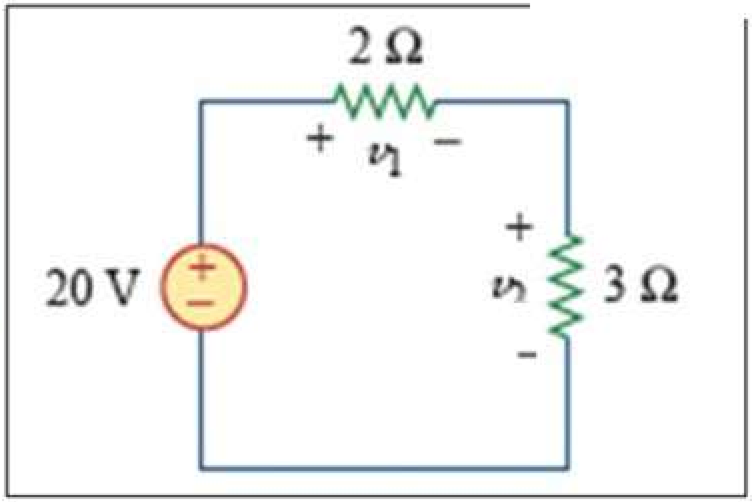
E_1 is +ve (rise in potential)



$$-I_1R_1 - I_2R_2 + I_3R_3 - I_4R_4 - E_2 + E_1 = 0$$

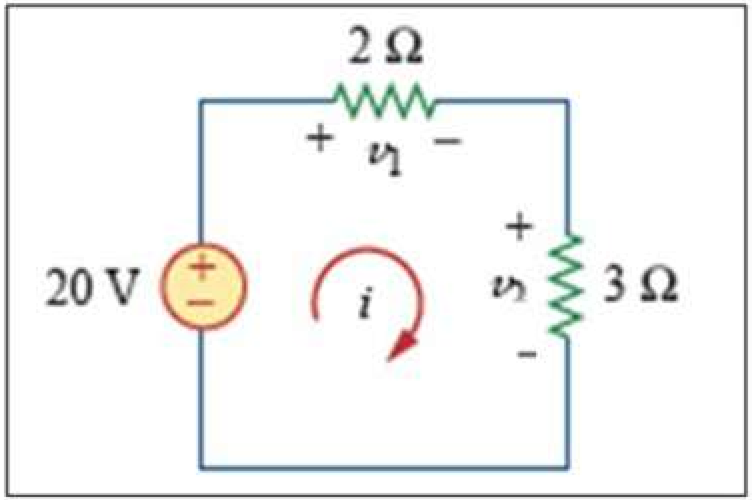
$$I_3R_3 + E_1 = I_1R_1 + I_2R_2 + I_4R_4 + E_2$$

Example-1: For the circuit in figure, find voltages v_1 and v_2.



- To find and we apply Ohm's law and Kirchhoff's voltage law.

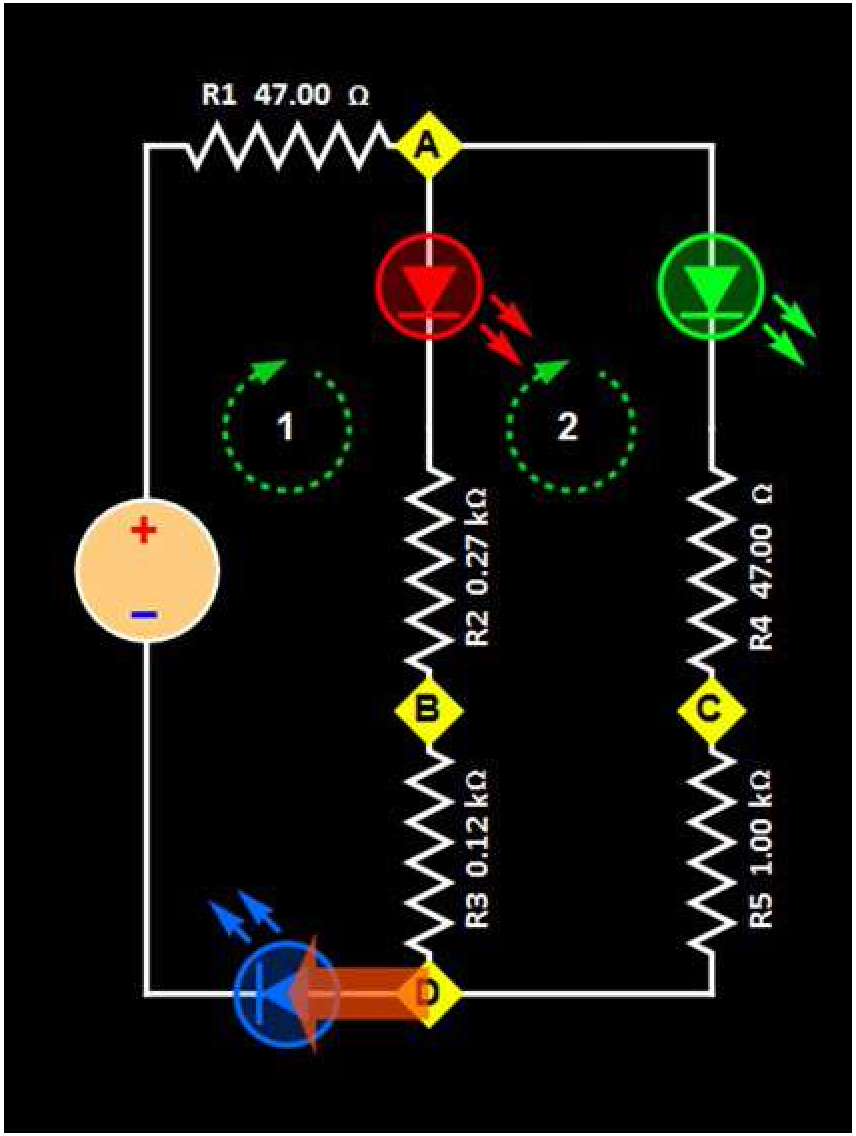
- Assume that current **i** flows through the loop as shown in figure.



Kirchhoff's Laws

- **From ohm's law**
- $V_1 = 2 \times i \qquad V_2 = 3 \times i$ ______________(1)
- **Applying KVL around the loop gives**
- $20 - V_1 - V_2 = 0$ __________________(2)
- **Substituting Eq.(1) into Eq.(2)**
- $20 - 2i - 3i = 0$ or $5i = 20$ therefore, $i = 4$ A.
- **Substituting I in Eq.(1) finally gives**
- $V_1 = 2 \times i = 8$ V and $V_2 = 3 \times i = 12$ V.

Kirchhoff's Laws



Observations from the Circuit

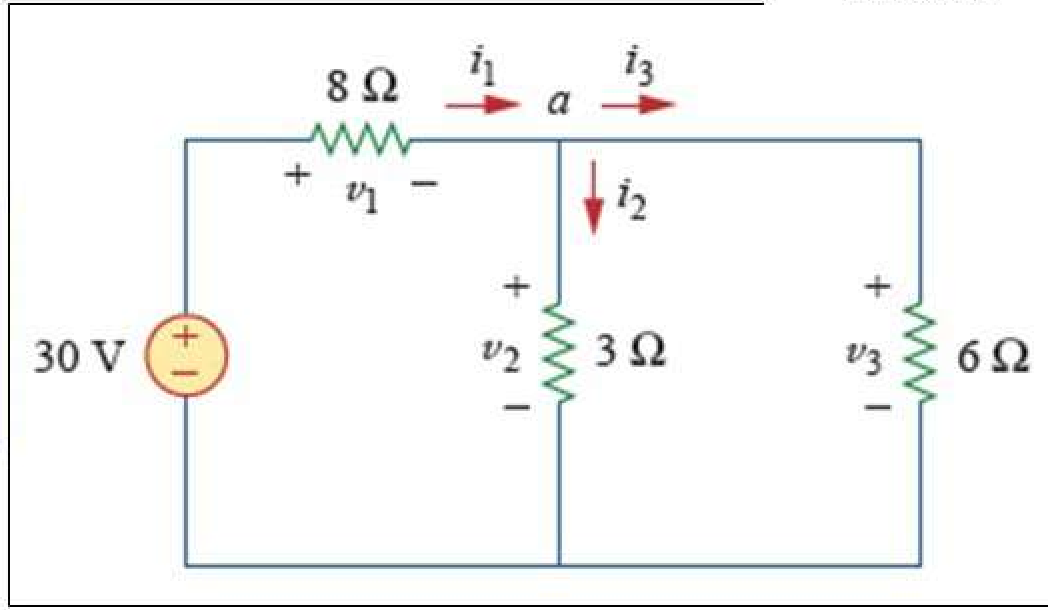
Junction: A & D
Loop: ABDA & ACDBA

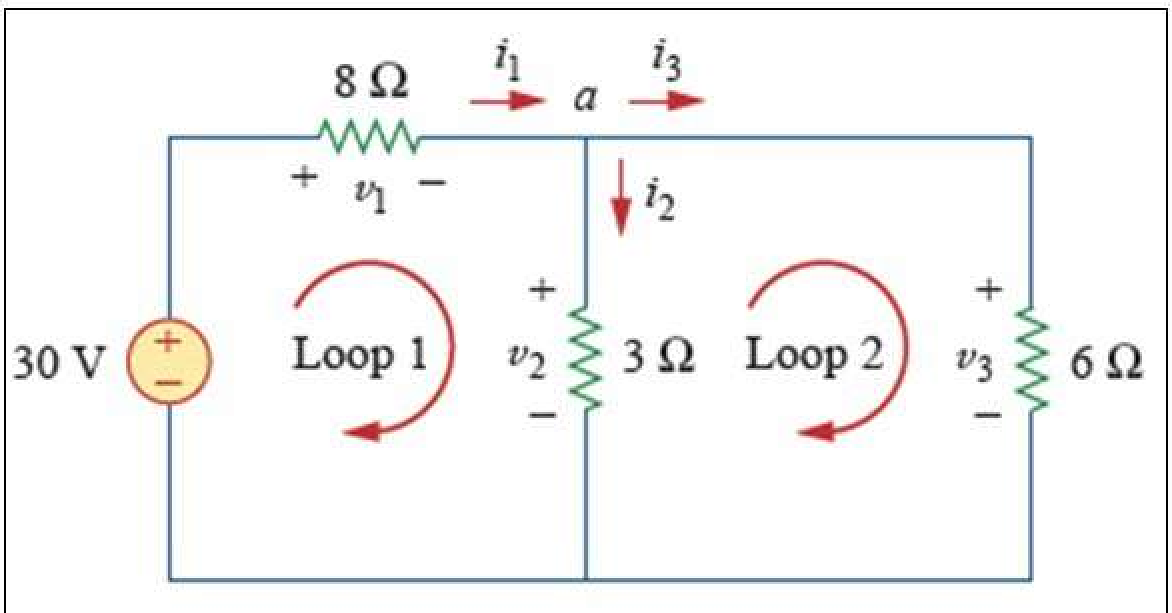
Current follows the Ohm's law

$$I \,\alpha\, \frac{1}{R}$$

Kirchhoff's Laws

Example-2: **Find currents and voltages in the circuit shown.**





Kirchhoff's Laws

- We will apply Ohm's Law and Kirchhoff's Laws. By Ohm's Law,
- $V_1 = 8 \times I_1$ $V_2 = 3 \times I_2$ $V_3 = 6 \times I_3$
- Applying KCL at node a,
- $i_1 - i_2 - i_3 = 0$ ________________(1)
- Applying KVL to Loop 1,
- $30 - V_1 - V_2 = 0$ ________________(2)
- We express Eq.(2) in terms of i_1 and i_2
- $30 - (8 \times I_1) - (3 \times I_2) = 0$ _________(3)
- Therefore, $i_1 = [30 - (3 \times I_2)] / 8$

Kirchhoff's Laws

- Applying KVL to Loop 2,
- $-V_3 + V_2 = 0$. Therefore, $V_2 = V_3$
- As expected, since the two resistors are in parallel, we will express two voltage drops V_2 and V_3 in terms of currents i_2 and i_3
- $6 \times I_3 = 3 \times I_2$. Therefore, $I_3 = I_2 /2$
- Now putting the values of i_1 , i_2 and i_3 in Eq.(1) we get,
- $[30 - (3 \times I_2)] / 8 - i_2 - I_2 /2 = 0$
- $30 - 3 I_2 - 8 i_2 - 4 i_2 = 0$

Kirchhoff's Laws

- $30 - 3\,I_2 - 8\,i_2 - 4\,i_2 = 0$
- $30 - 15\,I_2 = 0$
- Which gives the value of $I_2 = 2$ A.
- From the value of I_2 the value of $i_1 = [30 - (3 \times I_2)] / 8 = 3$ A and $I_3 = I_2 / 2 = 1$ A.
- $V_1 = 8 \times I_1 = 24$ V,
- $V_2 = 3 \times I_2 = 6$ V,
- $V_3 = 6 \times I_3 = 6$ V.

Star-Delta Transformation

- Standard 3-phase circuits or networks take on two major forms with names that represent the way in which the resistances are connected

  1) a **Star** connected network which has the symbol of the letter, **Y (wye)**
  2) a **Delta** connected network which has the symbol of a triangle, **Δ/D (delta)**

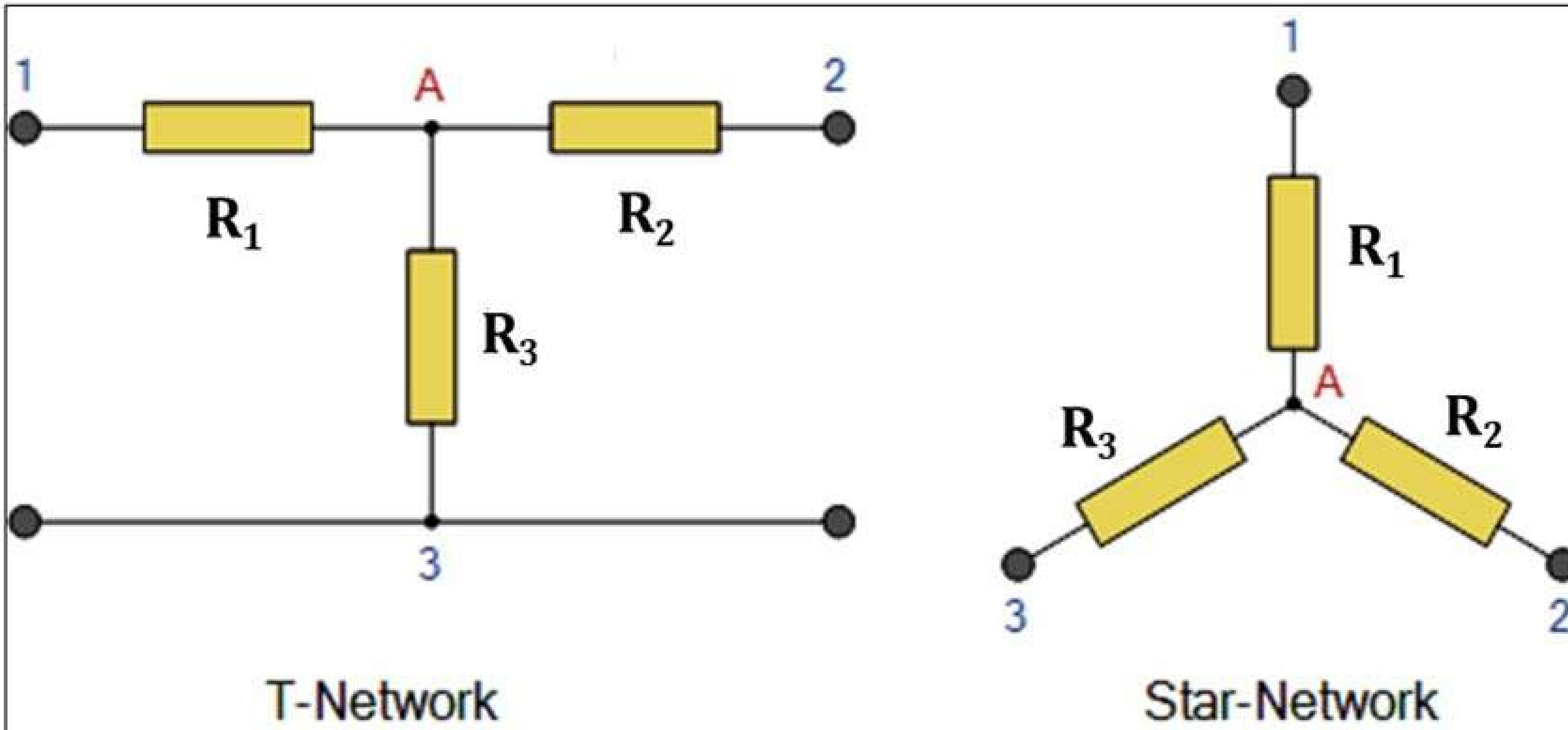
- If a 3-phase, 3-wire supply or a 3-phase load is connected in one type of configuration, it can be easily transformed or changed it into an equivalent configuration of the other type by using

  1) Star-Delta Transformation
  2) Delta-Star Transformation

Star-Delta Transformation

Star Connection

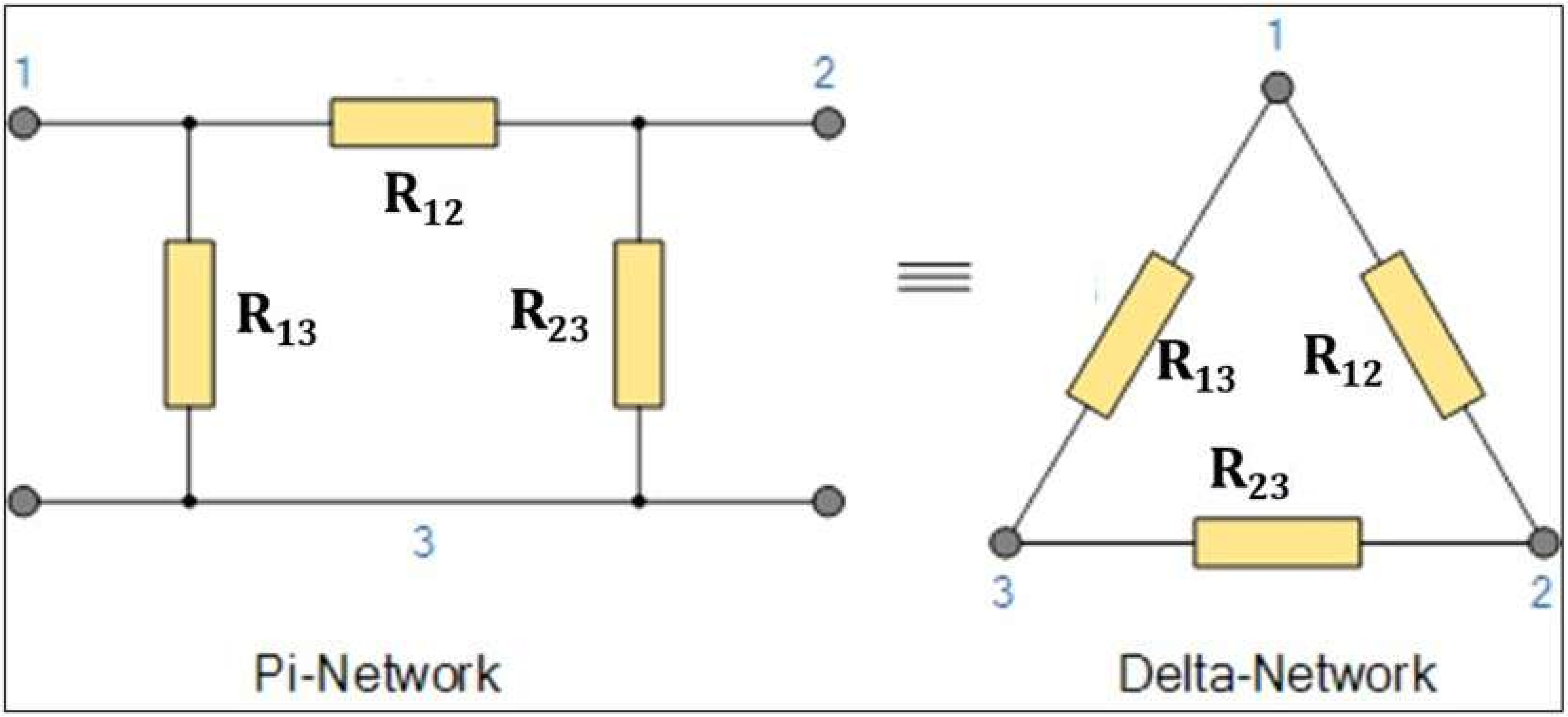
- A resistive network consisting of three resistors can be connected together to form a **T** or "**Tee**" configuration but the network can also be redrawn to form a **Star** or **Y** type network as shown below.



Star-Delta Transformation

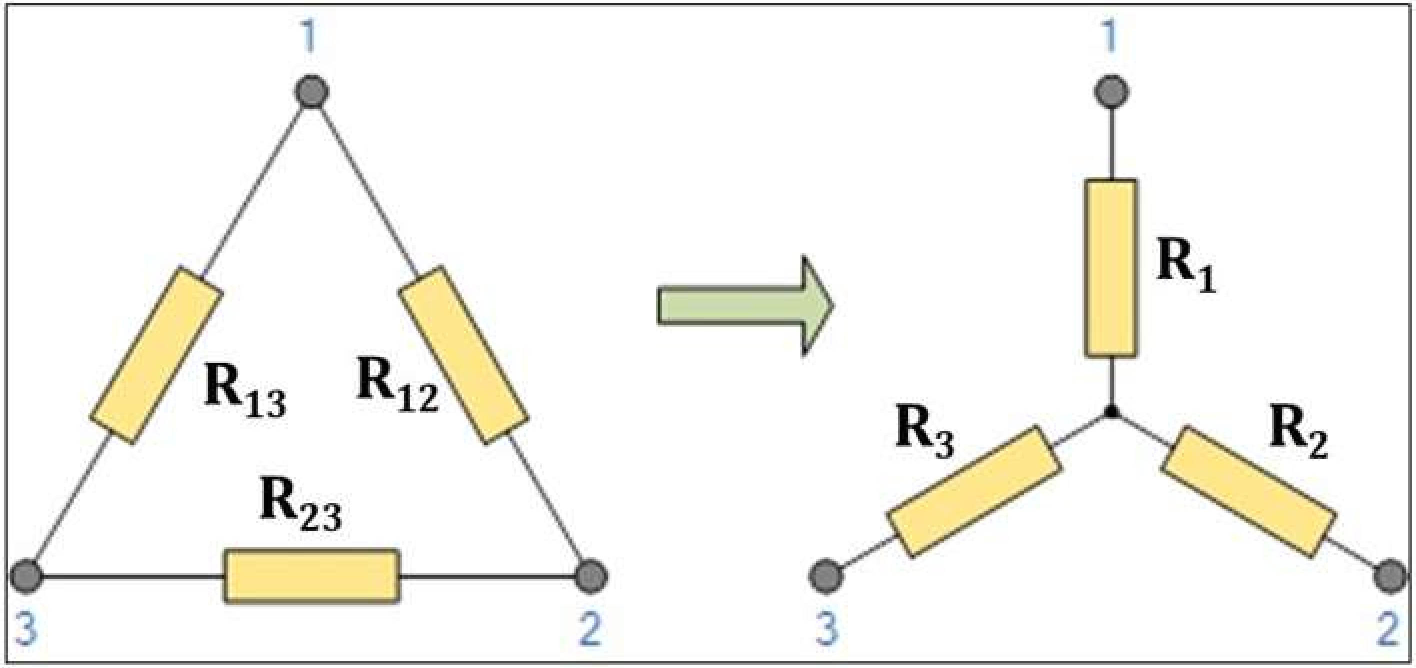
Delta Connection

- A resistive network consisting of three resistors can be connected together to form a **π** or "**Pi**" configuration but the network can also be redrawn to form a **Delta** or **Δ/D** type network as shown below.



Star-Delta Transformation

Delta to Equivalent Star Network



- Compare the resistances between terminals 1 and 2.

$$R_1 + R_2 = R_{12} \parallel (R_{23} + R_{31})$$

$$\therefore R_1 + R_2 = \frac{R_{12}(R_{23} + R_{31})}{(R_{12} + R_{23} + R_{31})} \qquad (1)$$

Star-Delta Transformation

- Resistance between the terminals 2 and 3.

$$R_2 + R_3 = R_{23} \,||\, (R_{31} + R_{12})$$

$$\therefore R_2 + R_3 = \frac{R_{23}(R_{31} + R_{12})}{(R_{12} + R_{23} + R_{31})} \qquad (2)$$

- Resistance between the terminals 1 and 3.

$$R_3 + R_1 = R_{31} \,||\, (R_{12} + R_{23})$$

$$\therefore R_3 + R_1 = \frac{R_{31}(R_{12} + R_{23})}{(R_{12} + R_{23} + R_{31})} \qquad (3)$$

Star-Delta Transformation

- Subtracting Eq. (2) from Eq. (1) and adding the result to Eq. (3), we have,

$$\boxed{R_1 = \frac{R_{12}\,R_{31}}{R_{12} + R_{23} + R_{31}} \qquad (4)}$$

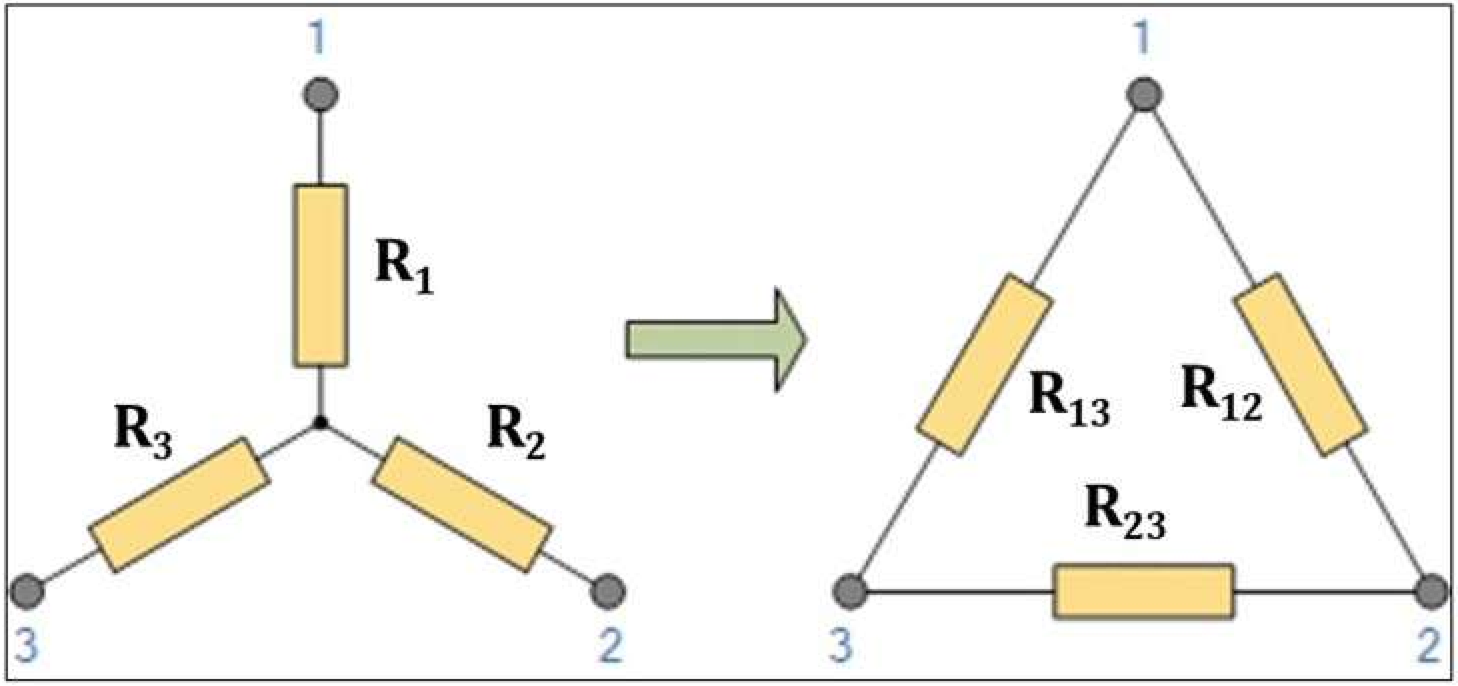
- Similarly, we get,

$$\boxed{R_2 = \frac{R_{23}\,R_{12}}{R_{12} + R_{23} + R_{31}} \qquad (5)}$$

$$\boxed{R_3 = \frac{R_{31}\,R_{23}}{R_{12} + R_{23} + R_{31}} \qquad (6)}$$

Star-Delta Transformation

Star to Equivalent Delta Network



- Dividing Eq. (4) by (5), we have,

$$\frac{R_1}{R_2} = \frac{R_{31}}{R_{23}}$$

$$\therefore R_{31} = \frac{R_1 R_{23}}{R_2}$$

Star-Delta Transformation

- Dividing Eq. (4) by (6), we have,

$$\frac{R_1}{R_3} = \frac{R_{12}}{R_{23}}$$

$$\therefore R_{12} = \frac{R_1 R_{23}}{R_3}$$

- Substituting the values of **R_{31} and R_{12}** in Eq. (4), we have,

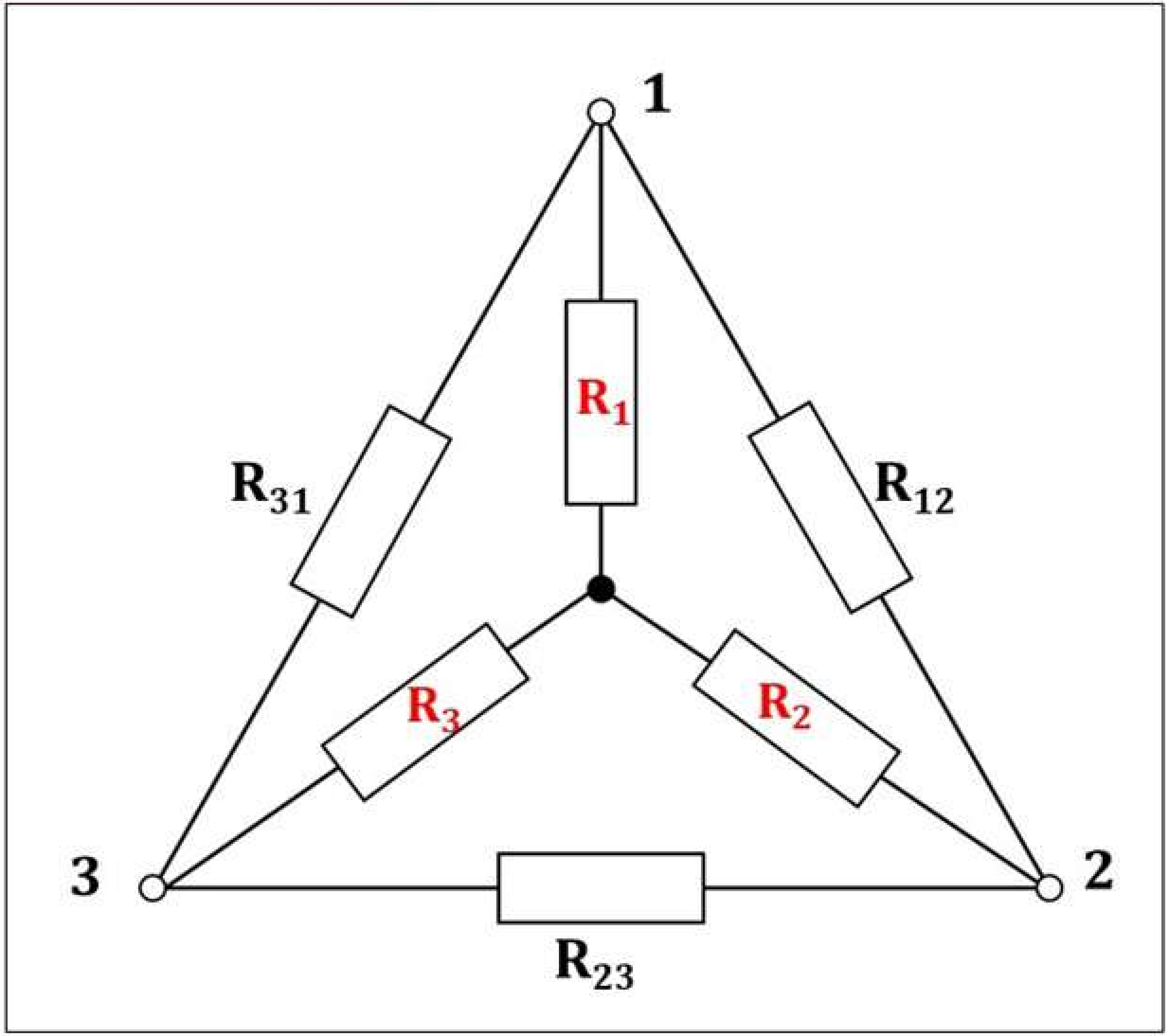
$$R_{23} = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_1}$$

- Similarly,

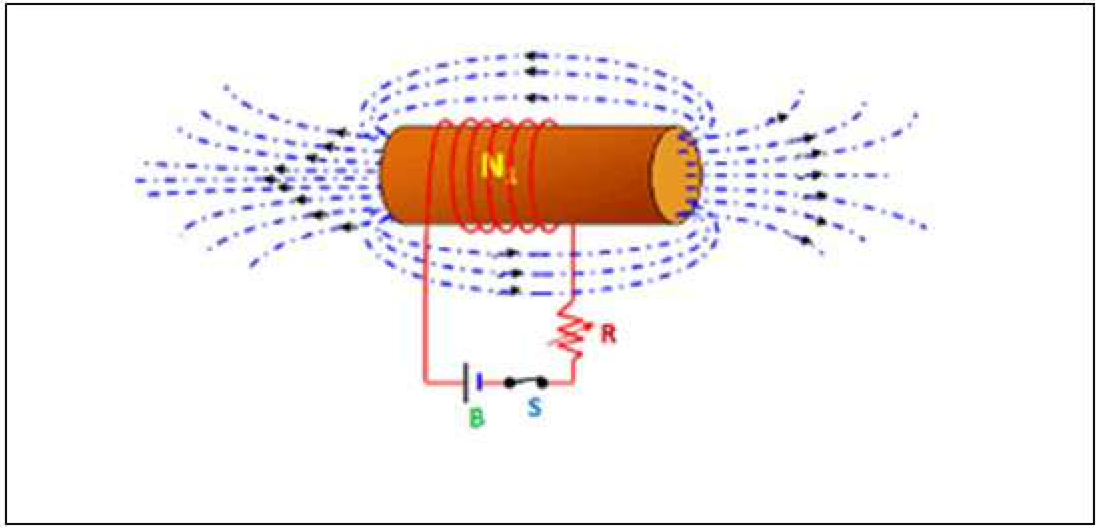
$$R_{31} = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_2}$$

$$R_{12} = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_3}$$

Star-Delta Transformation



Electromagnetism



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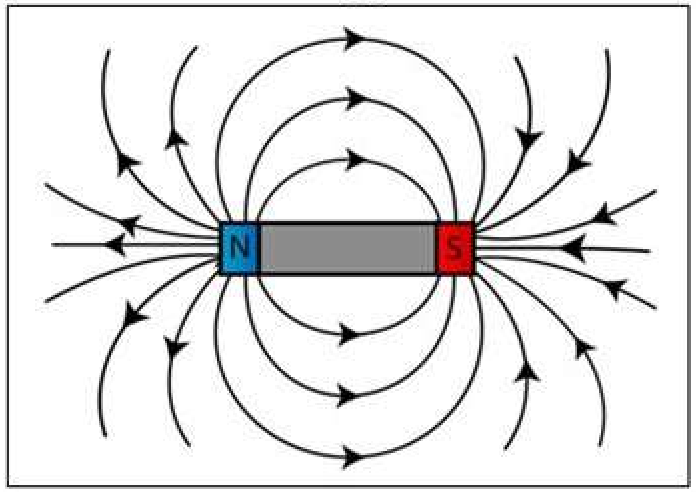
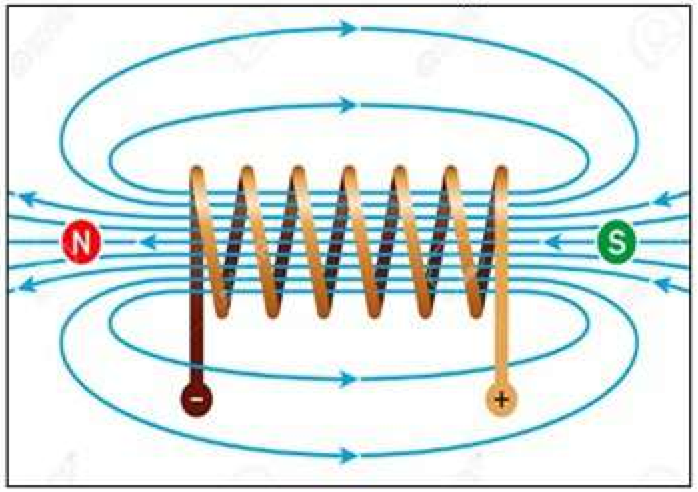
Magnetic Field

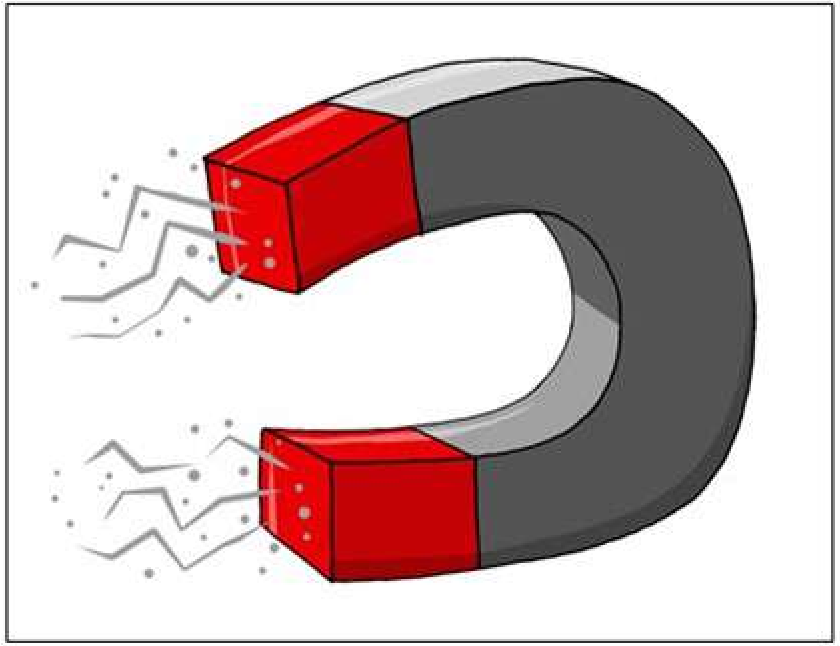
- **Magnetic field** is a force generated due to energy change in a volume of space.
- A **magnetic field** is produced by an **electrical charge in motion** e.g. current flowing in a conductor, orbital movement and spin of electrons.
- The magnetic field can be described by **imaginary lines** as shown in the figure for a magnet and a current loop.

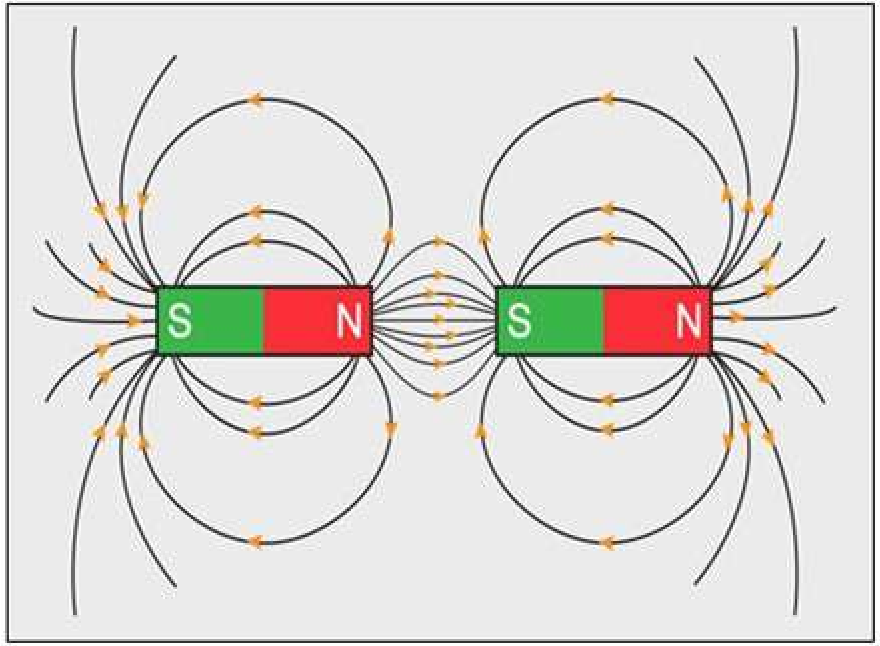




Magnetic Field: Permanent Magnet

- There are the orbital motions and spins of electrons within the **permanent magnet** material which lead to a **magnetization** within the material and a magnetic field outside.



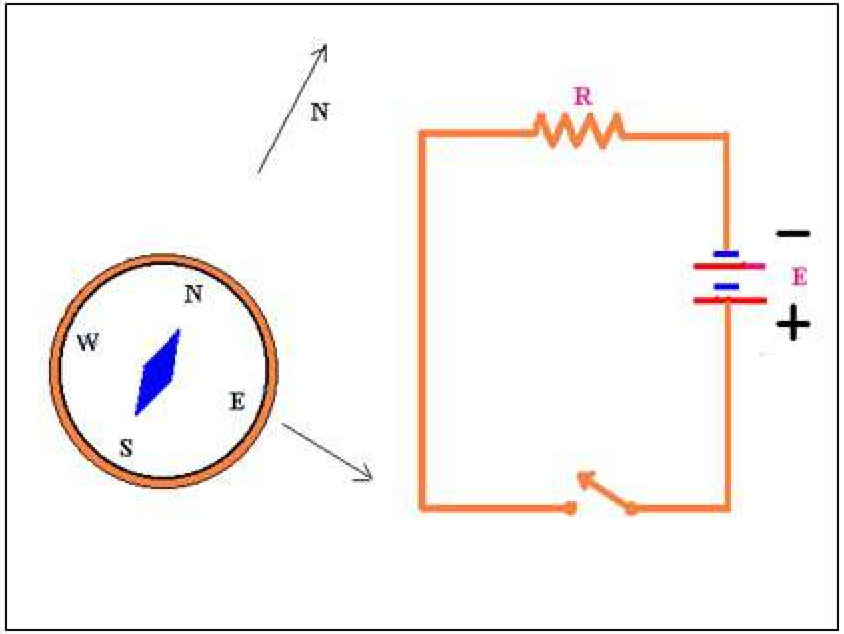


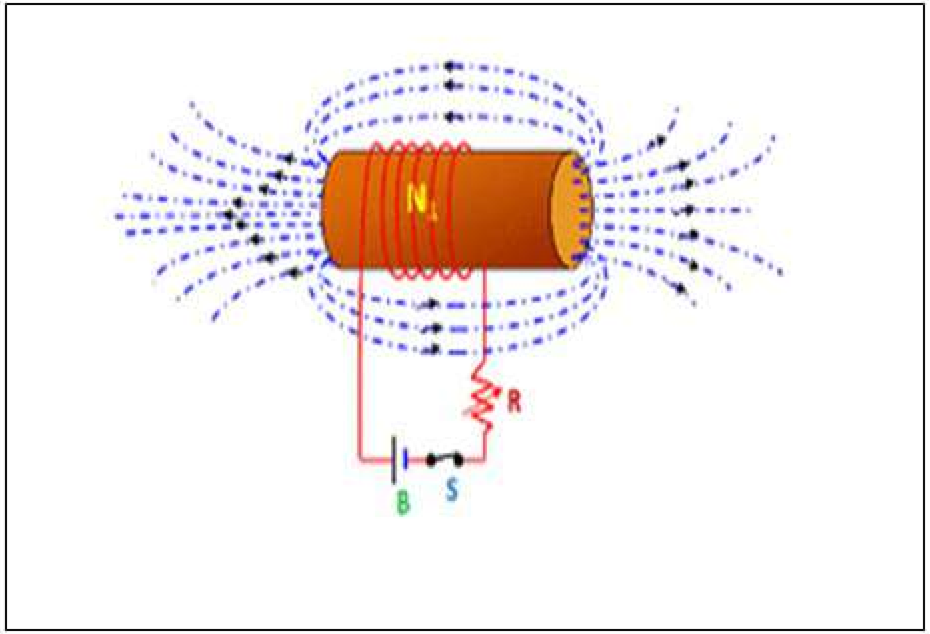
Magnetic field of permanent magnet cannot be changed.

Electromagnetism

Magnetic Field: Electromagnet

➢ Here, Magnetism **exists only when current flows** through the coil/winding placed on a magnetic material.



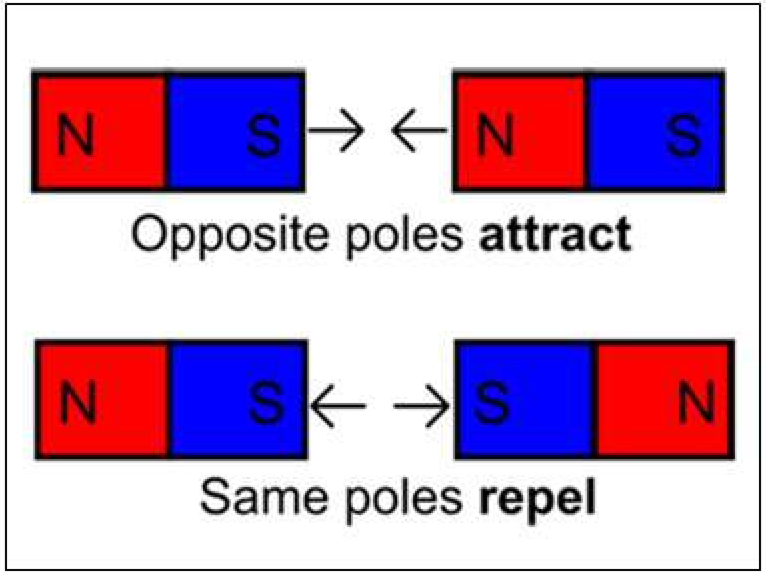


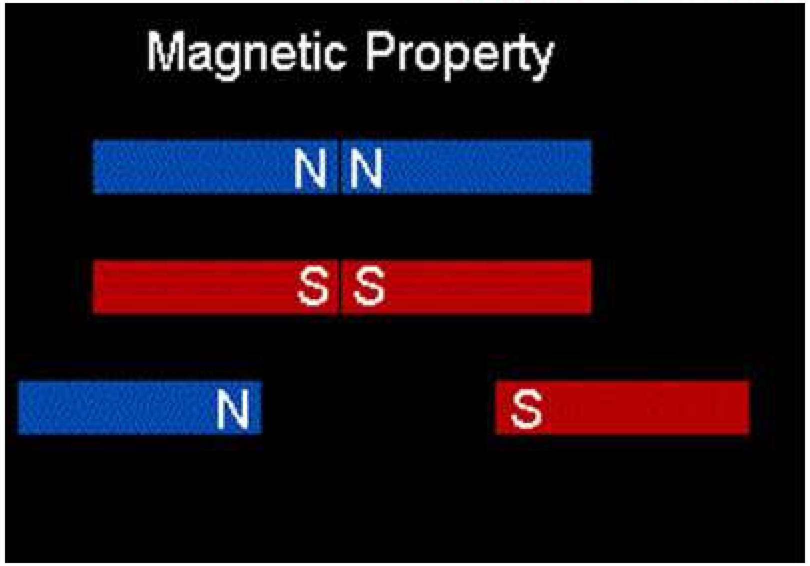
Controllable magnetic field can be created.

Laws of Magnetic Force (Coulomb's Laws)

➢ **First Law:** **Like poles repel each other while unlike poles attract each other.**

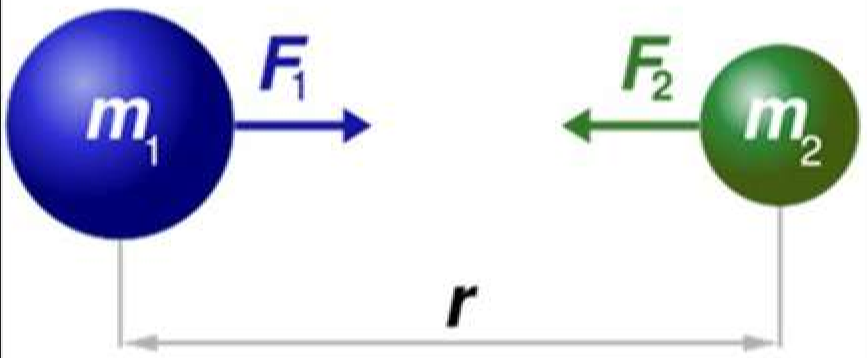
Charles Coulomb





Laws of Magnetic Force (Coulomb's Laws)

➢ **Second Law:** The force between two magnetic poles is directly proportional to the product of their pole strengths and inversely proportional to the square of distance between their centers.



$$F_1 = F_2 = K\frac{m_1 \times m_2}{r^2}$$

$$\text{Where, } K = \frac{1}{4\pi\mu_0\mu_r}$$

μ_0 = Absolute permeability = $4\pi \times 10^{-7}$ H/m

μ_r = Relative permeability

Faraday's Law of Electromagnetic Induction

- While **Oersted's** surprising discovery of electromagnetism paved the way for more practical applications of electricity, it was **Michael Faraday** who gave us the key to the practical generation of electricity: electromagnetic induction.

Hans Oersted (1777-1851)

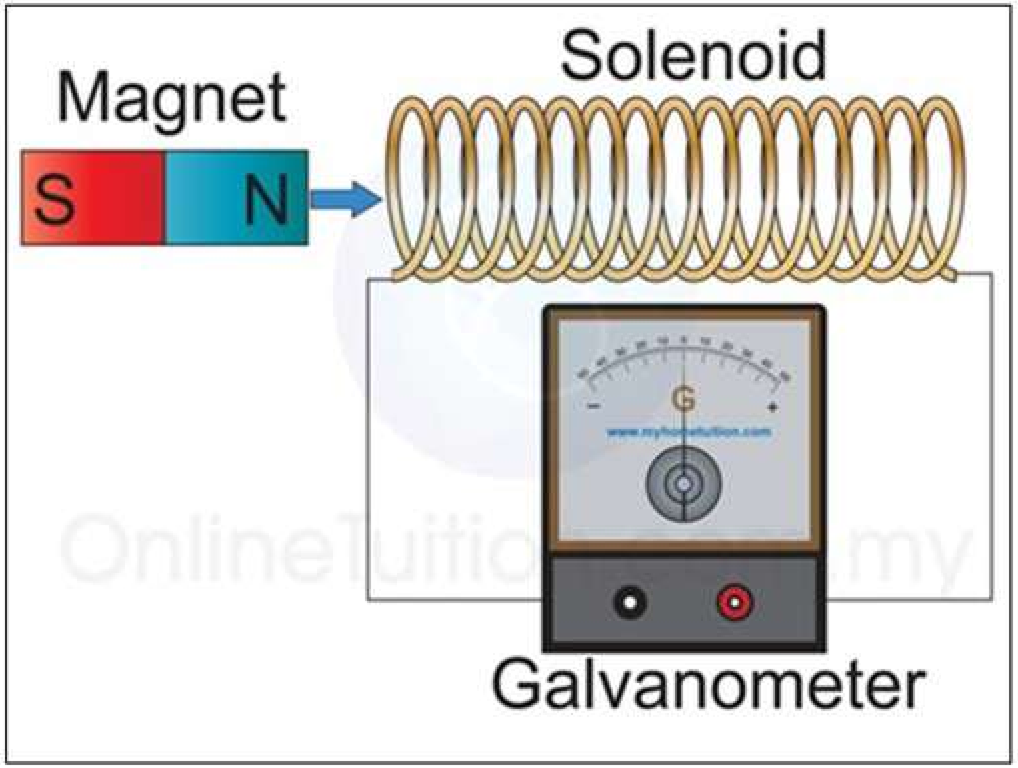
Michael Faraday (1791-1867)

Electromagnetism

What Electromagnetic induction?

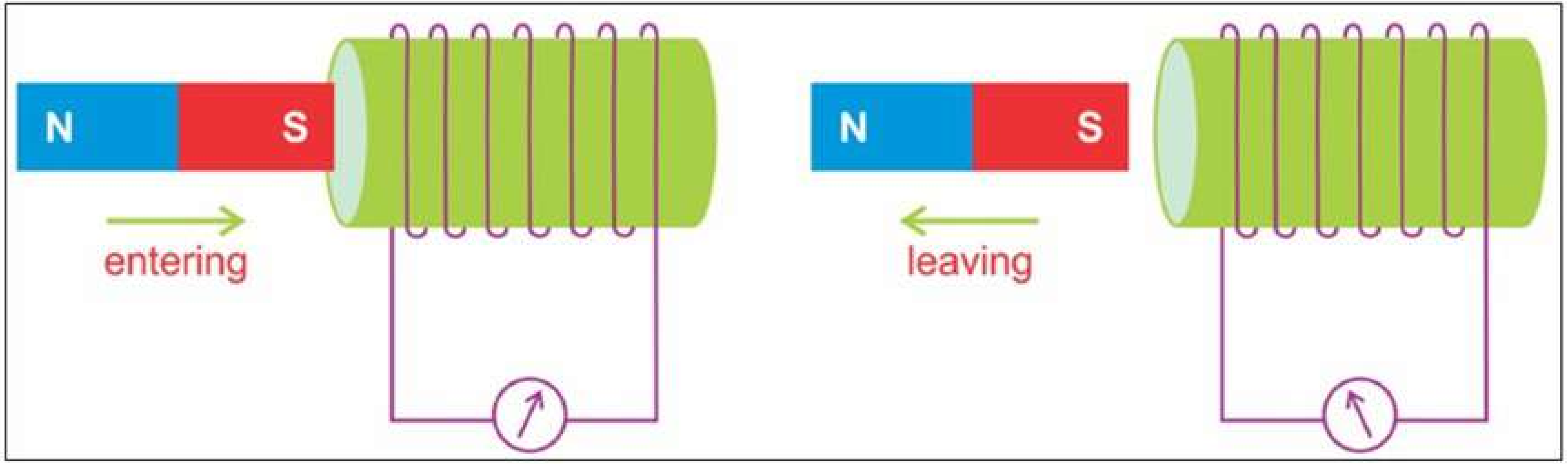
- Electromagnetic induction is the process by which a current can be induced to flow due to a changing magnetic field.

Faraday's Experiment



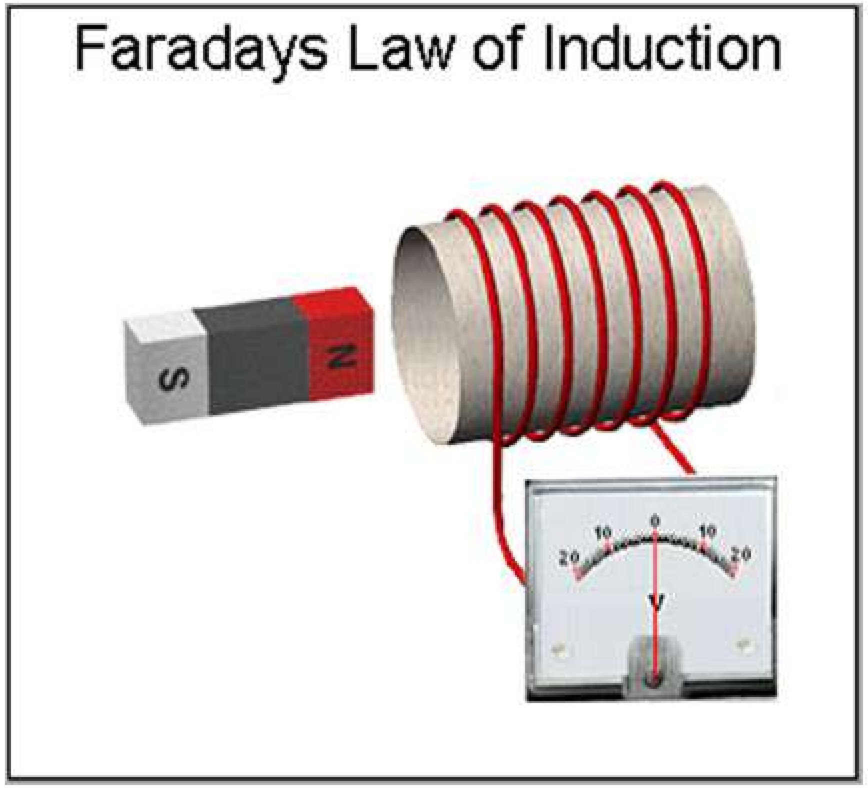
Electromagnetism

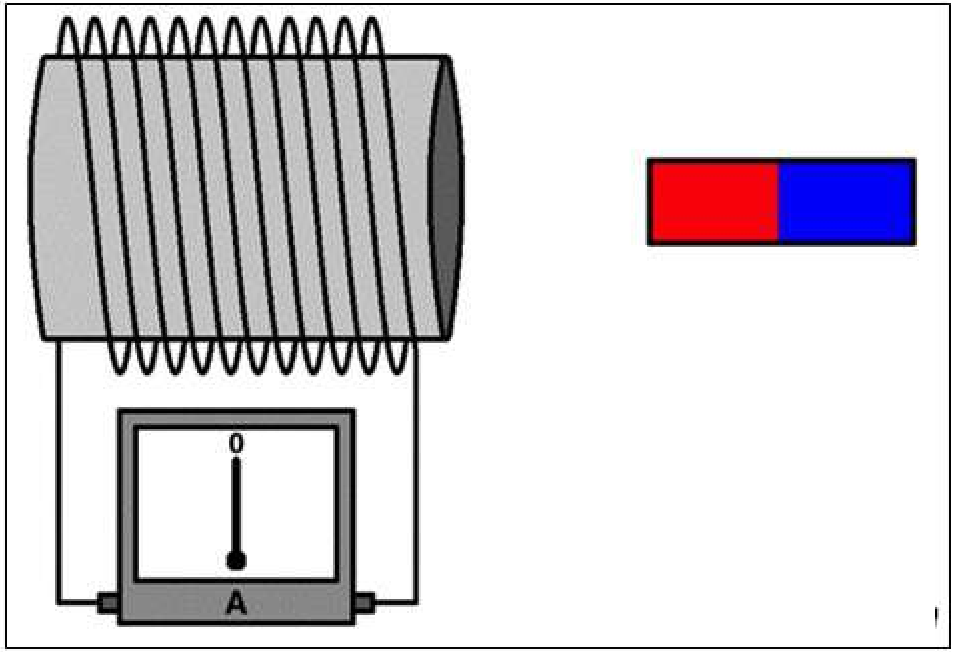
- Faraday discovered that when he moved a magnet near a wire a voltage was generated across the conductor.
- If the magnet was held stationary no voltage was generated, the voltage only existed while the magnet or coil was moving.



- This voltage is known as "**induced emf/voltage**" and the current due to this voltage is called "**induced current**".

Electromagnetism





Observe the direction of pointer of the galvanometer when motion of the magnet is reversed.

Faraday's Laws of Electromagnetic Induction

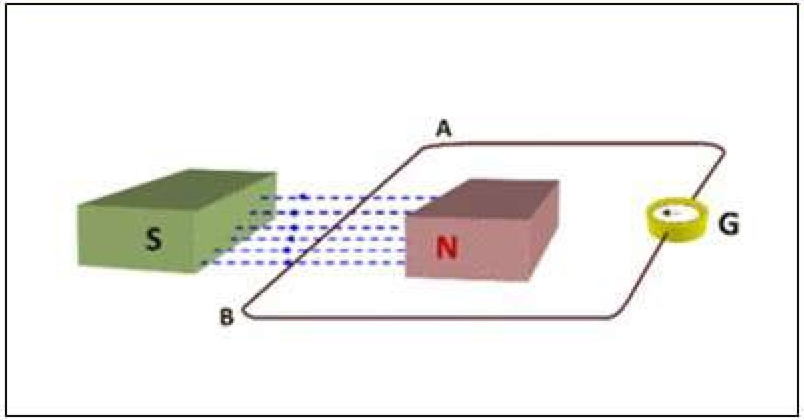
- Faraday summed up the facts from his experiment into two laws known as **Faraday's Laws of Electromagnetic Induction**.

Faraday's First Law

- Whenever the magnetic flux linked with a circuit changes, an emf is always induced in it.

OR

- Whenever a conductor cuts magnetic flux, an emf is induced in that conductor.



Faraday's Second Law

- The magnitude of the induced emf is equal to **the rate of change of flux-linkages**.

- Suppose a coil has **N turns** and flux through it changes from an initial value of $\boldsymbol{\Phi_1}$ webers to the final value of $\boldsymbol{\Phi_2}$ webers in **time t** seconds.

Initial flux linkages = $N\Phi_1$

Final flux linkages = $N\Phi_2$

$$\text{Induced emf} = \frac{\text{Change in flux}}{\text{Time}} = \frac{N\Phi_2 - N\Phi_1}{t} \; Wb/s$$

$$e = N\frac{\Phi_2 - \Phi_1}{t} \text{ volt}$$

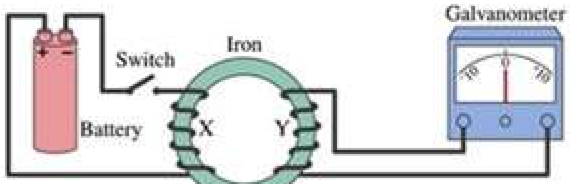
- Putting the above expression in its differential form, we get

$$e = \frac{d}{dt}(N\Phi) = N\frac{d\Phi}{dt} \text{ volt}$$

- Usually, a minus sign is given to the right-hand side expression to signify the fact that the induced emf sets up current in such a direction that magnetic effect produced by it opposes the very cause producing it.

$$e = -N\frac{d\Phi}{dt} \text{ volt}$$

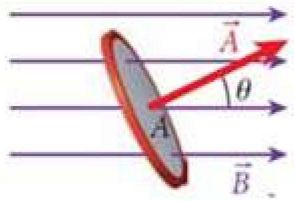
Electromagnetism



$$\mathcal{E} = -\frac{d\Phi}{dt}$$

Magnetic flux, ϕ → **Faraday's Experiment** → **Faraday's Law (1831)** → **Lenz's Law (1834)**

$$\Phi = \vec{B} \bullet \vec{A} = BA\cos\theta$$



- a *steady magnetic flux/ field* produces *no current*
- a *changing magnetic* flux/ field can *produce an electric current* → *induce current*

- the magnitude of the induced emf is proportional to the rate of change of the magnetic flux

- an induced electric current always flows in such a direction that it opposes the change producing it

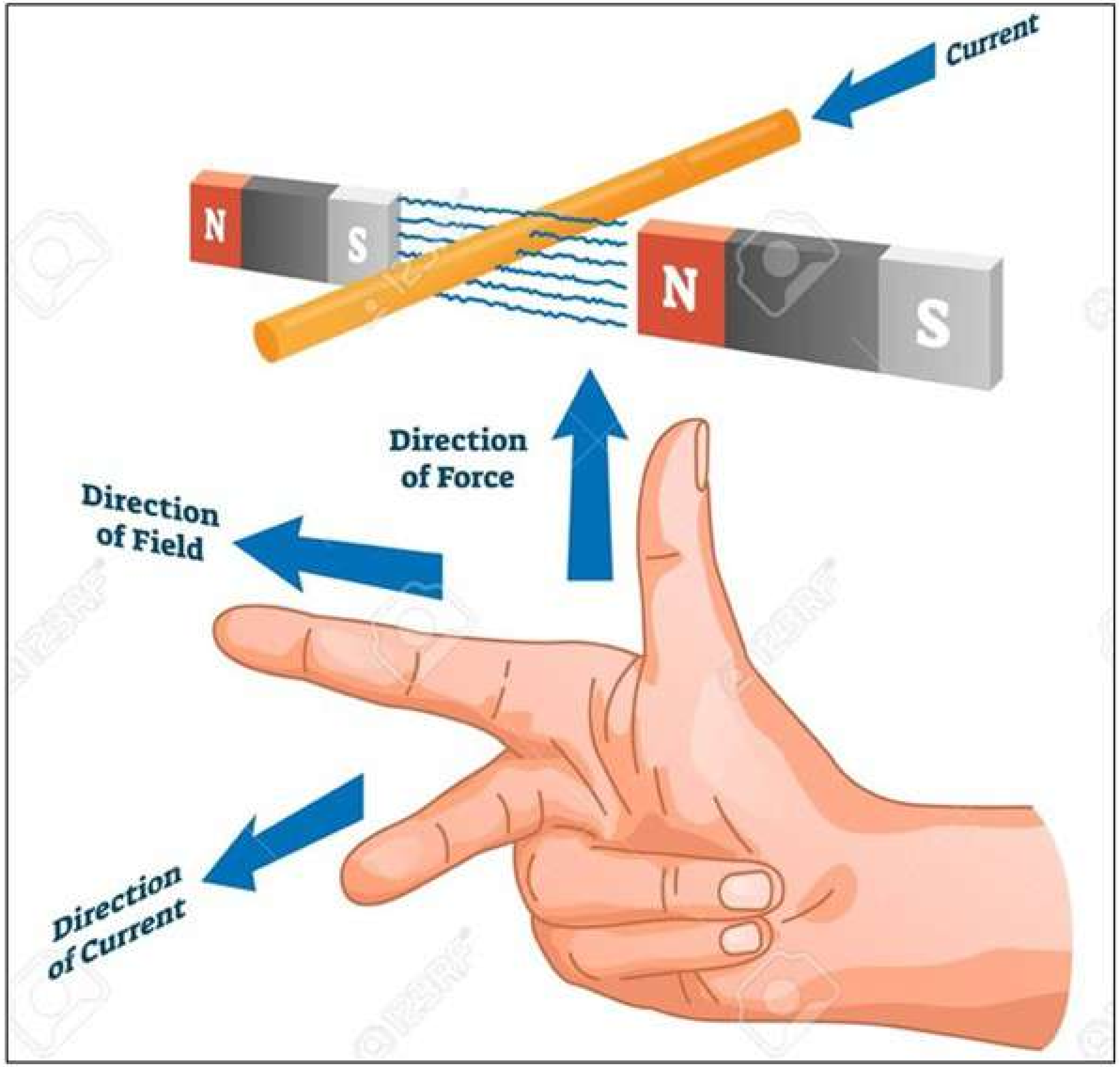
Direction of Induced emf and Currents

- There exists a definite relation between
  - the direction of the induced current,
  - the direction of the flux and
  - the direction of motion of the conductor
- The direction of the induced current may be found easily by applying either **Fleming's Right-hand Rule** or **Flat-hand rule** or **Lenz's Law**.

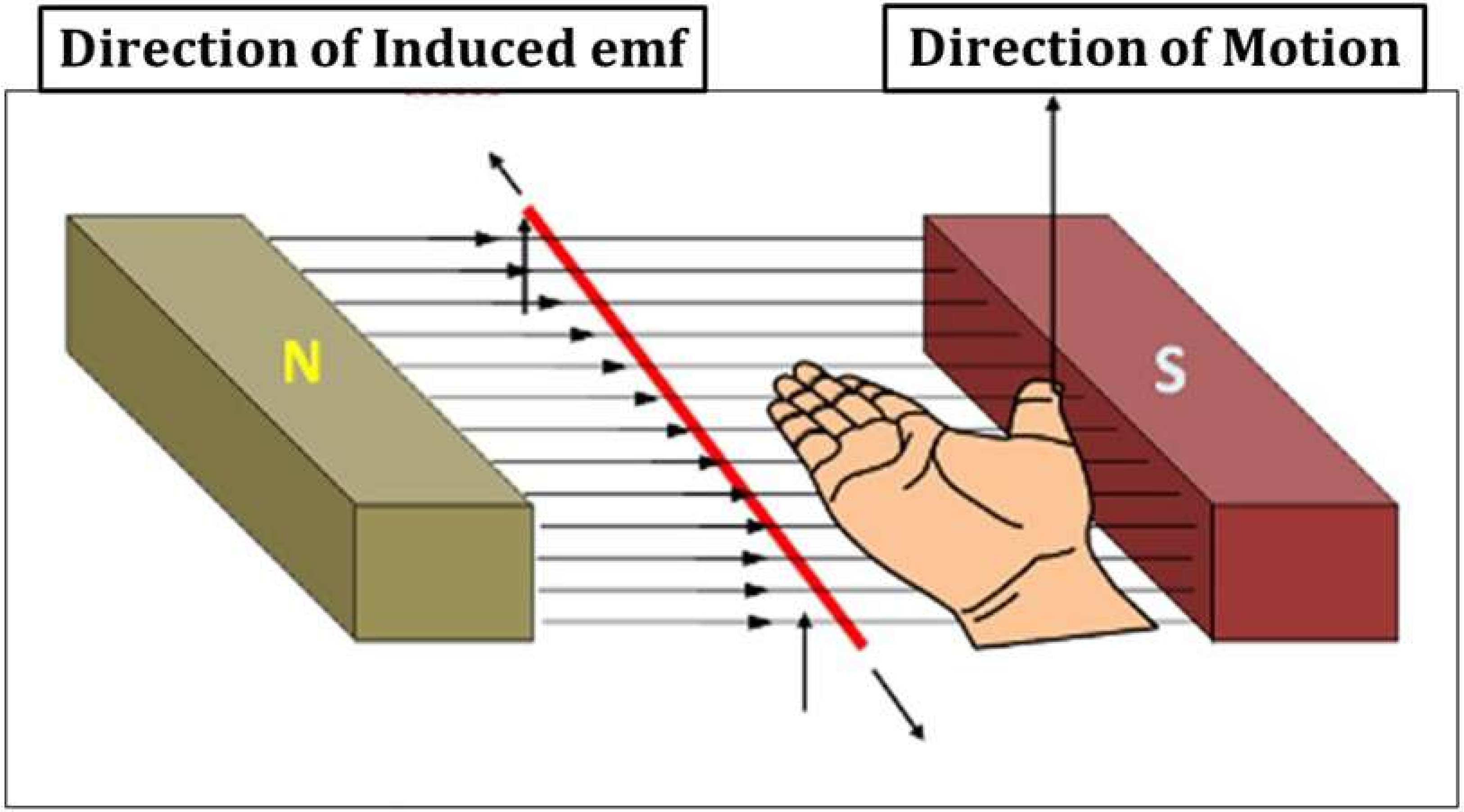
Fleming's Rule → **Dynamically induced emf**

Lenz's Law → **Statically induced emf**

Electromagnetism



Fleming's Right-hand Rule



Right Flat-hand Rule

Lenz's Law

- Electromagnetically induced current always flows in such direction that the action of the magnetic field set up by it tends to oppose the very cause which produces it.