Basics of Electrical and Electronics

BTEC101

Unit-1

Prof. Mansi Rastogi

- **Electric Charges**

Charge is the most fundamental quantity of electric circuits. In most electric circuits, the basic charge is that of an electron, which is -1.602×10^{-19} coulombs (C).
A proton has a charge of $+1.6 \times 10^{-19}$ C.

The entity, charge, is expressed as Q or q. If the charge is constant, we use Q. If the charge is in motion we use q(t) or q.

1.The Coulomb is a large unit for charges. In 1 C of charge, there are $1/(1.602 \times 10^{-19}) = 6.24 \times 10^{18}$ electrons.

2. The law of conservation charge states that charge can be neither be created nor destroyed, only transferred.

3.The charge of an object, Q, is always a multiple of this elementary charge: $Q = Ne$, where N is an integer.

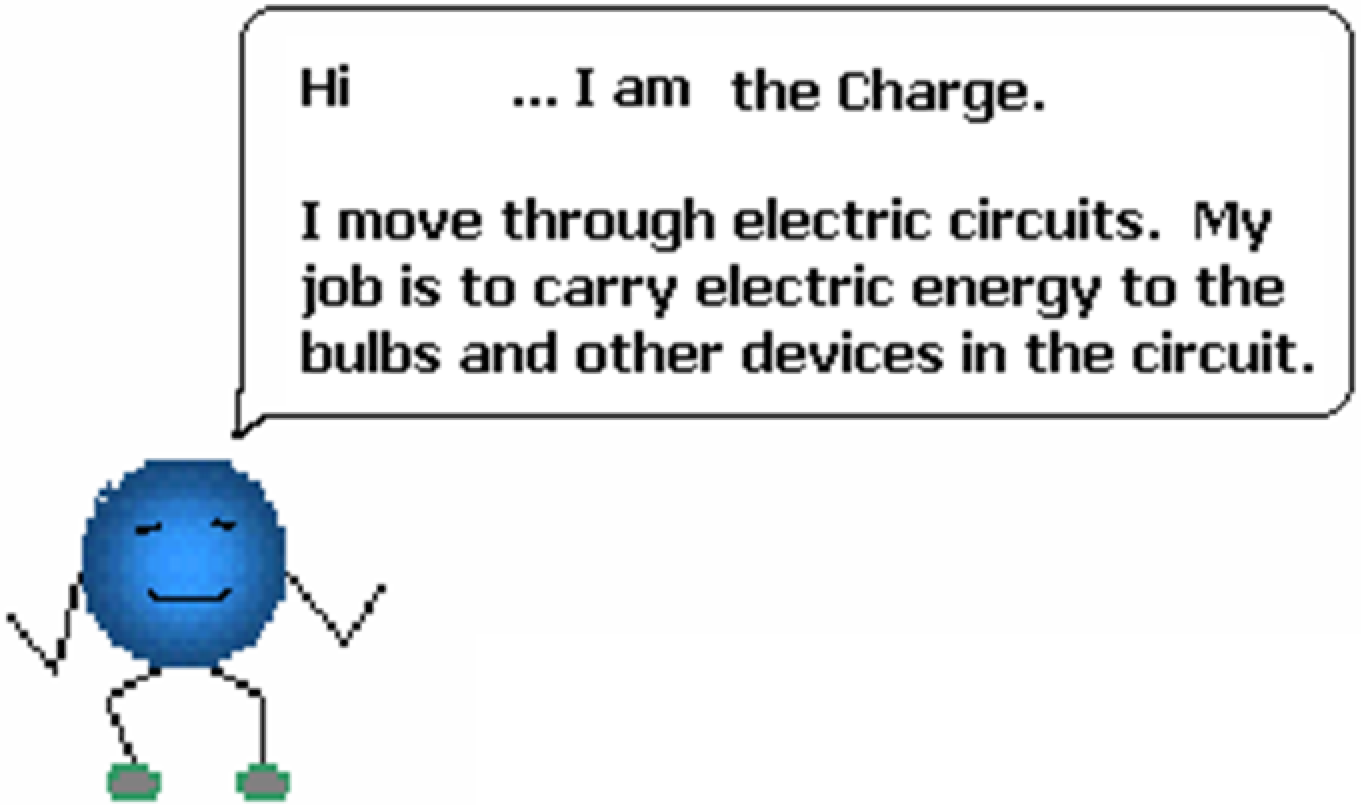
Electron  Proton

−1.602×10−19 C 1.602×10−19 C

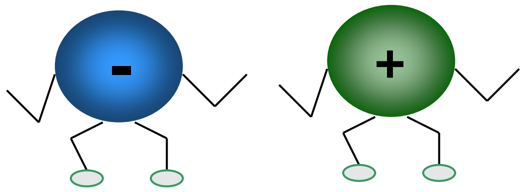
The unit of quantity of electric charge is **coloumb (C)**

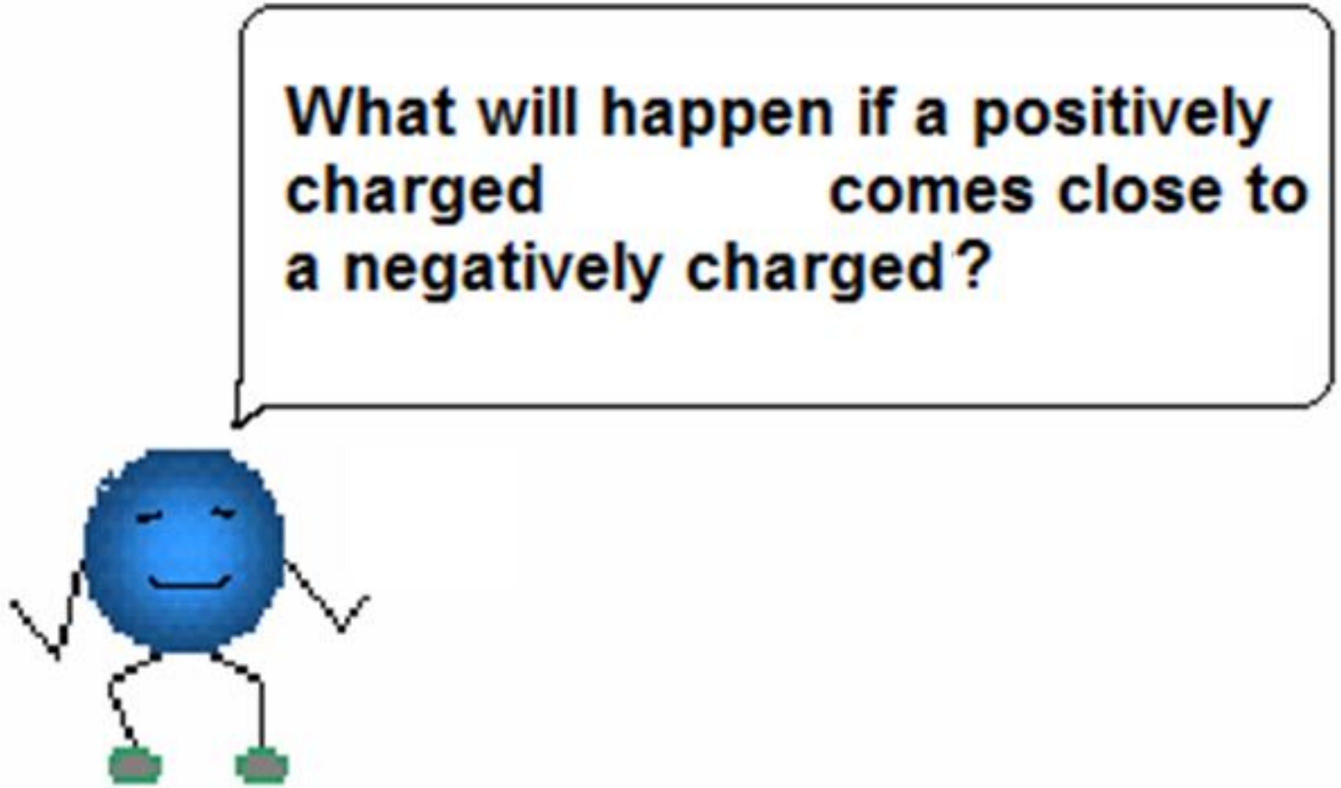
1 coloumb = 6.25 × 1018 ***e***

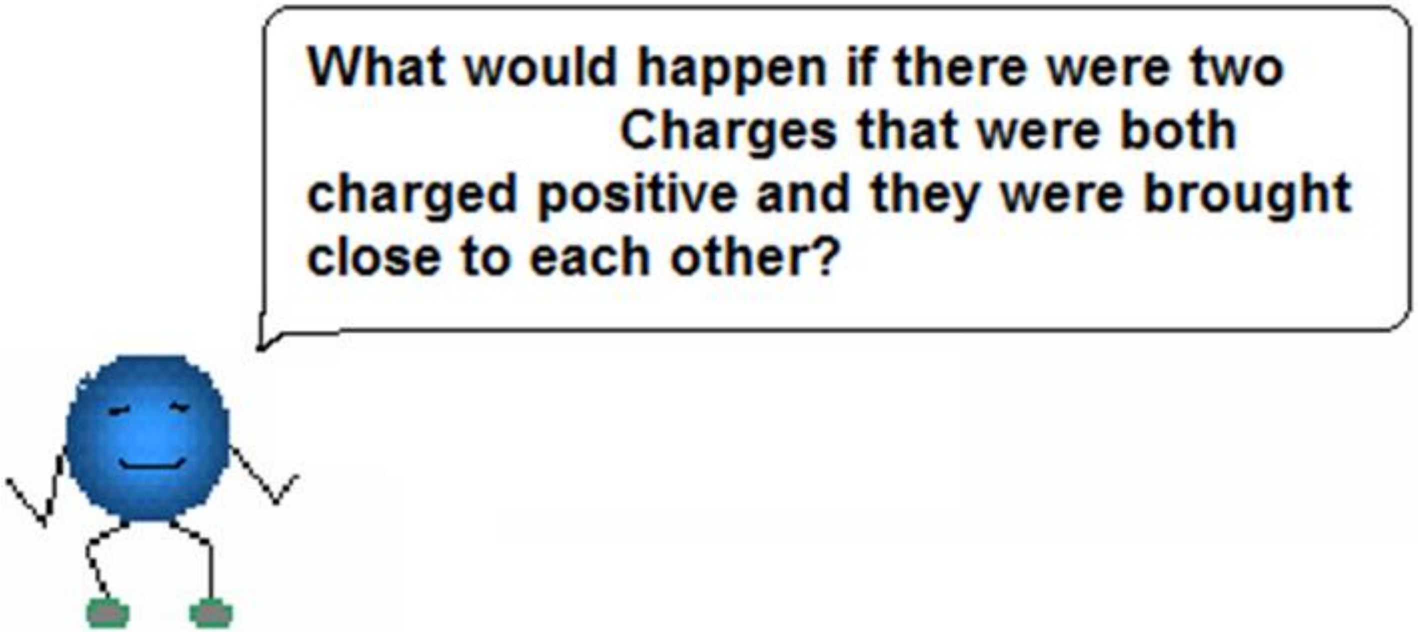
e = elementary charge = charge of proton

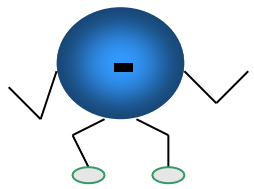

Hi ... I am the Charge.
I move through electric circuits. My job is to carry electric energy to the bulbs and other devices in the circuit.

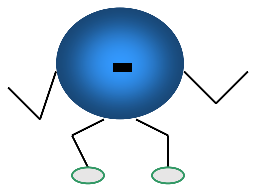
Charge can have a **Negative** or **Positive** charge




What will happen if a positively charged comes close to a negatively charged?

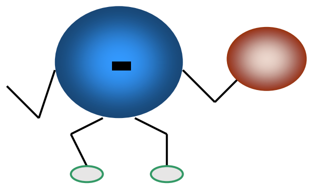

What would happen if there were two Charges that were both charged positive and they were brought close to each other?

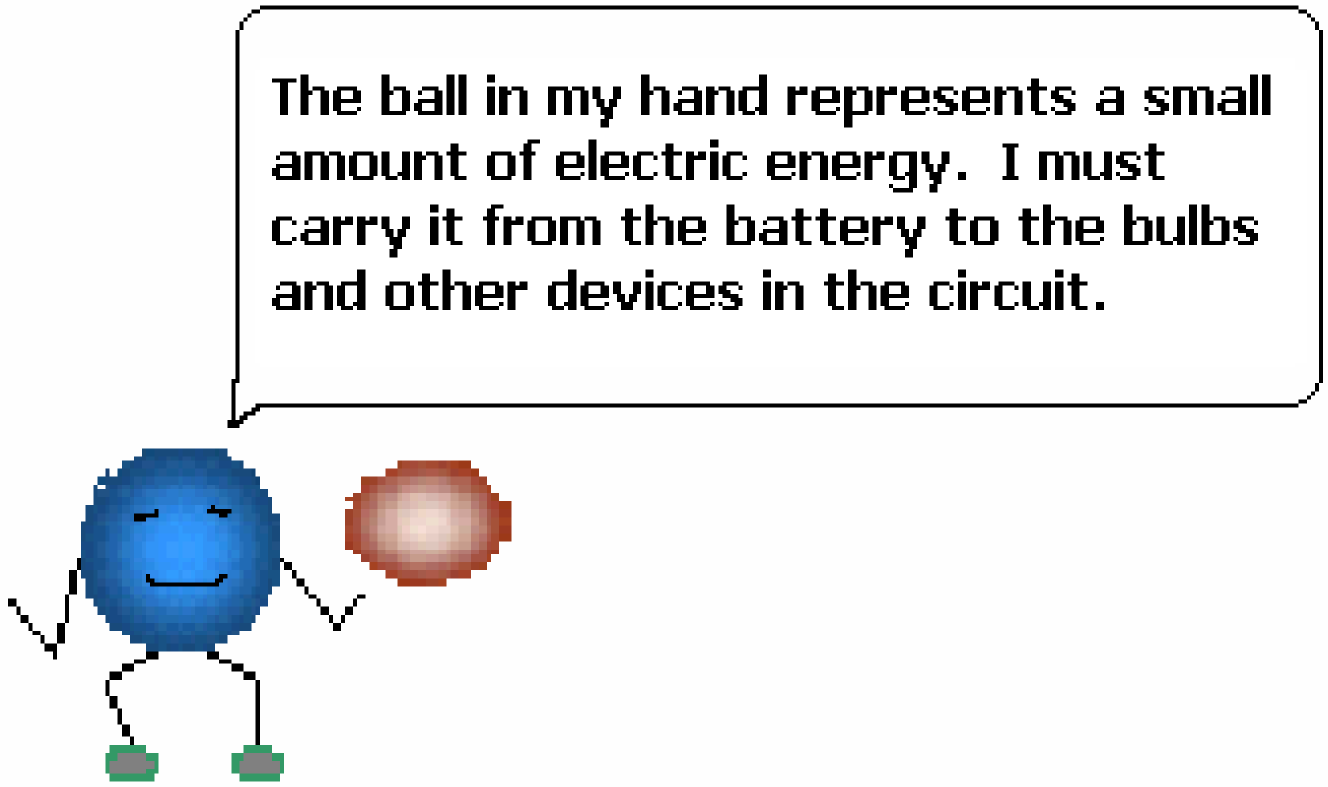


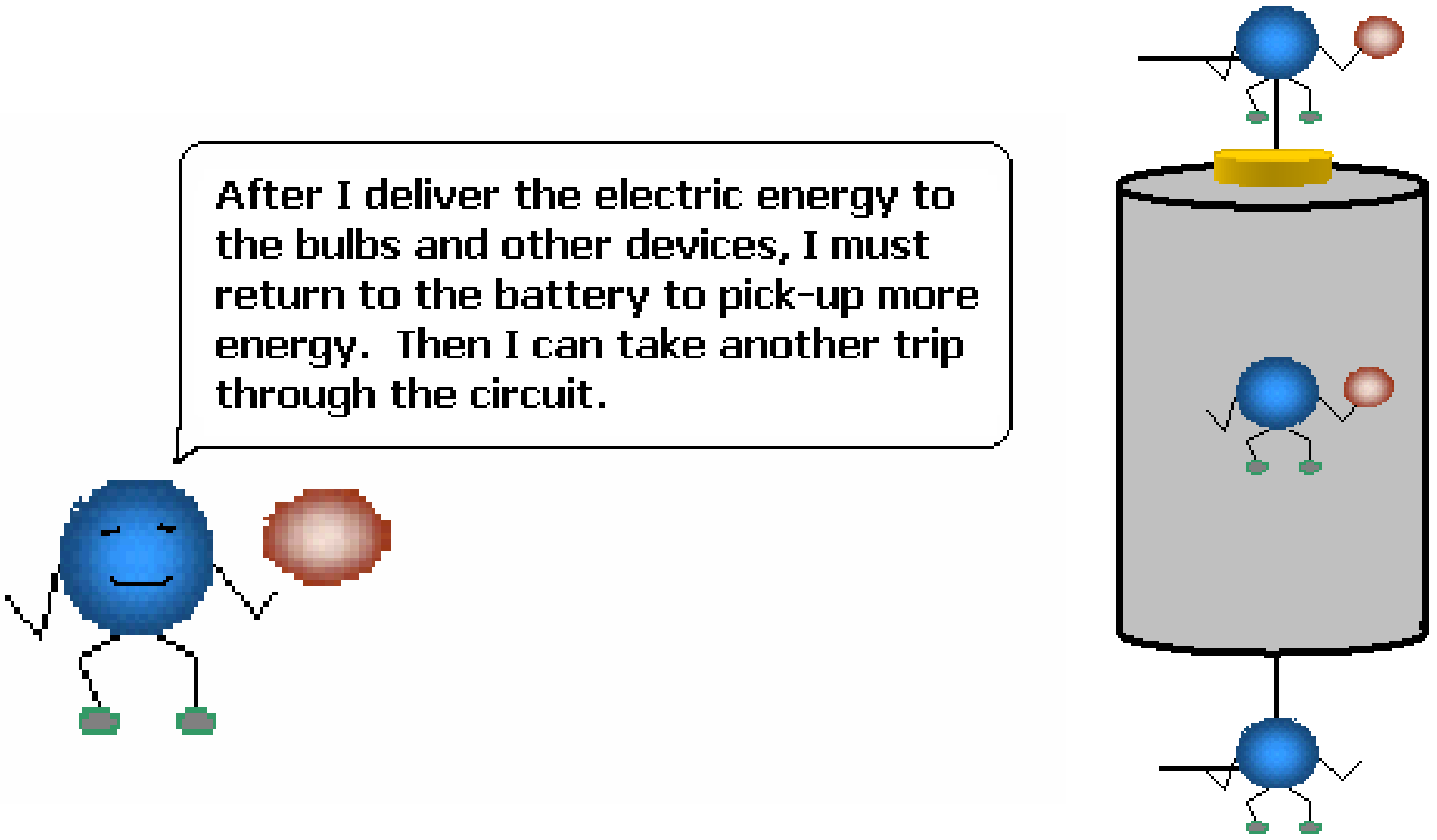


Charge can also have

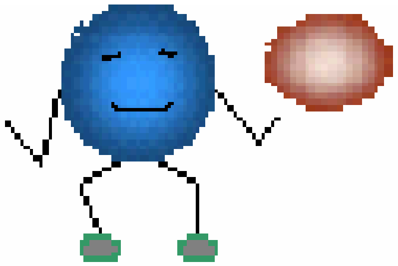
Energy

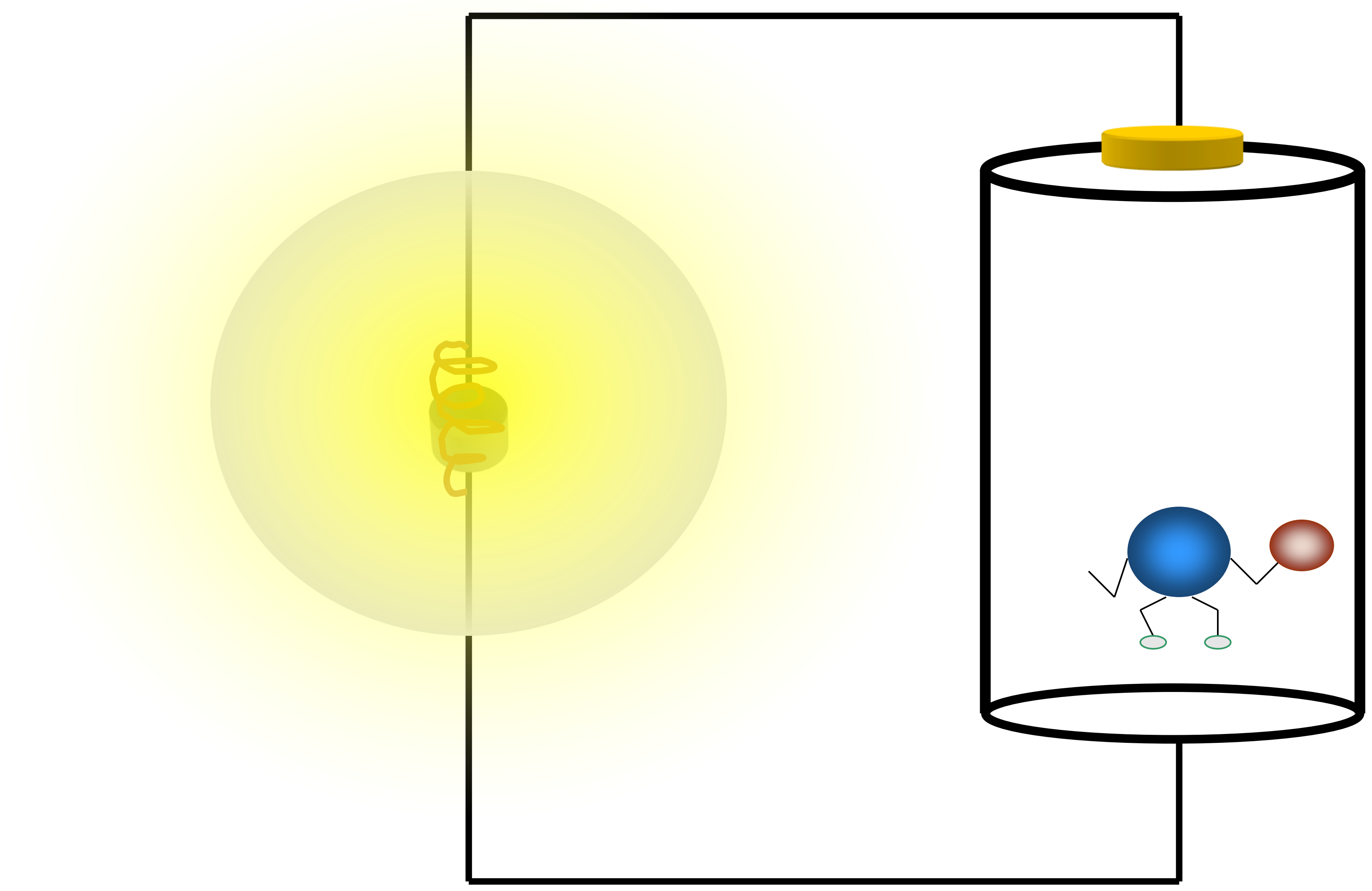


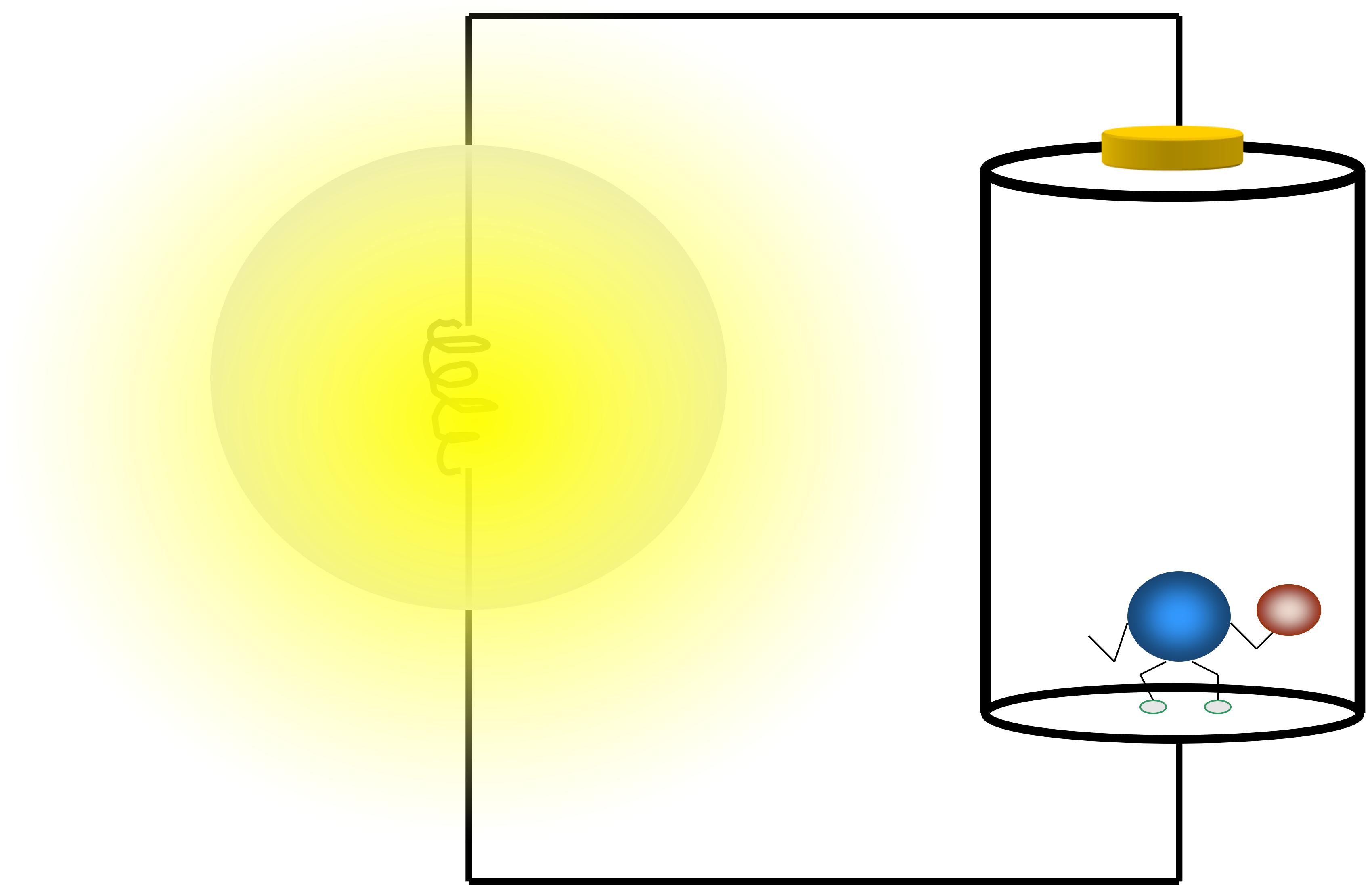

The ball in my hand represents a small amount of electric energy. I must carry it from the battery to the bulbs and other devices in the circuit.


After I deliver the electric energy to the bulbs and other devices, I must return to the battery to pick-up more energy. Then I can take another trip through the circuit.

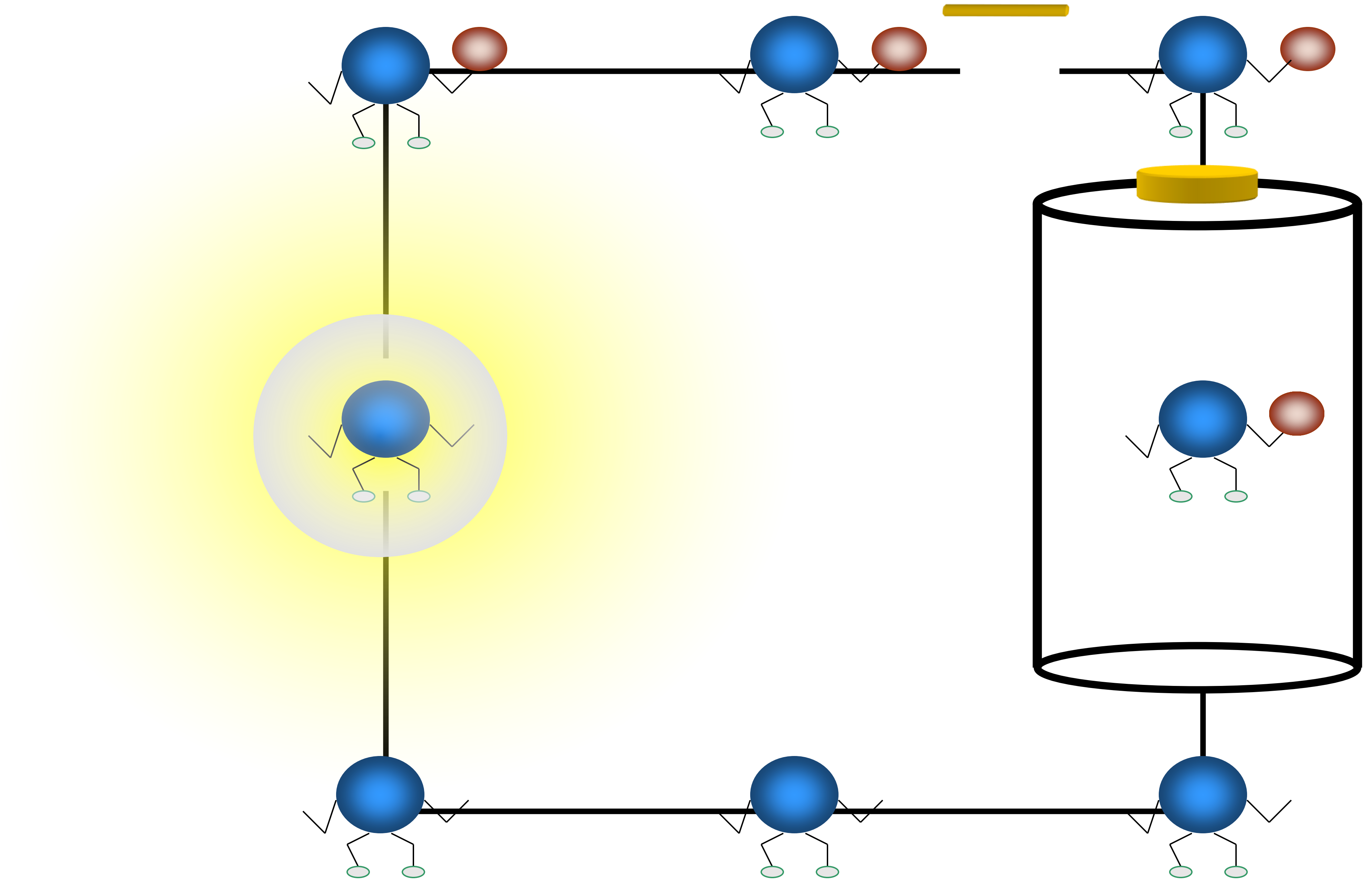
Carefully watch me as I deliver electric energy to the bulb in the circuit. In the first animation, I will go through the circuit step-by-step, but in the second animation I will move normally through the circuit. Watch carefully as I deliver the energy!

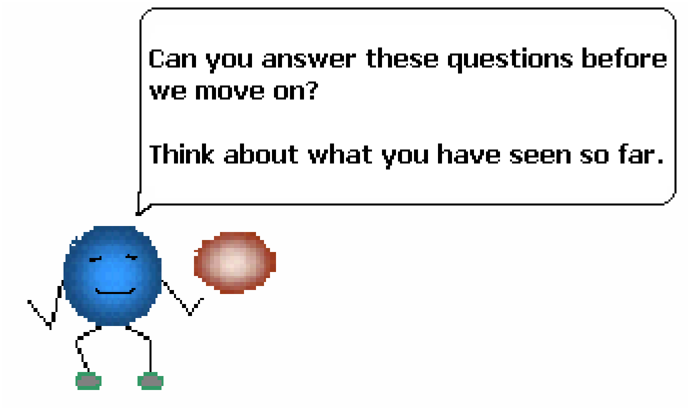




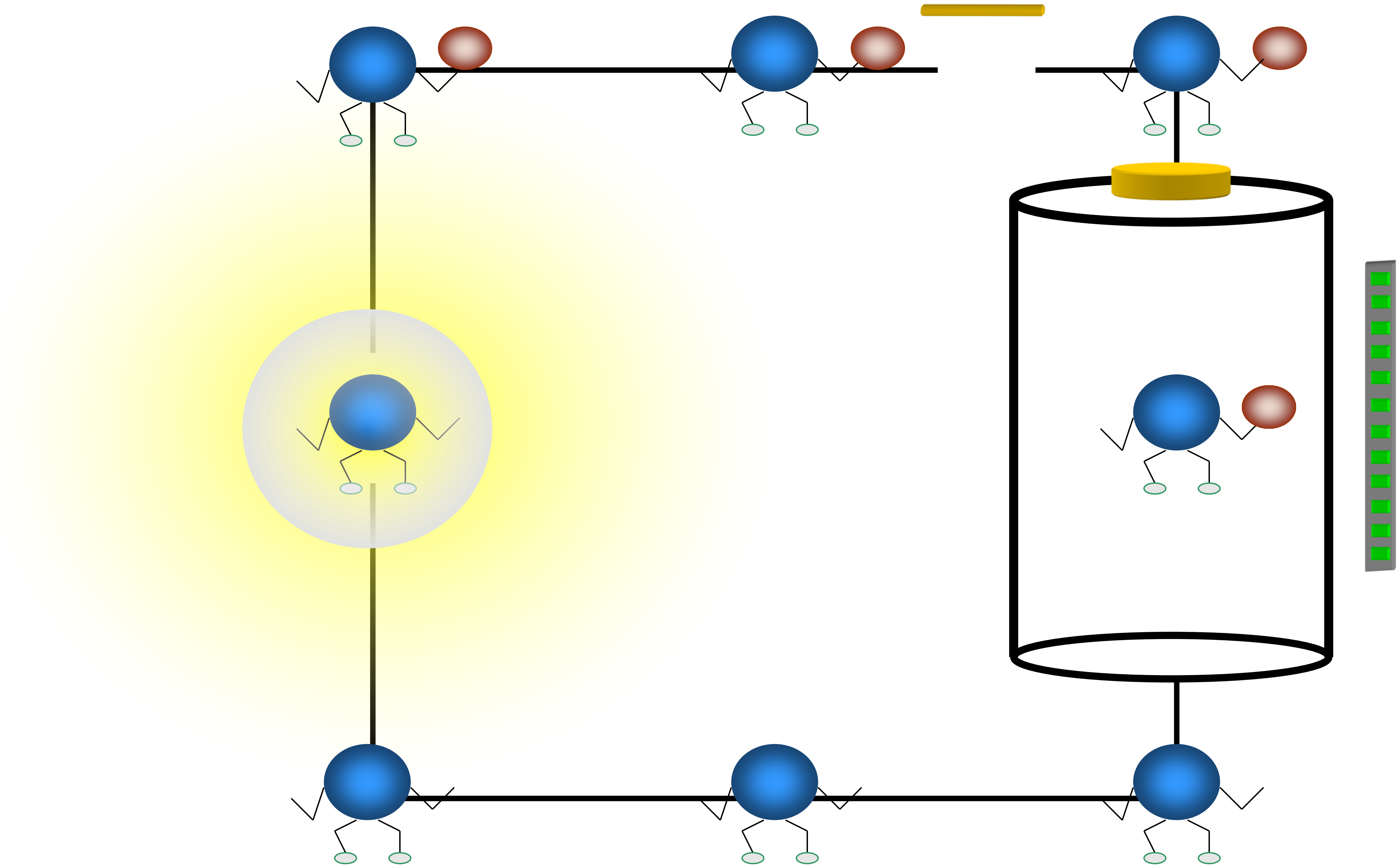



Now I can't keep things going all by myself, so I have a few friends help me out.
Let's see a more realistic model...





- What happens to the electric charge after one full loop through the circuit?
- What happens to the electric energy that the charge carries?

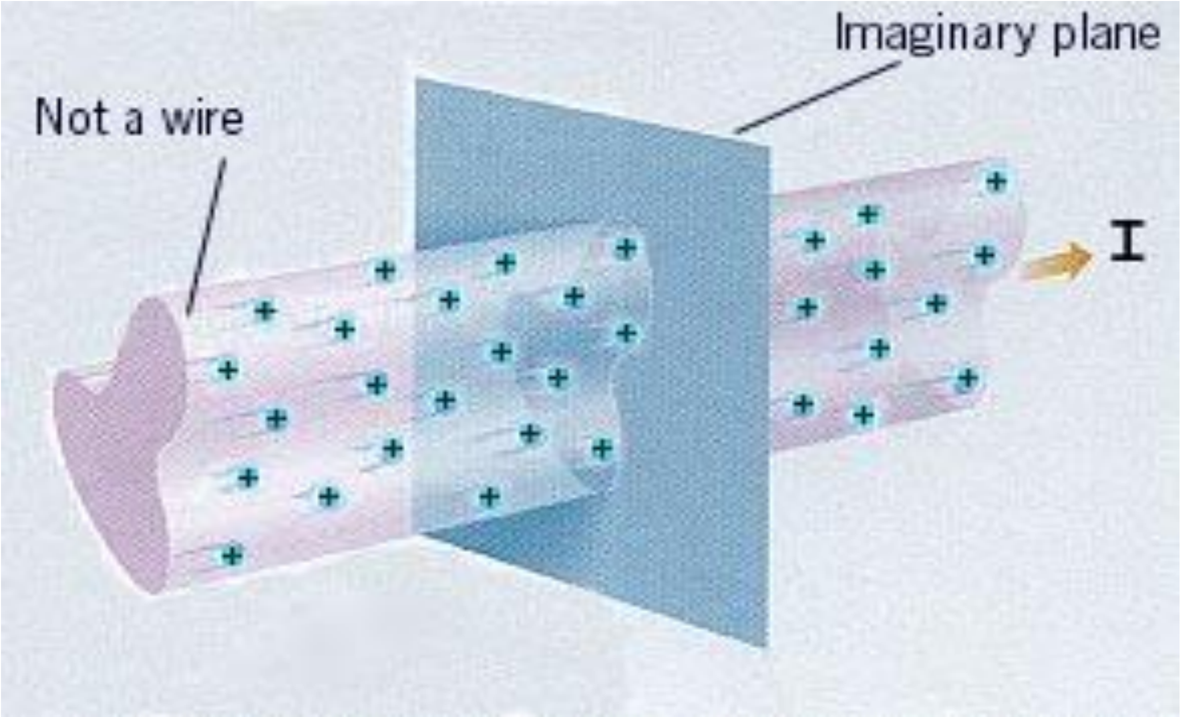


Electric Current

- An electric current is a flow of charge.
- In metals, current is the movement of negative charge, i.e. electrons
- In gases and electrolytes ($NaCl$ solution), both positive and negative charges may be involved.

Electric Current

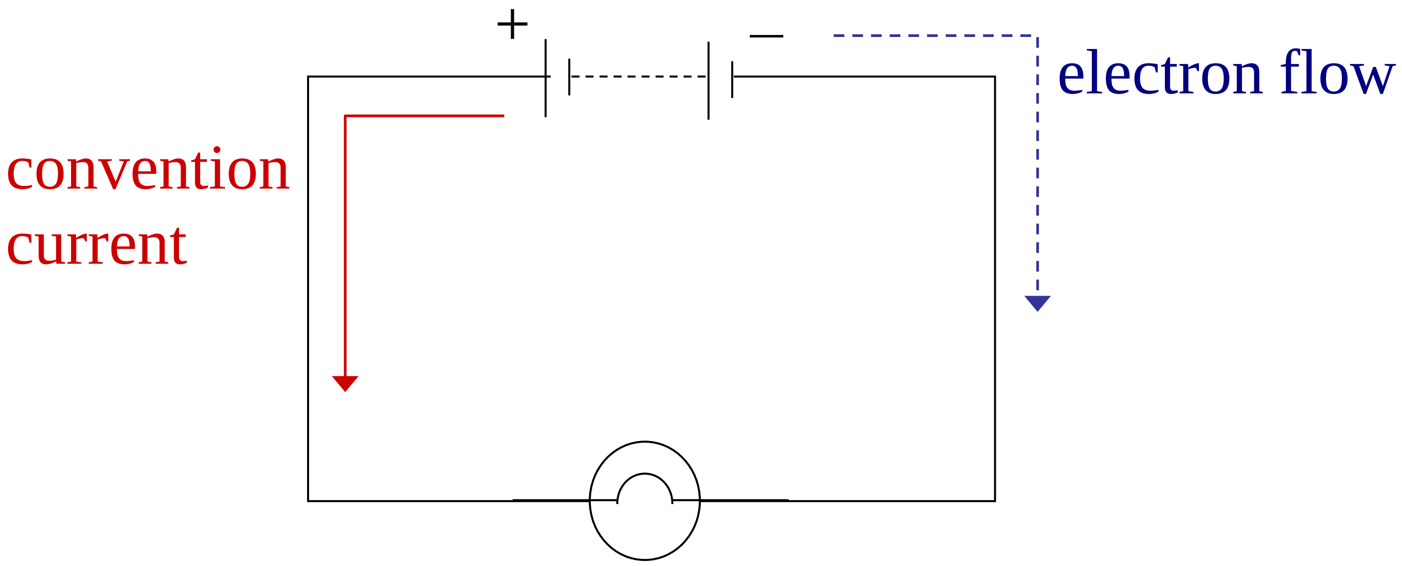
- *Current is the rate at which charge is flowing in a circuit. It is the amount of charges that pass through any point of the circuit per unit time.*
- i.e. $I = Q / t$



- Current is measured in ampere, A, where $1\ A = 1\ C\ s^{-1}$.

Conventional current

- Scientist first thought that positive charges flow from the positive terminal of a cell to the negative terminal. This is called the **conventional current** direction.
- However, it was found that a current in a metal wire is in fact a flow of negatively-charged electrons in the opposite direction. Nevertheless, the conventional current is still used.



1) Electric current :-

Electric current :- is the flow of electrons through a conductor.

The device which causes the flow of electrons through a conductor is called a cell.

Electrons flow from the negative terminal to the positive terminal.

Electric current flows from the positive terminal to the negative terminal.

This is called conventional current.

Electric current is expressed as :- The rate of flow of charges through a conductor or the quantity of charges flowing through a conductor in unit time.

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

I – current

Q – quantity of charge

t – time

The SI unit of electric charge is coulomb (C). It is the charge contained in 6×10^{18} electrons.

The SI unit of current is called ampere (A).

One ampere is the current flowing through a conductor if I coulomb of charge flows through it in 1 second.

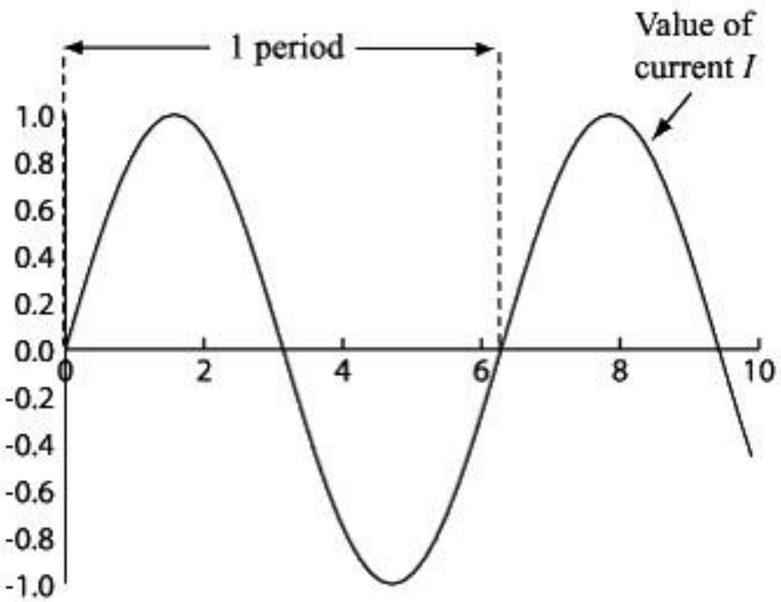
$$1\text{ampere} = \frac{1\text{coulomb}}{1\text{ second}}$$

Electric Current is measured by an ammeter. It is always connected in series in a circuit.

AC vs DC Current

Direct Current (DC) - electricity that you get from batteries - current (movement of electrons) flows in one direction - from positive (high potential) to negative (low potential) - note: electrons actually flow from negative to positive.

Alternating Current (AC) - electricity that comes from the wall plug in your home - current alternates in direction flowing first one way then the other - electrons move back and forth in wire



1. *A direct current (dc) is a current that remains constant with time (I)*
2. *An alternating current (ac) is a current that varies sinusoidally with time (i).*

2) Electric potential and Potential difference :-

Electric current will flow through a conductor only if there is a difference in the electric potential between the two ends of the conductor. This difference in electric potential between the two ends of a conductor is called potential difference.

The potential difference in a circuit is provided by a cell or battery. The chemical reaction in the cell produces a potential difference between the two terminals and sets the electrons in motion and produces electric current.

Potential difference :- between two points A and B of a conductor is the amount of work done to move a unit charge from A to B.

$$\text{Potential difference} = \frac{\text{Work done}}{\text{Charge}} \quad \text{or} \quad V = \frac{W}{Q}$$

The SI unit of potential difference is volt (V).

One volt is the potential difference when 1 joule of work is done to move a charge of 1 coulomb from one point to the other.

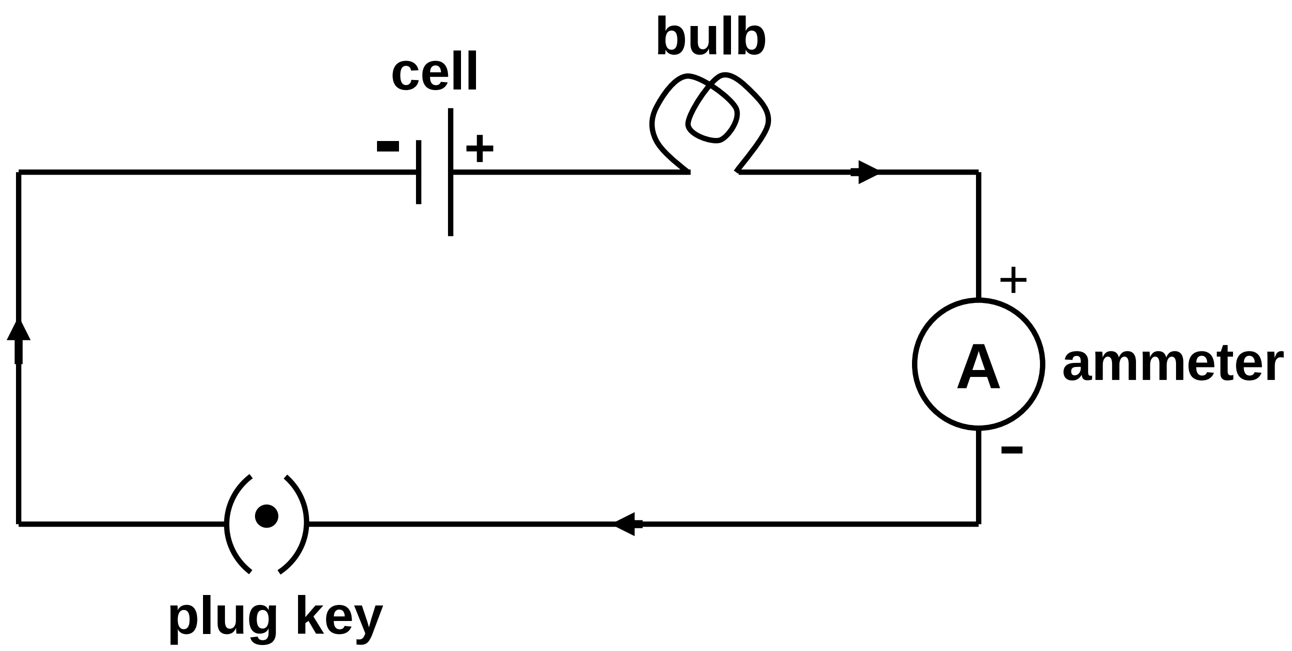
$$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}} \quad \text{or } 1\ V = \frac{1J}{1C}$$

Potential difference is measured by a voltmeter. It is always connected in parallel across the two point between which the potential difference is to be measured.

3a) Electric circuit :-

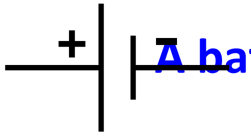
Electric circuit :- is a continuous and closed path of an electric current.

A schematic diagram of an electric circuit comprising of a cell, electric bulb, ammeter and plug key.

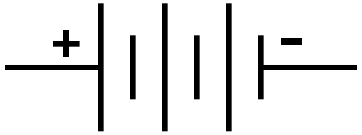


b) Symbols of components used in electric circuits :-

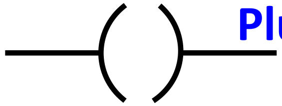
An electric cell

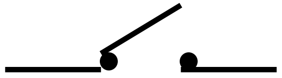


A battery or combination of cells

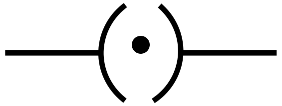


Plug key or switch (open)

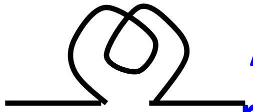




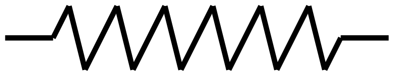
Plug key or switch (closed)



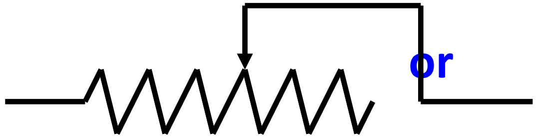
Electric bulb



A resistor of resistance R

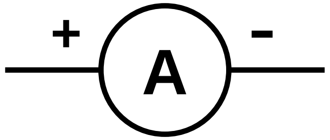


Variable resistance or rheostat

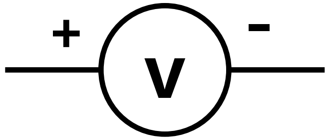


or

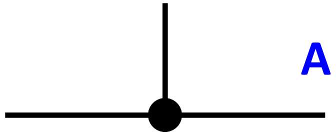
Ammeter



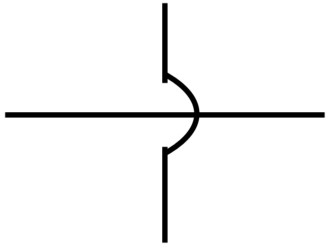
Voltmeter



A wire joint

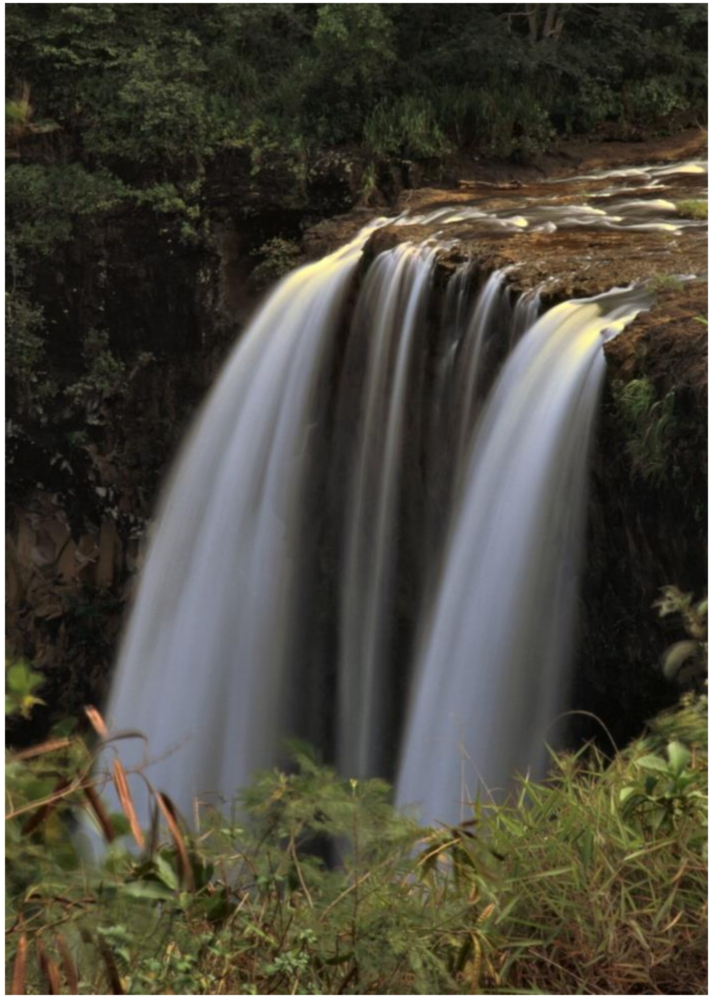


A wire crossing over without joining



How you should be thinking about electric circuits:

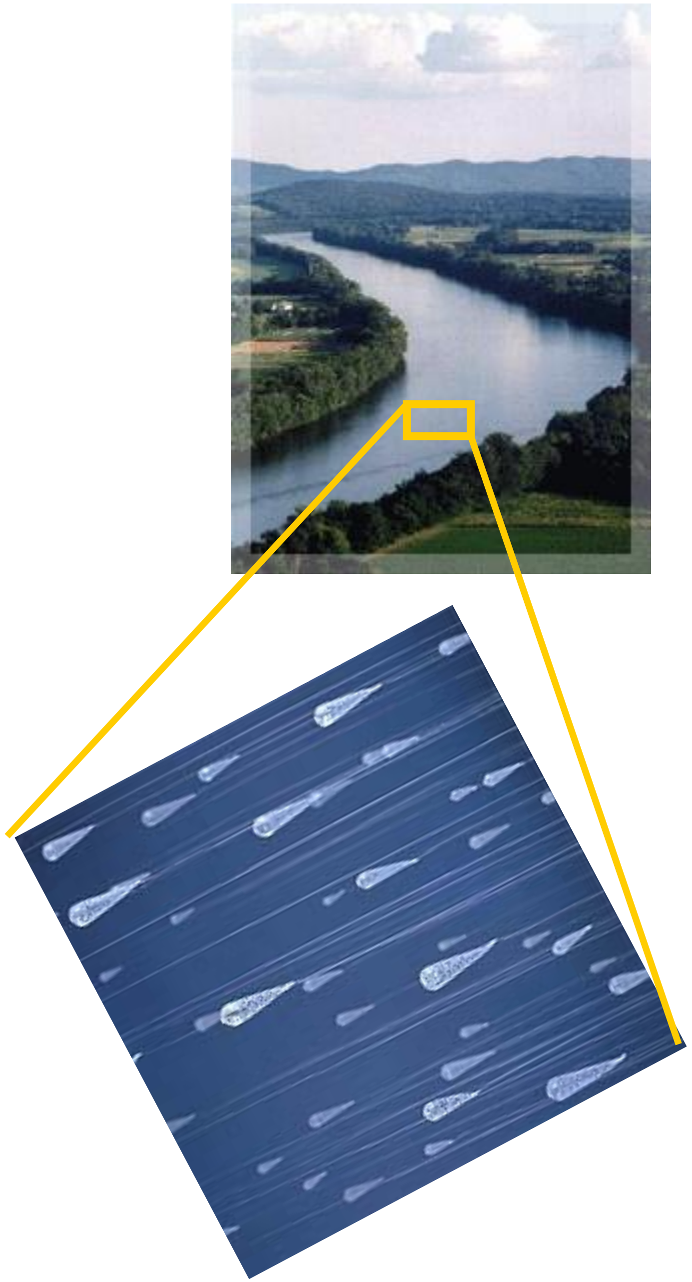
<u>Voltage</u>: a force that pushes the current through the circuit (in this picture it would be equivalent to gravity)



How you should be thinking about electric circuits:

Resistance: friction that impedes flow of current through the circuit (rocks in the river)

How you should be thinking about electric circuits:



Current: the actual "substance" that is flowing through the wires of the circuit (electrons!)

Would This Work?

Would This Work?

Would This Work?

The Central Concept: Closed Circuit

RESISTANCE

The opposition offered to the flow of electric current or free electrons, as shown in Figure 1.5, is called resistance.

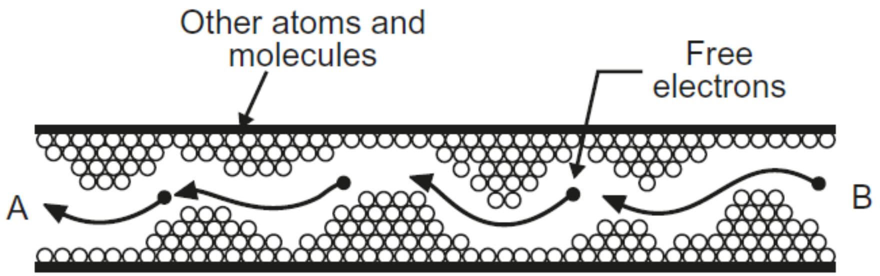


Fig. 1.5 **Opposition offered to electric current**

Unit: Resistance is measured in ohm (or kilo ohm) and is denoted by symbol Ω or kΩ.

A wire is said to have a resistance of one ohm if one ampere current passing through it produces a heat of 0.24 calorie (or one joule).

Laws of Resistance

The resistance (R) of a wire depends upon the following factors:

1. It is directly proportional to its length, l, that is, $R \propto l$.
2. It is inversely proportional to its area of cross section, a, that is,

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

3. It depends upon the nature (i.e., atomic structure) of the material of which the wire is made.
4. It also depends upon the temperature of the wire.

Neglecting the last factor for the time being $R \propto \frac{1}{a}$ or $R = \rho \frac{1}{a}$

where ρ ('Rho' a Greek letter) is a constant of proportionality called resistivity of the wire material. Its value depends upon the nature (i.e., atomic structure) of the wire material representing the third factor earlier.

RESISTIVITY

The resistivity of a wire is given by the relation: $R = \rho \frac{1}{a}$

If $l = 1$ m and $a = 1$ m^2 (Fig. 1.6(a)), then $R = \rho$

Hence, the resistance offered by one-metre length of wire of given material having an area of cross-section of one square metre is called the resistivity of the wire material.

In place of wire, if a cube of one metre side of a given material is taken as shown in Figure 1.6(b), then consider opposite two faces of the cube.

$$l = 1 \text{ m}; a = 1 \times 1 = 1 \text{ m}^2 \text{ and } R = \rho$$

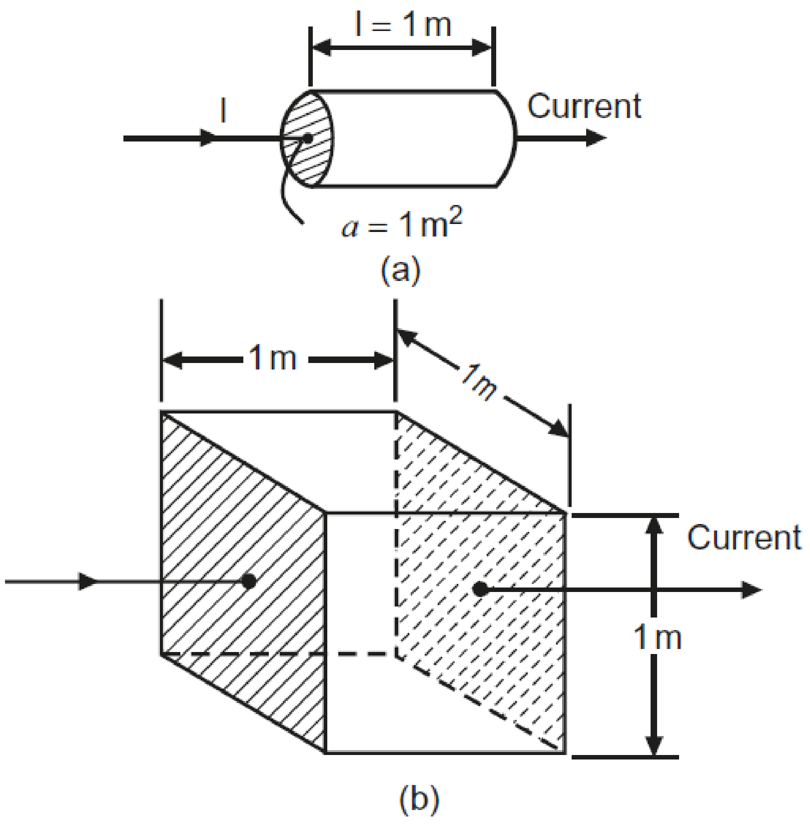


Fig. 1.6 Conductor size to determine specific resistance (a) Wire (b) Cube of 1 m side

RESISTIVITY

Hence, the resistance offered between the opposite two faces of one-metre cube of the given material is called the resistivity of that material.

Unit: We know that $R = \rho\dfrac{l}{a}$ or $\rho = \dfrac{Ra}{l}$

Substituting the units of various quantities as per SI units, we get

$$\rho = \frac{\Omega \times \mathrm{m}^2}{\mathrm{m}} = \Omega - \mathrm{m}$$

Hence, the unit of resistivity is ohm metre in SI units.

SPECIFIC RESISTANCE

Specific resistance of a material is defined as the resistance of the material having specific dimensions, that is, one-metre length and one square metre as area of cross-section.

CONDUCTANCE

The ease to the flow of current is called conductance. It is generally denoted by letter G.

We know that the opposition to the flow of current is called resistance. Hence, conductance is just reciprocal of resistance, that is,

$$G = \frac{1}{R} = \frac{1 \times a}{\rho\, l} = \sigma \frac{a}{l}$$

Unit: The unit of conductance is mho (i.e., ohm spelt backward). The symbol for its unit is ℧.

Conductivity

From the expression given earlier, σ('Sigma' a Greek letter) is called the conductivity or specific conductance of the material. It is basically the property or nature (i.e., atomic structure) of the material due to which it allows the current to flow (conduct) through it.

$$G = \sigma \frac{a}{l} \quad \text{or} \quad \sigma = G \frac{l}{a}$$

Substituting the units of various quantities, we get

$$\sigma = \frac{\mho \times \mathrm{m}}{\mathrm{m}^2} = \mho/\mathrm{m}$$

Hence, the unit of conductivity in SI units is mho/metre.

ELECTROMOTIVE FORCE

The electromotive force (emf) of a source, for example, a battery, is a measure of the energy that it gives to each coulomb of charge. Initially, emf implies that it is a force that causes the electrons (the charged particles, i.e., current) to flow through the circuit. In fact, it is not a force but it is an energy supplied by some active source such as battery to one coulomb of charge.

EMF AND POTENTIAL DIFFERENCE

The amount of energy supplied by the source to each coulomb of charge is known as emf of the source, whereas the amount of energy used by one coulomb of charge in moving from one point to the other is known as potential difference between the two points.

For instant, consider a circuit as shown in Figure 1.7. If a battery has an emf of 12 V, it means that the battery supplies 12 joule of energy to each coulomb of charge continuously. When each coulomb of charge travels from positive terminal to negative terminal through external circuit, it gives up whole of the energy originally supplied by the battery.

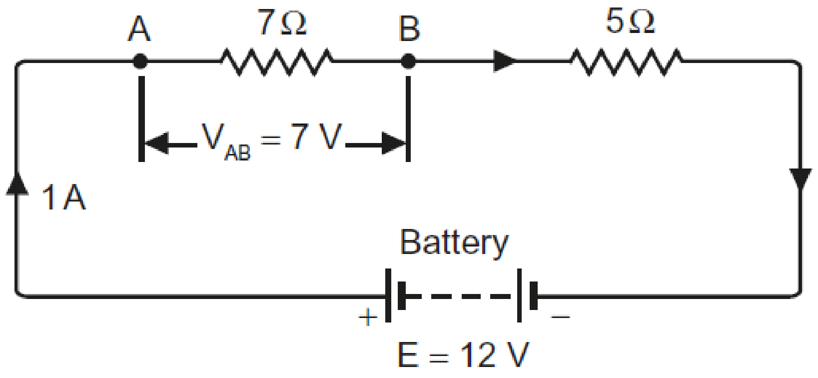


Fig. 1.7 Electric circuit to represent emf and potential difference

The potential difference between any two points, say A and B, is the energy used by one coulomb of charge in moving from one point (A) to the other (B). Therefore, potential difference between points A and B is 7 V.

OHM'S LAW

Ohm's law states that the current flowing between any two points of a conductor (or circuit) is directly proportional to the potential difference across them, as shown in Figure 1.8, provided physical conditions i.e. temperature etc. do not change.

Mathematically $I \propto V$

or $$\frac{V}{I} = \text{constant} \quad \text{or} \quad \frac{V_1}{I_1} = \frac{V_2}{I_2} = \cdots = \frac{V_n}{I_n} = \text{constant}$$

In other words, Ohm's law can also be stated as follows:

The ratio of potential difference across any two points of a conductor to the current flowing between them is always constant, provided the physical conditions, that is, temperature, etc., do not change.

This constant is called the resistance (R) of the conductor (or circuit).

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

It can also be written as $V = IR$ and $I = \dfrac{V}{R}$.

In a circuit, when current flows through a resistor, the potential difference across the resistor is known as voltage drop across it, that is, $V = IR$.

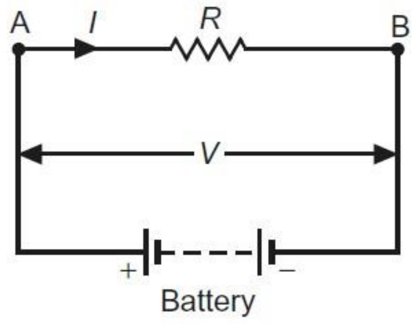


Fig. 1.8 Potential difference (voltage) applied across a wire having resistance R ohm

Limitations of Ohm's Law

Ohm's law cannot be applied to the non-linear clients such as circuits containing electronic tubes or transistors and the circuits used to produce electric arc.

Example

A current of 0.75 A is passed through a coil of nichrome wire which has a cross sectional area of 0.01 cm². If the resistivity of the nichrome is 108×10^{-6} ohm cm and the potential difference across the ends of the coil is 81 V. What is the length of the wire? What is the conductivity and conductance of the wire?

Solution:

Resistance, $$R = \rho\frac{1}{a}$$

$$R = \frac{V}{I} = \frac{81}{0.75} = 108\ \Omega;\ a = 0.01\,\text{cm}^2 = 0.01\times10^{-4}\,\text{m}^2$$

Where $$\rho = 108\times10^{-6}\,\Omega\ \text{cm} = 108\times10^{-8}\,\Omega\ \text{m}$$

∴ $$l = \frac{V}{I} = \frac{Ra}{\rho} = \frac{108\times0.01\times10^{-4}}{108\times10^{-8}} = 100\ \text{m (Ans.)}$$

Conductivity, $$\sigma = \frac{1}{\rho} = \frac{1}{108 \times 10^{-8}} = 92.59 \times 10^{4} \text{ mho/m (Ans.)}$$

Conductance, $$G = \frac{1}{R} = \frac{1}{108} = 9.259 \times 10^{-3} \text{ mho (Ans.)}$$

EFFECT OF TEMPERATURE ON RESISTANCE

The electrical resistance generally changes with the change of temperature. The resistance does not only increase with the rise in temperature but it also decreases in some cases. In fact, the increase or decrease in resistance with the rise in temperature depends on the nature of the resistance material discussed as follows:

1. **Pure metals:** When the resistance is made of some pure metal (copper, aluminium, silver, etc.), its resistance increases with the increase in temperature. The increase is large and fairly uniform for normal range of temperature, and therefore, temperature–resistance graph is a straight line. Thus, pure metals have positive temperature coefficient of resistance.

2. **Alloys:** When the resistance is made of some alloy (e.g., Eureka, Manganin, Constantan, etc.), its resistance increases with the increase in temperature. But the increase is very small and irregular. In the case of above-mentioned alloys, the increase in resistance is almost negligible over a considerable range of temperature.
3. **Semiconductors, insulators, and electrolytes:** The resistance of semiconductors, insulators, and electrolytes (silicon, glass, varnish, etc.) decreases with the increase in temperature. The decrease is non-uniform. Thus, these materials have negative temperature co-efficient of resistance.

ELECTRICAL ENERGY

When a potential difference V (volt) is applied across a circuit, as shown in Figure 1.11, a current I (ampere) flows through it for a particular period (t second). A work is said to be done by the moving stream of electrons (or charge) and is called electrical energy.

Thus, the total amount of work done in an electrical circuit is called electrical energy.

By definition, $$V = \frac{\text{Workdone}}{Q}$$

Therefore, work done or electrical energy expanded

$$VQ = VIt \text{ (since } I = Q/t\text{)}$$

$$= I^2Rt = \frac{V^2}{R}t$$

where V = potential difference in volt;
I = current in ampere;
t = time in second; and
R = resistance in ohm.

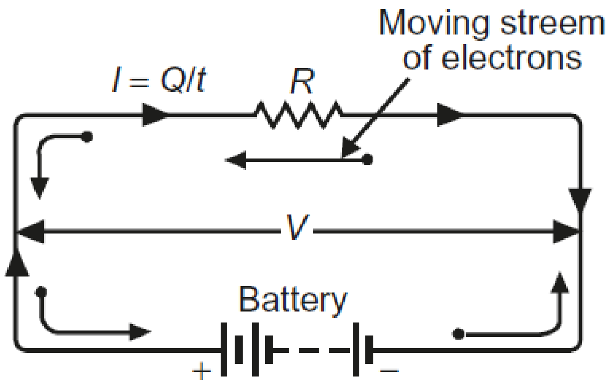


Fig. 1.11 Electrical energy consumed in a circuit

Units: The basic unit of electrical energy is joule (or Watt- second).

If, $V = 1$ V, $I = 1$ A, and $t = 1$ second

Then, electrical energy = 1 joule

Hence, the energy expanded in an electrical circuit is said to be one joule (or 1 watt-second) if one ampere current flows through the circuit for one second when a potential difference of 1 V is applied across it.

However, the practical or commercial unit of electrical energy is kilowatt-hour (kWh) which is also known as B.O.T. (Board of Trade) unit.

$$1 \text{ kWh} = 1000 \times 60 \times 60 \text{ watt-second} = 36 \times 10^5 \text{ Ws or joule}$$

Usually, 1 kWh is called one unit.

ELECTRICAL POWER

The rate at which work is being done in an electrical circuit is called electrical power.

$$\text{Hence, electrical power} = \frac{\text{Work done in an electric circuit}}{\text{Time}}$$

$$P = \frac{VIt}{t} = VI = I^2R = \frac{V^2}{R}$$

Unit: The unit of electrical power is watt (W).

If, $V = 1$ volt and $I = 1$ A. Then, $P = 1$ W.

Thus, the power consumed in an electrical circuit is said to be 1 W if 1 A current flows through the circuit when a potential difference of 1 V is applied across it.

However, the bigger unit of electrical power is kilowatt (kW), it is usually used in the power system.

$$1 \text{ kW} = 1000 \text{ W}$$

HEAT ENERGY

The form of energy which produces a sensation of warmth is called heat.

Mathematically,

Heat, $H = m\,S\,\theta$

Where m = mass of the body;

S = specific heat of the body; and

θ = rise or fall in temperature.

Unit: The unit of heat is kilocalorie (kcal)

If, $m = 1$ kg; $\theta = 1°C$, and $S = 1$, that is, specific heat of water.

Then, $H = 1$ kcal

Hence, the amount of heat required to raise the temperature of 1 kg of water through 1°C is called one kilocalorie.

However, the smaller unit of heat energy is calorie.

One calorie is defined as the amount of heat required to raise the temperature of 1 gram of water through 1°C.

$$1 \text{ kilocalorie} = 1000 \text{ calories}$$

MECHANICAL WORK

When a body, to which force is applied, moves in or opposite direction of the applied force, work is said to be done by or against the body.

Mathematically, Work = Force × distance or $W = F \times d$

Unit: The unit of work is Newton metre (Nm) or joule.

If, $F = 1$ N and $d = 1$ m; then, $W = 1$ Nm or joule.

Thus, when a force of 1 N applied on the body moves it to a distance of 1 m, the work done on the body is said to be 1 Nm or joule.

MECHANICAL POWER

The rate of doing work or the amount of work done per unit time is called power, that is,

$$\text{Power} = \frac{\text{Work done}}{\text{Time}}$$

Unit: The unit of mechanical power is Newton metre per second (i.e., Nm/s) or joule/second (i.e., J/s).

However, the practical unit of mechanical power is horse power.

In fact, the rate of doing 75 kg m of work per second is known as one horse power.

JOULES LAW OF ELECTRICAL HEATING

Joule (James Prescott Joule) established that there exists a definite relation between electrical energy expended and amount of heat produced. Thus, the relation is called Joule's law of electrical heating.

This law stated that the amount of heat produced (H) is directly proportional to the electrical energy expended (W).

That is, $$H \propto W \quad \text{or} \quad \frac{W}{H} = \text{J (constant)} \tag{1.11}$$

Where J is a constant called mechanical equivalent of heat and its value is determined as 4.18 joule per calorie (i.e., 1 calorie = 4.18 joule). It means that to produce one calorie of heat, 4.18 J of electrical energy is expended.

From equation (1.8), we get,

$$H = \frac{W}{\text{J}} \quad \text{or} \quad H = \frac{I^2 Rt}{4.18} \text{calorie}$$

where I^2Rt is the electrical energy in joule.

RELATION BETWEEN VARIOUS QUANTITIES

Some of the important relations between various electrical, mechanical, and thermal (heat) quantities are given below:

Relation between Horse Power and kW

By definition, 1 H.P. = 75 kg wt m/s

= 75 × 9.81 Nm/s or joule/s or watt

= 735.5 W, that is, 1 H.P. = 0.7355 kW

Relation between Horse Power and Torque

If a rotor of a radius r m rotates at a speed of N r.p.m. The force acting on the rotor tangential to its radius is F newton, then

$$\text{Work done in one rotation} = \text{Force} \times \text{distance covered/rev}$$

$$= F \times 2\pi r = 2\pi T \text{ Nm or joule}$$

where T is the torque, that is, moment acting on the rotor.

Work done/minute = $2\pi NT$ (since N revolutions are made in one minute)

$$\text{Work done/sec or power} = \frac{2\pi NT}{60} \text{ joule/s or watt}$$

$$\therefore \text{H.P.} = \frac{2\pi NT}{60 \times 735.5} \text{(because 1 H.P. = 735.5 W)}$$

Relation between kWh and kcal

Since, $1 \text{ kWh} = 1000 \times 60 \times 60 \text{ Ws or joule}$

$$= \frac{36 \times 10^5}{4.18} \text{calorie} = \frac{36 \times 10^5}{4.8 \times 1000} \text{kcal}$$

$\therefore$ $1 \text{ kWh} = 860 \text{ kcal}$

Example

An electric kettle was marked 500 W, 230 V and was found to take 13 minute to bring 1 kg of water at 20°C to boiling point. Determine the heat efficiency of the kettle.

Solution:

Heat absorbed by water, that is, output of kettle,

$$H = m\,S\theta$$

where $m = 1 \text{ kg} = 1000 \text{ g};\ S = 1;\ \theta = t_2 - t_1 = 100 - 20 = 80°\text{C}$

$\therefore$ $H = 1000 \times 1 \times 80 = 80000$ calorie

Energy input to kettle $=$ Power $\times$ time

$= 500 \times 13 \times 60 = 390000$ wattsec or joule

$= 390000/4.18$ calorie $= 93301$ calorie

$$\text{Heat efficiency of kettle} = \frac{\text{Heat utilized by water}}{\text{Heat produced by kettle}} = \frac{80000}{93301} = 85.74\%\ \text{(Ans.)}$$

Example

A geyser heater rated at 3 kW is used to heat its copper tank weighing 20 kg and holds 80 L of water. How long will it take to raise the temperature of water from 10°C to 60°C, if 20 per cent of energy supplied is wasted in heat losses?

Assuming specific heat of copper to be 0.095 and 4.2 joule to be equivalent to one calorie.

Solution

Mass of water, $m_1 = 80$ kg (since 1 L of water weighs 1 kg)

Mass of tank, $m_2 = 20$ kg

Specific heat of copper, $S_2 = 0.095$

Change in temperature, $\theta = (t_2 - t_1) = 60 - 10 = 50°C$

Heat utilized to raise the temperature of water and tank or output

$$= m_1 S_1 \theta + m_2 S_2 \theta = 80 \times 1 \times 50 + 20 \times 0.095 \times 50$$

$$= 4095 \text{ kcal} = 4095 \times 10^3 \times 4.2 \text{ joule}$$

Thermal efficiency, $\eta = 80\%$ (since loss = 20%)

$$\therefore \qquad \text{Input energy} = \frac{\text{Output}}{\eta} = \frac{4095 \times 10^3 \times 4.2}{0.8} \text{ joule}$$

$$= \frac{4095 \times 10^3 \times 4.2}{0 \times 8 \times 36 \times 10^5} \text{kWh} = 5.973 \text{ kWh}$$

Time required to increase the temperature

$$= \frac{\text{Input energy}}{\text{Power}} = \frac{5.973}{3} = 1.991 \text{ hour (Ans.)}$$

Example *Two heater A and B are in parallel across supply voltage V. Heater A produces 500 kcal in 20 min. and B produces 1000 kcal in 10 min. The resistance of A is 10 ohm. What is the resistance of B ? If the same heaters are connected in series across the voltage V, how much heat will be prduced in kcal in 5 min ?*

Solution. Heat produced $= \dfrac{V^2 t}{JR}$ kcal

For heater A, $$500 = \frac{V^2 \times (20 \times 60)}{10 \times J} \quad \ldots(i)$$

For heater B, $$1000 = \frac{V^2 \times (10 \times 60)}{R \times J} \quad \ldots(ii)$$

From Eq. (*i*) and (*ii*), we get, $R =$ **2.5 Ω**

When the two heaters are connected in series, let H be the amount of heat produced in kcal. Since combined resistance is $(10 + 2.5) = 12.5\ \Omega$, hence

$$H = \frac{V^2 \times (5 \times 60)}{12.5 \times J} \quad \ldots(iii)$$

Dividing Eq. (*iii*) by Eq. (*i*), we have H = **100 kcal.**

Example

A hydroelectric power station operates at a mean heat of 25 m and is supplied from a reservoir having area of 6 sq. km. Calculate the energy produced by the water if the water level in the reservoir decreases by 1 m. The overall efficiency of the power station may be considered 80 per cent.

Solution:

Area of reservoir = $6\ km^2 = 6 \times 10^6\ m^2$

Decrease in water level = 1 m

Volume of water used = $6 \times 10^6 \times 1 = 6 \times 10^6\ m^3$

Mass of water, $m = 6 \times 10^6 \times 1000$ kg (1 m^3 of water weighs 1000 kg)

Height of water fall or head, $H = 25$ m

Potential energy of water fall = mgH

$$= 6 \times 10^9 \times 9.81 \times 25 \ (g = 9.81)$$

$$= 14.715 \times 10^8\ \text{Nm}$$

Energy utilized to generate electrical energy, that is,

$$\text{Output} = \text{Input} \times \eta = \frac{14715 \times 10^8 \times 80}{100}\ \text{Nm or joules}$$

$$= \frac{14715 \times 10^8 \times 80}{100 \times 1000 \times 60 \times 60} = 3,27,000\ \text{kWh (Ans.)}$$

Example

A diesel electric generating set supplies an output of 100 kW. The calorific value of the fuel oil used is 12500 kcal/kg. If overall efficiency of the unit is 36 per cent, (1) calculate the mass of oil required per hour and (2) the electrical energy generated per tonne of the fuel.

Solution:

Calorific value: The heat produced by the complete combustion of 1 kg of fuel is called the calorific value of the fuel.

$$\text{Output} = 100 \text{ kW}$$

$$\text{Energy delivered/hour} = 100 \times 1 = 100 \text{ kWh}$$

$$\text{Energy input} = \frac{\text{Output}}{\eta} = \frac{100 \times 100}{36} = 277.78 \text{ kWh}$$

$$\text{Heat energy required} = 277.78 \times 860 \text{ kcal} = 238889 \text{ kcal}$$

$$\text{Fuel required/hour} = \frac{\text{Heat produced}}{\text{Calorific value of the fuel}} = \frac{238889}{12500} = 19.11 \text{ kg (Ans.)}$$

$$\text{Heat produced/tonne of fuel} = 12500 \times 1000 \text{ kcal}$$

$$\text{Electrical energy generated} = \frac{\text{Heat produced}}{860} \times \eta = \frac{12500 \times 1000}{860} \times \frac{36}{100}$$

$$= 5232.56 \text{ kWh (Ans.)}$$

SERIES CIRCUITS

In the circuit, a number of resistors are connected end to end so that same current flows through them is called series circuit.

Figure 1.14 shows a simple series circuit. In the circuit, three resistors R_1, R_2, and R_3 are connected in series across a supply voltage of V volt. The same current (I) is flowing through all the three resistors.

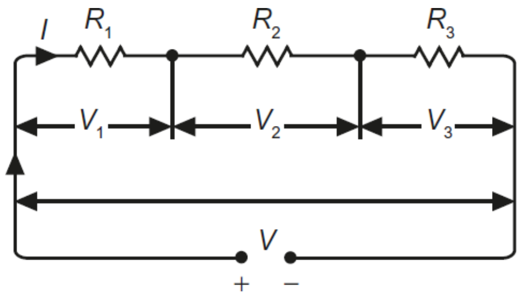


Fig. 1.14 **Resistors connected in series**

If V_1, V_2, and V_3 are the voltage drops across the three resistors R_1, R_2, and R_3, respectively, then

$$V = V_1 + V_2 + V_3 = IR_1 + IR_2 + IR_3 \text{ (Ohm's law)}$$

Let 'R' be the total resistance of the circuit, then

$$IR = IR_1 + IR_2 + IR_3 \quad \text{or} \quad R = R_1 + R_2 + R_3$$

that is, Total resistance = Sum of the individual resistances.

The common application of this circuit is in the marriages for decoration purposes where a number of low-voltage lamps are connected in series. In this circuit, all the lamps are controlled by a single switch, and they cannot be controlled individually. In domestic, commercial, and industrial wiring system, the main switch and fuses are connected in series to provide the necessary control and protection.

Parallel Circuits

In this circuit, one end of all the resistors is joined to a common point and the other ends are also joined to another common point so that different current flows through them is called parallel circuit.

Figure 1.15 shows a simple parallel circuit. In this circuit, three resistors R_1, R_2, and R_3 are connected in parallel across a supply voltage of V volt. The current flowing through them is I_1, I_2, and I_3, respectively.

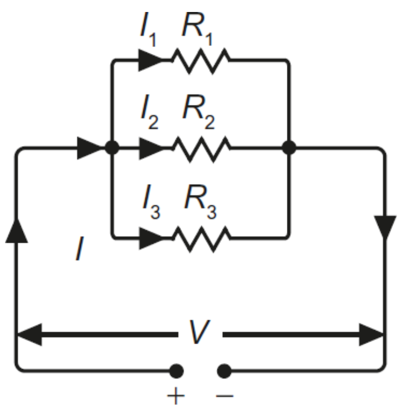


Fig. 1.15 Resistors connected in parallel

The total current drawn by the circuit,

$$I = I_1 + I_2 + I_3 = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \quad \text{(according to Ohm's law)}$$

Let 'R' be the total or effective resistance of the circuit, then

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \quad \text{or} \quad \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

that is, Reciprocal of total resistance = sum of reciprocal of the individual resistances.

All the appliances are operated at the same voltage, and therefore, all of them are connected in parallel. Each one of them can be controlled individually with the help of a separate switch.

SERIES–PARALLEL CIRCUITS

The circuit in which series and parallel circuits are connected in series is called series–parallel circuit.

Figure 1.16 shows a simple series–parallel circuit. In this circuit, two resistors R_1 and R_2 are connected in parallel with each other across terminals AB. The other three resistors R_3, R_4, and R_5 are connected in parallel with each other across terminal BC. The two groups of resistors R_{AB} and R_{BC} are connected in series with each other across the supply voltage of V volt.

The total or effective resistance of the whole circuit can be determined as given below:

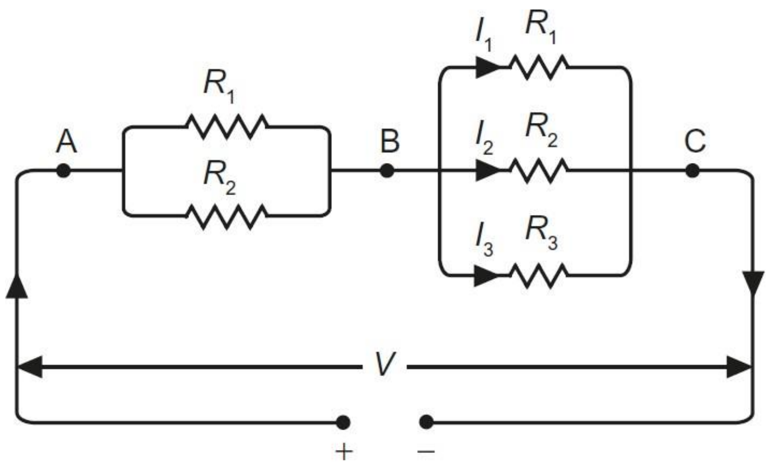


Fig. 1.16 **Resistors connected in series-parallel combination**

$$\frac{1}{R_{AB}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_1 + R_2}{R_1 R_2} \text{ or } R_{AB} = \frac{R_1 R_2}{R_1 + R_2}$$

Similarly, $$\frac{1}{R_{BC}} = \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5} = \frac{R_3 R_4 + R_4 R_5 + R_5 R_3}{R_3 R_4 R_5} \quad \text{or} \quad R_{BC} = \frac{R_3 R_4 R_5}{R_3 R_4 + R_4 R_5 + R_5 R_3}$$

Total or effective resistance of the circuit, $R = R_{AB} + R_{BC}$

DIVISION OF CURRENT IN PARALLEL CIRCUITS

In parallel circuits, current is divided depending upon the value of resistors and the number of branches as discussed below.

When Two Resistors are Connected in Parallel

Figure 1.17 shows two resistors having resistance R_1 and R_2 connected in parallel across supply voltage of V volt. Let the current in each branch be I_1 and I_2, respectively.

According to Ohm's law, $I_1R_1 = I_2R_2 = V$ or $\dfrac{I_1}{I_2} = \dfrac{R_2}{R_1}$

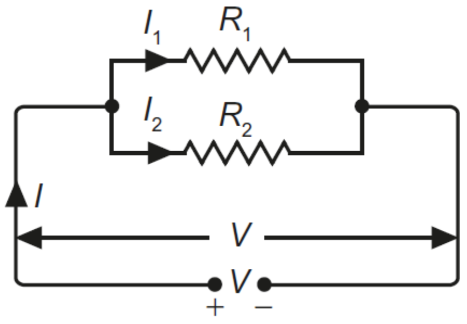


Fig. 1.17 **Division of current in two resistors connected in parallel**

Hence, the current in each branch of a parallel circuit is inversely proportional to its resistance. The value of branch current can also be expressed in terms of total circuit current, that is,

$$I_1R_1 = I_2R_2 = IR = V$$

where R is total or effective resistance of the circuit and I is the total current.

$$R = \frac{R_1R_2}{R_1 + R_2}$$

Now, $$I_1R_1 = IR = I\frac{R_1R_2}{R_1+R_2} \quad \text{or} \quad I_1 = I\frac{R_2}{R_1+R_2}$$

Similarly, $$I_2 = I\frac{R_1}{R_1+R_2}$$

When Three Resistors are Connected in Parallel

Now, $$R = \frac{R_1R_2R_3}{R_1R_2+R_2R_3+R_3R_1}$$

Figure 1.18 shows three resistors having resistance R_1, R_2, and R_3 connected in parallel across a supply voltage of V volt. Let the current in each branch be I_1, I_2, and I_3, respectively.

According to Ohm's law,

$$I_1R_1 = I_2R_2 = I_3R_3 = IR = V$$

Where R is the total or effective resistance of the circuit and I is the total current.

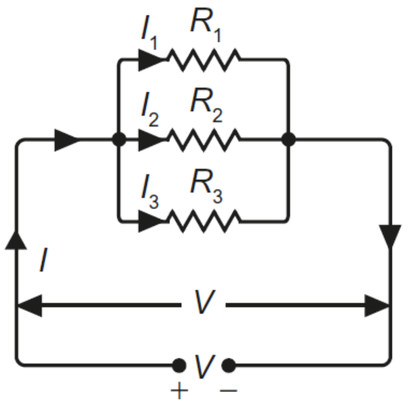


Fig. 1.18 Division of current in three resistors connected in parallel

Now, $$R = \frac{R_1R_2R_3}{R_1R_2+R_2R_3+R_3R_1}$$

$$\therefore \qquad I_1R_1 = IR = I \times \frac{R_1R_2R_3}{R_1R_2 + R_2R_3 + R_3R_1}$$

$$\text{or} \qquad I_1 = I \times \frac{R_2R_3}{R_1R_2 + R_2R_3 + R_3R_1}$$

$$\text{Similarly,} \qquad I_2 = I \times \frac{R_1R_3}{R_1R_2 + R_2R_3 + R_3R_1}$$

$$\text{and} \qquad I_3 = I \times \frac{R_1R_2}{R_1R_2 + R_2R_3 + R_3R_1}$$

Example

Determine current I in the circuit shown in Figure 1.21, if all the resistors are given in ohms.

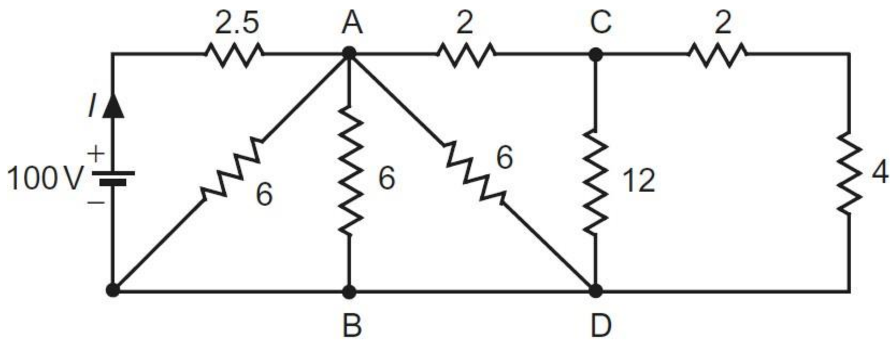


Fig. 1.21 Circuit diagram as per data

Solution:

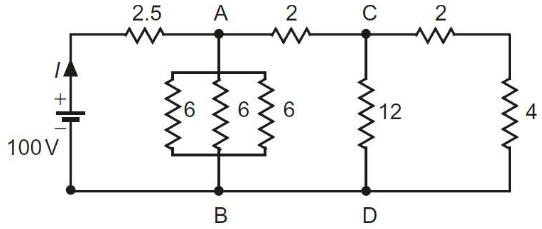


Fig. 1.22 Simplified circuit

To solve this type of circuit, start from the far end of the supply. A simplified circuit is shown in Figure 1.22.

The far end resistors of value 2 Ω and 4 Ω are connected in series with each other. Let their effective value be R_1 ohms.

$\therefore$ $$R_1 = 2 + 4 = 6\,\Omega$$

Then 12 Ω resistor and R_1 are connected in parallel with each other (Figure 1.23). Let their effective value be R_{CD}.

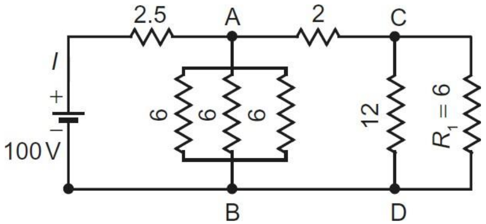


Fig. 1.23 Simplified circuit

$$\therefore \qquad R_{CD} = \frac{6\times 12}{6+12} = 4\ \Omega$$

This resistance (R_{CD}) is connected in series with 2 Ω resistor as shown in Figure 1.24. Their effective value is say R_2.

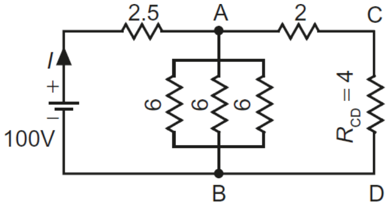


Fig. 1.24 Simplified circuit

$$\therefore \qquad R_2 = 2 + 4 = 6\ \Omega$$

This resistance (R_2) is connected in parallel with the three resistors of 6 Ω each already connected in parallel as shown in Figure 1.25. Their effective value is say R_{AB}.

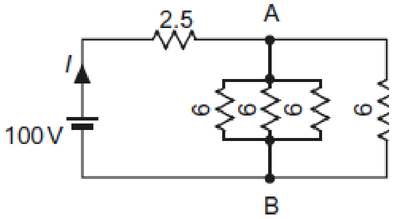


Fig. 1.25 Simplified circuit

$$R_{AB} = \frac{6}{4} = 1.5\ \Omega$$

This resistance (R_{AB}) is connected in series with 2.5 Ω resistor as shown in Figure 1.26. The total resistance of the circuit is say R ohm.

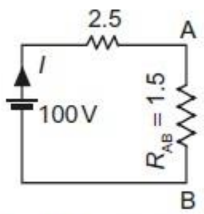


Fig. 1.26 Simplified circuit

Then,
$$R = 2.5 + 1.5 = 4\ \Omega$$

$\therefore$
$$\text{Current, } I = \frac{V}{R} = \frac{100}{4} = 25 \text{ A (Ans.)}$$

Example

A circuit consists of three resistances of 12 ohm, 18 ohm, and 3 ohm, respectively, joined in parallel is connected in series with a fourth resistance. The whole circuit is supplied at 60 V and it is found that power dissipated in 12 ohm resistance is 36 W. Determine the value of fourth resistance and the total power dissipated in the group.

Solution:

The circuit diagram is shown in Figure 1.20.

Power dissipated in 12 ohm resistor, $P_1 = 36$ W.

If the current in this resistor is I_1 ampere,

then, $$I_1^2 \times 12 = P_1$$

$$I_1^2 = \frac{36}{12} = 3 \quad \text{or} \quad I_1 = \sqrt{3} = 1.732 \text{ A}$$

Voltage across parallel resistors, $V_1 = I_1 \times 12$

$$= 1.732 \times 12 = 20.785 \text{ V}$$

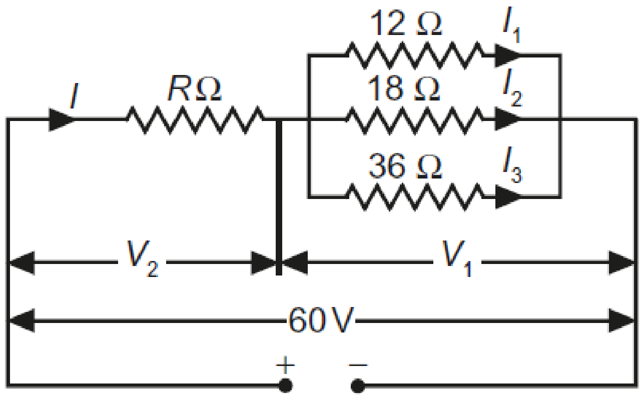
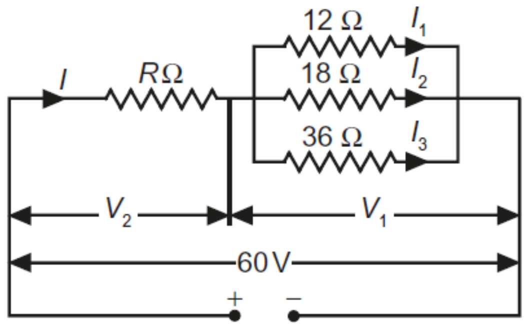


Fig. 1.20 Circuit diagram as per data



Current in 18 ohm resistor,

$$I_2 = \frac{V_1}{18} = \frac{20.785}{18} = 1.155 \text{ A}$$

Current in 36 ohm resistor, $$I_3 = \frac{V_1}{36} = \frac{20.785}{36} = 0.577 \text{ A}$$

Current in resistor R, $$I_1 + I_2 + I_3 = 1.732 + 1.155 + 0.577 = 3.464 \text{ A}$$

Voltage across resistor R, $$V_2 = 60 - V_1 = 60 - 20.785 = 39.215 \text{ V}$$

∴ Value of series resistor, $$R = \frac{V_2}{I} = \frac{39.215}{3.464} = 11.32 \text{ ohm (Ans.)}$$

ELECTRIC NETWORK

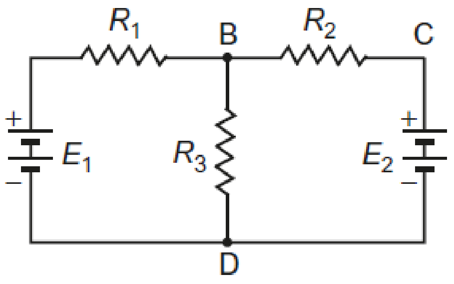


Fig. 2.1 **An electric network**

A simple electric network is shown in Figure 2.1. It contains two voltage sources E_1 and E_2 and three resistors R_1, R_2, and R_3. In fact, the interconnection of either passive elements or the interconnection of active and passive elements constitute an electric network.

Active elements

The elements that supply energy in an electric network are called active elements.
In the circuit shown in Figure 2.1, E_1 and E_2 are the active elements.

Note: When a battery is delivering current from its positive terminal, it is under discharging condition. However, if it is receiving current at its positive terminal, then it is under charging condition. In both the cases, it will be considered as an active element.

Passive Elements

The elements that receive electrical energy and dispose the same in their own way of disposal are called passive elements. In the circuit shown in Figure 2.1, R_1, R_2, and R_3 are the passive elements. The other passive elements that are not used in this circuit are inductors and capacitors.

Network Terminology

Network theorems are applied to analyse the electrical network. While discussing these theorems, we come across the following terms:

1. **Electric network:** A combination of various electric elements connected in any manner is called an electric network.
2. **Electric circuit:** An electric circuit is a closed conducting path through which an electric current either flows or is intended to flow.
3. **Parameters:** The various elements of an electric circuit are called its parameters such as resistors, inductors, and capacitors.
4. **Linear circuit:** An electric circuit that contains parameters of constant value, that is, their value do not change with voltage or current is called linear circuit.
5. **Non-linear circuit:** An electric circuit that contains parameters whose value changes with voltage or current is called non-linear circuit.
6. **Bilateral circuit:** An electric circuit that possesses the same properties or characteristics in either direction is called bilateral circuit. A transmission line is bilateral because it can be made to perform its function equally well in either direction.
7. **Unilateral circuit:** An electric circuit whose properties or characteristics change with the direction of its operation is called unilateral circuit. A diode rectifier circuit is a unilateral circuit because it cannot perform similarly in both the directions.

8. **Unilateral elements:** The elements that conduct only in one direction, such as semiconductor diode, are called unidirectional elements.

9. **Bilateral elements:** The elements that conduct in both the directions similarly, such as a simple piece of wire (resistor), diac, and triac, are called bilateral elements.

10. **Active network:** An electric network that contains one or more sources of emf is called active network.

11. **Passive network:** An electric network that does not contain any source of emf is called passive network.

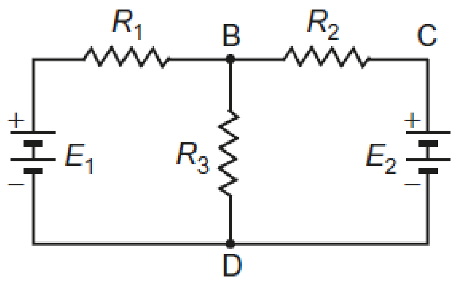


Fig. 2.1 An electric network

12. **Node:** A node is a point in the network where two or more circuit elements are joined. In Figure 2.1, A, B, C, and D are the nodes.

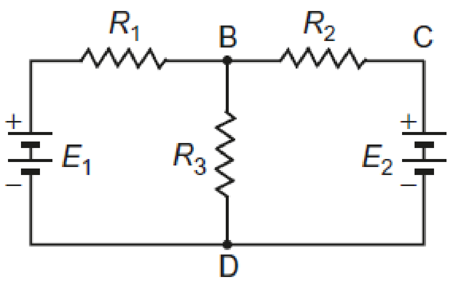


Fig. 2.1 An electric network

13. **Junction:** A junction is a point in the network where three or more circuit elements are joined. In fact, it is a point where current is divided. In Figure 2.1, B and D are junctions.

14. **Branch:** The part of a network that lies between two junction points is called branch. In Figure 2.1, DAB, BCD, and BD are the three branches.

15. **Loop:** The closed path of a network is called a loop. In Figure 2.1, ABDA, BCDB, and ABCDA are the three loops.

16. **Mesh:** The most elementary form of a loop that cannot be further divided is called a mesh. In Figure 2.1, ABDA and BCDB are the two meshes, but ABCDA is the loop.

Limitations of Ohm’s Law

1.Ohm’s law is not applicable for unilateral electrical elements like diodes and transistors as they allow the current to flow through in one direction only.

2.For non-linear electrical elements with parameters like capacitance, resistance, etc. the voltage and the current won’t be constant with respect to time making it difficult to use Ohm’s law. Non-linear elements are those which do not have current exactly proportional to the applied voltage, which means the resistance value of those elements changes for different values of voltage and current. Examples of non – linear elements are thyristor, electric arc, etc.

3.The relation between V and I depends on the sign of V(+ or -). In other words, if I is the current for a certain V, then reversing the direction of V keeping its magnitude fixed, does not produce a current of the same magnitude as I in the opposite direction. This happens for example in the case of a diode.

4.Ohm’s law is only applicable in metallic conductors. So it won’t work in the case of non-metallic conductors.

Applications of Ohm’s law in Daily Life

Ohm’s law can determine the voltage applied in a circuit, the value of resistance, and the current flowing through the circuit. With the help of the above three values, we can find the value of other factors like resistivity and many more. Some daily applications of Ohm’s law:

•**In fuses:** In order to protect a circuit, fuses and circuit breakers are used. These are connected in series with the electrical appliances. Ohm’s law allows us to find the value of the current which could flow through the fuses. If the current value is too large, then it could damage the circuit and even lead to the explosion of the electronic device.

•**To know power consumption:** The electrical heaters have a high-resistance metal coil that allows a certain amount of current to pass across them to provide the heat needed. Using this law, the power to be given to the heaters is determined.

•**To control the speed of fans:** By shifting the regulator to the end from start, we can regulate the speed of the fans in our houses. By controlling the resistance via the regulator, the current flowing through the fan is managed here. We can measure the resistance, current, and thus power flowing via Ohm’s Law for any particular value of the input.

•**For deciding the size of resistors:** Electric appliances like electric kettles and irons have a lot of resistors inside them. In order to provide the necessary amount of heat, the resistors restrict the amount of current that can flow through them. By using Ohm’s law, the size of resistors included in them is defined.

LIMITATIONS OF OHM'S LAW

In a series circuit or in any branch of a simple parallel circuit the calculation of the current is easily effected by the direct application of Ohm's law. But such a simple calculation is not possible if one of the branches of a parallel circuit contains a source of e.m.f., or if the current is to be calculated in a part of a network in which sources of e.m.f. may be present in several meshes or loops forming the network. The treatment of such cases is effected by the application of fundamental principles of electric circuits. These principles were correlated by Kirchhoff many years ago and enunciated in the form of *two laws*, which can be considered as the foundations of circuit analysis. Other, later, methods have been developed, which when applied to special cases considerably shorten the algebra and arithmetic computation compared with the original Kirchhoff's method.

KIRCHHOFF'S LAWS

For complex circuit computations, the following two laws first stated by Gutsav R. Kirchhoff (1824–87) are indispensable.

(*i*) Kirchhoff's Point Law or Current Law (KCL). It states as follows :

The sum of the currents entering a junction is equal to the sum of the currents leaving the junction. Refer Fig. 27.

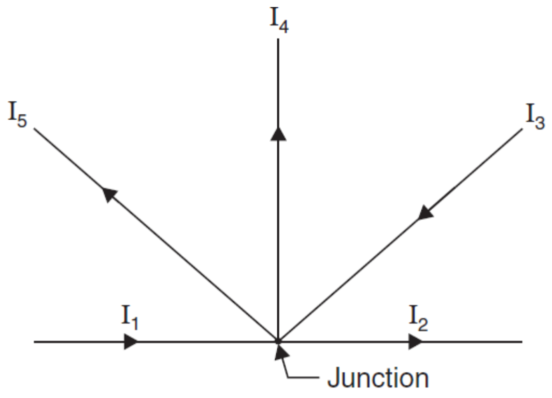


Fig. 27

If the currents *towards* a junction are considered *positive* and those *away* from the same junction *negative*, then this law states that the *algebraic sum of all currents meeting at a common junction is zero*.

i.e., Σ Currents entering = Σ Currents leaving

$$I_1 + I_3 = I_2 + I_4 + I_5 \qquad \text{...[20 (a)]}$$

or $$I_1 + I_3 - I_2 - I_4 - I_5 = 0 \qquad \text{...[20 (b)]}$$

(*ii*) Kirchhoff's Mesh Law or Voltage Law (KVL). It states as follows :

The sum of the e.m.fs (rises of potential) around any closed loop of a circuit equals the sum of the potential drops in that loop.

Considering a rise of potential as positive (+) and a drop of potential as negative (–), the *algebraic sum* of potential differences (voltages) around a closed loop of a circuit is zero :

$$\Sigma E - \Sigma IR \text{ drops} = 0 \text{ (around closed loop)}$$

i.e., $$\Sigma E = \Sigma IR \qquad \text{...[21 (a)]}$$

or $$\Sigma \text{ Potential rises} = \Sigma \text{ Potential drops} \qquad \text{...[21 (b)]}$$

To apply this law in practice, assume an arbitrary current direction for each branch current. The end of the resistor through which the current enters, is then positive, with respect to the other end. *If the solution for the current being solved turns out negative, then the direction of that current is opposite to the direction assumed.*

In tracing through any single circuit, whether it is by itself or a part of a network, the following **rules** must be applied :

1. A *voltage drop exists* when tracing through a resistance *with or in the same direction as the current*, or through a battery or generator against their voltage, that is from *positive (+) to negative (–)*. Refer Fig. 28.

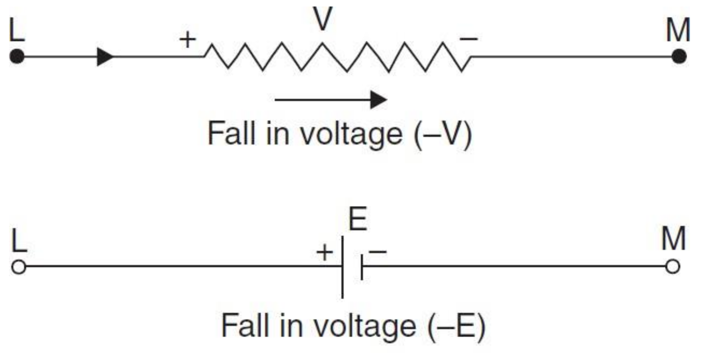


Fig. 28

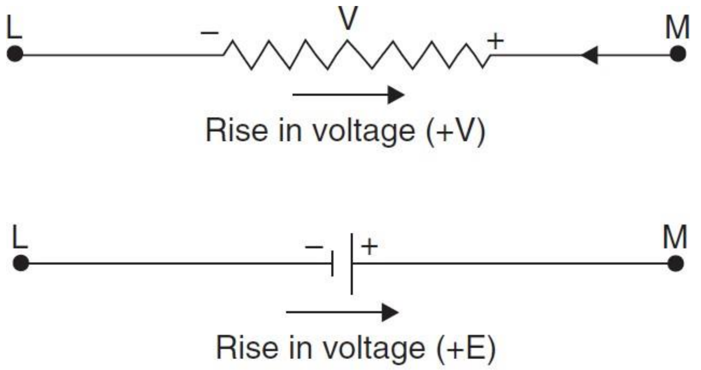


Fig. 29

2. A *voltage rise exists* when tracing through a resistance *against* or *in opposite direction to the current* or through a battery or a generator with their voltage that is from *negative (–) to positive (+)*. Refer Fig. 29.

APPLICATIONS OF KIRCHHOFF'S LAWS

Kirchhoff's laws may be employed in the following methods of solving networks :

1. Branch-current method
2. Maxwell's loop (or mesh) current method
3. Nodal voltage method.

Branch-Current Method

For a multi-loop circuit the following ***procedure*** is adopted for writing equations :

1. Assume currents in different branch of the network.

2. Write down the smallest number of voltage drop loop equations so as to include all circuit elements ; these loop equations are independent.

If there are n nodes of three or more elements in a circuit, then write $(n - 1)$ equations as per current law.

3. Solve the above equations simultaneously.

The assumption made about the directions of the currents initially is arbitrary. In case the actual direction is *opposite to the assumed one*, it will be reflected as a negative value for that current in the answer.

The branch-current method (the most primitive one) involves more labour and is not used *except for very simple circuits.*

Example *Find the magnitude and direction of currents in each of the batteries shown in Fig. 33.*

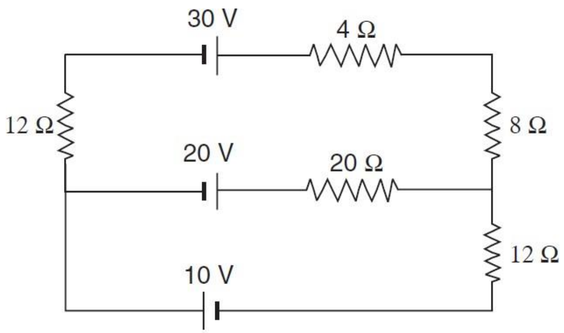


Fig. 33

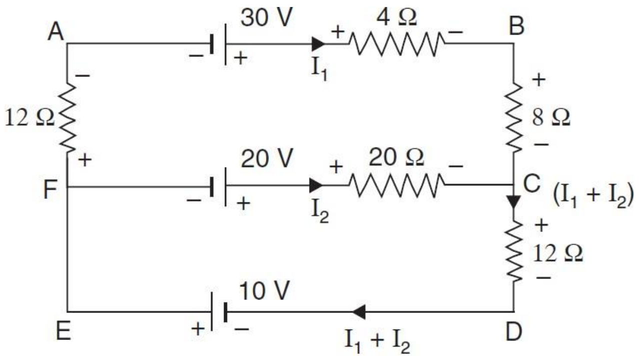


Fig. 34

Solution.

Let the directions of currents I_1, I_2 and I_3 in the batteries be as shown in Fig. 34.

Applying Kirchhoff's voltage law to the circuit **ABCFA**, we get

$$30 - 4I_1 - 8I_1 + 20I_2 - 20 - 12I_1 = 0$$

$$-24I_1 + 20I_2 + 10 = 0$$

or

$$12I_1 - 10I_2 - 5 = 0 \quad ...(i)$$

Circuit **ECDEF** gives,

$$20 - 20I_2 - 12(I_1 + I_2) + 10 = 0$$

$$20 - 20I_2 - 12I_1 - 12I_2 + 10 = 0$$

$$-12I_1 - 32I_2 + 30 = 0$$

or $$6I_1 + 16I_2 - 15 = 0 \quad \text{...}(ii)$$

Multiplying eqn. (*ii*) by 2 and subtracting it from (*i*), we get

$$-42I_2 + 25 = 0$$

i.e., $$I_2 = 0.595 \text{ A}$$

Substituting this value of I_2 in eqn. (*i*), we get

$$12I_1 - 10 \times 0.595 - 5 = 0$$

or $$I_1 = 0.912 \text{ A}$$

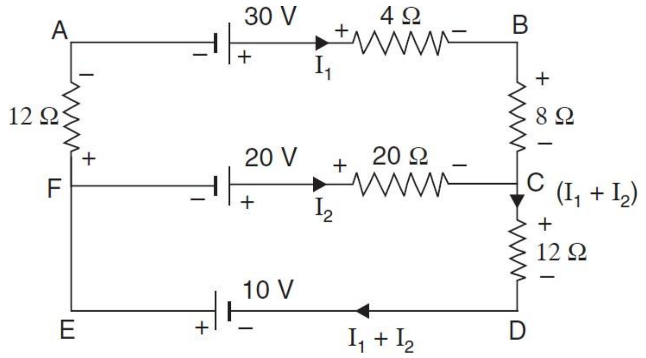


Fig. 34

Hence current through,

30 V battery, I_1 = **0.912 A. (Ans.)**

20 V battery, I_2 = **0.595 A. (Ans.)**

10 V battery, $(I_1 + I_2)$ = **1.507 A. (Ans.)**

Example *Determine the current in the 4 Ω resistance of the circuit shown in Fig. 40.*

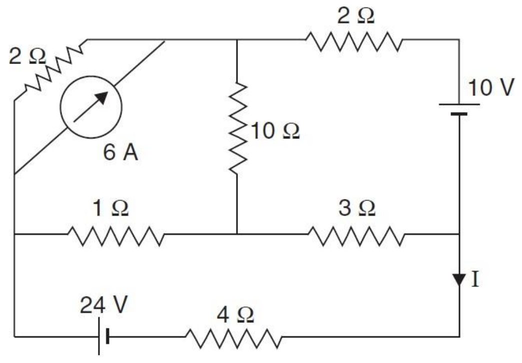


Fig. 40

Solution. Refer Fig. 41.

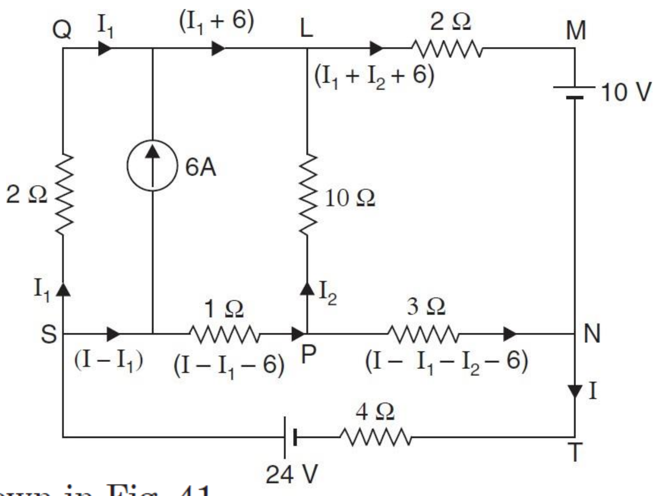


Fig. 41

Let the directions of various currents in different circuits be as shown in Fig. 41.

Applying Kirchhoff's voltage law to the circuit **SQLPS**, we get

$$-2I_1 + 10I_2 + 1(I - I_1 - 6) = 0$$

$$I - 3I_1 + 10I_2 = 6 \quad \text{...}(i)$$

Circuit **LMNPL** gives,

$$-2(I_1 + I_2 + 6) - 10 + 3(I - I_1 - I_2 - 6) - 10I_2 = 0$$

$$3I - 5I_1 - 15I_2 = 40 \quad \text{...}(ii)$$

Circuit **SPNTS** gives,

$$-1(I - I_1 - 6) - 3(I - I_1 - I_2 - 6) - 4I + 24 = 0$$

$$-8I + 4I_1 + 3I_2 = -48$$

$$8I - 4I_1 - 3I_2 = 48 \qquad ...(iii)$$

Multiplying eqn. (*i*) by 3 and subtracting eqn. (*ii*) from eqn. (*i*), we get

$$-4I_1 + 45I_2 = -22$$

or $$I_1 - 11.25I_2 = 5.5 \qquad ...(iv)$$

Multiplying eqn. (*i*) by 8 and subtracting eqn. (*iii*) from eqn. (*i*), we get

$$-20I_1 + 83I_2 = 0 \qquad ...(v)$$

Multiplying eqn. (*iv*) by 20 and adding eqn. (*v*), we get

$$-142I_2 = 110$$

$\therefore$ $$I_2 = -0.774 \text{ A}$$

and $$I_1 = -3.212 \text{ A}$$

Substituting the values of I_1 and I_2 in eqn. (*i*), we get

$$I - 3 \times (-3.212) + 10 \times (-0.774) = 6$$

i.e., **I = 23.37 A. (Ans.)**

Determine the current supplied by the battery in the circuit shown in Fig. 45.

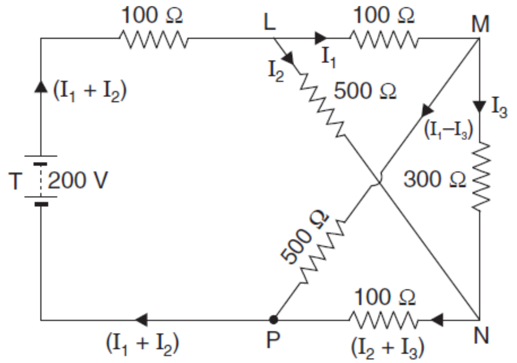


Fig. 45

Solution. Refer Fig. 45.

Applying Kirchhoff's voltage law to the circuit **LMNL**, we get

$$-100I_1 - 300I_3 + 500I_2 = 0$$

$$I_1 - 5I_2 + 3I_3 = 0 \quad \ldots(i)$$

Circuit **MNPM** gives,

$$-300I_3 - 100(I_2 + I_3) + 500(I_1 - I_3) = 0$$

$$500I_1 - 100I_2 - 900I_3 = 0$$

$$I_1 - 0.2I_2 - 1.8I_3 = 0 \quad \ldots(ii)$$

Circuit **LMPTL** gives,

$$-100I_1 - 500(I_1 - I_3) + 200 - 100(I_1 + I_2) = 0$$

$$-700I_1 - 100I_2 + 500I_3 = -200$$

$$I_1 + 0.143I_2 - 0.714I_3 = 0.286 \quad \text{...(iii)}$$

Multiplying (*i*) by 1.8 and (*ii*) by 3 and adding, we get

$$\begin{array}{r} 1.8I_1 - 9I_2 + 5.4I_3 = 0 \\ 3I_1 - 0.6I_2 - 5.4I_3 = 0 \\ \hline 4.8I_1 - 9.6I_2 = 0 \end{array}$$

or $$I_1 - 2I_2 = 0 \quad \text{...(iv)}$$

Multiplying (*ii*) by 0.714 and (*iii*) by 1.8 and subtracting, we get

$$\begin{array}{r} 0.714I_1 - 0.143I_2 - 1.285I_3 = 0 \\ 1.8I_1 + 0.257I_2 - 1.285I_3 = 0.515 \\ - \quad\quad - \quad\quad\quad + \quad\quad\quad - \\ \hline -1.086I_1 - 0.4I_2 = -0.515 \end{array}$$

or $$I_1 + 0.368I_2 = 0.474 \quad \text{...(v)}$$

Subtracting (*v*) from (*iv*), we get $2.368I_2 = 0.474$

i.e., $I_2 = 0.2$ A

and $I_1 = 0.4$ A

∴ **Current supplied by the battery** $= I_1 + I_2 = 0.2 + 0.46 =$ **0.6 A. (Ans.)**

MAXWELL'S MESH CURRENT METHOD (LOOP ANALYSIS)

In this method, mesh or loop currents are taken instead of branch currents (as in Kirchhoff's laws). The following steps are taken while solving a network by this method:

1. The whole network is divided into number of meshes. Each mesh is assigned a current having continuous path (current is not split at a junction). These mesh currents are preferably drawn in clockwise direction. The common branch carries the algebraic sum of the mesh currents flowing through it.
2. Write KVL equation for each mesh using the same signs as applied to Kirchhoff's laws.
3. Number of equations must be equal to the number of unknown quantities. Solve the equations and determine the mesh currents.

Example

Using loop current method, find the current I_1 and I_2 as shown in Figure 2.43.

Solution:

Let the current flowing through the two loops be I_1 and I_2, as shown in Figure 2.44.

By applying KVL to different loops, we get

Loop ABEFA

$$-2I_1 - 6(I_1 - I_2) - 6 + 10 = 0$$

$$8I_1 - 6I_2 = 4$$

$$4I_1 - 3I_2 = 2 \qquad (2.29)$$

Loop BCDEB

$$-3I_2 - 2 + 6 - 6(I_2 - I_1) = 0$$

$$-6I_1 + 9I_2 = 4 \qquad (2.30)$$

Multiplying Equation (2.29) by 3 and Equation (2.30) by 2, we get

$$12I_1 - 9I_2 = 6 \qquad (2.31)$$

$$-12I_1 + 18I_2 = 8 \qquad (2.32)$$

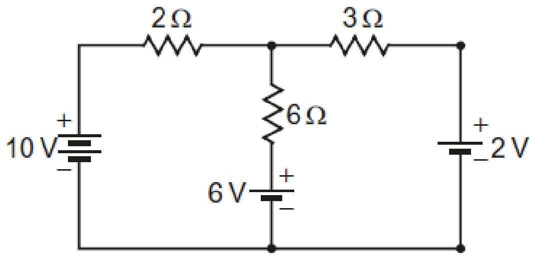


Fig. 2.43 Given network

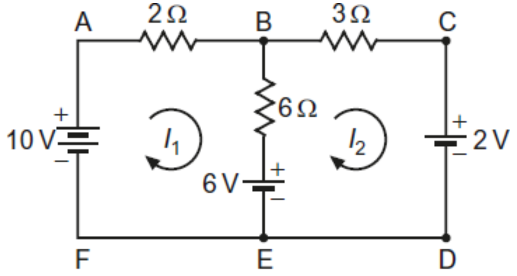


Fig. 2.44 Loop currents in various sections

Adding Equations (2.31) and (2.32), we get

$$I_1 = \frac{5}{3} = 1.667\text{A}$$

Example Using mesh current method, determine current I_x in the circuit shown in Figure 2.47.

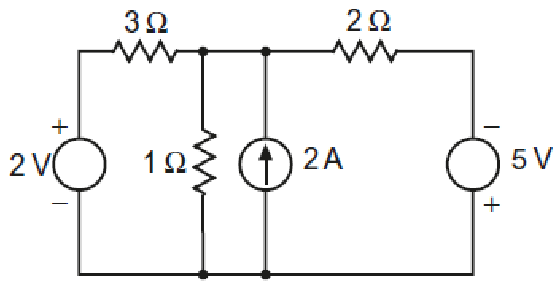


Fig. 2.47 Given network

Solution:

Let the circuit be as shown in Figure 2.48. Suppose voltage across 2 A current source is V_x,

By applying KVL in mesh 1; $3I_1 + (I_1 - I_2) = 2$

$$4I_1 - I_2 = 2 \tag{2.35}$$

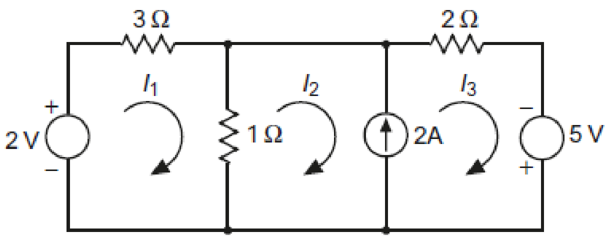


Fig. 2.48 Loop currents in various sections

By applying KVL in mesh 2; $(I_2 - I_1) + V_x = 0$

$$I_1 - I_2 = V_x \tag{2.36}$$

By applying KVL in mesh 3; $2I_3 = 5 + V_x$ (2.37)

Further, $I_3 - I_2 = 2$ (2.38)

From Equations (2.36) and (2.37) $2I_3 = 5 + (I_1 - I_2)$

or $$-I_1 + I_2 + 2I_3 = 5 \tag{2.39}$$

From Equations (2.35), (2.38), and (2.39),

$$\text{In matrix form} \begin{bmatrix} 4 & -1 & 0 \\ 0 & -1 & 1 \\ -1 & 1 & 2 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 2 \\ 2 \\ 5 \end{bmatrix} = 4\,(-2-1) + 1\,(0+1) = -11$$

$$\Delta = \begin{vmatrix} 4 & -1 & 0 \\ 0 & -1 & 1 \\ -1 & 1 & 2 \end{vmatrix} = 4\,(-2-1) + 1\,(0+1) = -11$$

$$\Delta_{11} = \begin{vmatrix} 2 & -1 & 0 \\ 2 & -1 & 1 \\ 5 & 1 & 2 \end{vmatrix} = 2\,(-2-1) - (-1)\,(4-5) = -7$$

$$\Delta_{12} = \begin{vmatrix} 4 & 2 & 0 \\ 0 & 2 & 1 \\ -1 & 5 & 2 \end{vmatrix} = 4\,(4-5) - (2)\,(0+1) = -4-2 = -6$$

$$I_1 = \frac{\Delta_{11}}{\Delta} = \frac{-7}{-11} = \frac{7}{11}\,\text{A}$$

$$I_2 = \frac{\Delta_{12}}{\Delta} = \frac{-6}{-11} = \frac{6}{11}\,\text{A}$$

Current, $I_x = I_1 - I_2 = \frac{7}{11} - \frac{6}{11} = \frac{1}{11}\,\text{A}$

NODAL ANALYSIS

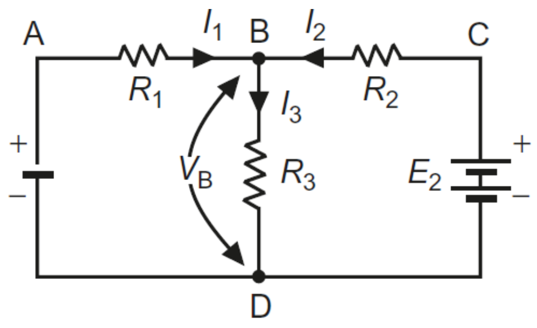


Fig. 2.49 **Network with Node B and D**

In this method, one of the nodes is taken as the reference node and the other as independent nodes. The voltages at the different independent nodes are assumed and the equations are written for each node as per KCL. After solving these equations, the node voltages are determined. Then, the branch currents are determined.

Consider a circuit shown in Figure 2.49, where D and B are the two independents nodes. Let D be the reference node and the voltage of node B be V_B.

According to KCL, $\quad I_1 + I_2 = I_3 \quad$ (2.40)

In mesh ABDA, the potential difference across R_1 is $E_1 - V_B$

$$I_1 = \frac{E_1 - V_B}{R_1}$$

In mesh BCDB, the potential difference across R_2 is $E_2 - V_B$

$$I_2 = \frac{E_2 - V_B}{R_2}$$

Further, current, $I_3 = \dfrac{V_B}{R_3}$

Substituting these values in Equation (2.40), we get

$$\frac{E_1 - V_B}{R_1} = \frac{E_1 - V_B}{R_2} = \frac{V_B}{R_3}$$

Rearranging the terms, $$V_B\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right) - \frac{E_1}{R_1} - \frac{E_2}{R_2} = 0$$

Since all other value are known, except V_B, calculate the value of V_B. Then, determine the value of I_1, I_2, and I_3. This method is faster as the result are obtained by solving lesser number of equations.

Example

Using nodal analysis, find current I through 10-Ω resistor in Figure 2.53.

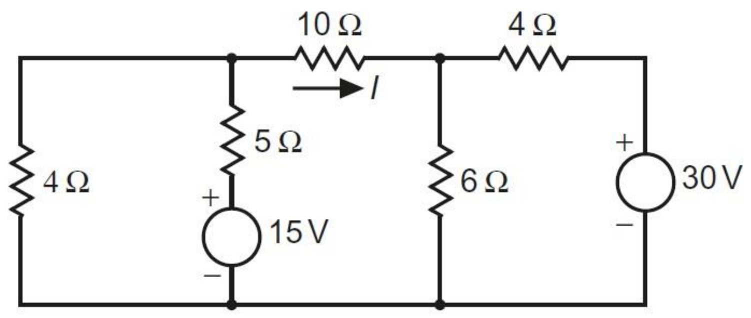


Fig. 2.53 **Given network**

Solution:

The independent nodes are A, B, and C. Let C be the reference node and V_A and V_B be the voltages at node A and B, respectively. Let us assume the direction of flow of current is as marked in Figure 2.54. By applying KCL at node A, we get

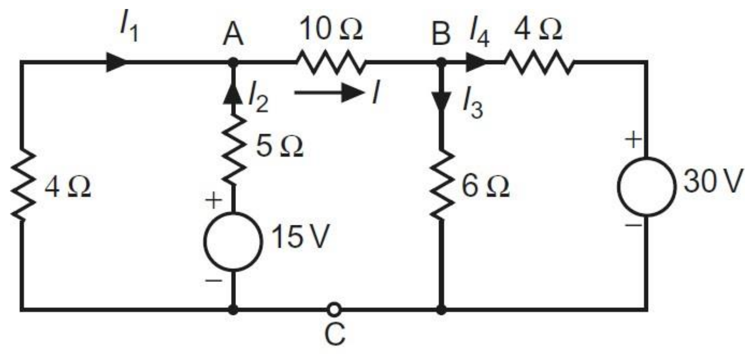


Fig.2.54 **Assumed direction of flow of current in various branches**

$$I_1 + I_2 = I$$

$$\frac{0 - V_A}{4} + \frac{15 - V_A}{5} = \frac{V_A - V_B}{10}$$

or $$-5V_A + 60 - 4V_A = 2V_A - 2V_B$$

or $$11V_A - 2V_B = 60 \tag{2.45}$$

By applying KCL at node B, we get

$$I = I_4 + I_3$$

$$\frac{V_A - V_B}{10} = \frac{V_B - 30}{4} + \frac{V_B}{6}$$

or $$12V_A - 12V_B = 30V_B - 900 + 20V_B$$

or $$12V_A - 62V_B = -900 \tag{2.46}$$

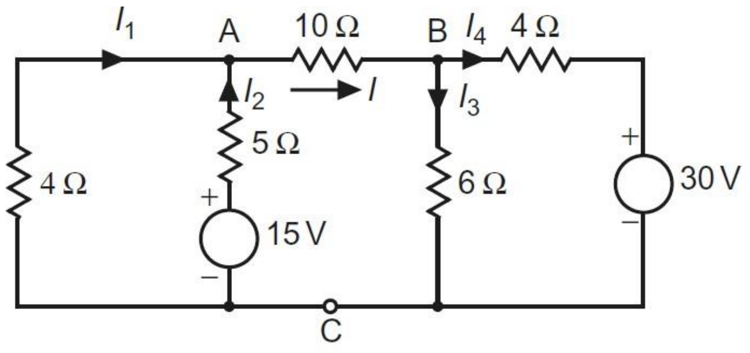


Fig.2.54 Assumed direction of flow of current in various branches

Solving Equation (2.45) and (2.46), we get

$$V_A = 8.39 \text{ V} \quad \text{and} \quad V_B = 16.14 \text{ V}$$

Current, $$I = \frac{V_A - V_B}{10} = \frac{8.39 - 16.14}{10} = \frac{-7.75}{10} = -0.775 \text{ A}$$

$$I = 0.775 \text{ A (from B to A)}$$

Example Use nodal analysis to find the current in various resistors of the circuit shown in Figure 2.57.

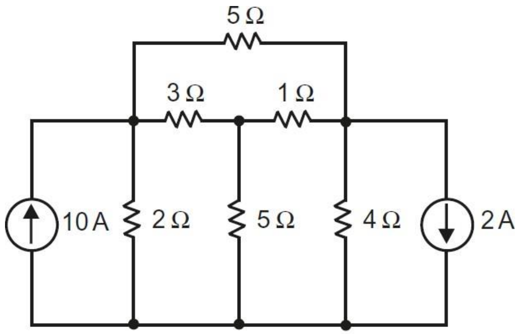


Fig. 2.57 Given network

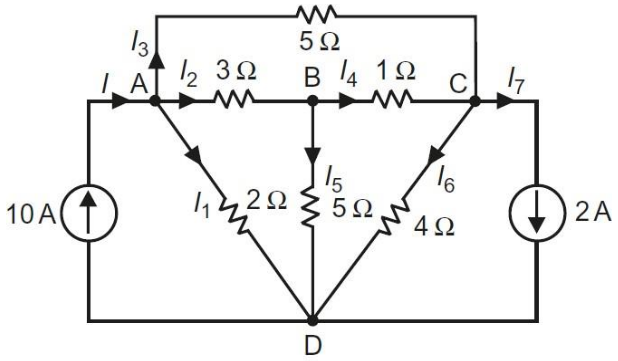


Fig. 2.58 Assumed direction of flow of current in various branches

Solution: The independent nodes are A, B, C, and D. Let D be the reference node and V_A, V_B, and V_C be the voltages at nodes A, B, and C, respectively, The current flowing through various branches are marked in Figure 2.58.

By applying KCL at different nodes, different node voltage equations are obtained as follows:

Node A

$$I_1 + I_2 + I_3 = I$$

$$\frac{V_A}{2} + \frac{V_A - V_B}{3} + \frac{V_A - V_C}{5} = 10$$

$$15V_A + 10(V_A - V_B) + 6(V_A - V_C) = 300$$

$$\text{or} \quad 31V_A - 10\,V_B - 6\,V_C = 300 \qquad (2.47)$$

Node B

$$I_2 - I_4 - I_5 = 0$$

$$\frac{V_A - V_B}{3} - \frac{V_B - V_C}{1} - \frac{V_B}{5} = 0$$

$$5\,(V_A - V_B) - 15\,(V_B - V_C) - 3\,V_B = 0$$

or $$5V_A - 23\,V_B + 15\,V_C = 0 \qquad (2.48)$$

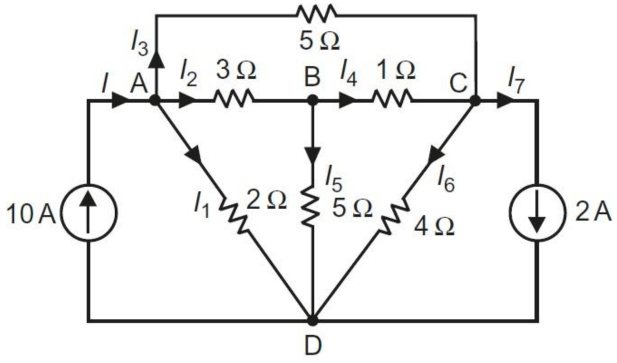


Fig. 2.58 Assumed direction of flow of current in various branches

Node C

$$I_3 + I_4 - I_6 - I_7 = 0$$

$$\frac{V_A - V_C}{5} + \frac{V_B - V_C}{1} - \frac{V_C}{4} - 2 = 0$$

$$4\,(V_A - V_C) + 20\,(V_B - V_C) - 5V_C - 40 = 0$$

or $$4V_A + 20\,V_B - 29\,V_C = 40 \qquad (2.49)$$

The three equations in matrices form are:

$$\begin{bmatrix} 31 & -10 & -6 \\ 5 & -23 & 15 \\ 4 & 20 & -29 \end{bmatrix} \begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \begin{bmatrix} 300 \\ 0 \\ 40 \end{bmatrix}$$

$$D_0 = \begin{bmatrix} 31 & -10 & -6 \\ 5 & -23 & 15 \\ 4 & 20 & -29 \end{bmatrix} = 31\,(667 - 300) + 10\,(-145 - 60) - 6\,(100 + 92)$$

$$= 11{,}377 - 2{,}050 - 1{,}152 = 8{,}175$$

$$D_1 = \begin{bmatrix} 300 & -10 & -6 \\ 0 & -23 & 15 \\ 40 & 20 & -29 \end{bmatrix} = 300\,(667 - 300) + 10\,(-600) - 6\,(+920)$$

$$= 110{,}100 - 6{,}000 - 5{,}520 = 98{,}580$$

$$D_2 = \begin{bmatrix} 31 & 300 & -6 \\ 5 & 0 & 15 \\ 4 & 40 & -29 \end{bmatrix} = 31\,(0 - 600) - 300\,(-145 - 60) - 6\,(200)$$

$$= -18{,}600 + 61{,}500 - 1{,}200 = 41{,}700$$

$$D_3 = \begin{bmatrix} 31 & -10 & 300 \\ 5 & -23 & 0 \\ 4 & 20 & 40 \end{bmatrix} = 31\,(-920 - 0) + 10\,(200 - 0) + 300\,(100 + 92)$$

$$= -28{,}520 + 2{,}000 + 57{,}600 = 31{,}080$$

$$V_A = \frac{D_1}{D_0} = \frac{98{,}580}{8{,}175} = 12.06; \qquad V_B = \frac{D_2}{D_0} = \frac{41{,}700}{8{,}175} = 5.1\,\text{V} \qquad V_C = \frac{D_3}{D_0} = \frac{31{,}080}{8{,}175} = 3.802\,\text{V}$$

Current in various resistors:

$$I_1 = \frac{V_A}{2} = \frac{12.06}{2} = 6.03\,\text{A}; \quad I_2 = \frac{V_A - V_B}{3} = \frac{12.06 - 5.1}{3} = 2.32\,\text{A};$$

$$I_3 = \frac{V_A - V_C}{5} = \frac{12.06 - 3.802}{5} = 1.652\,\text{A}; \quad I_4 = \frac{V_B - V_C}{1} = \frac{5.1 - 3.802}{1} = 1.298\,\text{A};$$

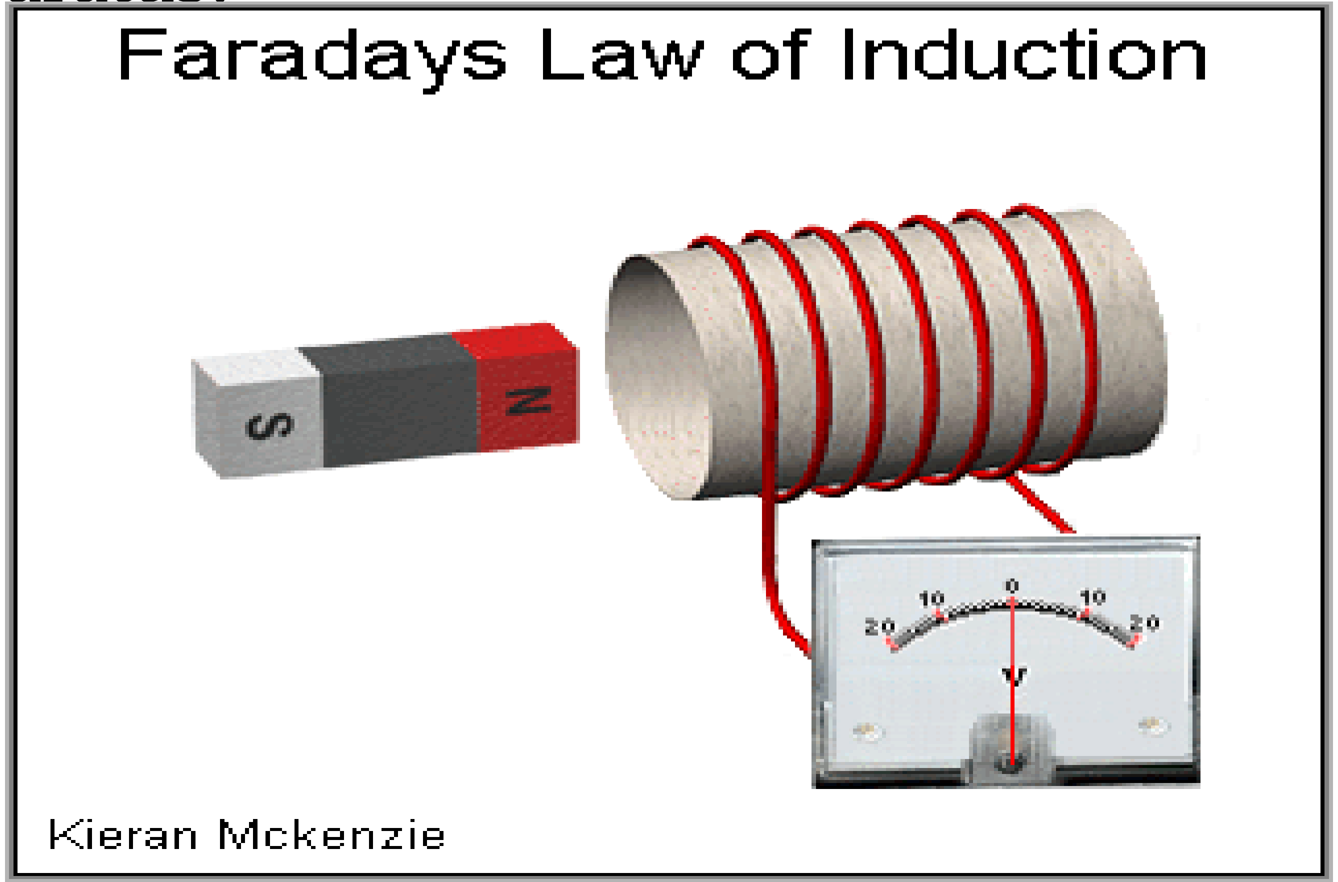
$$I_5 = \frac{V_B}{5} = \frac{5.1}{5} = 1.02\,\text{A}; \qquad I_6 = \frac{V_C}{4} = \frac{3.802}{4} = 0.95\text{A}$$

Electromagnetic Induction & Lenz’s Law

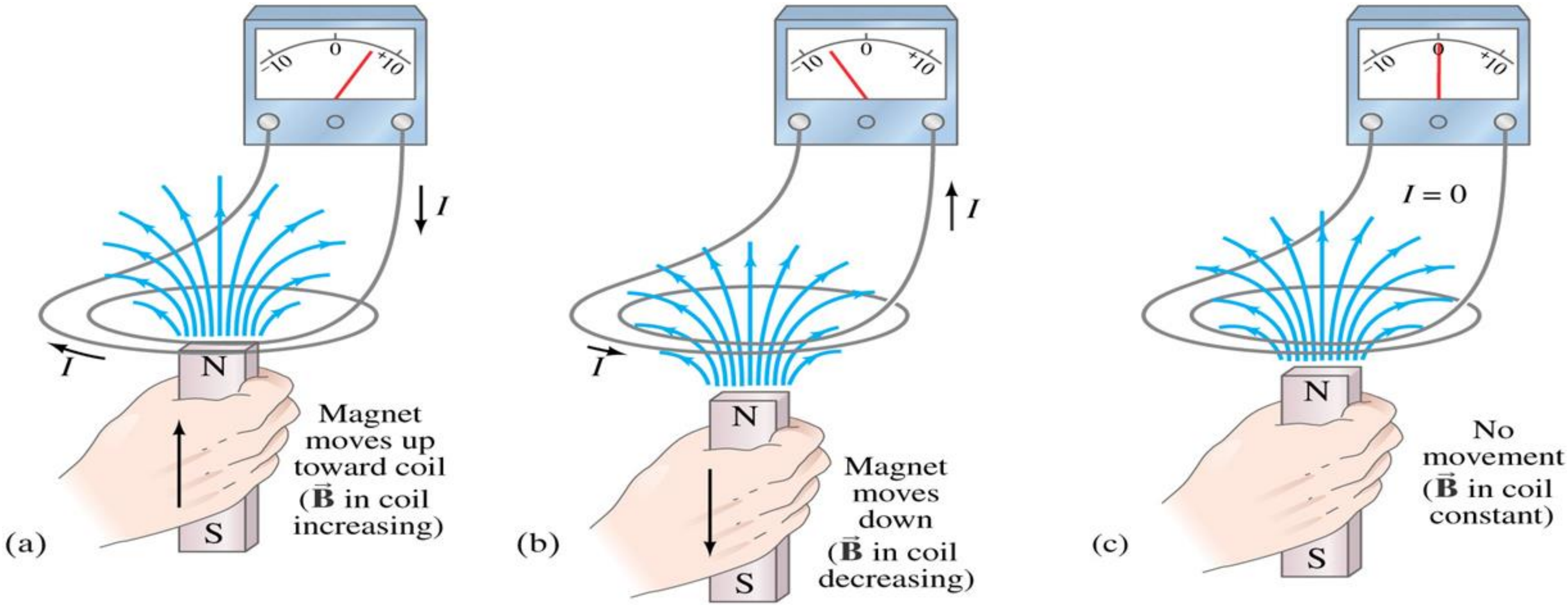
FARADAY'S EXPERIMENT

FARADAY'S EXPERIMENT

Almost 200 years ago, around 1831, Faraday looked for evidence that a magnetic field would induce an electric current with this apparatus:



He found no evidence when the magnet was stationary, but did see a deflection in the galvanometer when the magnet was moved away or towards the coil



He then changed the:

- no. of turns of the coil,
- the relative speed of the magnet and coil
- the direction of relative motion of the coil and magnet

and observed the change in the deflections shown by the galvanometer.

IMPORTANT CONCLUSIONS

With the help of his experiment, Faraday drew four important Conclusions, which provided the basis of his law:

1.The galvanometer showed deflection whenever there was relative motion between the magnet and the coil.

2.The deflection was more when the relative motion was faster and less when the relative motion was slower.

3.The direction of the deflection changed if the polarity of the magnet was changed

4.The deflection in galvanometer changes with the change in the number of turns of coil-more the number of turns, greater the deflection.

Faraday's Law of Induction

Faraday Law: changing the flux induces an emf.

$$\mathcal{E} = - d\Phi_B /dt$$

The emf induced around a loop

equals the rate of change of the flux through that loop

A non-zero value of $d\varphi/dt$ may result from any of the following situations:

1. A time changing flux linking a stationary closed path or total emf made by a changing field within a stationary path (transformer emf)
2. Relative motion between a steady flux and a closed path or a moving path within a constant (motional or generator emf)
3. A combination of the two

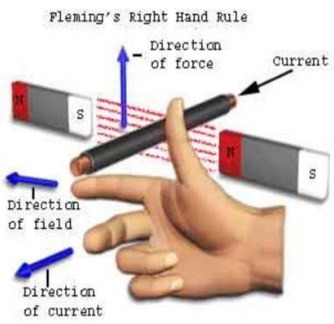
The dynamically induced emf in a conductor of length $l(m)$ placed at angle θ to a stationary magnetic field of flux density B(T) cutting across it at speed v(m/s) is given by

$$e = |v \times B|\, l \text{ V}$$

$$= Blv \sin\theta \text{ V} \tag{5.22}$$

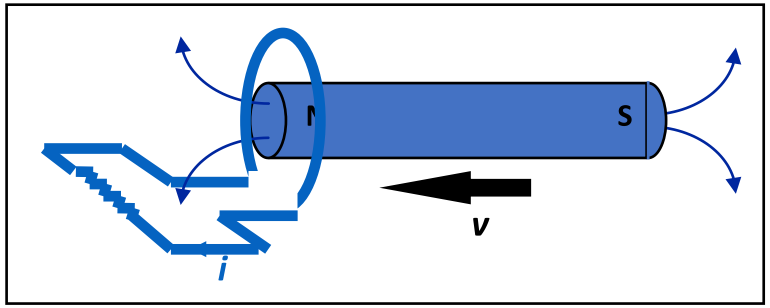
where θ is the angle between the direction of flux density and conductor velocity. In electric machines $\theta = 90°$, so that

$$e = Blv \text{ V} \tag{5.23}$$

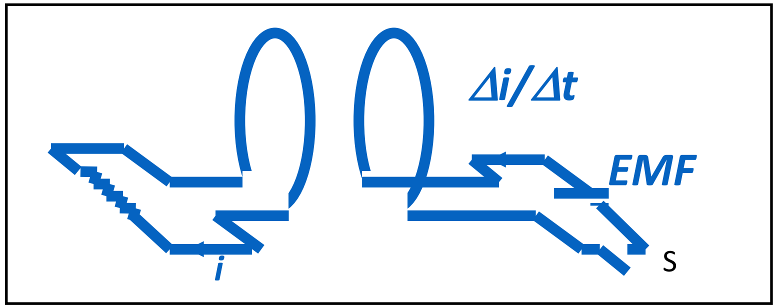


This is known as the *flux-cutting rule* with the direction of emf given by $v \times B$ or by the well-known *Fleming's right-hand rule*.

Extend the thumb, first and second fingers of the right hand mutually at right angles to each other. If the thumb represents the direction of v (motion of conductor with respect to B), first finger the direction of B then the second finger gives the direction of emf along l (the conductor).



Moving the magnet changes
the flux Φ_B



Changing the current changes
the flux Φ_B

The induced e.m.f. in a wire loop is proportional to the rate of change of magnetic flux through the loop.

Magnetic flux:

$$\Phi_B = B_\perp A = BA\cos\theta$$

Unit of magnetic flux: **WEBER (Wb)**

1 Wb = 1 T·m²

Faraday's law of induction:

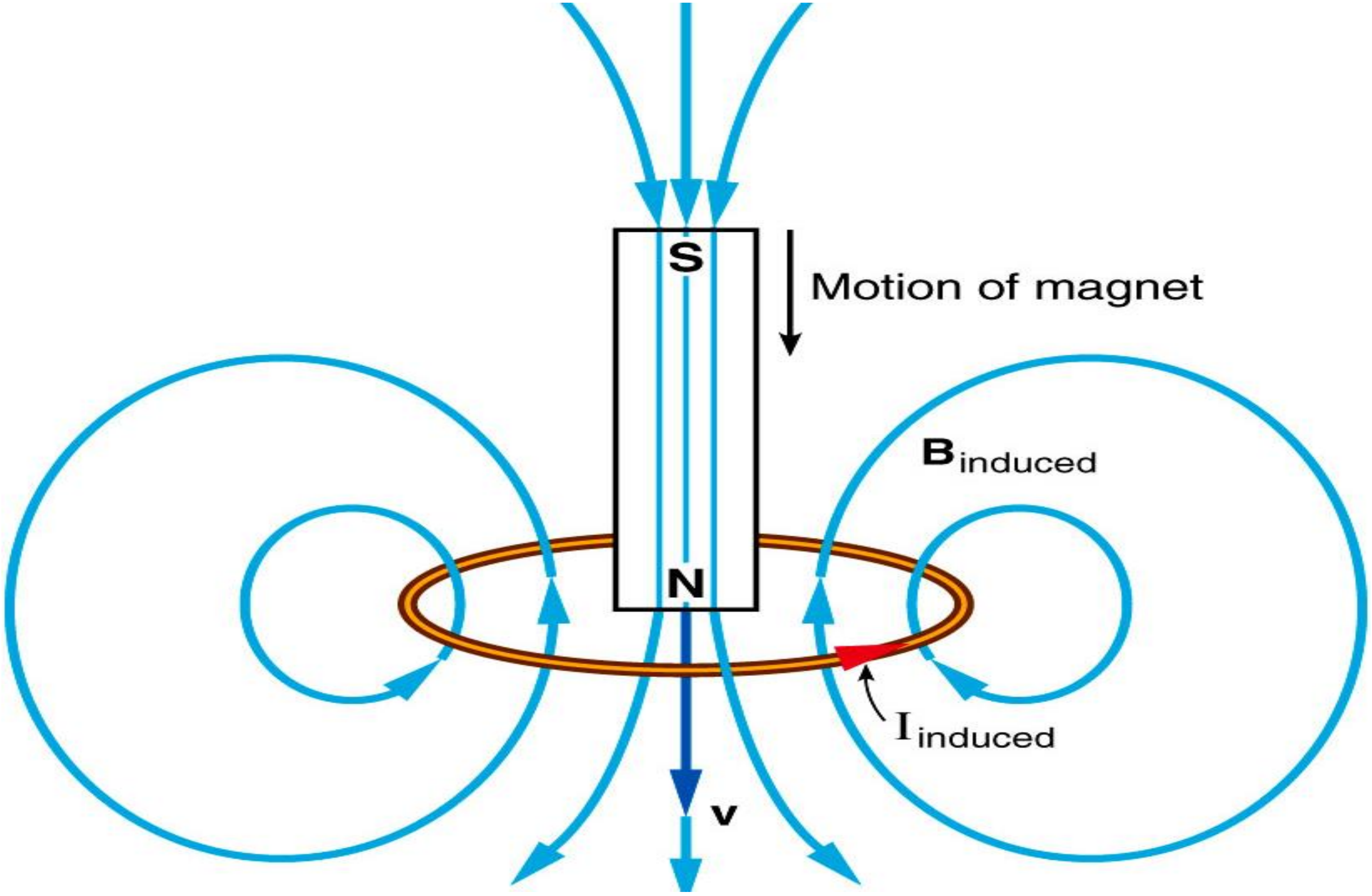
$$\mathcal{E} = -\frac{\Delta \Phi_B}{\Delta t}$$

[1 loop only]

$$\mathcal{E} = -N\frac{\Delta \Phi_B}{\Delta t}$$

[For N loops]

A current produced by an induced EMF moves in a direction so that the magnetic field it produces tends to restore the changed field.



The -ve sign gives the direction of The induced EMF

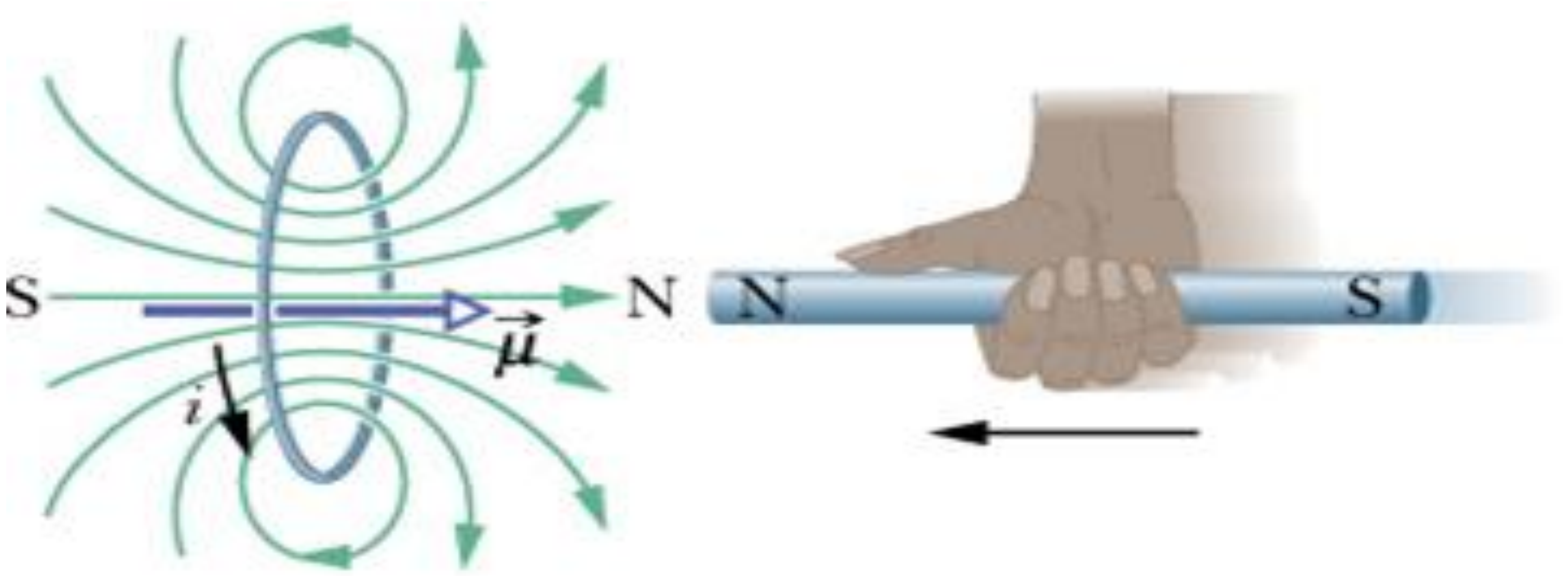
Lenz's law

Faraday's law gives the magnitude and direction of the induced emf, and therefore the direction of any induced current.

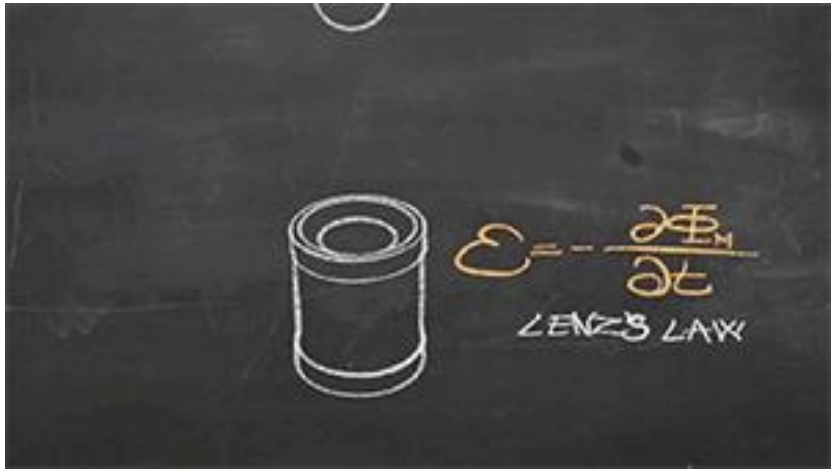
Lenz's law is a simple way to get the directions straight, with less effort.

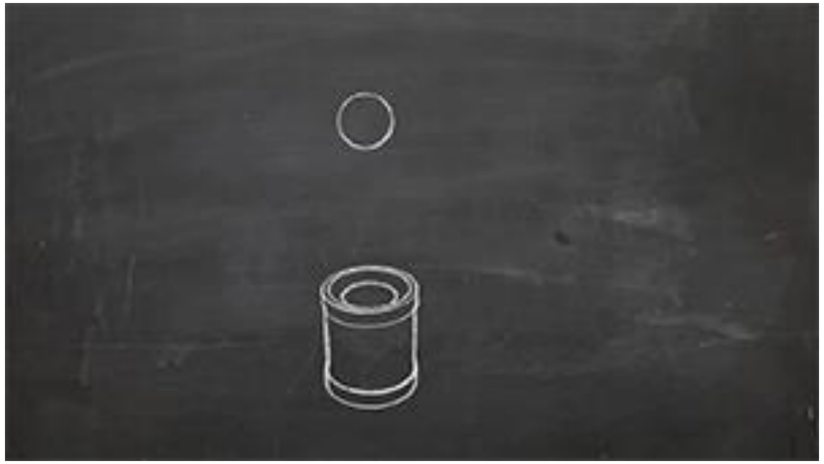
Lenz's Law:

The induced emf is directed so that any induced current flow will *oppose* the *change* in magnetic flux (which causes the induced emf).



Lenz’s law states that if you create a changing magnetic field by moving a magnet, it will produce a mechanical force which will try to slow down the motion. The faster you move, the stronger the force gets.





Define Lorentz force and obtain force on current element using it.

OR

Prove the following $F = Q(E + v \times B)$

OR

Derive an equation of force on moving charge under effect of EM field.

Force On A Moving Charge

A charged particle in motion in a magnetic field of flux density B is found to experience a force whose magnitude is proportional to the product of the magnitude of the charge Q, its velocity v and the flux density B and to the sine of the angle between the vectors v and B.

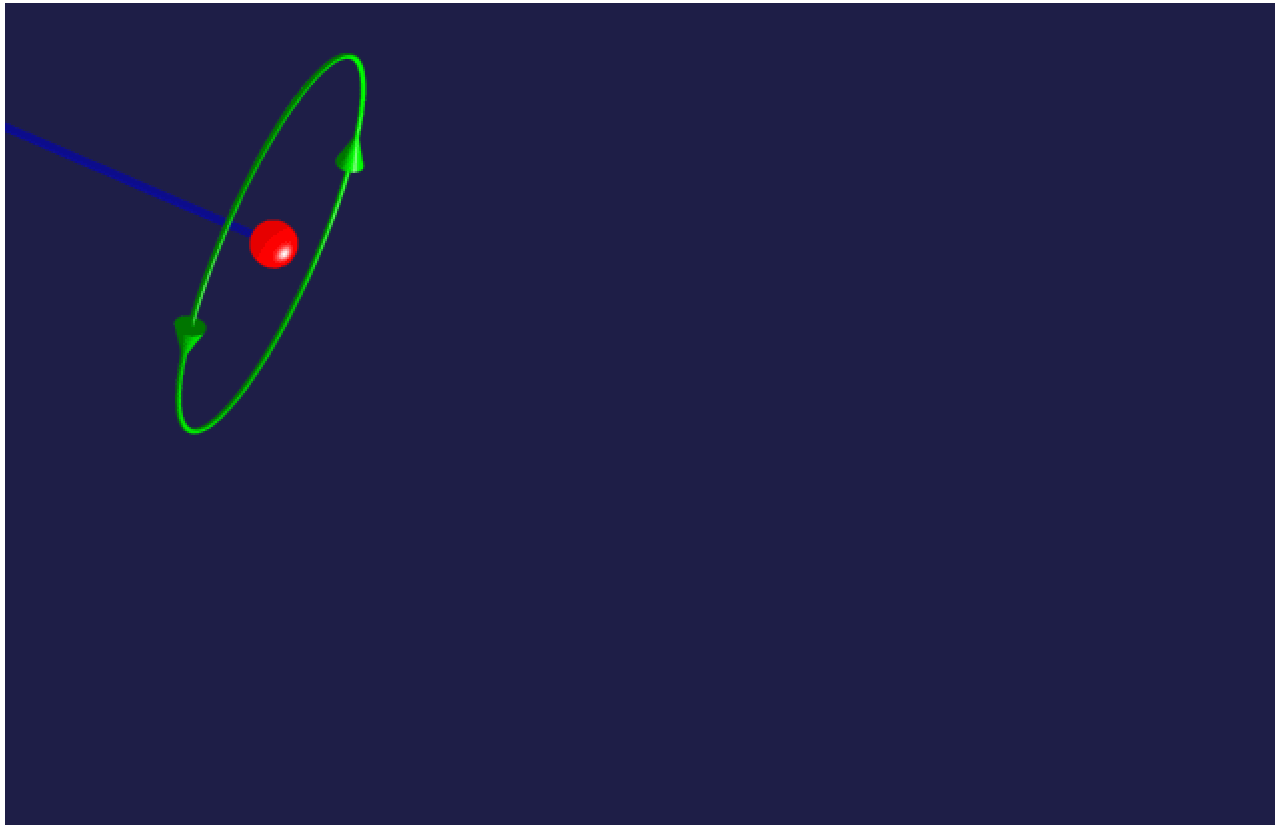
$$F = qv \times B$$

1. The force is perpendicular to both the velocity v of the charge q and the magnetic field B.

2. The magnitude of the force is $F = qvB \sin\theta$ where θ is the angle < 180 degrees between the velocity and the magnetic field. This implies that the magnetic force on a stationary charge or a charge moving parallel to the magnetic field is zero.

3. The direction of the force is given by the right hand rule. The force relationship above is in the form of a vector product.

The magnetic force is at right angles to the magnetic field.
The magnetic force requires that the charged particle be in motion.

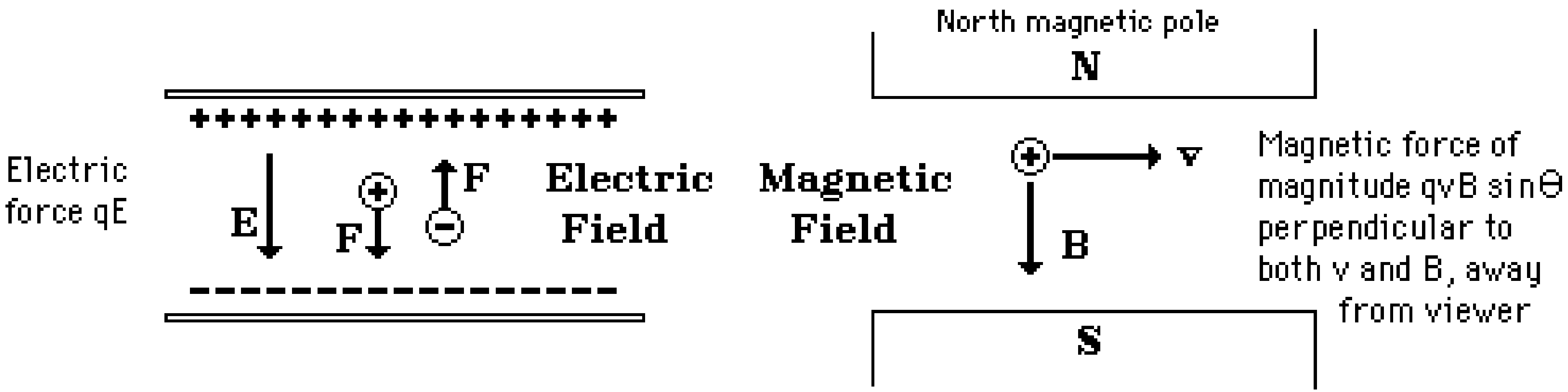


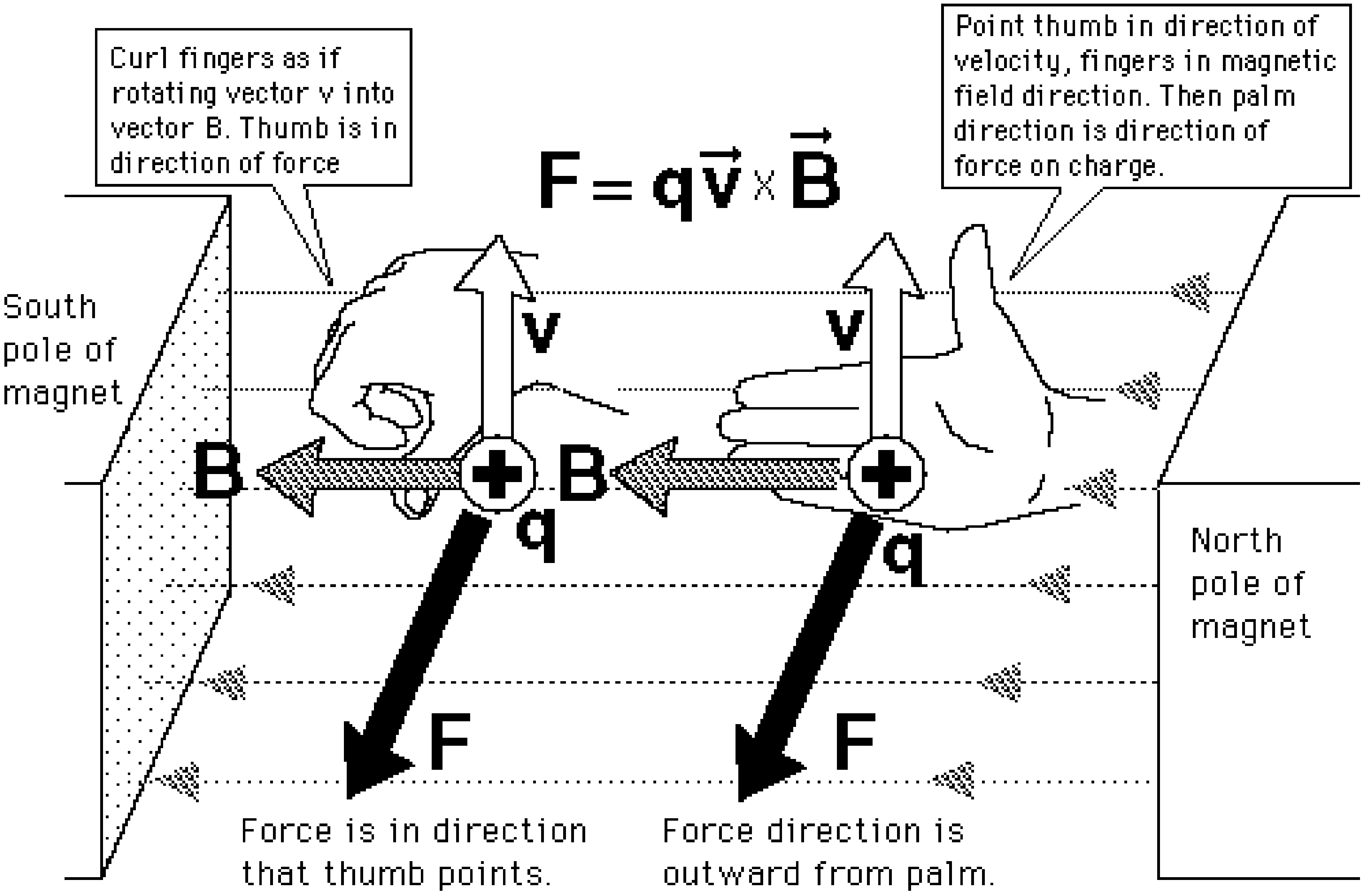
Lorentz Force Law

Both the electric field and magnetic field can be defined from the Lorentz force law:

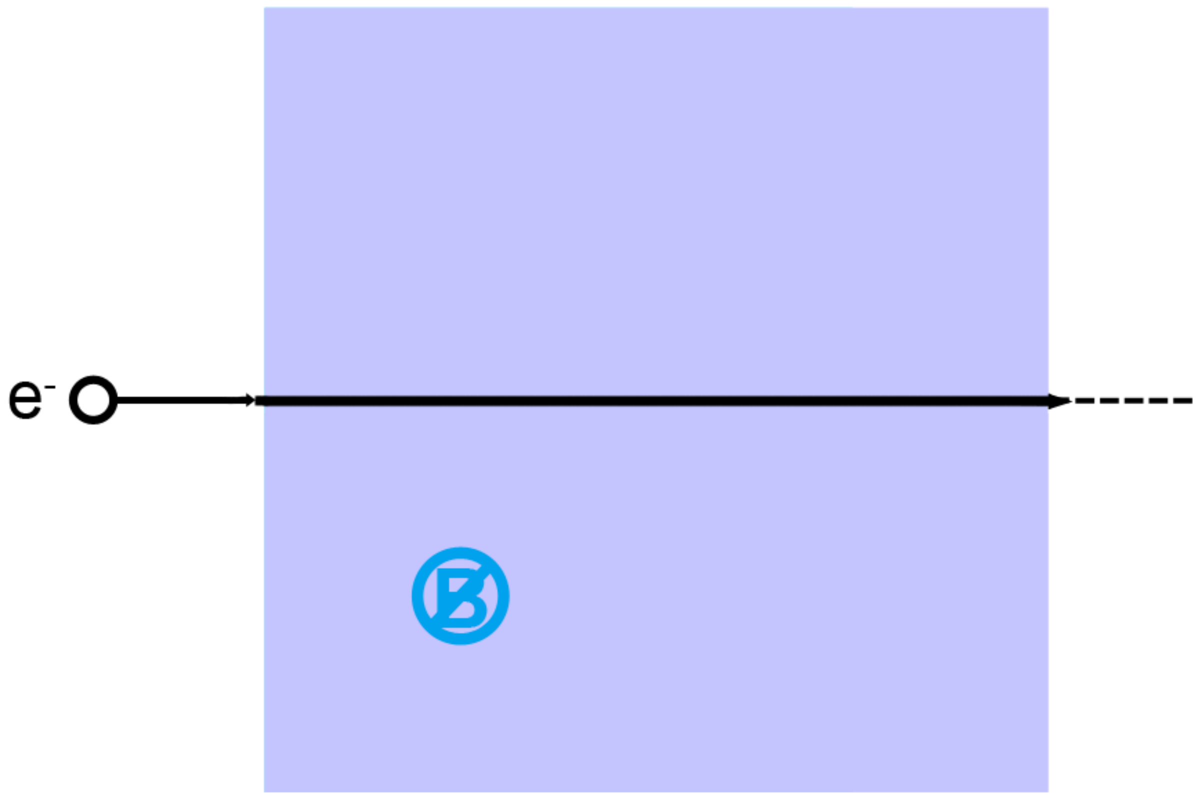
$$\vec{F} = \underbrace{q\vec{E}}_{\text{Electric Force}} + \underbrace{q\vec{v} \times \vec{B}}_{\text{Magnetic Force}}$$

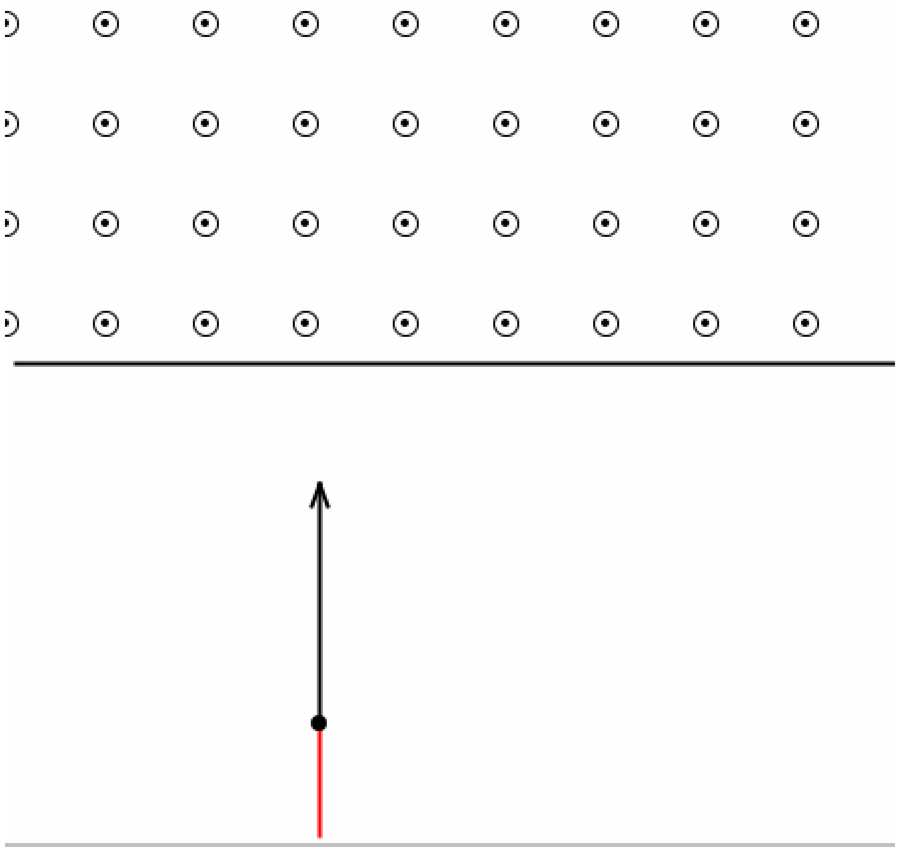
The electric force is straightforward, being in the direction of the electric field if the charge q is positive, but the direction of the magnetic part of the force is given by the right hand rule.





Curl fingers as if rotating vector v into vector B. Thumb is in direction of force
$\mathbf{F} = q\vec{v} \times \vec{B}$
Point thumb in direction of velocity, fingers in magnetic field direction. Then palm direction is direction of force on charge.
South pole of magnet
v
v
B
B
q
q
North pole of magnet
F
F
Force is in direction that thumb points.
Force direction is outward from palm.


e⁻



8.1 FORCE ON A MOVING POINT CHARGE

Force in electric field: $\boxed{\bar{F}_e = Q\bar{E}}$

Force in magnetic field: $\bar{F}_m = Q\bar{V} \times \bar{B}$

Total force: $\boxed{\bar{F} = \bar{F}_e + \bar{F}_m \quad \text{or} \quad \bar{F} = Q\left(\bar{E} + \bar{V} \times \bar{B}\right)}$

Also known as ***Lorentz force equation.***

Force on charge in the influence of fields:

Charge Condition	$\overline{E}$ Field	$\overline{B}$ Field	Combination $\overline{E}$ and $\overline{B}$
Stationary	$Q\overline{E}$	-	$Q\overline{E}$
Moving	$Q\overline{E}$	$\overline{F}_m = Q\overline{V} \times \overline{B}$	$\overline{F} = Q\left(\overline{E} + \overline{V} \times \overline{B}\right)$

Force of electromagnetic origin is given by

$$\mathbf{F} = l\,\mathbf{i} \times \mathbf{B} \ \ \mathrm{N} \tag{5.24}$$

where $\mathbf{F}$ is the force acting on a straight conductor of length l (m) carrying current i (A) placed in a uniform field of flux density B(T). The magnitude of force is given by

$$F = Bil \sin\theta \ \ \mathrm{N} \tag{5.25}$$

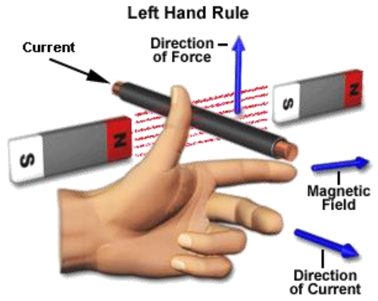
where direction is along $\mathbf{i} \times \mathbf{B}$ and θ is the angle between current direction and flux density. If $\theta = 90°$ as in electric machines

$$F = Bil \ \ \mathrm{N} \tag{5.26}$$

which is the well-known *Bil rule* or *Biot-Savart Law*.

The direction of force can also be found by the *Fleming's left-hand rule*.

Extend the thumb, first and second fingers of the left hand mutually at right angles to each other. If the thumb represents the direction of B, the second finger the direction of I then the first finger points in the direction of force on the conductor.

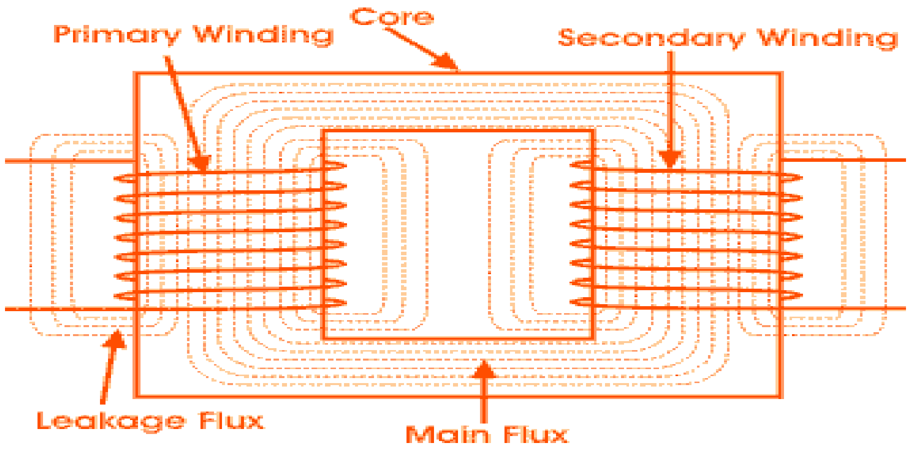


WHAT IS TRANSFORMER

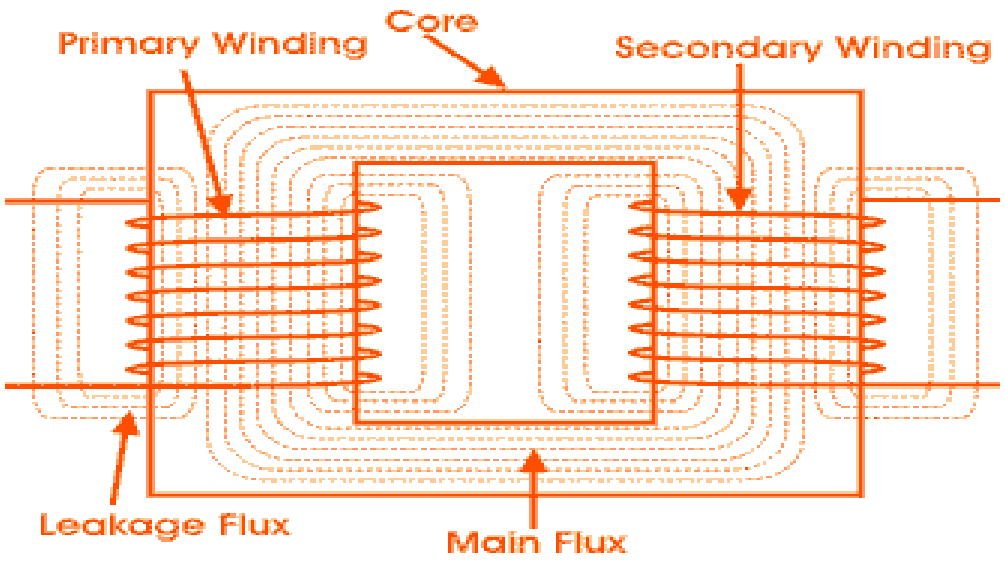
- A transformer is a static device.
- The word ‘transformer’ comes form the word ‘transform’.
- Transformer is not an energy conversion device, but it is device that changes AC electrical power at one voltage level into AC electrical power at another voltage level through the action of magnetic field.
- There is no electrical contact between them.
- The desirechange in voltage or current without any change in frequency.
- It can be either to step-up or step down.
- *It works on the principle of mutual induction.*

STRUCTURE OF TRANSFORMER

- The transformer has two inductive coils ,these are electrical separated but linked through a common magnetic current circuit
- These two coils have a high mutual induction



- One of the two coils is connected of alternating voltage .this coil in which electrical energy is fed with the help of source called primary winding (P) shown in fig.
- The other winding is connected to a load the electrical energy is transformed to this winding drawn out to the load .this winding is called secondary winding(S) shown in fig.



- The primary and secondary coil wound on a ferromagnetic metal core.
- The function of the core is to transfer the changing magnetic flux from the primary coil to the secondary coil.
- The primary has N_1 no of turns and the secondary has N_2 no of turns the of turns plays major important role in the function of transformer.

WORKING PRINCIPLE

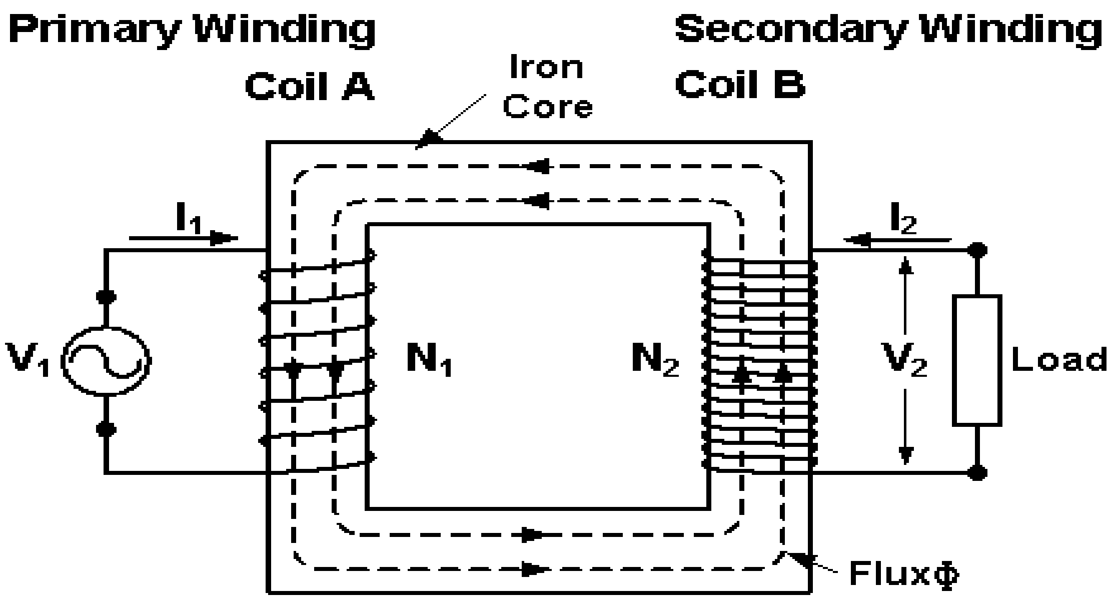
- The transformer works in the principle of mutual induction

“The principle of mutual induction states that when the two coils are inductively coupled and if the current in coil change uniformly then the e.m.f. induced in the other coils. This e.m.f can drive a current when a closed path is provide to it.”

- When the alternating current flows in the primary coils, a changing magnetic flux is generated around the primary coil.
- The changing magnetic flux is transferred to the secondary coil through the iron core
- The changing magnetic flux is cut by the secondary coil, hence induces an e.m.f in the secondary coil

- Now if load is connected to a secondary winding, this e.m.f drives a current through it
- The magnitude of the output voltage can be controlled by the ratio of the no. of primary coil and secondary coil

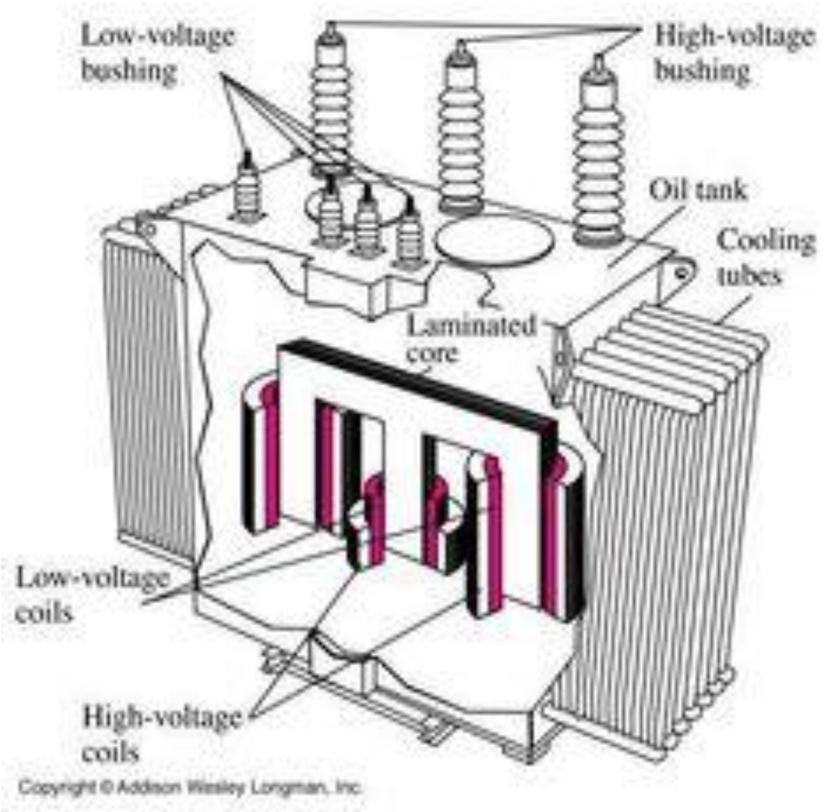
The frequency of mutually induced e.m.f as same that of the alternating source which supplying to the primary winding b



CONSTRUCTION OF TRANSFORMER

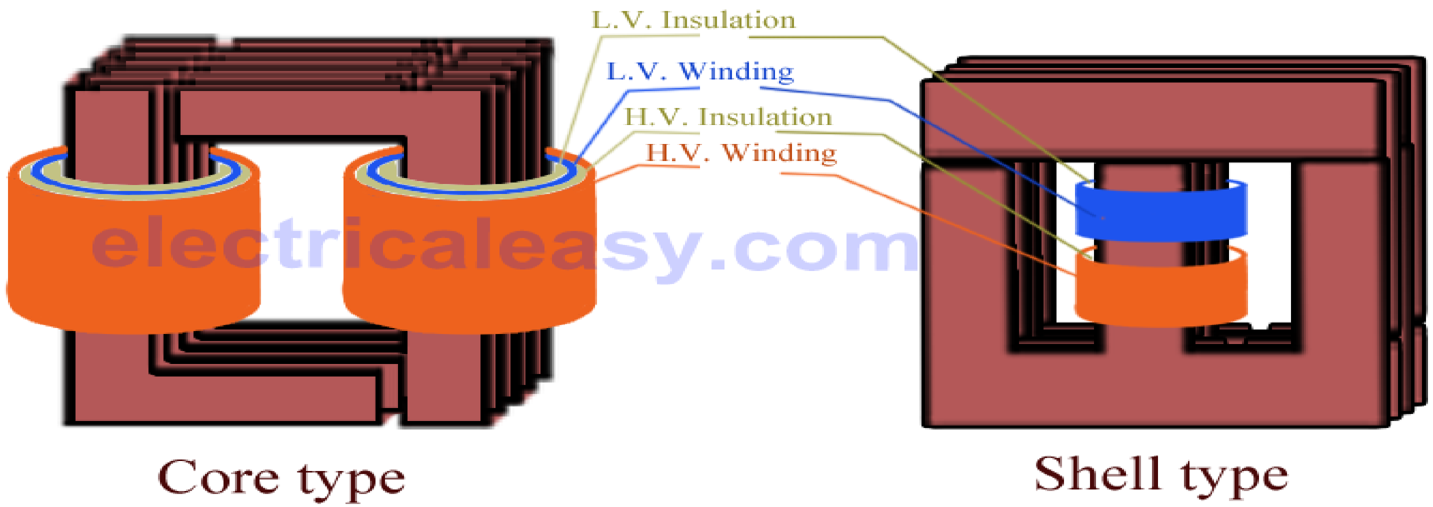
Main parts:

1. ***Iron core***-provides magnetic circuit
2. ***Two inductive coils*** wound on core-insulated from each other and also from core.
3. Suitable ***container*** for assembled core and windings
4. Suitable ***medium*** for insulating core and windings . This medium cools the windings and core.
5. Suitable ***porcelain bushings*** for insulating and bringing out winding terminals from tank.



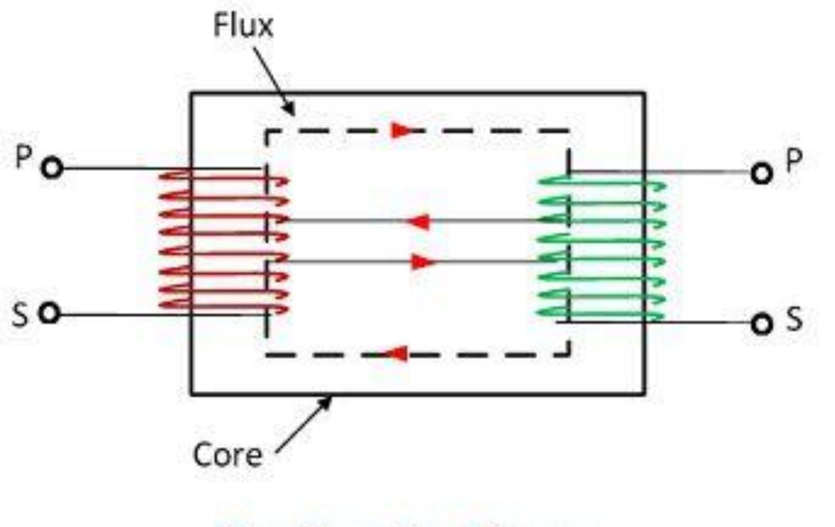
CORE OF TRANSFORMER

- Core is made of steel laminations to minimize eddy current loss
- Laminations are about 0.35mm thick and pressed together to form continuous magnetic path with min. air gap
- Depending upon construction of core, there are two types: (i) Core type (ii) Shell type



CORE TYPE TRANSFORMER

- Windings surround considerable part of core.
- To reduce leakage of magnetic flux, windings are divided into two parts and half of each winding is placed on each limb, side by side.



Core Type Transformer

- To minimize cost of insulation, the low voltage (LV) winding is placed adjacent to core and high voltage (HV) winding is placed around LV.

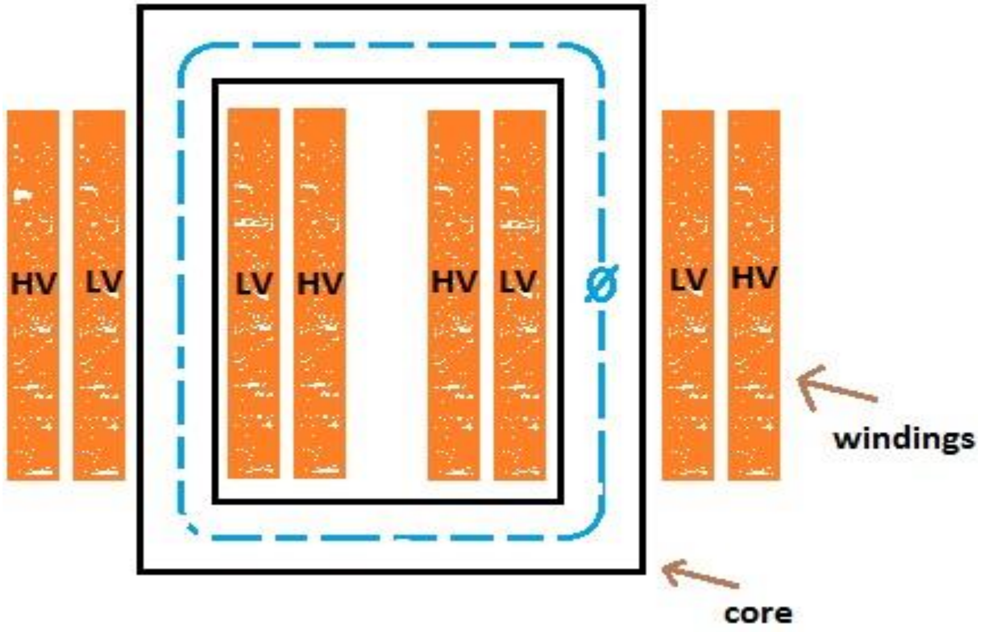
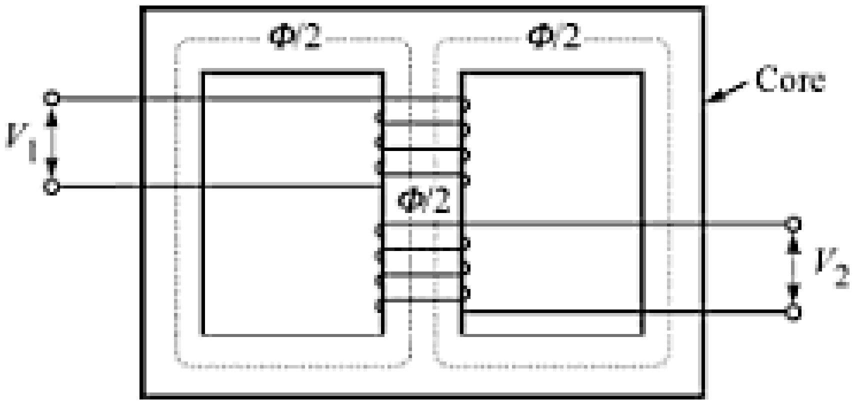
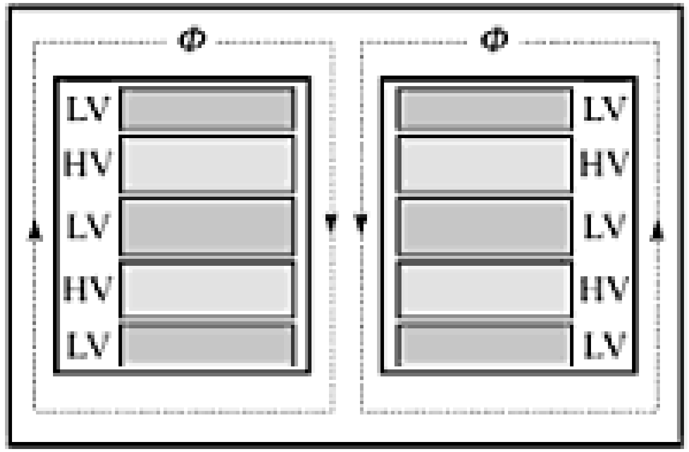


Fig (b)

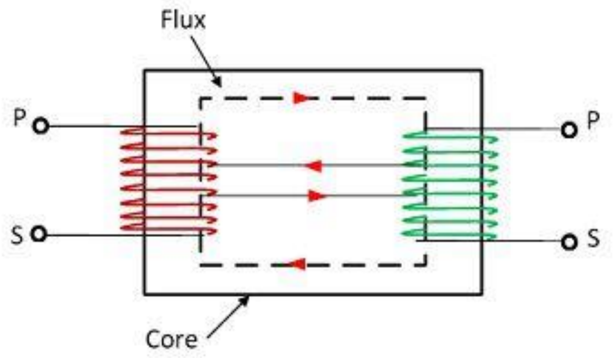
SHELL TYPE TRANSFORMER

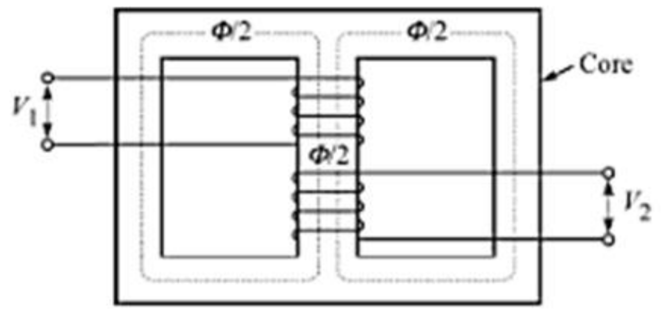
- It has three limbs.
- Both windings are placed on central limb as shown in fig a.
- The LV and HV windings are sandwiched as shown in fig b.
- Here core surrounds considerable part of windings.





CORE TYPE VS SHELL TYPE





CORE TYPE TRANSFORMER	SHELL TYPE TRANSFORMER
1. Flux has single path	1. Flux in central limb divides equally and returns through outer two legs
2. More space for insulation. Hence preferred for high voltages	2. More economical for low voltages
3. Mean length of coil turn is shorter	3. Mean length of coil turn is longer
4. Core is either circular or rectangular	4. Core is either rectangular or cylindrical
5.Core has two limbs	5. Core has three limbs
6. Coils can be easily removed for maintenance	6. Coils cannot be removed easily.

IDEAL TRANSFORMER

A transformer is said to be ideal if it satisfies the following properties, but no transformer is ideal in practice.

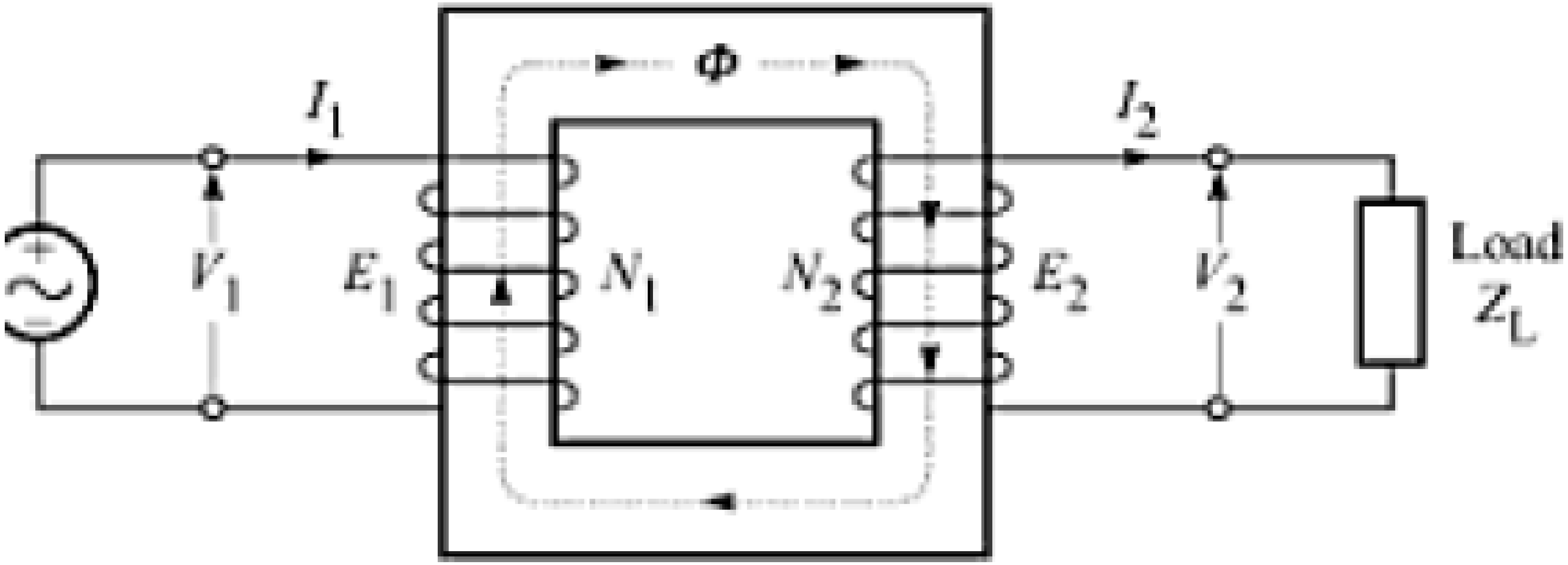
- It has no core losses
- Windings resistance are zero, no I^2R losses in windings, *Zero resistance* result in *zero voltage drops* between the terminal voltages and induced voltages
- There is no flux leakage, entire flux in the core links both the windings
- The permeability μ of the magnetic circuit (core) is infinite, i.e. magnetic circuit has zero reluctance so that no mmf is needed to set up the flux in the core.

magnetomotive force (MMF)

→ In case of electromagnet, the force which is setting up flux in magnetic material is called magnetomotive force.

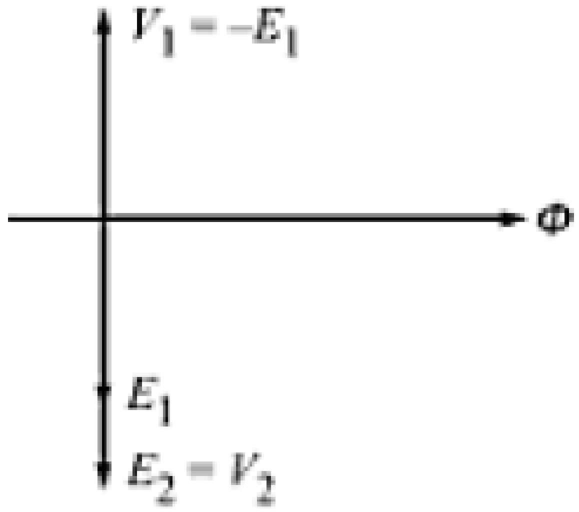
$\boxed{mmf = N \cdot I}$, ~~[illegible]~~ unit → Amp. turns or Amps.

While the practical transformer has windings resistance , some leakage flux and has losses also.



$V1 = -E1$ → E1 is counter or back emf in primary which exactly counterbalance V1 due to ideal transformer.

$E2 = V2$ → E2 is mutually induced emf in the secondary.



TRANSFORMATION RATIO

- The ratio of secondary voltage to primary voltage is known as transformation or turns ratio.
- Denoted by K.

$$K = \frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{N_2}{N_1}$$

- Where N1 and N2 are the number of turns in primary and secondary windings.

- Thus the side of the transformer with the larger number of turns has the larger voltage.

$$E_1 = 4.44 f N \varphi_m \qquad E_2 = 4.44 f N \varphi_m$$

1. When K>1 i.e. $N_2>N_1$, $V_2>V_1$; Step up transformer
2. When K<1 i.e. $N_2<N_1$, $V_2<V_1$; Step down transformer

- If a transformer have more than two windings; primary, secondary, tertiary and so on. In this case primary is connected to supply and rest are connected to different loads.

$$E1 : E2 : E3 :: N1 : N2 : N3$$

RELATION B/W CURRENT AND K

$$I_1 N_1 = I_2 N_2 \qquad OR \qquad \frac{I_2}{I_1} = \frac{N_1}{N_2} = \frac{1}{K}$$

- For an ideal transformer, current I_1 in primary is just sufficient to provide mmf I_1N_1 to overcome the demagnetising effect of the secondary mmf I_2N_2.

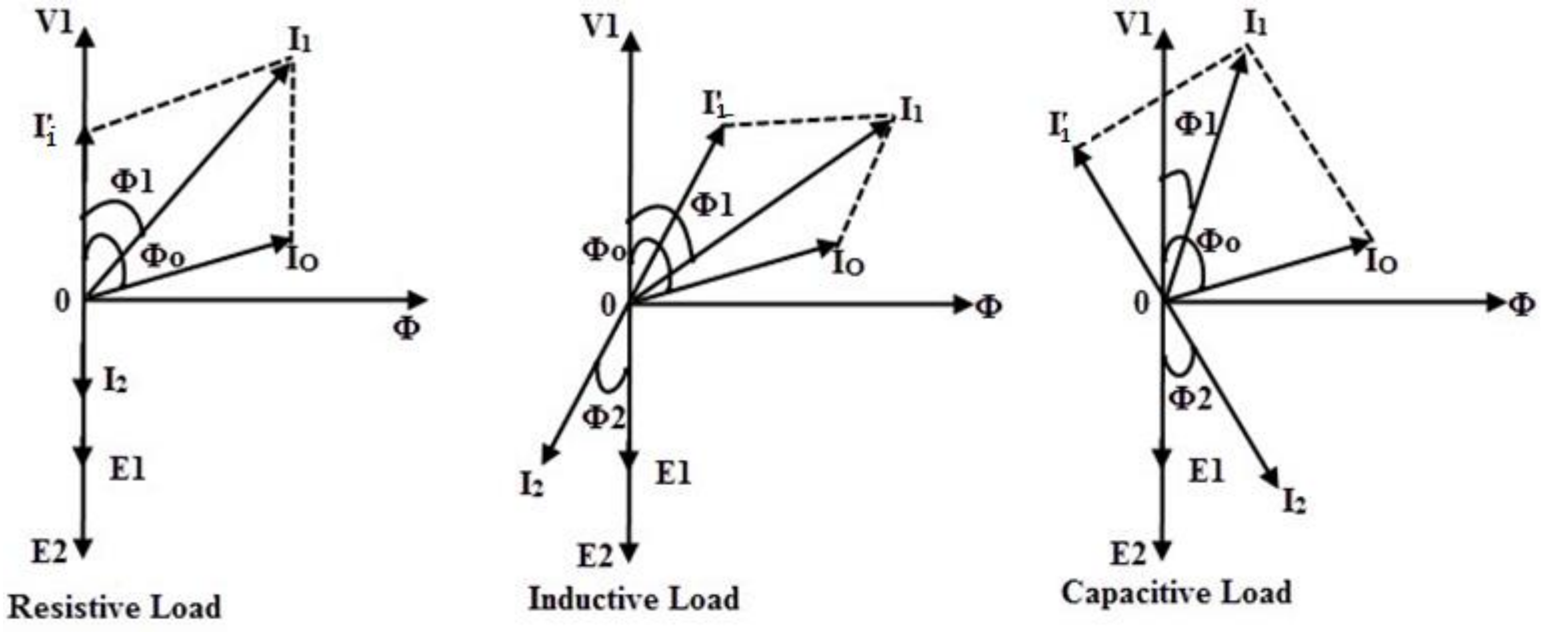
- So if voltage is stepped up, current is stepped down or vice versa.
- Side with larger number of turns has smaller current.

$$E_1 I_1 = E_2 I_2$$

- In ideal transformer input VA is equal to output VA.

Phasor diagram

- flux ϕ is taken as reference phasor as it is common to both primary and secondary.
- E_1 and E_2 lags flux ϕ by 90^o.
- Assuming step-up transformer, $E_2 > E_1$, $V_2 = E_2$.
- Since no load current is negligibly small, primary current I_1 is almost opposite in phase to secondary current I_2.



TRANSFORMER ON DC

A transformer cannot work on DC supply. If a rated DC voltage is applied across the primary, a flux of constant magnitude will be set up in the core. Hence, there will not be any self-induced emf (which is only possible with the rate of change of flux linkages) in the primary winding to oppose the applied voltage. As the resistance of the primary winding is very low, the primary current will be quite high as given by the Ohm's law.

$$\text{Primary current} = \frac{\text{DC applied voltage}}{\text{Resistance of primary winding}}$$

This current is much more than the rated full-load current of primary winding. Thus, it will produce lot of heat (I^2R) loss and burns the insulation of the primary winding, and consequently, the transformer will be damaged. Hence, DC is never applied to a transformer.