Resistor

Building the circuit requires the knowledge of various components like resistors, inductors, capacitors, battery sources, connecting wires and more. The resistor is one of the main components of the circuit. In this session, let us know in detail about the resistor.

Table of Contents:

What is Resistor?

Resistor is defined as

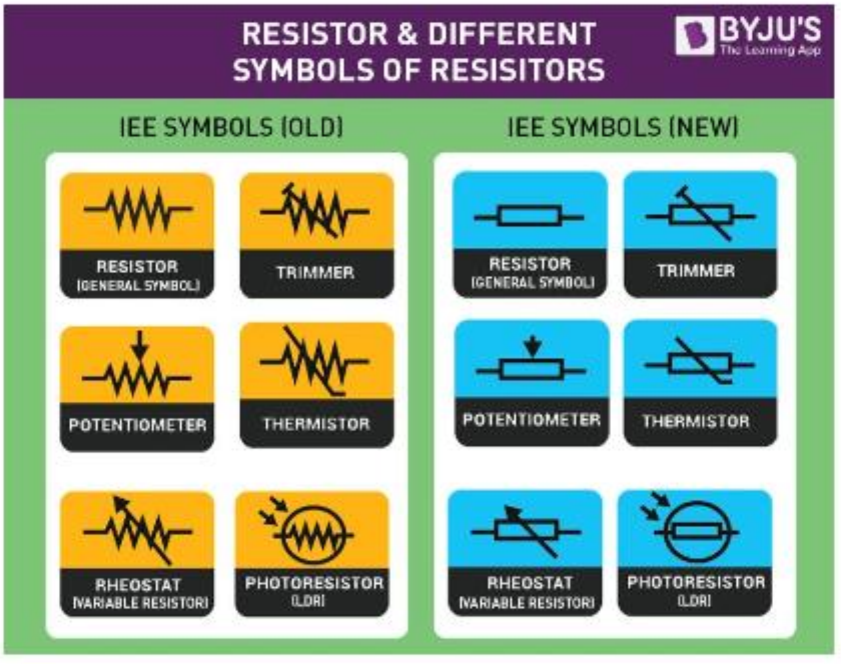
> A passive electrical component with two terminals that are used for either limiting or regulating the flow of electric current in electrical circuits.

The main purpose of resistor is to reduce the current flow and to lower the voltage in any particular portion of the circuit. It is made of copper wires which are coiled around a ceramic rod and the outer part of the resistor is coated with an insulating paint.

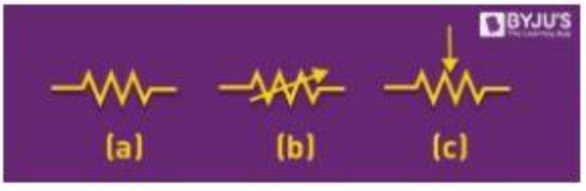
What is the SI Unit of Resistor?

The SI unit of resistor is Ohm.

Symbol of Resistor



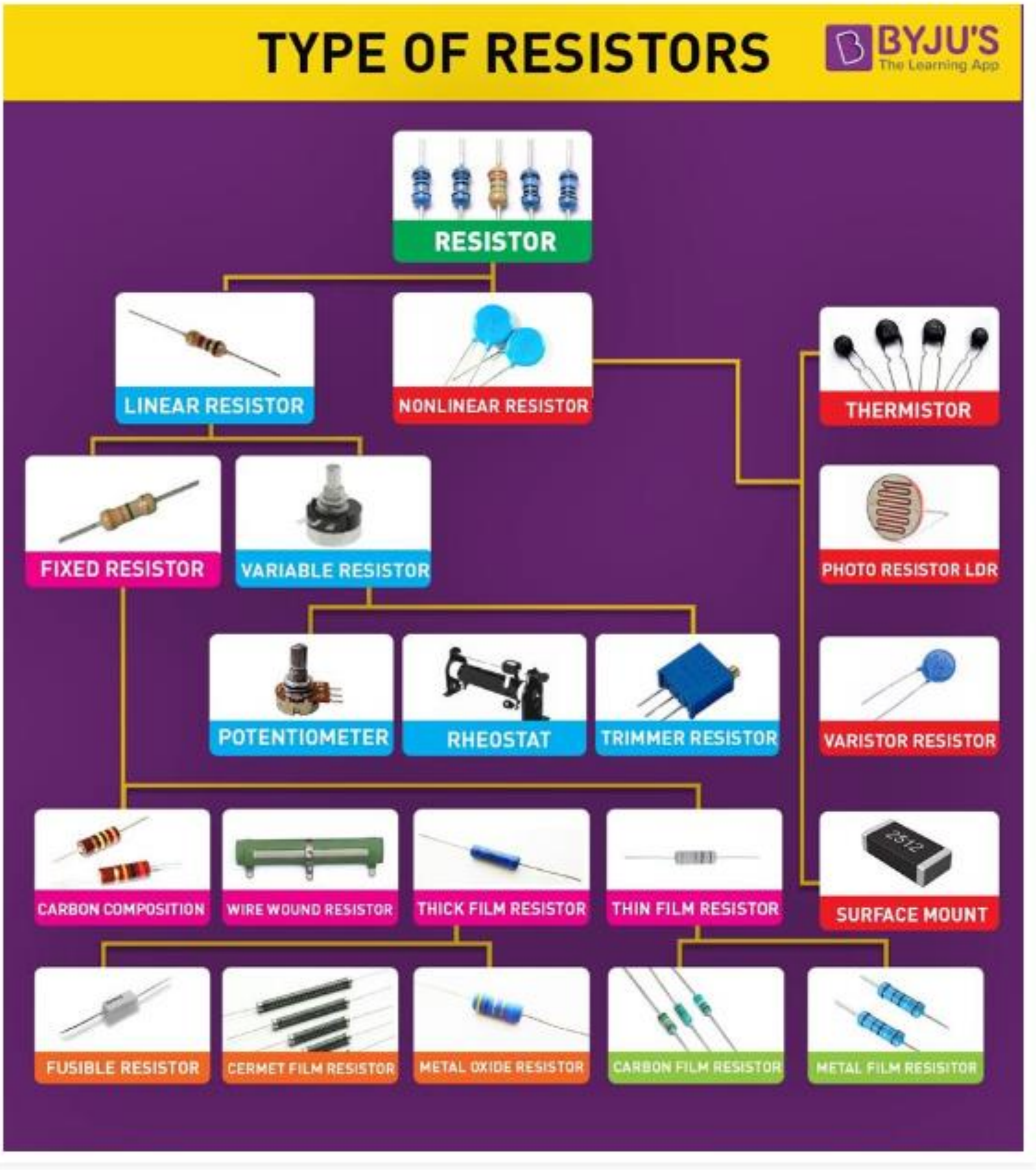
Each resistor has one connection and two terminals. We will look at the three types of symbols that are used to represent the resistor.



The terminals of the resistor are each of the lines extending from the squiggle (or rectangle). Those are what connect to the rest of the circuit. The resistor circuit symbols are usually enhanced with both a resistance value and a name. The value, displayed in ohms, is obviously critical for both evaluating and actually constructing the circuit.

Types of Resistors

Resistors are available in different shapes and sizes. Common types that are available are through-hole and surface mount. A resistor might be static, standard resistor, special, or a pack of variable resistors.



There are two basic types of resistors as follows:

- Linear resistor
- Non-linear resistor

Linear resistors

The resistors whose values change with change in applied temperature and voltage are known as linear resistors. There are two types of linear resistors:

Fixed resistors: These resistors have a specific value and these values cannot be changed. Following are the different types of fixed resistors:

- Carbon composition resistors
- Wire wound resistors
- Thin film resistors
- Thick film resistors

Variable resistors: These resistors do not have a specific value and the values can be changed with the help of dial, knob, and screw. These resistors find applications in radio receivers for controlling volume and tone. Following are the different types of variable resistors:

- Potentiometers
- Rheostats
- Trimmers

Non-linear resistors

The resistor values change according to the temperature and voltage applied and is not dependent on Ohm's law. Following are the different types of non-linear resistors:

- Thermisters
- Varisters
- Photo resistors

What is Colour Coding of Resistors?

Resistors may not display the value outside but their resistance can be calculated through their colour pattern PTH (plated-through-hole) resistors use a colour-coding system (which really adds some flair to circuits), and SMD (surface-mount-device)resistors have their own value-marking system.

Following is a table with colour code of resistors:

Colour	Colour code
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9

What is Tolerance in Resistors?

Following is a table with tolerance of resistor:

Colour	Tolerance
Brown	±1%
Red	±2%
Gold	±5%
Silver	±10%

Resistors in Series

Resistors are said to be in series when the current flowing through all the resistors is the same. These resistors are connected from head to tail in series. The overall resistance of the circuit is equal to the sum of individual resistance values.

Resistors in Series Formula

$$R_{total} = R_1 + R_2 + R_3 + ...+R_n$$

Where,

- R_{total} is the sum of reciprocal of all the individual resistances

Resistors in Parallel

Resistors are said to be in parallel when the terminals of resistors are connected to the same two nodes. Resistors in parallel share the same voltage at their terminals.

Resistors in Parallel Formula

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots\cdots + \frac{1}{R_n}$$

Where,

- $\frac{1}{R_{total}}$ *is the sum of all the individual resistances.*

Applications of Resistor

Following are the applications of resistors:

- Wire wound resistors find applications where balanced current control, high sensitivity, and accurate measurement are required like in shunt with ampere meter.
- Photoresistors find application in flame detectors, burglar alarms, in photographic devices, etc.
- Resistors are used for controlling temperature and voltmeter.
- Resistors are used in digital multi-meter, amplifiers, telecommunication, and oscillators.
- They are also used in modulators, demodulators, and transmitters.

Capacitor - Types of Capacitor and Capacitance

What Is a Capacitor?

A **capacitor** is a device in which electrical energy can be stored. It is an arrangement of two conductors, generally carrying charges of equal magnitudes and opposite signs, and separated by an insulating medium. The non-conductive region can either be an electric insulator or vacuum, such as glass, paper or air, or a semi-conductor called a dielectric.

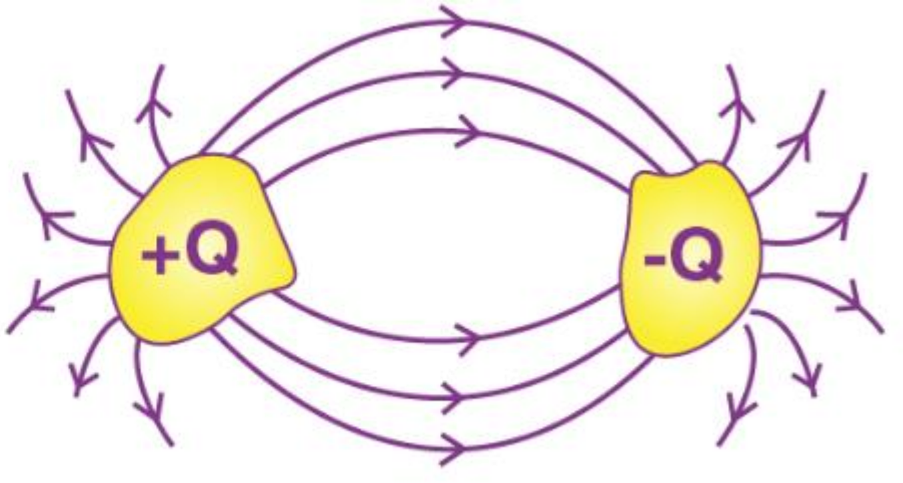
Capacitors vary in shape and size, and they have many important applications in electronics.

Related Physics Concepts:

- Capacitor, Types and Capacitance
- Combination of Capacitors
- Energy Stored in a Capacitor

What Are Capacitors Used for?

- Storing electric potential energy such as batteries.
- Filtering out unwanted frequency signals
- Delaying voltage changes when coupled with resistors.
- Used as a sensing device.
- Used in the audio system of the vehicle.
- Used to separate AC and DC.



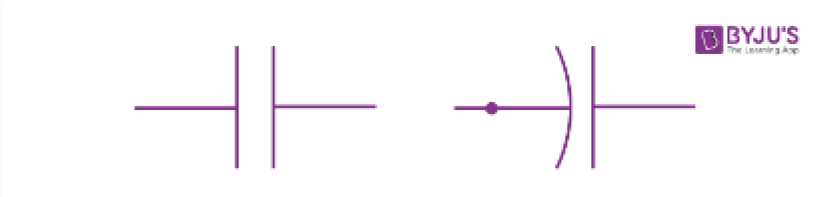
One of the conductors has a positive charge of +Q, and it is at potential +V, whereas the other has an equal negative charge -Q and is at potential -V.

Charge on Capacitor

Note: The charge on the capacitor is Q.

The total charge/the net charge on the capacitor is −Q + Q = 0.

Circuit Symbols



Capacitance

The charge on the capacitor (Q) is directly proportional to the potential difference (V) between the plates, i.e.,

$Q \alpha V$
or **Q = CV.**

The constant of proportionality (C) is termed as the **capacitance of the capacitor**.

Dimensional Formula and Unit of Capacitance

- **Unit of Capacitance:** Farad (F)

The capacitor value can vary from a fraction of a picofarad to more than a microfarad. Voltage levels can range from a couple to a substantial couple of hundred thousand volts.

- **Dimensional Formula:** $M^{-1}L^{-2}I^{2}T^{4}$

Commonly Used Scales

- μF
  = 10^{-6}F
- nF = 10^{-9}F
- pF = 10^{+2}F

Factors Affecting Capacitance

Capacitance depends on the following factors:

1. Shape and size of the conductor
2. Medium between them
3. Presence of other conductors near it

Calculation of Capacitance

We will try to calculate the capacitance of differently shaped capacitors, and the steps are as follows:

1. Assume the charge on the conductors (Q)
2. Calculate the electric field between the plates (E)
3. Calculate the potential difference from the electric field (V)
4. Apply the relation,
   $C = \frac{Q}{V}$

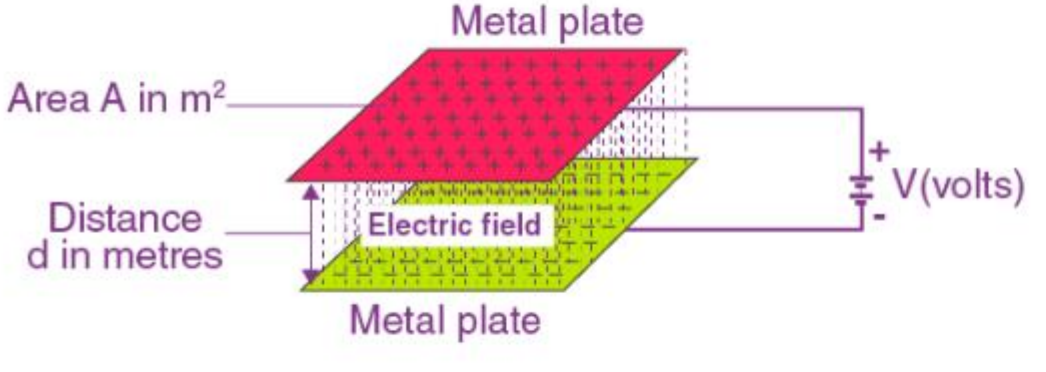
Types of Capacitors

- **Parallel Plate Capacitor**
- **Spherical Capacitor**
- **Cylindrical Capacitor**

Parallel Plate Capacitor

The parallel plate capacitor consists of two metal plates of area A, and is separated by a distance d. The plate on the top is given a charge +Q, and that at the bottom is given the charge −Q. A potential difference of V is developed between the plates.

The separation is very small compared to the dimensions of the plate, so the effect of bending outward of electric field lines at the edges and the non-uniformity of surface charge density at the edges can be ignored.



The charge density on each plate of the parallel plate capacitor has a magnitude of σ.

σ = Q/A

From Gauss's law, $E = Q/\varepsilon_0 A$

Also, **E = V/d**

Now, taking field due to the surface charges outside the capacitor,

$$E = \frac{\sigma}{2\varepsilon_0} - \frac{\sigma}{2\varepsilon_0} = 0$$

$$Inside\ E = \frac{\sigma}{2\varepsilon_0} + \frac{\sigma}{2\varepsilon_0} = \frac{\sigma}{\varepsilon_0} = \frac{q}{A\varepsilon_0}$$

$$\frac{v}{d} = \frac{q}{A\varepsilon_0}$$

$$or, C = \frac{q}{v} = \frac{A\varepsilon_0}{d}$$

This result is valid for the vacuum between the capacitor plates. For other media, then capacitance will be

$$C = \frac{kA\varepsilon_0}{d}$$

, where k is the dielectric constant of the medium,

$$\varepsilon_0 = Permittivity\ of\ free\ space = 8.85 \times 10^{-12} C^2/Nm^2$$

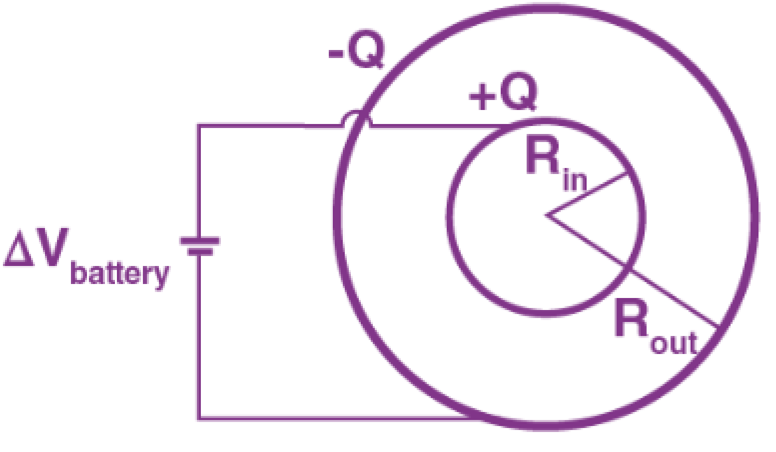
If there is a vacuum between the plates, k = 1.

Spherical Capacitor

Let's consider a spherical capacitor that consists of two concentric spherical shells. Suppose the radius of the inner sphere, R_{in} = a and the radius of the outer sphere, R_{out} = b. The inner shell is given a positive charge +Q, and the outer shell is given −Q.

The potential difference,

$$V = \frac{q}{4\pi\varepsilon_0 ka} + \frac{-q}{4\pi\varepsilon_0 kb}$$



$V=\frac{q}{4\pi\epsilon_0 k}\left[\frac{1}{a}-\frac{1}{b}\right]$

$V=\frac{q}{4\pi\epsilon_0 k}\left[\frac{b-a}{ab}\right]$

$C=\frac{q}{V}=\frac{q}{\frac{q}{4\pi\epsilon_0 k}\left[\frac{b-a}{ab}\right]}$

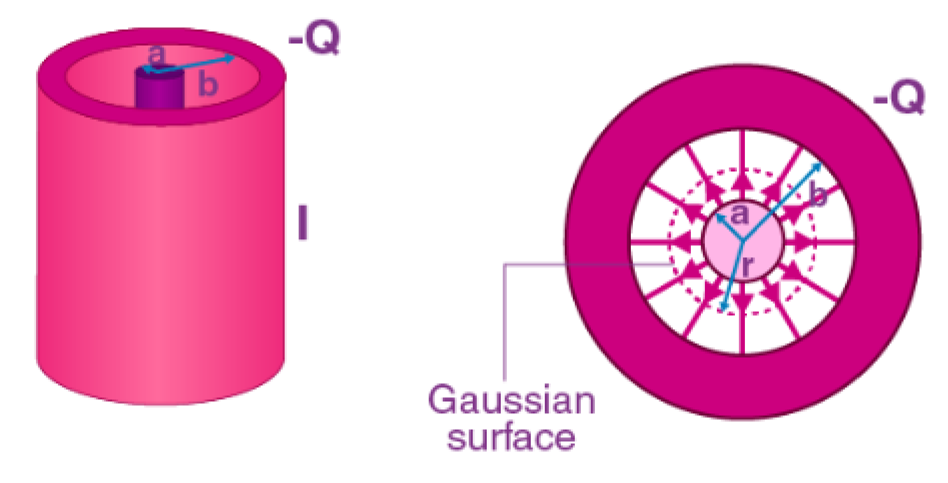
$C=4\pi\epsilon_0 k\left[\frac{ba}{b-a}\right]$
Farad

Cylindrical Capacitor

Consider a solid cylinder of radius a surrounded by a cylindrical shell, b. The length of the cylinder is l and is much larger than a-b to avoid edge effects. The capacitor is charged so that the charge on the inner cylinder is +Q and the outer cylinder is –Q.

From Gauss's law,

$E=\frac{Q}{2\pi\varepsilon_0 rl}=\frac{\lambda}{2\pi\varepsilon_0 r}$
Where λ = Q/l, linear charge density



The potential difference of cylindrical capacitor is given by,

$$\Delta V = V_b – V_a = -\int_a^b E_r dr = -\frac{\lambda}{2\pi\varepsilon_0}\ln\left(\frac{b}{a}\right)$$

Where, we have chosen the integration path to be along the direction of the electric field lines. As expected, the outer conductor with a negative charge has a lower potential, which gives

$$C = \frac{Q}{|\Delta V|} = \frac{\lambda L}{\lambda \ln(b/a)/2\pi\varepsilon_0} = \frac{2\pi\varepsilon_0 L}{\ln(b/a)}$$

Once again, we see that the capacitance C depends only on the geometrical L, a and b.

Problems on Capacitor and Capacitance

Problem 1: Find the capacitance of a conducting sphere of radius R.

Sol: Let charge Q is given to sphere. The field outside the sphere at distance r is:

$$E = \frac{kQ}{r^2}$$

$$\therefore -\frac{dV}{dr} = E$$

$$\therefore \int_0^v dV = -\int_\infty^R E dr$$

$$\Rightarrow V = kQ\left[-\frac{1}{r}\right]_\infty^R$$

$$\Rightarrow V = \frac{kQ}{R}$$

$$\therefore C = \frac{Q}{V} = \frac{R}{1/4\pi\varepsilon_0} = 4\pi\varepsilon_0 R$$

Problem 2: A parallel plate air capacitor is made using two plates 0.2 m square, spaced 1 cm apart. It is connected to a 50 V battery.

1. **What is the capacitance?**
2. **What is the charge on each plate?**
3. **What is the electric field between two plates?**
4. **If the battery is disconnected and then the plates are pulled apart to a separation of 2 cm, what are the answers to the above parts?**

Sol:

- $C_0 = \frac{\varepsilon_0 A}{d_0} = \frac{8.85\times10^{-12}\times0.2\times0.2}{0.01}$
  = 35.4×10^{-12} F
- $Q_0 = C_0V_0 = (35.4 \times 10^{-12} \times 50)C = 1.77 \times 10^{-5}C = 1770 \times 10^{-12}C$
- $E_0 = \frac{V_0}{d_0} = \frac{50}{0.01} = 5000V/m$
- If the battery is disconnected, the charge on the capacitor plates remains constant, while the potential difference between plates can change.

$\Rightarrow C = \frac{A\varepsilon_0}{2d} = 1.77 \times 10^{-5}\mu f$

$\Rightarrow Q = Q_0 = 1.77 \times 10^{-3}\mu F$

$\therefore V = \frac{Q}{C} = \frac{Q_0}{C_0/2} = 2V_0 = 100 volts$

$\therefore E = \frac{V}{C} = \frac{2V_0}{2d_0} = E_0 = 5000V/m$

Problem 3: A parallel plate conductor connected in the battery with a plate area of 3.0 cm^2 and plate separation of 3 mm if the charge stored on the plate is 4.0pc. Calculate the voltage of the battery.

Sol:

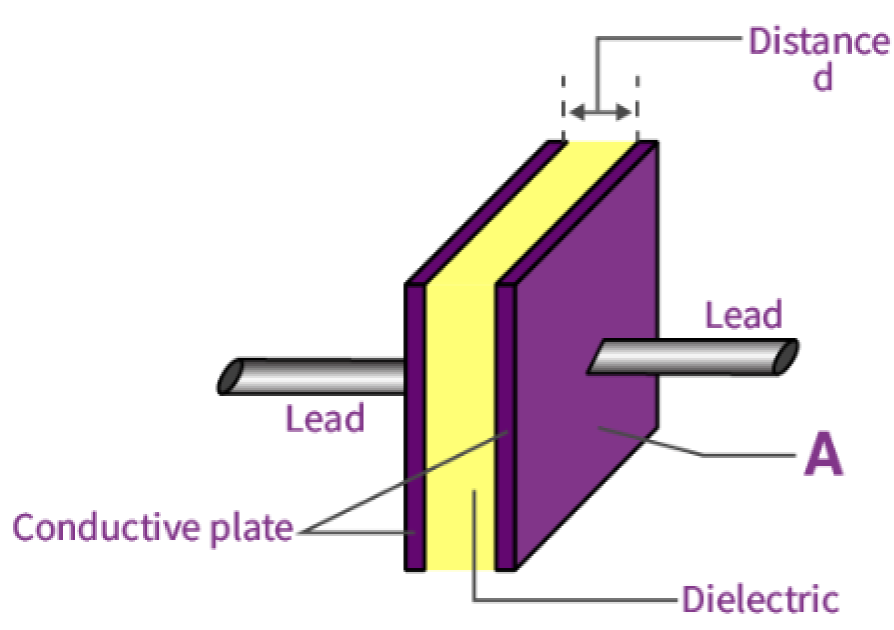
Area A = 3.0 cm^2 = 3.0×10^{-4} m^2

$C_a = \frac{\varepsilon_0 A}{d_0}$
$C_a = \frac{\varepsilon_0 A}{d_0} = \frac{8.85\times10^{-12}(3\times10^{-4})}{3\times10^{-3}}$
$C_a = 8.85 \times 10^{-13}$

$C = \frac{Q}{V}$
$V = \frac{Q}{C}$
$V = \frac{4\times10^{-12}}{8.85\times\times10^{-13}}$
V = 4.52 V

Dielectrics and Capacitance

What Are Dielectrics?

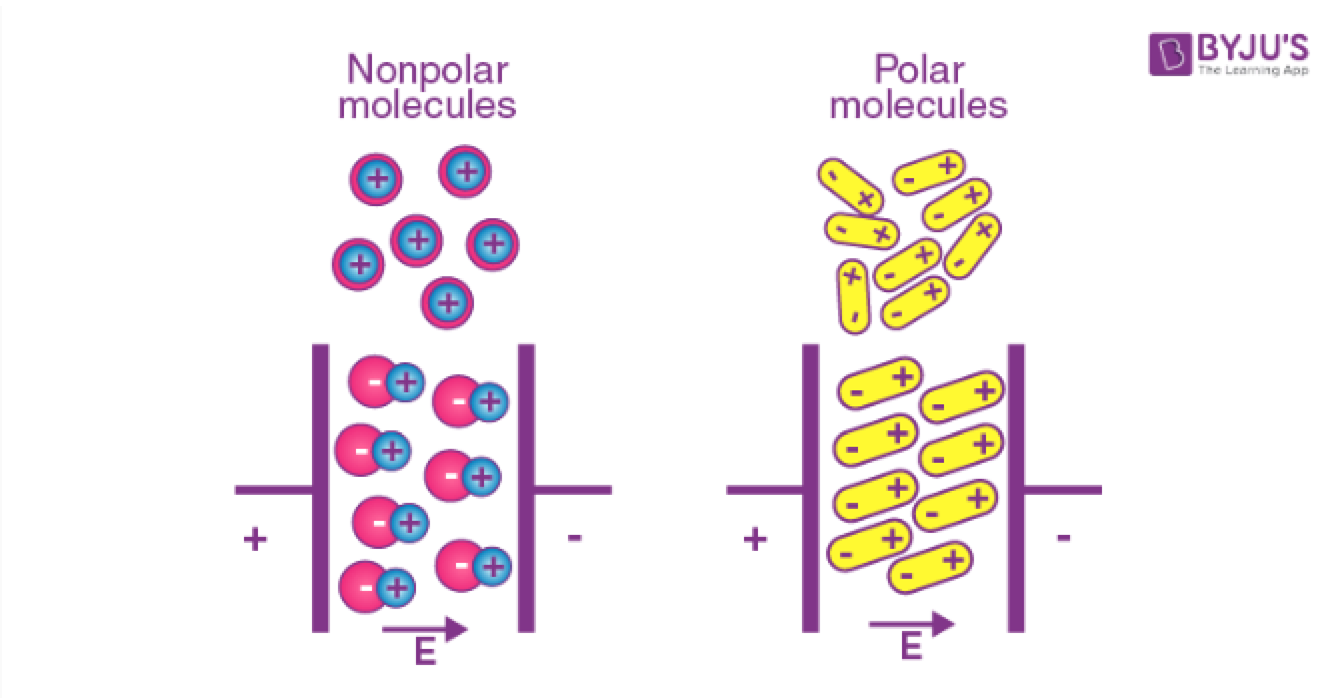


It is an insulating material (non-conducting) which has no free electrons. But a microscopic displacement of charges is observed in the presence of an electric field. It is found that the capacitance increases as the space between the conducting plates is filled with dielectrics.

Polar and Non-polar Dielectrics

Each atom is made of a positively charged nucleus surrounded by electrons. If the centre of the negatively charged electrons does not coincide with the centre of the nucleus, then a permanent dipole (separation of charges over a distance) moment is formed. Such molecules are called *polar molecules*. If a polar dielectric is placed in an electric field, the individual dipoles experience a torque and try to align along the field.

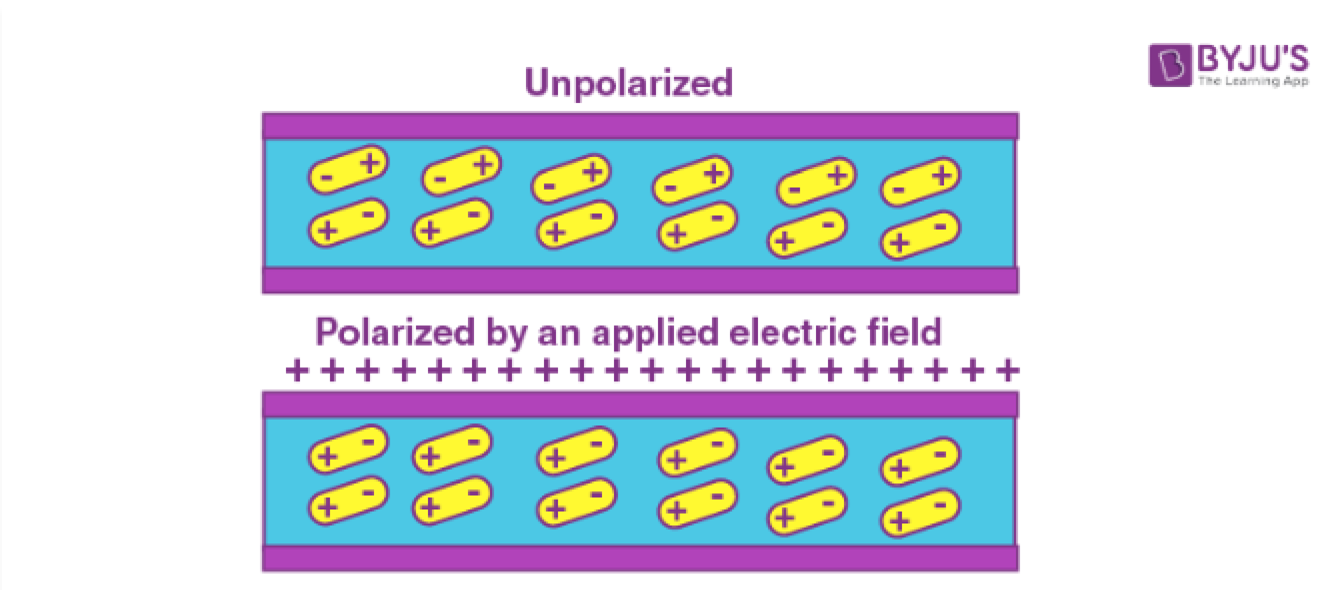
In non-polar molecules, the centres of the positive and negative charge distributions coincide. There is no permanent dipole moment created. But in the presence of an electric field, the centres are slightly displaced. This is called *induced dipole moments.*

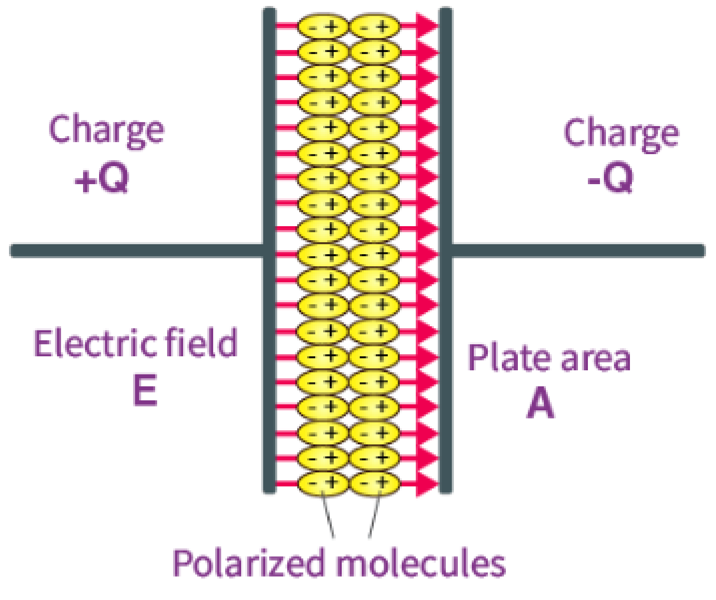


Polarization of a Dielectric Slab

It is the process of inducing charges on the dielectric and creating a dipole moment. Dipole moment appears in any volume of a dielectric.

The polarization vector $\vec{p}$ is defined as the dipole moment per unit volume.





Dielectric Constant

Let $\overrightarrow{E_0}$ be the electric field due to external sources and $\overrightarrow{E_p}$ be the field due to polarization (induced). The resultant field is:

$$\vec{E} = \overrightarrow{E_0} + \overrightarrow{E_p}$$

The induced electric field is opposite in direction to the applied field. But the resultant field is in the direction of the applied field with reduced magnitude.

$$\vec{E} = \frac{\overrightarrow{E_0}}{K}$$

K is called the dielectric constant or relative permittivity of the dielectric. For vacuum,

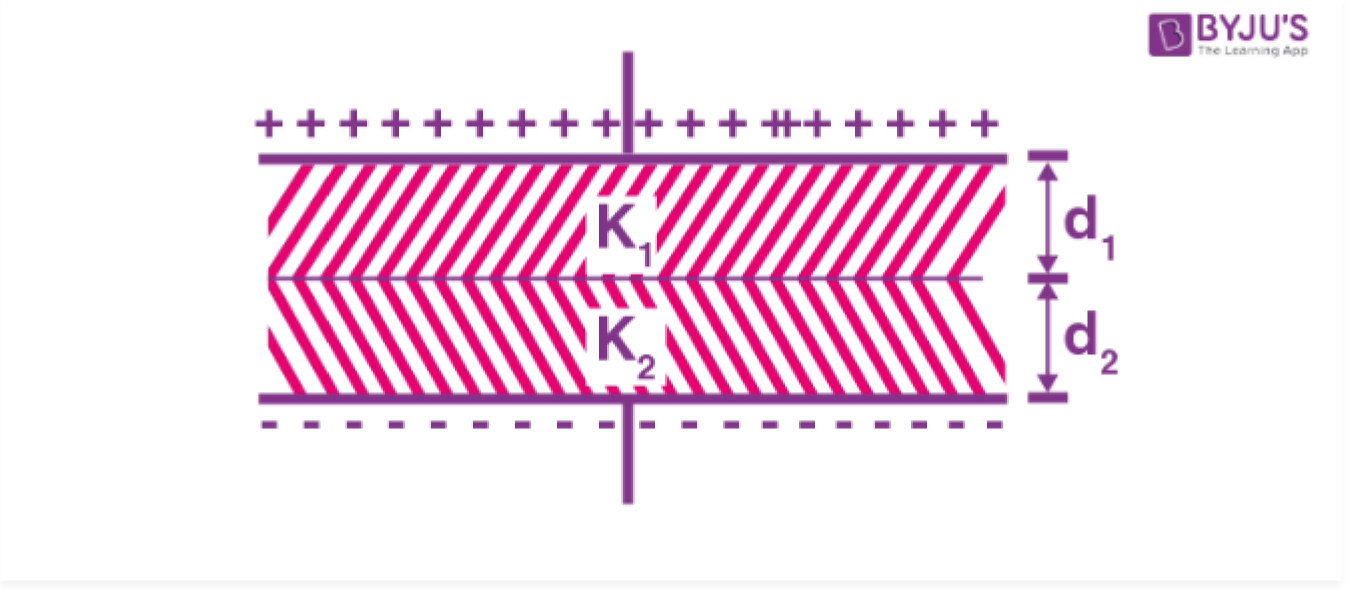
$\overrightarrow{E_p} = 0, K = 1$

. It is also denoted by ε.

Effect of Dielectric on Capacitance

Dielectric Slabs in Series

A parallel plate capacitor contains two dielectric slabs of thickness d_1, d_2 and dielectric constant k_1 and k_2, respectively. The area of the capacitor plates and slabs is equal to A.



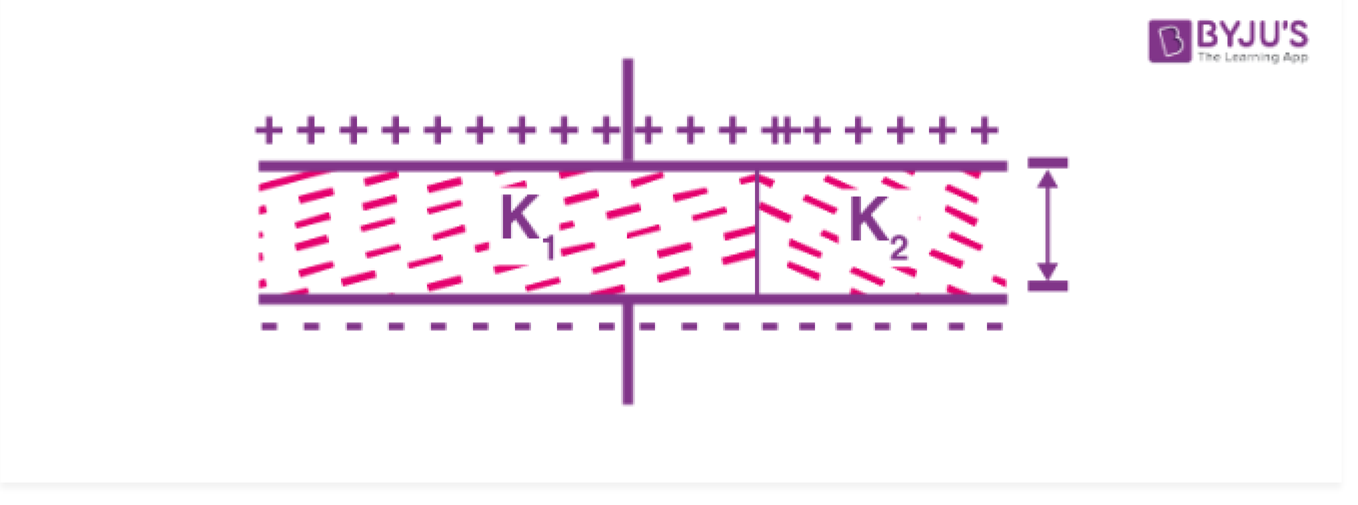
Considering the capacitor as a combination of two capacitors in series, the equivalent capacitance C is given by:

$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$

$\frac{1}{C} = \frac{d_1}{k_1 \varepsilon_0 A} + \frac{d_2}{k_2 \varepsilon_0 A}$

$C = \frac{\varepsilon_0 A}{\frac{d_1}{k_1} + \frac{d_2}{k_2}}$

Dielectric Slabs in Parallel



Consider a capacitor with two dielectric slabs of the same thickness d placed inside it, as shown in the figure. The slabs have dielectric constants k_1 and k_2 and areas A_1 and A_2, respectively. Treating the combination as two capacitors in parallel,

$$C = C_1 + C_2$$

$$C = \frac{k_1\varepsilon_0 A_1}{d} + \frac{k_2\varepsilon_0 A_2}{d} \quad \Rightarrow \quad C = \frac{\varepsilon_0}{d}[k_1A_1 + k_2A_2]$$

Dielectric and Vacuum

If there exists a dielectric slab of thickness t inside a capacitor whose plates are separated by distance d, the equivalent capacitance is given as:

$$C = \frac{\varepsilon_0 A}{\frac{t}{k}+\frac{d-t}{1}} \qquad (k = 1\ for\ vacuum)$$

$$C = \frac{\varepsilon_0 A}{\frac{t}{k}+d-t}$$

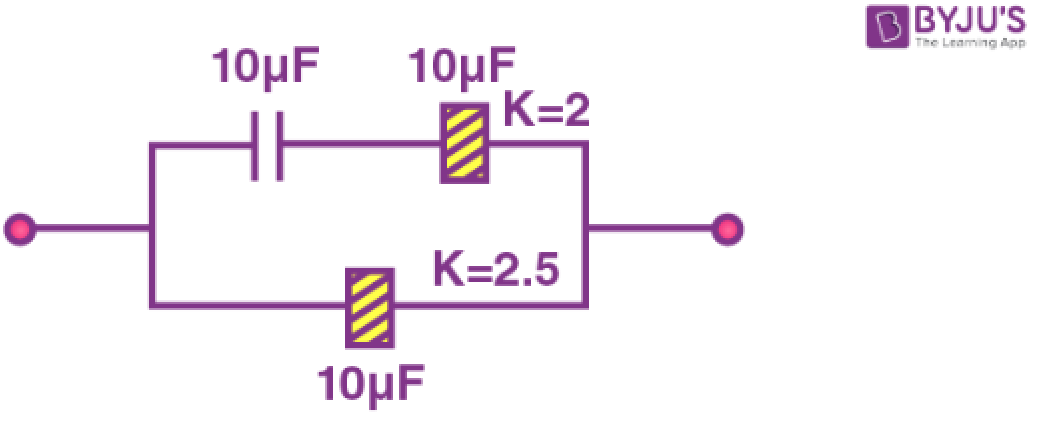
The equivalent capacitance is not affected by changing the distance of the slab from the parallel plates. If the slab is of metal, the equivalent capacitance is:

$$C = \frac{\varepsilon_0 A}{d-t}$$

.

Problems on Capacitance and Dielectrics

Problem 1: Three capacitors of 10μF each are connected, as shown in the figure. Two of them are now filled with dielectric with K = 2, and K = 2.5. Find the equivalent capacitance.

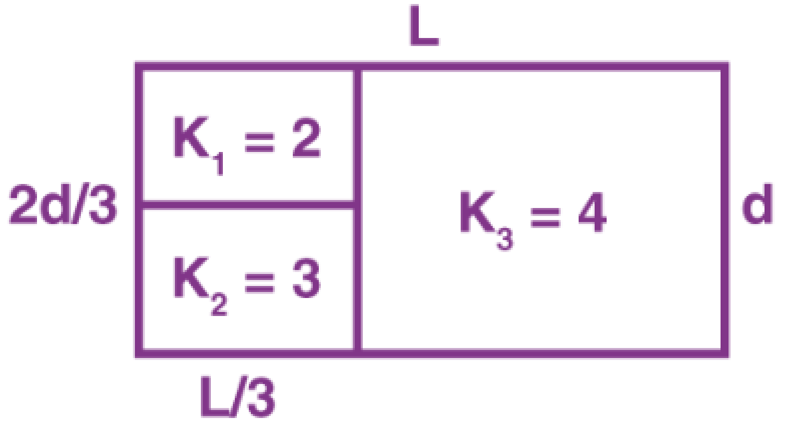


After the insertion of dielectrics,

C_1 = 10μF; $C_2 = KC_0$ = 2 x 10 = 20μF; $C_3 = KC_0$ = 2.5 x 10 = 25 μF

$\therefore\ C_{eff} = \frac{10\times20}{10+20} + 25 = 31\frac{2}{3}\mu F$

Problem 2: Find the equivalent capacitance of the system shown in the figure (assume square plates).



Taking $K_1 = 2$ to be series in $K_2 = 3$

$\Rightarrow\ \frac{1}{C_{left}} = \frac{1}{\frac{(2)\varepsilon_0\left\{(L)\left(\frac{L}{3}\right)\right\}}{\left(\frac{d}{3}\right)}} + \frac{1}{\frac{(3)\varepsilon_0\left\{(L)\left(\frac{L}{3}\right)\right\}}{\left(\frac{2d}{3}\right)}} \Rightarrow\ C_{left} = \frac{6\varepsilon_0 L^2}{7d}$

Now

$\Rightarrow C_{right} = \frac{(4)\varepsilon_0\{(L)(\frac{2L}{3})\}}{d} = \frac{8\varepsilon_0 L^2}{3d}$

Now, C_{left} and C_{right} are in parallel.

$\Rightarrow\ C_{eq} = C_{left} + C_{right} = \frac{6\varepsilon_0 L^2}{7d} + \frac{8\varepsilon_0 L^2}{3d} = \frac{74\varepsilon_0 L^2}{21d}$

Problem 3: Calculate the effective capacitance connected in series and parallel. The capacitors are connected to a 40 V battery. Also, calculate the voltage across the capacitors for each connection type.

Given

C_1 = 12 F

C_2 = 6 F

Solu:

When capacitors are connected in series,

$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$

$\frac{1}{C} = \frac{1}{12} + \frac{1}{6}$

$\frac{1}{C} = 0.25$

C = 4 F

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

Q = 4 × 40

Q = 160 C

For the 12 F capacitor:

$12 = \frac{160}{V}$
V = 13.33V

For the 6F capacitor:

$6 = \frac{160}{V}$
V = 26.66V

When capacitors are connected in parallel,

$C = C_1 + C_2$

$C = 12 + 6$

$C = 18$ F

The voltage is the same as 40V across each capacitor.

Inductor

Inductors, much like conductors and resistors, are simple components that are used in electronic devices to carry out specific functions. Normally, inductors are coil-like structures that are found in electronic circuits. The coil is an insulated wire that is looped around the central core.

Inductors are mostly used to decrease or control the electric spikes by storing energy temporarily in an electromagnetic field, and then releasing it back into the circuit.

What Is an Inductor?

An inductor is a passive component that is used in most power electronic circuits to store energy in the form of magnetic energy when electricity is applied to it. One of the key properties of an inductor is that it impedes or opposes any change in the amount of current flowing through it. Whenever the current across the inductor changes, it either acquires charge or loses the charge in order to equalise the current passing through it. The inductor is also called a choke, a reactor or just a coil.

Also Read: Induction

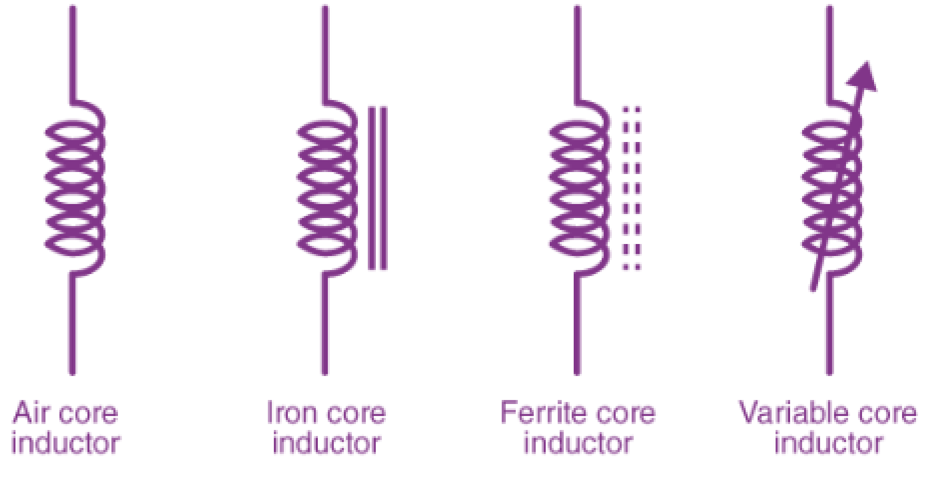
An inductor is described by its distinctive nature of inductance, which is defined as the ratio of the voltage to the rate of change of current. Inductance is a result of the induced magnetic field on the coil. It is also determined by several factors, such as

- The shape of the coil.
- The number of turns and layers of the wire.
- The space that is given between the turns.
- Permeability of the core material.
- The size of the core.

The SI unit of inductance is henry (H), and when we measure magnetic circuits, it is equivalent to weber/ampere. It is denoted by the symbol L.

Moreover, an inductor is totally different from a capacitor. In the case of a capacitor, it stores energy as electrical energy, but as mentioned above, an inductor stores energy in the form of magnetic energy. One key feature of the inductor is that it also changes its polarity while discharging. In this way, polarity during discharging can be made opposite to the polarity during charging. The polarity of the induced voltage is well explained by Lenz's law.

Symbols for an inductor are given below:



Construction of an Inductor

If we look at the construction of an inductor, it usually consists of a coil of conducting material (widely used ones include insulated copper wire) that is wrapped around a core that is made up of plastic material or ferromagnetic material. One advantage of using a ferromagnetic core is that it has high permeability, which helps in increasing the magnetic field and, at the same time, confining it closely to the inductor. Ultimately this results in higher inductance.

On the other hand, inductors with low frequency are usually constructed like transformers. They have cores made up of electrical steel that is laminated to help prevent eddy currents. 'Soft' ferrites are also widely used for cores above audio frequencies.

Inductors come in many shapes and types. In some inductors, you will find an adjustable core that allows changing the inductance. Inductors that are used in blocking very high frequencies are mostly made by stringing a ferrite bead on a wire.

Planar inductors are made using a planar core, while small-value inductors are built on integrated circuits using the processes of making interconnects. Typically, an aluminium interconnect is used and fixed in a spiral coil pattern. However, small dimensions have some limitations. They restrict the inductance.

There are also shielded inductors which are commonly used in power regulation systems, lighting, and other systems requiring low-noise operating conditions. These inductors are often partially or fully shielded.

Different Types of Inductors

Depending on the type of material used, inductors can be classified as follows:

1. Iron Core Inductor
2. Air Core Inductor
3. Iron Powder Inductor
4. Ferrite Core Inductor, which is divided into:

- Soft Ferrite
- Hard Ferrite

Iron Core Inductor

As the name suggests, the core of this type of inductor is made of iron. These inductors are low-space inductors that have high power and high inductance value. However, they are limited in high-frequency capacity. These inductors are used in audio equipment.

Air Core Inductor

These inductors are used when the amount of inductance required is low. Since there is no core, it does not have a core loss. But the number of turns the inductor must have is more for this type when compared to the inductors with the core. This results in a high-quality factor. Usually, ceramic inductors are often referred to as air-core inductors.

Iron Powder Inductor

In this type of inductor, the core is iron oxide. They are formed by very fine and insulating particles of pure iron powder. High magnetic flux can be stored in it due to the air gap. The permeability of the core of this type of inductor is very less and is usually below 100. They are mainly used in switching power supplies.

Ferrite Core Inductor

In this type of inductor, ferrite materials are used as the core. The general composition of ferrites is XFe_2O_4, where X represents transition material. Ferrites can be classified into two types: soft ferrites and hard ferrites.

- Soft Ferrite: These are materials that have the ability to reverse their polarity without any external energy.
- Hard Ferrite: These are permanent magnets, that is, their polarity will not change even when the magnetic field is removed.

Choke

A choke is a type of inductor that is used mainly for blocking high-frequency alternating current (AC) in an electrical circuit. On the other hand, it will allow DC or low-frequency signals to pass. As the function of this inductor is to restrict the changes in current, it is called a choke. This inductor consists of a coil of insulated wire wound on a magnetic core. The main difference between chokes and other inductors is that they do not require high Q factor construction techniques, which aim to reduce the resistance in inductors found in tuned circuits.

Functions of an Inductor

Inductors can be used for two primary functions:

1. To control signals.
2. To store energy.

Controlling Signals

Coils in an inductor can be used to store energy. The function of the inductor depends upon the frequency of the current passing through it. That is, higher frequency signals will be passed less easily and vice versa. This function tells that it blocks AC Current and passes DC Current. Hence, it can be used to block AC signals.

Inductors can be used along with capacitors to form LC filters.

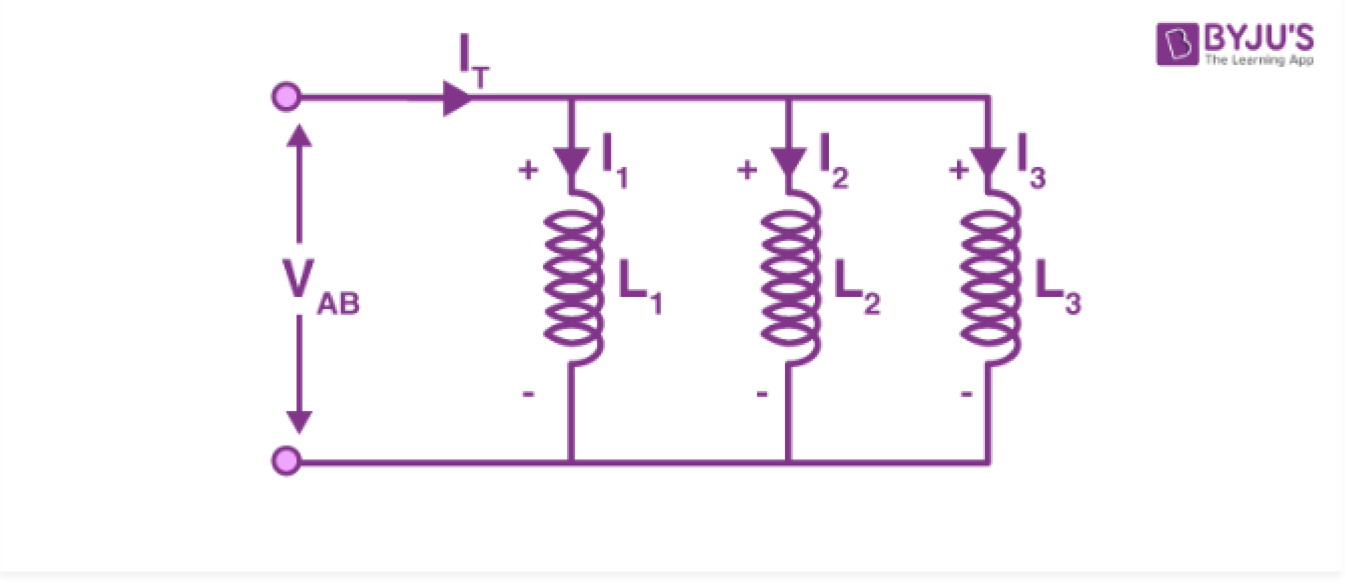
Storing Energy

Inductor stores energy in the form of magnetic energy. Coils can store electrical energy in the form of magnetic energy, using the property that an electric current flowing through a coil produces a magnetic field, which in turn, produces an electric current. In other words, coils offer a means of storing energy on the basis of inductivity.

Inductors in Parallel Form

If two terminals of an inductor are connected to two terminals of another inductor, then the inductors are said to be parallel. We know that when resistors are connected in parallel, their effective resistance decreases. Similarly, when inductors are connected in parallel form, their effective inductance decreases. Inductors in parallel are somewhat similar to the capacitors in series.

Consider the example below:



Here, the current flowing through each inductor will be different. This current depends upon the inductance value. However, the voltage across each conductor will be the same. By using Kirchoff's Current law, the total current is the sum of the current through each branch. That is,

$I_T = I_1 + I_2 + I_3$

We know that the voltage across an inductor is given by the equation

$V = L\, di / dt$

We can write,

$v_{AB} = L_{Total} \times dI_t / dt$

$V_{AB} = L_{Total} \times d\,(I_1 + I_2 + I_3) / dt$

We can further write it as

$v_{AB} = L_{Total} \times dI_1 / dt + L_{Total} \times dI_2 / dt + L_{Total} \times dI_3 / dt$

That is,

$v_{AB} = L_{Total}\,(V / L_1 + V / L_2 + V / L_3)$

Since voltage are equal, we can simplify the equation as,

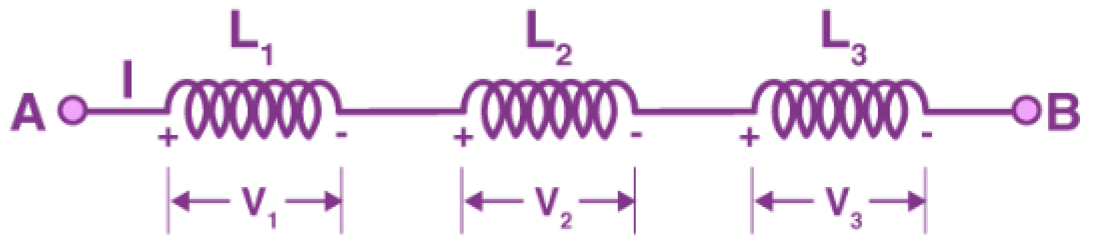
$1 / L_{Total} = 1 / L_1 + 1 / L_2 + 1 / L_3$

Inductors in Series

When the inductors are chained together in a straight line or when they are connected end to end, then the inductors are said to be in a series connection. We know that when resistors are connected in series, their effective resistance increases.

Similarly, when inductors are connected in series, their effective inductance increases. Inductors in series are somewhat similar to the capacitors in parallel. In order to get the total inductance, it is very easy. You only have to add every inductance. That is, when inductors are connected in series, the total inductance is the sum of all inductance.

Consider the connection below:



Here, three inductors are connected in series. In this case, the current flowing through each inductor is the same, while the voltage across each inductor is different. This voltage depends upon the inductance value. By using Kirchoff's voltage law, the total voltage drop is the sum of the voltage drop across each inductor. That is,

$V_T = V_1 + V_2 + V_3$

We know that the voltage across an inductor is given by the equation

$V = L\, di / dt$

So, here we can write,

$L_{Total}\, dI / dt = L_1 \times dI_1 / dt + L_2 \times dI_2 / dt + L_3 \times dI_3 / dt$

But

$I = I_1 = I_2 = I_3$

Therefore,

$L\, dI / dt = L_1 \times dI / dt + L_2 \times dI / dt + L_3 \times dI / dt$

$L_{Total} = L_1 + L_2 + L_3$

Energy Stored in an Inductor

When a current passes through an inductor, an emf is induced in it. This back emf opposes the flow of current through the inductor. So, in order to establish a current in the inductor, work has to be done against this emf by the voltage source.

Consider a time interval dt.

During this period, work done, dW, is given by

$dW = Pdt = - Eidt = iL\, di / dt \times dt = Lidi$

To find the total work done, the above expression must be integrated.

$W = \int_0^I Lidi = \frac{1}{2} LI^2$

Therefore, energy stored in an inductor is given by the equation,

$W = \frac{1}{2} LI^2$

Impedance of an Inductor

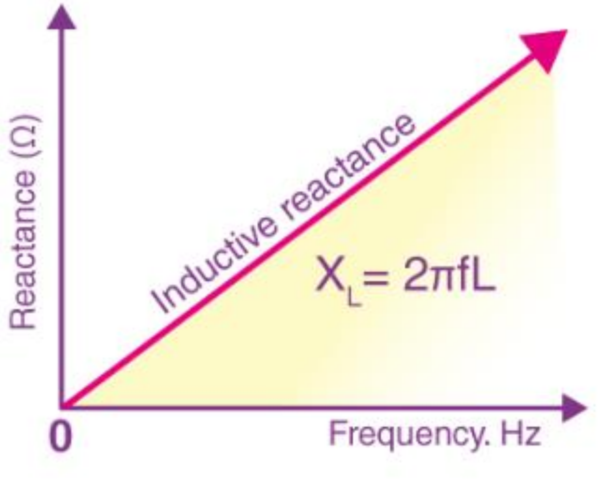
AC resistance mostly determines the opposition of current flowing through a coil. This AC resistance is most commonly known as impedance. In this section, since we are discussing the opposition given by the inductor, this can be called inductive reactance. Inductive reactance, which is given the symbol X_L, is the property in an AC circuit that opposes the change in the current.

It is given by the equation,

$X_L = V_L / I_L = L\omega$

From the equation, it is clear that inductive reactance is proportional to frequency.

The plot of frequency vs reactance is given below:



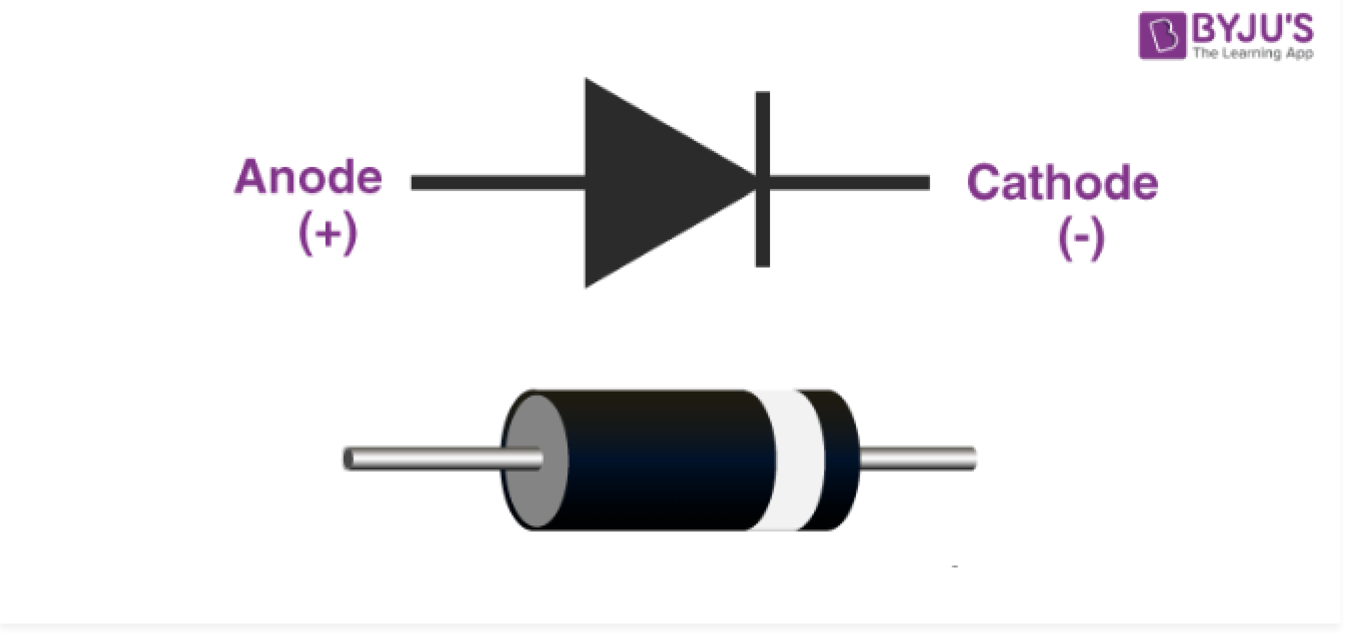
Diodes

A diode is a two-terminal electronic component that conducts electricity primarily in one direction. It has high resistance on one end and low resistance on the other end. In this article, let us understand in detail about what is diode and diode symbol.

What Is a Diode?

Diodes are used to protect circuits by limiting the voltage and to also transform AC into DC. Semiconductors like silicon and germanium are used to make the most of the diodes. Even though they transmit current in a single direction, the way with which they transmit differs. There are different kinds of diodes and each type has its own applications.

Diode Symbol



A standard diode symbol is represented as above. In the above diagram, we can see that there are two terminals that are known as anode and cathode. The arrowhead is the anode that represents the direction of the conventional current flow in the forward biased condition. The other end is the cathode.

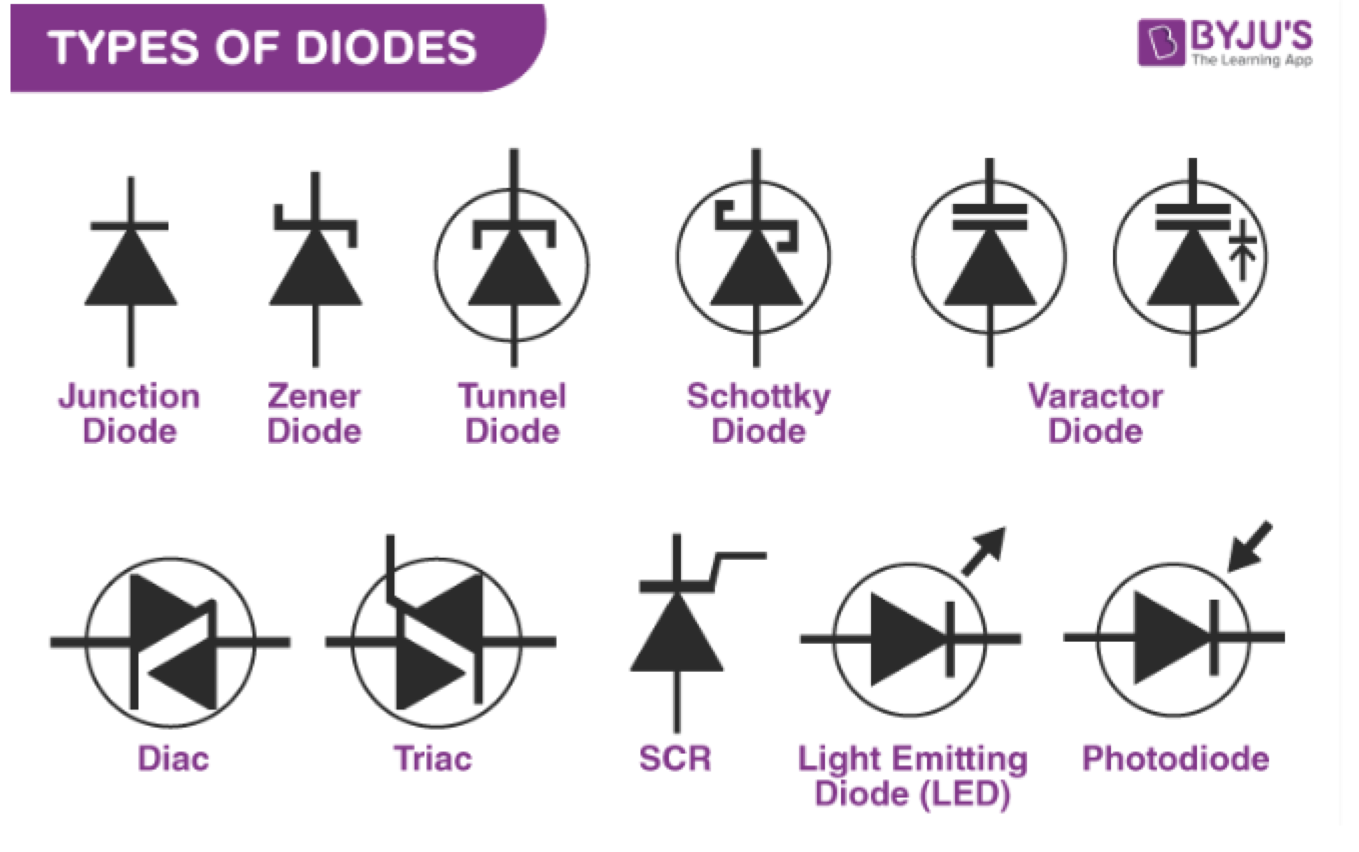
Diode Construction

Diodes can be made of either of the two semiconductor materials, silicon and germanium. When the anode voltage is more positive than the cathode voltage, the diode is said to be forward-biased, and it conducts readily with a relatively low-voltage drop. Likewise, when the cathode voltage is more positive than the anode, the diode is said to be reverse-biased. The arrow in the diode symbol represents the direction of conventional current flow when the diode conducts.

This article lets you understand in detail about various types of diodes.

Types of Diodes

1. Light Emitting Diode
2. Laser diode
3. Avalanche diode
4. Zener diode
5. Schottky diode
6. Photodiode
7. PN junction diode



Light Emitting Diode (LED)

When an electric current between the electrodes passes through this diode, light is produced. In other words, light is generated when a sufficient amount of forwarding current passes through it. In many diodes, this light generated is not visible as there are frequency levels that do not allow visibility. LEDs are available in different colours. There are tricolour LEDs that can emit three colours at a time. Light colour depends on the energy gap of the semiconductor used.

Laser Diode

It is a different type of diode as it produces coherent light. It is highly used in CD drives, DVDs and laser devices. These are costly when compared to LEDs and are cheaper when compared to other laser generators. Limited life is the only drawback of these diodes.

Avalanche Diode

This diode belongs to a reverse bias type and operates using the avalanche effect. When voltage drop is constant and is independent of current, the breakdown of avalanche takes place. They exhibit high levels of sensitivity and hence are used for photo detection.

Zener Diode

It is the most useful type of diode as it can provide a stable reference voltage. These are operated in reverse bias and break down on the arrival of a certain voltage. If current passing through the resistor is limited, a stable voltage is generated. Zener diodes are widely used in power supplies to provide a reference voltage.

Schottky Diode

It has a lower forward voltage than other silicon PN junction diodes. The drop will be seen where there is low current and at that stage, voltage ranges between 0.15 and 0.4 volts. These are constructed differently in order to obtain that performance. Schottky diodes are highly used in rectifier applications.

Photodiode

A photo-diode can identify even a small amount of current flow resulting from the light. These are very helpful in the detection of the light. This is a reverse bias diode and used in solar cells and photometers. They are even used to generate electricity.

P-N Junction Diode

The P-N junction diode is also known as rectifier diodes. These diodes are used for the rectification process and are made up of semiconductor material. The P-N junction diode includes two layers of semiconductors. One layer of the semiconductor material is doped with P-type material and the other layer with N-type material. The combination of these both P and N-type layers form a junction known as the P-N junction. Hence, the name P-N junction diode.

P-N junction diode allows the current to flow in the forward direction and blocks the flow of current in the reverse direction.

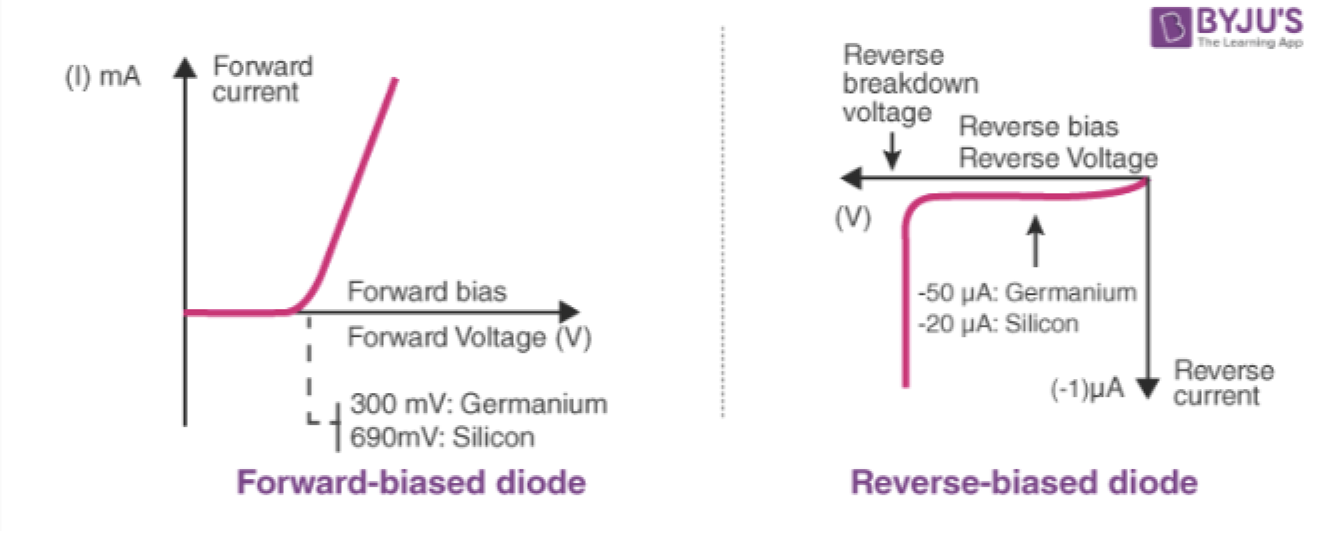
Related Articles:

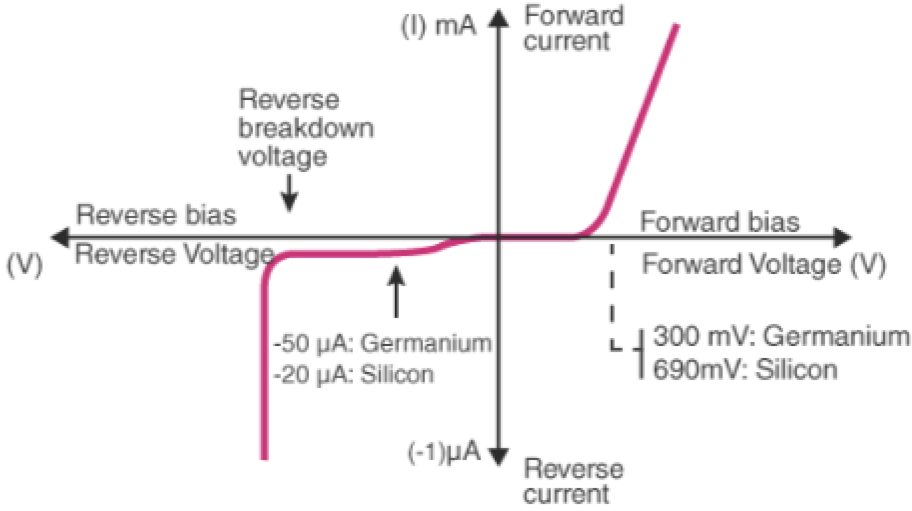
- How do Diodes Work as a Rectifier?
- Zener Diode as a Voltage Regulator
- Laser Diode
- Light Emitting Diode (LED)
- Zener diodes
- Schottky diodes

Characteristics of Diode

The following are the characteristics of the diode:

- Forward-biased diode
- Reverse-biased diode
- Zero biased diode





VI characteristics of Diode

Forward-biased Diode

There is a small drop of voltage across the diode when the diode is forward-biased and the current is conducting. For silicon diodes, the forward voltage is 690mV and for germanium, 300mV is the forward voltage. The potential energy across the p-type material is positive and across the n-type material, the potential energy is negative.

Reverse-biased Diode

A diode is said to be reverse-biased when the battery's voltage is dropped completely. For silicon diodes, the reverse current is -20μA and for germanium, -50μA is the reverse current. The potential energy across the p-type material is negative and across the n-type material, the potential energy is positive.

Zero-biased Diode

When the diode is zero-biased, the voltage potential across the diode is zero.

Diode Applications

Following are the applications and uses of the diode:

- Diodes as a rectifier
- Diodes in the clipping circuit
- Diodes in clamping circuits
- Diodes in logical gates
- Diodes in reverse current protection

Transistor

What is a transistor? A transistor is a type of semiconductor device that can be used to conduct and insulate electric current or voltage. A transistor basically acts as a switch and an amplifier. In simple words, we can say that a transistor is a miniature device that is used to control or regulate the flow of electronic signals.

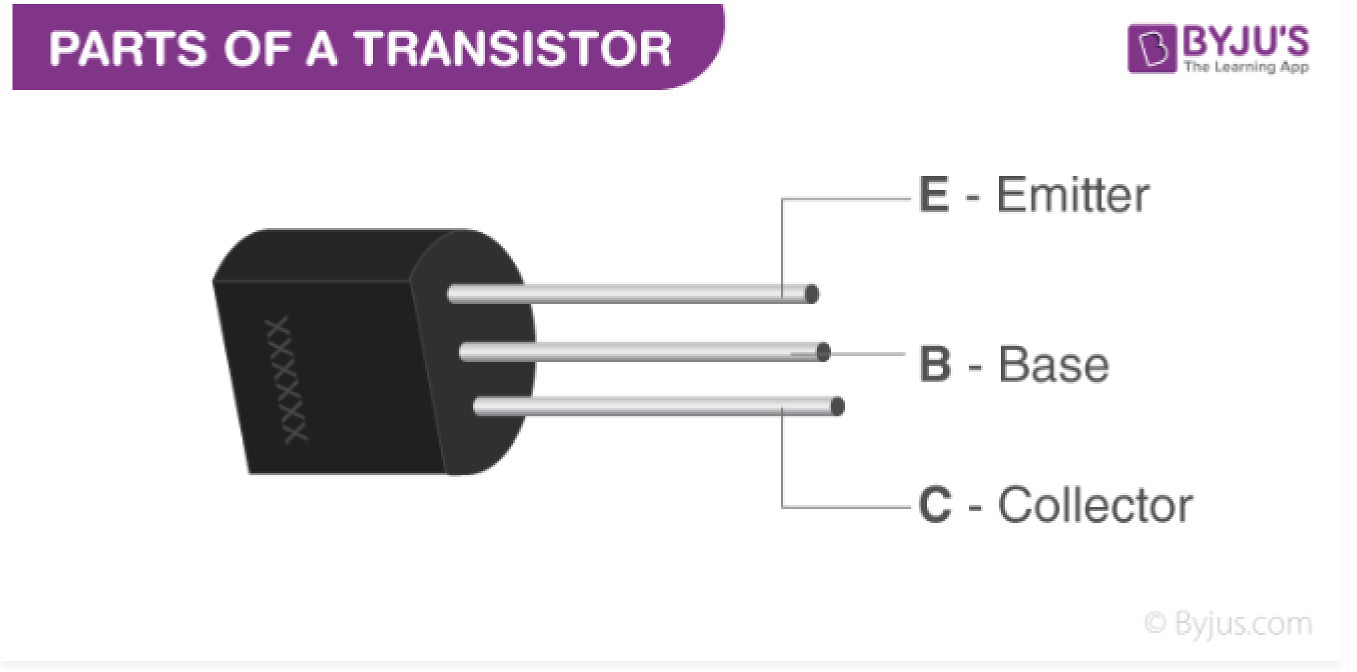
Transistors are one of the key components in most of the electronic devices that are present today. Developed in the year 1947 by three American physicists, John Bardeen, Walter Brattain and William Shockley, the transistor is considered one of the most important inventions in the history of science.

Table of Contents

Parts of a Transistor

A typical transistor is composed of three layers of semiconductor materials or, more specifically, terminals which help to make a connection to an external circuit and carry the current. A voltage or current that is applied to any one pair of the terminals of a transistor controls the current through the other pair of terminals. There are three terminals for a transistor. They are listed below:

- Base: This is used to activate the transistor.
- Collector: It is the positive lead of the transistor.
- Emitter: It is the negative lead of the transistor.



Well, the very basic working principle of a transistor is based on controlling the flow of current through one channel by varying the intensity of a smaller current that is flowing through a second channel.

Also Read:

- Transistor as a Switch
- Transistor as an Amplifier

Types of Transistors

There are mainly two types of transistors, based on how they are used in a circuit.

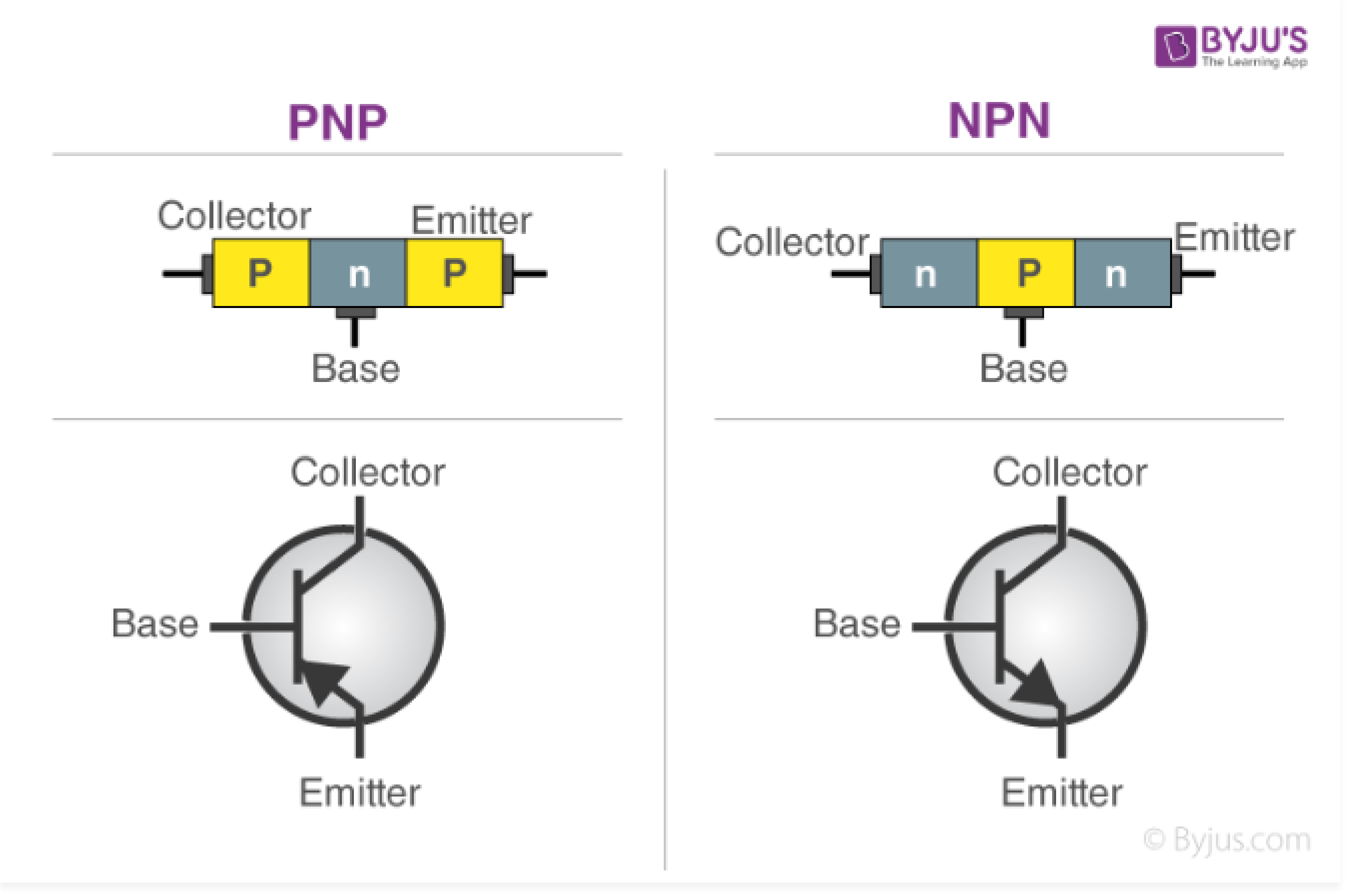
Bipolar Junction Transistor (BJT)

The three terminals of BJT are the base, emitter and collector. A very small current flowing between the base and emitter can control a larger flow of current between the collector and emitter terminal.

Furthermore, there are two types of BJT, and they include:

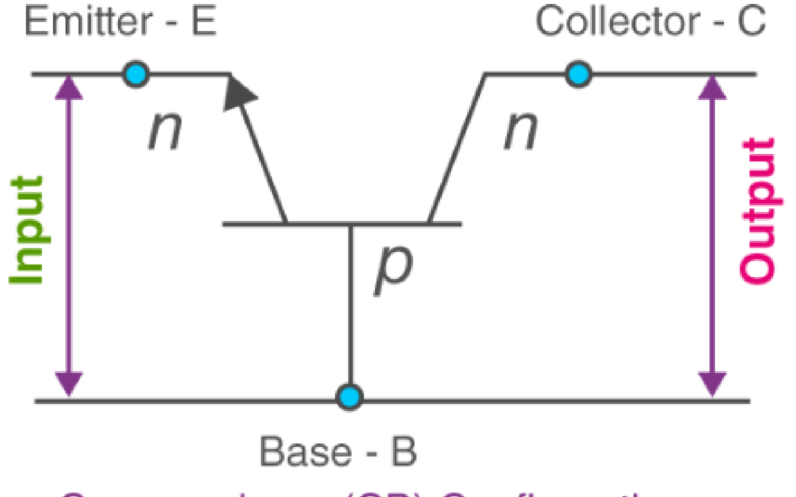
- P-N-P Transistor: It is a type of BJT where one n-type material is introduced or placed between two p-type materials. In such a configuration, the device will control the flow of current. PNP transistor consists of 2 crystal diodes which are connected in series. The right side and left side of the diodes are known as the collector-base diode and emitter-base diode, respectively.

- N-P-N Transistor: In this transistor, we will find one p-type material that is present between two n-type materials. N-P-N transistor is basically used to amplify weak signals to strong signals. In an NPN transistor, the electrons move from the emitter to the collector region, resulting in the formation of current in the transistor. This transistor is widely used in the circuit.



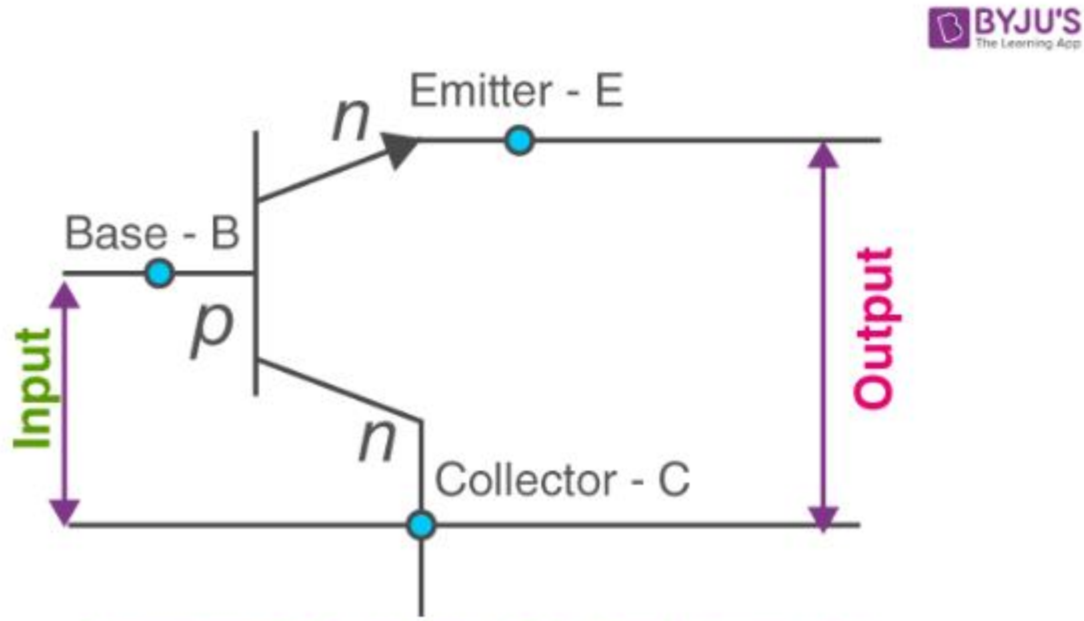
There are three types of configuration, which are common base (CB), common collector (CC) and common emitter (CE).

In common base (CB) configuration, the base terminal of the transistor is common between input and output terminals.



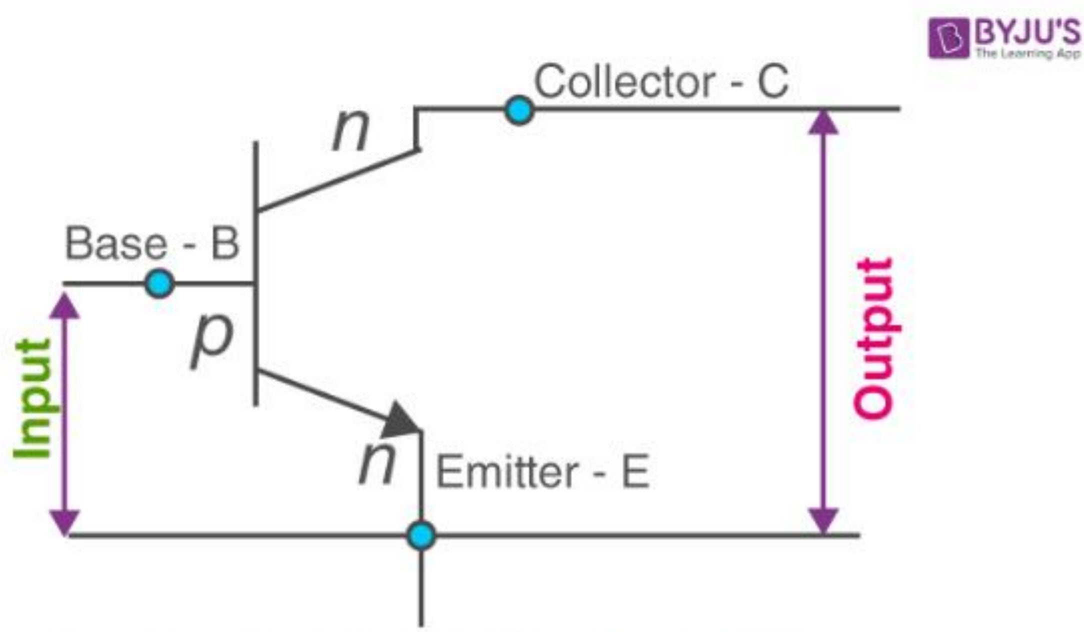
Common base (CB) Configuration

In common collector (CC) configuration, the collector terminals are common between the input and output terminals.



Common Collector (CC) Configuration

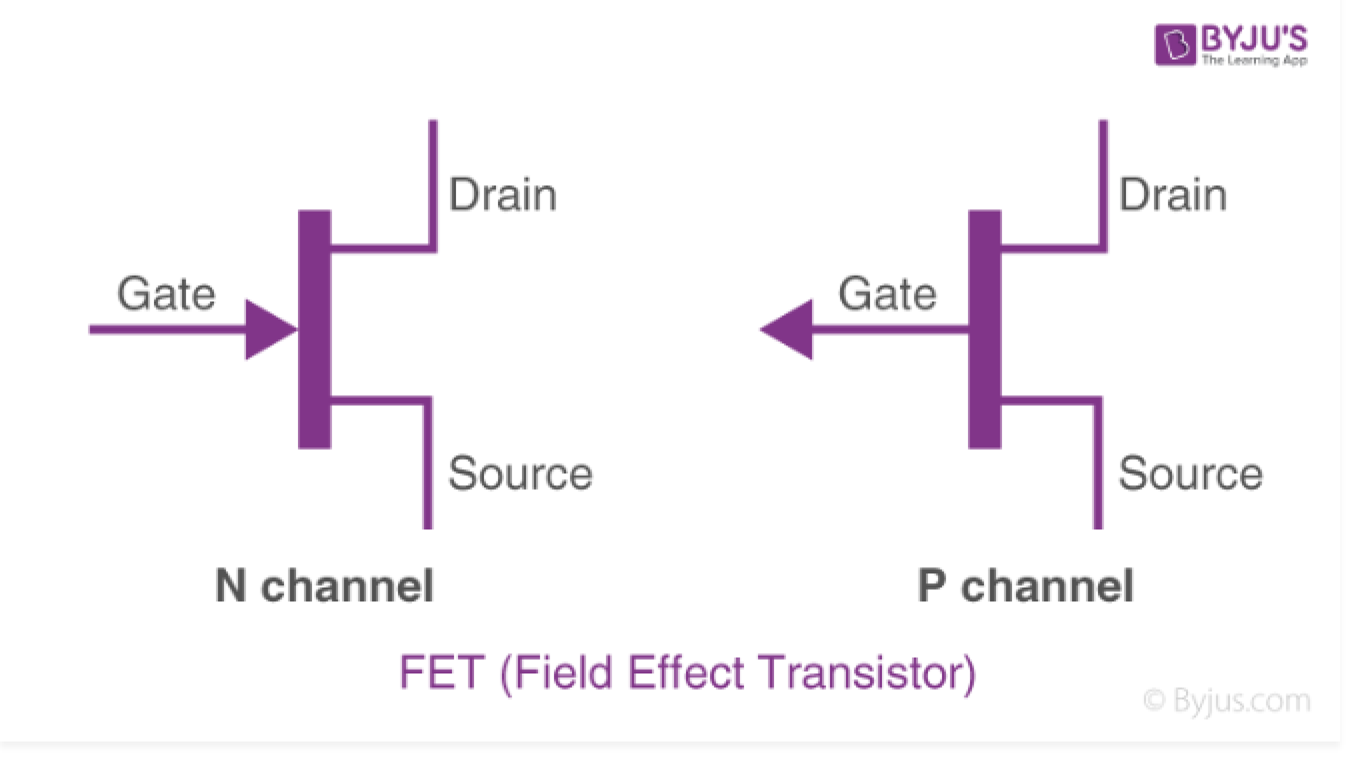
In common emitter (CE) configuration, the emitter terminal is common between the input and the output terminals.



Common Emitter (CE) Configuration

Field Effect Transistor (FET)

For FET, the three terminals are Gate, Source and Drain. The voltage at the gate terminal can control a current between the source and the drain. FET is a unipolar transistor in which N-channel FET or P-channel FET are used for conduction. The main applications of FETs are in low noise amplifiers, buffer amplifiers and analogue switches.



Other Types

Apart from these, there are many other types of transistors which include MOSFET, JFET, insulated-gate bipolar transistor, thin-film transistor, high electron mobility transistor, inverted-T field-effect transistor (ITFET), fast-reverse epitaxial diode field-effect transistor (FREDFET), Schottky transistor, tunnel field-effect transistor, organic field-effect transistor (OFET), diffusion transistor, etc.

How Do Transistors Work?

Let us look at the working of transistors. We know that BJT consists of three terminals (Emitter, Base and Collector). It is a current-driven device where two P-N junctions exist within a BJT.

One P-N junction exists between the emitter and base region, and the second junction exists between the collector and base region. A very small amount of current flow through the emitter to the base can control a reasonably large amount of current flow through the device from the emitter to the collector.

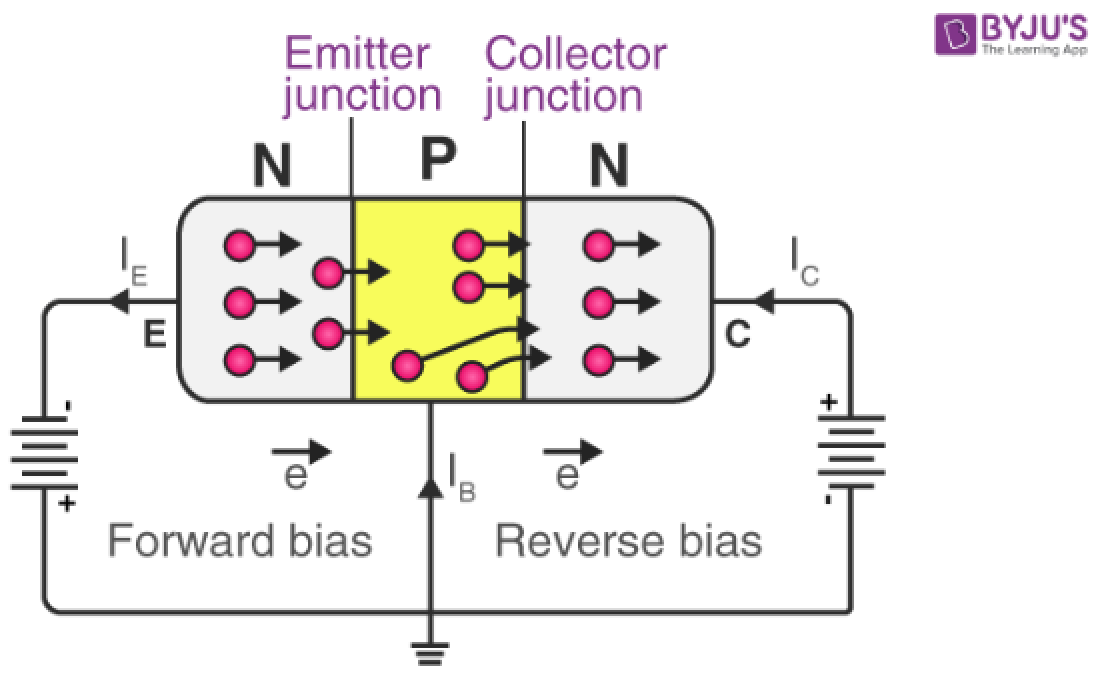
In the usual operation of BJT, the base-emitter junction is forward-biased, and the base-collector junction is reverse-biased. When a current flows through the base-emitter junction, the current will flow in the collector circuit.

In order to explain the working of the transistor, let us take an example of an NPN transistor. The same principles are used for the PNP transistor, except that the current carriers are holes, and the voltages are reversed.

Operation of NPN Transistor

The emitter of the NPN device is made of n-type material; hence, the majority of carriers are electrons. When the base-emitter junction is forward-biased, the electrons will move from the n-type region towards the p-type region, and the minority carrier holes move towards the n-type region.

When they meet each other, they will combine, enabling a current to flow across the junction. When the junction is reverse-biased, the holes and electrons move away from the junction, and now, the depletion region forms between the two areas and no current will flow through it.



When a current flows between the base and emitter, the electrons will leave the emitter and flow into the base, as shown above. Normally, the electrons will combine when they reach the depletion region.

But the doping level in this region is very low, and the base is also very thin. This means that most of the electrons are able to travel across the region without recombining with holes. As a result, the electrons will drift towards the collector.

In this way, they are able to flow across what is effectively a reverse-biased junction, and the current flows in the collector circuit.

Also Read: p-n Junction

Characteristics of Transistor

Characteristics of the transistor are the plots which can represent the relation between the current and the voltage of a transistor in a particular configuration.

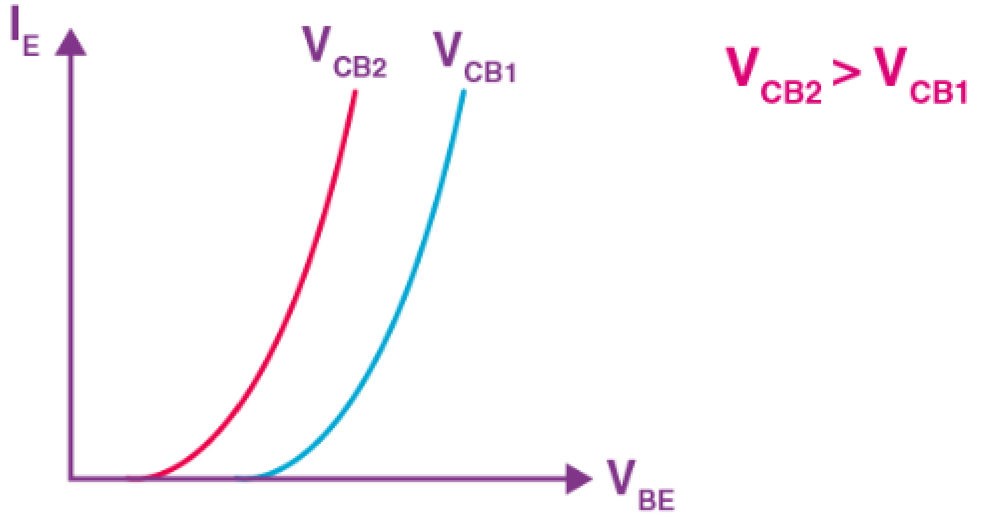
There are two types of characteristics.

- Input characteristics: It will give us the details about the change in input current with the variation in input voltage by keeping output voltage constant.
- Output characteristics: It is a plot of output current with output voltage by keeping the input current constant.
- Current transfer characteristics: This plot shows the variation of the output current with the input current by keeping the voltage constant.

Input Characteristics

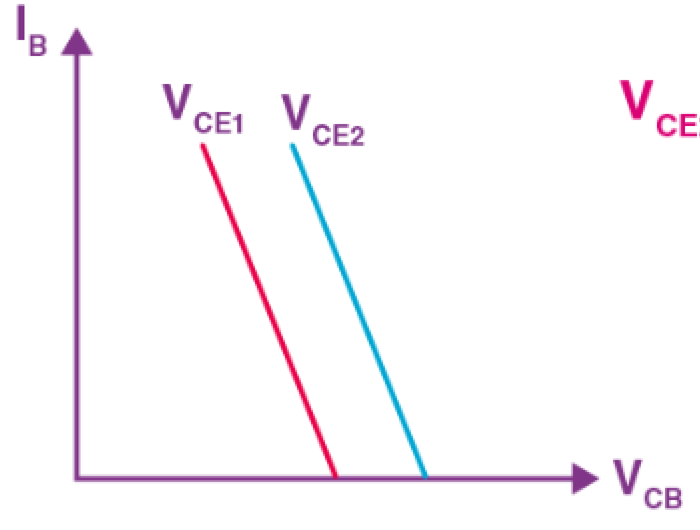
CB Configuration

The following chart will describe the variation of emitter current, I_E with base – Emitter voltage, V_{BE} keeping collector voltage constant, V_{CB}.



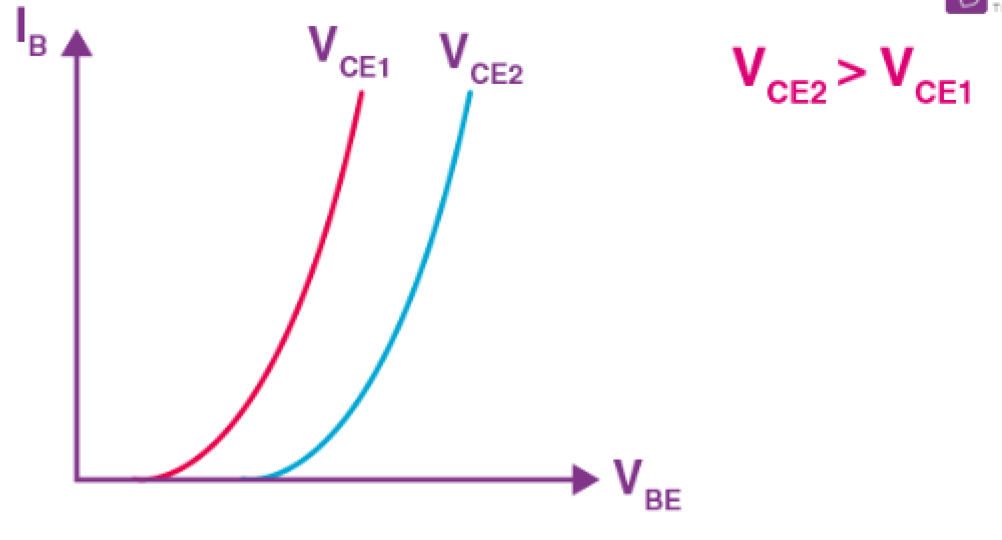
CC Configuration

It shows the variation in I_B in accordance with V_{CB} with collector-emitter voltage V_{CE} keeping constant.



CE Configuration

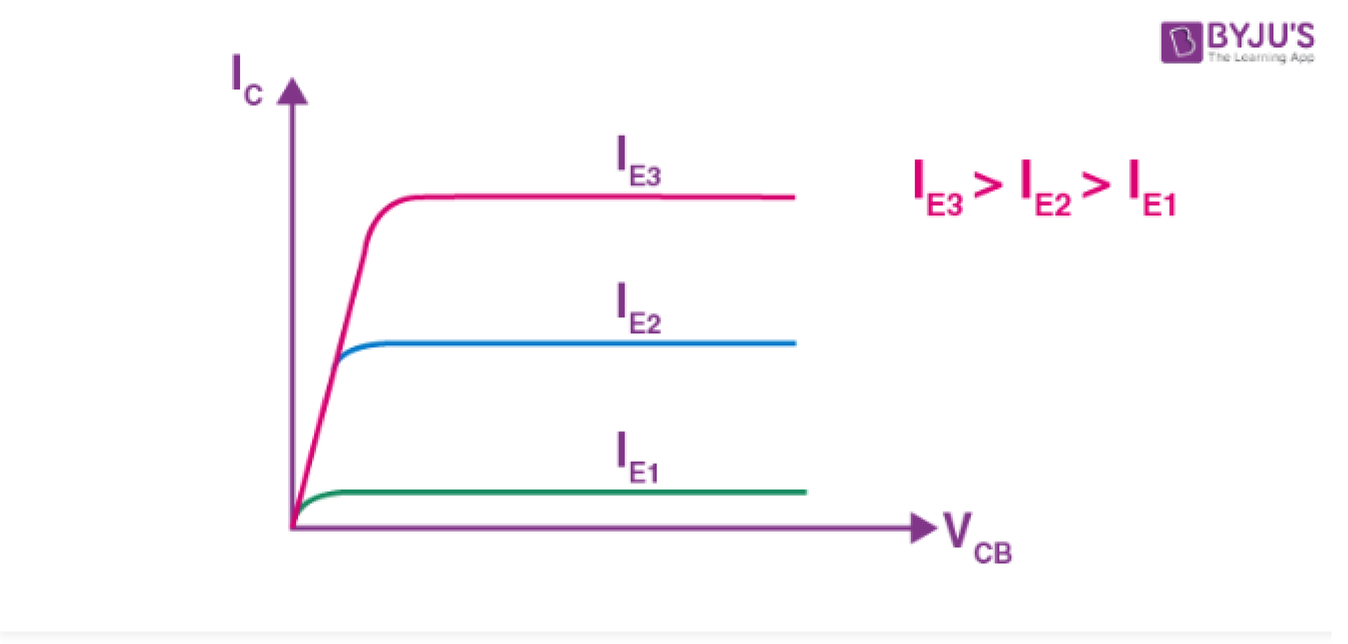
Here it shows the variation in I_B in accordance with V_{BE} by keeping V_{CE} constant.



Output Characteristics

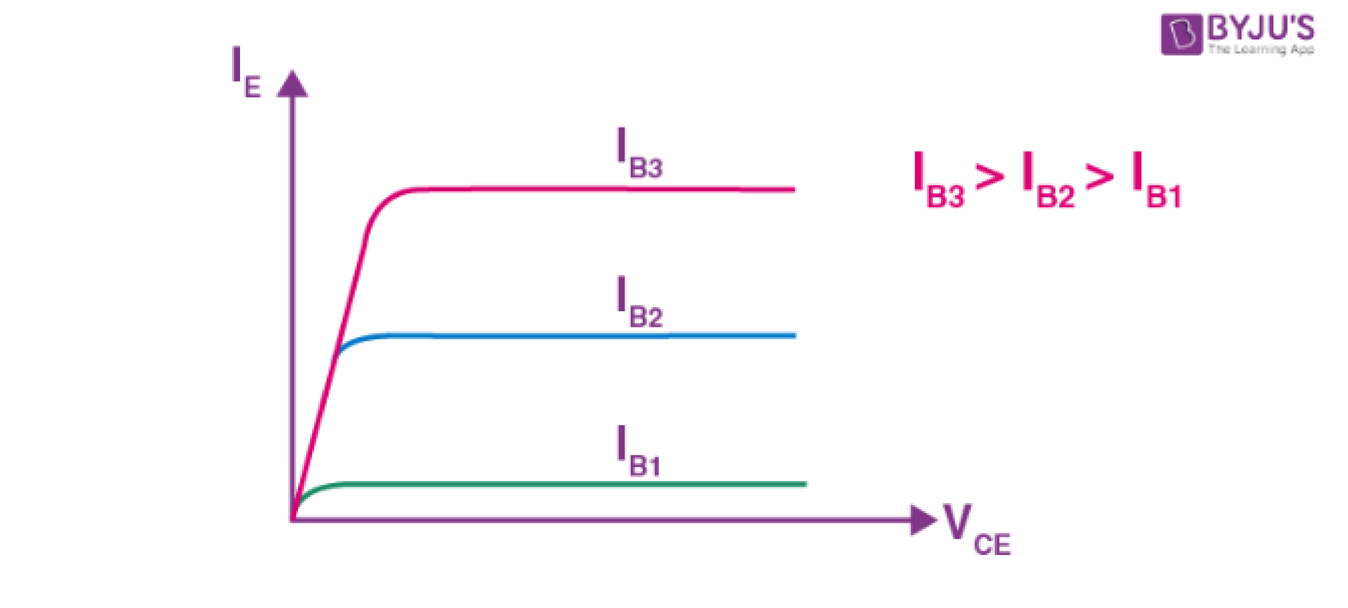
CB Configuration

This chart shows the variation of collector current, I_C with V_{CB}, by keeping the emitter current I_E constant.



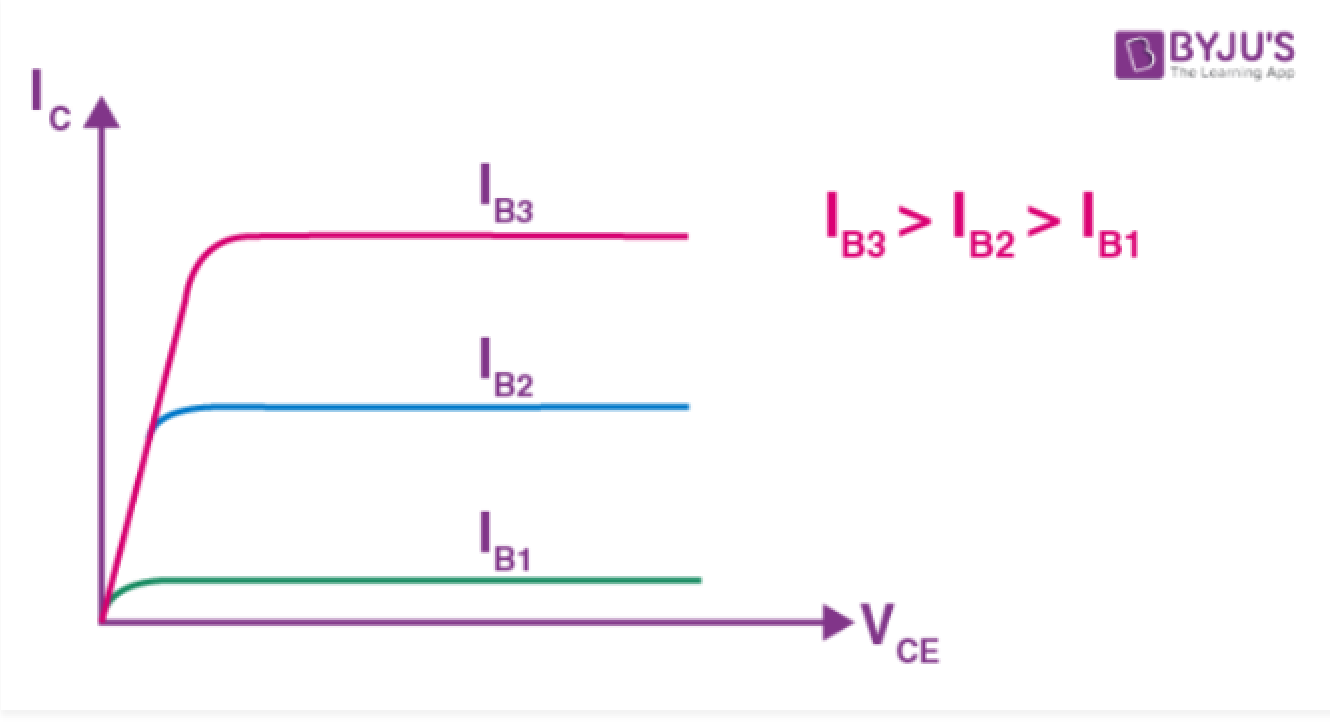
CC Configuration

This exhibits the variation in I_E against the changes in V_{CE} by keeping I_B constant.



CE Configuration

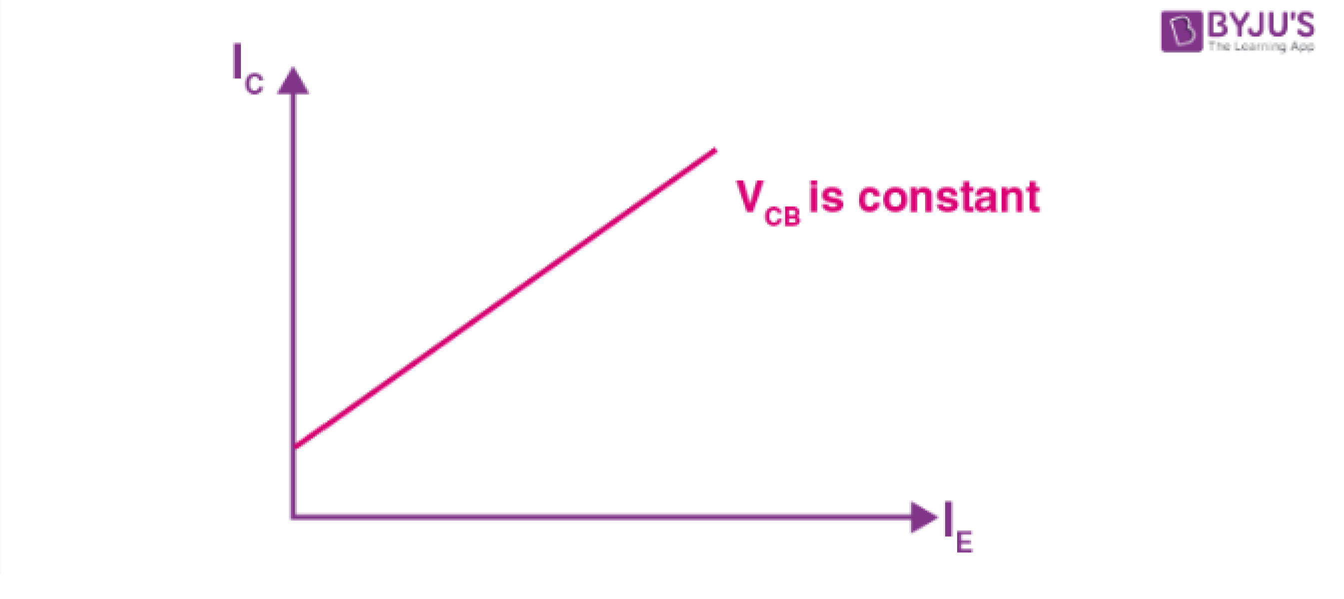
Here, it shows the variation in I_C with the changes in V_{CE} by keeping I_B constant.



Current Transfer Characteristics

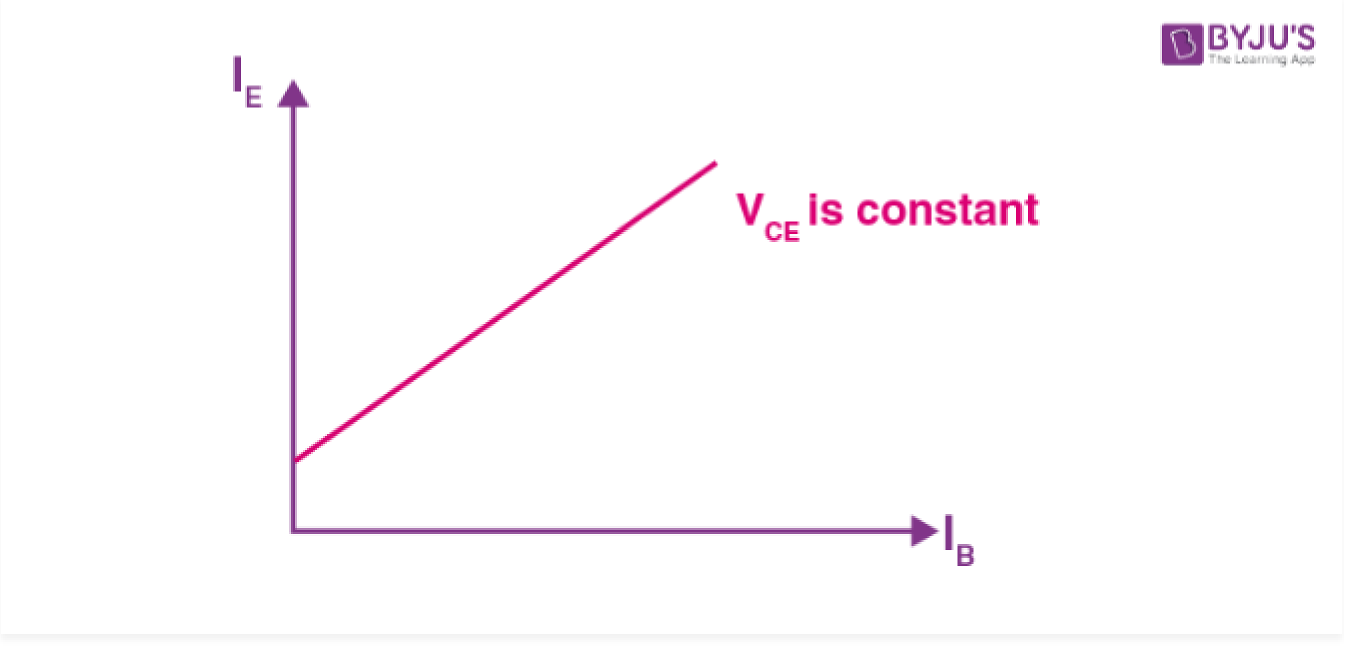
CB Configuration

It gives the variation of I_C with the I_E by keeping V_{CB} as constant.



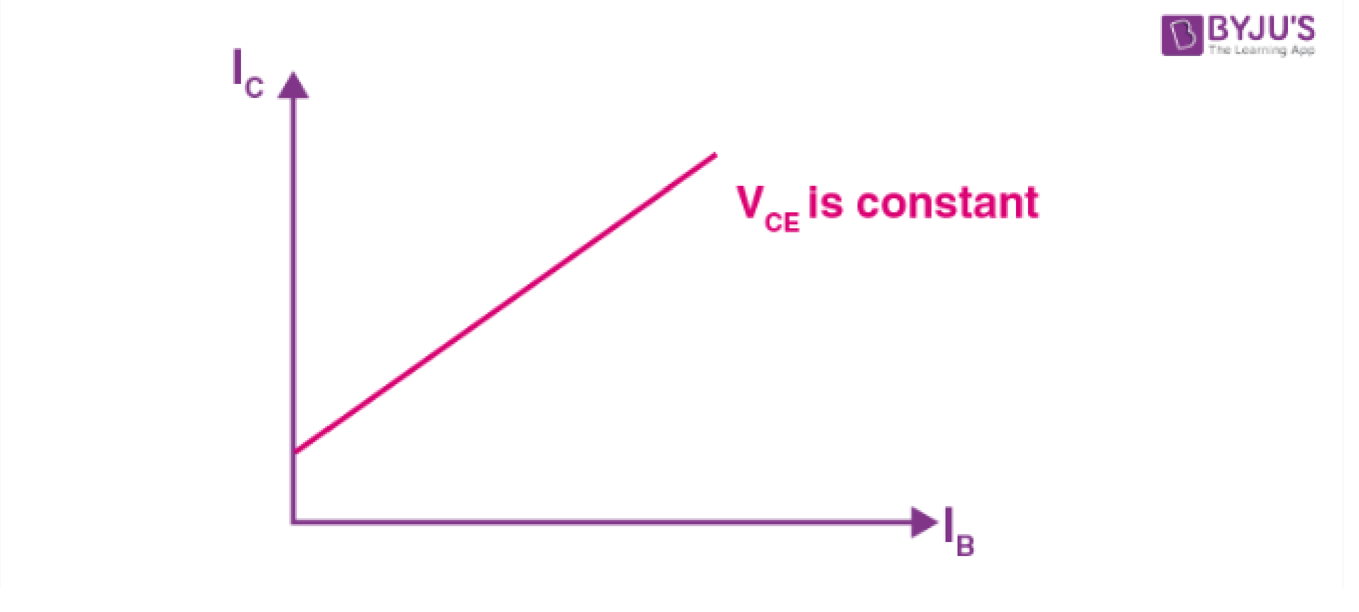
CC Configuration

This shows the variation of I_E with I_B by keeping V_{CE} constant.



CE Configuration

Here, it shows the variation of I_C with I_B by keeping V_{CE} constant.



Advantages of Transistor

- Lower cost and smaller in size.
- Smaller mechanical sensitivity.
- Low operating voltage.
- Extremely long life.
- No power consumption.
- Fast switching.
- Better efficiency circuits can be developed.
- Used to develop a single integrated circuit.

Limitations of Transistors

Transistors have a few limitations, and they are as follows:

- Transistors lack higher electron mobility.
- Transistors can be easily damaged when electrical and thermal events arise. For example, electrostatic discharge in handling.
- Transistors are affected by cosmic rays and radiation.

Transformer

The **transformer**, in a simple way, can be described as a device that steps up or steps down voltage. In a step-up transformer, the output voltage is increased, and in a step-down transformer, the output voltage is decreased. The step-up transformer will decrease the output current, and the step-down transformer will increase the output current to keep the input and output power of the system equal.

The transformer is basically a voltage control device that is used widely in the distribution and transmission of alternating current power. The idea of a transformer was first discussed by Michael Faraday in the year 1831 and was carried forward by many other prominent science scholars. However, the general purpose of using transformers was to maintain a balance between the electricity that was generated at very high voltages and consumption which was done at very low voltages.

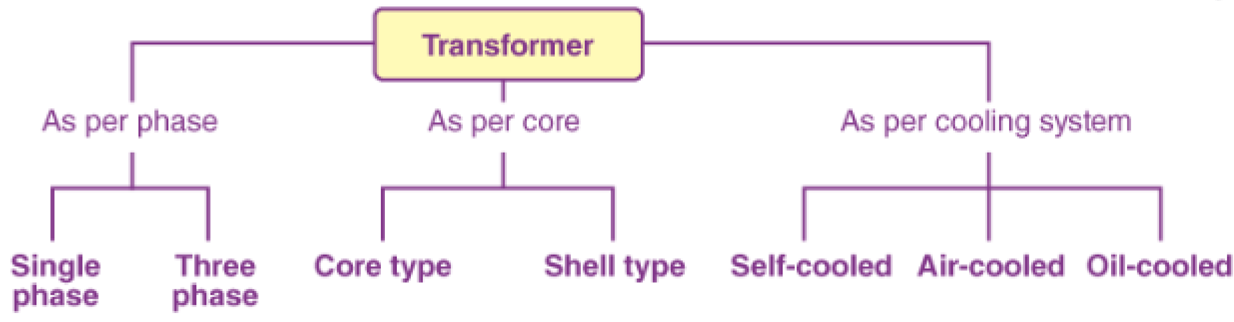
What Is a Transformer?

A transformer is a device used in the power transmission of electric energy. The transmission current is AC. It is commonly used to increase or decrease the supply voltage without a change in the frequency of AC between circuits. The transformer works on the basic principles of electromagnetic induction and mutual induction.

Transformer Types

Transformers are used in various fields like power generation grid, distribution sector, transmission and electric energy consumption. There are various types of transformers which are classified based on the following factors:

- Working voltage range
- The medium used in the core
- Winding arrangement
- Installation location



Based on Voltage Levels

Commonly used transformer types, depending on the voltage, are classified as follows:

- **Step-up Transformer:** They are used between the power generator and the power grid. The secondary output voltage is higher than the input voltage.
- **Step-down Transformer:** These transformers are used to convert high-voltage primary supply to low-voltage secondary output.

Based on the Medium of Core Used

In a transformer, we will find different types of cores that are used.

- **Air Core Transformer:** The flux linkage between primary and secondary winding is through the air. The coil or windings wound on the non-magnetic strip.
- **Iron Core Transformer:** Windings are wound on multiple iron plates stacked together, which provides a perfect linkage path to generate flux.

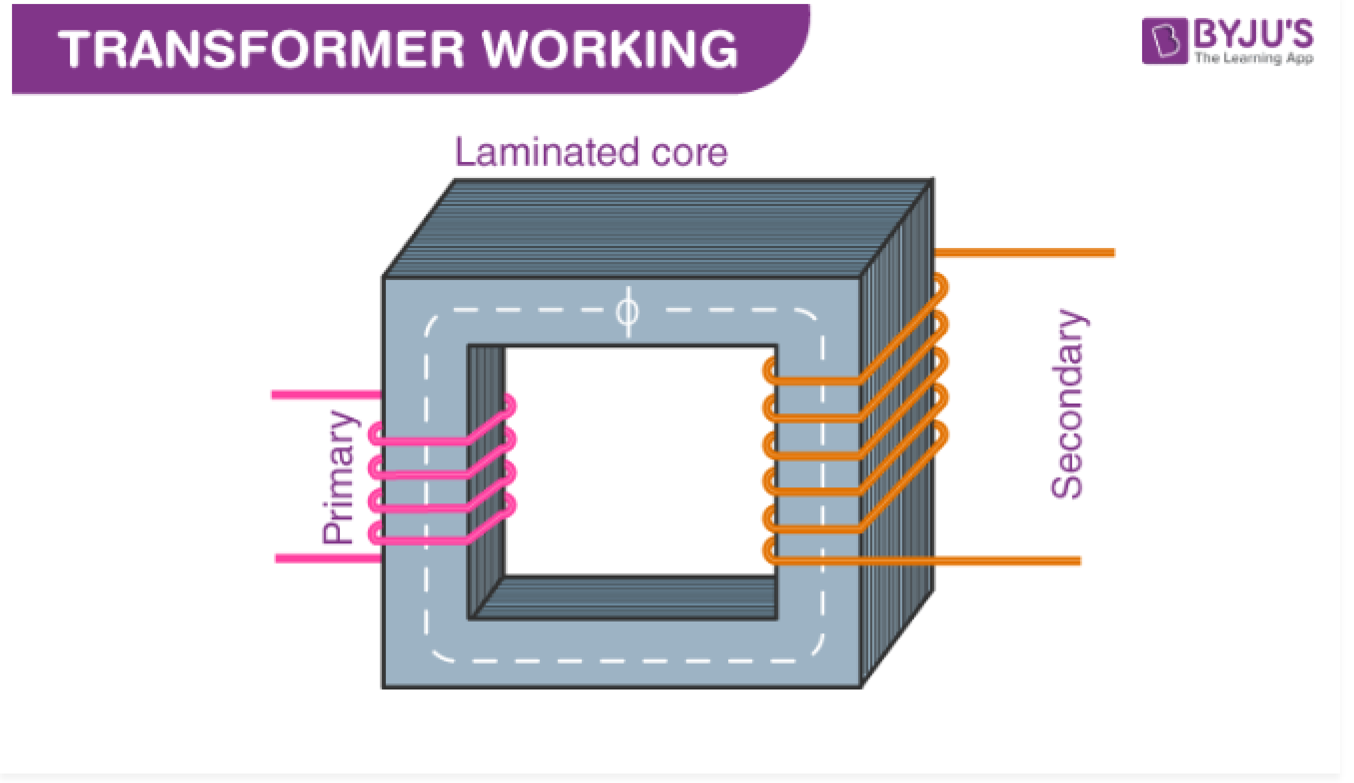
Based on the Winding Arrangement

- **Autotransformer:** It will have only one winding wound over a laminated core. The primary and secondary share the same coil. Auto means "self" in the Greek language.

Based on Install Location

- **Power Transformer:** It is used at power generation stations, as they are suitable for high voltage application
- **Distribution Transformer:** It is mostly used at distribution lanes for domestic purposes. They are designed for carrying low voltages. It is very easy to install and characterised by low magnetic losses.
- **Measurement Transformers:** They are mainly used for measuring voltage, current and power.
- **Protection Transformers:** They are used for component protection purposes. In circuits, some components must be protected from voltage fluctuation, etc. Protection transformers ensure component protection.

Working Principle of a Transformer

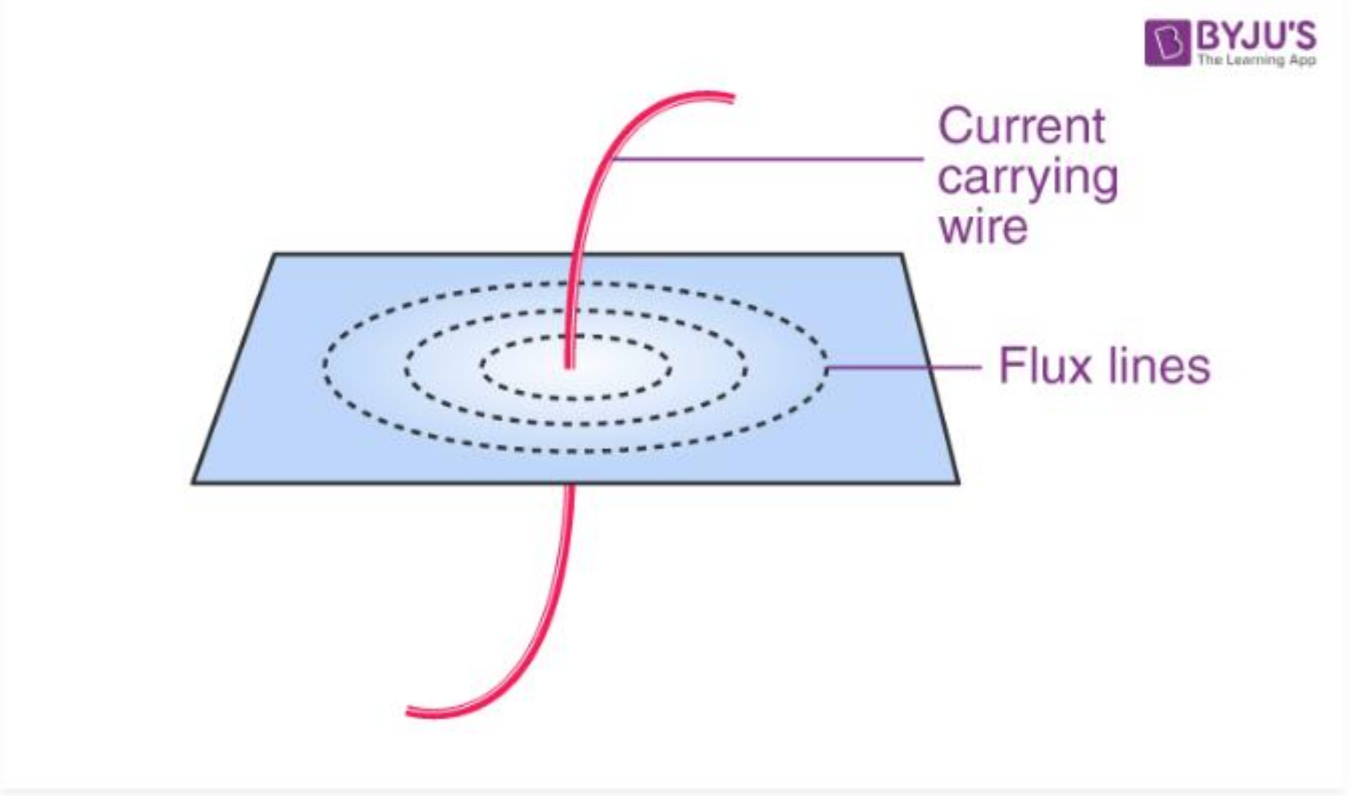


The transformer works on the principle of Faraday's law of electromagnetic induction and mutual induction.

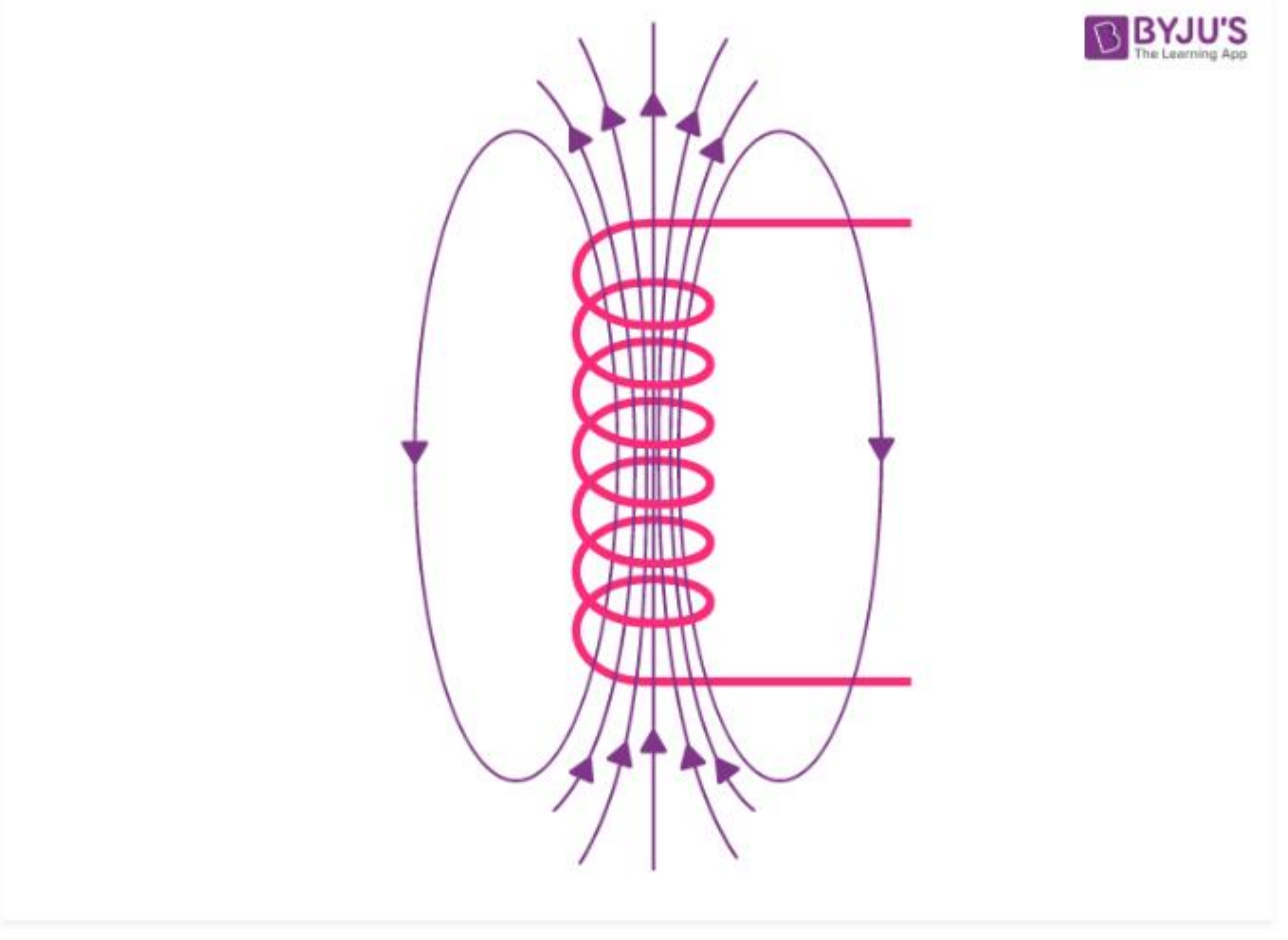
There are usually two coils – primary coil and secondary coil – on the transformer core. The core laminations are joined in the form of strips. The two coils have high mutual inductance. When an alternating current passes through the primary coil, it creates a varying magnetic flux. As per Faraday's law of electromagnetic induction, this change in magnetic flux induces an EMF (electromotive force) in the secondary coil, which is linked to the core having a primary coil. This is mutual induction.

Overall, a transformer carries out the following operations:

1. Transfer of electrical energy from one circuit to another
2. Transfer of electrical power through electromagnetic induction
3. Electric power transfer without any change in frequency
4. Two circuits are linked with mutual induction

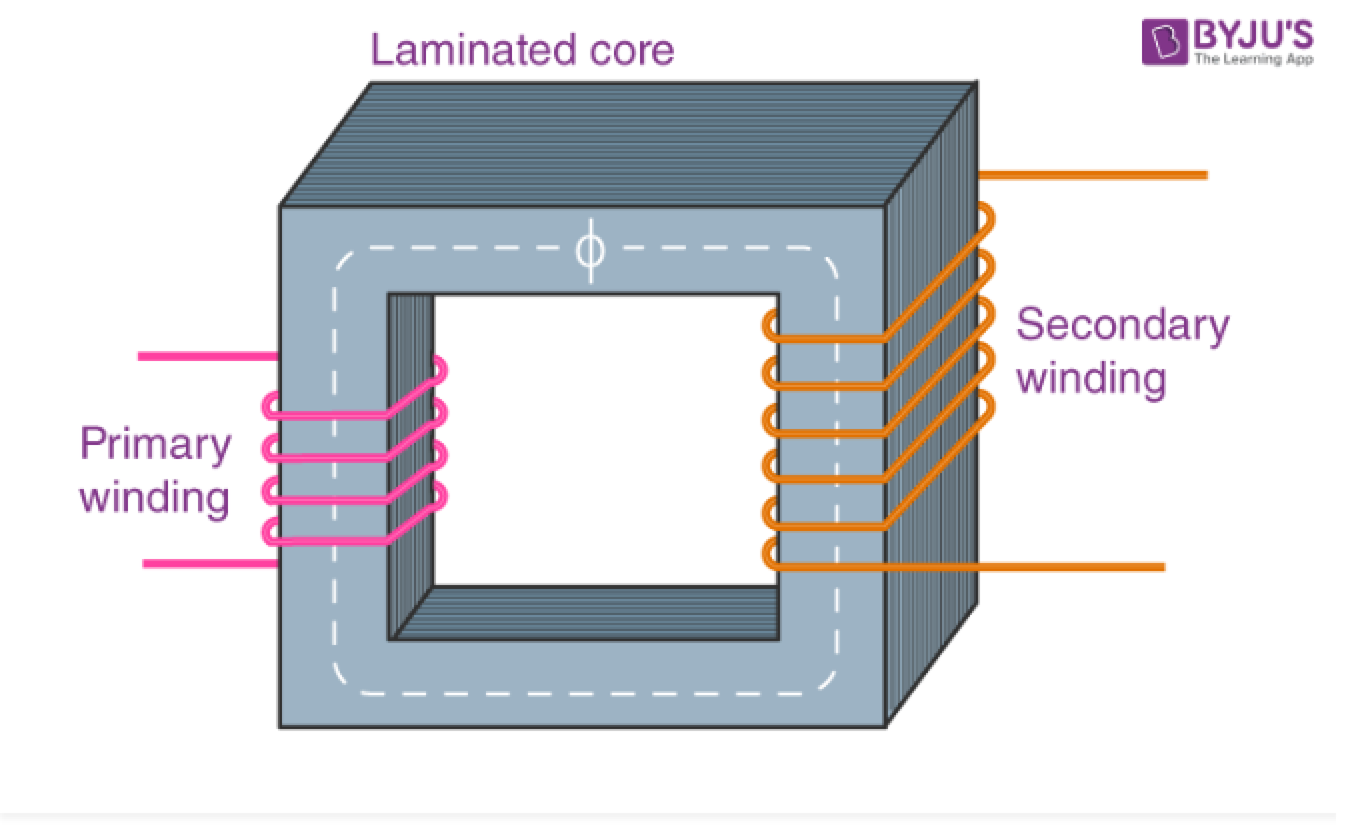


The figure shows the formation of magnetic flux lines around a current-carrying wire. The normal of the plane containing the flux lines is parallel to the normal of a cross-section of a wire.



The figure shows the formation of varying magnetic flux lines around a wire wound. The interesting part is that the reverse is also true; when a magnetic flux line fluctuates around a piece of wire, a current will be induced in it. This was what Michael Faraday found in 1831, which is the fundamental working principle of electric generators, as well as transformers.

Parts of a Single-phase Transformer



The major parts of a single-phase transformer consist of

1. Core

The core acts as a support to the winding in the transformer. It also provides a low reluctance path to the flow of magnetic flux. The winding is wound on the core, as shown in the picture. It is made up of a laminated soft iron core in order to reduce the losses in a transformer. The factors, such as operating voltage, current, power, etc., decide core composition. The core diameter is directly proportional to copper losses and inversely proportional to iron losses.

2. Windings

Windings are the set of copper wires wound over the transformer core. Copper wires are used due to the following:

- The high conductivity of copper minimises the loss in a transformer because when the conductivity increases, resistance to current flow decreases.
- The high ductility of copper is the property of metals that allows it to be made into very thin wires.

There are mainly two types of windings: primary windings and secondary windings.

- Primary winding: The set of turns of windings to which the supply current is fed.
- Secondary winding: The set of turns of winding from which output is taken.

The primary and secondary windings are insulated from each other using insulation coating agents.

3. Insulation Agents

Insulation is necessary for transformers to separate windings from each other and to avoid short circuits. This facilitates mutual induction. Insulation agents have an influence on the durability and stability of a transformer.

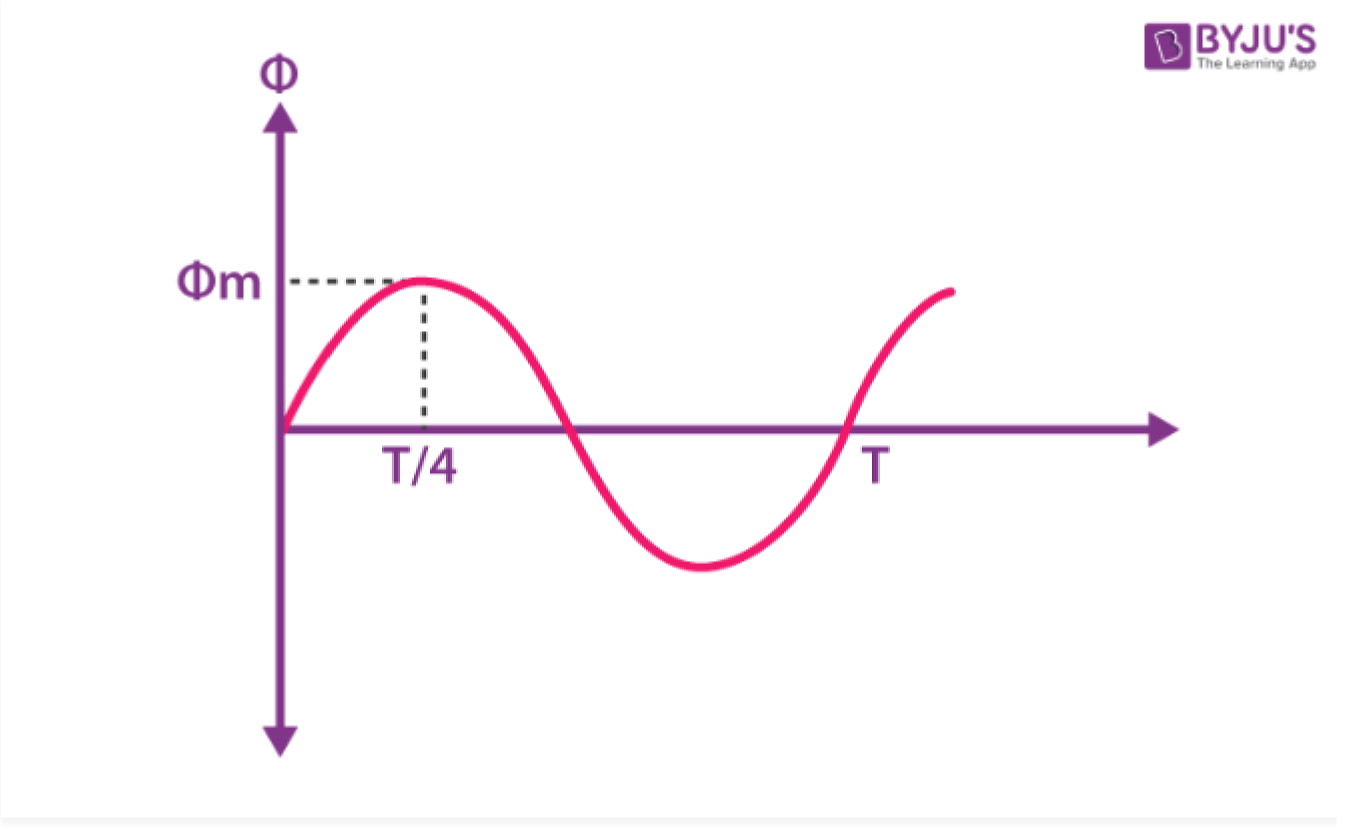
The following are used as insulation mediums in a transformer:

- Insulating oil
- Insulating tape
- Insulating paper
- Wood-based lamination

Ideal Transformer

The ideal transformer has no losses. There is no magnetic leakage flux, ohmic resistance in its windings and no iron loss in the core.

EMF Equation of Transformer



N_1 – Number of turns in the primary

N_2 – Number of turns in the secondary

Φ_m – Maximum flux in the weber (Wb)

T – Time period. It is the time taken for 1 cycle.

The flux formed is a sinusoidal wave. It rises to a maximum value of Φ_m and decreases to a negative maximum of Φ_m. So, flux reaches a maximum in one-quarter of a cycle. The time taken is equal to T/4.

Average rate of change of flux = $\Phi_m/(T/4) = 4f\Phi_m$

Where, f = frequency

$T = 1/f$

Induced EMF per turn = Rate of change of flux per turn

Form factor = RMS value / average value

RMS value = 1.11 $(4f\Phi_m)$ = 4.44 $f\Phi_m$ [form factor of a sine wave is 1.11]

RMS value of EMF induced in winding = RMS value of EMF per turn x No. of turns

Primary Winding

RMS value of induced EMF = E_1 = 4.44 $f\Phi m$ * N_1

Secondary Winding

RMS value of induced EMF = E_2 = 4.44 $f\Phi m$ * N_2

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} = 4.44 f\,\Phi m$$

This is the EMF equation of the transformer.

For an ideal transformer at no load condition,

E_1 = Supply voltage on the primary winding

E_2 = Terminal voltage (theoretical or calculated) on the secondary winding

Voltage Transformation Ratio

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} = k$$

K is called the voltage transformation ratio, which is a constant.

Case 1:If $N_2 > N_1$, K>1, it is called a step-up transformer.

Case 2: If $N_2 < N_1$, K<1, it is called a step-down transformer.

Transformer Efficiency

Comparing system output with input will confirm transformer efficiency. The system is called better when its efficiency is high.

$$Efficiency\,(\eta) = \frac{Outputpower}{Inputpower} \times 100$$

$$Efficiency\,(\eta) = \frac{P_{out}}{P_{out}+P_{loses}} \times 100$$

$$Efficiency\,(\eta) = \frac{V_2 I_2 cos\theta}{V_2 I_2 cos\theta + P_c + P_{cm}} \times 100$$

Where, $P_{cu} = P_{sc}$

$P_c = P_{oc}$

$$\eta(fullload) = \frac{V\,Acos\theta}{V\,Acos\theta + P_c + P_{cm}} \times 100$$

$$\eta(loadn) = \frac{nV\,Acos\theta}{nV\,Acos\theta + P_c + n^2 P_{cm}} \times 100$$

Applications of Transformer

- The transformer transmits electrical energy through wires over long distances.
- Transformers with multiple secondaries are used in radio and TV receivers, which require several different voltages.
- Transformers are used as voltage regulators.

Transformer-related Solved Examples

1. A transformer has 600 turns of the primary winding and 20 turns of the secondary winding. Determine the secondary voltage if the secondary circuit is open and the primary voltage is 140 V.

Given

Total number of turns of the primary coil (N_1) = 600 turns

Total number of turns of the secondary coil (N_2) = 20 turns

Primary voltage (V_1) = 140 V

Solution:

The voltage on the primary coil = N_1V_1

The voltage on the secondary coil = N_2V_2

The voltage on one turn

$$V_t = \frac{V_2}{N_2} = \frac{V_1}{N_1}$$

$$k = \frac{V_2}{N_2} = \frac{V_1}{N_1}$$

k is a transformation ratio.

$$V_2 = \frac{N_2}{N_1} \times V_1$$

$$V_2 = \frac{20}{600} \times \times 140$$

V_2 = 4.6 V

2. A transformer has a primary coil with 1600 loops and a secondary coil with 1000 loops. If the current in the primary coil is 6 Ampere, then what is the current in the secondary coil?

Given:

Primary coil (N_1) = 1600 loops

Secondary coil (N_2) = 1000 loops

The current in the primary coil (I_1) = 4 A

Solution :

$$\frac{I_2}{I_1} = \frac{N_1}{N_2}$$

$$\frac{I_2}{4} = \frac{1600}{1000}$$

I_2 = 6.4 A

The current on the secondary coil is 6.4 Ampere.

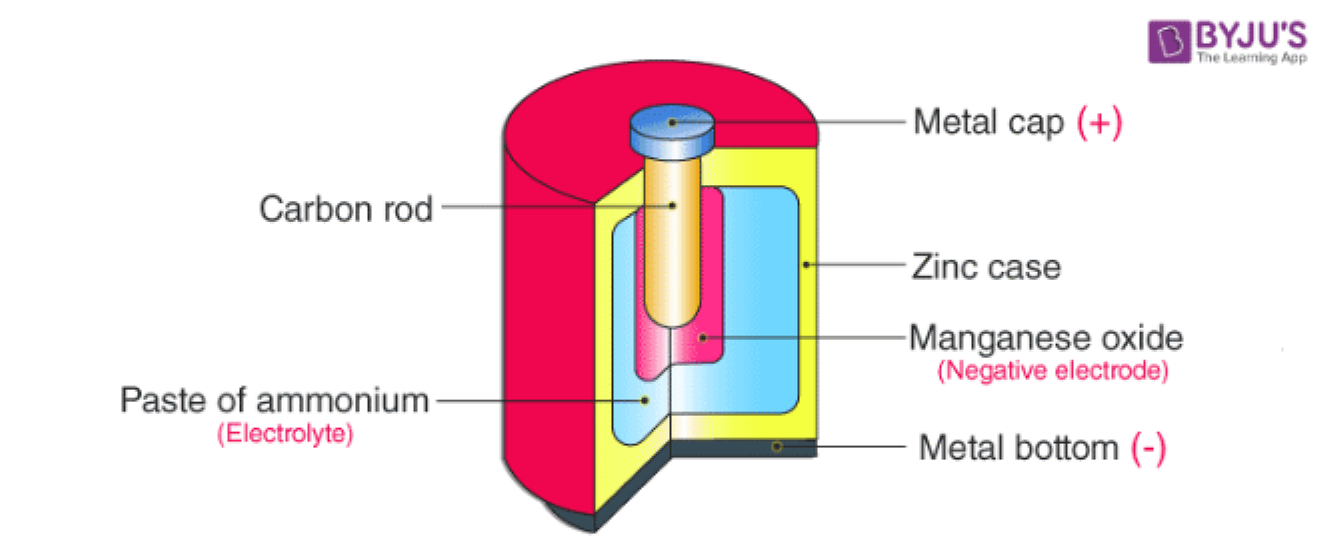
EMF: Cells, Electromotive Force And Internal Resistance

Batteries and cells are important inventions that have made a lot of our everyday tasks and life much easier. They are practically used in most of the portable electronic devices that we use today. Besides, we can say that we cannot imagine a world without them. In this article, let us know more about the cells and their working principle in detail.

Cell or Electrochemical Cell

A cell or an electrochemical cell is a device that is capable of obtaining electrical energy from chemical reactions or vice versa. You have definitely seen a cell, the small AAA or AA batteries we use in our remotes.

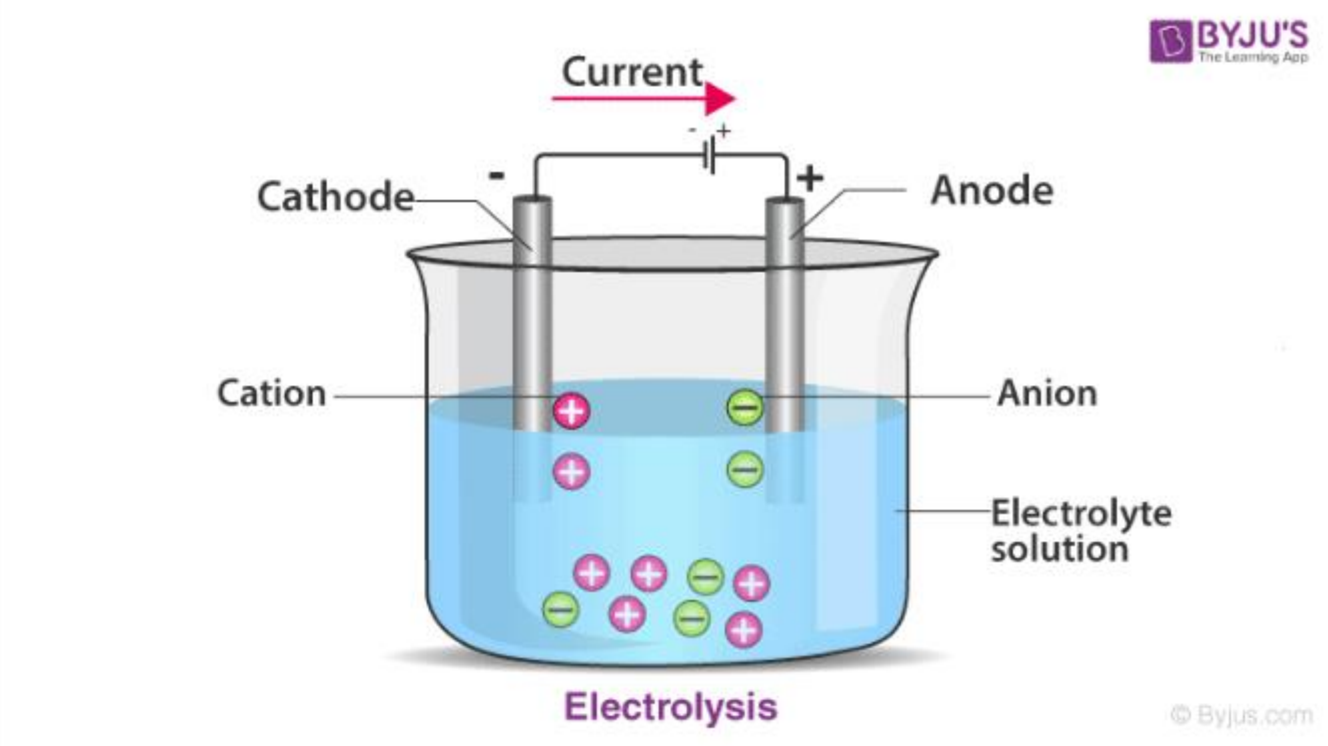
An electric battery is a device made up of two or more cells that make use of the chemical energy stored in the chemicals and converts it into electrical energy. A battery is used to provide a continuous steady current source by way of providing constant EMF or Electromotive force to an electrical circuit or a machine.



Anatomy of a battery

Each cell comprises two half-cells connected in series by a conductive electrolyte containing anions and cations. One half-cell is made up of the electrolyte and the negative electrode, the Anode. The negatively charged ions, also known as anions, migrate to the Anode. The other half-cell includes the electrolyte and the positive electrode, the Cathode, to which cations (positively charged ions) migrate.

Redox reactions, reduction and oxidation occur simultaneously and this powers the battery. Cations are reduced (it gains electrons) at the cathode during charging, while anions are oxidised (it loses electrons) at the anode during charging. During discharge, the process is reversed. The electrodes do not touch each other but are electrically connected by the electrolyte.



What Is an Electromotive Force (EMF) of a Cell?

When there is no electrical equipment attached to a cell i.e. no current is flowing through the cell, the electrolyte has the same potential throughout the cell. The condition of no current flowing through a cell is also known as an open circuit. In an open circuit, the potential of the cell becomes equal to the difference in the potentials of the electrodes. Anode has a positive potential (V_+) whereas Cathode has a negative potential ($-V_-$). This potential difference is known as the Electromotive Force (EMF) of the cell and it is equal to;

$$\xi = V_+ - (-V_-) = V_+ + V_-$$

We know that when we connect an appliance to the battery, a current flows through the circuit that is proportional to the voltage. The ratio of the voltage (V) across an object to the current flowing through it because of the potential is known as the resistance of that object. Resistance in Electricity can be linked to Friction in Mechanics. The electrical resistance of a body is the measure of the difficulty in passing an electric current through it. The SI unit of electrical resistance is ohm (Ω). The phenomenon of electrical resistance has led to the creation of electrical heaters and induction cooktops. Resistance is given by

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

Internal Resistance

Similar to how a body opposes the flow of electricity through it, leading to resistance, the electrolytes in batteries have a finite value of resistance. The resistance generated inside a battery to the flow of current is referred to as the internal resistance of a battery (r). When a power source delivers current, the measured voltage output is lower than the voltage when no current is flowing through the circuit. This voltage drop is caused by the internal resistance of the battery to the flow of current through it.

Measuring Internal Resistance

The voltage of the battery can be measured using a voltmeter with no load connected to it. This is known as the open circuit voltage (V_{OC}). V_{OC} is equal to the voltage of the ideal voltage source in the battery. battery. If we connect a load across the battery, the voltage across the terminals drops. Let us look at an example to better understand this.

Measuring the current with a 8Ω external resistor between the poles of a 8 V battery, we would expect a current of the following value:

$I = \frac{V}{R} = 1A$

In reality, when we measure we measure 0.8 A.

Hence the resistance is:

$R = \frac{V}{I} = 10\,\Omega$

So the internal resistance of the battery in this case is:

$R_{internal} = R_{total} – R_{external}$

Substiuting the values in the above equation, we get:

$R_{internal} = 10\,\Omega – 8\,\Omega = 2\,\Omega$

Battery Definition

What is a Battery?

A battery can be defined as an electrochemical device (consisting of one or more electrochemical cells) which can be charged with an electric current and discharged whenever required. Batteries are usually devices that are made up of multiple electrochemical cells that are connected to external inputs and outputs. Batteries are widely employed in order to power small electric devices such as mobile phones, remotes, and flashlights. Historically, the 'term' battery has always been used in order to refer to the combination of two or more electrochemical cells. However, the modern definition of the term 'battery' is believed to accommodate devices that only feature a single cell.

Batteries are broadly classified into two categories, namely primary batteries and secondary batteries. Primary batteries can only be charged once. When these batteries are completely discharged, they become useless and must be discarded. The most common reason why primary batteries cannot be recharged is that the electrochemical reaction that takes place inside of them is irreversible in nature. It is important to note that primary batteries are also referred to as use-and-throw batteries.

On the other hand, secondary batteries are the batteries than can be charged and reused for many charging-discharging cycles. The electrochemical reactions that take place inside these batteries are usually reversible in nature. Therefore, secondary batteries are also known as rechargeable batteries. When discharging, the reactants combine to form products, resulting in the flow of electricity. When charging, the flow of electrons into the battery facilitates the reverse reaction, in which the products react to form the reactants.

Important Examples of Batteries

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The Lead-Acid Battery

The lead-acid battery is believed to have been invented by the French physicist and inventor Gaston Planté in the year 1859. It is known to be one of the earliest rechargeable batteries. Despite the fact that the lead-acid battery has a very high energy-to-volume ratio and also a very low energy-to-weight ratio, the electrochemical cells in this battery are known to have a fairly large power-to-weight ratio. This can be attributed to their ability to produce strong surge currents. These features of the lead-acid battery, along with its relatively low cost, makes it highly desirable for use in motor vehicles and automobiles in order to provide the high current required to start the engine.

Some key characteristics of the lead-acid battery are:

- It has the ability to hold an electric charge for up to 3 years.
- It is ideal for use as an emergency power backup.
- It is one of the most inexpensive batteries in its output range.

The Nickel-Cadmium Battery (also known as the NiCad Battery)

The nickel-cadmium battery (sometimes referred to as the 'NiCad' battery) is a type of rechargeable battery that employs metallic cadmium and nickel oxide hydroxide as the electrodes o the battery. The NiCad battery is known to offer varying discharge rates that are dependent on the size of the battery itself. For example, the discharge rate (maximum) for a typical AA sized cell is approximately equal to 1.8 amperes. On the other hand, the discharge rate for a D size battery can be as high as 3.5 amperes.

The key features of the NiCad battery are listed below.

- The nickel-cadmium battery features a very fast and even discharge of electrical energy.
- This type of battery is widely available and is also known to be relatively inexpensive.
- The NiCad battery can most commonly be found in certain toys and small electronic devices such as TV remotes.

The Lithium-Ion Battery (also known as the LIB Battery)

The lithium-ion battery, often abbreviated to LIB, is a type of secondary battery which is rechargeable. LIBs are known to have many applications in powering electric vehicles and is also known to be used extensively in the aerospace industry.

Within the batteries, during the discharging process, lithium ions are known to pass from the negative electrode to the positive electrode (through an electrolyte). These lithium ions are also known to travel back when charging. Lithium-ion batteries usually employ an intercalated lithium compound in the positive electrode and usually graphite in the negative electrode as the fuel. Lithium-ion batteries are highly desirable due to their high energy capacity, no memory effect (with the exception of LFP cells), and low self-discharge.

Some key characteristics of LIBs are listed below.

- The lithium-ion battery is regarded to be one of the most stable and safe batteries. This battery is also known to have a very high energy capacity.
- LIBs are widely used in mobile phones and portable computers (such as laptops and tablets).
- This battery has a very slow self-discharge. Furthermore, it is known to have twice the energy capacity of the NiCad battery.