Ohm's Law

Ohm’s law states the relationship between electric current and potential difference. The current that flows through most conductors is directly proportional to the voltage applied to it. Georg Simon Ohm, a German physicist was the first to verify Ohm’s law experimentally.

Ohm’s Law Explanation

One of the most basic and important laws of electric circuits is Ohm’s law.

> Ohm’s law states that the voltage across a conductor is directly proportional to the current flowing through it, provided all physical conditions and temperatures remain constant.

Mathematically, this current-voltage relationship is written as,

$$V = IR$$

In the equation, the constant of proportionality, R, is called Resistance and has units of ohms, with the symbol Ω.

The same formula can be rewritten in order to calculate the current and resistance respectively as follows:

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

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

Ohm's law only holds true if the provided temperature and the other physical factors remain constant. In certain components, increasing the current raises the temperature. An example of this is the filament of a light bulb, in which the temperature rises as the current is increased. In this case, Ohm's law cannot be applied. **The lightbulb filament violates Ohm's Law**.

Ohm's Law Statement: Ohm's law states that the voltage across a conductor is directly proportional to the current flowing through it, provided all physical conditions and temperature, remain constant.

Ohm's Law Equation: $V = IR$, where V is the voltage across the conductor, I is the current flowing through the conductor and R is the resistance provided by the conductor to the flow of current.

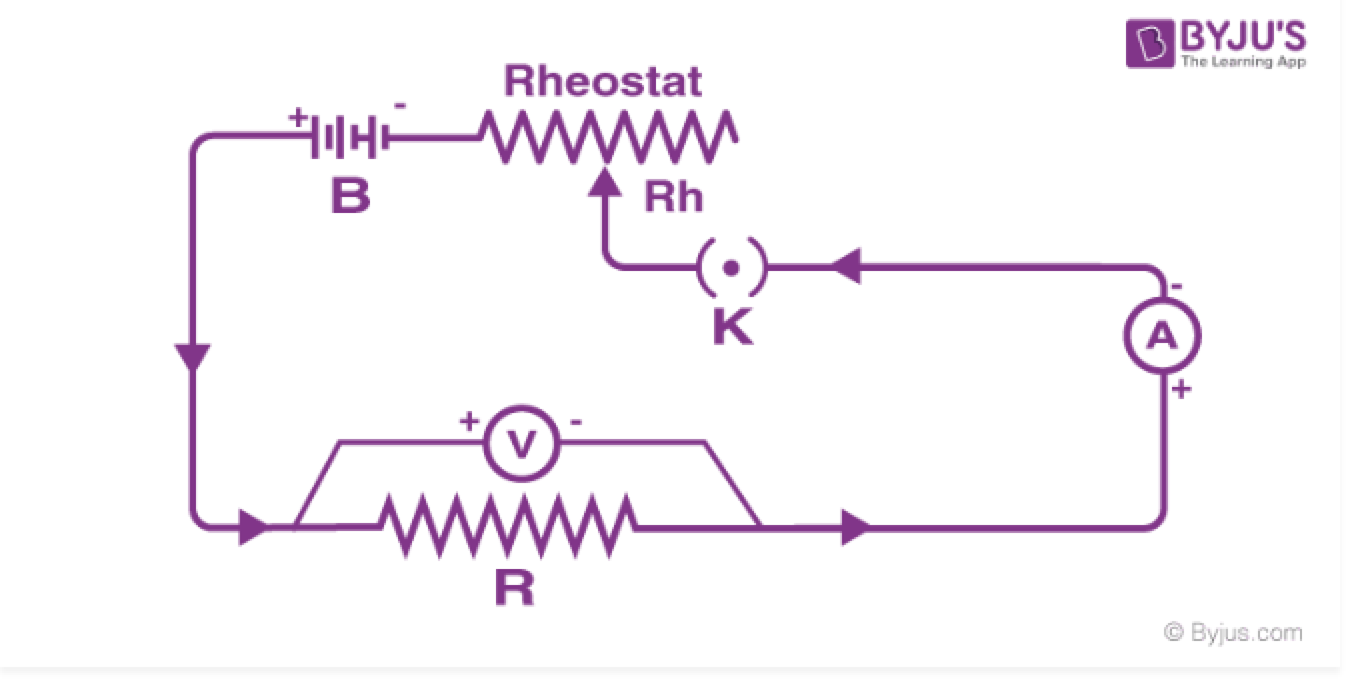
Experimental Verification of Ohm's Law

Ohm's Law can be easily verified by the following experiment:

Apparatus Required:

- Resistor
- Ammeter
- Voltmeter
- Battery
- Plug Key
- Rheostat

Circuit Diagram:



Procedure:

1. Initially, the key K is closed and the rheostat is adjusted to get the minimum reading in ammeter A and voltmeter V.
2. The current in the circuit is increased gradually by moving the sliding terminal of the rheostat. During the process, the current flowing in the circuit and the corresponding value of potential difference across the resistance wire R are recorded.
3. This way different sets of values of voltage and current are obtained.
4. For each set of values of V and I, the ratio of V/I is calculated.
5. When you calculate the ratio V/I for each case, you will come to notice that it is almost the same. So V/I = R, which is a constant.
6. Plot a graph of the current against the potential difference, it will be a straight line. This shows that the current is proportional to the potential difference.

Ohm's Law Solved Problems

Example 1: If the resistance of an electric iron is 50 Ω and a current of 3.2 A flows through the resistance. Find the voltage between two points.

Solution:

If we are asked to calculate the value of voltage with the value of current and resistance, then cover V in the triangle. Now, we are left with I and R or more precisely I × R.

Therefore, we use the following formula to calculate the value of V:

$V = I \times R$

Substituting the values in the equation, we get

$V = 3.2\ A \times 50\ \Omega = 160\ V$

$V = 160V$

Example 2: An EMF source of 8.0 V is connected to a purely resistive electrical appliance (a light bulb). An electric current of 2.0 A flows through it. Consider the conducting wires to be resistance-free. Calculate the resistance offered by the electrical appliance.

Solution:

When we are asked to determine the value of resistance when the values of voltage and current are given, we cover R in the triangle. This leaves us with only V and I, more precisely V ÷ I.

Substituting the values in the equation, we get

$R = V \div I$

$R = 8\ V \div 2\ A = 4\ \Omega$

$R = 4\ \Omega$

Calculating Electrical Power Using Ohm's Law

The rate at which energy is converted from the electrical energy of the moving charges to some other form of energy like mechanical energy, heat energy, energy stored in magnetic fields or electric fields, is known as electric power. The unit of power is the watt. The electrical power can be calculated using Ohm's law and by substituting the values of voltage, current and resistance.

Formula to find power

When the values for voltage and current are given,

$$P=VI$$

When the values for voltage and resistance are given,

$$P = V^2 \div R$$

When the values for current and resistance are given,

$$P=I^2R$$

Ohm's Law Applications

The main applications of Ohm's law are:

- To determine the voltage, resistance or current of an electric circuit.
- Ohm's law maintains the desired voltage drop across the electronic components.
- Ohm's law is also used in DC ammeter and other DC shunts to divert the current.

Limitations of Ohm's Law

Following are the limitations of Ohm's law:

- 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.
- For non-linear electrical elements with parameters like capacitance, resistance etc the ratio ofvoltage and current won't be constant with respect to time making it difficult to use Ohm's law.

Frequently Asked Questions – FAQs

Q1 **What does Ohm's law state?**

Ohm's law states that the current through a conductor between two points is directly proportional to the voltage across the two points.

Q2 **What can Ohm's law be used for?**

Ohm's law is used to validate the static values of circuit components such as current levels, voltage supplies, and voltage drops.

Q3 **Is Ohm's law Universal?**

No. Ohm's law is not a universal law. This is because Ohm's law is only applicable to ohmic conductors such as iron and copper but is not applicable to non-ohmic conductors such as semiconductors.

Q4 **Why is Ohm's law not applicable to semiconductors?**

Ohm's law doesn't apply to semiconducting devices because they are nonlinear devices. This means that the ratio of voltage to current doesn't remain constant for variations in voltage.

Q5 **When does Ohm's law fail?**

Ohm's law fails to explain the behaviour of semiconductors and unilateral devices such as diodes. Ohm's law may not give the desired results if the physical conditions such as temperature or pressure are not kept constant.

Kirchhoff's Law

Kirchhoff's circuit laws lie at the heart of circuit analysis. With the help of these laws and the equation for individual components (resistor, capacitor and inductor), we have the basic tool to start analyzing circuits. In this article, we will discuss Kirchhoff's current and voltage law and how to employ them in circuit analysis.

History about Gustav Robert Kirchhoff

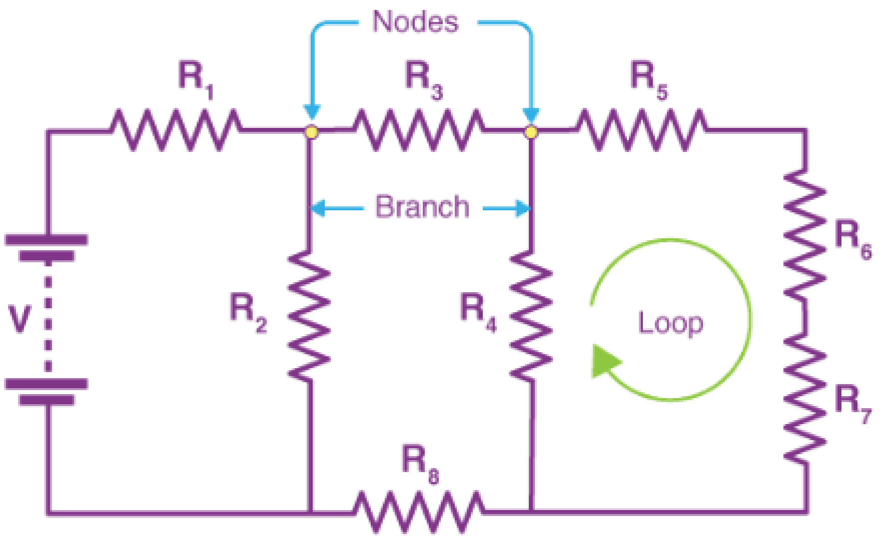
Gustav Robert Kirchhoff

Gustav Robert Kirchhoff (1824-1887)

Gustav Robert Kirchhoff, a German physicist, was born on March 12, 1824, in Konigsberg, Prussia. His first research topic was the conduction of electricity. This research led to Kirchhoff formulating the Laws of Closed Electric Circuits in 1845. These laws were eventually named after Kirchhoff and are now known as Kirchhoff's Voltage and Current Laws. Since these laws apply to all electric circuits, understanding their fundamentals is paramount in understanding how an electronic circuit functions. Although these laws have immortalised Kirchhoff in Electrical Engineering, he has additional discoveries. He was the first person to verify that an electrical impulse travelled at the speed of light. Furthermore, Kirchhoff made a major contribution to the study of spectroscopy, and he advanced the research into blackbody radiation.

What Are Kirchhoff's Laws?

In 1845, a German physicist, Gustav Kirchhoff, developed a pair of laws that deal with the conservation of current and energy within electrical circuits. These two laws are commonly known as Kirchhoff's Voltage and Current Law. These laws help calculate the electrical resistance of a complex network or impedance in the case of AC and the current flow in different network streams. In the next section, let us look at what these laws state.



- Kirchhoff's Current Law goes by several names: Kirchhoff's First Law and Kirchhoff's Junction Rule. According to the Junction rule, the total of the currents in a junction is equal to the sum of currents outside the junction in a circuit.
- Kirchhoff's Voltage Law goes by several names: Kirchhoff's Second Law and Kirchhoff's Loop Rule. According to the loop rule, the sum of the voltages around the closed loop is equal to null.

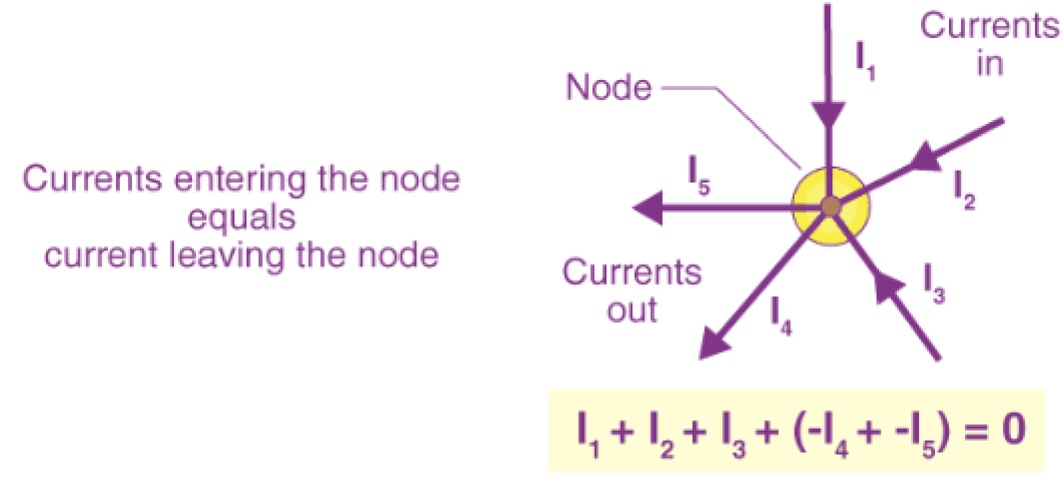
Kirchhoff's First Law or Kirchhoff's Current Law

According to Kirchhoff's Current Law,

> The total current entering a junction or a node is equal to the charge leaving the node as no charge is lost.

Put differently, the algebraic sum of every current entering and leaving the node has to be null. This property of Kirchhoff law is commonly called conservation of charge, wherein I(exit) + I(enter) = 0.

Read More: Kirchhoff's First Law



In the above figure, the currents I_1, I_2 and I_3 entering the node is considered positive, likewise, the currents I_4 and I_5 exiting the nodes is considered negative in values. This can be expressed in the form of an equation:

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

A node refers to a junction connecting two or more current-carrying routes like cables and other components. Kirchhoff's current law can also be applied to analyse parallel circuits.

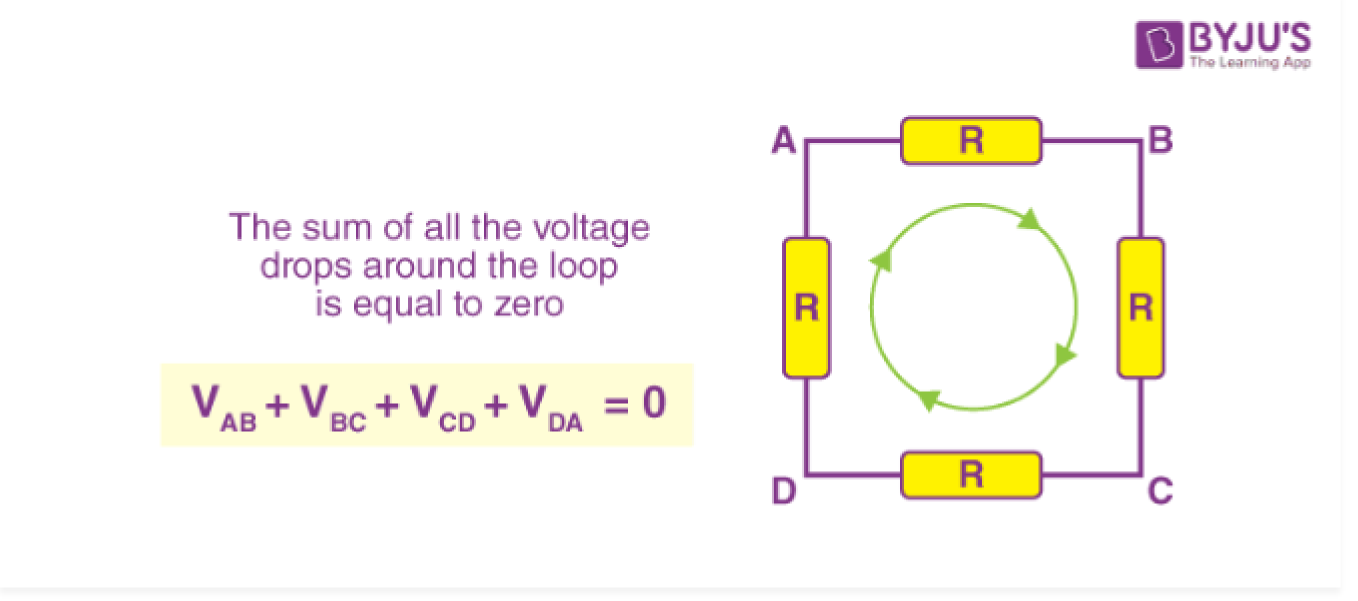
Kirchhoff's Second Law or Kirchhoff's Voltage Law

According to Kirchhoff's Voltage Law,

> The voltage around a loop equals the sum of every voltage drop in the same loop for any closed network and equals zero.

Put differently, the algebraic sum of every voltage in the loop has to be equal to zero and this property of Kirchhoff's law is called conservation of energy.

Read More: Kirchhoff's Second Law

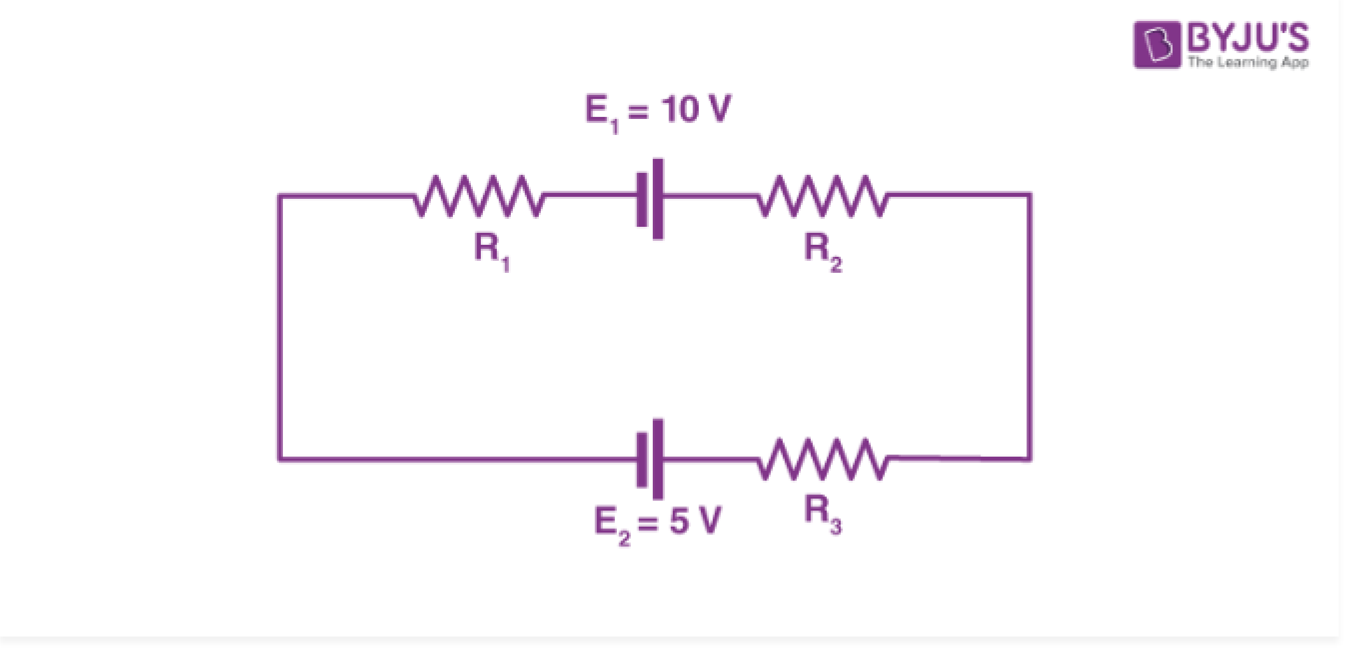


When you begin at any point of the loop and continue in the same direction, note the voltage drops in all the negative or positive directions and returns to the same point. It is essential to maintain the direction either counterclockwise or clockwise; otherwise, the final voltage value will not be zero. The voltage law can also be applied in analyzing circuits in series.

When either AC circuits or DC circuits are analysed based on Kirchhoff's circuit laws, you need to be clear with all the terminologies and definitions that describe the circuit components like paths, nodes, meshes, and loops.

Kirchhoff's Law Solved Example

If $R_1 = 2\Omega$, $R_2 = 4\Omega$, $R_3 = 6\Omega$, determine the electric current that flows in the circuit below.



Solution:

Following are the things that you should keep in mind while approaching the problem:

- You need to choose the direction of the current. In this problem, let us choose the clockwise direction.
- When the current flows across the resistor, there is a potential decrease. Hence, V = IR is signed negative.
- If the current moves from low to high, then the emf (E) source is signed positive because of the energy charging at the emf source. Likewise, if the current moves from high to low voltage (+ to -), then the source of emf (E) is signed negative because of the emptying of energy at the emf source.
  In this solution, the direction of the current is the same as the direction of clockwise rotation.
  $-IR_1 + E_1 - IR_2 - IR_3 - E_2 = 0$
  Substituting the values in the equation, we get
  $-2I + 10 - 4I - 6I - 5 = 0$
  $-12I + 5 = 0$
  $I = -5/-12$
  I = 0.416 AThe electric current that flows in the circuit is 0.416 A. The electric current is signed positive which means that the direction of the electric current is the same as the direction of clockwise rotation. If the electric current is negative then the direction of the current would be in anti-clockwise direction.

Frequently Asked Questions – FAQs

Q1 **State Kirchhoff's Current Law**

Kirchhoff's Current Law states that the total current entering a junction or a node equals the charge leaving the node as no charge is lost.

Q2 **What is Kirchhoff's First Law also known as?**

Kirchhoff's First Law is also known as Kirchhoff's Current Law.

Q3 **State Kirchhoff's voltage law**

Kirchhoff's voltage law states that the voltage around a loop equals the sum of every voltage drop in the same loop for any closed network and equals zero.

Q4 **Who put forth Kirchhoff's laws?**

Kirchhoff's laws were put forth by Gustav Robert Kirchhoff

Q5 **Kirchhoff's second law is also known as?**

Kirchhoff's second law is also known as Kirchhoff's voltage law.

Series and Parallel circuit's connection

When there are two or more electrical devices in a circuit with an energy source, there are a couple of basic ways by which we connect them. They can either be connected in series or in parallel combinations. A series circuit is a circuit in which two components share a common node and the same current flows through them. However, in a parallel circuit, components share two common nodes. In this article, let us look at more differences between series connection and parallel connection circuits.

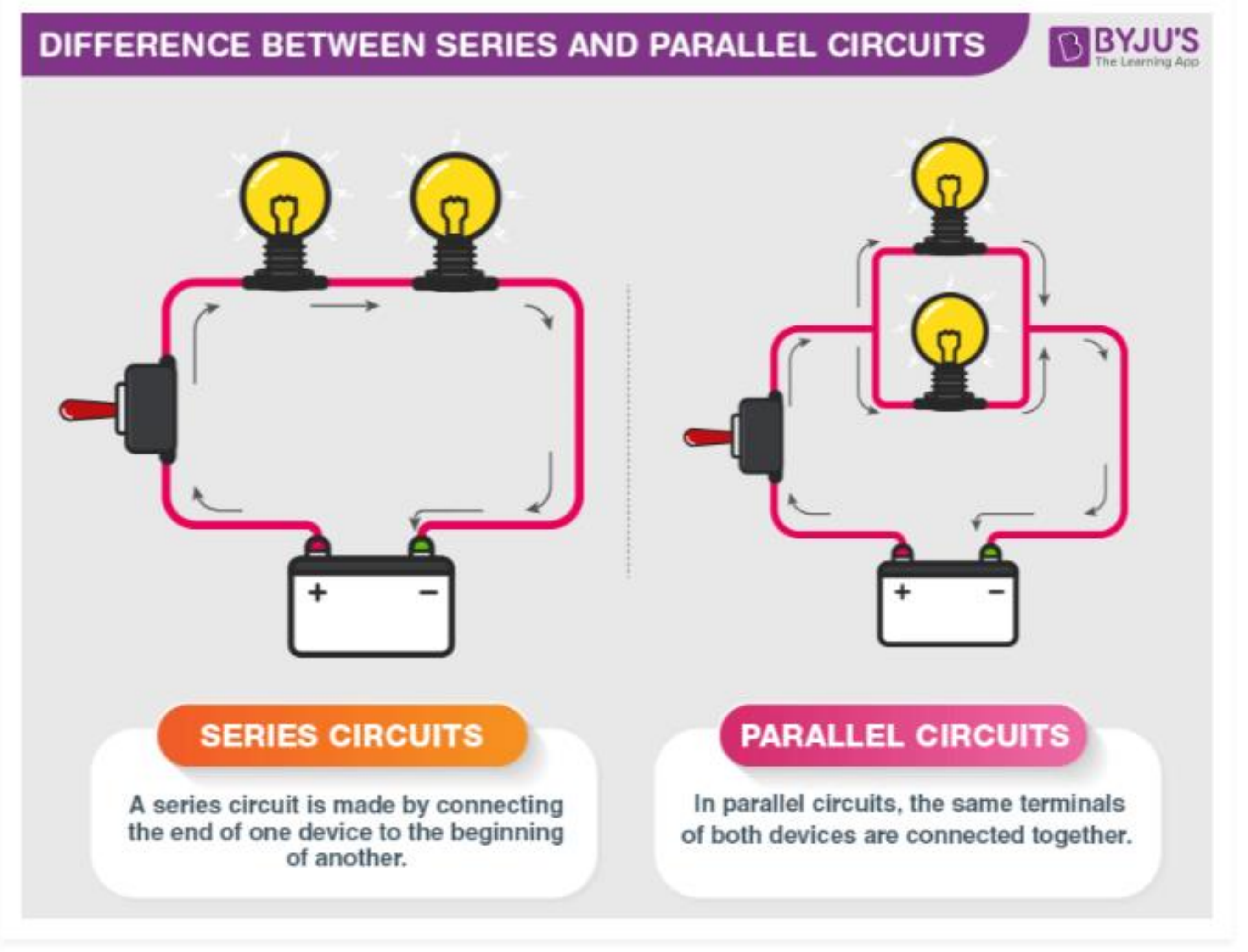
What is a Series Circuit?

A circuit is said to be connected in series when the same current flows through all the components in the circuit. In such circuits, the current has only one path. Let us consider the household decorative string lights as an example of a series circuit. This is nothing but a series of multiple tiny bulbs connected in series. If one bulb fuses, all the bulbs in the series do not light up.

What is a Parallel Circuit?

A circuit is said to be parallel when the electric current has multiple paths to flow through. The components that are a part of the parallel circuits will have a constant voltage across all ends.

Difference Between Series and Parallel Circuits



The major difference between series and the parallel circuit is the amount of current that flows through each of the components in the circuit. In a series circuit, the same amount of current flows through all the components placed in it. On the other hand, in parallel circuits, the components are placed in parallel with each other due to which the circuit splits the current flow. The current flowing from the source will be divided into the current flowing through each of these components.

Difference Between Series and Parallel Circuits	
Series	**Parallel**
The same amount of current flows through all the components	The current flowing through each component combines to form the current flow through the source.
In an electrical circuit, components are arranged in a line	In an electrical circuit, components are arranged parallel to each other
When resistors are put in a series circuit, the voltage across each resistor is different even though the current flow is the same through all of them.	When resistors are put in a parallel circuit, the voltage across each of the resistors is the same. Even the polarities are the same
If one component breaks down, the whole circuit will burn out.	Other components will function even if one component breaks down, each has its own independent circuit
If V_t is the total voltage then it is equal to $V_1 + V_2 + V_3$	If V_t is the total voltage then it is equal to $V_1=V_2=V_3$

Frequently Asked Questions – FAQs

Q1 **In which type of circuit connection, the same amount of current flows through all the components?**

Series Connection.

Q2 **What are the two types of circuit connections?**

The two types of circuit connections are:

- Series connection
- Parallel connection

Q3 **What is a parallel circuit?**

A circuit is said to be parallel when the electric current has multiple paths to flow through.

Q4 **How is the total resistance of any series circuit calculated?**

Total resistance in a series circuit is equal to the sum of the individual resistances.

Q5 **What is the total resistance of a circuit, which has 2kΩ, 3kΩ and 4kΩ resistance connected in series with each other?**

Total Resistance(R) = $2k\Omega + 3k\Omega + 4k\Omega = 9k\Omega$

Diode as a Rectifier: Half Wave Rectifier and Full Wave Rectifier

The main application of p-n junction diode is in rectification circuits. These circuits are used to describe the conversion of a.c signals to d.c in power supplies. Diode rectifier gives an alternating voltage which pulsates in accordance with time. The filter smoothes the pulsation in the voltage and to produce d.c voltage, a regulator is used which removes the ripples.

There are two primary methods of diode rectification:

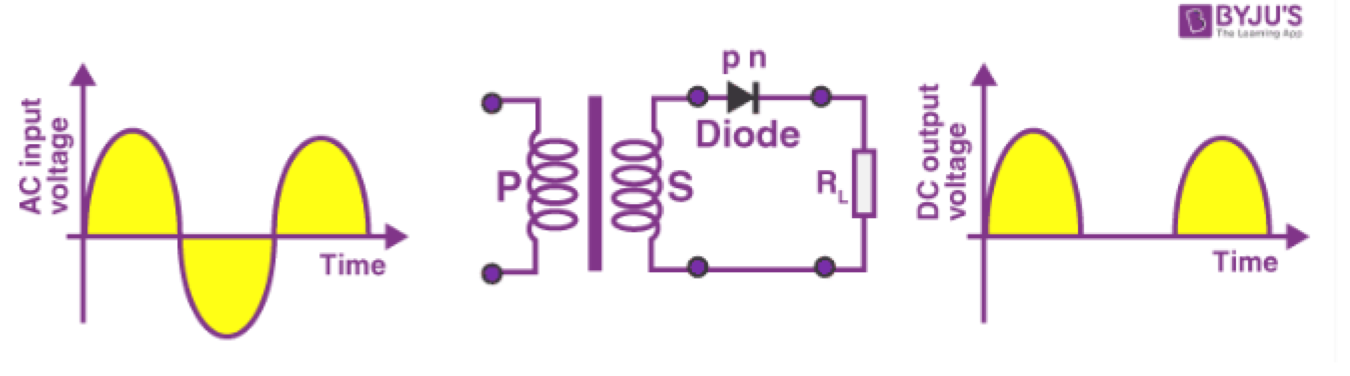
- Half Wave Rectifier
- Full Wave Rectifier

What Is Half Wave Rectifier?

In a half-wave rectifier, one half of each a.c input cycle is rectified. When the p-n junction diode is forward biased, it gives little resistance and when it is reversed biased it provides high resistance. During one-half cycles, the diode is forward biased when the input voltage is applied and in the opposite half cycle, it is reverse biased. During alternate half-cycles, the optimum result can be obtained.

Working of Half Wave Rectifier

The half-wave rectifier has both positive and negative cycles. During the positive half of the input, the current will flow from positive to negative which will generate only a positive half cycle of the a.c supply. When a.c supply is applied to the transformer, the voltage will be decreasing at the secondary winding of the diode. All the variations in the a.c supply will reduce, and we will get the pulsating d.c voltage to the load resistor.



In the second half cycle, the current will flow from negative to positive and the diode will be reverse biased. Thus, at the output side, there will be no current generated, and we cannot get power at the load resistance. A small amount of reverse current will flow during reverse bias due to minority carriers.

Read More: Half-wave Rectifier

Characteristics of Half Wave Rectifier

Following are the characteristics of half-wave rectifier:

Ripple Factor

Ripples are the oscillations that are obtained in DC which are corrected by using filters such as inductors and capacitors. These ripples are measured with the help of the ripple factor and are denoted by γ. Ripple factor tells us the number of ripples presents in the output DC. Higher the ripple factor, more is the oscillation at the output DC and lower is the ripple factor, less is the oscillation at the output DC.

Ripple factor is the ratio of RMS value of the AC component of the output voltage to the DC component of the output voltage.

$$\gamma = \sqrt{(\frac{V_{rms}}{V_{DC}})^2 - 1}$$

DC Current

DC current is given as:

$$I_{DC} = \frac{I_{max}}{\pi}$$

Where,

- I_{max} is the maximum DC load current

DC Output Voltage

The output DC voltage appears at the load resistor R_L which is obtained by multiplying output DC voltage with the load resistor R_L. The output DC voltage is given as:

$$V_{DC} = \frac{V_{Smax}}{\pi}$$

Where,

- V_{Smax} is the maximum secondary voltage

Form Factor

The form factor is the ratio of RMS value to the DC value. ***For a half-wave rectifier, the form factor is 1.57.***

Rectifier Efficiency

Rectifier efficiency is the ratio of output DC power to the input AC power. ***For a half-wave rectifier, rectifier efficiency is 40.6%.***

Advantages of Half Wave Rectifier

- Affordable
- Simple connections
- Easy to use as the connections are simple
- Number of components used are less

Disadvantages of Half Wave Rectifier

- Ripple production is more
- Harmonics are generated
- Utilization of the transformer is very low
- The efficiency of rectification is low

Applications of Half Wave Rectifier

Following are the uses of half-wave rectification:

- **Power rectification:** Half wave rectifier is used along with a transformer for power rectification as powering equipment.
- **Signal demodulation:** Half wave rectifiers are used for demodulating the AM signals.
- **Signal peak detector:** Half wave rectifier is used for detecting the peak of the incoming waveform.

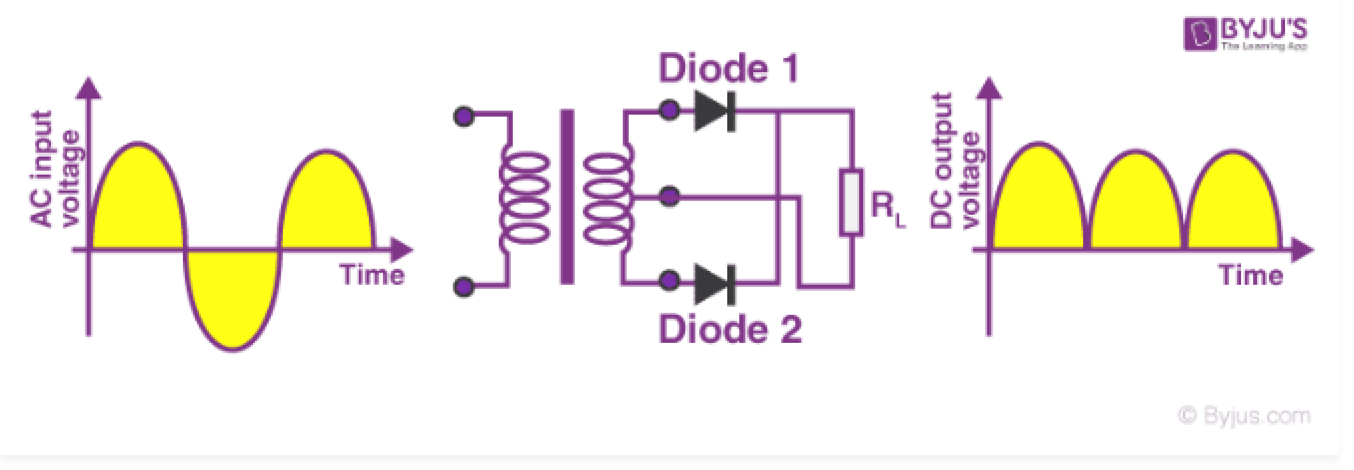
What Is Full Wave Rectifier?

Full-wave rectifier circuits are used for producing an output voltage or output current which is purely DC. The main advantage of a full-wave rectifier over half-wave rectifier is that such as the average output voltage is higher in full-wave rectifier, there is less ripple produced in full-wave rectifier when compared to the half-wave rectifier.

Read More: Full-wave Rectifier

Working of Full Wave Rectifier

The full-wave rectifier utilizes both halves of each a.c input. When the p-n junction is forward biased, the diode offers low resistance and when it is reverse biased it gives high resistance. The circuit is designed in such a manner that in the first half cycle if the diode is forward biased then in the second half cycle it is reverse biased and so on.



Characteristics of Full Wave Rectifier

Following are the characteristics of full-wave rectifier:

Ripple Factor

Ripple factor for a full-wave rectifier is given as:

$$\gamma = \sqrt{(\frac{V_{rms}}{V_{DC}})^2 - 1}$$

DC Current

Currents from both the diodes D_1 and D_2 are in the same direction when they flow towards load resistor R_L. The current produced by both the diodes is the ratio of I_{max} to π, therefore the DC current is given as:

$$I_{DC} = \frac{2I_{max}}{\pi}$$

Where,

- I_{max} is the maximum DC load current

DC Output Voltage

DC output voltage is obtained at the load resistor R_L and is given as:

$$V_{DC} = \frac{2V_{max}}{\pi}$$

Where,

- V_{max} is the maximum secondary voltage

Form Factor

The form factor is the ratio of RMS value of current to the output DC voltage. The form ***factor of a full-wave rectifier is given as 1.11***

Rectifier Efficiency

Rectifier efficiency is used as a parameter to determine the efficiency of the rectifier to convert AC into DC. It is the ratio of DC output power to the AC input power. The rectifier ***efficiency of a full-wave rectifier is 81.2%.***

Types of Full Wave Rectifier

There are two main types of full-wave rectifiers, and they are:

- **Two diodes full-wave rectifier circuit** (requires a center-tapped transformer and is used in vacuum tubes)
- **Bridge rectifier circuit** (doesn't require a centre-tapped transformer and is used along with transformers for efficient usage)

Advantages of Full Wave Rectifier

- The rectifier efficiency of a full-wave rectifier is high
- The power loss is very low
- Number of ripples generated are less

Disadvantages of Full Wave Rectifier

- Very expensive

Applications of Full Wave Rectifier

Following are the uses of full-wave rectifier:

- Full-wave rectifiers are used for supplying polarized voltage in welding and for this bridge rectifiers are used.
- Full-wave rectifiers are used for detecting the amplitude of modulated radio signals.

Difference between Half Wave Rectifier and Full Wave Rectifier

Parameter	Half Wave Rectifier	Full Wave Rectifier
Definition	The half-wave rectifier is a rectifier which is used for converting the one-half cycle of AC input to DC output	A full-wave rectifier is a rectifier which is used for converting both the half cycles of AC input into DC output
No. of diodes used	1	2 or 4 depending on the type of circuit
Form factor	1.57	1.11
Rectifier efficiency	40.6%	81.2%
Ripple factor	Ripple factor of a half-wave rectifier is more	Ripple factor of a full-wave rectifier is less

Frequently Asked Questions – FAQs

Q1 **Why half-wave rectifiers are not used in dc power supply?**

Half-wave rectifiers are not used in dc power supply because the supply provided by the half-wave rectifier is not satisfactory.

Q2 **What is PIV of a diode in a rectifier circuit?**

PIV stands for peak inverse voltage and it is the maximum voltage that is possible to occur across the diode when it is operated in reverse biased.

Q3 **What is a ripple in a rectifier circuit?**

Ripple is defined as the ac component that has a pulsating output in a rectifier.

Q4 **What are the advantages of a bridge rectifier over a center-tapped full-wave rectifier?**

Following are the three advantages of bridge rectifier over a center-tapped full-wave rectifier:

- The TUF of a bridge rectifier is 81.2% while the TUF of a center-tapped is 67.2%.
- The output of the bridge rectifier is twice that of the center-tapped full-wave rectifier.
- A bridge rectifier as a PIV half of the center-tapped full-wave rectifier.

Q5 **What is the cycle followed by the current in a full-wave rectifier?**

In a full-wave rectifier, the current flows in the half cycle of the input signal.

Q6 **What happens to the peak current if the value of the shunt capacitor filter is increased?**

When the value of the shunt capacitor filter is increased, the peak current will also increase in a rectifying diode.

Q7 **Why bridge rectifier is preferred over an ordinary two diodes full-wave rectifier?**

A bridge rectifier is preferred over an ordinary two diodes full-wave rectifier because:

- The PIV is less per diode
- There is no need for the centre tap
- The transformer required is smaller with the same output