INTRINSIC SEMICONDUCTOR:

An intrinsic semiconductor is a pure semiconductor material that has no impurities added to it. It has an equal number of electrons and holes, making it electrically neutral. Examples of intrinsic semiconductors include pure **silicon (Si)** and **germanium (Ge).** Intrinsic semiconductors behave like insulators at absolute zero temperature since no free-charge carriers exist. As the temperature increases, some electrons gain enough thermal energy to jump from the valence band to the conduction band, creating electron-hole pairs. This process increases conductivity.

EXTRINSIC SEMICONDUCTOR:

An extrinsic semiconductor is a semiconductor material that has been intentionally doped with specific impurities to improve its electrical conductivity. Unlike intrinsic semiconductors, extrinsic semiconductors have an unequal number of electrons and holes, making them more conductive and suitable for practical applications in electronic devices.

Comparison: Intrinsic vs. Extrinsic Semiconductors

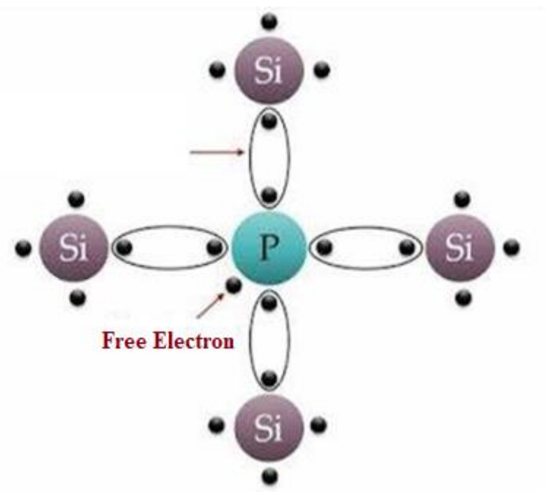
PROPERTY	Intrinsic Semiconductors	Extrinsic Semiconductors
Composition	Pure conductor material	Dopped with impurities
Conductivity	Low	High (due to added charge carriers)
Charge Carriers	Equal number of electrons and holes	Majority and minority carriers depend on doping
Examples	Pure silicon and germanium	n-type (Si + P), P-type (Si + B)

PRODUCTION OF P-TYPE AND N-TYPE SEMICONDUCTORS:

P-type and N-type semiconductors are produced through a process called doping, where a small amount of impurity is intentionally added to a pure semiconductor (e.g., silicon or germanium) to enhance its electrical conductivity.

1. n-Type Semiconductor:

An n-type semiconductor is an extrinsic semiconductor doped with a material to increase the number of free electrons, which serve as the primary charge carriers. The "n" in n-type refers to the negative charge of the electrons.

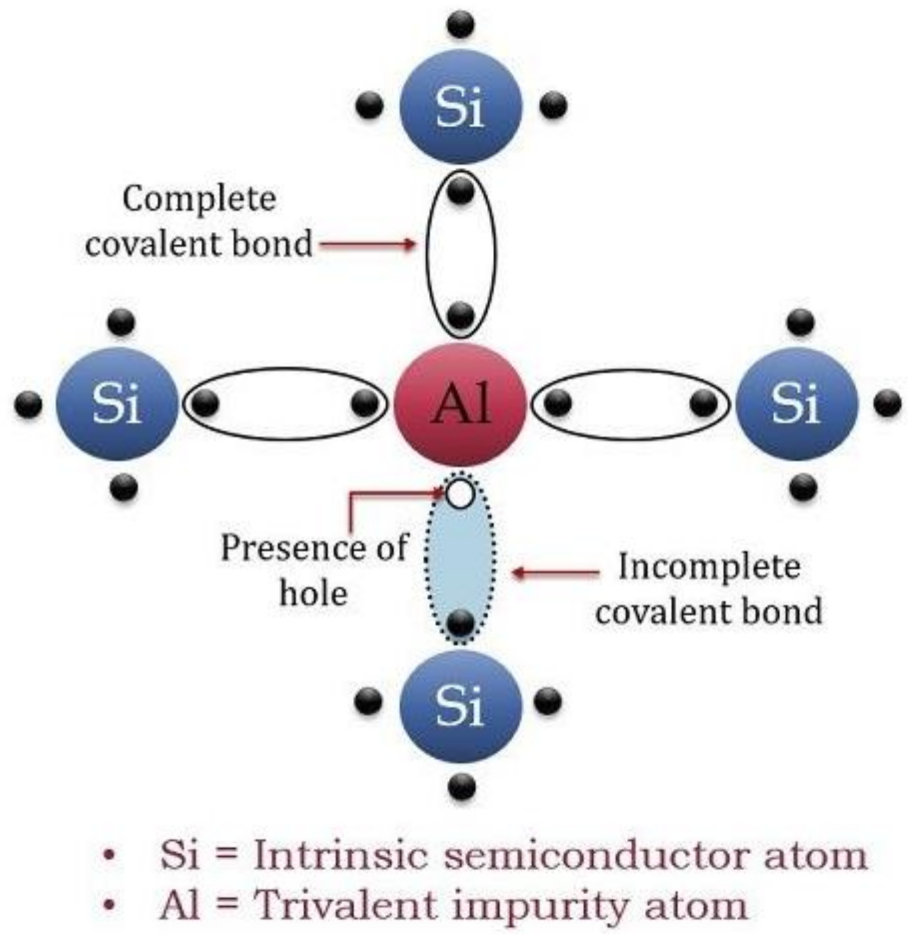


Silicon (Si) or Germanium (Ge) is commonly used as the base material because they have four valence electrons. A small amount of a pentavalent impurity (an element with five valence electrons), such as phosphorus (P), arsenic (As), or

Antimony (Sb) is added to the base material. The pentavalent impurity contributes an extra electron, which becomes free to move through the crystal lattice.

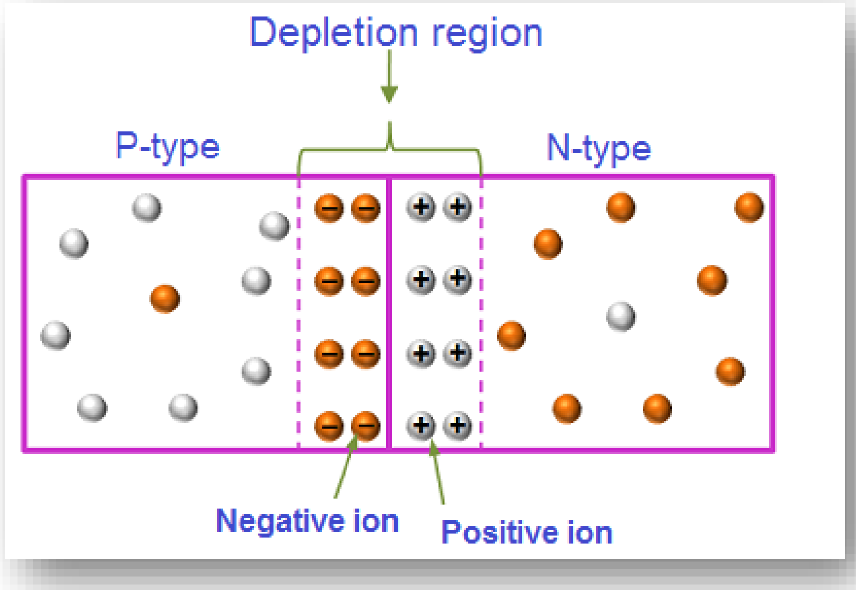
2. p-Type Semiconductor:

A p-type semiconductor is another type of extrinsic semiconductor that is doped to create an abundance of holes, which act as the primary charge carriers. The "p" in p-type refers to the positive charge of the holes.



Silicon (Si) or Germanium (Ge) is used as the base material due to its four valence electrons. A small amount of a trivalent impurity (an element with three valence electrons), such as boron (B), aluminum (Al), or gallium (Ga) is added to the base material. The trivalent impurity creates a deficiency of one electron (a "hole") in the crystal lattice, allowing it to accept electrons from neighboring atoms.

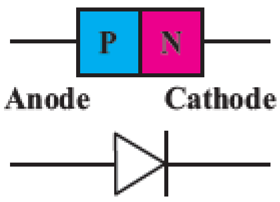
P-N junction:



The P-N junction combines p-type and n-type semiconductors within a single crystal. It serves as a fundamental component in electronics and is the basis for devices such as diodes and transistors.

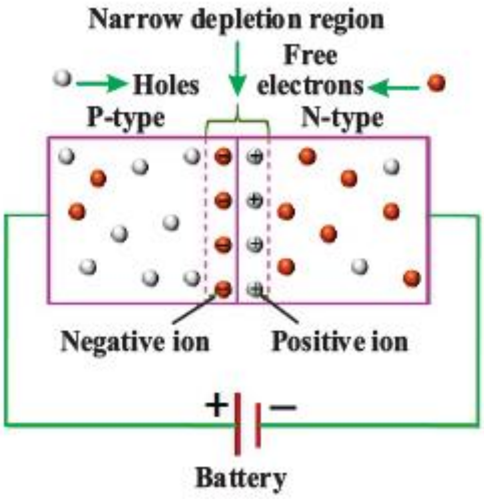
Initially, a high carrier density across the junction causes electrons to migrate from the N-type region to the P-type region, leaving behind negative ions. Simultaneously, holes move from the P-type region to the N-type region, forming positive ions. This process, known as diffusion, continues until equilibrium is reached. At this point, a depletion layer forms around the junction, which is devoid of free charge carriers. The resulting potential barrier prevents further movement of carriers across the junction.

PN JUNCTION DIODE:



A PN junction diode is a semiconductor device formed by joining a p-type and an n-type material. It allows current to flow in one direction while blocking it in the opposite direction, making it a key component in electronics for rectification and signal control.

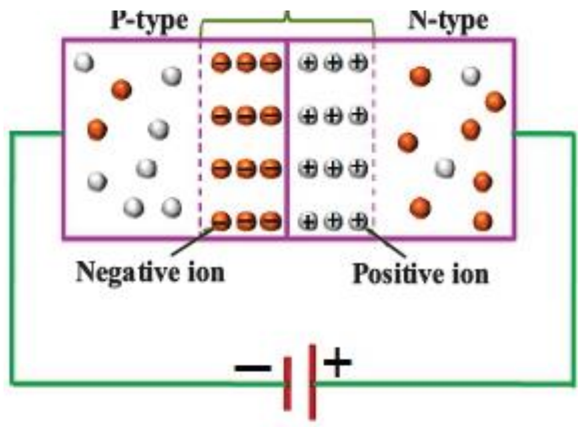
FORWARD-BIASED PN JUNCTION DIODE:



In forward bias, the P-type is connected to the positive terminal of the battery and the N-type to the negative terminal. The applied electric field opposes the built-in electric field at the P-N junction, resulting in a reduced net electric field. This causes the depletion region to thin and its resistance to decrease. When the applied voltage reaches 0.3V to 0.6V in silicon, the depletion region's resistance becomes negligible, allowing current to flow freely through the diode.

REVERSE-BIASED PN JUNCTION DIODE:

In reverse-biased, the positive terminal of the battery is connected to the n-type region, and the negative terminal is connected to the p-type region. This configuration increases the potential barrier at the junction, preventing the flow of current (except for a small leakage current).

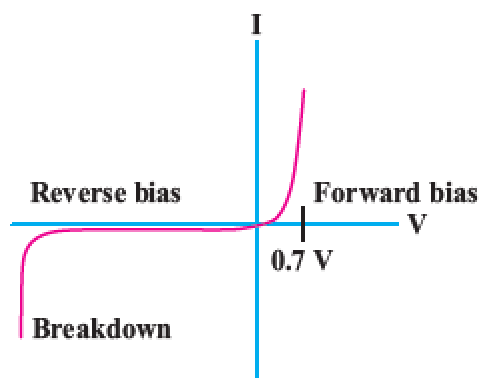


(V - I) Characteristics of a P-N junction diode:

The V-I characteristics of a **P-N** junction diode describe the relationship between the voltage across the junction and the current through it. These characteristics can be explained under three conditions:

i) Zero Bias (Unbiased): No external voltage is applied, so no current flows through the diode.

ii) Forward Bias: When the external voltage is applied in the forward direction, current begins to flow once the diode voltage reaches the threshold voltage (0.7 V for silicon, 0.3 V for germanium). Initially, the current increases non-linearly, but after surpassing the potential barrier, the curve steepens linearly with increasing voltage.



iii) Reverse Bias: A small leakage current flows due to minority carriers. This current remains low until the breakdown voltage is reached, at which point, a large current flows that can damage the diode unless a series resistance limits it.

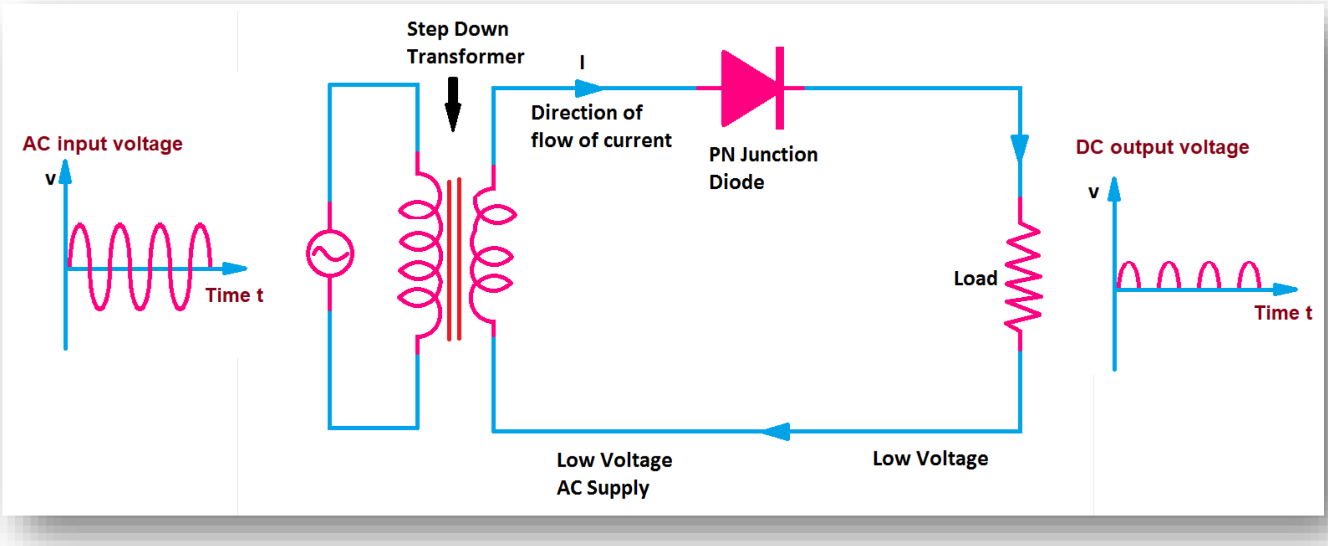
These behaviors are typically illustrated in V-I characteristic curves for P-N junction diodes.

RECTIFICATION:

Rectification is the process of converting alternating current (AC) into direct current (DC) using a device called a rectifier. This process is essential for powering most electronic devices, as they require a steady DC voltage to operate. Rectification is achieved using diodes, which allow current to flow only in one direction.

HALF-WAVE RECTIFICATION:

Half-wave rectification is a process where a diode allows only the positive half of an alternating current (AC) signal to pass through, blocking the negative half. During the positive cycle, the diode is forward-biased and conducts current, producing an output across the resistor R. During the negative cycle, the diode is reverse-biased, blocking current flow, resulting in no output. This produces a unidirectional, pulsating DC voltage across the load.



Applications of Half-Wave Rectification:

1. **Power Supply Circuits:** Converts AC into DC to power low-current devices.
2. **Signal Demodulation:** Extracts audio or information signals from modulated carrier waves in communication systems.
3. **Battery Charging:** Charges batteries in simple and low-power applications.
4. **Signal Filtering:** Acts as the first step in smoothing AC signals for further processing.

FULL-WAVE RECTIFICATION:

In full-wave rectification using two diodes, the circuit operates as follows:

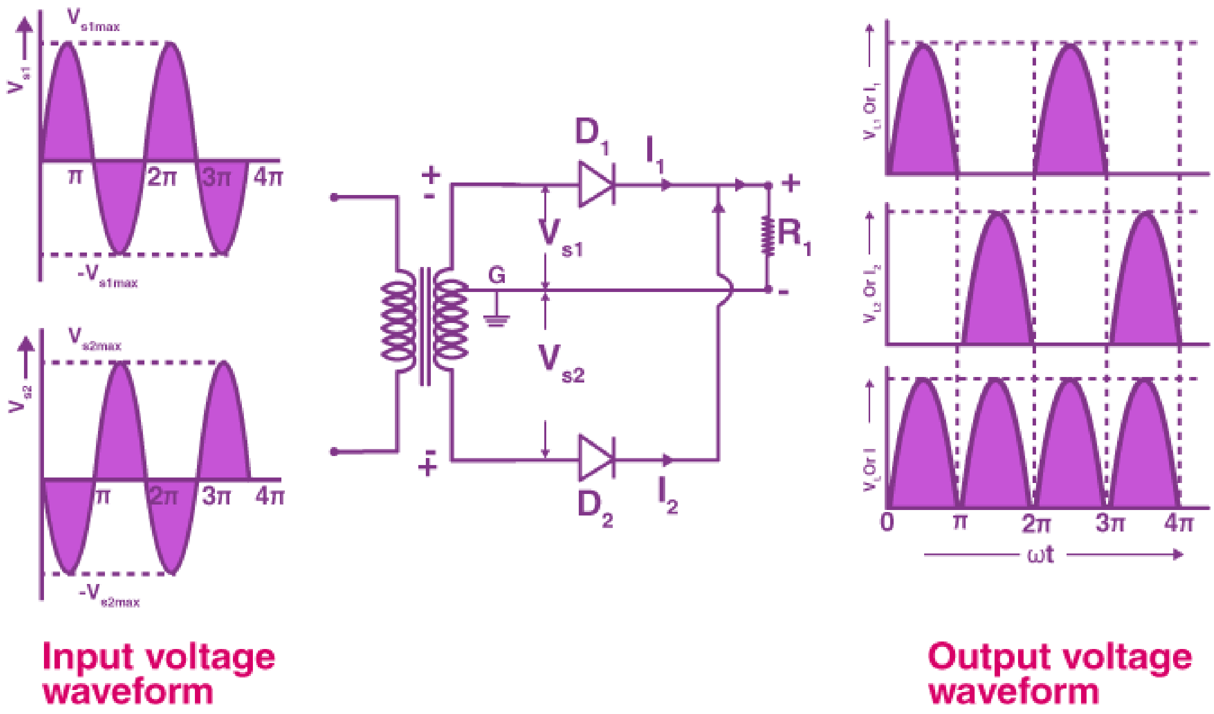
Positive Half Cycle:

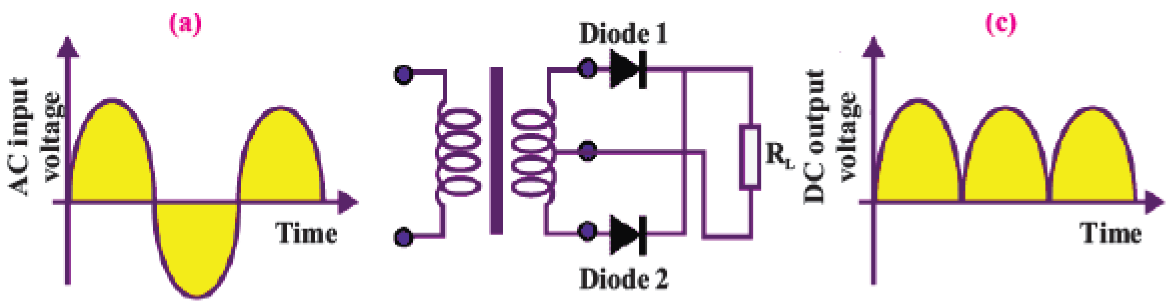
During the positive half of the input AC signal, diode D_1 becomes forward-biased and conducts, acting as a closed switch, while diode D_2 is reverse-biased and blocks current. The current flows through D_1, the load resistor R, and the upper half of the transformer's secondary winding.

Negative Half Cycle:

During the negative half of the AC signal, diode D_2 becomes forward-biased and conducts, while D_1 is reverse-biased and blocks current. The current flows through D_2, the load resistor R, and the lower half of the secondary winding.

In both cases, the current through the load resistor R flows in the same direction, producing a continuous unidirectional output.





Applications of Full-Wave Rectification:

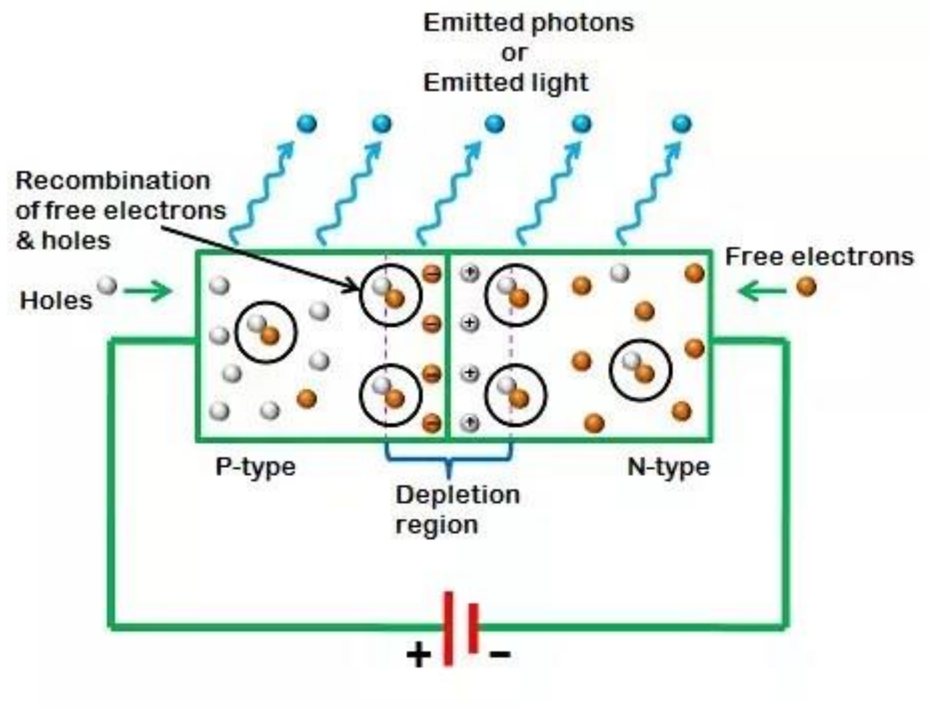
1. **DC Power Supplies**: Used in devices requiring a steady DC voltage.
2. **Battery Charging:** Provides efficient and continuous charging for batteries.
3. **Radio Communication:** Converts AC signals to DC for better signal processing.
4. **Welding Equipment:** Provides the high-power DC needed for welding applications.

LED (Light Emitting Diode):

An LED is a semiconductor device that emits light when an electric current flows through it. It is a type of diode that allows current to flow in only one direction, and as the current passes, it produces light as a result of electroluminescence.

WORKING:

LEDs are made from a semiconductor material, typically a combination of gallium, arsenic, or phosphide, designed to emit light of a specific wavelength (color). When a voltage is applied in the forward direction (positive to the anode and negative to the cathode), electrons from the n-type region and holes from the p-type region combine at the junction.



Light Emitting Diode (LED)

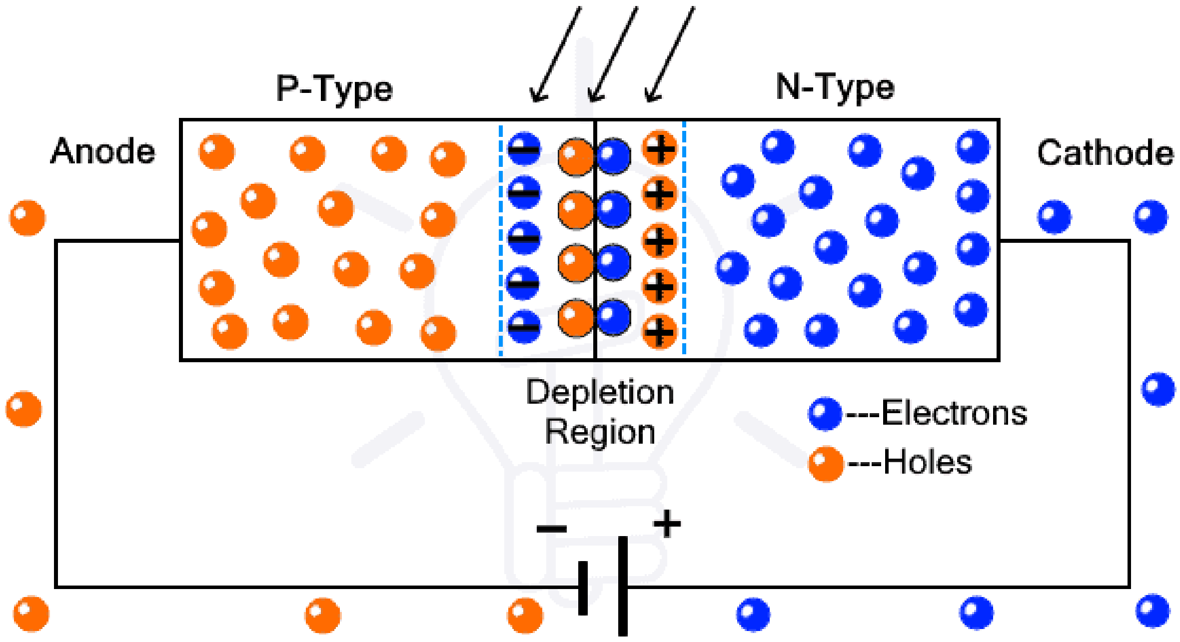
This combination of electrons and holes releases energy in the form of photons (light). The wavelength (and color) of the light depends on the semiconductor material used.

PHOTODIODE:

A photodiode is a type of light detector that converts light into current or voltage. It includes optical filters, built-in lenses, and surface areas. Photodiodes are often used in reverse bias, where a voltage encourages the flow of photocurrent, maximizing sensitivity. Photodiodes are usually made of semiconductor materials like silicon, which can absorb photons of light.

WORKING:

When light particles (photons) hit the semiconductor material, they transfer energy to electrons, creating electron-hole pairs. This process generates an electric current proportional to the incident light's intensity. In simple terms, brighter light results in a higher current from the photodiode.



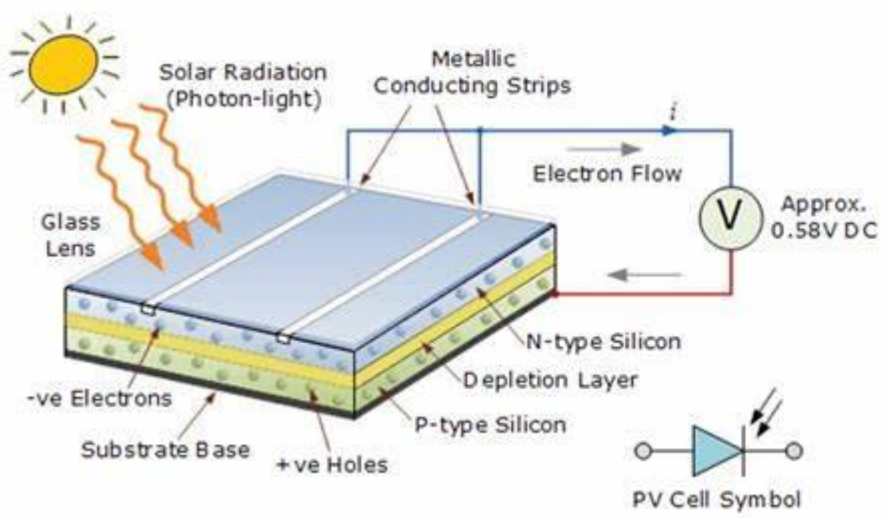
Photodiode Working

Photodiodes play a crucial role in various applications:

- **Optical Communication:** Used in fiber optics to detect and convert light signals into electrical signals.
- **Light Sensors:** Found in cameras, light meters, and automatic lighting systems to measure ambient light levels.
- **Barcode Readers:** Detect reflected light from barcodes for scanning.
- **Medical Devices:** Utilized in instruments to measure oxygen levels in blood and other tasks.

PHOTOVOLTAIC CELL:

A photovoltaic cell, commonly known as a solar cell, is a device that converts sunlight directly into electrical energy using the photovoltaic effect.



Construction of a solar cell

WORKING:

A photovoltaic cell (solar cell) converts sunlight into electricity using the photovoltaic effect. When photons with energy greater than the band gap hit the semiconductor (usually silicon), electron-hole pairs are created. The excited electrons generate a current when connected to an external circuit, acting as a source of power. A silicon P-N junction produces about 0.6 V; multiple cells are connected in series and parallel in a solar panel to increase output. A quality solar panel generates about 50 W/m² on average, considering day and night and weather conditions.

Uses of Photodiodes:

- **Cameras:** Light meters, automatic shutter control, flash control.
- **Medical Devices:** CAT scanners, X-ray detection, pulse oximeters, blood analysis.
- **Automotive:** Headlight dimmers, twilight detectors.
- **Communication:** Fiber optic links, optical remote controls.
- **Industry:** Barcode scanners, light pens, encoders, surveying instruments, copier toner analysis.

TRANSISTOR:

A transistor is a semiconductor device used to amplify or switch electronic signals and power by controlling current flow between its three layers.

Transistors have three terminals:

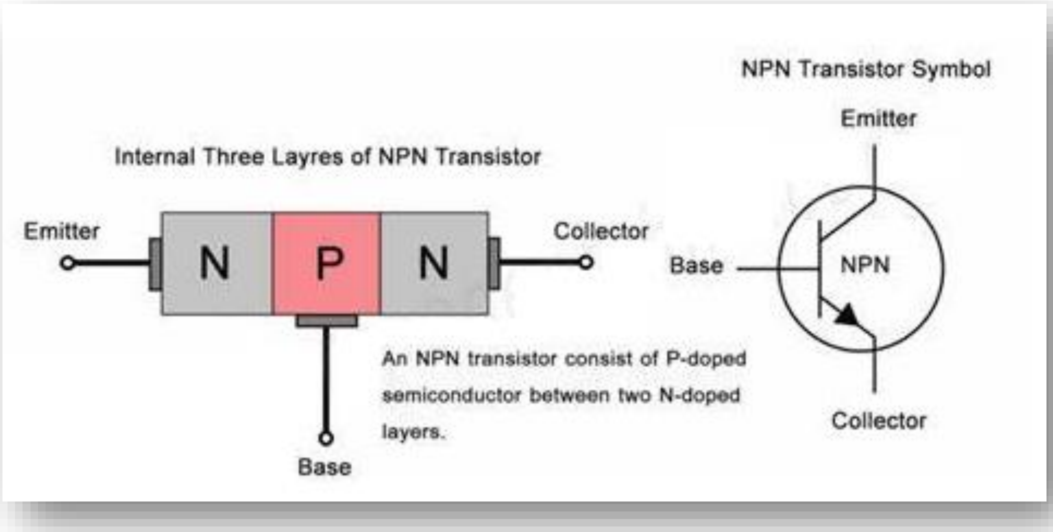
1. **Emitter (E):** Heavily doped; Emits charge carriers.
2. **Base (B):** Thin and lightly doped; Controls the flow of charge carriers.
3. **Collector (C):** Moderately doped; Collects charge carriers.

BIPOLAR JUNCTION TRANSISTOR (BJT)

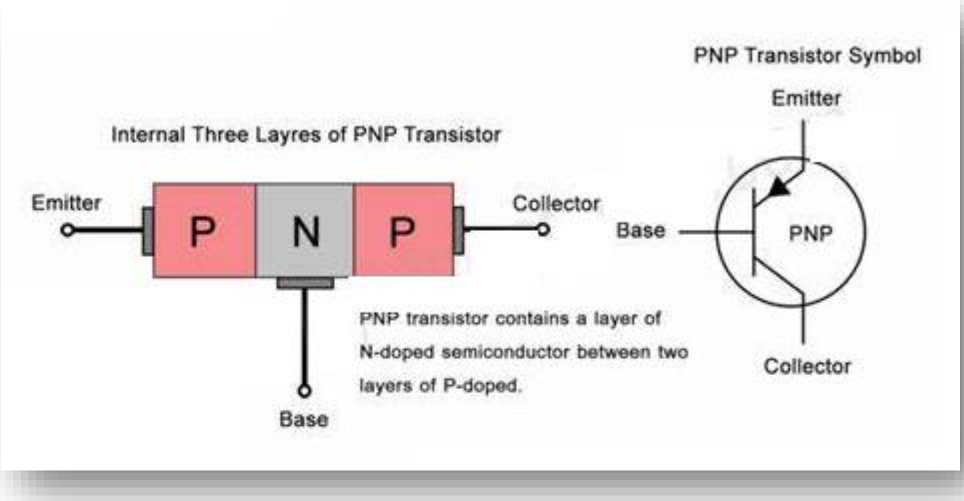
A Bipolar Junction Transistor (BJT) is a type of transistor that uses both electrons and holes (bipolar charge carriers) to conduct current. It is widely used in amplification and switching applications.

There are two types of BJTs:

NPN: Two layers of n-type material sandwich a layer of p-type material. Current flows when a positive voltage is applied to the base relative to the emitter.



PNP: Two layers of p-type material sandwich a layer of n-type material. Current flows when a negative voltage is applied to the base relative to the emitter.



DISTINGUISH BETWEEN NPN AND PNP

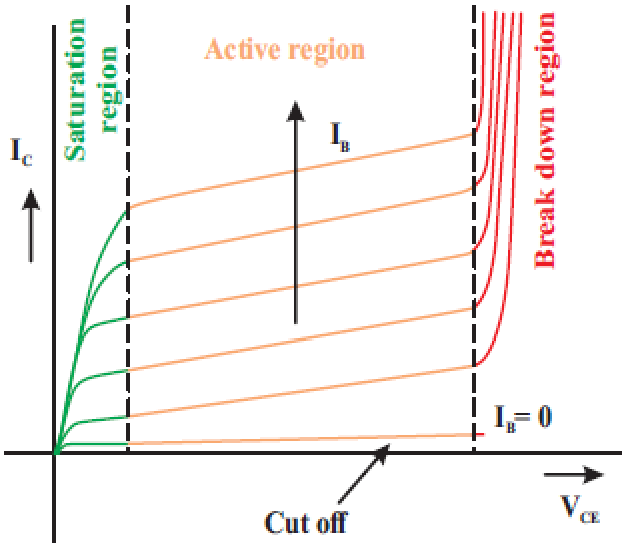
N-P-N	*P-N-P*
It contains two N-type semiconductors.	It contains two P-type semiconductors.
Its current is directed outwardly.	Its current is directed inwardly.
In this transistor combination, electrons are majority current carriers.	In this transistor combination, holes are majority current carriers.
Its current direction is emitter to base.	Its current direction is base to emitter.
It has holes as minority current carriers.	It has electrons as minority carriers.
It's switched on when electrons enter the base.	It's switched on when holes enter the base.
As current reduces at base, transistor does not function across the collector terminal and switches off.	When current is available at base, then transistor switches off.

OPERATION OF TRANSISTORS:

Biasing:

Base-Emitter Junction: Forward-bias (small voltage applied to allow current flow).

Collector-Base Junction: Reverse-bias (higher voltage to attract the flow of charge carriers).



WORKING:

A small input current at the Base controls a much larger current between the Collector and Emitter.

In an NPN transistor, electrons move from the Emitter to the Collector, while in a PNP transistor, holes move in the opposite direction.

MODES OF OPERATION:

Cutoff Region: No current flows (transistor OFF).

Active Region: The transistor amplifies the input signal.

Saturation Region: Maximum current flows through the transistor (transistor ON).

CURRENTS IN A TRANSISTOR:

Base Current (I_B): The base current is a small current flowing into the base terminal of the transistor. It is responsible for controlling the larger current flow between the collector and the emitter. The base current is typically very small compared to the collector current since the base-emitter junction is forward-biased.

Collector Current (I_C): The collector current is the large current flowing from the collector to the emitter in an NPN transistor (or from the emitter to the collector in a PNP transistor). It is controlled by the base current and depends on the transistor's current gain. The collector current is almost equal to the emitter current ($I_C \approx I_E$), as the base current is very small.

Emitter Current (I_E): The emitter current is the total current flowing out of (or into) the emitter terminal. It is the sum of the base current and the collector current:

$$I_E = I_B + I_C$$

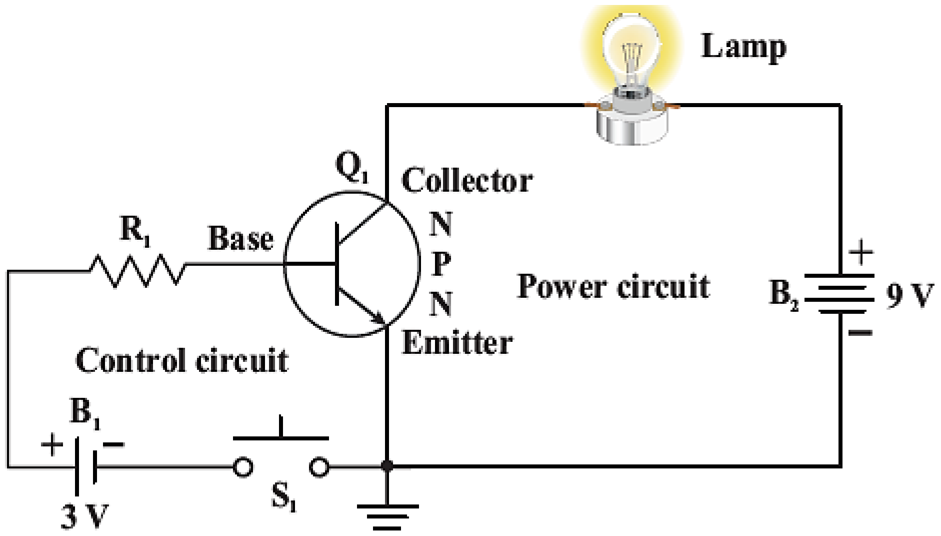
$$I_E = (1 + \beta)I_B$$

Current Gain (β): Current gain (β) is the ratio of the collector current to the base current in the transistor. It shows how much the base current amplifies the collector current.

$$\beta = \frac{I_C}{I_B}$$

TRANSISTOR AS A SWITCH:

A transistor operates as an electronic switch in digital and power circuits to control the flow of current. It switches between **ON** and **OFF** states, enabling or disabling the flow of current through a connected load.



1. OFF State (No Current Flow)

- In its OFF state, the transistor does not allow any current to flow through the power circuit, unless a forward voltage is applied to its base-emitter junction.
- When the transistor is in the OFF state, there is high resistance between the emitter and collector, meaning no current flows through the load, and the lamp remains off.

2. ON State (Current Flow)

- The forward voltage applied to the base of the transistor controls the flow of output current.
- The input control circuit determines the base current, and the collector current is the output current that flows through the power circuit.
- In this example, Q_1 is an NPN transistor, which requires a positive VBE (base-emitter voltage) to become forward-biased and conduct.
- The common-emitter (CE) circuit configuration is commonly used, where the emitter is connected to both the input control and power circuits.

Operation of Q_1 Transistor:

When switch S_1 is open:

i) No current flows into the base-emitter circuit because no forward voltage is applied.

ii) The transistor's resistance between the emitter and collector remains very high.

iii) No current flows through the power circuit, and the lamp stays off.

When switch S_1 is closed:

i) A small current flows through the base circuit.

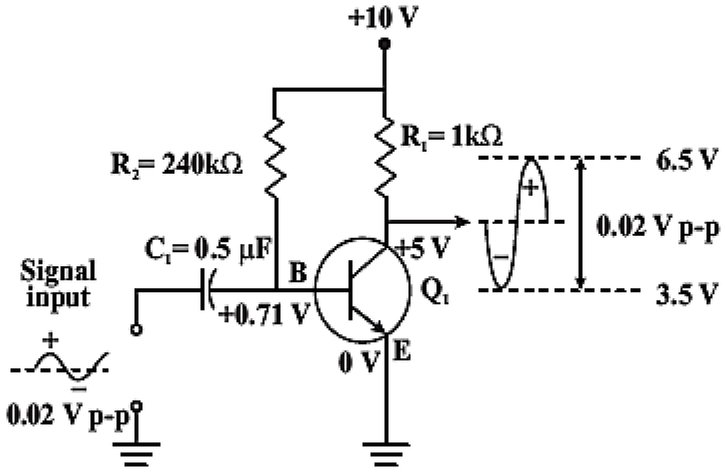
ii) R_1 limits the current to the base.

iii) The resistance between the emitter and collector decreases, allowing a large current to flow through the power circuit.

iv) This current flows through the lamp, causing it to light up.

Opening the SI switch in the control circuit turns off the lamp in the power circuit because resistance from the emitter to the collector of Q increases again, almost to infinity.

TRANSISTOR AS AN AMPLIFIER:



In the given circuit, an NPN transistor is used as an amplifier. The DC operating voltages are set by the feedback resistor R_2, ensuring the transistor operates in a partially turned-on state. The collector-to-emitter voltage V_C is maintained at half the supply voltage (5V for a 10V supply), with a base voltage of 0.7V enabling proper forward biasing.

When an input signal of **0.02 V_{PP}** is applied through coupling capacitor **C_1**, the transistor amplifies it, producing an output signal of **3 V_{PP}** at the collector. The voltage gain (A_V) of the amplifier is calculated as:

$$A_V = \frac{V_{out}}{V_{in}}$$

$$A_V = \frac{3}{0.02} = 150$$

Thus, the output signal is **150 times greater** than the input signal, demonstrating a voltage gain of **150** for this amplifier stage.

The Common Emitter Amplifier Circuit:

The common emitter amplifier circuit is a widely used transistor configuration known for its substantial current gain. In this setup, the emitter current (I_E) is the sum of the collector current (I_C) and base current (I_B):

$$I_E = I_C + I_B$$

The current gain is represented by Beta (β), defined as the ratio of collector current to base current:

$$\beta = \frac{I_C}{I_B},$$

Another important parameter is Alpha (α), which represents the ratio of collector current to emitter current:

$$\alpha = \frac{I_C}{I_E}$$

The relationship between α and β is given by:

$\alpha = \frac{I_C}{I_E}$	$\beta = \frac{I_C}{I_B}$
$\alpha = \frac{I_C}{I_C + I_B}$	$\beta = \frac{I_C}{I_E - I_C}$
$\alpha = \frac{\beta\, I_B}{I_B\left(1 + \frac{I_C}{I_B}\right)}, \quad I_C = \beta\, I_B$	$\beta = \frac{\alpha I_E}{I_E\left(1 - \frac{I_C}{I_E}\right)}, \quad I_C = \alpha\, I_E$
$\alpha = \frac{\beta}{1 + \beta}$	$\beta = \frac{\alpha}{1 - \alpha}$

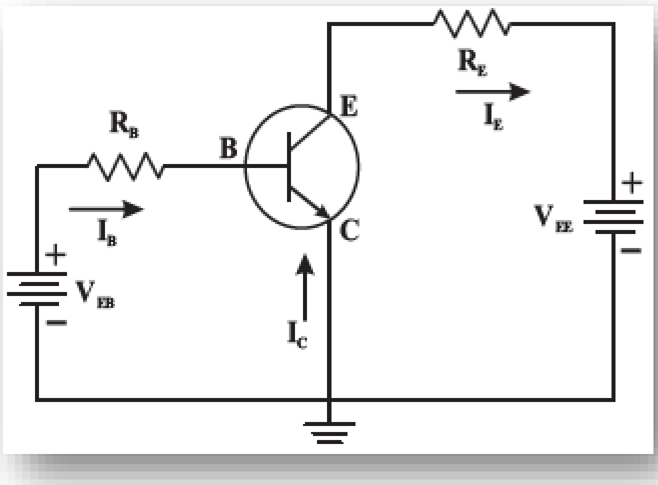
Since α is always less than one, a small change in I_B results in a significantly larger change in I_C, making the transistor an effective amplifier. The β value typically ranges between 20 and 200, meaning that for a transistor with β = 100, one electron from the base controls 100 electrons in the emitter-collector circuit.

The common emitter configuration offers higher input impedance, current gain, and power gain compared to the common base configuration, but it has a lower voltage gain. Additionally, this configuration acts as an inverting amplifier, meaning the output signal undergoes a 180° phase shift relative to the input.

Common collector circuit:

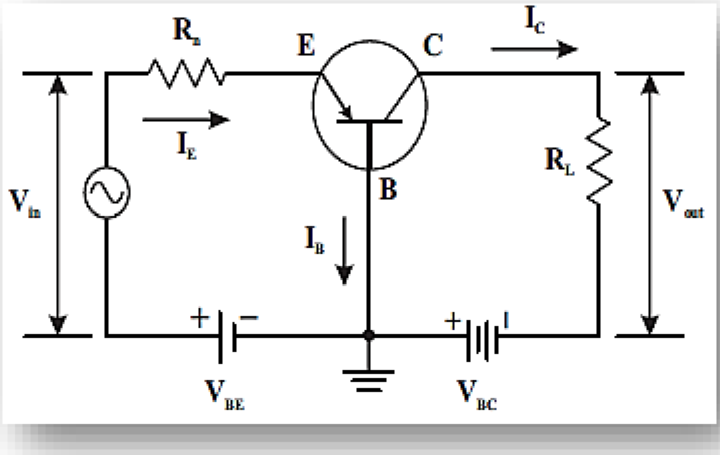
In a Common Collector (CC) configuration, the input signal is applied to the base, and the output signal is taken from the emitter, with the collector serving as the common terminal.

The given figure illustrates this setup. When the base-emitter junction is forward-bias, a small base current (IB) results in a significantly larger collector current (IC). Since the emitter current (IE) is the sum of the base and collector currents ($I_E = I_B + I_C$) and I_B is relatively small compared to I_C, the emitter current is approximately equal to the collector current.



Common Base (CB) Circuit:

In a Common Base (CB) configuration, the input and output signals share the base terminal of the transistor.



The given figure illustrates this setup. In this configuration, the input signal is applied to the emitter, while the output signal is taken from the collector. The base-emitter junction is forward-biased to enable transistor operation.

CB amplifiers are characterized by low input impedance and an approximately unity voltage gain. The current gain in a CB configuration is represented by **α**, which is defined as the ratio of the collector current (I_C) to the emitter current (I_E). Since the base current (I_B) is extremely small compared to the collector current, the emitter current is approximately equal to the collector current, expressed as:

$$I_E \approx I_C$$

Operational Amplifier (Op-Amp):

An Operational Amplifier (Op-Amp) is a high-gain, direct-coupled electronic voltage amplifier with differential inputs and a single-ended output. It is widely used in analog circuits for signal amplification, filtering, mathematical operations, and more.

Properties of an Ideal Operational Amplifier (Op-Amp):

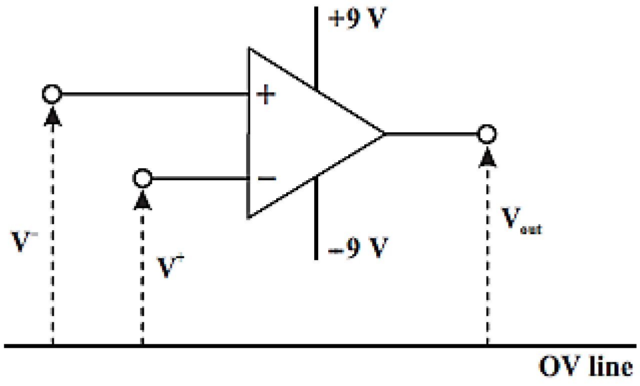
An ideal operational amplifier (op-amp) exhibits the following key characteristics:

1. **Infinite Gain:** The ideal op-amp provides infinite open-loop gain, ensuring maximum signal amplification.

2. **Infinite Input Impedance**: This prevents current draw from the input source, minimizing circuit loading and preserving the original signal.
3. **Zero Output Impedance:** Ensures maximum voltage transfer to the load without internal resistance affecting the output.
4. **Constant Gain Across Frequencies:** The gain remains stable and does not vary with the input signal's frequency.
5. **Infinite Bandwidth:** The op-amp amplifies signals of all frequencies equally, allowing for an ideal frequency response.
6. **Infinite Slew Rate:** The output instantly responds to changes in the input, eliminating any delay.
7. **No Internal Noise:** The ideal op-amp does not introduce any additional noise, though it still amplifies existing noise in the input signal.

Op-Amp as a Comparator:

An operational amplifier (op-amp) can function as a comparator by comparing two input voltages, V^+ (non-inverting input) and V^- (inverting input).



In the given setup, the op-amp is powered by two voltage sources: +9V and -9V. Although these power supplies are not shown in the circuit diagram, they provide the necessary operating range. The output voltage of the op-amp is determined by the equation:

$$V_{out} = G_o(V^+ - V^-)$$

where G_o represents the open-loop voltage gain.

For instance, if $G_o = 10^5$ and that $V^+ = 0.15V$ and $V^- = 0.10V$., then:

$$V_{out} = 10^5(0.15 - 0.10) = 5000\text{ V}$$

Since this output voltage exceeds the available power supply range, the op-amp saturates. In this case, because V^+ is greater than V^-, the output voltage will be approximately equal to the positive supply voltage (+9V).

The behavior of the comparator can be summarized as follows:

- If $V^+ > V^-$, the output voltage saturates at the positive supply voltage (+9V).
- If $V^+ > V^-$, the output voltage saturates at the negative supply voltage (-9V).

Thus, the op-amp acts as a comparator, determining which of the two input voltages is larger and producing a corresponding high or low output voltage.

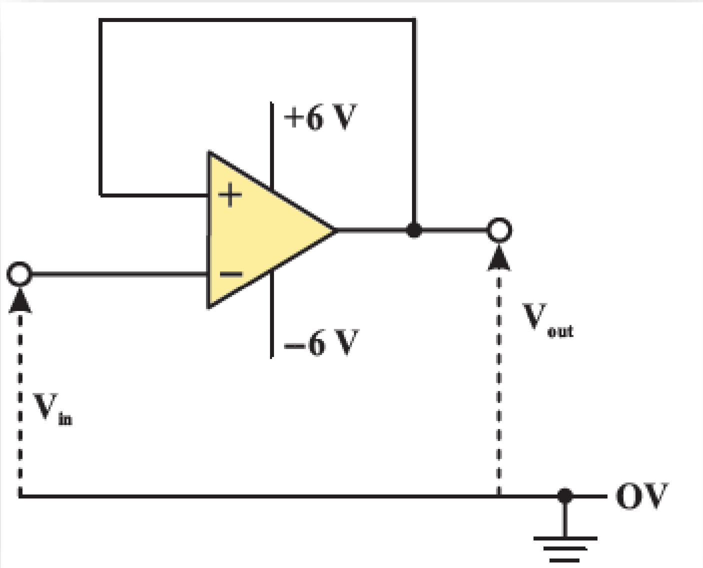
Negative Feedback:
Negative feedback occurs when a portion of the output signal, such as voltage or current, is fed back into the input in a manner that opposes or reduces the original input signal.

Advantages of Negative Feedback:

1. Reduced Gain: The overall gain of the system decreases.
2. Minimized Distortion and Noise: Negative feedback helps reduce distortion and noise, resulting in a cleaner output signal.
3. Enhanced Stability: The system’s gain becomes more stable and less sensitive to external factors like temperature variations.
4. Increased Bandwidth: It improves the system's bandwidth, allowing a wider frequency range.
5. Optimized Impedance: Negative feedback lowers the output impedance while increasing the input impedance, enhancing circuit performance.

Operation in Electronic Systems:

Feedback is unidirectional, flowing from output to input, ensuring the loop gain (G) remains independent of load and source impedances. A summing point at the input subtracts the feedback signal from the input signal, creating an error signal that drives the system. Example Circuit (Figure 2.28):



Setup:

Input V_{in} is connected to the non-inverting input (+) of an op-amp. The output V_{out} is fed back to the inverting input (-).

Operation:

With an infinite open-loop gain and no saturation, V^- equals V^+. As V_{in} changes, V_{out} adjusts to maintain, $V^- = V^+$.Equation $V_{out} = G_0 \times (V^+ - V^-)$: Simplified: Since $V_{out} = V^-$. and $V_{in} = V^+$. then we have

$$V_{out} = G_0 \times (V_{in} - V_{out})$$

$$V_{out} = G_0 V_{in} - G_0 V_{out}$$

$$V_{out} + G_0 V_{out} = G_0 V_{in}$$

$$V_{out} (1 + G_0) = G_0 V_{in}$$

$$\frac{V_{out}}{V_{in}} (1 + G_0) = G_0$$

$$\frac{V_{out}}{V_{in}} = \frac{G_0}{(1 + G_0)} \quad \ldots\ldots\ldots (i)$$

The closed-loop gain G is given by:

$$G = \frac{V_{out}}{V_{in}} \quad \ldots\ldots\ldots\ldots (ii)$$

Comparing equations (i) and (ii)

$$G = \frac{G_0}{(1 + G_0)} \ldots\ldots\ldots..(iii)$$

As G_0 is very high about 10^5, There is little difference between G_0 and $(1 + G_0)$, so the closed-loop gain is very nearly 1. This analysis is true as long as the output voltage is smaller than the supply voltage, in this case, as long as V_{out} is between -6V and +6V.

Practical Example:

A Piezo-electric microphone with high internal resistance can be connected to an op- amp to increase current output while maintaining the same voltage.

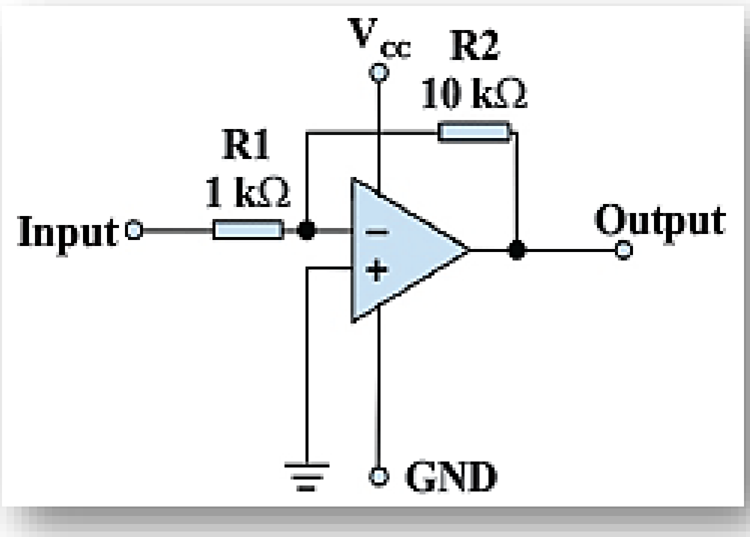
Negative Feedback Benefits Summary:

- Less distortion.
- Increased bandwidth.
- The gain is more stable and not affected by changes in temperature, etc.

The output resistance (impedance) can be low, and the input resistance high.

Inverting Operational Amplifier:

In an inverting operational amplifier configuration, the operational amplifier (op-amp) forces the voltage at the inverting terminal (-) to be equal to the voltage at the non-inverting terminal (+), which is typically grounded. As a result, the input current is determined by the ratio V_{IN}/R_1, as shown in the figure.



Since the op-amp has a high input impedance Z_{IN}, ideally, no current flows into the inverting terminal.

Instead, the same current that flows through R_1 continues through R_2 towards the output. The voltage drop across R_2 creates an inverted voltage polarity with respect to V_{IN}, which is why this configuration is known as an inverting amplifier.

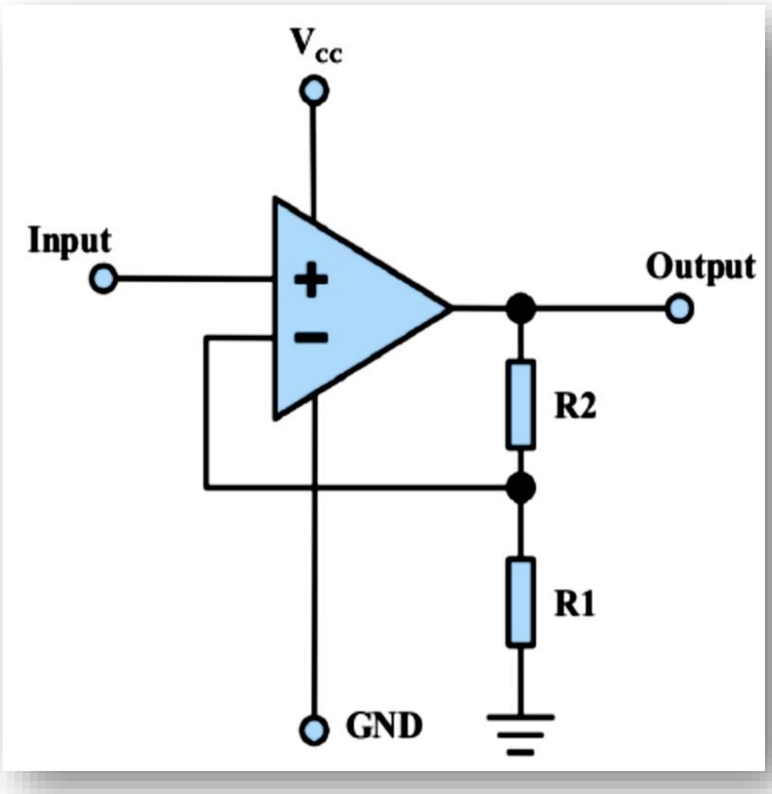
It is important to note that the op-amp's output can only swing within the range of its positive and negative supply voltages. Therefore, to generate a negative output voltage, the op-amp must be powered with a negative supply rail. The output voltage V_{OUT} of an inverting op-amp is given by the equation:

$$V_{out} = -\frac{R_2}{R_1} \times V_{in}$$

This equation shows that the output is an amplified and inverted version of the input signal, with the gain determined by the ratio of $\frac{R_2}{R_1}$.

Non-Inverting Operational Amplifier:

In a non-inverting amplifier circuit, the input signal is applied to the non-inverting terminal (+) of the operational amplifier, as shown in the figure. The op-amp forces the voltage at the inverting terminal (-) to be equal to the input voltage, which causes a current to flow through the feedback resistors.



Since the output voltage is always in phase with the input voltage, this configuration is called a non-inverting amplifier. Unlike the inverting configuration, the voltage gain in a non-inverting amplifier is always greater than 1.

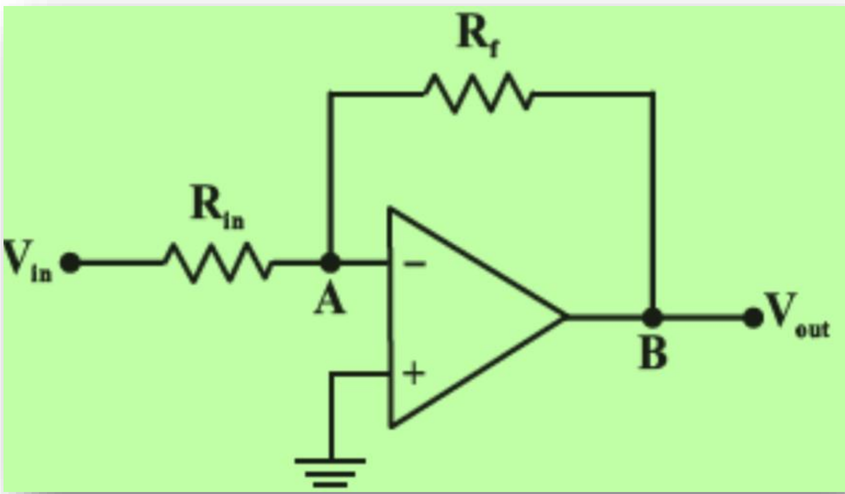
The output voltage V_{out} is given by the equation:

$$V_{out} = \frac{1 + R_2}{R_1} \times V_{in}$$

This equation shows that the gain is determined by the resistor ratio, with a minimum gain of 1 when $R_2 = 0$.

Virtual Earth Approximation

To understand how the inverting amplifier works, you need to understand the concept of virtual earth approximation. In this approximation, the potential at the inverting input (-) is very close to 0V. There are two steps in the argument:



The op-amps multiplies the difference in potential between the inverting and non-inverting inputs, V^- and V^+ to produce the output voltage V_{out} because the open-loop voltage gain is very high, the difference between V^- and V^+must be almost zero.

The non-inverting input (+) is connected to the zero-volt line, so $V^+ = 0$. Thus, V^- must be close to zero, and the inverting input (-) is almost at earth potential.

Point A is known as a virtual earth as shown in the figure. It cannot be 0 V but it is very close to 0 V. This approximation is true as long as the op-amp is not saturated, and for frequencies where the open-loop voltage gain is high.

Applications:

This approximation is often used in summing amplifier circuits and other applications where it simplifies analysis.

Summing Amplifier Example:

► In a summing amplifier, multiple input voltages can be summed using resistors connected to the
Inverting input.

► The virtual ground assumption makes it easier to analyze the currents and voltages in the circuit.

Gain of an Inverting Amplifier:

If the current in the input resistor R_{in} is I_{in} and the current in the feedback resistor R_f is I_f, Then point P is at 0 V:

$$I_{in} = \frac{V_{in}}{R_{in}} \quad and \quad I_f = \frac{V_{out}}{R_f}$$

The input resistance of the op-amp is very high, and so virtually no current enters or leaves the inverting input (-) of the op-amp. This means that I_{in} and I_f must be equal in size.

If V_{in} is a positive potential, then the current in the two resistors flows from left to right. V_{out} will be negative because the current flows from P, which is at O V, to the output connection, which must have a lower voltage than 0 V. Thus

$$I_f = -I_{in}$$

$$\frac{V_{out}}{R_f} = -\frac{V_{in}}{R_{in}}$$

The gain of the inverting amplifier is thus given by

$$G = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

The negative sign shows that when the input voltage is positive, the output voltage is negative, and when the input is negative, the output is positive. If the input voltage is alternating, then there will be a phase difference of 180° or π rad between the input and the output voltages.