## 1. What is electronics? What is analog electronics?

Electronics is the branch of science that deals with the study of flow and control of electrons (*electricity*) and the study of their behavior and effects in vacuums, gases, and semiconductors, and with devices using such electrons.

Analog electronics is composed of two words you see first ‘analog' and second ‘electronics’, as you know the word analog refers to application of finite duration pulses (as practically no system can have infinite bandwidth). The second term is electronics which deals with the movement of electrons or we study behavior of electrons.

So ***analog electronics is the branch of electronics which deals with the study of electrons behavior or electronic systems under application of finite duration pulses.***

## 2. About conductor, semiconductor, insulator with example.

**Conductor:** Most metals are good at conducting heat and electricity. Things like copper, aluminum, iron and gold.

**Insulator:** Most (but not all) polymers (plastics) and ceramics are not very at conducting heat and electricity.
Things like polyethylene, polypropylene, PET, –and for ceramics– clay, porcelain, alumina.

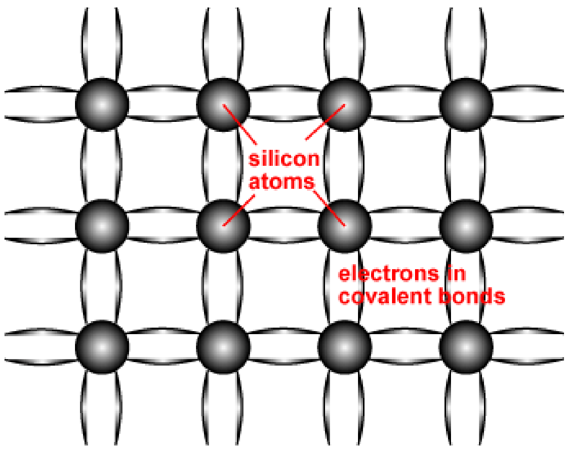
**Semiconductor:** Properties in between the two (but especially in terms of electrical conductivity (silicon, gallium arsenide)

## 3. Details about semiconductor (let say bond, properties, used, Energy, temperature, types).

A semiconductor device is an electronic component that relies on the electronic properties of a semiconductor material (primarily silicon, germanium, and gallium arsenide, as well as organic semiconductors) for its function. Semiconductor devices have replaced vacuum tubes in most applications. They use electrical conduction in the solid state rather than the gaseous state or thermionic emission in a vacuum.

Understanding how these atoms are arranged is vital in understanding the material properties of different semiconductors, and how best to engineer them.

Semiconductors, such as Silicon (Si) are made up of individual atoms bonded together in a regular, periodic structure to form an arrangement whereby each atom is surrounded by 8 electrons. An individual atom consists of a nucleus made up of a core of protons (positively charged particles) and neutrons (particles having no charge) surrounded by electrons. The number of electrons and protons is equal, such that the atom is overall electrically neutral. The electrons surrounding each atom in a semiconductor are part of a covalent bond. A covalent bond consists of two atoms "sharing" a pair of electrons. Each atom forms 4 covalent bonds with the 4 surrounding atoms. Therefore, between each atom and its 4 surrounding atoms, 8 electrons are being shared. The structure of a semiconductor is shown in the figure below.




Semiconductors can conduct electricity under preferable conditions or circumstances. This unique property makes it an excellent material to conduct electricity in a controlled manner as required.

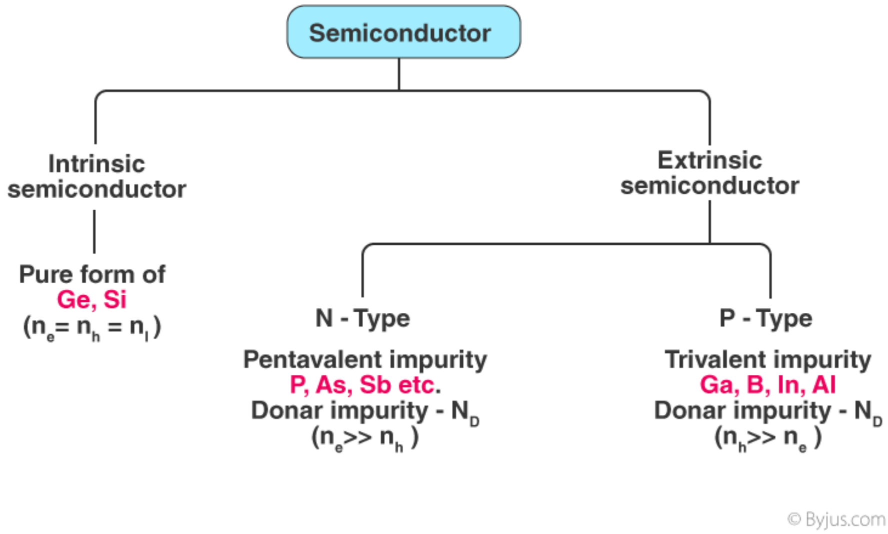
Unlike conductors, the charge carriers in semiconductors arise only because of external energy (thermal agitation). It causes a certain number of valence electrons to cross the energy gap and jump into the conduction band, leaving an equal amount of unoccupied energy states, i.e. holes. Conduction due to electrons and holes are equally important.

- **Resistivity:** $10^{-5}$ to $10^{6}$ Ωm
- **Conductivity:** $10^{5}$ to $10^{-6}$ mho/m

- **Temperature coefficient of resistance:** Negative
- **Current Flow:** Due to electrons and holes

Semiconductors can be classified as:

- **Intrinsic Semiconductor**
- **Extrinsic Semiconductor**




## 4. About P-N junction, Biasing

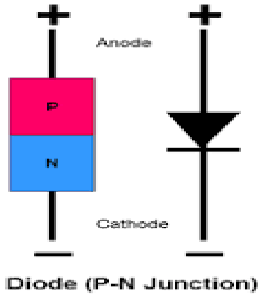
When a p-type semiconductor is suitably joined to n-type semiconductor, the contact surface is called **p-n junction**

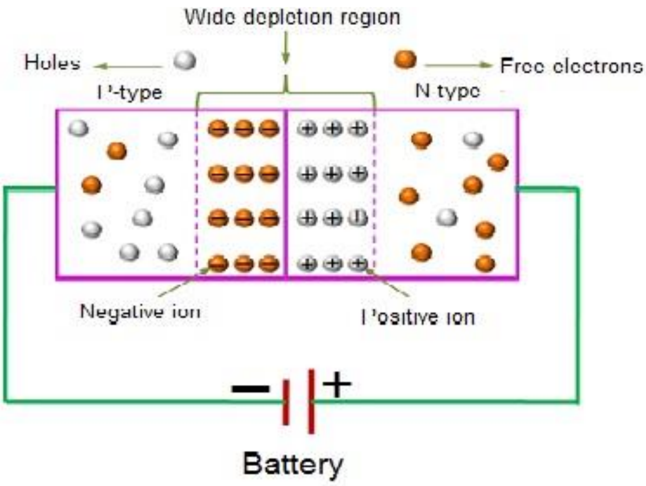
**Ex: semiconductor diode.**

- Depletion region.
- Barrier potential.

## Barrier potential :

For silicon, V0 = 0.7 V ; For germanium, V0 = 0.3 V

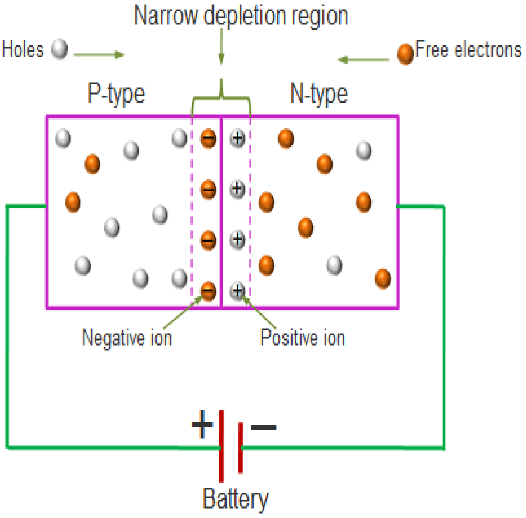



- A p–n **junction diode** allows electric charges to flow in one direction, but not in the opposite direction; negative charges (electrons) can easily flow through the **junction** from n to p but not from p to n, and the reverse is true for holes.

## <u>Biasing a pn Junction</u>:

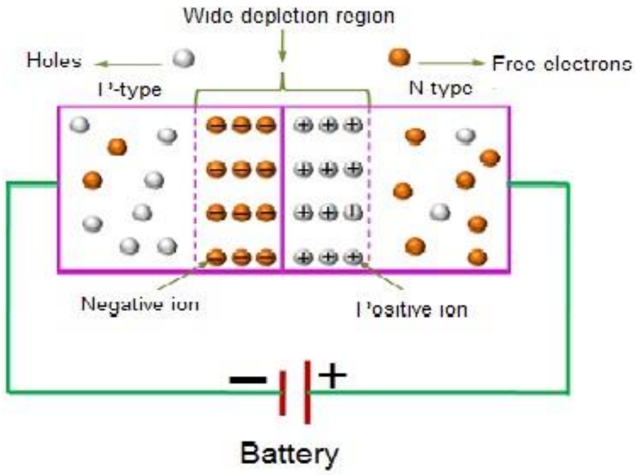
**<u>Forward biasing</u>:** The positive terminal of the battery is connected to the p-type semiconductor material and the negative terminal is connected to the n-type semiconductor material.




Forward bias

- Junction offers low resistance to current flow.
- Current flows in the circuit.

**Reverse biasing:** The positive terminal of the battery is connected to the n-type semiconductor material and the negative terminal is connected to the p-type semiconductor material.



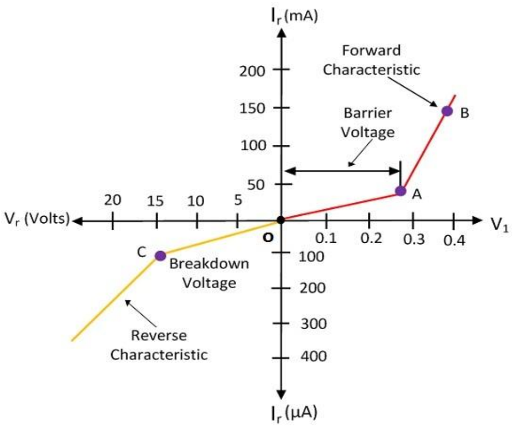

Reverse Bias

- Junction offers very high Resistance to current flow.
- No current flows in the circuit.

## 5. Voltage ampere characteristics

The **volt-ampere characteristic** of the PN-junction diode is a curve between the **voltage** over the junction and the **circuit current.**

- No current flows through the diode when the external voltage becomes zero.
- In forward bias, the current increase slightly till the depletion region is completely wiped off.

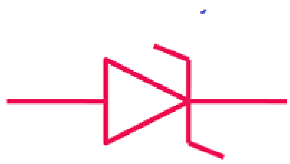



Volt-Ampere Characteristic

At the stage of breakdown a sudden rise of reverse current and a sudden fall of the resistance of barrier region. This may destroy the junction permanent.

## 6. Zener diode, Photo diode, LED

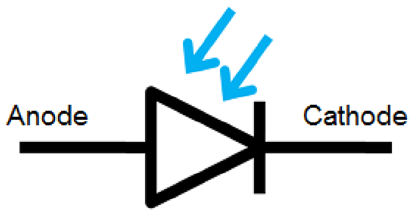
**Zener diode:** A *Zener diode* is a type of diode that allows current to flow in the conventional manner - from its anode to its cathode i.e. when the anode is positive with respect.



**Zener diode**

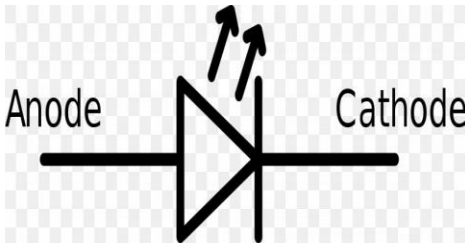
## Photo diode:

A *photodiode* is a semiconductor device that converts light into an electrical current. The current is generated when photons are absorbed in the *photodiode*. *Photodiodes* may contain optical filters, built-in lenses, and may have large or small surface areas.




Photodiode symbol

**<u>LED:</u>** A light-emitting diode is a semiconductor light source that emits light when current flows through it. Electrons in the semiconductor recombine with electron holes, releasing energy in the form of photons.



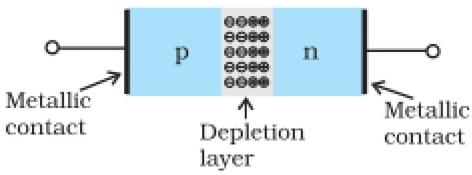

Light-emitting diode

## 7. Semiconductor diode, crystal diode, rectifier, Equivalent circuit of crystal diode, Circuit of crystal diode.

A semiconductor diode, the most commonly used type today, is a crystalline piece of semiconductor material with a p–n junction connected to two electrical terminals. Semiconductor diodes were the first semiconductor electronic devices.

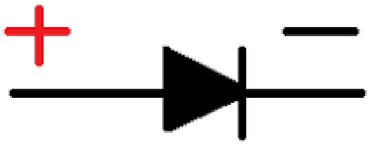
Imagine a p-n junction with metallic contacts at both the ends for application of external voltage. This is a semiconductor diode.

Symbol for p-n junction diode.



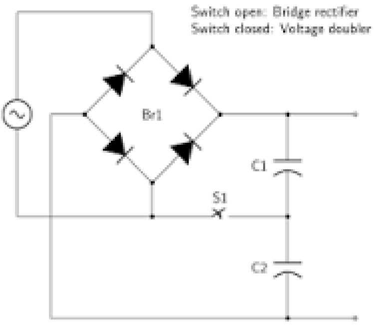

Semiconductor diode.

Crystal diode is also called as a Cat’s-whisker diode or Point-contact diode or Crystals. The circuit used for converting AC into DC is known as rectifier. Most of the rectifier circuit which uses crystal diode along with some resistors for this conversion are known as crystal diode rectifier.




**Schematic Symbol of crystal diode**

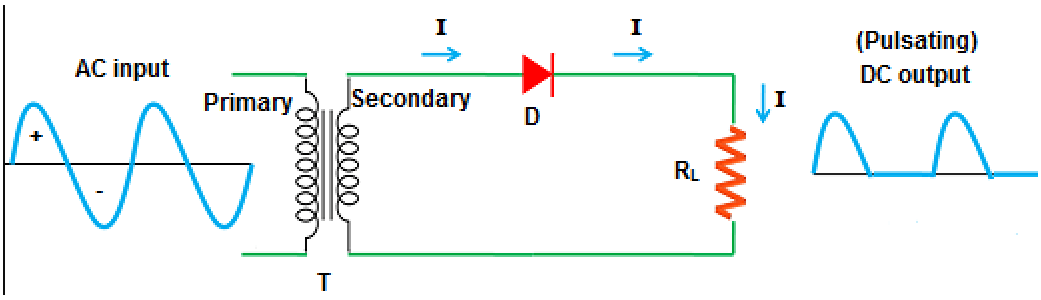
A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. The process is known as rectification, since it "straightens" the direction of current.



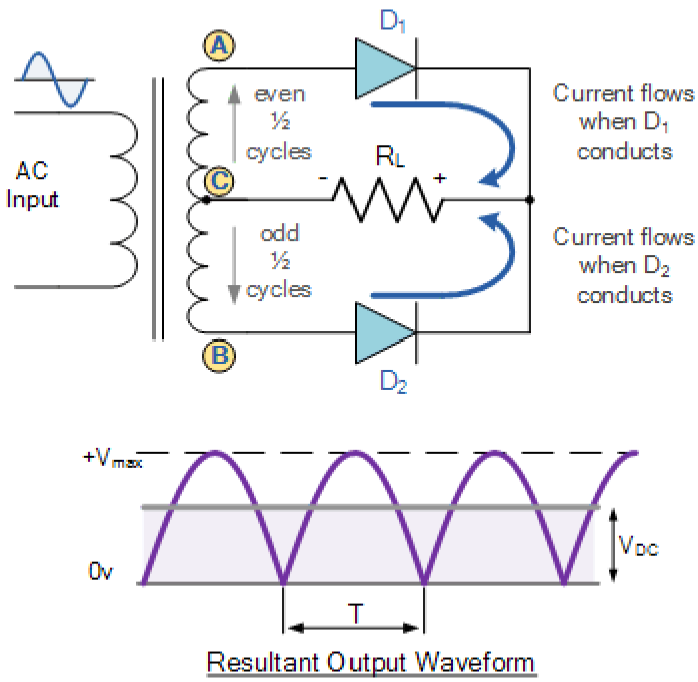

It is generally profitable to replace a device or system by its equivalent circuit. An equivalent circuit of a device (e.g. crystal diode, transistor etc.) is a combination of electric elements, which when connected in a circuit, acts exactly as does the device when connected in the same circuit. Once the device is replaced by its equivalent circuit, the resulting network can be solved by traditional circuit analysis techniques. We shall now find the equivalent circuit of a crystal diode.

## 8. Half wave rectifier, full wave rectifier, efficiency all of this detail

A half wave rectifier is defined as a type of rectifier that only allows one half-cycle of an AC voltage waveform to pass, blocking the other half-cycle. Half-wave rectifiers are used to convert AC voltage to DC voltage, and only require a single diode to construct.




A Full Wave Rectifier is a circuit, which converts an ac voltage into a pulsating dc voltage using both half cycles of the applied ac voltage. It uses two diodes of which one conducts during one half cycle while the other conducts during the other half cycle of the applied ac voltage.




## 9. Ripple factor

Ripple Factor is the ratio of rms value of ac component present in the rectified output to the average value of rectified output. It is a dimensionless quantity and denoted by $\gamma$. Its value is always less than unity.

$$\text{Ripple Factor}, \gamma = \frac{\text{RMS value of AC component present in Rectifier Output}}{\text{Average Value of Rectifier Output}}$$

$$\gamma = \frac{I'_{rms}}{I_{dc}} = \frac{V'_{rms}}{V_{dc}}$$

where $I'_{rms}$ and $V'_{rms}$ are the rms value of alternating component of load current and voltage respectively.

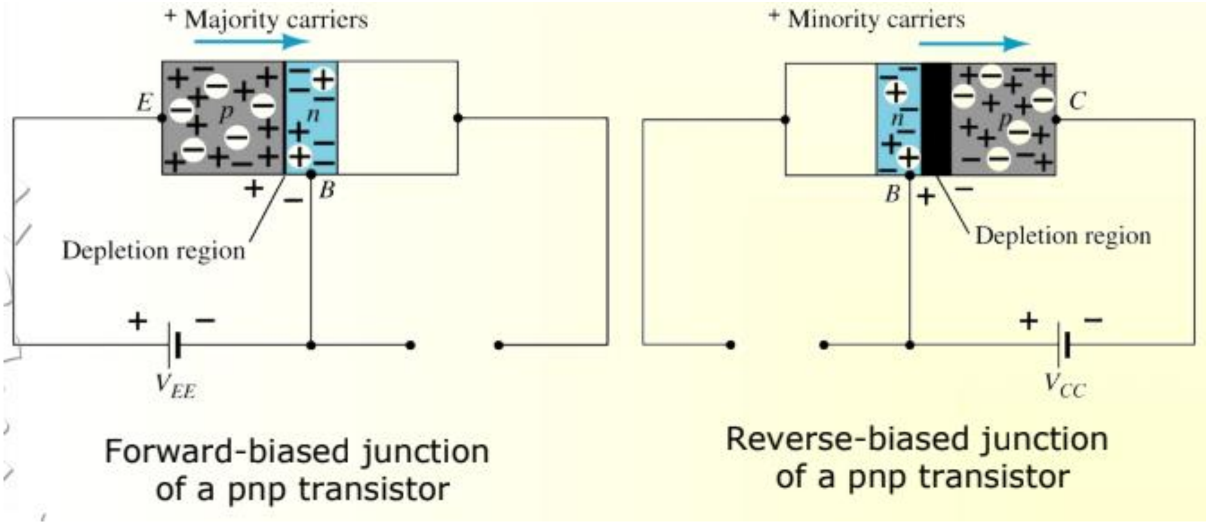
## 10. Transistor

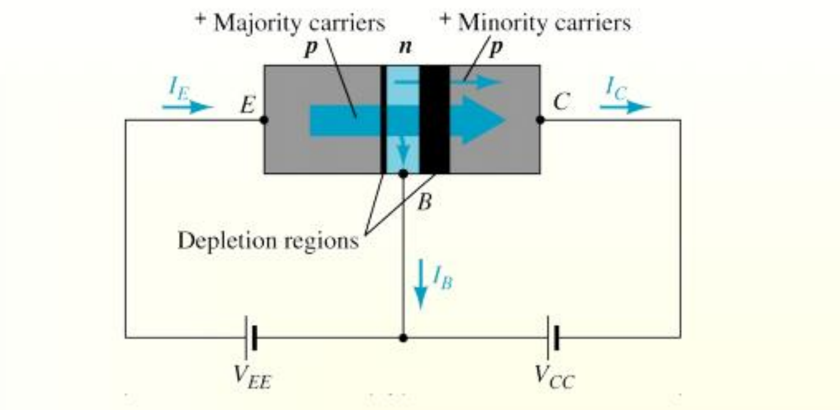
**Transistor Construction:**

1. 3 Layer semiconductor device consisting:
   a. 2 n – and 1 p – type layers of material = npn transistor
   b. 2 p – and 1 n – type layers of material = pnp transistor
2. The term bipolar reflects the fact that holes and electrons participate in the injection process into the oppositely polarized material
3. A single pn junction has two different types of bias:
   a. Forward bias
   b. Reverse bias
4. Thus, a two – pn – junction device has four types of bias.

**Transistor Operation:**

1. The basic operation will be described using the pnp transistor. The operation of the pnp transistor is exactly the same if the roles played by the electron and hole are interchanged.
2. One p-n junction of a transistor is reverse-biased, whereas the other is forward-biased.




3. Both biasing potentials have been applied to a pnp transistor and resulting majority and minority carrier flows indicated.
4. Majority carriers (+) will diffuse across the forward biased p-n junction into the n-type material.
5. A very small number of carriers (+) will through n-type material to the base terminal. Resulting IB is typically in order of microamperes.
6. The large number of majority carriers will diffuse across the reverse – biased junction into the p-type material connected to the collector terminal.
7. Majority carriers can cross the reverse –biased junction because the injected majority carriers will appear as minority carriers in the n-type material.
8. Applying KCL to the transistor:

$$I_E = I_{C+}I_B$$

9. The comprises of two components – the majority and minority carriers

$$I_c = I_{Cmajority+}I_{cominority}$$

10. $I_{co-}I_c$ current with emitter terminal open and is called leakage current.

## 11. Relationship between α and β

Case 1

$$I_E = I_C + I_B \text{-------------------------------}(1)$$

Substitute equ. $I_C = \beta I_B$ into (1) we get

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

Case 2

Known: $\alpha = \frac{I_C}{I_E}$ => $I_E = \frac{I_C}{\alpha}$ --------------------------(2)

Known: $\beta = \frac{I_C}{I_B}$ => $I_B = \frac{I_C}{\beta}$ --------------------------(3)

Substitute (2) and (3) into (1) we get,

$\alpha = \frac{\beta}{\beta+1}$ and $\beta = \frac{\alpha}{1-\alpha}$

## 12. Common – Emitter Configuration:

- It is called common-emitter configuration since:
  - Emitter is common or reference to both input and output terminals.
  - Emitter is usually the terminal closest to or at ground potential.
- Almost amplifier design is using connection of CE due to the high gain for current and voltage.
- Two set of characteristics are necessary to describe the behavior for CE; input (base terminal) and output (collector terminal) parameters.

**<u>Proper Biasing Common-emitter configuration in active region</u>**

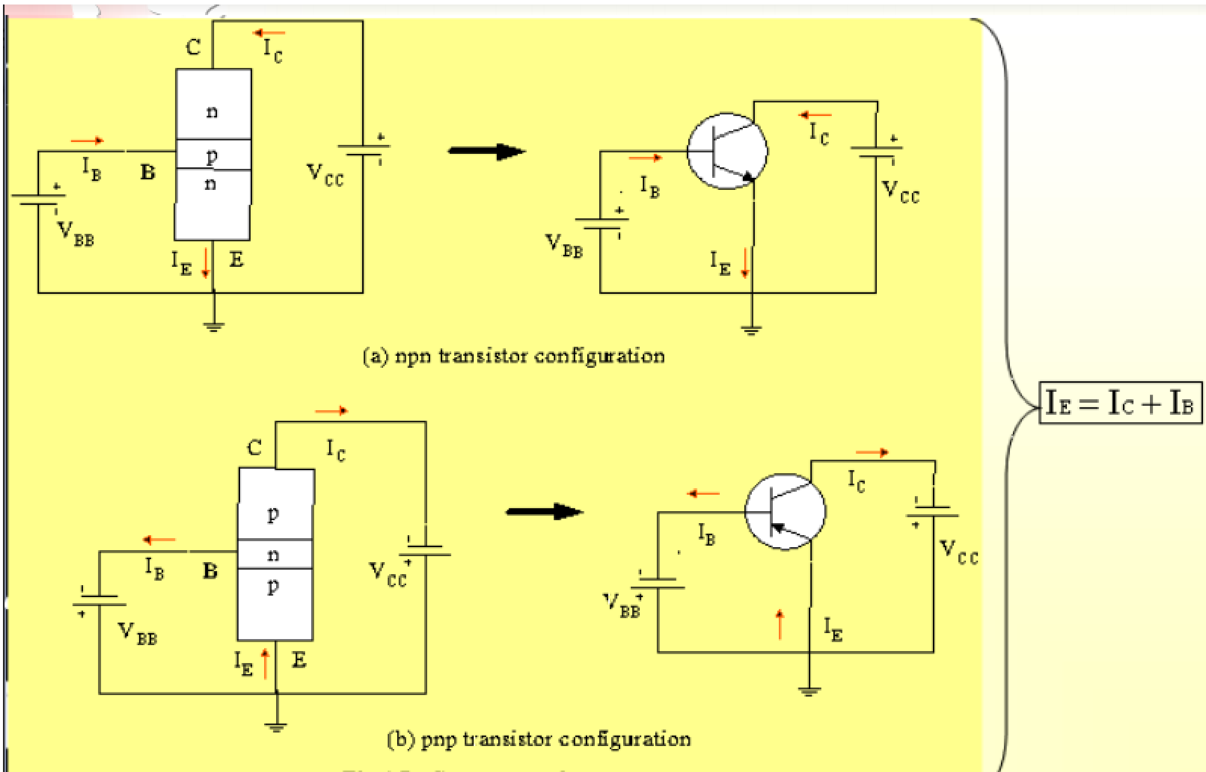
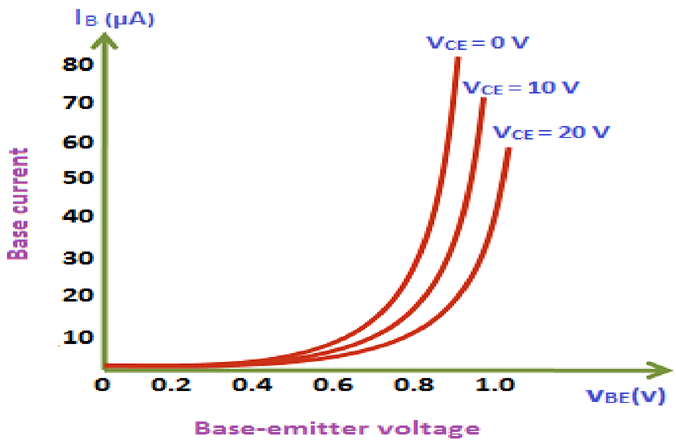


Fig 4.7 : Common-emitter configuration

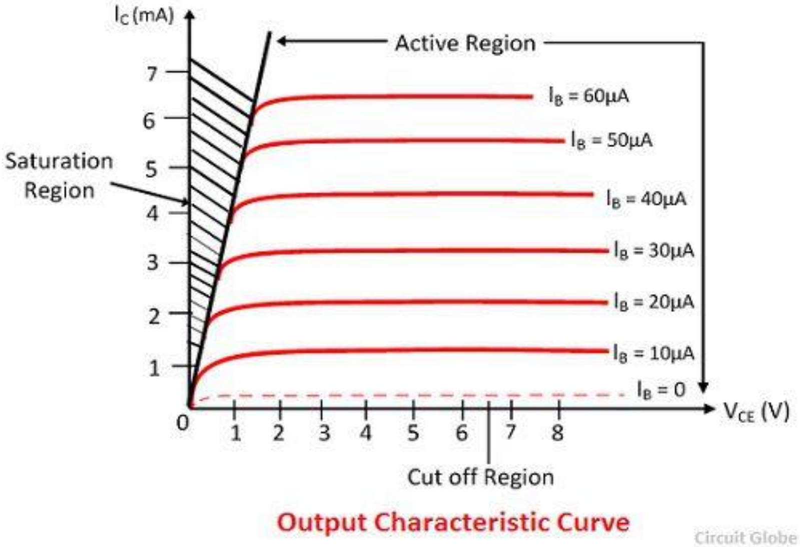
**<u>Input Characteristics for a common-emitter NPN transistor</u>**



I/P characteristics CE configuration

- $I_B$ is microamperes compared to miliamperes of $I_C$ .
- $I_B$ will flow when $V_{BE} > 0.7V$ for silicon and 0.3V for germanium.
- Before this value $I_B$ is very small and no $I_B$ .
- Base-emitter junction is forward bias.
- Increasing $V_{CE}$ will reduce $I_B$ for different values.

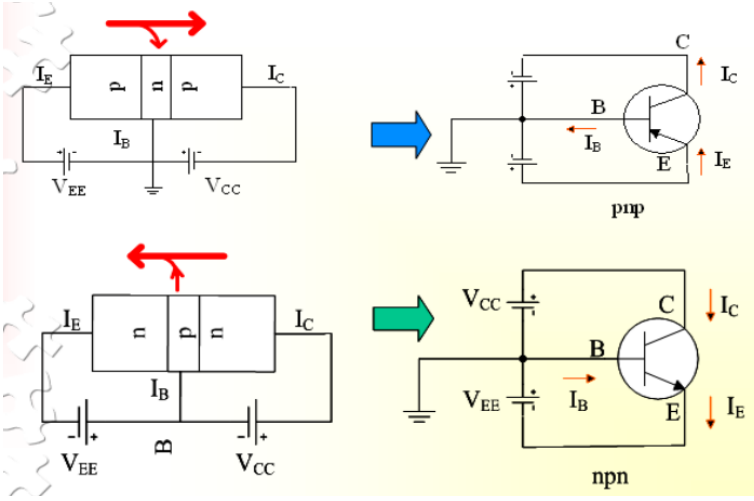
**Output Characteristics for a common-emitter NPN transistor**



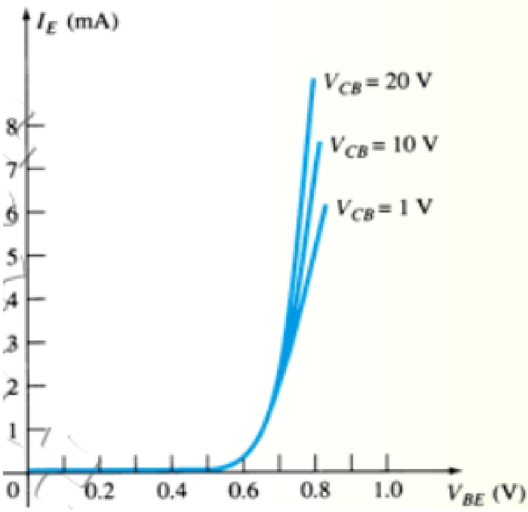

- For Small $V_{CE}$ ($V_{CE} < V_{CESAT}, I_C$ increase linearly with increasing of $V_{CE}$ .
- $V_{CE} < V_{CESAT}, I_C$ not totally depends on $V_{CE}$ → constant $I_C$
- $I_B$ (µA) is very small compare to $I_C(mA)$ . Small increase in $I_B$ cause big increase in $I_C$
- $I_B = 0\ A \rightarrow I_{CEo}$ Occur.
- Nothing the value when $I_C = 0A$. There is still some value of current flows.

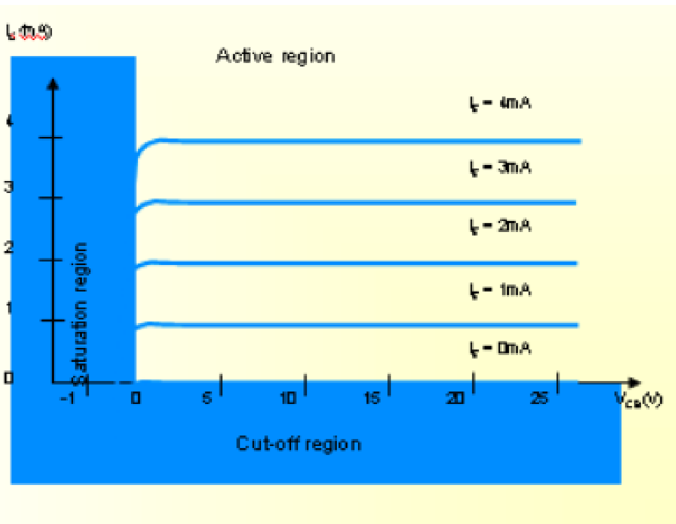
## 12. Common – Base Configuration:

- Common-base terminology is derived from the fact that the:
  - Base is common to both input and output of the configuration.
  - Base is usually the terminal closest to or at ground potential.
- All current directions will refer to conventional (hole) flow and the arrows in all electronic symbols have a direction defined by this convention.
- Note that the applied biasing (voltage sources) are such as to establish current in the direction indicated for each branch.




- To describe the behavior of common-base amplifiers requires two set of characteristics:
  - Input or driving point characteristics.
  - Output or collector characteristics.
- The output characteristics has 3 basic regions:
  - Active region – defined by the biasing arrangements.
  - Cutoff region – region where the collector current is 0A.
  - Saturation region – region of the characteristics to the left of $V_{CB} = 0V$




Output of collector characteristics for common-base transistor

- The curves(output characteristics) clearly indicate that a first approximation to the relationship between IE and IC in the active region is given by

$$I_C = IE$$

- Once a transistor is in the 'on' state, the base-emitter voltage will be assumed to be

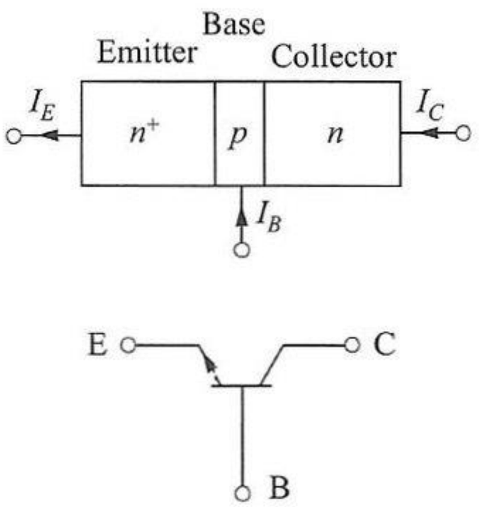
$$V_{BE} = 0.7v$$

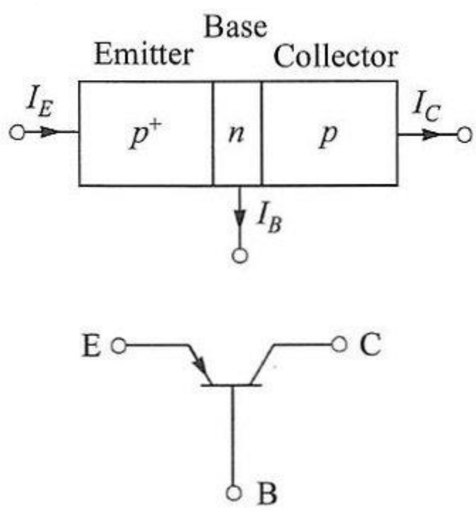
- In the dc mode the level of $I_C$ and $I_E$ due to the majority carriers are related by a quantity called alpha

α = $\frac{I_C}{I_E}$

- It can then be summarize to $I_C = \alpha I_E$
- Alpha a common base current gain factor that shows the efficiency by calculating the current percent from current flow from emitter to collector.

## 13. N-P-N and P-N-P symbolic Diagram:



## 14. Relationship analysis between α and β:

CASE 1:

$I_E = I_C + I_B$--------------------------(1)

Substitute equ. $I_C = \beta I_B$ into (1) we get

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

CASE 2:

Known: $\alpha = \frac{I_C}{I_E}$ => $I_E = \frac{I_C}{\alpha}$-----------------(2)

Known: $\beta = \frac{I_C}{I_B}$ => $I_B = \frac{I_C}{\beta}$-----------------(3)

Substitute (2) and (3) into (1) we get,

$\alpha = \frac{\beta}{\beta+1}$ and $\beta = \frac{\alpha}{1-\alpha}$

## 15. FETs vs. BJTs:

Similarities: 1. Amplifiers.

2. Switching devices.

3. Impedance matching circuits.

Differences:

1. FETs are voltage controlled devices. BJTs are current controlled devices.

2. FETs have higher input impedance. BJTs have higher gain.

3. FETs are generally more static sensitive than BJTs.

## 16. FET Types:

**JFET** : junction FET

**MOSFET**: Metal-oxide-semiconductor FET

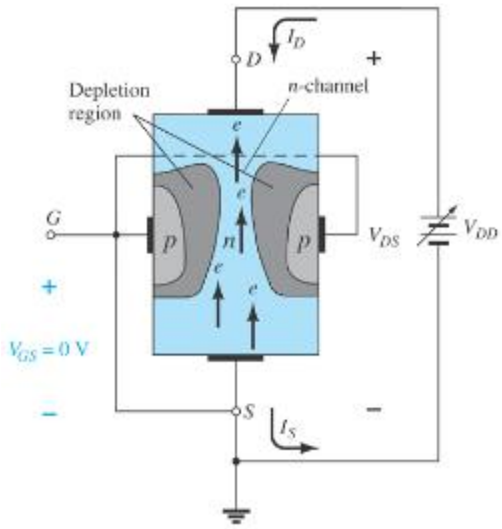
**D-MOSFET**: Depletion MOSFET

**E-MOSFET**: Enhancement MOSFET

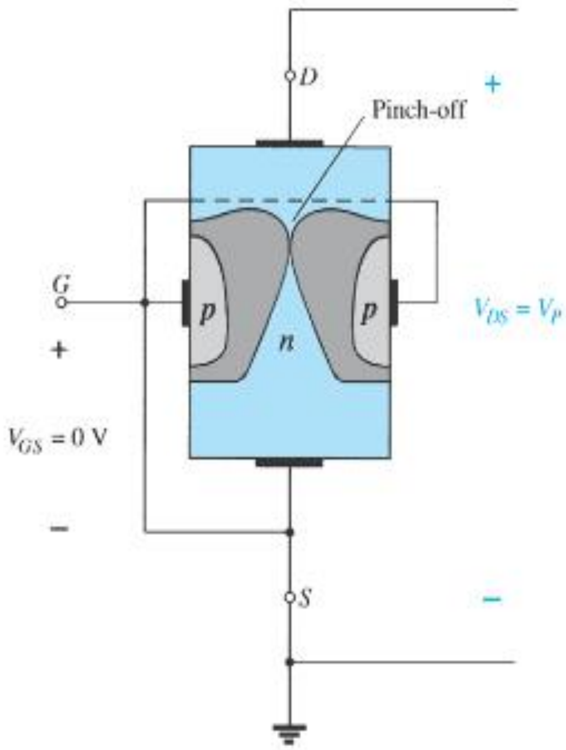
## 17. JFET Operation Characteristics:

There are three basic operating conditions for a JFET:

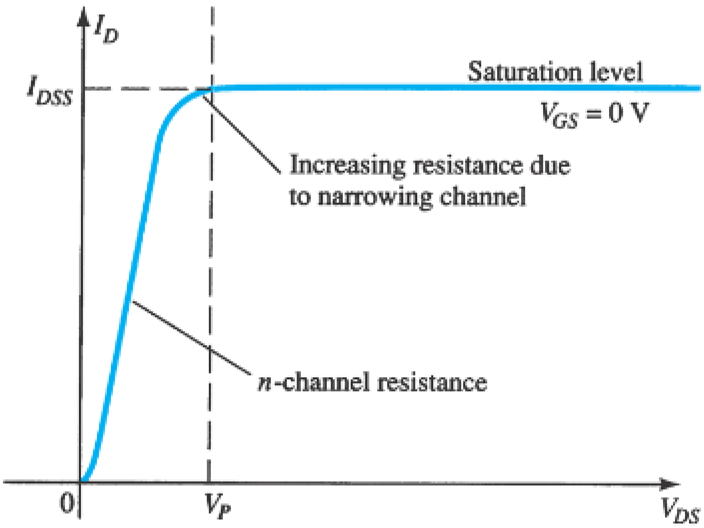
- $V_{GS}$=0V, $V_{DS}$ increasing to some positive value
- $V_{GS}$<0V, $V_{DS}$ at some positive value
- Voltage-controlled resistor



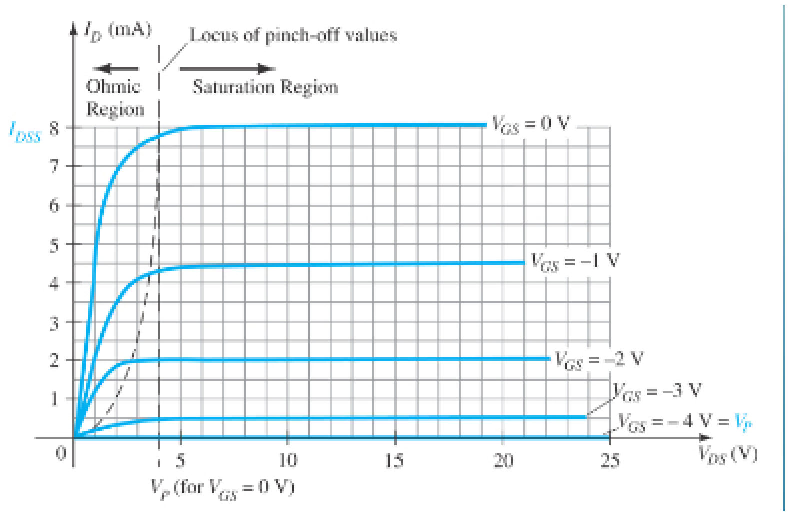

**JFET Characteristics: Pinch Off**



## JFET Characteristics: Saturation

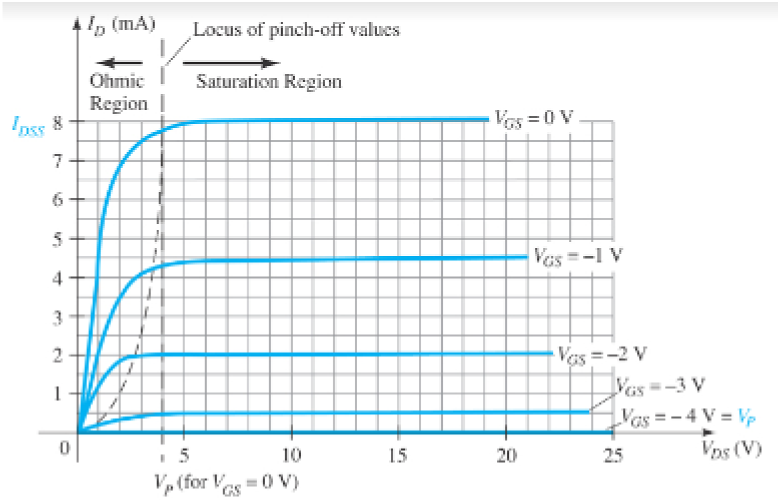



## JFET Operating Characteristics

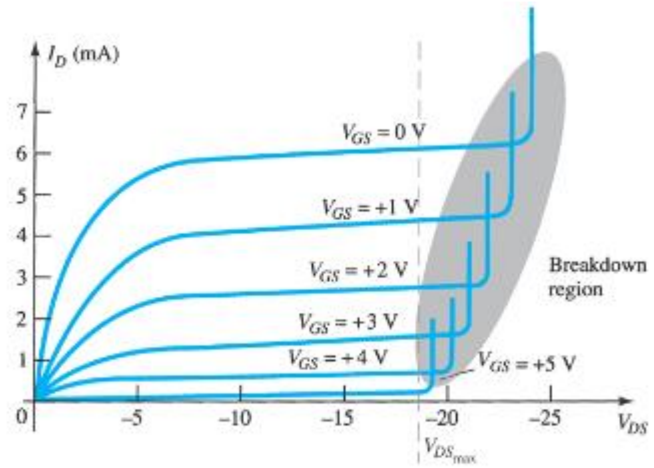



## Voltage Controlled Register

- The region to the left of the pinch-off point is called the ohmic Region.
- The JFET can be used as a variable resistor, where VGS controls the drain-source resistance.




## P-channel JFET Characteristics




## JFET Transfer Curve