Nepal Institute of Engineering

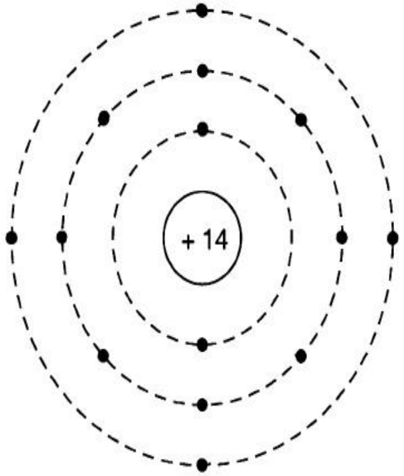
Nepal Engineering Council Registration Examination Preparation Class

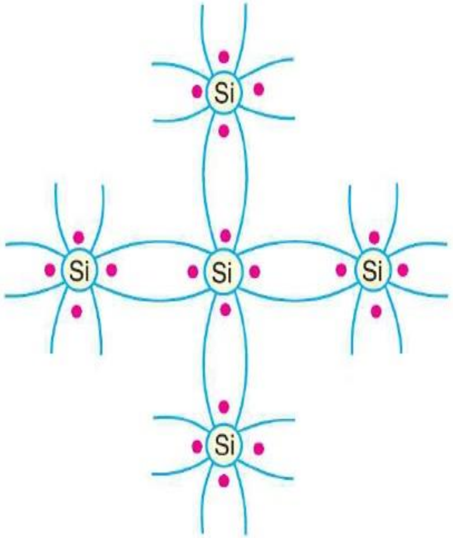
Computer Engineering

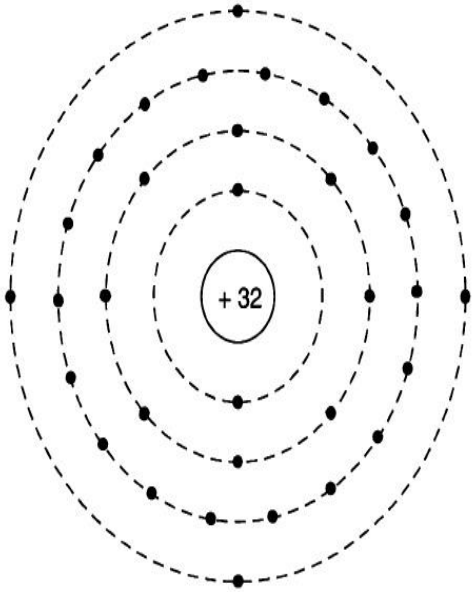
Semiconductor Devices

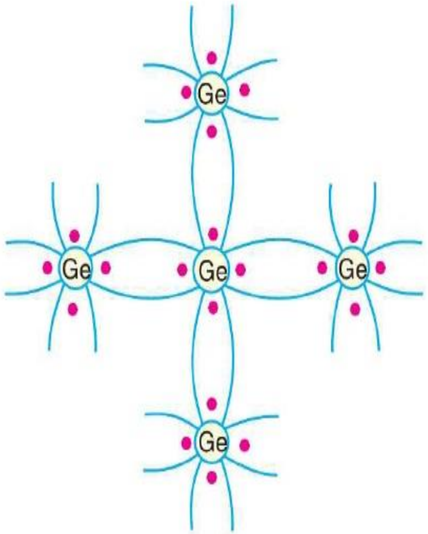
SEMICONDUCTOR MATERIALS

- A semiconductor is a material that has a conductivity level somewhere between the extremes of an insulator and a conductor.
- Pure form of semiconductor is known as intrinsic semiconductor.





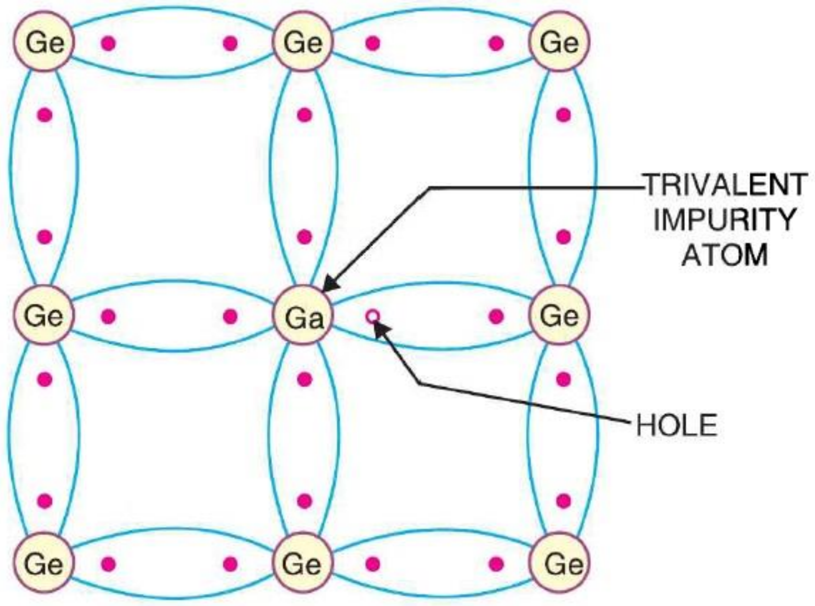


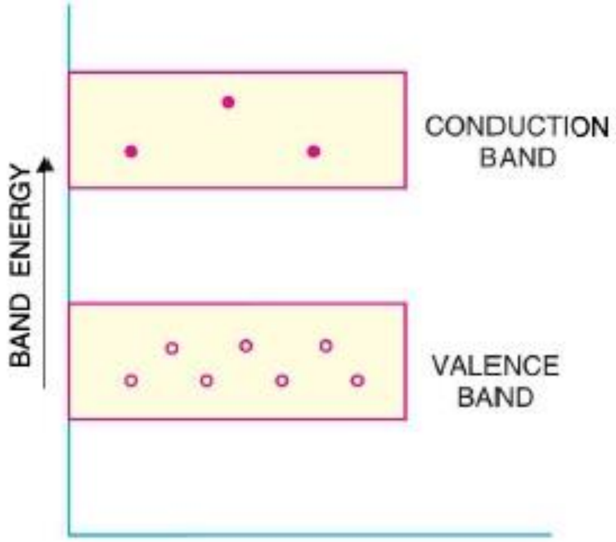


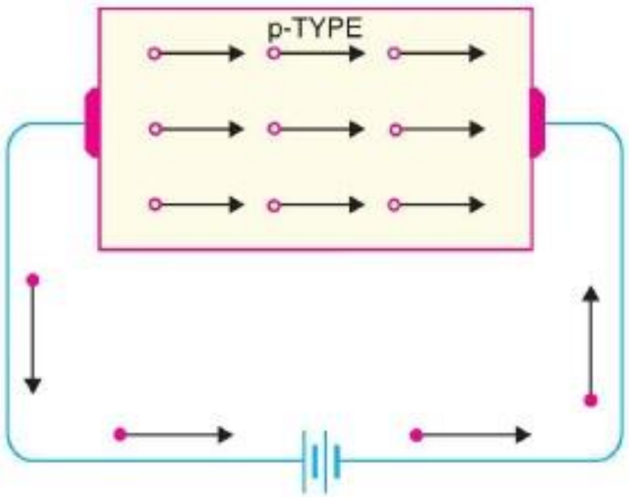
Extrinsic Semi conductor

- When some impurities atoms are added in intrinsic semiconductor, the thus formed semiconductor is known as extrinsic semiconductor.
- **P-types Semi conductor :**

When some amount of trivalent impurity is added to the pure semi conductor, it is called p-type semi conductor.

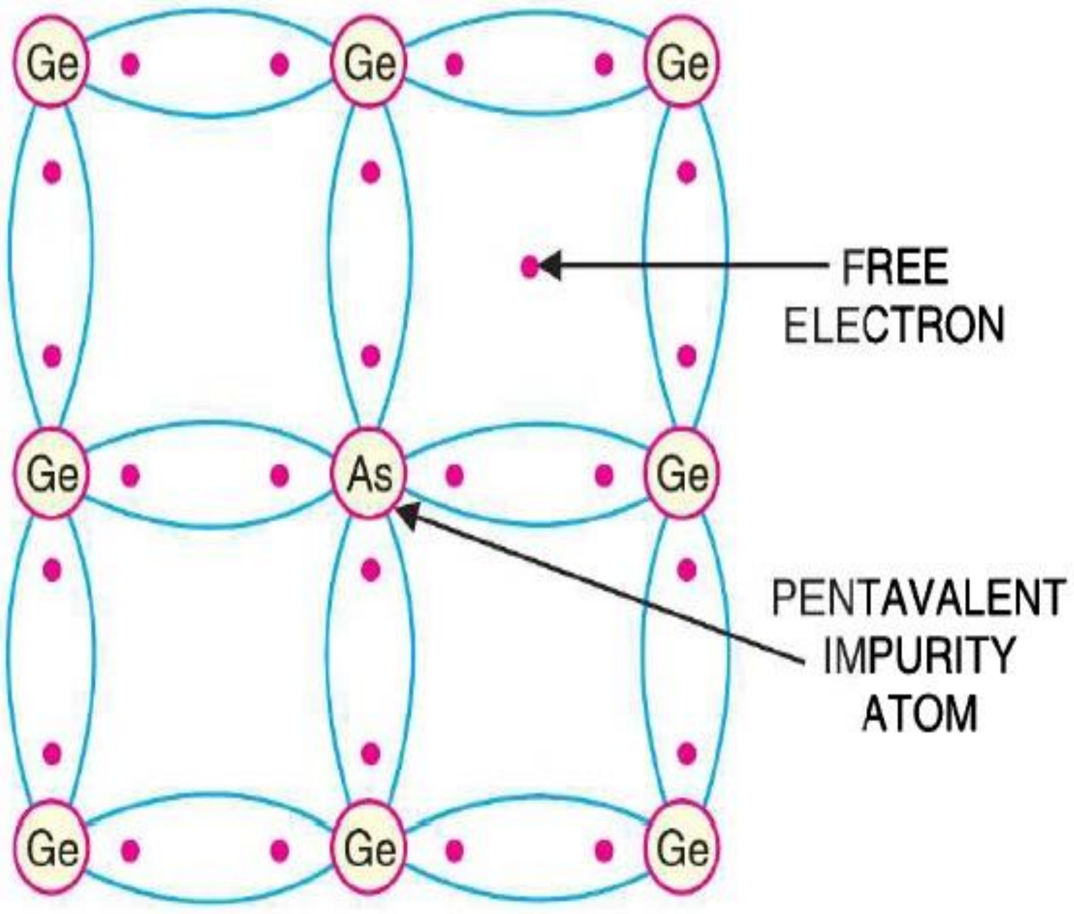


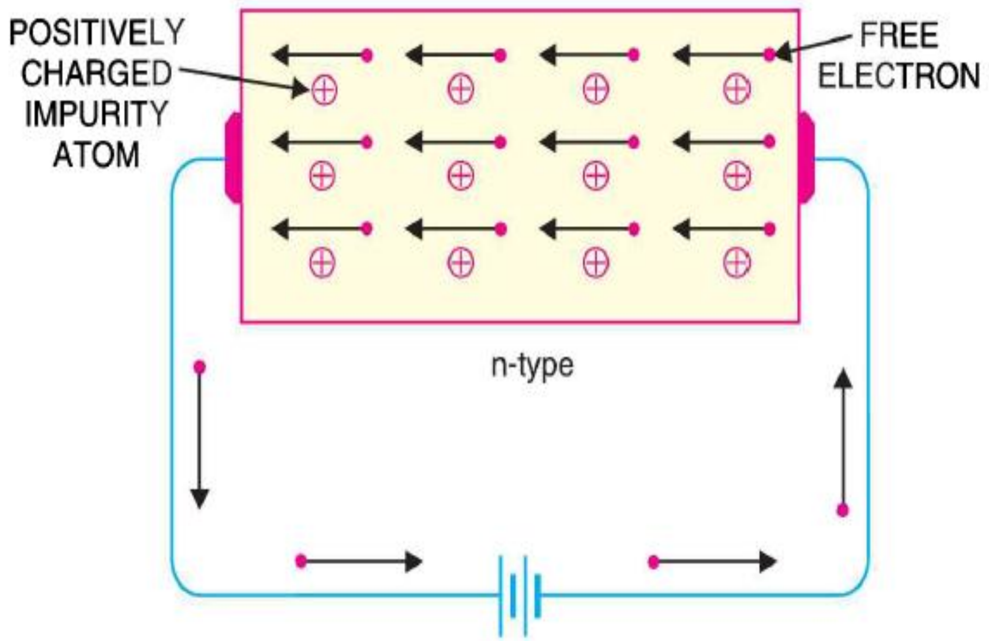




- **n-type Semi conductor:**

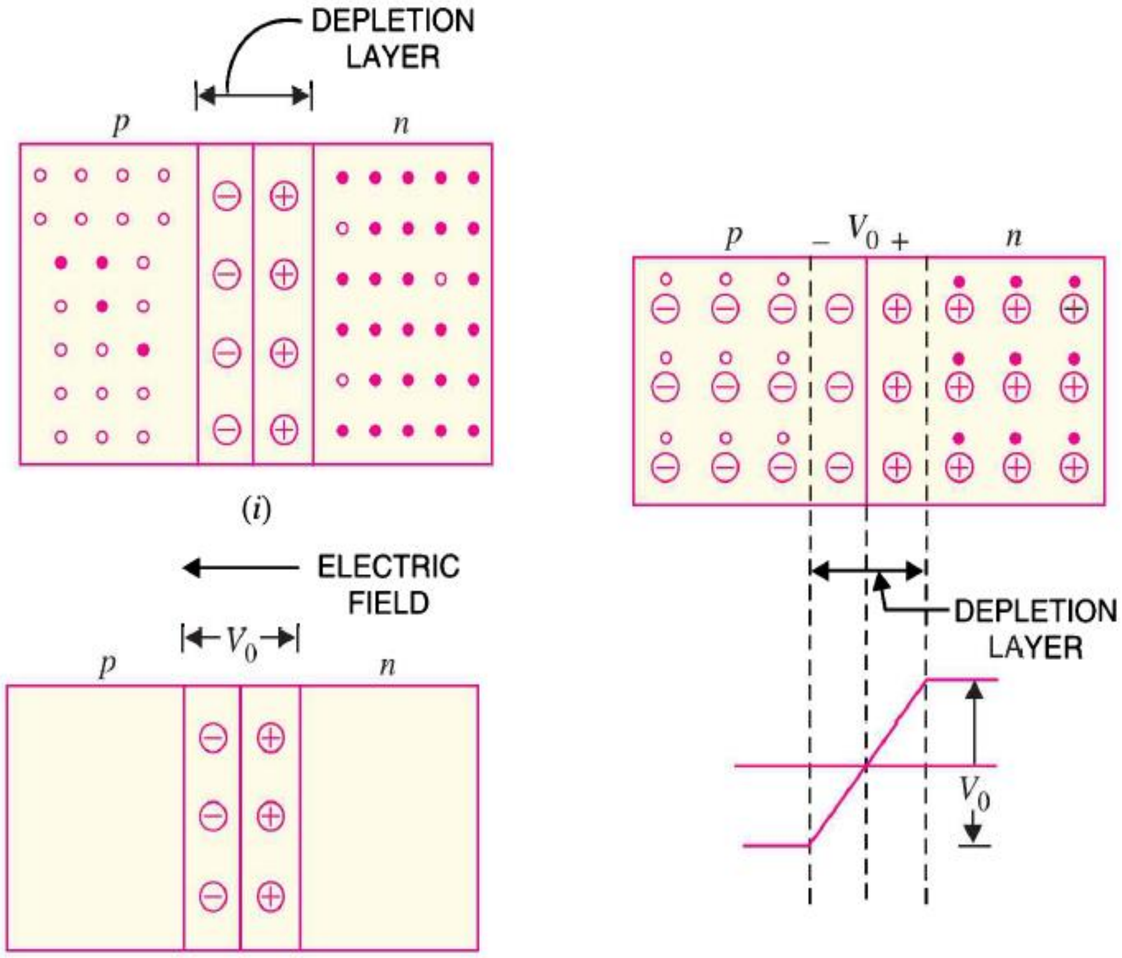
When some amount of pentavalent impurity is added to the pure semi conductor, it is called n-type semi conductor.





P-N Junction

- When p type semiconductor is suitably joined with n type semiconductor, the contact surface is called pn junction.
- At the instant of pn junction formation , free electrons near the junction in the n region begin to diffuse across the junction into the p region and combines with holes near the junction.
- This creates a layer of positive and negative charges near the junction, which is known as depletion layer.

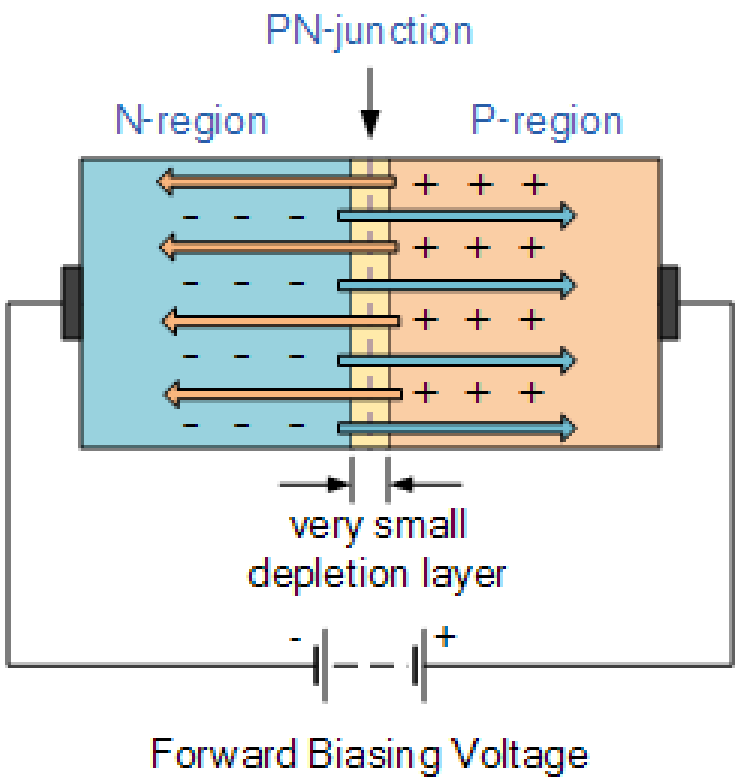


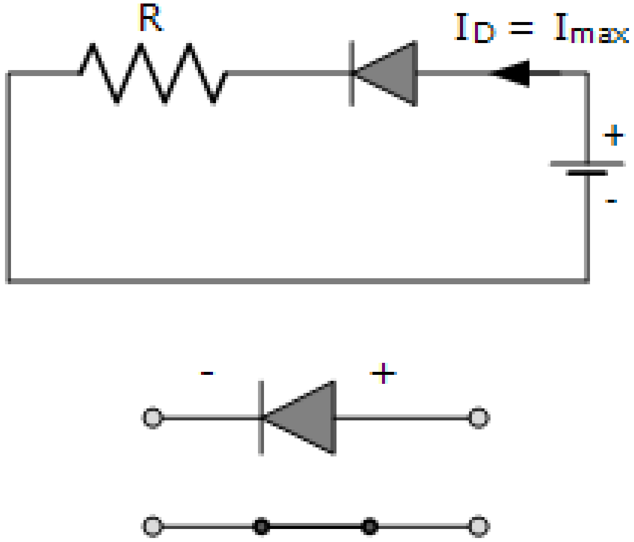
- Once pn junction is formed and depletion layer created, the diffusion of free electrons stops.
- The positive and negative charges set up an electric fields and there exists a potential difference across the depletion layer which is call barrier potential.
- Typical barrier potential is approximately 0.7 V for silicon and 0.3V for germanium

- **Biasing :**
- Bias refers to the use of d.c. voltage to establish certain operating conditions.

Forward biasing

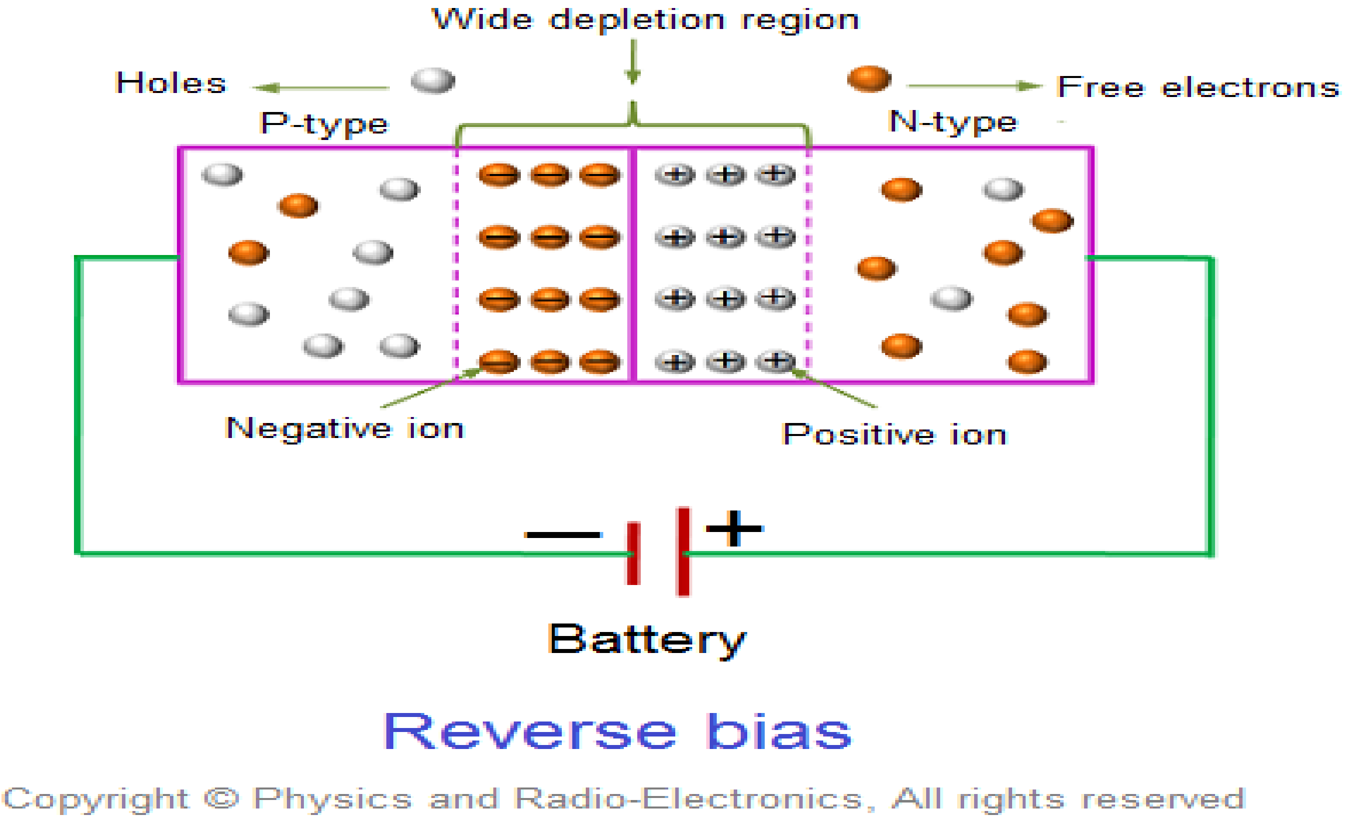
- When external dc voltage applied to the junction is in such a direction that it cancels the potential barrier, thus permitting current flow, it is called forward biasing.





Reverse biasing

- When external dc voltage applied to the junction is in such a direction that potential barrier is increased, it is called reverse biasing.



V-I Characteristics of PN junction

- It is the curve between voltage across the junction and the circuit current.
- When the external voltage is zero, the potential barrier at the junction does not permit current flow. Therefore , the circuit current is zero.
- With forward bias to the pn junction, the potential barrier is reduced. At some forward voltage, the potential barrier is altogether eliminated and current starts flowing in the circuit. From now onwards, the current increases with the increase in forward voltage.
- With reverse bias to the pn junction, the potential barrier is increased.

• Therefore the junction resistance becomes very high and practically no current flows through the circuit.

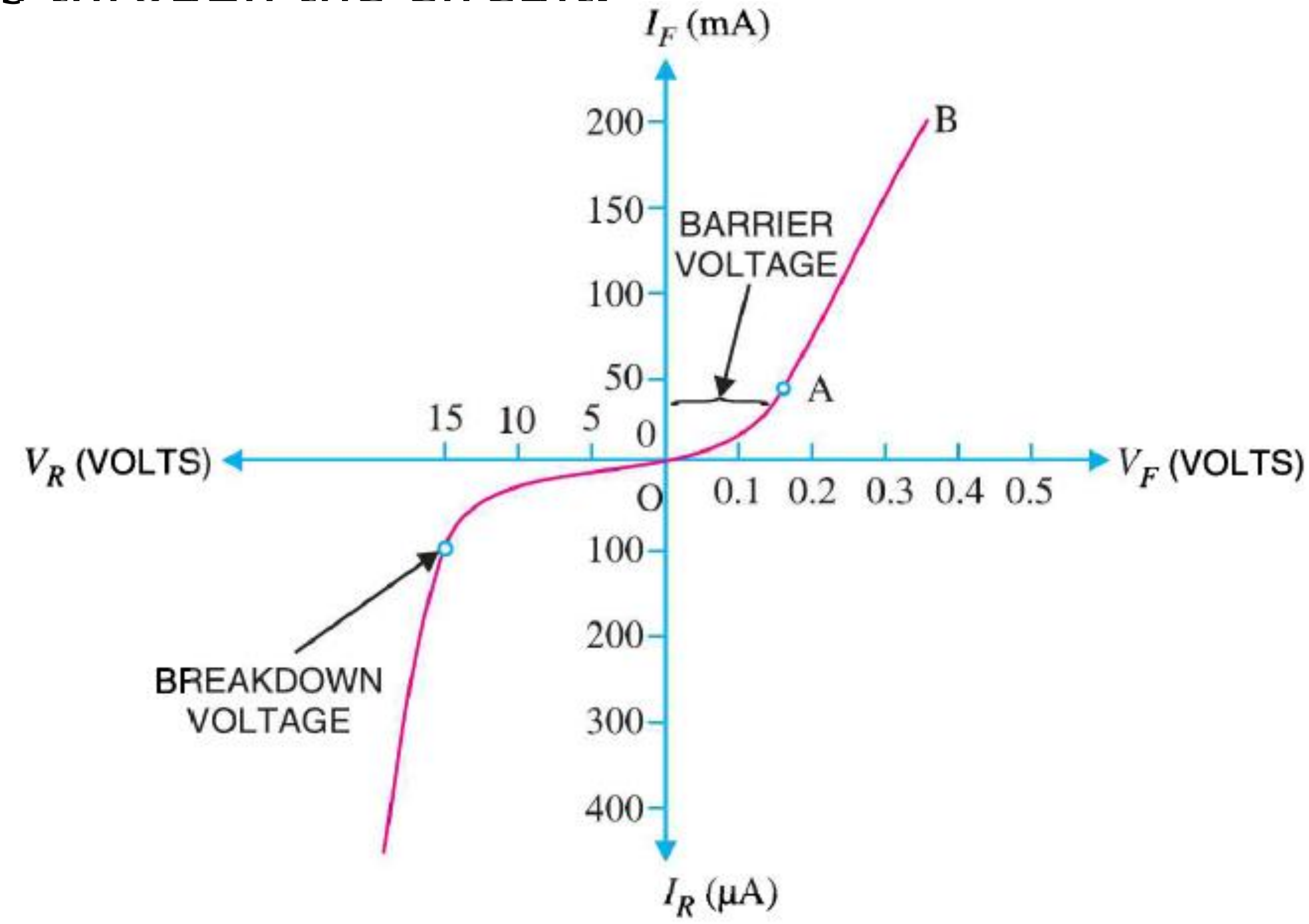
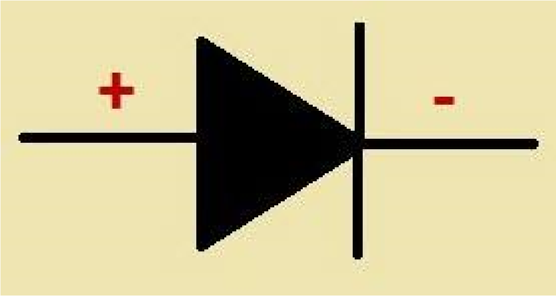


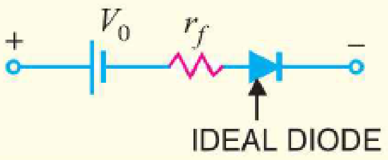
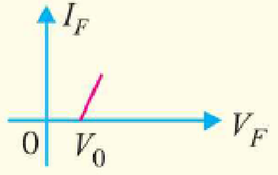
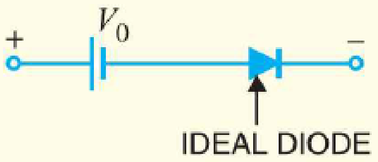
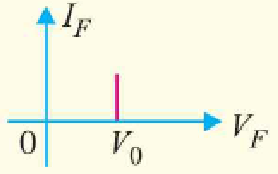
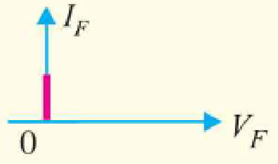
Figure: V-I Characteristics of PN junction

Semiconductor Diode

- A pn junction is known as semiconductor diode.



Crystal Diode Equivalent Circuits

S.No.	Type	Model	Characteristic
1.	Approximate model		
2.	Simplified model		
3.	Ideal Model		

Effect of temperature variation on pn junction diode

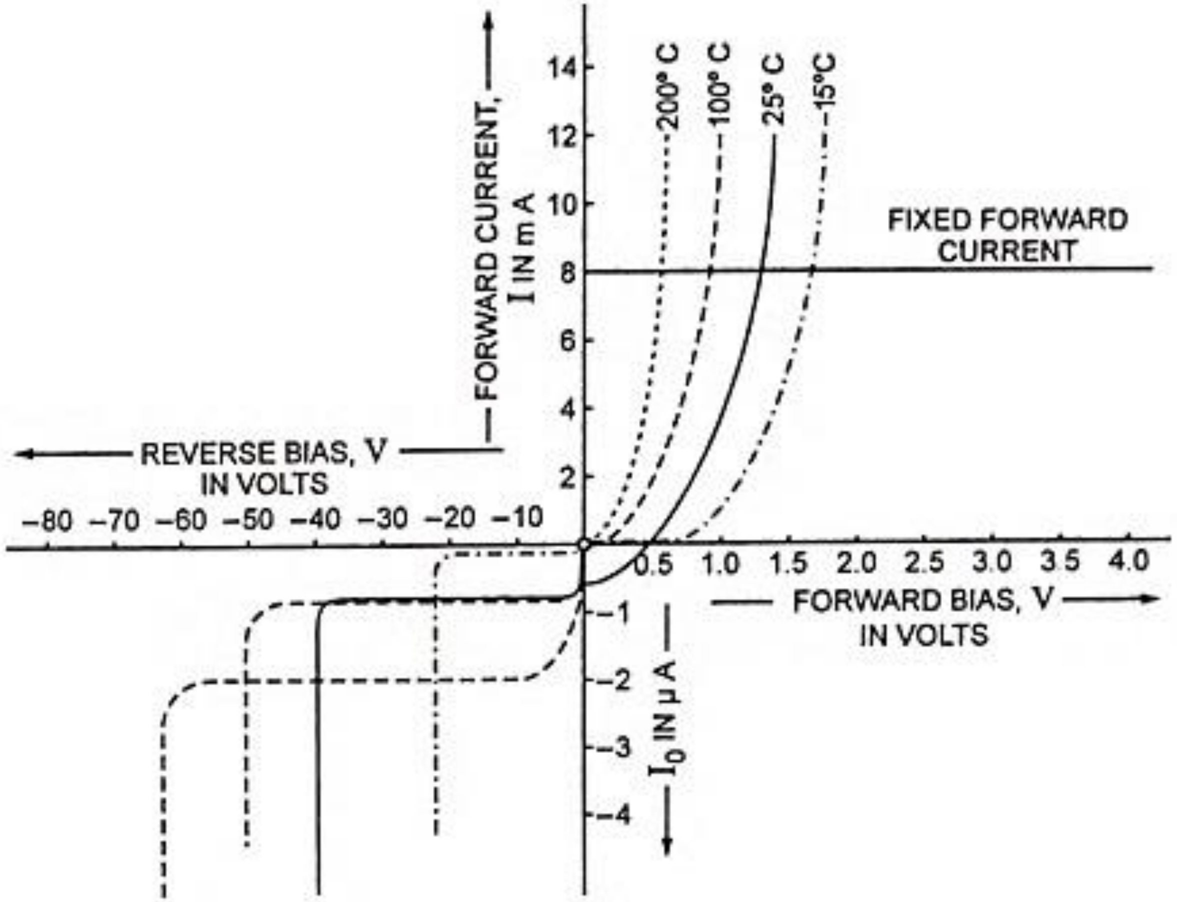


Fig. 7.18 *Variation in Diode Characteristics With Variations in Temperature*

Diode Equation: $$I_D = I_s\left(e^{V_D/nV_T} - 1\right)$$

- I_D is the total diode current
- I_s reverse saturation current
- V_D applied voltage across the diode
- n an ideality factor, value between 1&2.
- V_T thermal voltage:

$$V_T = \frac{kT}{q}$$

k = 1.38 x 10^{-23} J/K
q = 1.6x10^{-19} C

PN junction diode parameters like reverse saturation current, bias current, reverse breakdown voltage and barrier voltage are dependent on temperature.

- Mathematically diode current is given by

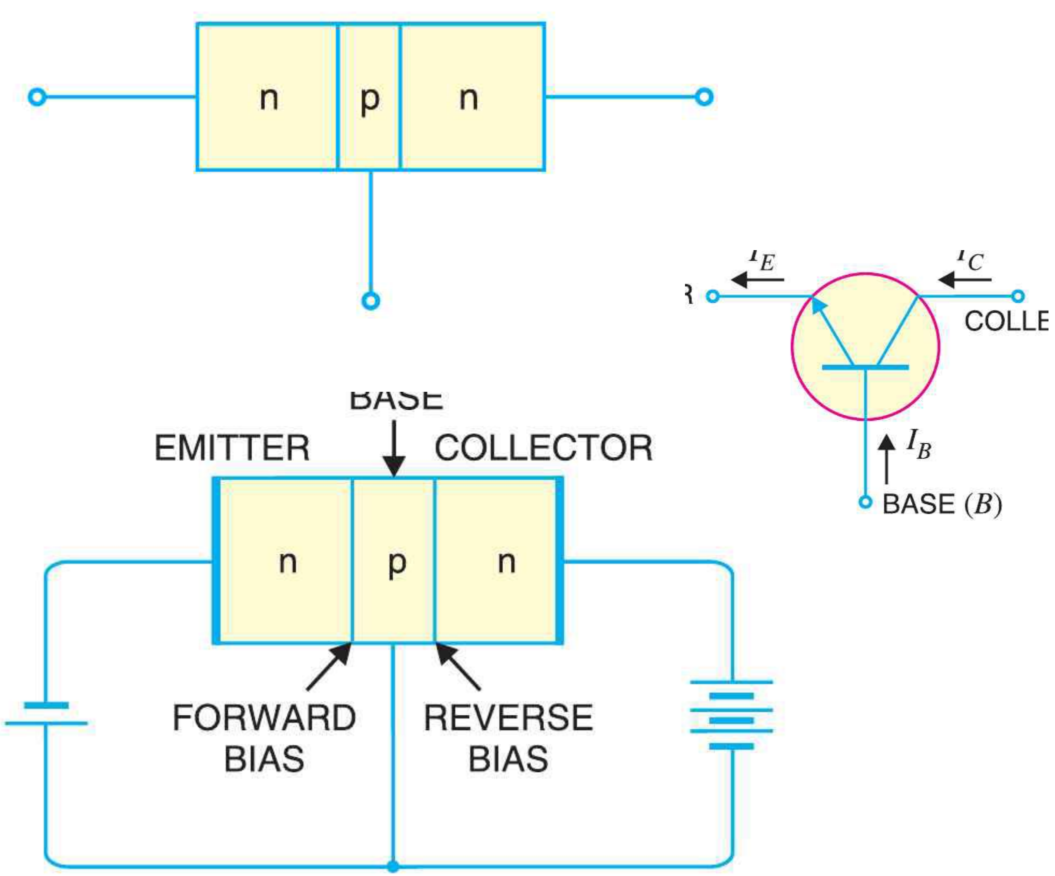
$I_D = I_s * (\exp((V_D / (n * k * T/q))) - 1)$

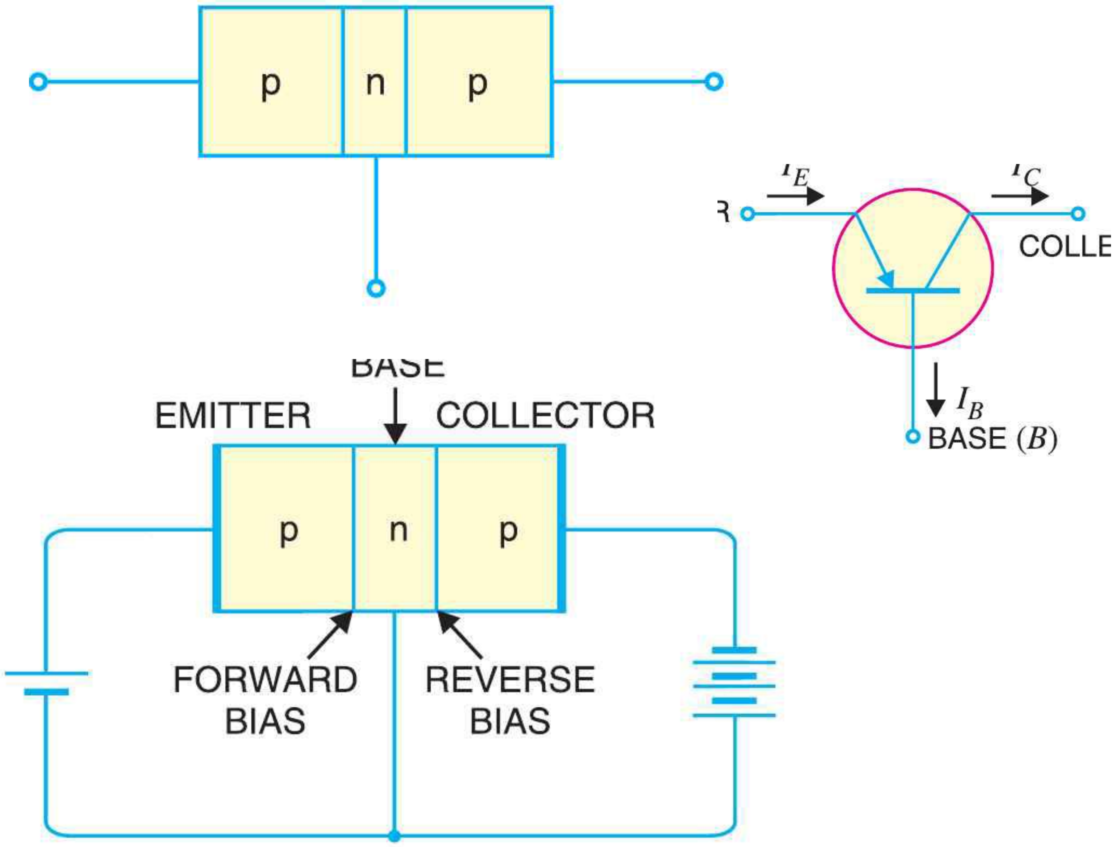
- Rise in temperature generates more electron-hole pair thus conductivity increases and thus increase in current
- Increase in reverse saturation current with temperature offsets the effect of rise in temperature
- Reverse saturation current (I_s)of diode increases with increase in the temperature, the rise is 7%/°C for both germanium and silicon and approximately doubles for every 10°C rise in temperature.

Transistor

A **transistor** *consists of two pn junctions formed by *sandwiching either p-type or n-type semiconductor between a pair of opposite types.* Accordingly ; there are two types of transistors, namely;

(*i*) *n-p-n* transistor (*ii*) *p-n-p* transistor



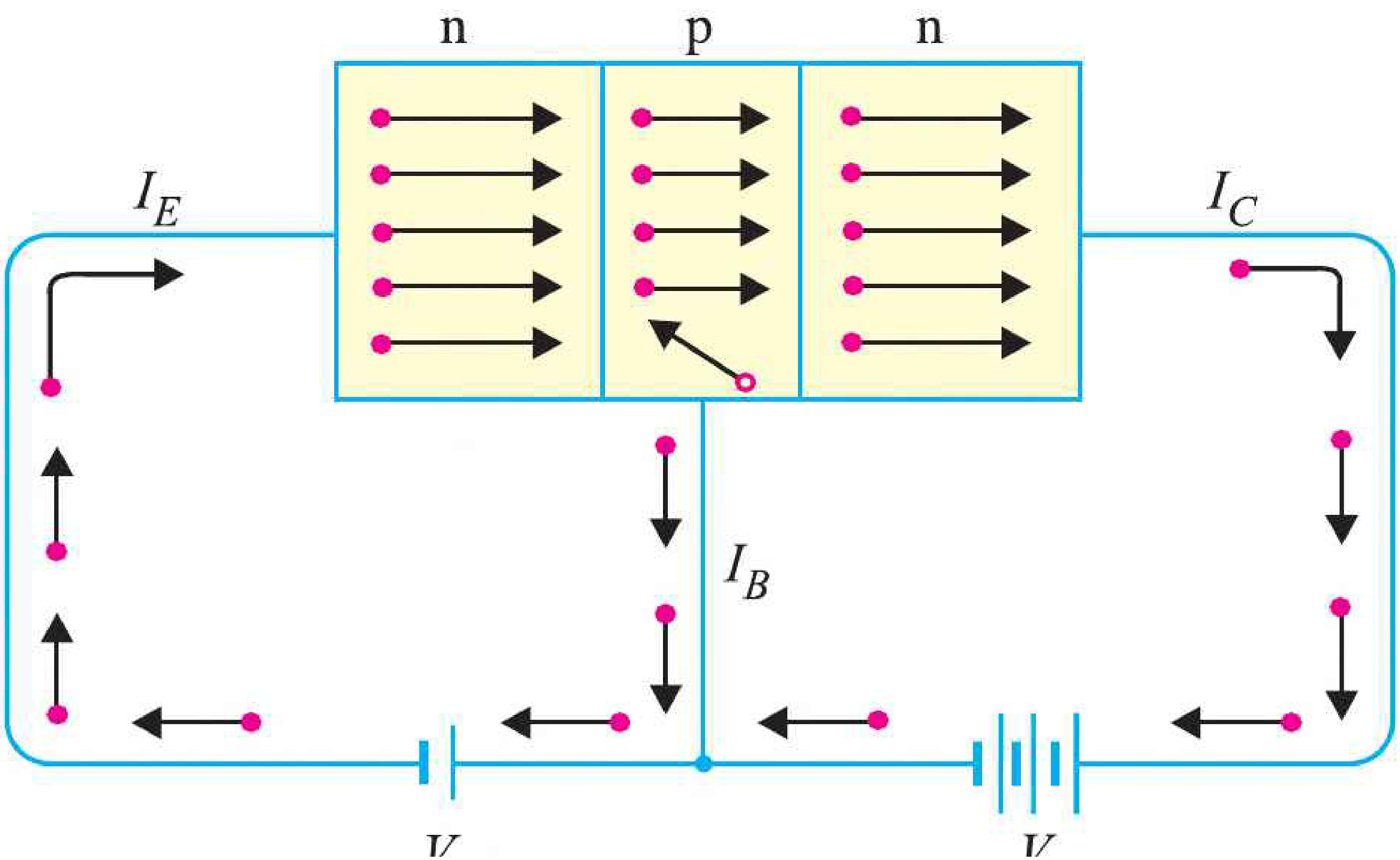


(*i*) The transistor has three regions, namely ; *emitter*, *base* and *collector*. The base is much thinner than the emitter while collector is wider than both as shown in Fig. However, for the sake of convenience, it is customary to show emitter and collector to be of equal size.

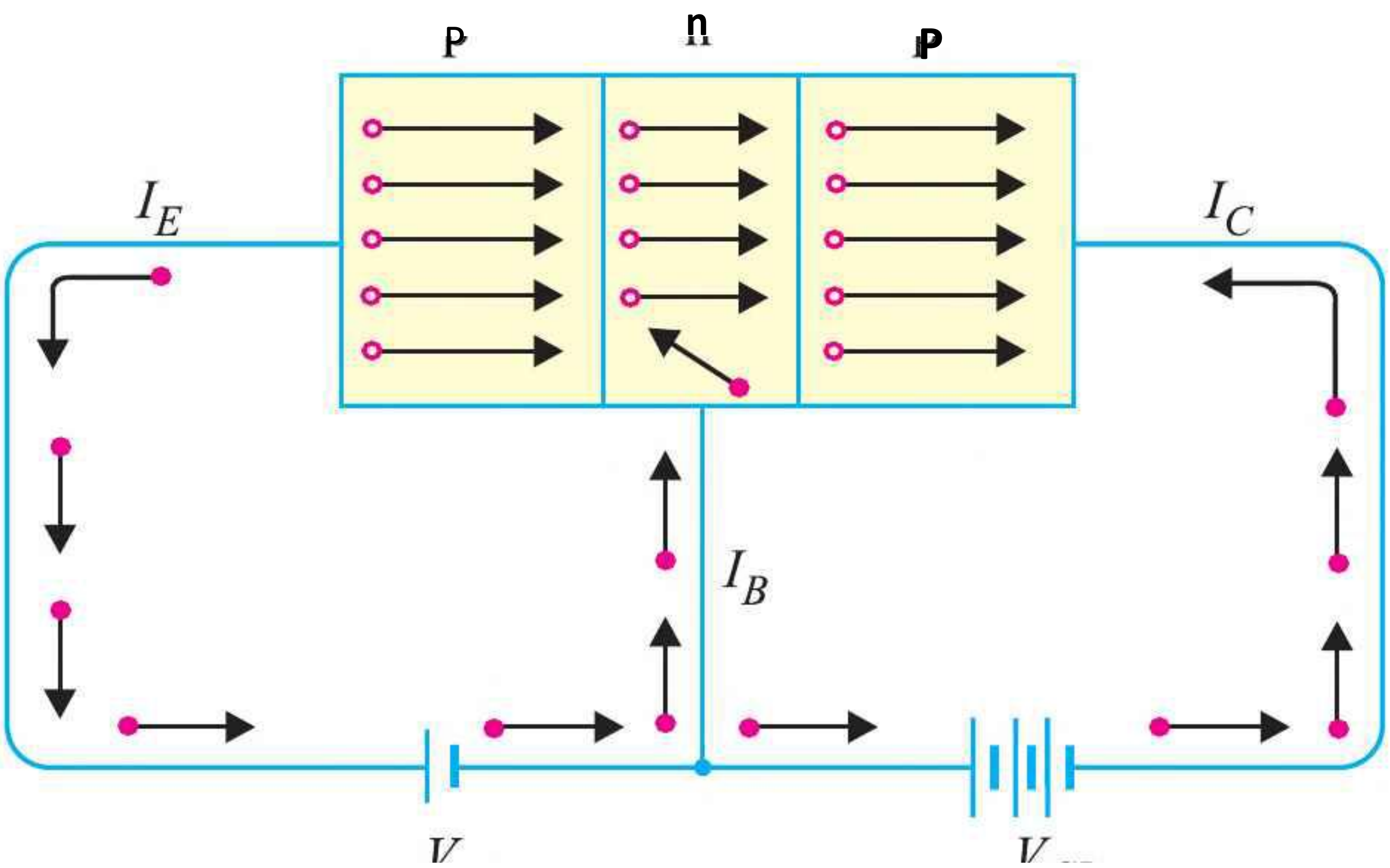
(*ii*) The emitter is heavily doped so that it can inject a large number of charge carriers (electrons or holes) into the base. The base is lightly doped and very thin ; it passes most of the emitter injected charge carriers to the collector. The collector is moderately doped.

$$I_E = I_B + I_C$$

Working of npn transistor.



Working of pnp transistor.



Transistor Connections

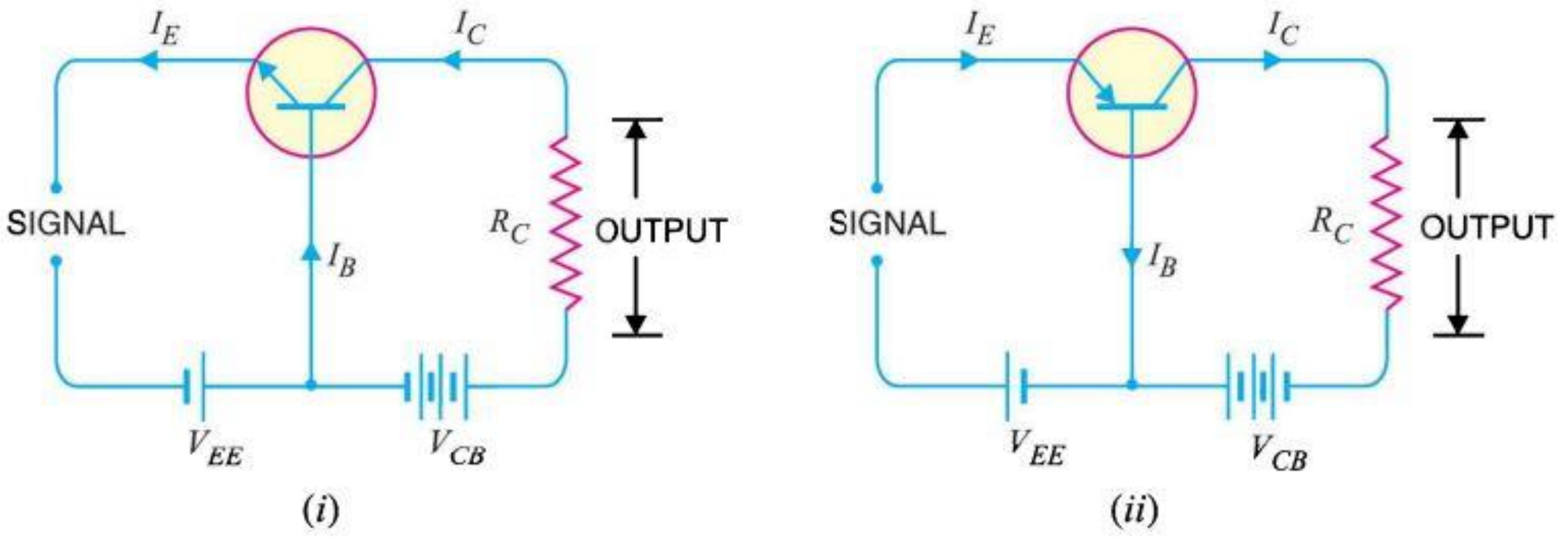
(*i*) common base connection

(*ii*) common emitter connection

(*iii*) common collector connection

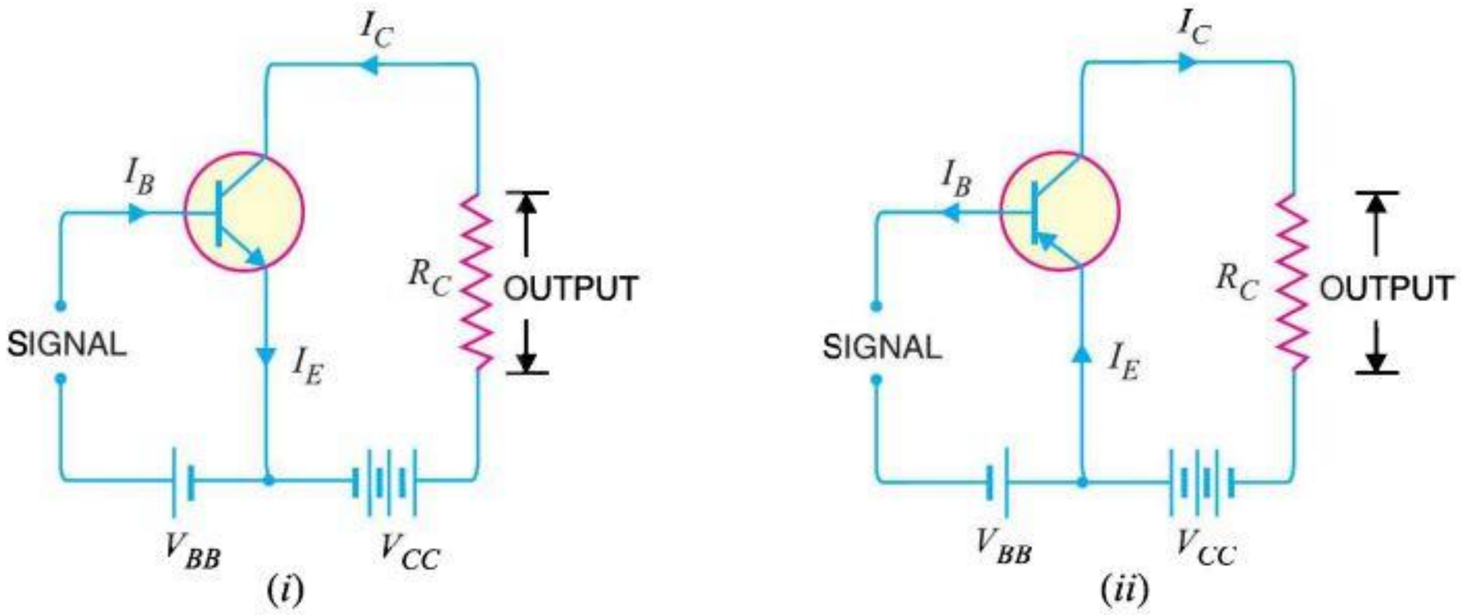
S. No.	Characteristic	Common base	Common emitter	Common collector
1.	Input resistance	Low (about 100 Ω)	Low (about 750 Ω)	Very high (about 750 kΩ)
2.	Output resistance	Very high (about 450 kΩ)	High (about 45 kΩ)	Low (about 50 Ω)
3.	Voltage gain	about 150	about 500	less than 1
4.	Applications	For high frequency applications	For audio frequency applications	For impedance matching
5.	Current gain	No (less than 1)	High (β)	Appreciable

Common Base Connection



Current amplification factor, $\alpha = I_C/I_E$

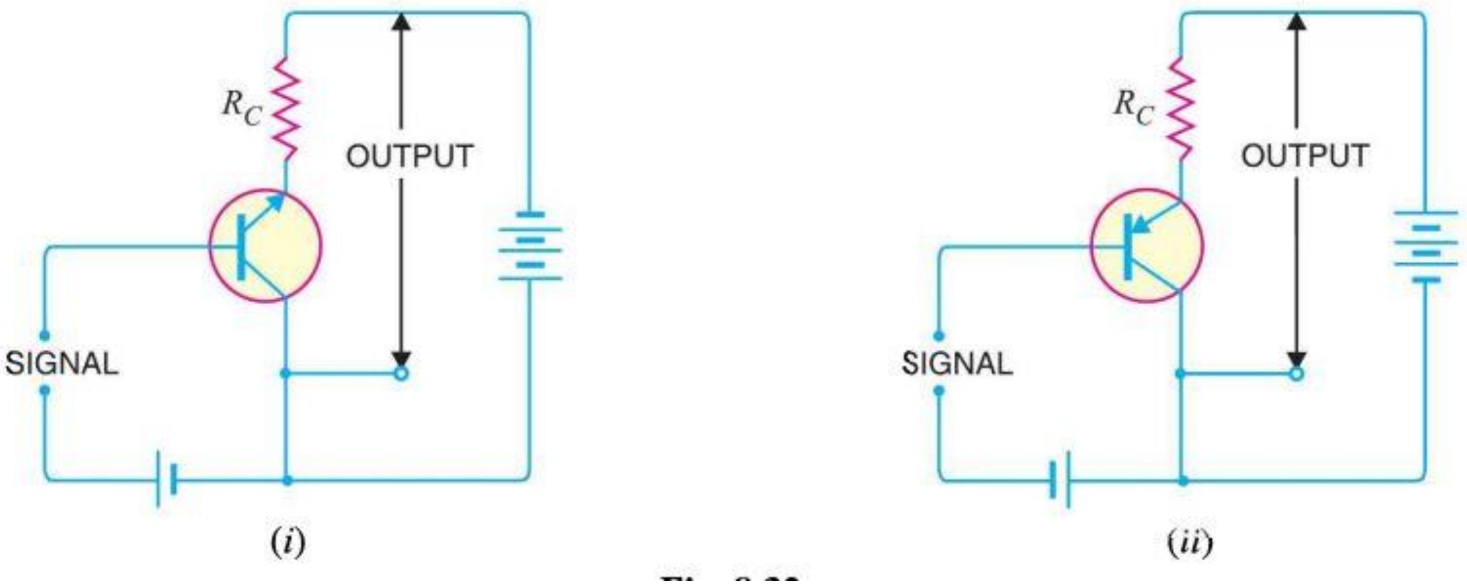
Common Emitter Connection



Current amplification factor, $\beta = I_C/I_B$

$$\beta = \alpha /(1-\alpha)$$

Common Collector Connection



Current amplification factor, $\gamma = I_E/I_B$

$$\gamma = 1/(1-\alpha)$$

1. Operating Point

The zero signal value of I_C and V_{CE} is known as operating point.

It is also known as Q- point or quiescent point.

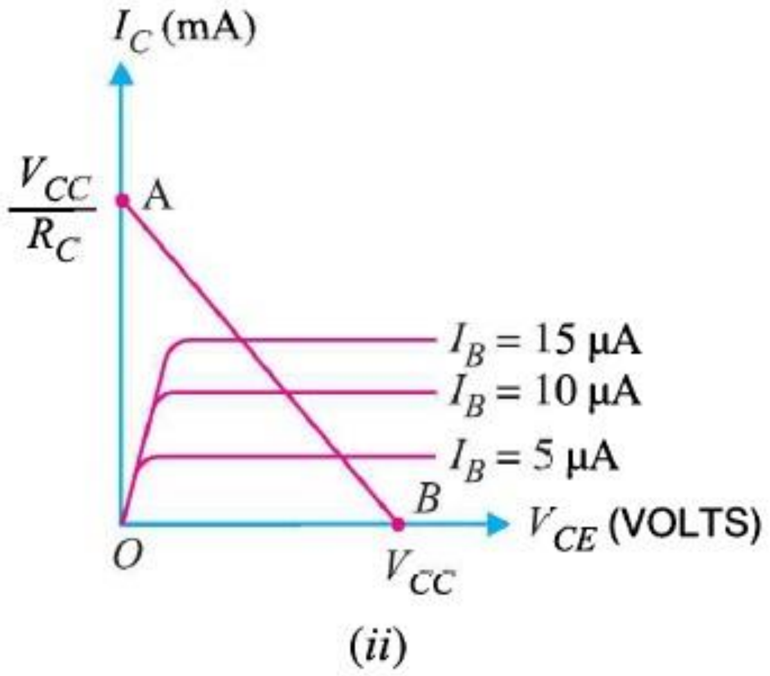
2. Biasing

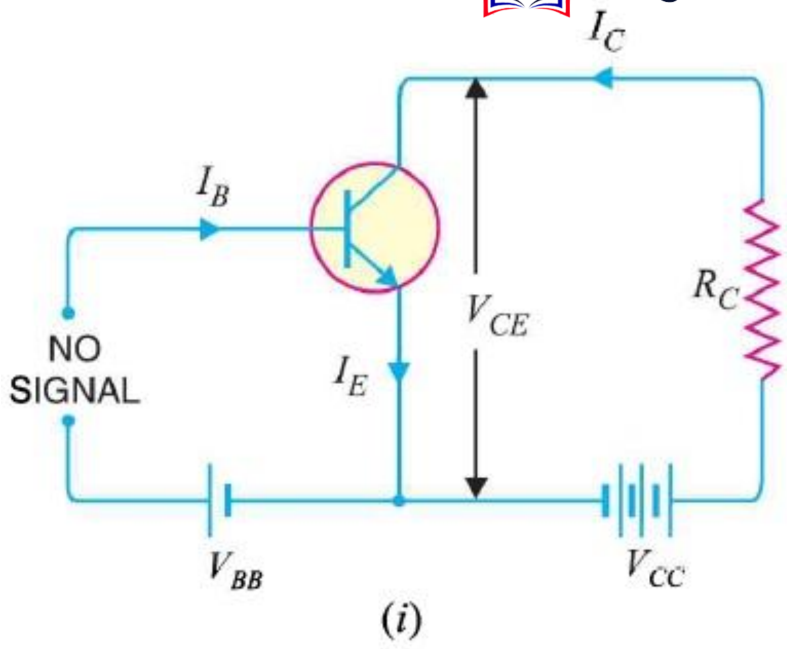
The proper flow of zero signal collector current and maintenance of proper collector-emitter voltage during passage of signal is known as transistor biasing.

The basic propose of transistor biasing is to keep base emitter junction properly forward biased and collector base junction properly reverse bias during the application of signal.

Biasing can be achieved with a bias battery or associating circuit with a transistor.

d.c. load line





The value of collector-emitter voltage V_{CE} at any time is given by

$$V_{CE} = V_{CC} - I_C R_C$$

When the collector current $I_C = 0$,

$$V_{CE} = V_{CC} - I_C R_C$$
$$= V_{CC}$$

When collector-emitter voltage $V_{CE} = 0$

$$V_{CE} = V_{CC} - I_C R_C$$
$$0 = V_{CC} - I_C R_C$$
$$I_C = V_{CC}/R_C$$

Transistor Biasing

The proper flow of zero signal collector current and the maintenance of proper collector-emitter voltage during the passage of signal is known as **transistor biasing.**

Methods of Transistor Biasing

(*i*) Base resistor method

(*ii*) Emitter bias method

(*iii*) Biasing with collector-feedback resistor

(*iv*) Voltage-divider bias

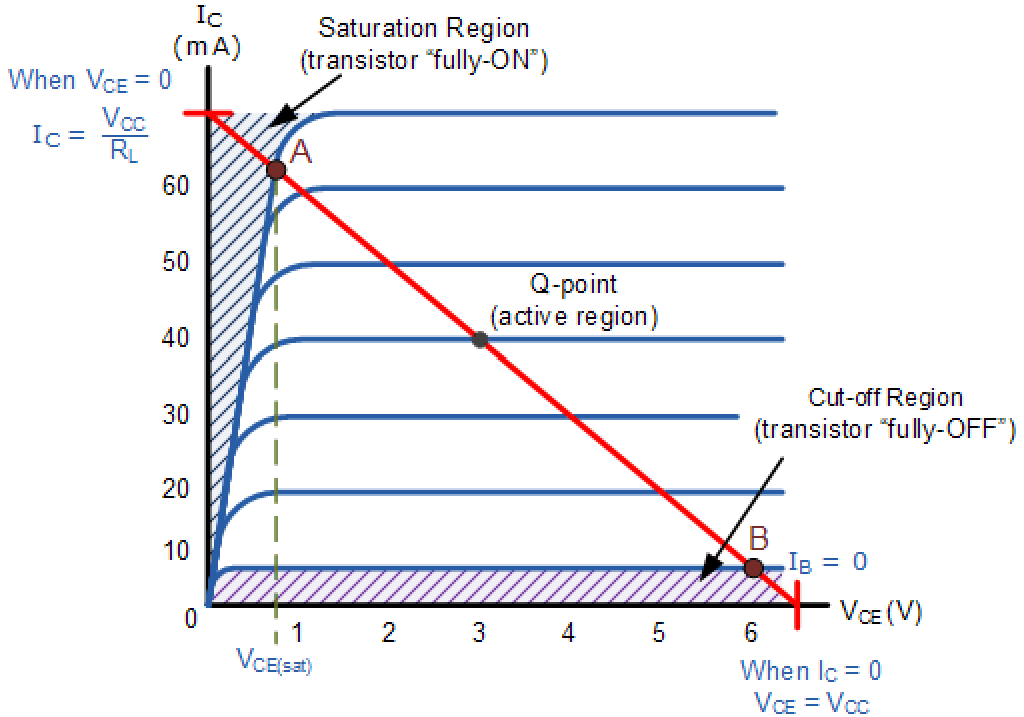
- Transistor can operate in three region:

1. Active region: Emitter base junction forward biased and collector base junction reverse biased.
2. Cut-off region: Both Emitter base junction and collector base junction reverse biased
3. Saturation region: Both Emitter base junction and collector base junction forward biased

Aplification: Active region

Swithc off : Cutoff region

Switch on: Saturation region

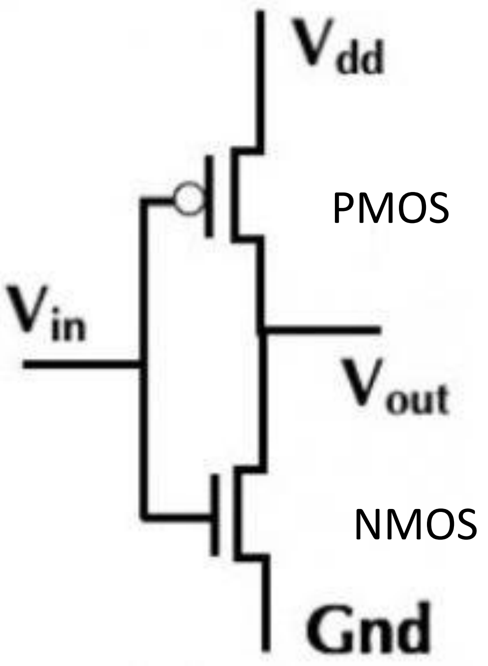


CMOS

- The term CMOS stands for “Complementary Metal Oxide Semiconductor”. This is one of the most popular technology in the computer chip design industry and it is broadly used today to form integrated circuits in numerous and varied applications. Today’s computer memories, CPUs, and cell phones make use of this technology due to several key advantages. This technology makes use of both P channel and N channel semiconductor devices. One of the most popular MOSFET technologies available today is the Complementary MOS or CMOS technology. This is the dominant semiconductor technology for microprocessors, microcontroller chips, memories like RAM, ROM, EEPROM and application-specific integrated circuits (ASICs).

- There are two primary types of MOSFETs: p-channel MOS (PMOS) and n-channel MOS (NMOS). Both PMOS and NMOS transistors use p-type and n-type semiconductors. In a PMOS transistor, the source and drain use a p-type semiconductor, and the substrate uses an n-type semiconductor. An NMOS transistor takes the opposite approach. The source and drain use an n-type semiconductor, and the substrate uses a p-type semiconductor.

INPUT	LOGIC INPUT	OUTPUT	LOGIC OUTPUT
0 v	0	Vdd	1
Vdd	1	0 v	0



CMOS technology has been used for the following digital IC designs.

- Computer memories, CPUs
- Microprocessor designs
- Flash memory chip designing
- Used to design application-specific integrated circuits (ASICs)

Transistor Hybrid model

h-parameters are obtained by following equations:

$V_1 = h_{11}\, i_1 + h_{12}\, v_2$ ....(i)

$i_2 = h_{21}\, i_1 + h_{22}\, v_2$ ....(ii)

h-parameters are:

h_{11} = hi = input resistance with output shorted (Ω)

h_{12} = hr = Reverse voltage gain with input open (V)

h_{21} = hf = Forward current gain with output shorted.

h_{22} = ho = Output conductance with input open.

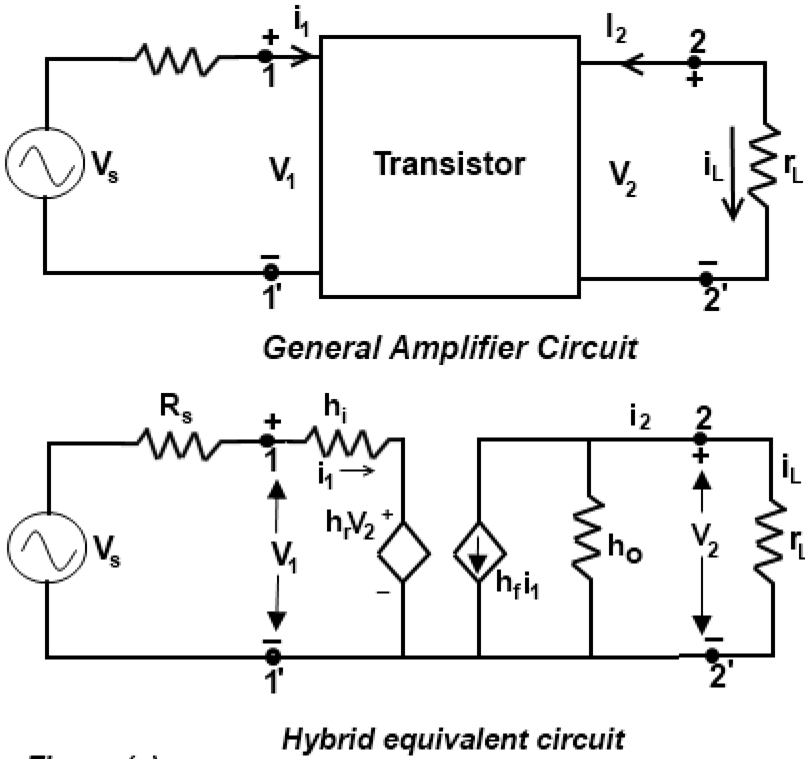


Figure (a)