UNIT – V

Bipolar Junction Transistors

Construction and working of Bipolar junction transistor, CB & CE configurations and characteristics, basic concepts of amplifiers, operational amplifiers.

→ A Bipolar Junction Transistor (BJT) is a three terminal semiconductor device in which the operation depends on the interaction of both majority and minority carriers and hence the name Bipolar.

→ Transistor is used in amplifier & oscillators & as a switch in digital circuits.

Construction:

→ The BJT consists of a silicon (or Germanium) crystal in which a thin layer of N-type silicon is sandwiched between two layers of P-type silicon. This transistor is referred as PNP transistor.

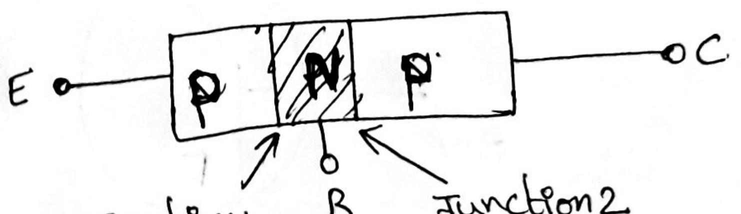


fig: PNP Transistor

→ In NPN transistor, a layer of P-type material is sandwiched between two layers of N-type material.

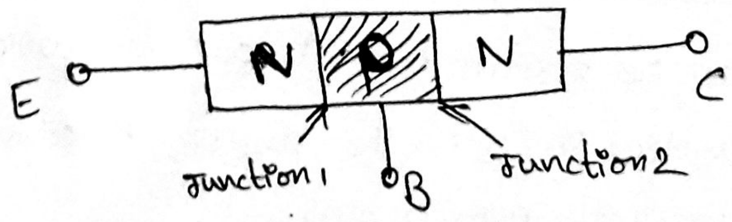


fig: NPN transistor.

-> The three portions of the transistor are Emitter, Base & collector, shown as E, B, & C respectively.

-> The arrow on the Emitter specifies the direction of current flow.

-> In each type of transistor, there are two PN Junctions (two depletion layers).

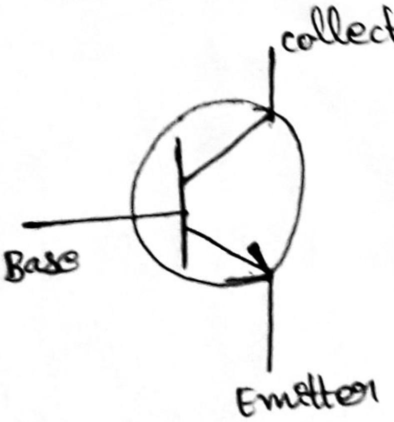
-> The middle section is very thin. This is the most important factor in the function of a transistor.

-> Emitter is heavily doped so that it can inject a large number of charge carriers into the base.

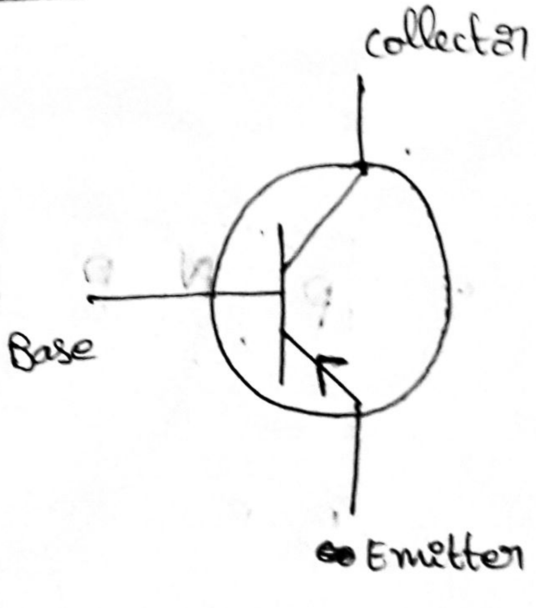
Base is lightly doped and very thin. It passes most of the injected charge carriers from the emitter into the collector.

Collector is moderately doped.

Transistor symbols:



NPN transistor



PNP transistor

-> The emitter has an arrowhead, the base is a straight line and collector is shaped like the emitter but without an arrowhead.

-> The arrow on the emitter indicates the direction of conventional current in the emitter with forward bias.

-> The base is much thinner than the emitter while collector is wider than both.

-> The emitter-base junction is always forward biased where as collector-base junction is reverse biased. This is the basic condition for the proper functioning of the transistor.

~~Working of Transistor.~~

Transistor Biasing :

-> The process of applying d.c voltages across the different terminals of a transistor is called biasing.

condition	Emitter-Base (EB) Junction	collector-Base (CB) Junction	Region of operation
1) Forward-Reverse (FR)	Forward Biased	Reverse Biased	Active Region
2) Forward-Forward (FF)	Forward Biased	Forward Biased	Saturation Region
3) Reverse-Reverse (RR)	Reverse Biased	Reverse Biased	Cutoff Region
4) Reverse-forward (RF)	Reverse Biased	forward Biased	Inverted.

Operation of transistor :

-> For normal operation the emitter-base junction is always forward biased while the collector-base junction is always reverse biased.

Working of npn transistor:

-> The npn transistor, Emitter-Base Junction is forward biased and collector-Base Junction is reverse biased.

-> The forward bias causes the electrons in the n-type emitter to flow towards the base.

-> This constitutes the emitter current I_E.

-> As these electrons flow through the p-type base, they tend to combine with holes.

-> As the base is lightly doped and very thin, therefore, only a few electrons (less than 5%) combine with the holes to constitute base current I_B.

-> The remaining (more than 95%) electrons cross over into the collector region to constitute collector current I_C.

-> In this way, almost the ~~end~~ entire emitter current flows in the collector circuit.

$\therefore$ Emitter current is the sum of collector current & Base current.

$$\boxed{I_E = I_B + I_C}$$

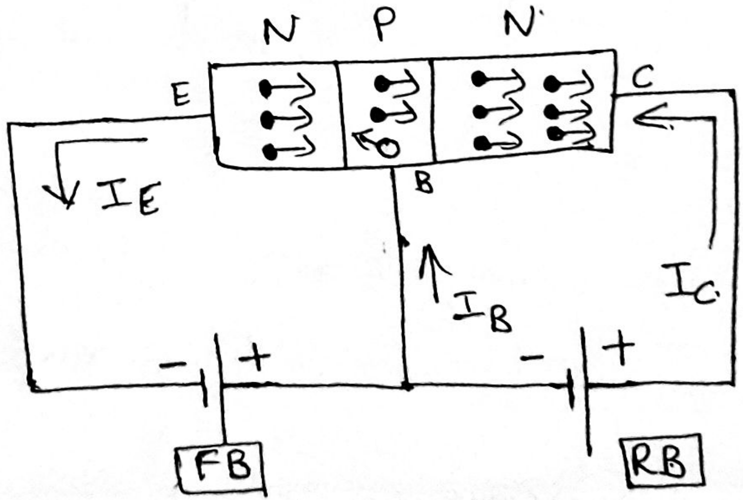


fig: current in NPN transistor.

working of PNP transistor:

-> PNP transistor, Emitter - Base junction is forward biased & collector - Base Junction is reverse biased.

-> The forward bias causes the holes in the p type emitter to flow towards the base.

-> this constitutes the emitter current. (I_E)

-> As these holes cross into the n-type base, they tend to combine with the electrons.

-> As the base is lightly doped & very thin, therefore, only a few holes (less than 5%) combine with the electrons.

-> the remaining (more than 95%) holes cross into the collector region to constitute collector current I_C.

-> In this way, almost the entire emitter current flows in the collector circuit.

$$\therefore \boxed{I_E = I_B + I_C}$$

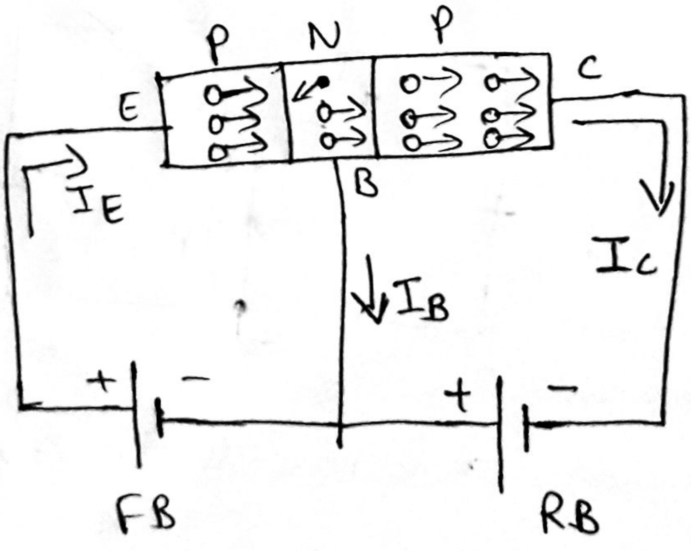


fig: current in PNP transistor.

Note: current conduction within PNP transistor is by holes.

→ It is seen that emitter current entirely flows in the collector circuit.

→ If the emitter current is zero, then collector current is nearly zero. However, if the emitter current is 1mA, then collector current is also about 1mA.

~~Types of config~~

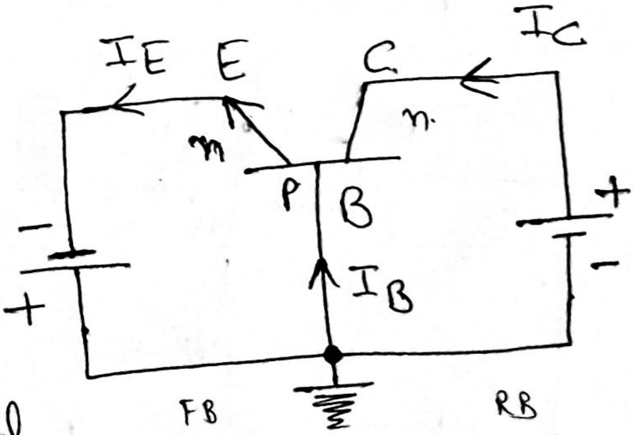
Types of configuration:

→ when a transistor is to be connected in a circuit, one terminal is used as an input terminal, the other terminal is used as an output terminal and the ~~tra~~ third terminal is common to the i/p & o/p.

→ Depending upon the input, output & common terminal, a transistor can be connected in three configurations.

→ They are (i) common Base configuration (CB) (ii) common emitter (CE) configuration (iii) common collector (CC) configuration.

(i) CB configuration:



→ This is also called grounded base configuration.

→ In this configuration, Emitter is the input terminal, collector is the output terminal and Base is the common terminal.

(ii) CE configuration :

→ this is also called grounded emitter configuration.

→ In this base is the input terminal, collector is the output terminal and emitter is the common terminal.

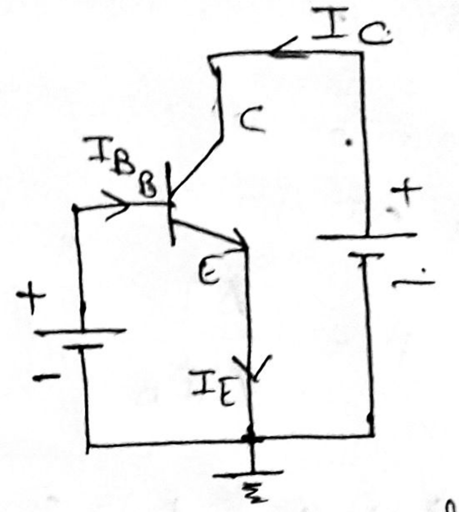


fig : CE configuration.

(iii) CC configuration:

→ this is also called grounded collector configuration.

→ In this Base is the input terminal, emitter is the output terminal and collector is the common terminal.

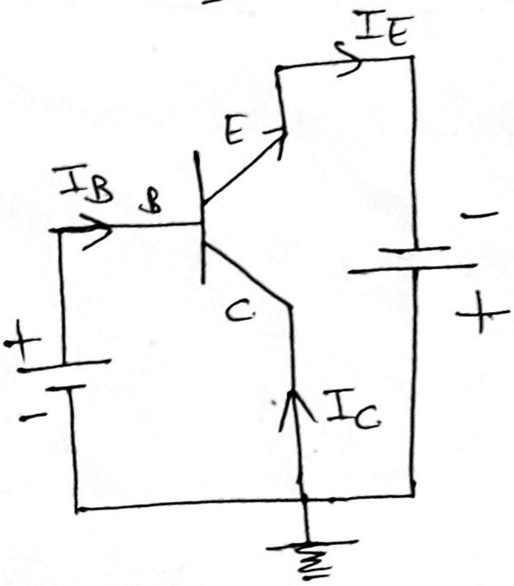


fig : CC configuration.

Definitions of α, β & γ :

Alpha factor (α) : It is also called as current amplification factor. and it is the ratio of collector current (I_C) to emitter current (I_E)

$$\boxed{\alpha = \frac{\Delta I_C}{\Delta I_E} \text{ at } V_{CB} \text{ remaining constant}}$$

→ current amplification factor α is less than unity. practical values of α in commercial transistors range from 0.9 to 0.99

Beta factor (β) : It is a current gain factor & also called as transport factor of a common emitter circuit. It is defined as the ratio of collector current (I_C) and base current (I_B).

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

→ ~~therefore~~, the value of β is generally greater than 20. usually, its value ranges from 20 to 500.

Gama (γ) factor : It is a current gain in common collector configuration and it is the ratio of emitter current and base current.

$$\boxed{\gamma = \frac{\Delta I_E}{\Delta I_B}}$$

→ It is also called emitter efficiency that how much current is injected from the emitter to base after recombination of minority charge carriers in base.

→ It's value is high compared to α, β.

Relationship between α and β :

$$\boxed{\because \Delta I_E = \Delta I_B + \Delta I_C}$$

$$\beta = \frac{\Delta I_C}{\Delta I_B} \quad \& \quad \alpha = \frac{\Delta I_C}{\Delta I_E} = \frac{\Delta I_C}{\Delta I_C + \Delta I_B}$$

$$\frac{1}{\alpha} = \frac{\Delta I_C + \Delta I_B}{\Delta I_C} = \frac{\cancel{\Delta I_C}}{\cancel{\Delta I_C}} + \frac{\Delta I_B}{\Delta I_C} = 1 + \frac{1}{\beta}$$

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

Hence $\boxed{\alpha = \frac{\beta}{1+\beta}}$ & $\boxed{\beta = \frac{\alpha}{1-\alpha}}$

$$\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{\Delta I_C}{\Delta I_E - \Delta I_C}$$

$\because I_E = I_B + I_C$

$I_E - I_C = I_B$

$$= \frac{\Delta I_C / \Delta I_E}{\Delta I_E/\Delta I_E - \Delta I_C/\Delta I_E}$$

$$= \frac{\alpha}{1-\alpha}$$

$$\boxed{\beta = \frac{\alpha}{1-\alpha}}$$

Common Base (CB) configuration:

-> In common base (CB) configuration, input is connected between emitter and base & output is taken across collector and base. Thus base is common between input & output circuits.

-> The emitter base junction is forward biased & collector-base junction is reverse biased.

-> The emitter current I_E flows in input circuit & collector current I_C in the output circuit.

-> The common base configuration circuit has low resistance emitter-base circuit & high resistance collector-Base circuit.

-> current Amplification factor $\boxed{(\alpha) = \frac{\Delta I_C}{\Delta I_E}}$

Collector current :

-> The collector current consists of two parts

(i) The current produced by normal transistor action i.e., emitter current (αI_E) which is produced by majority charge carriers.

(ii) the leakage current due to movement of minority carriers across base-collector junction (collector base current with emitter open)

leakage current is abbreviated as I_{CBO}.

$\therefore$ collector current $I_C = \alpha I_E + I_{CBO}$

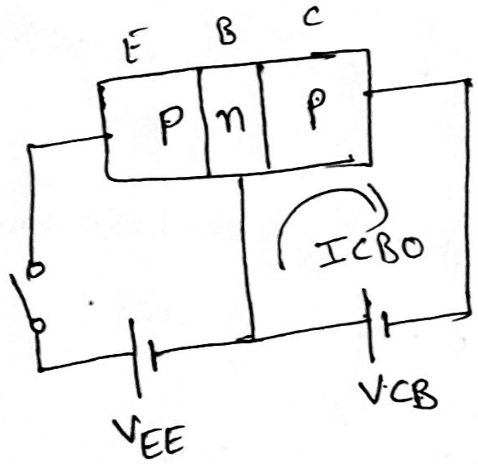
$$\boxed{I_E = I_B + I_C}$$

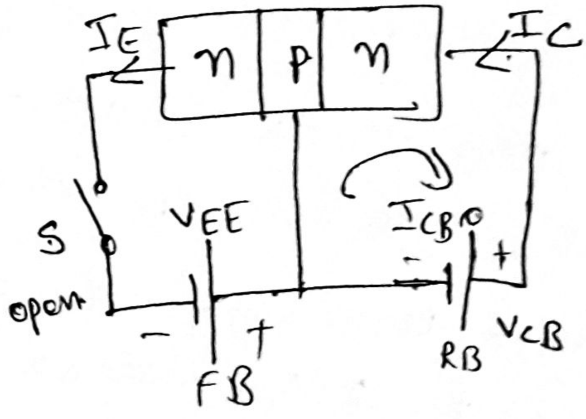
Base current $I_B = I_E - I_C$

$$= I_E - \alpha I_E + I_{CBO}$$

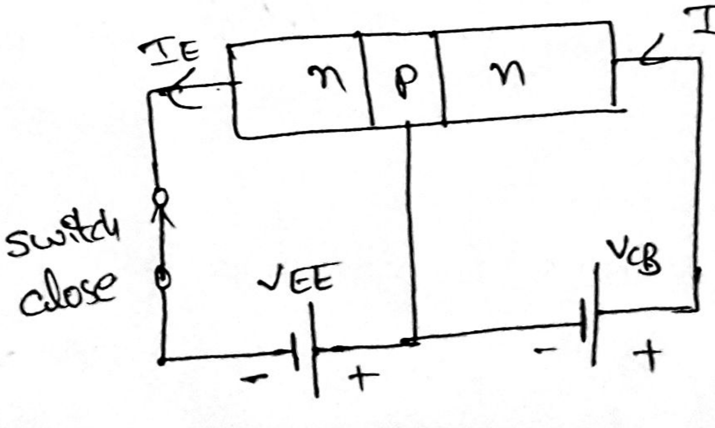
$$= I_E(1-\alpha) + I_{CBO}$$

$$\boxed{\begin{aligned} I_C &= \alpha I_E + I_{CBO} \\ I_B &= (1-\alpha) I_E + I_{CBO} \end{aligned}}$$





$I_C = \alpha I_E + I_{CBO}$



Input characteristics :

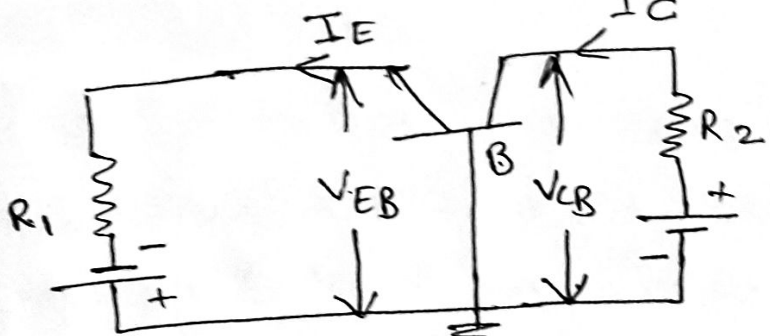
→ It is the curve between emitter current (I_E) & emitter-base voltage V_{EB}.

→ The emitter current I_E is generally taken along Y-axis & emitter-base voltage (V_{EB}) along X-axis.

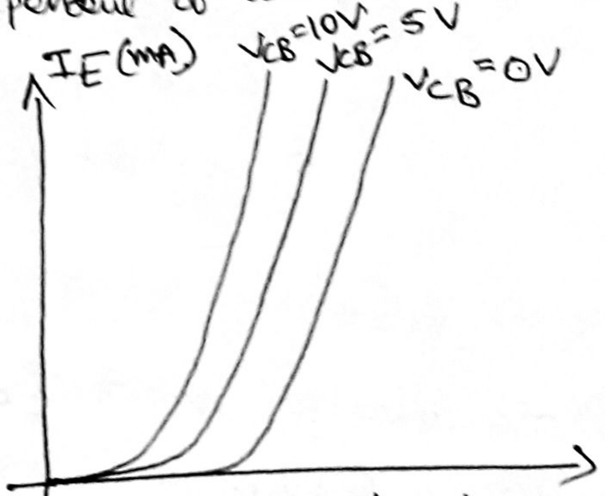
→ Two things are worth noting about these characteristics.

1) the emitter current I_E increases rapidly with small increase in emitter base voltage V_{EB}. It means input resistance is very small.

2) emitter current is almost independent of collector base voltage V_{CB}.



circuit diagram



Input characteristics V_{EB} of CB configuration

Input resistance : It is the ratio of change in emitter-base voltage (ΔV_{EB}) to the resulting change in emitter current (ΔI_E) at constant collector-base voltage (V_{CB})

$$\boxed{\text{Input resistance } r_i = \frac{\Delta V_{EB}}{\Delta I_E} \text{ at constant } V_{CB}}$$

→ Input resistance is quite small, of the order of a few ohms.

output characteristics

→ It is the curve between collector current I_C and collector-base voltage (V_{CB}) at constant emitter current I_E.

→ collector current is taken along Y-axes & collector-base voltage along X-axes.

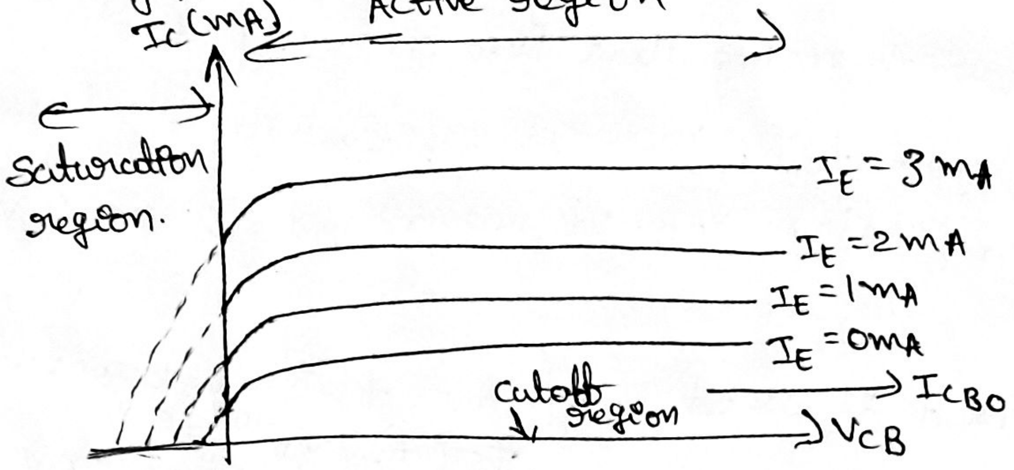


fig: output characteristics.

→ the following points may be noted from the characteristics:-

(i) The collector current I_C varies with V_{CB} only at very low voltages (<1V). The transistor is never operated in this region.

(ii) when the value of V_{CB} is raised above 1-2V, ~~then~~ the collector current becomes constant as indicated by straight horizontal curves.

→ It means that now I_C is independent of V_{CB} and depends upon I_E only.

→ The transistor is always operated in this region.

(iii) A very large change in collector-base voltage produces only a tiny change in collector current. This means that output or resistance is ~~very~~ very high.

output resistance : It is the ratio of change in collector-base voltage (ΔV_{CB}) to the resulting change in collector current (ΔI_C) at constant emitter current.

$$\boxed{\text{output resistance } r_o = \frac{\Delta V_{CB}}{\Delta I_C} \text{ at constant } I_E}$$

→ The output resistance of CB circuit is very high, of the order of several tens of Kilo-ohms.

Common Emitter connection :

→ In common Emitter configuration, input is connected between base and emitter & output is taken across collector and Emitter. thus emitter is common between input and output circuits.

→ Base current I_B flows in input circuit and collector current I_C flows in output circuit.

→ current amplification factor $\beta = \dfrac{\Delta I_C}{\Delta I_B}$

→ As we know the relationship between α & β.

$$\boxed{\beta = \frac{\alpha}{1-\alpha}}$$

α is approximately equal to unity. & β approaches infinity.

i.e., the current gain of common emitter configuration is very high.

→ Due to this reason common emitter configuration circuit is mostly used for transistor applications.

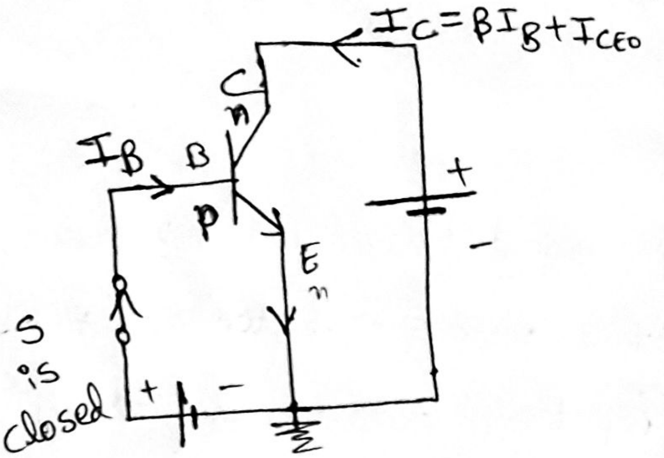
collector current :

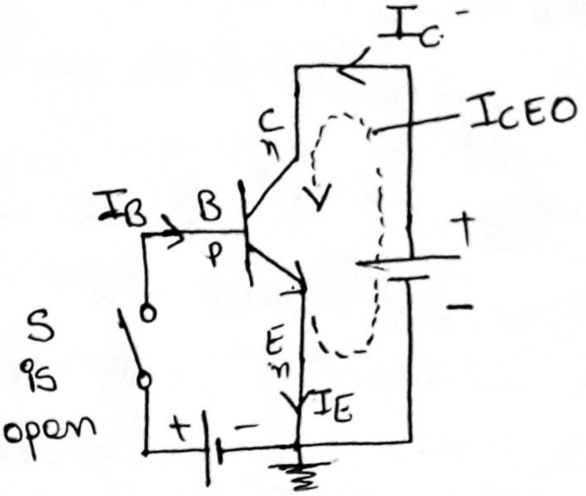
→ collector current consists of two parts.

(i) when switch S is closed, base current I_B causes a collector current (βI_B) to flow in the collector circuit.

(ii) The leakage current is due to minority charge carriers & it flows from collector to emitter when switch S is open.

It is abbreviated as I_{CEO}.





$$\boxed{\text{collector current } I_C = \beta I_B + I_{CEO}}$$

Relation between I_{CBO} & I_{CEO}

collector current of CE configuration = collector current of CB configuration

$$\therefore I_C = \alpha I_E + I_{CBO}$$

$$\boxed{\because I_E = I_B + I_C}$$

$$\because \beta = \frac{\alpha}{1-\alpha}$$

$$I_C = \alpha(I_B + I_C) + I_{CBO}$$

$$I_C = \alpha I_B + \alpha I_C + I_{CBO}$$

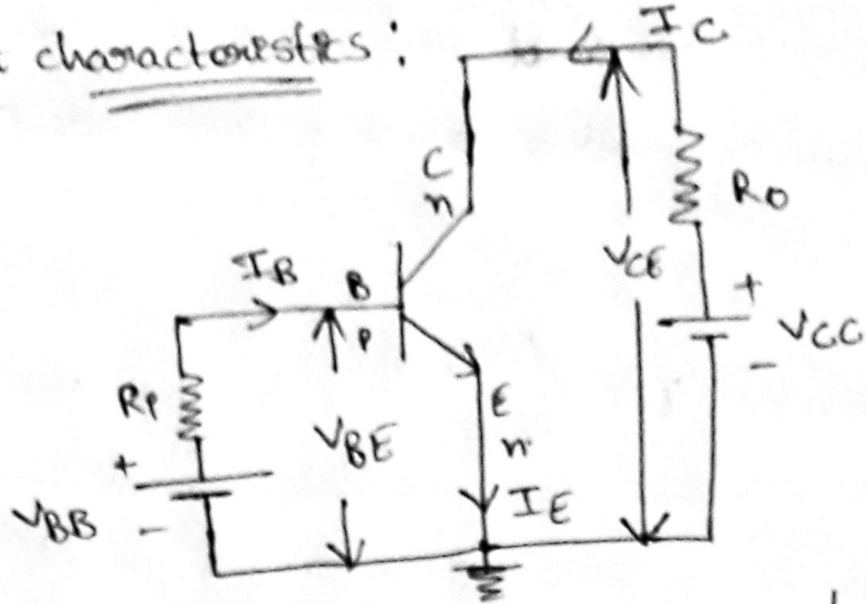
$$I_C - \alpha I_C = \alpha I_B + I_{CBO}$$

$$(1-\alpha) I_C = \alpha I_B + I_{CBO}$$

$$I_C = \frac{\alpha}{1-\alpha} I_B + \underbrace{\frac{1}{1-\alpha} I_{CBO}}_{\to I_{CEO}}$$

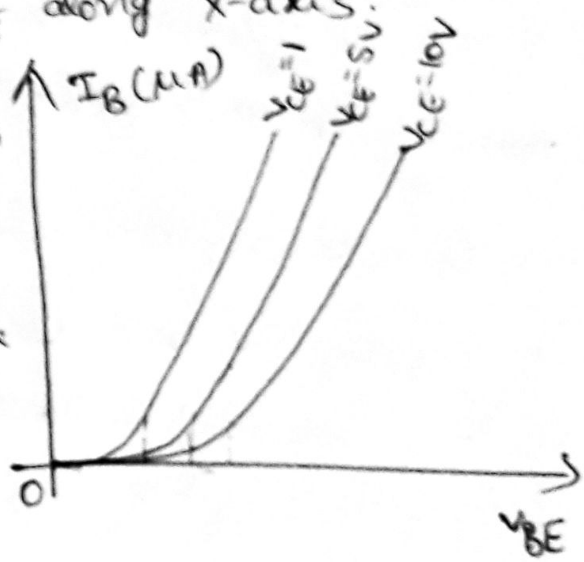
$$\boxed{I_C = \beta I_B + I_{CEO}} \qquad \boxed{\therefore I_{CEO} = \frac{I_{CBO}}{1-\alpha}}$$

Input charactoristics:



→ It is the curve between base current I_B and base-emitter voltage V_{BE} at constant collector-emitter voltage V_{CE}.

→ I_B taken along Y-axis and V_{BE} along X-axis.



The following points may be noted from the charactoristics.

(i) The charactoristics resemble those of a forward biased diode curve. This is expected since the base-emitter section of the transistor is a diode that is forward biased.

(ii) As compared to CB arrangement, I_B ~~increased~~ increases less rapidly with V_{BE}. Therefore, input resistance of a CE circuit is higher than that of CB circuit.

"By varying V_{BE}, I_B is noted and keeping V_{CE} is constant".

Input resistance: It is the ratio of change in base-emitter voltage (ΔV_{BE}) to the resulting ~~voltage~~ change in base current (ΔI_B) at constant V_{CE}.

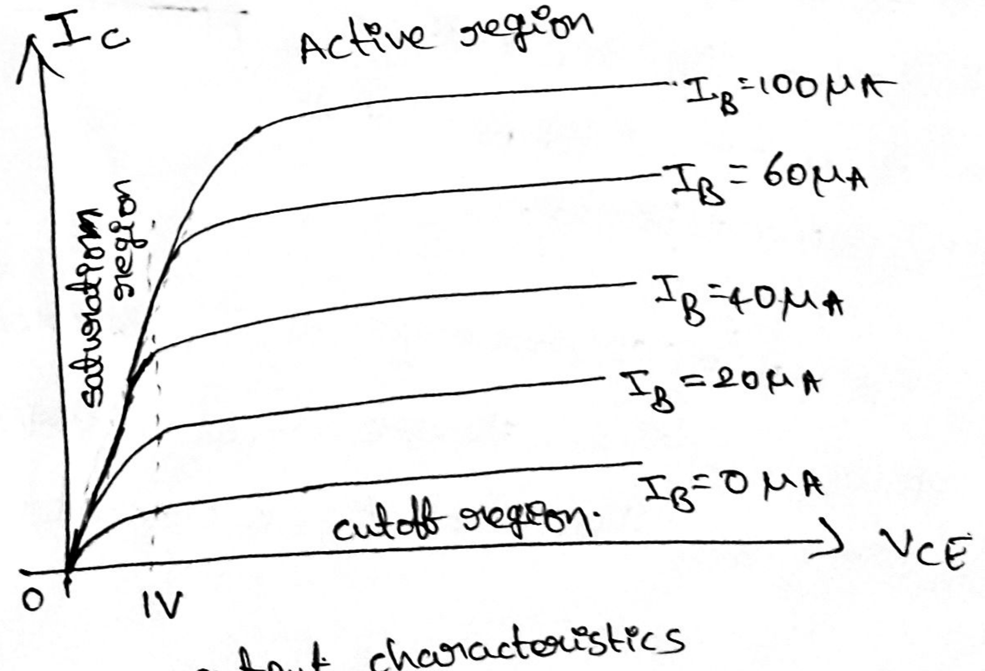
$$\boxed{\text{Input resistance } r_i = \frac{\Delta V_{BE}}{\Delta I_B} \text{ at constant } V_{CE}}$$

→ Input resistance of CE is greater than input resistance of CB.

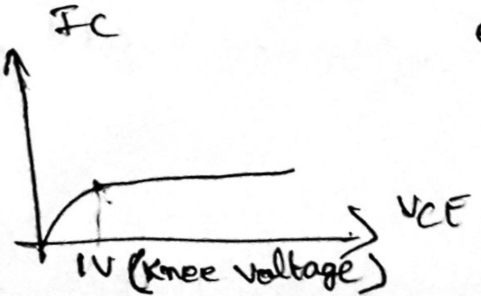
Output characteristics:

→ It is the curve between collector current I_C and collector-emitter voltage V_{CE} at constant base current I_B.

→ I_C taken along Y-axes and V_{CE} ~~is~~ taken along X-axes. Keeping the base current I_B fixed, note the collector current I_C for various values of V_{CE}.



output characteristics



The following points may be noted from the characteristics :

(i) The collector current I_C varies with V_{CE} for V_{CE} between (0 and 1V). After this, collector current becomes almost constant and independent of V_{CE}. This value of V_{CE} upto which collector current I_C changes is called the Knee voltage (V_{knee}).

→ The transistor always operates in the region above Knee voltage.

(ii) Above Knee voltage, I_C is almost constant.

output resistance : It is the ratio of change in collector-emitter voltage (ΔV_{CE}) to the resulting change in collector current (ΔI_C) at constant I_B.

$$\boxed{\text{output resistance } r_o = \frac{\Delta V_{CE}}{\Delta I_C} \text{ at constant } I_B}$$

note:
→ output resistance of CE configuration is less than that in CB configuration.

① In a transistor collector current is 50mA and base current is 0.5mA, find the current amplification factor α?

sol: Given data :

$I_C = 50mA$

$I_B = 0.5mA$

$I_E = I_B + I_C$

$= 50 + 0.5 = 50.5mA$

$$\alpha = \frac{I_C}{I_E} = \frac{50mA}{50.5mA}$$

$$\alpha = 0.99$$

Configuration / Characteristics	Common Base configuration	Common Emitter configuration	Common collector configuration.
Input resistance	Low (about 100 Ω)	Medium (about 800 Ω)	very high (about 750kΩ)
output Resistance	very high (about 500k Ω)	High (about 50K Ω)	low (about 50 Ω)
current gain (α, β & γ)	α is less than unity 0.9 to 0.99	β value is high. (20 to 500)	γ value is also high (about 100)
voltage gain	About 150	About 500	Less than unity
Leakage current	very small (5μA for Ge & 1μA for Si)	very large (500μA for Ge & 20μA for Si)	very large
Applications	For high frequency applications	For AF Applications	For impedence matching.