Bipolar Junction Transistor (BJT)

BPT: 401: Electronics and Modern Physics

Tutorial – 10

Banaras Hindu University 26/05/2021

Sterlin

Bipolar Junction Transistors (BJT)

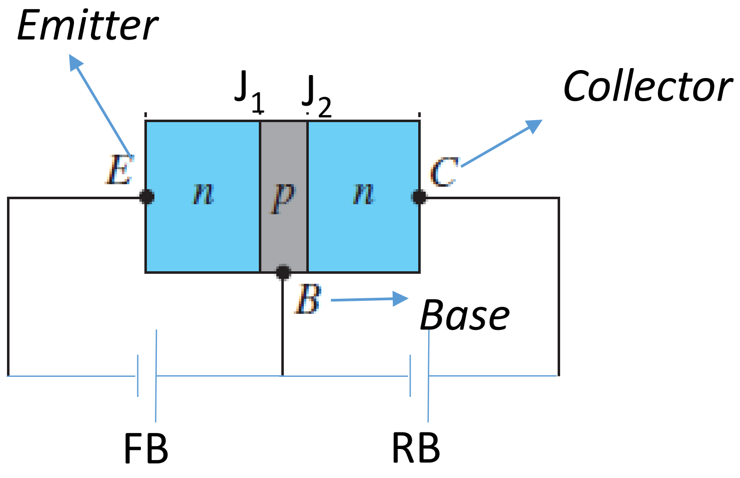
1. **Emitter**
2. **Base**
3. **Collector**

The transistor is a three terminal device having three-layer semiconductor consisting of either two *N-type* and one *P*-type layers or two *P-type* and one *N*-type layers of material. The former is called an ***NPN transistor***, and the latter is called a ***PNP transistor***.

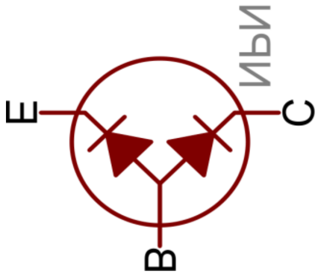
A Transistor consists of two PN junctions (J_1 and J_2).

B **J** **T**

Bipolar (both electrons and holes are involved)



Junction
(J_1, J_2)



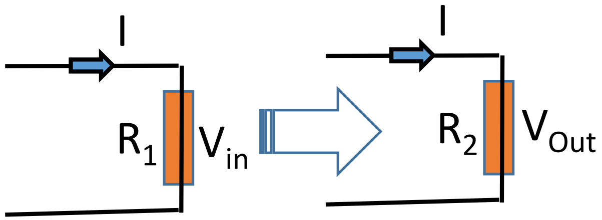
Two PN junction diode connected back to back

Transistor – Transferred Resistor

Active Mode:

J_1 – Forward Biased (FB) & J_2 – Reverse Biased (RB)

Junction Resistance: $R_1 \approx 0$, $R_2 \approx \infty$

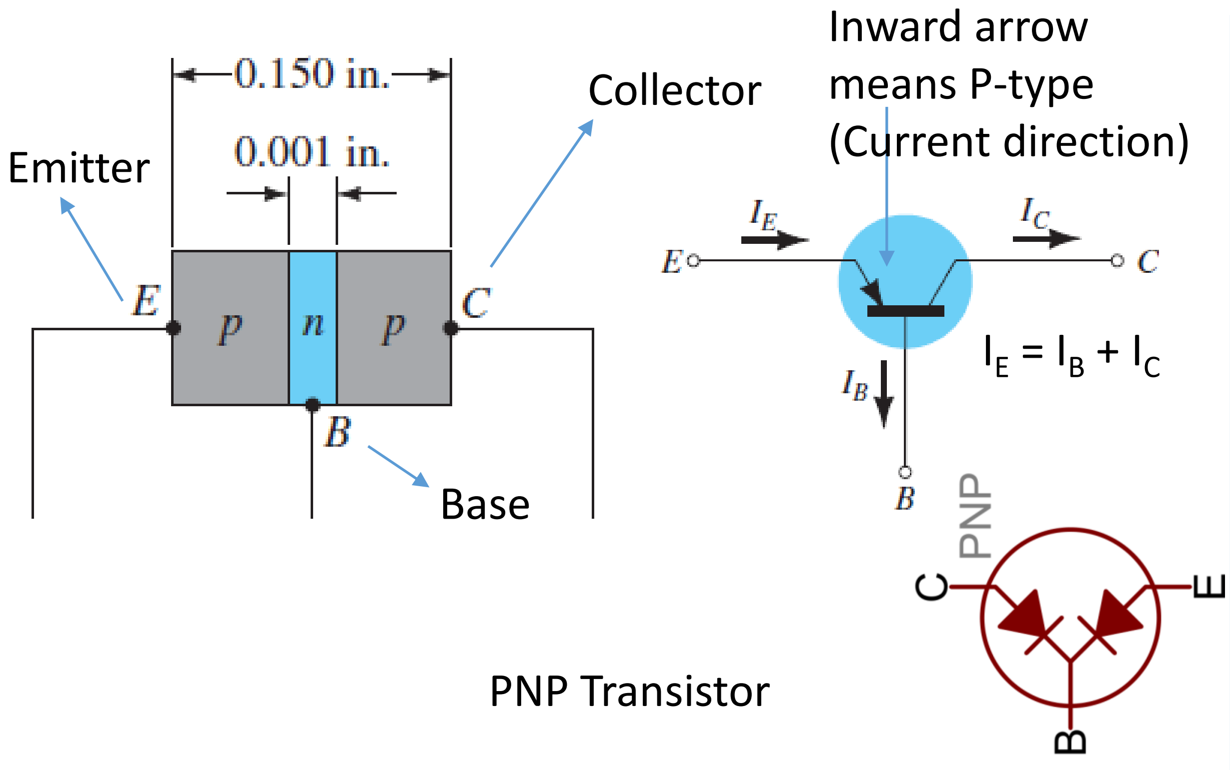


$V_{in} = I \times R_1$ $V_{Out} = I \times R_2$

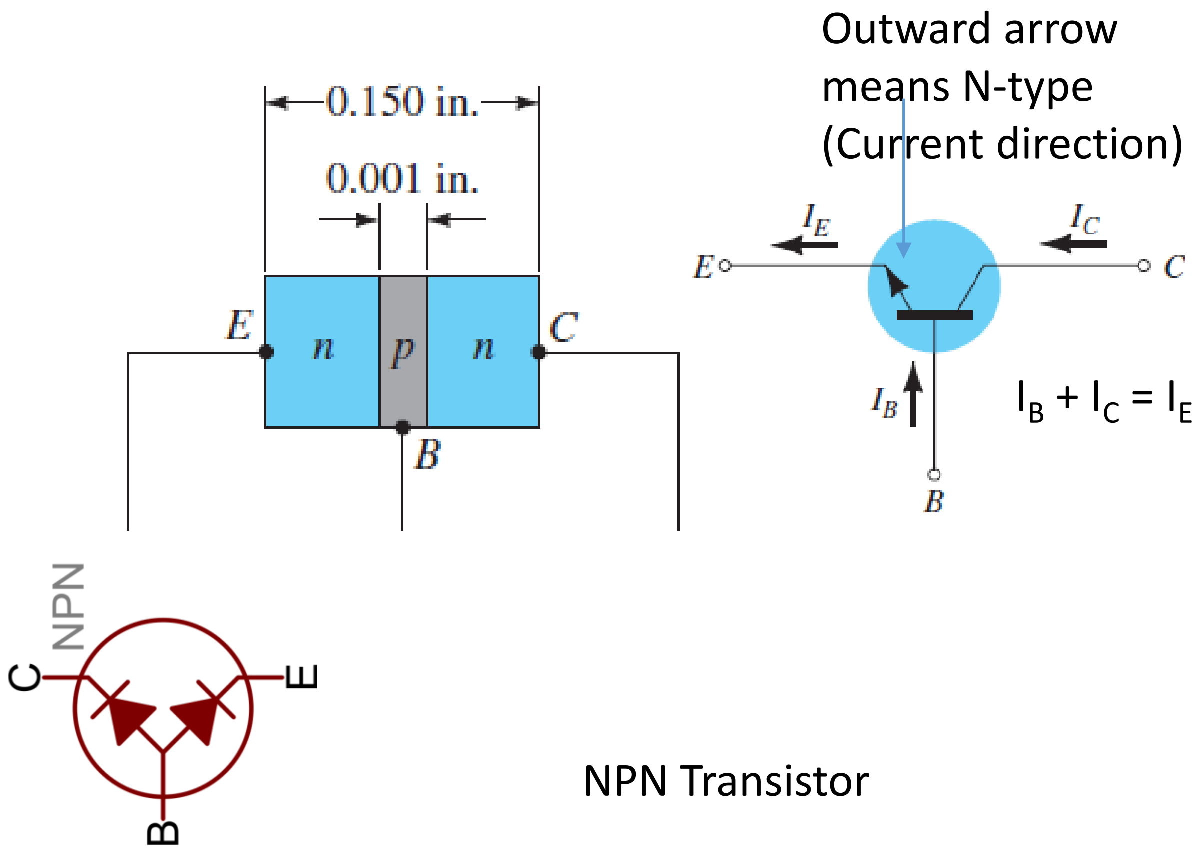
For same current (I), $V_{Out} > V_{in}$ (amplification)

The term *bipolar* represents the fact that holes *and* electrons participate in the injection process into the oppositely polarized material. If only one carrier is employed (electron or hole), it is considered a *unipolar* device. The Schottky diode is such an unipolar device.

Bipolar Junction Transistors (BJT)



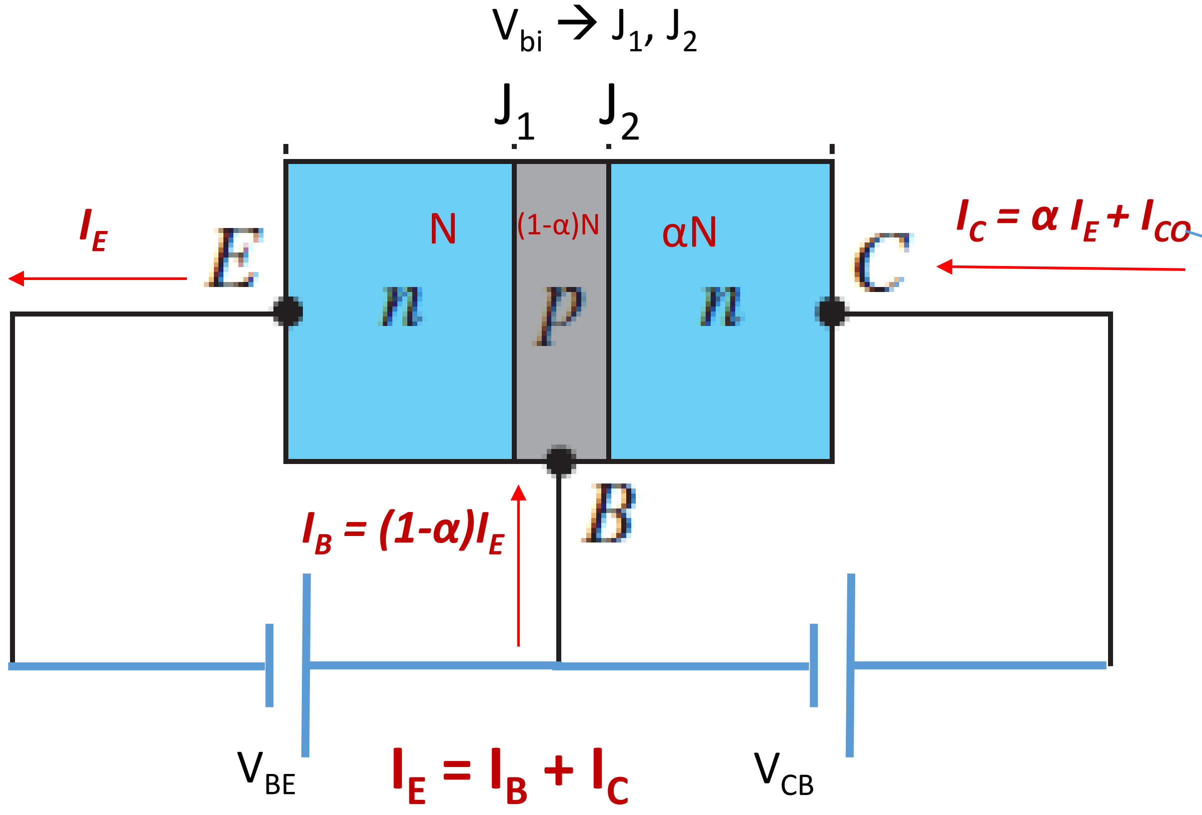
PNP Transistor



NPN Transistor

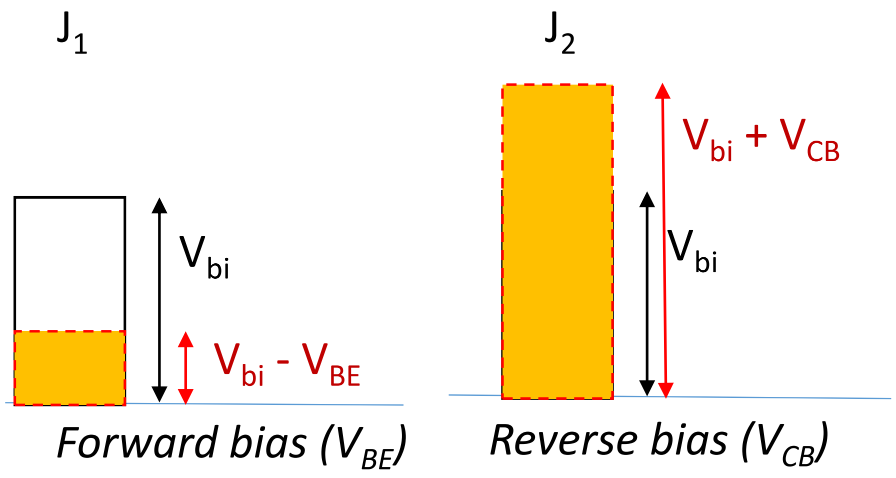
Emitter region is **heavily doped** and **thick**
Base region is **lightly doped** and **very thin**
Collector region is **moderately doped** and **thick**

Arrow on the schematic symbol shows ***which way current is intended to flow*** through the transistor.
The conventional current direction is opposite to the direction of flow of electrons and same direction of the flow of holes



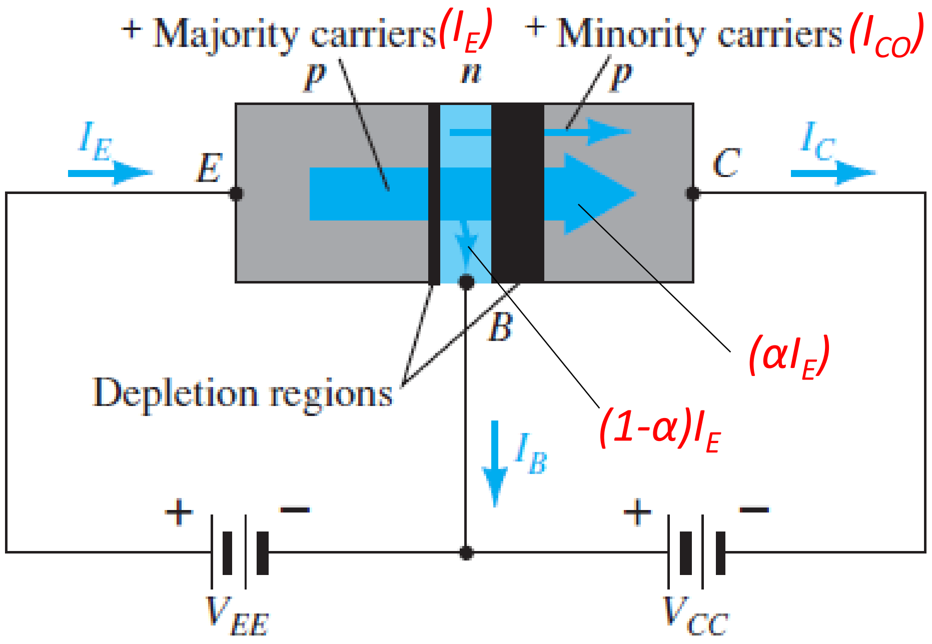
Emitter - Heavily doped
Base – Very thin and lightly doped
Collector – Moderately doped

I_{CO} is reverse saturation current (OR) leakage current



- Let us assume *N* number of electrons enter into the base due to forward bias potential V_{BE}
- Out of which, let αN cross the junction J_2 (Base is thin) and enters the Collector
- $(1-\alpha)N$ combines with holes in the Base (due to forward bias), **contributing base current I_B**
- In transistor, since the Base is very thin, **only 2% to 5% of carriers combines with holes in the Base terminal** and the rest 98% to 95% carriers reach the collector.
- α – Current gain in common base mode
- β – Current gain in common emitter mode
- γ – Current gain in common collector mode

Pictorial representation of carrier movement in PNP transistor under forward (input) and reverse (output) biased



Alpha (α): It is a large signal current gain in ***common base configuration***. It is the ratio of collector current (output current) to the emitter current (input current).

Since in this example PNP transistor is shown: where, the current in transistor is due to holes movement and hence the current direction is same as the direction of carriers movement.

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

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

It is a current gain in CB amplifier and it indicates that the amount of emitter current reaching to collector. *Its value is unity ideally and practically less than unity.*

Beta (β): It is a current gain factor in the ***common emitter configuration***. It is the ratio of collector current (output current) to base current (output current).

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

$$\beta = \frac{\alpha}{(1-\alpha)}$$

normally Its value is between 20 to 400.

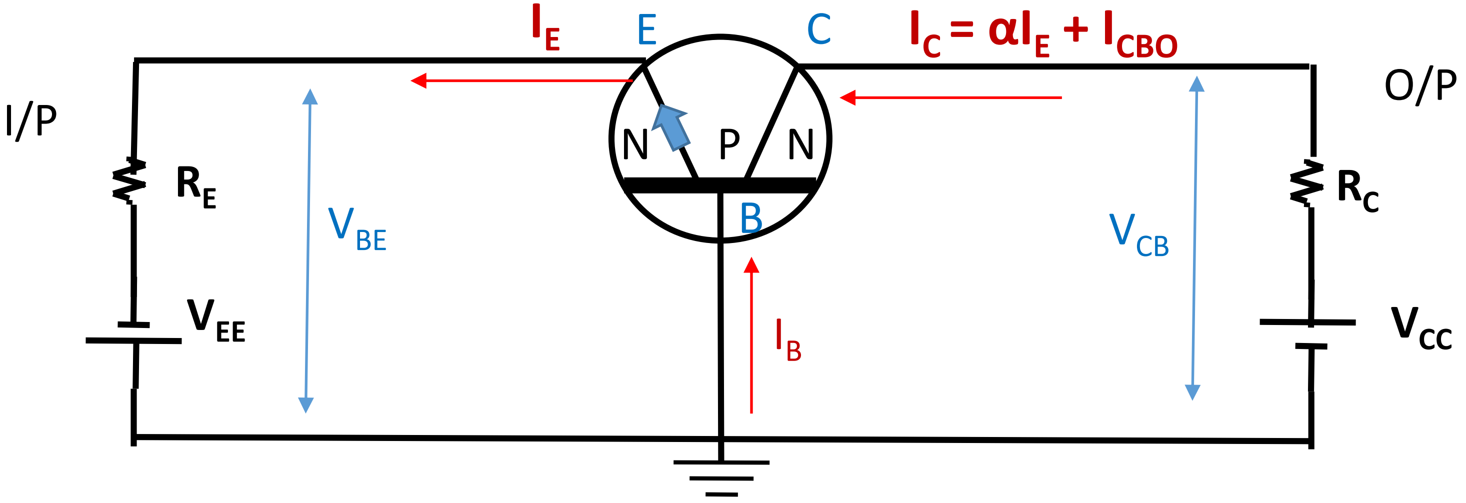
Gama (γ): It is a current gain in **common collector configuration** and it is the ratio of emitter current (output current) to base current (input current).

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

$$\gamma = (1+\beta)$$

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** or **β**.*

Common Base Configuration of Transistor



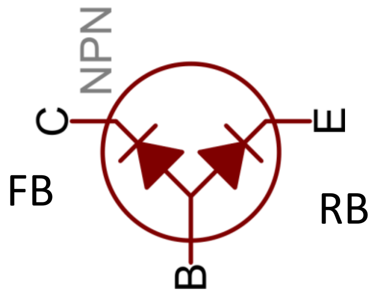
Active Mode

J_1 – FB & J_2 - RB

(Weak I/P signal can be amplified at the O/P)

Diode (D1) is forward biased

Diode (D2) is reverse biased



Similar to I-V characteristics in Diode, Transistor has input I-V characteristics and output I-V characteristics

Input: I_E vs V_{BE}

Output: I_C vs V_{CB}

The ratio of change in collector current to the change in emitter current at constant collector base voltage V_{CB} is known as **current amplification factor, α.**

KCL : $I_E = I_C + I_B$ → (1)

$I_C = \alpha I_E + I_{CO}$, where I_{CO} is the reverse saturation current ($I_E >> I_{CO}$)

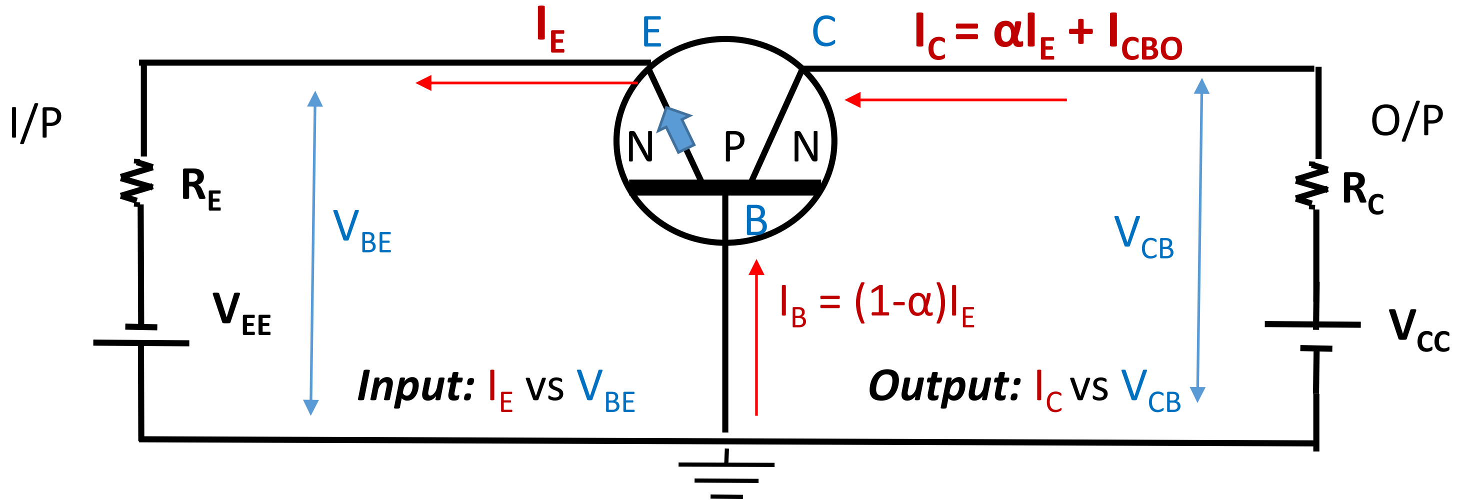
$I_C = \alpha I_E$ → $\alpha = I_C/I_E$, ***where α is common base current gain (or) amplification factor***

$$I_B = (1-\alpha)I_E$$

α is between 0.95 to 0.98 (ie., 95% to 98% gain)

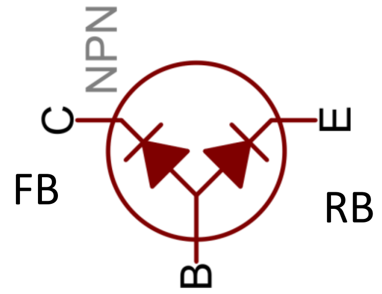
Common Base Transistor (Input and Output Characteristics)

Similar to I-V characteristics in Diode, Transistor has both input I-V characteristics and output I-V characteristics



Active Mode

J_1 – FB & J_2 - RB

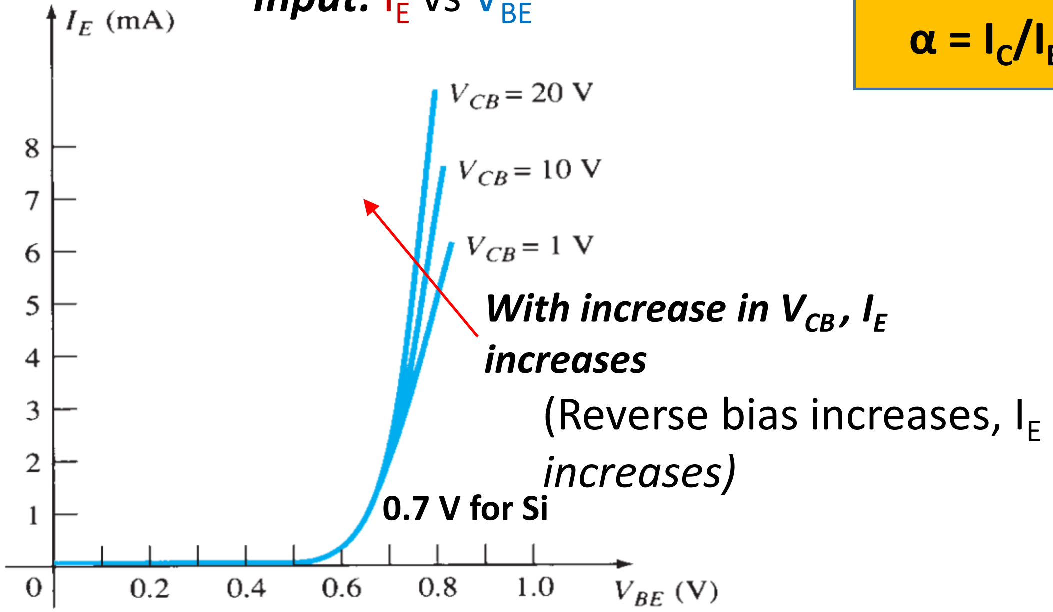


Early Effect:

Base width modulation because of Base collector bias voltage

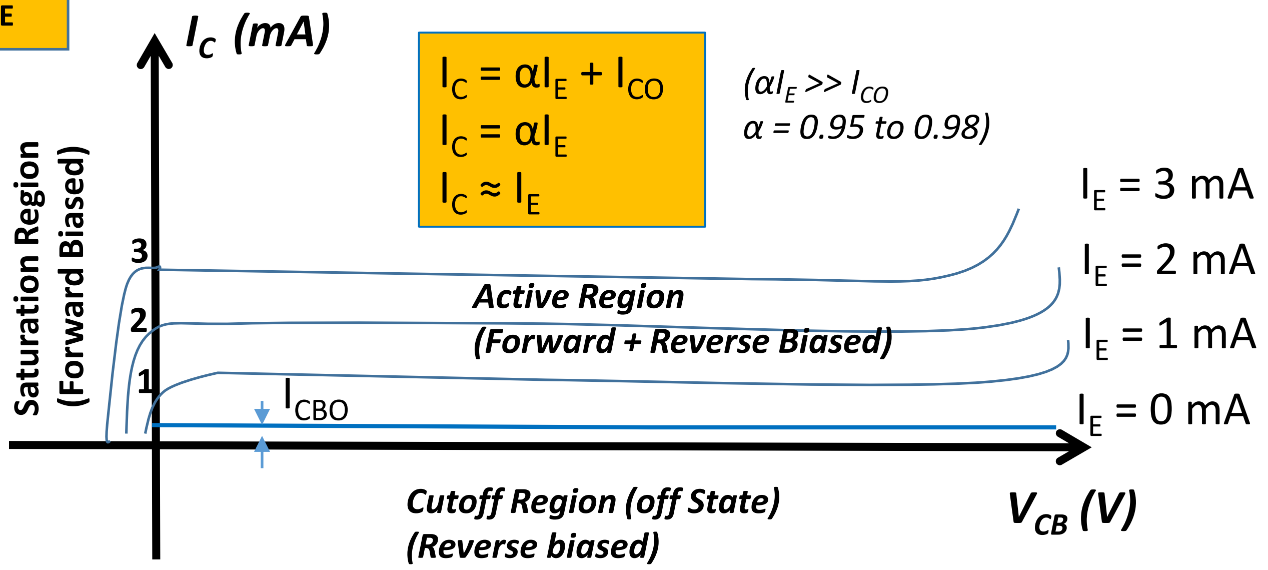
- ***The input I-V characteristics of CB transistor relates with the Input I-V (I_E vs V_{BE}) with respect to const output Voltage (V_{CB})***
- ***The Output I-V characteristics of CB transistor relates with the Output I-V (I_C vs V_{CB}) with respect to the Input Current (I_E)***

Input: I_E vs V_{BE}

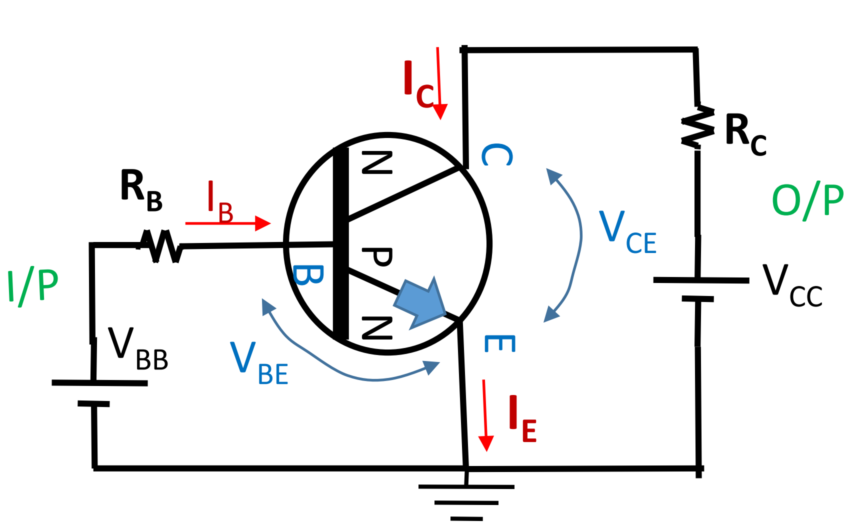


$$\alpha = I_C/I_E$$

Output: I_C vs V_{CB}

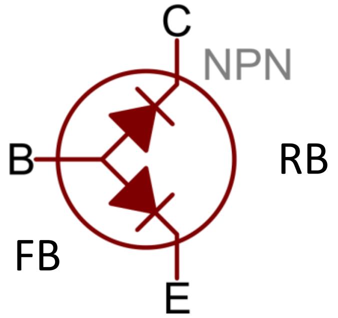


Common Emitter Configuration of Transistor



Input: I_B, V_{BE}
Output: I_C, V_{CE}

$I_E = I_B + I_C$



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

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

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

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

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

$$I_C = \beta I_B + \underbrace{(\beta + 1) I_{CO}}_{I_{CEO}} \qquad \left[\beta = \frac{\alpha}{(1-\alpha)}\right]$$

I_{CEO} → Reverse saturation current in common emitter configuration

$I_C = \beta I_B + I_{CEO}$

$I_{CEO} << \beta I_B$

Therefore, $\mathbf{I_C = \beta I_B}$

$$\boxed{\boldsymbol{\beta} = \frac{I_C}{I_B} = \frac{\alpha}{(1-\alpha)}}$$

(Current Amplification factor)

We know α is between 95% to 98%

Case 1: When α = 98% = 0.98

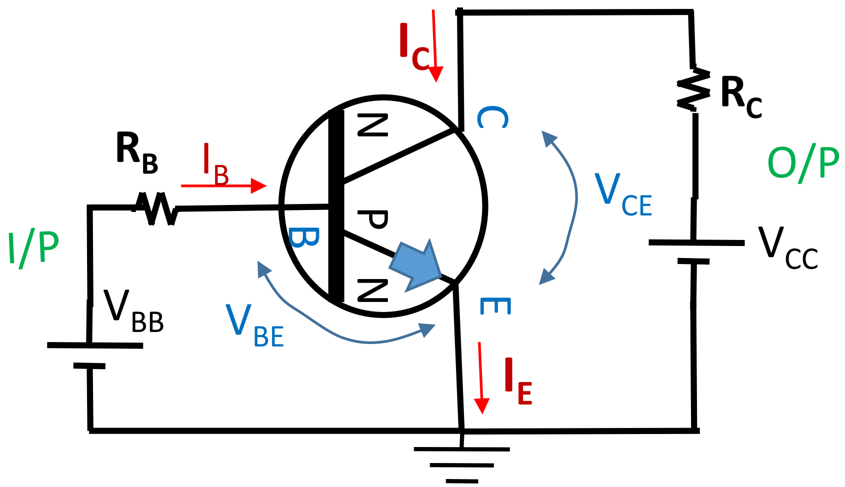
$$\beta = \frac{\alpha}{(1-\alpha)} = \frac{0.98}{0.02} = \mathbf{49}$$

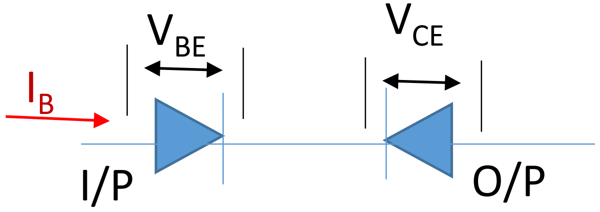
Case 1: When α = 95% = 0.95

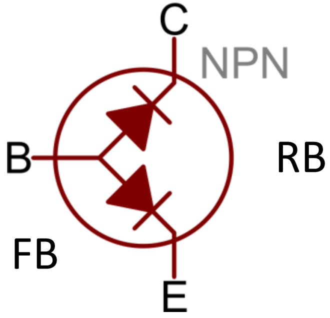
$$\beta = \frac{\alpha}{(1-\alpha)} = \frac{0.95}{0.05} = \mathbf{19}$$

β is between 20 to 400

Common Emitter Transistor (Input and Output Characteristics)





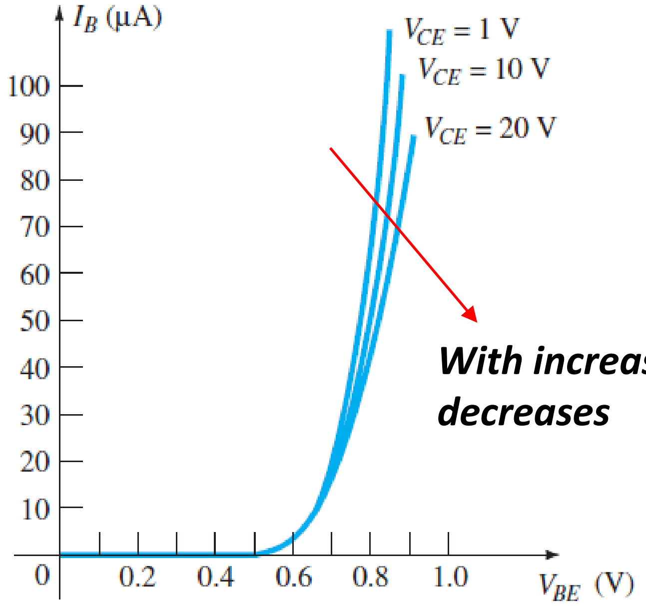


- ***The input I-V characteristics of CE transistor relates with the Input I-V (I_B vs V_{BE}) with respect to constant output Voltage (V_{CE})***
- ***The Output I-V characteristics of CB transistor relates with the Output I-V (I_C vs V_{CE}) with respect to the Input Current (I_B)***

KCL : $I_E = I_C + I_B$

$I_B = I_E - I_C$

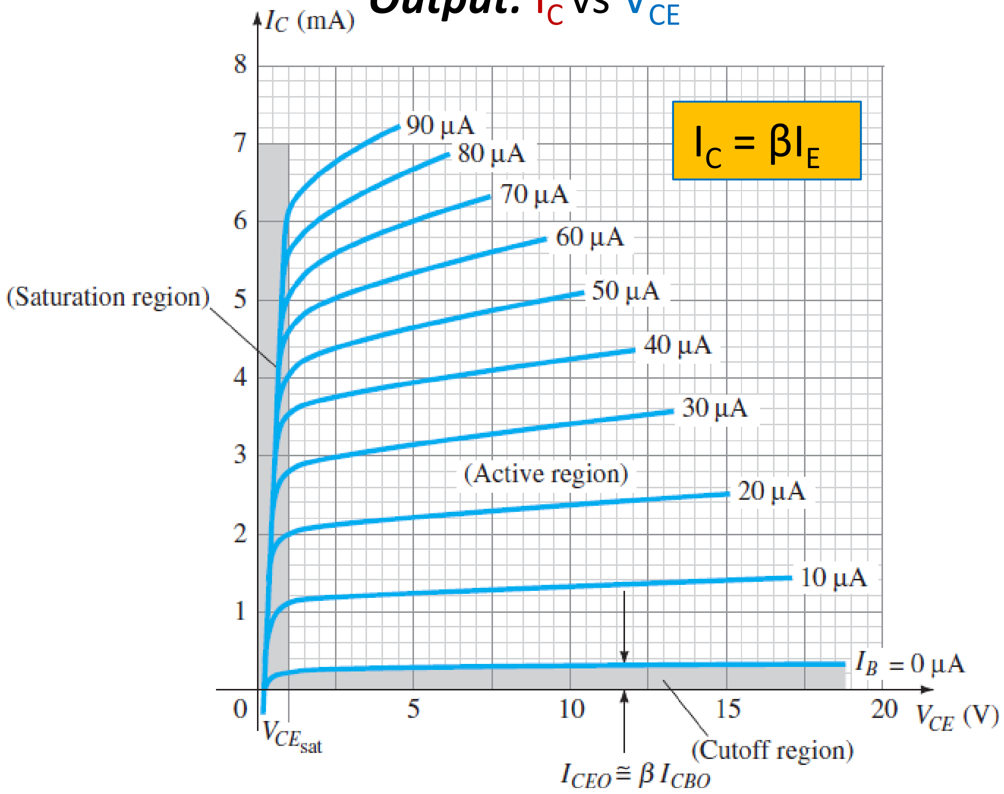
Input: I_B vs V_{BE}



With increase in V_{CE}, I_B decreases

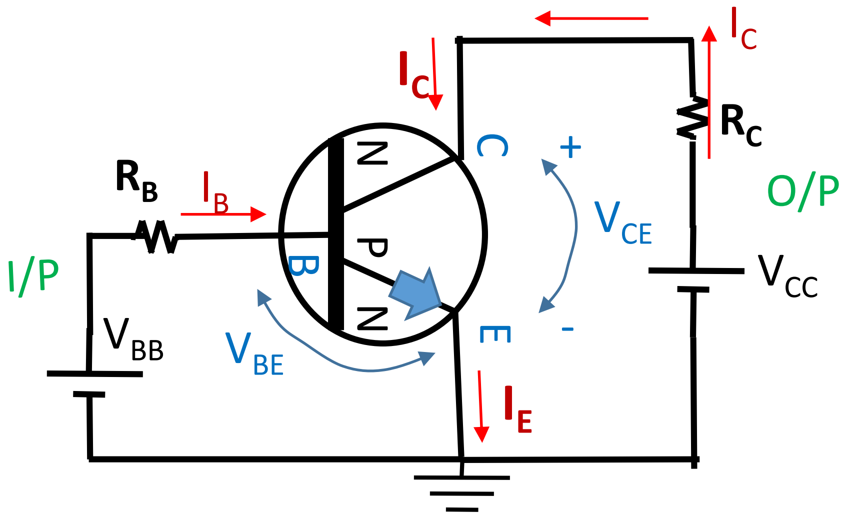
(Reverse bias increases, I_B *decreases due to less recombination)*

Output: I_C vs V_{CE}

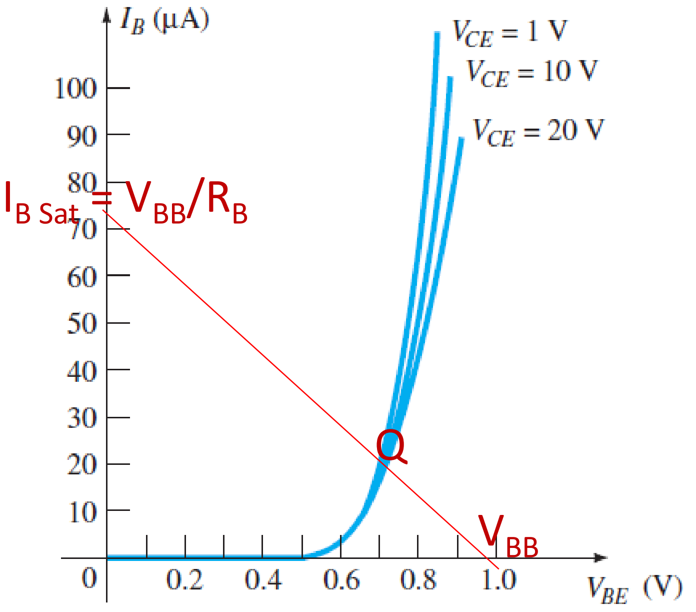


Operating Point (OR) Q-point of transistor:

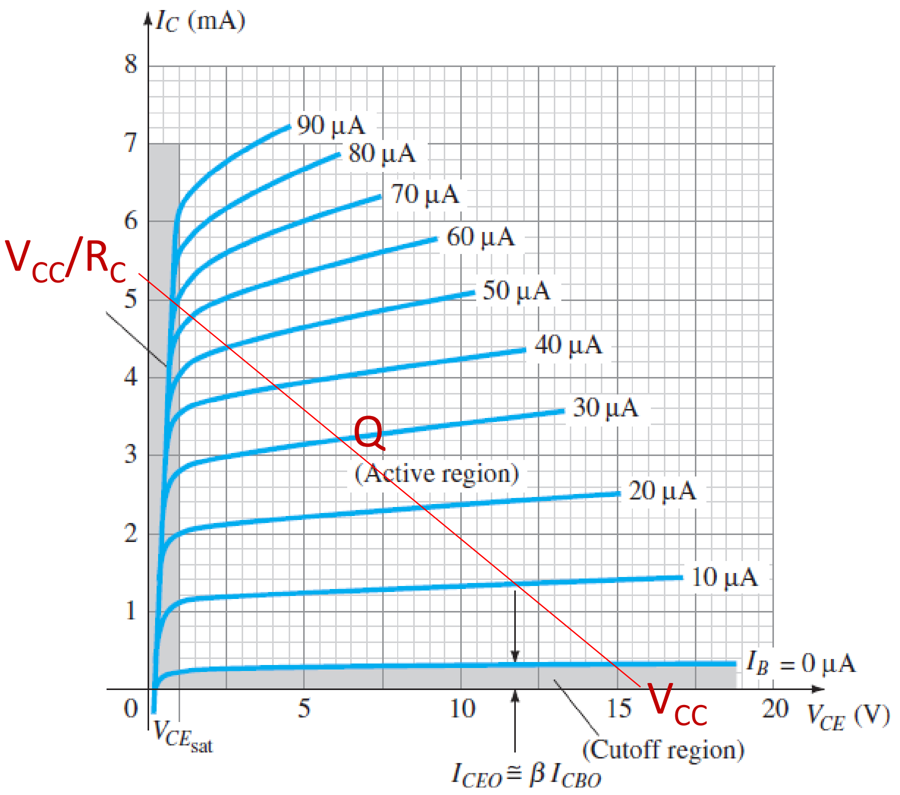
Biasing is the process in which DC voltage is applied to select the appropriate ***operating point or Q-point or quiescent (silent) point*** of the transistor.



I/P DC load line and Q-point



O/P DC load line and Q-point



Using KVL in the I/P

y axis   x axis

$V_{BB} - I_B R_B - V_{BE} = 0$

To draw DC load line we have to derive two points P_1 and P_2 when x = 0 and y = 0.

When x =0 → $I_B = V_{BB}/R_B$
When y =0 → $V_{BE} = V_{BB}$

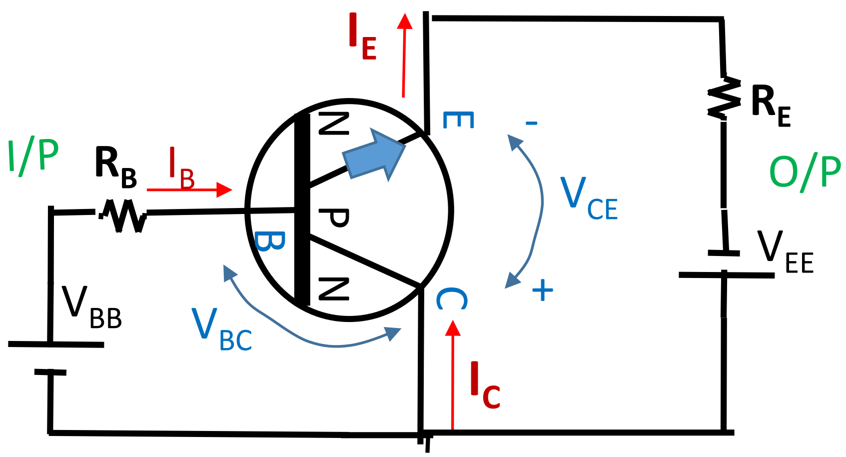
Using KVL in the O/P

y axis   x axis

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

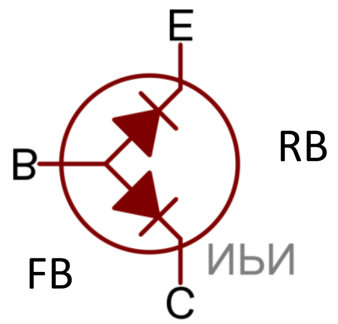
When x =0 → $I_C = V_{CC}/R_C$
When y =0 → $V_{CE} = V_{CC}$

Common Collector Configuration of Transistor



Input: I_B, V_{BC}
Output: I_E, V_{CE}

$V_{EC} = V_{BE} + V_{BC}$



$I_E = I_B + I_C$

$I_C = \alpha I_E + I_{CO}$ → Reverse saturation current in common collector configuration

$(I_E - I_B) = \alpha I_E + I_{CO}$

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

$I_E = \frac{1}{(1-\alpha)} I_B + \frac{1}{(1-\alpha)} I_{CO}$

$\boldsymbol{I_E = \gamma I_B + \gamma I_{CO}}$ $\quad [\gamma = \frac{1}{(1-\alpha)}]$

$\gamma I_{CO} << \gamma I_B$

Therefore, $\boldsymbol{I_E = \gamma I_B}$

$$\gamma = \frac{I_E}{I_B} = \frac{1}{(1-\alpha)}$$

(Current Amplification factor in common collector mode)

We know α is between 95% to 98%

Case 1: When α = 98% = 0.98

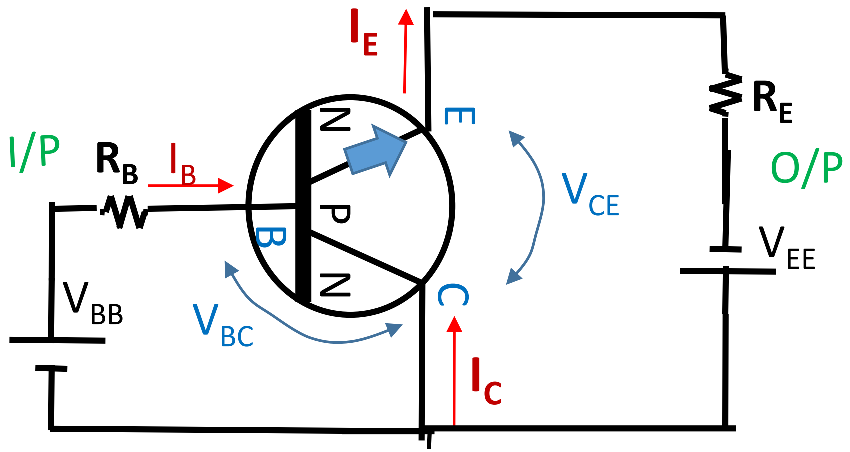
$$\gamma = \frac{1}{(1-\alpha)} = \frac{1}{0.02} = \mathbf{50}$$

Case 1: When α = 95% = 0.95

$$\gamma = \frac{1}{(1-\alpha)} = \frac{1}{0.05} = \mathbf{20}$$

γ value is high compared to α or β.

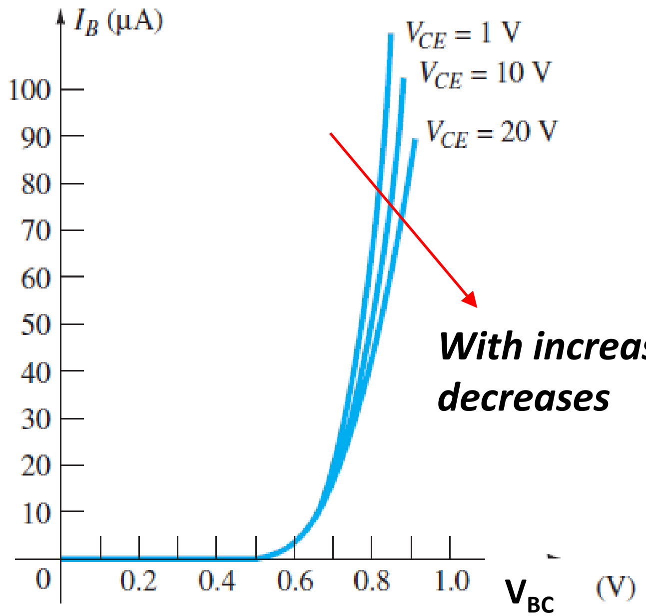
Common Collector Transistor (Input and Output Characteristics)



- *The input I-V characteristics of CE transistor relates with the Input I-V (I_B vs V_{BC}) with respect to constant output Voltage (V_{CE})*
- *The Output I-V characteristics of CB transistor relates with the Output I-V (I_E vs V_{CE}) with respect to the Input Current (I_B)*

KCL : $I_E = I_C + I_B$

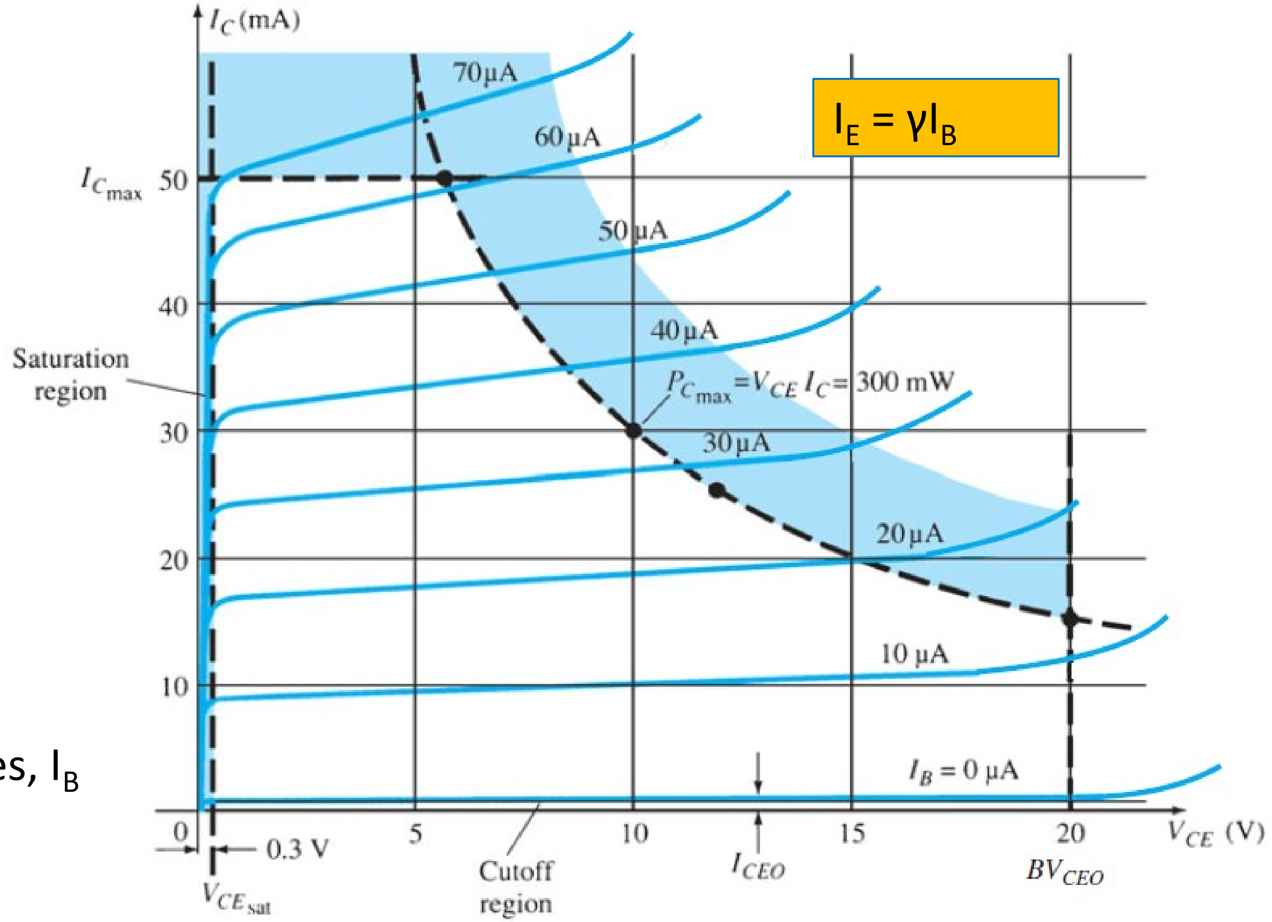
Input: I_B vs V_{BC}



With increase in V_{CE}, I_B decreases

(Reverse bias increases, I_B *decreases due to less recombination)*

Output: I_E vs V_{CE}



Relation between α, β and γ

$\alpha \rightarrow \alpha_{dc} = I_C/I_E$

$\alpha \rightarrow \alpha_{ac} = \Delta I_C/\Delta I_E \quad |V_{CB}$ const

$\beta \rightarrow \beta_{dc} = I_C/I_B$

$\beta \rightarrow \beta_{ac} = \Delta I_C/\Delta I_B \quad |V_{CE}$ const

$\gamma \rightarrow \gamma_{dc} = I_E/I_B$

$\gamma \rightarrow \gamma_{ac} = \Delta I_E/\Delta I_B \quad |V_{CE}$ const

We have, $I_E = I_B + I_C$

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

$$\boxed{\gamma = 1 + \beta}$$

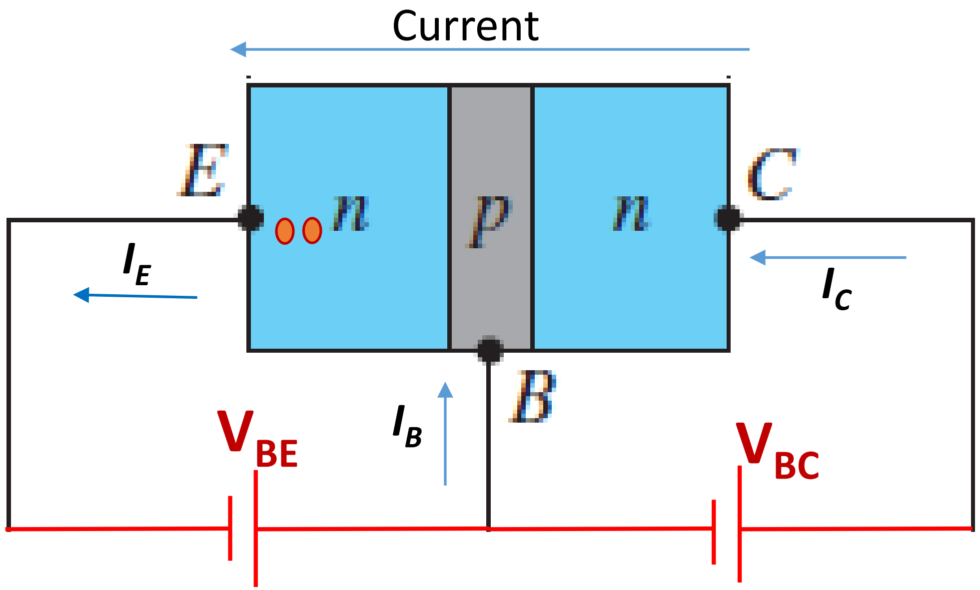
$\beta = \alpha/(1-\alpha)$

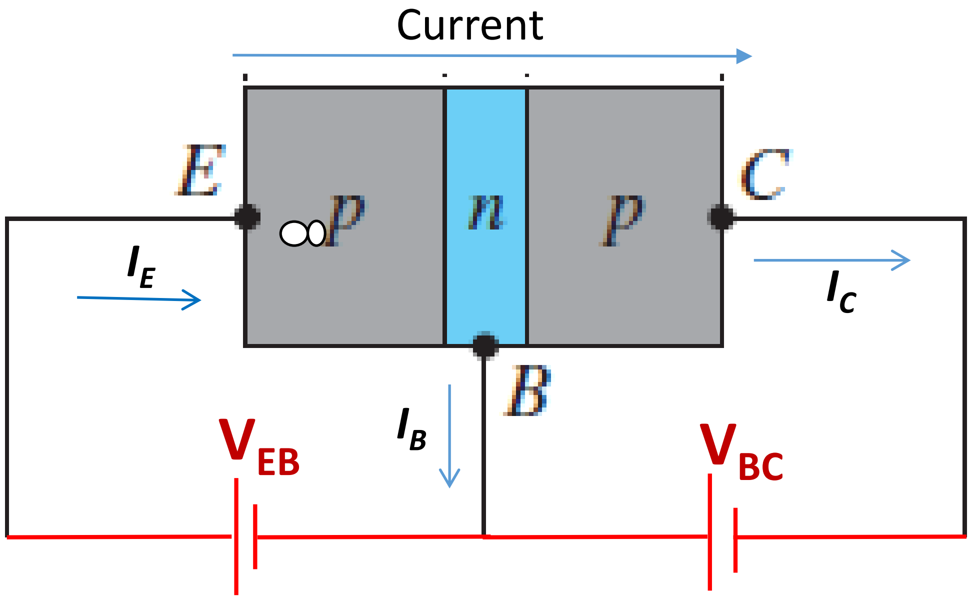
$\gamma = 1+ \alpha/(1-\alpha) = (1 - \alpha + \alpha)/(1- \alpha) = 1/(1-\alpha)$

$$\boxed{\gamma = 1+ \beta = 1/(1- \alpha)}$$

Transistor Operation :

We know that **electrons can easily flow from *N* regions to *P* regions**, as long as they have a little external force (voltage) to push them. But flowing from a *P* region to an *N* region is really hard (requires a *lot* of voltage). But the special thing about a transistor is that **electrons *can* easily flow from the P-type base to the N-type collector as long as the Base-Emitter (BE) junction is forward biased and Base-Collection junction is reverse biased.**





The NPN transistor is designed to pass electrons from the emitter to the collector (so conventional current flows from collector to emitter). The emitter "emits" electrons into the base, which controls the number of electrons the emitter emits. Most of the electrons emitted are "collected" by the collector, which sends them along to the next part of the circuit. A PNP works in a same but opposite fashion. The base still controls current flow, but that current flows in the opposite direction from emitter to collector. Instead of electrons, the emitter emits "holes" (a conceptual absence of electrons) which are collected by the collector.

One P-N junction of a transistor is reverse-biased, whereas the other is forward-biased.

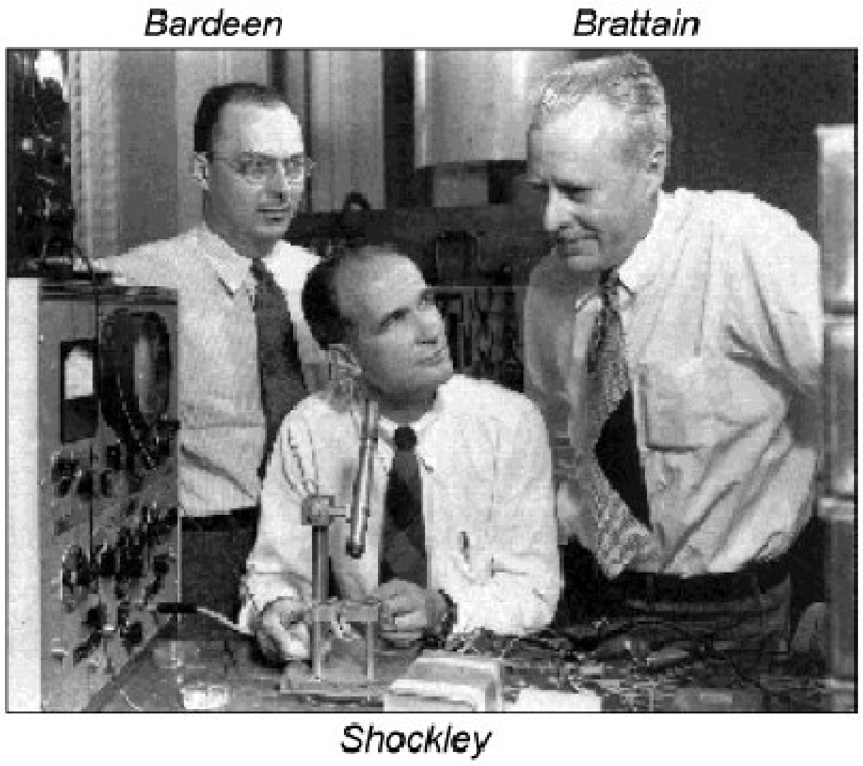
Point-Contact Transistor – first transistor ever made

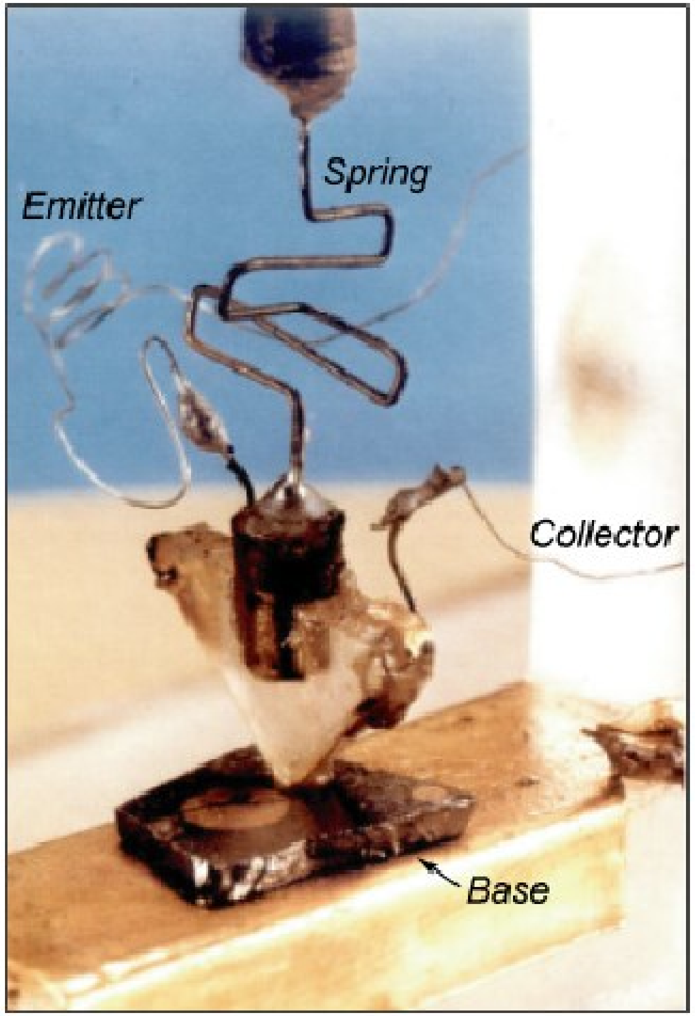
The first transistor was a point-contact transistor

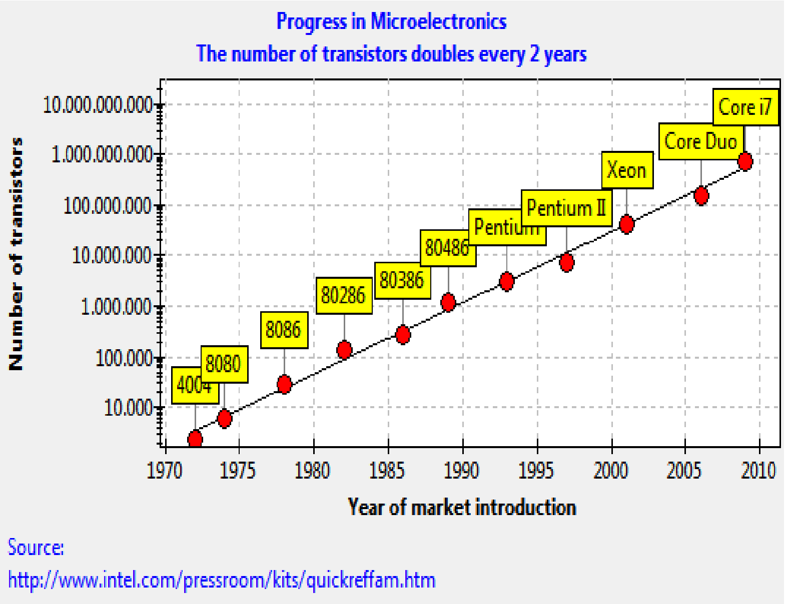
The first point-contact transistor

John Bardeen, Walter Brattain, and William Shockley

Bell Laboratories, Murray Hill, New Jersey (1947)



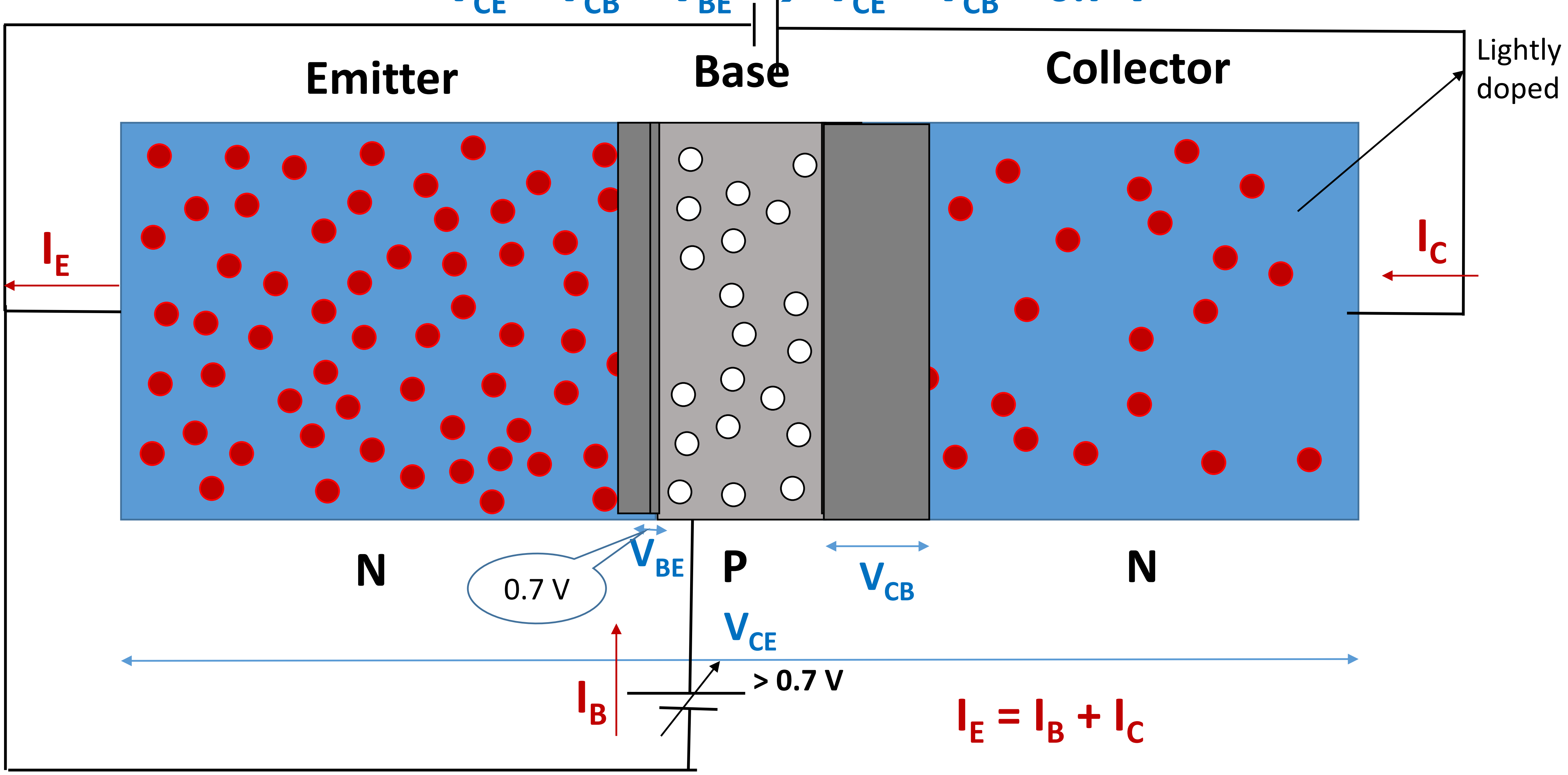




All the three scientist got Physics Nobel prize in 1956

NPN Transistor (Active Mode)

$$V_{CE} = V_{CB} + V_{BE} \rightarrow V_{CE} = V_{CB} + 0.7\ V$$



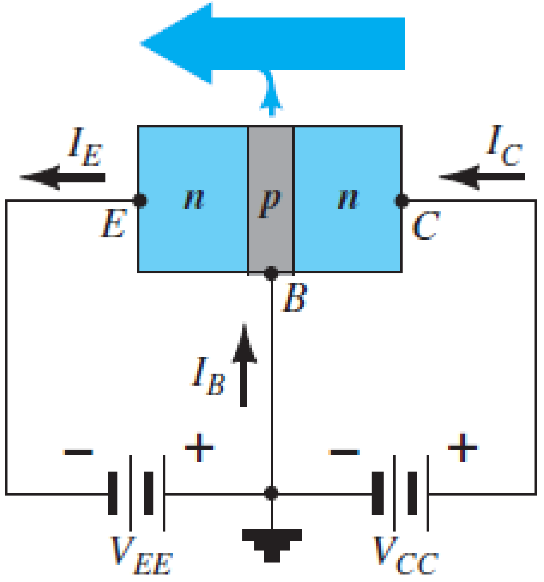
$$I_E = I_B + I_C$$

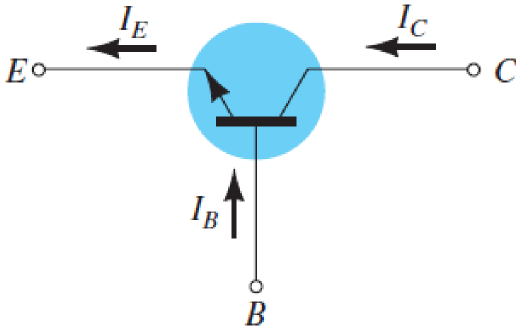
Please read:

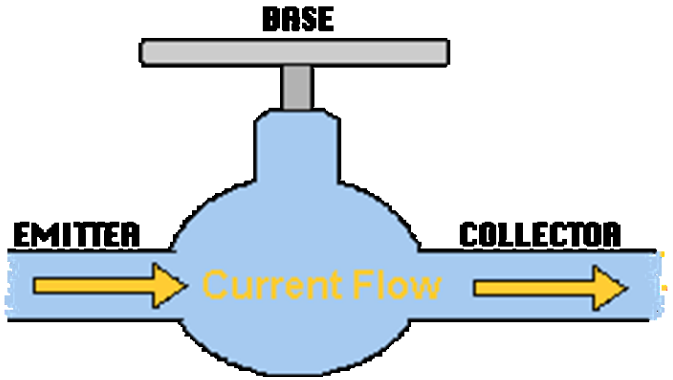
Electronic Devices and Circuit Theory, Robert L Boylestad, 11th Ed., Page 129 – 159

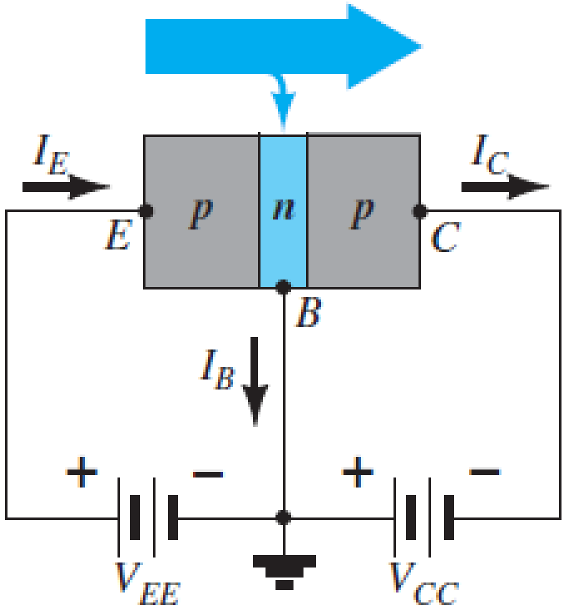
PRINCIPLES OF ELECTRONICS , V.K. Mehtha

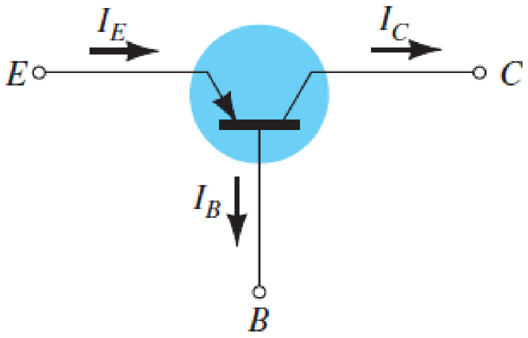
The transistor is kind of like an **electron valve**. The base pin is like a handle which adjust whether to allow more or less electrons to flow from emitter to collector.







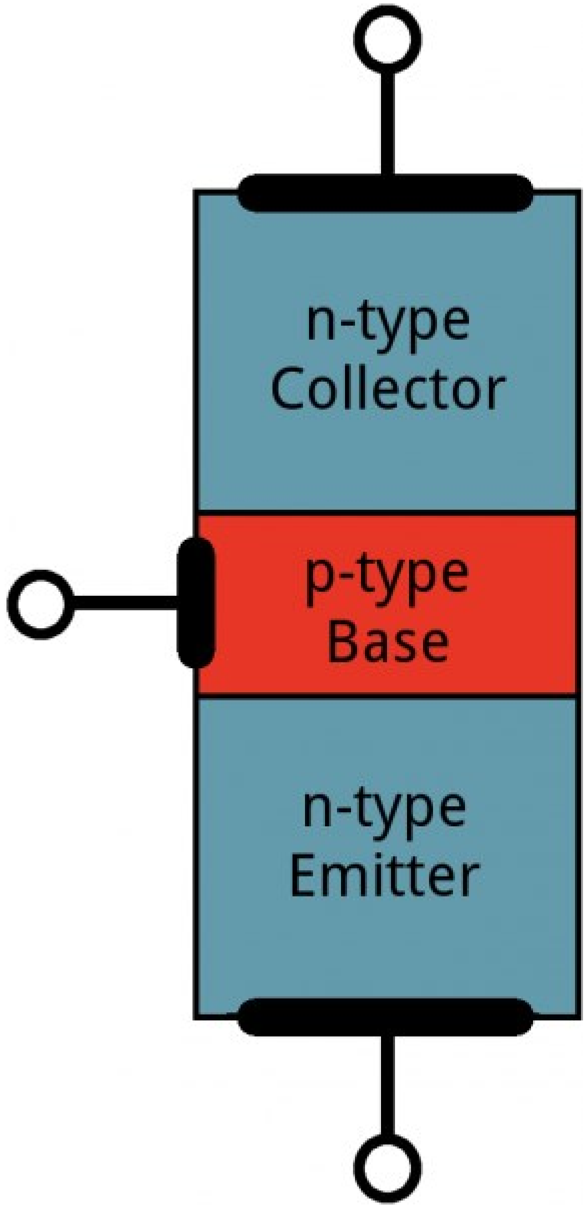




Under both biasing potentials across a *PNP* transistor, a large number of majority carriers will diffuse across the forward biased *P-N* junction into the *N*-type material. The question then is whether these carriers will contribute directly to the base current I_B or pass directly into the *P*-type material. Since the
sandwiched *N*-type material is very thin and has a low conductivity, a very small number of these carriers will take this path of high resistance to the base terminal. The magnitude of the base current is typically on the order of microamperes, as compared to milliamperes for the emitter and collector currents. The larger number of these majority carriers will diffuse across the reverse-biased junction into the *N* -type material connected to the collector terminal

Transistor Structure :

Transistors are built by stacking three different layers of semiconductor material together. Some of those layers have extra electrons added to them (a process called "doping"), and others have electrons removed (doped with "holes" – the absence of electrons). A semiconductor material with *extra* electrons is called an **N-type** (*N* for negative because electrons have a negative charge) and a material with electrons removed is called a **P-type** (*P* for positive). Transistors are created by either stacking an *N* on top of a *P* on top of an *N*, or *P* over *N* over *P*.



Test our understanding about PN junction diode:

- Why the forward bias current of a PN junction diode is high ?

Because the current is due to injection of ***majority carriers (diffusion)*** through the junction

- Why the reverse bias current of a PN junction diode is significantly small ?

Because the current is due to injection of ***minority carriers*** through the junction

- How the reverse bias current of a PN junction diode can be increased ?

increasing the minority carrier injection across the depletion region