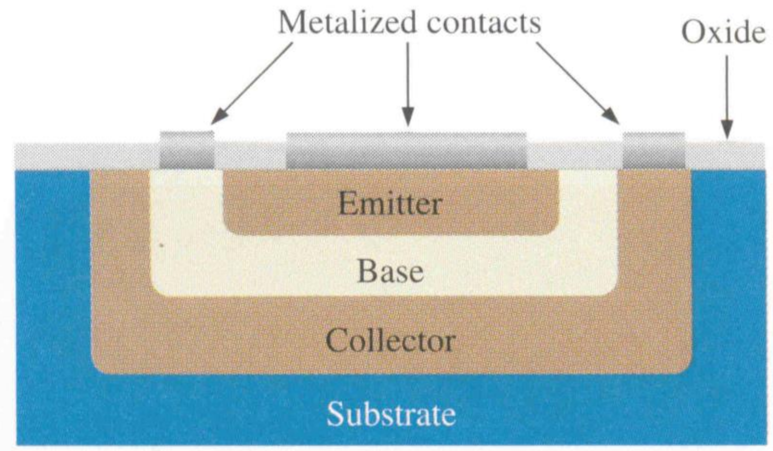
Lecture 24: Bipolar Junction Transistors (1)

Bipolar Junction Structure, Operating Regions, Biasing

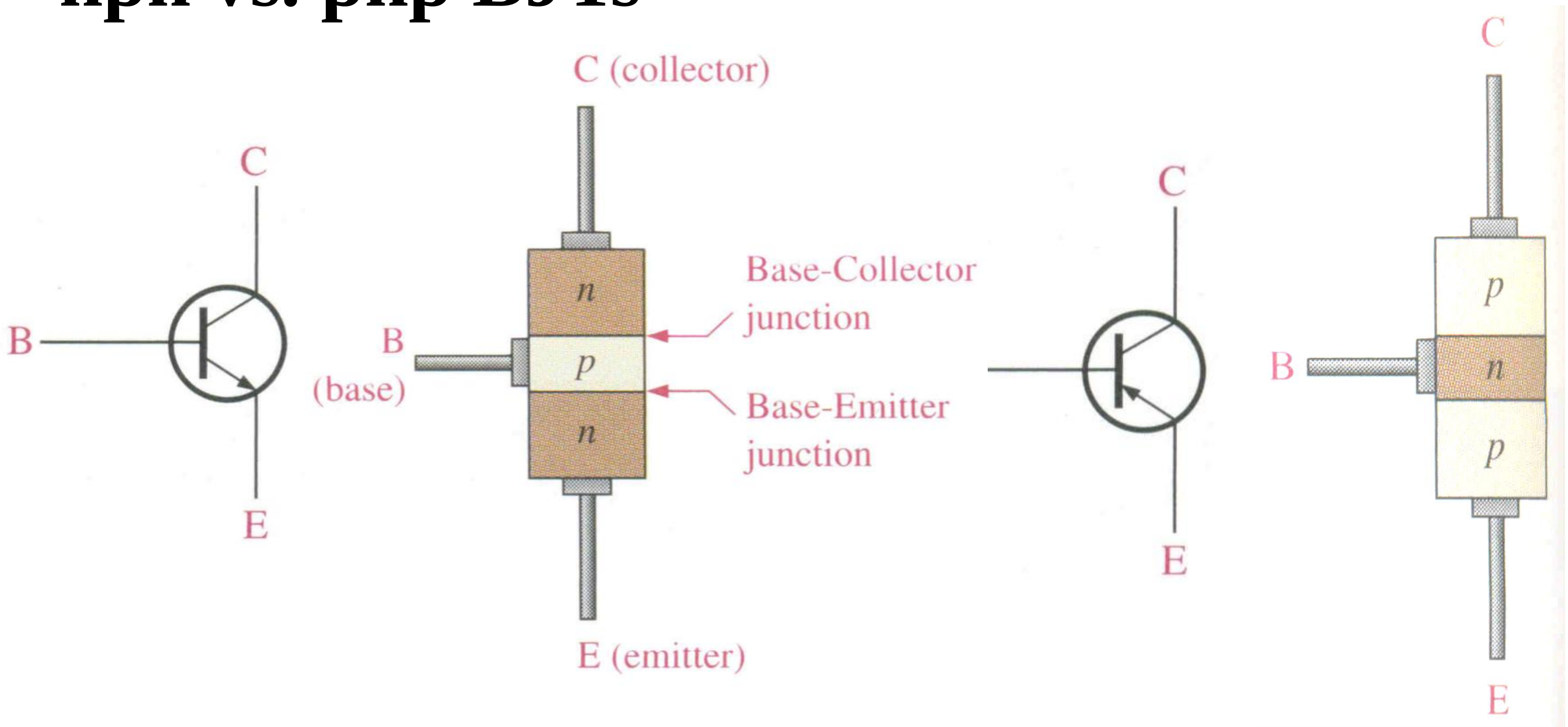
BJT Structure

the BJT is formed by doping three semiconductor regions (emitter, base, and collector) adjacent to each other



the emitter (E) is heavily doped, the base (B) is thin and lightly doped, and the collector (C) is moderately doped

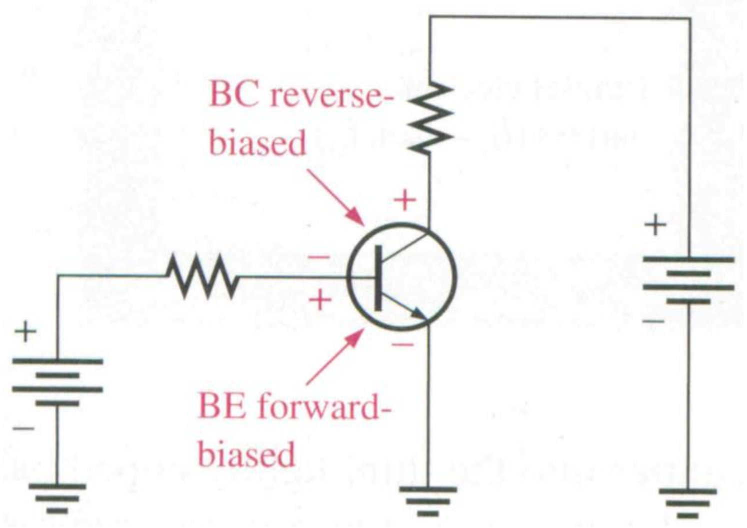
npn vs. pnp BJTs

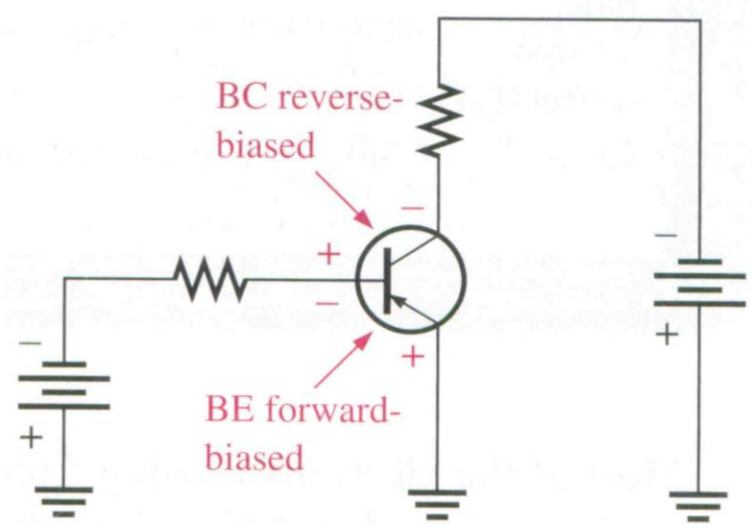


according to the doping materials used, BJT can be either npn or pnp

the term bipolar indicates that both types of carriers (electrons and holes) are present in this type of transistors.

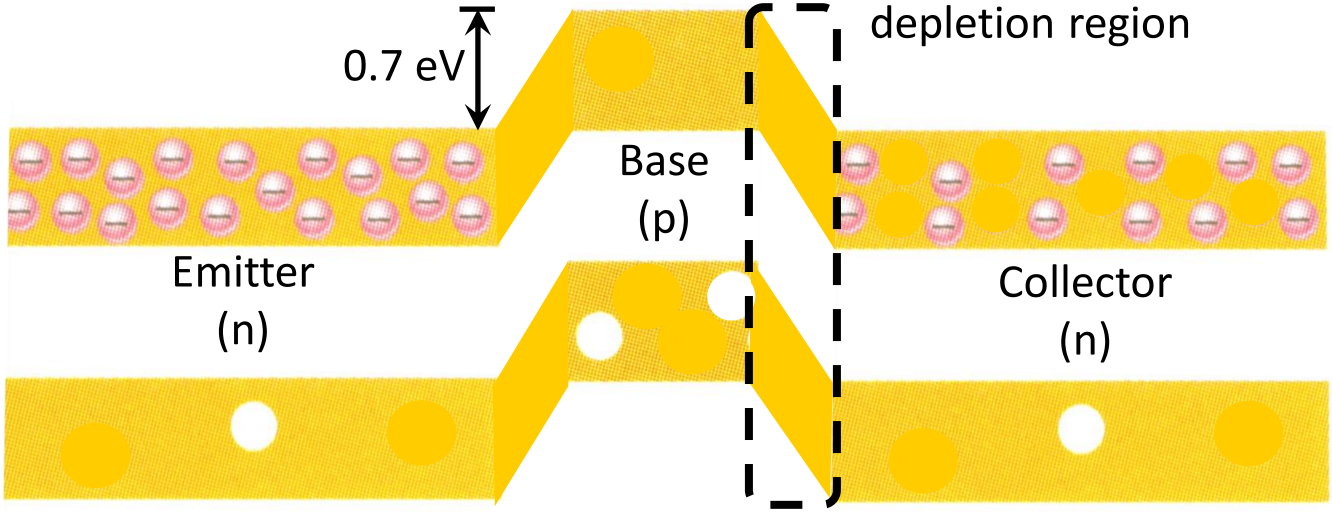
Biasing of the BJT





the BJT is biased such that the base-emitter (BE) junction is forward-biased and the base-collector (BC) junction is revere-biased. This way of biasing put the BJT in the active mode.

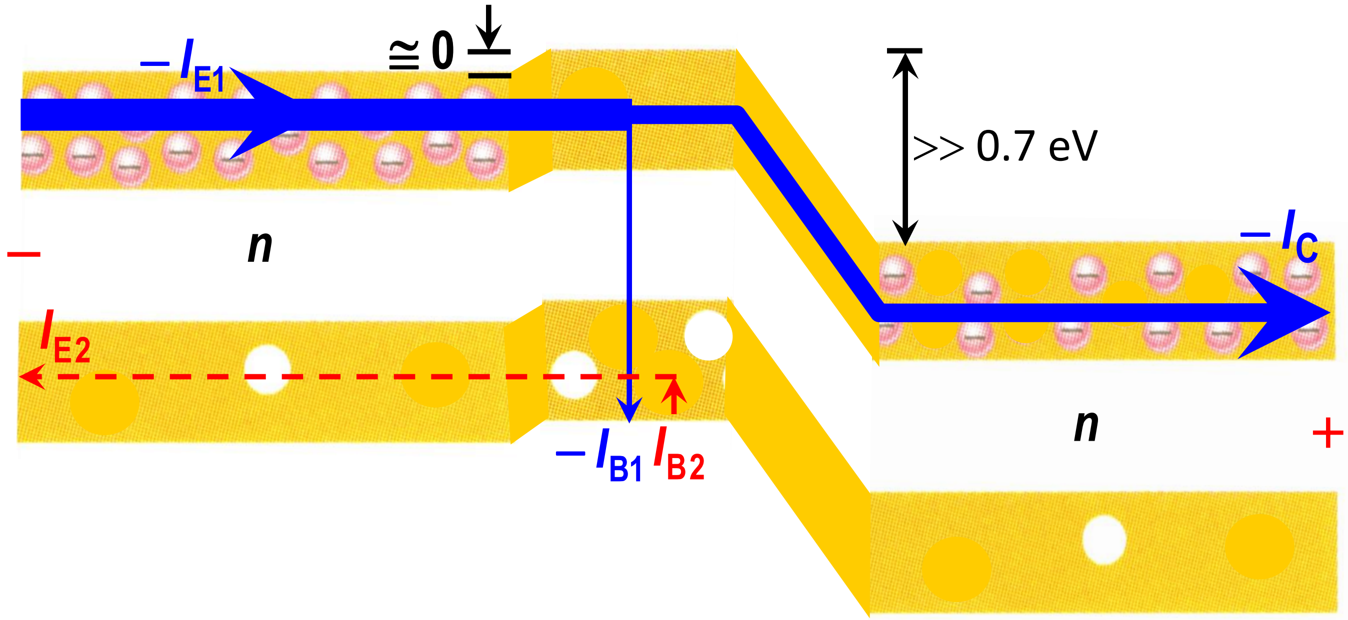
Before Biasing



depletion regions are formed around both junctions

the majority electron carriers in both emitter and collector can not "roll-up" the energy hills

Active Region Biasing

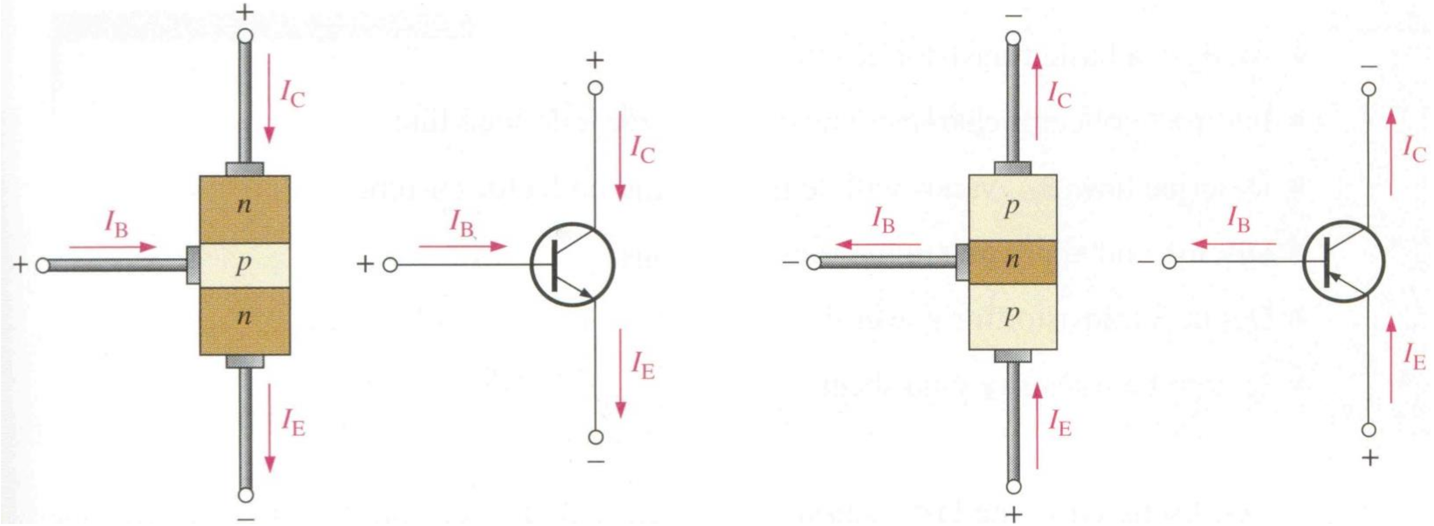


Emitter Current (I_E): electrons of the emitter are now able to cross the BE junction

Base Current (I_B): a small fraction of these electrons recombine with the few holes of the narrow base

Collector Current (I_C): the rest of electrons "roll-down" the energy hill of the BC junction.

Transistor Currents



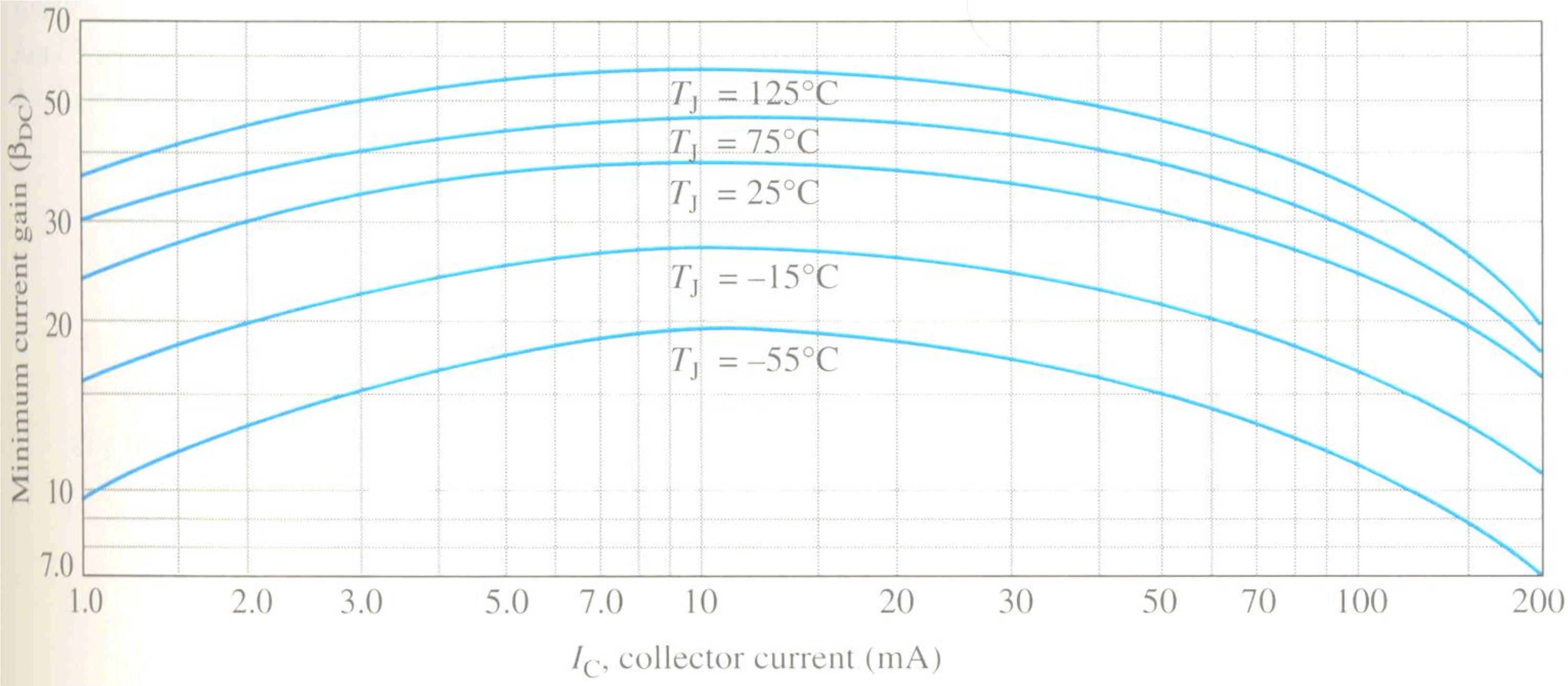
the emitter current (I_E) equals the sum of the base (I_B) and collector (I_C) currents: $I_E = I_C + I_B$, where $I_E \cong I_C >> I_B$

these currents are related to each other using β_{DC} and α_{DC} ratios:

$\beta_{DC} \equiv$ DC current gain of the transistor $= I_C / I_B$ (β_{DC} ranges from 20 to 200),

$$\alpha_{DC} = \frac{I_C}{I_E} = \frac{I_C}{I_C + I_B} = \frac{I_C/I_B}{(I_C/I_B)+1} = \frac{\beta_{DC}}{\beta_{DC}+1}$$ (α_{DC} ranges from 0.95 to 0.99).

DC Current Gain



β_{DC} increases with small values of I_C up to a certain maximum value and then decreases with large values of I_C.

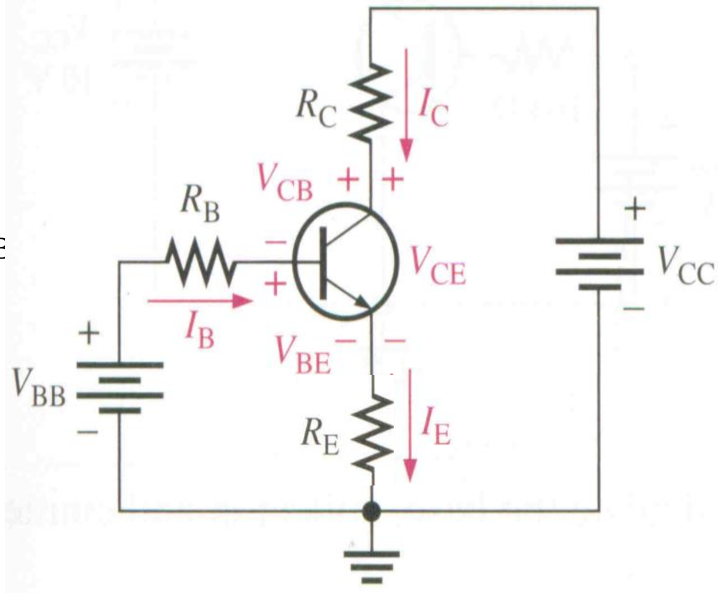
β_{DC} increases monotonically with the temperature (T), as increasing temperature generates more electron-hole pairs, which increases the number of charge carriers and so as I_C and β_{DC}.

Data Sheets

Data sheets give manufacturer's specifications for maximum operating conditions, thermal, and electrical characteristics. For example, an electrical characteristic is β_{DC}, which is given as h_{FE}. The 2N3904 shows a range of β's on the data sheet from 100 to 300 for I_C = 10 mA.

Characteristic		Symbol	Min	Max	Unit
ON Characteristics					
DC current gain		h_{FE}			–
(I_C = 0.1 mA dc, V_{CE} = 1.0 V dc)	2N3903		20	–	
	2N3904		40	–	
(I_C = 1.0 mA dc, V_{CE} = 1.0 V dc)	2N3903		35	–	
	2N3904		70	–	
(I_C = 10 mA dc, V_{CE} = 1.0 V dc)	2N3903		50	150	
	2N3904		100	300	
(I_C = 50 mA dc, V_{CE} = 1.0 V dc)	2N3903		30	–	
	2N3904		60	–	
(I_C = 100 mA dc, V_{CE} = 1.0 V dc)	2N3903		15	–	
	2N3904		30	–	

Current and Voltage Analysis



BE junction is forward-biased $\Rightarrow$ $V_{BE} \cong 0.7$ V

$$V_{BB} = I_E R_E + V_{BE} + I_B R_B \cong \beta_{DC} I_B R_E + V_{BE} + I_B R_E$$

$$I_B = \left(V_{BB} - V_{BE}\right) / \left(R_B + \beta_{DC} R_E\right)$$

DC current gain: $I_C = \beta_{DC} \; I_B$

Kirchhoff's current law on the transistor node: $I_E = I_C + I_B$

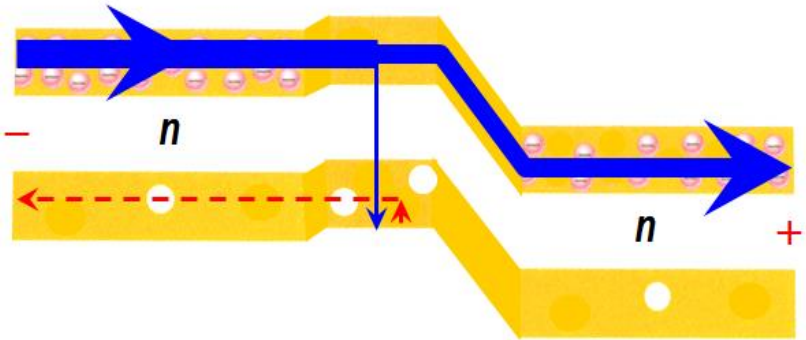
applying Kirchhoff's voltage law :

$$V_{CE} = V_{CC} - I_C \; R_C - I_E \; R_E$$

knowing V_{BE} and V_{CE} : $V_{CB} = V_{CE} - V_{BE}$

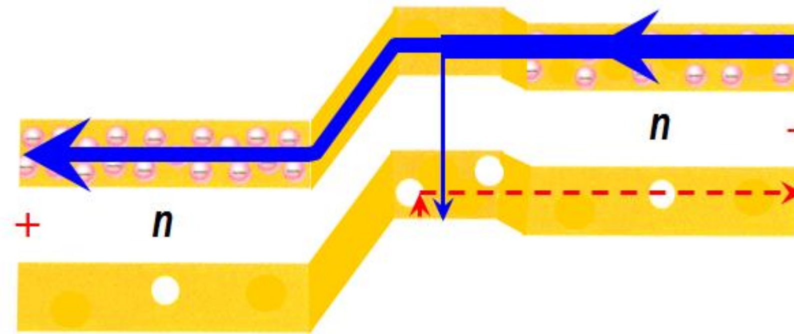
Modes of Operation of BJT

Active Mode



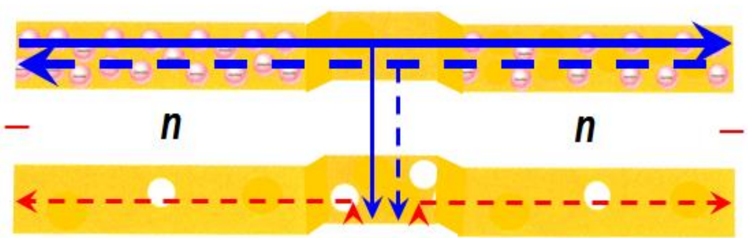
BE is FB, BC is RB, Large current can flow

Reverse Active Mode



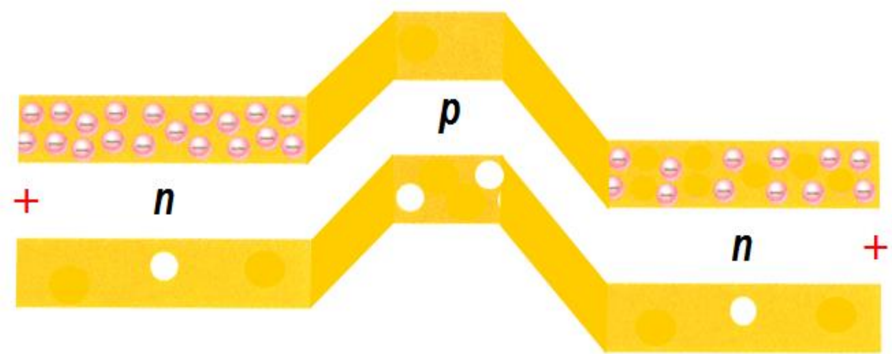
BE is RB, BC is FB, Moderate current can flow

Saturation Mode



BE is FB, BC is FB, The larger | V_{CE} | the larger the current

Cut-Off Mode

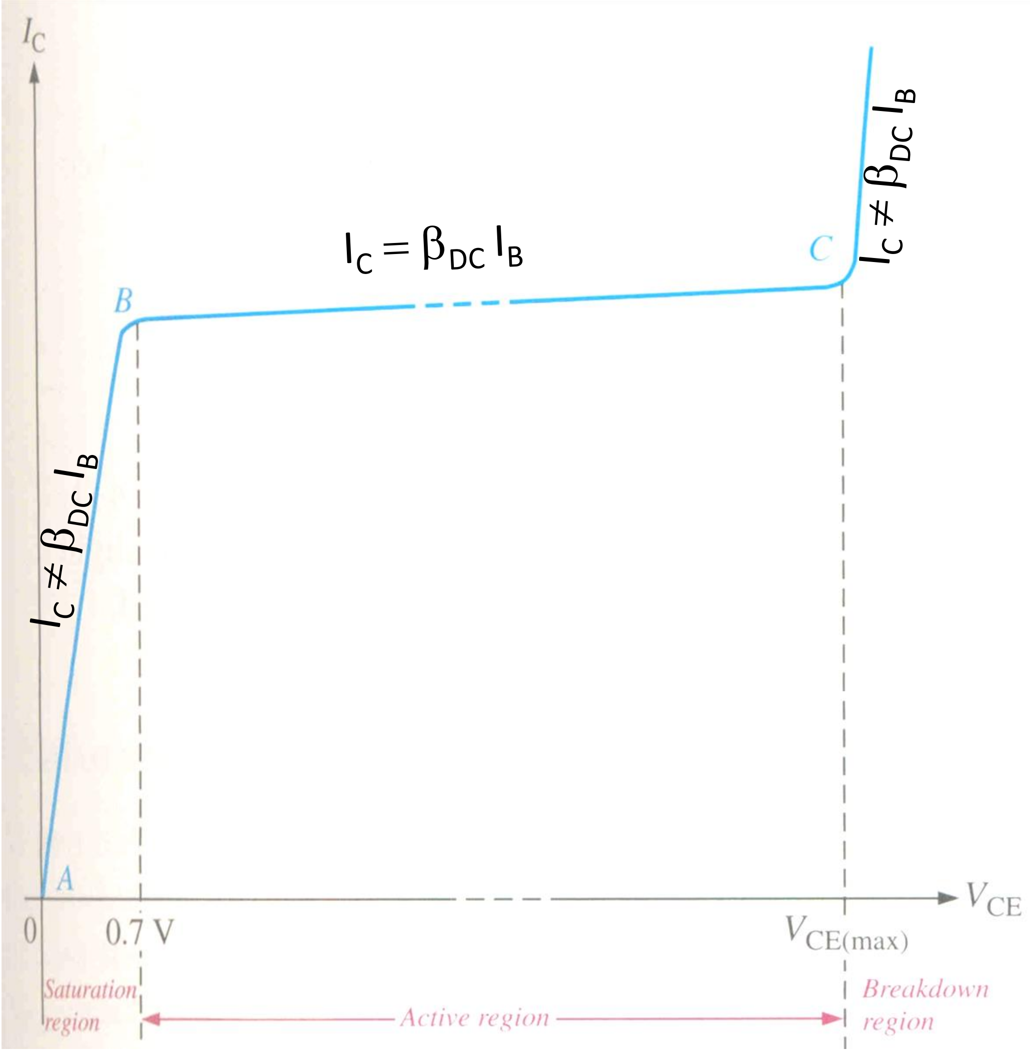


BE is RB, BC is RB, No current can flow

Collector Characteristic Curves

$V_{CE} < 0.7$ V (Saturation region):

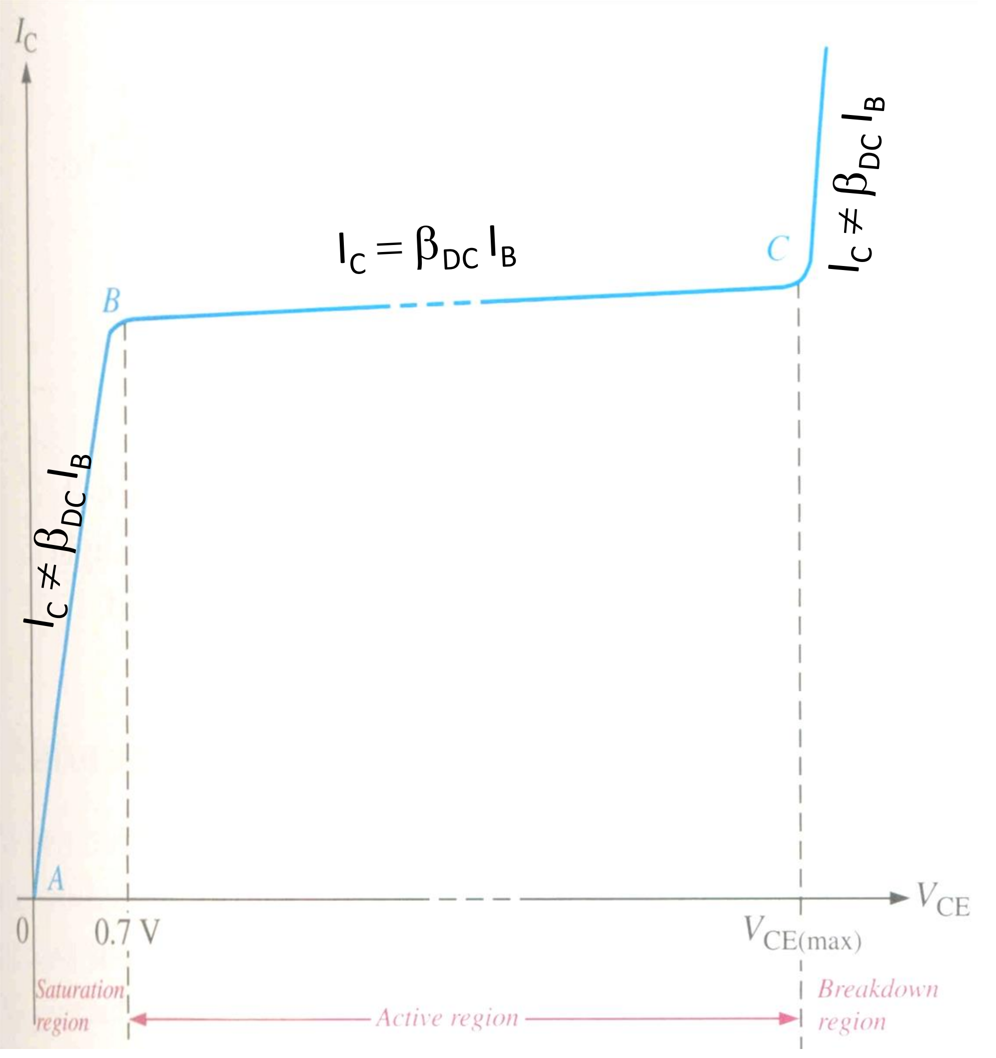
in this region both BE and BC are forward-biased. The higher V_{CE}, the higher the directing electric field, and the higher the collector current.



Collector Curves (Cont'd)

$0.7\ V < V_{CE} < V_{CE(max)}$ (Active region):

in this region BE is forward-biased and BC is reverse-biased. The increase in V_{CE} results in increasing the width of the BC depletion region, while its electric field remains the same, which leads to an almost constant collector current.



Characteristic Curves

$V_{CE} > V_{CE(\max)}$ (Breakdown region):
The BC depletion region can not expand, and the increase in V_{CE} results in an increase in the electric field and current.

when $I_B = 0 \Rightarrow I_C \cong 0$ regardless of the value of V_{CE}. This defines the *cutoff region* on the collector characteristic curves, in which both BE and BC are reverse-biased.