

# **Lecture 17**

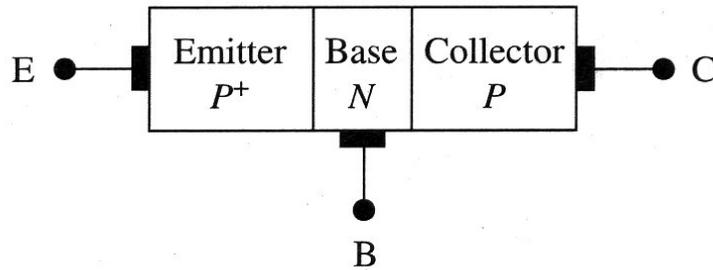
## **Bipolar Junction Transistors (BJT): Part 1**

### **Qualitative Understanding - How do they work?**

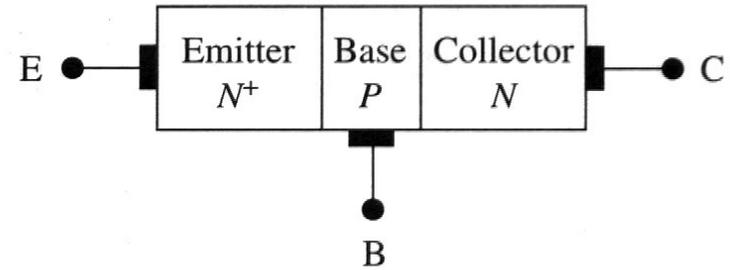
**Reading:**

**Pierret 10.1-10.6, 11.1**

# Bipolar Junction Transistor Fundamentals

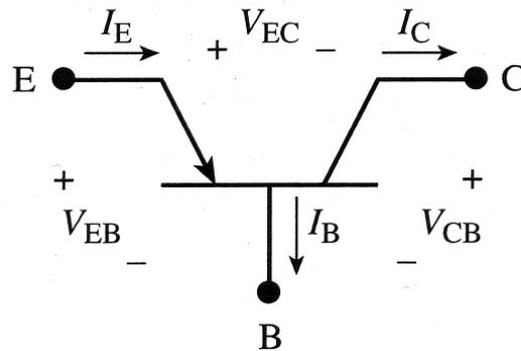
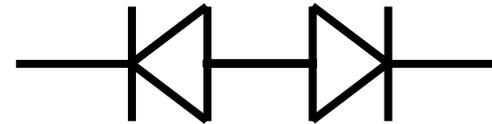
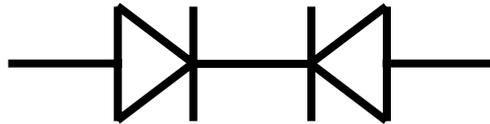


*pnp*

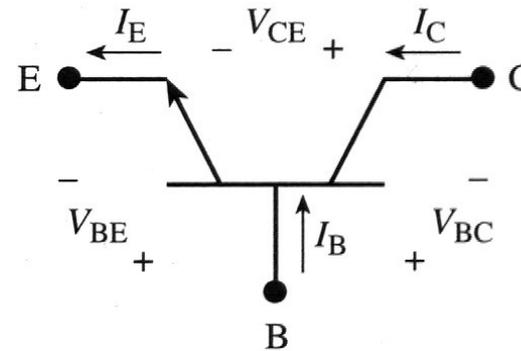


*npn*

Looks sort of  
like two diodes  
back to back



pnp mnemonic:  
“Pouring ‘N’ Pot”

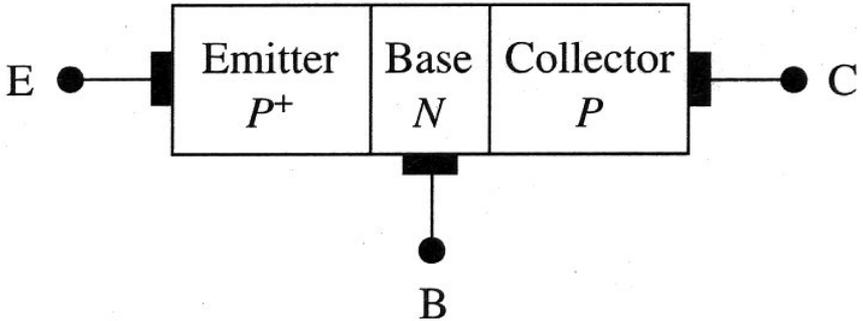


npn mnemonic:  
“Not Pouring ‘N’ ”

**Voltage Nomenclature Standard  $V_{+-}$**

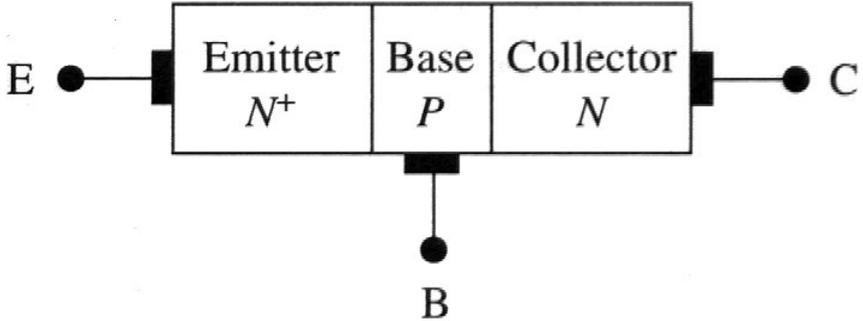
# Bipolar Junction Transistor Fundamentals

**Emitter “emits” holes**  
**Narrow Base controls number of holes emitted**  
**Collector “collects” holes emitted by the emitter**



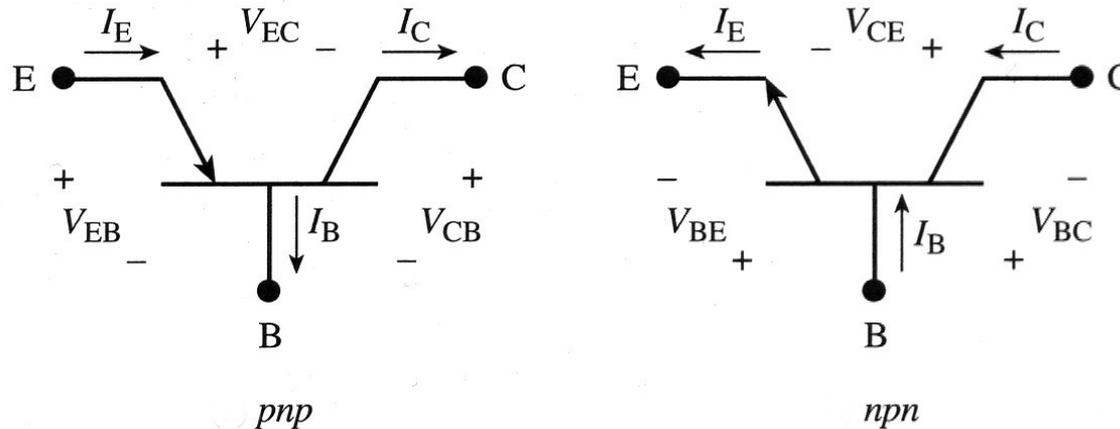
*pnp*

**Emitter “emits” electrons**  
**Narrow Base controls number of electrons emitted**  
**Collector “collects” electrons emitted by the emitter**



*npn*

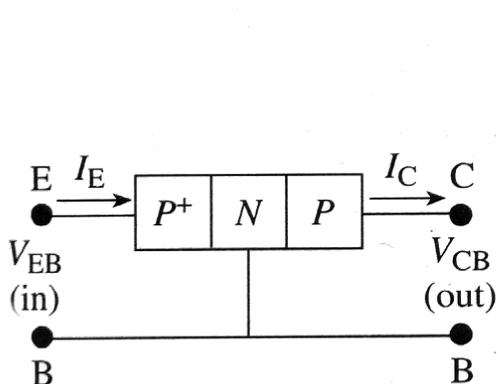
# Bipolar Junction Transistor Fundamentals



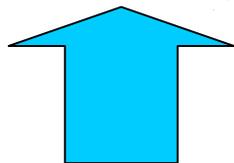
$$I_E = I_B + I_C$$

$$V_{EB} + V_{BC} + V_{CE} = 0$$

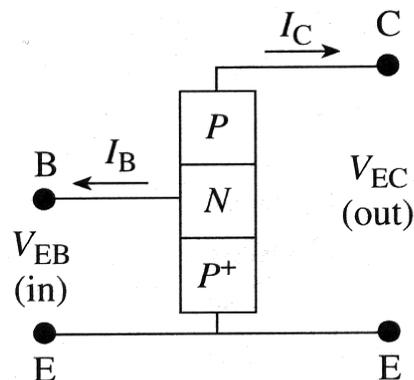
# Bipolar Junction Transistor Fundamentals



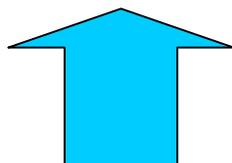
Common base



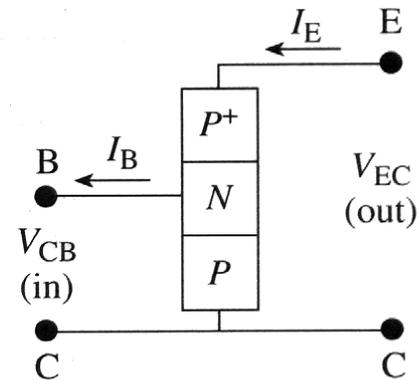
Both the input and output share the base “in common”



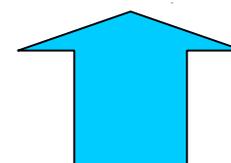
Common emitter



Both the input and output share the emitter “in common”



Common collector



Both the input and output share the Collector “in common”

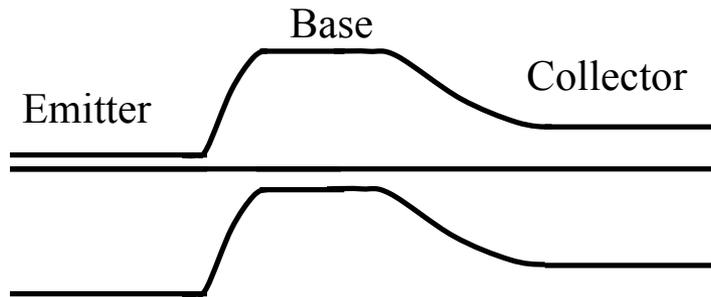
# Bipolar Junction Transistor Fundamentals

<i>Biasing Mode</i>	<i>Biasing Polarity E–B Junction</i>	<i>Biasing Polarity C–B Junction</i>
Saturation	Forward	Forward
<b>Active</b>	<b>Forward</b>	<b>Reverse</b>
Inverted	Reverse	Forward
Cutoff	Reverse	Reverse

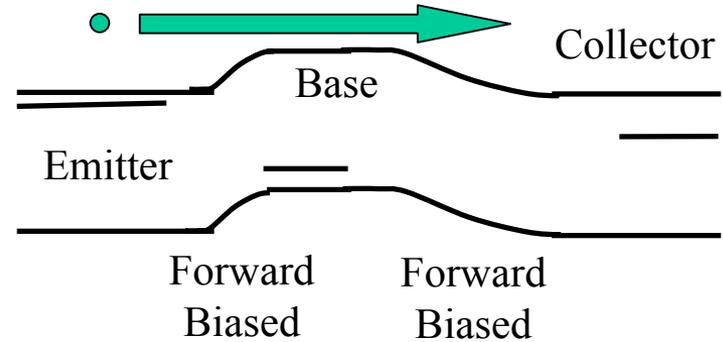
- Active: Is useful for amplifiers. Most common mode
- Saturation: Equivalent to an on state when transistor is used as a switch
- Cutoff : Equivalent to an off state when transistor is used as a switch
- Inverted: Rarely if ever used.

# Bipolar Junction Transistor Fundamentals

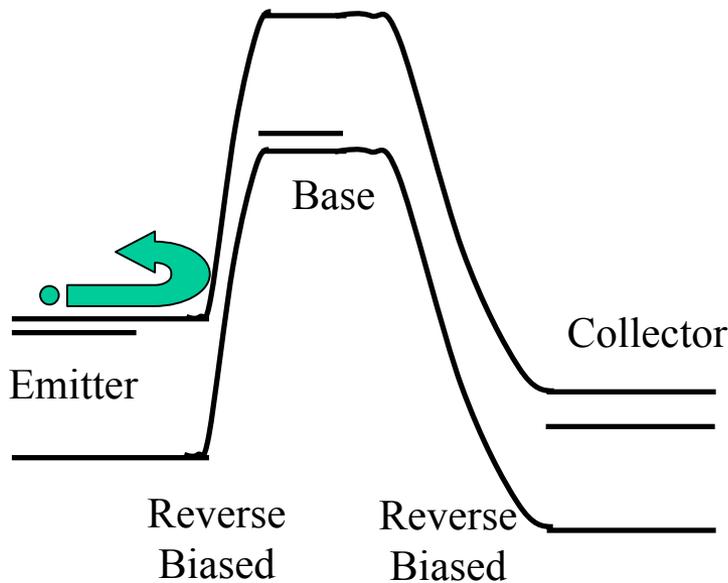
## Equilibrium



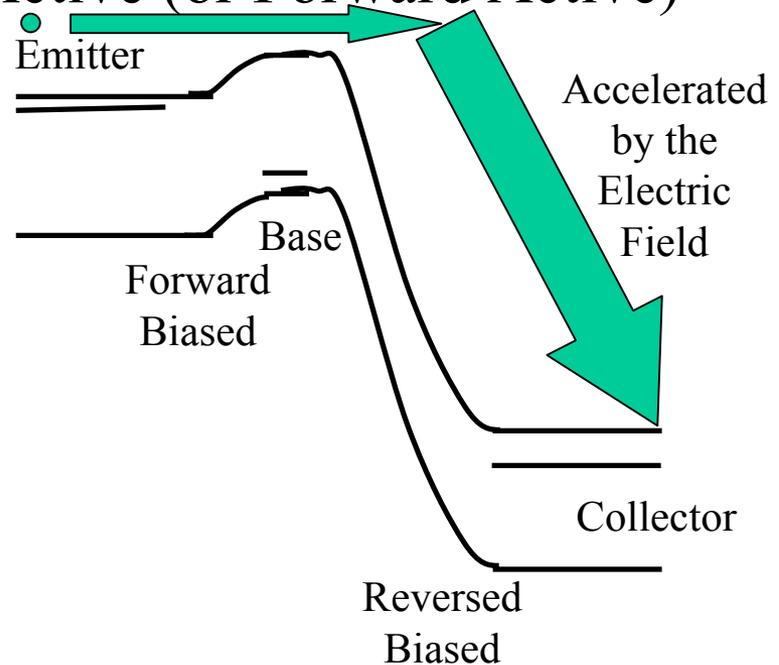
## Saturation



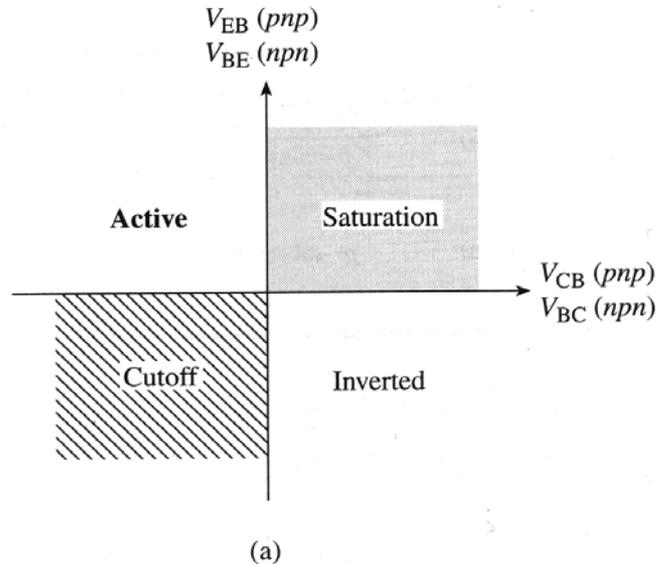
## Cutoff



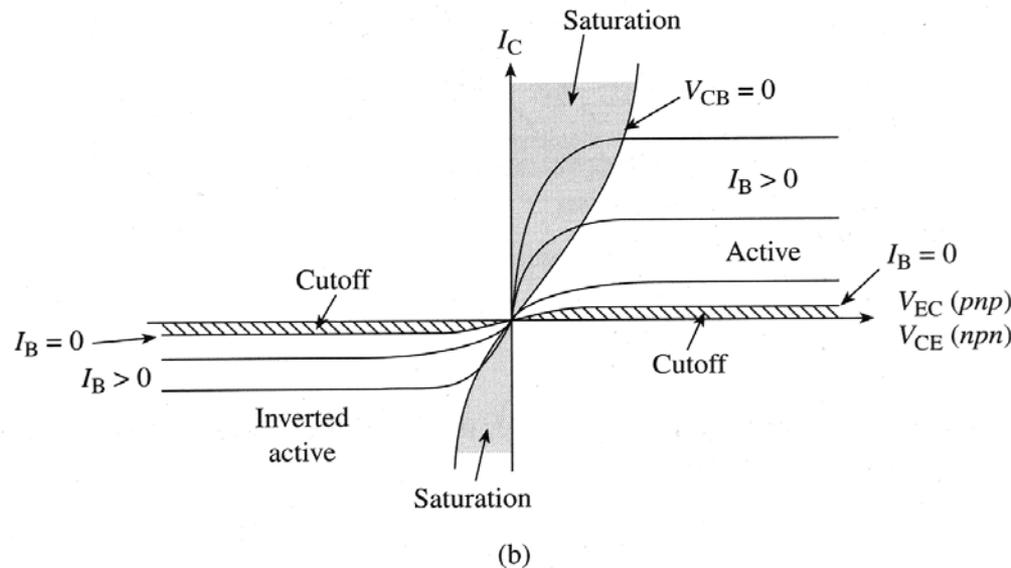
## Active (or Forward Active)



# Bipolar Junction Transistor Fundamentals



- Operational modes can be defined based on base-emitter voltages and base-collector voltages



- When there is no base current, almost no collector current flows
- When base current flows, a collector current can flow
- The device is then a current controlled current device

# Bipolar Junction Transistor Fundamentals: Electrostatics in Equilibrium

Emitter Doping > Base Doping > Collector Doping

Emitter is heavily doped

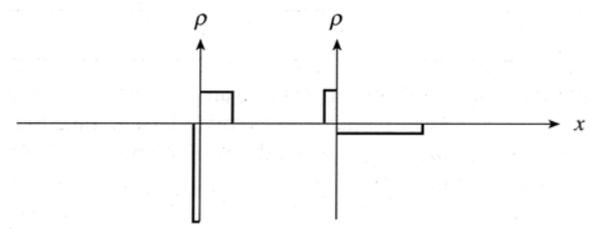
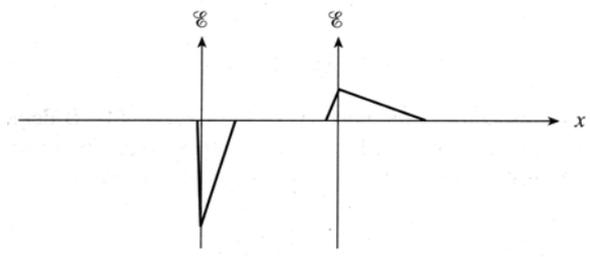
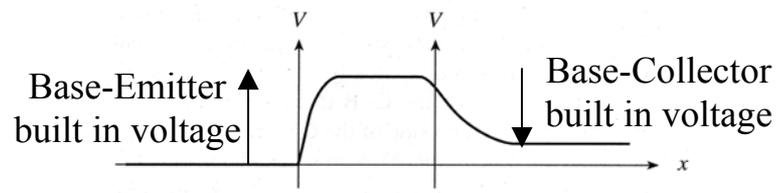
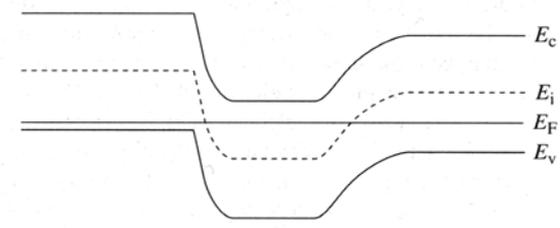
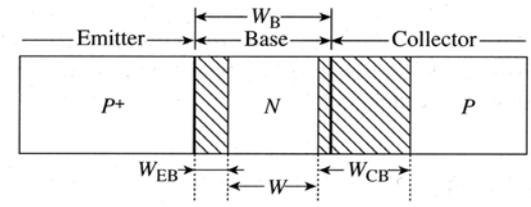
$W$  = width of the base quasi-neutral region

$W_B$  = Total Base width

$W_{EB}$  = Base-Emitter depletion width

$W_{CB}$  = Base-Collector depletion width

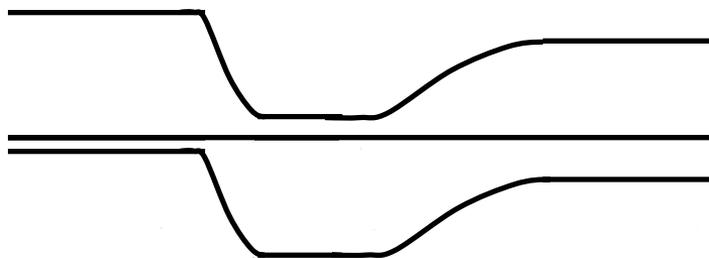
$$W_{EB} < W_{CB}$$



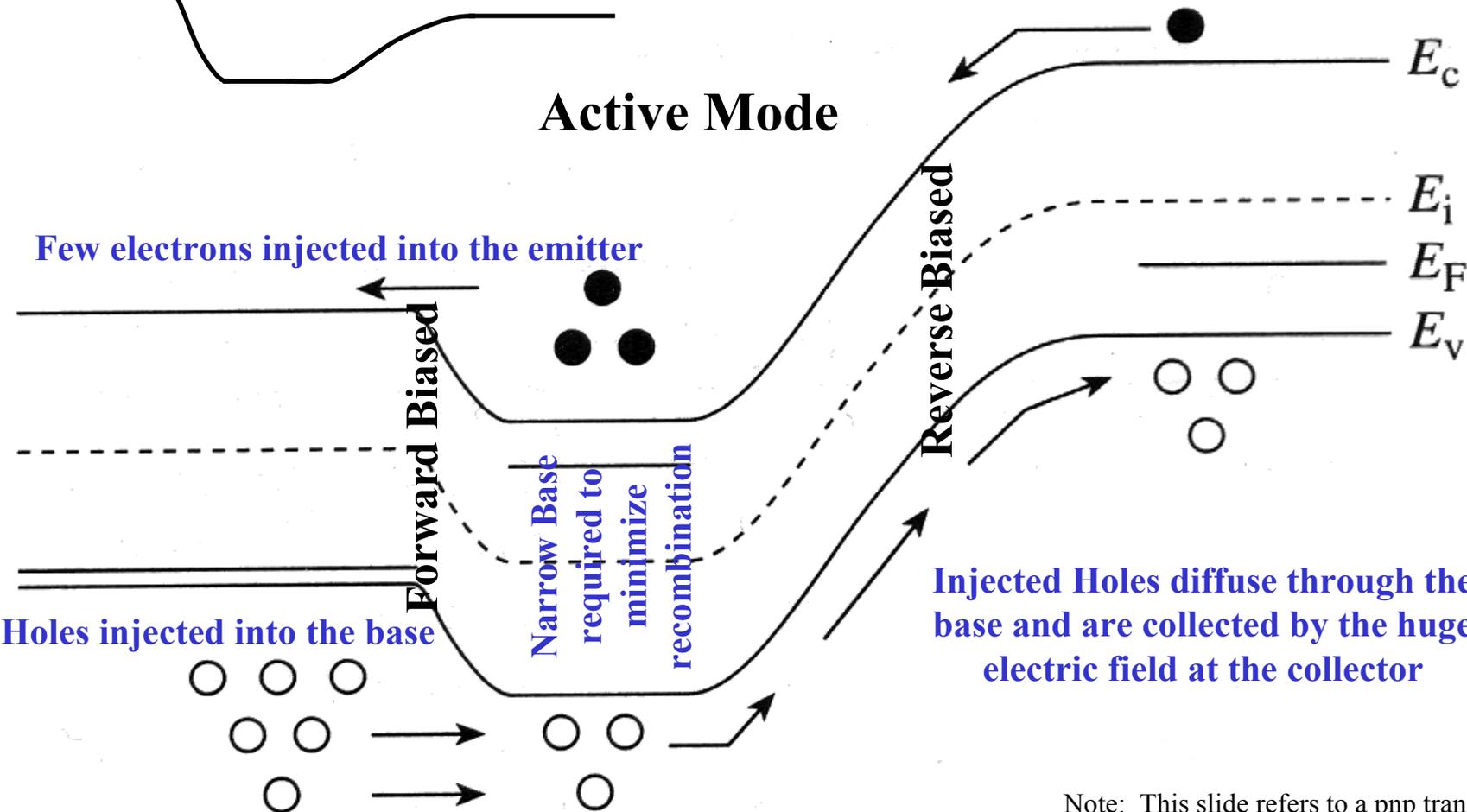
Note: This slide refers to a pnp transistor

# Bipolar Junction Transistor Fundamentals

Equilibrium



Active Mode



Few electrons injected into the emitter

Forward Biased

Narrow Base required to minimize recombination

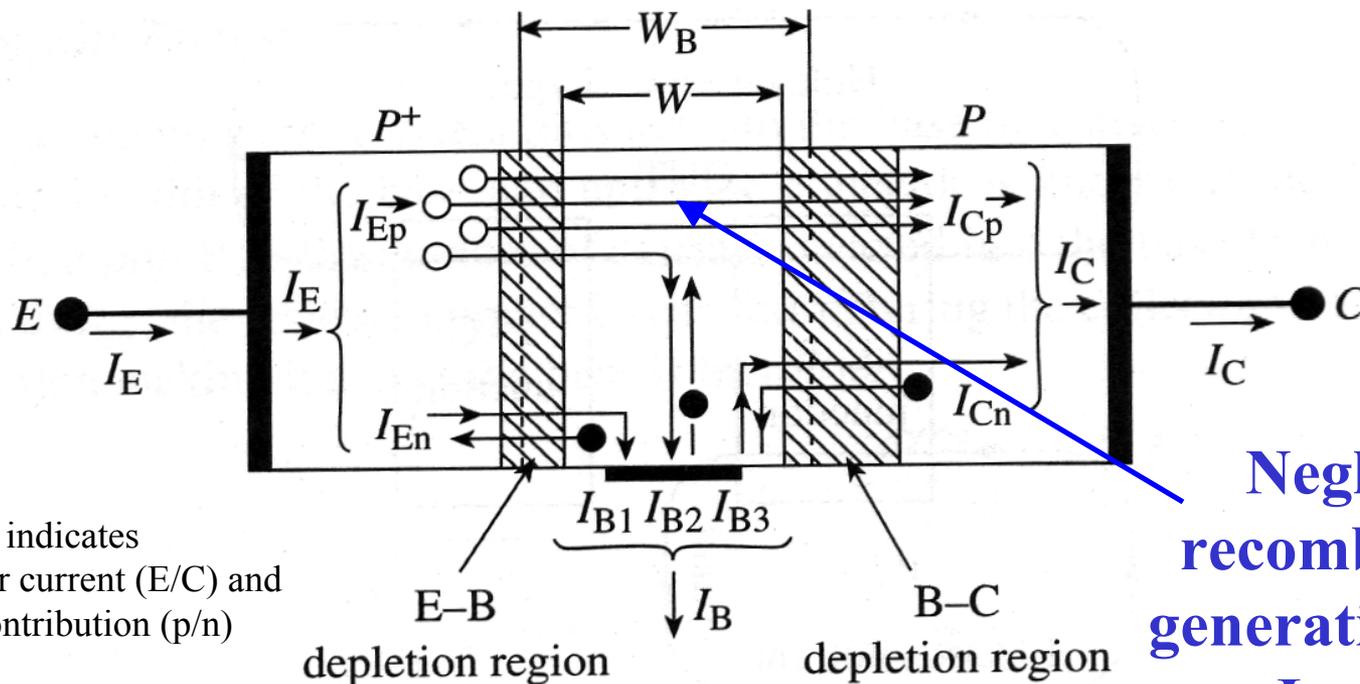
Reverse Biased

Injected Holes diffuse through the base and are collected by the huge electric field at the collector

$E_c$   
 $E_i$   
 $E_F$   
 $E_v$

Note: This slide refers to a pnp transistor

# Bipolar Junction Transistor Fundamentals



**Neglecting recombination-generation means  $I_{Cp} \approx I_{Ep}$**

Note: Subscript indicates emitter/collector current (E/C) and hole/electron contribution (p/n)

E-B depletion region      B-C depletion region

$$I_E = I_{Ep} + I_{En}$$

$$I_C = I_{Cp} + I_{Cn}$$

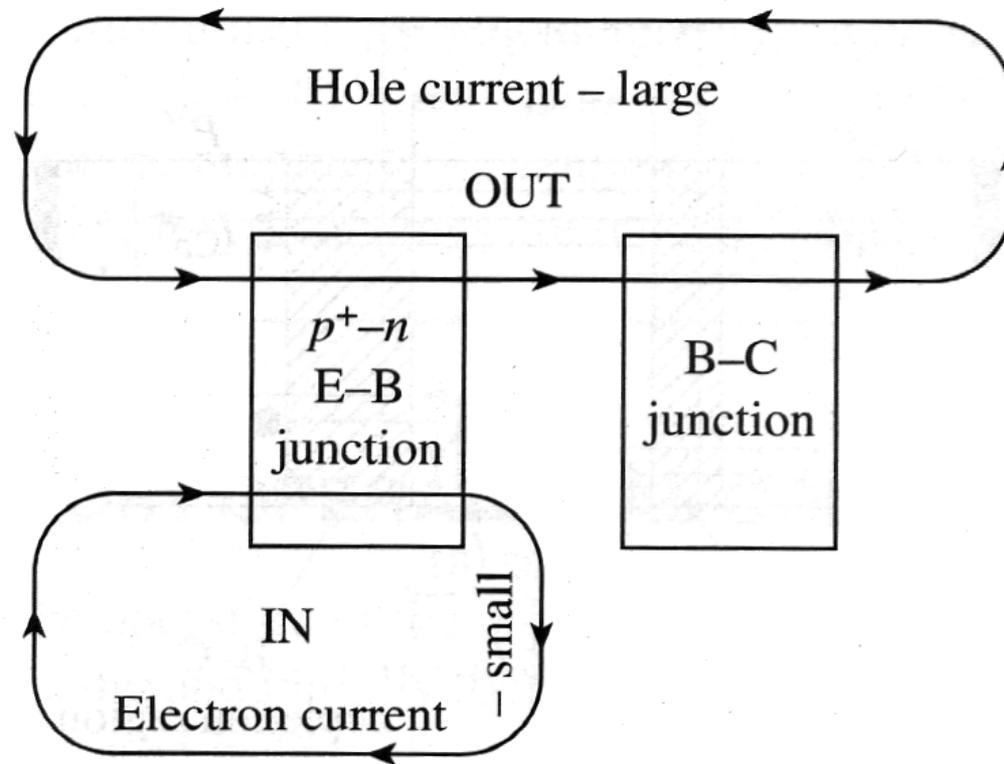
Since emitter is more heavily doped than the base,  $I_{En} \ll I_{Ep}$

Since the base-collector junction is reverse biased,  $I_{Cn} \ll I_{cp}$

$$I_C \approx I_E \text{ and } (I_B = I_E - I_C) \text{ is small compared to } I_C \text{ and } I_E$$

Note: This slide refers to a pnp transistor

# Bipolar Junction Transistor Fundamentals



Consider a pnp Transistor: A small electron base current (flowing into the emitter from the base) controls a larger hole current flowing from emitter to collector. Effectively, we can have the collector-emitter current controlled by the base-emitter current.

Note: This slide refers to a pnp transistor

# Bipolar Junction Transistor Fundamentals: Performance Parameters

$$(1) \quad \gamma = \frac{I_{Ep}}{I_E} = \frac{I_{Ep}}{I_{Ep} + I_{En}}$$

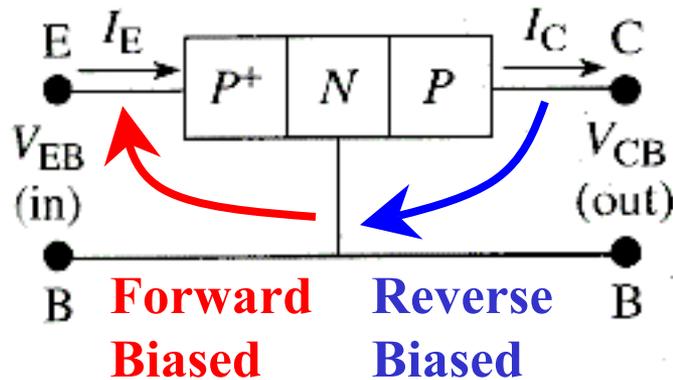
**Emitter Efficiency**: Characterizes how effective the large hole current is controlled by the small electron current. Unity is best, zero is worst.

$$(2) \quad \alpha_T = \frac{I_{Cp}}{I_{Ep}}$$

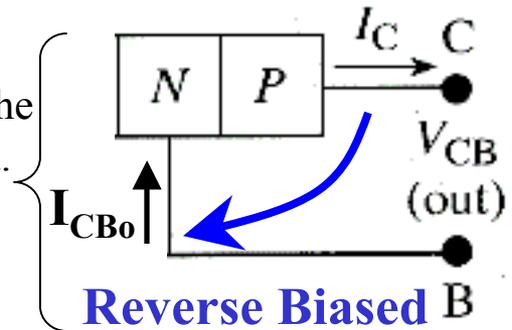
**Base Transport Factor**: Characterizes how much of the injected hole current is lost to recombination in the base. Unity is best, zero is worst.

# Bipolar Junction Transistor Fundamentals: Performance Parameters

## Active Mode, Common Base Characteristics



$I_{CB0}$  is defined as the collector current when the emitter is open circuited. It is the Collector-base junction saturation current.



$I_C$  = fraction of emitter current making it across the base + leakage current

$$(3) \quad I_C = \alpha_{dc} I_E + I_{CB0} \quad \text{where } \alpha_{dc} \text{ is the common base DC current gain}$$

Combining (1) and (2),

$$I_{Cp} = \alpha_T I_{Ep} = \gamma \alpha_T I_E$$

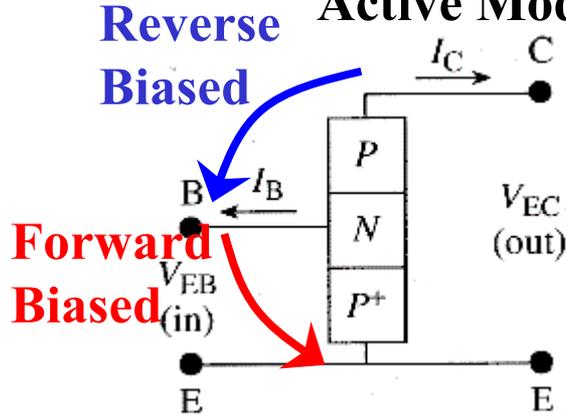
$$I_C = I_{Cp} + I_{Cn} = \alpha_T I_{Ep} + \underline{I_{Cn}} = \gamma \alpha_T I_E + I_{Cn}$$

Thus comparing this to (3),

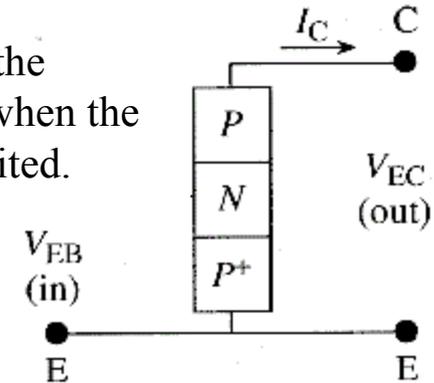
$$\alpha_{dc} = \gamma \alpha_T \quad \text{and} \quad I_{CB0} = I_{Cn}$$

# Bipolar Junction Transistor Fundamentals: Performance Parameters

## Active Mode, Common Emitter Characteristics



$I_{CE0}$  is defined as the collector current when the base is open circuited.



$I_C$  = multiple of the base current making it across the base + leakage current

$$(4) \quad I_C = \beta_{dc} I_B + I_{CE0} \quad \text{where } \beta_{dc} \text{ is the common emitter DC current gain}$$

But using  $I_E = I_C + I_B$  in (2), (5)  $I_C = \alpha_{dc} (I_C + I_B) + I_{CB0}$   
and solving for  $I_C$

$$(6) \quad I_C = \frac{\alpha_{dc}}{1 - \alpha_{dc}} I_B + \frac{I_{CB0}}{1 - \alpha_{dc}}$$

comparing (4) and (6)

$$\beta_{dc} = \frac{\alpha_{dc}}{1 - \alpha_{dc}} \quad \text{and} \quad I_{CE0} = \frac{I_{CB0}}{1 - \alpha_{dc}} \quad \text{and} \quad \beta_{dc} = \frac{I_C}{I_B}$$

Note: This slide refers to a pnp transistor