Lecture 17

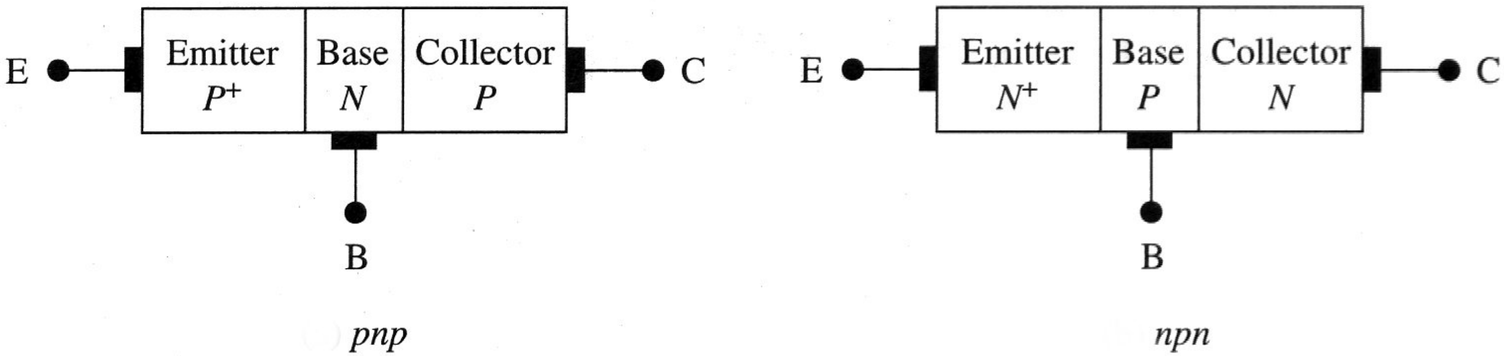
Bipolar Junction Transistors (BJT): Part 1

Qualitative Understanding - How do they work?

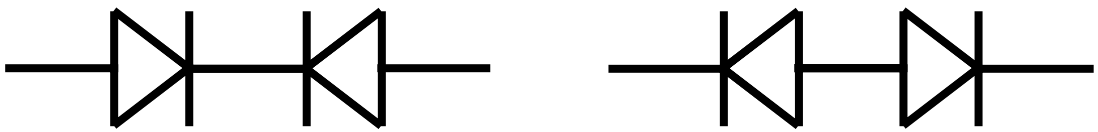
Reading:

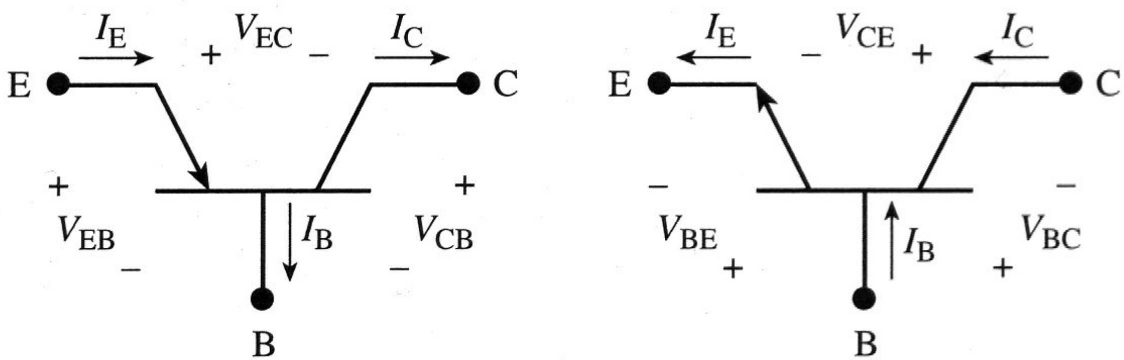
Pierret 10.1-10.6, 11.1

Bipolar Junction Transistor Fundamentals



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

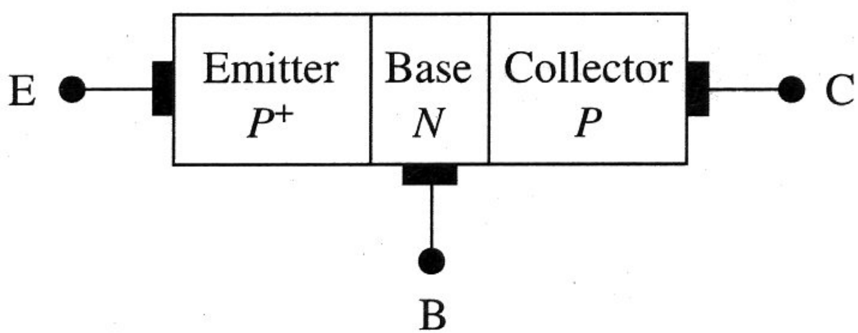
Narrow Base controls number of holes emitted

Collector "collects" holes emitted by the emitter

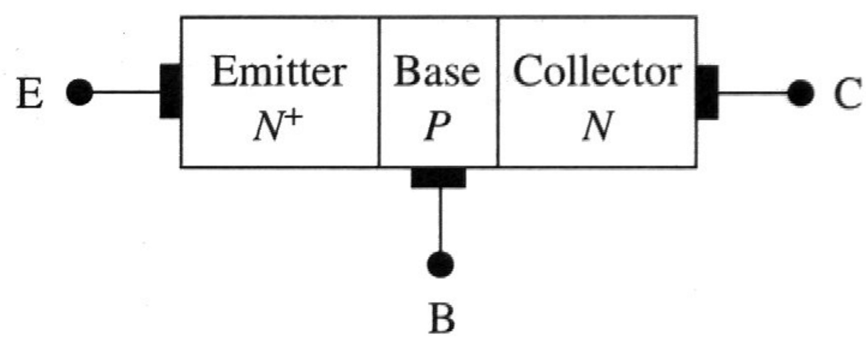
Emitter "emits" electrons

Narrow Base controls number of electrons emitted

Collector "collects" electrons emitted by the emitter

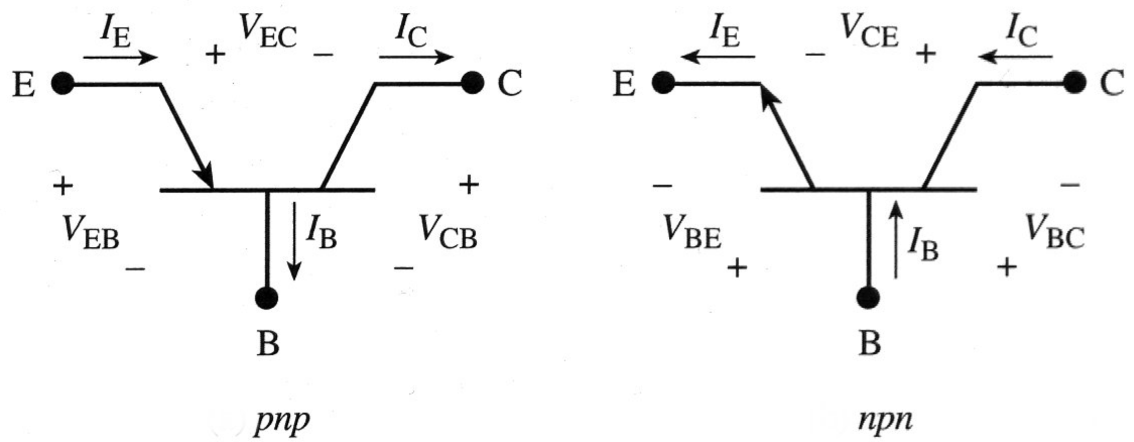


pnp



npn

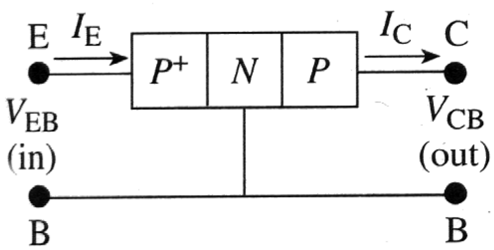
Bipolar Junction Transistor Fundamentals



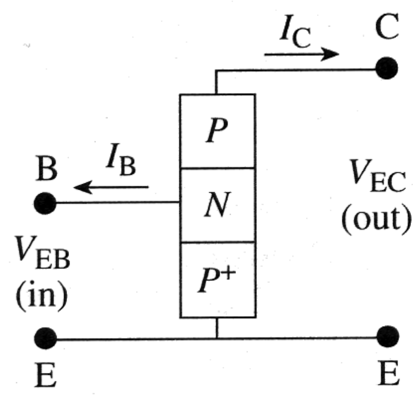
$$I_E = I_B + I_C$$

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

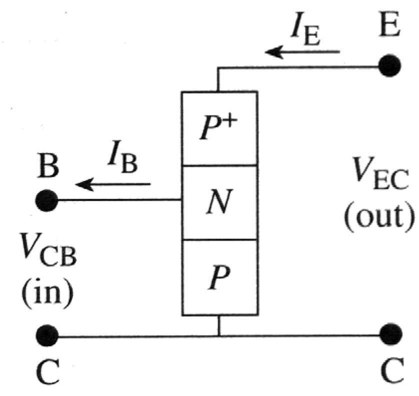
Bipolar Junction Transistor Fundamentals



Common base



Common emitter



Common collector

Both the input and output share the base "in common"

Both the input and output share the emitter "in common"

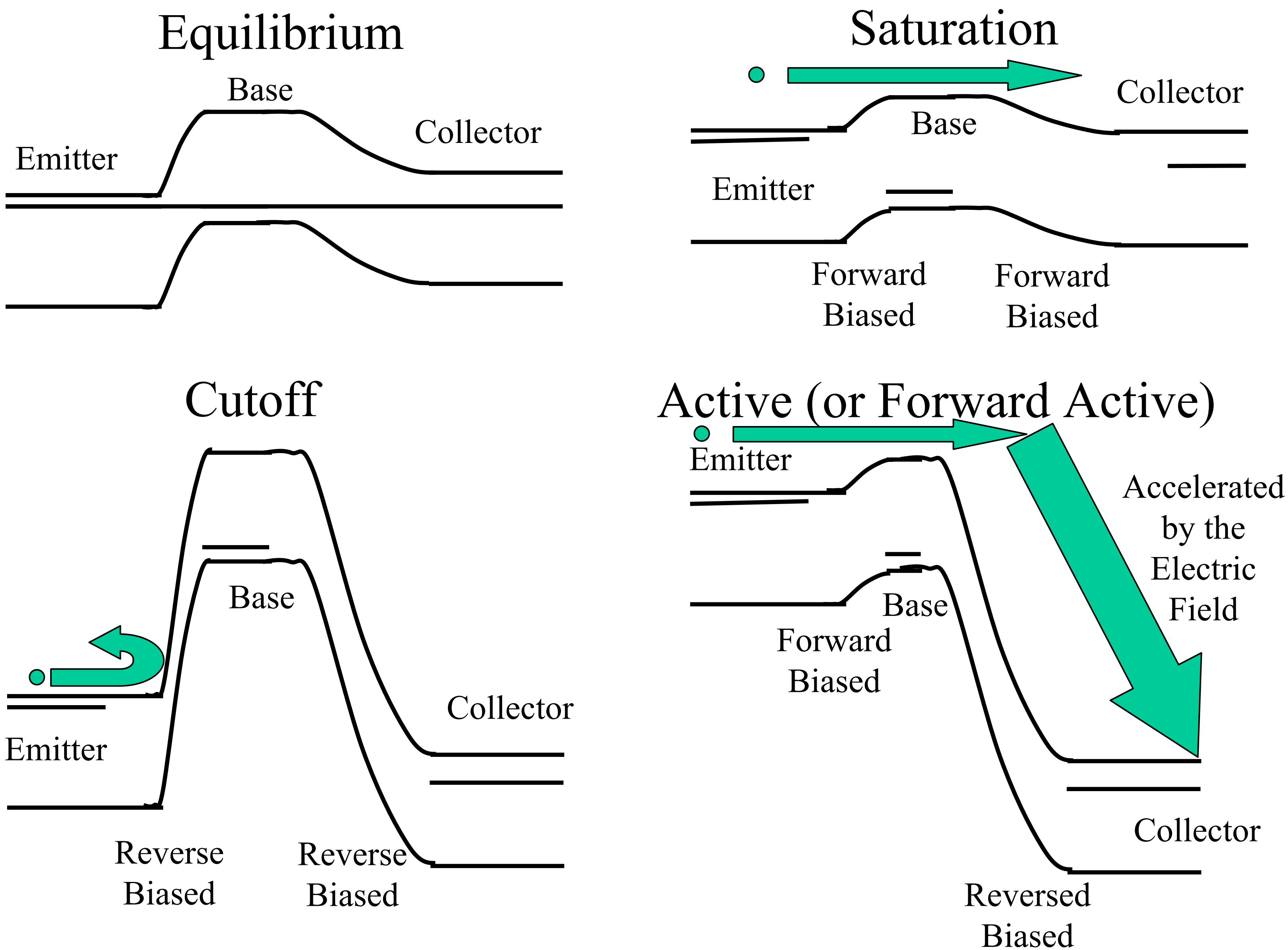
Both the input and output share the Collector "in common"

Bipolar Junction Transistor Fundamentals

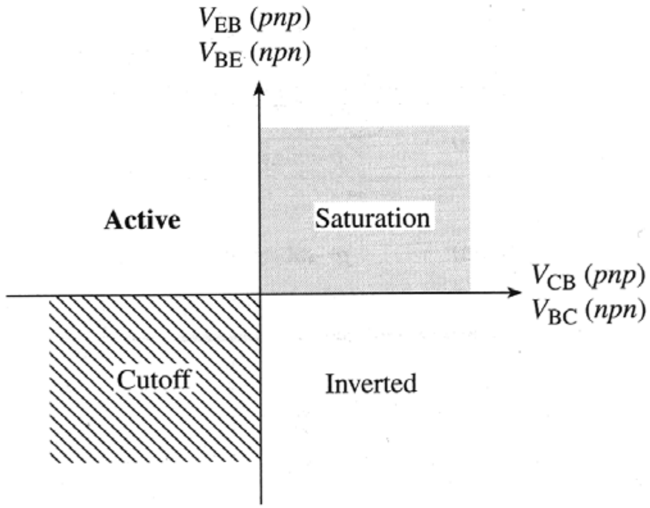
Biasing Mode	*Biasing Polarity E–B Junction*	*Biasing Polarity C–B Junction*
Saturation	Forward	Forward
Active	**Forward**	**Reverse**
Inverted	Reverse	Forward
Cutoff	Reverse	Reverse

- 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

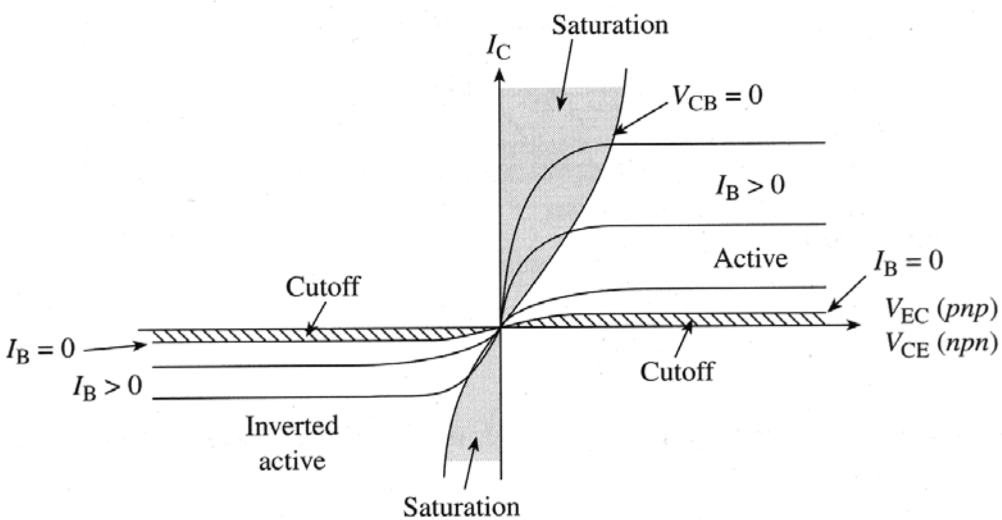


Bipolar Junction Transistor Fundamentals



(a)

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



(b)

•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

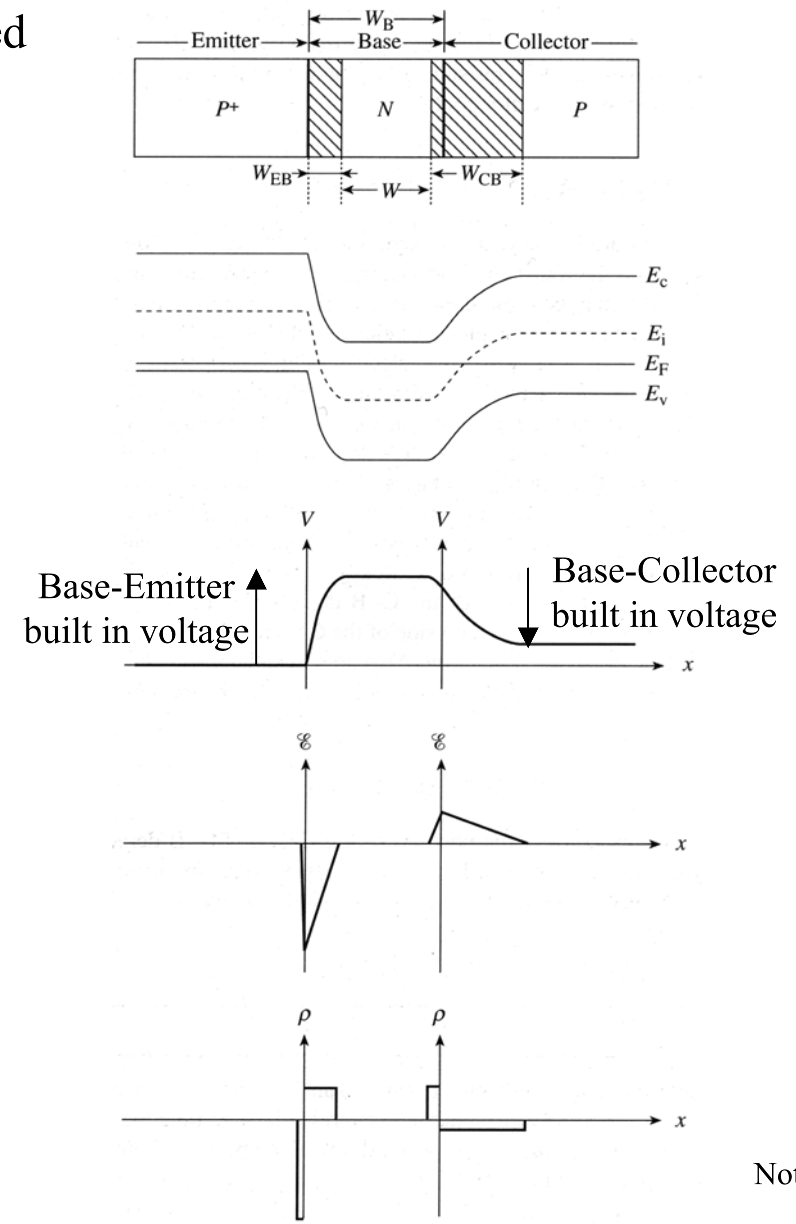
W=width of the base quasi-neutral region

W_B=Total Base width

W_{EB}=Base-Emitter depletion width

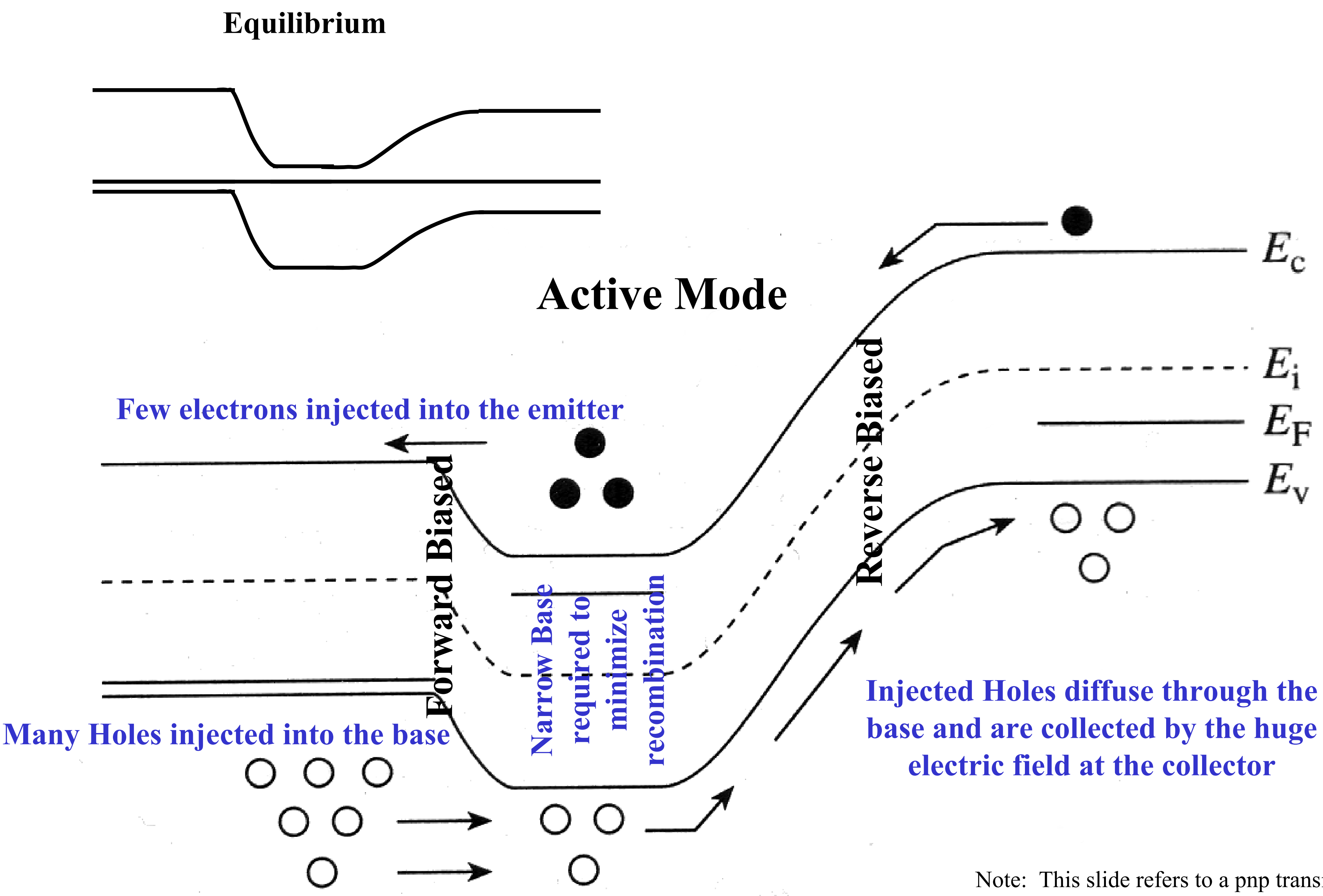
W_{CB}=Base-Collector depletion width

$W_{EB} < W_{CB}$



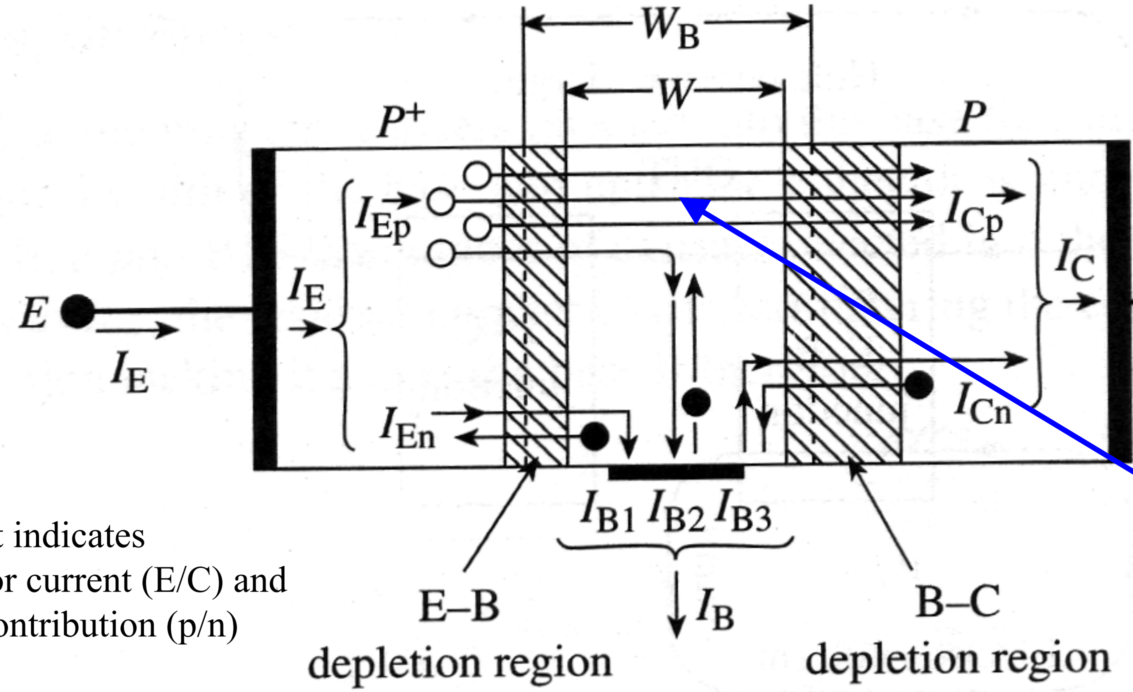
Note: This slide refers to a pnp transistor

Bipolar Junction Transistor Fundamentals



Note: This slide refers to a pnp transistor

Bipolar Junction Transistor Fundamentals



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

Neglecting recombination-generation means $I_{Cp} \sim= I_{Ep}$

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

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

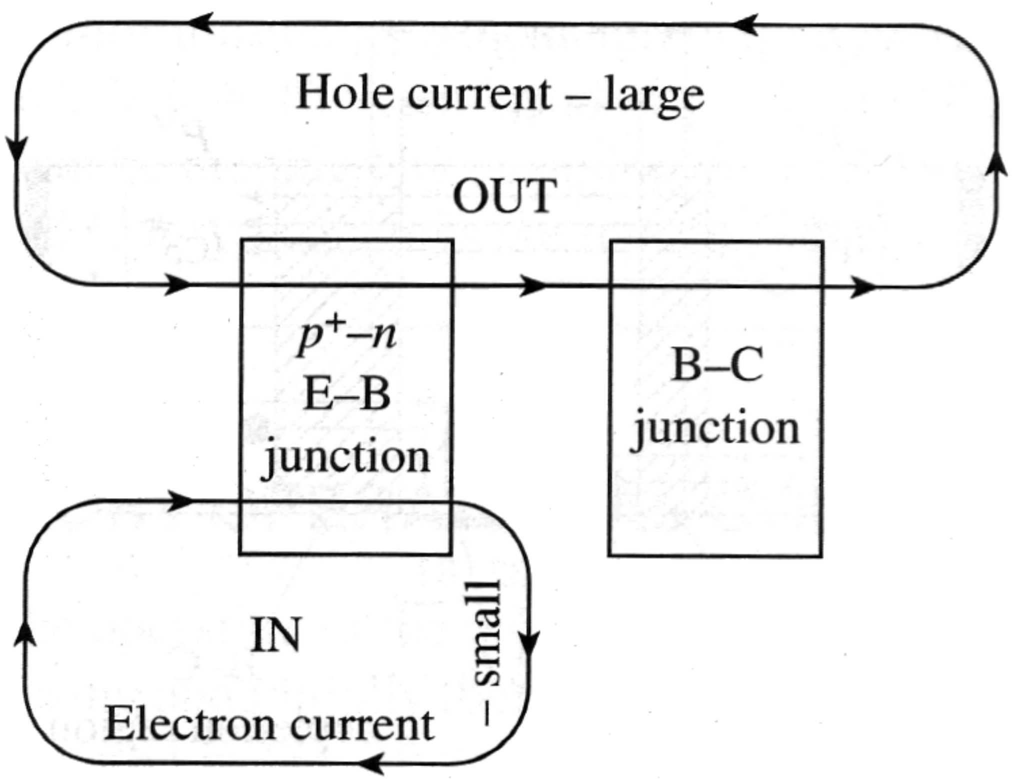
Since emitter is more heavily doped than the base, $I_{En} << I_{Ep}$

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

$I_C \sim= I_E$ and ($I_B = I_E - I_C$) is small compared to I_C 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.

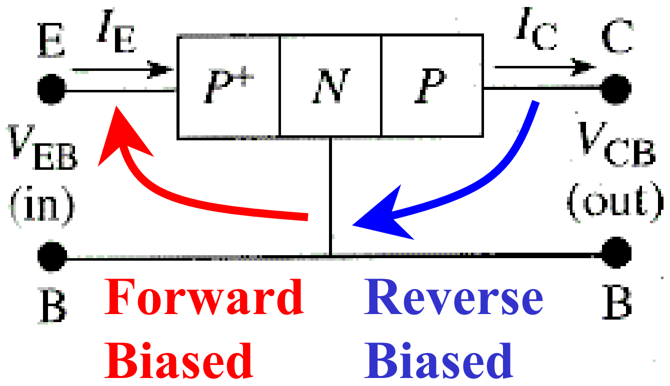
$$(2) \quad \alpha_T = \frac{I_{Cp}}{I_{Ep}}$$

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

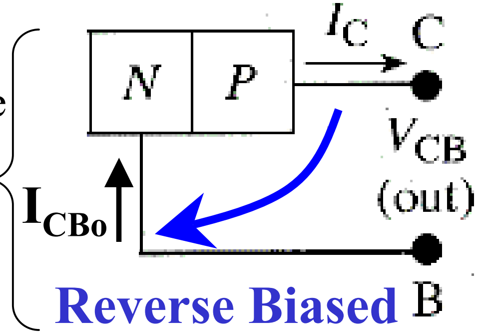
Note: This slide refers to a pnp transistor

Bipolar Junction Transistor Fundamentals:
Performance Parameters

Active Mode, Common Base Characteristics



I_{CBo} 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

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

Combining (1) and (2),

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

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

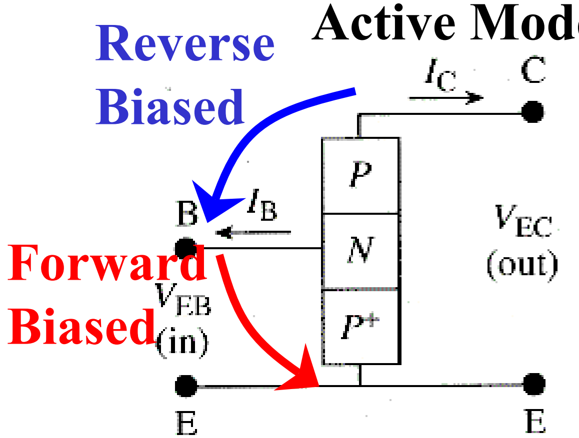
Thus comparing this to (3),

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

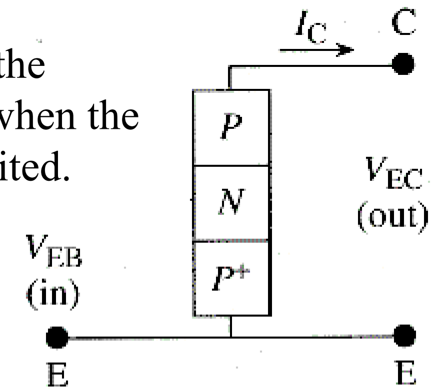
Note: This slide refers to a pnp transistor

Bipolar Junction Transistor Fundamentals:
Performance Parameters

Active Mode, Common Emitter Characteristics



I_{CEo} 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

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

But using I_E=I_C+I_B in (2), $$(5) \quad I_C = \alpha_{dc}\left(I_C + I_B\right) + I_{CBo}$$

and solving for I_C

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

comparing (4) *and* (6)

$$\beta_{dc} = \frac{\alpha_{dc}}{1-\alpha_{dc}} \quad and \quad I_{CEo} = \frac{I_{CBo}}{1-\alpha_{dc}} \quad and \quad \beta_{dc} = \frac{I_C}{I_B}$$

Note: This slide refers to a pnp transistor