ELL100: INTRODUCTION TO ELECTRICAL ENGG.

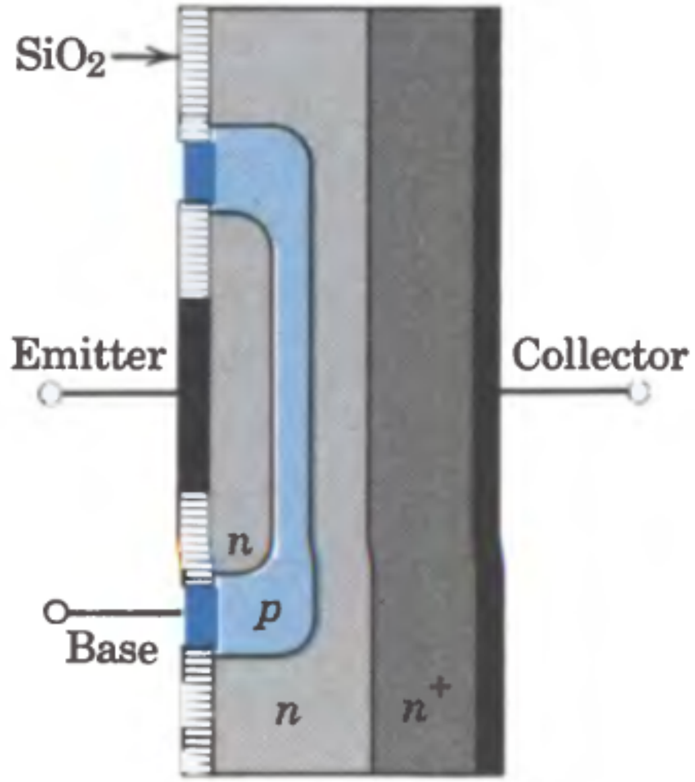
Bipolar Junction Transistors (BJT) - Basics

Instructor: Debanjan Bhowmik

Reference: Donald Neamen's 'Electronic Circuit Analysis'
Chapter 3 (BJT)

Bipolar Junction Transistor

- Three terminal device
- Transistor: Transfer of resistance
- Two pn junctions in close proximity
- Achieved by sandwiching a narrow n(p) type material between two p(n)-type material sections.
- Bipolar: Both electrons and holes contribute in curren
- Type: npn or pnp



Planar structure

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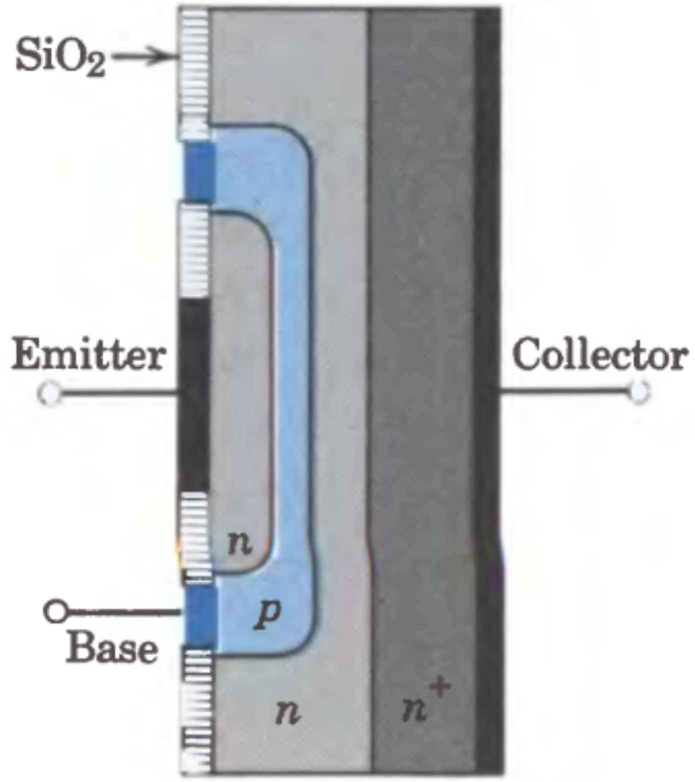


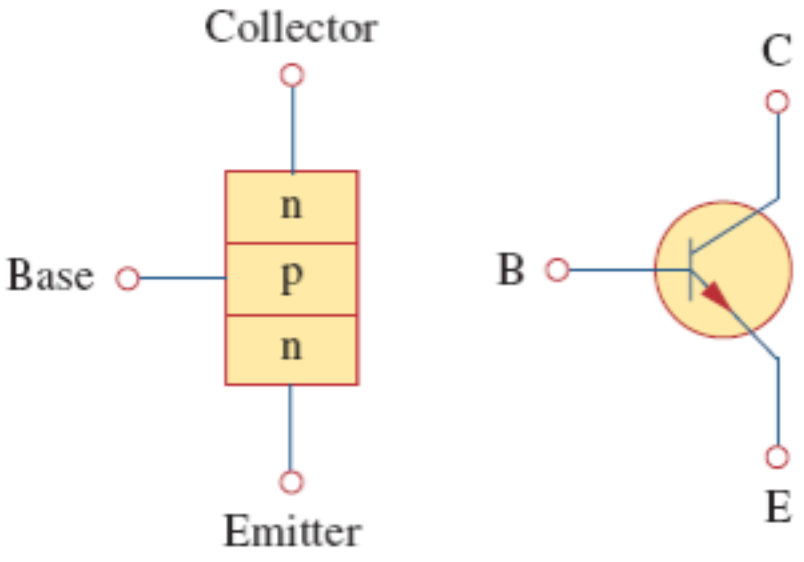
Planar structure

- **Doping order**

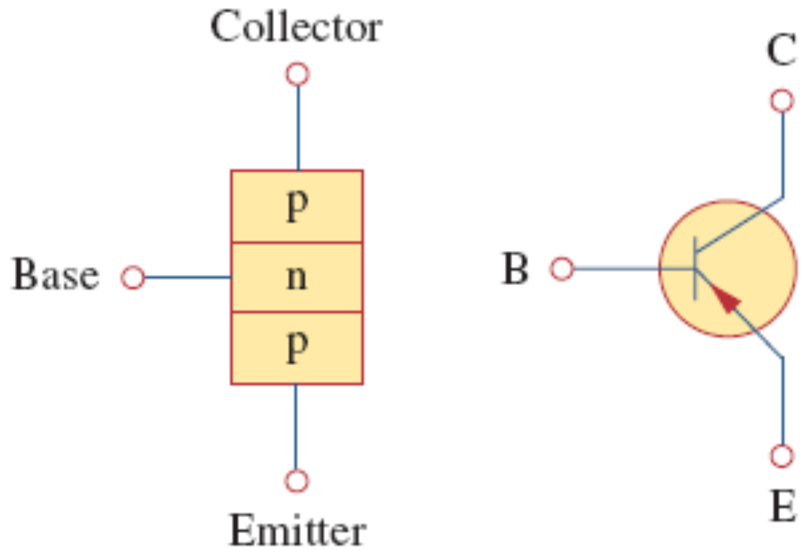
  $N_{emitter} > N_{collector} > N_{base}$
- **Thickness order**

  $T_{collector} > T_{emitter} > T_{base}$

Bipolar Junction Transistor: Symbol



npn transistor symbol

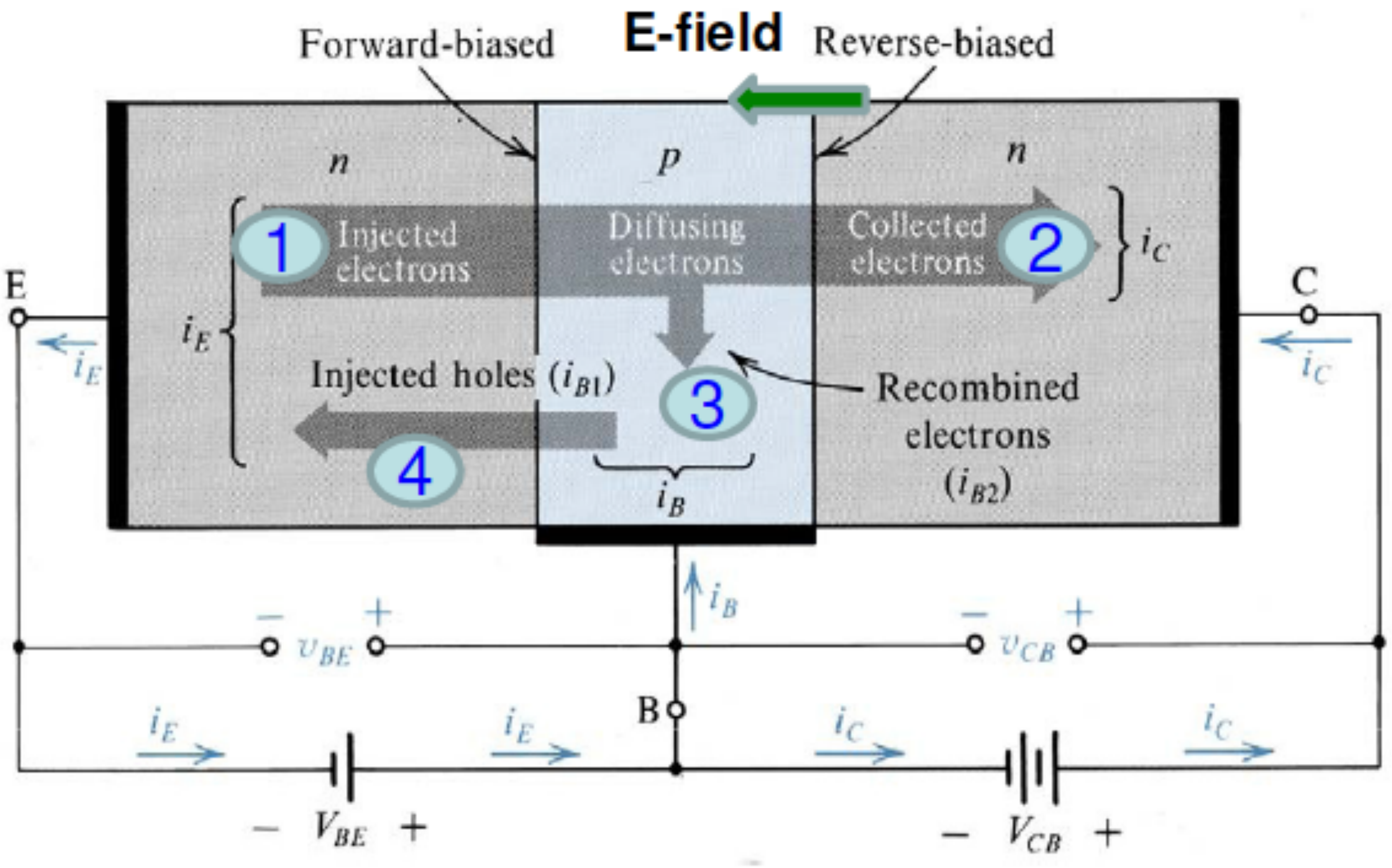


pnp transistor symbol

Emitter lead is identified by an arrow pointing in the direction of ‘positive’ charge flow in normal operation.

BJT- Basic Working

Mode	V_{BE}	V_{BC}
Forward active	Forward bias	Reverse Bias



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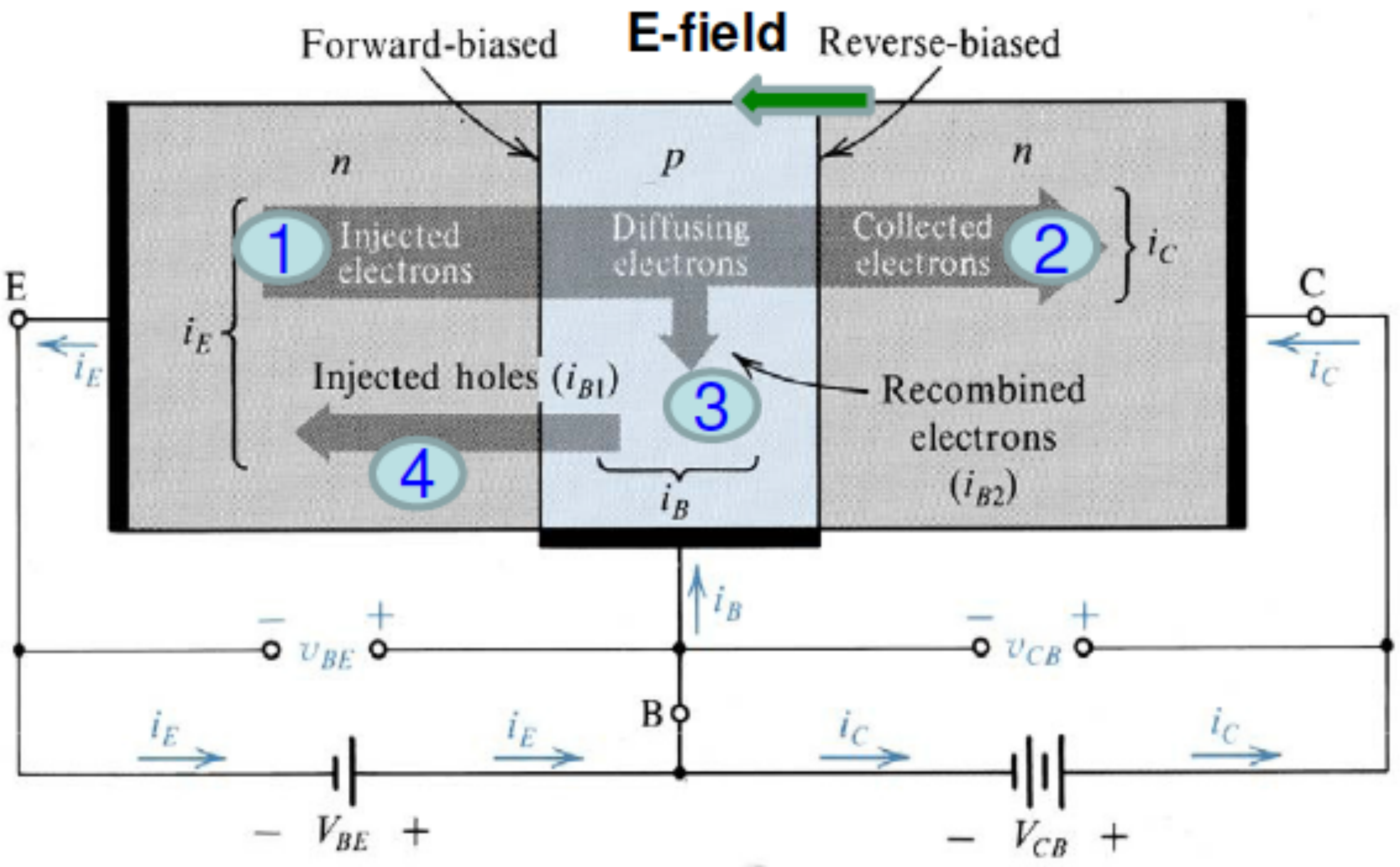

1. Forward bias of EB Jn causes electrons to diffuse from emitter into base.

2. As base region is very thin, the majority of electrons diffuse to the edge of the depletion region of CB Jn, and then are swept to the collector by the electric field of the reverse-biased CB Jn. **(Collected electrons recombine with 'holes' provided by VCB supply.)** $i_C = \alpha I_E$

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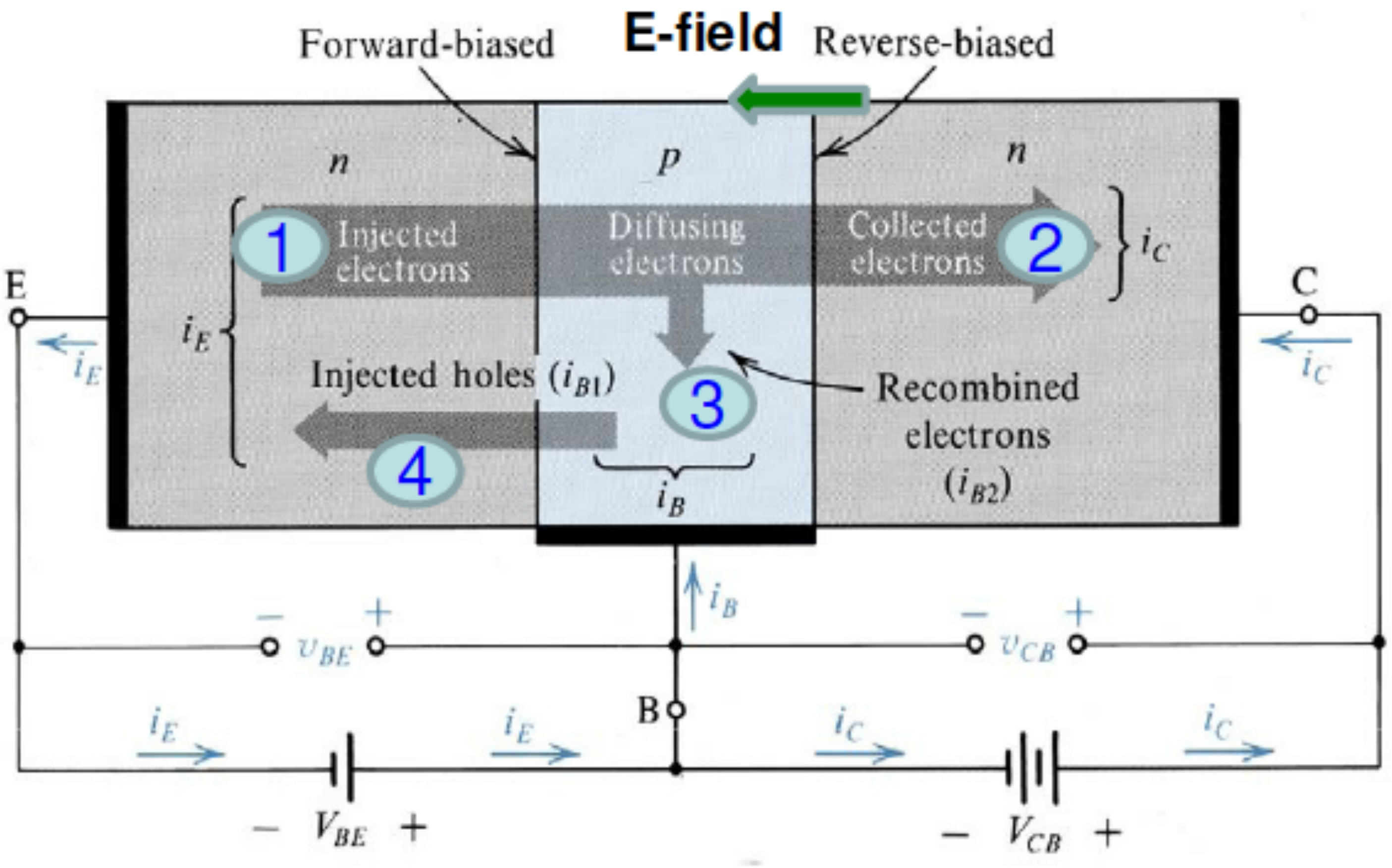

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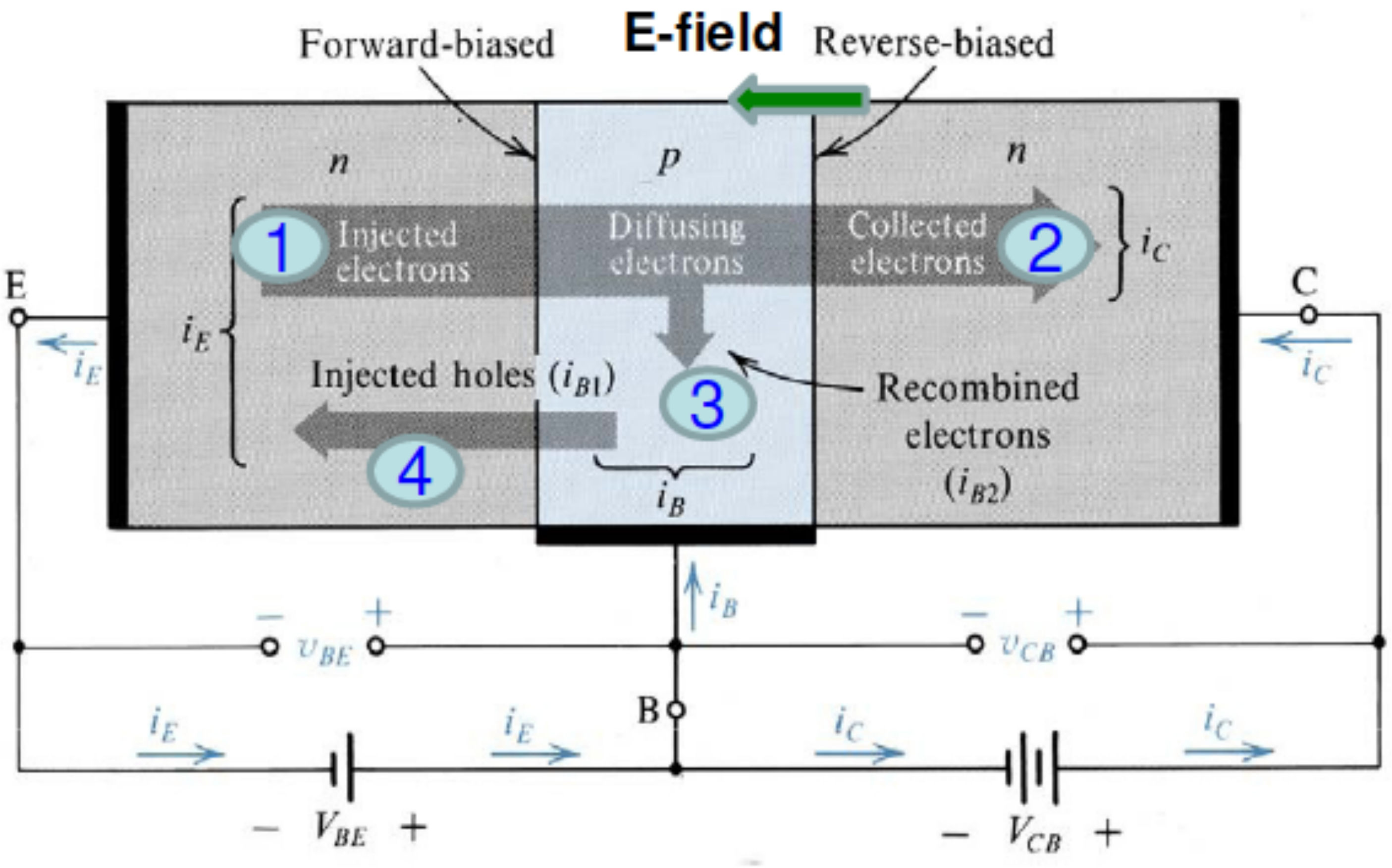

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The two-carrier flow from [(1) and (4)] forms the emitter current (I_E)

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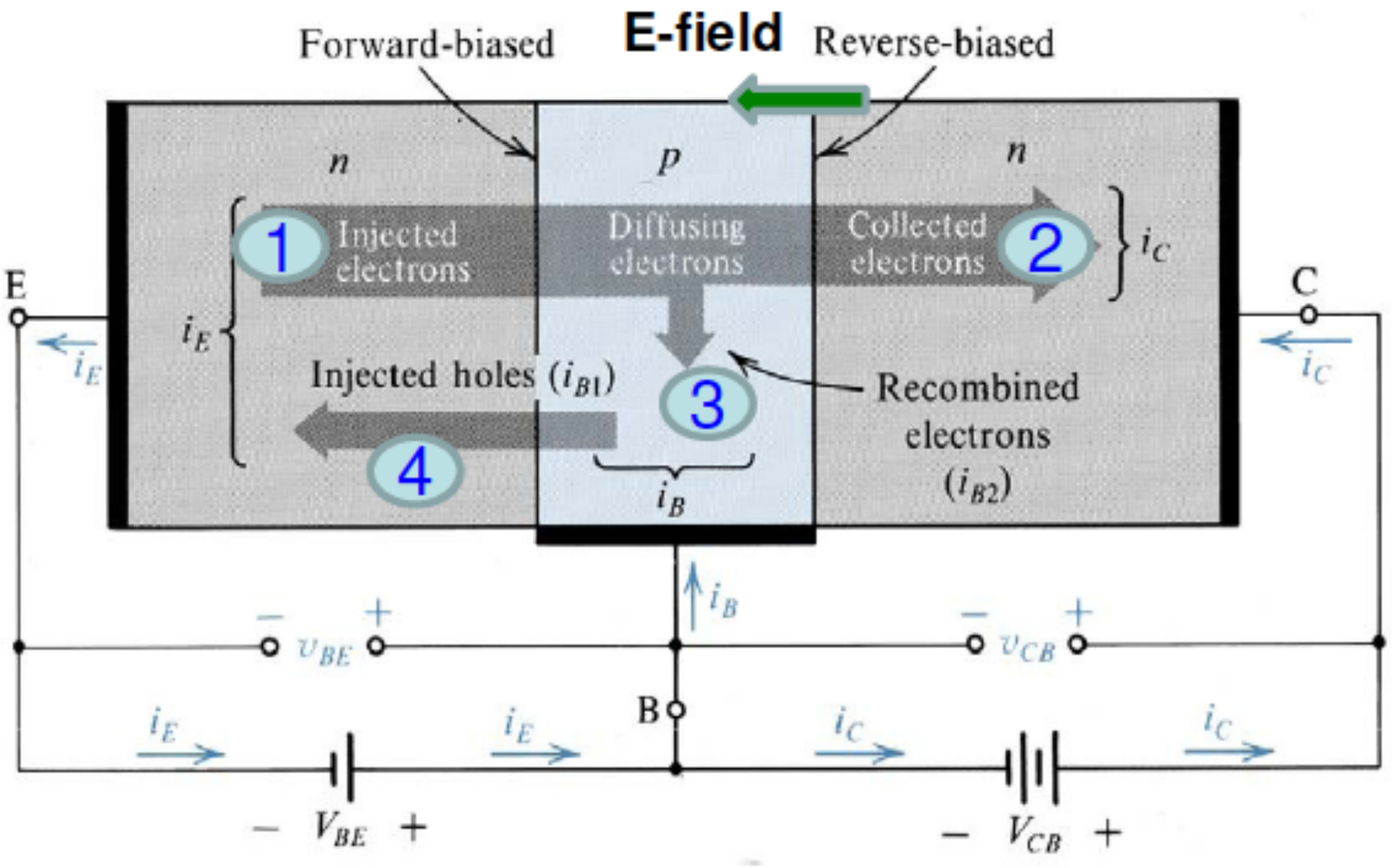

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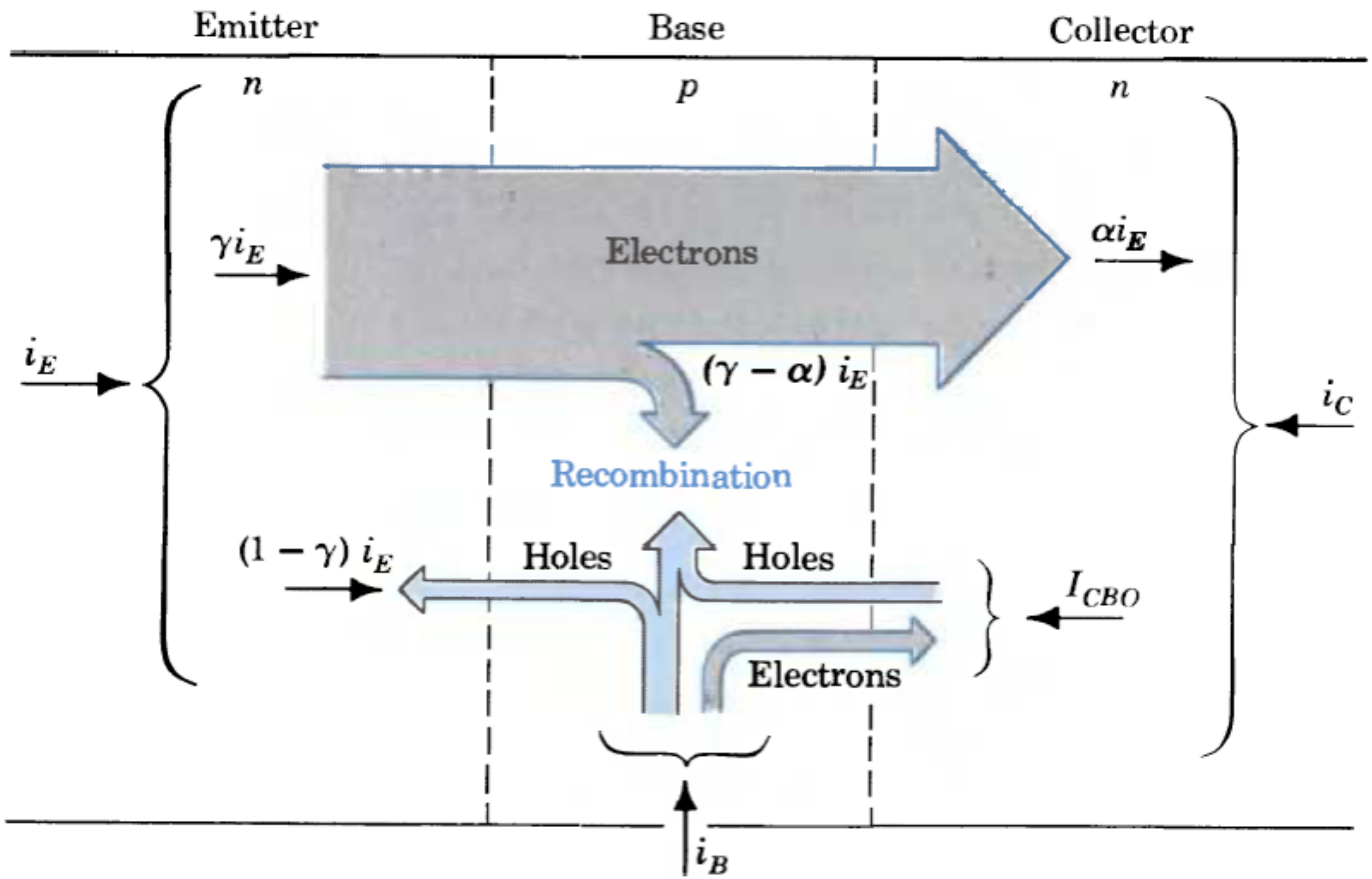
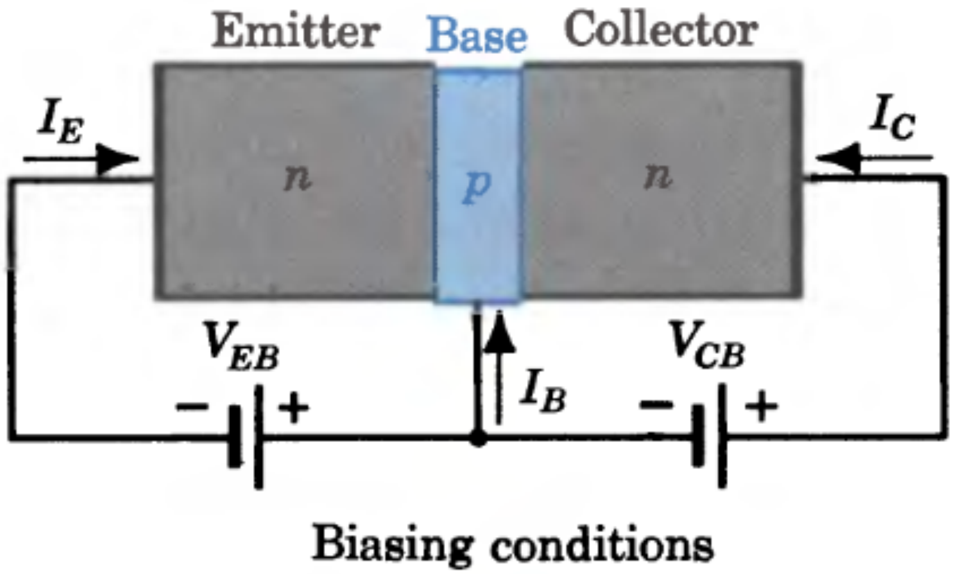
Ic is almost independent of the magnitude of VCB and (Ic = αIe, α=0.9~0.99)

BJT- Carrier Motion

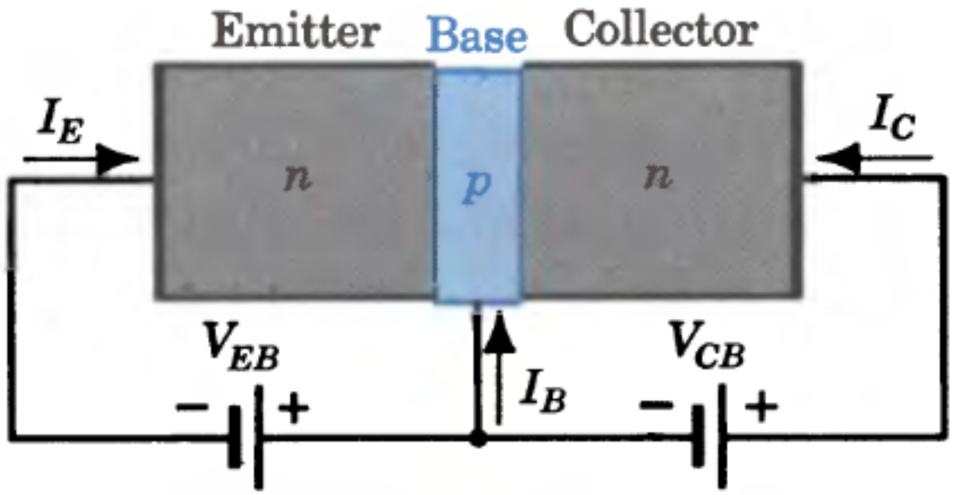


Bipolar Junction Transistor: Modes



Mode	V_{BE}	V_{BC}
Forward active	Forward bias	Reverse Bias
Reverse active	Reverse Bias	Forward Bias
Saturation	Forward bias	Forward bias
Cut off	Reverse Bias	Reverse Bias

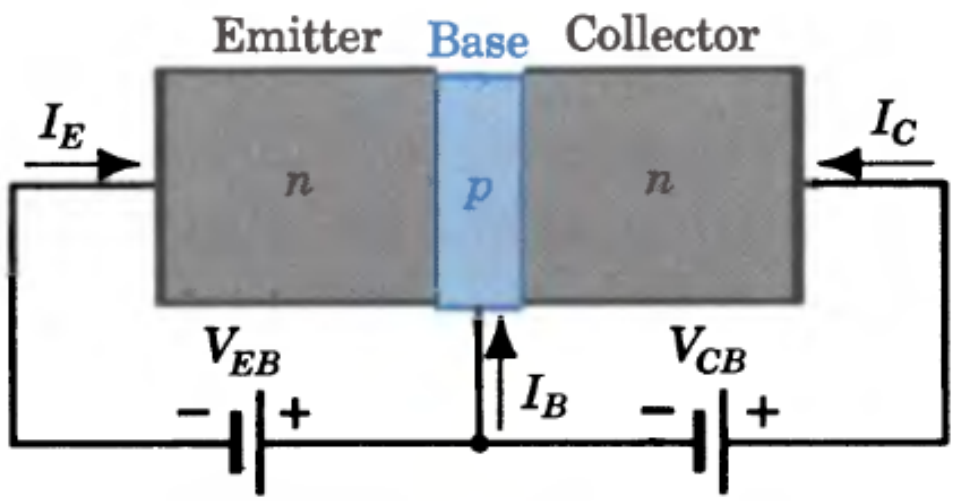
Bipolar Junction Transistor: Modes



Biasing conditions

Mode	V_{BE}	V_{BC}	
Forward active	Forward bias	Reverse Bias	Amplifier
Reverse active	Reverse Bias	Forward Bias	Amplifier (less effective)
Saturation	Forward bias	Forward bias	
Cut off	Reverse Bias	Reverse Bias	

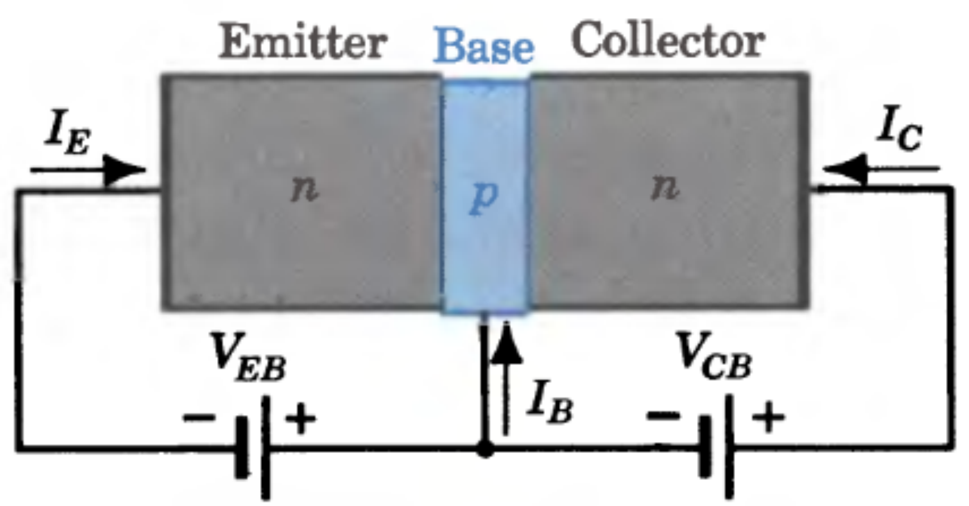
Bipolar Junction Transistor: Modes



Biasing conditions

Mode	V_{BE}	V_{BC}	
Forward active	Forward bias	Reverse Bias	Amplifier
Reverse active	Reverse Bias	Forward Bias	Amplifier (less effective)
Saturation	Forward bias	Forward bias	Small drop between E-B and Ic independent of Ib (Switch ON)
Cut off	Reverse Bias	Reverse Bias	

Bipolar Junction Transistor: Modes



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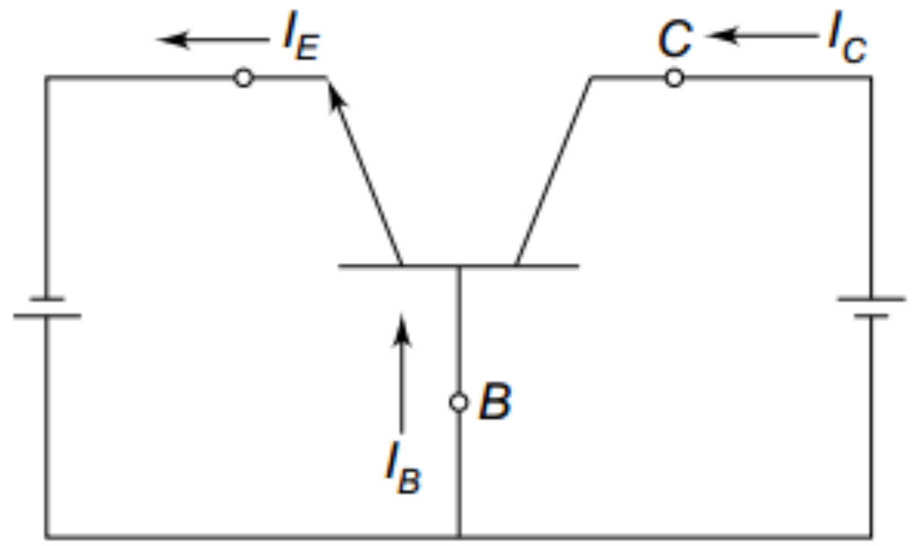
Mode	V_{BE}	V_{BC}	
Forward active	Forward bias	Reverse Bias	Amplifier
Reverse active	Reverse Bias	Forward Bias	Amplifier (less effective)
Saturation	Forward bias	Forward bias	Switch ON
Cut off	Reverse Bias	Reverse Bias	Only ICBO flows in collector (SWITCH OFF)

BJT currents:

I_E, I_B, I_C are the currents flowing thr
emitter, base and collector terminal

$$I_E = I_B + I_C$$



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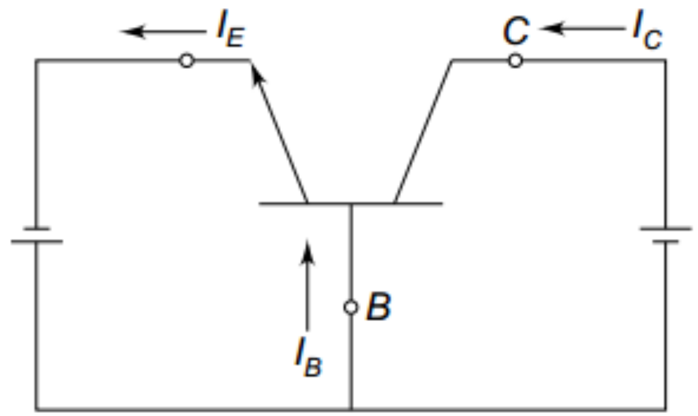
I_E, I_B, I_C are the currents flowing through emitter, base and collector terminal.



$$I_E = I_B + I_C$$

I_C is around 96% – 99.5% of I_E.

$$I_C = \alpha\ I_E$$

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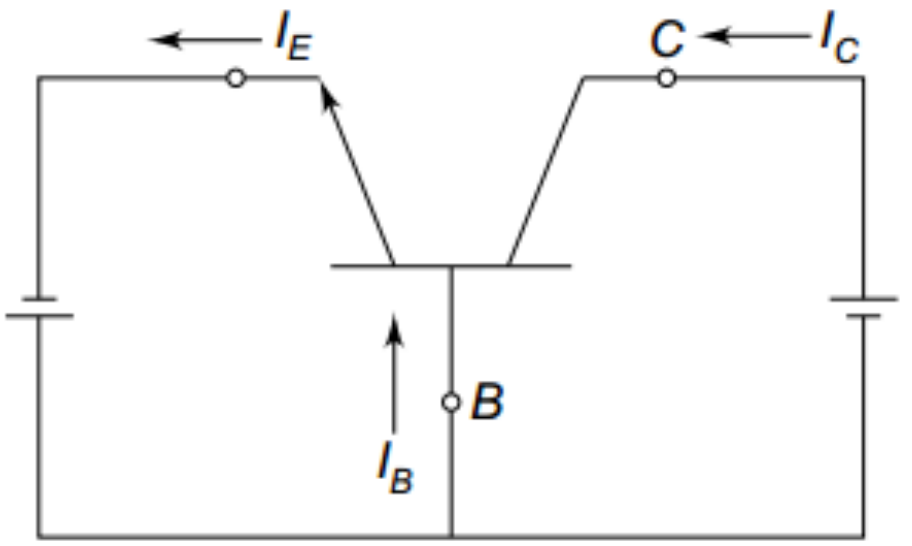

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I_C is approximately equal to I_E , but due to reverse biased C-B jn, a small reverse saturation current flows (I_{CBO}) .

collector-to-base leakage current with emitter open circuit

BJT currents:

$$I_E = I_B + I_C$$
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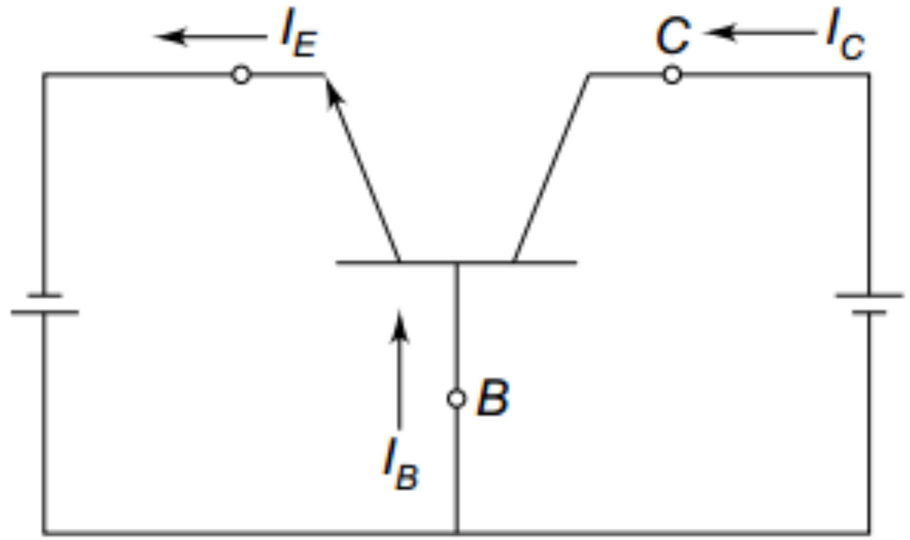
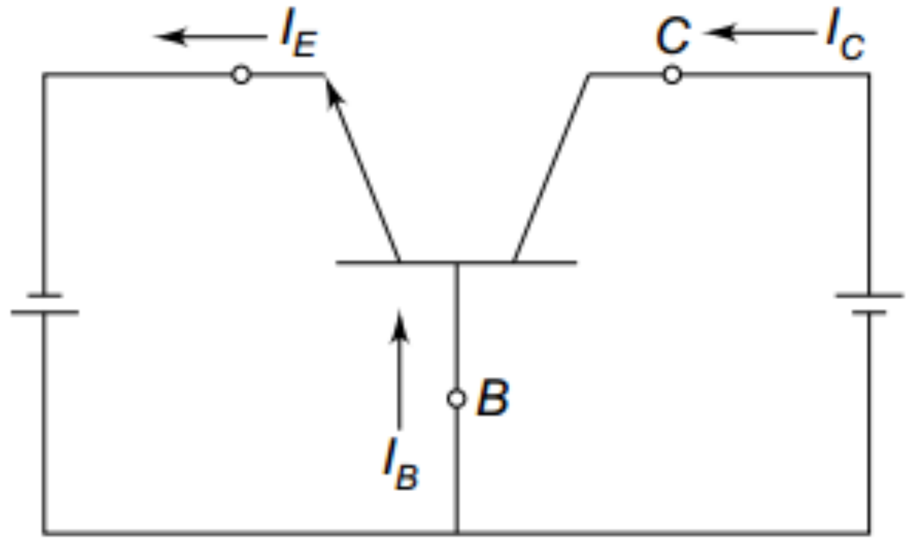


BJT currents:

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

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



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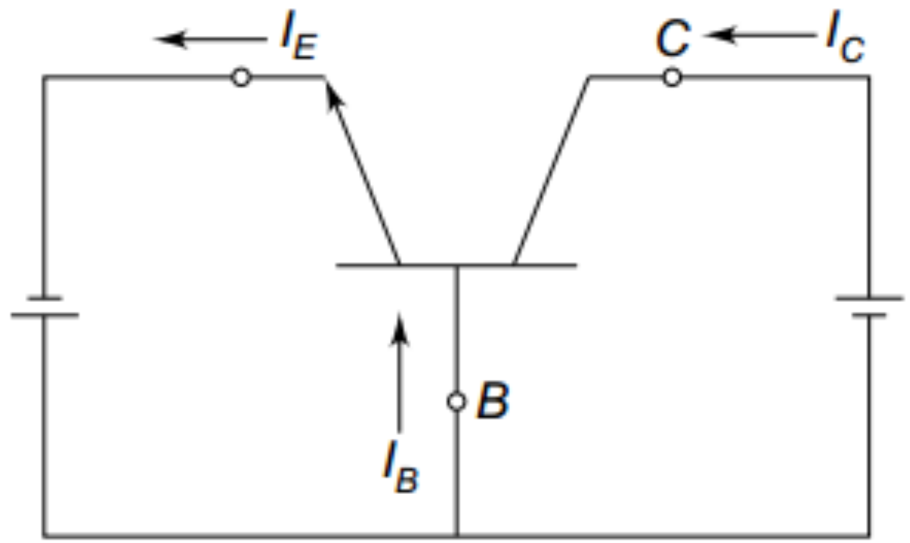

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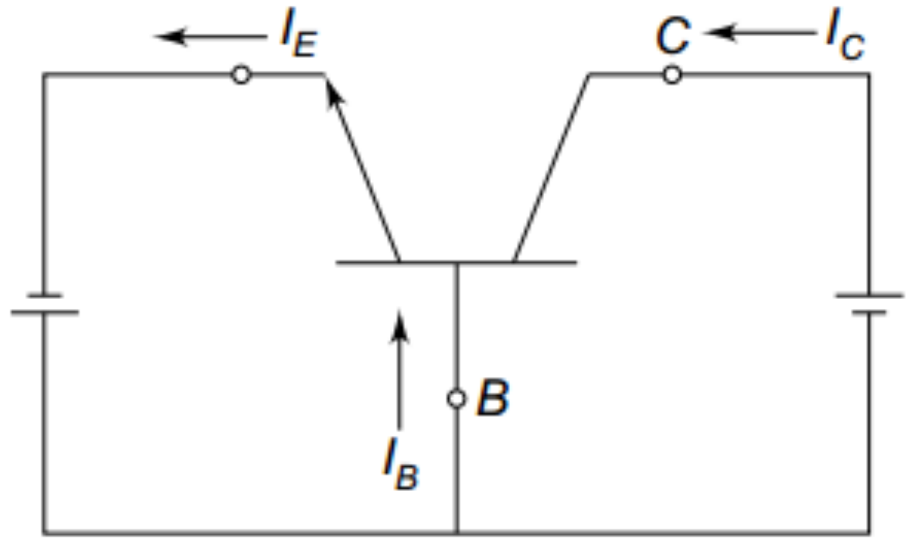

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$$I_C = \left(\frac{\alpha}{1-\alpha}\right) I_B + \left(\frac{1}{1-\alpha}\right) I_{CBO}$$

$$I_C = \beta I_B + (\beta + 1) I_{CBO}$$ **β, base-to-collector current gain (assuming no leakage)**

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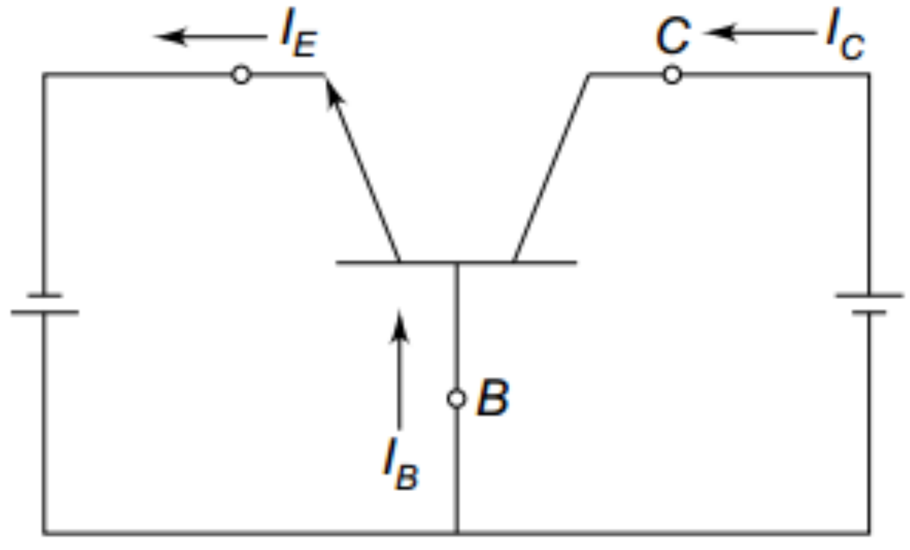
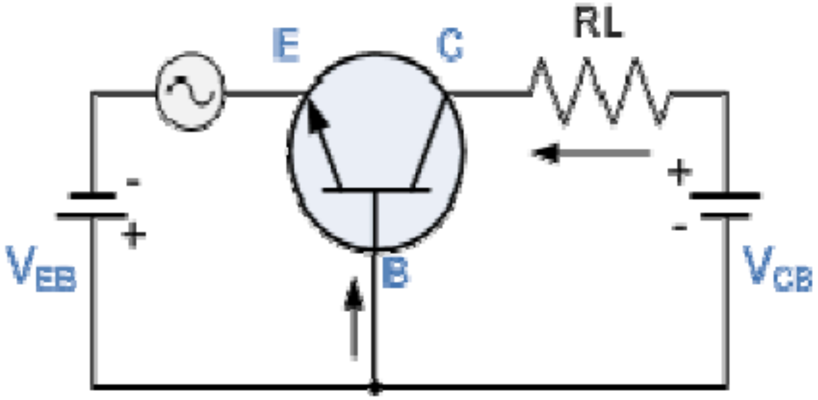
β, base-to-collector current gain (assuming no leakage)

I_{CEO}, reverse saturation current in CE configuration

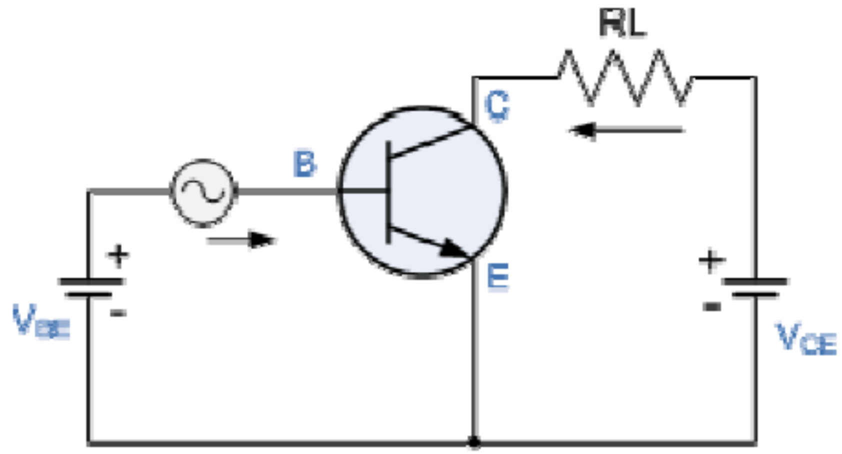


BJT configurations

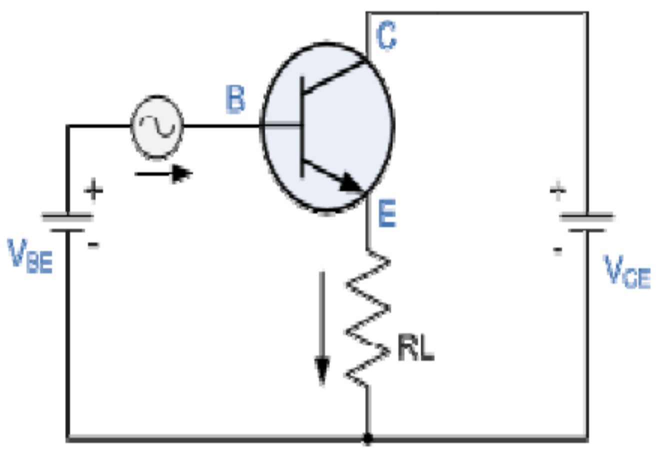
Common base configuration



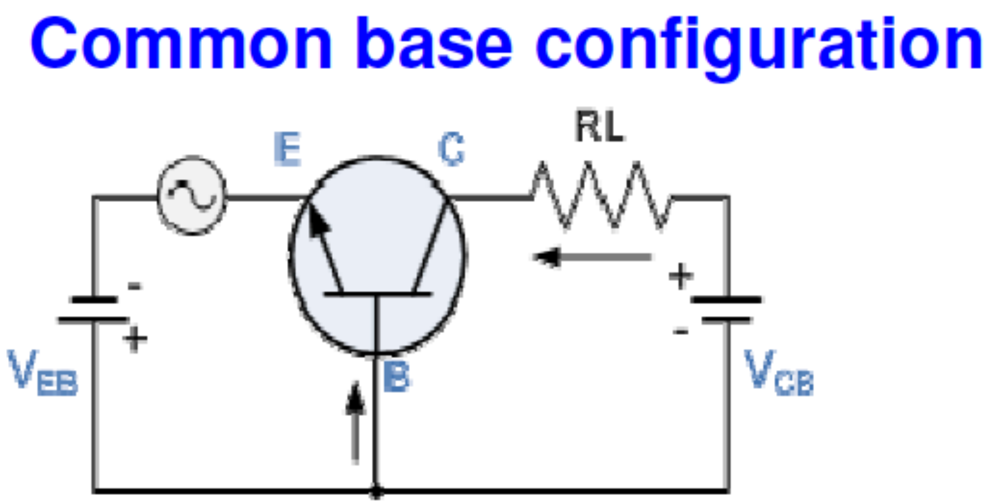
Common emitter configuration



Common collector configuration



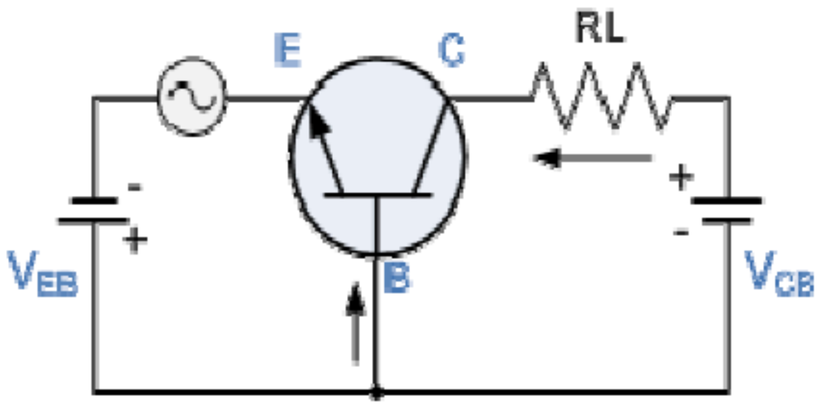
BJT configurations: CB



- Base is grounded/fixed.
- Base connected to both input and output side
- Input – Emitter terminal, Output – Collector terminal

BJT configurations: CB

Common base configuration



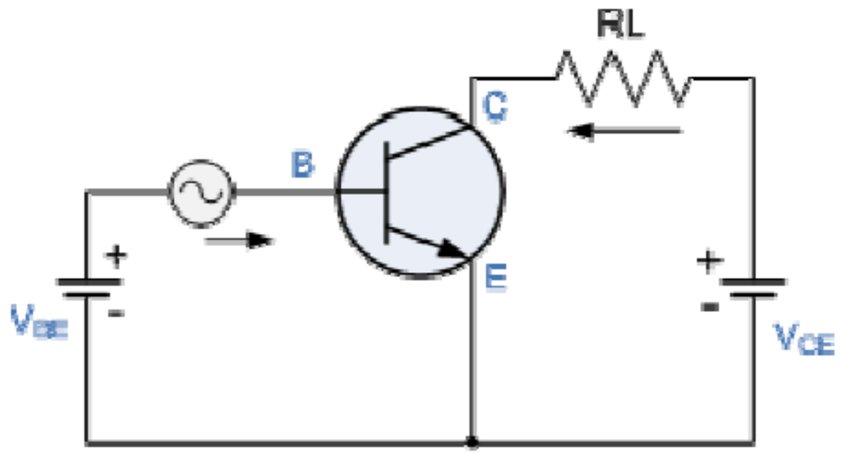
- Base is grounded/fixed.
- Base connected to both input and output side
- Input – Emitter terminal, Output – Collector terminal
- $I_e = I_c + I_b, I_c < I_e$
- CAN be used for voltage amplification.

$$A = \frac{I_c R_L}{I_e R_{IN}} \gg 1, R_L \gg R_{IN}$$

- Does not do current amplification (in fact attenuates)
- Low Zin, High Zout, Low power gain

BJT configurations: CE

Common emitter configuration

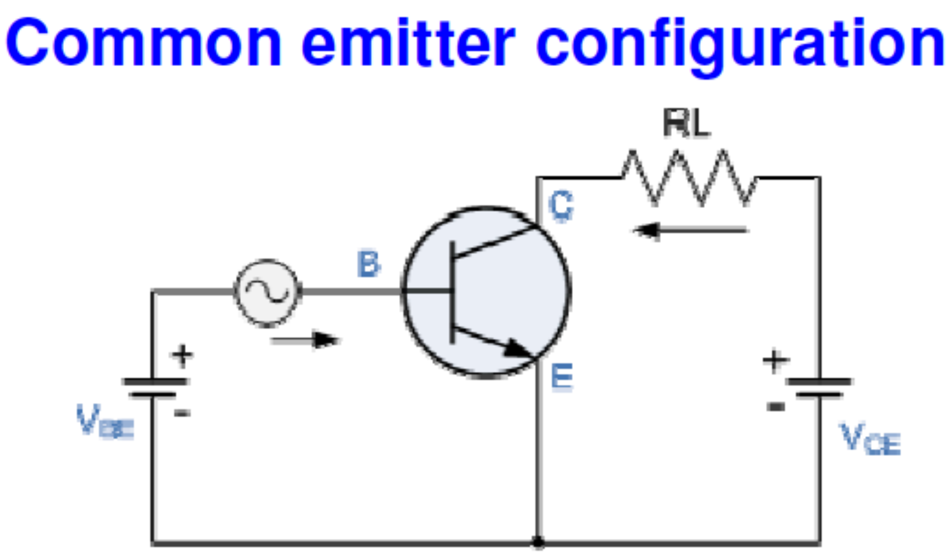


- Emitter is grounded/fixed. Collector connected to load.
- $V_C > V_E$, (for npn)

(Hint : $V_{CE} - V_{BE} > 0, V_{BE} > 0$)

- Input – Base terminal, Output – Collector terminal

BJT configurations: CE



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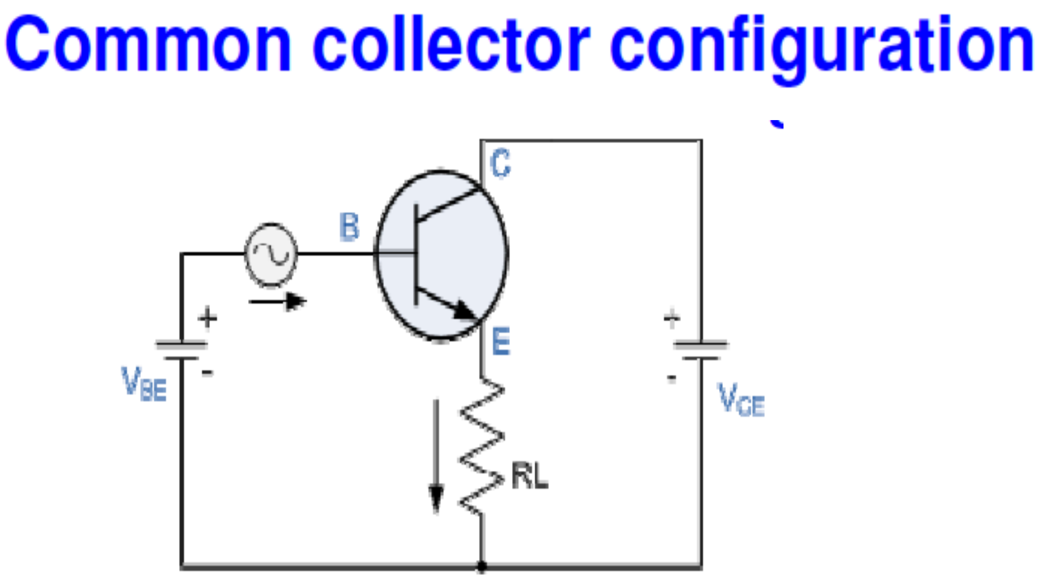
(Hint : $V_{CE} - V_{BE} > 0, V_{BE} > 0$)

- Input – Base terminal, Output – Collector terminal
- $I_e = I_c + I_b, I_c \gg I_b$
- Can be used for current amplification

$$A = \frac{I_c}{I_b} \gg 1,$$

- Can also be used as voltage amplifier but amplification less than CB mode, and gives 180 degree phase shift (inversion)
- Medium Zin, Zout; High Power Gain

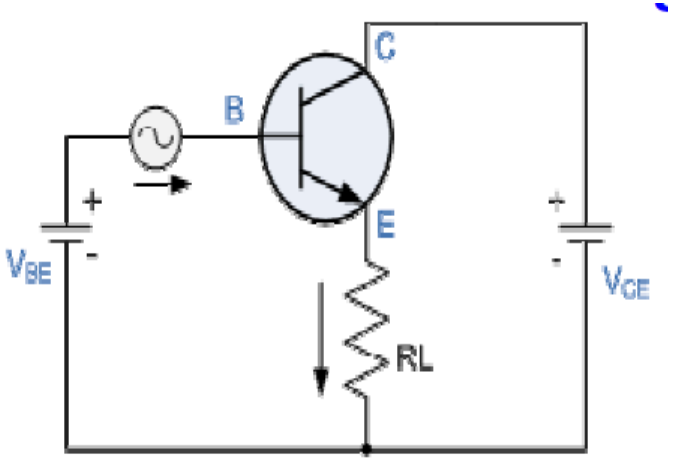
BJT configurations: CC



- Collector is grounded at fixed reference. Emitter connected to load.
- Input – Base terminal, Output – Emitter terminal

BJT configurations: CC

Common collector configuration



- Collector is grounded at fixed reference. Emitter connected to load.
- Input – Base terminal, Output – Emitter terminal
- $I_e = I_L = I_c + I_b$,
- Can be used for current amplification

$$A = \frac{I_e}{I_b} \gg 1,$$

- But, voltage gain is almost unity only.
- Voltage follower or buffer (zero phase difference)
- High Zin, Low Zout, Medium Power Gain

BJT configurations: Qualitative Summary

Characteristic	Common Base	Common Emitter	Common Collector
Input Impedance	Low	Medium	High
Output Impedance	Very High	High	Low
Phase Shift	0^o	180^o	0^o
Voltage Gain	High	Medium	Low
Current Gain	Low	Medium	High
Power Gain	Medium	Very High	Medium
	Preamplifier	Most Common	Buffer