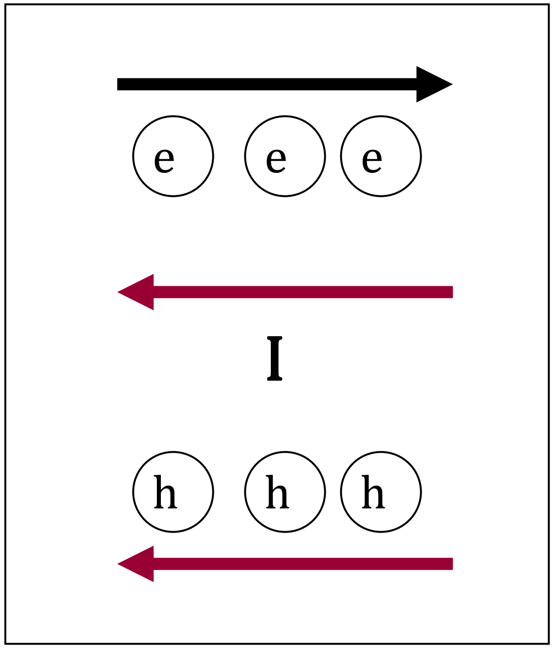
Chapter 4
Bipolar Junction Transistor

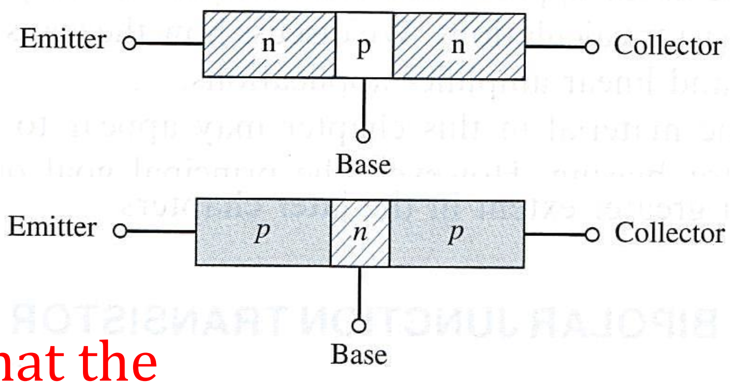
REMEMBER THIS

Current flow in the **opposite direction** of the electrons flow; same direction as holes



Transistor Structures

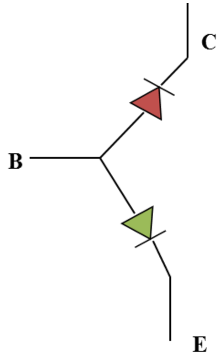
- The **bipolar junction transistor (BJT)** has three separately doped regions and contains two pn junctions.
- Bipolar transistor is a 3-terminal device.
  - Emitter (E)
  - Base (B)
  - Collector (C)



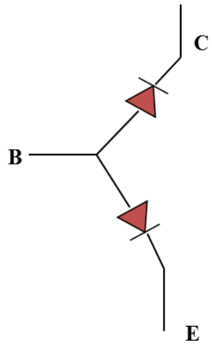
- The basic transistor principle is that the voltage between two terminals controls the current through the third terminal.
- Current in the transistor is due to the flow of both electrons and holes, hence the name **bipolar**.

3 Regions of Operation

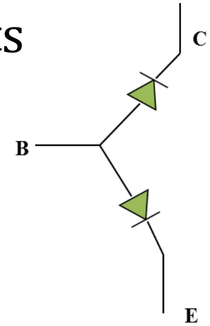
- **Active**
  Operating range of the amplifier.
  Base-Emitter Junction forward biased.
  Collector-Base Junction reverse biased



- **Cutoff**
  The amplifier is basically off. There is voltage but little current.
  Both junctions reverse biased

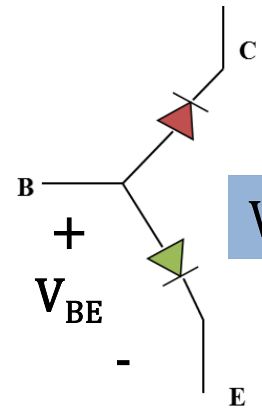


- **Saturation**
  The amplifier is full on. There is little voltage but lots of current.
  Both junctions forward biased

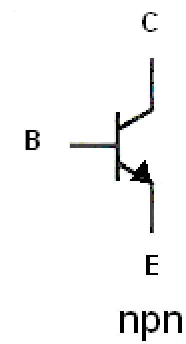


OPERATIONS - npn

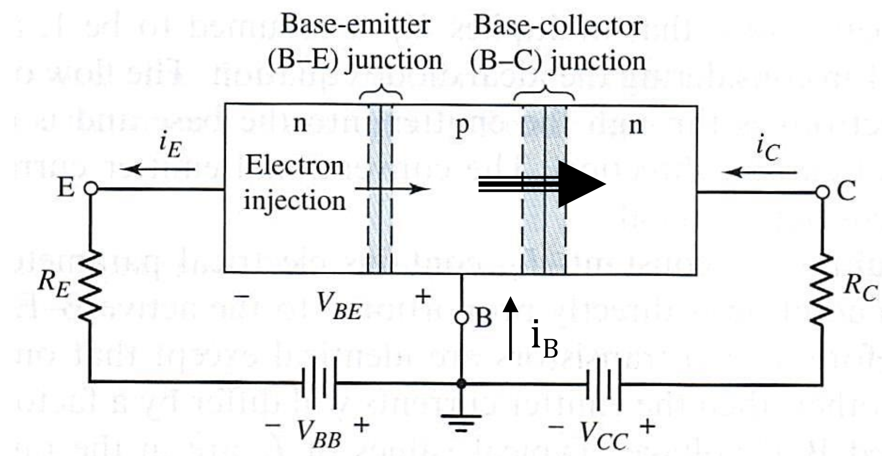
FORWARD ACTIVE MODE



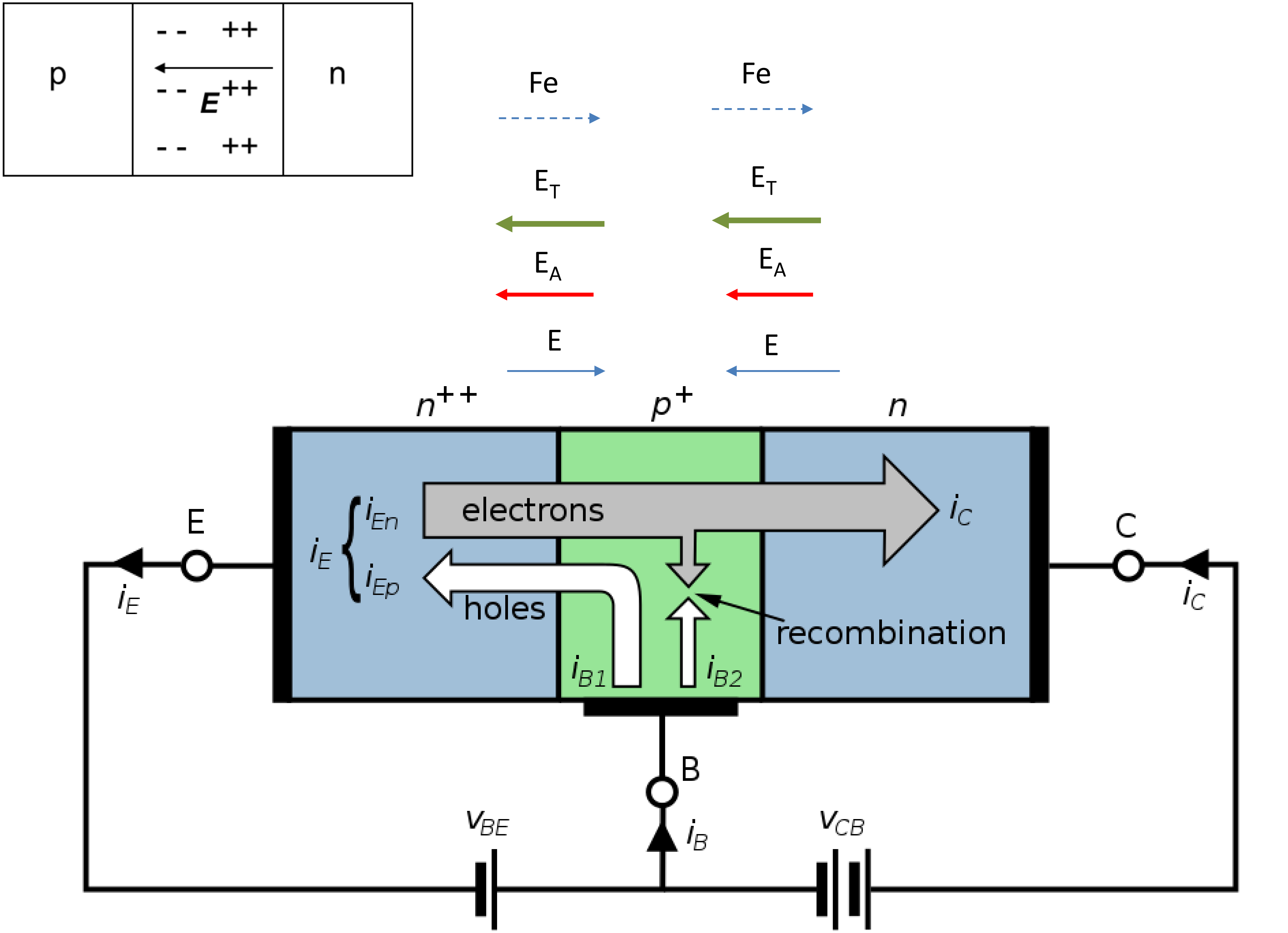
$V_{BE} = V\gamma$



- The **base-emitter (B-E) junction** is forward biased and the **base-collector (C-B) junction** is reverse-biased,.
- Since the B-E junction is forward biased, electrons from the emitter are injected across the B-E junction into the base → I_E
- Once in the base region, the electrons are quickly accelerated through the base due to the reverse-biased C-B region → I_C

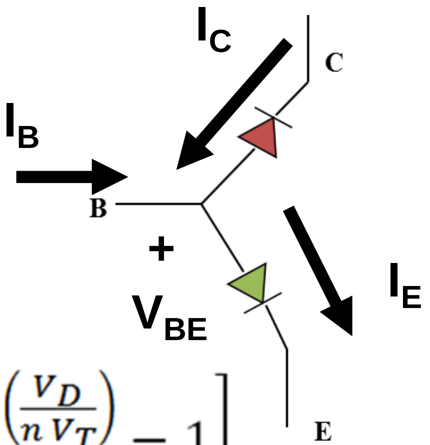


- Some electrons, in passing through the base region, recombine with majority carrier holes in the base. This produces the current →I_B

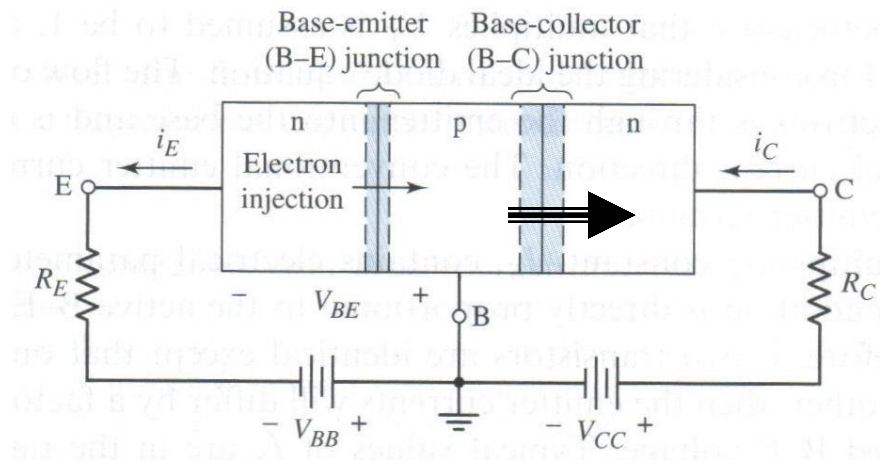


p
n
E
Fe
Fe
E_T
E_T
E_A
E_A
E
E
n++
p+
n
electrons
holes
recombination
E
C
B
i_En
i_Ep
i_E
i_E
i_C
i_C
i_B1
i_B2
i_B
v_BE
v_CB

MATHEMATICAL EXPRESSIONS



$$I_D = I_S \left[e^{\left(\frac{V_D}{n V_T}\right)} - 1 \right]$$



$$I_E = I_S \left[e^{V_{BE}/V_T} - 1 \right] = I_S e^{V_{BE}/V_T}$$

Based on KCL: $I_E = I_C + I_B$

No. of electrons crossing the base region and then directly into the collector region is a constant factor β of the no. of electrons exiting the base region

$$I_C = \beta I_B$$

No. of electrons reaching the collector region is directly proportional to the no. of electrons injected or crossing the base region.

$$I_C = \alpha I_E$$

Ideally $\alpha = 1$, but in reality it is between 0.9 and 0.998.

Based on KCL: $I_E = I_C + I_B$

$I_C = \beta I_B$

$I_C = \alpha I_E$

$$I_E = \beta I_B + I_B = I_B(\beta + 1) \Longrightarrow I_E = I_B(\beta + 1)$$

Now

With $I_C = \beta I_B \rightarrow I_B = I_C / \beta$

Hence,

$I_E = [\, I_C / \beta \,] \;\; (\beta + 1)$

$I_C = I_E [\, \beta \, / \, \beta + 1 \,]$

Comparing with $I_C = \alpha I_E \Longrightarrow \alpha = [\, \beta \, / \, \beta + 1 \,]$

NPN

$$I_E = I_S\,[\,e^{V_{BE}/V_T}\,]$$

$$I_C = \beta I_B$$

$$I_C = \alpha I_E$$

$$I_E = I_B(\beta + 1)$$

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

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

Based on KCL: $I_E = I_C + I_B$

EXAMPLE

Calculate the collector and emitter currents, given the base current and current gain. Assume a common-base current gain, $\alpha = 0.97$ and a base current of $i_B = 25\ \mu A$. Also assume that the transistor is biased forward in the forward active mode.

Solution: The common-emitter current gain is $\beta = \frac{\alpha}{1-\alpha} = \frac{0.97}{1-0.97} = 32.33$

The collector current is $i_C = \beta i_B = 32.33 \times 25 = 808.25\ \mu A$

And the emitter current is $i_E = i_B + i_C = 25 + 808.25 = 833.25\ \mu A$

Examples

- EXAMPLE 1
- Given $I_B = 6.0\mu A$ and $I_C = 510\ \mu A$. Determine β, α and I_E

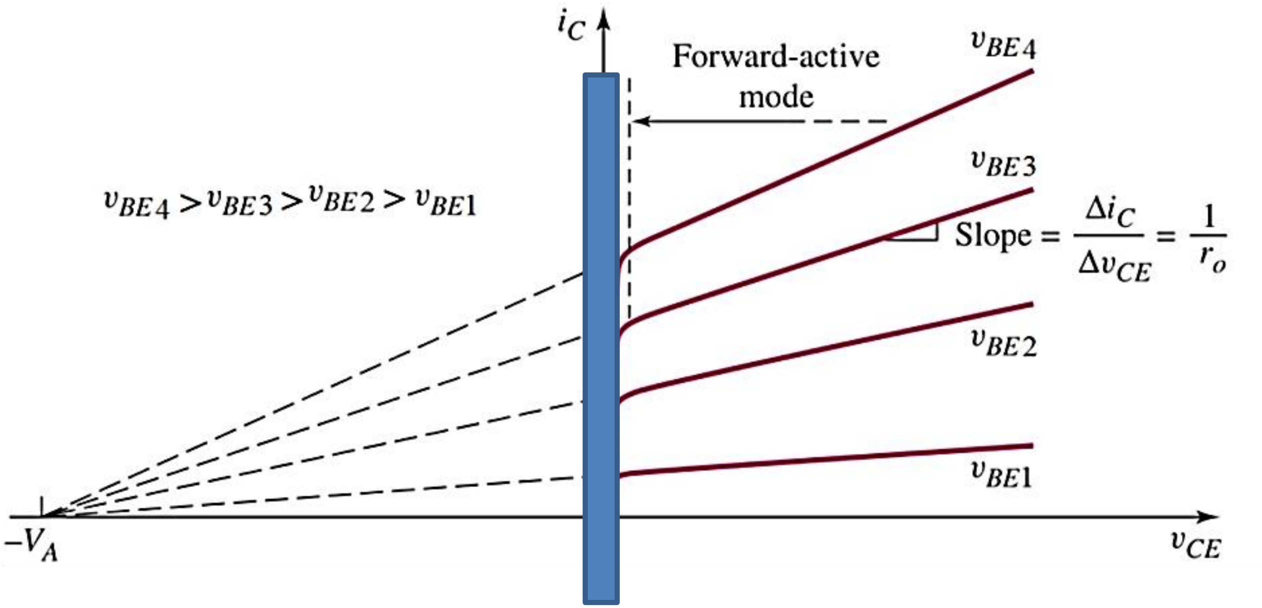
Answers:
$\beta = \underline{85}$
$\alpha = \underline{0.9884}$
$I_E = \underline{516\ \mu A}$

- EXAMPLE 2
- NPN Transistor
- Reverse saturation current $Is = 10^{-13}A$ with current gain, $\beta = 90$.
- Based on $V_{BE} = 0.685V$, determine I_C, I_B and I_E

Answers:
$I_E = 10^{-13}\ (e^{0.685/0.026}) = \underline{0.0277\ A}$
$I_C = (90/91)(0.0277) = \underline{0.0274\ A}$
$I_B = I_E - I_C = \underline{0.3\ mA}$

BJT: Current-Voltage Characteristic
I_C versus V_{CE}

Characteristics of Common-Emitter - npn



I-V characteristic of common-emitter BJT circuit, showing Early voltage and the finite output resistance, of the transistor

$$\longrightarrow \quad r_0 \cong \frac{V_A}{I_C}$$

James M. Early