Chapter 10. Bipolar junction transistor fundamentals

Invented in 1948 by Bardeen, Brattain and Shockley

Contains three adjoining, alternately doped semiconductor regions:
Emitter (E), Base (B), and Collector (C)

The middle region, base, is very thin compared to the diffusion length of minority carriers

Two kinds: npn and pnp

Schematic representation of pnp and npn BJTs

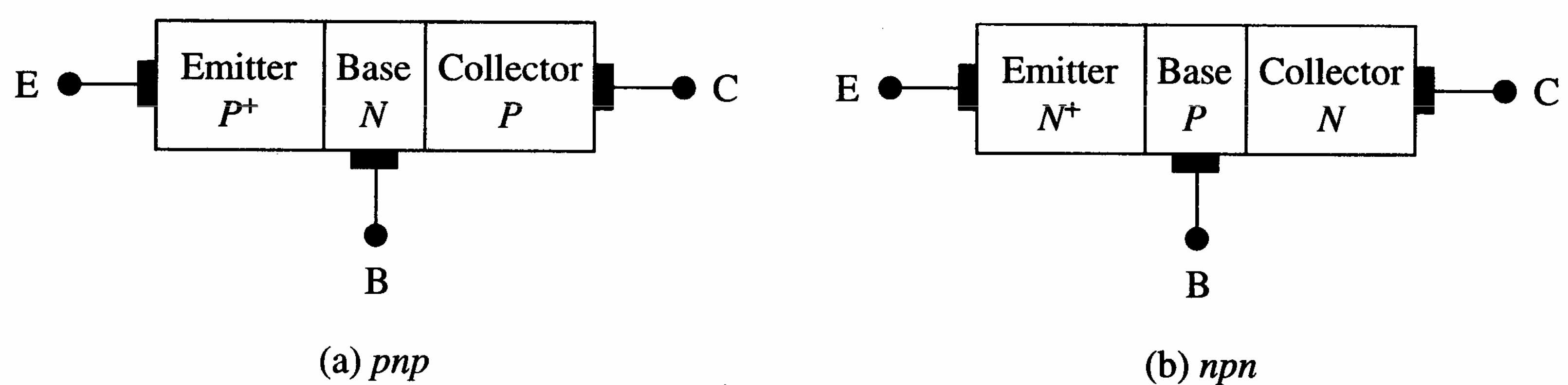


Figure 10.1

Emitter is heavily doped compared to collector. So, emitter and collector are not interchangeable.

The base width is small compared to the minority carrier diffusion length. If the base is much larger, then this will behave like back-to-back diodes.

BJT circuit symbols

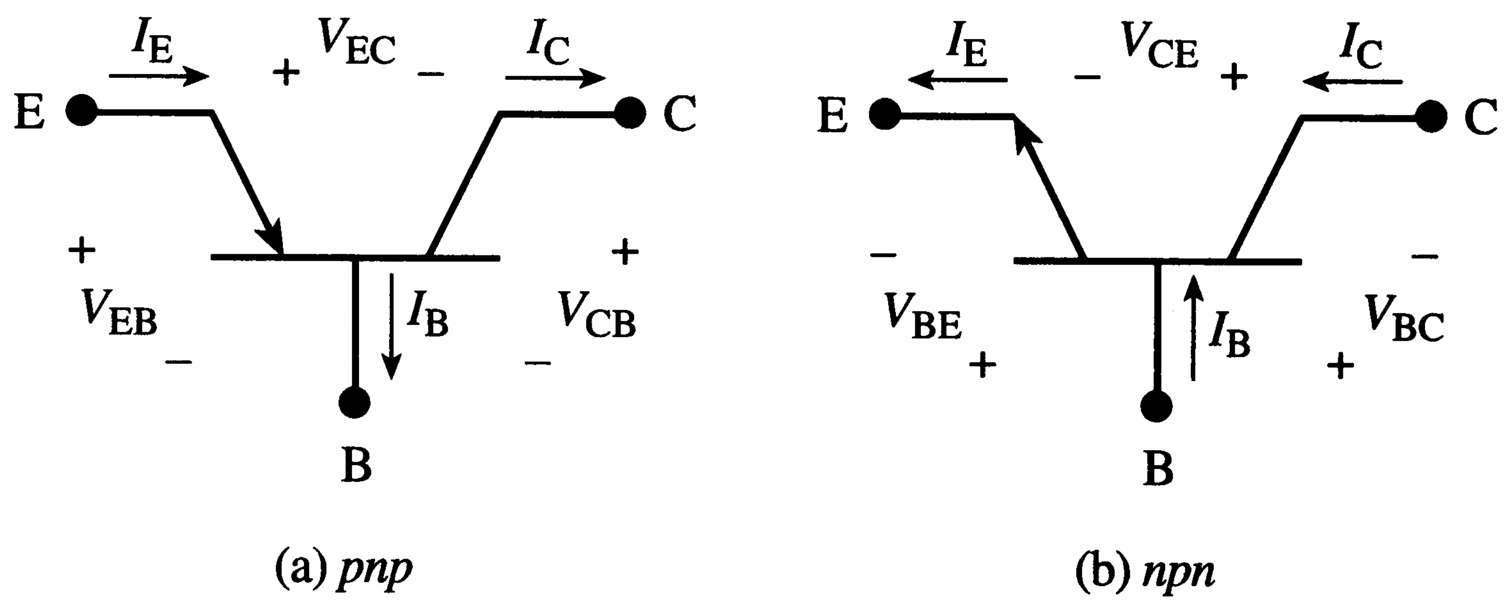
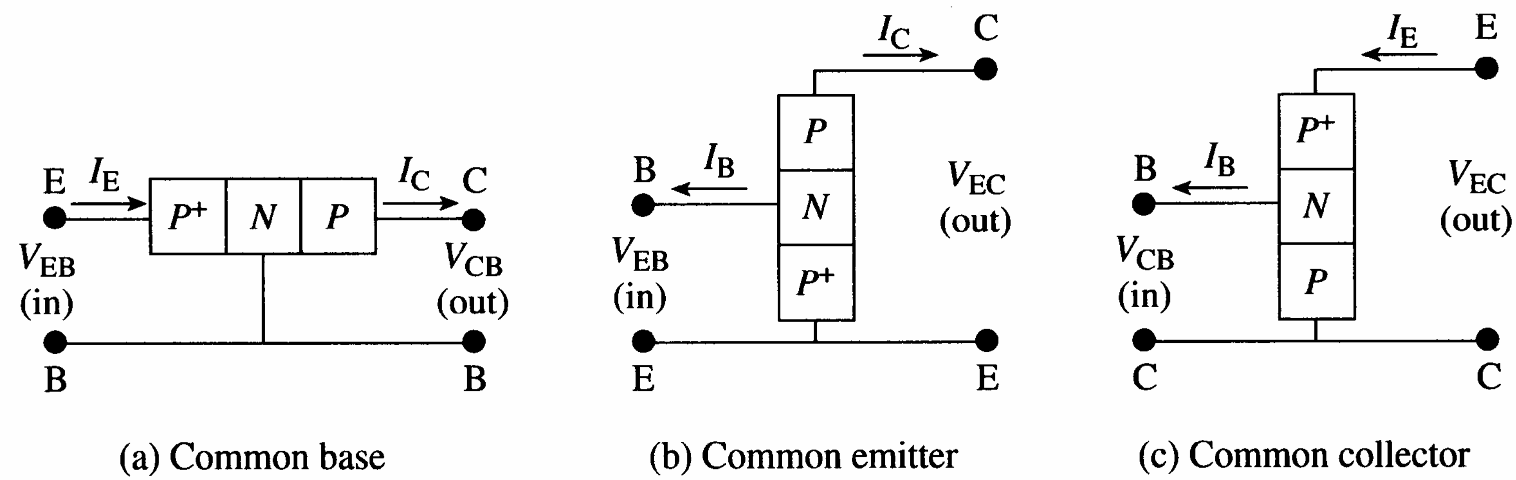


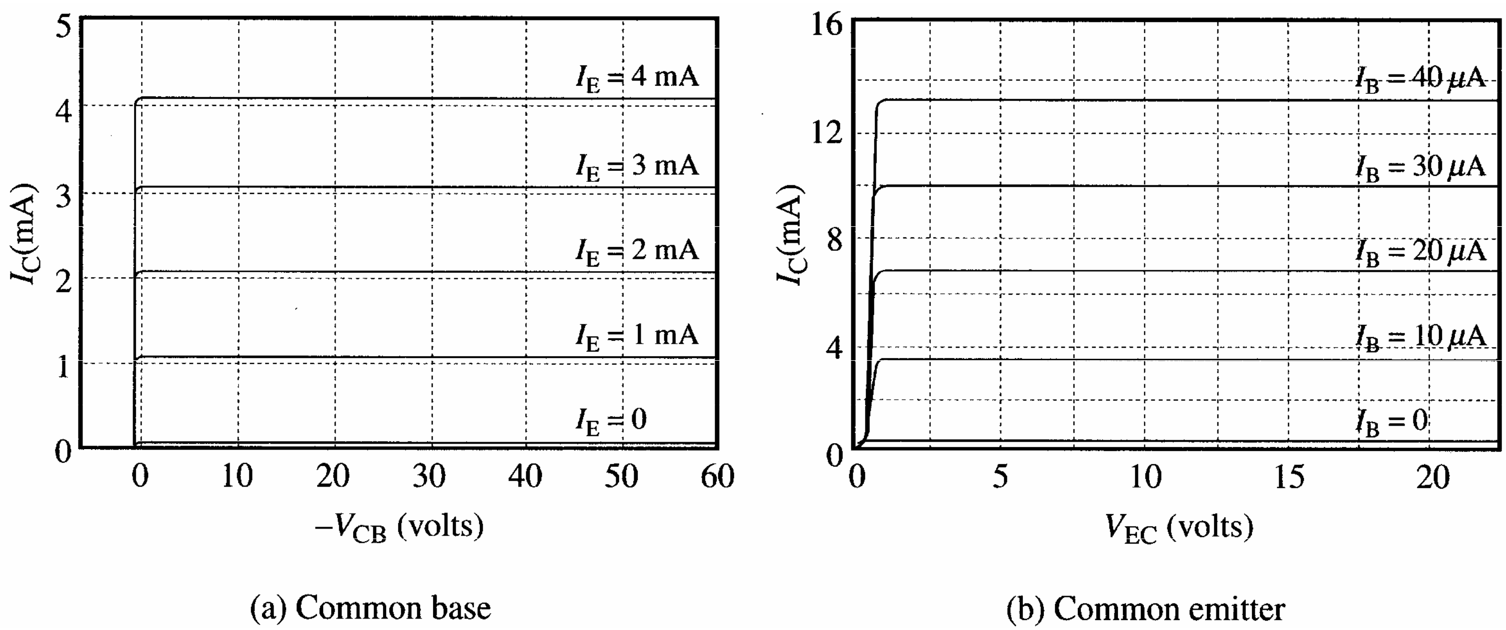
Figure 10.2

$I_E = I_B + I_C$ and $V_{EB} + V_{BC} + V_{CE} = 0$ $V_{CE} = -V_{EC}$

As shown, the currents are positive quantities when the transistor is operated in forward active mode.

BJT circuit configurations and output characteristics

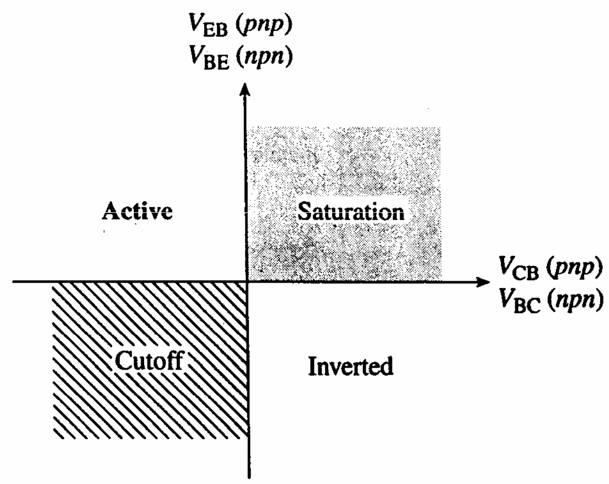




BJT biasing modes

Table 10.1 Biasing Modes.

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



Cross sections and simplified models of discrete and IC npn BJTs

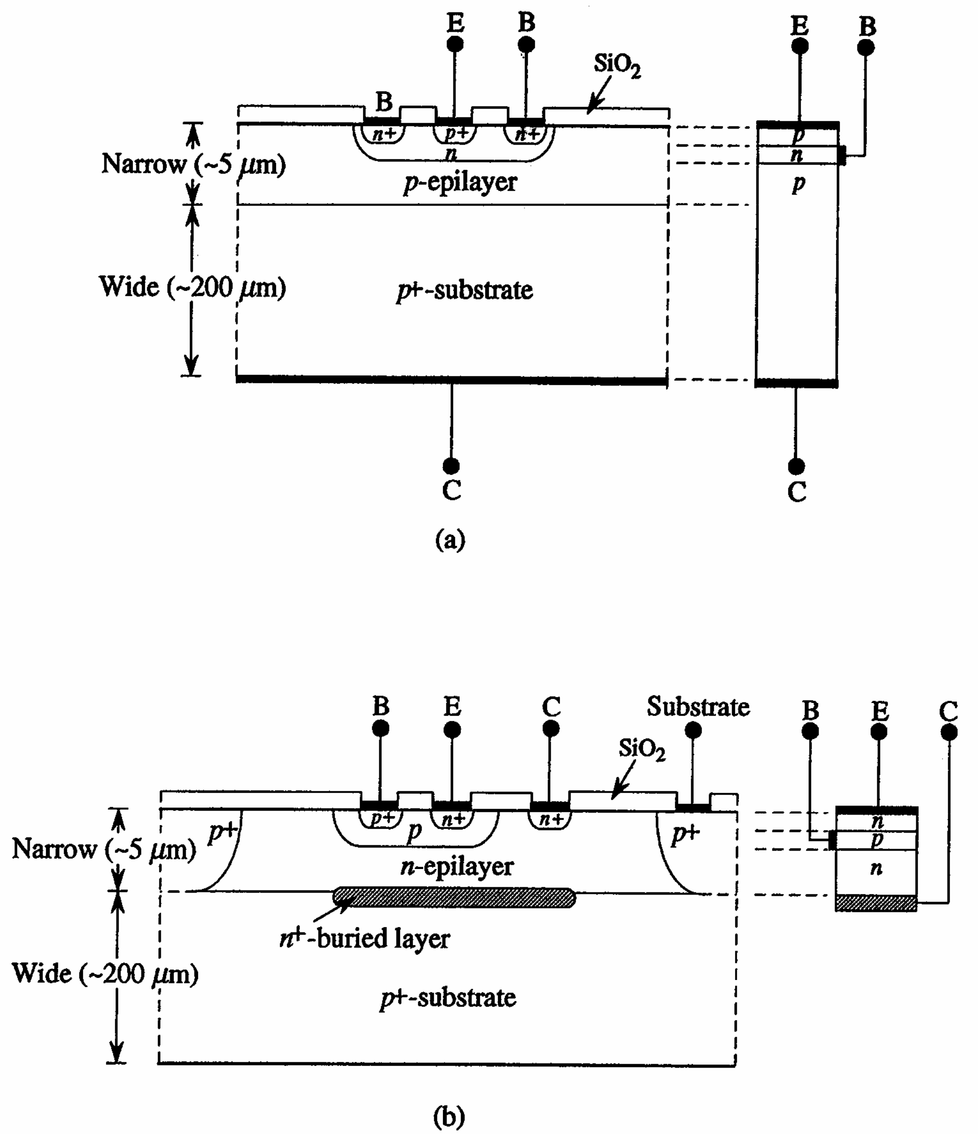


Figure 10.6

Electrostatic variables for a pnp BJT at equilibrium

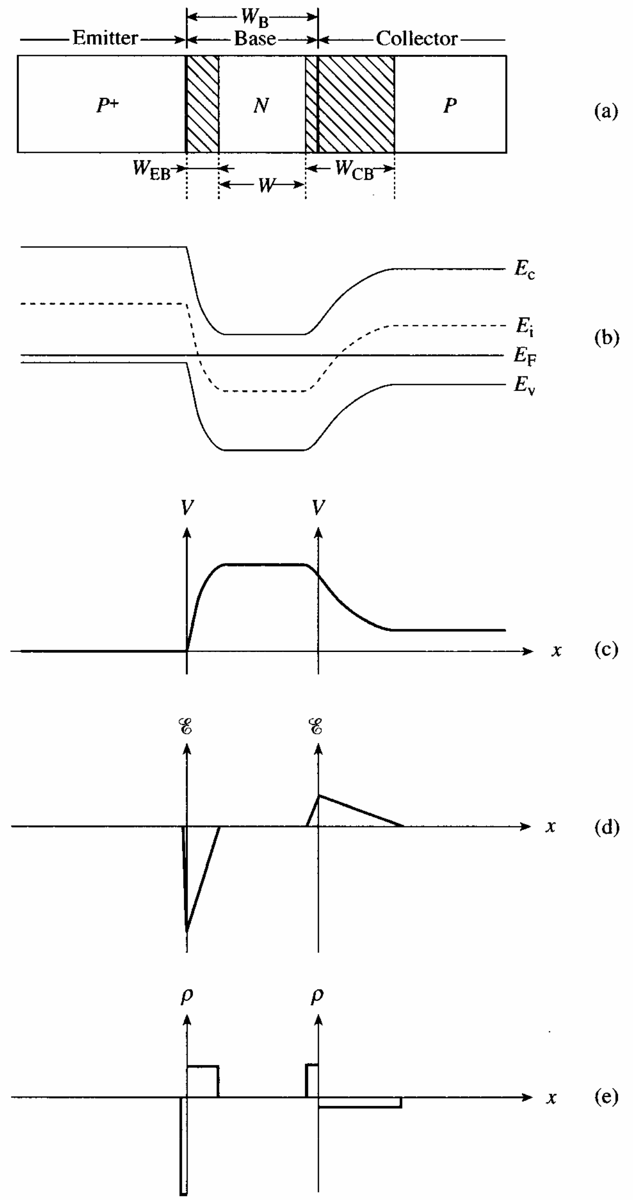
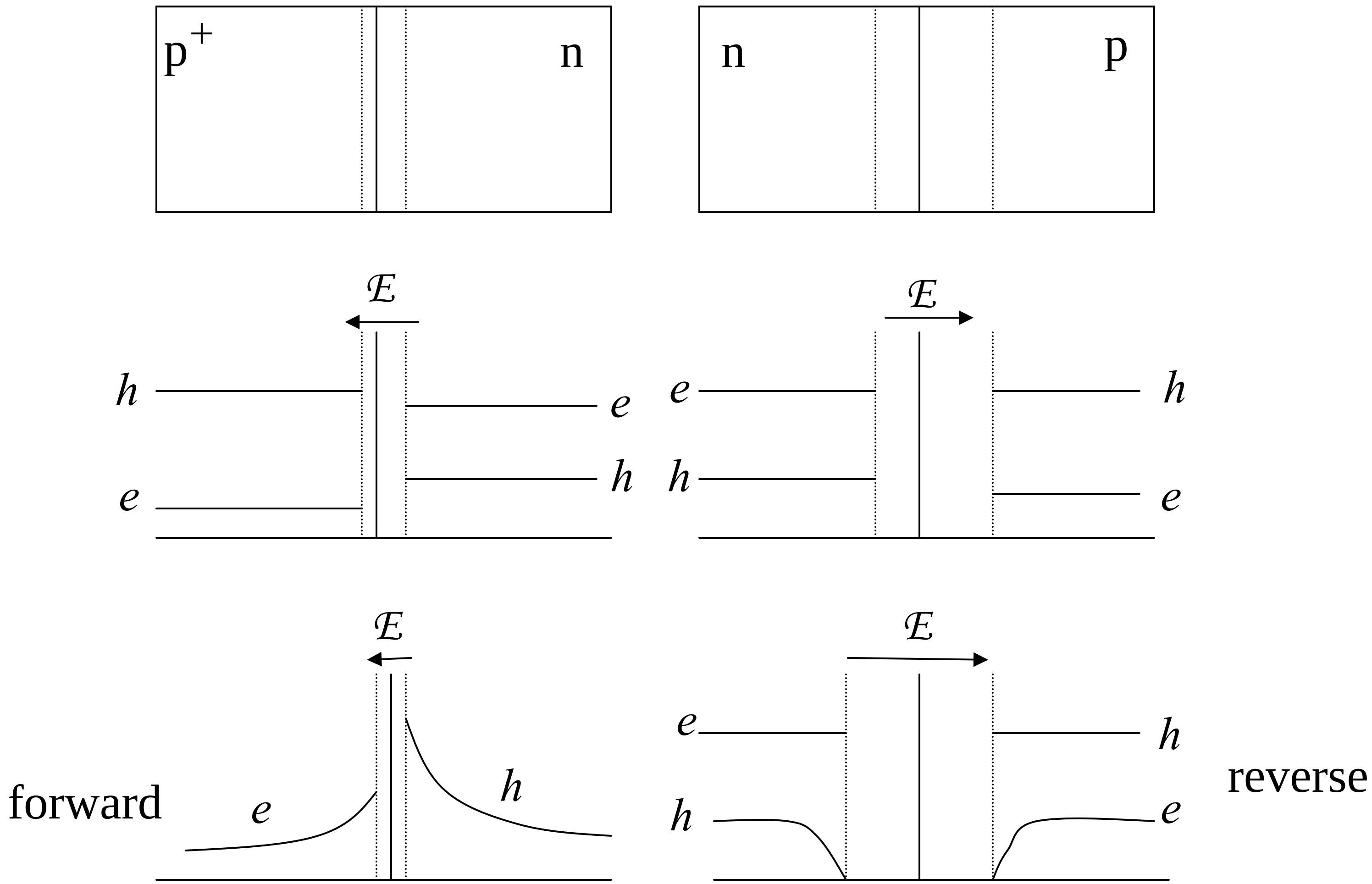


Figure 10.7

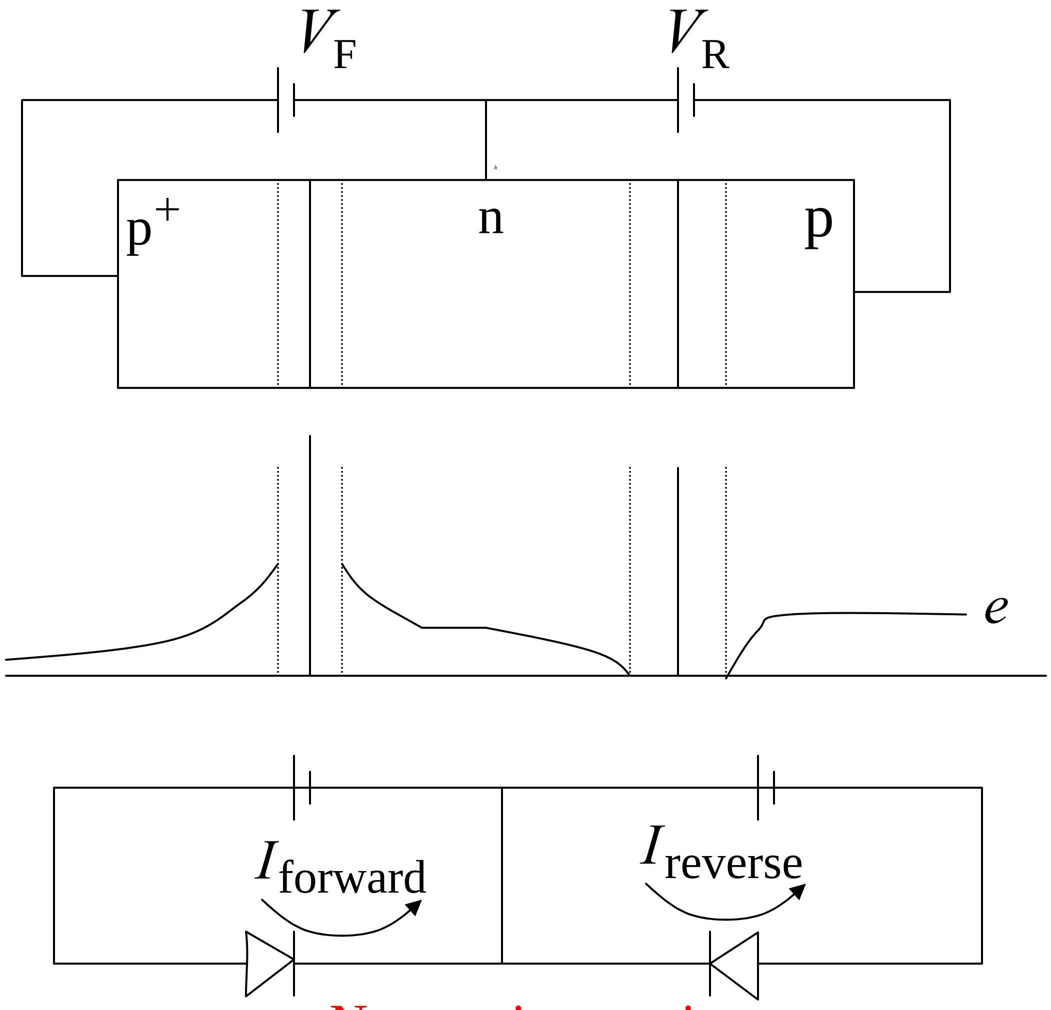
Qualitative discussions of operation

Consider two diodes, one forward biased and one reverse biased.



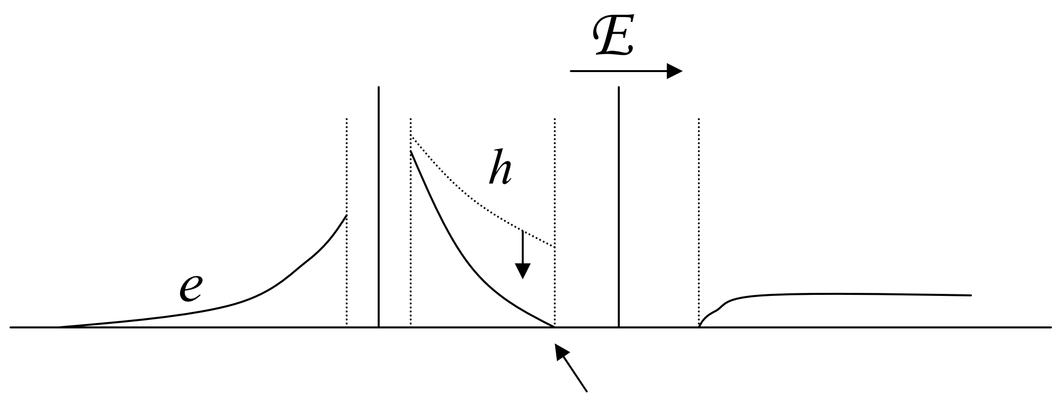
Qualitative discussion of transistor action

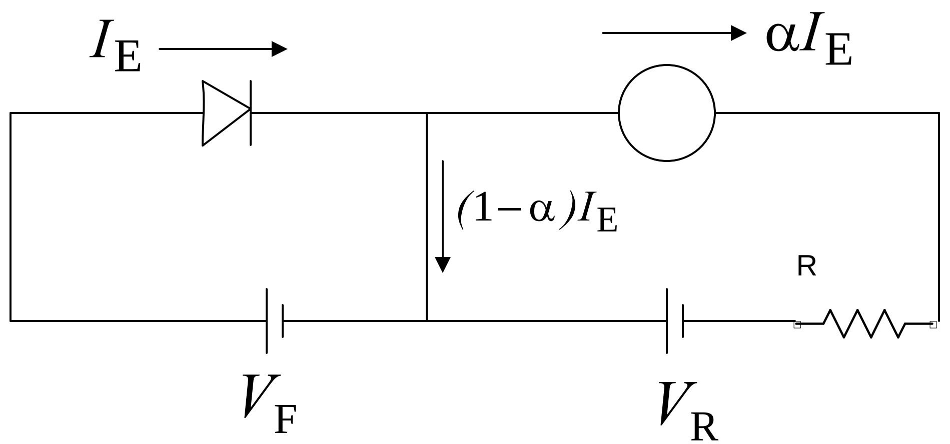
Combine the two diodes**!**



No transistor action

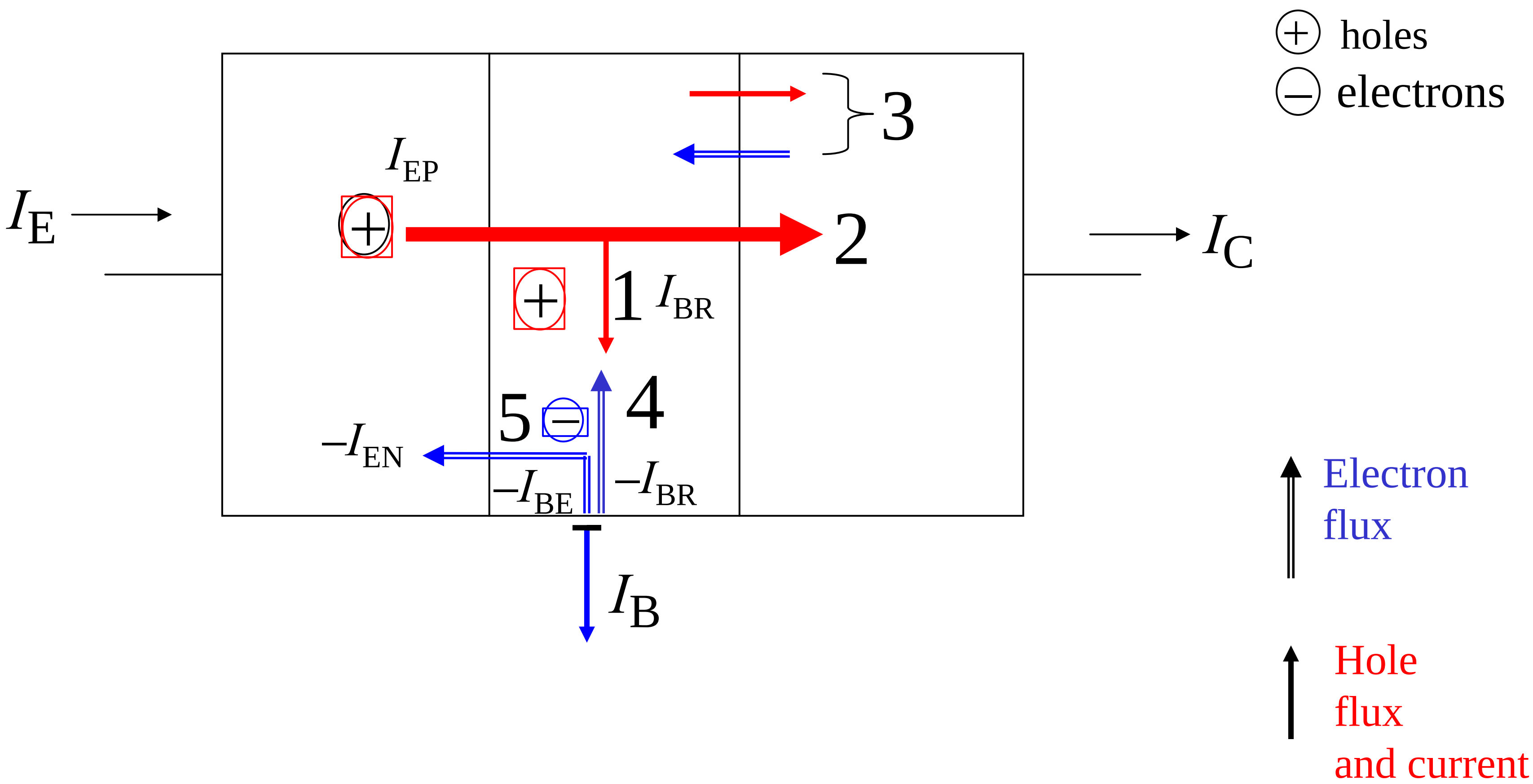
Consider very thin base width: Transistor action





The collector current I_C is almost equal to I_E, and collector current is controlled by the E-B junction bias. The loss, i.e. $\alpha < 1$ corresponds to the recombination of holes in base.

PNP under forward active mode



$$I_E = I_{EP} + I_{EN} = 1 + 2 + 5$$

$$I_B = I_{BR} + I_{BE} = I_{BR} + I_{EN} = -(4 + 5)$$

$$I_C = I_{EP} - I_{BR} = 2$$

Current components

1 = hole current lost due to recombination in base, I_{BR}

2 = hole current collected by collector, ~ I_C

1 + 2 = hole part of emitter current, I_{EP}

5 = electrons injected across forward biased E-B junction, $(-I_{BE})$;
same as electron part of emitter current, $-I_{EN}$

4 = electron supplied by base contact for recombination with
holes lost, $-I_{BR}$ (= 1)

3 = thermally generated e & h making up reverse saturation
current of reverse biased C-B junction. (generally neglected)

Performance parameters (Consider pnp)

Neglect the reverse leakage (electron) current of C-B junction

Emitter efficiency:

$$\gamma = \frac{I_{EP}}{I_{EP} + I_{EN}} = \frac{I_{EP}}{I_E}$$

Fraction of emitter current carried by holes.
We want γ close to 1.

Base transport factor:

$$\alpha_T = \frac{I_C}{I_{Ep}}$$

Fraction of holes collected by the collector.
We want α_T close to 1.

Common base dc current gain:

$$I_C = \alpha_T I_{EP} = \alpha_T \gamma I_E = \alpha_{dc} I_E$$

$$\alpha_{dc} = \alpha_T \gamma$$

Note that α is less than 1.0 but close to 1.0 (e.g. $\alpha = 0.99$)

Performance parameters (Consider pnp)

Common emitter dc current gain, β_{dc}:

$$I_C = \beta_{dc} I_B \qquad \text{But,} \qquad I_C = \alpha_{dc} I_E = \alpha_{dc}(I_C + I_B)$$

$$I_C = \left(\frac{\alpha_{dc}}{1-\alpha_{dc}}\right) I_B$$

$$\beta_{dc} = \frac{\alpha_{dc}}{1-\alpha_{dc}} = \frac{\alpha_T \gamma}{1-\alpha_T \gamma}$$

Note that β is large (e.g. $\beta = 100$)

For npn transistor, similar analysis can be carried out. However, the emitter current is mainly carried by electrons.

Example: $\gamma = \dfrac{I_{EP}}{I_{EP} + I_{EN}}$ etc.