# Bipolar Junction Transistor

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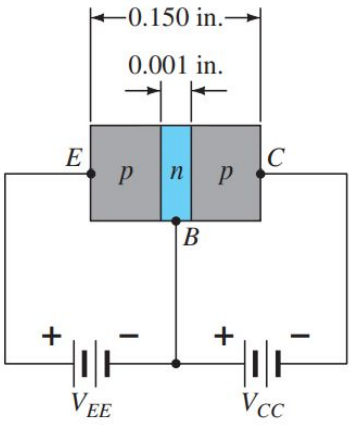
# Transistor Construction

- The transistor is a three-layer semiconductor device consisting of either two n - and one p -type layers of material or two p - and one n -type layers of material.
- The former is called an npn transistor , and the latter is called a pnp transistor.
- The emitter layer is heavily doped, with the base and collector only lightly doped.
- The outer layers have widths much greater than the sandwiched p - or n -type material.
- For the transistors shown in Fig. the ratio of the total width to that of the center layer is 0.150/0.001= 150:1.
- The doping of the sandwiched layer is also considerably less than that of the outer layers (typically, 1:10 or less).
- This lower doping level decreases the conductivity (increases the resistance) of this material by limiting the number of “free” carriers.



# Transistor operation

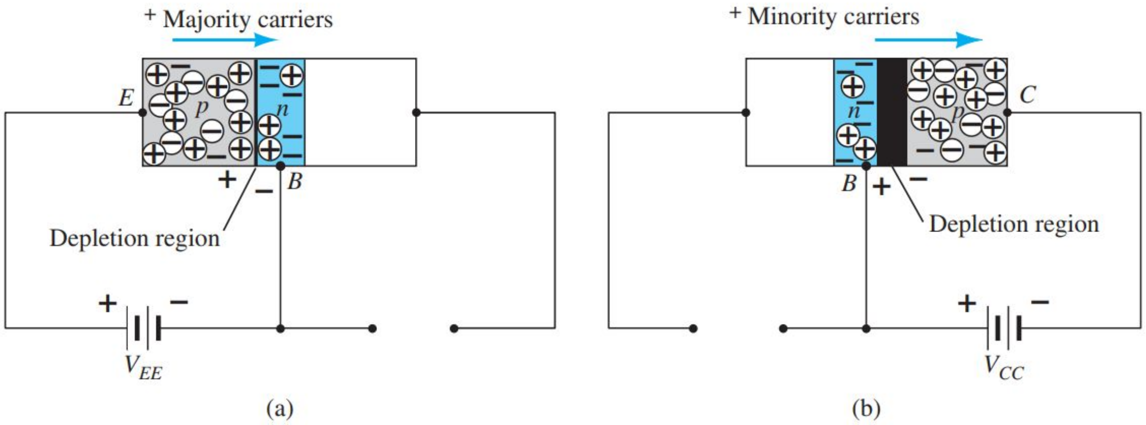



**FIG. 3.4**
*Biasing a transistor: (a) forward-bias; (b) reverse-bias.*

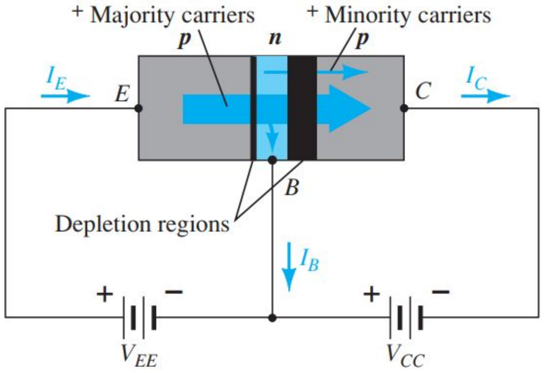



**FIG. 3.5**
*Majority and minority carrier flow of a pnp transistor.*

# Contd…

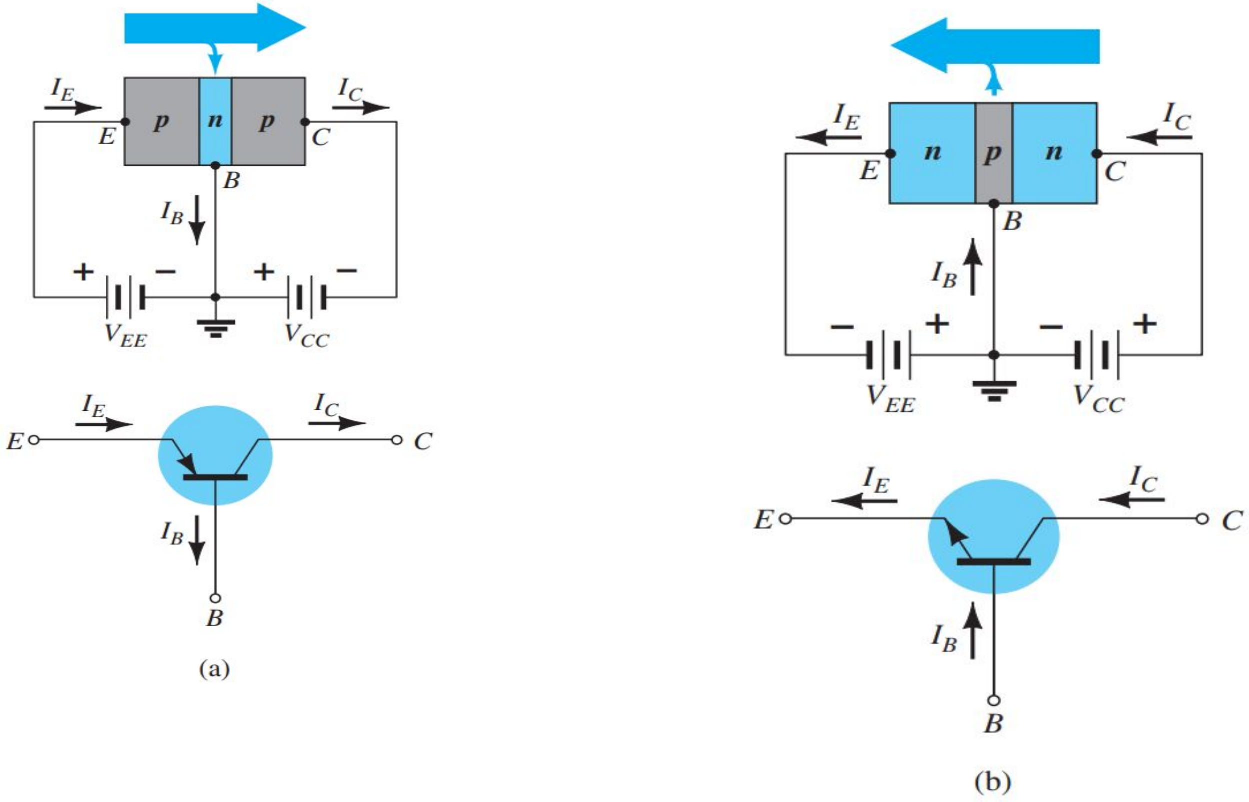
- Applying Kirchhoff's current law to the transistor as if it were a single node, we obtain

$$\boxed{I_E = I_C + I_B}$$

- The collector current, however, comprises two components—the majority and the minority carriers.
- The minority-current component is called the leakage current and is given the symbol $I_{CO}$ ( $I_C$ current with emitter terminal Open). The collector current, therefore, is determined in total by

$$\boxed{I_C = I_{C_{\text{majority}}} + I_{CO_{\text{minority}}}}$$

# Common Base Configuration



# Contd…

- Two sets of characteristics are required for 3 terminal device—one for the driving point or input parameters and the other for the output side.
- The input set for the common-base amplifier relates an input current ( $I_E$ ) to an input voltage ( $V_{BE}$ ) for various levels of output voltage ( $V_{CB}$ ).
- $V_{BE}$ = 0.7 for ON state.

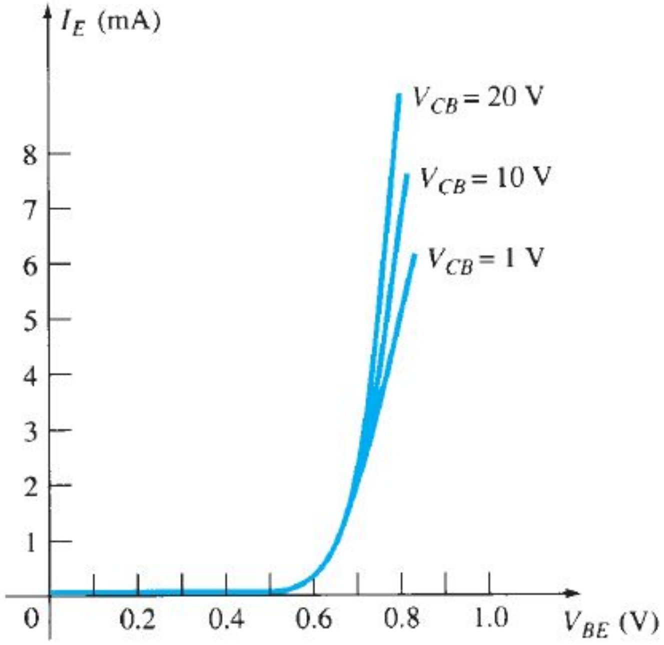



Fig. Input or driving point characteristics for a common-base silicon transistor amplifier.

# Contd…

- The output set relates an output current ( $I_C$ ) to an output voltage ( $V_{CB}$ ) for various levels of input current ( $I_E$ )
- The output or collector set of characteristics has three basic regions of interest: the active , cutoff , and saturation region.

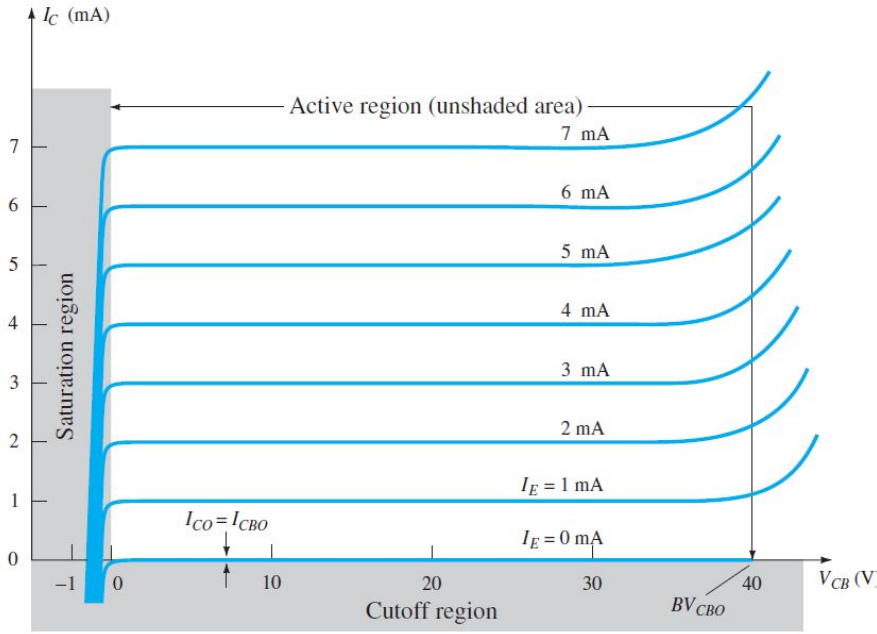



Fig. Output or collector characteristics for a common-base transistor amplifier.

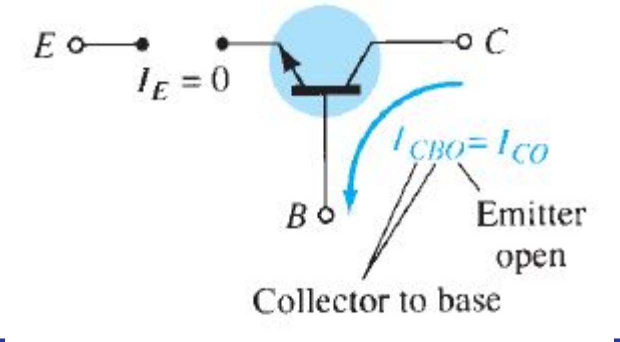



Fig. Reverse saturation current

# Common Base DC Current Gain ($\boldsymbol{\alpha}_{dc}$)

- Ratio of output current to input current is called current gain of a transistor.
- In the dc mode the levels of $I_C$ and $I_E$ due to the majority carriers are related by a quantity called alpha and defined by the following equation:

$$\boxed{\alpha_{dc} = \frac{I_C}{I_E}}$$

- $\boldsymbol{\alpha}$ ranges from : 0.90 to -0.998

$$\boxed{I_C = I_{C_{\text{majority}}} + I_{CO_{\text{minority}}}} \longrightarrow \boxed{I_C = \alpha I_E + I_{CBO}}$$

# Common Base AC Current Gain ($\alpha_{ac}$)

- The ac alpha is formally called the common-base , short-circuit , amplification factor.
- For ac situations where the point of operation moves on the characteristic curve, an ac alpha is defined by

$$\boxed{\alpha_{\mathrm{ac}} = \left.\frac{\Delta I_C}{\Delta I_E}\right|_{V_{CB=\mathrm{constant}}}}$$

# Common-Emitter Configuration

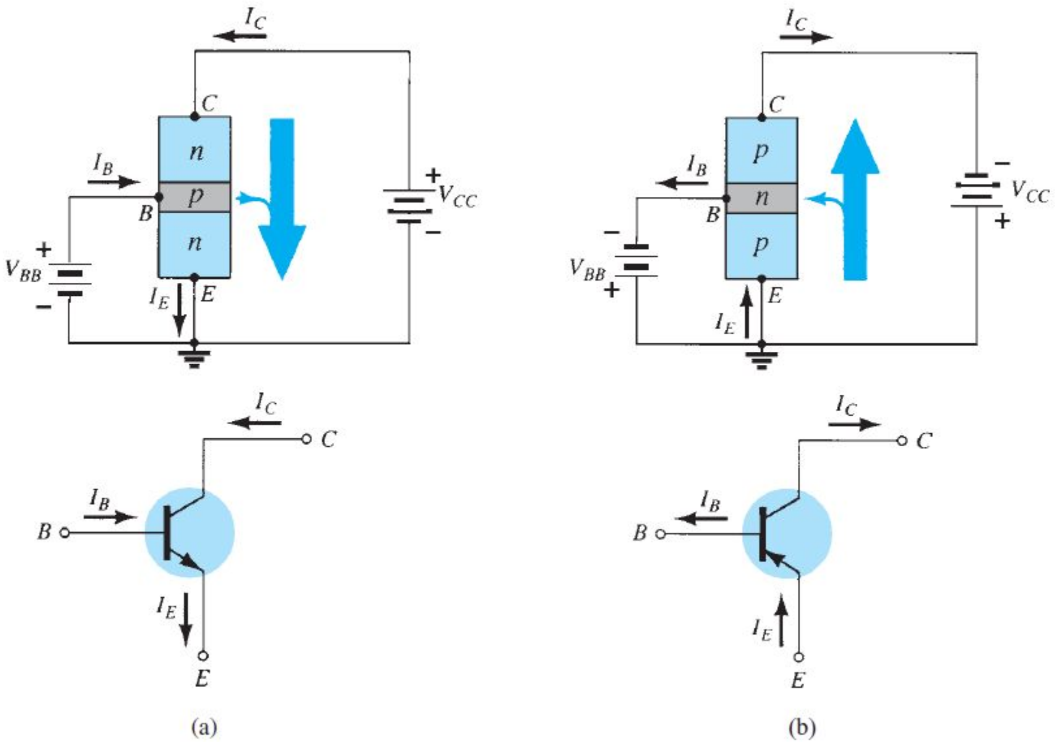



**FIG. 3.12**

*Notation and symbols used with the common-emitter configuration: (a) npn transistor; (b) pnp transistor.*

# Contd…

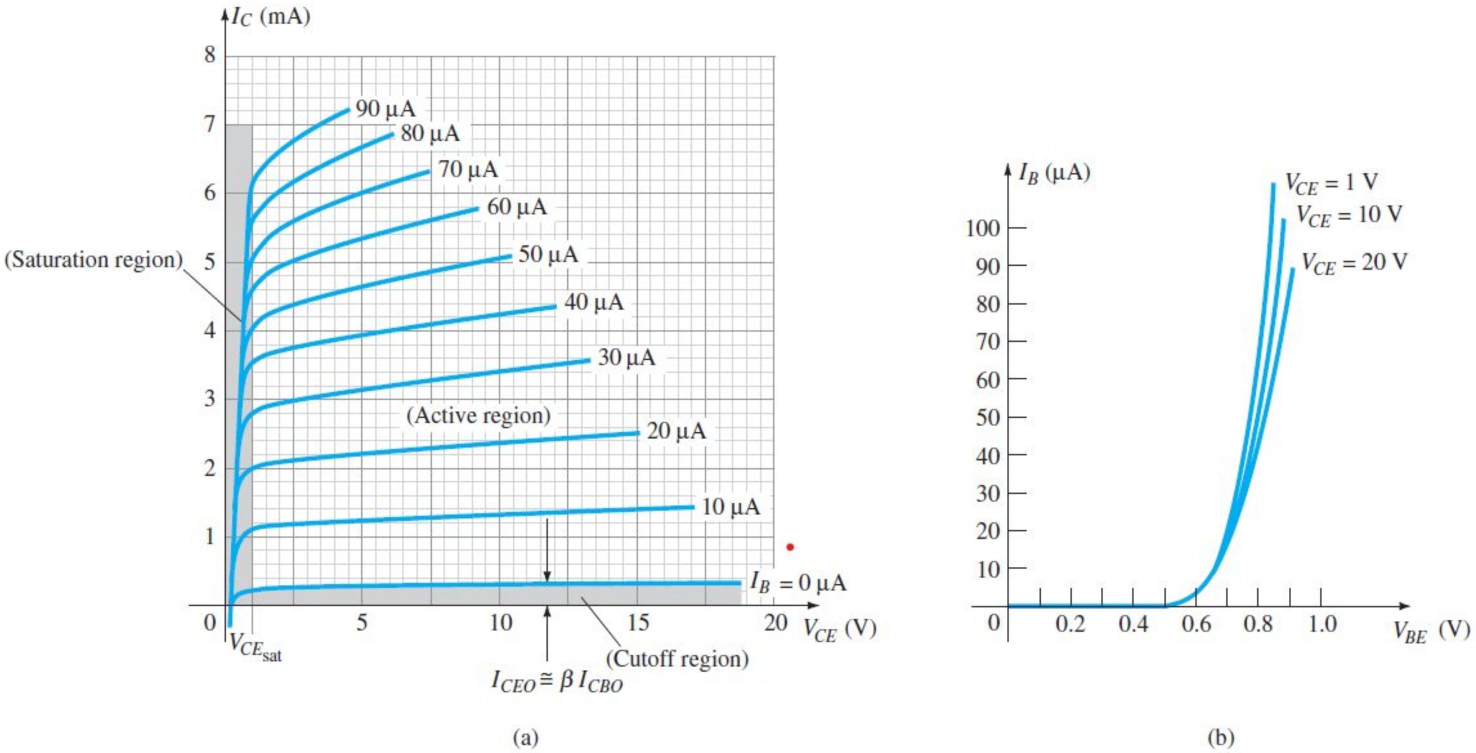



**FIG. 3.13**

*Characteristics of a silicon transistor in the common-emitter configuration: (a) collector characteristics; (b) base characteristics.*

# Contd…

- In the active region of a common-emitter amplifier, the base–emitter junction is forward-biased, whereas the collector–base junction is reverse-biased.
- In collector characteristics that $I_C$ is not equal to zero when $I_B$ is zero.
- The reason for this difference in collector characteristics can be derived through:

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

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

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

# Contd…

- The collector current defined by the condition $I_B$ = 0 mA is $I_{CEO}$
- For linear (least distortion) amplification purposes, cutoff for the common-emitter configuration will be defined by $I_C = I_{CEO}$ .

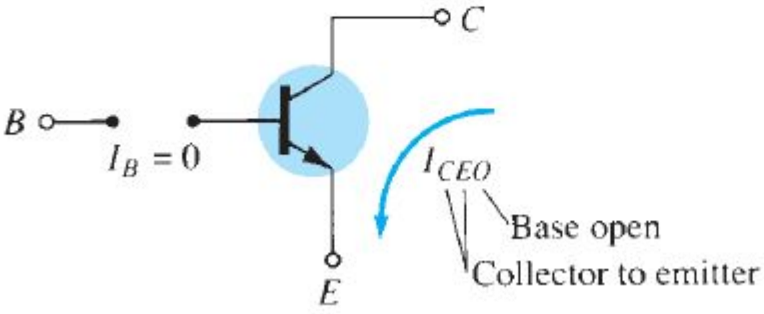



**FIG. 3.14**
*Circuit conditions related to $I_{CEO}$.*

$$\boxed{I_{CEO} = \left.\frac{I_{CBO}}{1-\alpha}\right|_{I_B = 0\,\mu A}}$$

# Common Emitter DC/AC Current Gain ($\beta_{dc}$/$\beta_{ac}$)

- Ratio of collector (output) current to base (input) current

$$\boxed{\beta_{dc} = \frac{I_C}{I_B}}$$

- The formal name $\beta_{ac}$ for is common-emitter , forward-current , amplification factor . Since the collector current is usually the output current for a common-emitter configuration and the base current is the input current
- 

# Relation between $\alpha_{dc}$ and $\beta_{dc}$

- A relationship can be developed between $\beta$ and $\alpha$ using the basic relationships introduced
- Using $\beta = I_C/IB$, we have $I_B = I_C/\beta$, and from $\alpha = I_C/I_E$ we have $I_E = I_C/\alpha$. Substituting into

$$I_E = I_C + I_B$$

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

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

or

$$\beta = \alpha\beta + \alpha = (\beta + 1)\alpha$$

so that

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

or

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

# Contd...

In addition, recall that

$$I_{CEO} = \frac{I_{CBO}}{1 - \alpha}$$

but using an equivalence of

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

derived from the above, we find that

$$I_{CEO} = (\beta + 1)I_{CBO}$$

or

$$\boxed{I_{CEO} \cong \beta I_{CBO}}$$

$$\boxed{I_C = \beta I_B}$$

and since

$$I_E = I_C + I_B$$
$$= \beta I_B + I_B$$

we have

$$\boxed{I_E = (\beta + 1)I_B}$$

# Common Collector Configuration

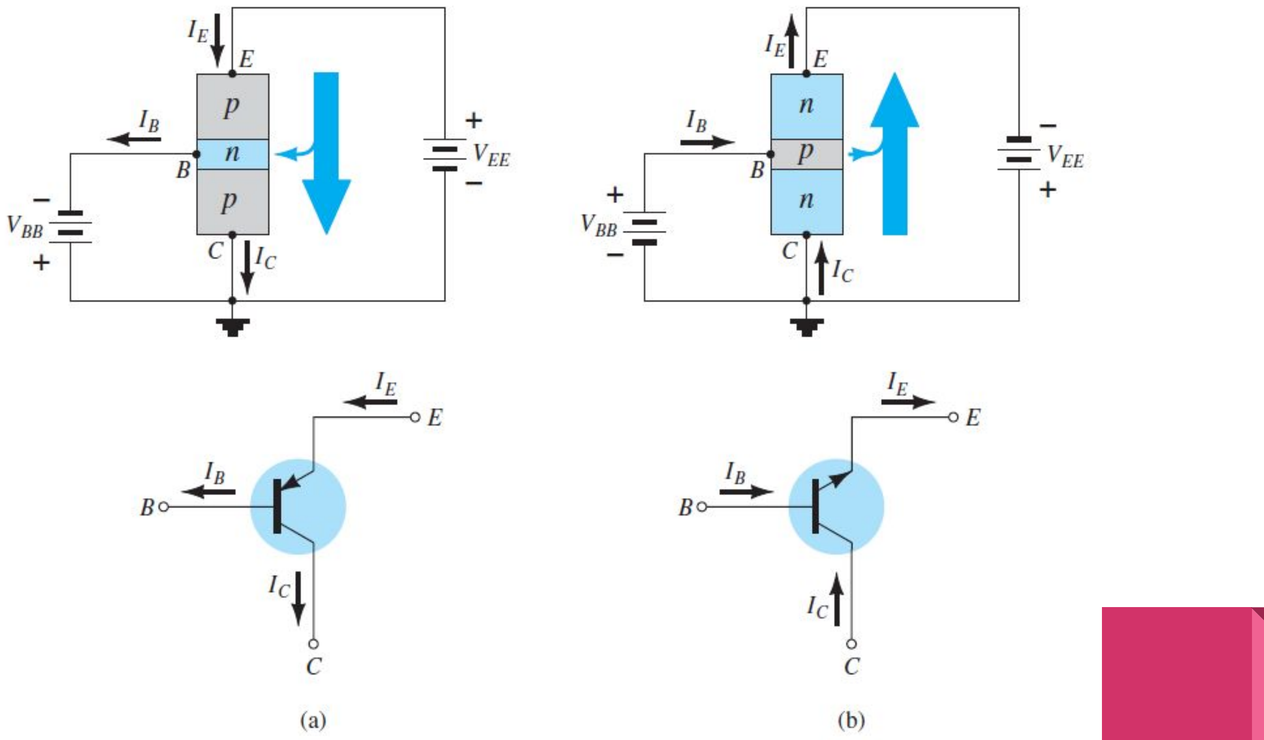



**FIG. 3.20**
*Notation and symbols used with the common-collector configuration: (a) pnp transistor; (b) npn transistor.*

# Contd...

The common-collector configuration is used primarily for impedance-matching purposes since it has a high input impedance and low output impedance, opposite to that of the common-base and common emitter configurations.

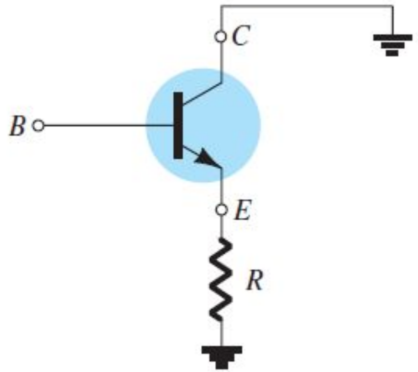



**FIG. 3.21**
*Common-collector configuration used for impedance-matching purposes.*

# Limits of Operation

- For each transistor there is a region of operation on the characteristics that will ensure that the maximum ratings are not being exceeded and the output signal exhibits minimum distortion.
- The maximum dissipation level is defined by the following equation:

$$\boxed{P_{C_{\max}} = V_{CE} I_C}$$

- The cutoff region is defined as that region below $I_C = I_{CEO}$.

# Contd…

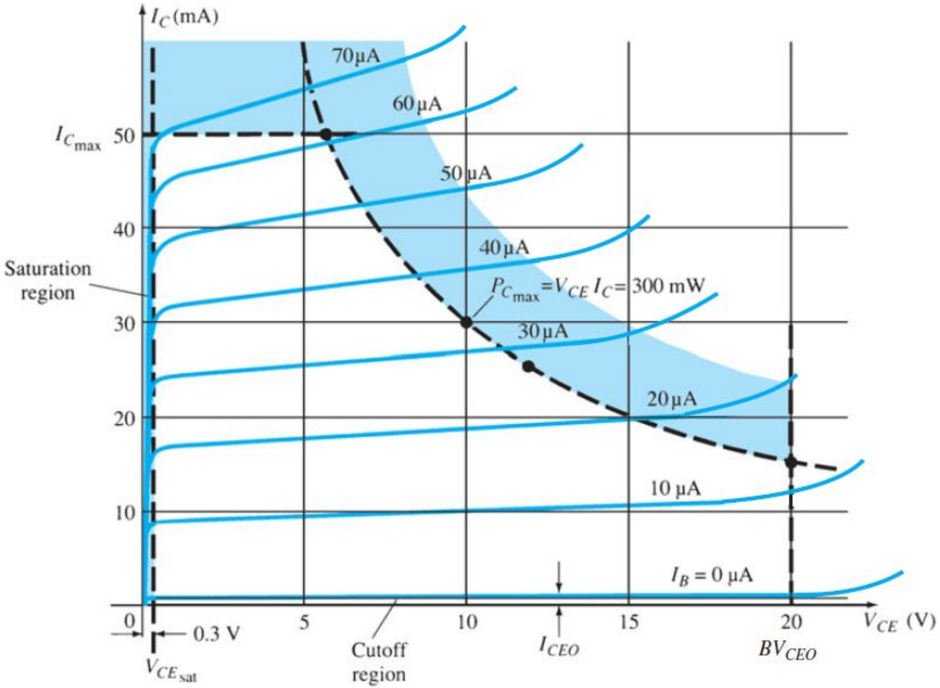



**FIG. 3.22**

*Defining the linear (undistorted) region of operation for a transistor.*

$$I_{CEO} \leqq I_C \leqq I_{C_{max}}$$
$$V_{CE_{sat}} \leqq V_{CE} \leqq V_{CE_{max}}$$
$$V_{CE} I_C \leqq P_{C_{max}}$$