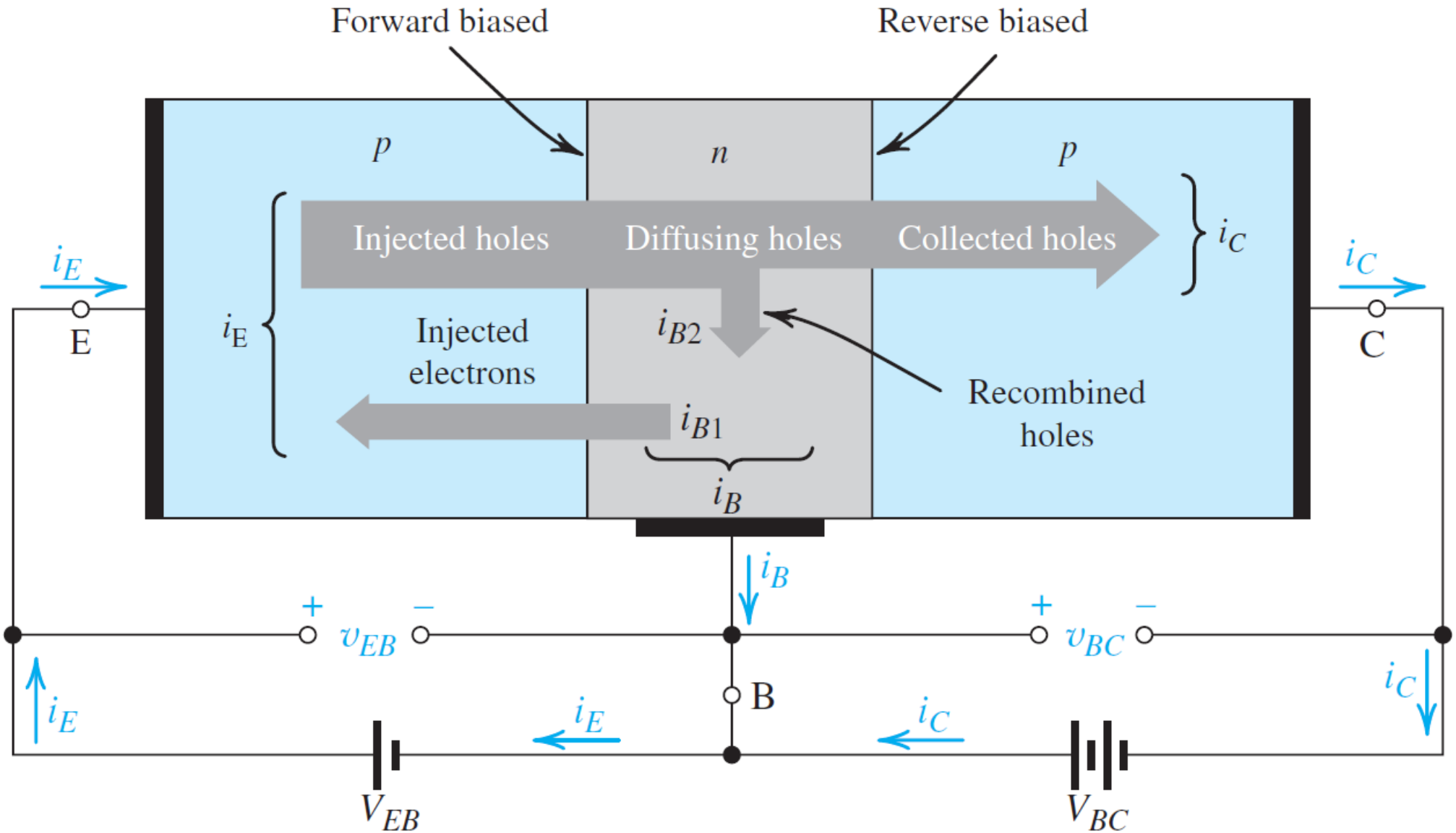
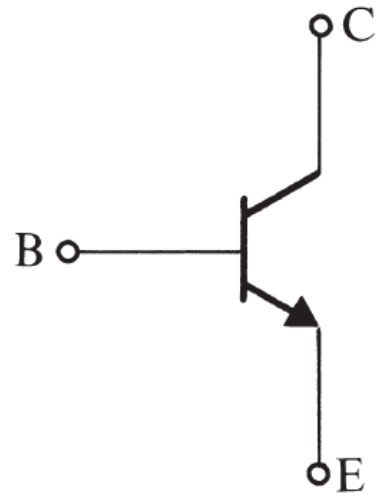
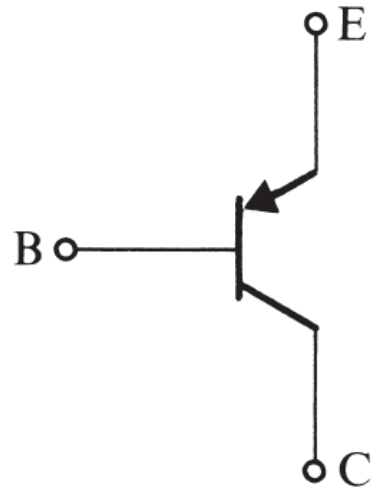
BJT

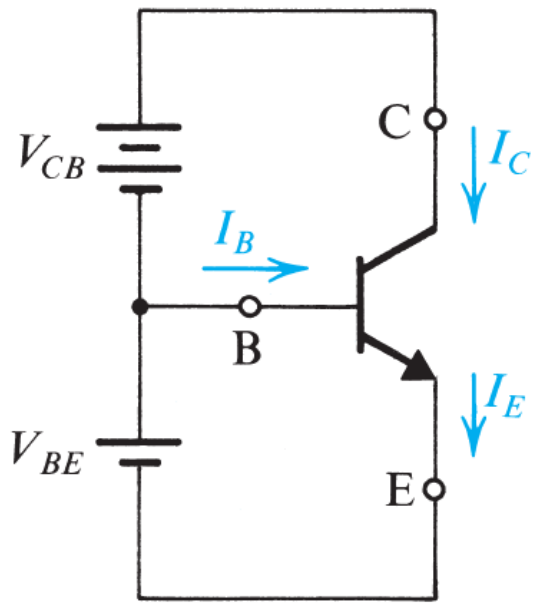

Forward biased
Reverse biased
p
n
p
Injected holes
Diffusing holes
Collected holes
i_C
i_E
E
i_E
Injected electrons
i_{B2}
Recombined holes
i_{B1}
i_B
i_C
C
i_B
+
v_{EB}
−
+
v_{BC}
−
i_E
B
i_E
i_C
i_C
V_{EB}
V_{BC}

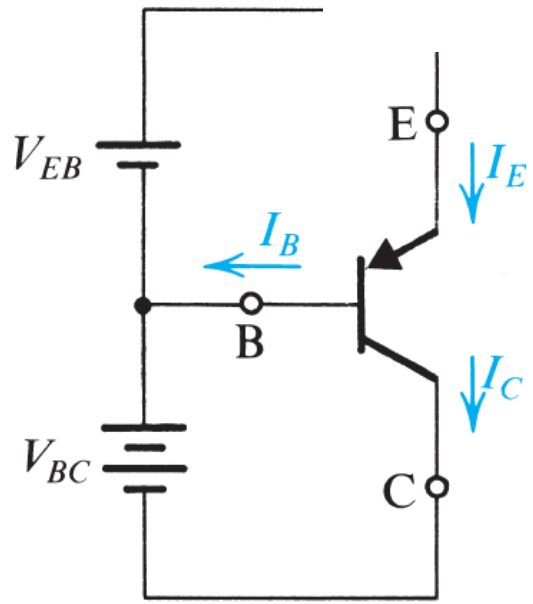


npn



pnp





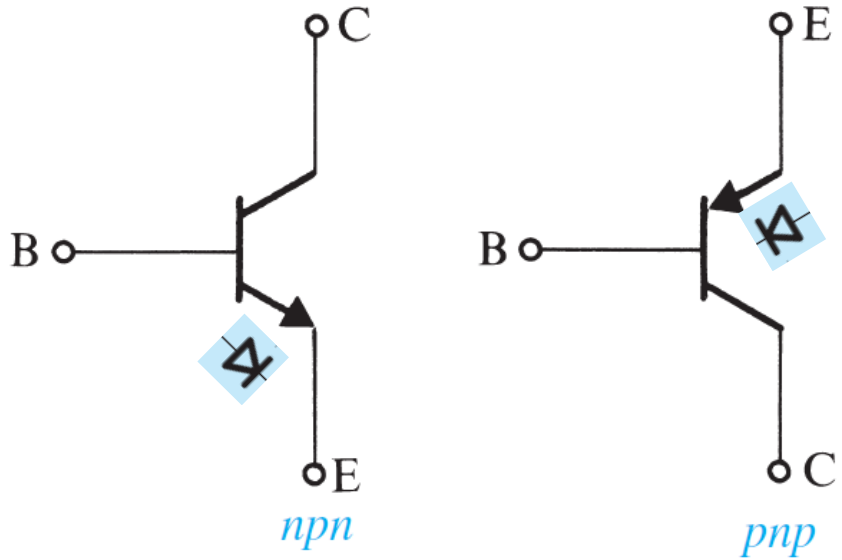


Table 6.1 BJT Modes of Operation

Mode	EBJ	CBJ
Cutoff	Reverse	Reverse
Active	Forward	Reverse
Saturation	Forward	Forward

Table 6.2 Summary of the BJT Current–Voltage Relationships in the Active Mode

$$i_C = I_S e^{v_{BE}/V_T}$$

$$i_B = \frac{i_C}{\beta} = \left(\frac{I_S}{\beta}\right) e^{v_{BE}/V_T} \qquad V_{BE} \simeq 0.7 \text{ V}$$

$$i_E = \frac{i_C}{\alpha} = \left(\frac{I_S}{\alpha}\right) e^{v_{BE}/V_T}$$

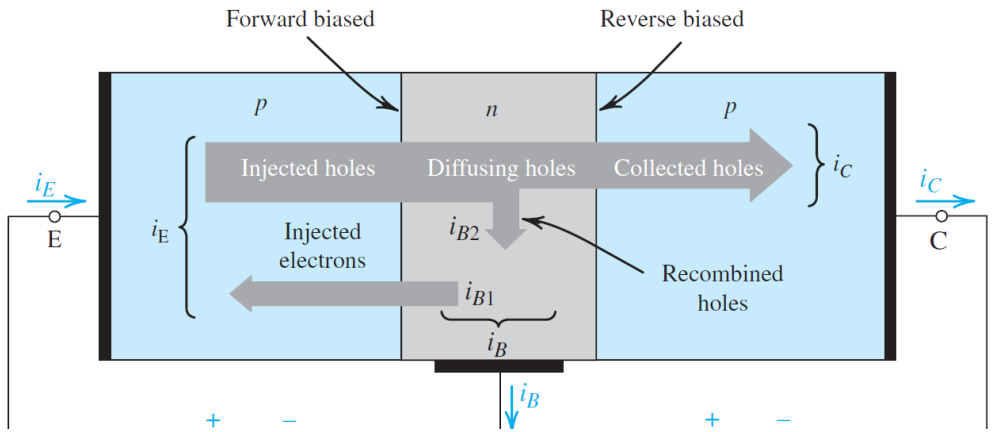
Note: For the *pnp* transistor, replace v_{BE} with v_{EB}.

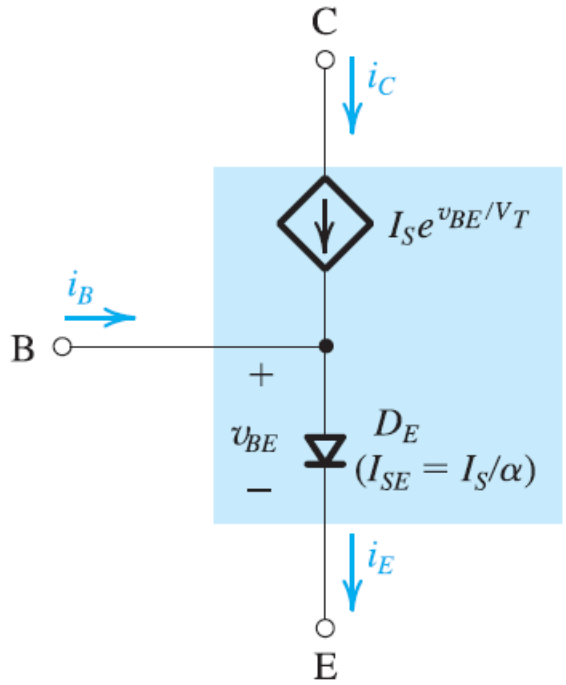
$$i_C = \alpha i_E \qquad i_B = (1-\alpha) i_E = \frac{i_E}{\beta+1}$$

$$i_C = \beta i_B \qquad i_E = (\beta+1) i_B$$

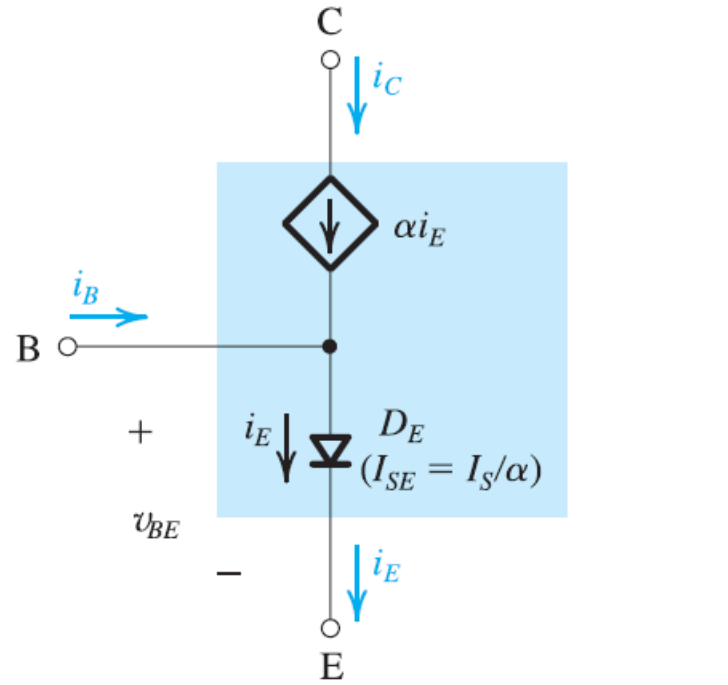
$$\beta = \frac{\alpha}{1-\alpha} \qquad \alpha = \frac{\beta}{\beta+1}$$

V_T = thermal voltage = $\dfrac{kT}{q} \simeq 25$ mV at room temperature

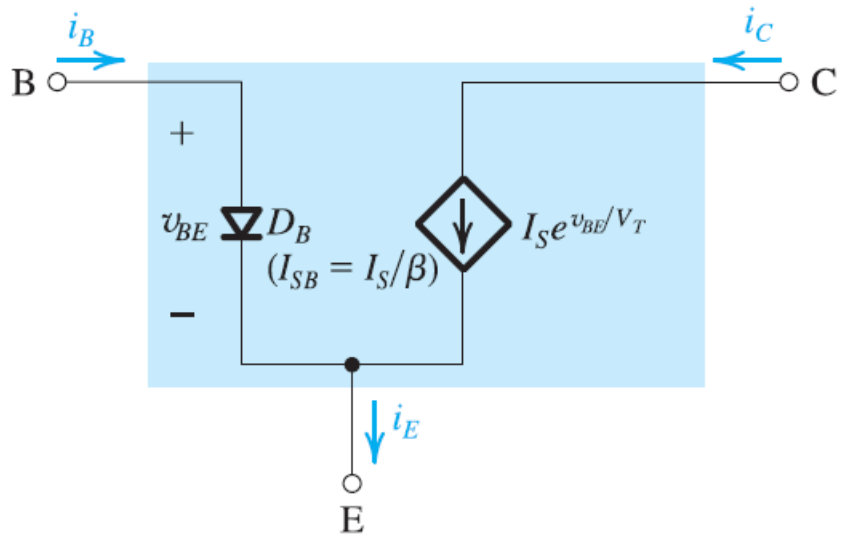


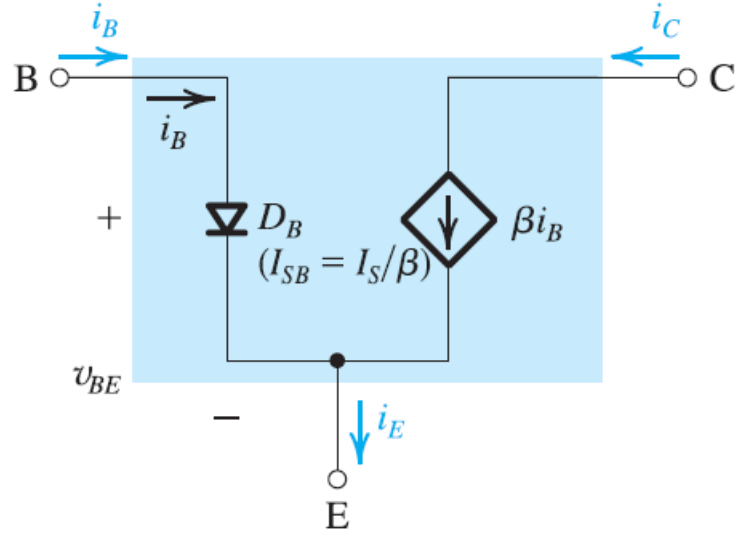

C
i_C
$I_S e^{v_{BE}/V_T}$
i_B
B
+
v_{BE}
–
D_E
$(I_{SE} = I_S/\alpha)$
i_E
E

(a)


C
i_C
αi_E
i_B
B
+
v_{BE}
–
i_E
D_E
$(I_{SE} = I_S/\alpha)$
i_E
E

(b)


i_B
i_C
B
C
+
v_{BE}
–
D_B
$(I_{SB} = I_S/\beta)$
$I_S e^{v_{BE}/V_T}$
i_E
E


i_B
i_C
B
C
i_B
+
v_{BE}
–
D_B
$(I_{SB} = I_S/\beta)$
βi_B
i_E
E

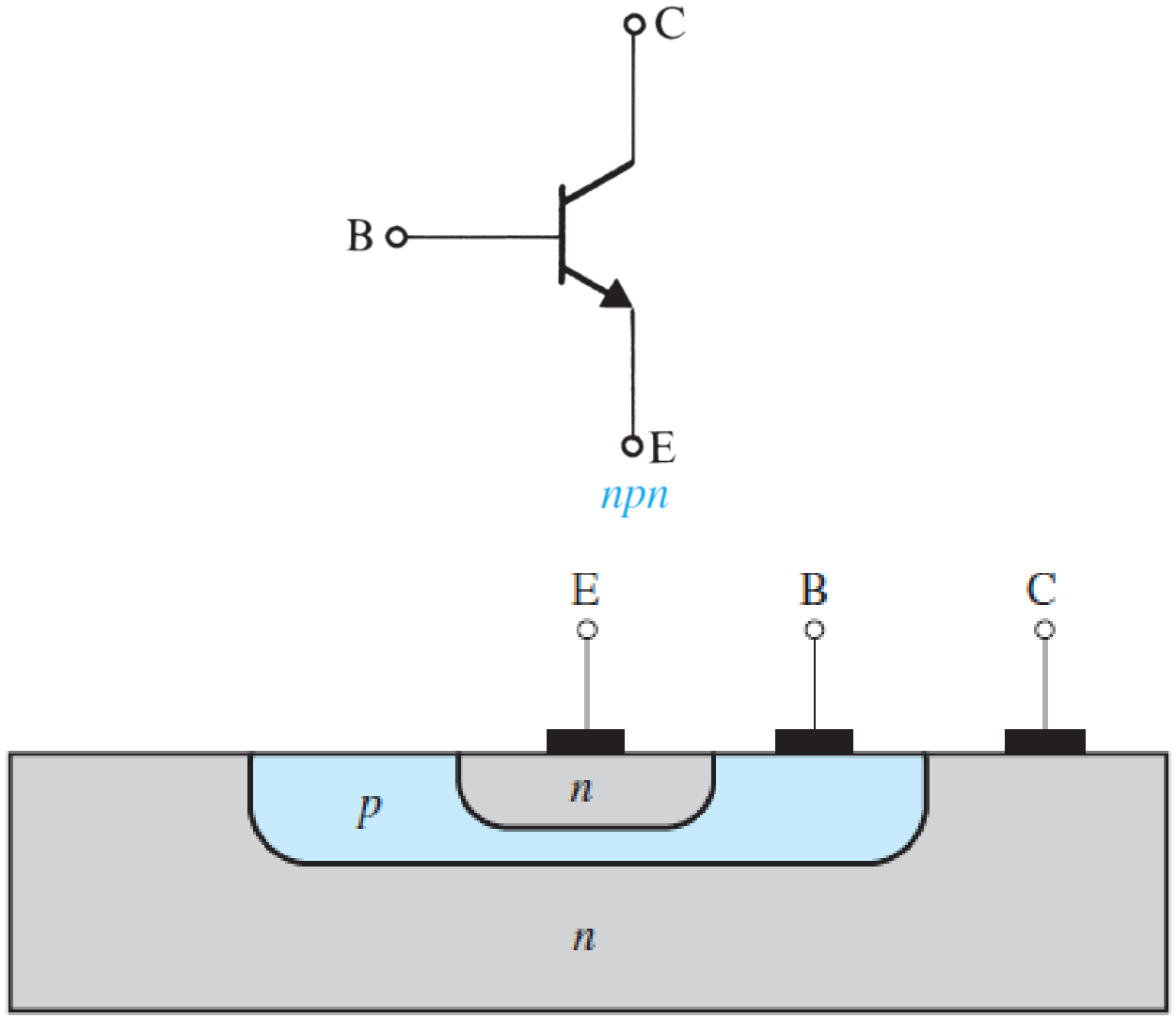
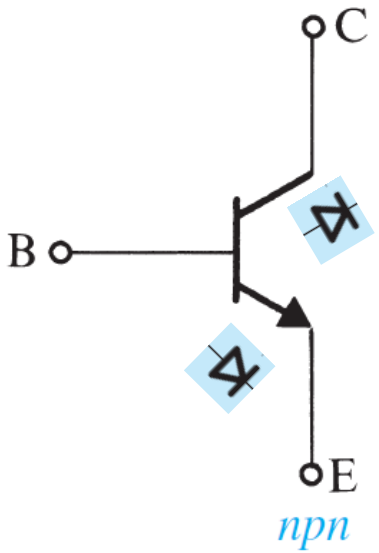
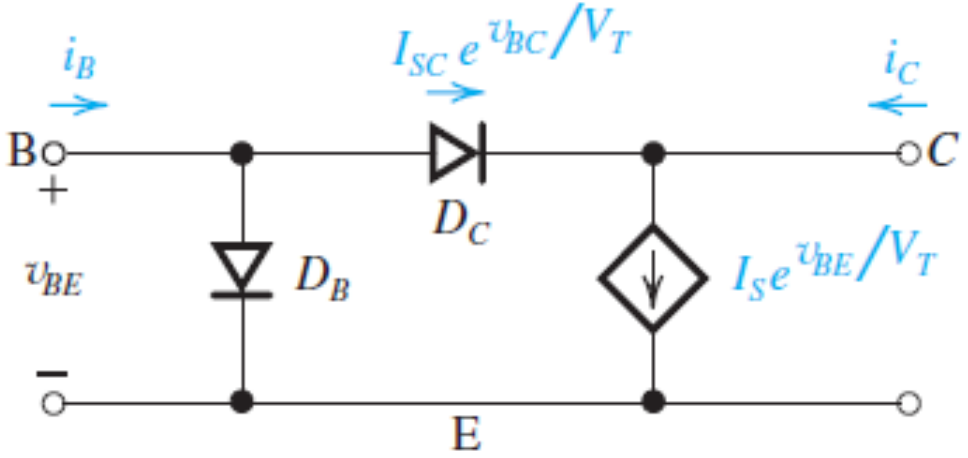


Figure 6.7 Cross section of an *npn* BJT.

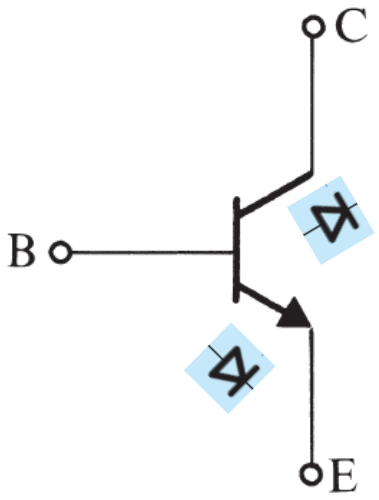
Operation in the Saturation Mode



v_{CB} going negative to approximately −0.4 V.



Operation in the Saturation Mode



v_{CB} going negative to approximately −0.4 V.

$$\beta_{\text{forced}} = \left.\frac{i_C}{i_B}\right|_{\text{saturation}} \leq \beta$$

$$V_{CEsat} \simeq 0.1 \text{ to } 0.3 \text{ V}$$

Typically we will assume that a transistor at the edge of saturation has $V_{CEsat} = 0.3$ V, while a transistor deep in saturation has $V_{CEsat} = 0.2$ V.

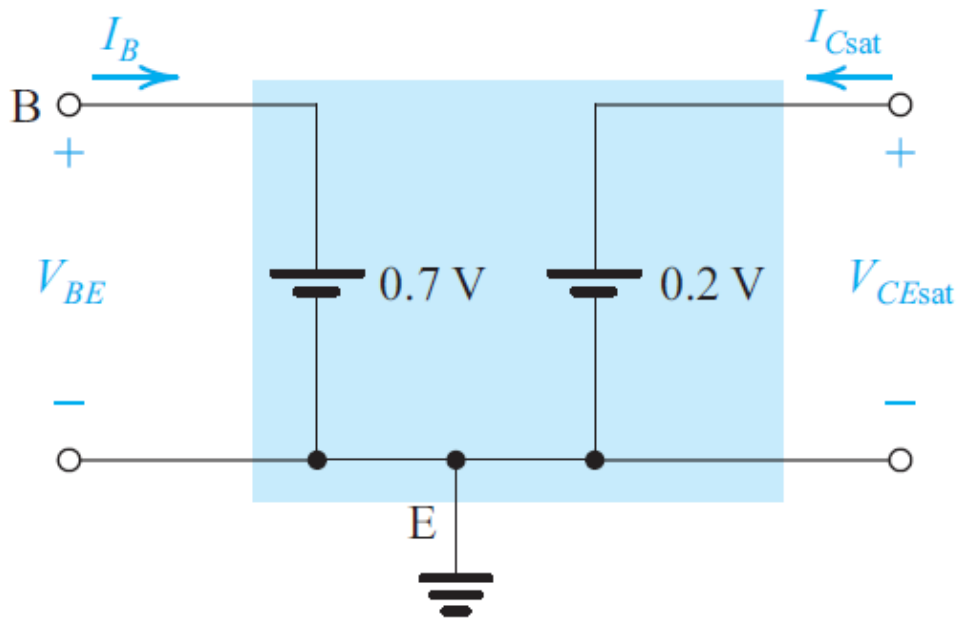


Figure 6.21 A simplified equivalent-circuit model of the saturated transistor.

The *pnp* Transistor

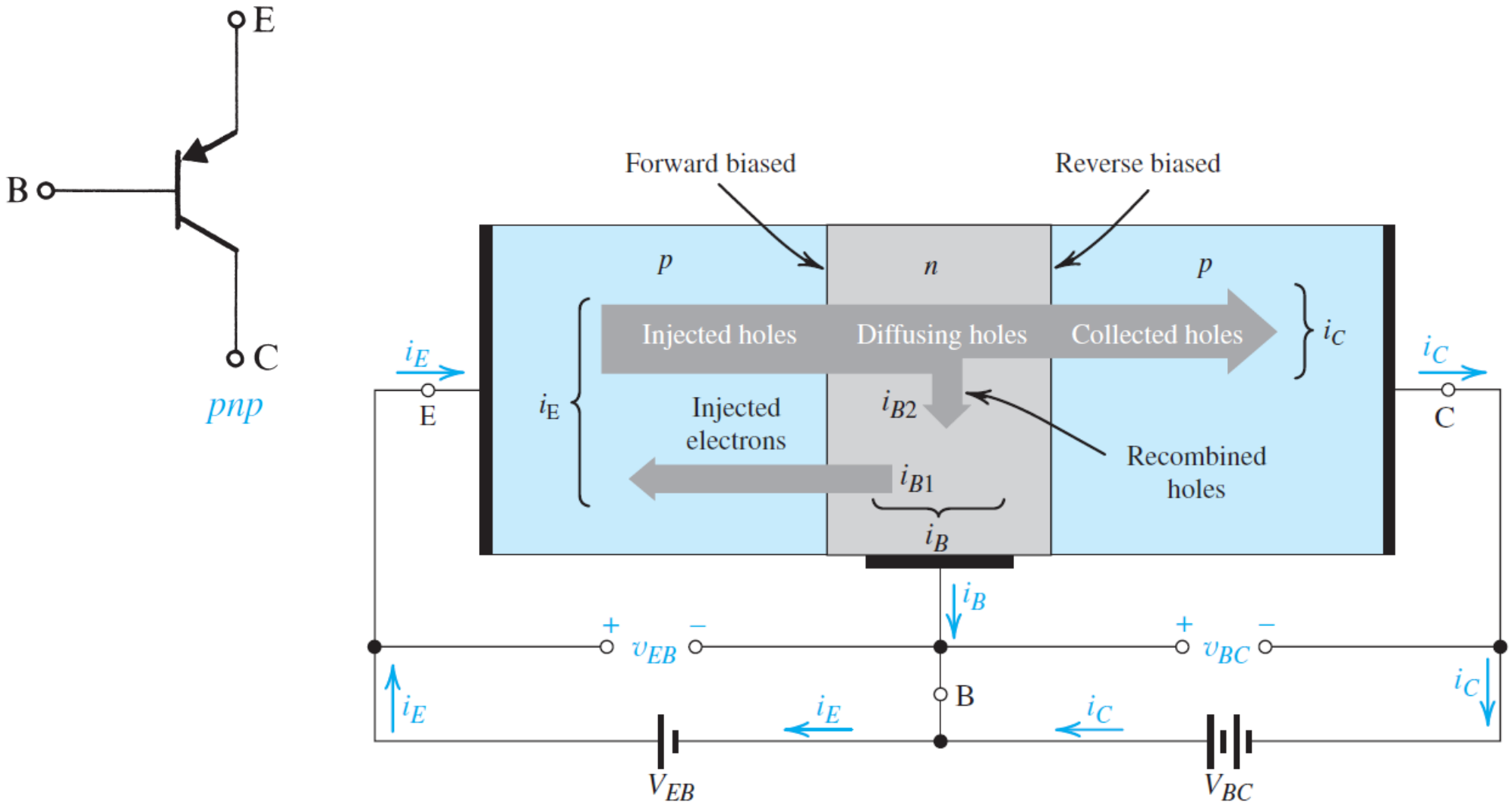


Figure 6.10 Current flow in a *pnp* transistor biased to operate in the active mode.

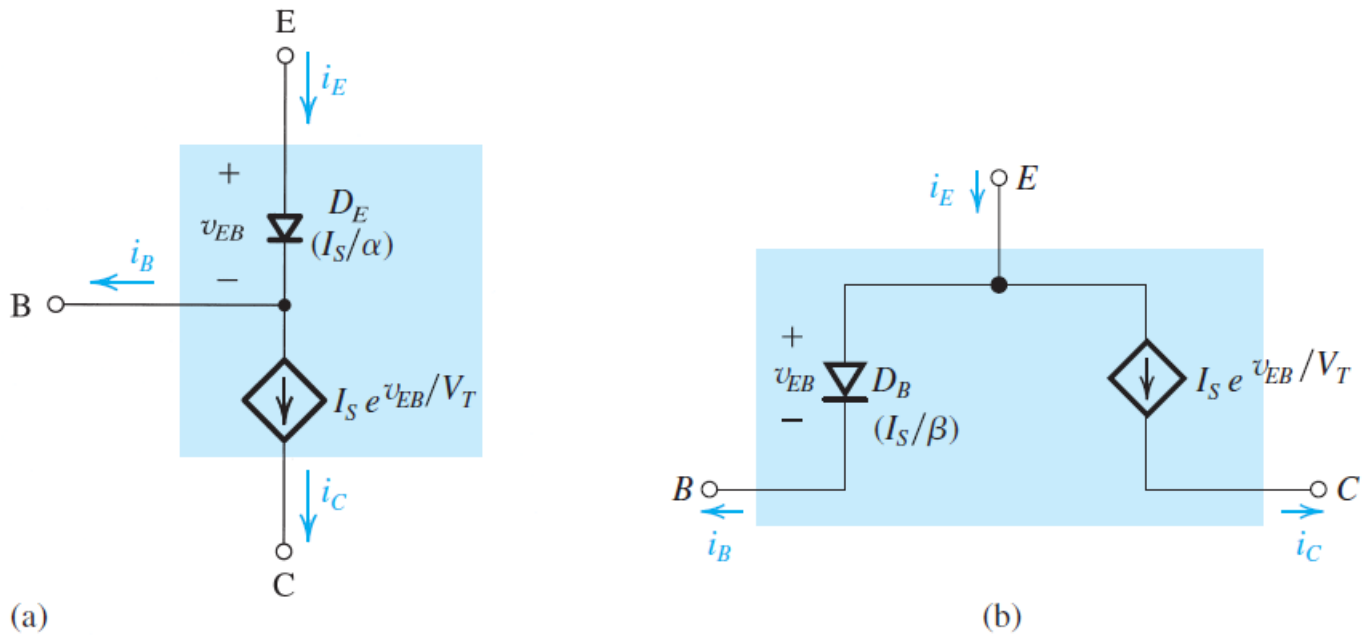
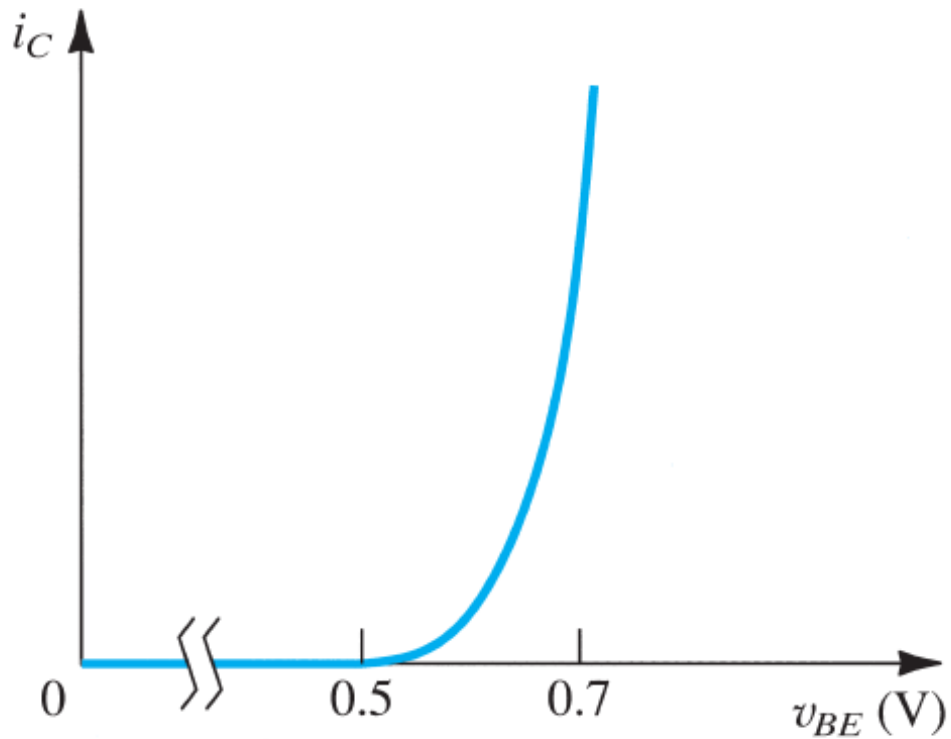
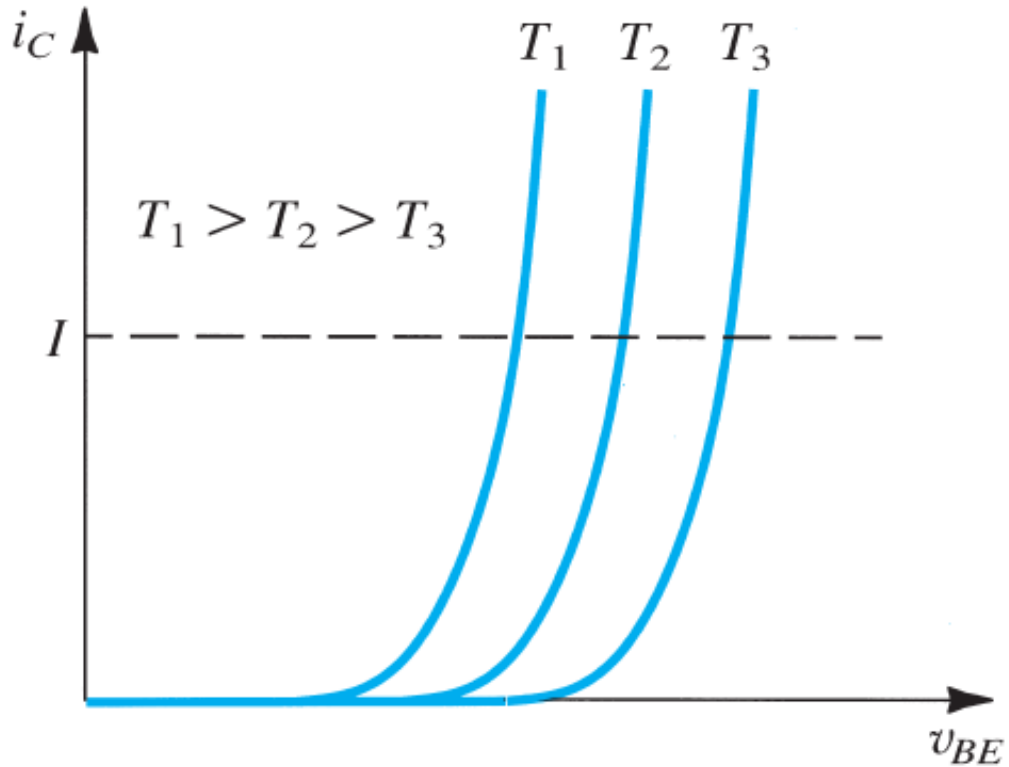


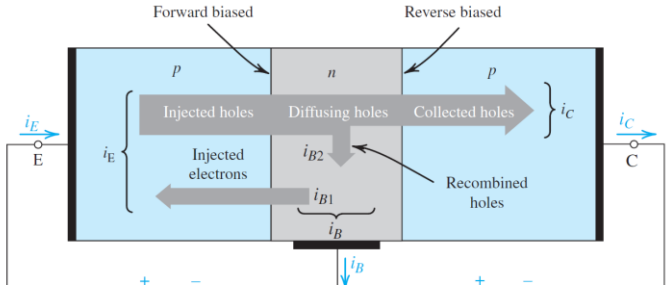
Figure 6.11 Two large-signal models for the *pnp* transistor operating in the active mode.



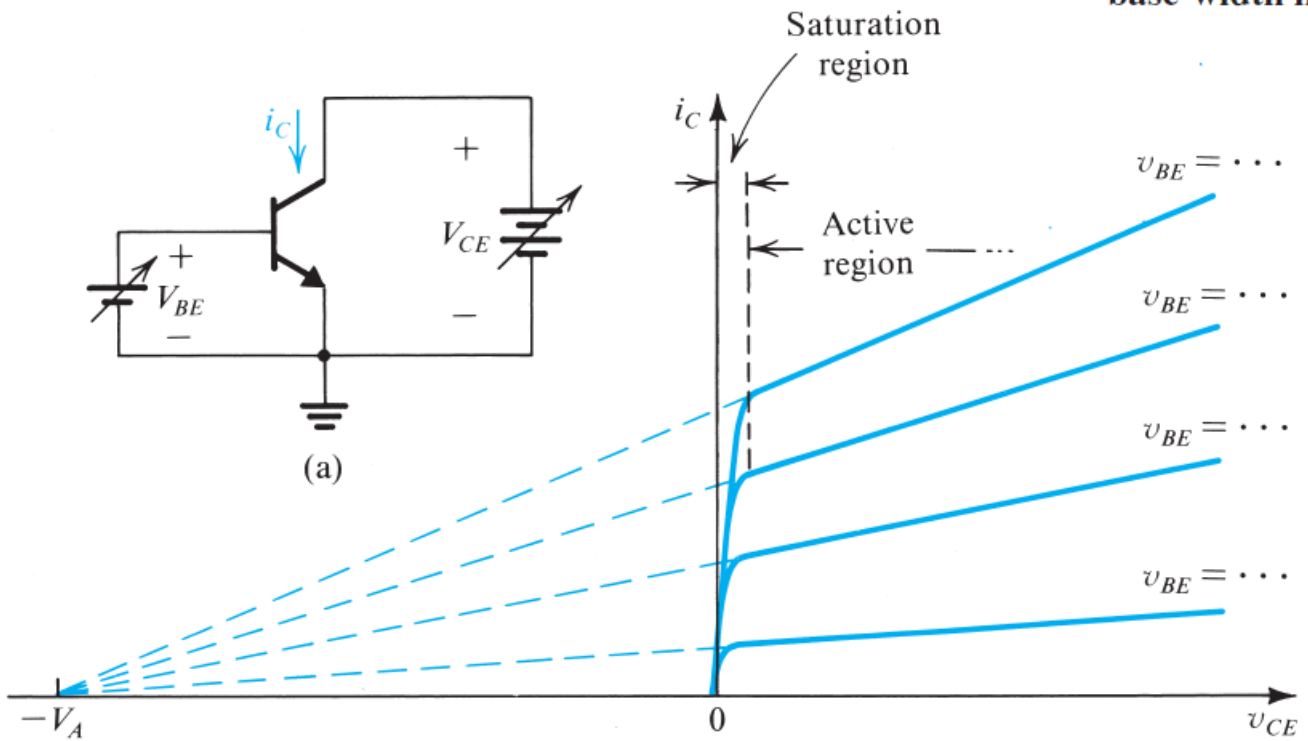
The i_C–v_{BE} characteristic for an *npn* transistor.

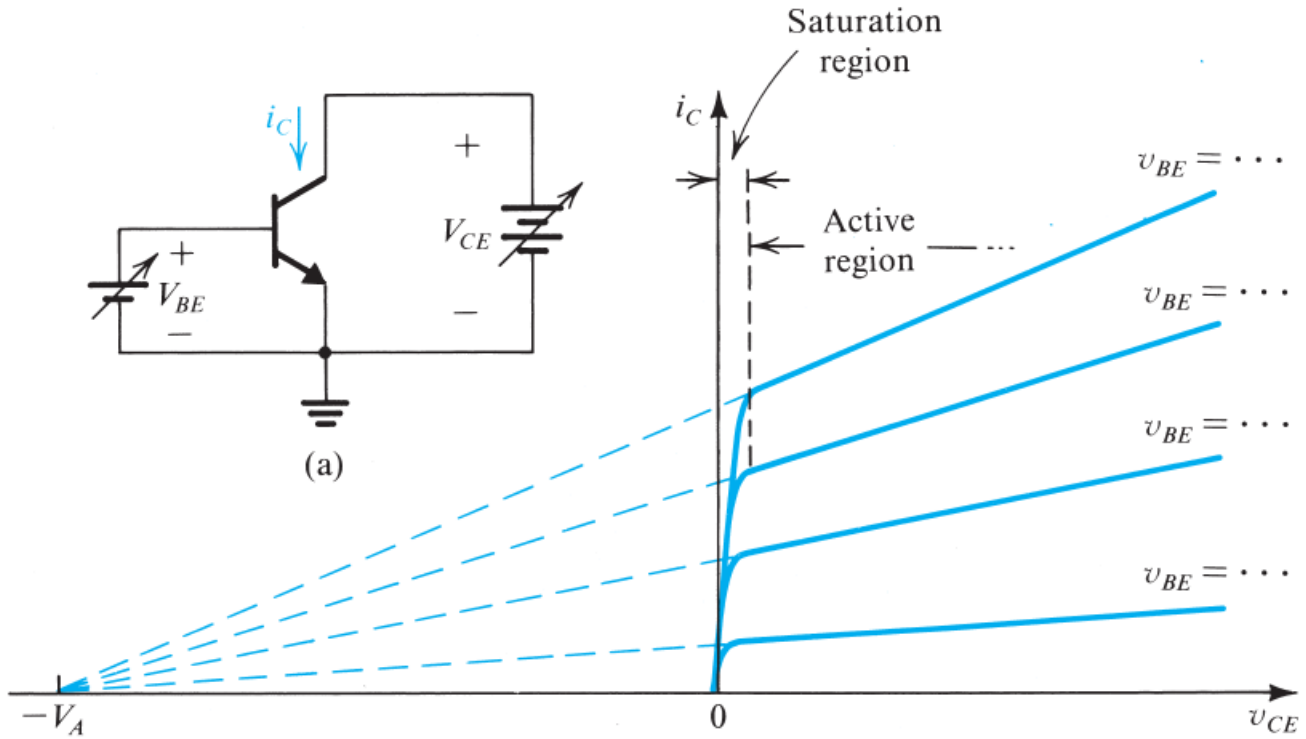


Effect of temperature on the i_C–v_{BE} characteristic. At a constant emitter current (broken line), v_{BE} changes by −2 mV/°C.



base-width modulation effect.

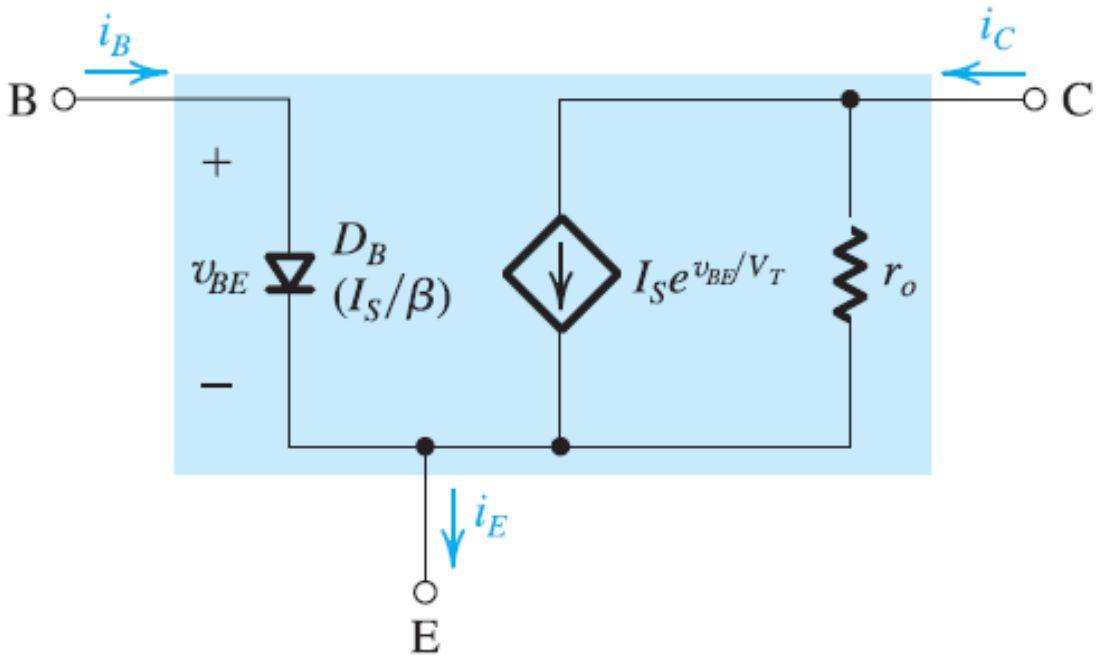


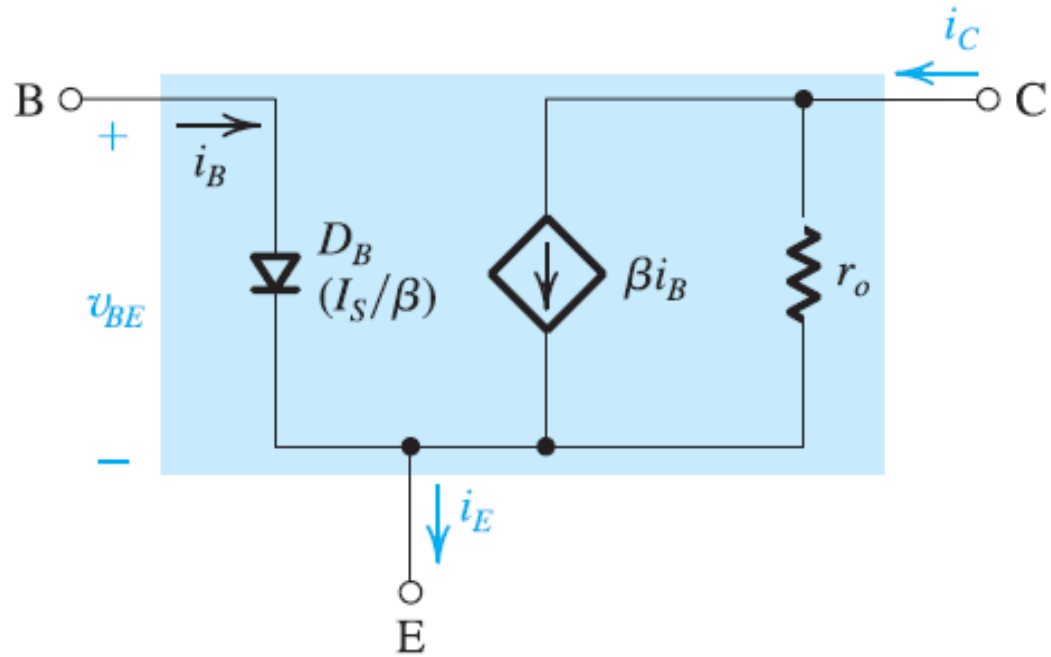


$$r_o \equiv \left[\left. \frac{\partial i_C}{\partial v_{CE}} \right|_{v_{BE} = \text{constant}} \right]^{-1}$$

$$r_o = \frac{V_A}{I_C'}$$

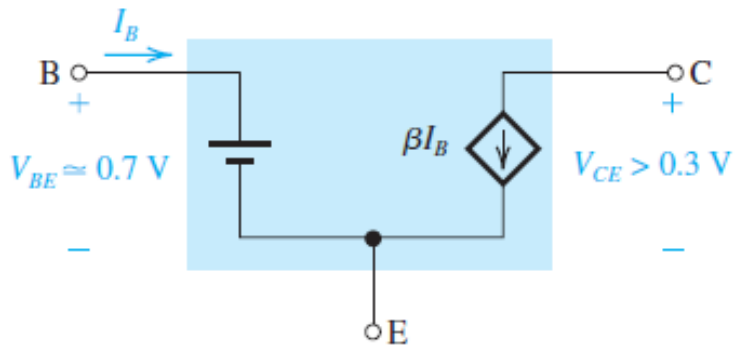
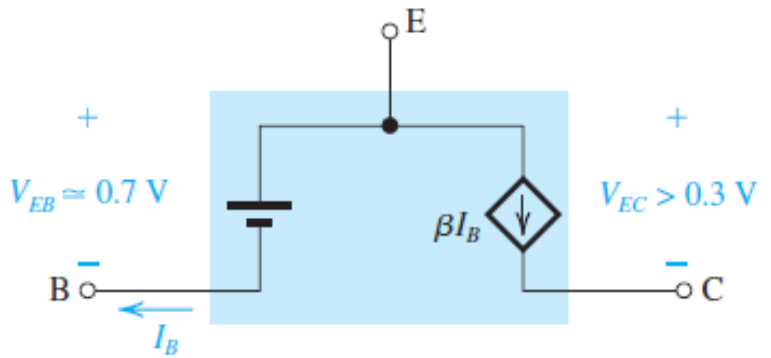
$$I_C' = I_S e^{V_{BE}/V_T}$$


i_B
i_C
B
C
+
v_{BE}
D_B
(I_S/β)
$I_S e^{v_{BE}/V_T}$
r_o
–
i_E
E


i_C
B
C
+
i_B
v_{BE}
D_B
(I_S/β)
βi_B
r_o
–
i_E
E

BJT Circuits at DC

Table 6.3 Simplified Models for the Operation of the BJT in DC Circuits

	npn	*pnp*
Active EBJ: Forward Biased CBJ: Reverse Biased		
Saturation EBJ: Forward Biased CBJ: Forward Biased