國立勤益科技大學

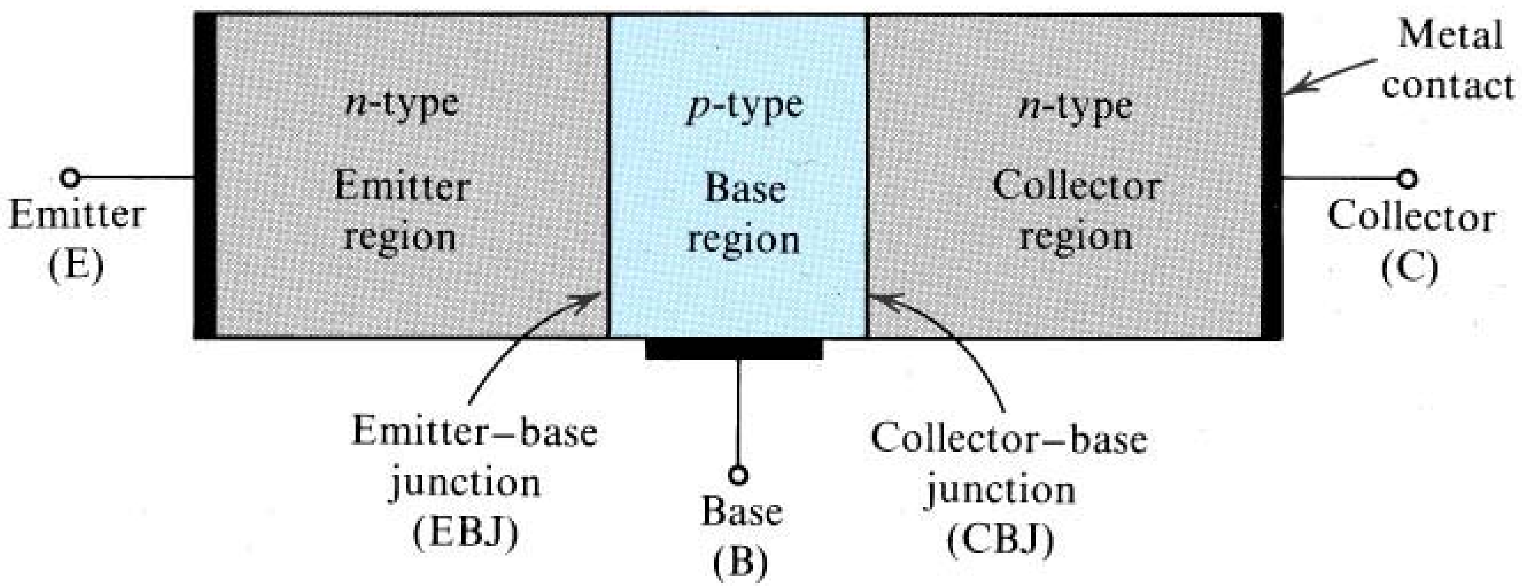
National Chin-Yi University of Technology

Sedra/Smith
Microelectronic Circuits 6/E

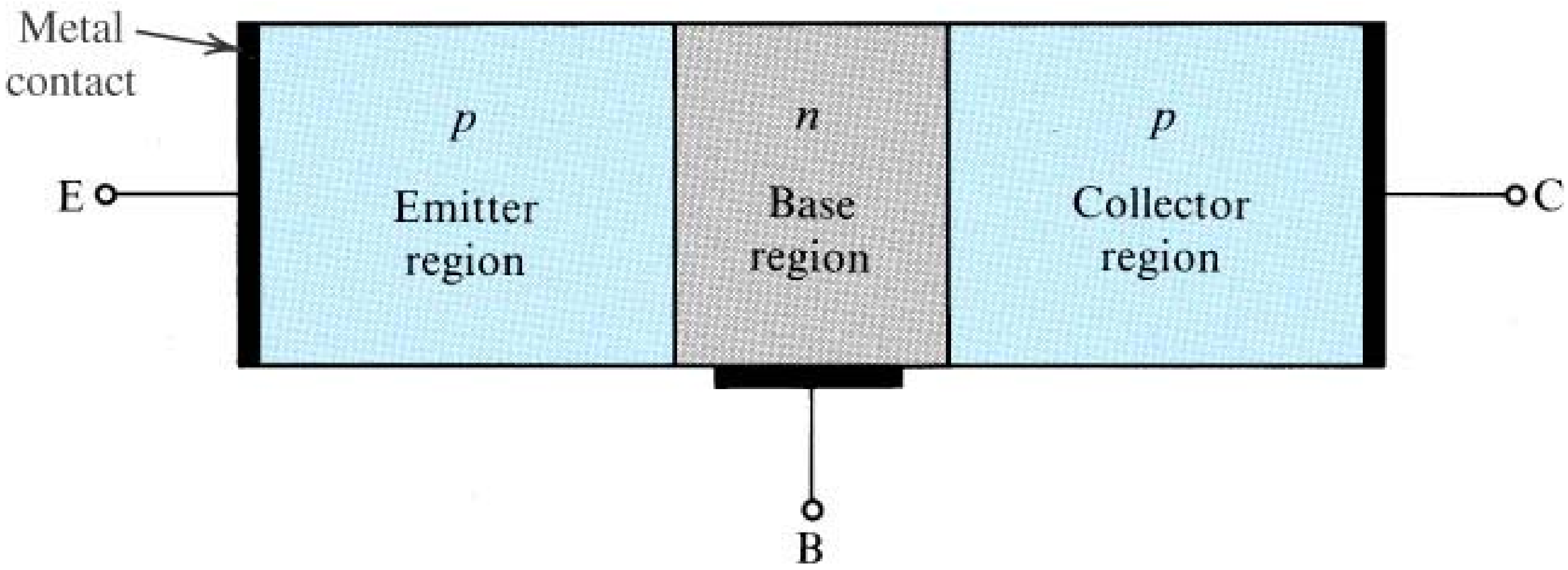
Chapter 4-A
Bipolar Junction Transistors (BJTs)

【Outline】

4.1 Device structure and physical operation



Emitter and collector regions having identical physical dimensions (C > E > B) and doping concentrations (E > C > B)



BJT modes operation

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

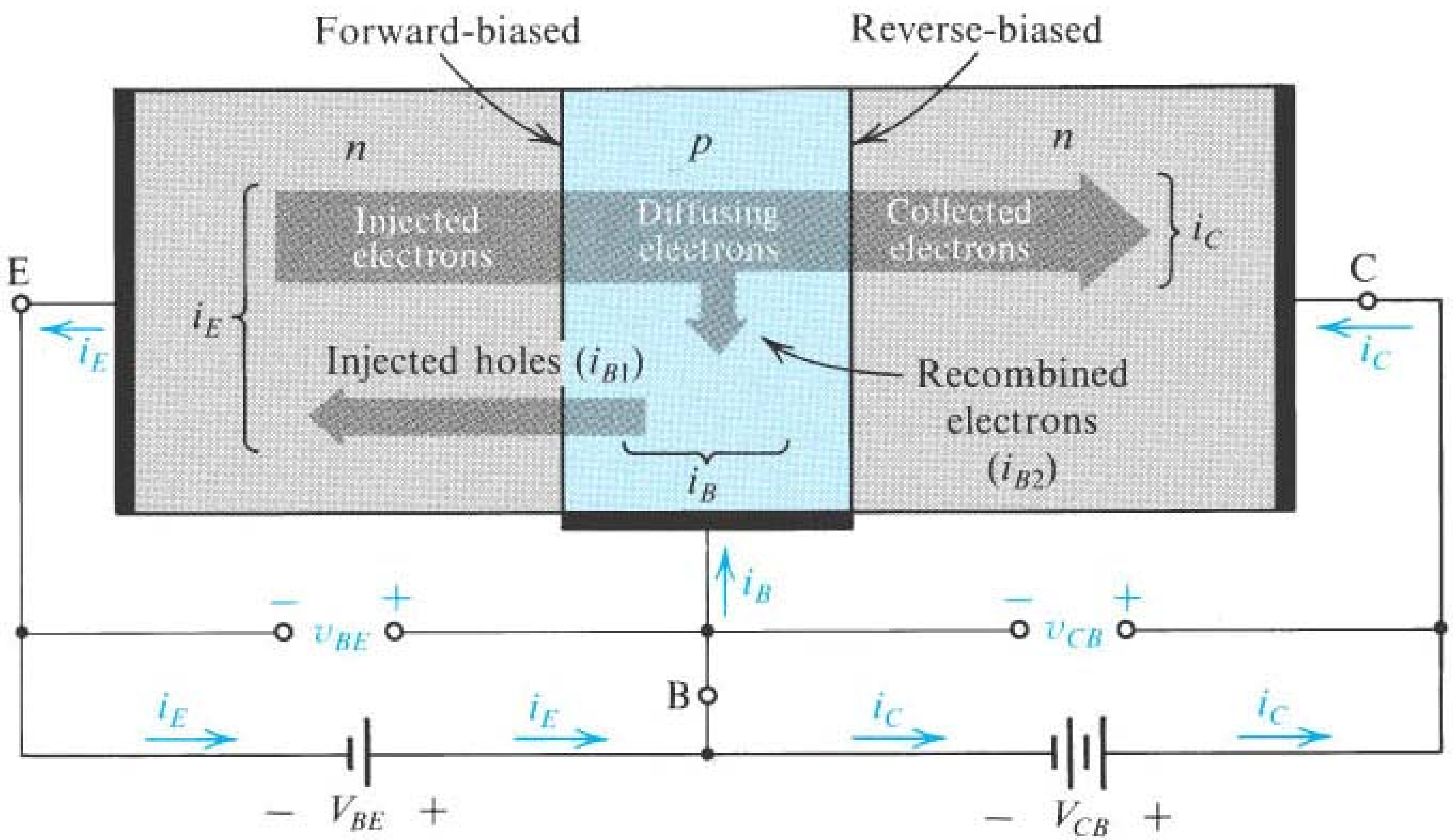


Figure 5.3 Current flow in an *npn* transistor biased to operate in the active mode. (Reverse current components due to drift of thermally generated minority carriers are not shown.)

$$n_{p(0)} = n_{p0} e^{V_{BE}/V_T} = 10^3 e^{0.7/0.025} \quad \text{highly}$$

$$n_{p(w)} = n_{p0} e^{V_{CB}/V_T} = 10^3 e^{-1/0.025} \cong 0$$

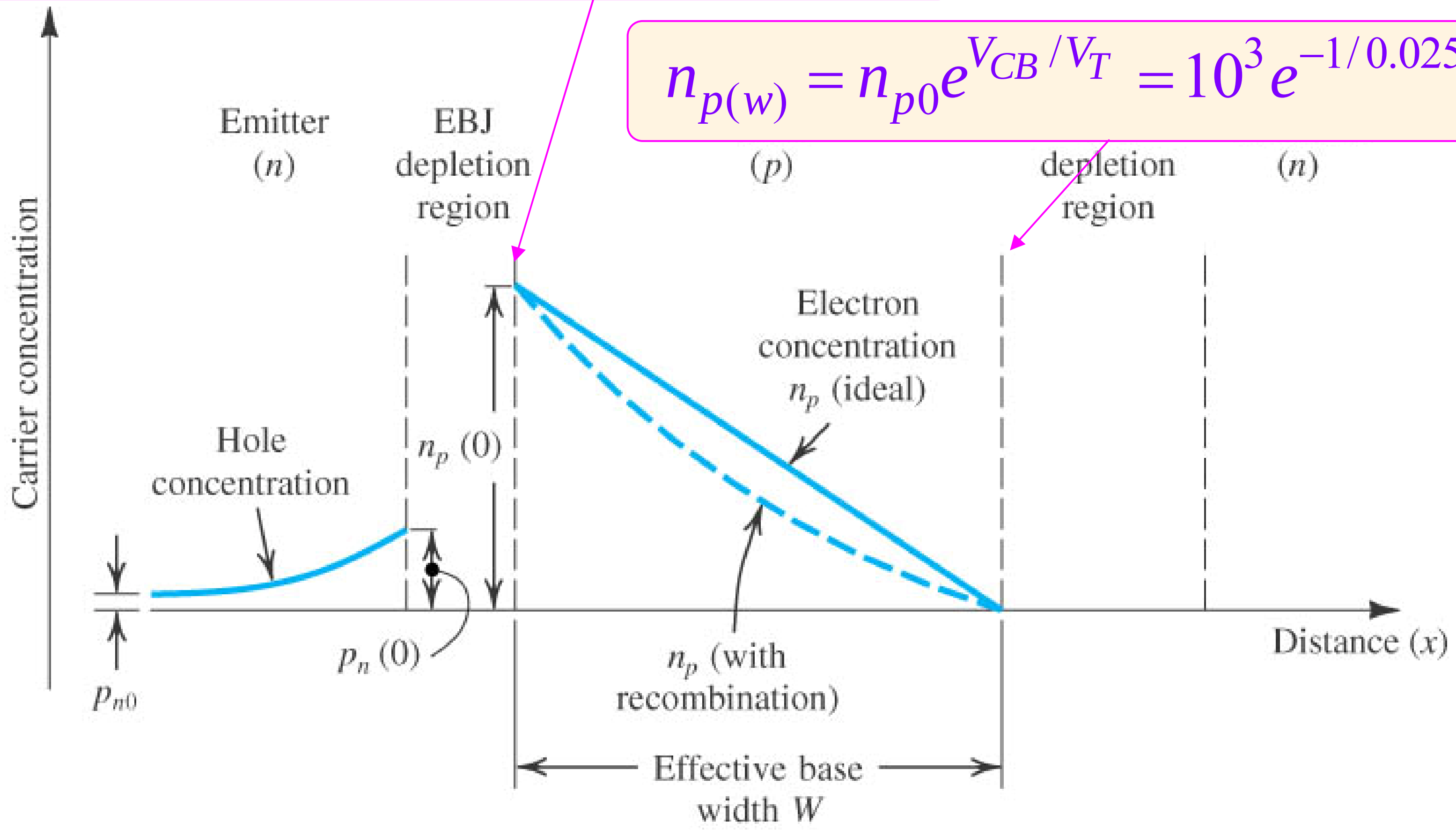


Figure 5.4 Profiles of minority-carrier concentrations in the base and in the emitter of an *npn* transistor operating in the active mode: $v_{BE} > 0$ and $v_{CB} \geq 0$.

According to the law of the junction (sec. p.61, eq.1.57)

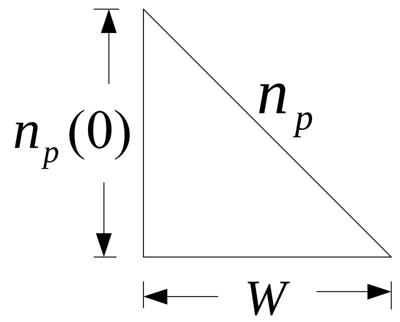
the concentration $n_p(0)$ will be propotional to e^{v_{BE}/V_T}

$$n_p(0) = n_{p0} e^{v_{BE}/V_T} \qquad (4.1)$$

where n_{p0} is the thermal- equilibrium value of the

minority-carrier (electron) concentration in the base region

V_T is the thermal-voltage ($V_T \approx$ 25mV)



This electron diffusion current I_n as follows :

$$I_n = A_E q D_n \frac{dn_p(x)}{dx} = A_E q D_n \left(-\frac{n_p(0)}{W} \right) \qquad (4.2)$$

where A_E is the cross-sectional area of B-E junction,

q is the magnitude of the base,

D_n is the electron diffusivity in the base,

W is the effective width of the base,

I_n flows from right to left(in the negtive direction of x)

The Collector Current

$$i_C = -I_n = A_E q D_n \frac{n_p(0)}{W} = A_E q D_n \frac{n_{p0} e^{v_{BE}/V_T}}{W} = I_s e^{v_{BE}/V_T}$$

where $I_s = A_E q D_n \dfrac{n_{p0}}{w}$, subtituting $n_{p0} = \dfrac{n_i^2}{N_A}$

$$\Rightarrow I_s = A_E q D_n \frac{n_i^2}{N_A W} \qquad (4.4)$$

❶ The I_s is inversely propotional to the base width W and is directly propotional to the area of the EBJ.

❷ Typically I_s is in the range of 10^{-12} A to 10^{-18} A (depending on the size of the device)

❸ The I_s is propotional to n_i^2, it is a strong function of temperature, approximately doubling for every $5^{\circ}C$ rise in temperature.

The Base Current

$$i_{B_1} = \frac{D_n \cdot A_E q D_p n_i^2 \cdot N_A W}{N_A W \cdot N_D L_p \cdot D_n} e^{v_{BE}/V_T} = \underbrace{\frac{D_n A_E q n_i^2}{N_A W}}_{I_s} \cdot \frac{D_p N_A W}{N_D L_p D_n} e^{v_{BE}/V_T} = I_s \frac{D_p N_A W}{N_D L_p D_n} e^{v_{BE}/V_T}$$

L_p is the hole diffusion length in the emitter

$i_{B_2} = \dfrac{Q_n}{\tau_b}$, $\quad \tau_b$ is minority-carrier lifetime,

Q_n is replenished by electron injection from the emitter

$$\Rightarrow Q_n = A_E q \cdot \frac{1}{2} n_p(0) W.$$

subtituting $n_p(0) = n_{p0} e^{v_{BE}/V_T}$ and $n_{p0} = \dfrac{n_i^2}{N_A}$, gives $Q_n = \dfrac{A_E q W n_i^2}{2N_A} e^{v_{BE}/V_T}$

$$\Rightarrow i_{B_2} = \frac{1}{2} \cdot \frac{A_E q W n_i^2}{N_A \tau_b} e^{v_{BE}/V_T} = \frac{1}{2} \cdot \frac{D_n A_E q W^2 n_i^2}{D_n N_A \tau_b W} e^{v_{BE}/V_T} = \frac{1}{2} \cdot \underbrace{\frac{D_n A_E q n_i^2}{N_A W}}_{I_s} \cdot \frac{W^2}{D_n \tau_b} e^{v_{BE}/V_T}$$

$$i_B = i_{B_1} + i_{B_2} = I_s\left(\frac{D_p}{D_n}\cdot\frac{N_A}{N_D}\cdot\frac{W}{L_p} + \frac{1}{2}\cdot\frac{W^2}{D_n\tau_b}\right)e^{v_{BE}/V_T}$$

$$i_B = \frac{i_C}{\beta} = \left(\frac{i_s}{\beta}\right)e^{v_{BE}/V_T} \qquad (4.6)$$

$$\text{where } \beta = \frac{1}{\left(\frac{D_p}{D_n}\cdot\frac{N_A}{N_D}\cdot\frac{W}{L_p} + \frac{1}{2}\cdot\frac{W^2}{D_n\tau_b}\right)}$$

The β is called the common- emitter current gain,

For moden npn transistor, β is in the range 50 to 200,

but it can be as high as1000 for special devices

The Emitter current

$$i_E = i_B + i_C$$

$$= \frac{1+\beta}{\beta} i_C = \frac{1+\beta}{\beta} i_s e^{v_{BE}/V_T} \qquad (4.9)$$

$$\because \alpha = \frac{\beta}{1+\beta}, \quad \beta = \frac{\alpha}{1-\alpha}$$

$$\therefore i_E = \frac{i_s}{\alpha} e^{v_{BE}/V_T} \qquad (4.12)$$

The α is common-base current gain, that is less than but very close to unity.

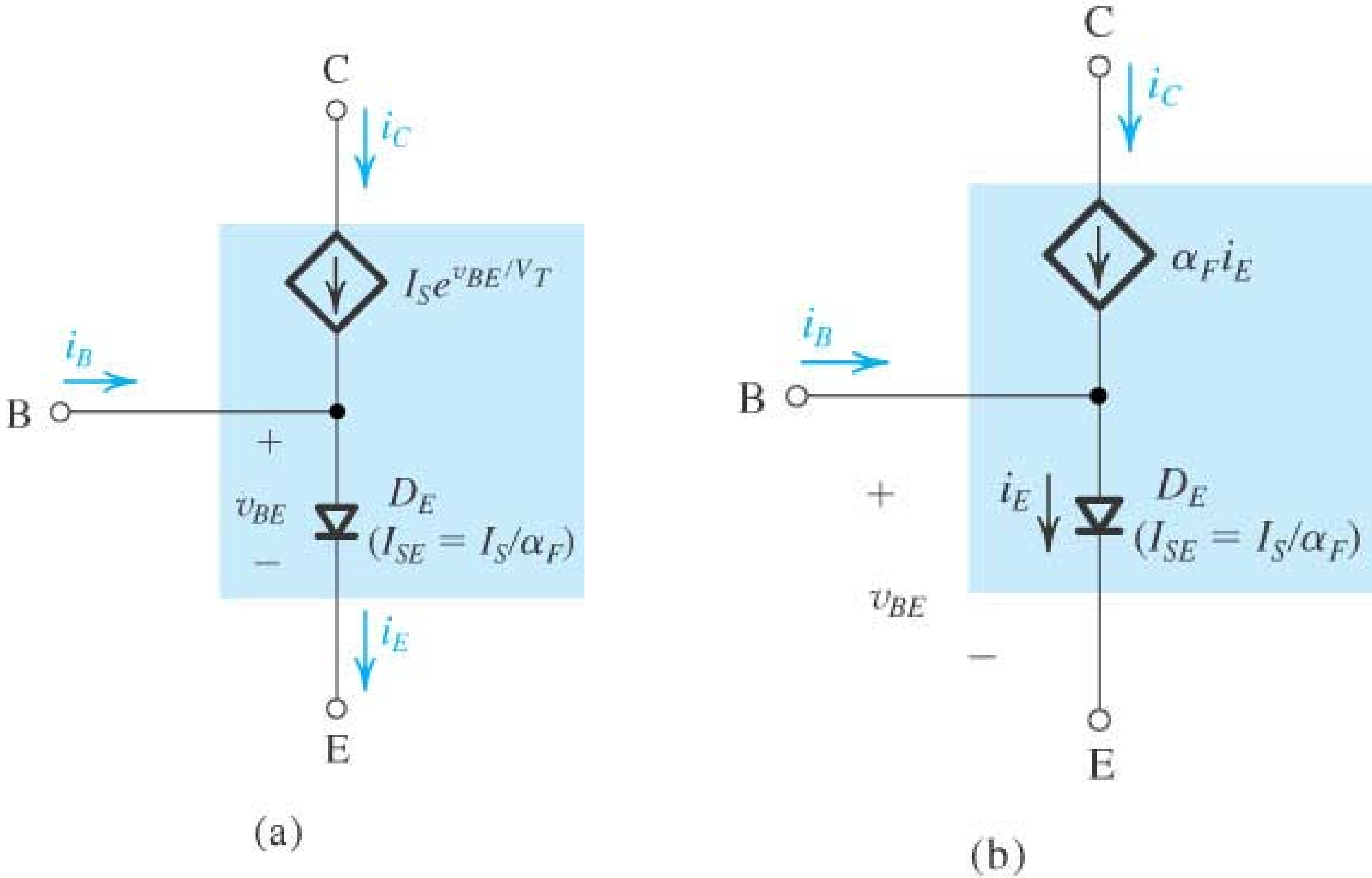


Figure 5.5 Large-signal equivalent-circuit models of the *npn* BJT operating in the forward active mode.

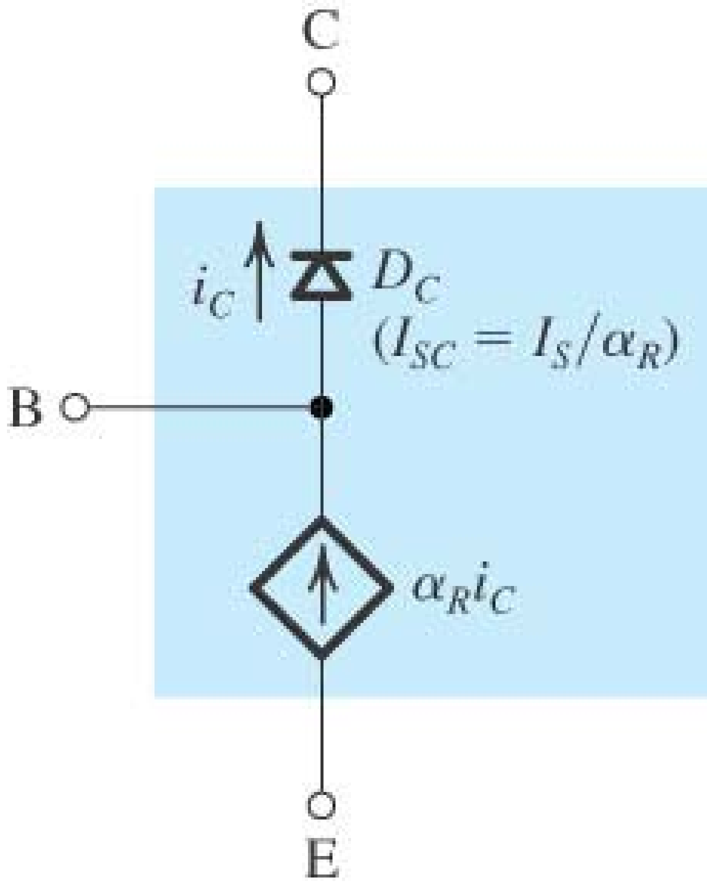
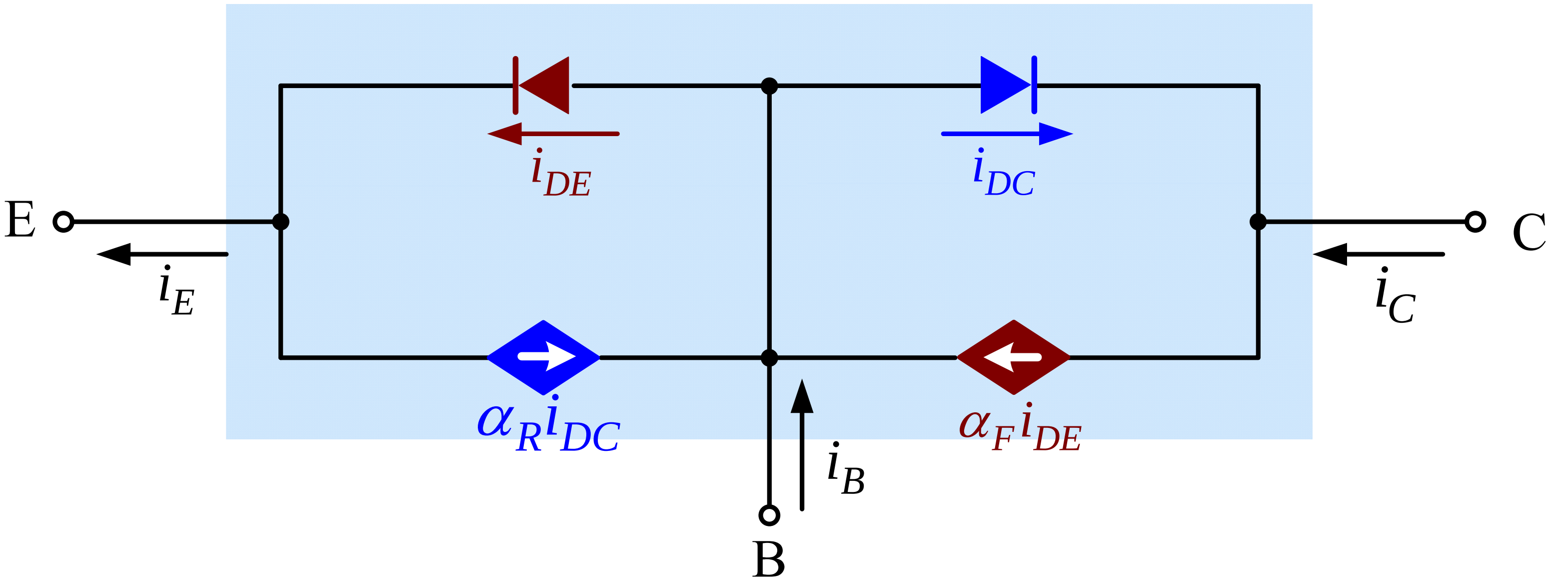


Figure 5.7 Model for the *npn* transistor when operated in the reverse active mode (i.e., with the CBJ forward biased and the EBJ reverse biased).

Ebers-Moll (EM) Model



$$i_E = i_{DE} - \alpha_R i_{DC}$$

$$i_C = -i_{DC} + \alpha_F i_{DE}$$

$$i_B = i_E - i_C$$

Figure The Ebers-Moll (EM) model of the *npn* transistor.

The diode D_C represents the collector-base junction, the scale current is I_{SC}

The diode D_E represents the emitter-base junction, the scale current is I_{SE}

$$I_{SC} >> I_{SE}$$

α_R is in the range of 0.01 to 0.5

β_R is in the range of 0.01 to 0.1

$$\alpha_F I_{SE} = \alpha_R I_{SC} = I_S$$

$$i_{DE} = I_{SE}\left(e^{v_{BE}/V_T} - 1\right) = \frac{I_S}{\alpha_F}\left(e^{v_{BE}/V_T} - 1\right) \qquad \text{(a)}$$

$$i_{DC} = I_{SC}\left(e^{v_{BE}/V_T} - 1\right) = \frac{I_S}{\alpha_R}\left(e^{v_{BE}/V_T} - 1\right) \qquad \text{(b)}$$

The transistor terminal current equtions:

$$i_E = i_{DE} - \alpha_R i_{DC} \qquad \text{(c)}$$

$$i_C = -i_{DC} + \alpha_F i_{DE} \qquad \text{(d)}$$

$$i_B = i_E - i_C = (1 - \alpha_F)i_{DE} + (1 - \alpha_R)i_{DC} \qquad \text{(e)}$$

Subtituting (a) and (b) into (c),(d)and(e), we have

$$i_E = \frac{I_S}{\alpha_F}\left(e^{v_{BE}/V_T} - 1\right) - I_S\left(e^{v_{BC}/V_T} - 1\right)$$

$$i_C = I_S\left(e^{v_{BE}/V_T} - 1\right) - \frac{I_S}{\alpha_R}\left(e^{v_{BC}/V_T} - 1\right)$$

$$i_B = \frac{I_S}{\beta_F}\left(e^{v_{BE}/V_T} - 1\right) + \frac{I_S}{\beta_R}\left(e^{v_{BC}/V_T} - 1\right)$$

$$\text{where } \beta_F = \frac{\alpha_F}{1-\alpha_F}, \quad \beta_R = \frac{\alpha_R}{1-\alpha_R}$$

Application of the EM model

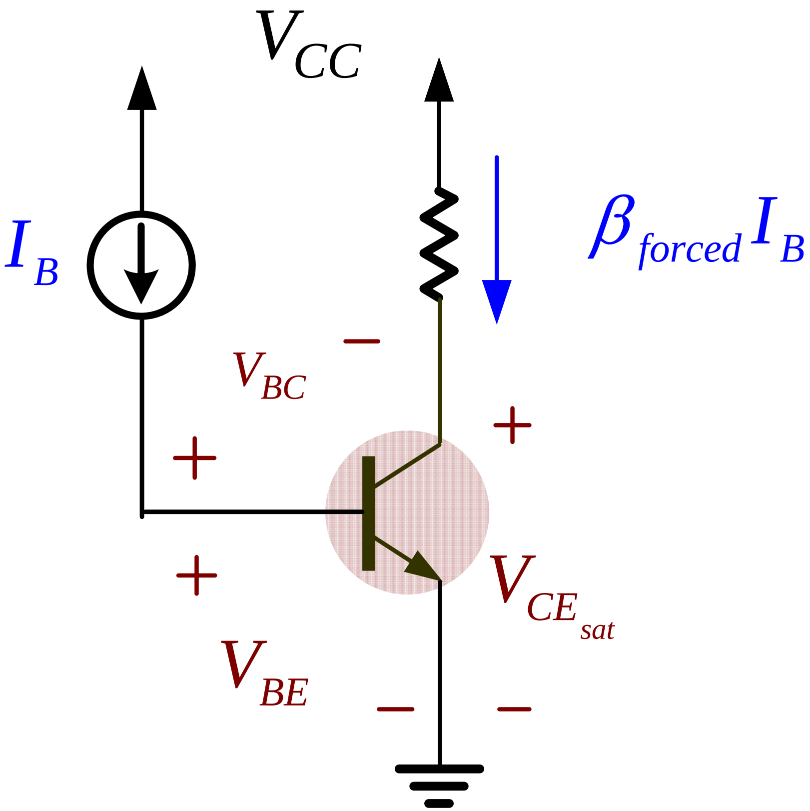
(A) Opoerating in the forard avtive mode

$$i_E = \frac{I_S}{\alpha_F}\left(e^{v_{BE}/V_T} - 1\right) - I_S\left(\underbrace{e^{v_{BC}/V_T}}_{0} - 1\right) \cong \frac{I_S}{\alpha_F}e^{v_{BE}/V_T} + I_S\left(1 - \frac{1}{\alpha_F}\right)$$

$$i_C = I_S\left(e^{v_{BE}/V_T} - 1\right) - \frac{I_S}{\alpha_R}\left(\underbrace{e^{v_{BC}/V_T}}_{0} - 1\right) \cong I_S e^{v_{BE}/V_T} + I_S\left(\frac{1}{\alpha_R} - 1\right)$$

$$i_B = \frac{I_S}{\beta_F}\left(e^{v_{BE}/V_T} - 1\right) - \frac{I_S}{\beta_R}\left(\underbrace{e^{v_{BC}/V_T}}_{0} - 1\right) \cong \frac{I_S}{\beta_F}e^{v_{BE}/V_T} - I_S\left(\frac{1}{\beta_F} - \frac{1}{\beta_R}\right)$$

4.1.4 Operation in the Saturation Mode



$$e^{v_{BE}/V_T} >> 1$$

$$e^{v_{BC}/V_T} >> 1$$

$$i_C = \beta_{\text{forced}} I_B$$

$$\alpha_R = \frac{\beta_R}{1+\beta_R}$$

The EM expression for i_C

$$i_C = \underbrace{I_S\left(e^{v_{BE}/V_T}-1\right)}_{\approx I_S e^{v_{BE}/V_T}} - \frac{1}{\alpha_R}\underbrace{I_S\left(e^{v_{BC}/V_T}-1\right)}_{\approx I_S e^{v_{BC}/V_T}}$$

$$i_C = \underbrace{I_S e^{v_{BE}/V_T}}_{X} - \frac{1+\beta_R}{\beta_R}\underbrace{I_S e^{v_{BC}/V_T}}_{Y}$$

$$\beta_{\text{forced}} i_B = X - \frac{1+\beta_R}{\beta_R}Y \Rightarrow i_B = \frac{X}{\beta_{\text{forced}}} - \frac{1+\beta_R}{\beta_R\beta_{\text{forced}}}Y \qquad \text{(a)}$$

The EM expression for $i_B \Rightarrow$ $i_B = \dfrac{X}{\beta_F} - \dfrac{Y}{\beta_R}$ (b)

$$(a)=(b)$$

$$\Rightarrow \frac{X}{\beta_{\text{forced}}}-\frac{1+\beta_R}{\beta_R\beta_{\text{forced}}}Y=\frac{X}{\beta_F}-\frac{Y}{\beta_R}$$

$$\frac{\beta_F-\beta_{forced}}{\beta_F\,\cancel{\beta_{forced}}}X=\frac{1+\beta_R+\beta_{forced}}{\beta_R\,\cancel{\beta_{forced}}}Y$$

$$\frac{X}{Y}=\frac{\dfrac{1+\beta_R+\beta_{forced}}{\beta_R}}{\dfrac{\beta_F-\beta_{forced}}{\beta_F}}=\frac{(1+\beta_R+\beta_{forced})\beta_F}{(\beta_F-\beta_{forced})\beta_R}$$

$$\because \frac{X}{Y}=\frac{I_S e^{v_{BE}/V_T}}{I_S e^{v_{BC}/V_T}}=e^{(v_{BE}-v_{BC})/V_T}=e^{v_{CE}/V_T}$$

$$\Rightarrow v_{CE(sat)} = V_T \ln \frac{\left(1+\beta_R+\beta_{forced}\right)\cancel{\beta_F}}{\left(\beta_F-\beta_{forced}\right)\cancel{\beta_R}} \cdot \frac{\dfrac{1}{\cancel{\beta_F}\,\beta_R}}{\dfrac{1}{\beta_F\,\cancel{\beta_R}}}$$

$$v_{CE(sat)} = V_T \ln \frac{1+\left[(1+\beta_{forced})/\beta_R\right]}{1-(\beta_{forced}/\beta_F)}$$

The $V_{CE}(sat)$ for the case $\beta_F = 50,$ and $\beta_R = 0.1$

β_{forced}	50	48	45	40	30	20	10	0
$v_{CE(sat)}$	∞	235	211	191	166	147	123	60

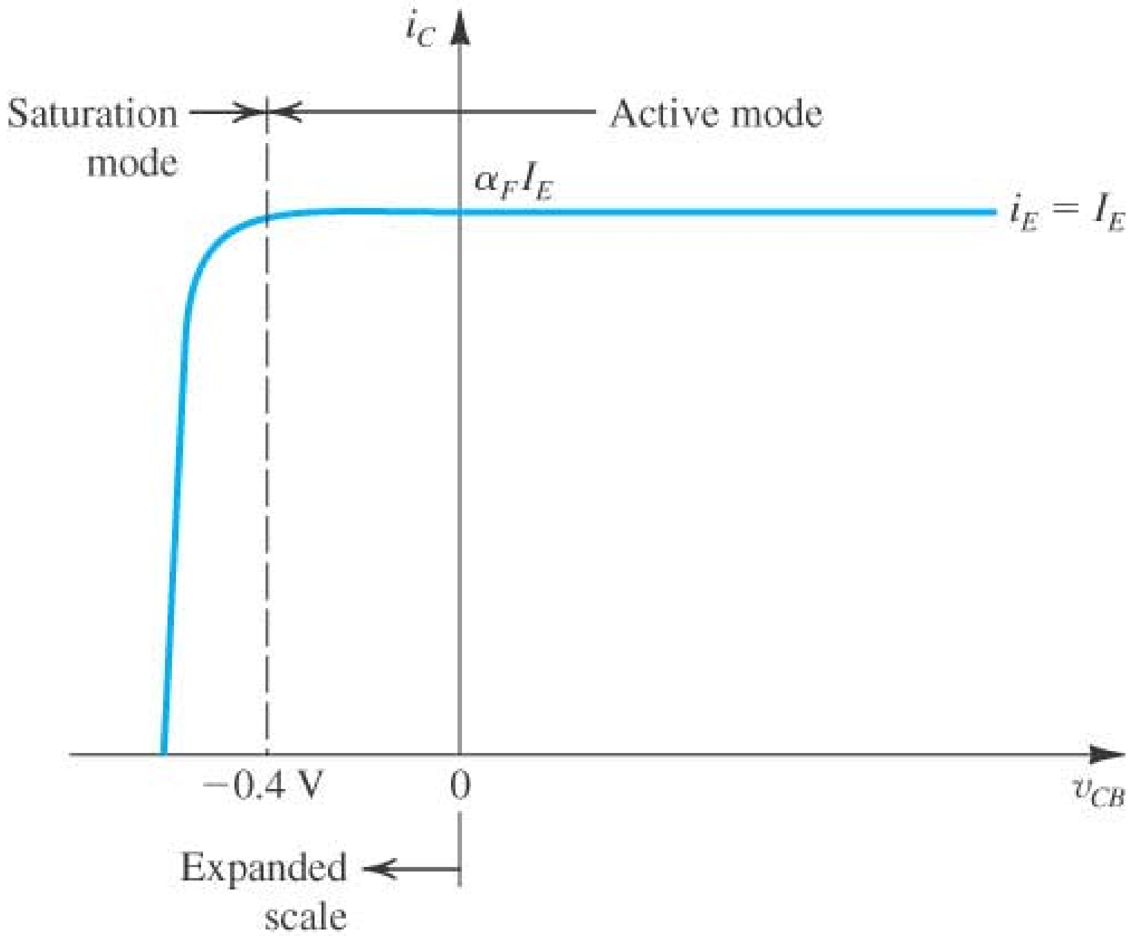


Figure 4.8 The i_C–v_{CB} characteristic of an *npn* transistor fed with a constant emitter current I_E. The transistor enters the saturation mode of operation for $v_{CB} < -0.4$ V, and the collector current diminishes.

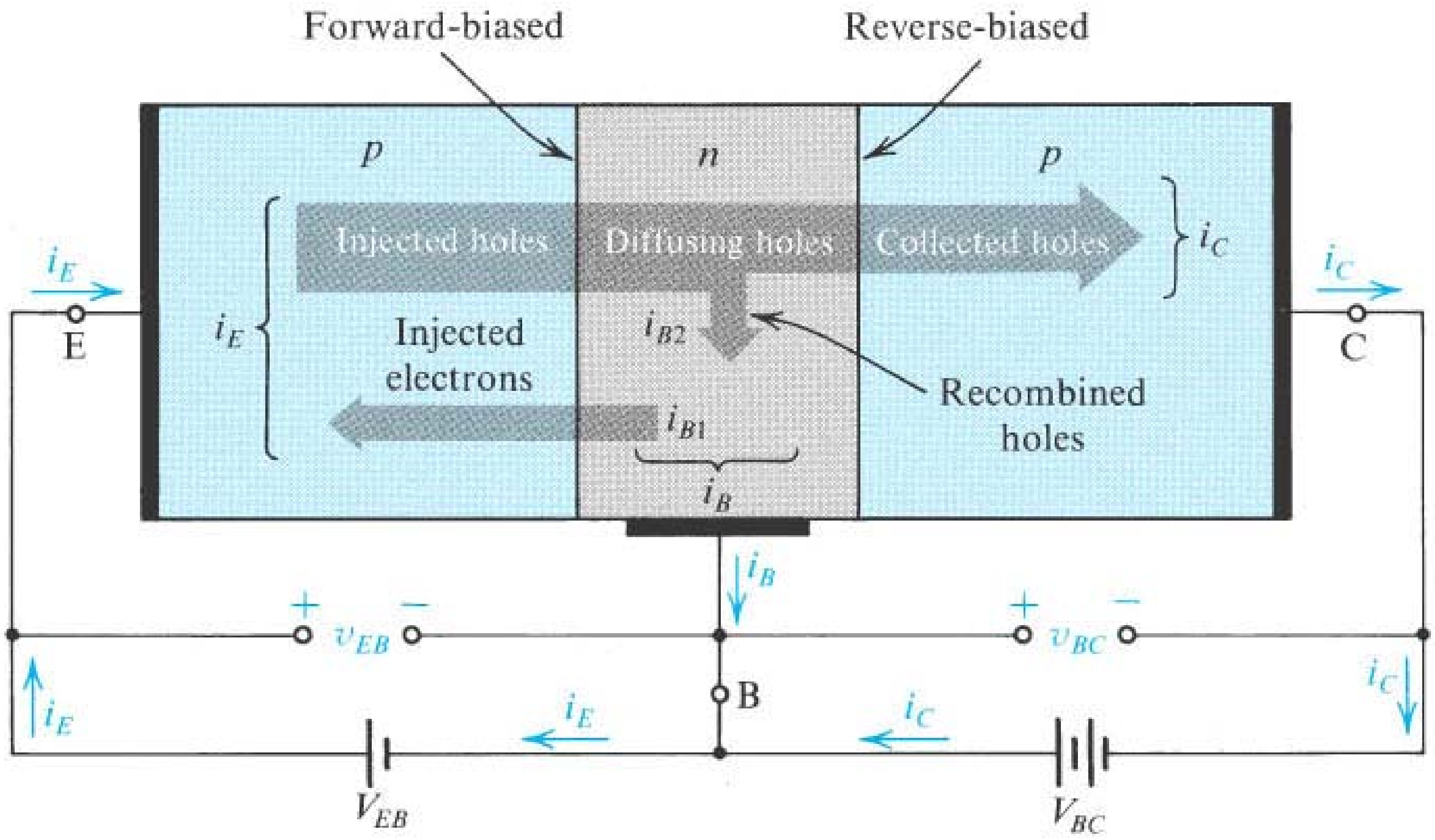


Figure 4.10 Current flow in a *pnp* transistor biased to operate in the active mode.

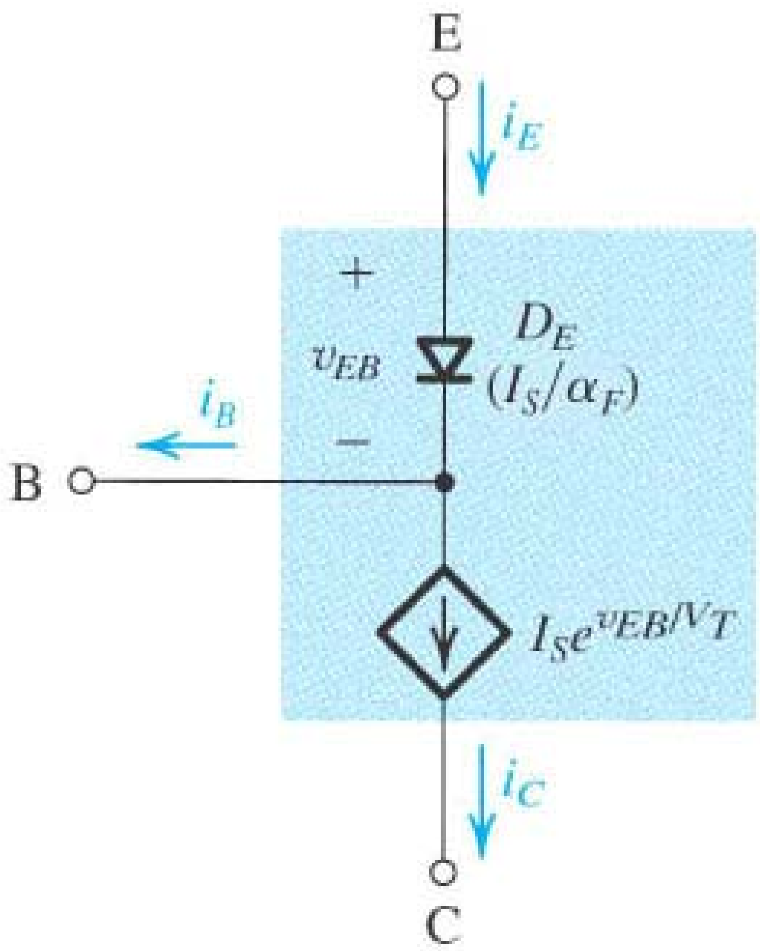


Figure 4.11 Large-signal model for the *pnp* transistor operating in the active mode.

4.2 Current－Voltage Characteristics

4.2.1 Circuit symbols and Conventions

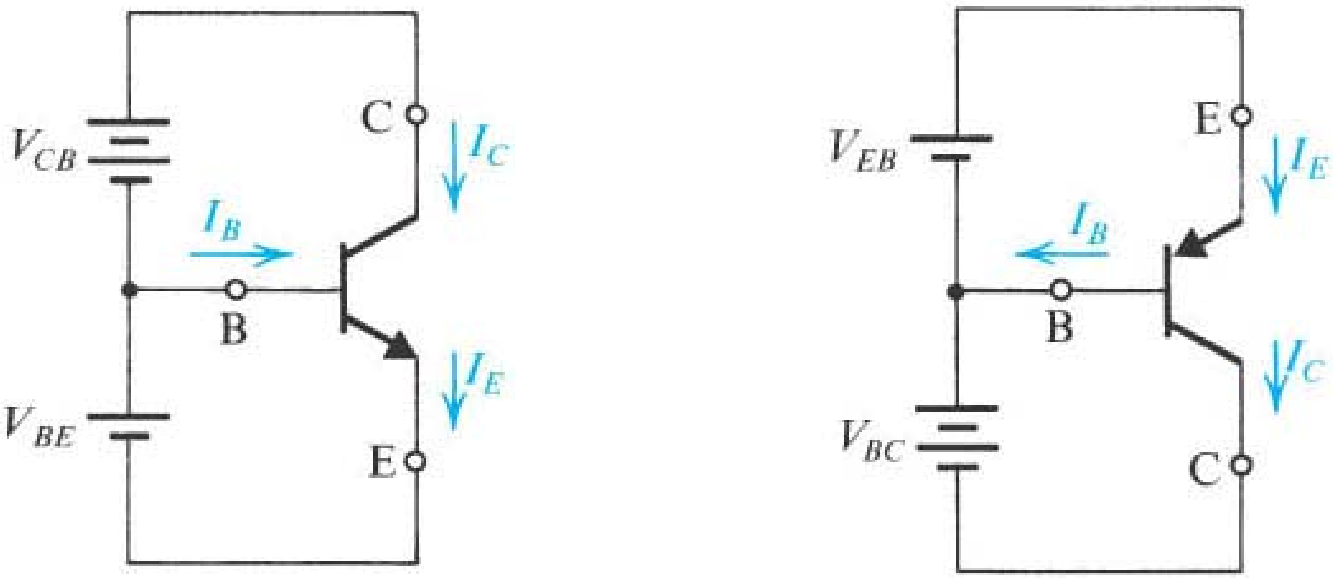


Figure 4.13 Voltage polarities and current flow in transistors biased in the active mode.

The constant n

The constant n , its value is between 1 and 2.

For modern BJT the constant n is close to unity except in special cases:

❶At high currents, the i_C - v_{BE} relationship exhibits a value for n that is close to 2 .

❷At low currents, the i_B - v_{BE} relationship shows a value for n approximately 2 .

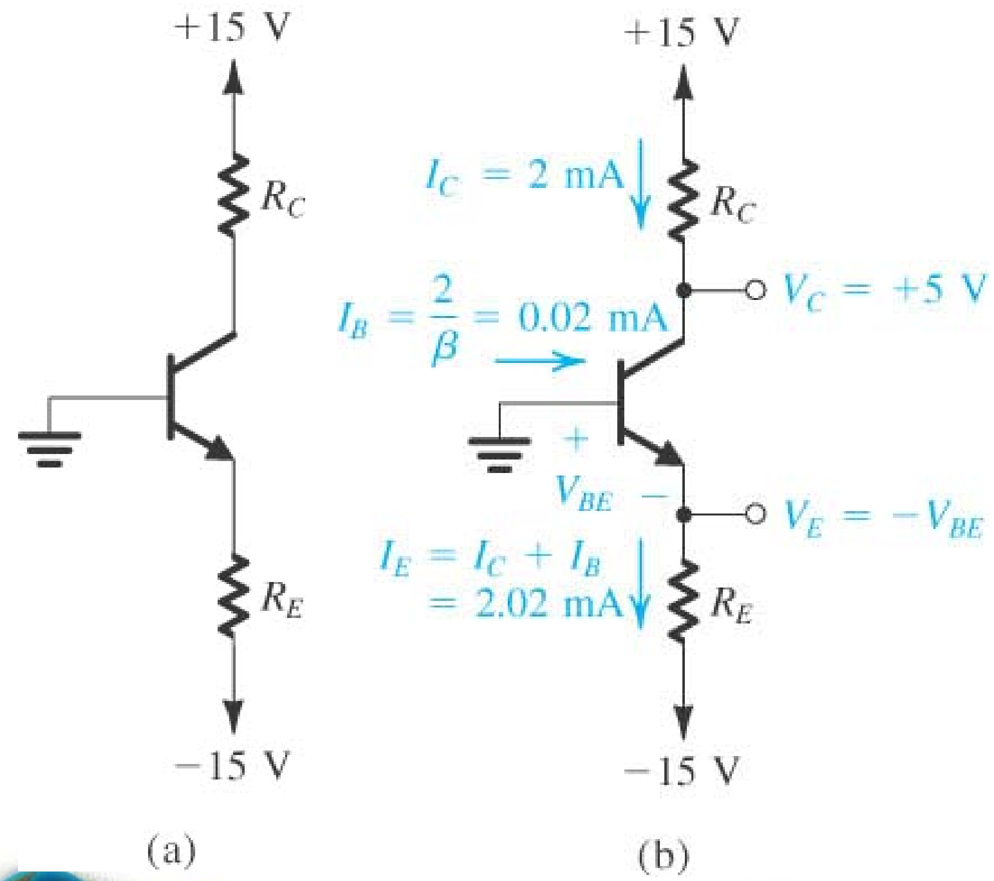
The Collector-Base Reverse Current (I_{CBO})

❶ The current I_{CBO} is the reverse current flowing from collector to base with the emitter open-circuited.

❷ The current I_{CBO} depends strongly on temperature, approximately doubling for 10^0C rise.

$$I_{CBO2} = I_{CBO1} \cdot 2^{(T_2 - T_1)/10}$$

Example 4.2 The transistor in the circuit of Fig (a) has $\beta = 100$ and exhibits v_{BE} of 0.7V at $i_C = 1\text{mA}$. Design the circuit so that a current of 2mA flows through the collector and a voltage of +5V appear at the collector.



Sol :

$$R_C = \frac{10\text{V}}{2\text{mA}} = 5\text{k}\Omega$$

$$V_{BE} = 0.7 + V_T \ln\left(\frac{I_2}{I_1}\right) = 0.717\text{V}$$

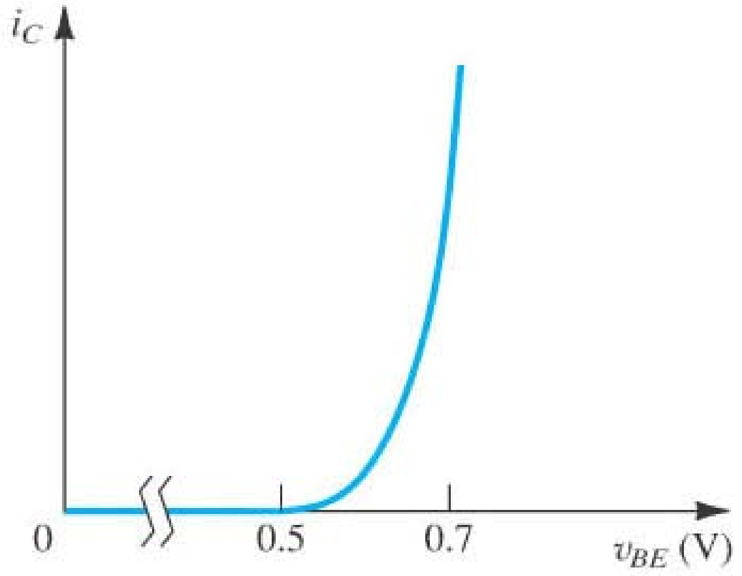
$$V_E = -0.717\text{V}$$

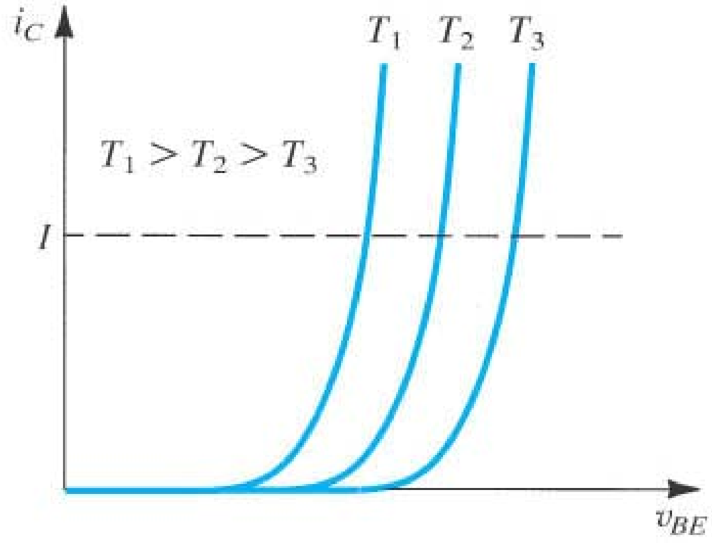
$$\beta = 100 \Rightarrow \alpha = 0.99$$

$$I_E = I_C / \alpha = 2\text{mA} / 0.99 = 2.02\text{mA}$$

$$R_E = \frac{V_E - (-15V)}{I_E} = 7.07\text{k}\Omega$$

4.4.2 Graphical Representation of Transistor Characteristic



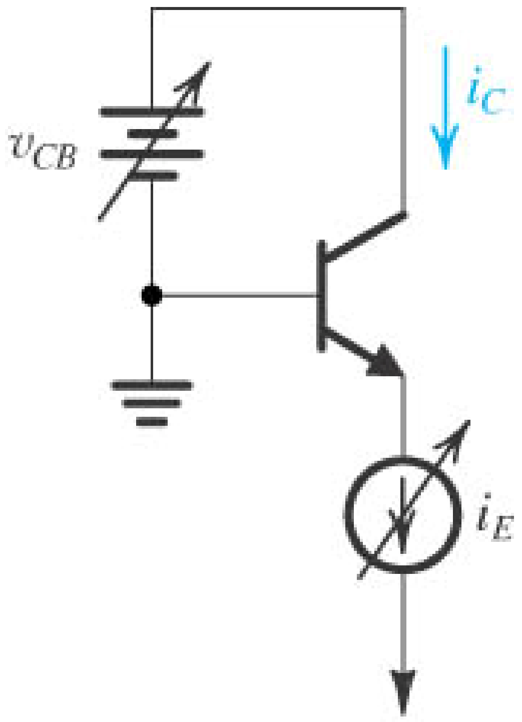


$$i_C = I_S e^{v_{BE}/V_T}$$

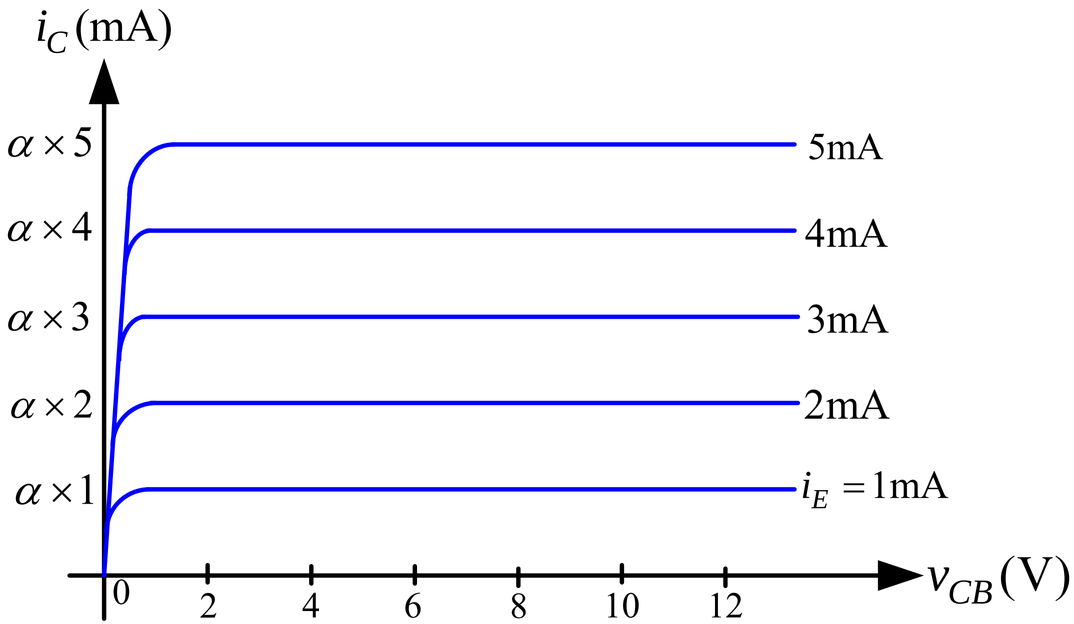
$$V_T \propto T \therefore T \uparrow V_T \uparrow i_C \downarrow$$

Figure (a) The i_C–v_{BE} characteristic for an *npn* transistor.
(b) Effect of temperature on the i_C–v_{BE} characteristic. At a constant emitter current (broken line), v_{BE} changes by –2 mV/°C.

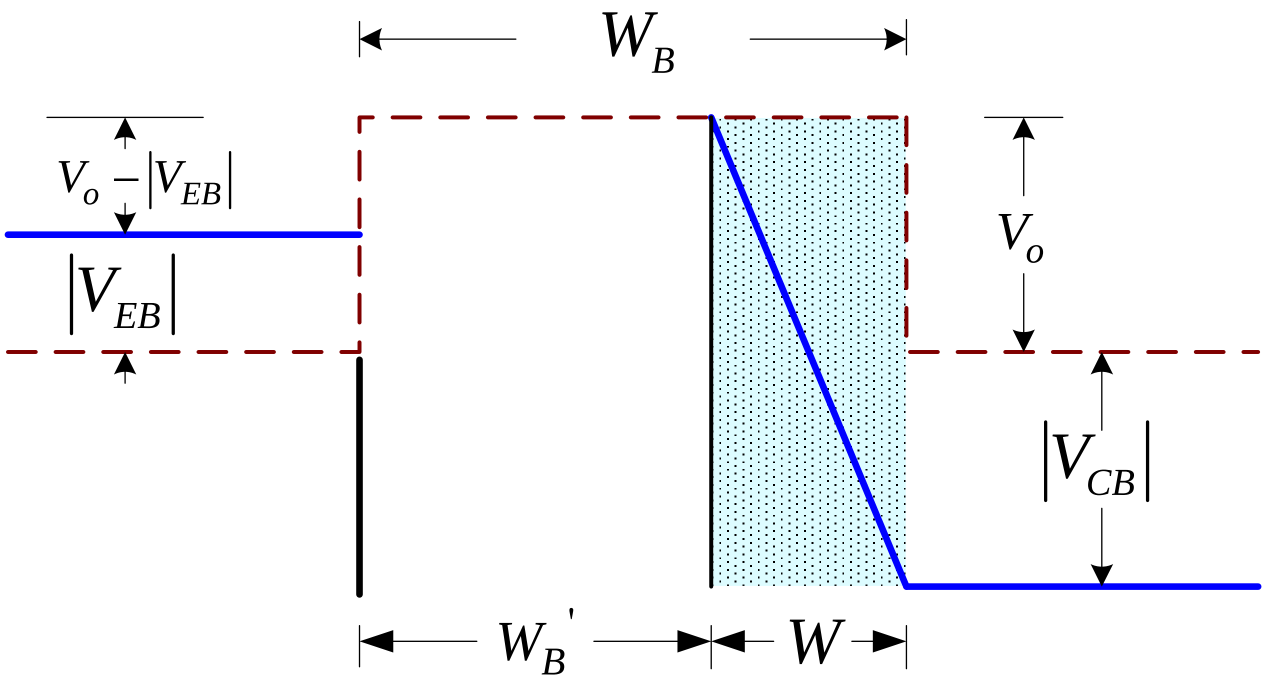
4.2.3 Dependence of i_c on the Collector Voltage–The Early effect



(a)



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

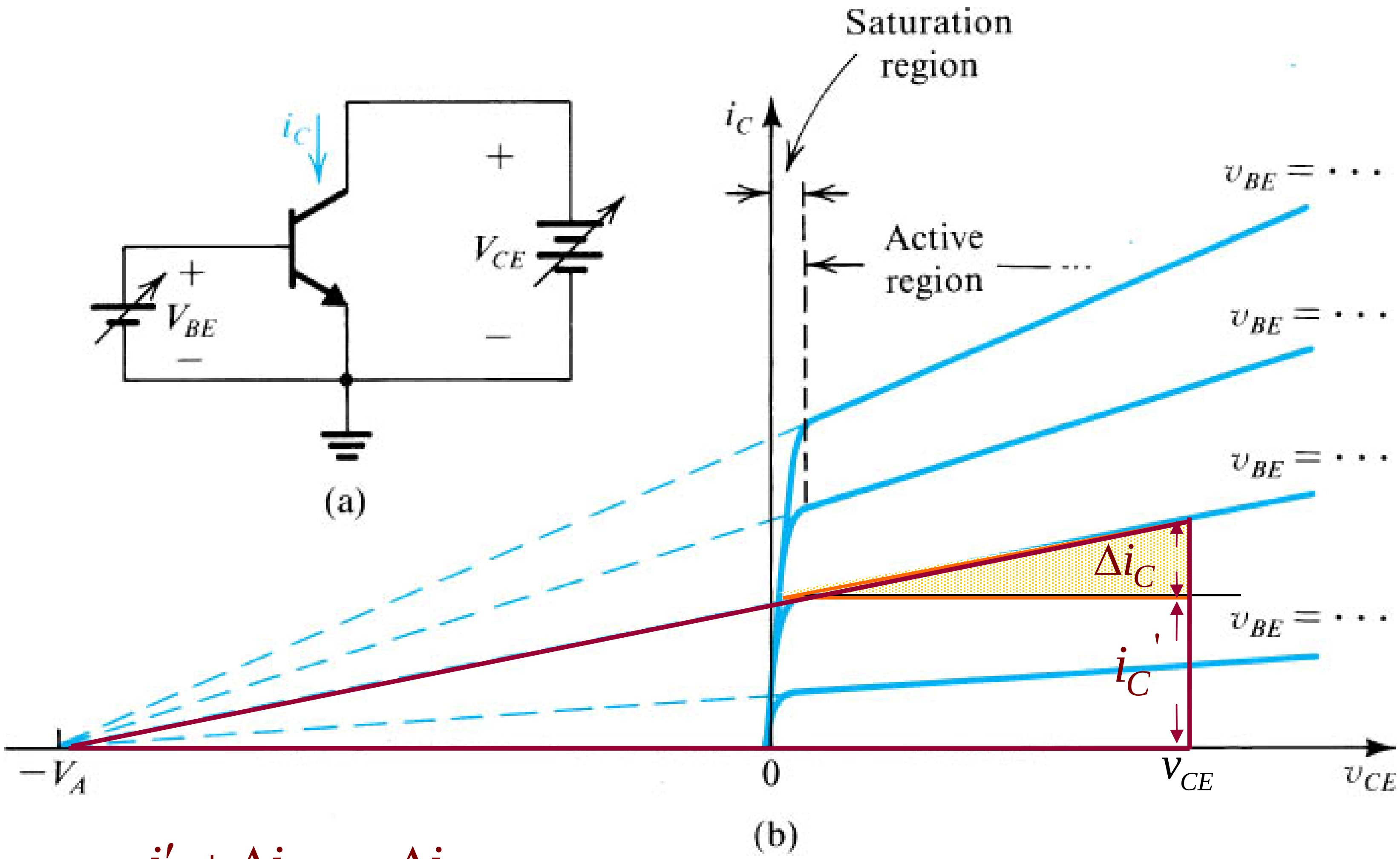


Early effect has three consequences:

(1) α increases with increasing $|V_{CB}|$

(2) I_C increases with increasing reverse collector voltage.

(3) punch through



$$\frac{i_C' + \Delta i_C}{V_A + v_{CE}} = \frac{\Delta i_C}{v_{CE}}$$

$$i_C' v_{CE} + \cancel{\Delta i_C v_{CE}} = \Delta i_C V_A + \cancel{\Delta i_C v_{CE}} \Rightarrow \Delta i_C = \frac{v_{CE}}{V_A} i_C'$$

The collector current (operation in the active mode)

neglected the Early effect: $i_C{}' = I_S e^{v_{BE}/V_T}$

including the Early effect: $i_C = i_C{}' + \Delta i_C = i_C{}' + i_C{}' \dfrac{v_{CE}}{V_A}$

$$= I_S e^{v_{BE}/V_T} \left(1 + \frac{v_{CE}}{V_A} \right)$$

The nonzero slopeof the $i_C - v_{CE}$ straight line indicates that the output resistance looking into the collector is not infinite. Rather, it is finite and defined by

$$r_o \equiv \left[\frac{\partial i_C}{\partial v_{CE}} \bigg|_{v_{BE} = constant} \right]^{-1} = \frac{V_A + V_{CE}}{I_C} = \frac{V_A}{I_C{}'}$$

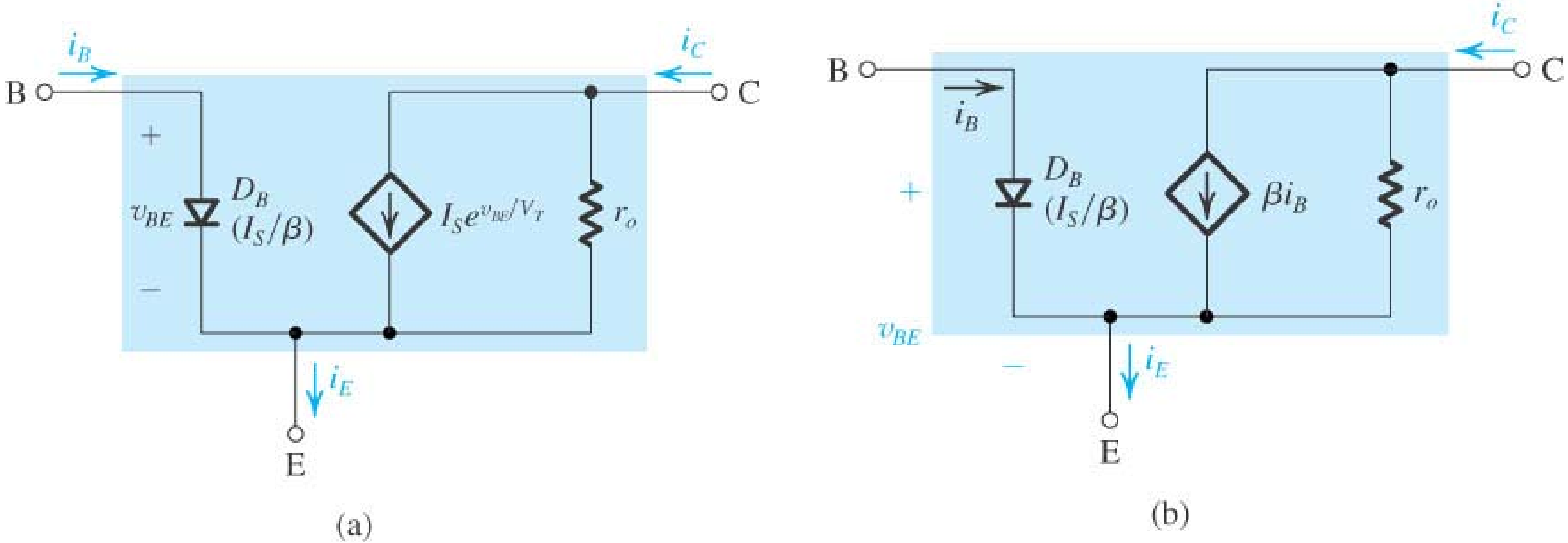
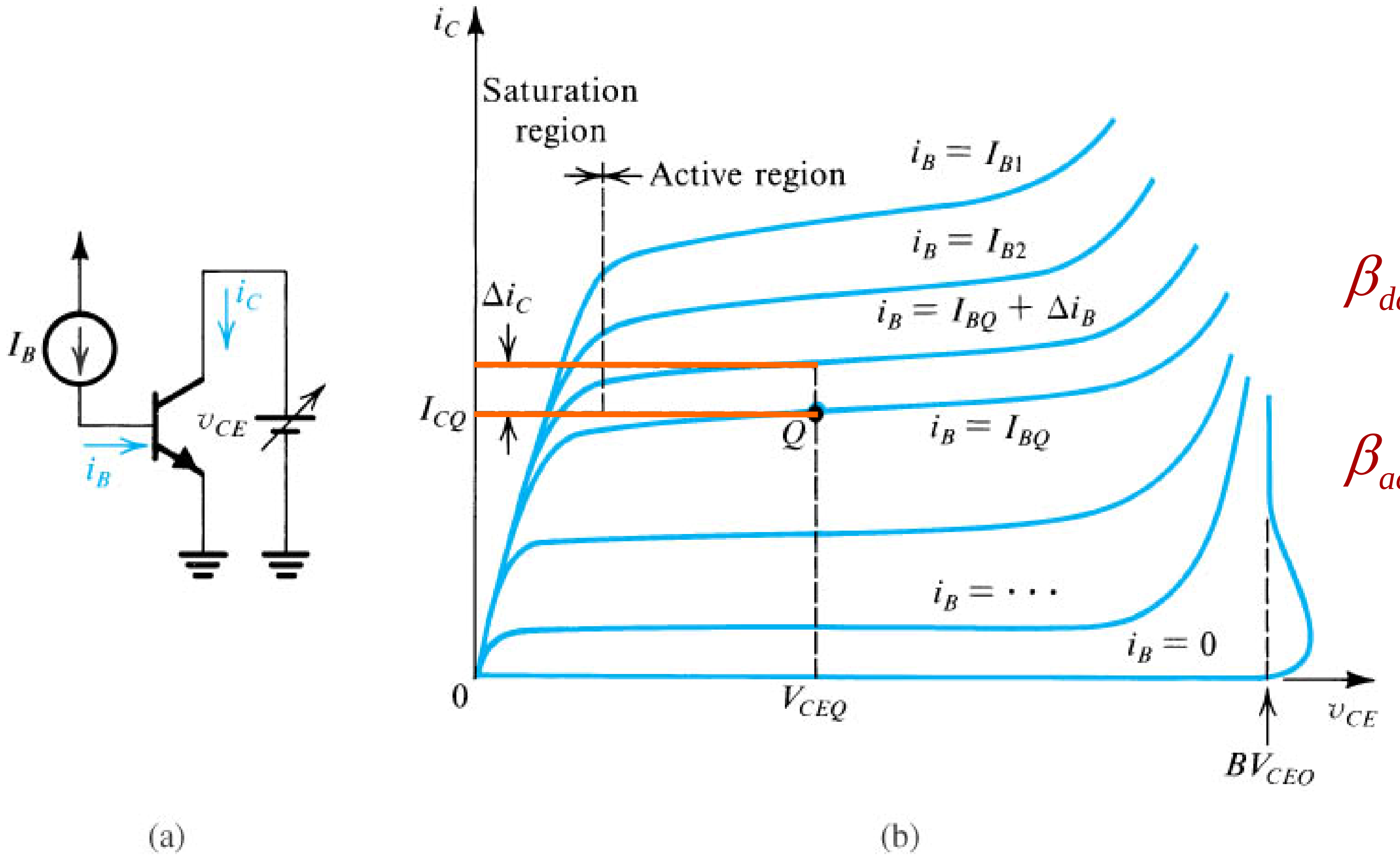


Figure 4.18 Large-signal equivalent-circuit models of an *npn* BJT operating in the active mode in the common-emitter configuration.

4.2.4 An Alternative Form of The Common-Emitter Characteristics

Common-emitter Current Gain

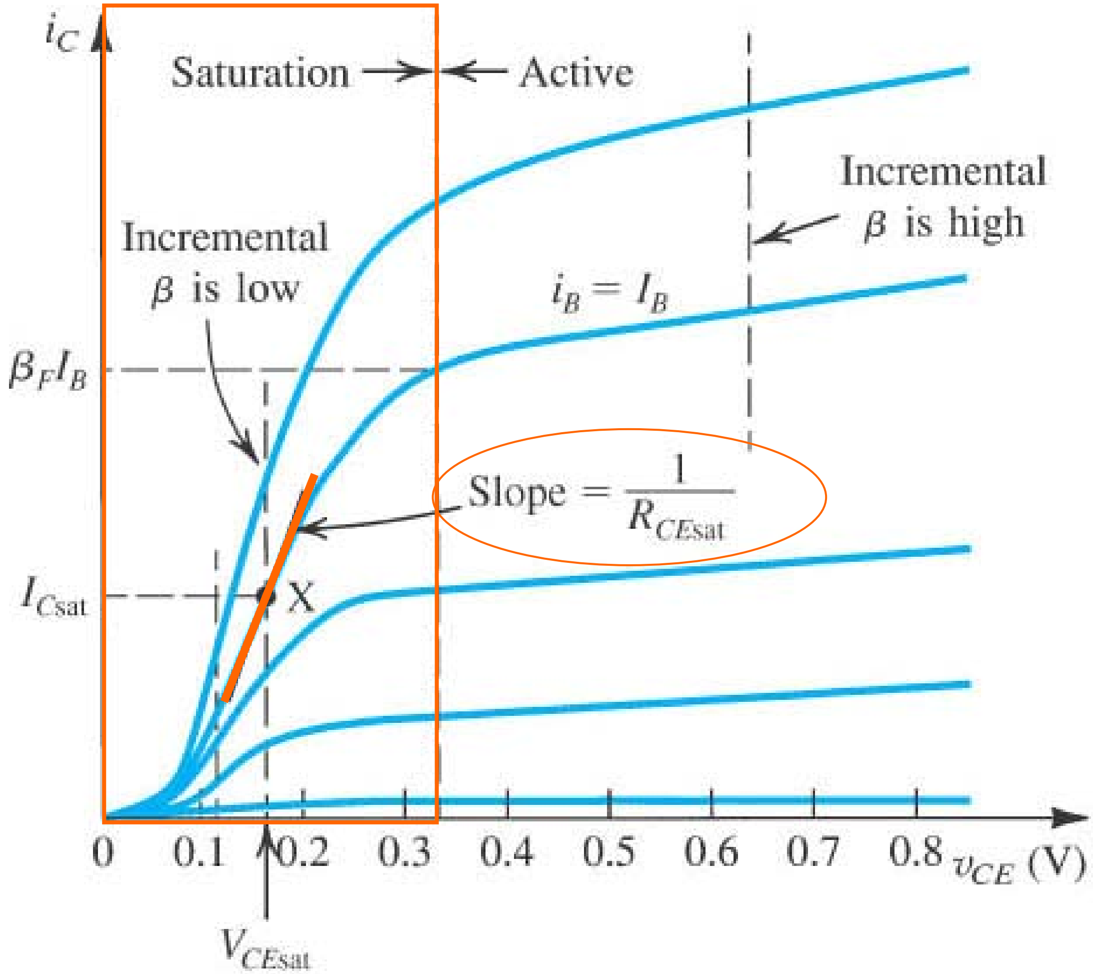


$$\beta_{dc} \equiv \frac{I_{CQ}}{I_{BQ}} \quad (h_{FE}),$$

$$\beta_{ac} \equiv \frac{\Delta i_C}{\Delta i_B} \quad (h_{fe})$$

Figure 4.19(a)(b) Common-emitter characteristics. Note that the horizontal scale is expanded around the origin to show the saturation region in some detail.

The saturation voltage V_{CEsat} *and* saturation resistance R_{CEsat}



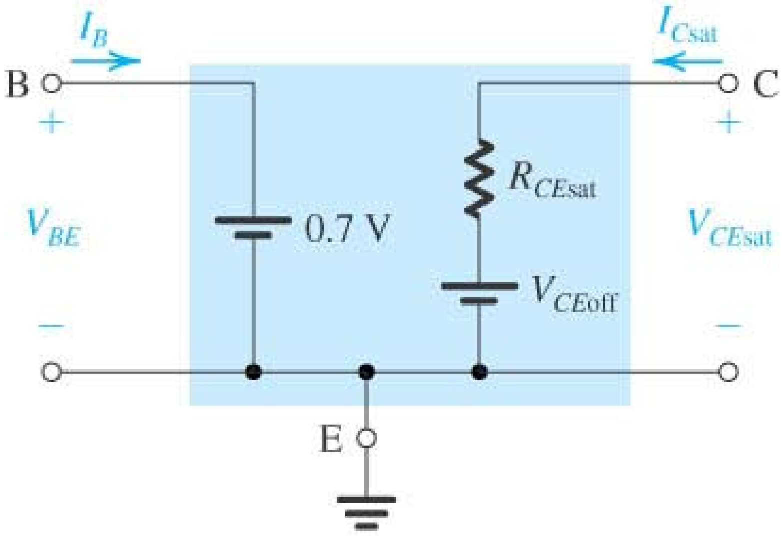
$$I_{C_{sat}} < \beta_F I_B$$

$$\beta_{forced} \equiv \frac{I_{C_{sat}}}{I_B}$$

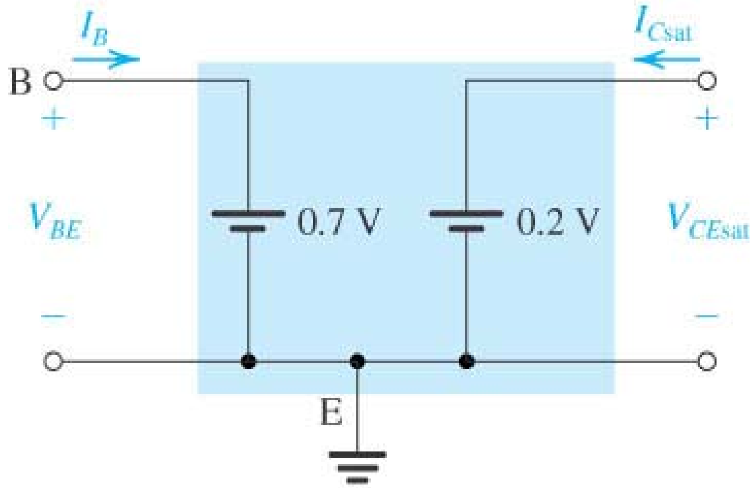
$$\beta_{forced} < \beta_F$$

$$R_{CE_{sat}} \equiv \left. \frac{\partial V_{CE}}{\partial i_C} \right|_{\substack{i_B = I_B \\ i_C = I_{Csat}}}$$

Figure 4.19(c) An expanded view of the common-emitter characteristics in the saturation region.



(c)



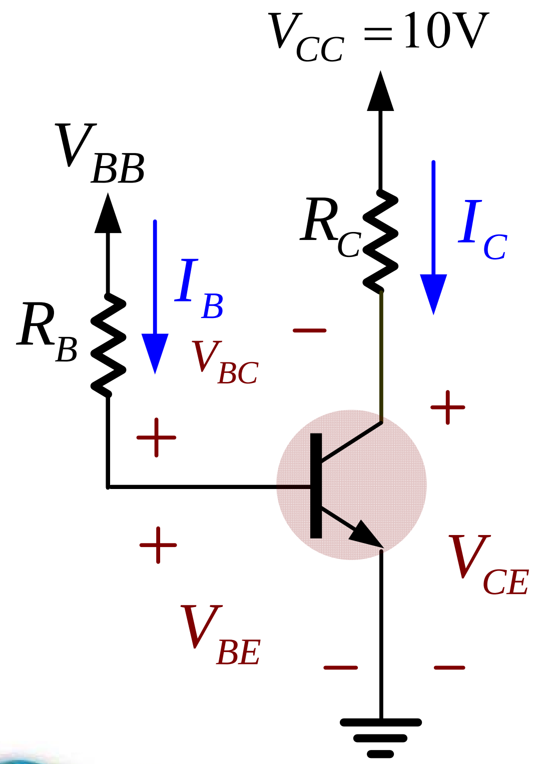
(d)

$$V_{CE\,sat} = V_{CEoff} + I_{Csat} R_{CEsat}$$

Typically, $V_{CE\,sat} \Rightarrow 0.1\ V$ to $0.3V$

Example 4.3 For the circuit in Fig.4.21 has $R_B = 10\text{k}\Omega$ and $R_C = 1\text{k}\Omega$, it is required to determine the value of the voltage V_{BB} that results the transistor operating (a) in the active mode with $V_{CE} = 5\text{V}$, (b) at the edge of saturation, (c) deep in saturation with $\beta_{\text{forced}} = 10$

For simplicity, assume that $V_{BE} = 0.7\text{V}$. The transistor $\beta =$ 50



Solution:

$$I_C = \frac{V_{CC} - V_{CE}}{R_C} = \frac{(10-5)\text{V}}{1\text{k}\Omega} = 5\text{mA}$$

$$I_B = I_C / \beta = 5\text{mA}/50 = 0.1\text{mA}$$

$$V_{BB} = I_B R_B + V_{BE}$$

$$= 0.1 \times 10 + 0.7 = 1.7\text{V}$$

$$(b)\ I_C = \frac{V_{CC} - V_{CE_{sat}}}{R_C} = \frac{(10-0.3)\,\mathrm{V}}{1\mathrm{k}\Omega} = 9.7\mathrm{mA}$$

$$I_B = I_C / \beta = 9.7\mathrm{mA} / 50 = 0.194\mathrm{mA}$$

$$V_{BB} = I_B R_B + V_{BE} = 0.194 \times 10 + 0.7 = 2.64\mathrm{V}$$

$$(c)\ V_{CE} = V_{CE_{sat}} \approx 0.2\mathrm{V}$$

$$I_C = \frac{V_{CC} - V_{CE_{sat}}}{R_C} = \frac{(10-0.2)\,\mathrm{V}}{1\mathrm{k}\Omega} = 9.8\mathrm{mA}$$

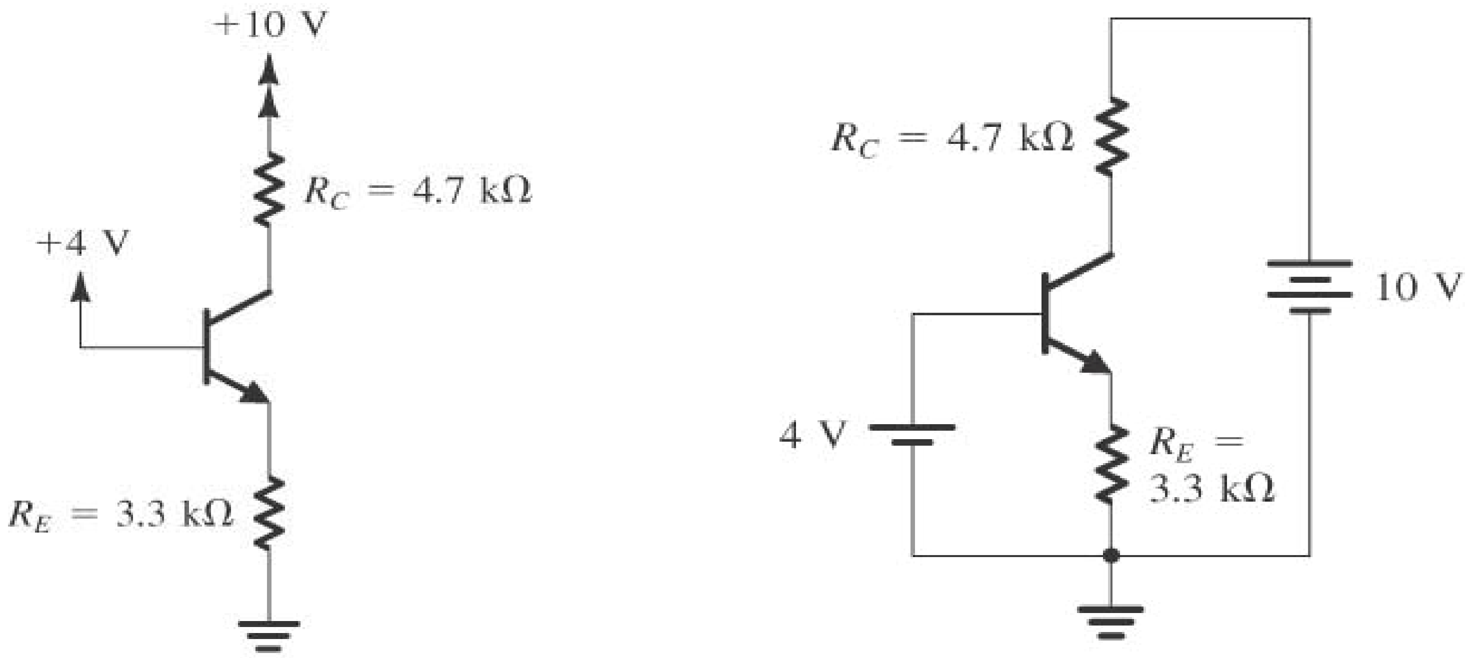
$$I_B = \frac{I_C}{\beta_{forced}} = \frac{9.8\mathrm{mA}}{10} = 0.98\mathrm{mA}$$

the requred V_{BB} can now be found as

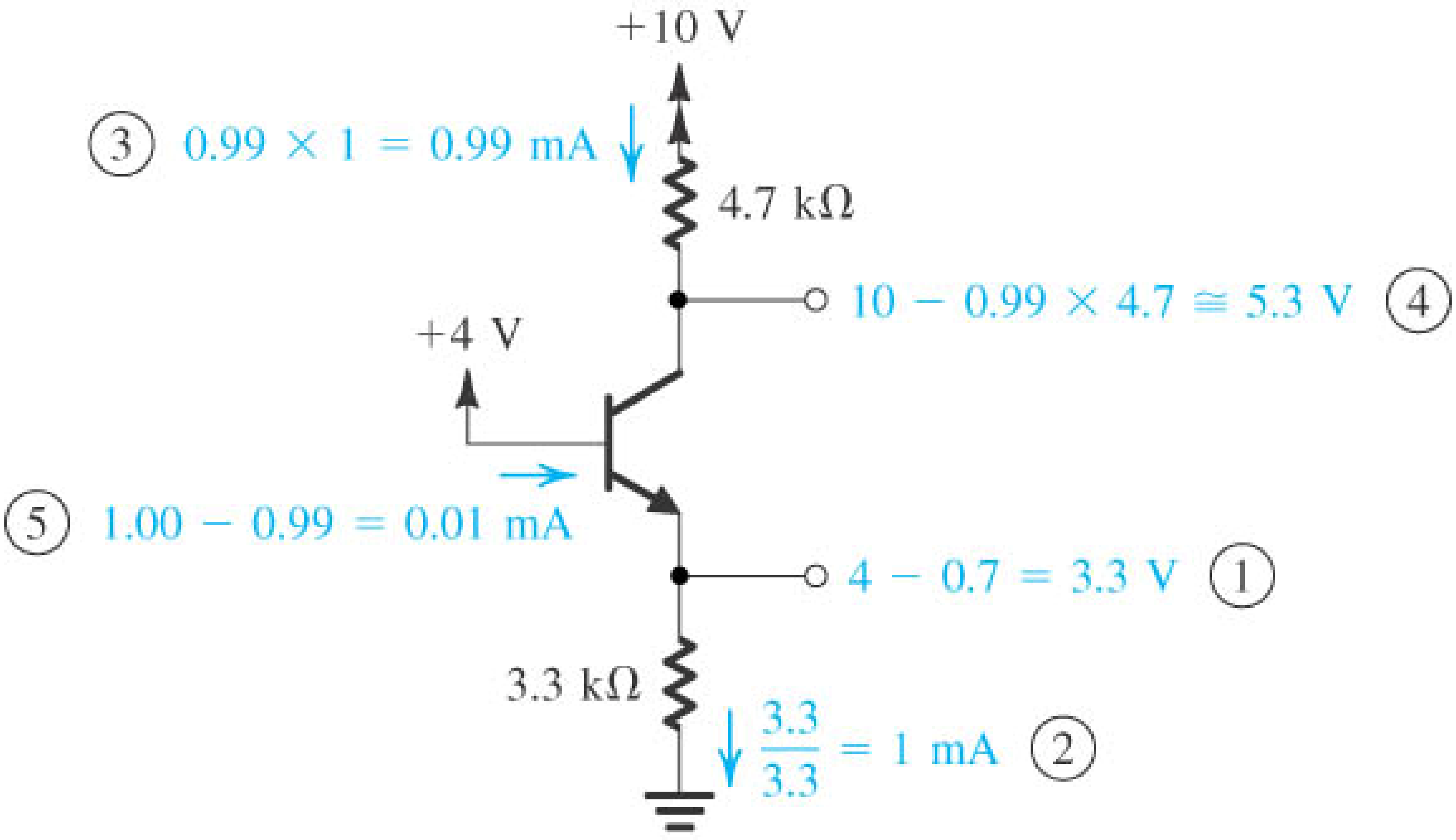
$$V_{BB} = I_B R_B + V_{BE} = 0.98 \times 10 + 0.7 = 10.5\mathrm{V}$$

4.3 BJT circuits at DC

Example 4.4 Consider the circuit shown in below Fig. We wish to analyze this circuit to determine all node voltages and branch currents. We will assume that β is specified to be 100

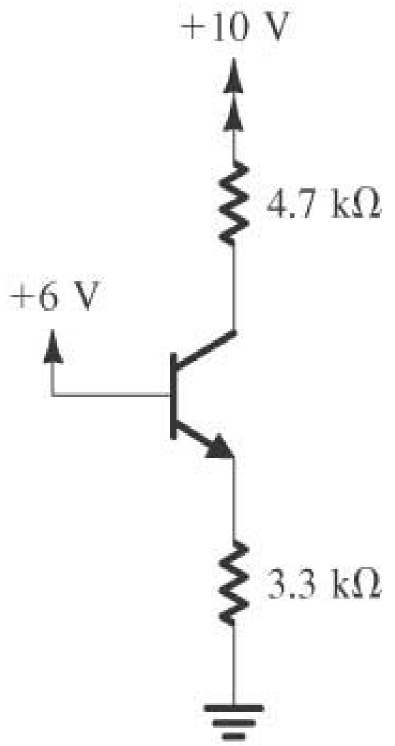


(a) (b)

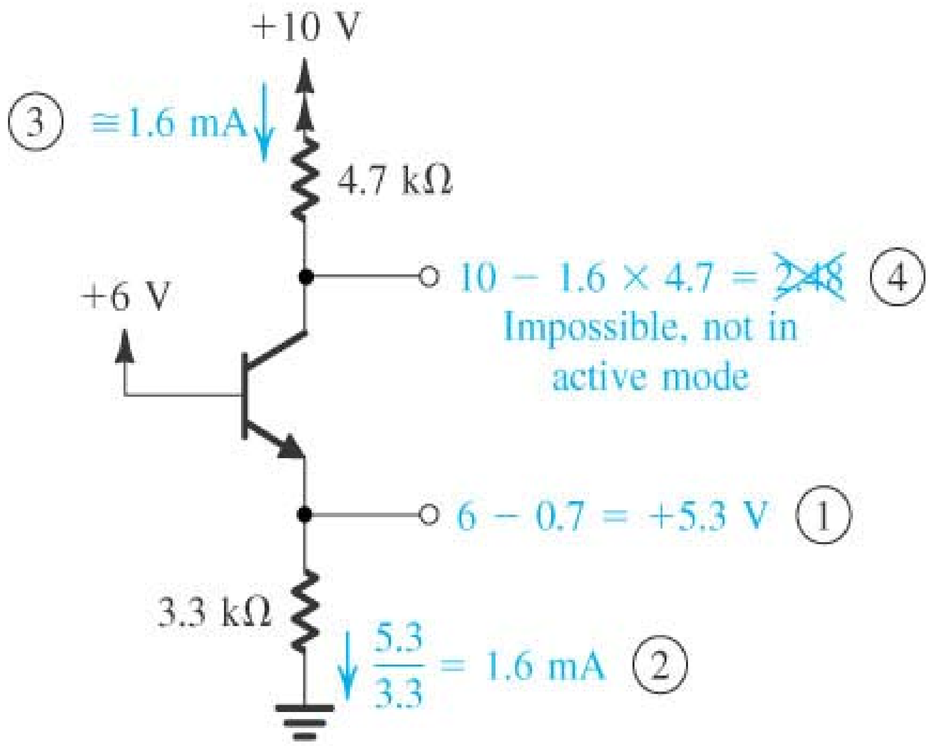

+10 V
③ 0.99 × 1 = 0.99 mA
4.7 kΩ
10 − 0.99 × 4.7 ≅ 5.3 V ④
+4 V
⑤ 1.00 − 0.99 = 0.01 mA
4 − 0.7 = 3.3 V ①
3.3 kΩ
3.3/3.3 = 1 mA ②

(c)

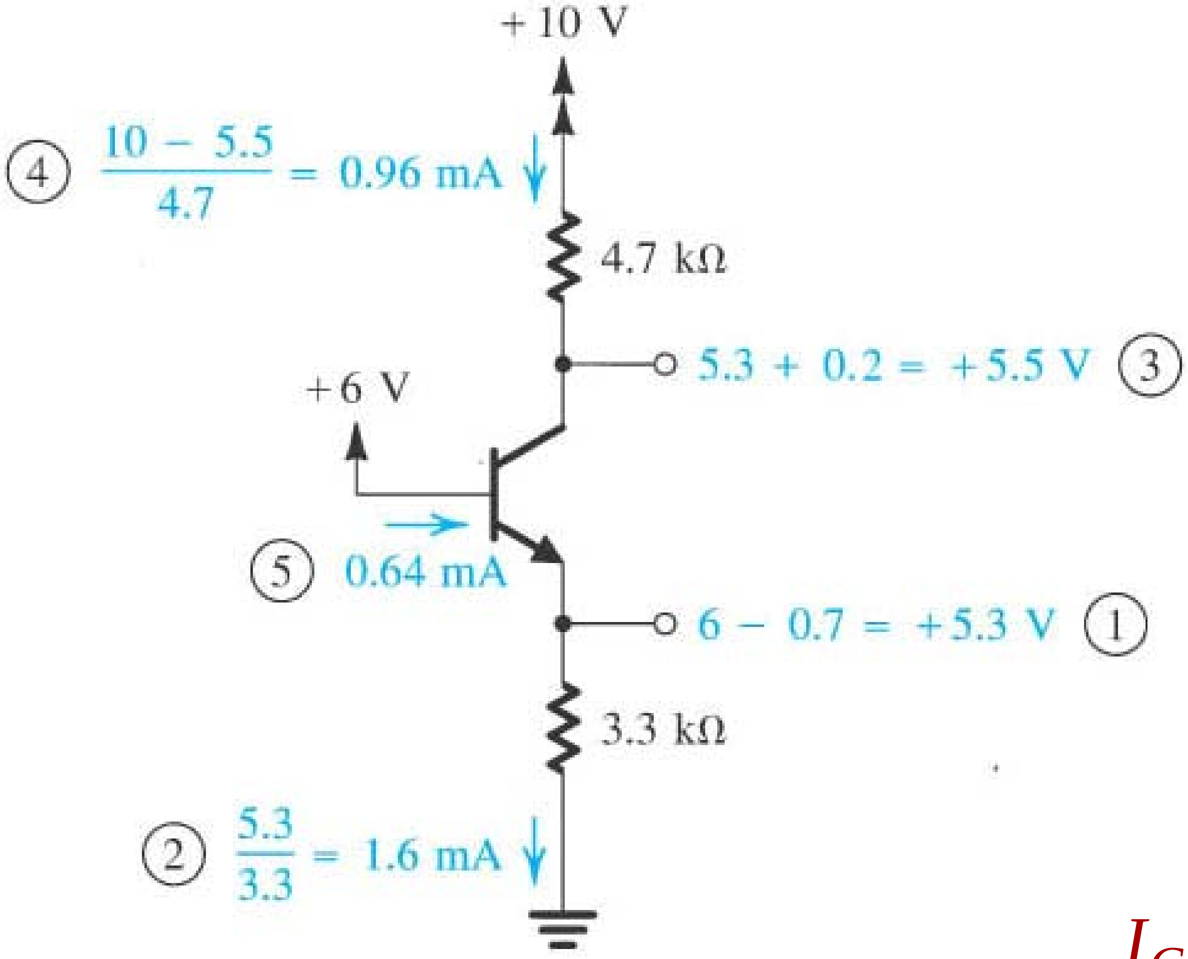
Example 4.5 We wish to analyze this circuit below Fig. to determine all node voltages and branch currents. We will assume that β is specified to be at least 50.



(a)



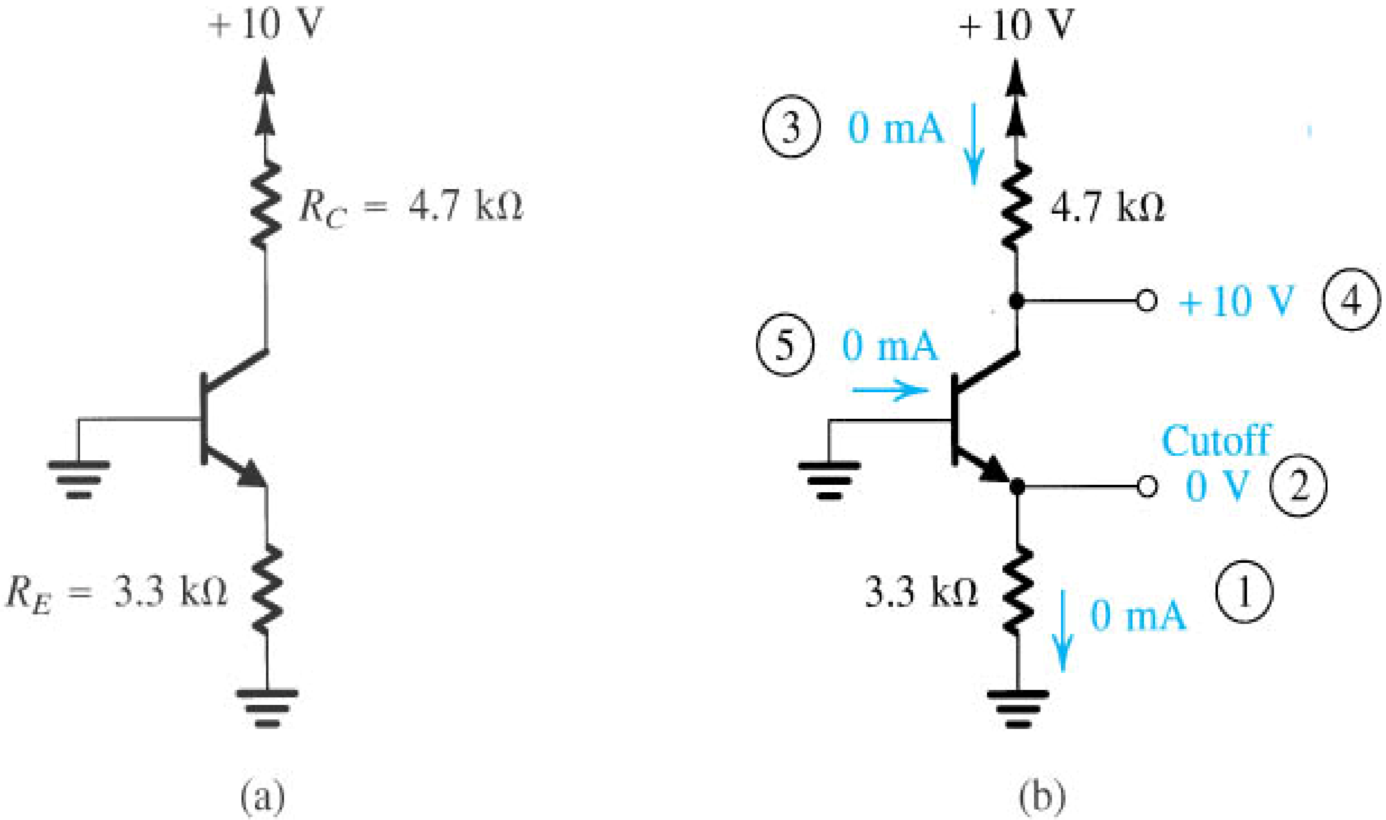
(b)



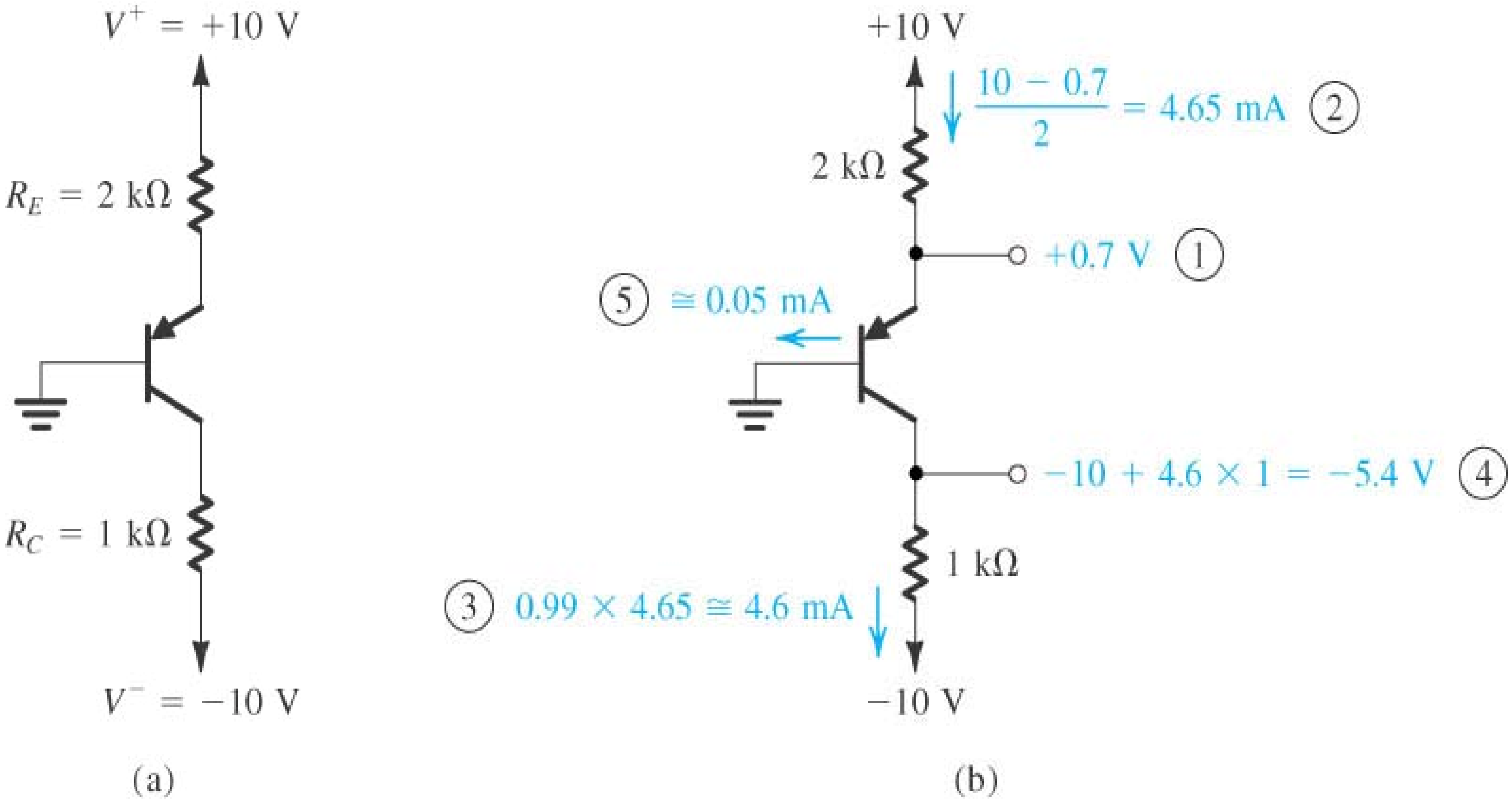
(c)

$$\beta_{forced} = \frac{I_C}{I_B} = \frac{0.96}{0.64} = 1.5$$

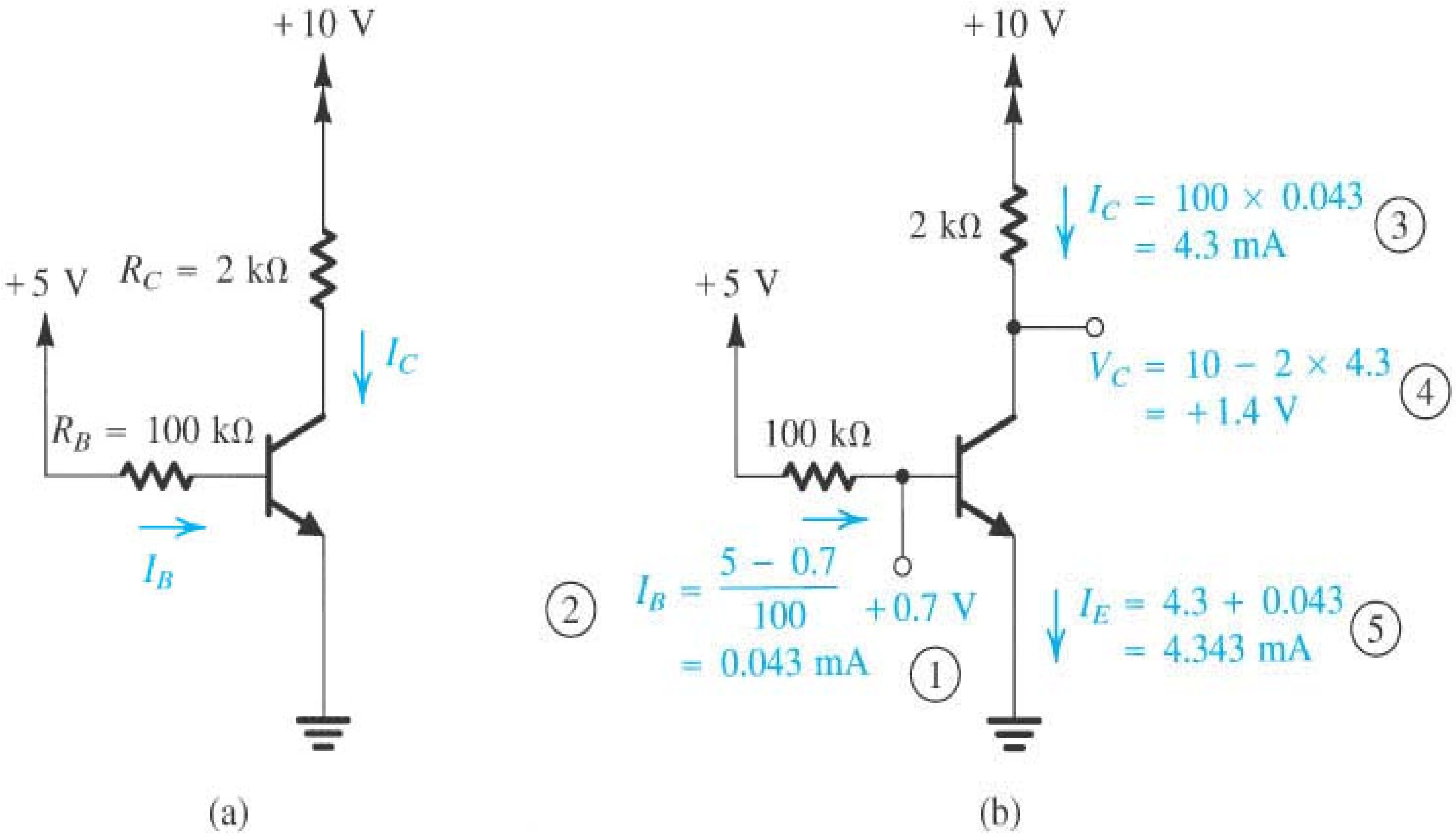
Example 4.6 We wish to analyze this circuit below Fig., to determine all node voltages and branch currents.



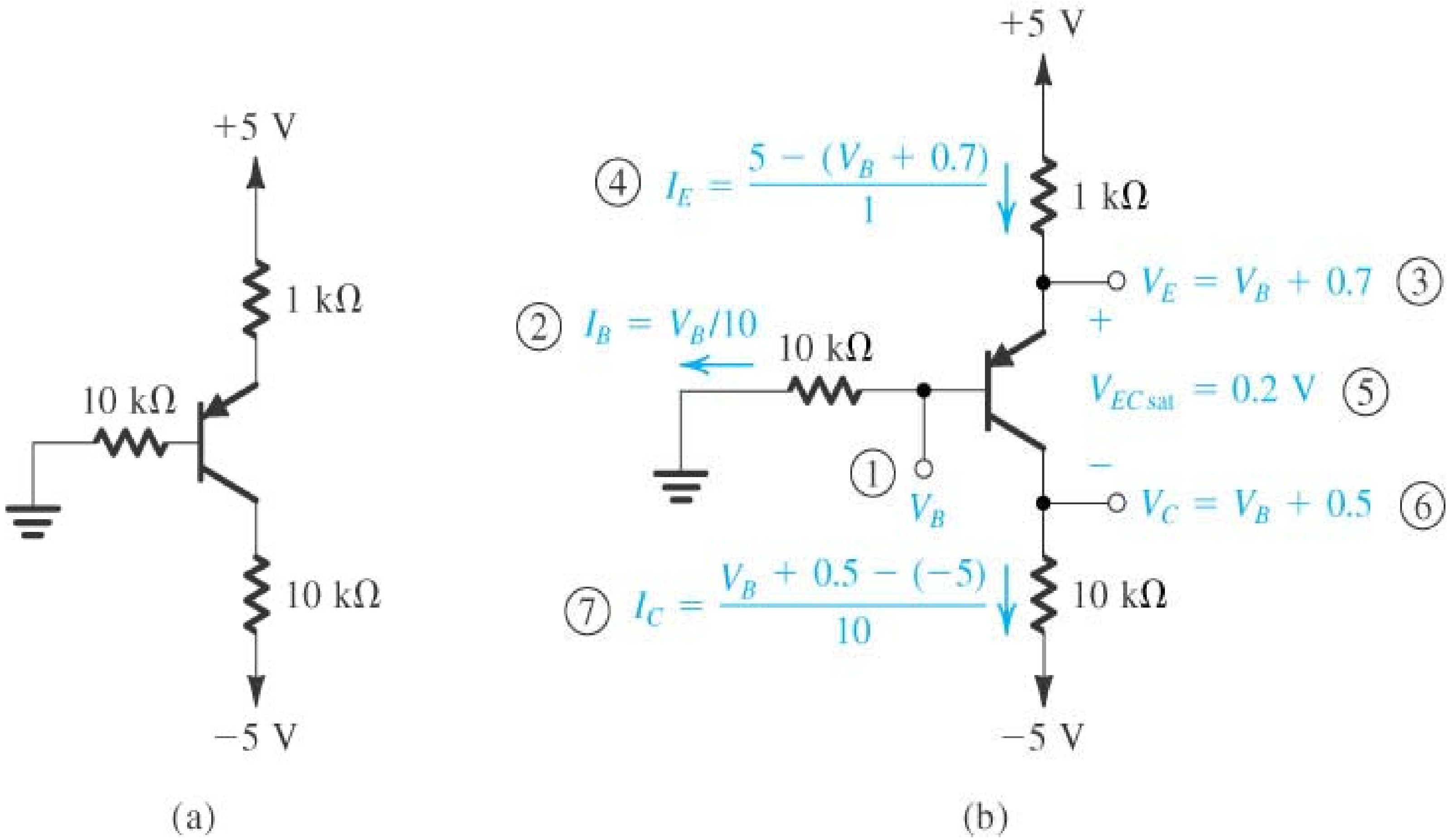
Example 4.7 We desire to analyze this circuit below Fig., to determine the voltages at all nodes and the currents though all branchs .Assume $\beta = 100$



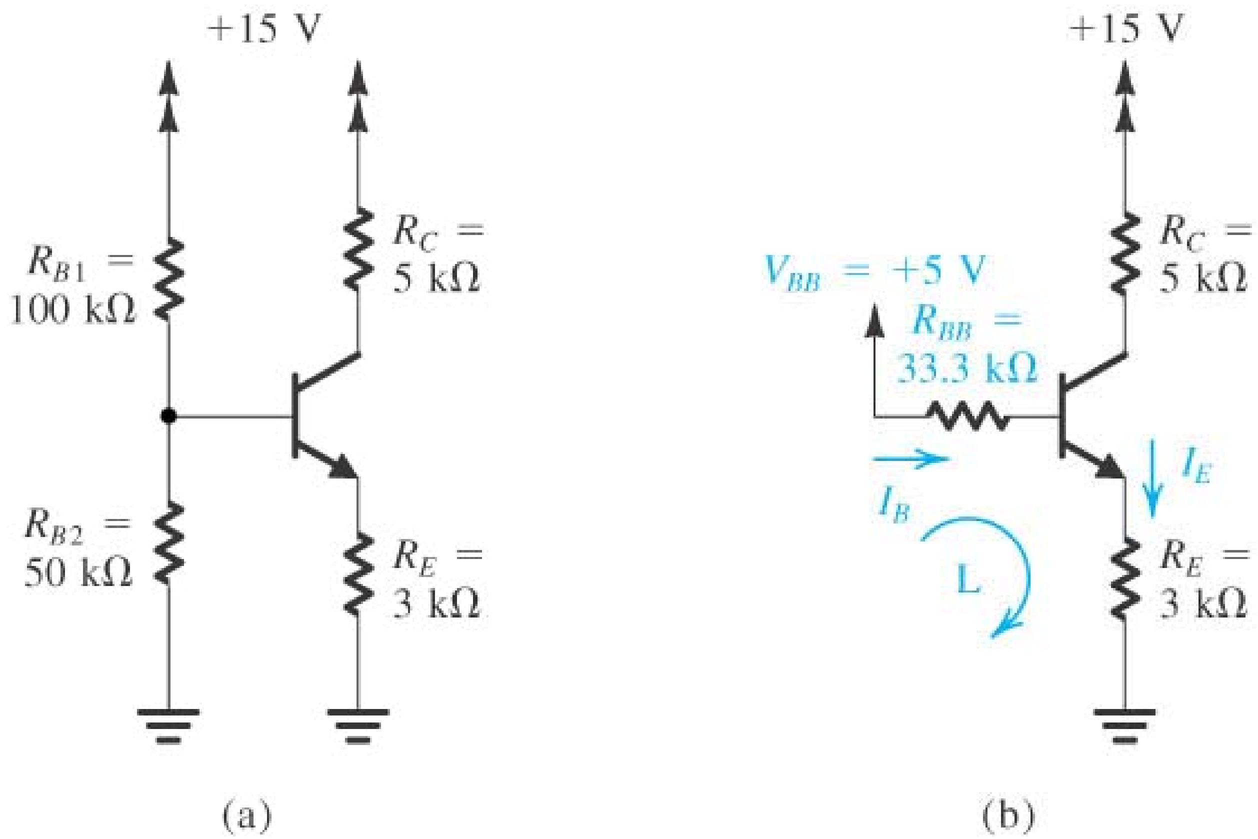
Example 4.8 We want to analyze the circuit in below Fig., to determine the voltages at all nodes and the currents in all branchs .Assume $\beta = 100$

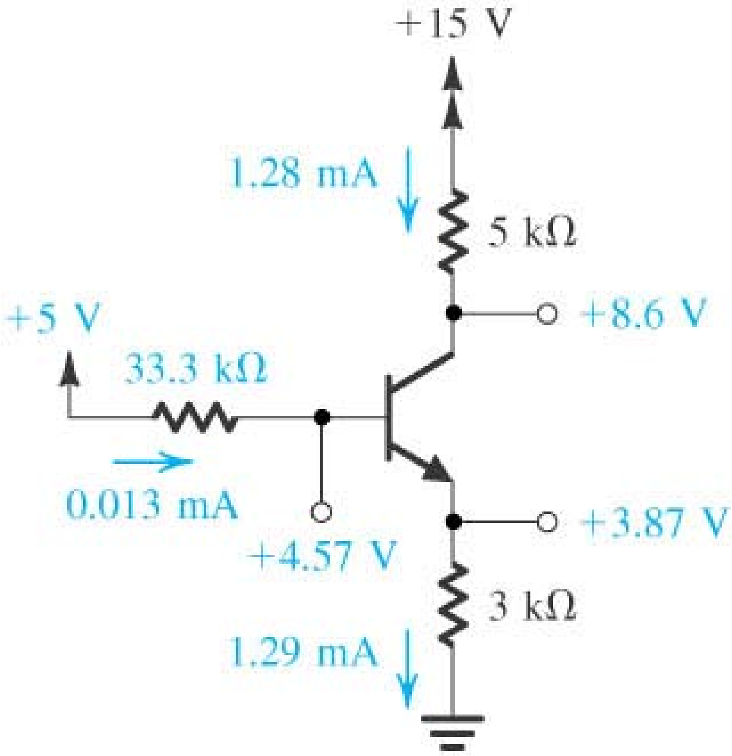


Example 4.9 We want to analyze the circuit in below Fig., to determine the voltages at all nodes and the currents in all branches .The minimum value of β is specified to be 30.

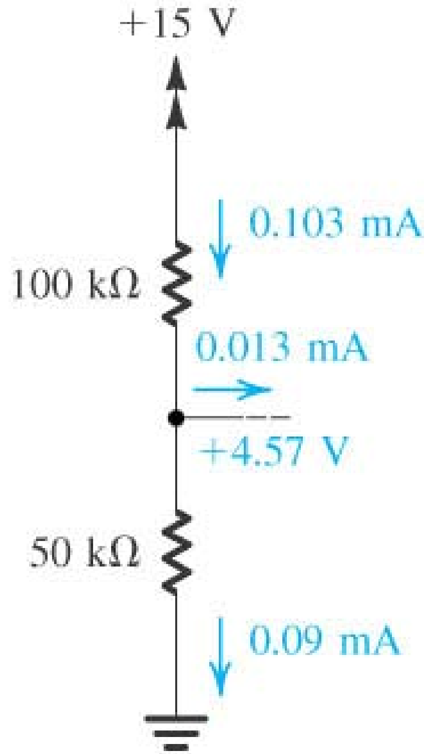


Example 4.10 We want to analyze the circuit in below Fig., to determine the voltages at all nodes and the currents though all branchs . Assume $\beta = 100$



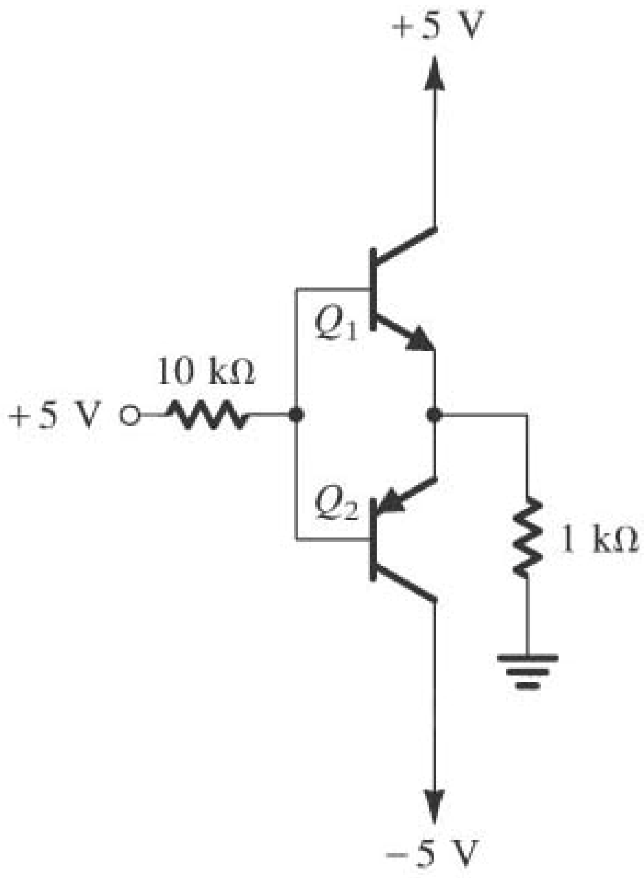

+15 V
1.28 mA
5 kΩ
+8.6 V
+5 V
33.3 kΩ
0.013 mA
+4.57 V
+3.87 V
3 kΩ
1.29 mA

(c)

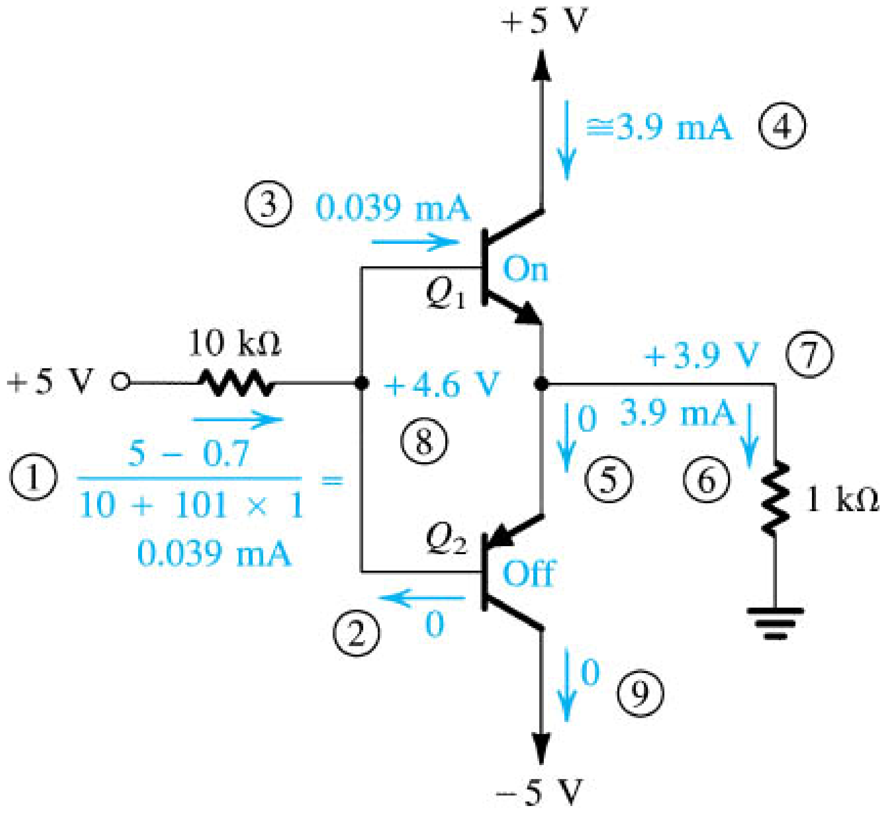

+15 V
0.103 mA
100 kΩ
0.013 mA
+4.57 V
50 kΩ
0.09 mA

(d)

Example 4.12 We desire to evaluate the voltages at all nodes and the currents though all branchs in the circuit of below Fig., Assume $\beta = 100$



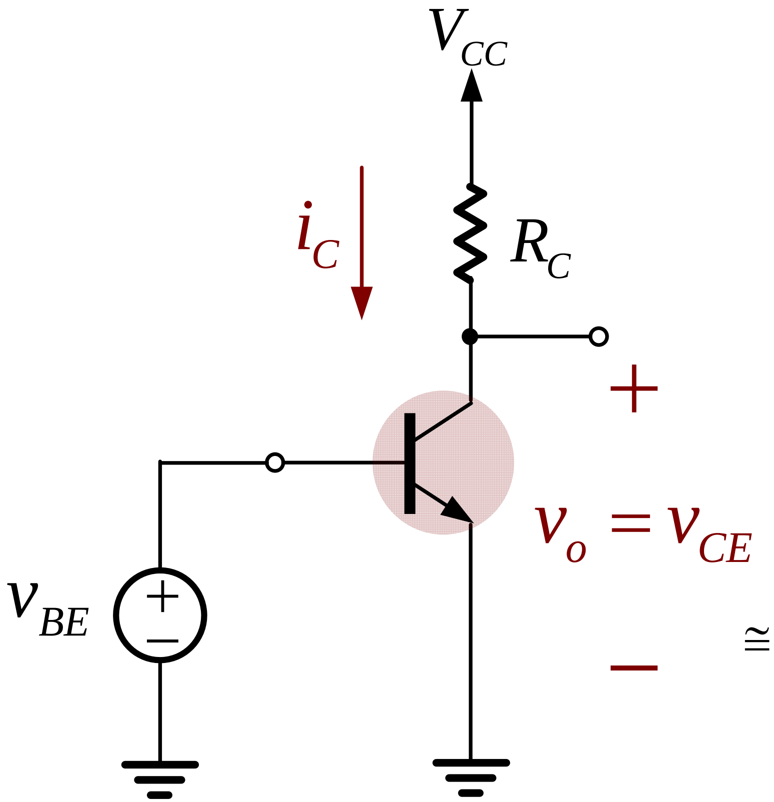
(a)

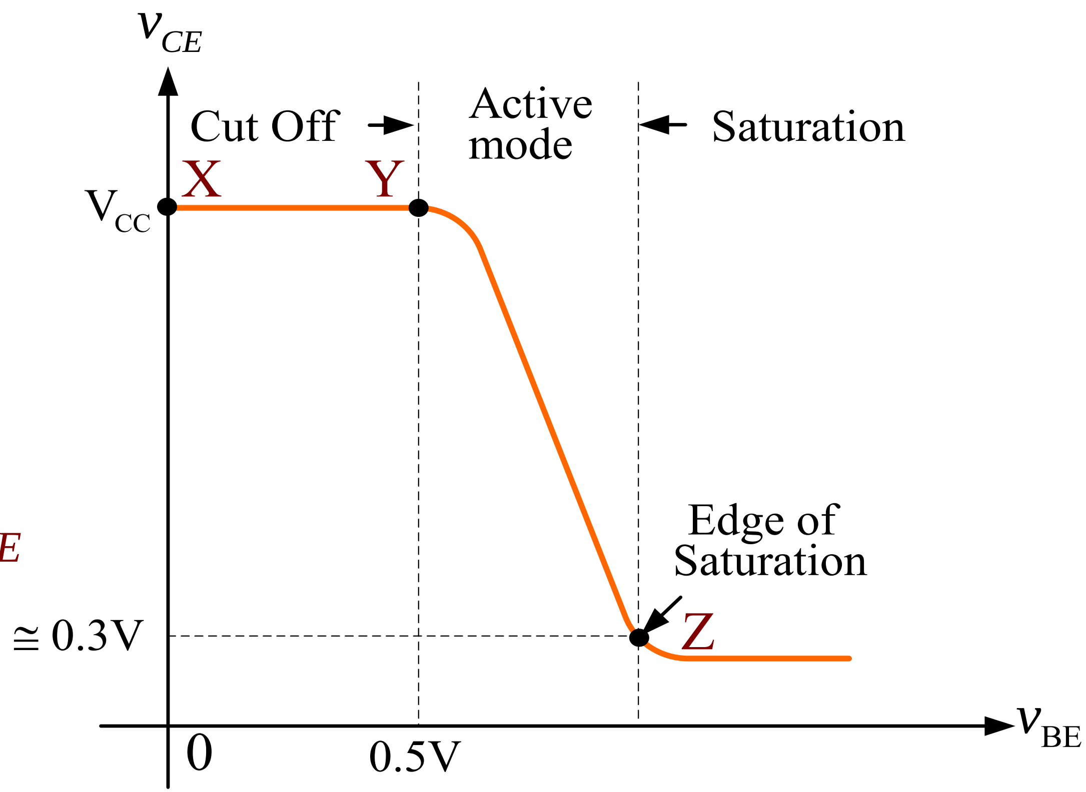


(b)

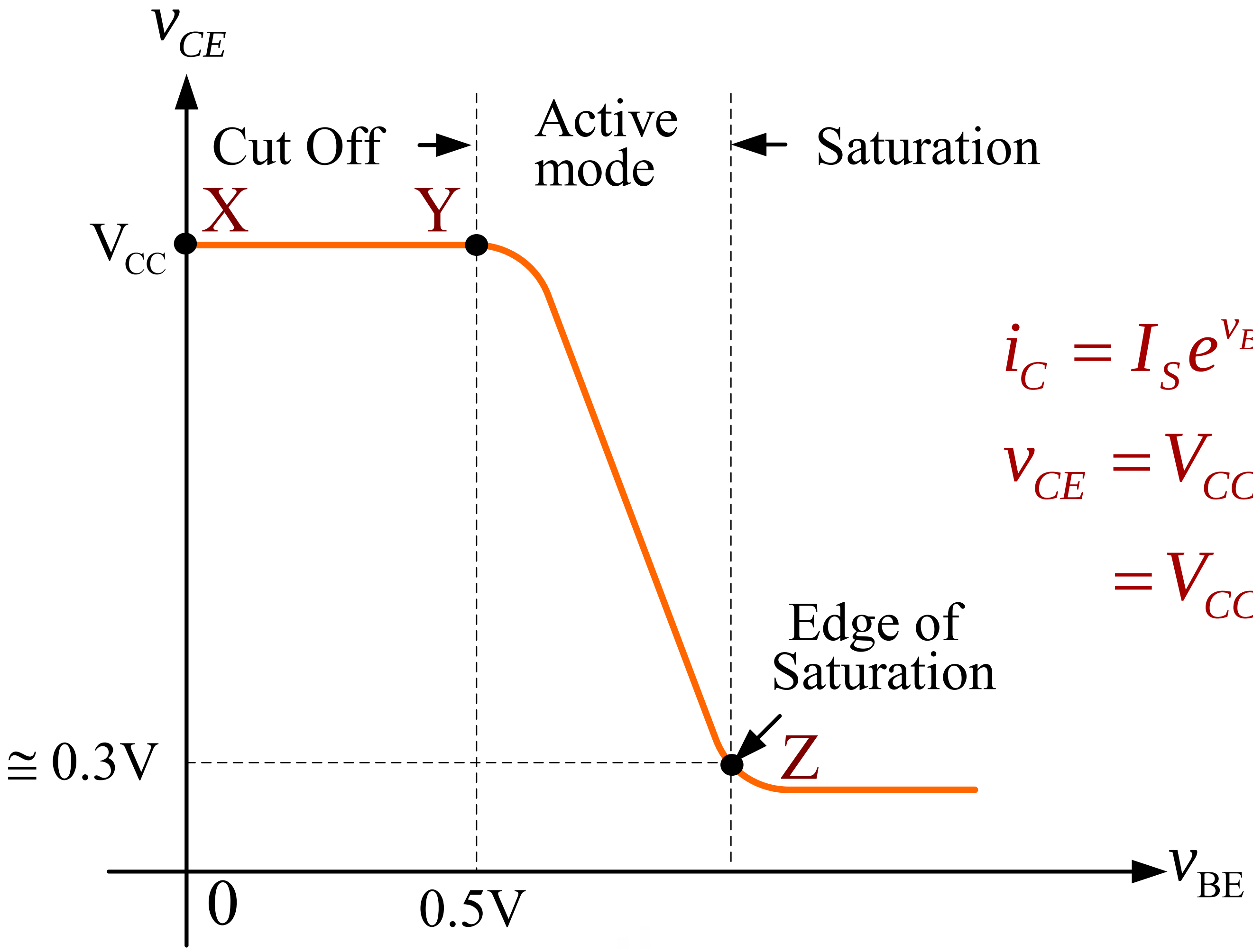
4.4 Applying the BJT in Amplifier Design

4.4.1 Obtaining a Voltage Amplifier





4.4.2 The Voltage Transfer Characteristic (VTC)

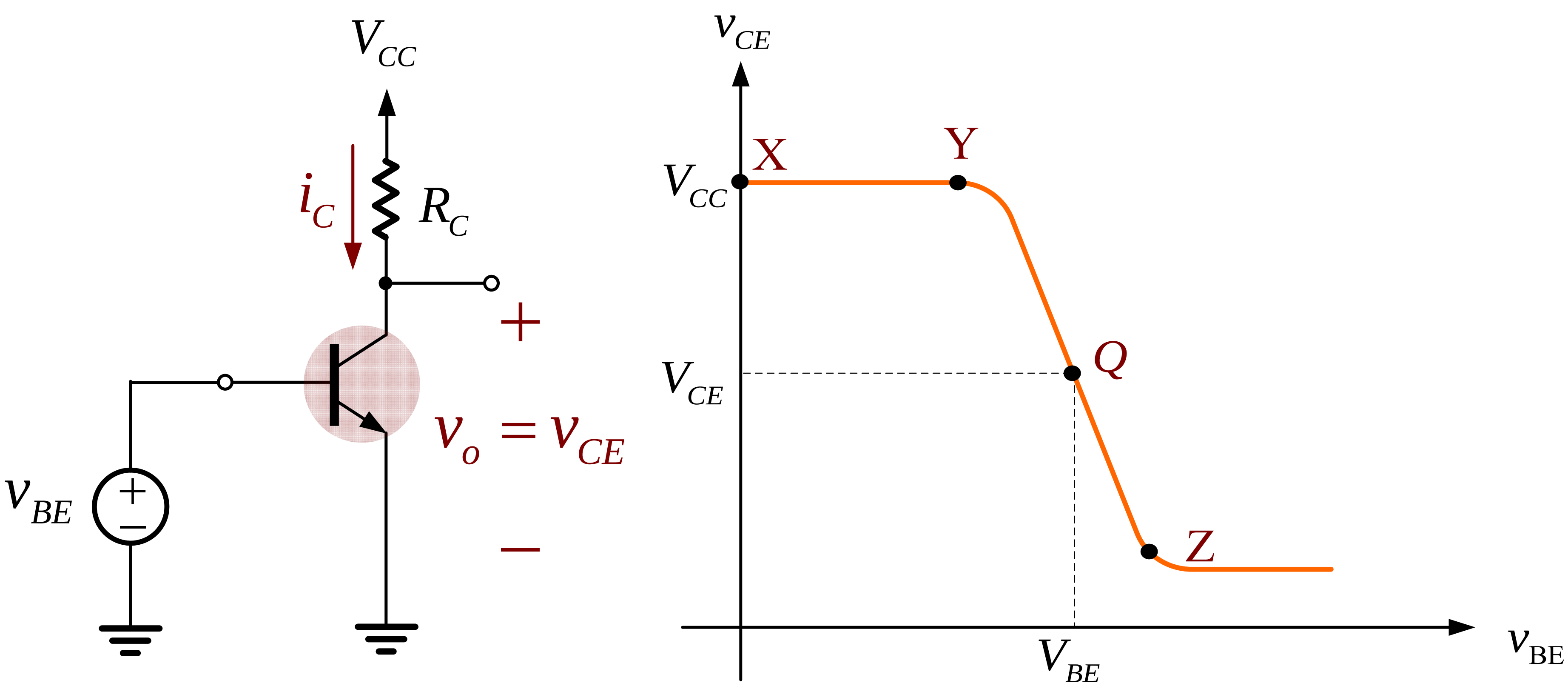


$$i_C = I_S e^{v_{BE}/V_T}$$

$$v_{CE} = V_{CC} - i_C R_C$$

$$= V_{CC} - R_C I_S e^{v_{BE}/V_T}$$

4.4.3 Biasing the BJT to Obtain Linear Amplification



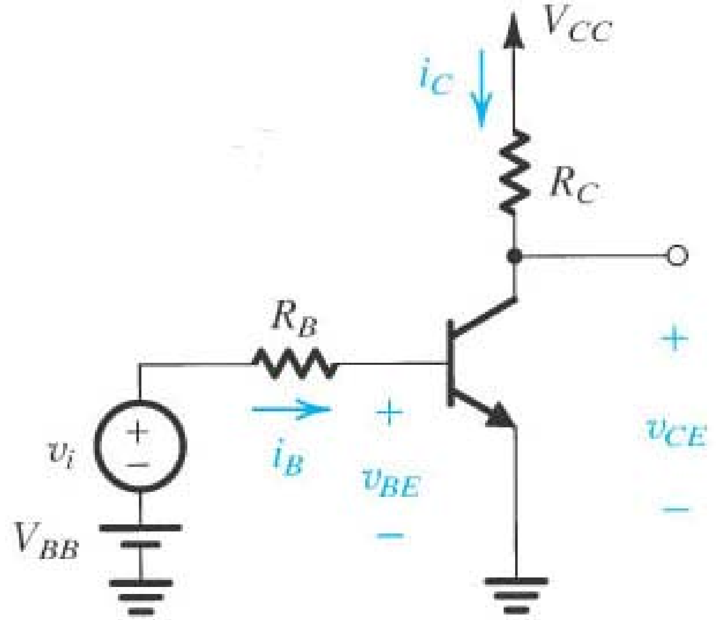
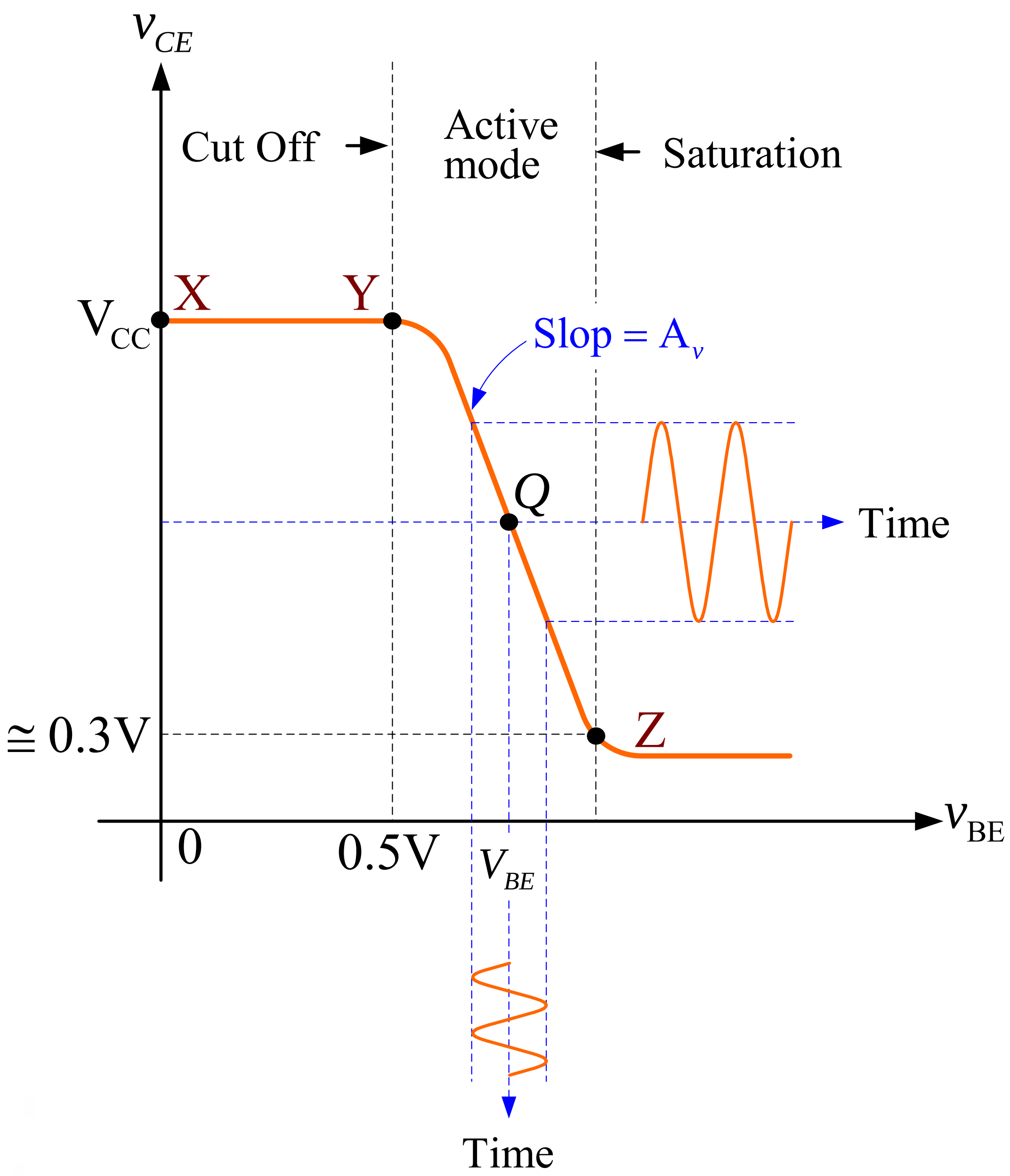


Figure 4.33(a)



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

$$v_{CE} = V_{CC} - R_C I_S e^{v_{BE}/V_T}$$

$$v_{BE}(t) = V_{BE} + v_{be}(t)$$

4.4.4 The Small-Signal Voltage Gain

$$A_v \equiv \left.\frac{dV_{CE}}{dV_{BE}}\right|_{v_{BE}=V_{BE}} \qquad (4.29)$$

$$\frac{dV_{CE}}{dV_{BE}} = -\frac{R_C}{V_T} I_S e^{v_{BE}/V_T} \Rightarrow A_v = -\left(\frac{I_C}{V_T}\right) R_C \qquad (4.30)$$

$$A_v = -\frac{I_C R_C}{V_T} = -\frac{V_{R_C}}{V_T}, \text{where } V_{R_C} = V_{CC} - V_{CE} \qquad (4.32)$$

The observations on this expression for the voltage gain:

❶ The gain is negative, which signifies that the amplifier is inverting ; that is, there is a 180° phase shift between the input and the output.

❷ The gain is propotional to the collector bias current I_C and to the load resistance R_C.

Example 4.13 Consider an amplifier circuit using a BJT having $I_s = 10^{-15}$ A, a collector resistance $R_C = 6.8\text{k}\Omega$, and a power supply $V_{CC} = 10\text{V}$.(a) Find V_{BE} ,and I_C, such that the BJT operate at $V_{CE} = 3.2\text{V}$ (b)Find the voltage gain A_v at this bias point. If $v_i = v_{be} = 5\sin\omega t(\text{mV})$ find v_o.(c)Find the positive increment in v_{BE} that drive the transistor to the edge of saturation($v_{CE_{sat}} = 0.3\text{V}$).(d)Find the negative increment in v_{BE} that drive the transistor to the within 1% of cut-off.

Solution:

$$(a) I_C = \frac{V_{CC} - V_{CE}}{R_C} = \frac{(10-3.2)\text{V}}{6.8\text{k}\Omega} = 1\,\text{mA} \blacktriangle$$

$$I_C = I_S e^{v_{BE}/V_T} \Rightarrow v_{BE} = V_T \ln(I_C / I_S) = 690.8\text{ mV} \blacktriangle$$

$$(b)\ A_v = \frac{V_{CC} - V_{CE}}{V_T} = \frac{(10-3.2)\text{V}}{0.025\text{V}} = -272\text{V/V} \quad \blacktriangle$$

$$v_o = \hat{V}_{ce} = 272 \times 0.005 \sin\omega t = 1.36 \sin\omega t(\text{V}) \quad \blacktriangle$$

(c) For $v_{CE_{sat}} = 0.3\text{V}$

$$i_C = \frac{V_{\text{CC}} - V_{CE}}{R_{\text{C}}} = \frac{(10-0.3)\text{V}}{6.8\text{k}\Omega} = 1.617\text{mA}$$

To increase i_C from 1mA to 1.617mA, v_{BE} must be increase by

$$\Delta v_{BE} = V_T \ln\left(\frac{I_{C2}}{I_{C1}}\right) = 0.025\ln\left(\frac{1.617}{1}\right) = 12\text{mV}$$ ▲

(d) For $v_{CE} = 0.99V_{CC} = 9.9\text{V}$

$$i_C = \frac{V_{\text{CC}} - v_{CE}}{R_{\text{C}}} = \frac{(10-9.9)\text{V}}{6.8\text{k}\Omega} = 0.0147\text{mA}$$

To decrease i_C from 1mA to 0.0147mA, v_{BE} must be change by

$$\Delta v_{BE} = 0.025\ln\left(\frac{0.0147}{1}\right) = -105.5\text{mV}$$ ▲

4.4.5 Determining The VTC by Graphical Analysis

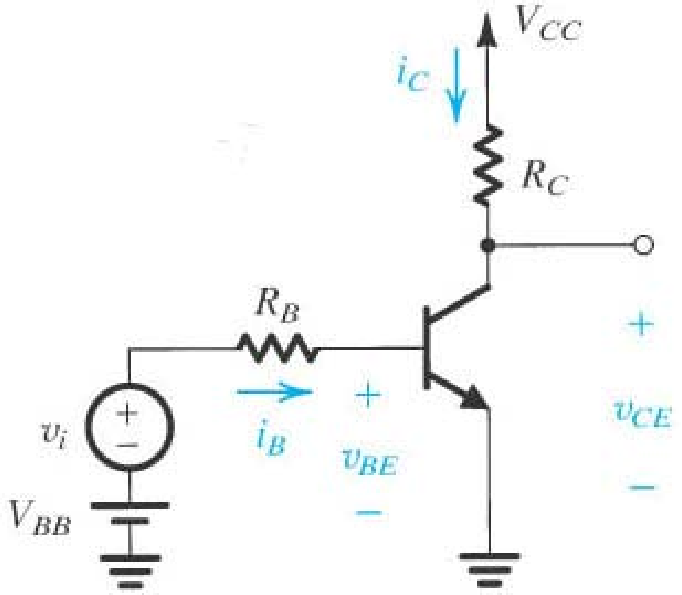


Figure 4.33(a)

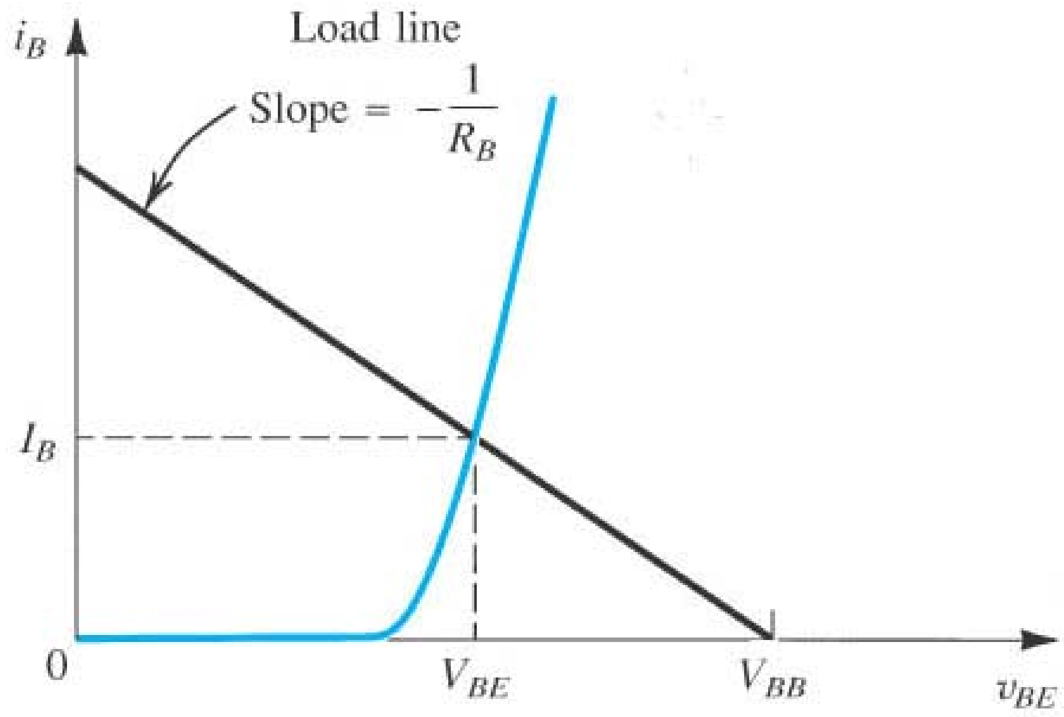
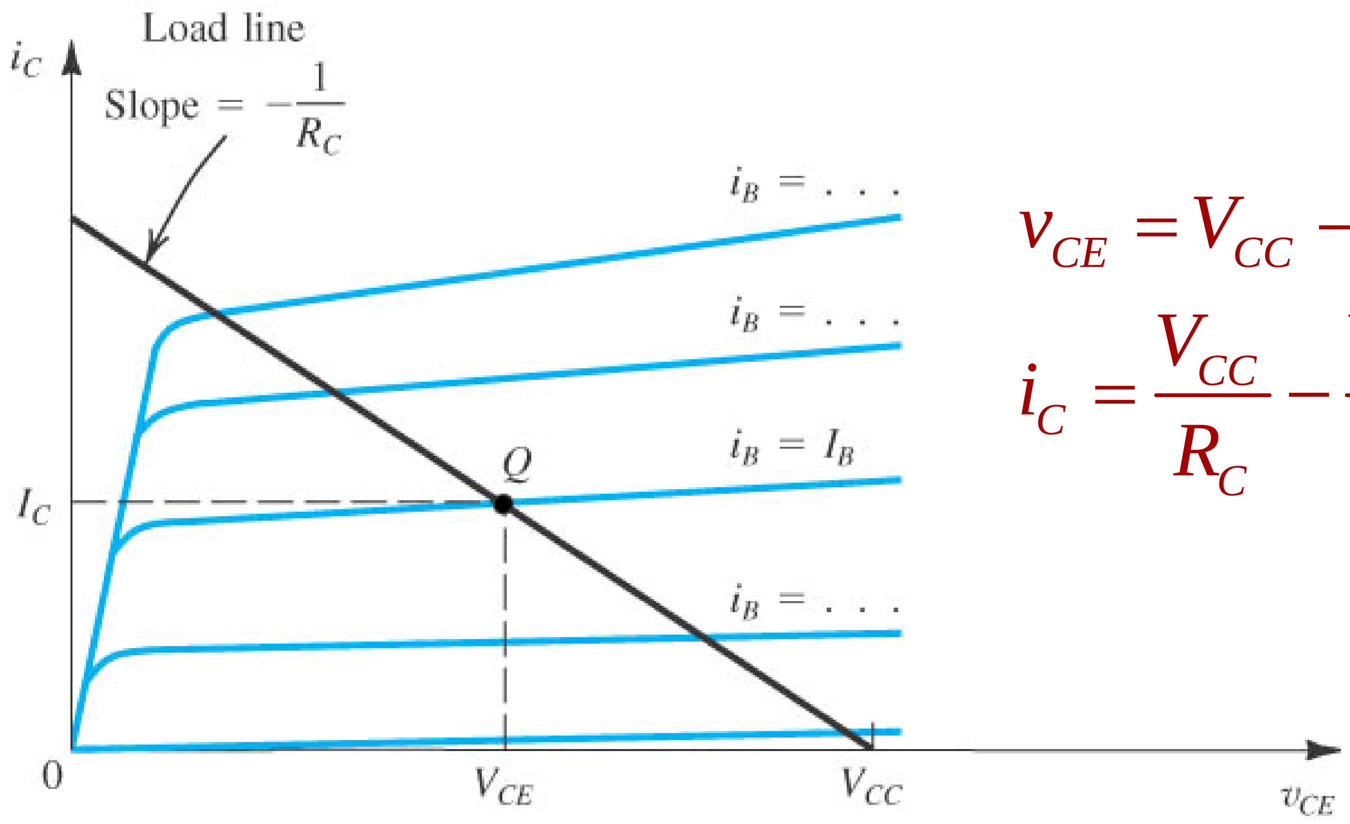


Figure Graphical construction for the determination of the dc base current in the circuit of Fig.**4.33(a)**.



$$v_{CE} = V_{CC} - i_C R_C$$

$$i_C = \frac{V_{CC}}{R_C} - \frac{V_{CE}}{R_C}$$

Figure 4.34 Graphical construction for determining the dc collector current I_C and the collector-to-emitter voltage V_{CE} in the circuit of Fig.4.33(a).

4.4.6 Locating the Bias Point Q

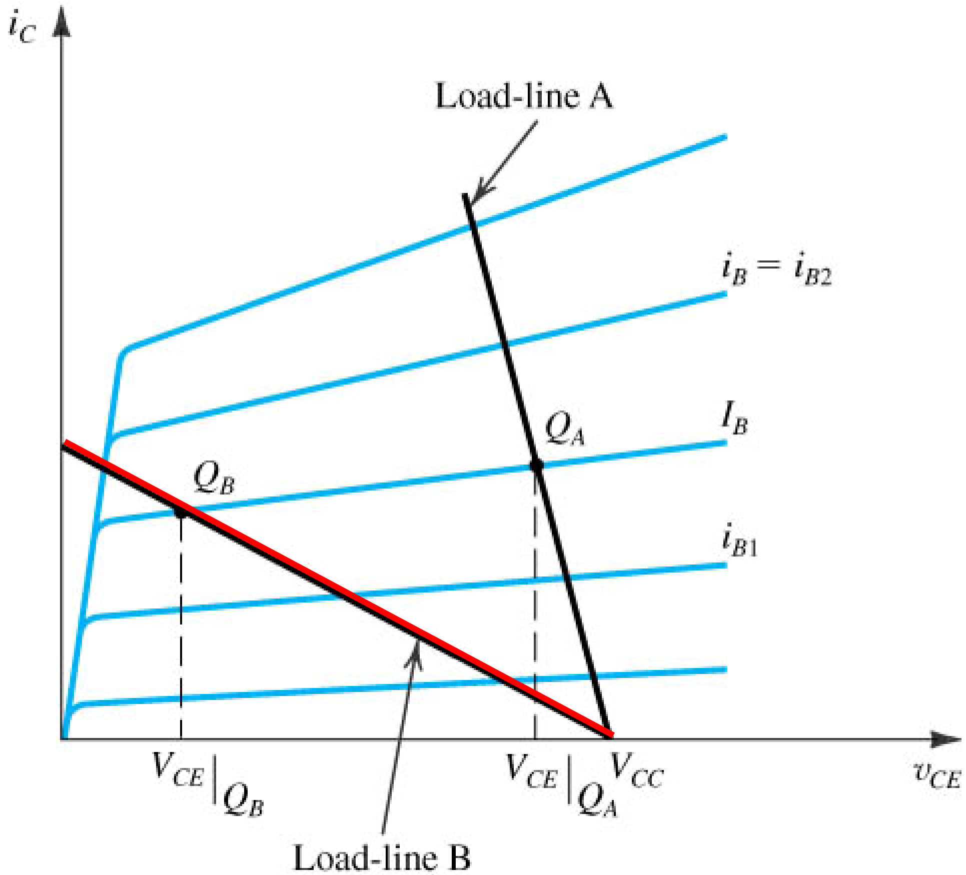


Figure 4.35 Effect of bias-point location on allowable signal swing: Load-line A results in bias point Q_A with a corresponding V_{CE} which is too close to V_{CC} and thus limits the positive swing of v_{CE}. At the other extreme, load-line B results in an operating point too close to the saturation region, thus limiting the negative swing of v_{CE}.

Thanks For Your Attention !

Q & A