Huazhong University of Science and Technology
The Department of Electronics and Information Engineering

Electronic Circuit Analysis and Design

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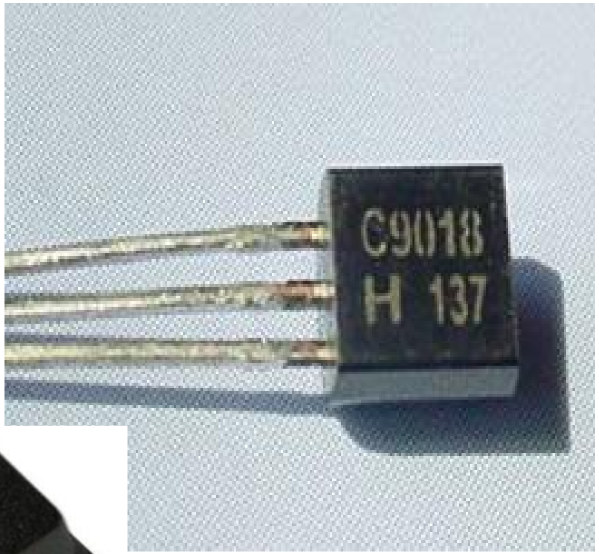

Ch5. The Bipolar Junction Transistor

5.1 Basic Bipolar Junction Transistor

Review:

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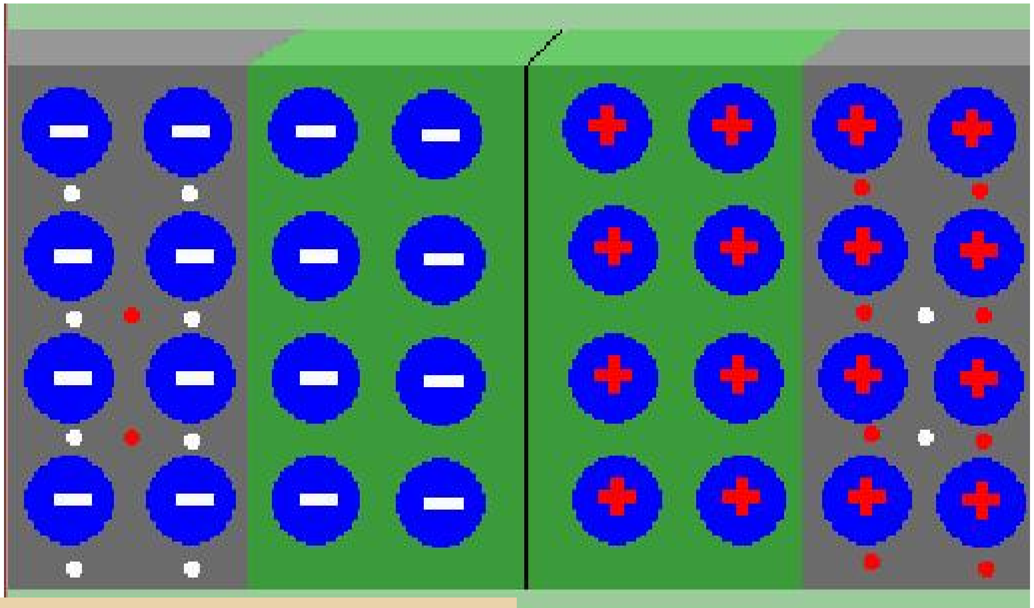
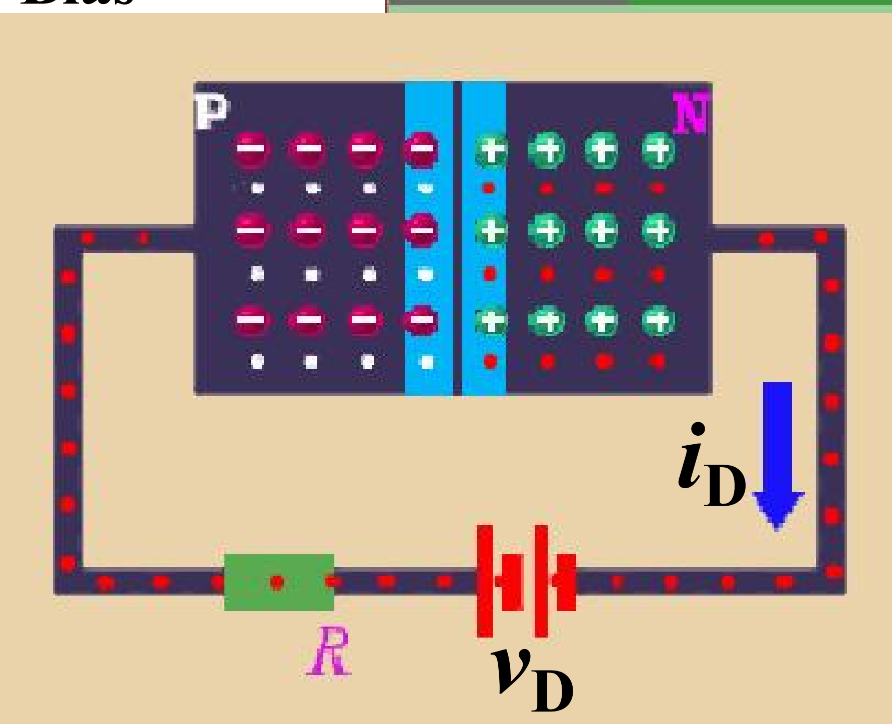
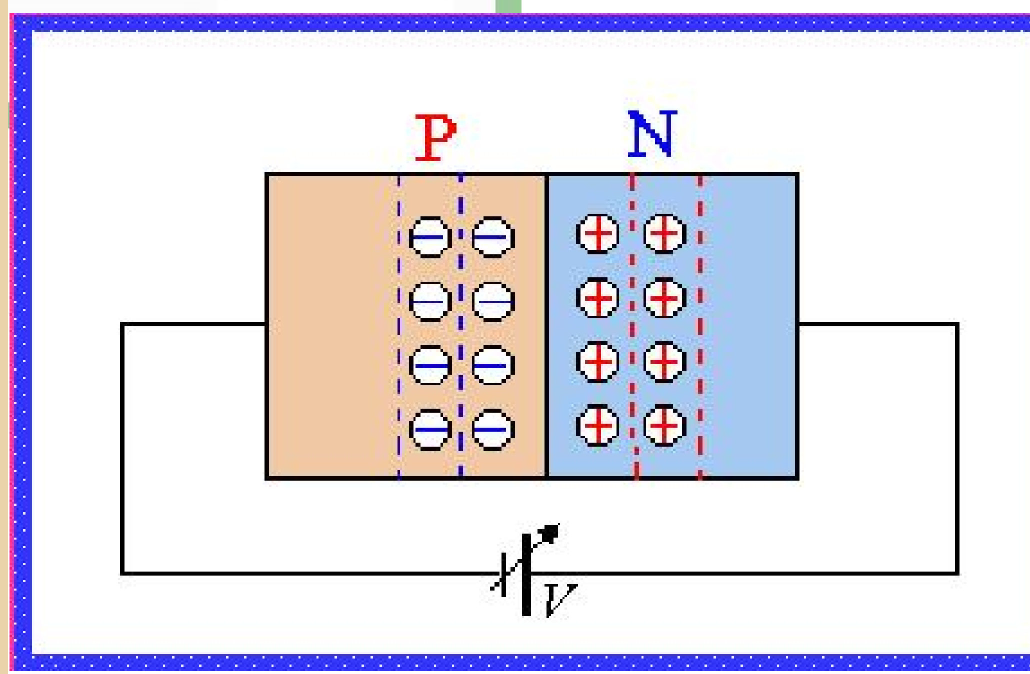


N

Forward Bias

Reverse Bias

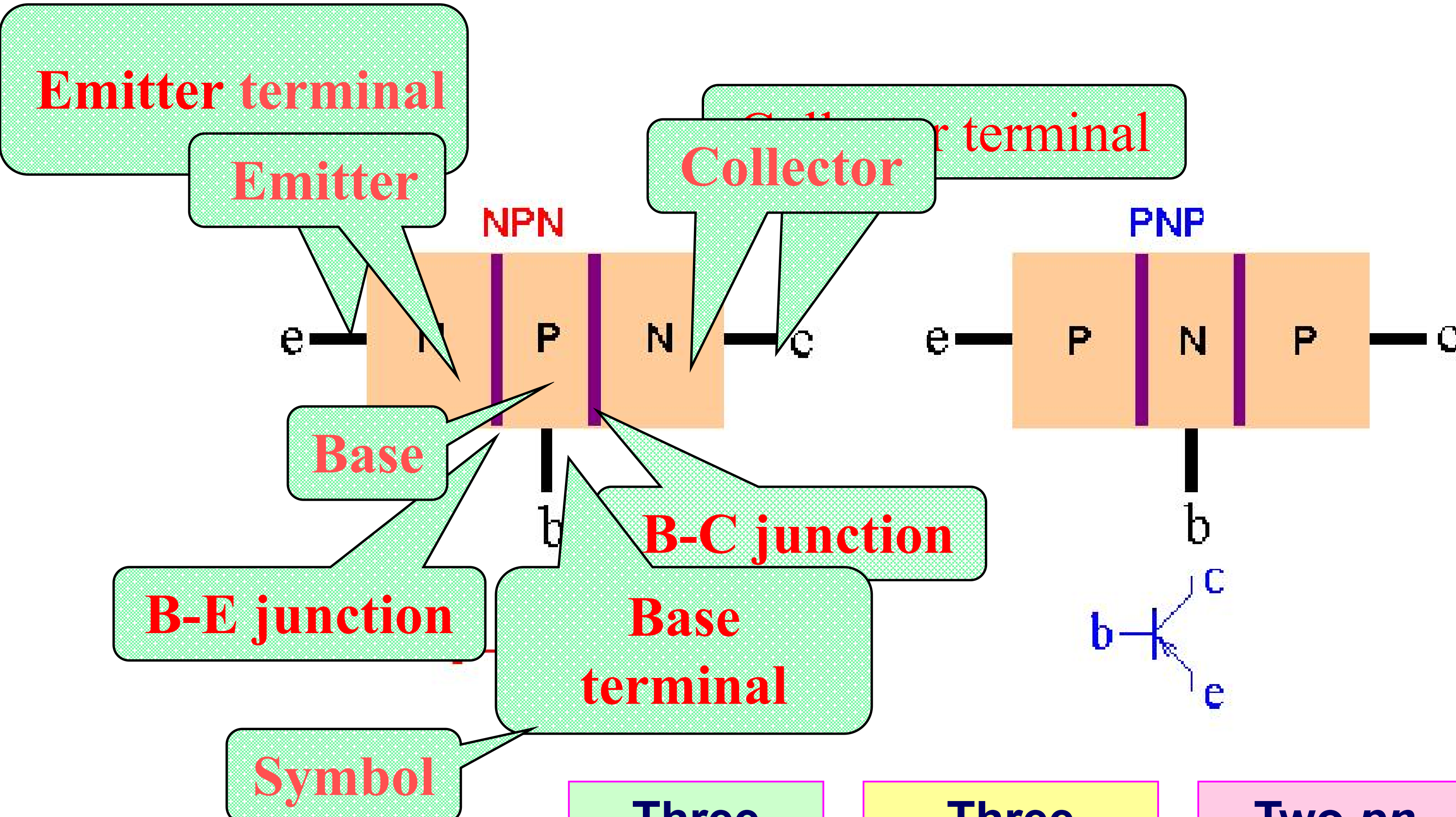




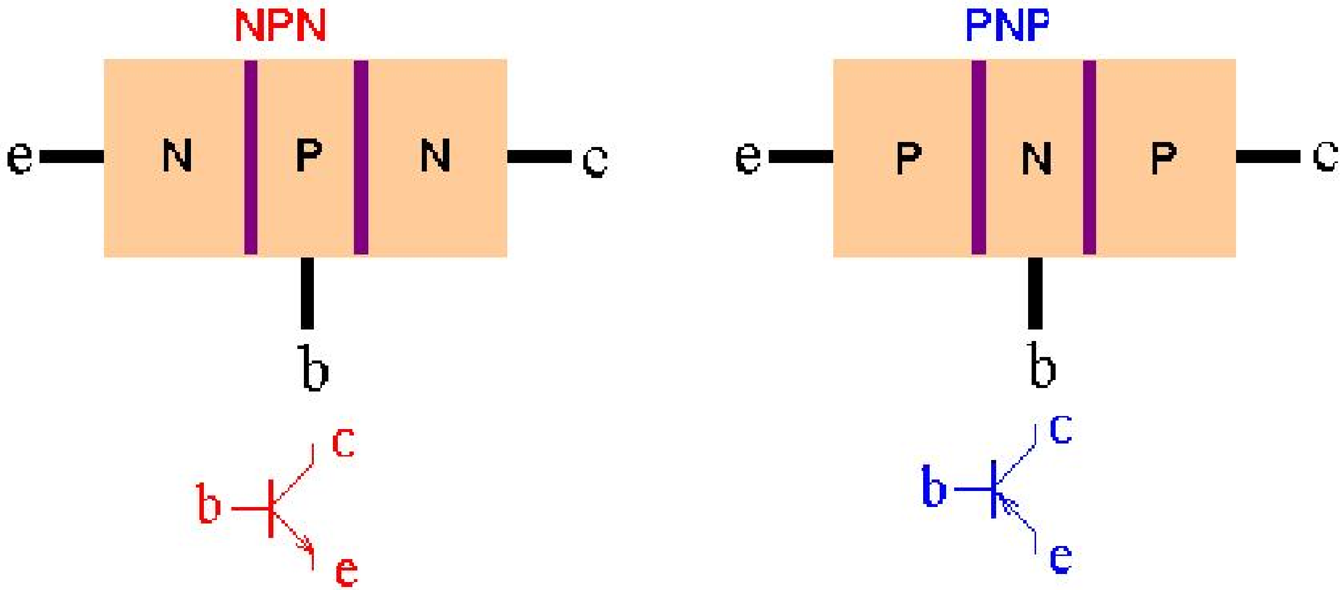
5.1 Basic Bipolar Junction Transistor (BJT)

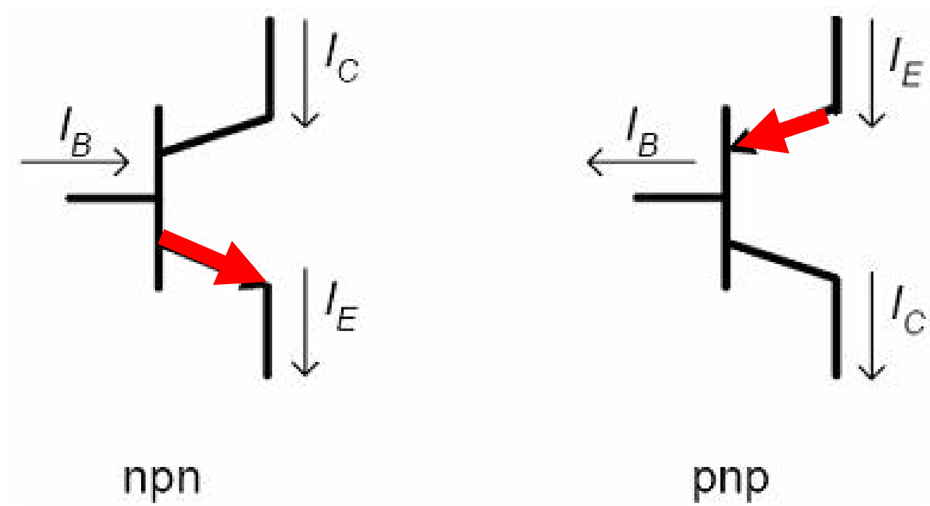
5.1.1 Transistor Structure

- There are two types of bipolar transistor: NPN and PNP.



Three regions:	Three terminals	Two *pn* junctions:

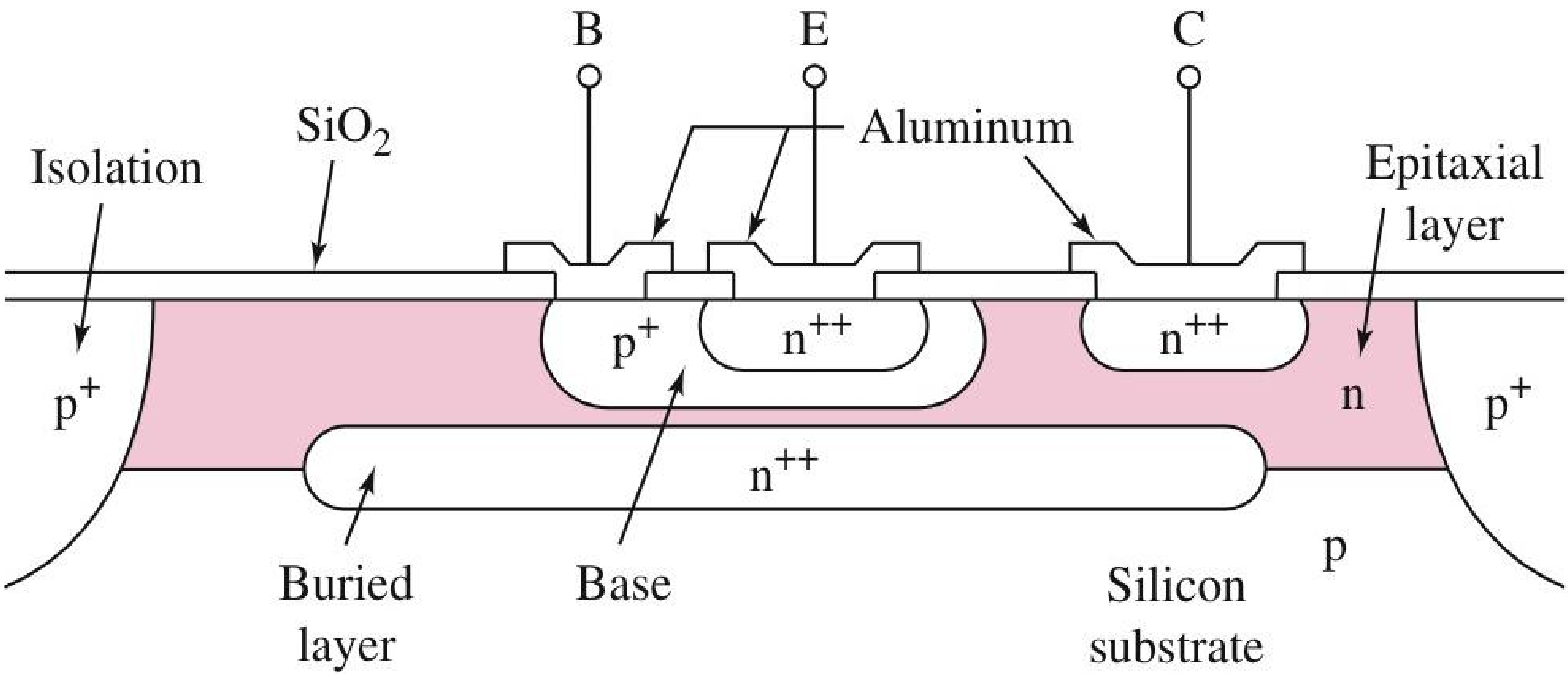




The emitter is distinguished by the arrowhead.

5.1.1 Transistor Structure

Cross Section of Integrated Circuit NPN Transistor



Not symmetrical

5.1.1 Transistor Structure

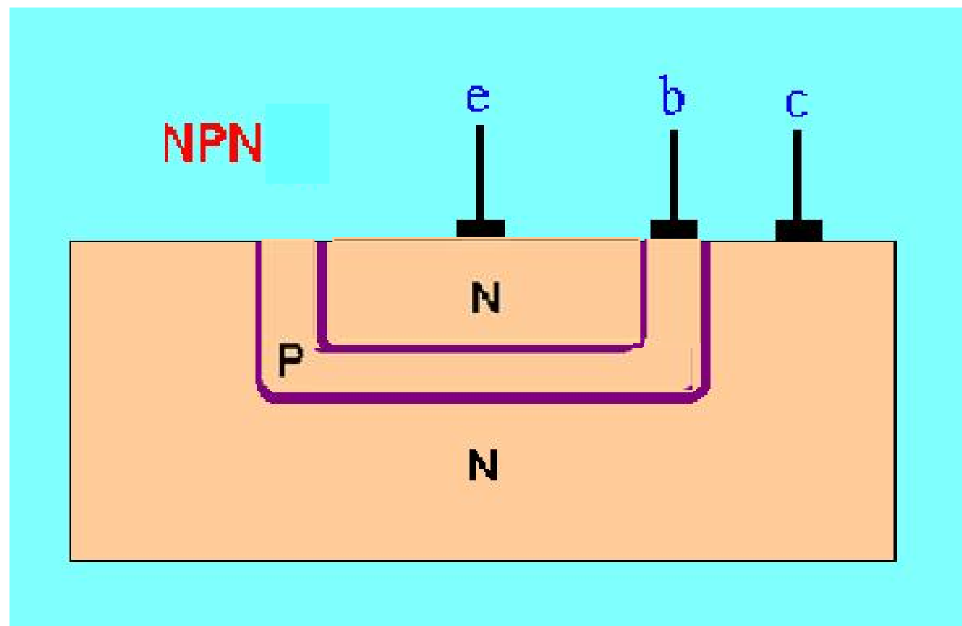
- Feature of transistor structure 浓度

(1) Impurity doping concentration in emitter region is much larger than other two regions.

(2) Area of collector region is bigger than that of emitter.

(3) Base must be very narrow.

- Emitter: heavily doped
- Base: very thin



Cross section of NPN bipolar Transistor

5.1.2 NPN Transistor: Forward-Active Mode Operation

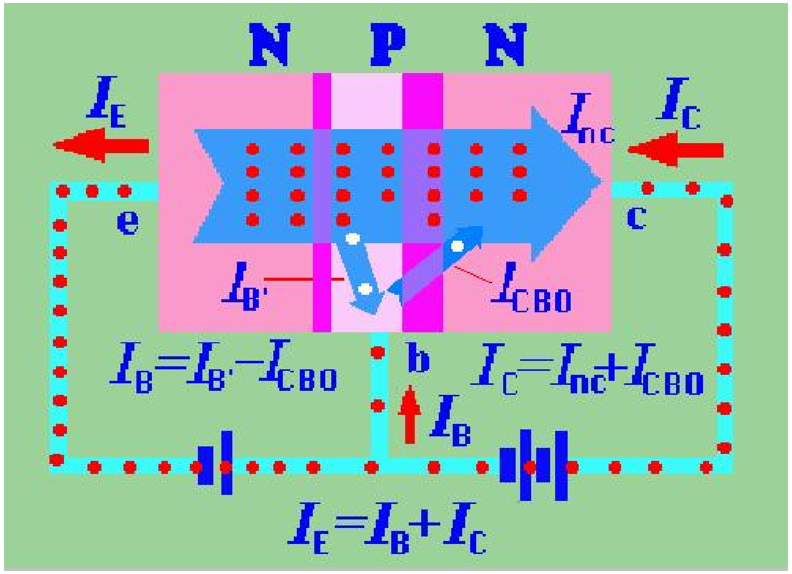
- Amplification condition

If transistor is used as an amplifying device.

•B-E junction is forward biased.

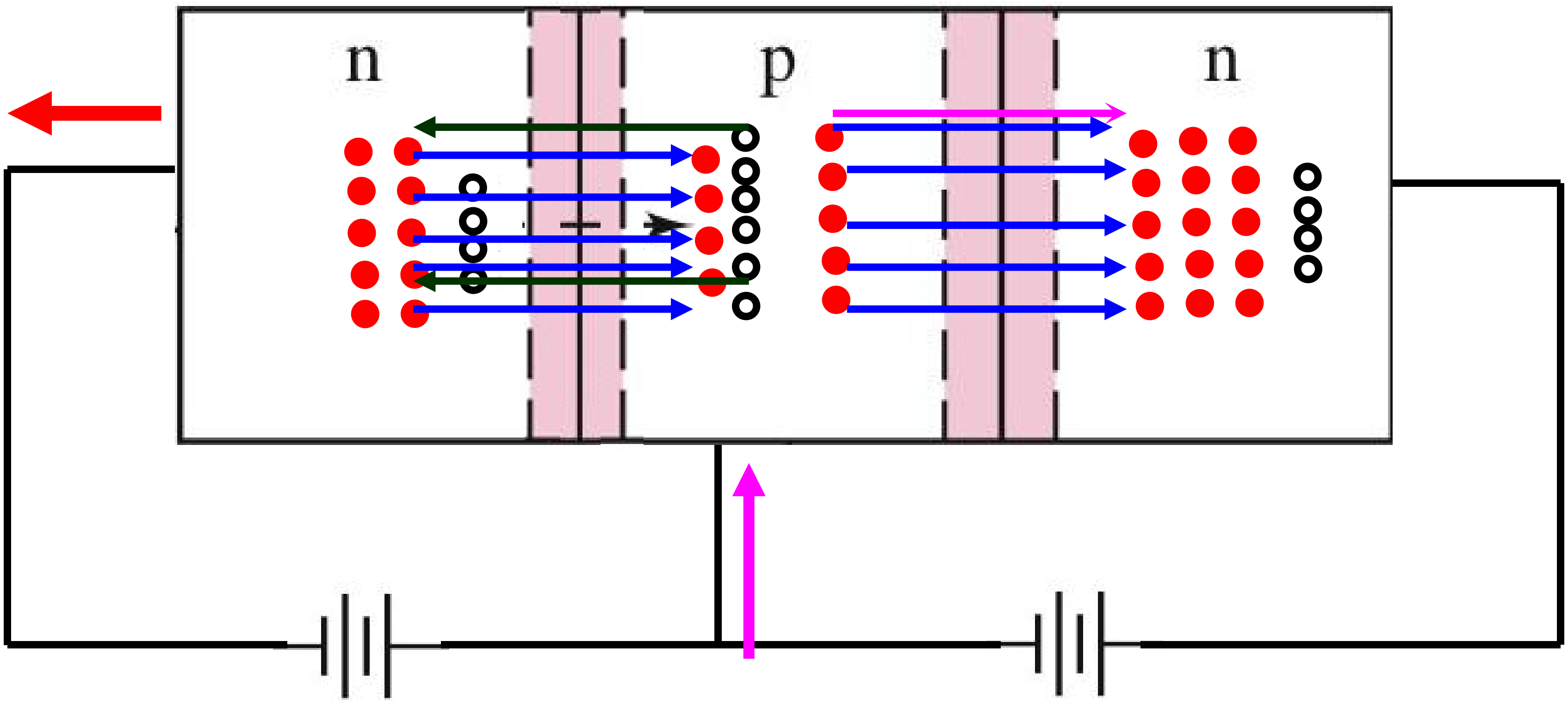
•B-C junction is reverse biased.

It is called the forward-active operating mode, or active region.

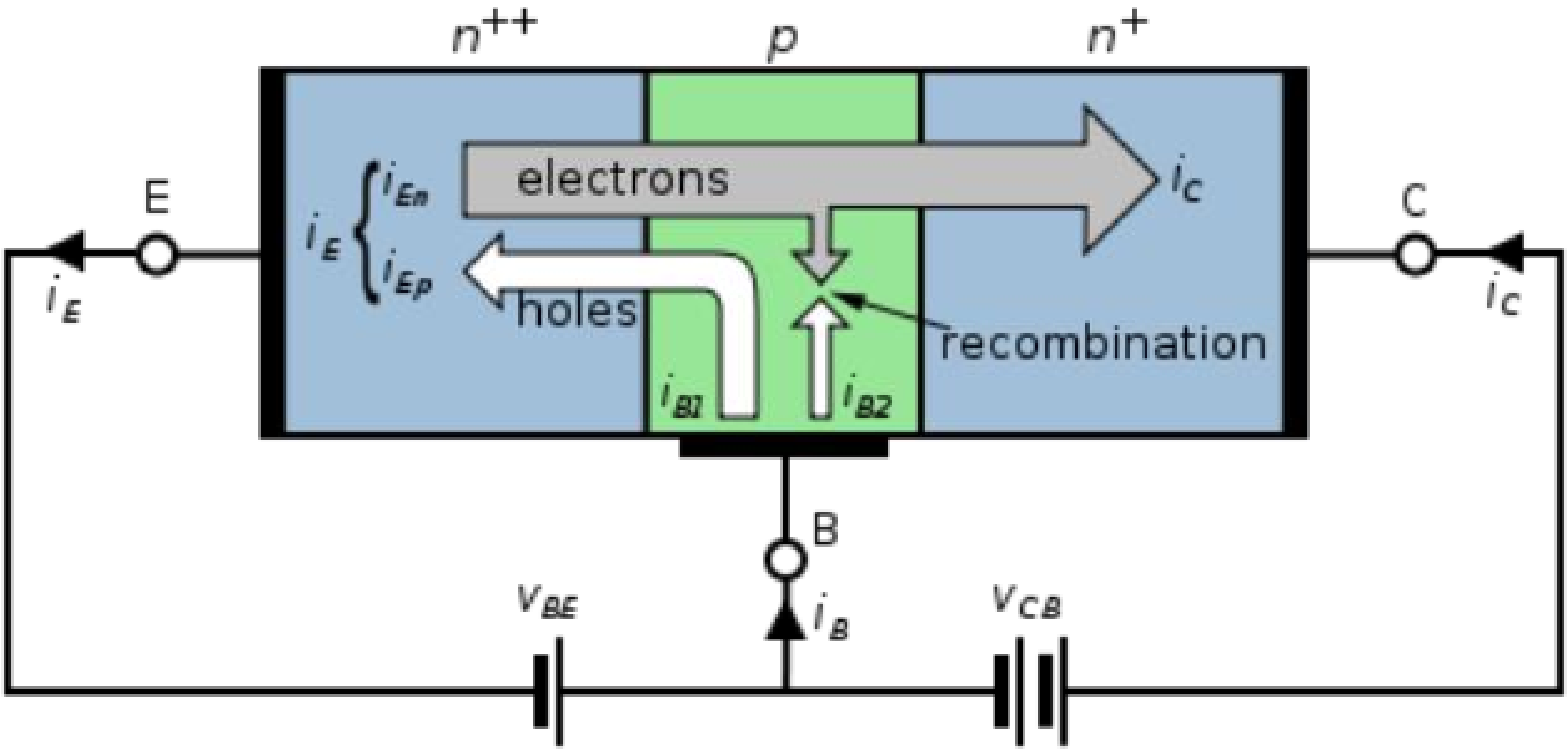


NPN bipolar transistor biased in the forward-active mode

- B-E junction is forward biased.
- B-C junction is reverse biased.

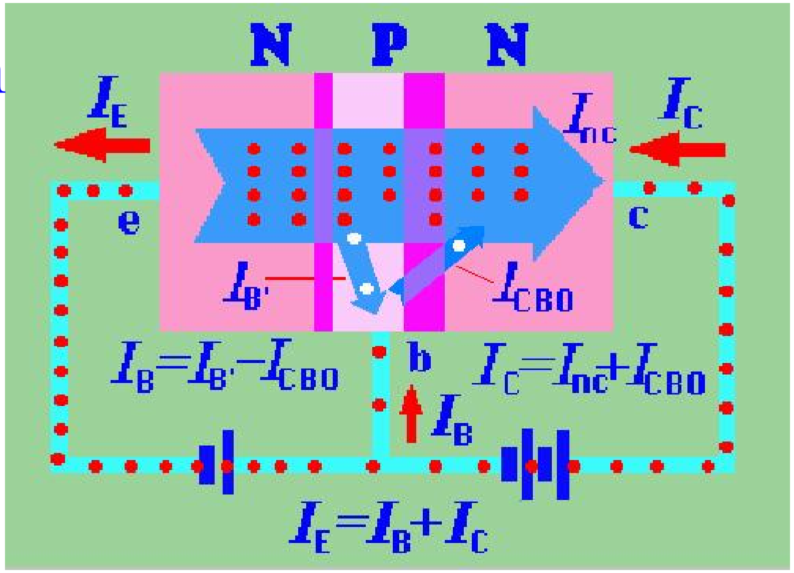


5.1.2 NPN Transistor: Forward-Active Mode Operation(**P289**)



5.1.2 NPN Transistor: Forward-Active Mode Operation

- Amplification condition



NPN bipolar transistor biased in the forward-active mode

1.Transfer process of carriers in npn

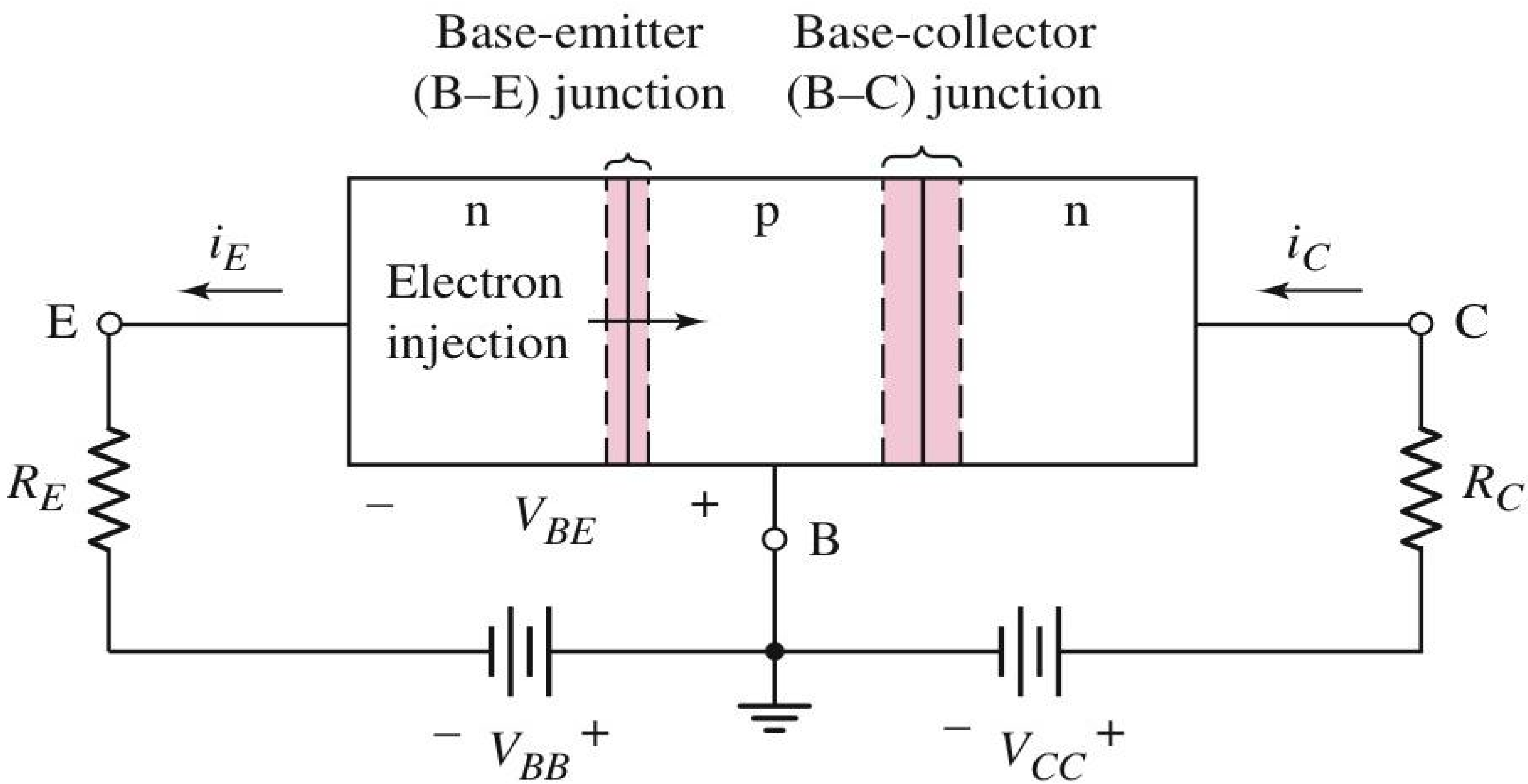
(1) Emitter region emit electrons into base.

(2) Collector region collect electrons injected base from emitter.

(3) B-E voltage controls collector current.

5.1.2 NPN Transistor: Forward-Active Mode Operation

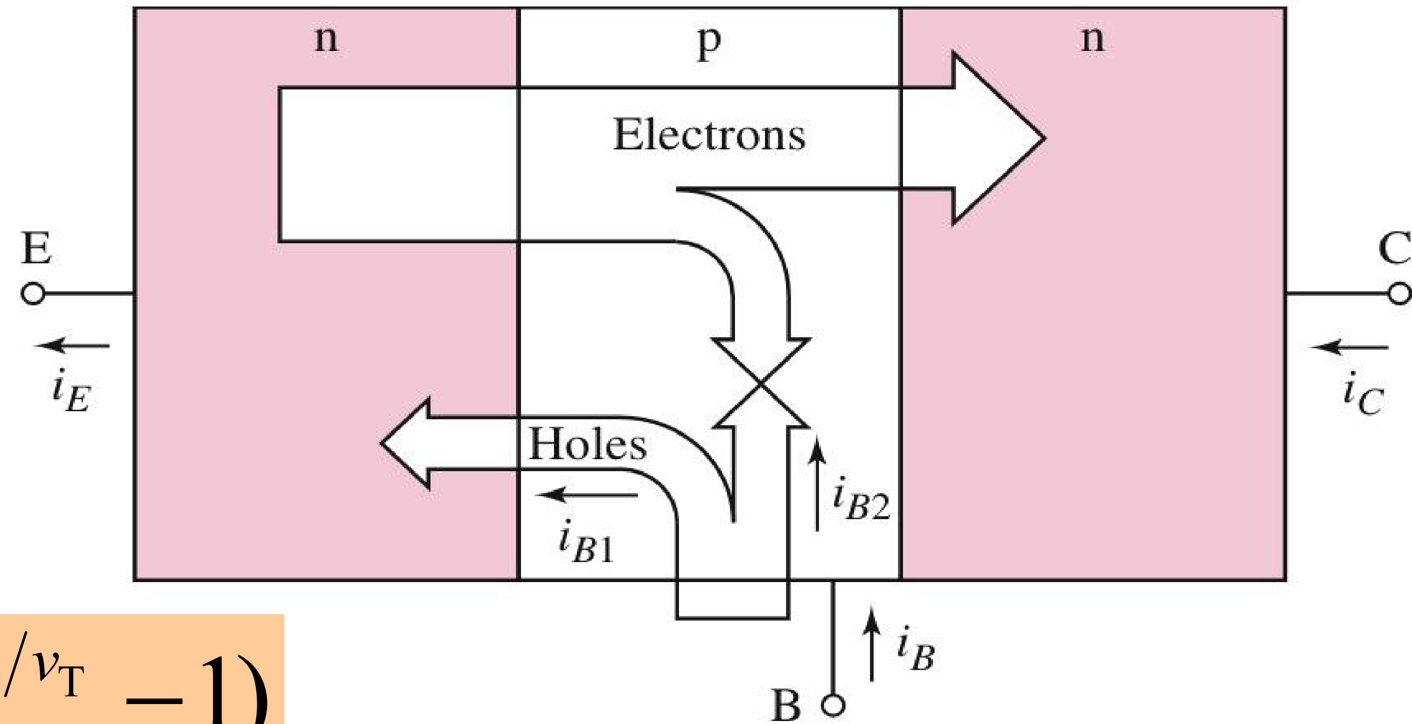
• **There are two types of carriers, electrons and holes contributing to the current, so the transistor is called bipolar junction transistor (BJT).**



5.1.2 NPN Transistor: Forward-Active Mode Operation

Electrons and Holes in NPN BJT（P290)

•**Emitter Current**



$$i_E = I_{ES}(e^{v_{BE}/v_T} - 1)$$
$$\approx I_{ES} e^{v_{BE}/v_T}$$

V_T __thermal voltage

I_{ES} __ emitter leakage current

2. Current relationships

- **We know from transfer process of carriers**

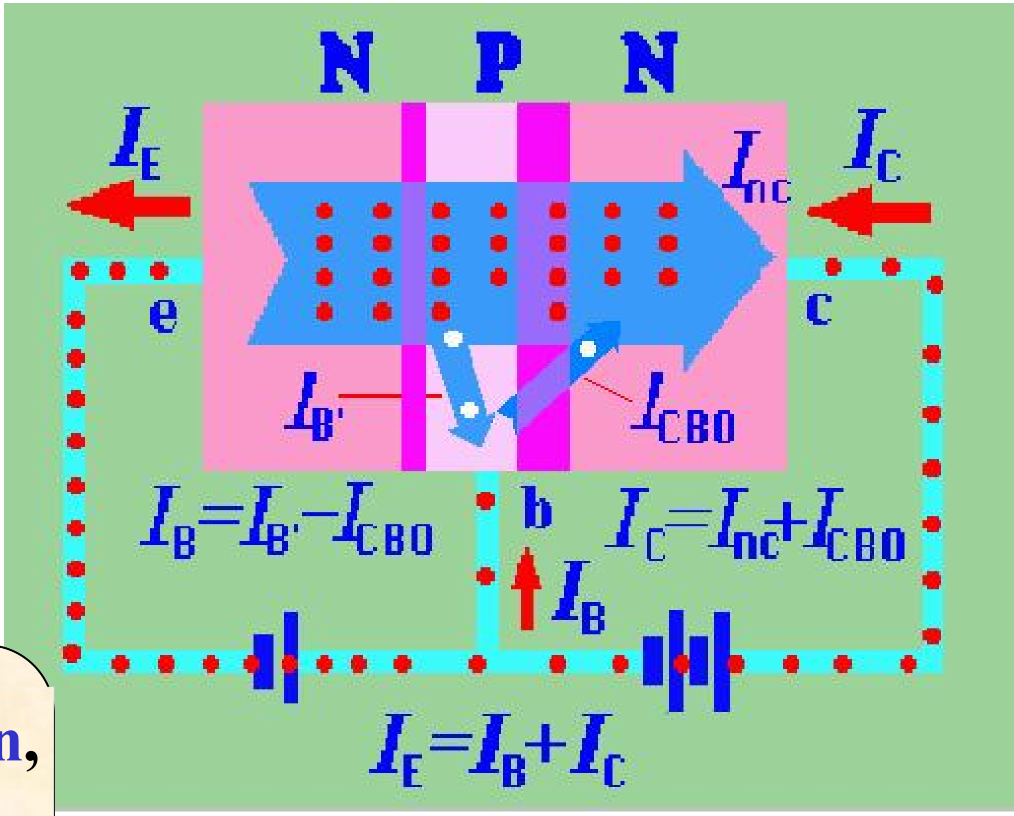
$$I_E = I_B + I_C, \quad I_C = I_{nC} + I_{CBO}, \quad I_B = I_{B'} - I_{CBO}$$

Assume $\alpha = \dfrac{\text{Collector current}}{\text{Emitter current}}$

that is $\alpha = \dfrac{I_{nC}}{I_E}$

generally $I_C >> I_{CBO}$

then $\boxed{\alpha \approx \dfrac{I_C}{I_E}}$



Transfer process of carriers

α --**common-base current gain, only depend on geometries and concentration, no relation with voltages. Generally** $\alpha = 0.9 \sim 0.99$

2. Current relationships

assume $\beta = \dfrac{\alpha}{1-\alpha}$ since $I_E = I_B + I_C$, $I_C = I_{nC} + I_{CBO}$, $\alpha = \dfrac{I_{nC}}{I_E}$

$$\beta = \frac{(I_C - I_{CBO})/I_E}{1-(I_C - I_{CBO})/I_E} = \frac{I_C - I_{CBO}}{I_E - I_C + I_{CBO}}$$

then $I_C = \beta(I_E - I_C) + (1+\beta)I_{CBO}$

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

then $\beta = \dfrac{I_C - I_{CEO}}{I_B}$ when $I_C >> I_{CEO}$, $\boxed{\beta \approx \dfrac{I_C}{I_B}}$

β **is common-emitter current gain, also, only depend on geometries and impurity concentration, independent of B-C and B-E voltages. Generally** $50 < \beta < 300$.

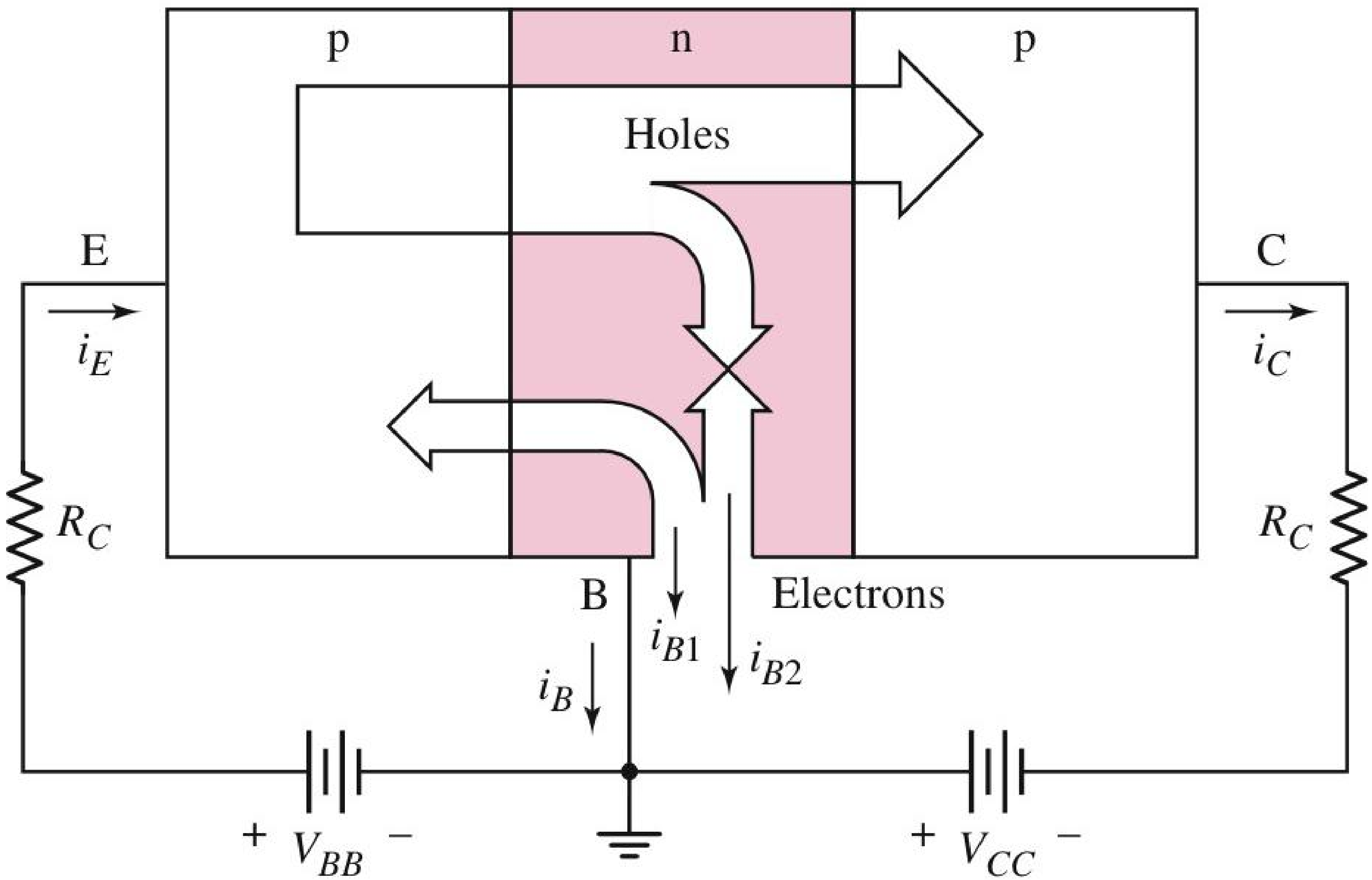
2. Current relationships

$$\boldsymbol{I}_{\mathbf{E}}=\boldsymbol{I}_{\mathbf{B}}+\boldsymbol{I}_{\mathbf{C}}$$

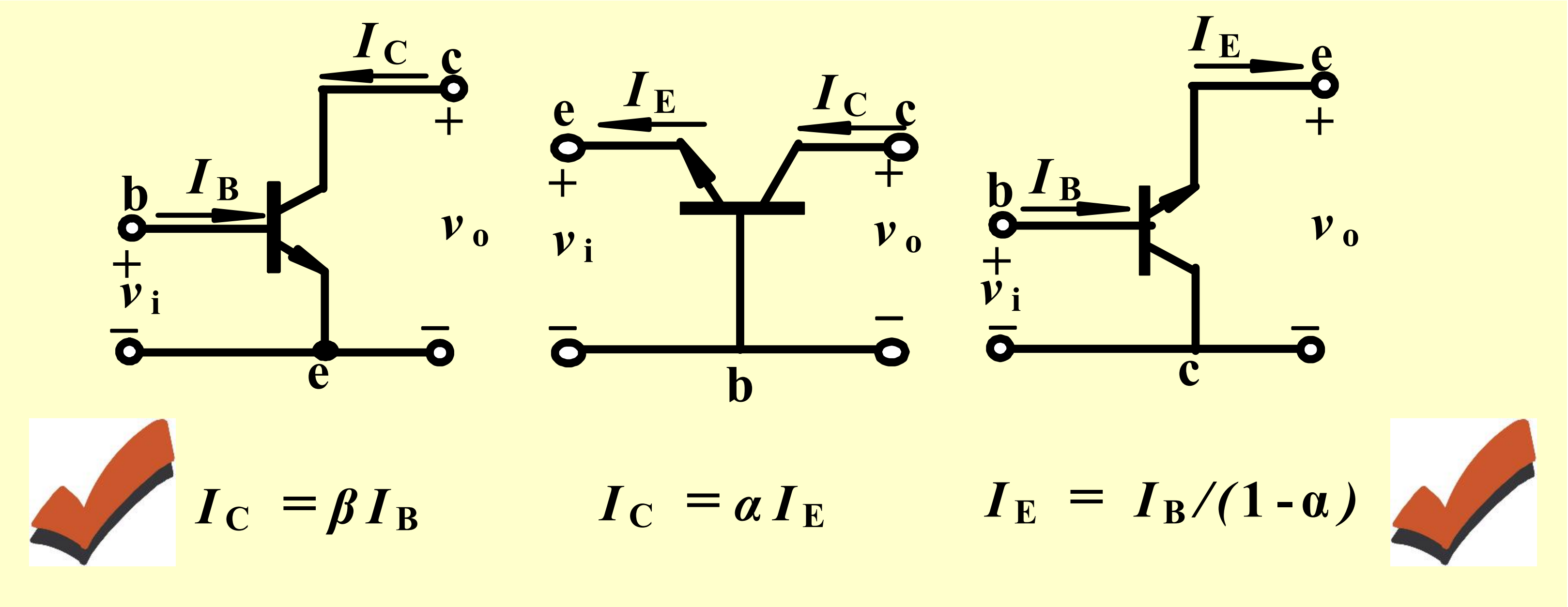
$$\alpha=\frac{I_C}{I_E} \Rightarrow I_C=\alpha I_E \qquad 1 \leftarrow \alpha<1$$

$$\beta=\frac{I_C}{I_B} \Rightarrow I_C=\beta I_B \qquad \beta>>1$$

5.1.3 PNP Transistor: Forward-Active Mode Operation



Three Types of Circuit Configurations



BJT Circuit Configurations

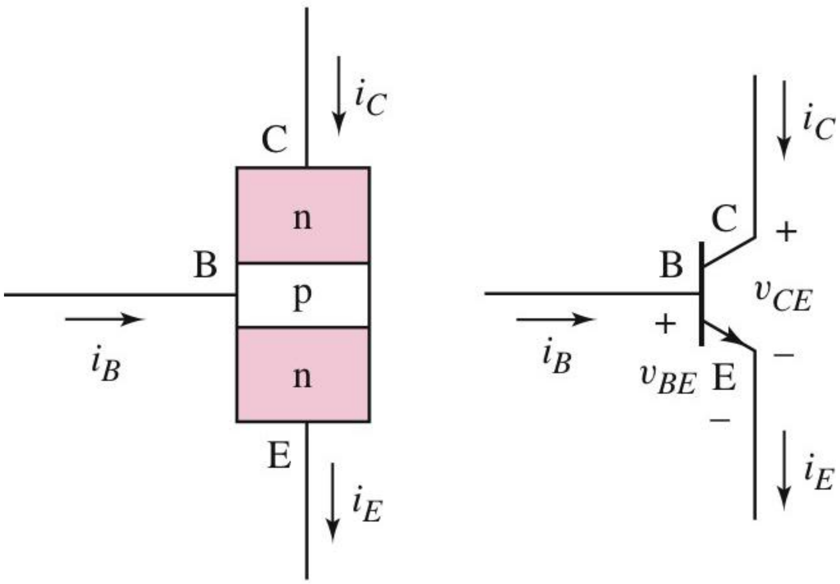
Common-emitter, **emitter is a common terminal**, **briefly CE**;

Common-base, **base is a common terminal**, **briefly CB**;

Common-collector, **collector is a common terminal**, **briefly CC**;

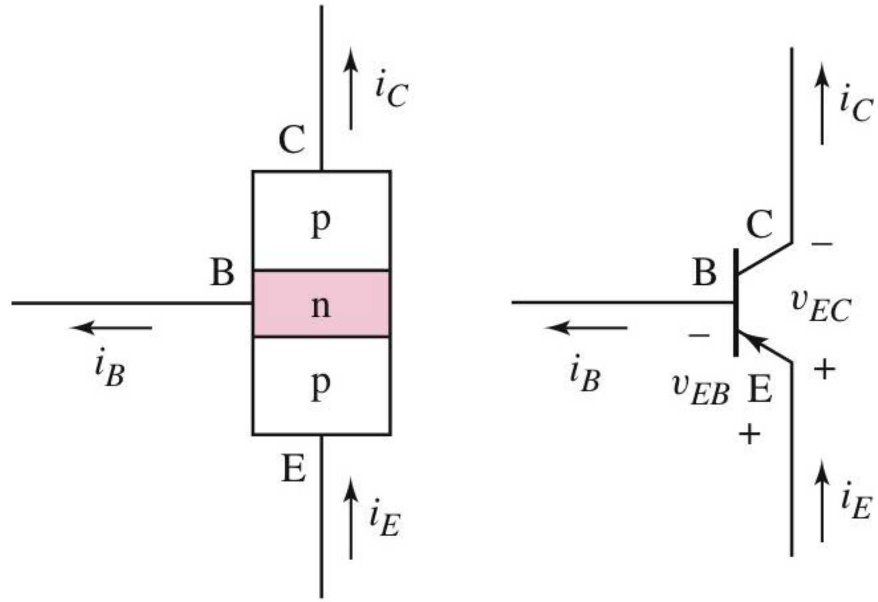
Which Configuration can amplify current?

5.1.4 Circuit Symbols and Conventions



(a) (b)

NPN



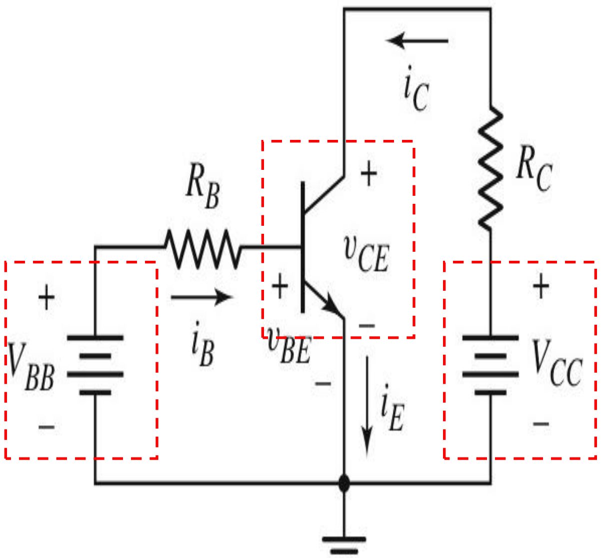
(a) (b)

PNP

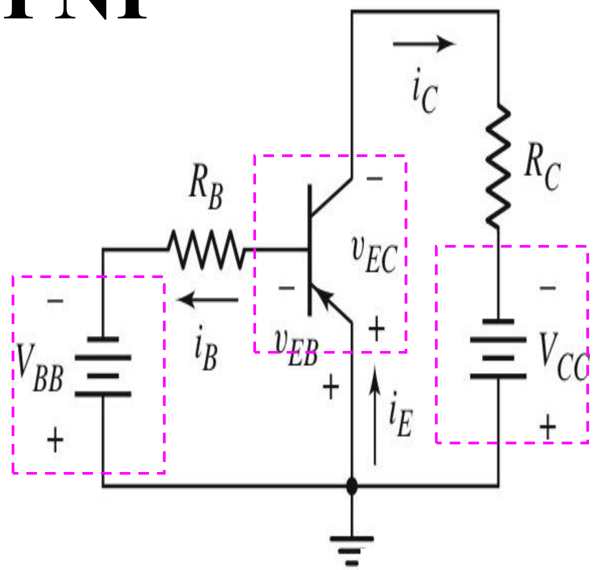
5.1.4 Circuit Symbols and Conventions

Common Emitter

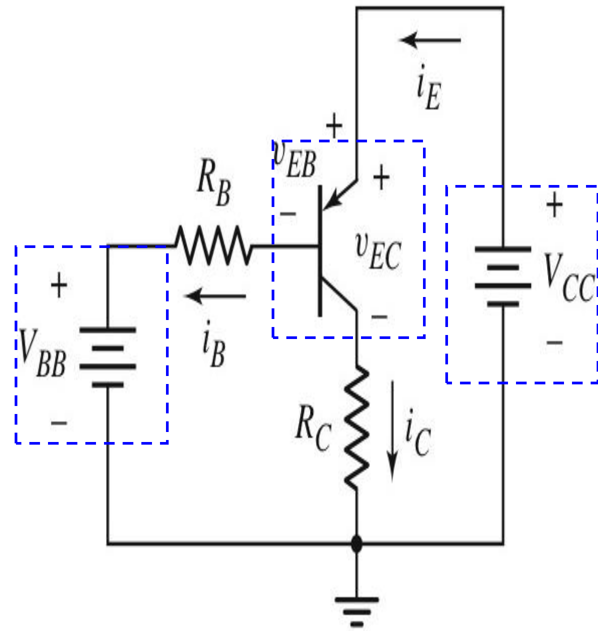
NPN

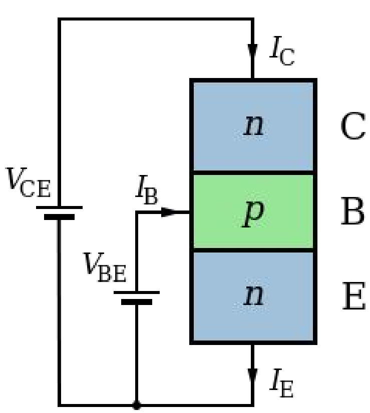


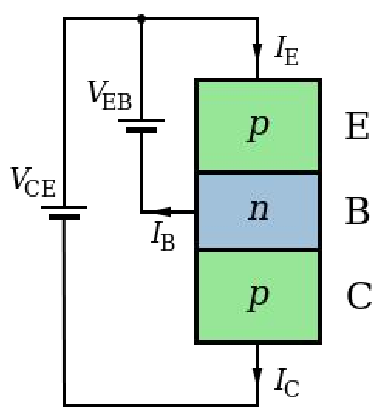
PNP



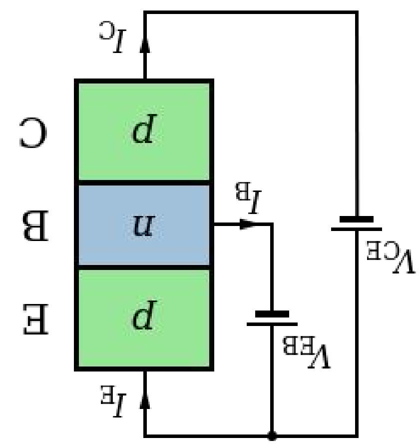
PNP







b)



(c)

5.1.5 Current-Voltage Characteristics

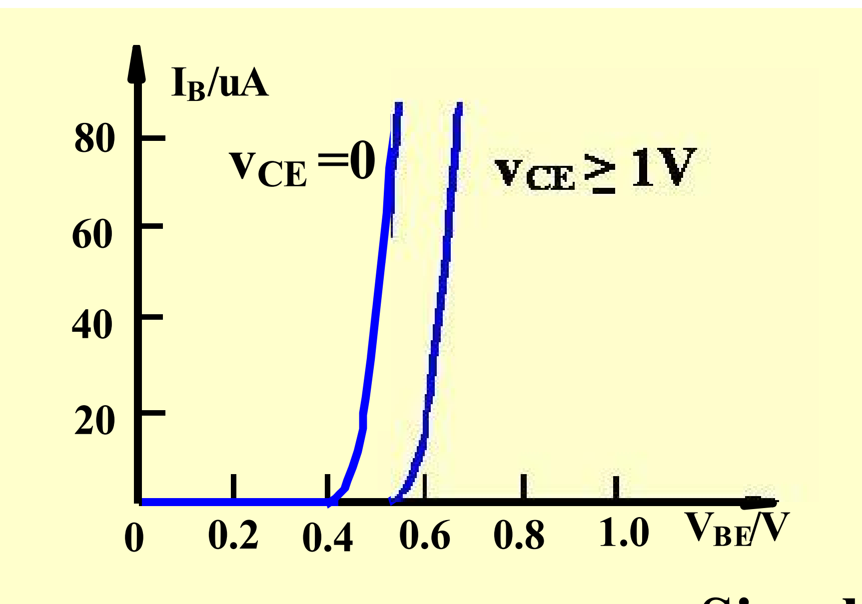
1. Input characteristic of CE

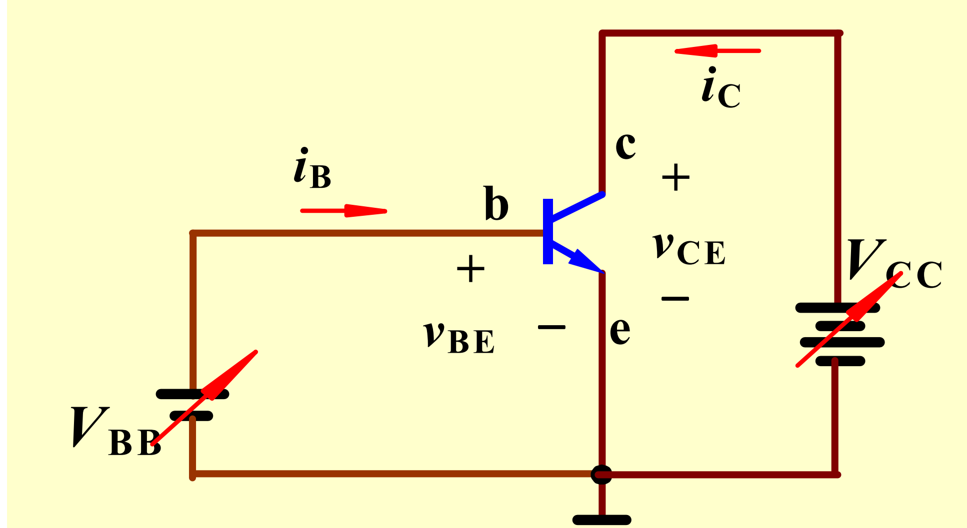
(Taking CE circuit as e.g.)

$$i_B = f(v_{BE})\big|_{v_{CE}=\text{const}}$$

(1) when v_{CE}=0V, it is same as forward exponential relation of a diode 。

(2) When v_{CE}≥1V， $v_{CB}= v_{CE}-v_{BE}$>0，B-C is reverse biased，some electrons begin to sweep into collector, recombination decreases in base, so I_B reduces under same v_{BE}， curve shifts to right。





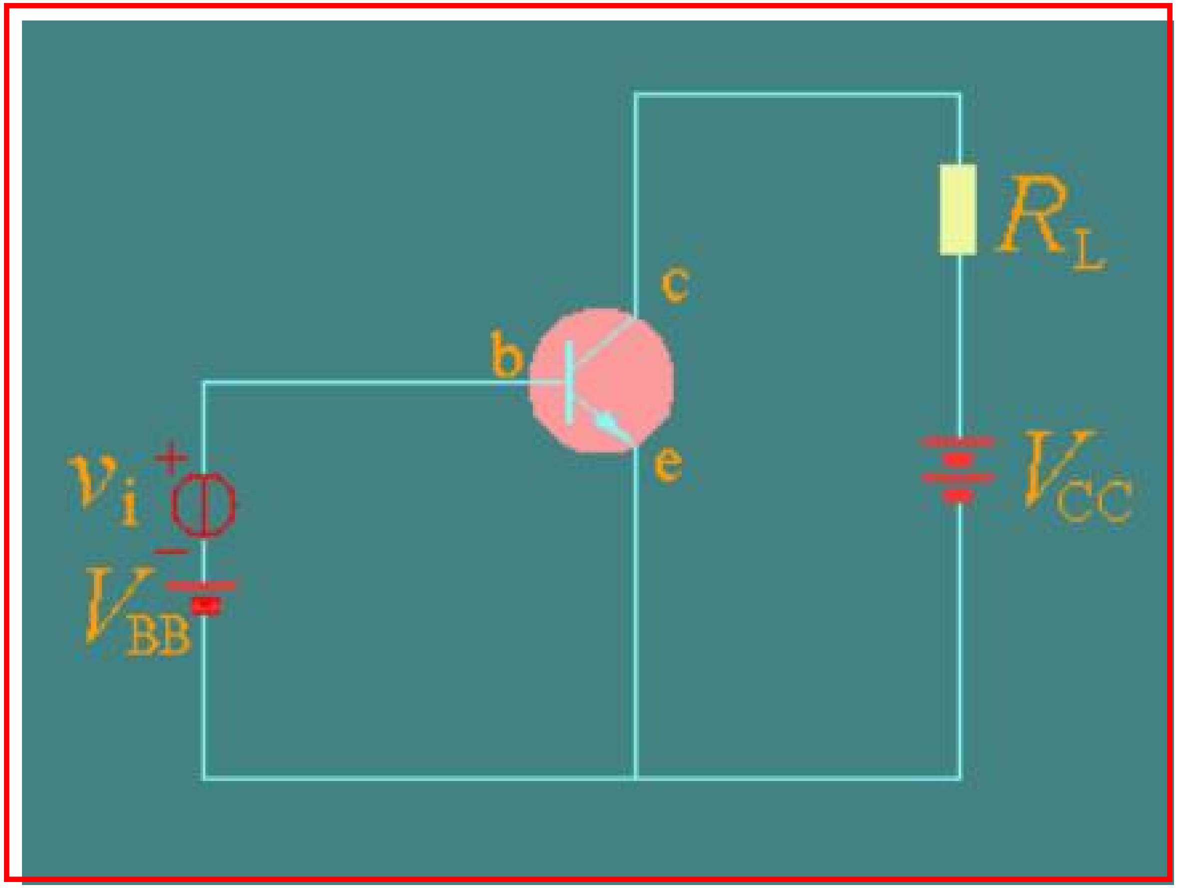
Common-emitter circuit

Simulation

5.1.5 Current-Voltage Characteristics

2. The output Characteristic of CE

$$i_C = f(v_{CE})\Big|_{i_B=\text{const}}$$



Simulation

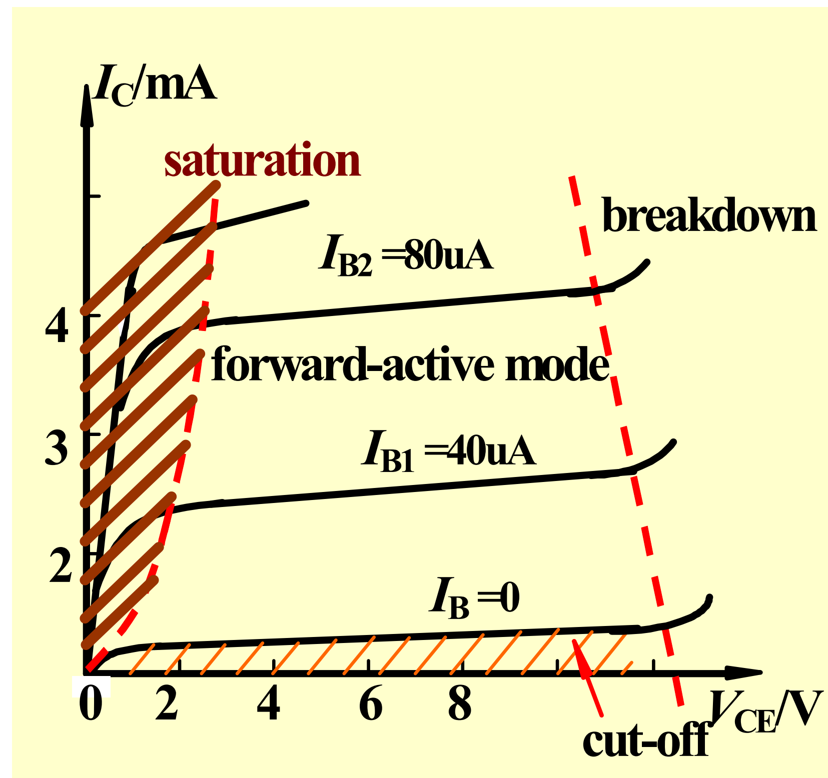
5.1.5 Current-Voltage Characteristics

2. Output characteristic of CE (Transistor characteristic)

$$i_C = f(v_{CE})\big|_{i_B=\text{const}}$$

Four regions for characteristic

Saturation： i_C **is controlled by** v_{CE}**,** i_C **increases rapidly as** v_{CE} **increases, and** v_{CE} **< 0.7V (Silicon)。 B-E is forward biased, B-C is forward biased, too, or voltage of reverse biased is very small.**



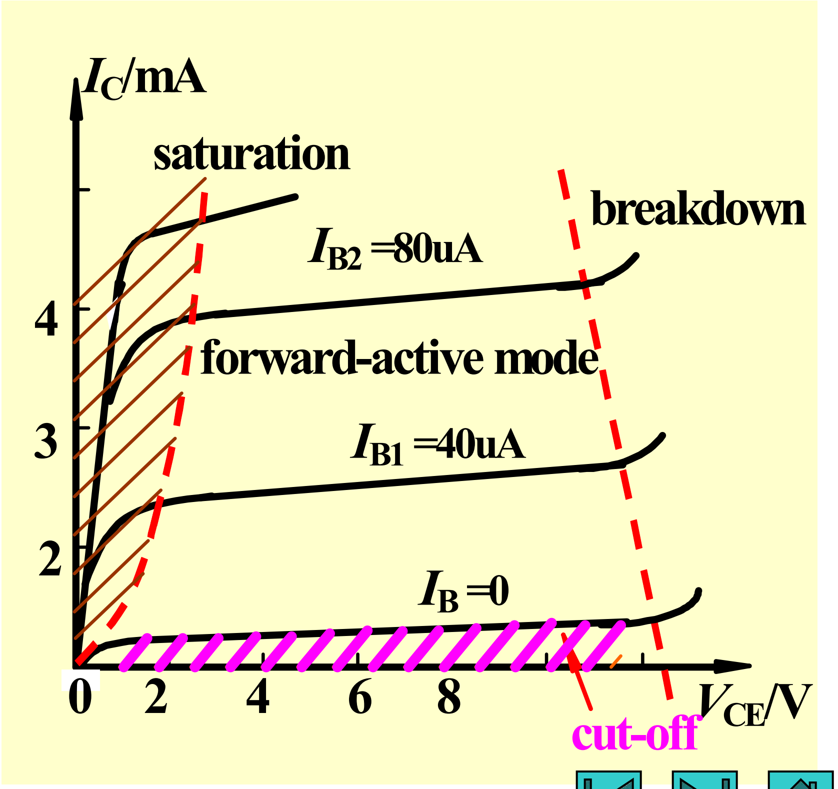
5.1.5 Current-Voltage Characteristics

2. Output characteristic of CE (Transistor characteristic)

$$i_C = f(v_{CE})\Big|_{i_B=\text{const}}$$

Four regions for characteristic

Cut-off: i_C **is nearly zero, Cut-off region is under** i_B**=0。** $V_{BE} < V_{th}$ (turn in voltage), **B-C is reverse biased。**



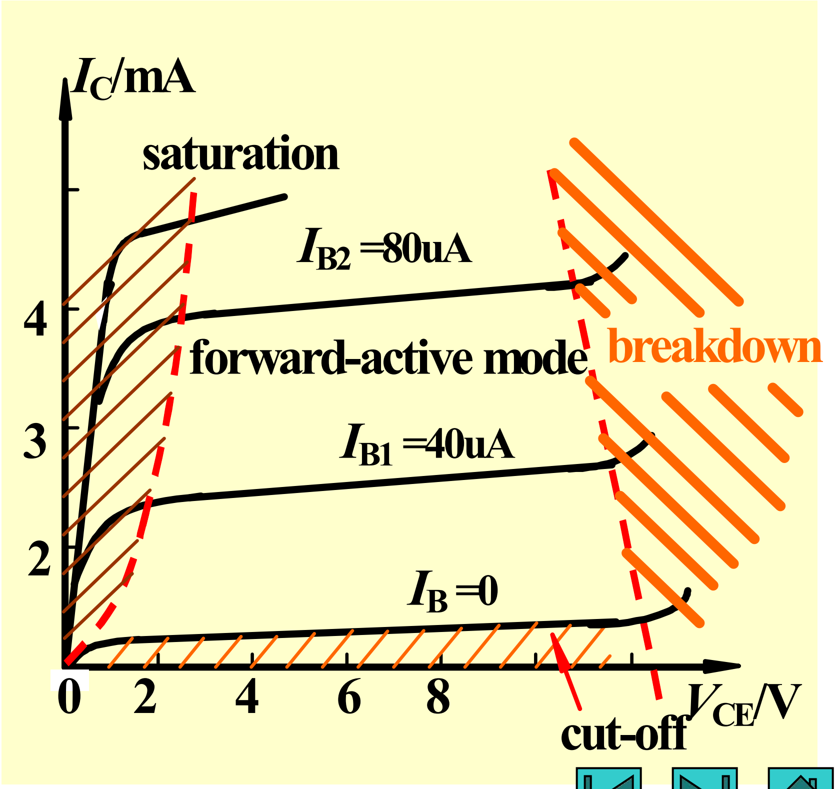
5.1.5 Current-Voltage Characteristics

2. Output characteristic of CE (Transistor characteristic)

$$i_C = f(v_{CE})\Big|_{i_B=\text{const}}$$

Four regions for characteristic

Breakdown: **Reverse-bias voltage of B-C increases too much, B-C junction begin to breakdown.**



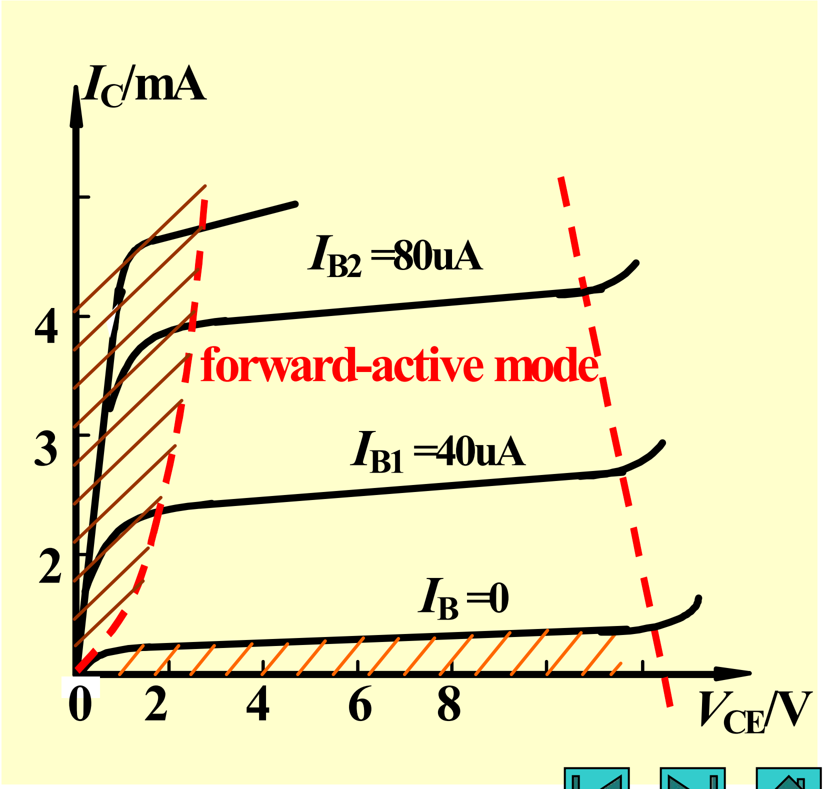
5.1.5 Current-Voltage Characteristics

2. Output characteristic of CE (Transistor characteristic)

$$i_C = f(v_{CE})\big|_{i_B=\text{const}}$$

Four regions for characteristic

Forward-active mode: i_C and i_B are related by $i_C = \beta i_B$. Curves are parallel and equidistance. B-E is forward biased, B-C is reverse biased.



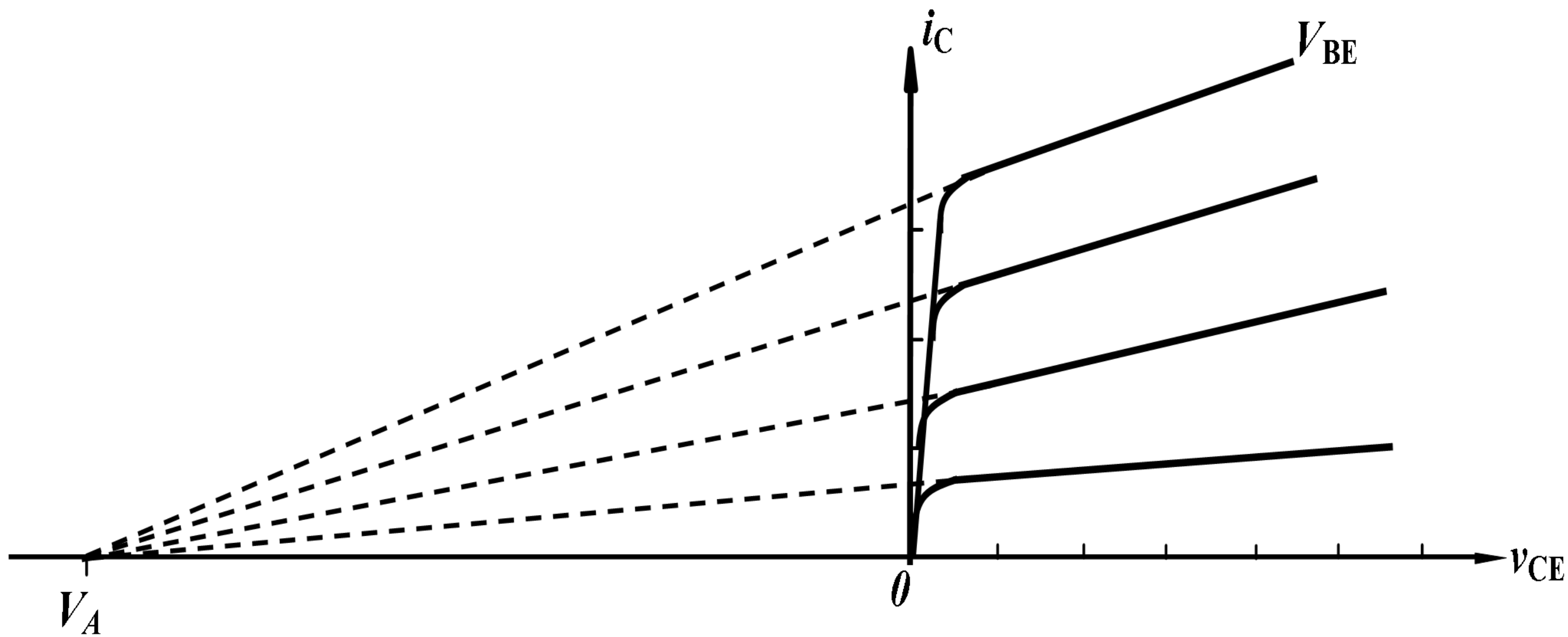
Modes of Operation

Modes	EBJ	CBJ
Cutoff	Reverse	Reverse
Saturation	Forward	Forward
Active	Forward	Reverse

5.1.5 Current-Voltage Characteristics

2. The output Characteristic of CE

Current-voltage characteristics for the common-emitter circuit, showing the Early voltage

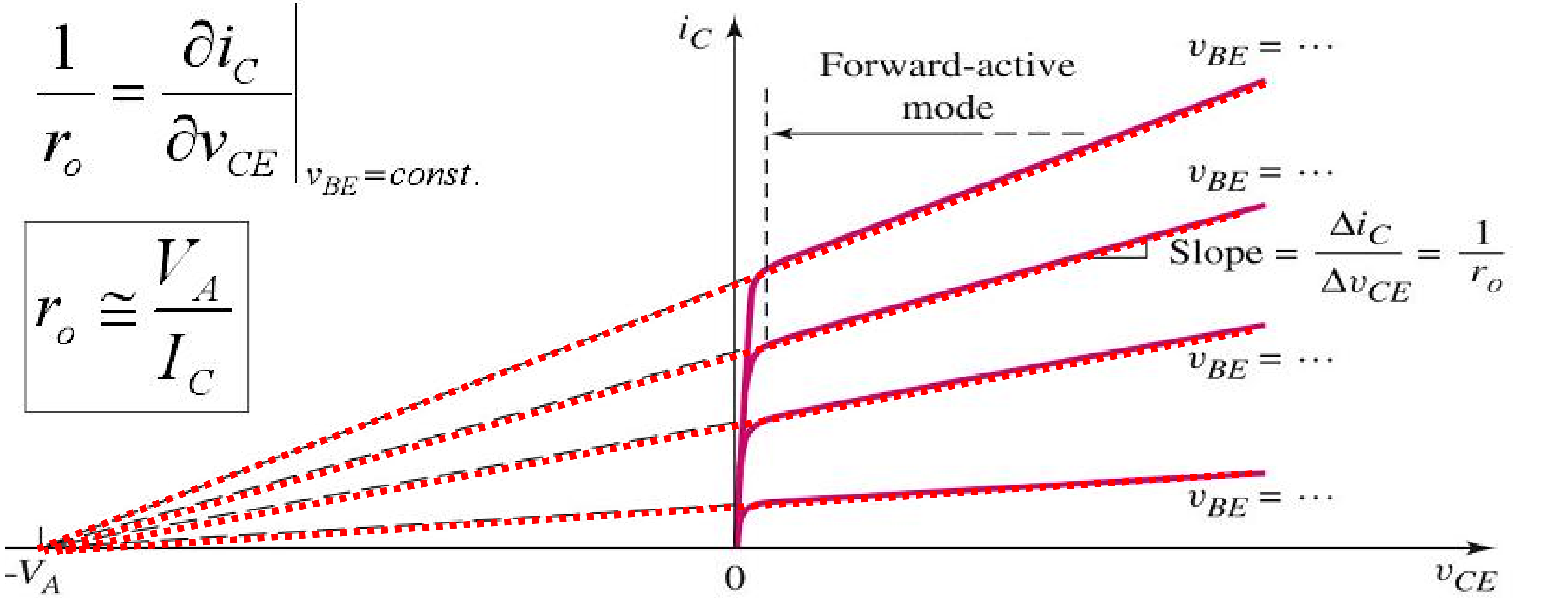


5.1.5 Current-Voltage Characteristics

2. The output Characteristic of CE

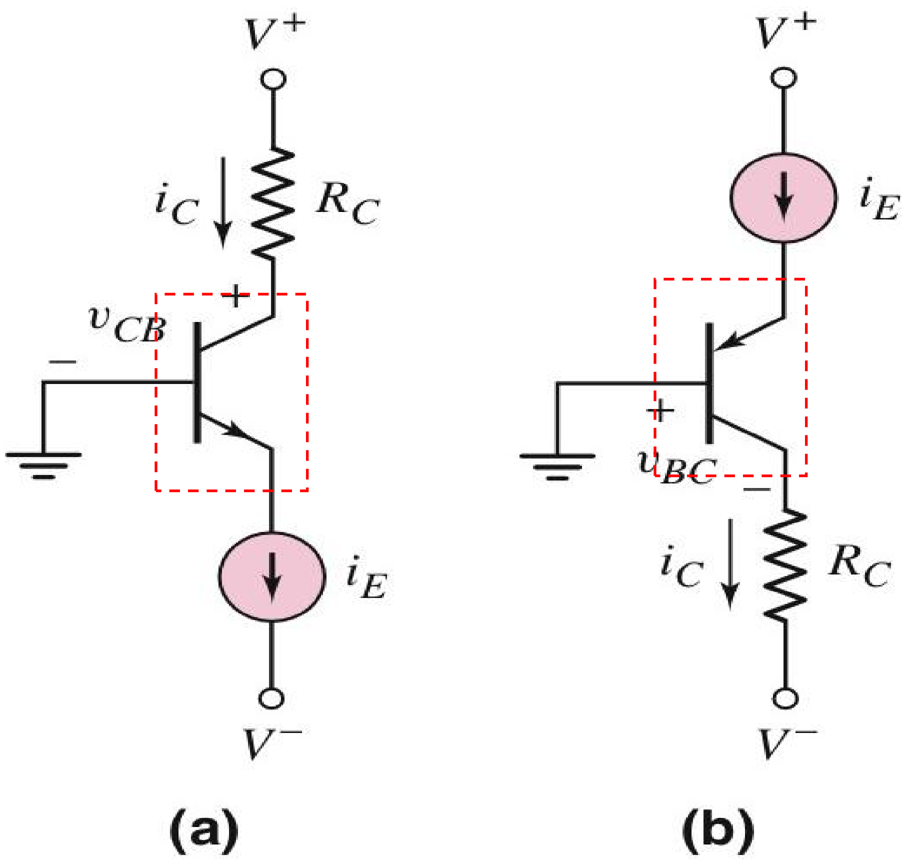
$$\frac{1}{r_o} = \left.\frac{\partial i_C}{\partial v_{CE}}\right|_{v_{BE}=const.}$$

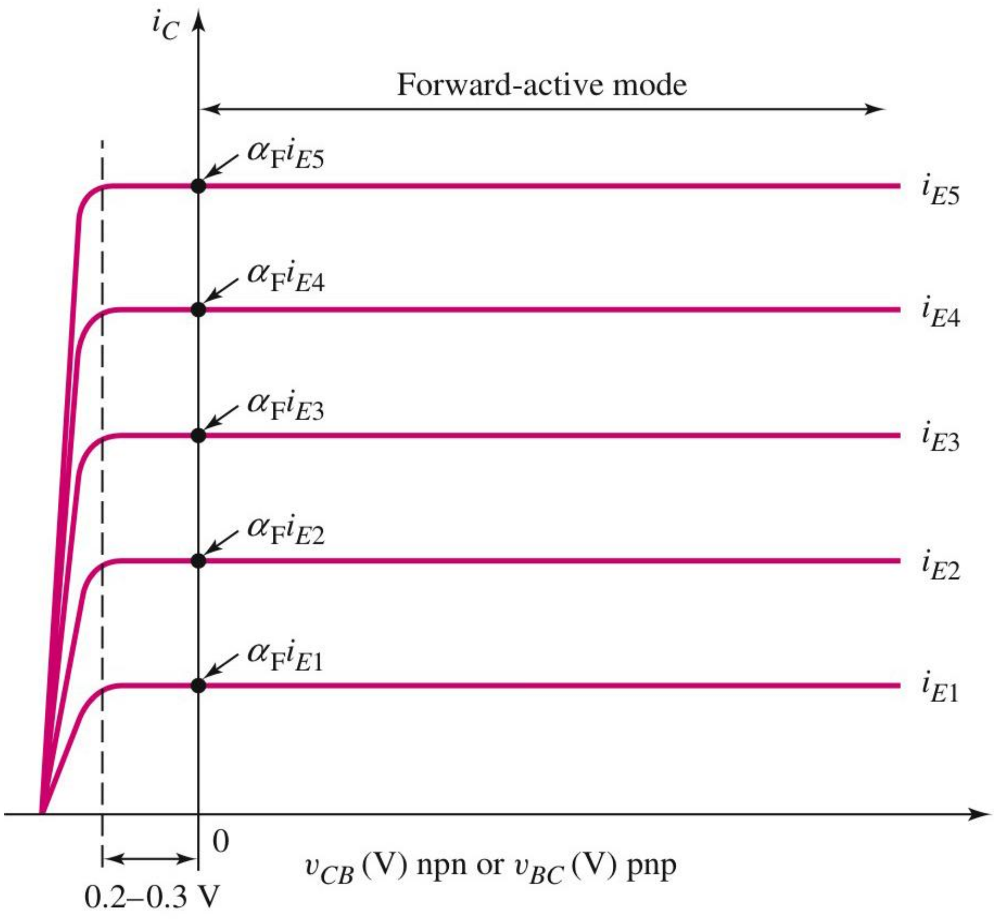
$$\boxed{r_o \cong \frac{V_A}{I_C}}$$



- V_A: Early voltage : a point at negative voltage axis where all curves meet
- Nonzero slope: finite output resistance r_o looking into collector

5.1.5 Current-voltage Characteristics





Common Base

Current-voltage Characteristics

1. Reverse-bias Leakage Currents

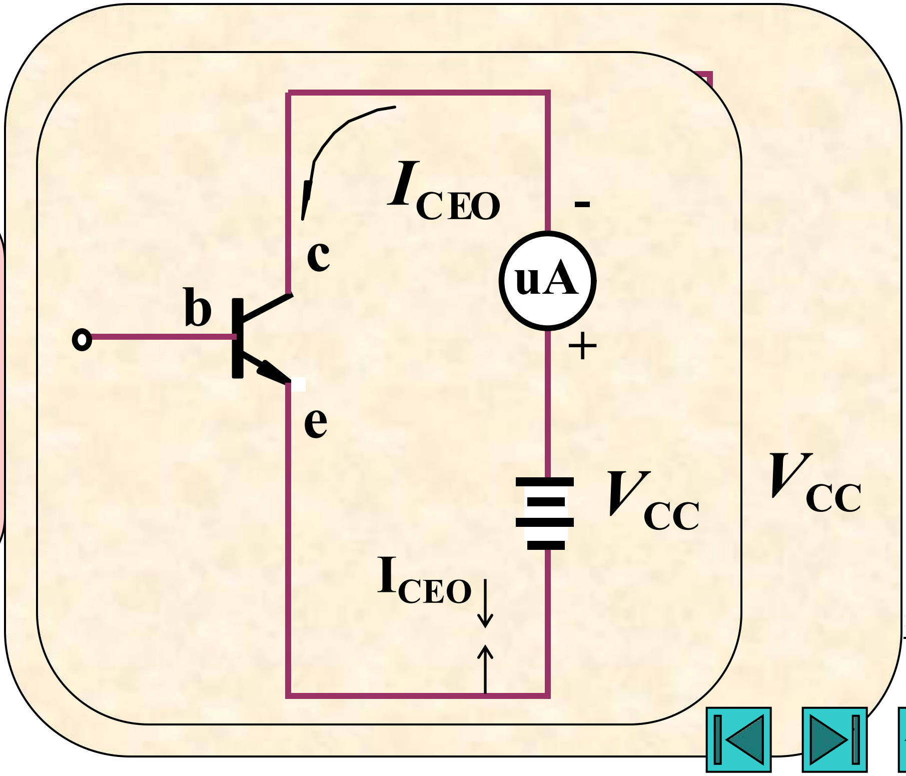
(1) Collector-base leakage current I_{CBO}

I_{CBO} is the collector leakage current in common-base configuration, when the emitter is an open circuit.

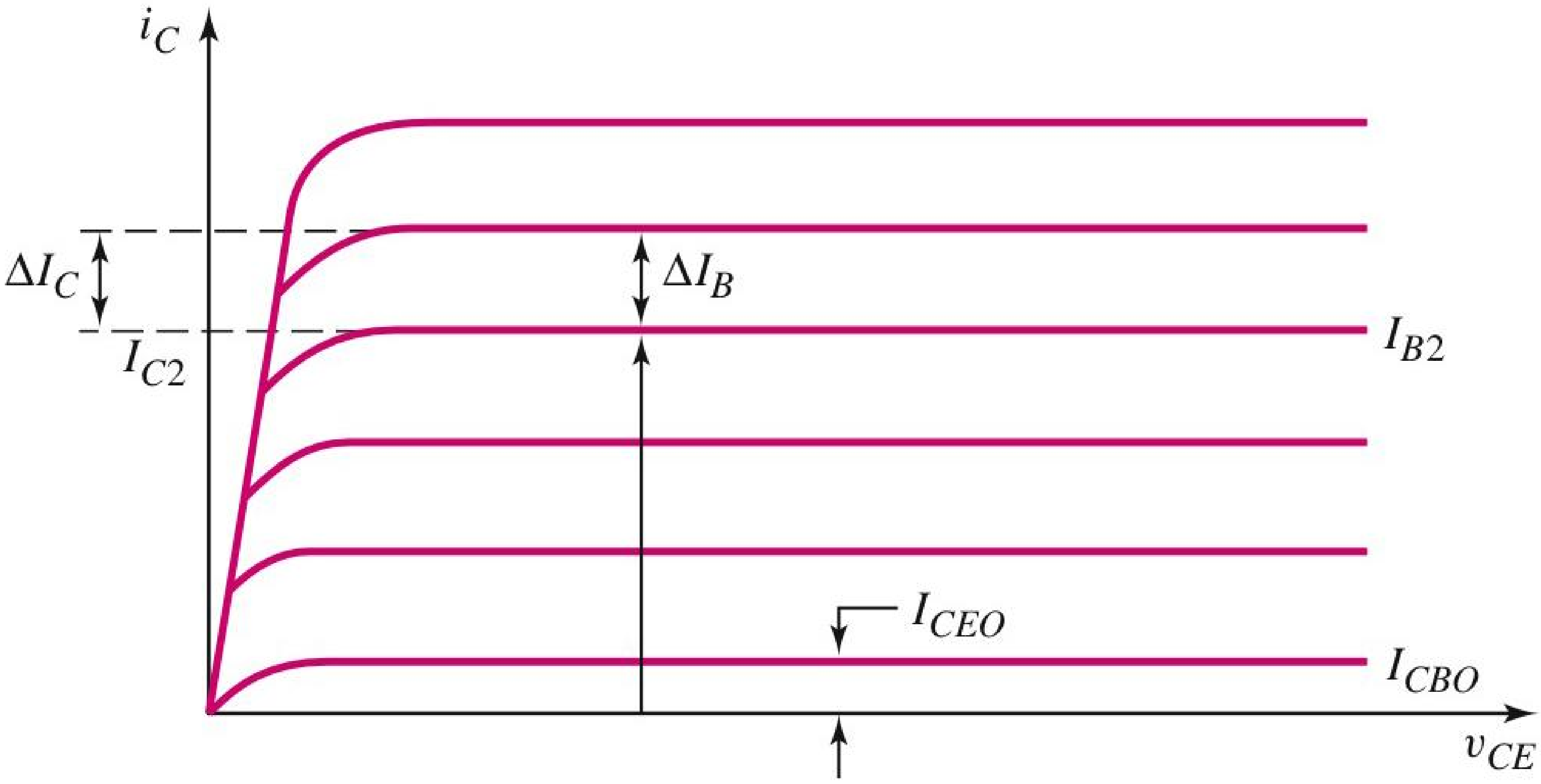
(2) Collector-emitter leakage current I_{CEO}

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

In most instances in this text, leakage will be completely negligible.



Effects of Leakage Currents on I-V Characteristics



5.1.6 Nonideal Transistor Leakage Current and Breakdown Voltage

2. Breakdown Voltage

BV_{CBO}——Collector-base junction breakdown voltage in open-emitter configuration。

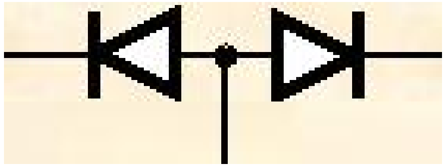
BV_{CEO}——Breakdown voltage between collector and emitter in open-base configuration.

BV_{EBO}——Base-emitter junction breakdown voltage in open-collector configuration。

$$V_{(BR)CBO} > V_{(BR)CEO} > V_{(BR)EBO}$$

•These will be a limiting factors in the size of the dc bias voltages which can be used.

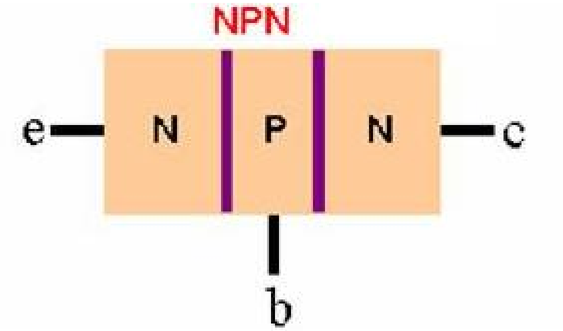
Review Questions



(1) Due to a BJT has two pn junction, can we conjoin two back-to-back diodes to be as a BJT? Why?

(2) Can we exchange the emitter and collector terminals of a BJT, when we use it as a amplifying device?

(3) Why we call a BJT as a current-controlled device?



Review Questions

4. The voltage values for three terminals are given, determine the region which BJT operates in.

(1) V_C=6V , V_B=0.7V , V_E=0V ,

(2) V_C=6V , V_B=6V , V_E=5.4V ,

(3) V_C=6V , V_B=4V , V_E=3.6V ,

(4) V_C=3.6V , V_B=4V , V_E=3.4V ,

(1)$V_C=6V, V_B=0.7V, V_E=0V$

$\Rightarrow$ $V_{BE}=0.7V > V_{th}=0.5V$

$V_{CE}=6V$

$V_C > V_B > V_E$

Forward active region

(2)V_C=6V,V_B=6V, V_E=5.4V

$\Rightarrow$ **V_{BE}=0.6V> V_{th}=0.5V**

V_{CE}=0.6V

V_C=V_B>V_E

Saturation Region

(3)V_C=6V,V_B=4V, V_E=3.6V

V_{BE}=0.4V<0.5V

Cut off region

4) V_C=3.6V, V_B=4V, V_E=3.4V

$\Rightarrow$ V_{BE}=0.6V

V_{CE}=0.2V

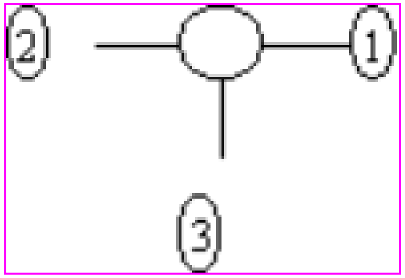
Saturation Region

Review Questions

5.Assume $I_1 = -1.2mA$, $I_2 = -0.03mA$, $I_3 = 1.23mA$,

(1) Determine ① is C , ② is B , ③ is E 。

(2) β=? **1.2/0.03=40**



Review Questions

6. In an amplifier, the voltage of the three terminals is
0V， - 10V， -9.3V，
Determine the BJT is NPN or PNP, is made of Si or Ge?

Sol:

0V， -10V， -9.3V

C ⇒ $U_C > U_B > U_E$ ⇒ **NPN**

$V_{BE} = 0.7V$ ⇒ **Si**

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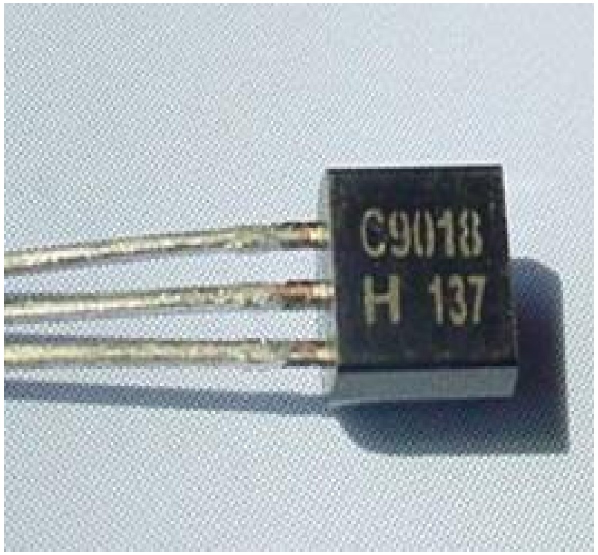
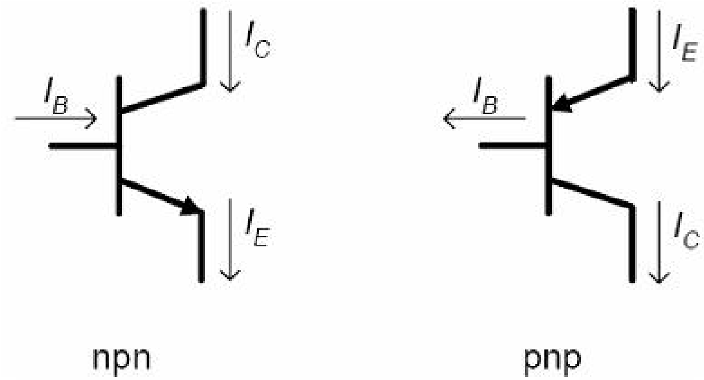
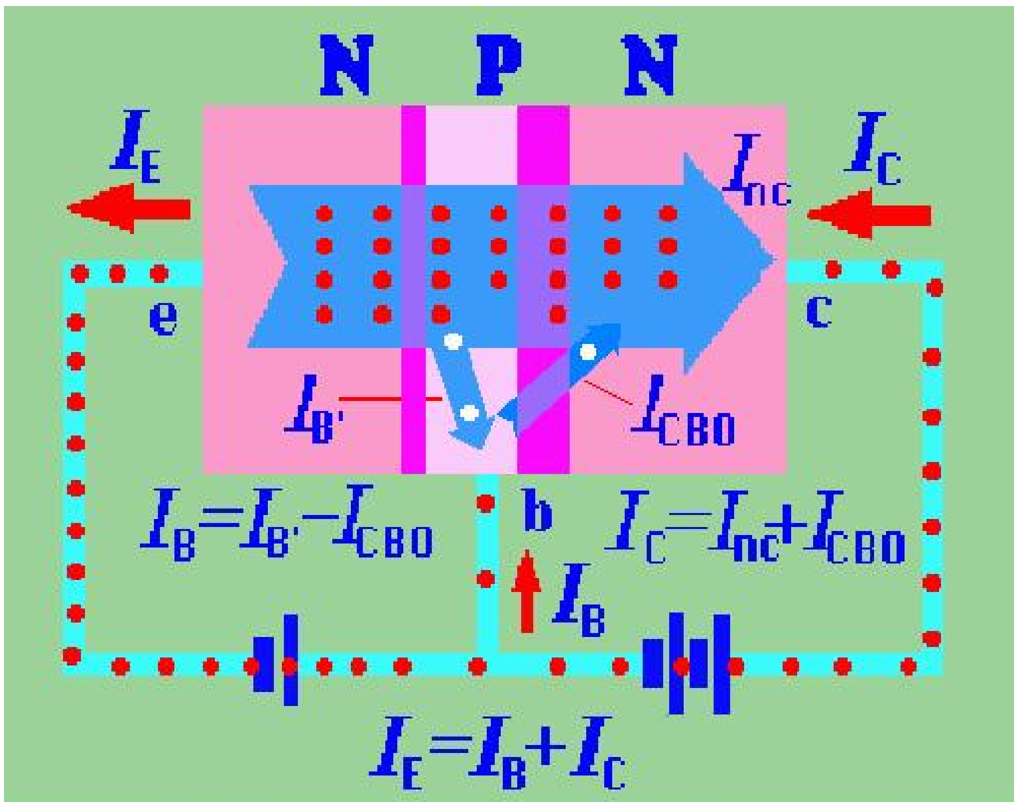




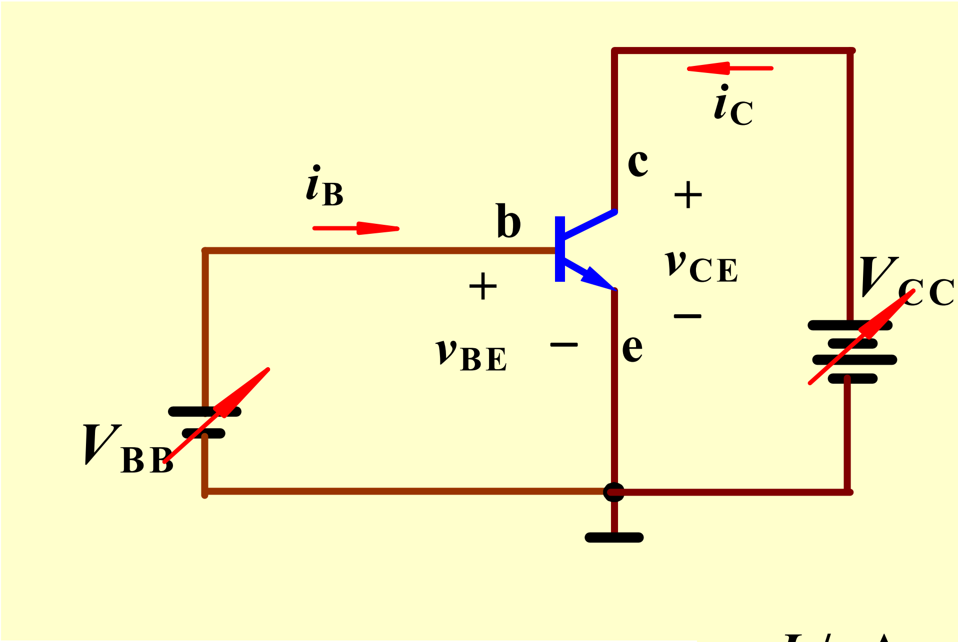


Transfer process of carriers

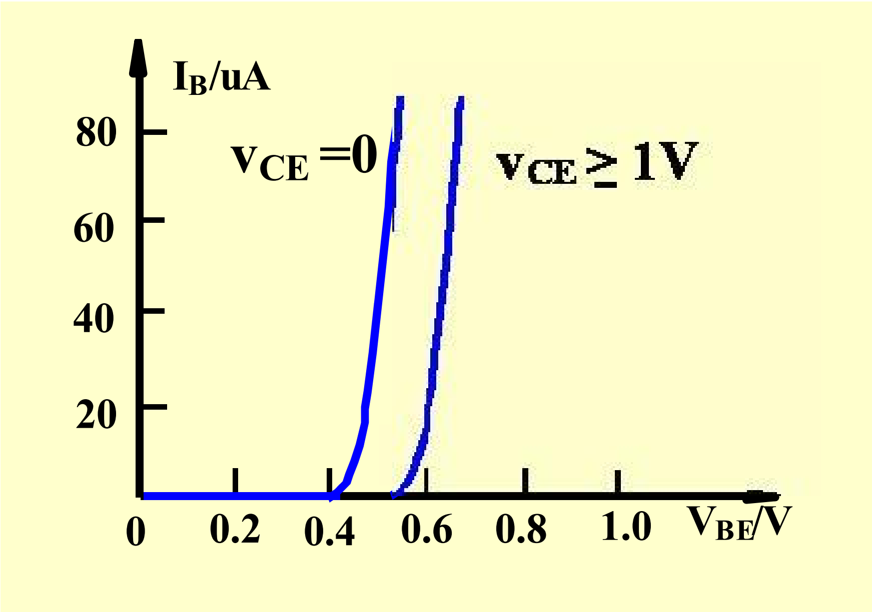
$$I_E = I_B + I_C$$

$$\alpha = \frac{I_C}{I_E}$$

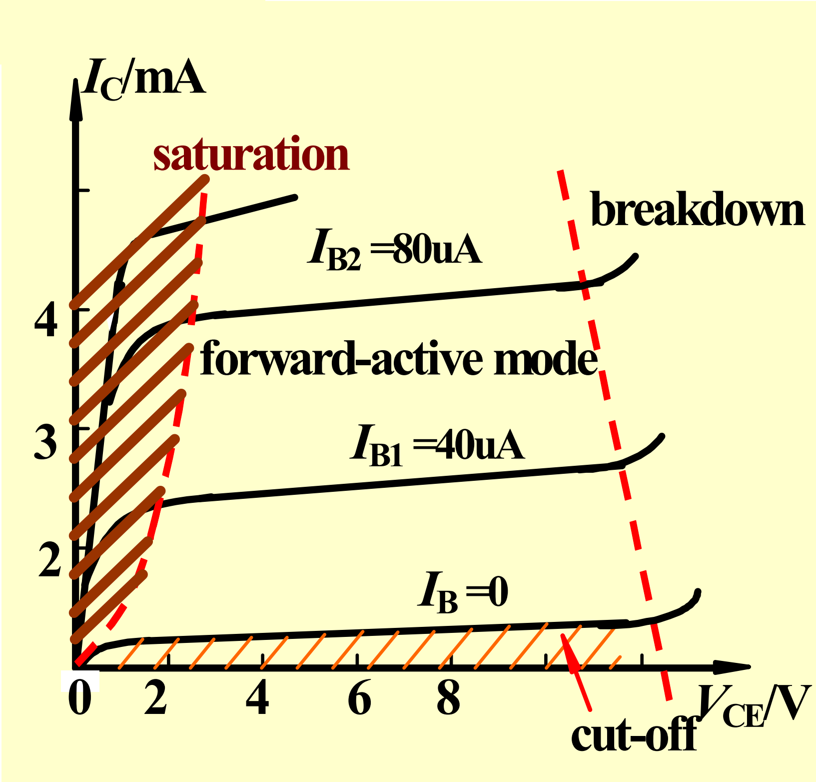
$$\beta = \frac{I_C}{I_B}$$



i_C
c
i_B
b
+
v_{CE}
−
V_{CC}
+
v_{BE}
−
e
V_{BB}



I_B/uA
80
60
40
20
v_{CE} =0
$v_{CE} \geq 1$V
0
0.2
0.4
0.6
0.8
1.0
V_{BE}/V



I_C/mA
saturation
breakdown
I_{B2} =80uA
4
forward-active mode
3
I_{B1} =40uA
2
I_B =0
0
2
4
6
8
V_{CE}/V
cut-off

Ch5. The Bipolar Junction Transistor

5.2 DC Analysis of Transistor Circuits(P303)

5.2.1 Common Emitter Circuit

5.2.2 Load Line and Modes of Operation

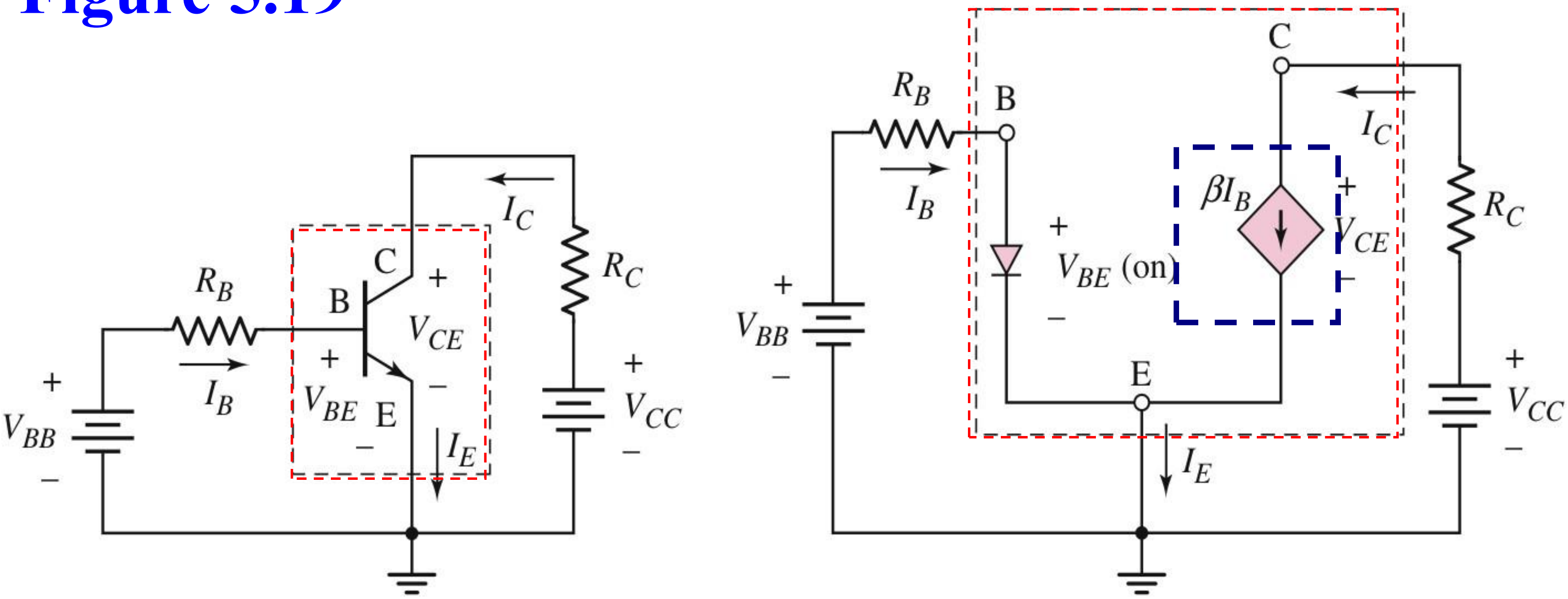
5.2.3 Voltage Transfer Characteristics

5.2.4 Commonly Used Bipolar Circuit : DC Analysis

5.2.1 Common Emitter Circuit

DC Equivalent Circuit

Figure 5.19



(a) (b)

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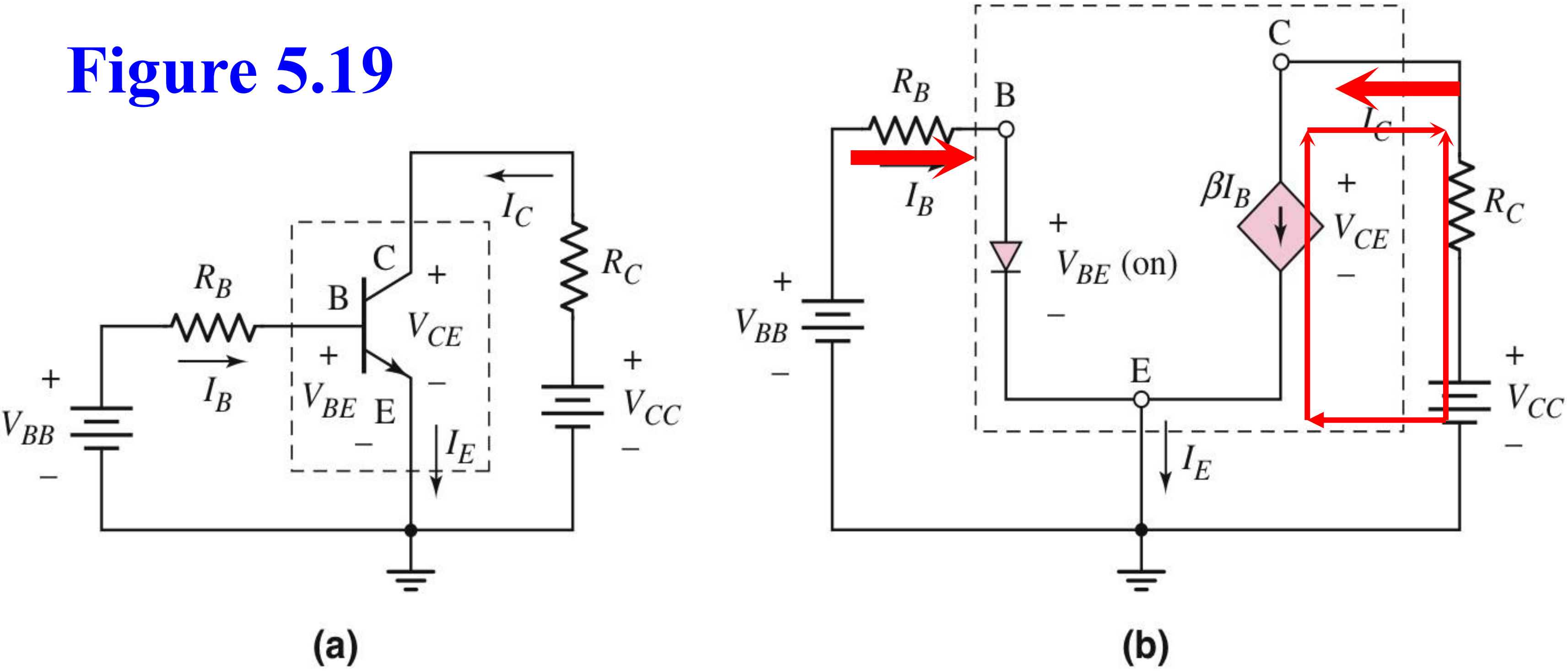
Common Emitter Circuit

$$\beta I_B = I_C$$

5.2.1 Common Emitter Circuit

Figure 5.19



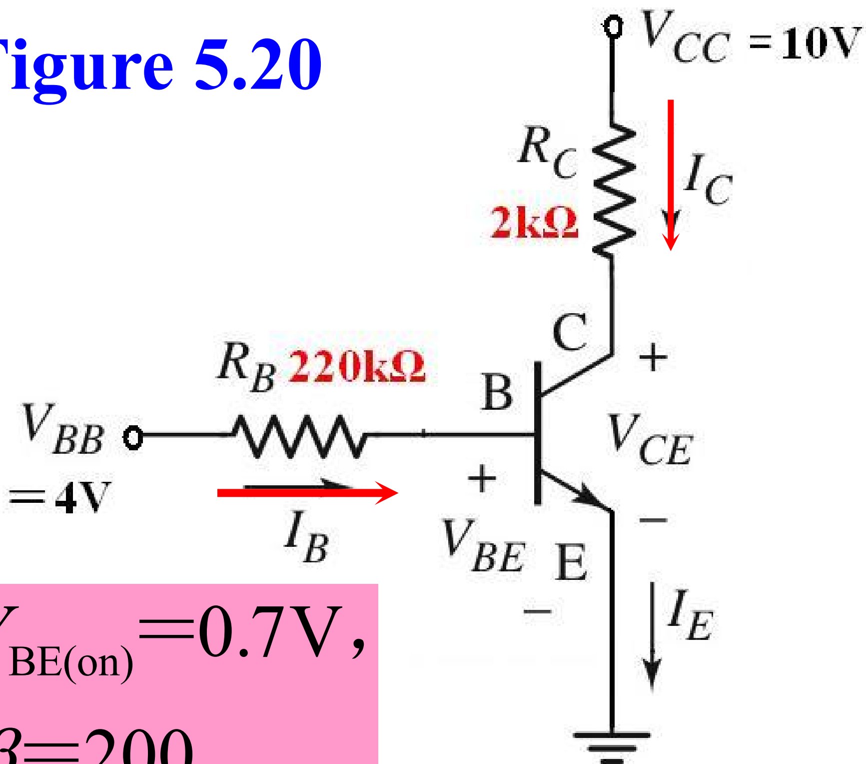
$$I_B = \frac{V_{\mathrm{BB}} - V_{\mathrm{BE(on)}}}{R_{\mathrm{B}}}$$

$$V_{\mathrm{CE}} = V_{\mathrm{CC}} - I_{\mathrm{C}} R_{\mathrm{C}}$$

$$I_{\mathrm{C}} = \beta I_{\mathrm{B}}$$

5.2.1 Common Emitter Circuit

Figure 5.20



$V_{BE(on)}$=0.7V,

β=200

Calculate the Q-point (I_B, I_C, V_{CE}).

Simulation

$$I_B = \frac{V_{BB} - V_{BE(on)}}{R_B}$$

$$= \frac{4 - 0.7}{220} = 15\mu A$$

$$I_C = \beta I_B$$

$$= 200 \cdot 15\mu A = 3mA$$

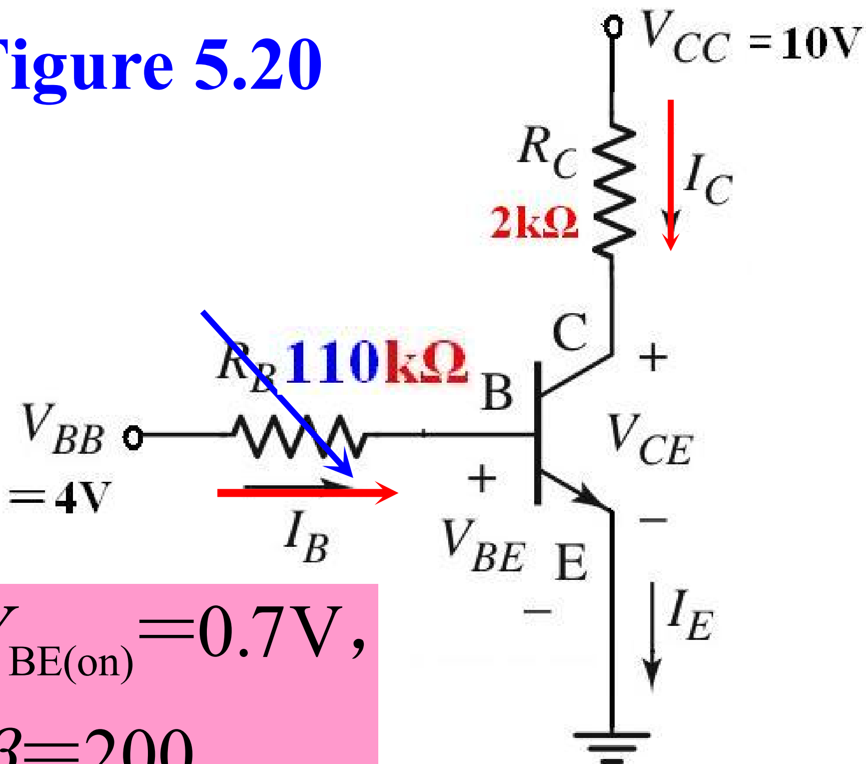
$$V_{CE} = V_{CC} - I_C R_C$$

$$= 10 - 3 \cdot 2$$

$$= 4V > 1V$$

5.2.1 Common Emitter Circuit

Figure 5.20



$V_{BE(on)}=0.7V$,

$\beta=200$

Calculate the Q-point (I_B, I_C, V_{CE}).

$$I_B=\frac{V_{BB}-V_{BE(on)}}{R_B}$$

$$=\frac{4-0.7}{110}=30\mu A$$

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

$$=200\cdot 30\mu A=6mA$$

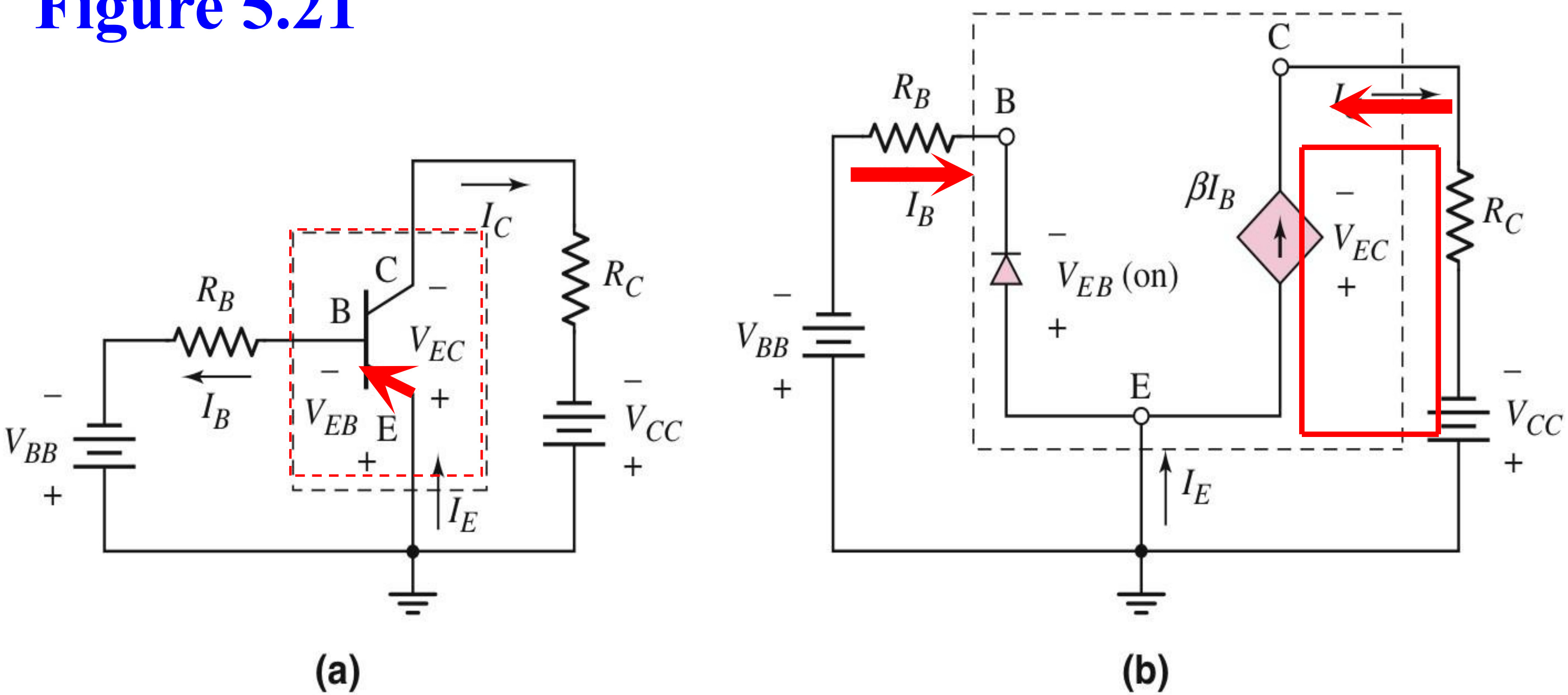
$$V_{CE}=V_{CC}-I_C R_C$$

$$=10-6\cdot 2$$

$$=-2V$$

5.2.1 Common Emitter Circuit

Figure 5.21



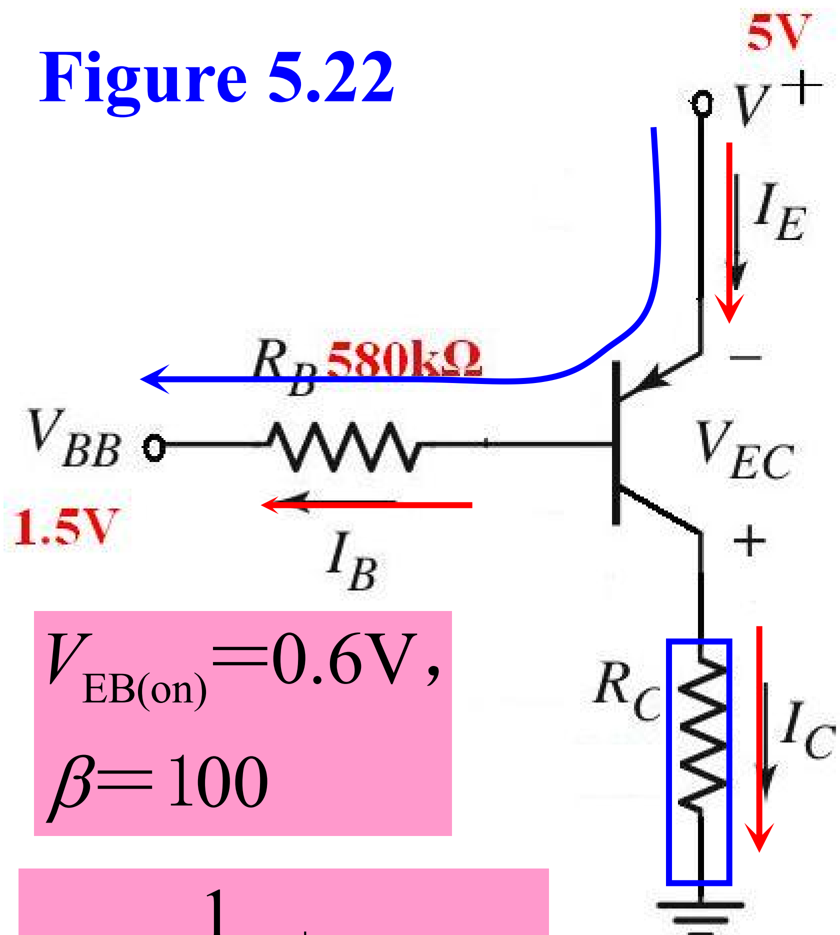
$$I_B = \frac{V_{\mathrm{BB}} - V_{\mathrm{EB(on)}}}{R_{\mathrm{B}}}$$

$$V_{EC} = V_{\mathrm{CC}} - I_{\mathrm{C}} R_{\mathrm{C}}$$

$$I_{\mathrm{C}} = \beta I_{\mathrm{B}}$$

5.2.1 Common Emitter Circuit

Figure 5.22



$V_{EB(on)}=0.6V$,

$\beta=100$

$V_{EC}=\frac{1}{2}V^+=2.5V$,

Find I_B, I_C, I_E, R_C.

$$I_B=\frac{V^+-V_{EB(on)}-V_{BB}}{R_B}$$

$$=\frac{5-0.6-1.5}{580}=5\mu A$$

$$I_C=\beta I_B=0.5mA$$

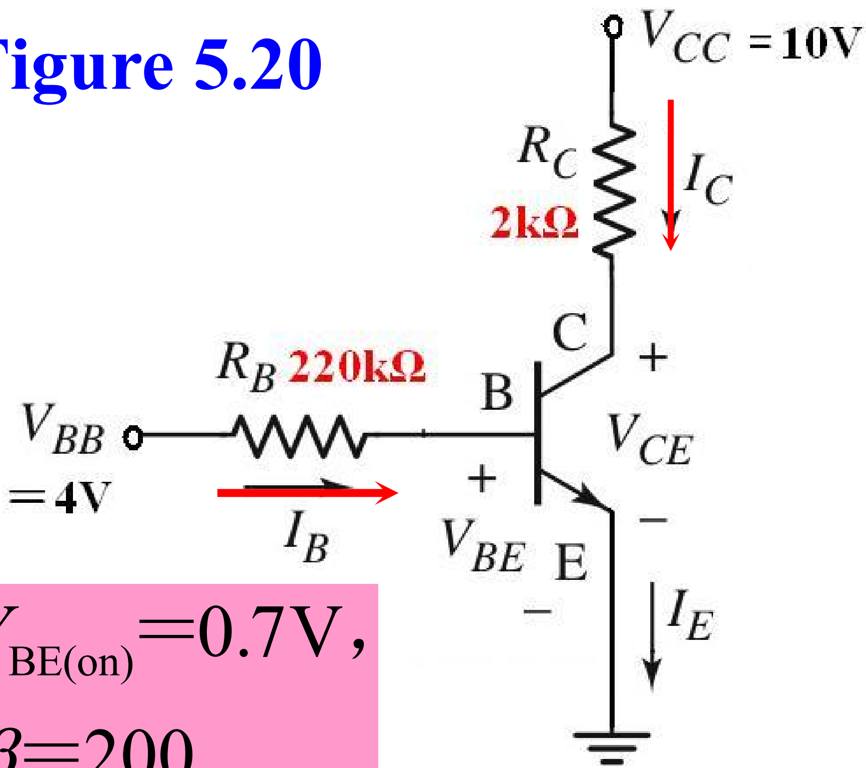
$$I_E=(1+\beta)I_B$$

$$=0.505mA$$

$$R_C=\frac{V^+-V_{EC}}{I_C}=\frac{5-2.5}{0.5}=5k\Omega$$

5.2.1 Common Emitter Circuit

Figure 5.20



$V_{BE(on)}=0.7V$,

$\beta=200$

Calculate the Q-point (I_B, I_C, V_{CE}).

$$I_B=\frac{V_{BB}-V_{BE(on)}}{R_B}$$

$$=\frac{4-0.7}{220}=15\mu A$$

$$I_C=\beta I_B$$

$$=200\cdot 15\mu A=3mA$$

$$V_{CE}=V_{CC}-I_C R_C$$

$$=10-3\cdot 2$$

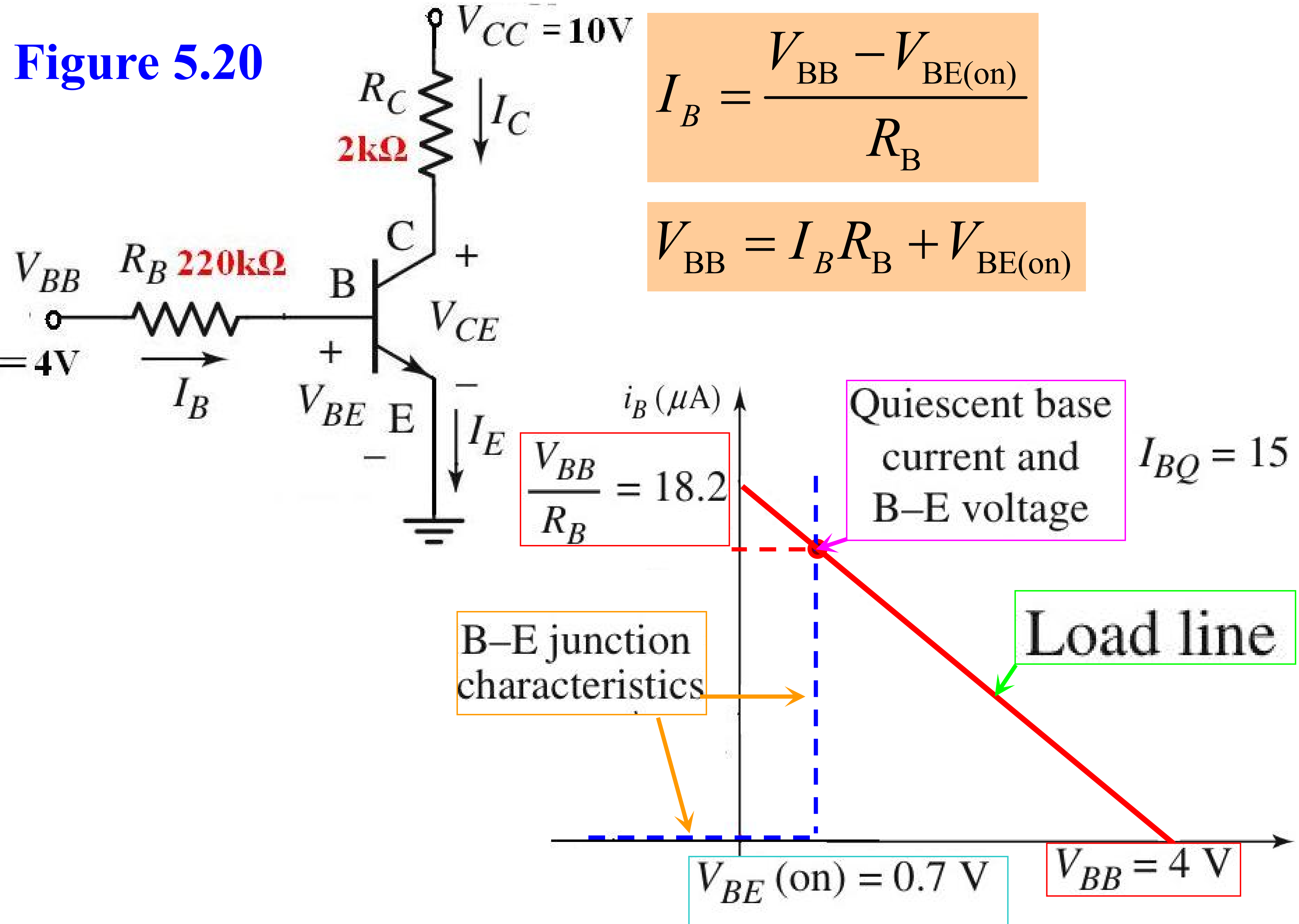
$$=4V$$

5.2.2 Load Line and Modes of Operation

Figure 5.20

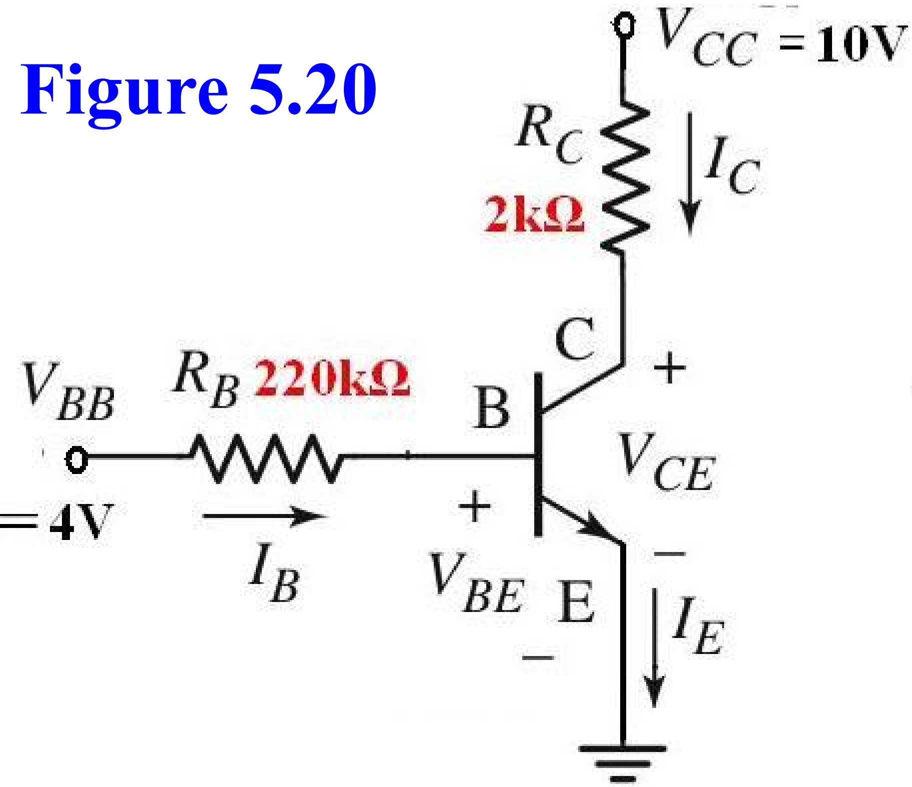
$$I_B = \frac{V_{\mathrm{BB}} - V_{\mathrm{BE(on)}}}{R_{\mathrm{B}}}$$

$$V_{\mathrm{BB}} = I_B R_{\mathrm{B}} + V_{\mathrm{BE(on)}}$$

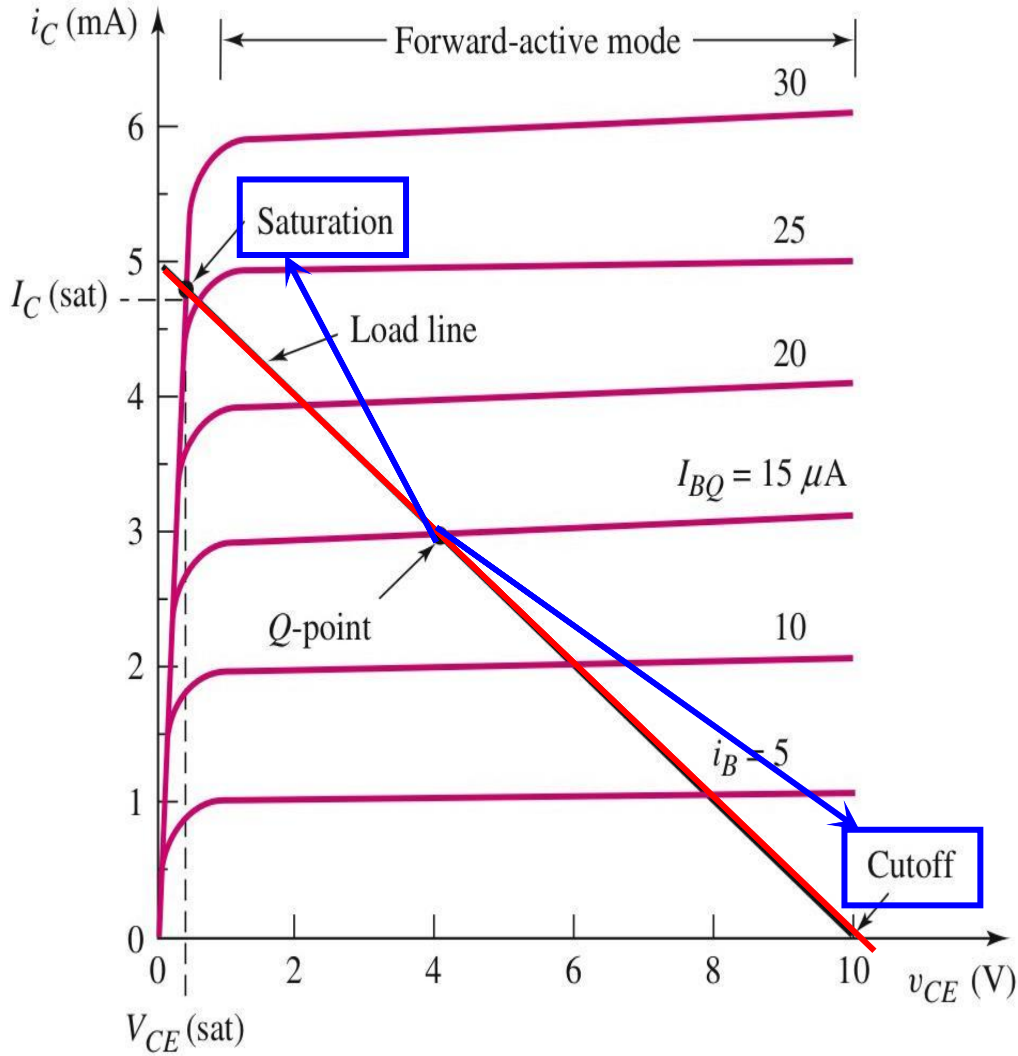


5.2.2 Load Line and Modes of Operation

Figure 5.20

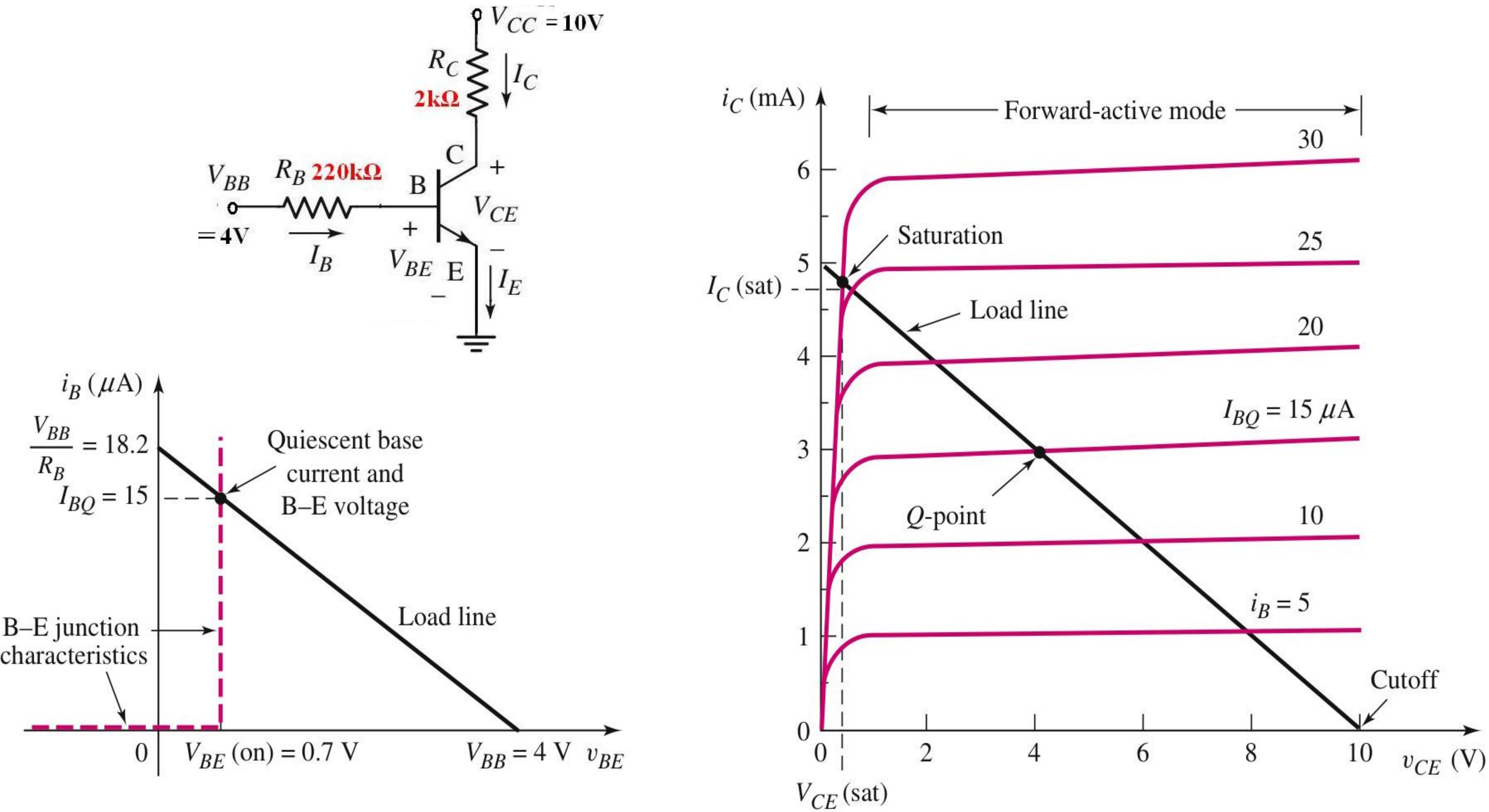


$$V_{\mathrm{CE}} = V_{\mathrm{CC}} - I_{\mathrm{C}} R_{\mathrm{C}}$$



(b)

5.2.2 Load Line and Modes of Operation



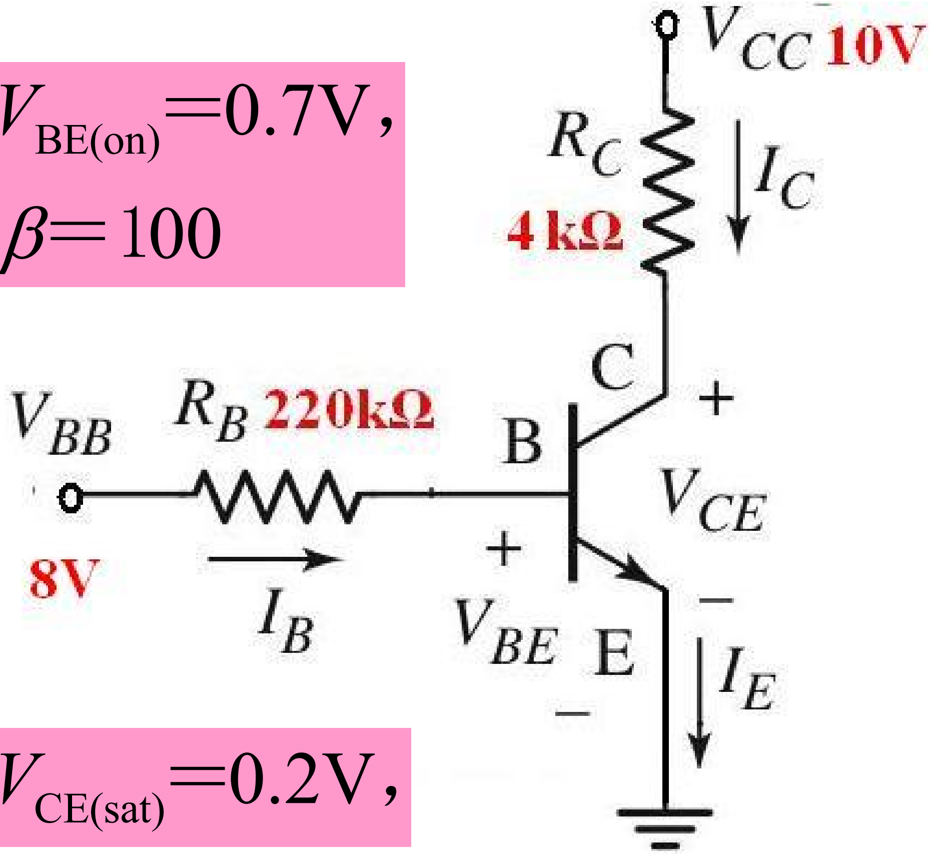
(a)

(b)

5.2.2 Load Line and Modes of Operation

$V_{\mathrm{BE(on)}}=0.7\mathrm{V}$,

$\beta=100$



$V_{\mathrm{CE(sat)}}=0.2\mathrm{V}$,

$$I_B=\frac{V_{\mathrm{BB}}-V_{\mathrm{BE(on)}}}{R_{\mathrm{B}}}$$

$$=\frac{8-0.7}{220}=33.2\mu A$$

$$I_{\mathrm{C}}=\beta I_{\mathrm{B}}$$

$$=100\cdot 33.2\mu\mathrm{A}=3.32\mathrm{mA}$$

$$V_{\mathrm{CE}}=V_{\mathrm{CC}}-I_{\mathrm{C}}R_{\mathrm{C}}$$

$$=10-3.32\cdot 4=\cancel{-3.28}\mathrm{V}$$

When the transistor is in the Saturation region, calculate th Currents and voltages.

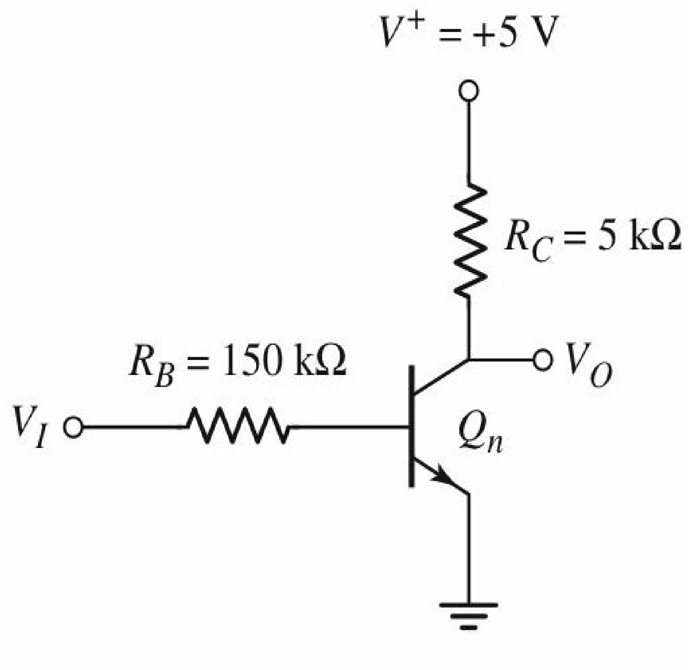
$$I_{\mathrm{C}}=\frac{V_{\mathrm{CC}}-V_{\mathrm{CE(sat)}}}{R_{\mathrm{C}}}$$

$$=\frac{10-0.2}{4}=2.45\mathrm{mA}$$

Problem-Solving Technique: Bipolar DC Analysis

1. Assume that the transistor is biased in forward active mode
   a. $V_{BE} = V_{BE}(on)$, $I_B > 0$, & $I_C = \beta I_B$
2. Analyze 'linear' circuit.
3. Evaluate the resulting state of transistor.
   a. If $V_{CE} > V_{CE}(sat)$, assumption is correct
   b. If $I_B < 0$, transistor likely in cutoff
   c. If $V_{CE} < 0$, transistor likely in saturation
4. If initial assumption is incorrect, make new assumption and return to Step 2.

Voltage Transfer Characteristic for npn Circuit



(a)

$V_I \leq 0.7$V

Which region? **Cut off**

$I_B = I_C = 0$ V_O=? $V_O = V^+ = 5$V

$V_I > 0.7$V

Which region? **Forward active or Saturation region**

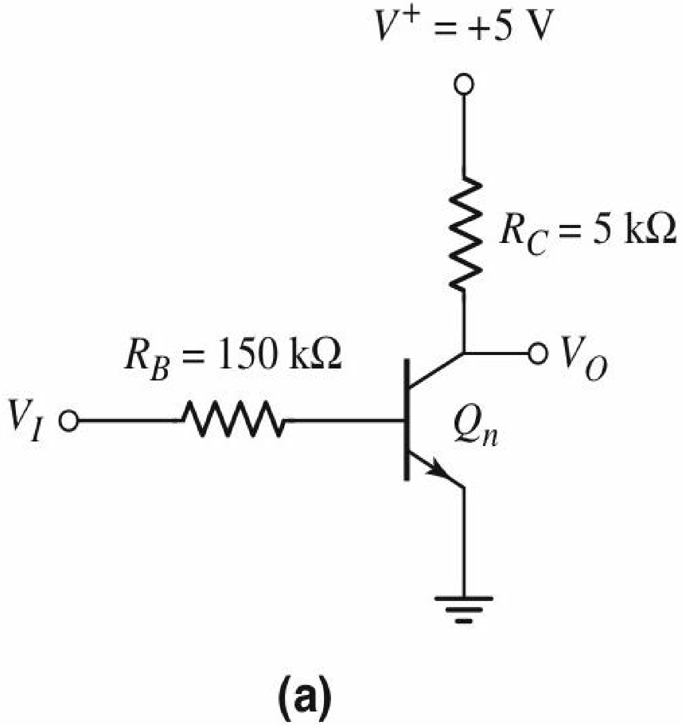
Forward active region

$$I_B = \frac{V_I - 0.7}{R_B}$$

$$I_C = \beta I_B$$

$$V_O = 5 - I_C R_C$$

Voltage Transfer Characteristic for npn Circuit



Forward active region

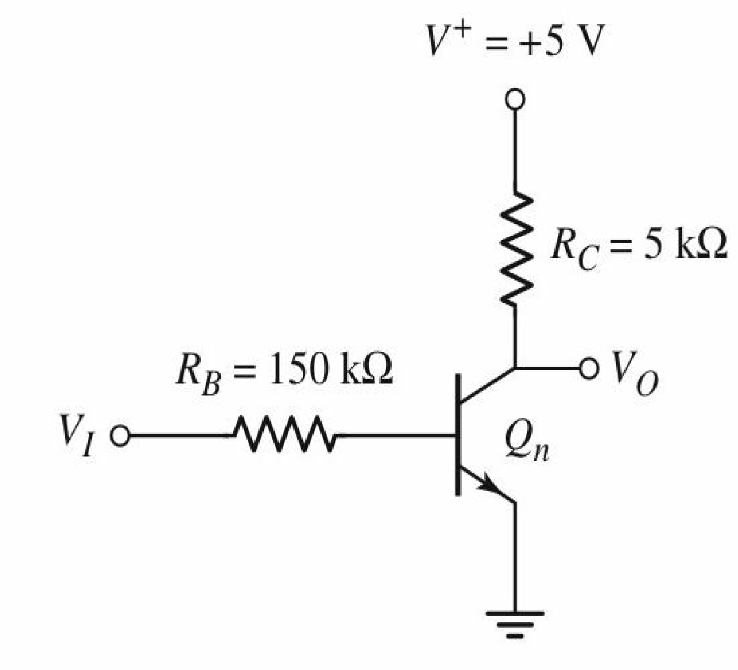
$$I_B = \frac{V_{\mathrm{I}} - 0.7}{R_{\mathrm{B}}}$$

$$I_{\mathrm{C}} = \beta I_{\mathrm{B}}$$

$$V_{\mathrm{O}} = 5 - I_{\mathrm{C}} R_{\mathrm{C}} = 5 - \frac{\beta (V_I - 0.7) R_C}{R_B}$$

$$0.2 \le V_{\mathrm{O}} \le 5V$$

Voltage Transfer Characteristic for npn Circuit



(a)

$$V_O = 0.2V$$

Which region?

Saturation region

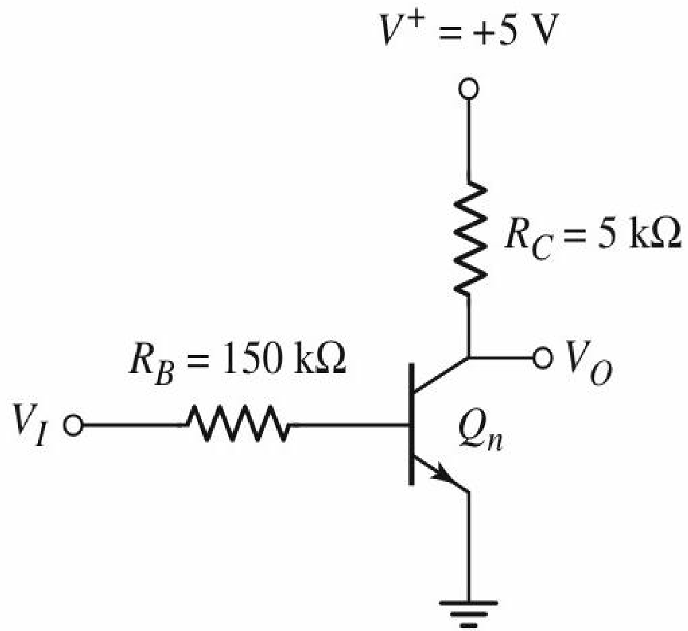
$V_I = ?$

$$V_O = 5 - \frac{\beta(V_I - 0.7)R_C}{R_B} = 0.2$$

$V_I = 1.9\text{V}$

$V_I \geq 1.9\text{V}$ **Saturation region**

Voltage Transfer Characteristic for npn Circuit



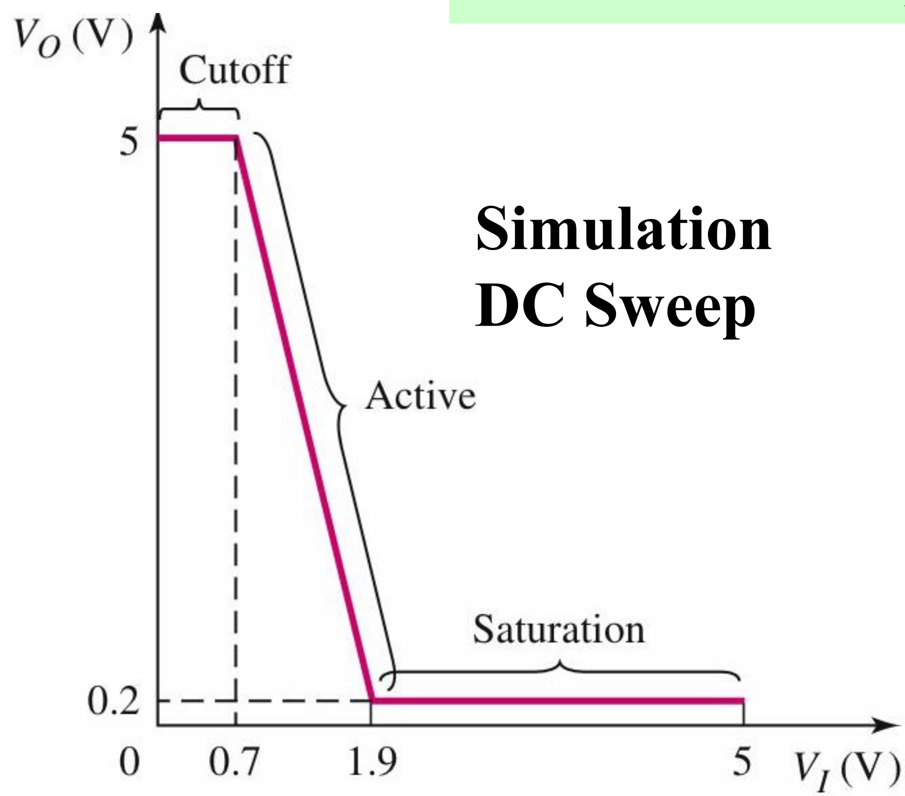
(a)

$V_I \leq 0.7$V **$V_O = V^+ = 5$V**

$V_I \geq 1.9$V **$V_O = 0.2$V**

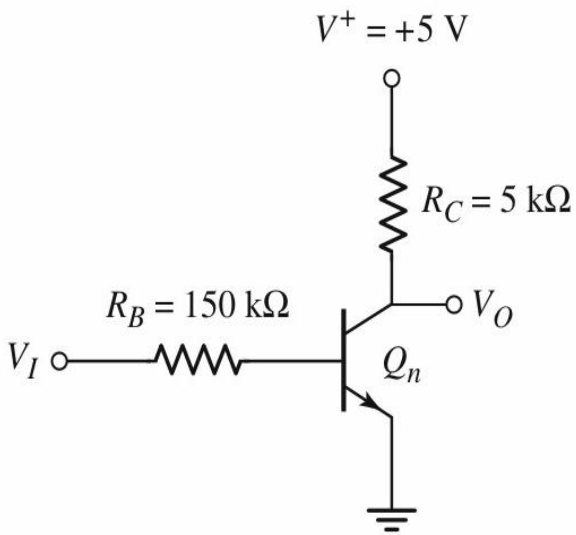
0.7V$< V_I <$1.9V

$$V_O = 5 - \frac{\beta(V_I - 0.7)R_C}{R_B}$$

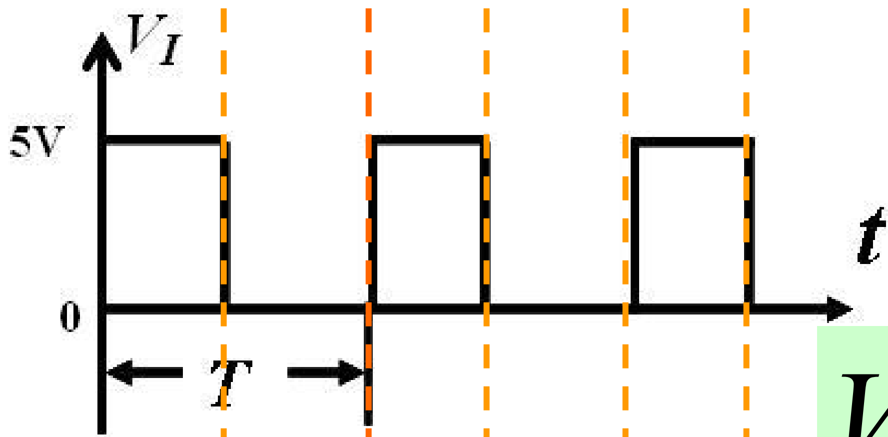


Simulation DC Sweep

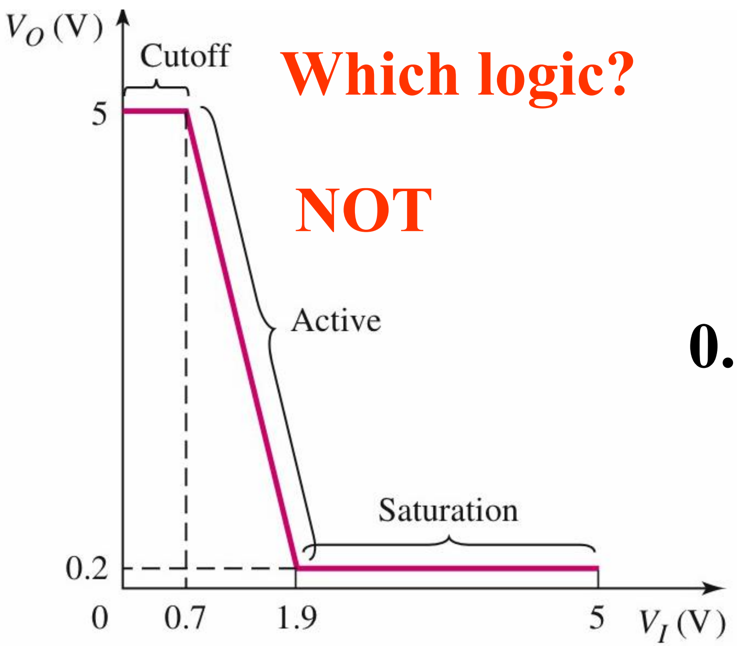
Voltage Transfer Characteristic for npn Circuit



(a)

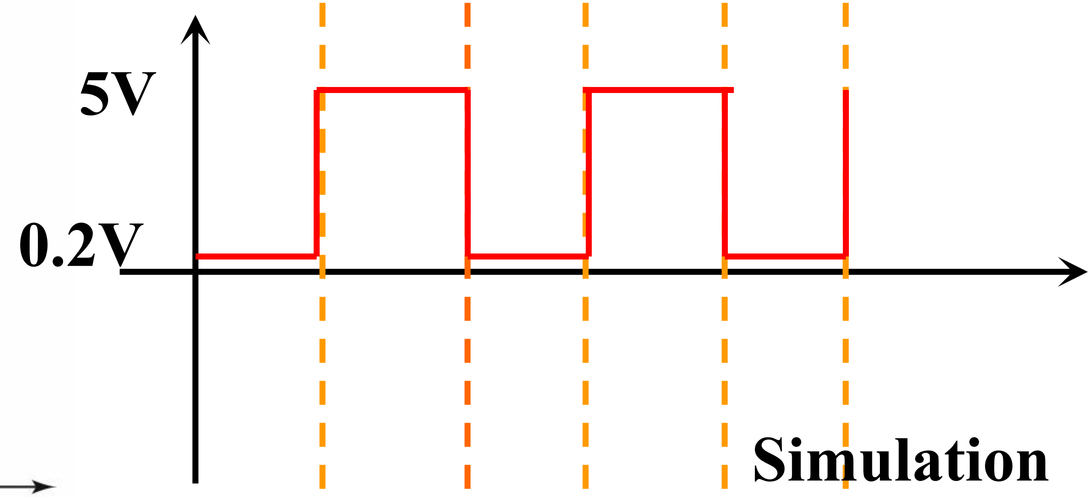


$V_O = ?$



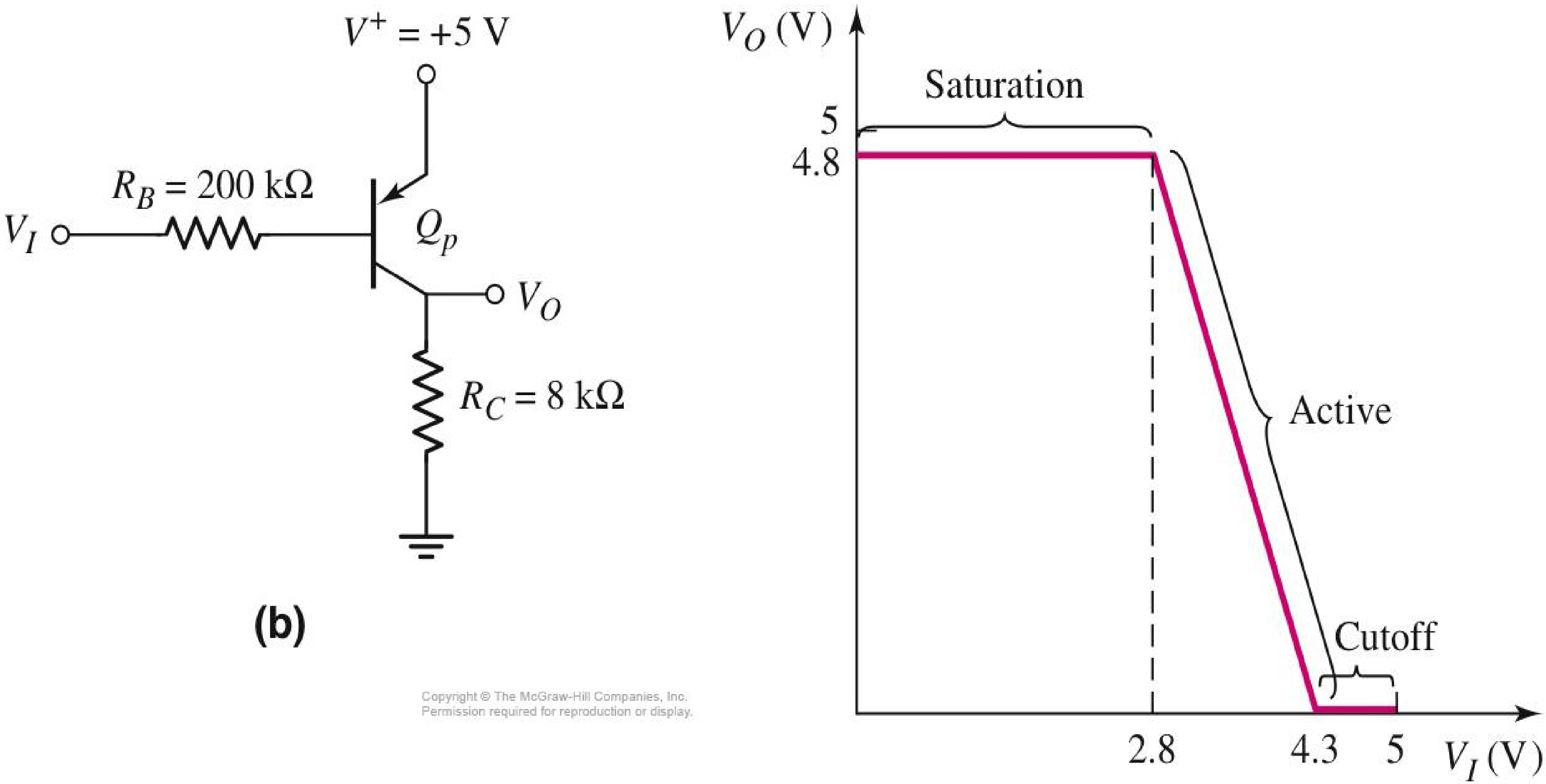
Which logic?

NOT

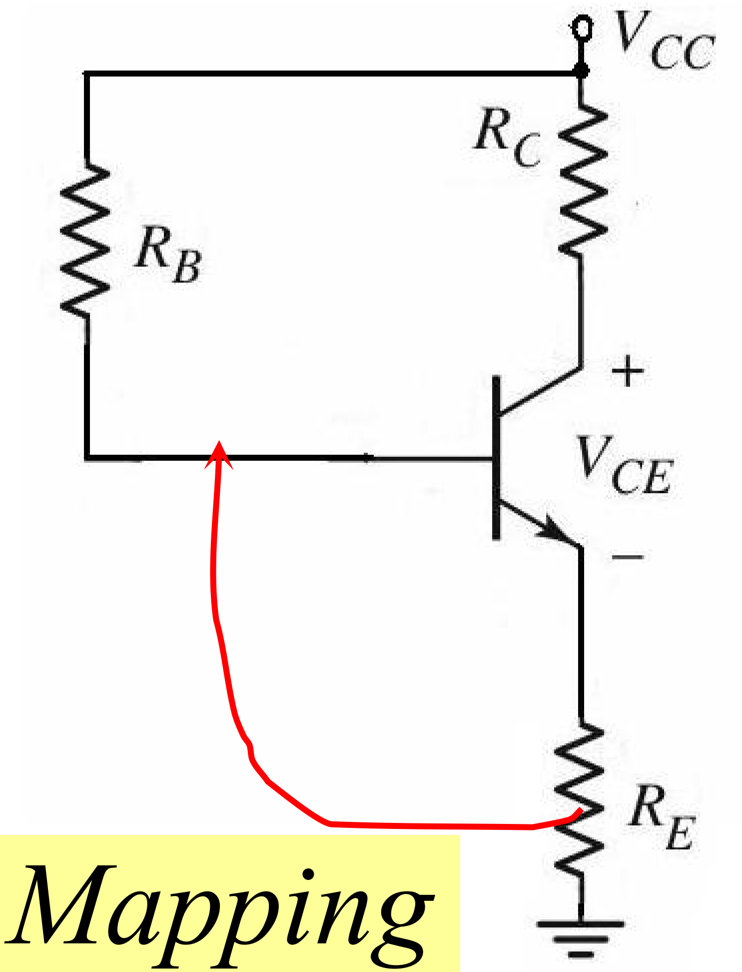


Simulation Transient

Voltage Transfer Characteristic for pnp Circuit



Review Questions



$$I_B = \frac{V_{\mathrm{BB}} - V_{\mathrm{BE(on)}}}{R_{\mathrm{B}} + (1+\beta)R_{\mathrm{E}}}$$

$$I_{\mathrm{C}} = \beta I_{\mathrm{B}}$$

$$V_{\mathrm{CE}} = V_{\mathrm{CC}} - I_{\mathrm{C}}\left(R_{\mathrm{C}} + R_{\mathrm{E}}\right)$$

Mapping

Calculate the Q-point (I_B, I_C, V_{CE}).

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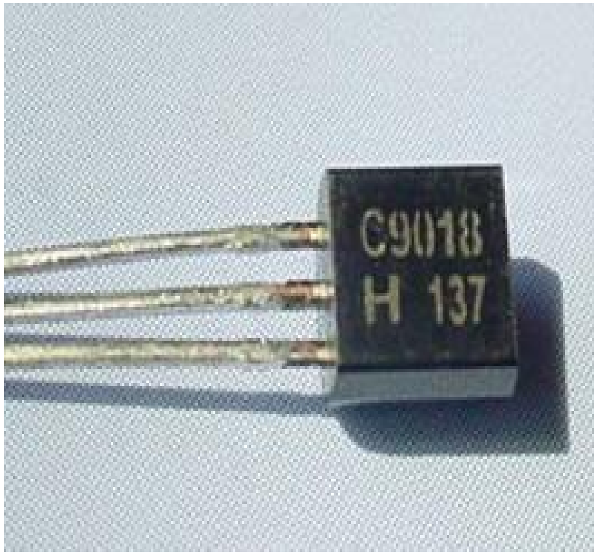
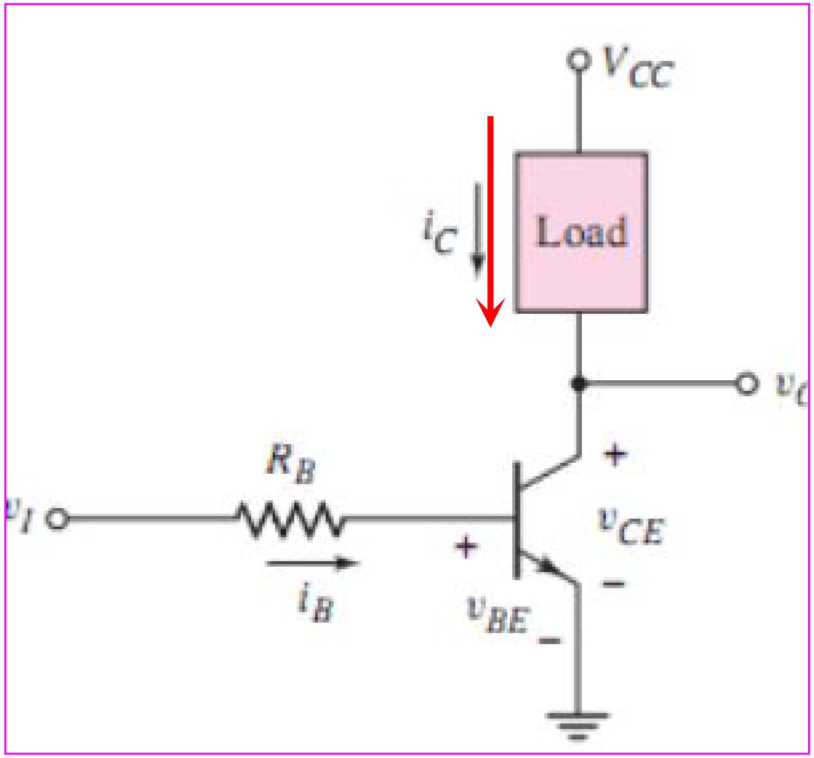
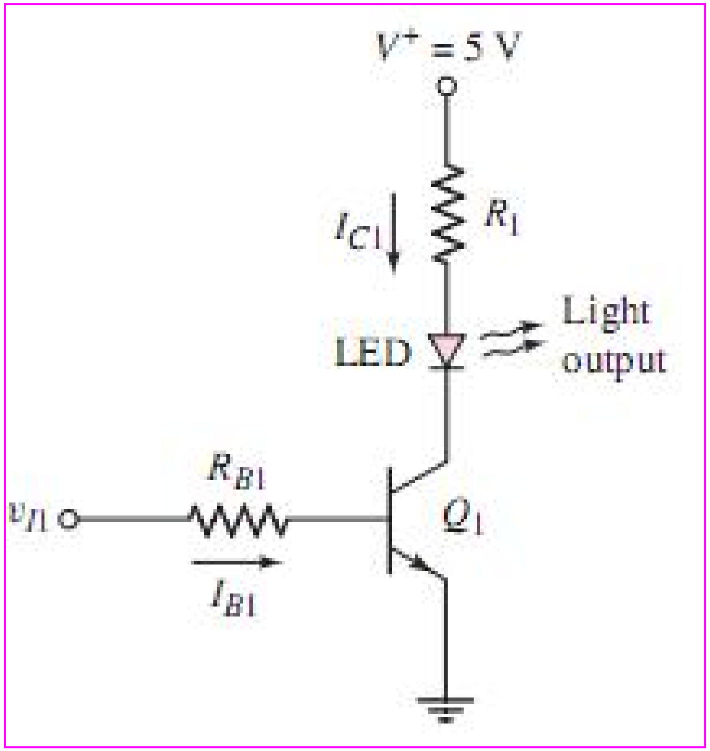
Ch5. The Bipolar Junction Transistor



5.3.1 Switch



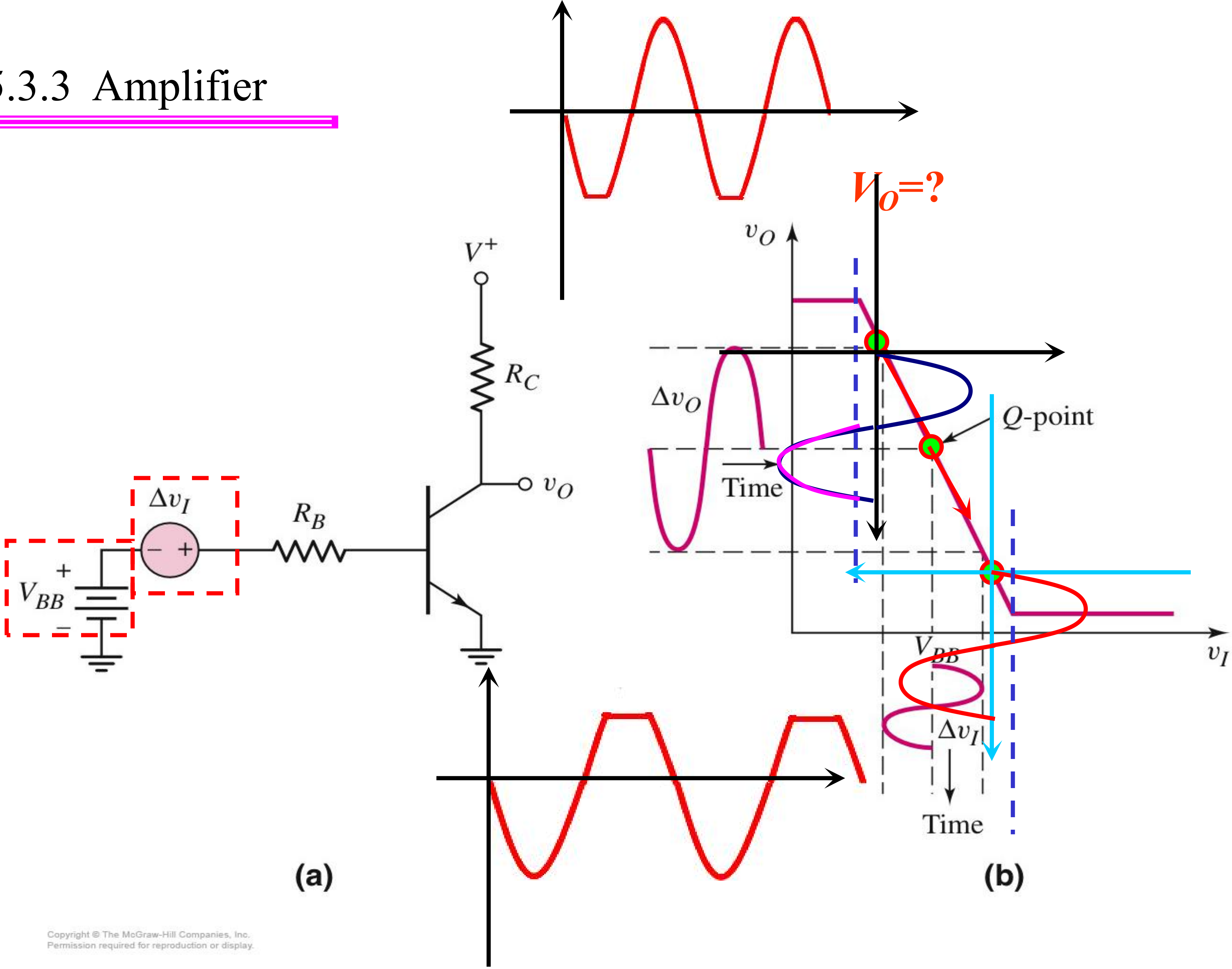


If $v_I < V_{BE}(\text{on})$ the transistor is cut off $\quad i_B = i_C = 0$

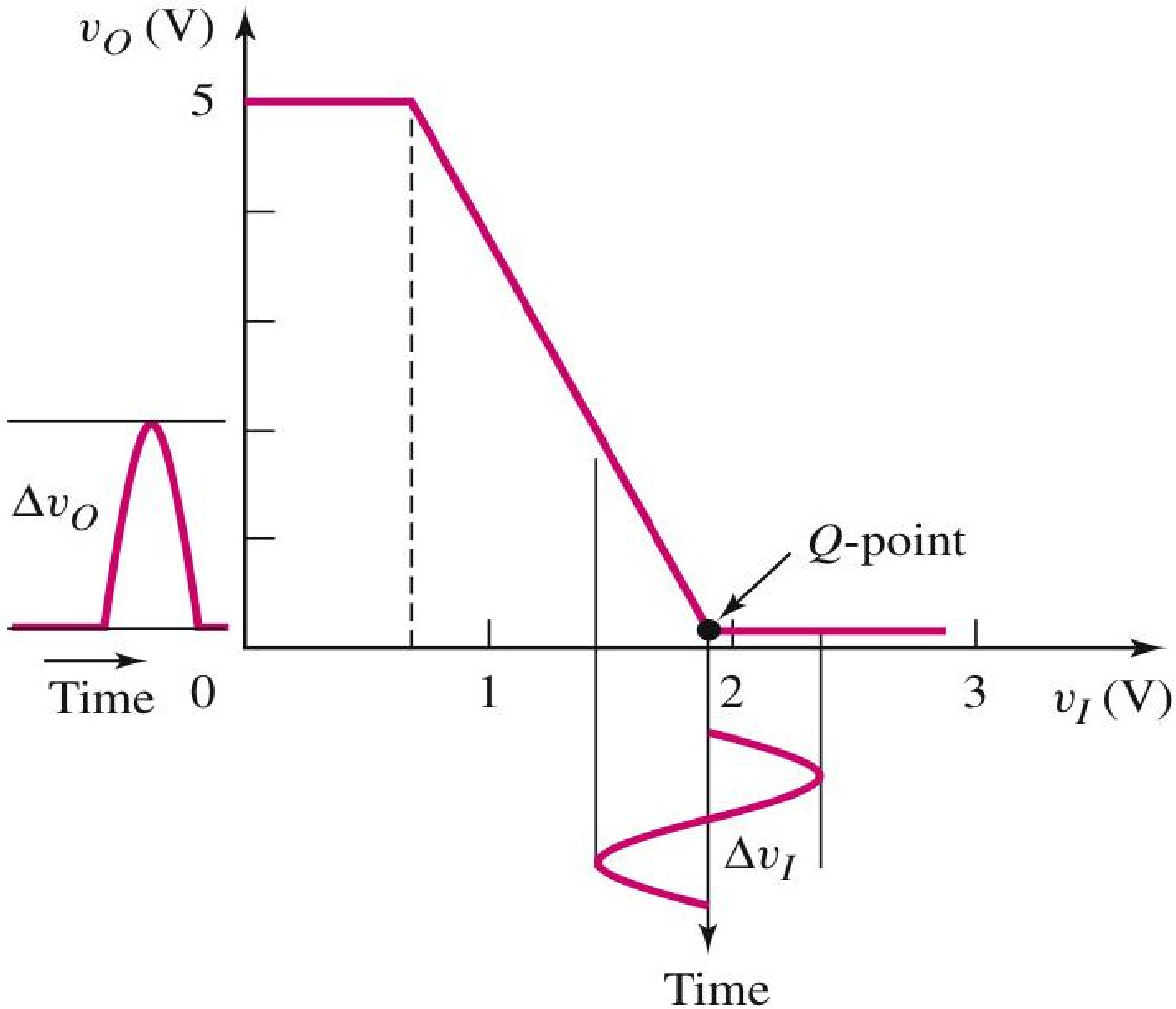
$$v_O = V_{CC}$$

$v_I = V_{CC} \quad \dfrac{R_B}{R_C} < \beta$ saturation $\quad v_O = V_{CE}(\text{sat})$

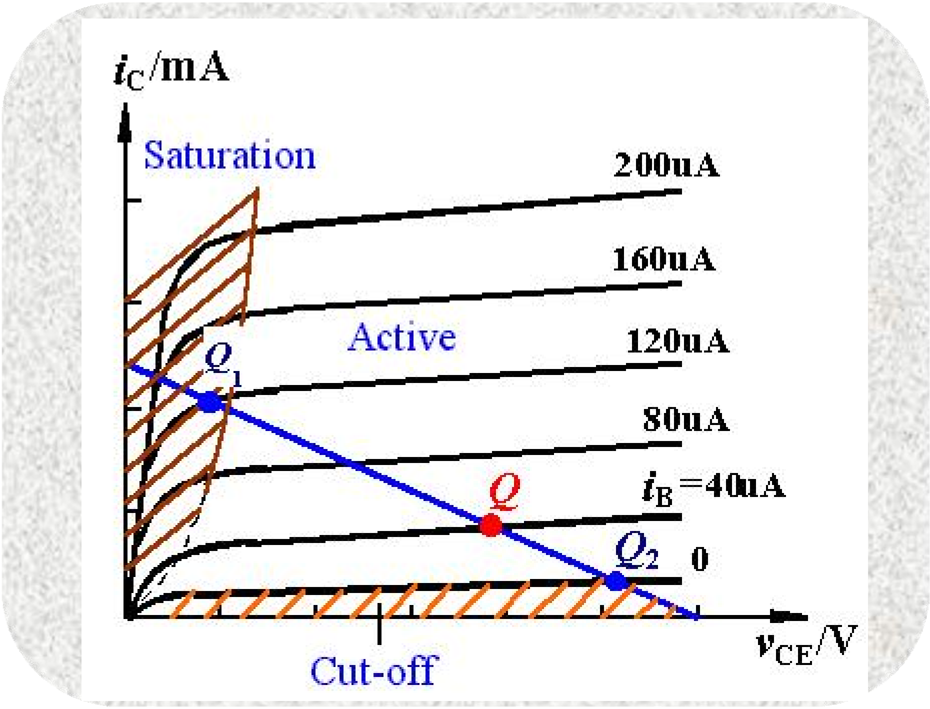
5.3.3 Amplifier



Effect of Improper Biasing on Amplified Signal Waveform



Effect of Improper Biasing on Amplified Signal Waveform

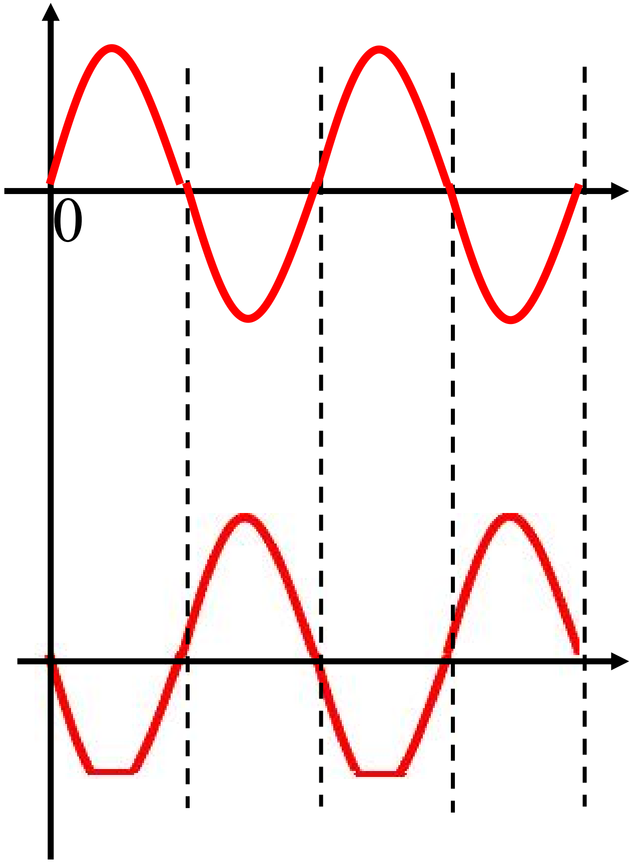


The i-v characteristic of npn

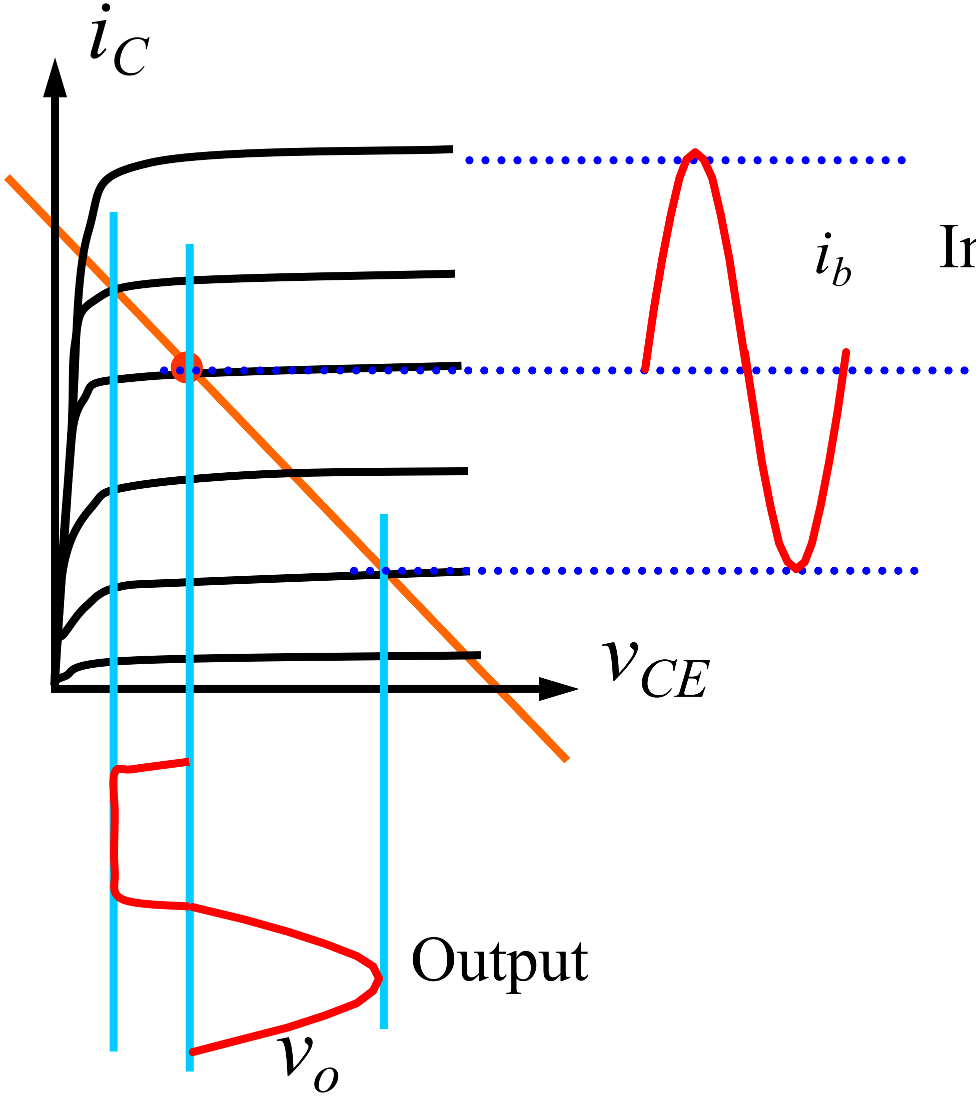
Effect of Improper Biasing on Amplified Signal Waveform

saturation distortion

For NPN BJT and the CE circuit

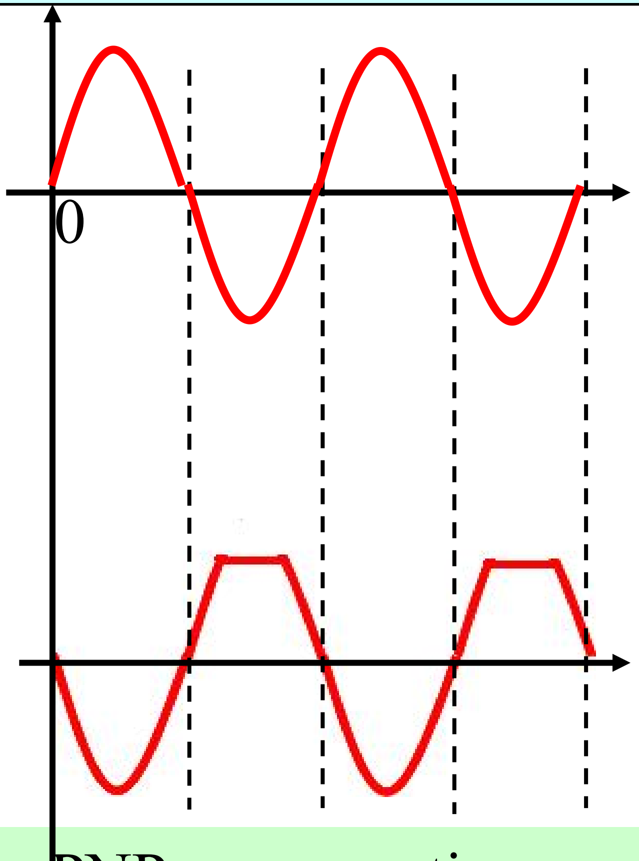


•The Q-point is too high, output waveform is distorted.



Cut-off distortion

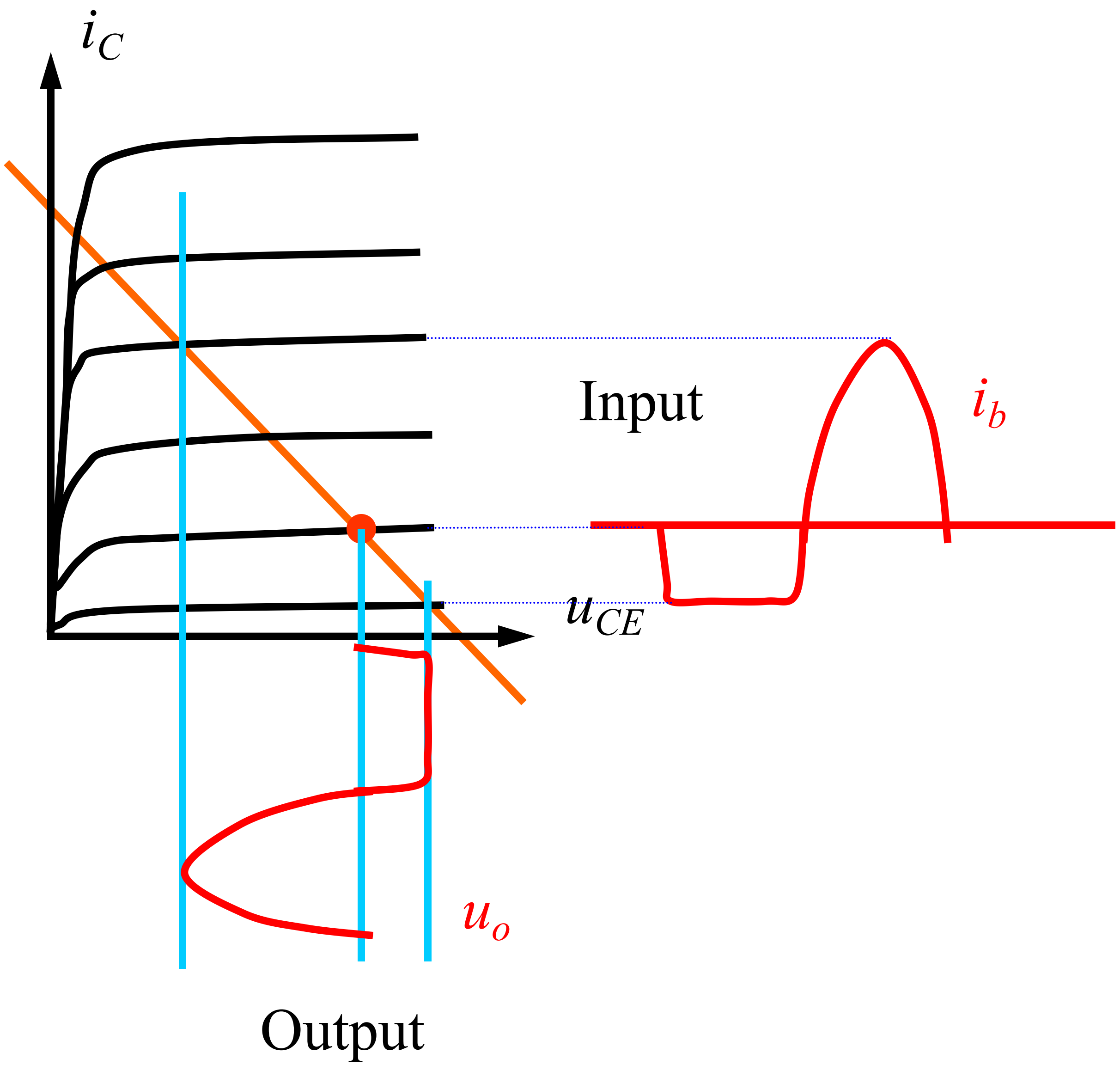
For NPN BJT and the CE circuit

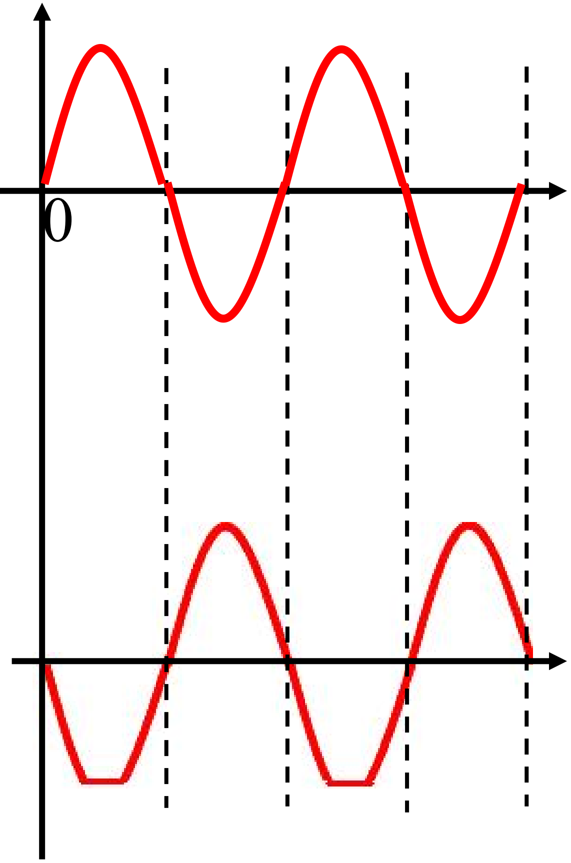


Note: For the PNP, as a negative power supply,

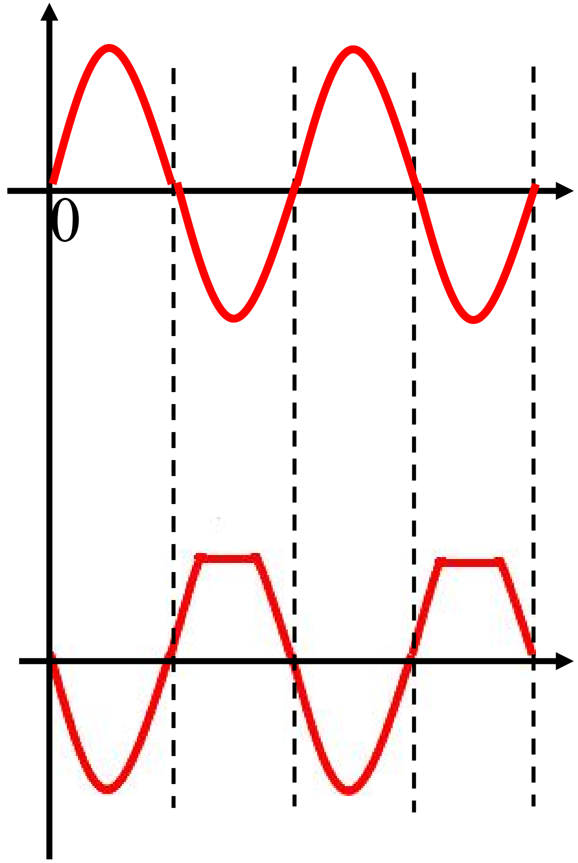
the distortion is against to NPN.

•The Q-point is too low, output waveform is distorted.

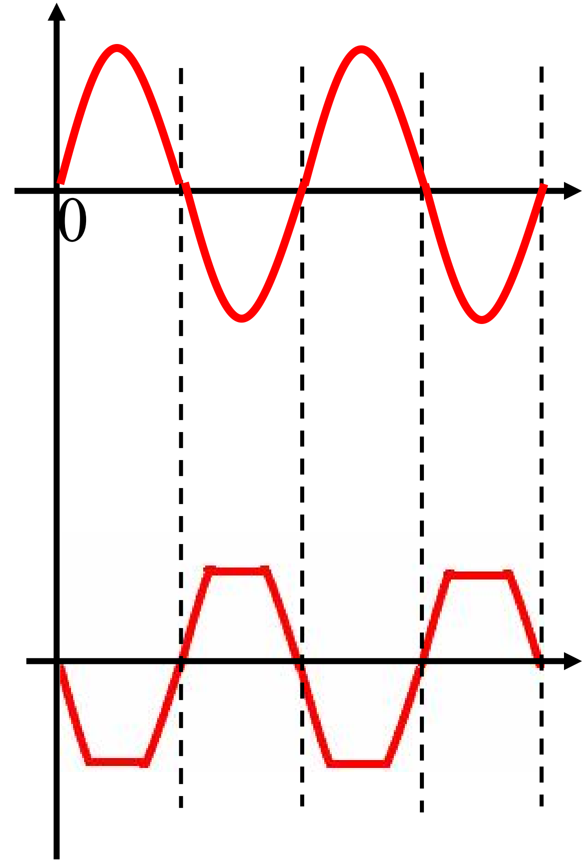




saturation distortion



Cut-off distortion



Clipping distortion

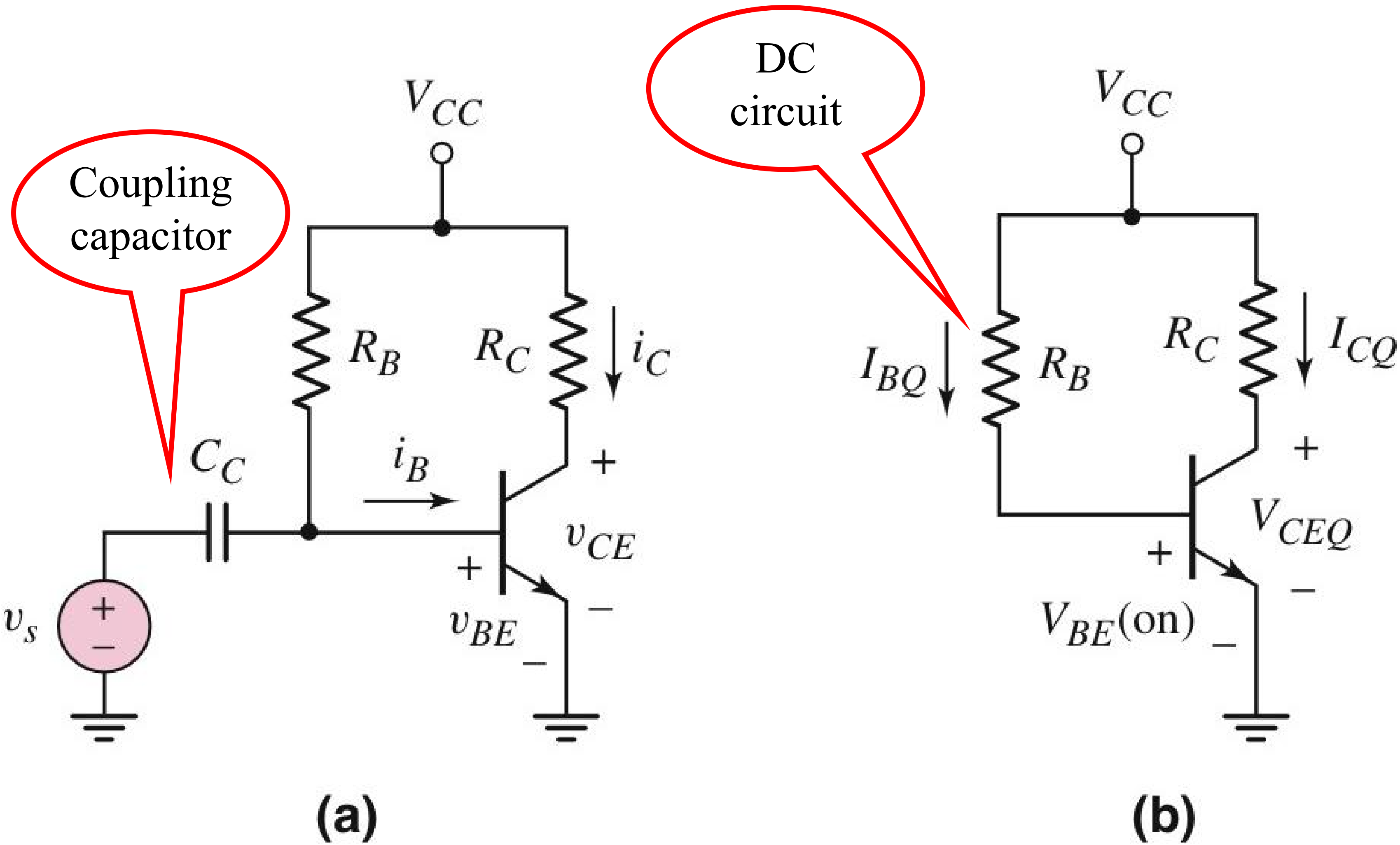
5.4 Basic Transistor Biasing

DC Biasing $\Rightarrow$ Establish Q-point

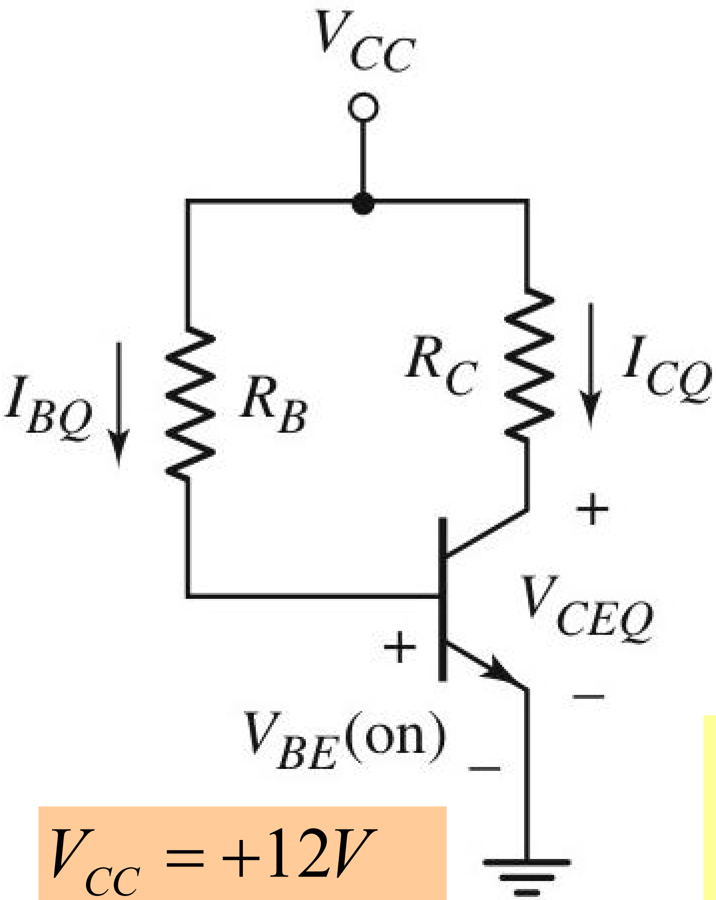
$\Downarrow$

Forward active region

5.4.1 Single Base Resistor Biasing



5.4.1 Single Base Resistor Biasing



Find R_C, R_B,
for I_{CQ}=1mA, V_{CEQ}=6V

$$R_C = \frac{V_{CC} - V_{CEQ}}{I_C} = \frac{12-6}{1} = 6\text{k}\Omega$$

$$I_B = \frac{I_C}{\beta} = \frac{1mA}{100} = 1\mu A$$

$$R_B = \frac{V_{CC} - V_{BE(on)}}{I_{BQ}}$$

$$= \frac{12-0.7}{10\mu A} = 1.13M\Omega$$

$V_{CC} = +12V$

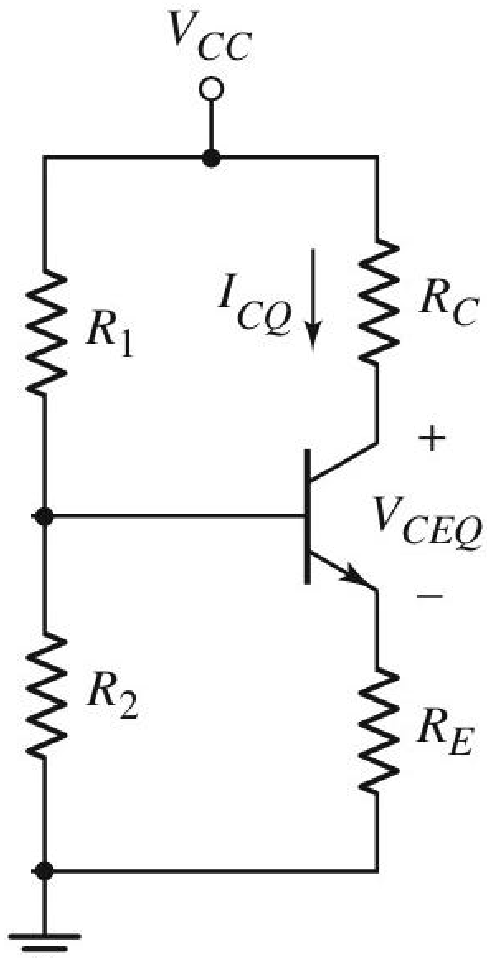
$\beta = 100$

$V_{BE(on)} = 0.7V$

IF Cut-off distortion?

5.4.2 Voltage Divider Biasing and Bias Stability

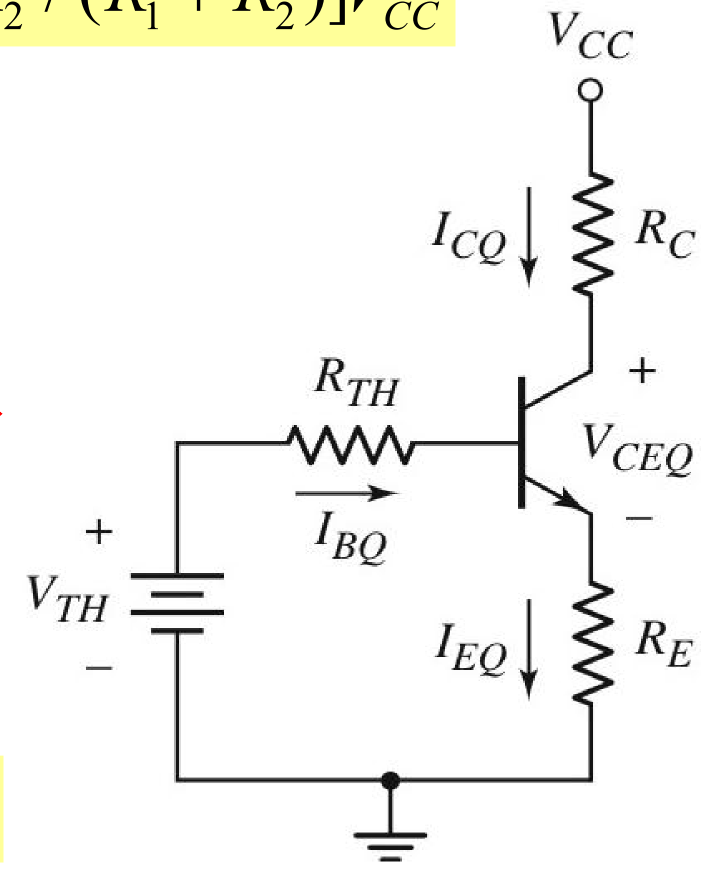
DC circuit



$$V_{TH} = ?$$

$$V_{TH} = [R_2 / (R_1 + R_2)]V_{CC}$$

Thevenin equivalent



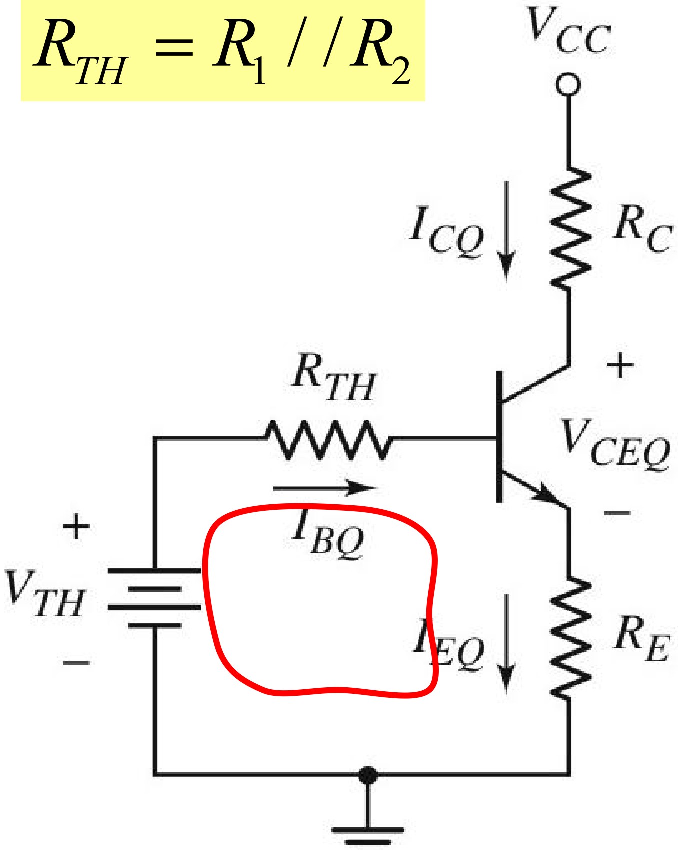
$$R_{TH} = ?$$

$$R_{TH} = R_1 // R_2$$

5.4.2 Voltage Divider Biasing and Bias Stability

$$V_{TH} = [R_2 / (R_1 + R_2) V_{CC}$$

$$R_{TH} = R_1 // R_2$$



Input loop

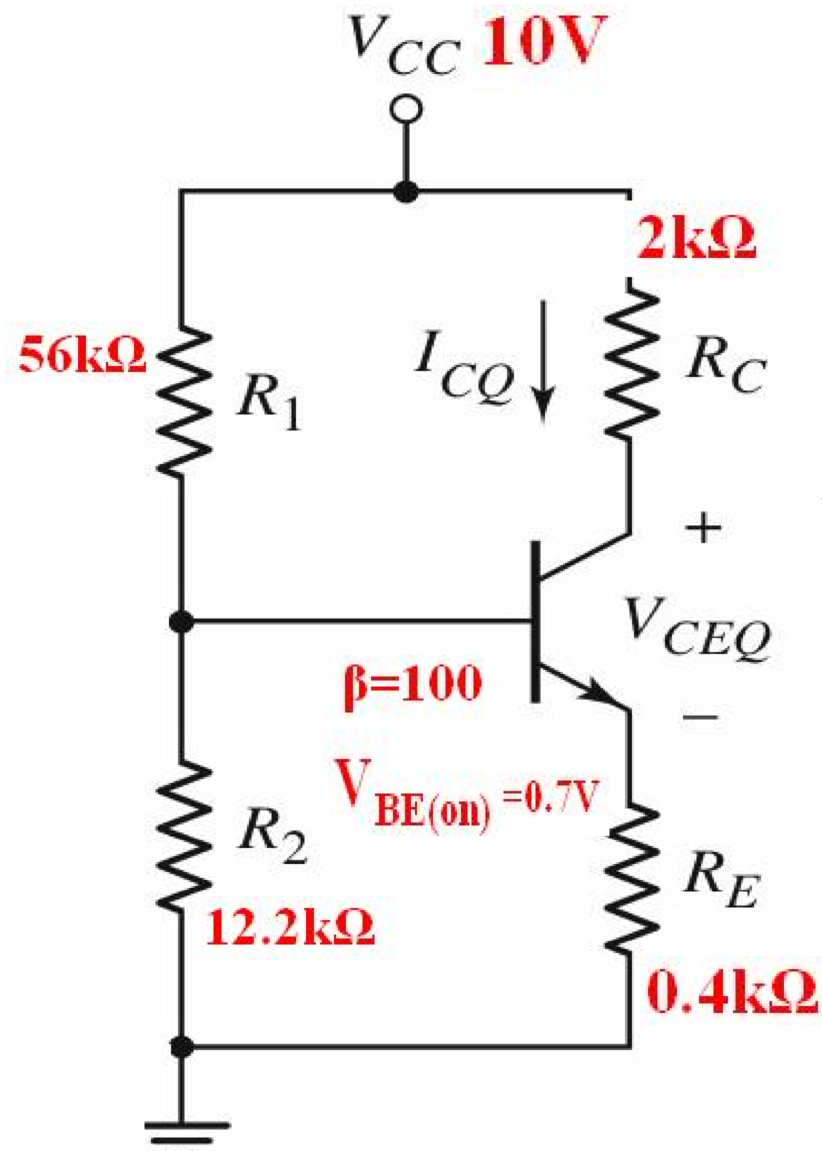
$$V_{TH} = I_B R_{TH} + V_{BE} + I_E R_E$$

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

Q-point

$$\begin{cases} I_B = \dfrac{V_{TH} - V_{BE}}{R_{TH} + (1+\beta) R_E} \\ I_C = \beta I_B \\ V_{CEQ} = V_{CC} - I_C R_C - I_E R_E \end{cases}$$

5.4.2 Voltage Divider Biasing and Bias Stability



Find Q-point.

$$R_{TH} = R_1 // R_2 \approx 10\text{k}\Omega$$

$$V_{TH} = [R_2 / (R_1 + R_2)]V_{CC} = 1.79\text{V}$$

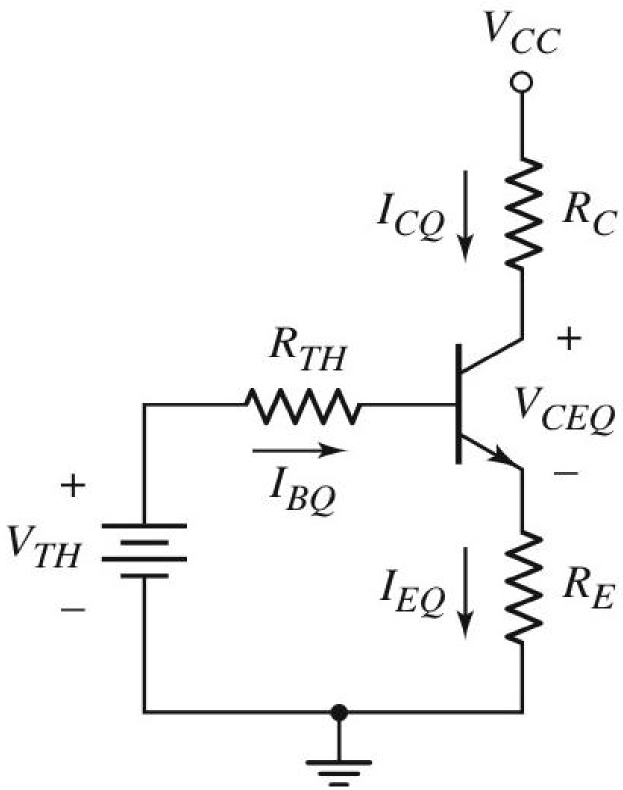
$$I_B = \frac{V_{TH} - V_{BE}}{R_{TH} + (1+\beta)R_E} = 21.6\mu\text{A}$$

$$I_C = \beta I_B = 2.16\text{mA}$$

$$V_{CEQ} = V_{CC} - I_C R_C - I_E R_E$$

$$= 4.81\text{V}$$

5.4.2 Voltage Divider Biasing and Bias Stability



Forward active region

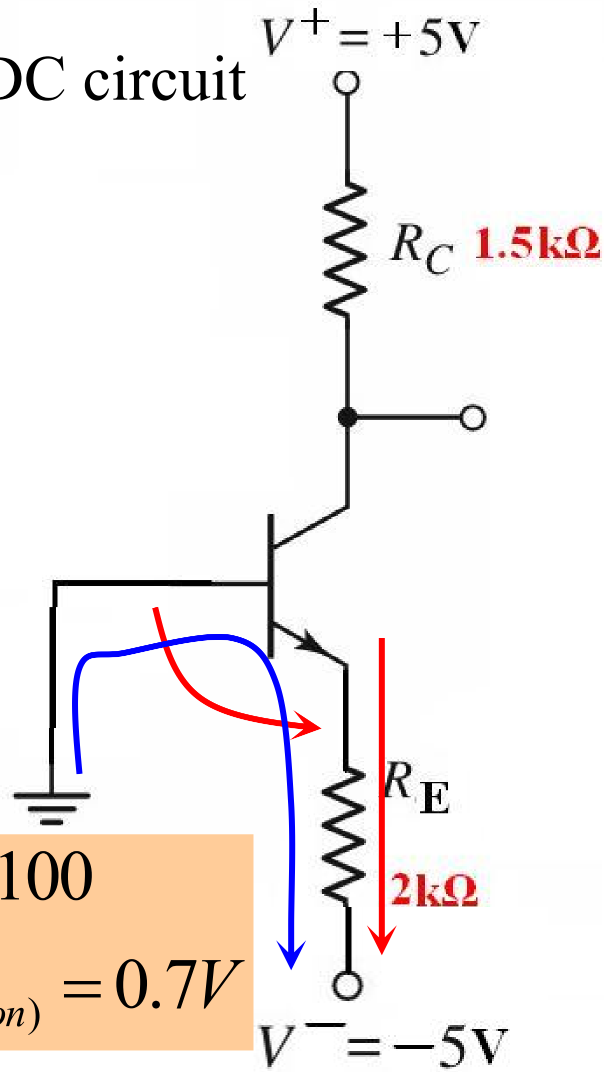
General rule of bias stable:

$$R_{\text{TH}} << (1+\beta)R_{\text{E}}$$

and $$R_{\text{TH}} \cong 0.1(1+\beta)R_{\text{E}}$$

5.4.3 Positive and Negative Voltage Biasing

DC circuit



$\beta = 100$

$V_{BE(on)} = 0.7V$

Forward active region? ×

Find the Q-point?

$$0 = I_{EQ} R_E + V_{BE(on)} + V^-$$

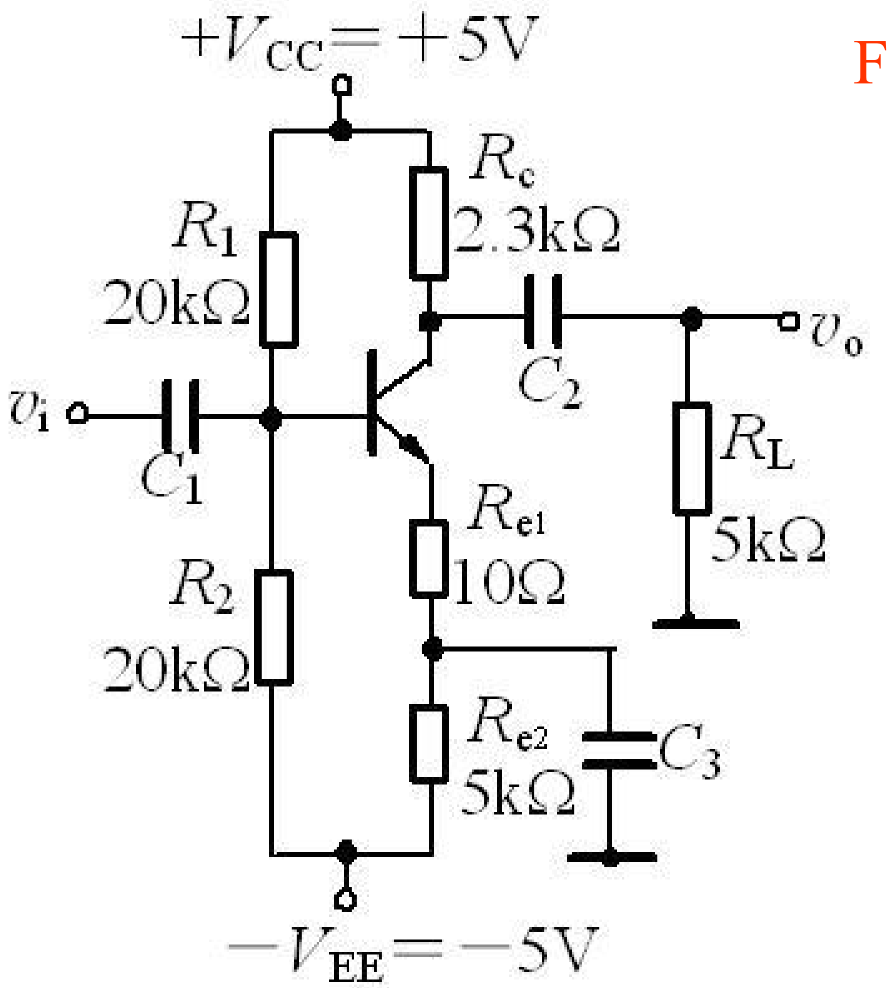
$$I_{EQ} = -\frac{V_{BE(on)} + V^-}{R_E} = -\frac{0.7 - 5}{2} = 2.15 mA$$

$$I_{CQ} = I_{EQ}$$

$$V_{CEQ} = V^+ - V^- - I_C R_C - I_E R_E$$

$$= 2V^+ - I_C R_C - I_E R_E$$

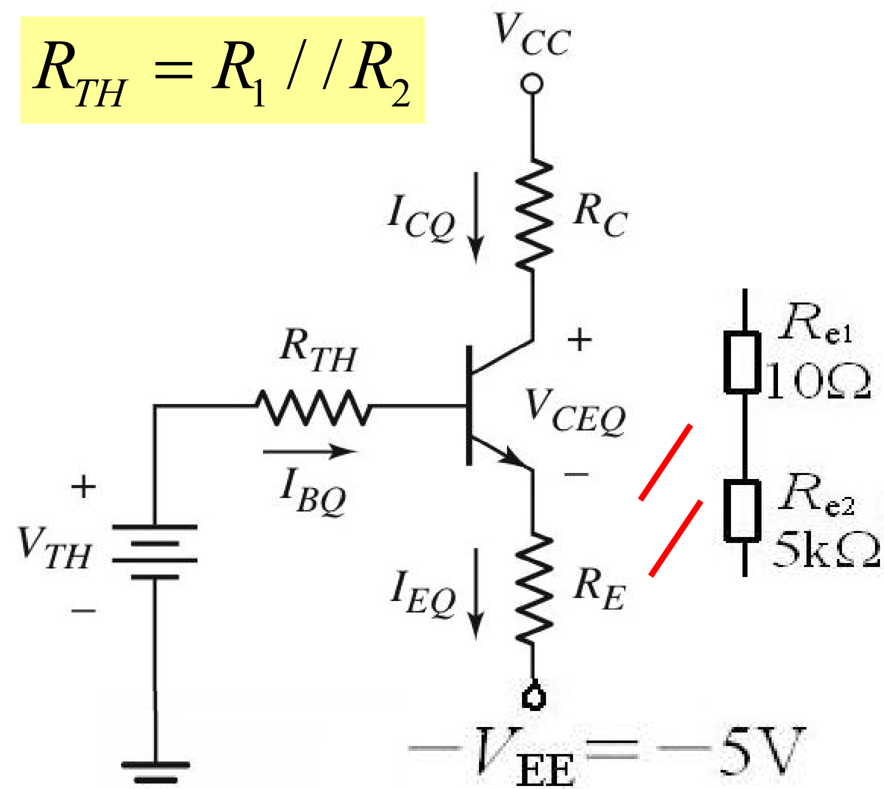
5.4.3 Positive and Negative Voltage Biasing



Find the Q-point?

DC circuit

$$R_{TH} = R_1 // R_2$$

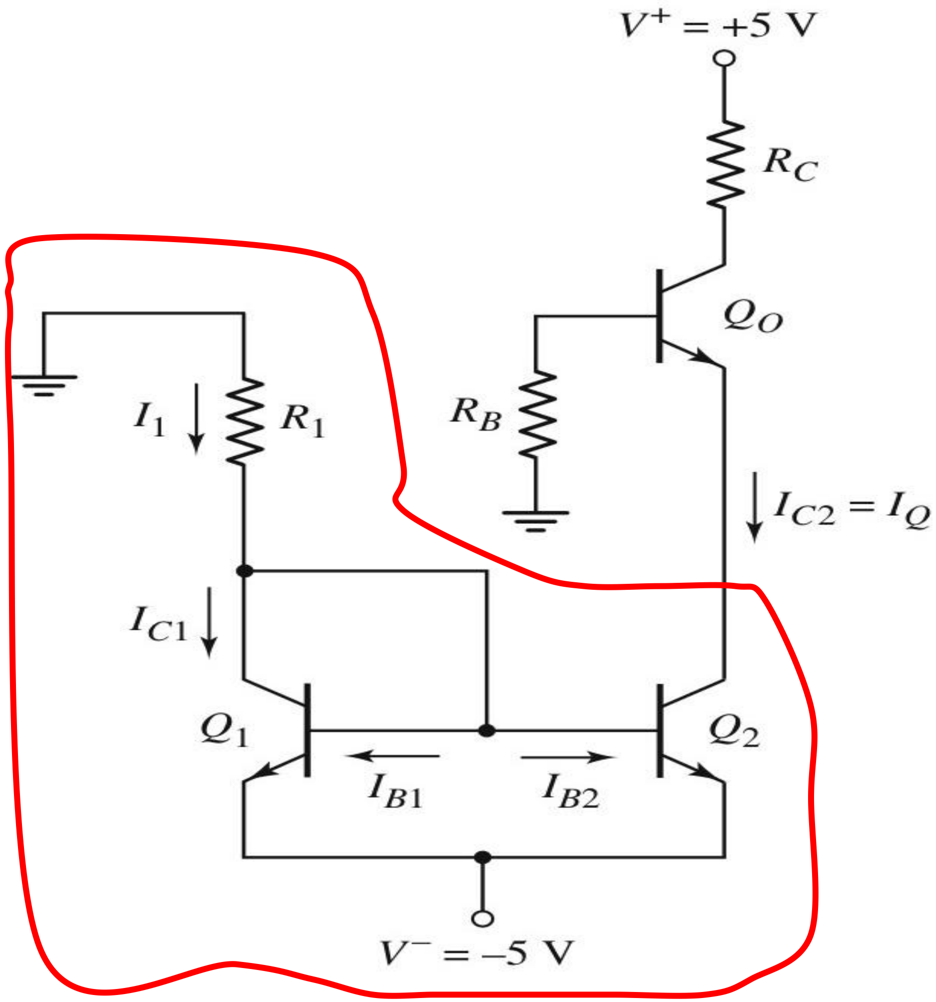


$$\beta = 125$$

$$V_{BE(on)} = 0.7V$$

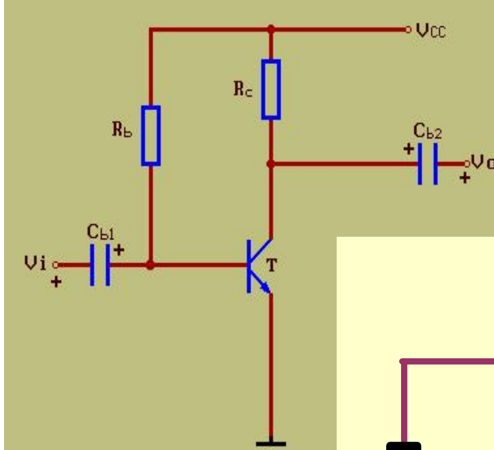
$$V_{TH} = [R_2 / (R_1 + R_2)][V_{CC} + V_{EE}] - V_{EE}$$

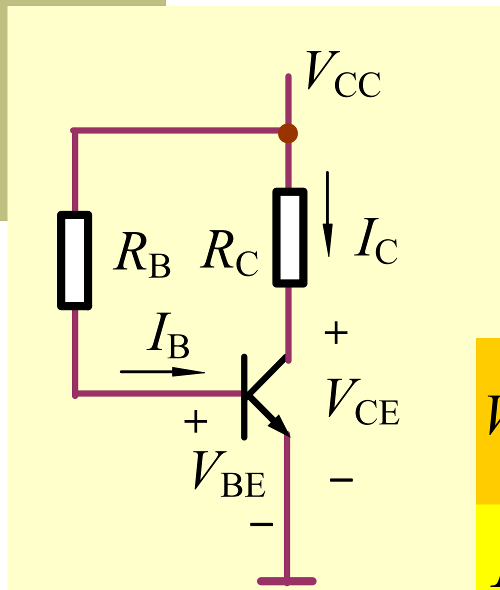
5.4.4 Integrated Circuit Biasing



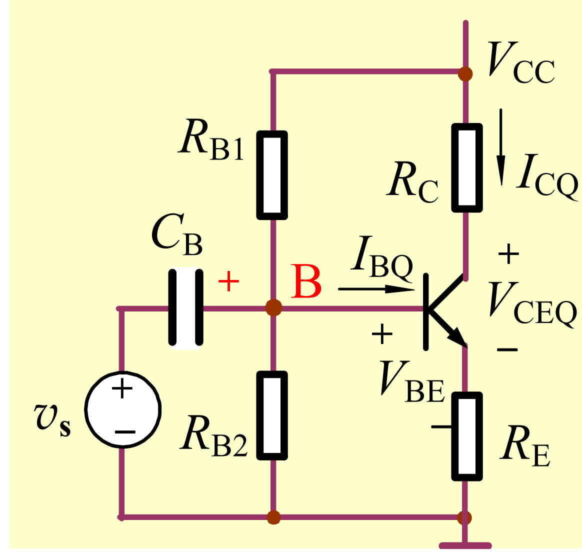
Current source

Chapter 10



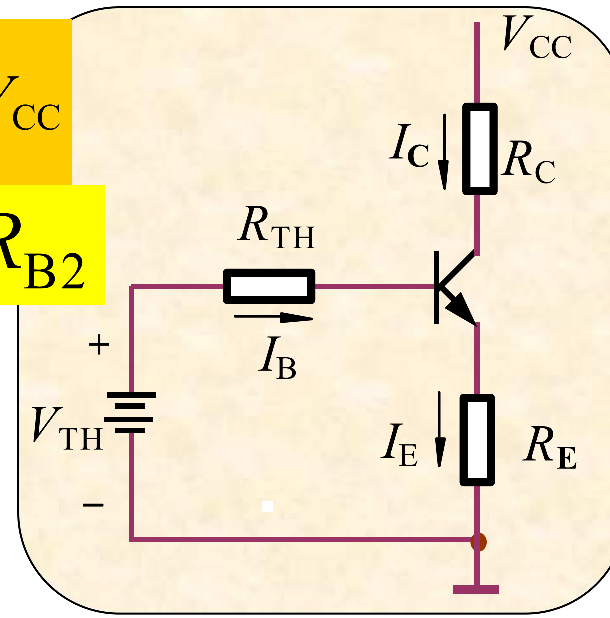


DC equivalent circuit



$$V_{TH} \approx \frac{R_{B2}}{R_{B1}+R_{B2}} \cdot V_{CC}$$

$$R_{TH} = R_{B1} // R_{B2}$$



$$\begin{cases} I_B = \dfrac{V_{BB}-V_{BE}}{R_B} \\ I_C = \beta I_B \\ V_{CE} = V_{CC} - I_C R_C \end{cases}$$

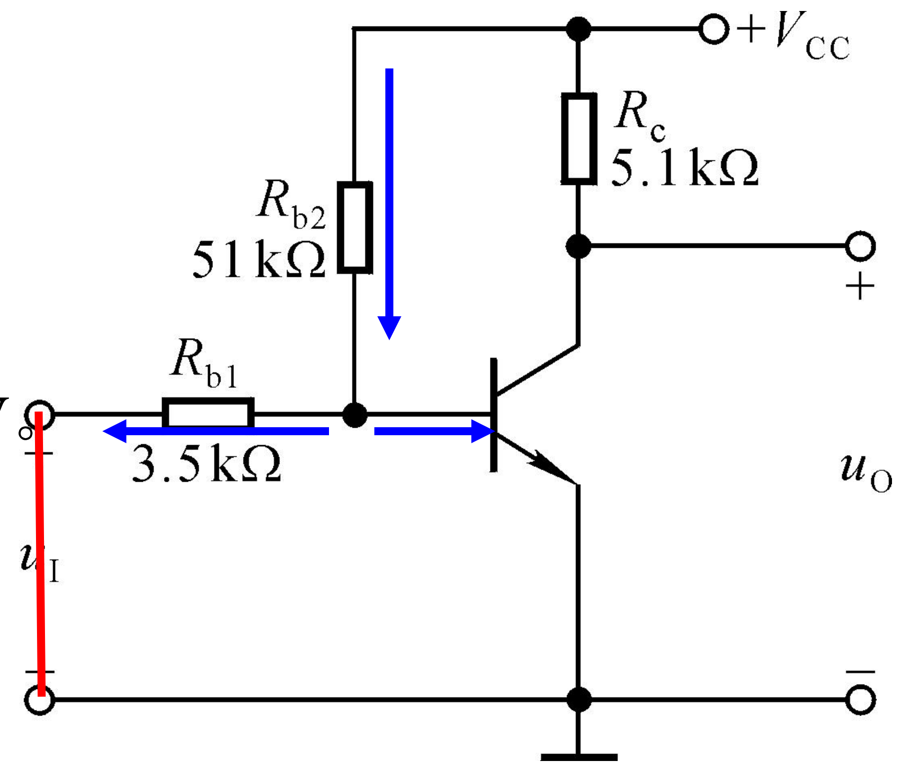
$$\begin{cases} I_B = \dfrac{V_{TH}-V_{BE}}{R_{TH}+(1+\beta)R_E} \\ I_C = \beta I_B \\ V_{CEQ} = V_{CC} - I_C R_C - I_E R_E \end{cases}$$

Example 1

Assume $\beta=50$, find out $V_{CQ}=?$ $V_{CC}=12V$, $U_{CES}=0.5V$。

(1) Normal;(2)R_{b1} is short; (3)R_{b1} is open;(4)R_{b2} open;

(5)R_C short。



Sol: assume $U_{BE}=0.7V$。 then

(1) $$I_B=\frac{V_{CC}-U_{BE}}{R_{b2}}-\frac{U_{BE}}{R_{b1}}\approx 0.022mA$$

$$U_C=V_{CC}-I_C R_c\approx 6.4V$$

(2) $U_{BE}=0V \rightarrow$ T cut off $\rightarrow U_C=12V$

(3) $$I_B=\frac{V_{CC}-U_{BE}}{R_{b2}}\approx 0.22mA$$

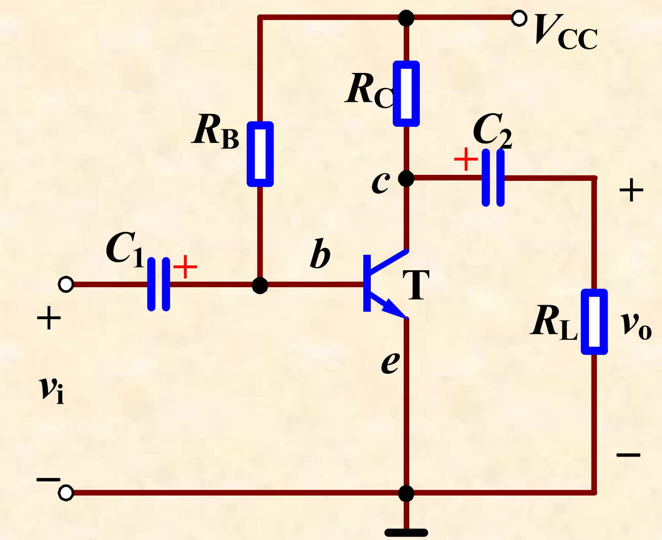
$$I_{BS}=\frac{V_{CC}-U_{CES}}{\beta R_c}\approx 0.045mA$$

$I_B>I_{BS}$, T saturation, $U_C=U_{CES}=0.5V$。

(4) T cutoff, $U_C=12V$。 (5) $U_C=V_{CC}=12V$

Review Questions

2. When V_{CE} of BJT is nearly equal V_{CC} , Which region is it operating in? What may the reasons?



Common-Emitter Circuit

Answer: Cut-off region

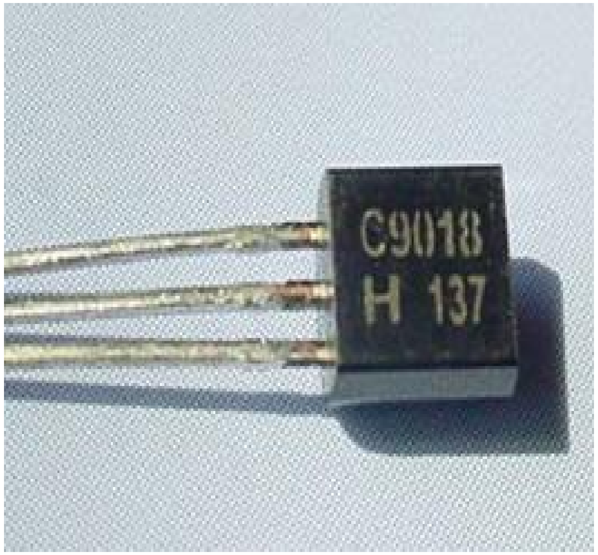
Reasons may:

- R_b may open circuit, I_B=0, I_C=0, $V_{CE}= V_{CC} - I_C R_c= V_{CC}$.
- C_1 may short circuit

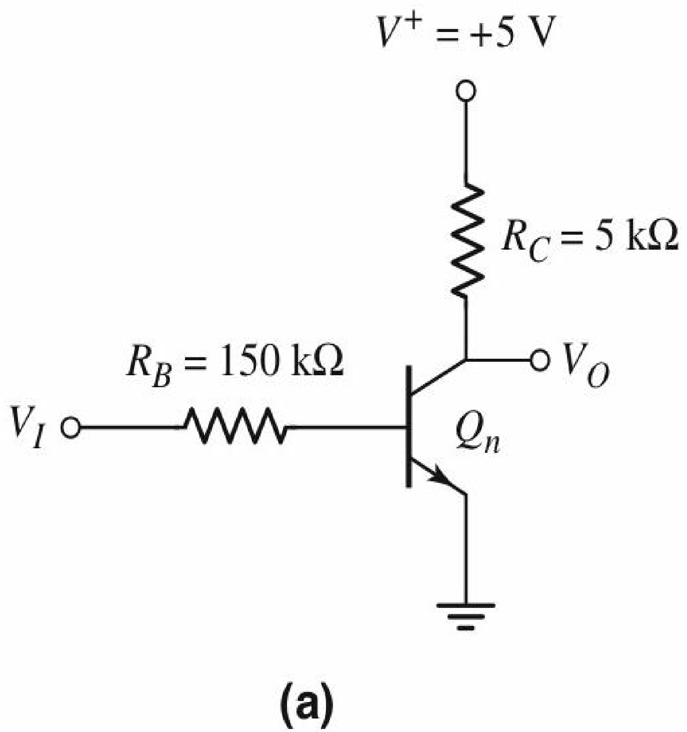
  $V_{BE}=0$, $I_B=0$, $I_C=0$, $V_{CE}= V_{CC} - I_C R_c= V_{CC}$.

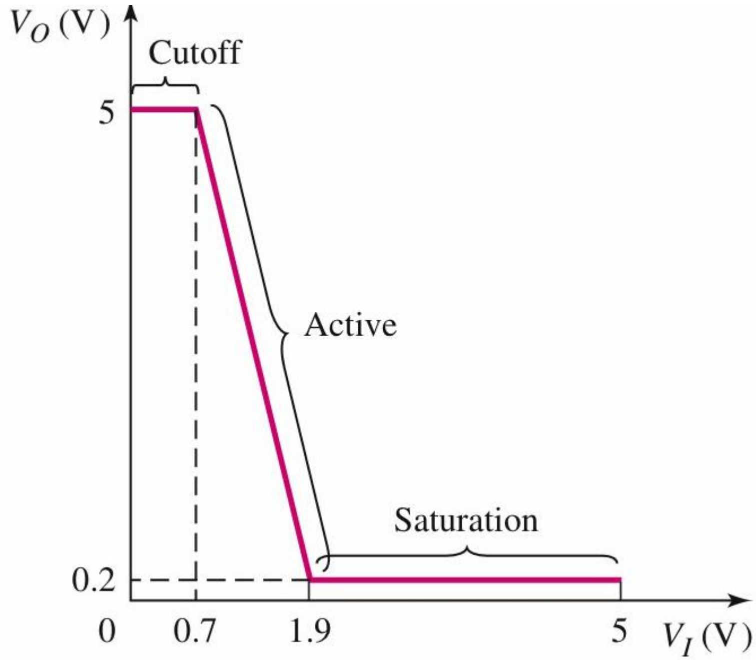
Contents

Ch5. The Bipolar Junction Transistor



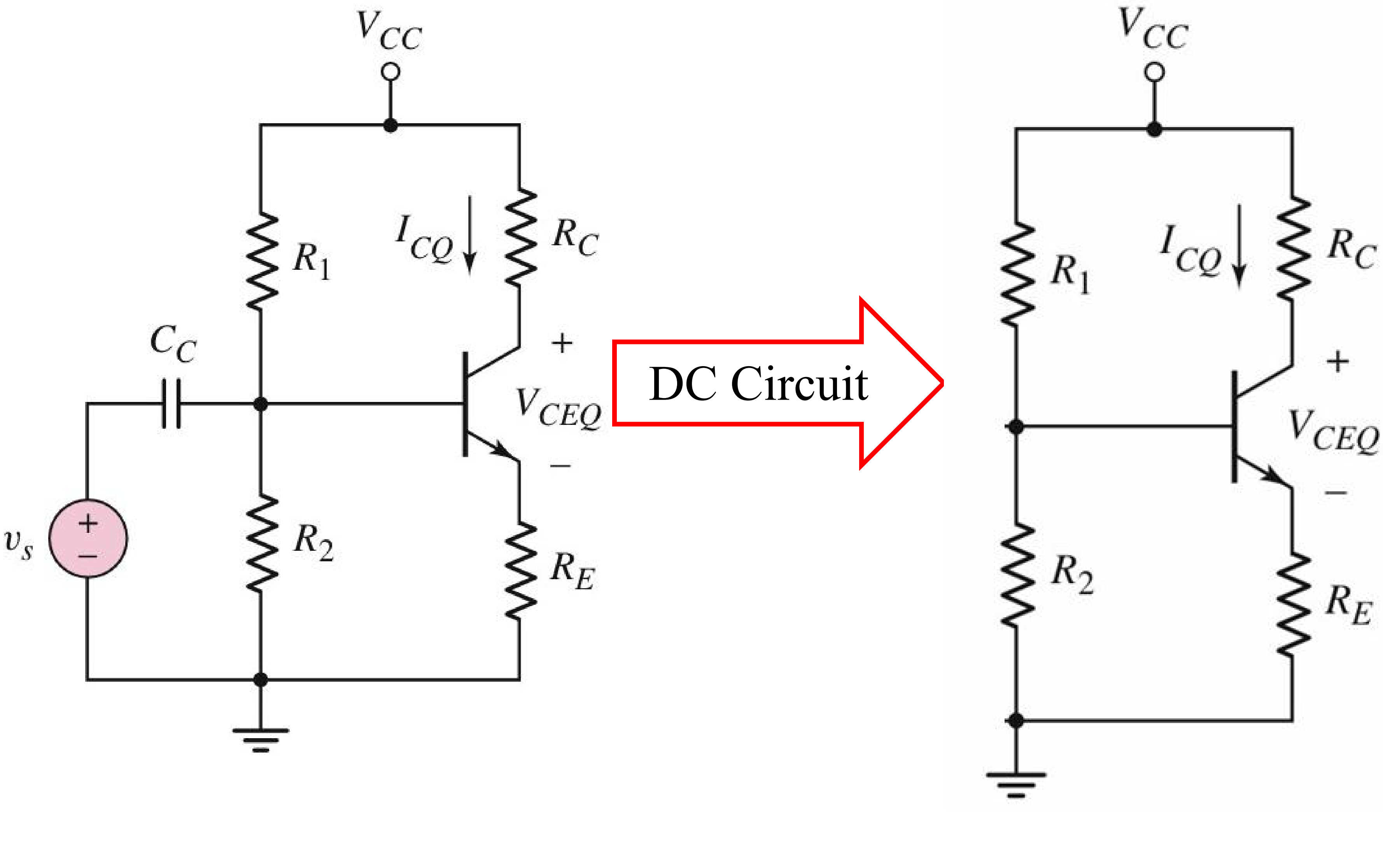
Review



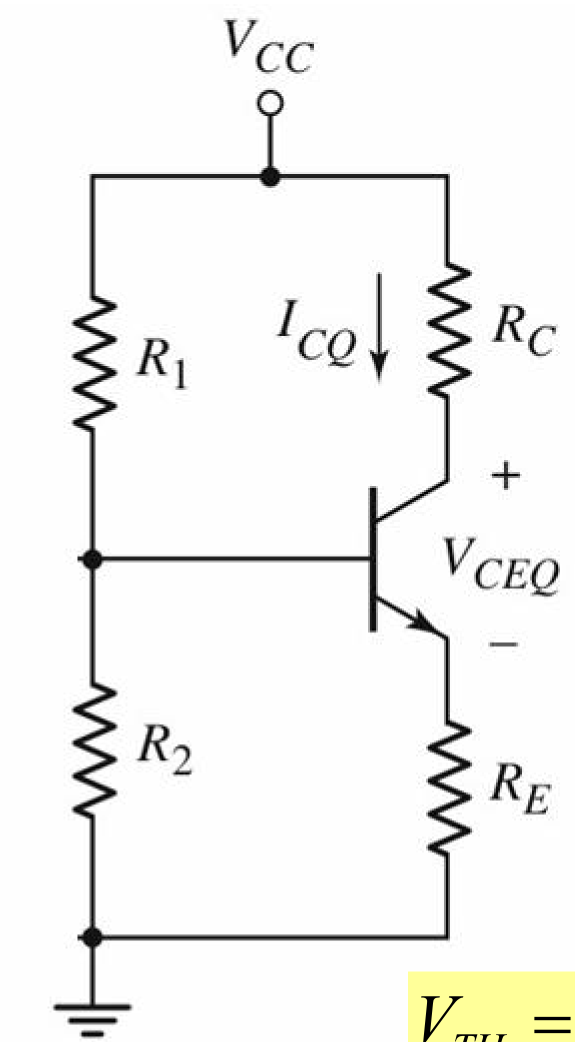


Voltage Transfer Characteristic

Review



Review



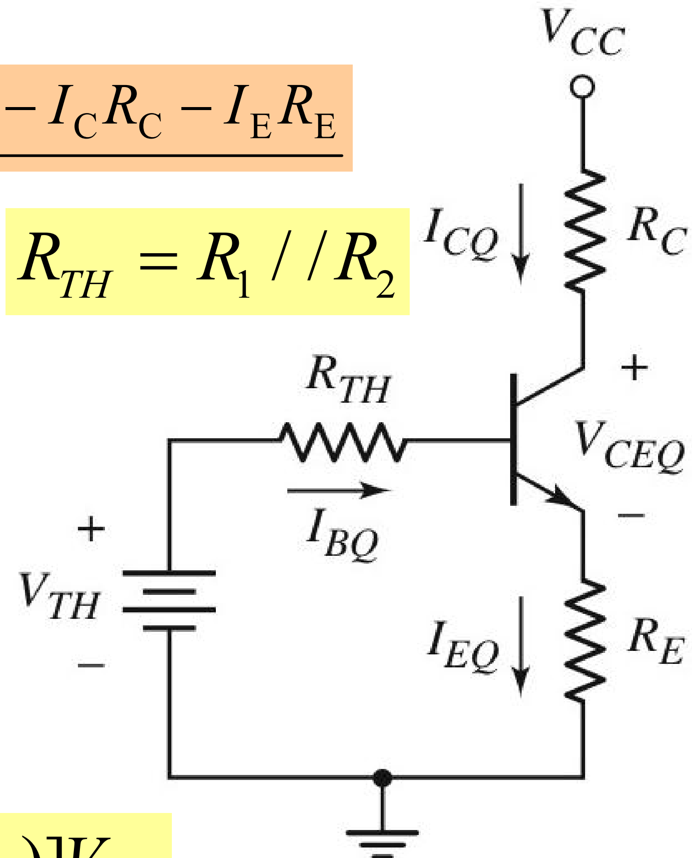
$$I_B = \frac{V_{TH} - V_{BE}}{R_{TH} + (1+\beta)R_E}$$

$$I_C = \beta I_B$$

$$V_{CEQ} = V_{CC} - I_C R_C - I_E R_E$$

$$R_{TH} = R_1 // R_2$$

Thevenin equivalent



$$V_{TH} = [R_2 / (R_1 + R_2)]V_{CC}$$

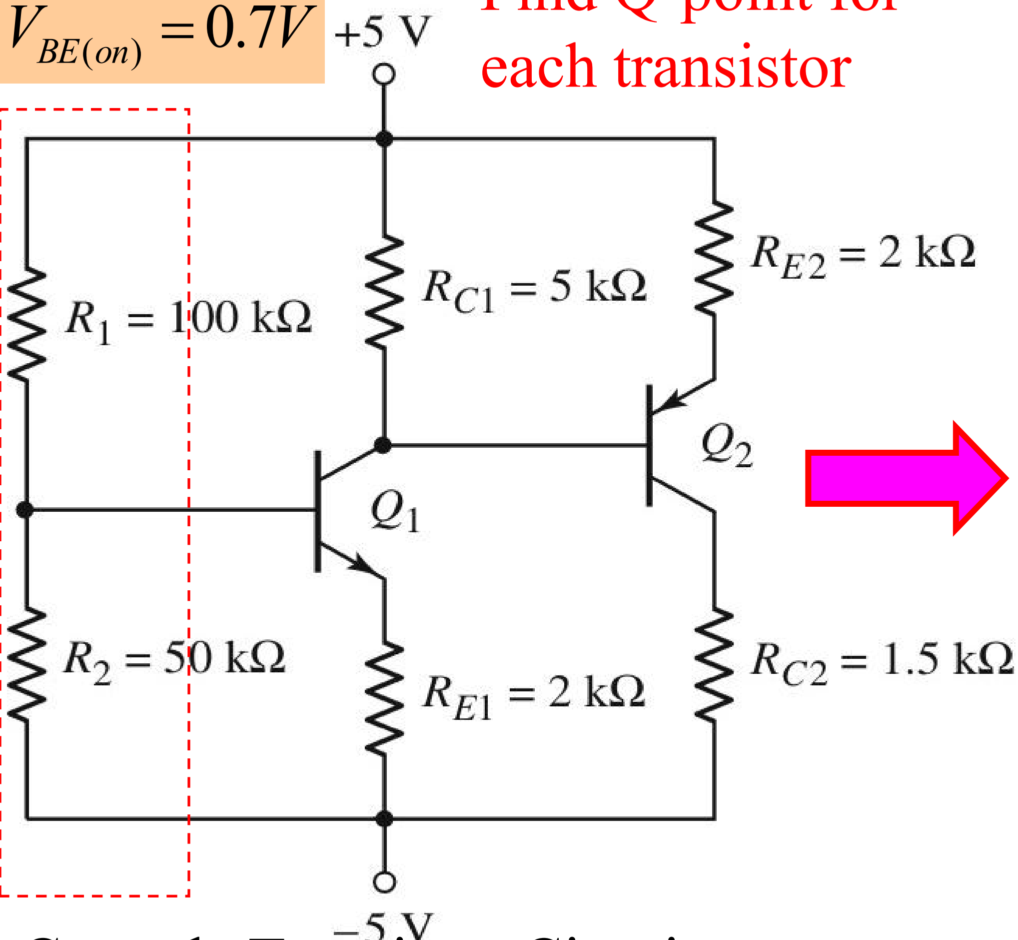
5.5 Multistage Circuits

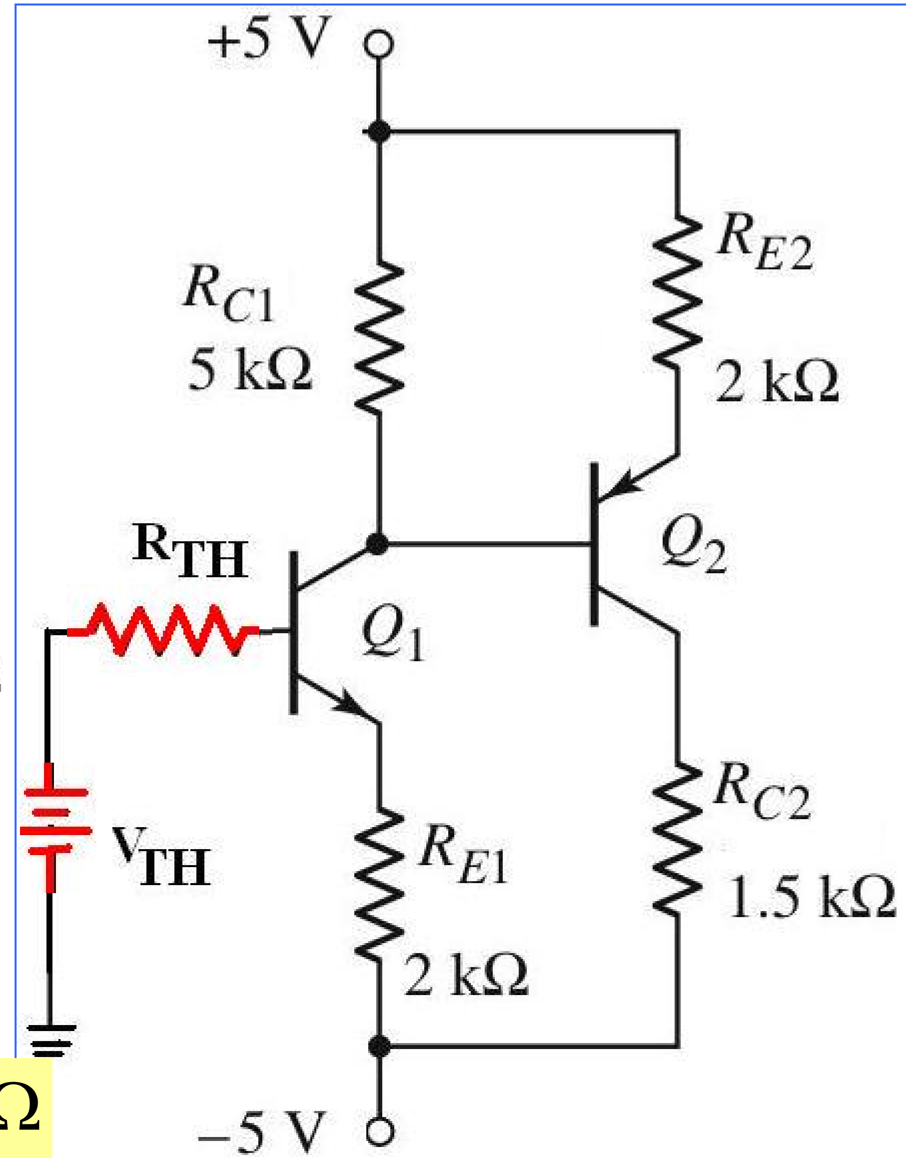
$$V_{TH} = [R_2 / (R_1 + R_2)][10] - 5 = -1.67\text{V}$$

$\beta = 100$

$V_{BE(on)} = 0.7V$

Find Q-point for each transistor

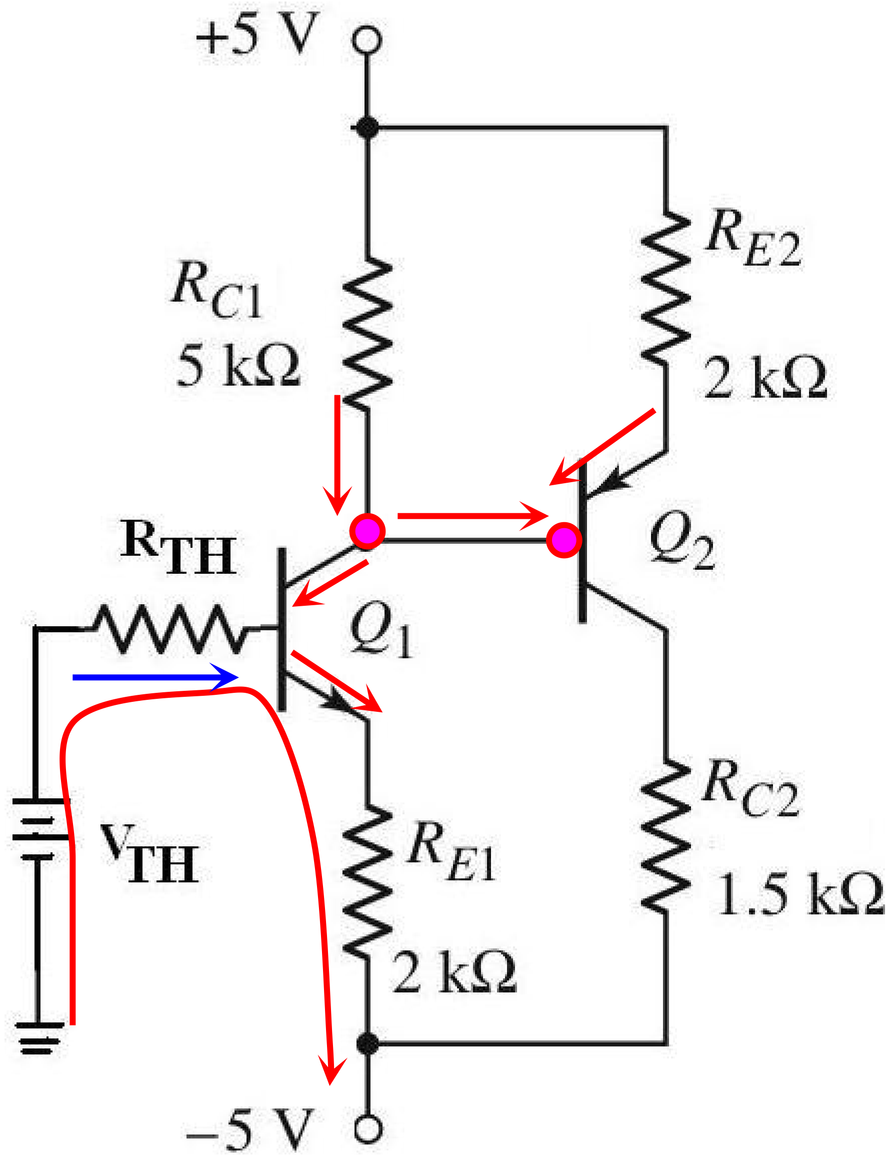




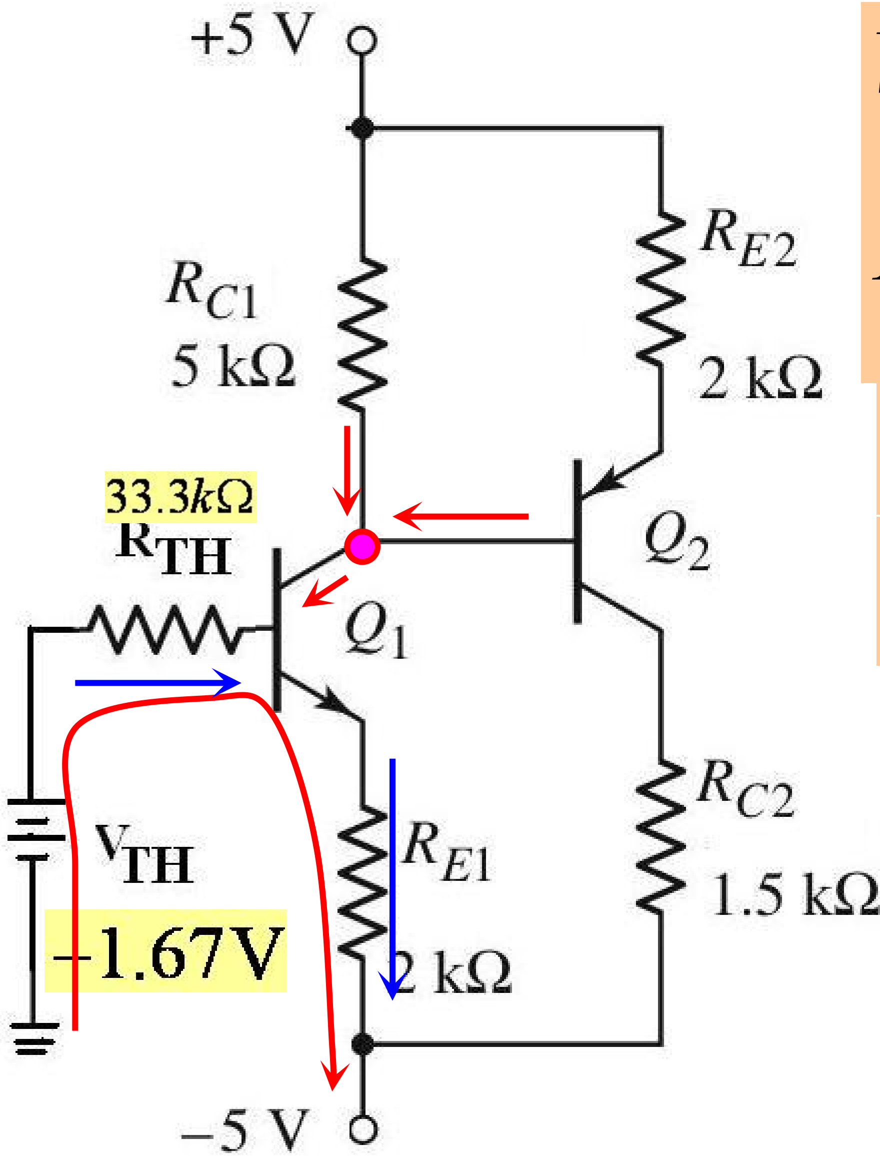
Cascade Transistor Circuit

级联

$$R_{TH} = R_1 // R_2 = 33.3k\Omega$$


+5 V
R_{E2}
R_{C1}
5 kΩ
2 kΩ
R_{TH}
Q_2
Q_1
R_{C2}
V_{TH}
R_{E1}
1.5 kΩ
2 kΩ
−5 V

5.5 Multistage Circuits



$$V_{TH} = I_{B1}R_{TH} + V_{BE(on)} + I_{E1}R_{E1} - 5$$

$$I_{B1} = \frac{-1.67+5-0.7}{33.3+(101)(2)} = 11.2\mu A$$

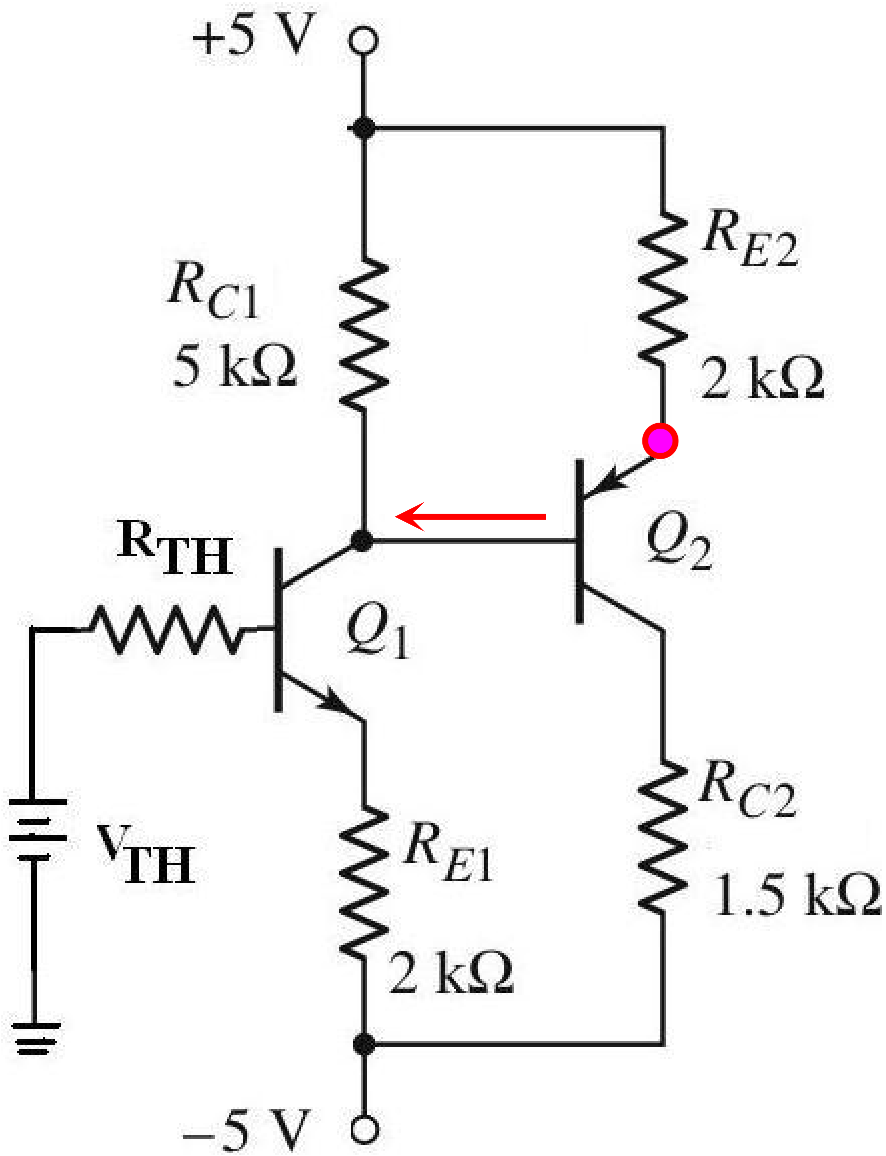
$$I_{C1} = \beta I_{B1} = 1.12mA$$

$$I_{E1} = (1+\beta)I_{B1} = 1.13mA$$

$$I_{RC1} + I_{B2} = I_{C1}$$

$$\frac{5-V_{C1}}{R_{C1}} + I_{B2} = I_{C1}$$

5.5 Multistage Circuits



$$\frac{5-V_{C1}}{R_{C1}}+I_{B2}=I_{C1} \quad \cdots\cdots(1)$$

$$I_{B2}=\frac{I_{E2}}{1+\beta}=\frac{5-V_{E2}}{(1+\beta)R_{E2}}$$

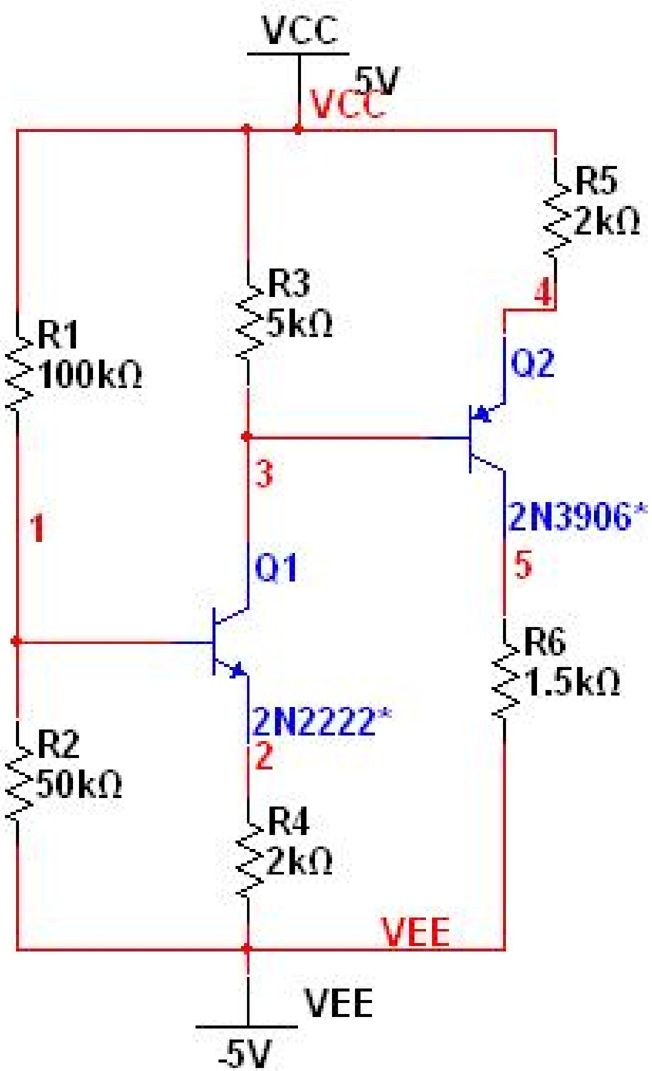
$$I_{B2}=\frac{5-(V_{C1}+0.7)}{(1+\beta)R_{E2}} \quad \cdots\cdots(2)$$

$$I_{C1}=1.12mA$$

$$V_{C1}=-0.482V$$

$$I_{B2}=23.7\mu A$$

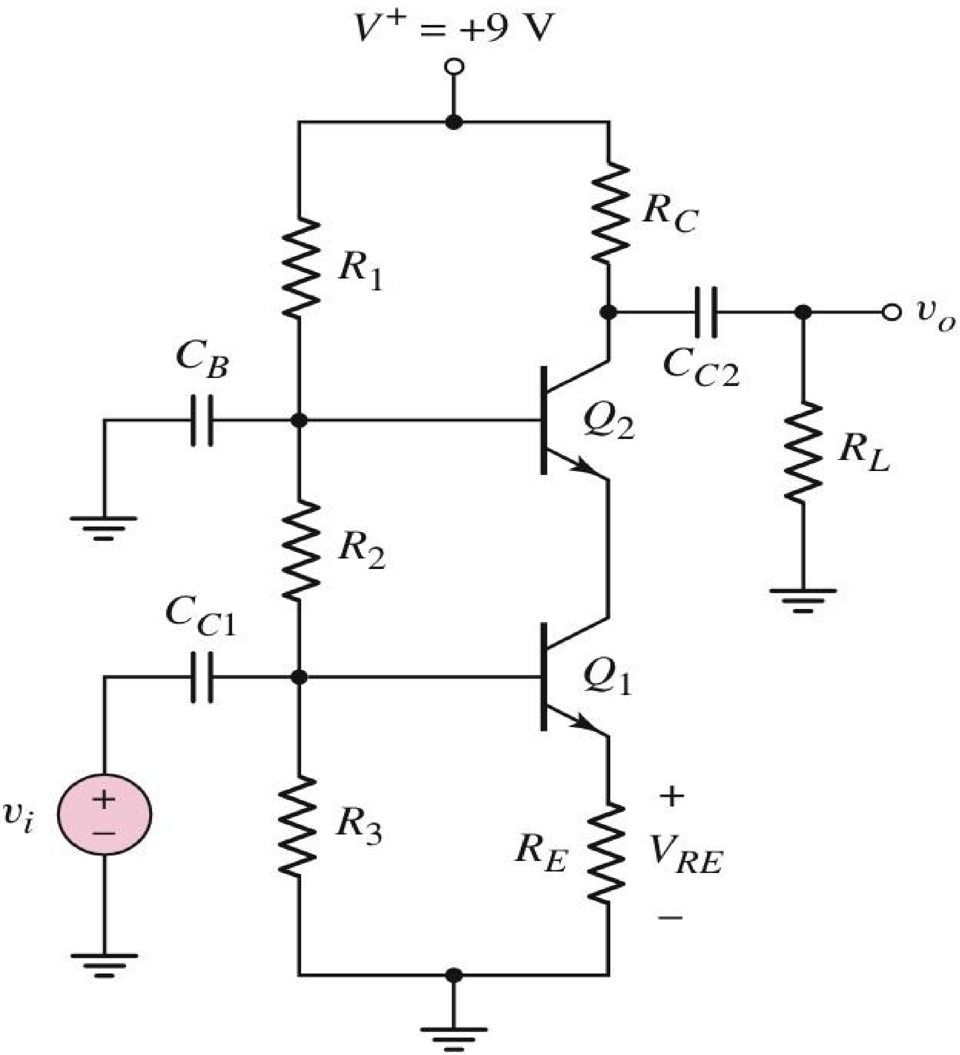
5.5 Multistage Circuits



multistage
DC Operating Point

	DC Operating Point		
1	I(Q1[IC])	$I_{C1} = 1.12mA$	1.09647 m
2	I(Q1[IB])	$I_{B1} = 11.2\mu A$	14.35467 u
3	I(Q2[IC])		2.30005 m
4	I(Q2[IB])	$I_{B2} = 23.7\mu A$	22.22821 u
5	V(5)		-1.54992
6	V(4)		355.44306 m
7	V(2)		-2.77835
8	V(3)	$V_{C1} = -0.482V$	-371.20615 m

5.5 Multistage Circuits



$$V_{CE1} = V_{CE2} = 2.5V$$

$$V_{RE} = 0.7V$$

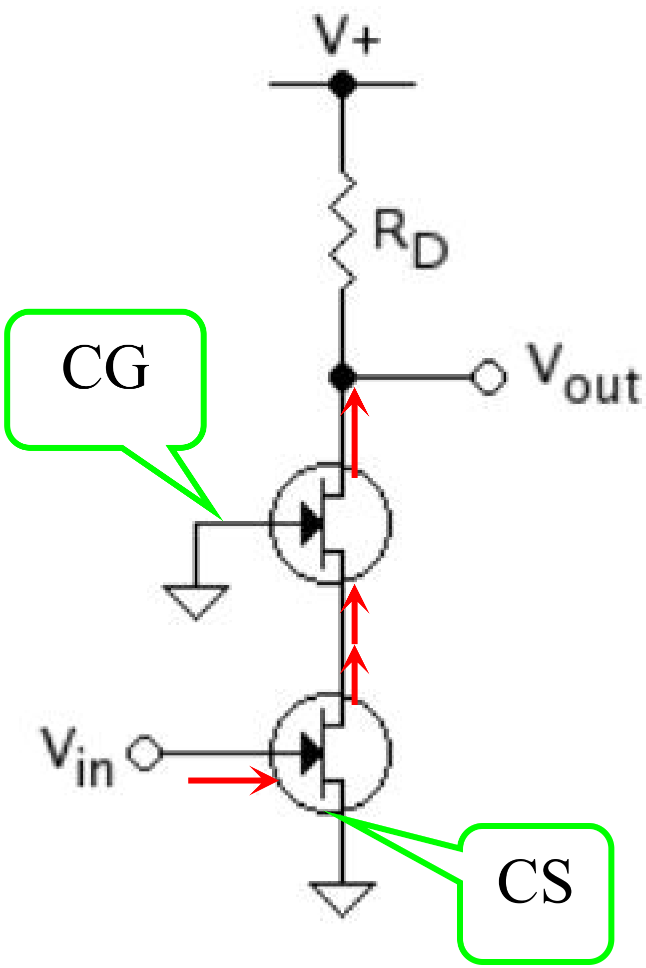
$$I_{C1} = I_{C2} = 1mA$$

$$I_{R1} = I_{R2} = I_{R3} = 0.1mA$$

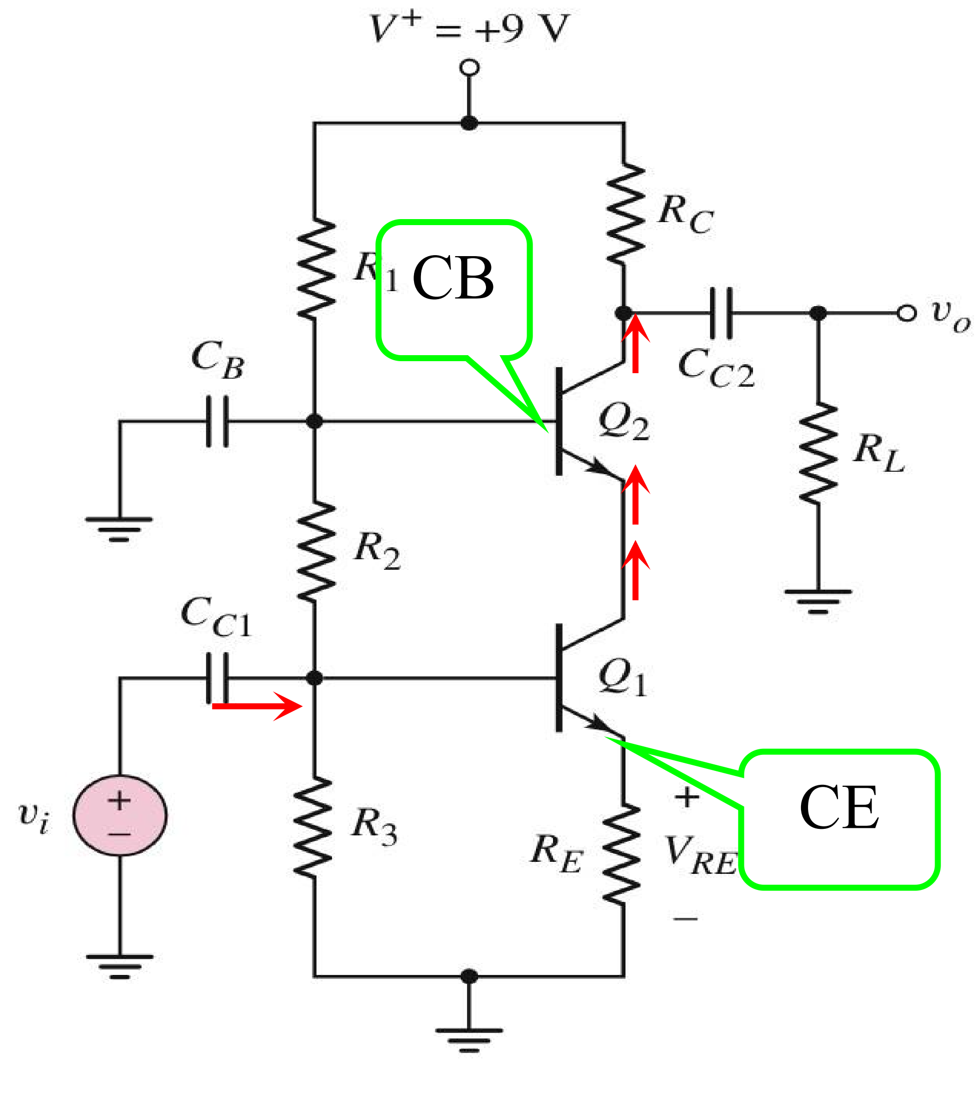
Design the circuit

Cascode Transistor Circuit

Cascode



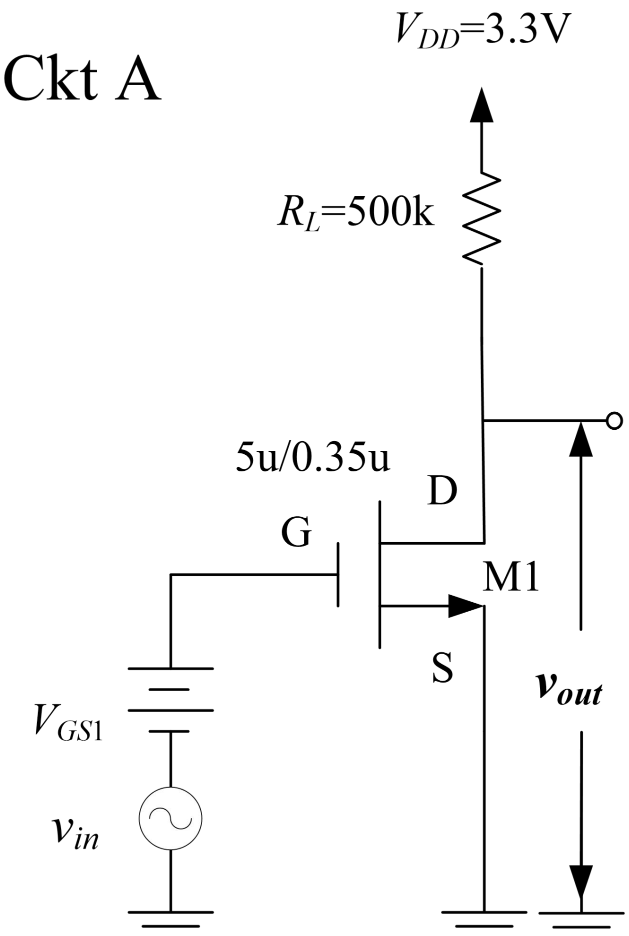
V+
RD
Vout
CG
Vin
CS



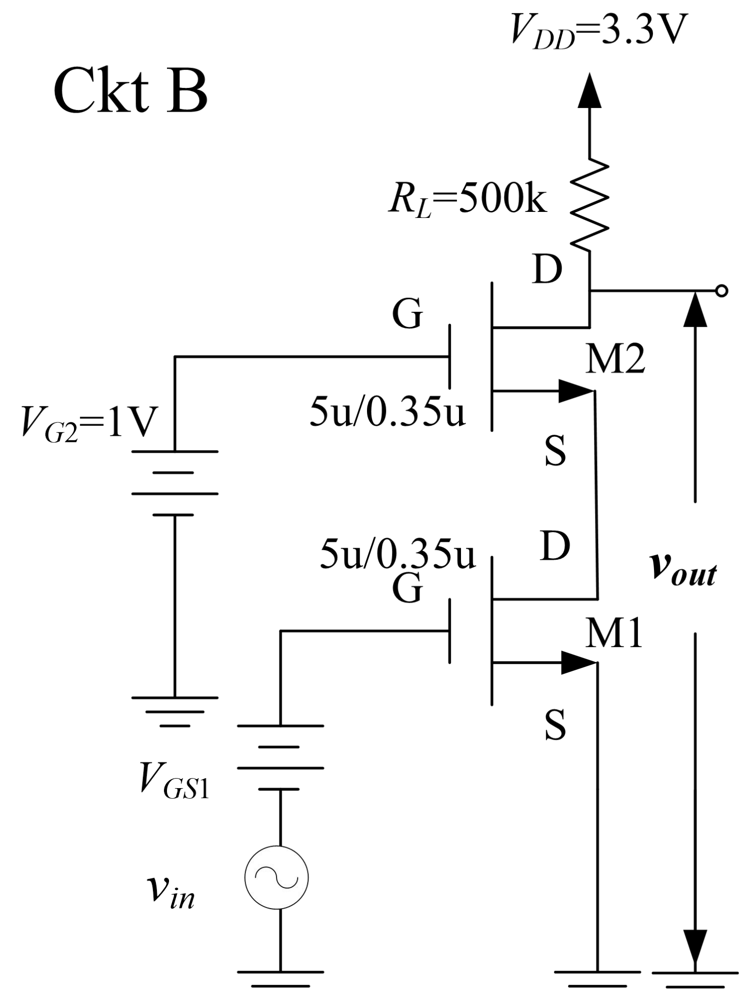
V+ = +9 V
RC
R1
CB
vo
CB
CC2
Q2
RL
R2
CC1
Q1
vi
+
–
R3
RE
+
VRE
–
CE

Simulation Homework

Ckt A

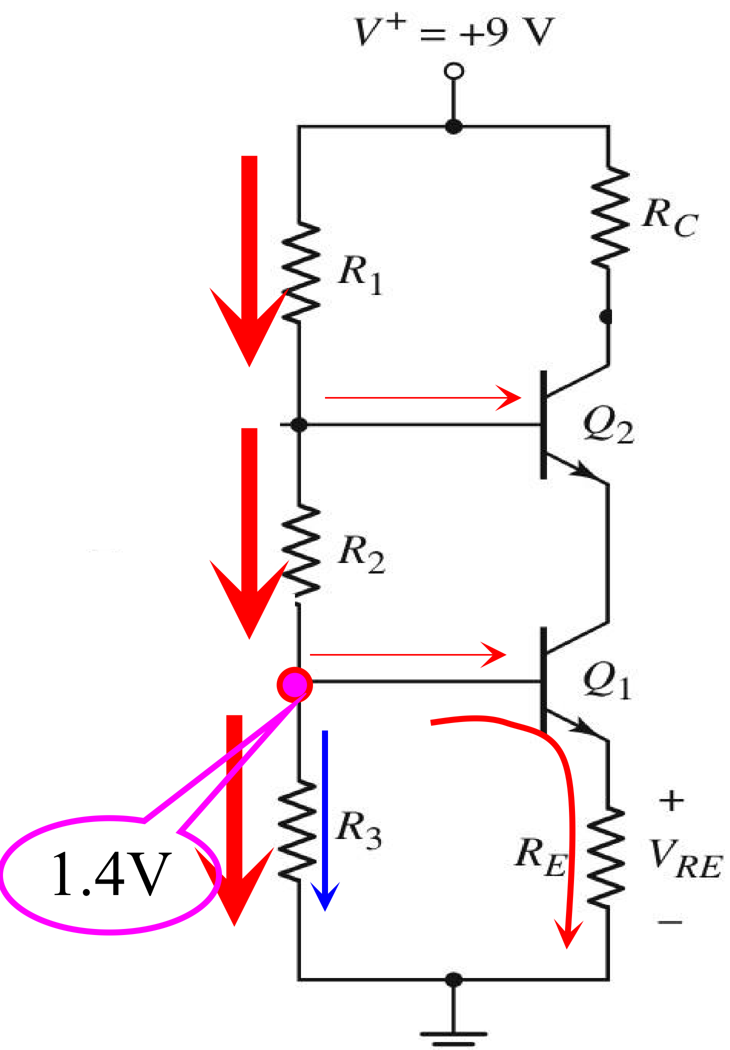


Ckt B



Comparing the I-V Curves of the Two Amplifiers.

5.5 Multistage Circuits



Cascode Transistor Circuit

$$V_{CE1} = V_{CE2} = 2.5V$$

$$V_{RE} = 0.7V$$

$$I_{C1} = I_{C2} = 1mA$$

$$I_{R1} = I_{R2} = I_{R3} = 0.1mA$$

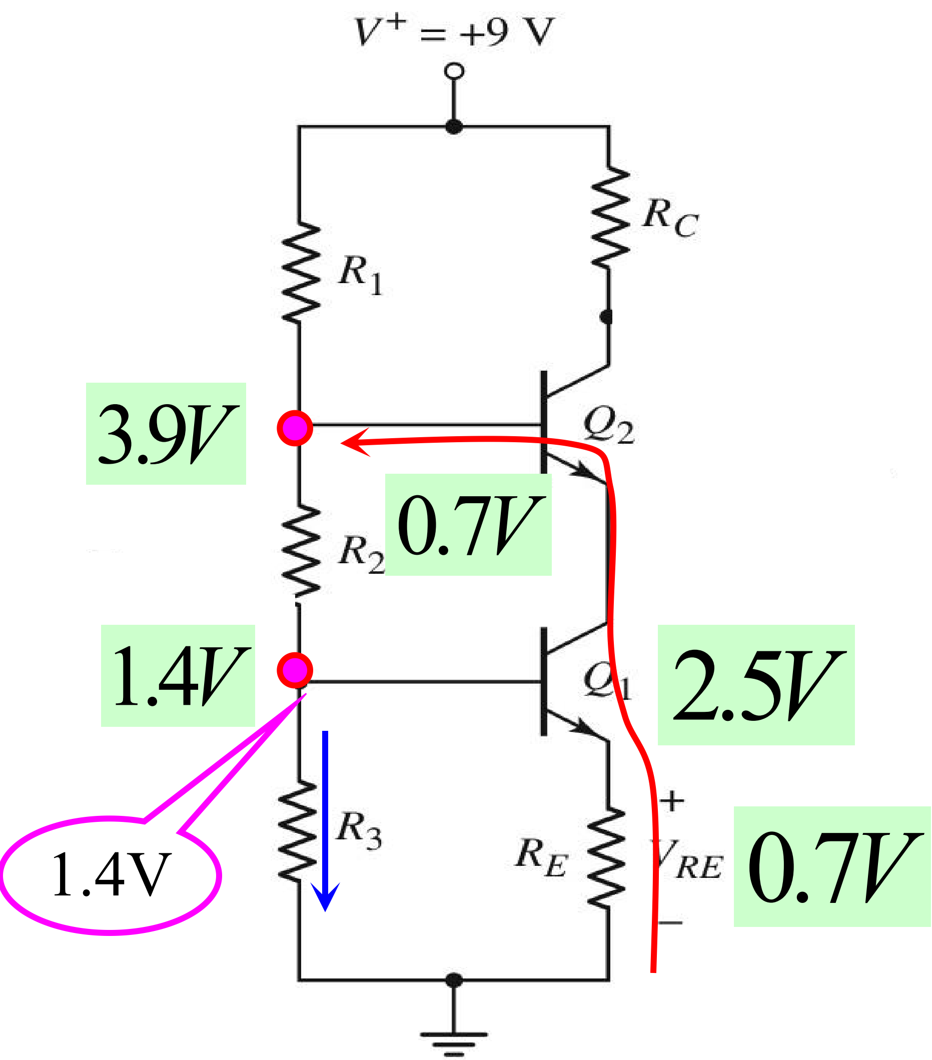
Design the circuit

$$I_{Bias} = I_{R1} = I_{R2} = I_{R3} = 0.1mA$$

$$R_1 + R_2 + R_3 = \frac{V^+}{I_{Bias}} = \frac{9}{0.10} = 90k\Omega$$

$$V_{RE} = 0.7V \qquad V_{\mathrm{BE(on)}} = 0.7V$$

5.5 Multistage Circuits



Cascode Transistor Circuit

$$V_{CE1} = V_{CE2} = 2.5V$$

$$V_{RE} = 0.7V$$

$$I_{C1} = I_{C2} = 1mA$$

$$I_{R1} = I_{R2} = I_{R3} = 0.1mA$$

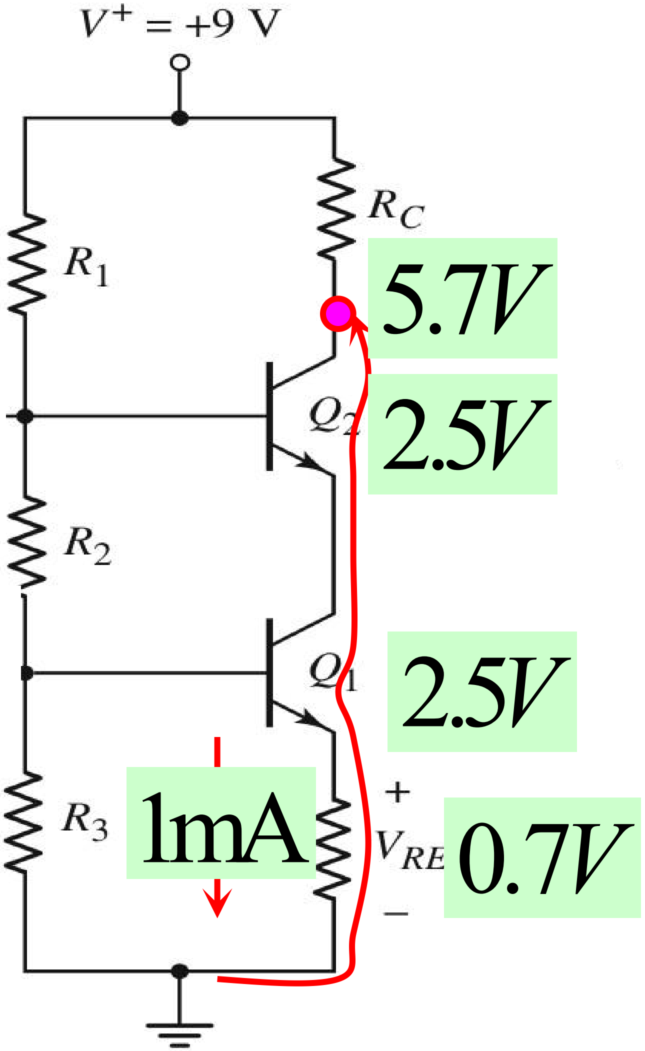
Design the circuit

$$R_3 = \frac{1.4V}{0.1mA} = 14k\Omega$$

$$R_2 = \frac{3.9\text{V} - 1.4V}{0.1mA} = 25k\Omega$$

$$R_1 = 90 - 25 - 14 = 51k\Omega$$

5.5 Multistage Circuits



Cascode Transistor Circuit

$$V_{CE1} = V_{CE2} = 2.5V$$

$$V_{RE} = 0.7V$$

$$I_{C1} = I_{C2} = 1mA$$

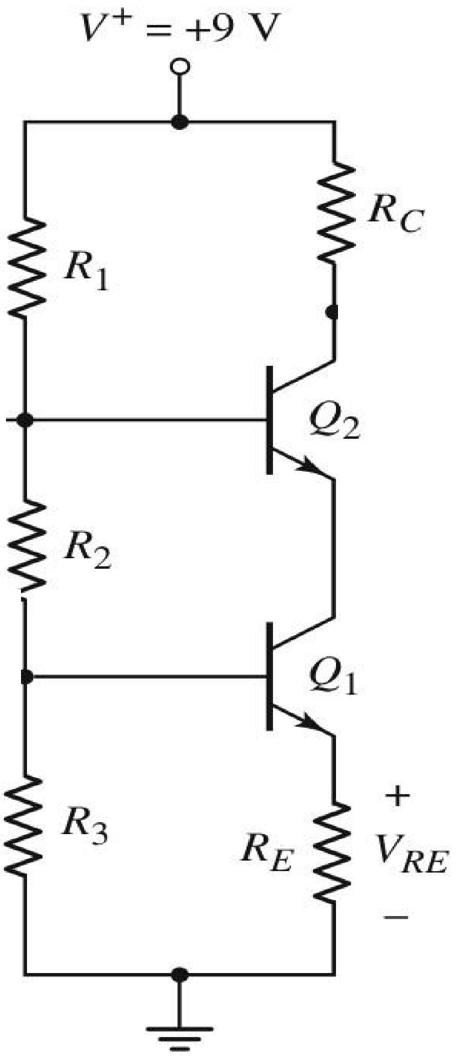
$$I_{R1} = I_{R2} = I_{R3} = 0.1mA$$

Design the circuit

$$R_E = \frac{0.7V}{1mA} = 0.7k\Omega$$

$$R_C = \frac{9-5.7}{1mA} = 3.3k\Omega$$

5.5 Multistage Circuits



$$V_{CE1} = V_{CE2} = 2.5V$$

$$V_{RE} = 0.7V$$

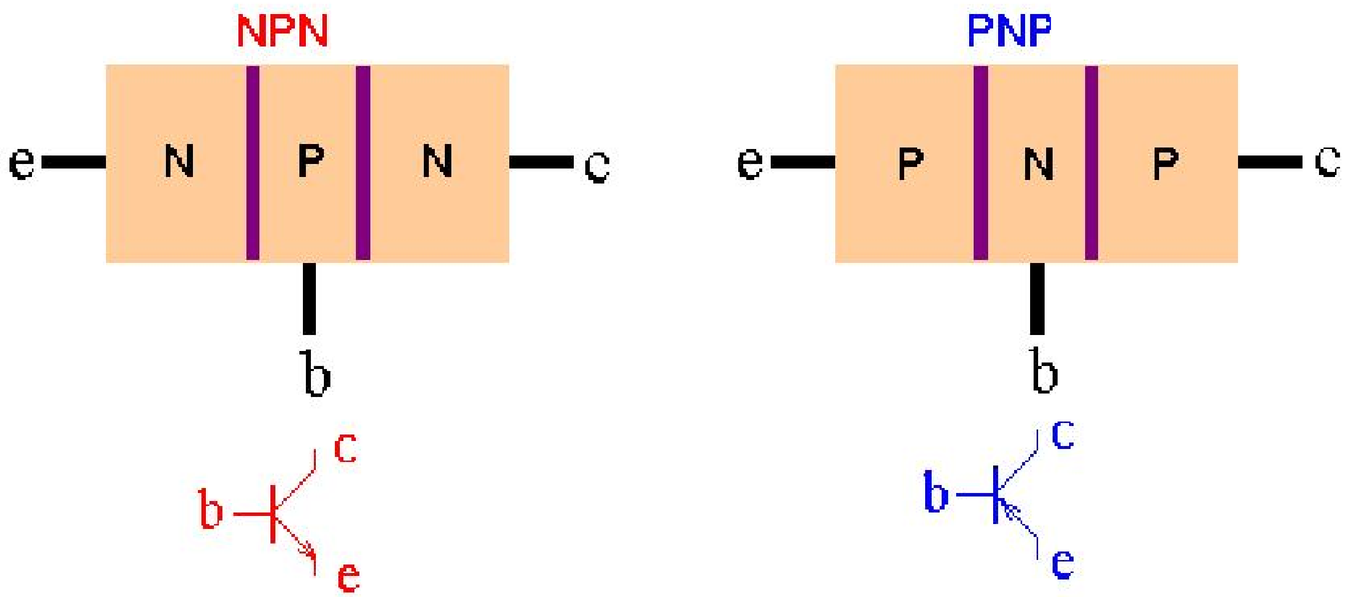
$$I_{C1} = I_{C2} = 1mA$$

$$I_{R1} = I_{R2} = I_{R3} = 0.1mA$$

Design the circuit

Cascode Transistor Circuit

5.7 Summary



Three regions:

Three terminals

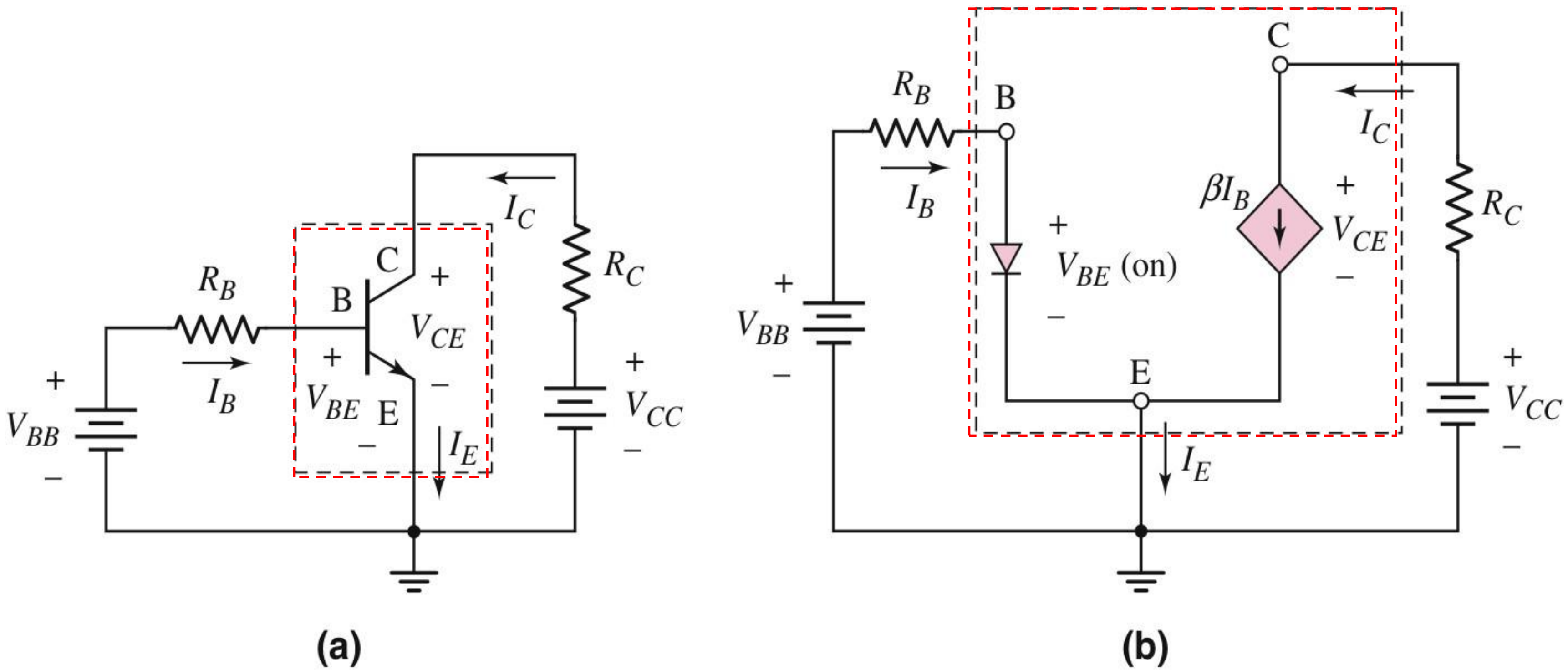
Two *pn* junctions:

Modes of Operation

Modes	EBJ	CBJ
Cutoff	Reverse	Reverse
Saturation	Forward	Forward
Active	Forward	Reverse

5.7 Summary

DC Equivalent Circuit



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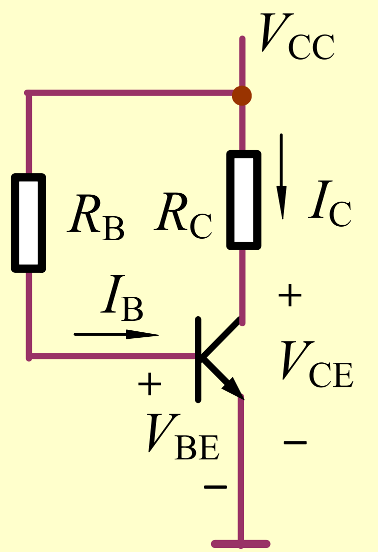
Common Emitter Circuit

5.7 Summary



DC equivalent circuit