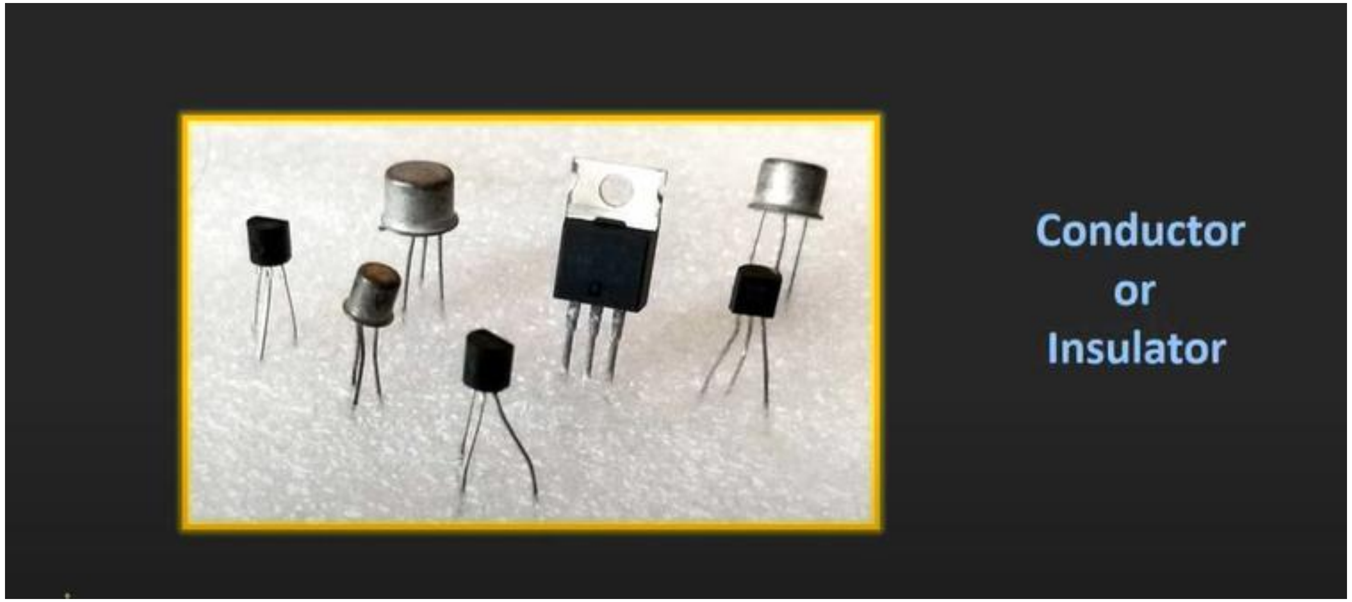
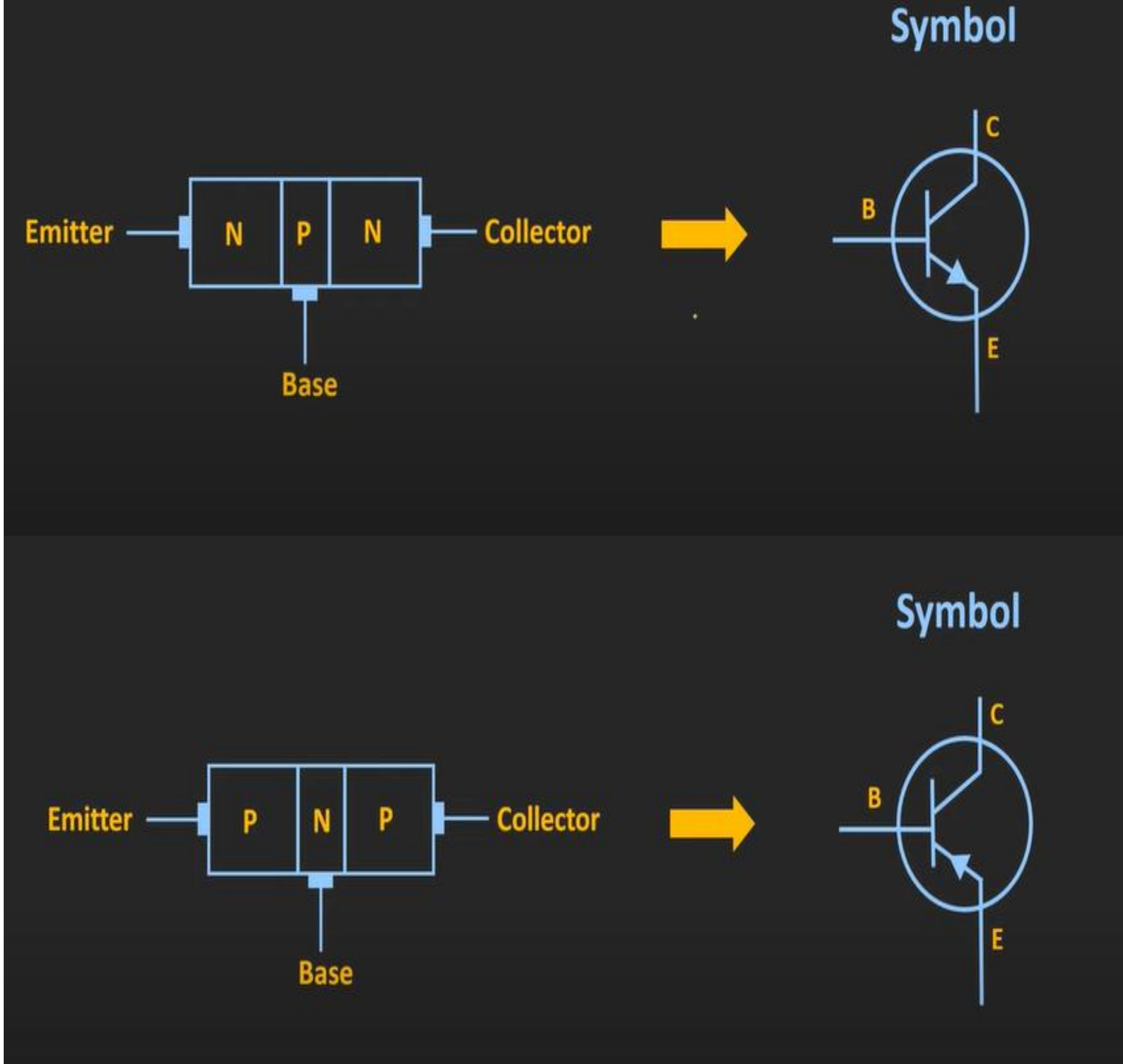
BIPOLAR JUNCTION TRANSISTOR (BJT)

Bipolar Junction Transistor

- The transistor is a three-layer semiconductor device.
- It consists of either two *n* - and one *p* -type layers of material or two *p* - and one *n* -type layers of material, the **emitter–base junction** (EBJ) and the **collector–base junction** (CBJ).
- They former is called an *npn transistor* and the latter is called a *pnp transistor* . The reason it is known as bipolar because there is a flow of current in BJT due to two types of charges Holes and Electrons



Symbols


Symbol
Emitter
N
P
N
Collector
Base
C
B
E
Symbol
Emitter
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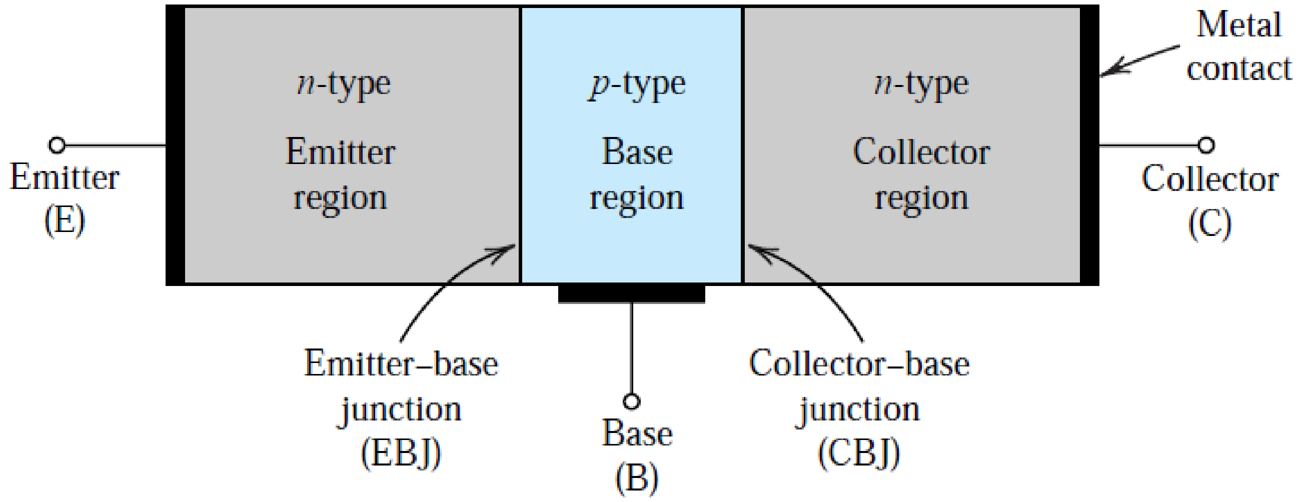


Figure 6.1 A simplified structure of the *npn* transistor.

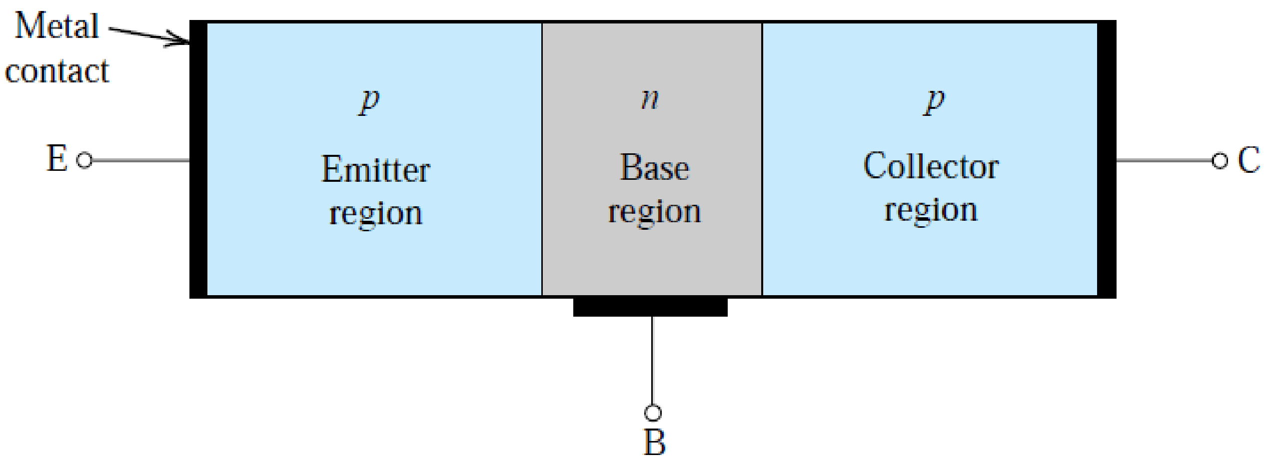


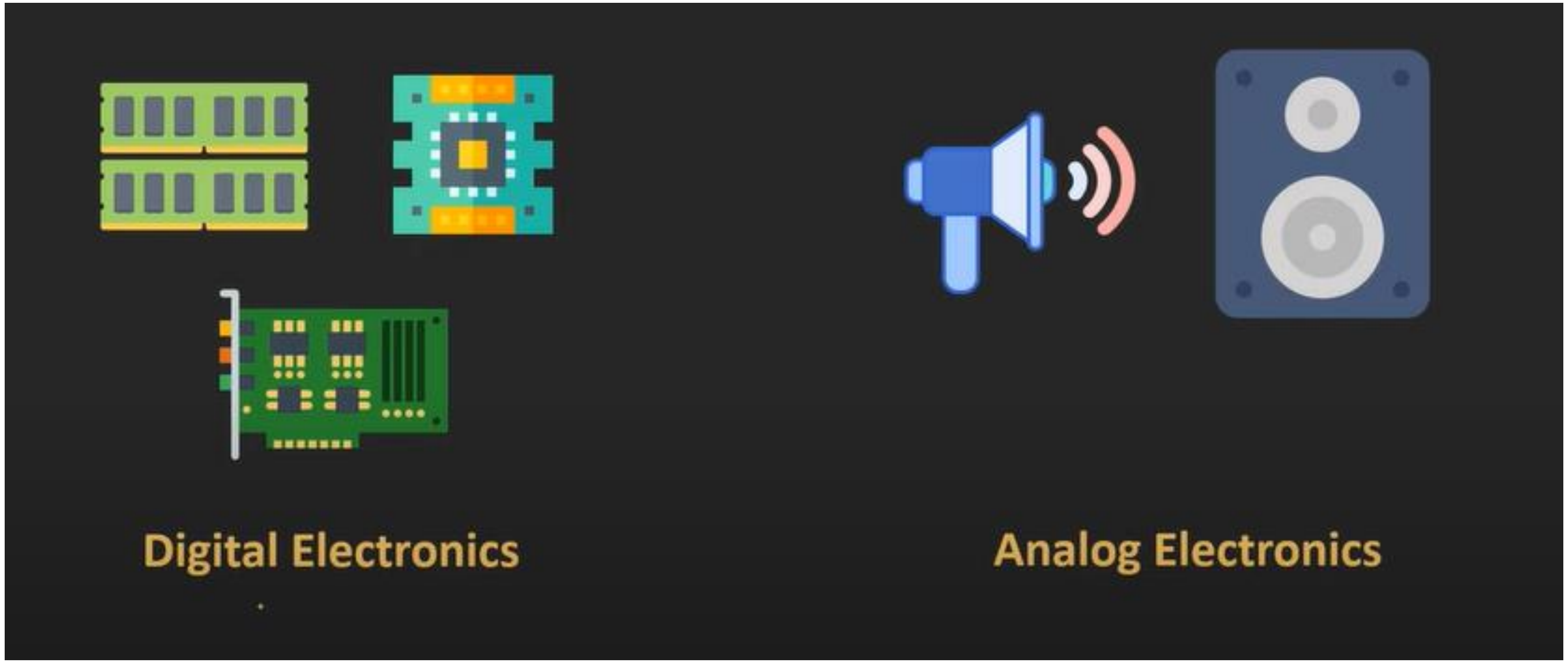
Figure 6.2 A simplified structure of the *pnp* transistor.

- The BJT consist of the three doped regions
- The three regions of the BJT are known as Emitter, Base, and Collector.
- Based on the doping of the three regions, it is known as either NPN or PNP transistor.
- In BJT, the emitter is heavily doped.
- Base is lightly doped
- the collector is moderately doped.
- The width of the base region is much smaller than the other two regions.
- The job of the emitter region is to supply the electrons (that's why it is known as the emitter) While the collector region collects the electrons supplied by the emitter

Application

BJT is used as

1. A switch or
2. An amplifier in the electronic circuits.



Different Regions of Operation of BJT

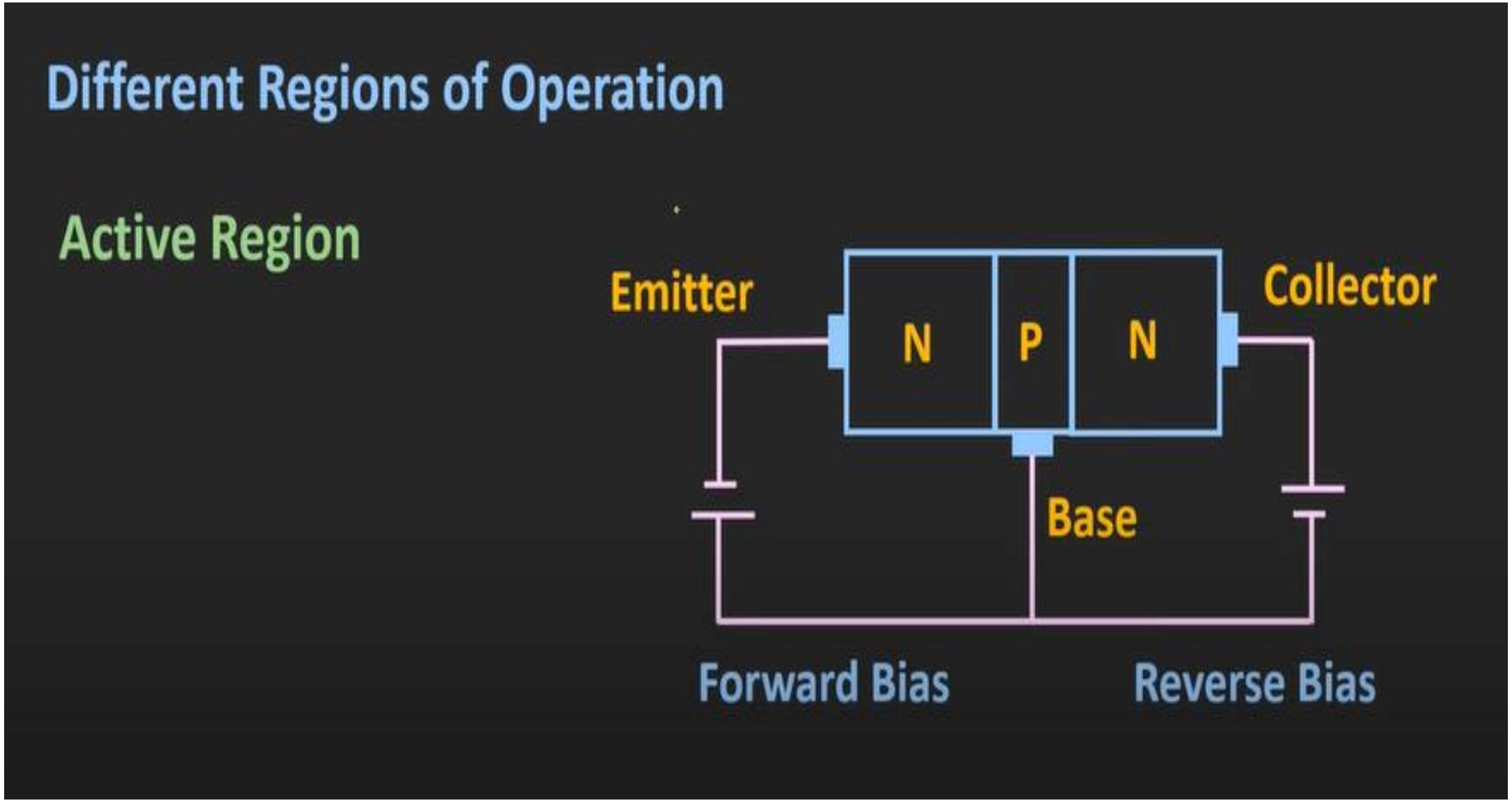
The BJT can be operated in the following regions:

1) Active Mode (BE Junction is Forward Biased, CB junction is reverse biased)
2) Cut-off Mode (Both BE and BC junctions are reverse biased)
3) Saturation Mode (Both BE and BC junctions are forward-biased)
4) Reverse Active Mode (BE junction is reverse biased, BC junction is forward biased)

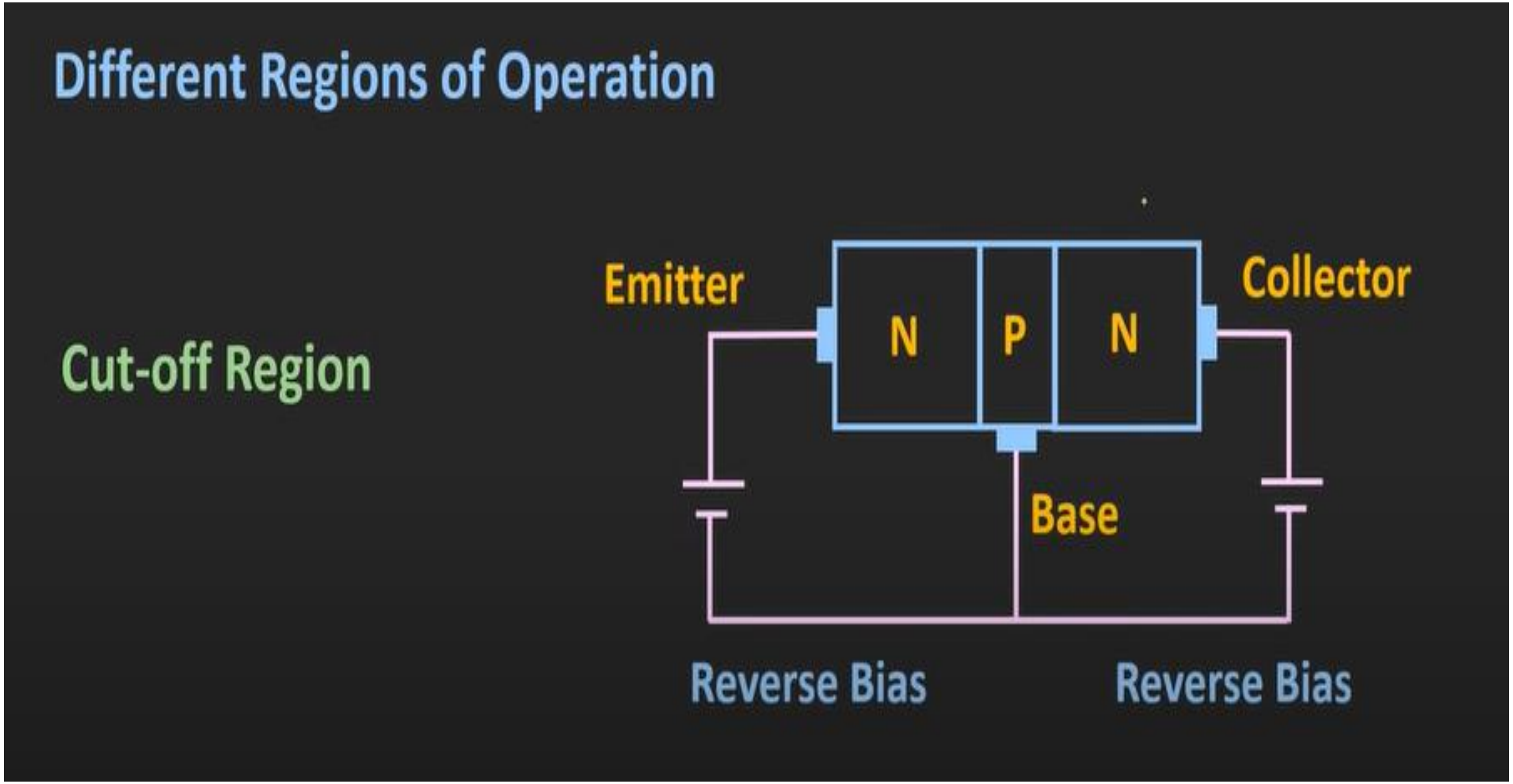
Table 6.1 BJT Modes of Operation

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

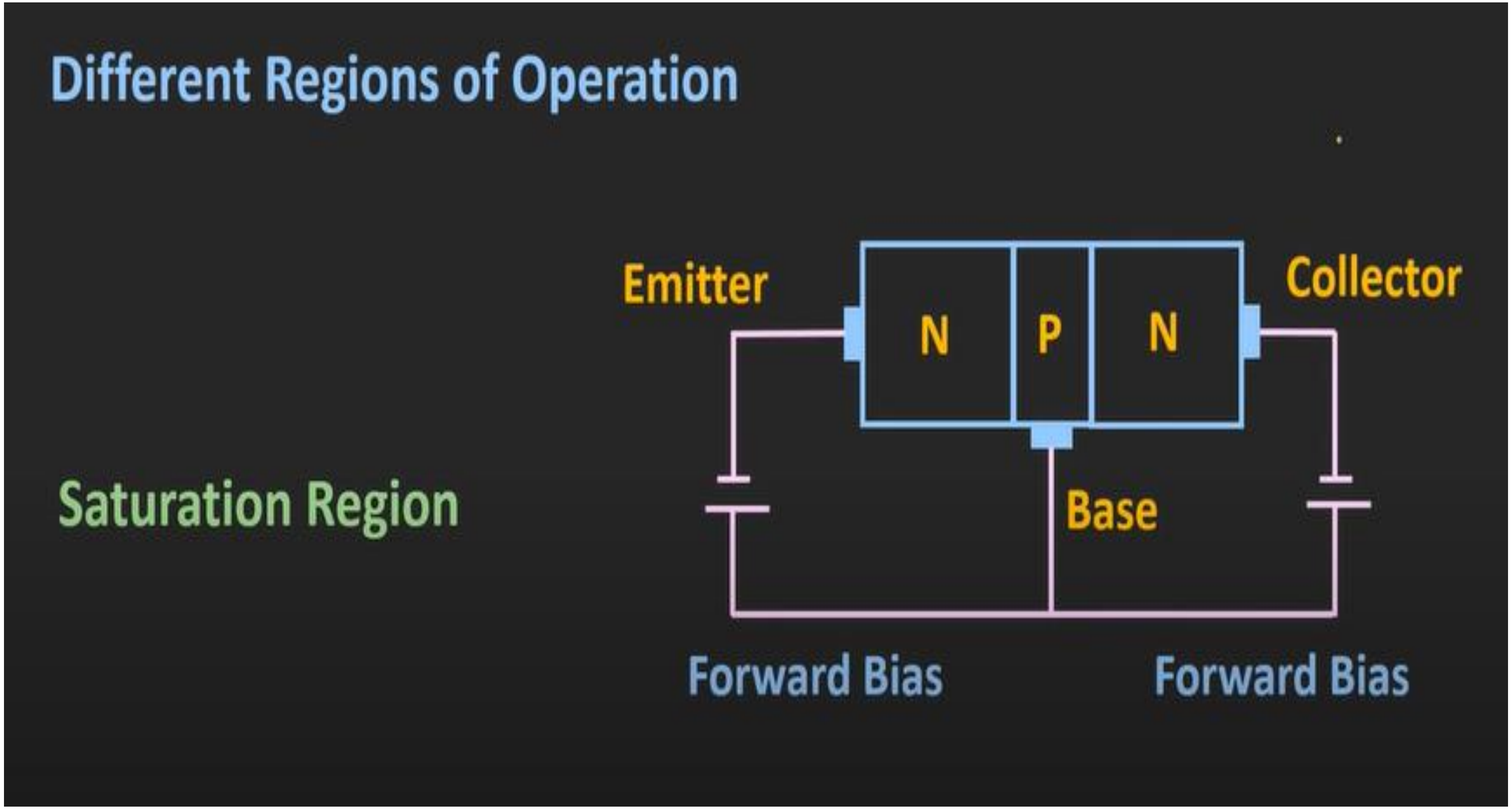
Active Mode of Operation



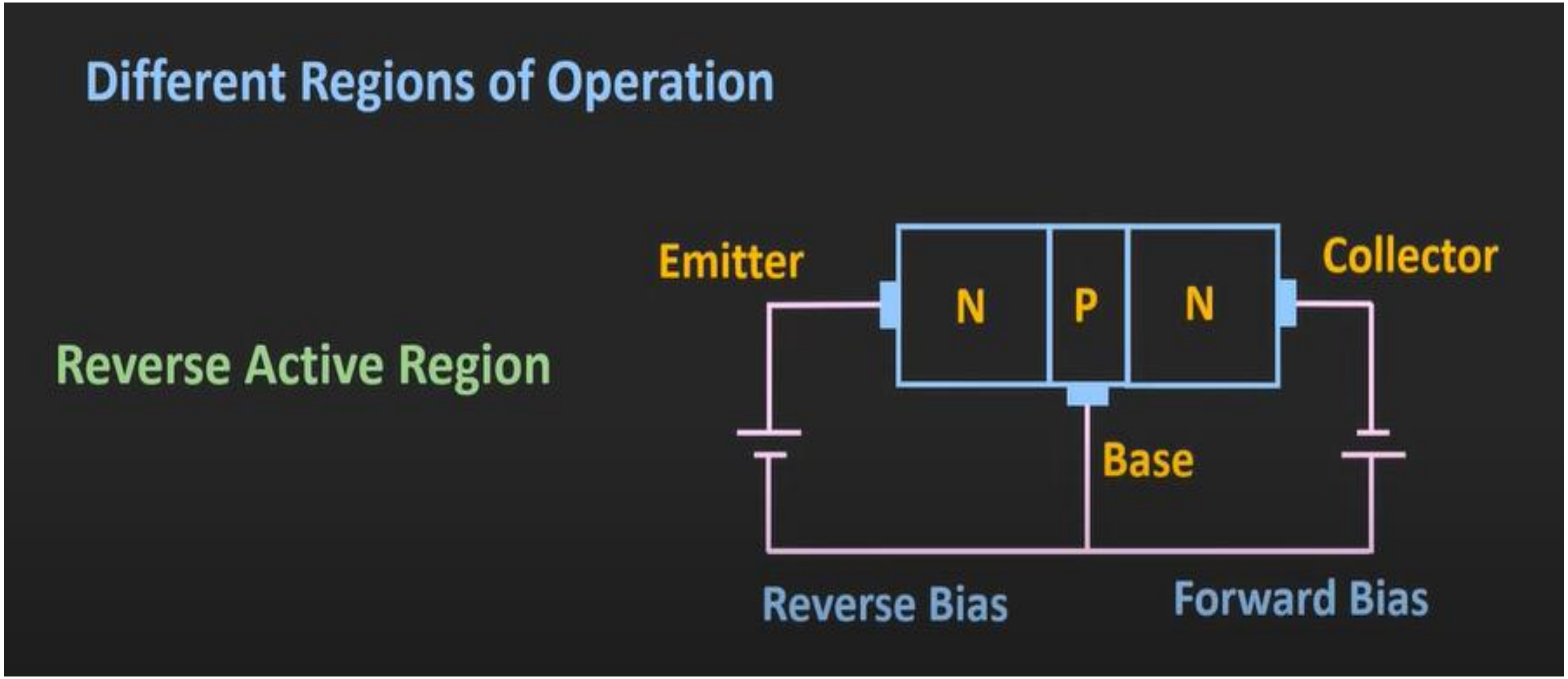
Cut-off Mode of Operation



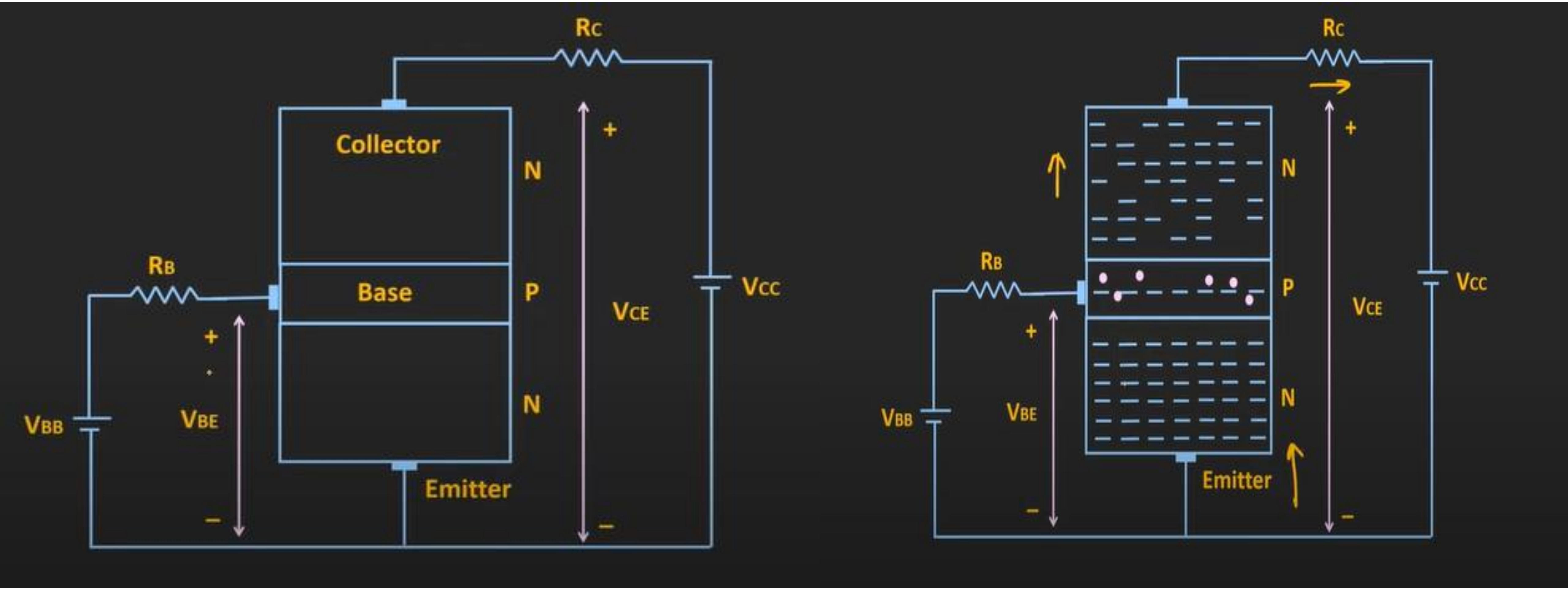
Saturation Mode of Operation



Reverse Active Mode of Operation



Working of BJT



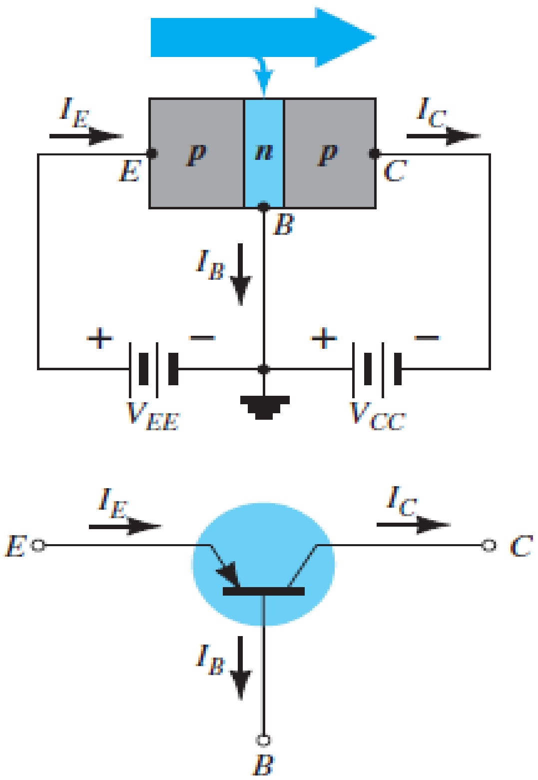
Different operating Configurations of BJT

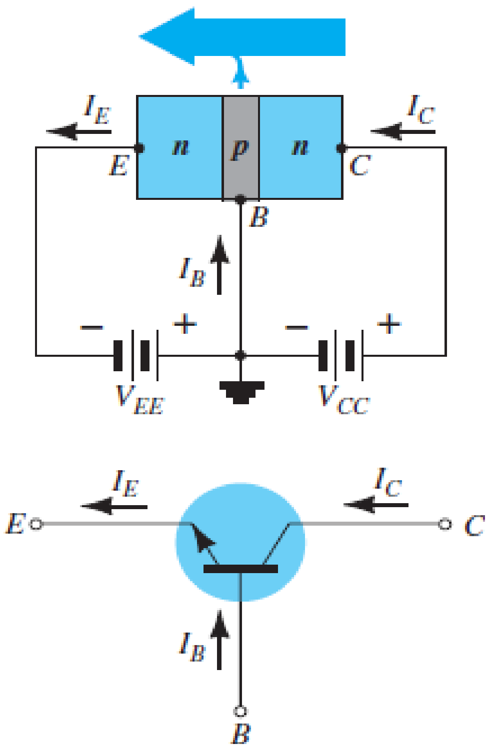
When BJT is used as an amplifier, it can be configured in the following configurations:

1) Common Emitter (CE) Configuration
2) Common Base (CB) Configuration
3) Common Collector (CC) Configuration

COMMON-BASE CONFIGURATION

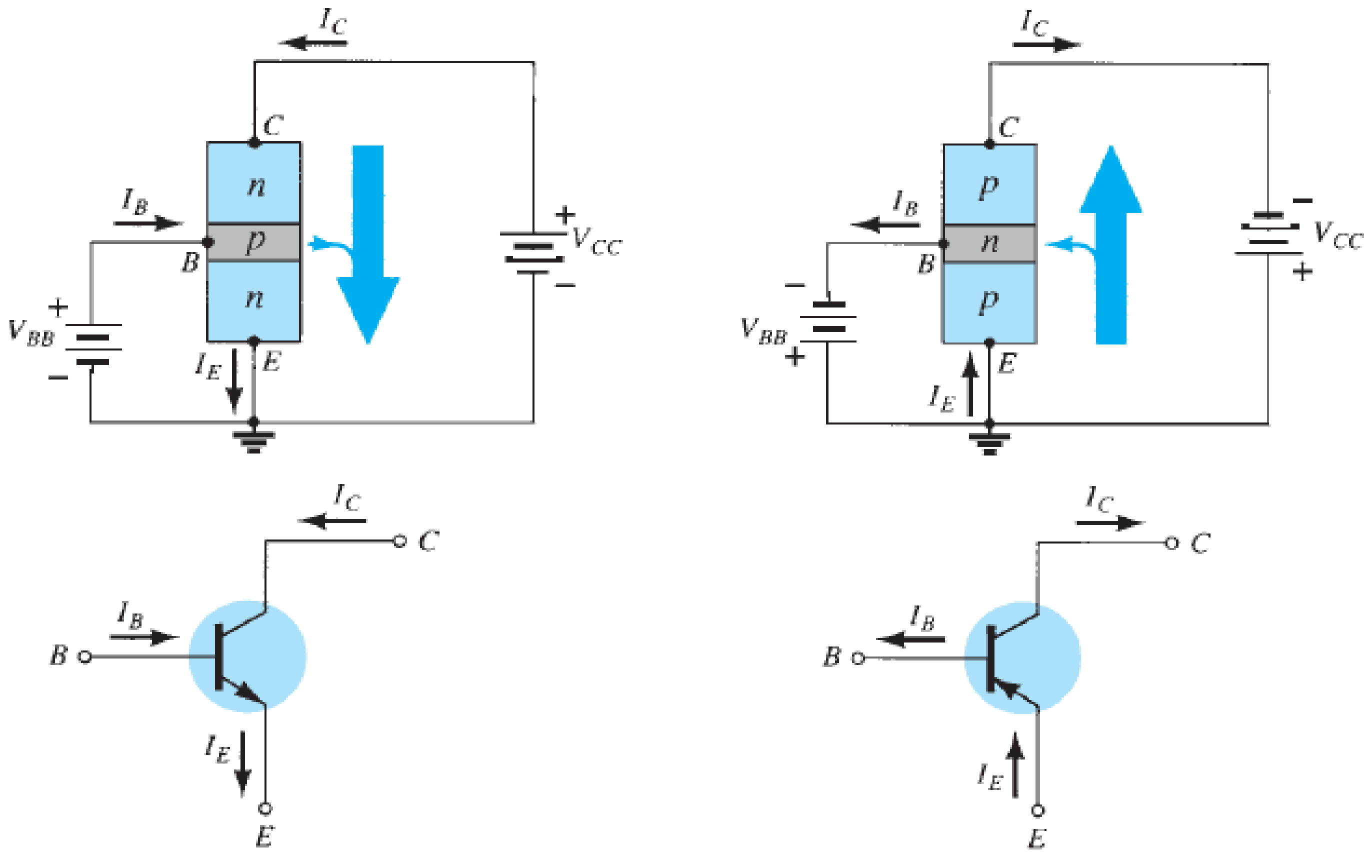
The common-base terminology is derived from the fact that the base is common to both the input and output sides of the configuration





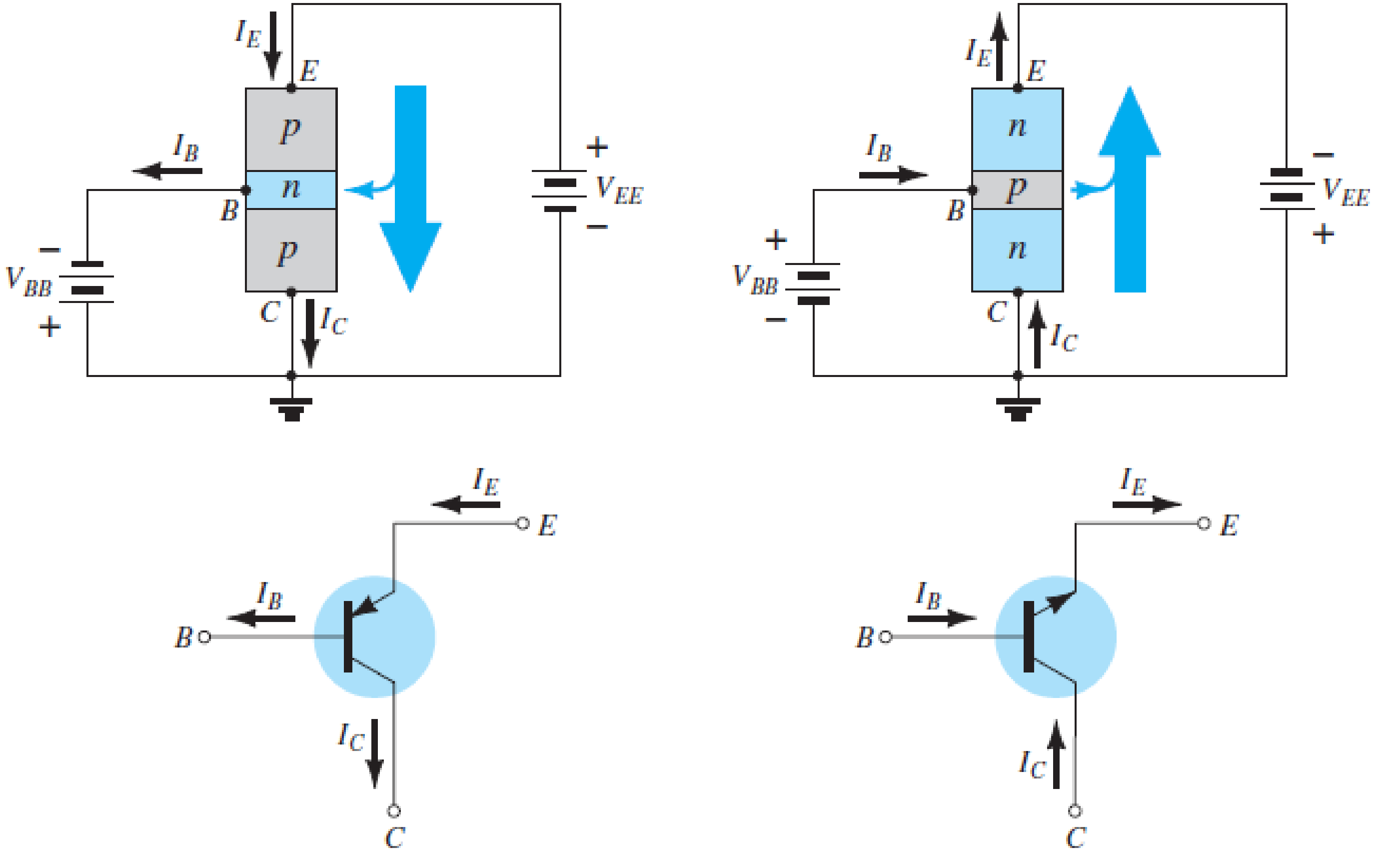
COMMON-EMITTER CONFIGURATION

The most frequently encountered transistor configuration appears in for the *pnp* and *npn* transistors. It is called the *common-emitter configuration* because the emitter is common to both the input and output terminals (in this case common to both the base and collector terminals).



COMMON-COLLECTOR CONFIGURATION

The third and final transistor configuration is the *common-collector configuration* .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.



Alpha (α) Is called the **common-base current gain**.

DC Mode 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:

$$\boxed{\alpha_{dc} = \frac{I_C}{I_E}} \tag{3.5}$$

- practical devices alpha typically extends from 0.90 to 0.998

Beta (β) is called the **common-emitter current gain.**

DC Mode In the dc mode the levels of I_C and I_B are related by a quantity called *beta* and defined by the following equation:

$$\boxed{\beta_{dc} = \frac{I_C}{I_B}} \tag{3.10}$$

- For practical devices the level of b typically ranges from about 50 to over 400

Relation between Alfa and Beta and E,C,B current

$$I_E = I_C + I_B$$

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

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

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

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

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

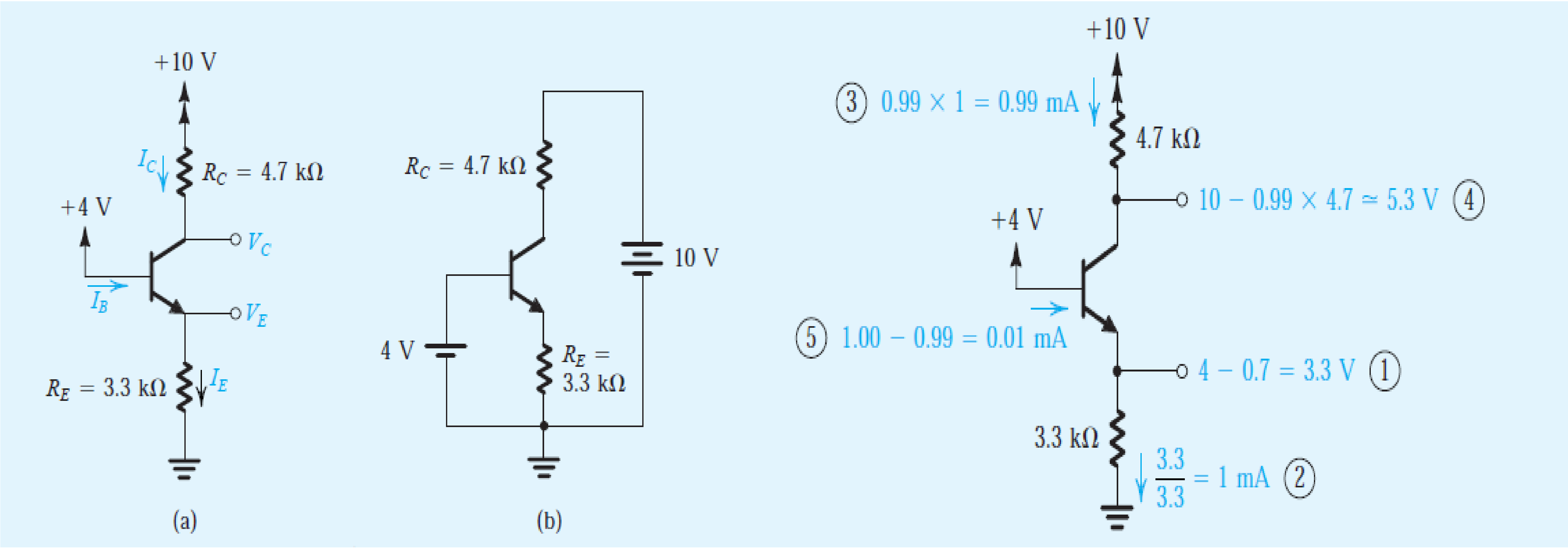
$$\boxed{\beta = \frac{\alpha}{1 - \alpha}}$$

$$\begin{aligned} I_E &= I_C + I_B \\ &= \beta I_B + I_B \end{aligned}$$

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

Power Dissipated by BJT = V_{CE} x I_C

Determine all node voltages and branch currents where β is specified to be 100



$$I_C = \alpha I_E$$

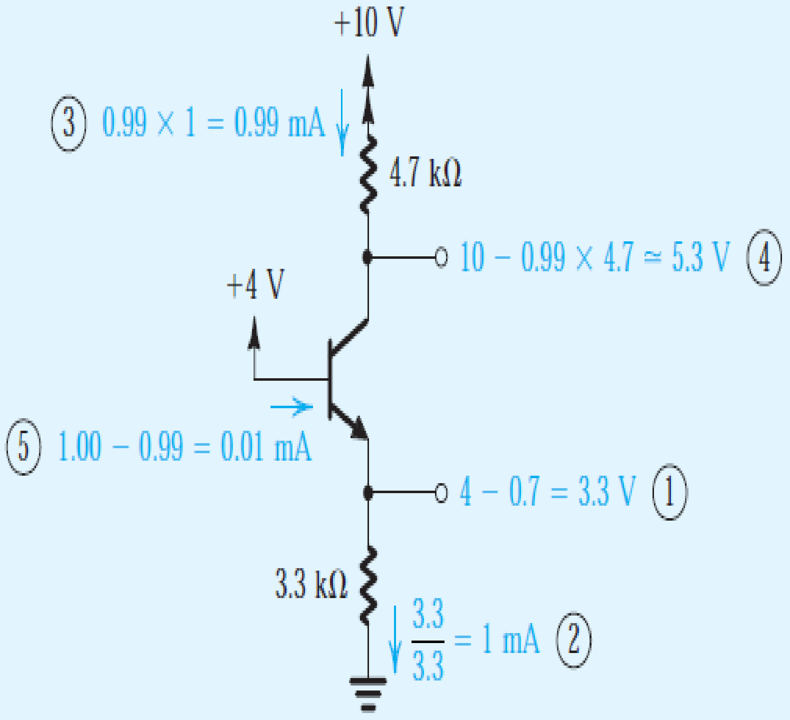
The value of α is obtained from

$$\alpha = \frac{\beta}{\beta+1} = \frac{100}{101} \simeq 0.99$$

Thus I_C will be given by

$$I_C = 0.99 \times 1 = 0.99 \text{ mA}$$

We are now in a position to use Ohm's law to determine the collector



$$V_C = 10 - I_C R_C = 10 - 0.99 \times 4.7 \simeq +5.3 \text{ V}$$

Since the base is at +4 V, the collector–base junction is reverse biased by 1.3 V, and the transistor is indeed in the active mode as assumed.

It remains only to determine the base current I_B, as follows:

$$I_B = \frac{I_E}{\beta+1} = \frac{1}{101} \simeq 0.01 \text{ mA}$$

6.13 In the circuit shown in Fig. E6.13, the voltage at the emitter was measured and found to be –0.7 V. If $\beta = 50$, find I_E, I_B, I_C, and V_C.

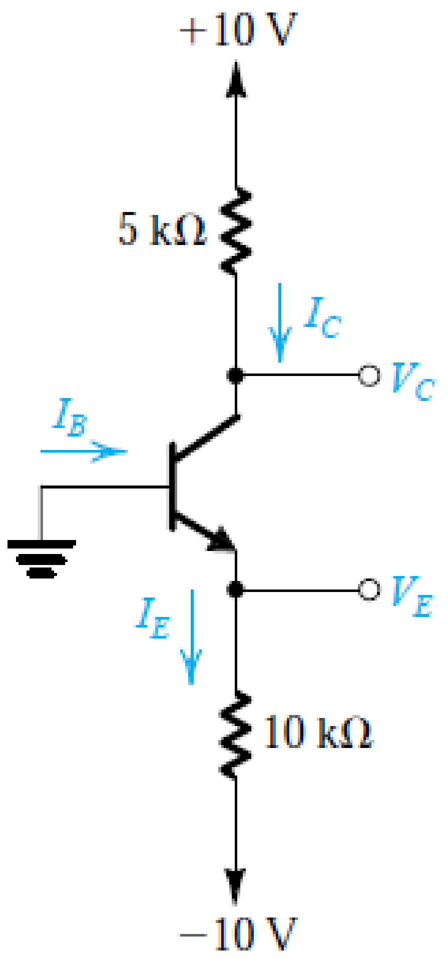
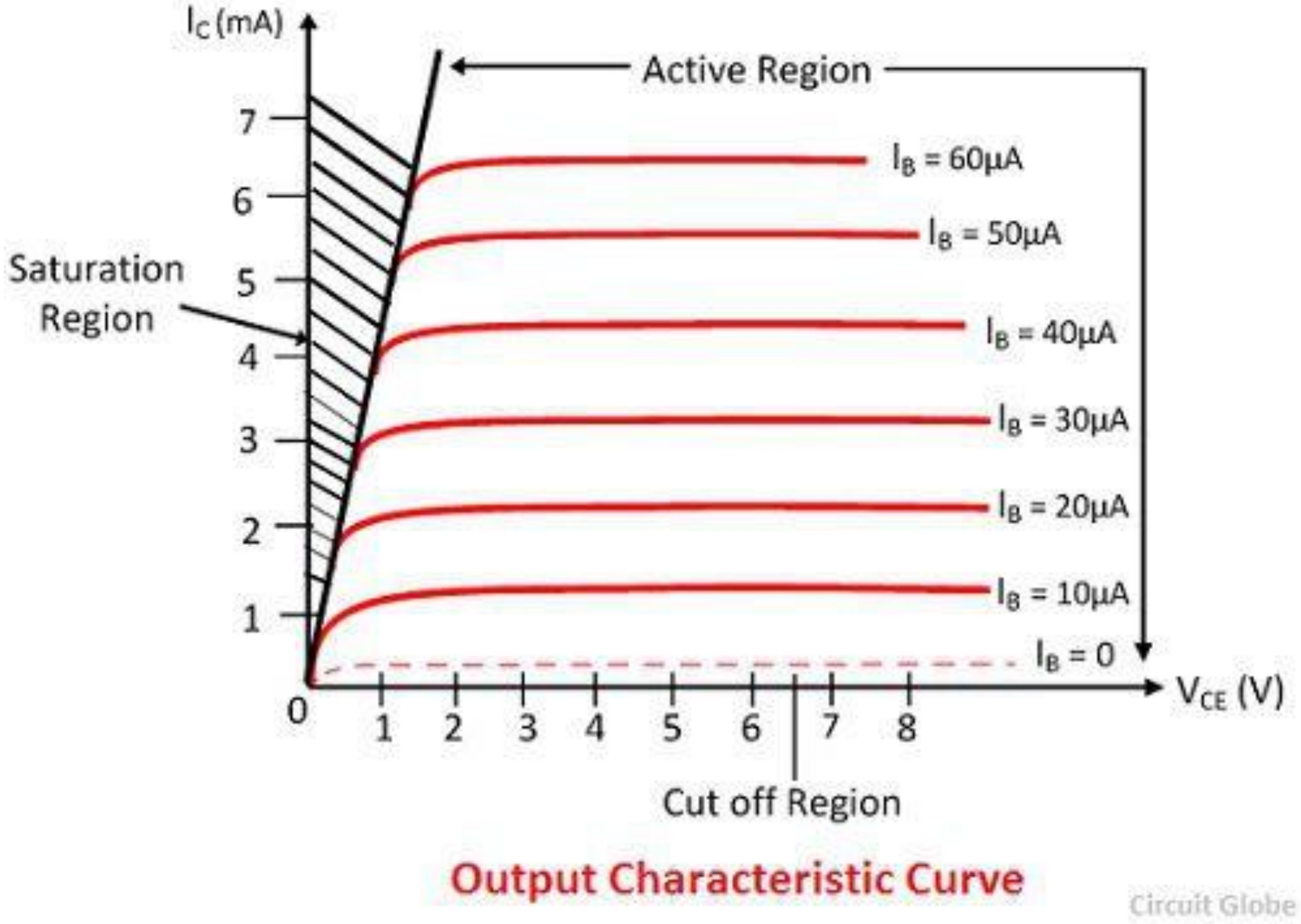
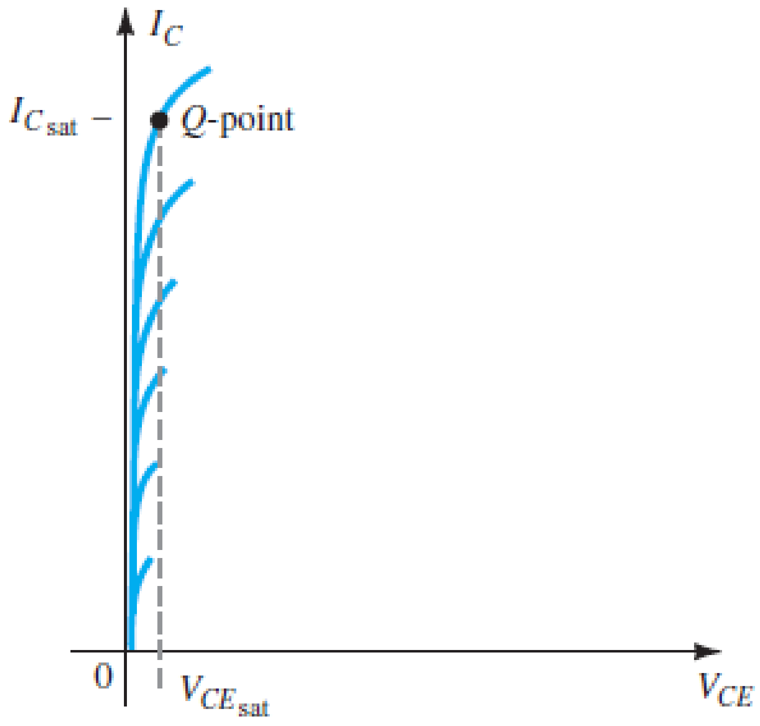


Figure E6.13

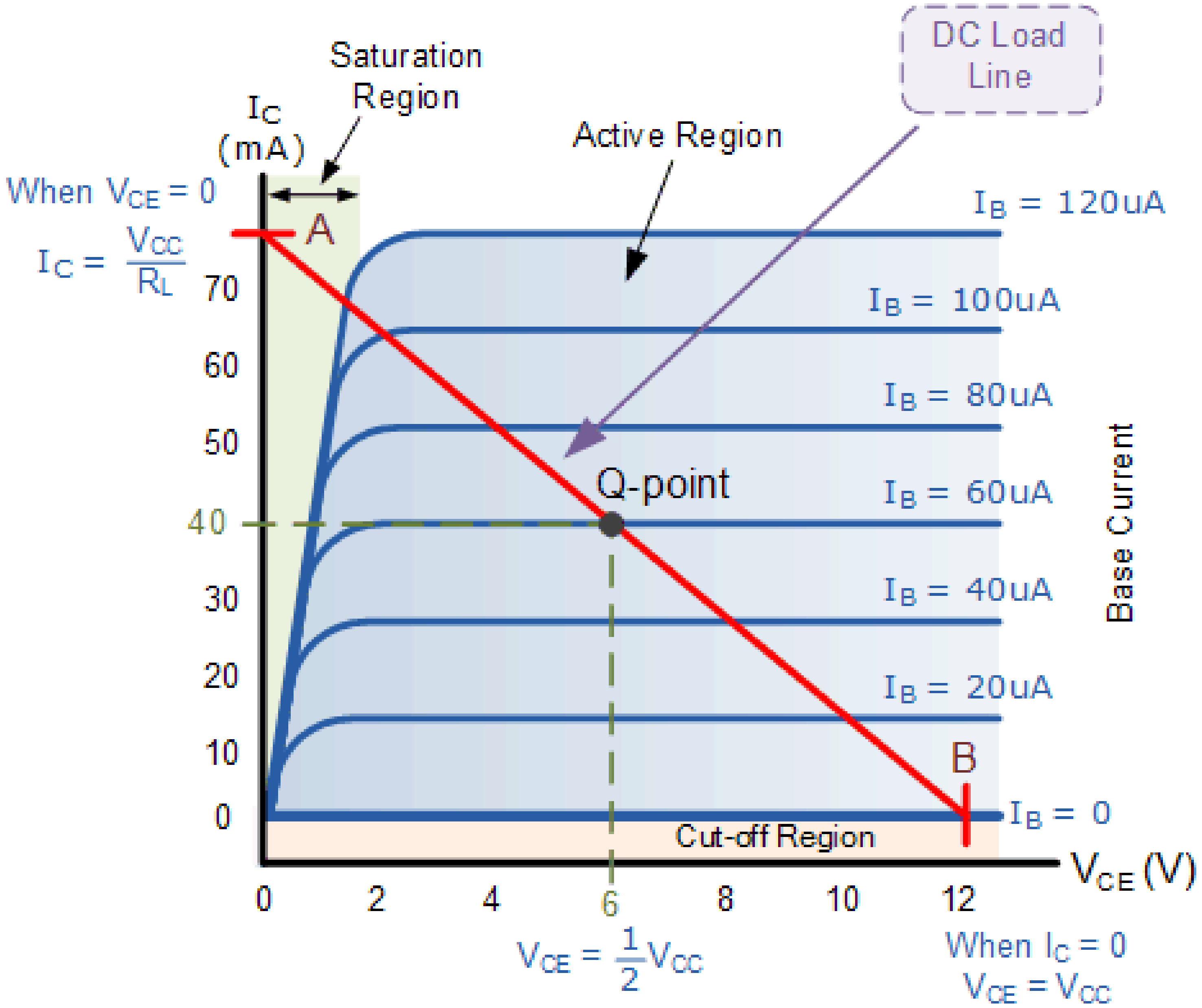
Ans. 0.93 mA; 18.2 μA; 0.91 mA; +5.45 V

Transistor Regions





Transistor Regions



Load-Line Analysis

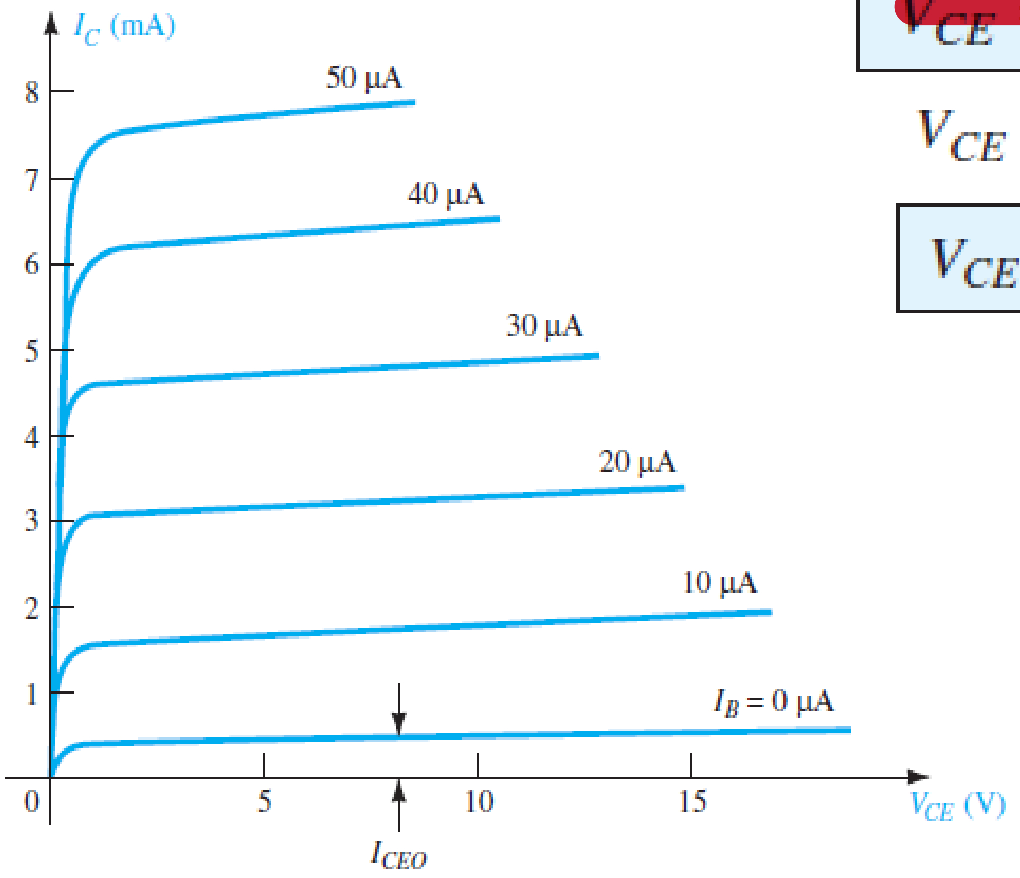
$$\boxed{V_{CE} = V_{CC} - I_C R_C}$$

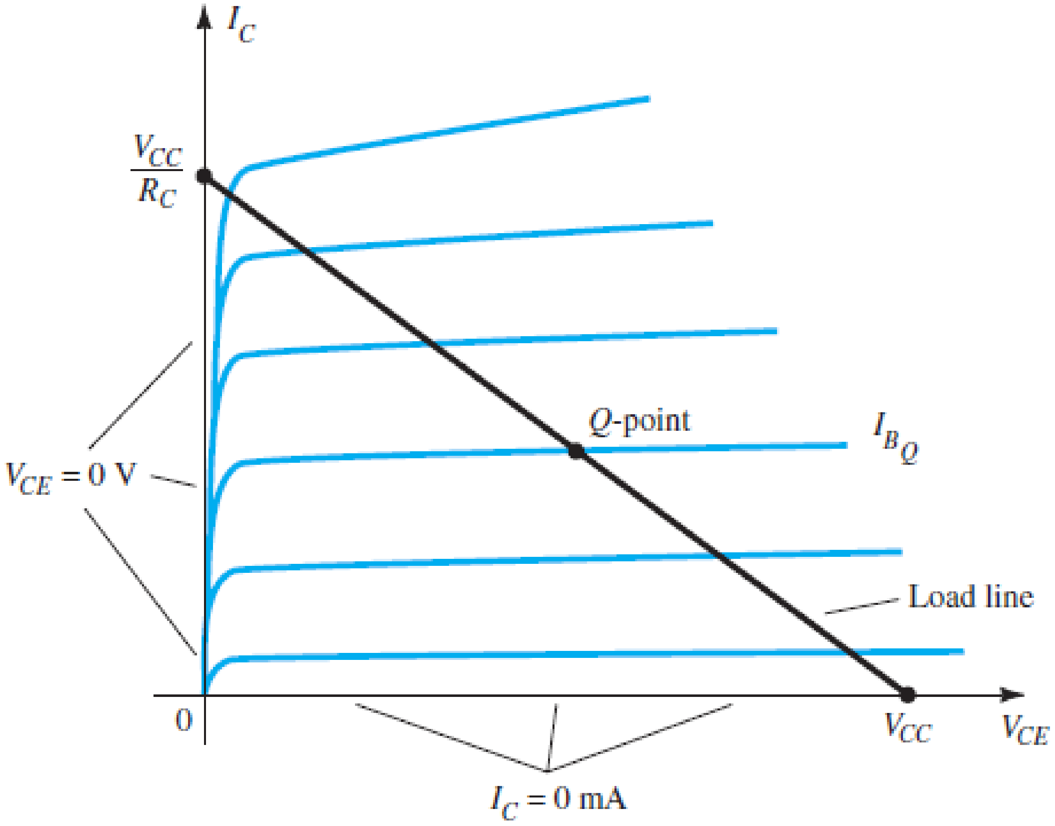
$$V_{CE} = V_{CC} - (0)R_C$$

$$\boxed{V_{CE} = V_{CC}\big|_{I_C = 0\,\text{mA}}}$$

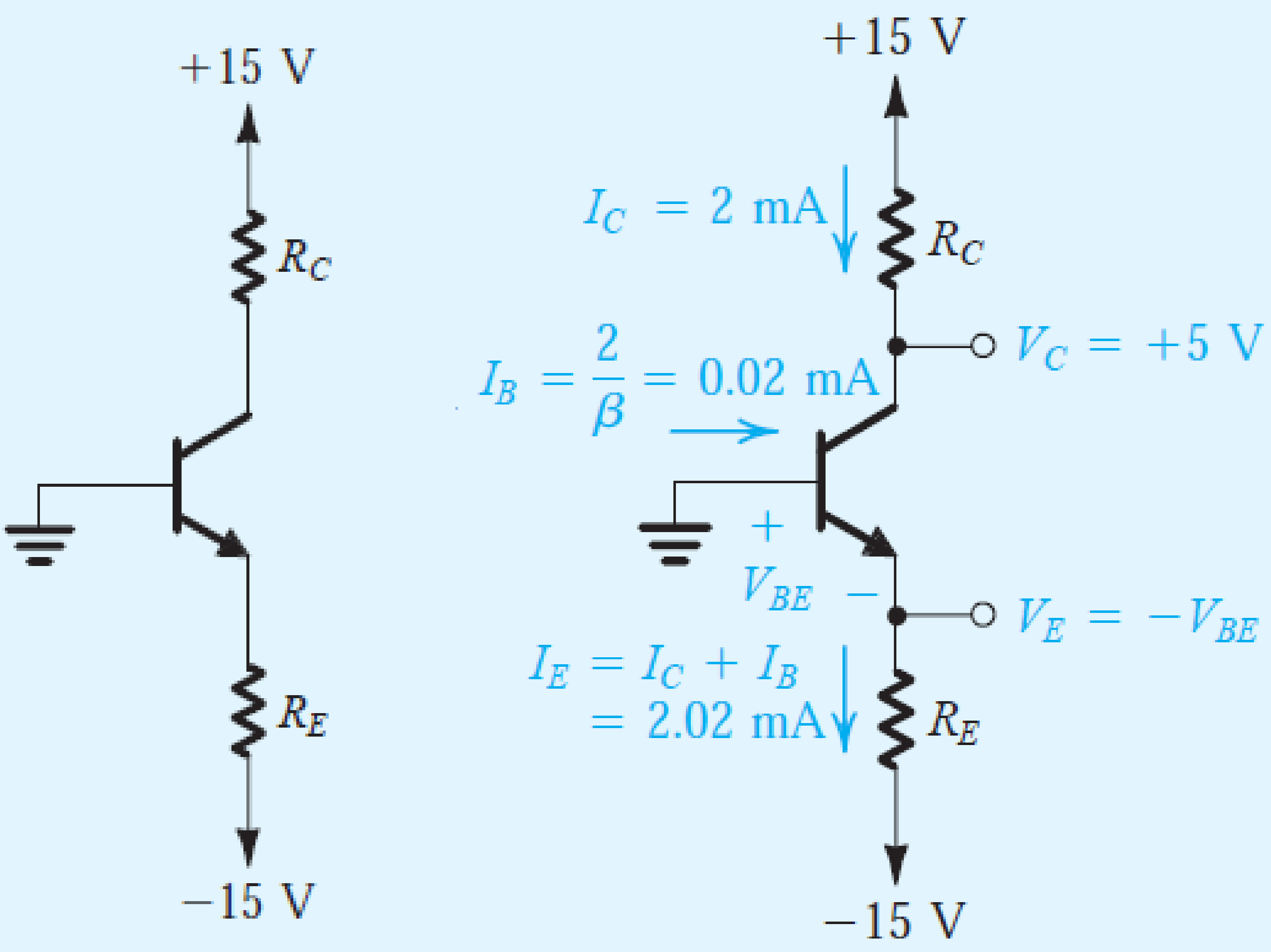
$$0 = V_{CC} - I_C R_C$$

$$\boxed{I_C = \frac{V_{CC}}{R_C}\bigg|_{V_{CE} = 0\,\text{V}}}$$





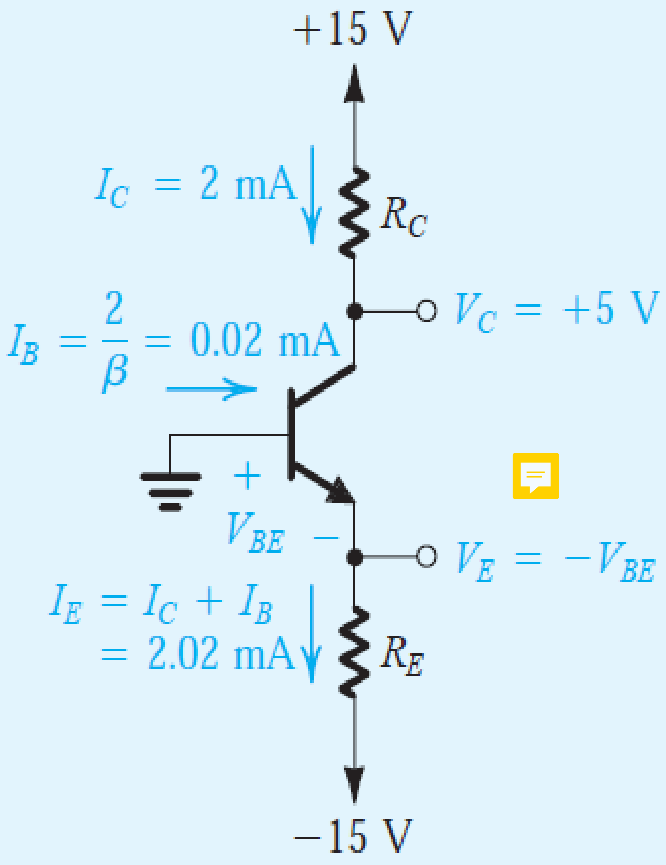
The transistor in the circuit of Fig. 6.14(a) has $\beta = 100$ and exhibits a v_{BE} of 0.7 V at $i_C = 1$ mA. Design the circuit so that a current of 2 mA flows through the collector and a voltage of +5 V appears at the collector.



Solution

Refer to Fig. 6.14(b). We note at the outset that since we are required to design for $V_C = +5$ V, the CBJ will be reverse biased and the BJT will be operating in the active mode. To obtain a voltage $V_C = +5$ V, the voltage drop across R_C must be 15 − 5 = 10 V. Now, since I_C = 2 mA, the value of R_C should be selected according to

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



Since $v_{BE} = 0.7$ V at $i_C = 1$ mA, the value of v_{BE} at $i_C = 2$ mA is

$$\boxed{V_{BE} = 0.7 + V_T \ln\left(\frac{2}{1}\right) = 0.717\ \text{V}}$$

Since the base is at 0 V, the emitter voltage should be

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

For $\beta = 100$, $\alpha = 100/101 = 0.99$. Thus the emitter current should be

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

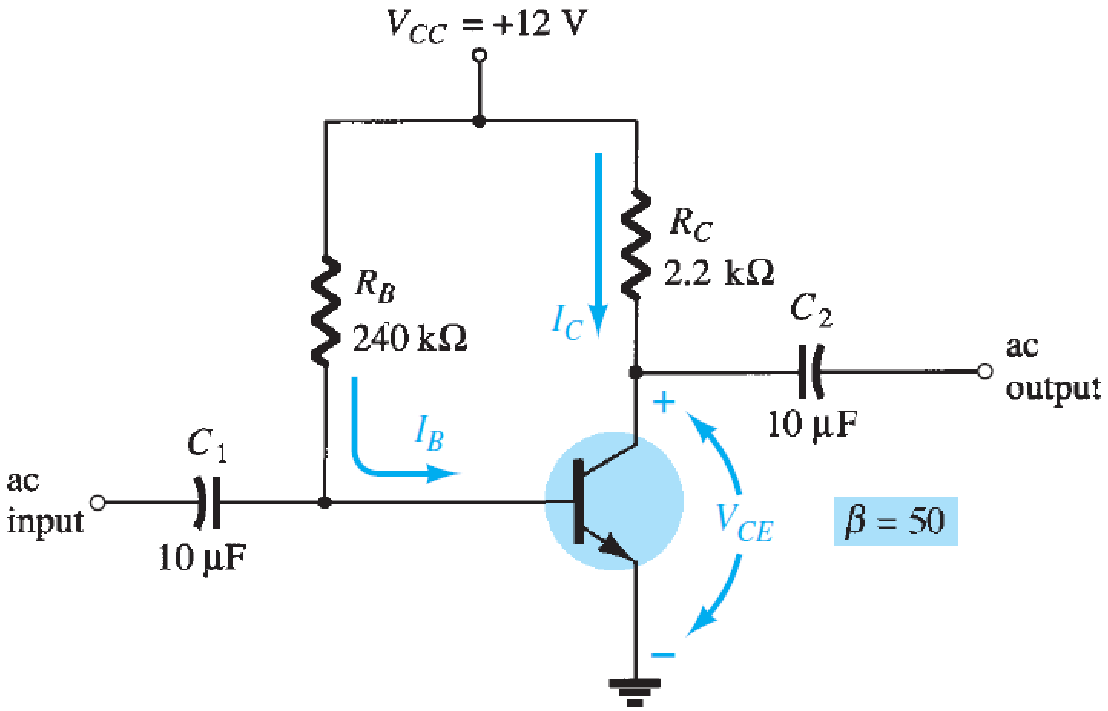
Now the value required for R_E can be determined from

$$R_E = \frac{V_E - (-15)}{I_E}$$

$$= \frac{-0.717 + 15}{2.02} = 7.07\ \text{k}\Omega$$

Determine the Value of

a. I_{B_Q} and I_{C_Q}.
b. V_{CE_Q}.
c. V_B and V_C.
d. V_{BC}.



Solution:

a. Eq. (4.4): $I_{B_Q} = \dfrac{V_{CC} - V_{BE}}{R_B} = \dfrac{12\text{ V} - 0.7\text{ V}}{240\text{ k}\Omega} = \mathbf{47.08\ \mu A}$

Eq. (4.5): $I_{C_Q} = \beta I_{BQ} = (50)(47.08\ \mu\text{A}) = \mathbf{2.35\ mA}$

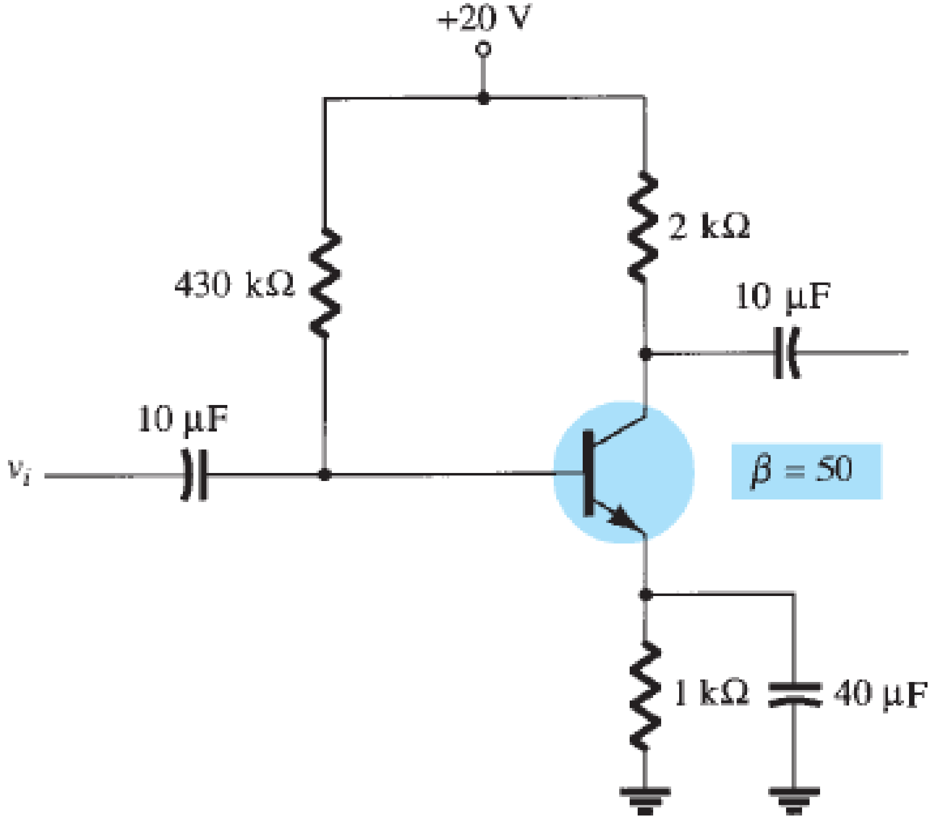
b. Eq. (4.6):
$$V_{CE_Q} = V_{CC} - I_C R_C$$
$$= 12\text{ V} - (2.35\text{ mA})(2.2\text{ k}\Omega)$$
$$= \mathbf{6.83\ V}$$

c. $V_B = V_{BE} = \mathbf{0.7\ V}$
$V_C = V_{CE} = \mathbf{6.83\ V}$

d. Using double-subscript notation yields
$$V_{BC} = V_B - V_C = 0.7\text{ V} - 6.83\text{ V}$$
$$= \mathbf{-6.13\ V}$$

EXAMPLE 4.4 For the emitter-bias network of Fig. 4.23, determine:

a. I_B.
b. I_C.
c. V_{CE}.
d. V_C.
e. V_E.
f. V_B.
g. V_{BC}.



Solution:

a. Eq. (4.17): $$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E} = \frac{20\text{ V} - 0.7\text{ V}}{430\text{ k}\Omega + (51)(1\text{ k}\Omega)}$$

$$= \frac{19.3\text{ V}}{481\text{ k}\Omega} = \mathbf{40.1\ \mu A}$$

b. $$I_C = \beta I_B$$
$$= (50)(40.1\ \mu\text{A})$$
$$\cong \mathbf{2.01\ mA}$$

c. Eq. (4.19): $V_{CE} = V_{CC} - I_C(R_C + R_E)$

$$= 20\text{ V} - (2.01\text{ mA})(2\text{ k}\Omega + 1\text{ k}\Omega) = 20\text{ V} - 6.03\text{ V}$$

$$= \mathbf{13.97\ V}$$

d. $V_C = V_{CC} - I_C R_C$

$$= 20\text{ V} - (2.01\text{ mA})(2\text{ k}\Omega) = 20\text{ V} - 4.02\text{ V}$$

$$= \mathbf{15.98\ V}$$

e. $V_E = V_C - V_{CE}$

$$= 15.98\text{ V} - 13.97\text{ V}$$

$$= \mathbf{2.01\ V}$$

or $V_E = I_E R_E \cong I_C R_E$

$$= (2.01\text{ mA})(1\text{ k}\Omega)$$

$$= \mathbf{2.01\ V}$$

f. $V_B = V_{BE} + V_E$

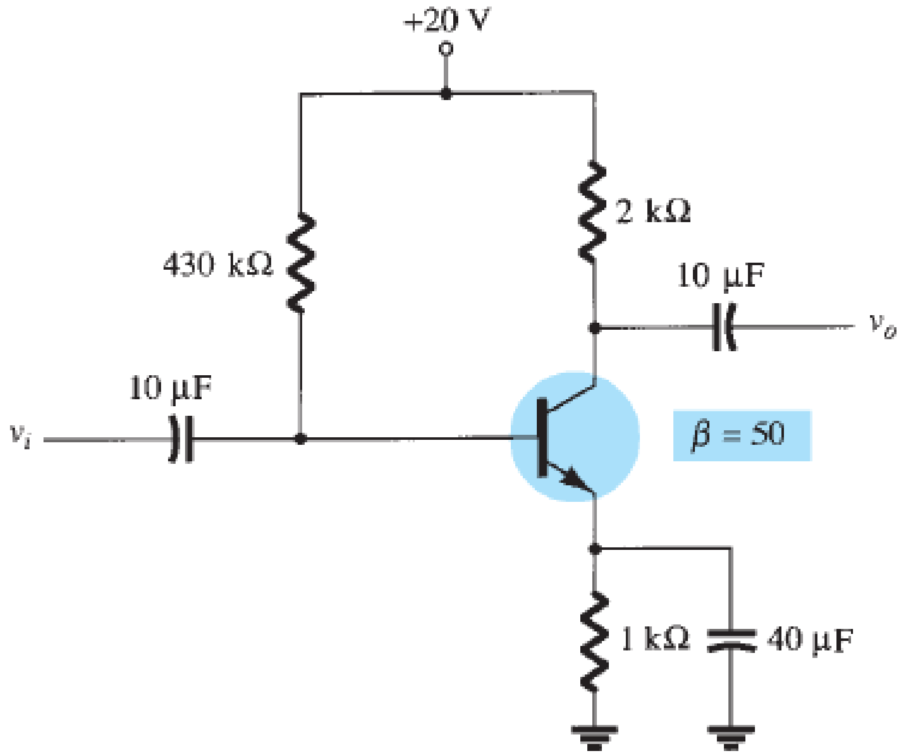
$$= 0.7\text{ V} + 2.01\text{ V}$$

$$= \mathbf{2.71\ V}$$

g. $V_{BC} = V_B - V_C$

$$= 2.71\text{ V} - 15.98\text{ V}$$

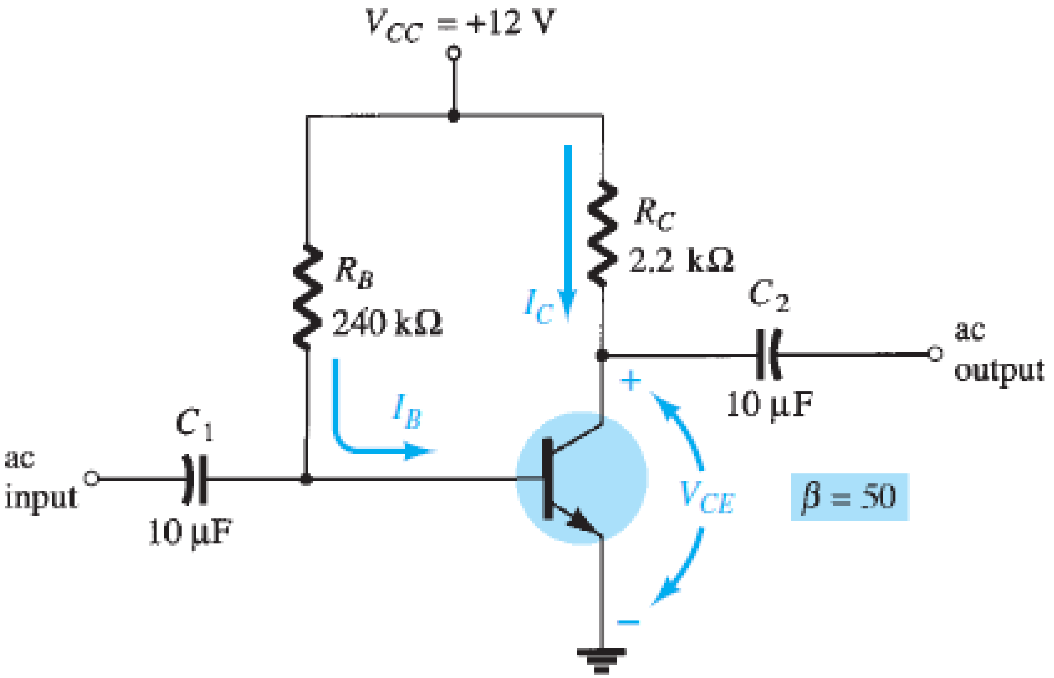
$= \mathbf{-13.27\ V}$ (reverse-biased as required)

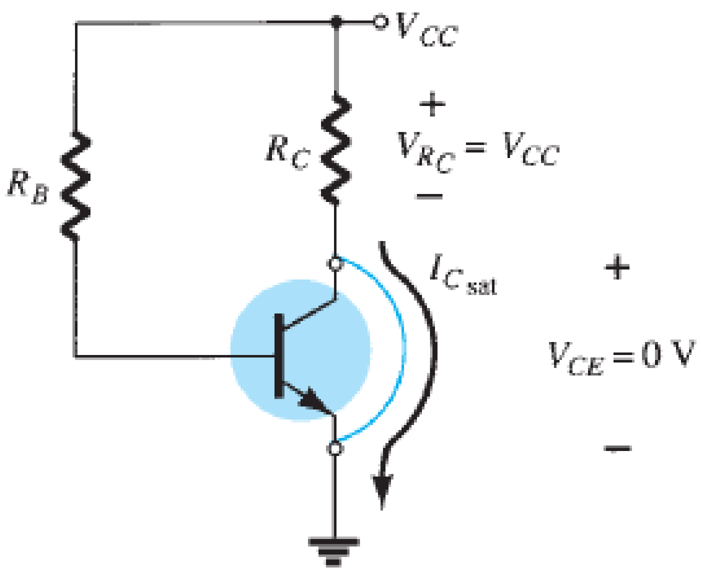


EXAMPLE 4.2 Determine the saturation level for the network of Fig. 4.7.

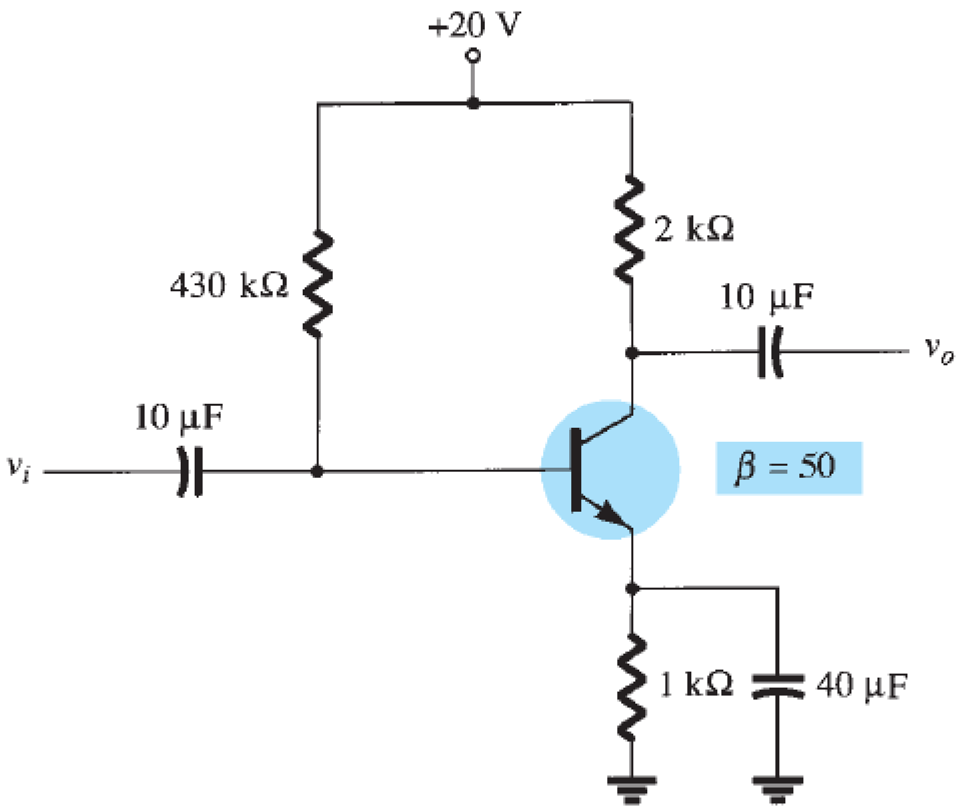
Solution:

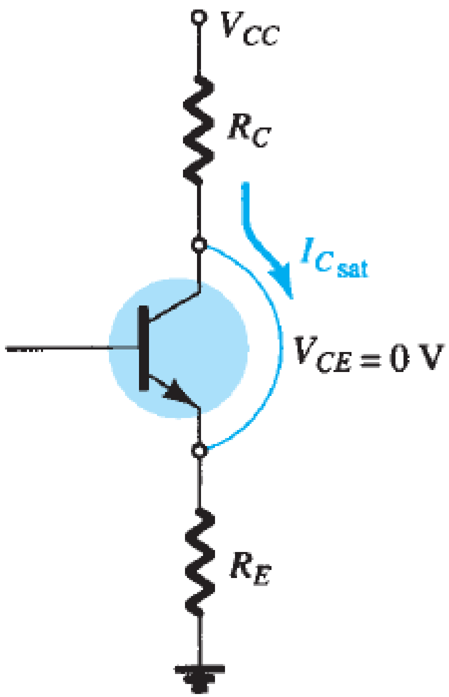
$$I_{C_{sat}} = \frac{V_{CC}}{R_C} = \frac{12\ \text{V}}{2.2\ \text{k}\Omega} = \mathbf{5.45\ mA}$$





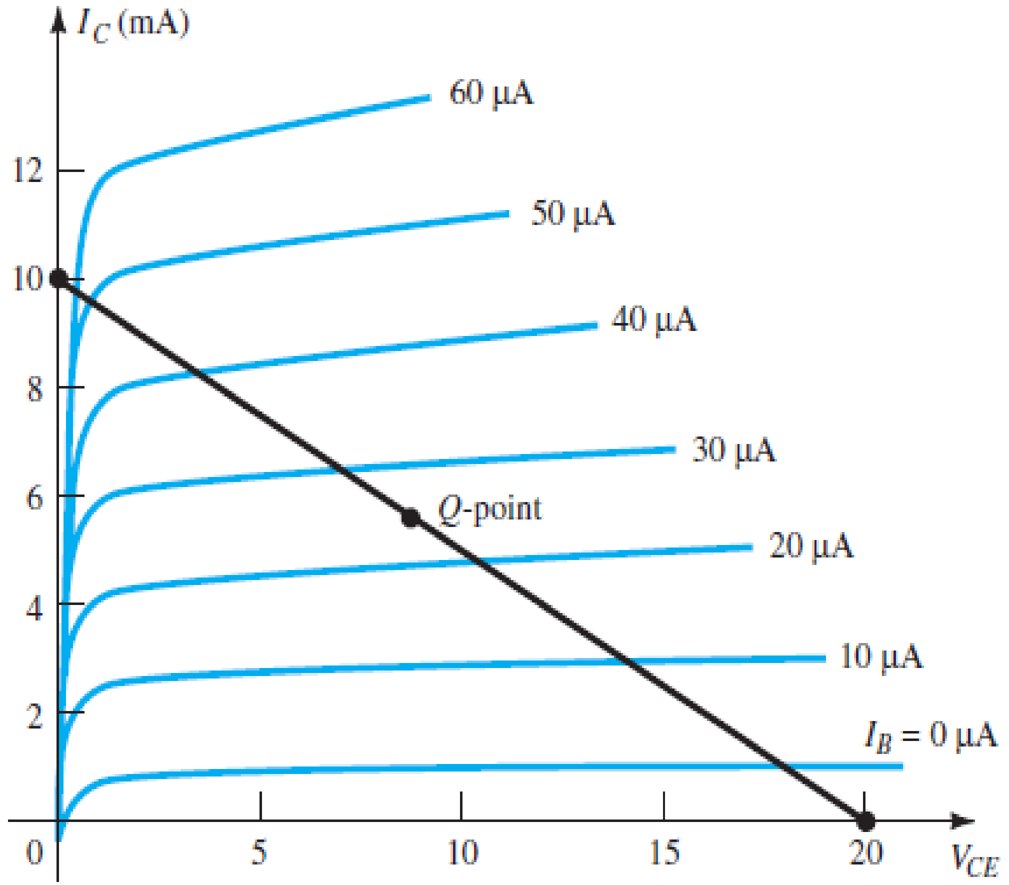
Determine the saturation current for the network

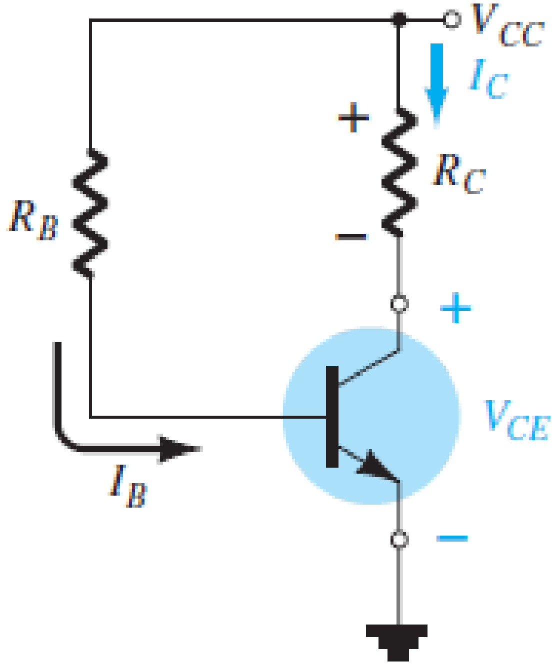


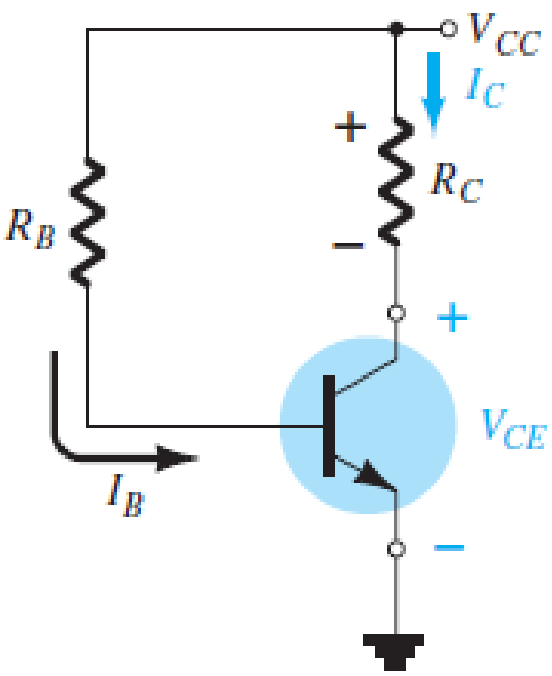


$$I_{C_{sat}} = \frac{V_{CC}}{R_C + R_E} = \frac{20\text{ V}}{2\text{ k}\Omega + 1\text{ k}\Omega} = \frac{20\text{ V}}{3\text{ k}\Omega} = \mathbf{6.67\text{ mA}}$$

EXAMPLE 4.3 Given the load line of Fig. 4.16 and the defined Q-point, determine the required values of V_{CC}, R_C, and R_B for a fixed-bias configuration.







Solution: From Fig. 4.16,

$$V_{CE} = V_{CC} = \mathbf{20\ V} \text{ at } I_C = 0\text{ mA}$$

$$I_C = \frac{V_{CC}}{R_C} \text{ at } V_{CE} = 0\text{ V}$$

and

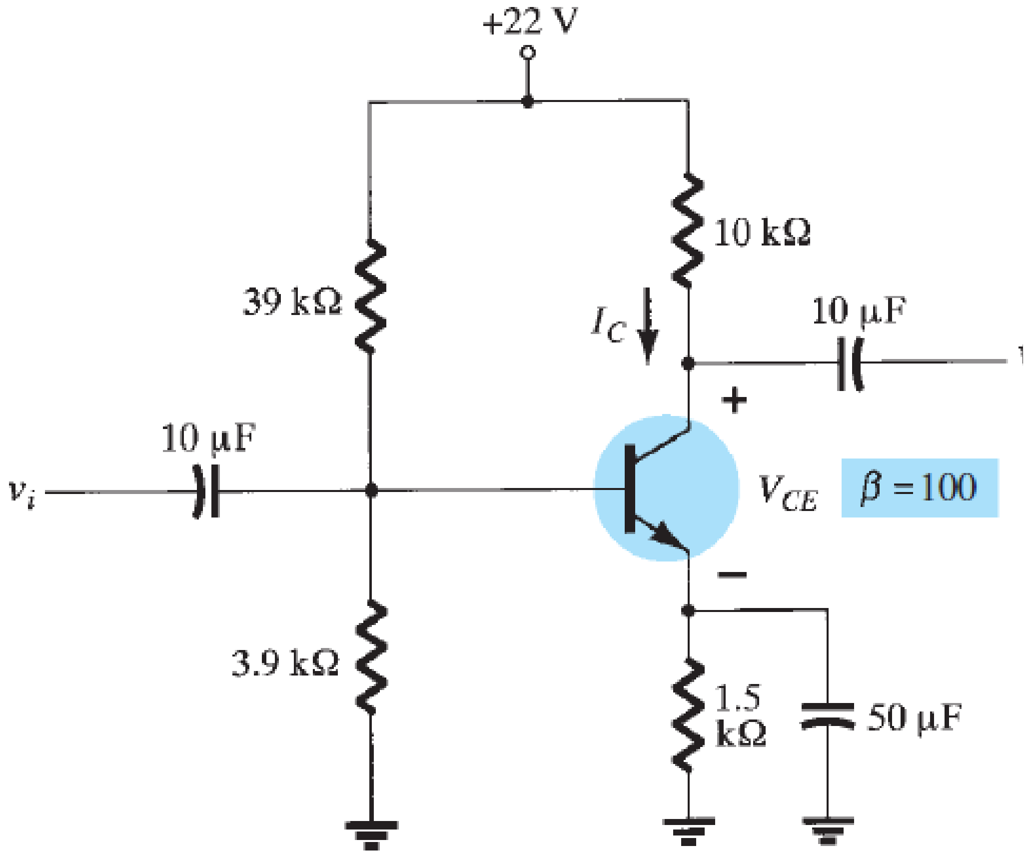
$$R_C = \frac{V_{CC}}{I_C} = \frac{20\text{ V}}{10\text{ mA}} = \mathbf{2\ k\Omega}$$

$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

and

$$R_B = \frac{V_{CC} - V_{BE}}{I_B} = \frac{20\text{ V} - 0.7\text{ V}}{25\ \mu\text{A}} = \mathbf{772\ k\Omega}$$

EXAMPLE 4.8 Determine the dc bias voltage V_{CE} and the current I_C for the voltage-divider configuration of Fig. 4.35.

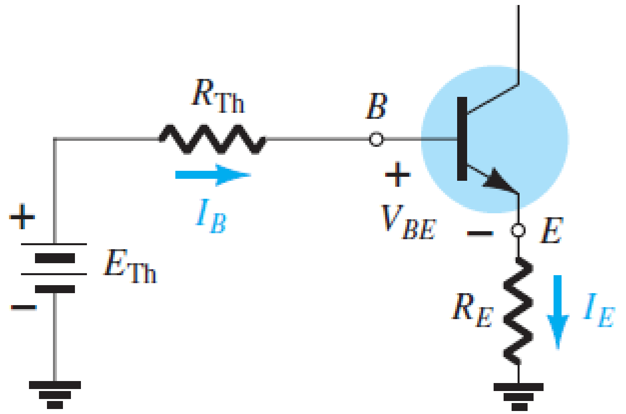


Solution: Eq. (4.28): $R_{Th} = R_1 \| R_2$

$$= \frac{(39\text{ k}\Omega)(3.9\text{ k}\Omega)}{39\text{ k}\Omega + 3.9\text{ k}\Omega} = 3.55\text{ k}\Omega$$

Eq. (4.29): $E_{Th} = \dfrac{R_2 V_{CC}}{R_1 + R_2}$

$$= \frac{(3.9\text{ k}\Omega)(22\text{ V})}{39\text{ k}\Omega + 3.9\text{ k}\Omega} = 2\text{ V}$$



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

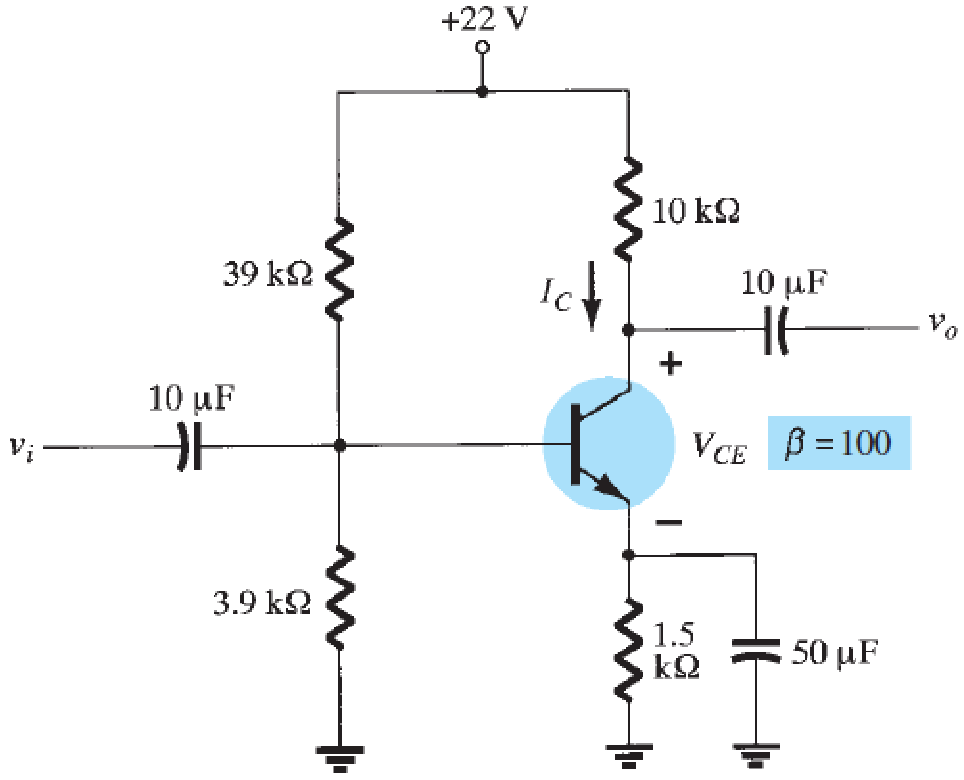
$$= \frac{2\text{ V} - 0.7\text{ V}}{3.55\text{ k}\Omega + (101)(1.5\text{ k}\Omega)} = \frac{1.3\text{ V}}{3.55\text{ k}\Omega + 151.5\text{ k}\Omega}$$

$$= 8.38\ \mu\text{A}$$

$$I_C = \beta I_B$$

$$= (100)(8.38\ \mu\text{A})$$

$$= \mathbf{0.84\ mA}$$

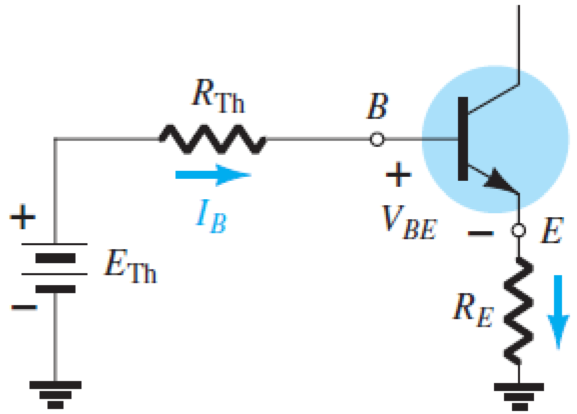


Eq. (4.31): $V_{CE} = V_{CC} - I_C(R_C + R_E)$

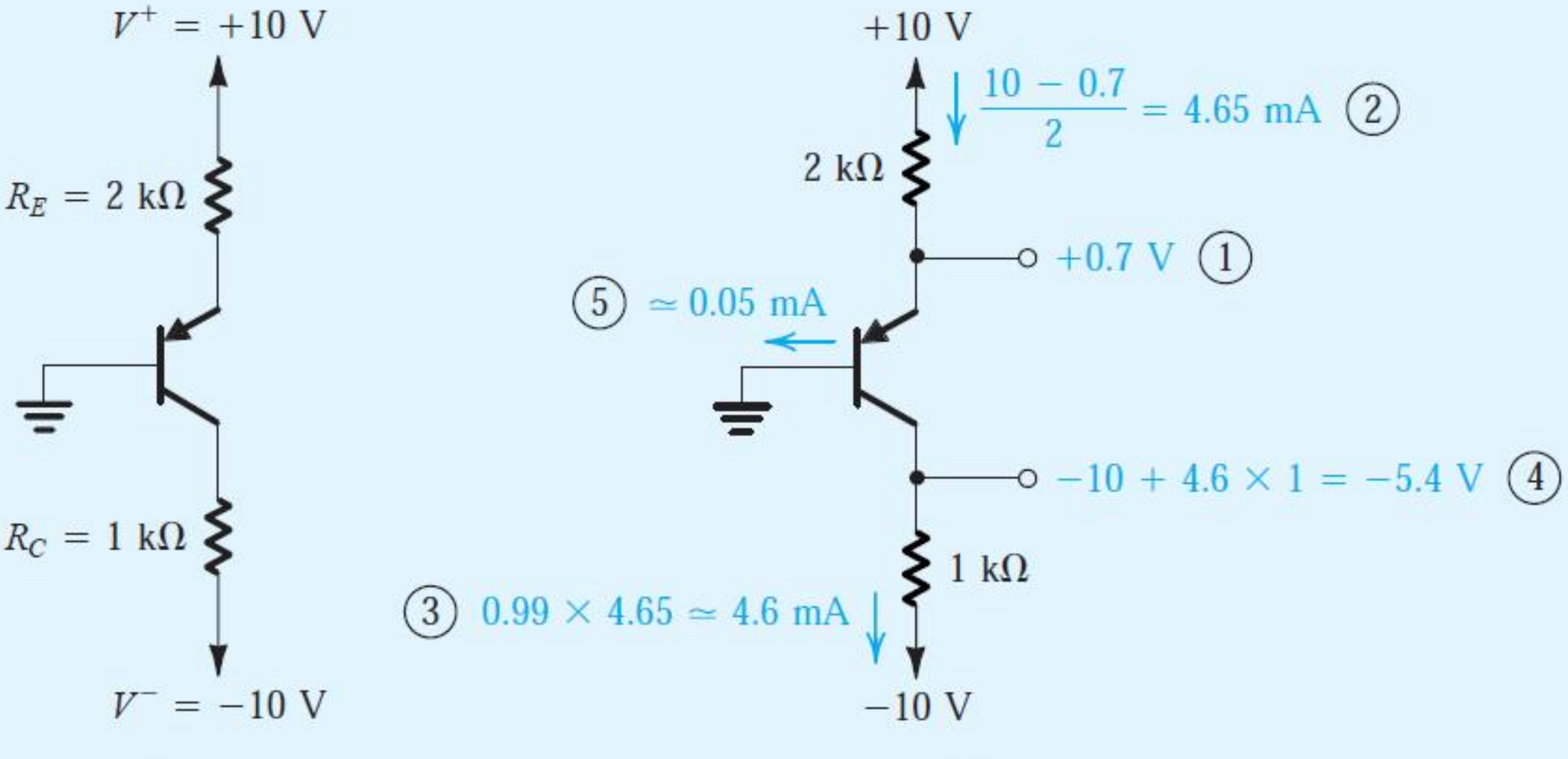
$$= 22\text{ V} - (0.84\text{ mA})(10\text{ k}\Omega + 1.5\text{ k}\Omega)$$

$$= 22\text{ V} - 9.66\text{ V}$$

$$= \mathbf{12.34\ V}$$



We want to analyze the circuit of Fig. 6.25(a) to determine the voltages at all nodes and the currents through all branches.



(a) (b)

Solution

The base of this *pnp* transistor is grounded, while the emitter is connected to a positive supply ($V^+ = +10$ V) through R_E. It follows that the emitter–base junction will be forward biased with

$$V_E = V_{EB} \simeq 0.7 \text{ V}$$

Thus the emitter current will be given by

$$I_E = \frac{V^+ - V_E}{R_E} = \frac{10 - 0.7}{2} = 4.65 \text{ mA}$$

Since the collector is connected to a negative supply (more negative than the base voltage) through R_C, it is *possible* that this transistor is operating in the active mode. Assuming this to be the case, we obtain

$$I_C = \alpha I_E$$

Since no value for β has been given, we shall assume $\beta = 100$, which results in $\alpha = 0.99$. Since large variations in β result in small differences in α, this assumption will not be critical as far as determining the value of I_C is concerned. Thus,

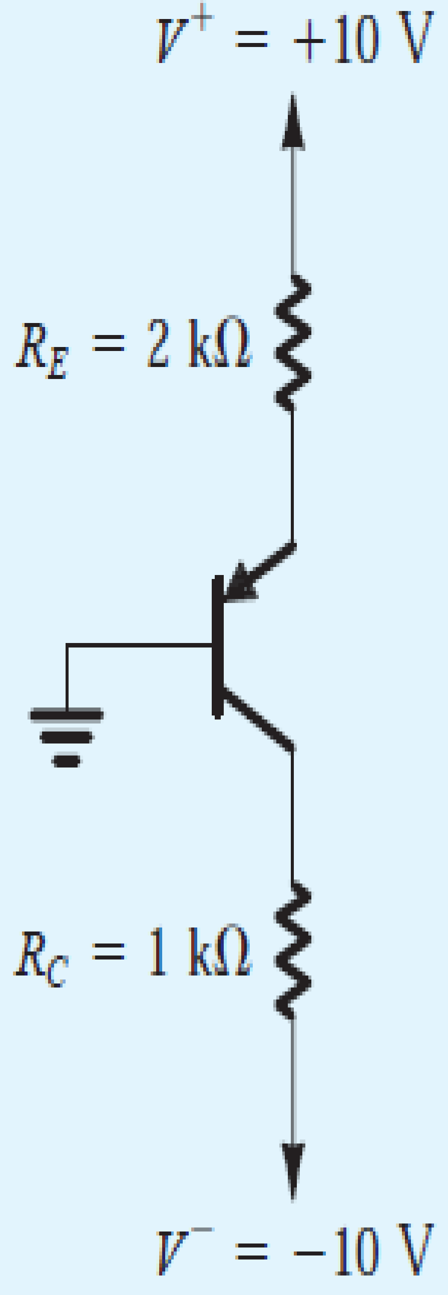
$$I_C = 0.99 \times 4.65 = 4.6 \text{ mA}$$

The collector voltage will be

$$V_C = V^- + I_C R_C$$

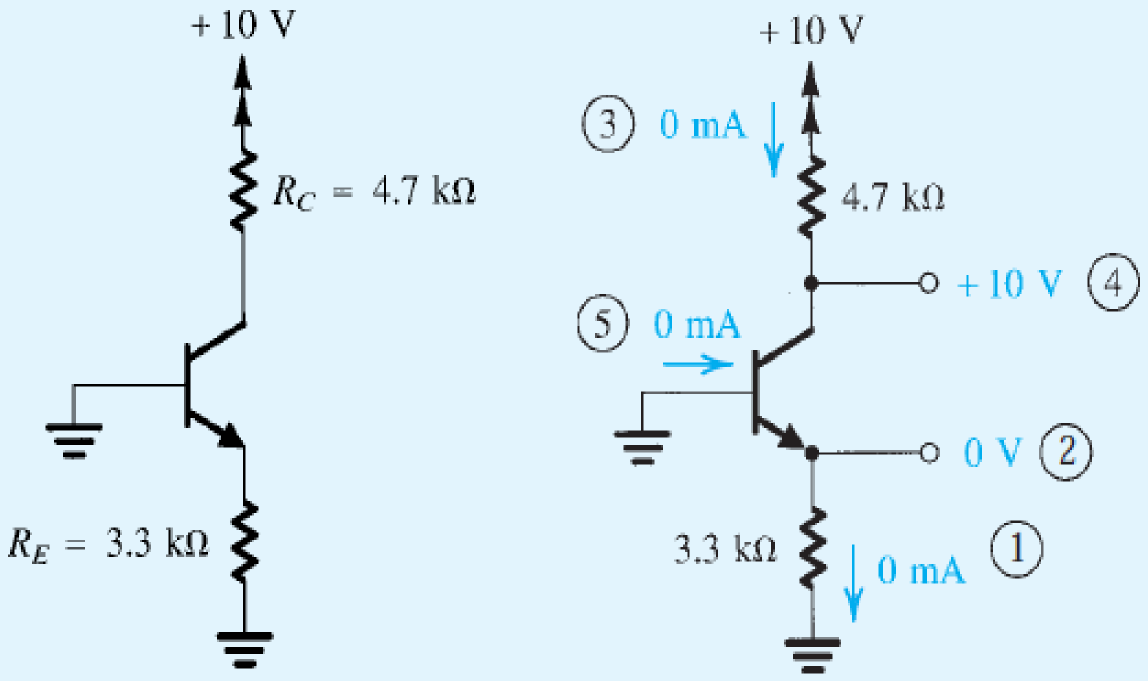
$$= -10 + 4.6 \times 1 = -5.4 \text{ V}$$

$$I_B = \frac{I_E}{\beta + 1} = \frac{4.65}{101} \simeq 0.05 \text{ mA}$$



Example 6.6

We wish to analyze the circuit in Fig. 6.24(a) to determine the voltages at all nodes and the currents through all branches. Note that this circuit is identical to that considered in Examples 6.4 and 6.5 except that now the base voltage is zero.



Solution

Since the base is at zero volts and the emitter is connected to ground through R_E, the base–emitter junction cannot conduct and the emitter current is zero. Note that this situation will obtain as long as the voltage at the base is less than 0.5 V or so. Also, the collector–base junction cannot conduct, since the n-type collector is connected through R_C to the positive power supply while the p-type base is at ground. It follows that the collector current will be zero. The base current will also have to be zero, and the transistor is in the *cutoff* mode of operation.