ET 212 Electronics

Bipolar Junction Transistors

Electrical and Telecommunication
Engineering Technology

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Acknowledgement

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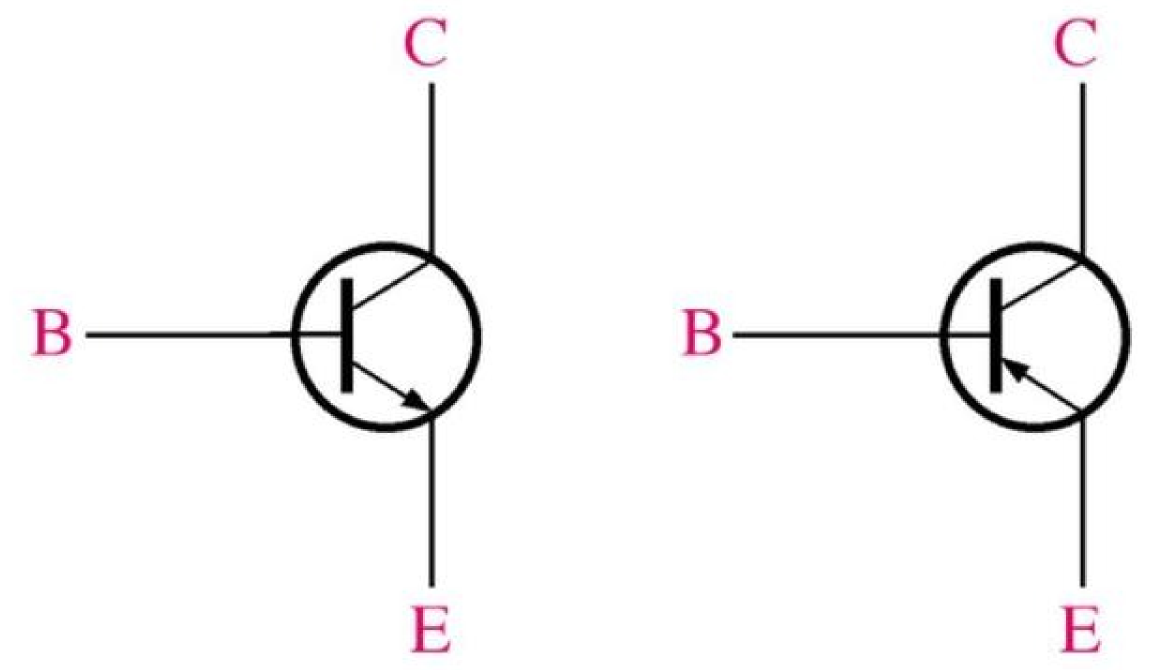
Objectives

- Introduction to Bipolar Junction Transistor (BJT)
- Basic Transistor Bias and Operation
- Parameters, Characteristics and Transistor Circuits
- Amplifier or Switch

Key Words: BJT, Bias, Transistor, Amplifier, Switch

Introduction

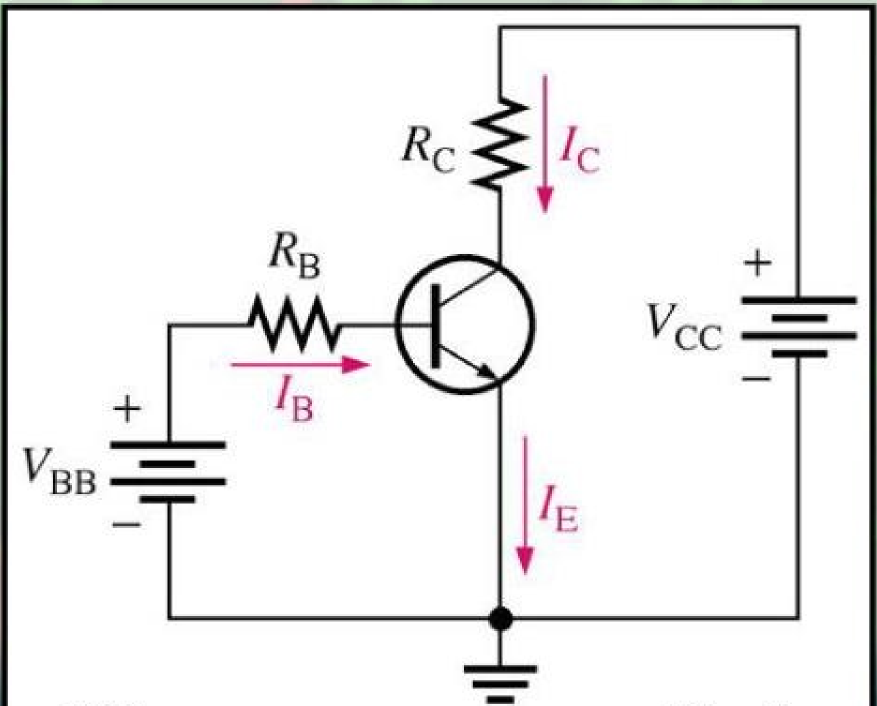
A **transistor** is a device which can be used as either an **amplifier** or a **switch**. Let's first consider its operation in a more simple view as a current controlling device.



(a) *npn* (b) *pnp*

Basic Transistor Operation

Look at this one circuit as two separate circuits, the base-emitter(left side) circuit and the collector-emitter(right side) circuit. Note that the emitter leg serves as a conductor for both circuits.The amount of current flow in the base-emitter circuit controls the amount of current that flows in the collector circuit. Small changes in base-emitter current yields a large change in collector-current.



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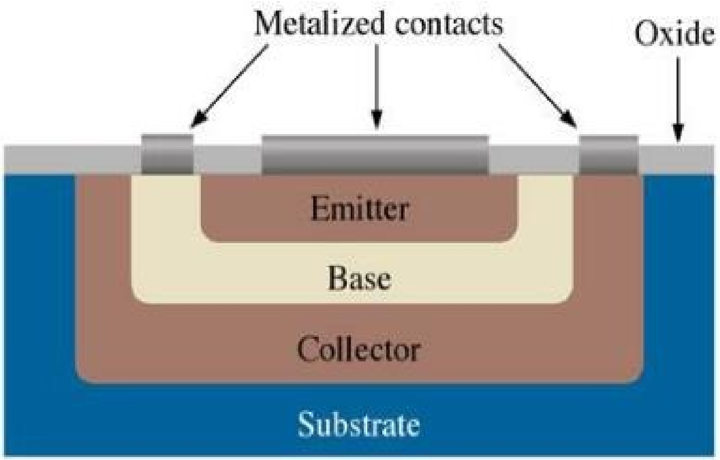
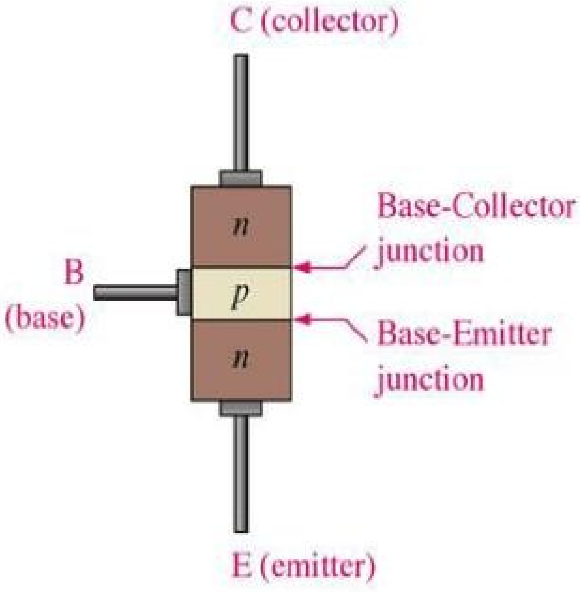
Transistor Structure

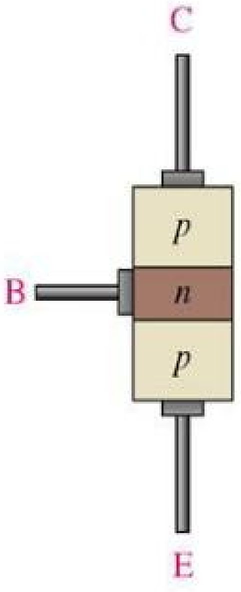
The **BJT (bipolar junction transistor)** is constructed with three doped semiconductor regions separated by two pn junctions, as shown in Figure (a). The three regions are called **emitter**, **base**, and **collector**. Physical representations of the two types of BJTs are shown in Figure (b) and (c). One type consists of two n regions separated by a *p* regions (*npn*), and other type consists of two p regions separated by an *n* region (*pnp*).



(a) Basic epitaxial planar structure



(b) *npn*

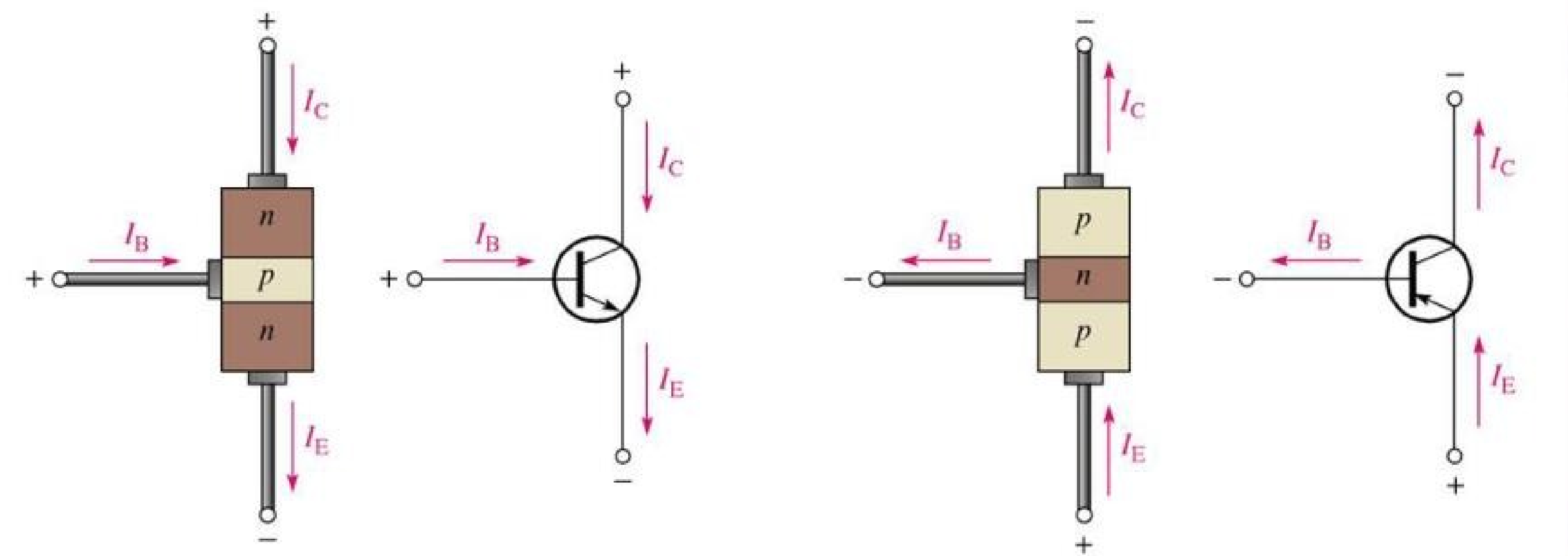


(c) *pnp*

Transistor Currents

The directions of the currents in both npn and pnp transistors and their schematic symbol are shown in Figure (a) and (b). Notice that the arrow on the emitter of the transistor symbols points in the direction of conventional current. These diagrams show that the emitter current (**I_E**) is the sum of the collector current (**I_C**) and the base current (**I_B**), expressed as follows:

$$I_E = I_C + I_B$$

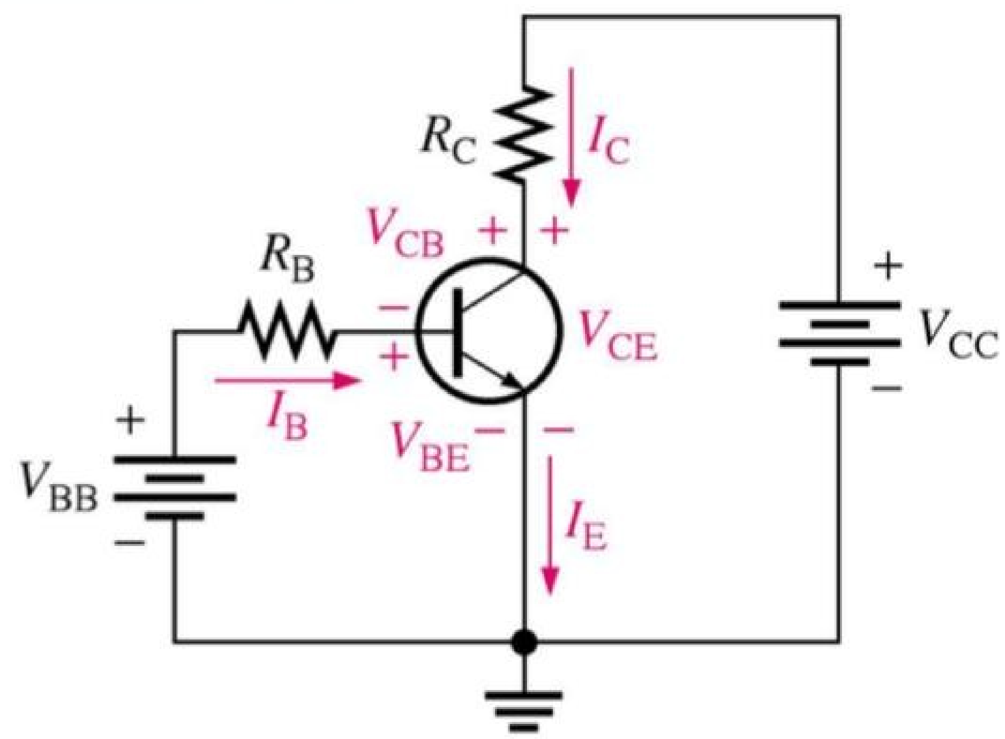


(a) *npn* (b) *pnp*

Transistor Characteristics and Parameters

Figure shows the proper bias arrangement for npn **transistor** for active operation as an amplifier.Notice that the base-emitter (**BE**) junction is forward-biased and the base-collector (**BC**) junction is reverse-biased. As previously discussed, base-emitter current changes yields large changes in collector-emitter current. The factor of this change is called ***beta***(β).

$$\beta = I_C/I_B$$



The ratio of the dc collector current (I_C) to the dc emitter current (I_E) is the alpha.

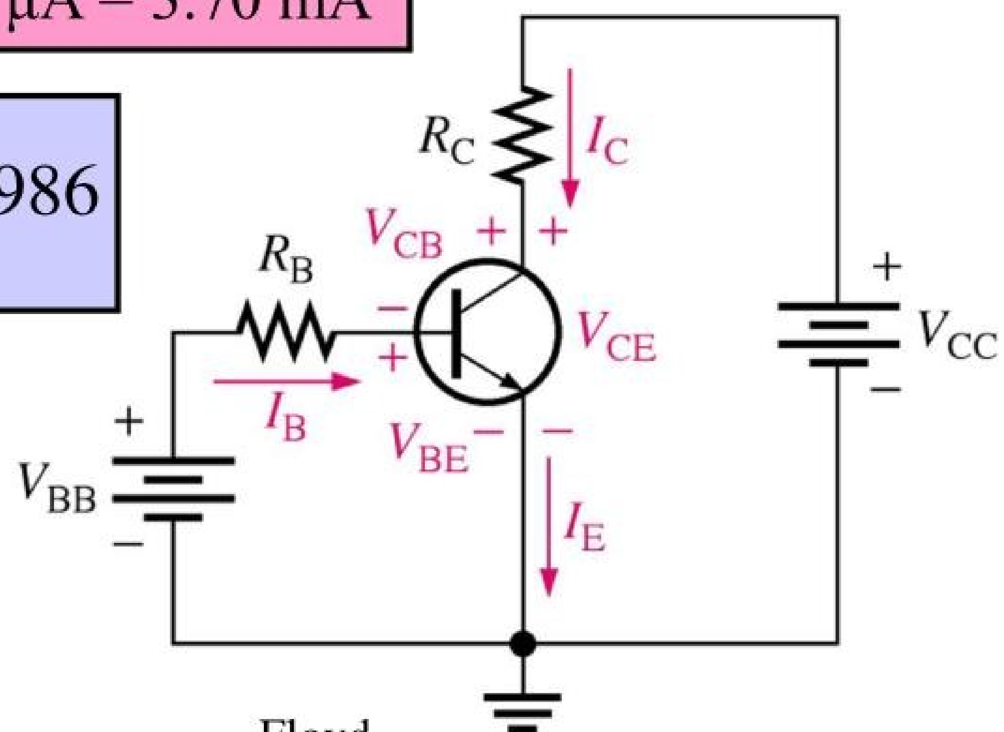
$$\alpha = I_C/I_E$$

Ex 3-1 Determine β_{DC} and I_E for a transistor where $I_B = 50\ \mu A$ and $I_C = 3.65\ mA$.

$$\beta_{DC} = \frac{I_C}{I_B} = \frac{3.65mA}{50\mu A} = 73$$

$$I_E = I_C + I_B = 3.65\ mA + 50\ \mu A = 3.70\ mA$$

$$\alpha_{DC} = \frac{I_C}{I_E} = \frac{3.65mA}{3.70mA} = 0.986$$

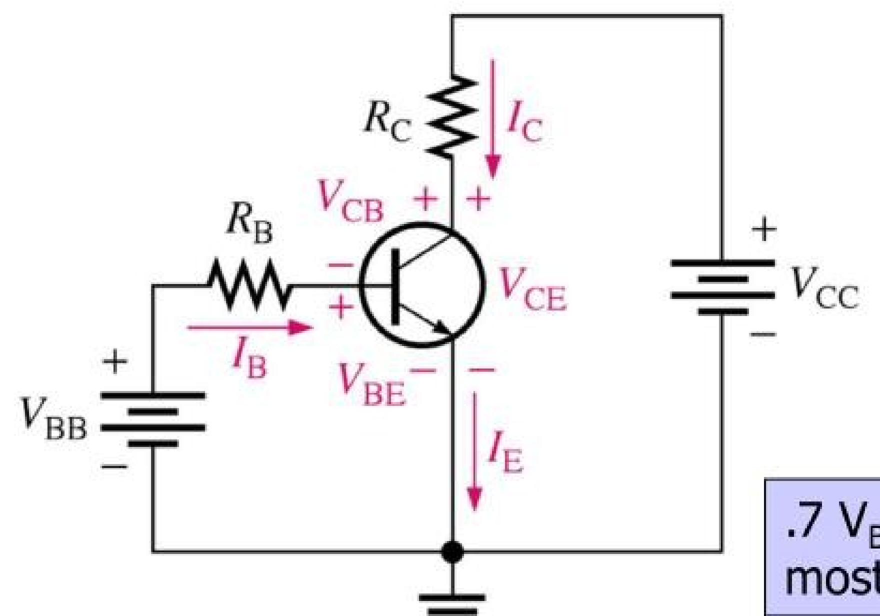


Transistor Characteristics and Parameters

Analysis of this transistor circuit to predict the dc voltages and currents requires use of Ohm's law, Kirchhoff's voltage law and the beta for the transistor.

Application of these laws begins with the base circuit to determine the amount of base current. Using Kichhoff's voltage law, subtract the .7 V_{BE} and the remaining voltage is dropped across R_B. Determining the current for the base with this information is a matter of applying of Ohm's law. $\mathbf{V_{RB}/R_B = I_B}$

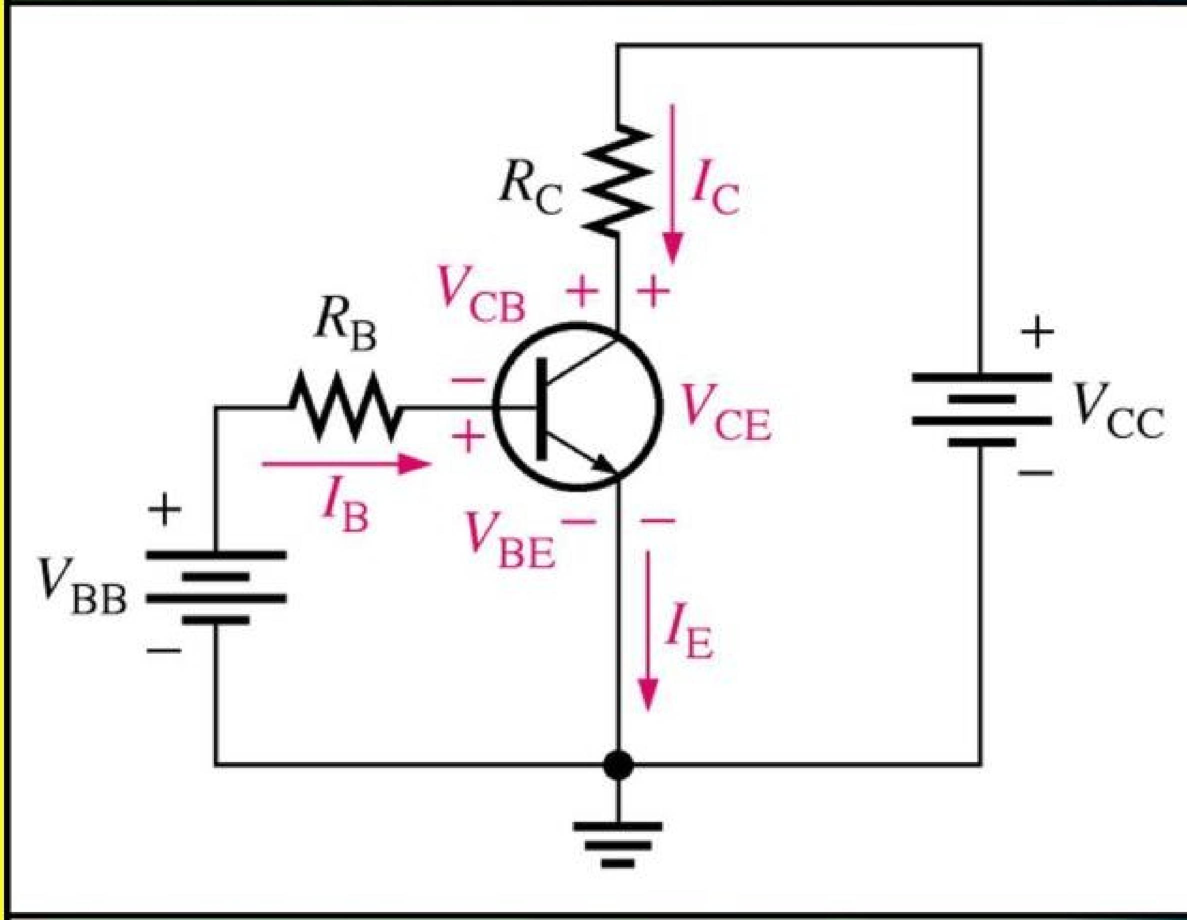
The collector current is determined by multiplying the base current by beta.



.7 V_{BE} will be used in most analysis examples.

Transistor Characteristics and Parameters

What we ultimately determine by use of Kirchhoff's voltage law for series circuits is that in the base circuit V_{BB} is distributed across the base-emitter junction and R_B in the base circuit. In the collector circuit we determine that V_{CC} is distributed proportionally across R_C and the transistor(V_{CE}).



Current and Voltage Analysis

There are three key dc voltages and three key dc currents to be considered. Note that these measurements are important for troubleshooting.

I_B: dc base current

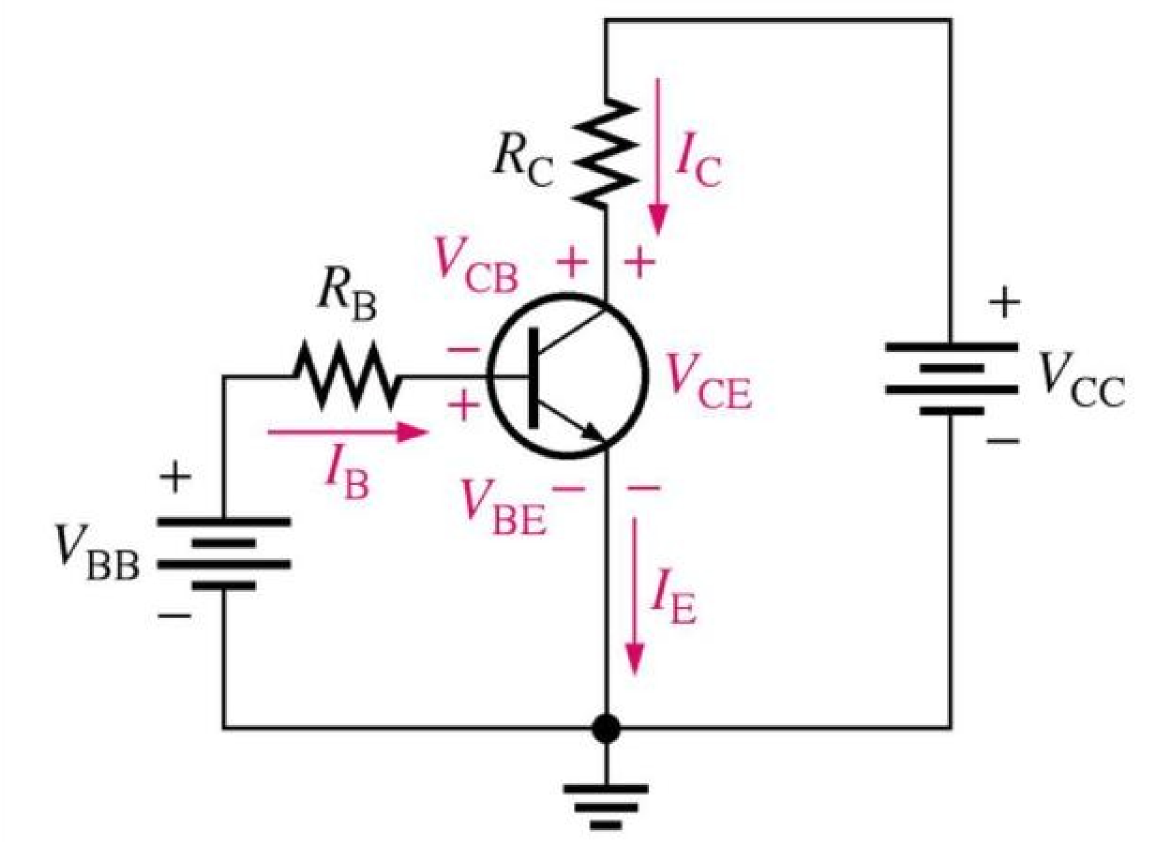
I_E: dc emitter current

I_C: dc collector current

V_{BE}: dc voltage across base-emitter junction

V_{CB}: dc voltage across collector-base junction

V_{CE}: dc voltage from collector to emitter



Current and Voltage Analysis-continued

When the base-emitter junction is forward-biased,

$V_{BE} \cong 0.7\ V$

$V_{R_B} = I_B R_B$: by Ohm's law

$I_B R_B = V_{BB} - V_{BE}$: substituting for V_{RB}

$I_B = (V_{BB} - V_{BE}) / R_B$: solving for I_B

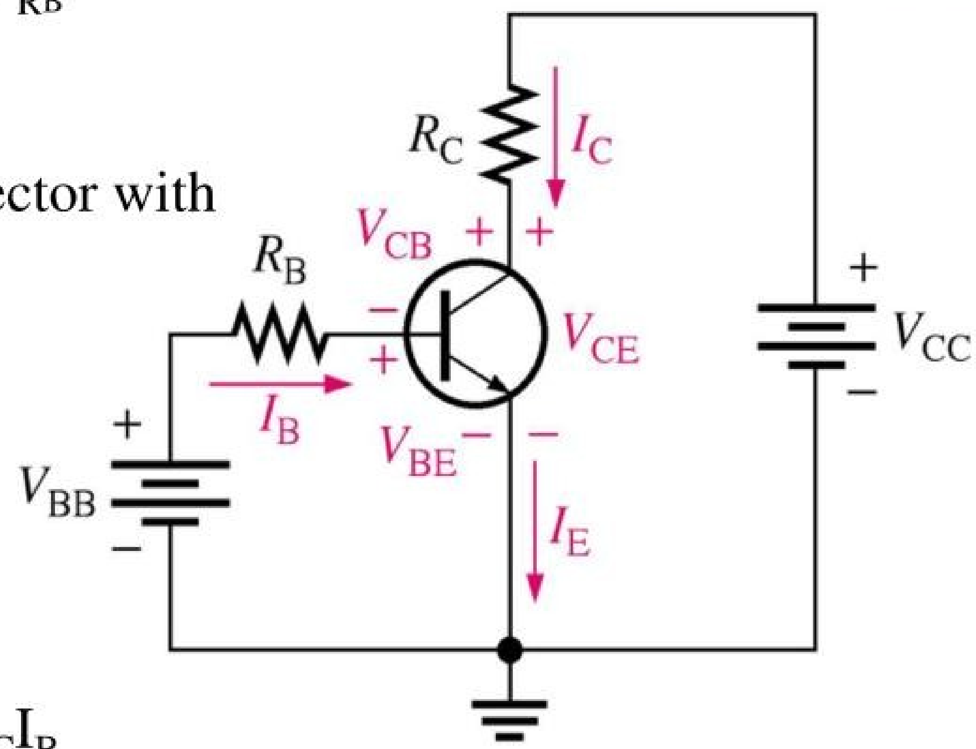
$V_{CE} = V_{CC} - V_{Rc}$: voltage at the collector with respect to emitter

$V_{Rc} = I_C R_C$

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

The voltage across the reverse-biased collector-base junction

$V_{CB} = V_{CE} - V_{BE}$ where $I_C = \beta_{DC} I_B$



Ex 3-2 Determine I_B, I_C, V_{BE}, V_{CE}, and V_{CB} in the circuit of Figure. The transistor has a $\beta_{DC} = 150$.

When the base-emitter junction is forward-biased,

$$\mathbf{V_{BE} \cong 0.7\ V}$$

$$\mathbf{I_B = (V_{BB} - V_{BE}) / R_B}$$

$$= (5\ V - 0.7\ V) / 10\ k\Omega = 430\ \mu A$$

$$\mathbf{I_C = \beta_{DC} I_B}$$

$$= (150)(430\ \mu A)$$

$$= 64.5\ mA$$

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

$$= 64.5\ mA + 430\ \mu A$$

$$= 64.9\ mA$$

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

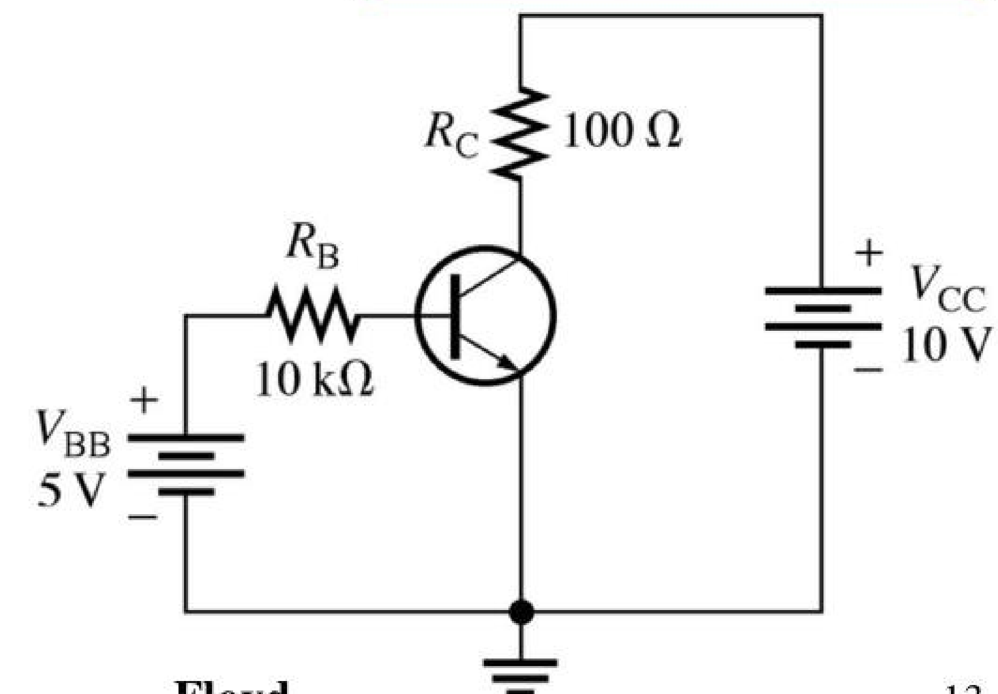
$$= 10\ V - (64.5\ mA)(100\ \Omega)$$

$$= 3.55\ V$$

$$\mathbf{V_{CB} = V_{CE} - V_{BE}}$$

$$= 3.55\ V - 0.7\ V$$

$$= 2.85\ V$$



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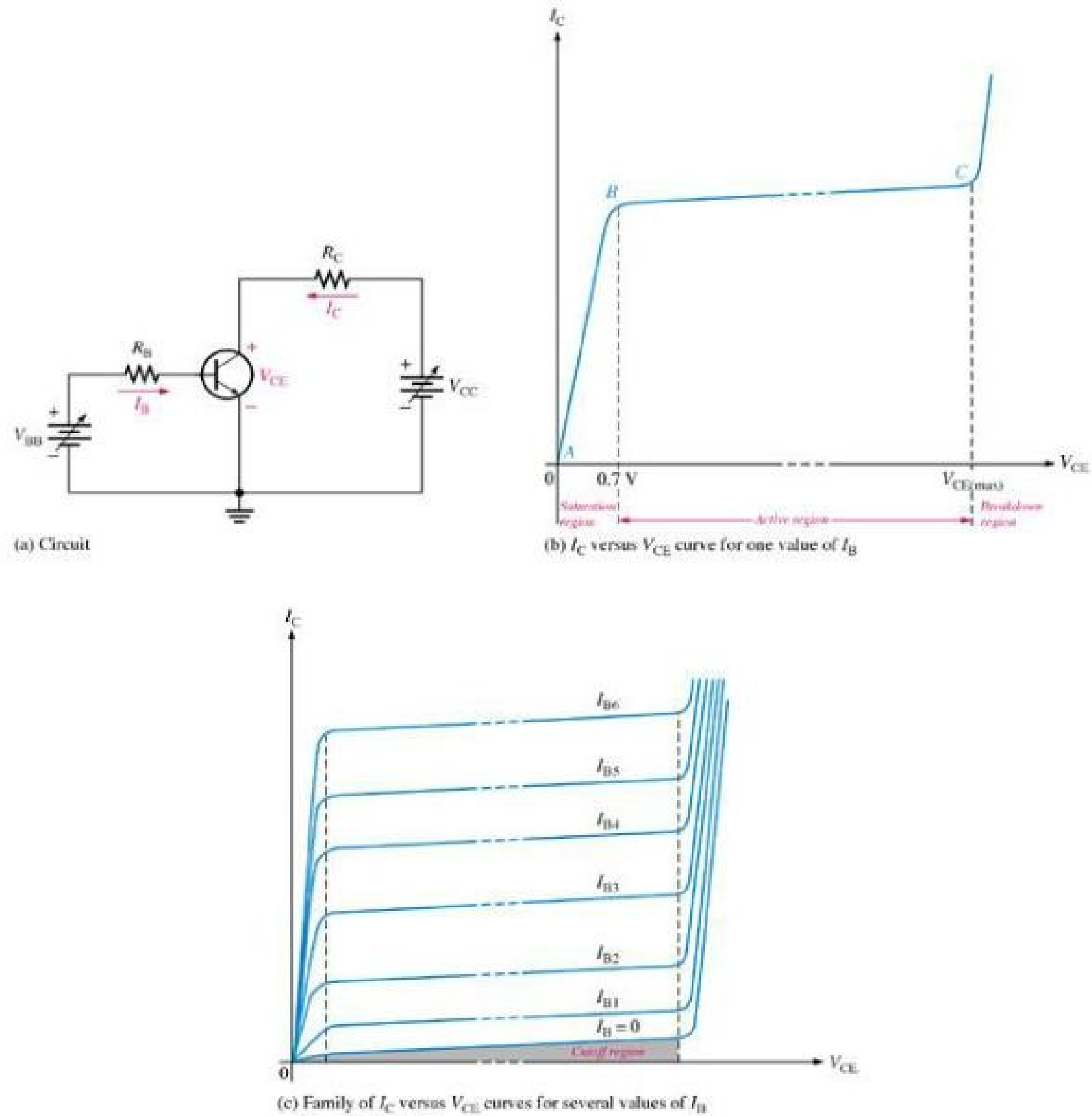
Collector Characteristic Curve

Collector characteristic curves gives a graphical illustration of the relationship of collector current and V_{CE} with specified amounts of base current. With greater increases of V_{CC}, V_{CE} continues to increase until it reaches breakdown, but the current remains about the same in the **linear** region from .7V to the breakdown voltage.

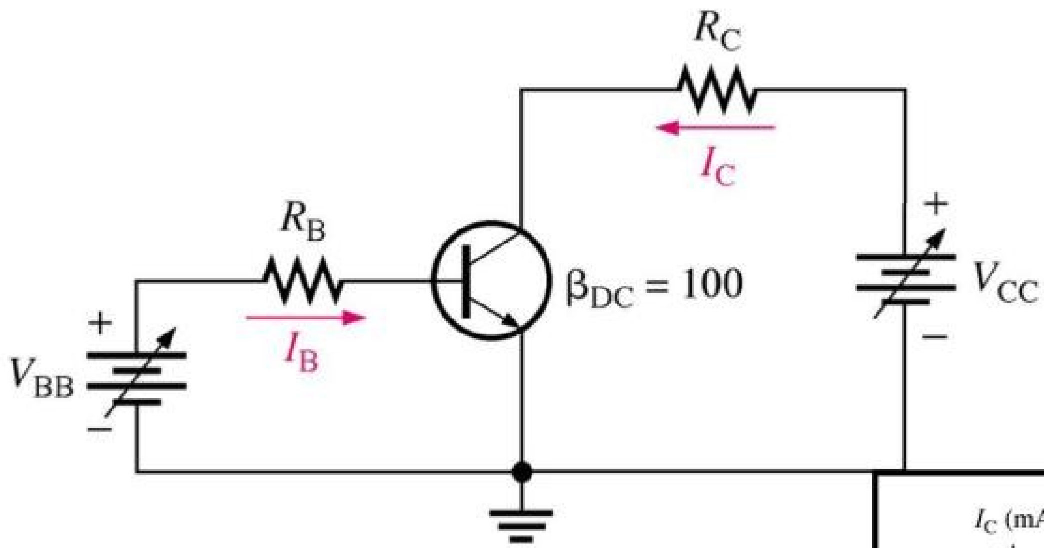


(a) Circuit

(b) I_C versus V_{CE} curve for one value of I_B

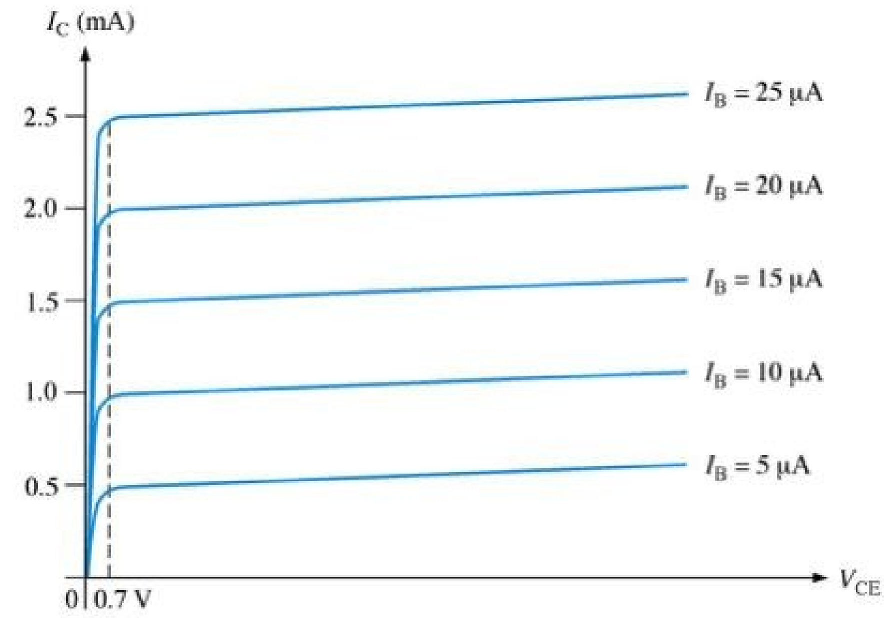
(c) Family of I_C versus V_{CE} curves for several values of I_B ($I_{B1} < I_{B2} < I_{B3}$, etc.)

Ex 3-3 Sketch an ideal family of collector curves for for the circuit in Figure for $I_B = 5\ \mu A$ increment. Assume $\beta_{DC} = 100$ and that V_{CE} does not exceed breakdown.



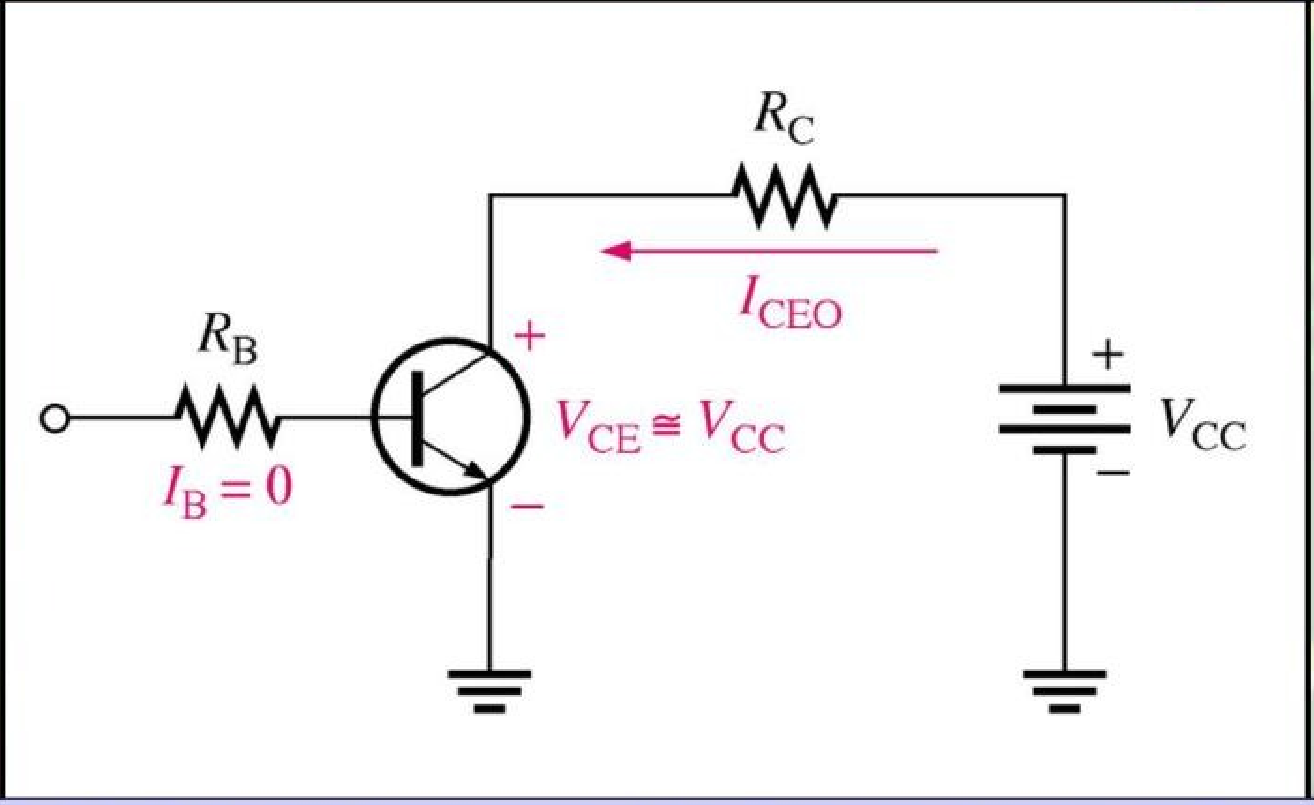
$I_C = \beta_{DC} I_B$

I_B	I_C
5 μA	0.5 mA
10 μA	1.0 mA
15 μA	1.5 mA
20 μA	2.0 mA
25 μA	2.5 mA



Transistor Characteristics and Parameters-Cutoff

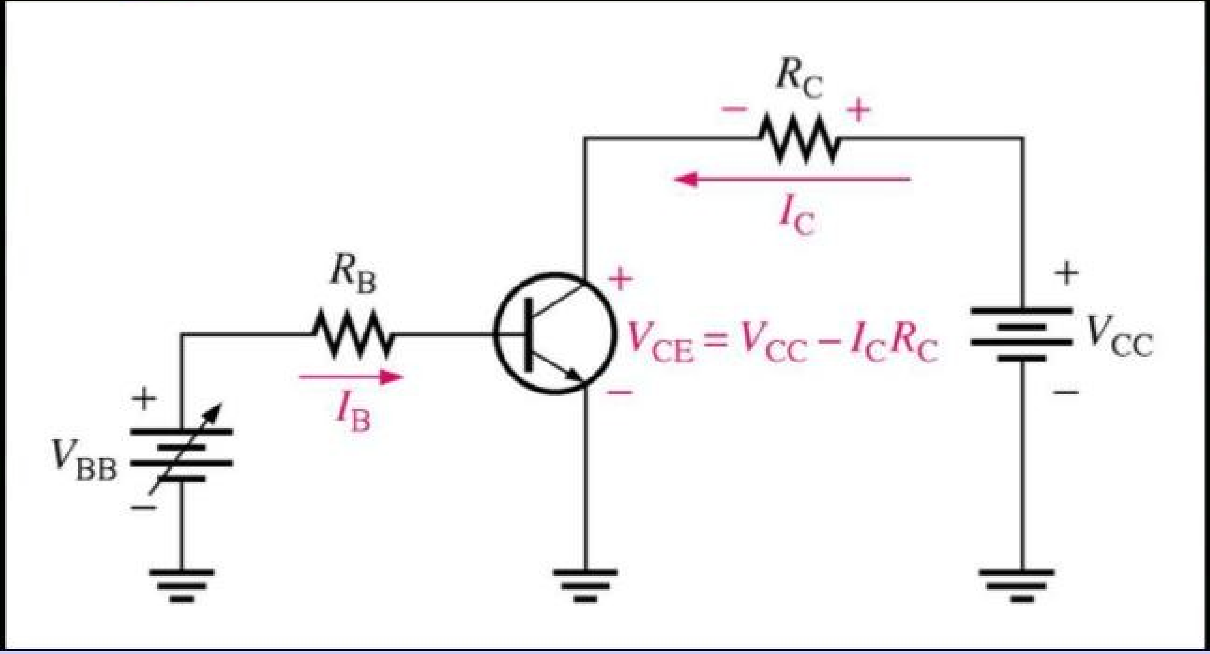
With no I_B the transistor is in the **cutoff** region and just as the name implies there is practically no current flow in the collector part of the circuit. With the transistor in a cutoff state the the full V_{CC} can be measured across the collector and emitter(V_{CE})



Cutoff: Collector leakage current (I_{CEO}) is extremely small and is usually neglected. Base-emitter and base-collector junctions are reverse-biased.

Transistor Characteristics and Parameters - Saturation

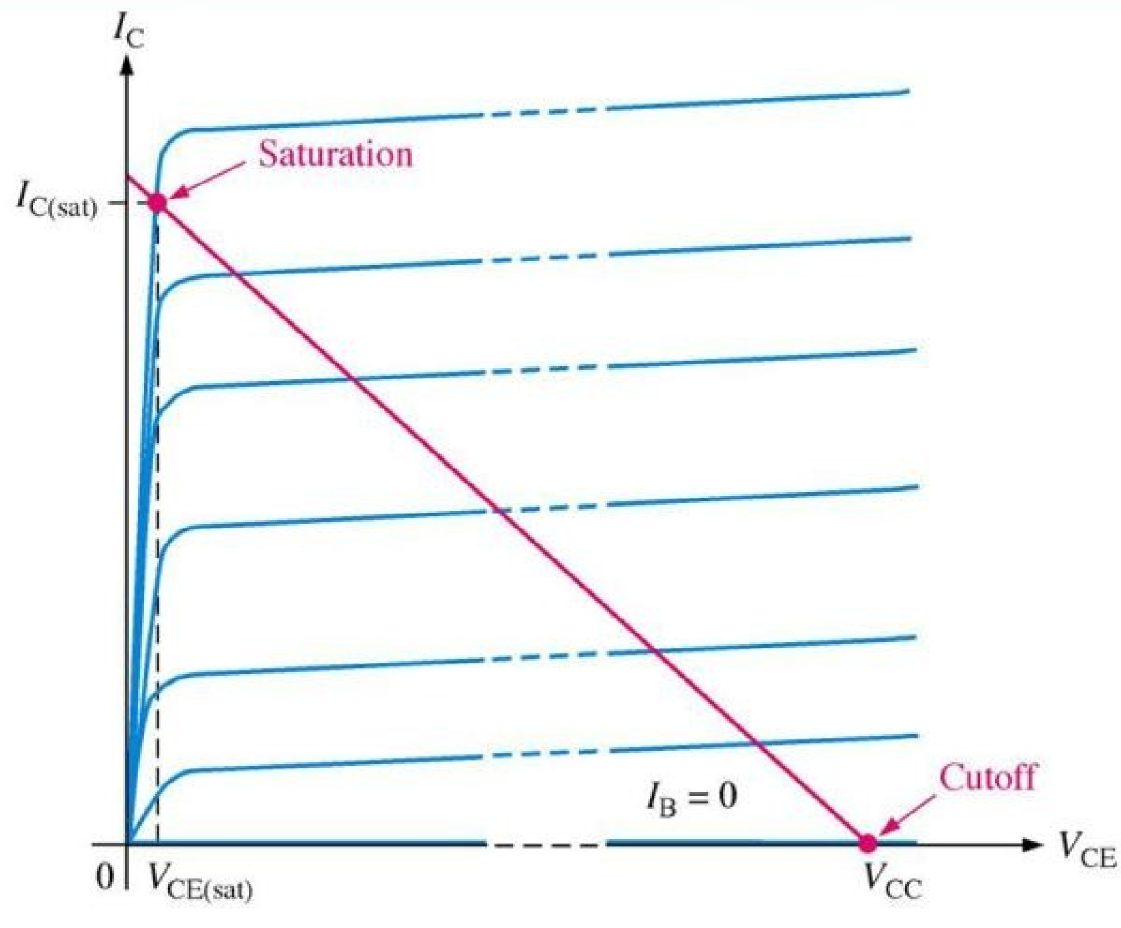
Once this maximum is reached, the transistor is said to be in **saturation**. Note that saturation can be determined by application of Ohm's law. $I_{C(sat)} = V_{CC}/R_C$ The measured voltage across this now seemingly "shorted" collector and emitter is 0V.



Saturation: As I_B increases due to increasing V_{BB}, I_C also increases and V_{CE} decreases due to the increased voltage drop across R_C. When the transistor reaches saturation, I_C can increase no further regardless of further increase in I_B. Base-emitter and base-collector junctions are forward-biased.

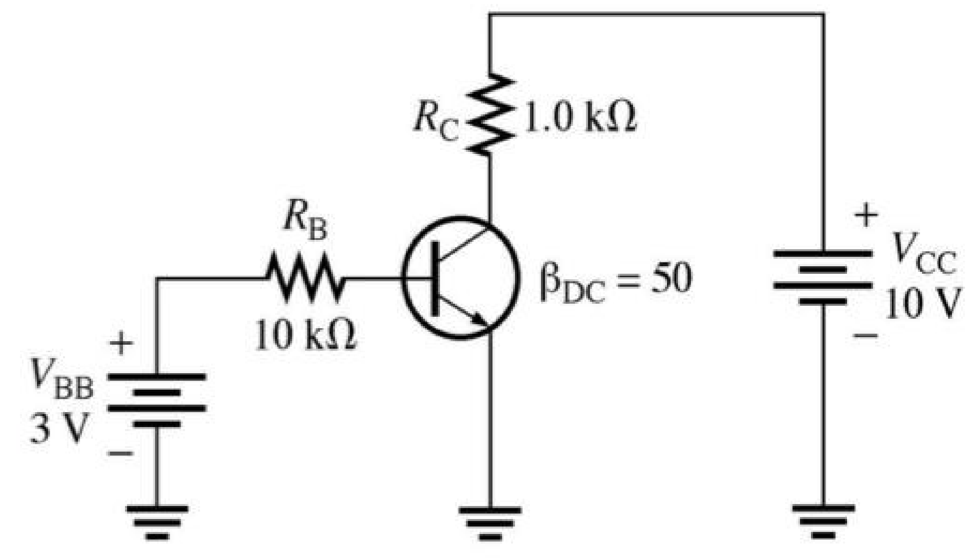
Transistor Characteristics and Parameters - DC Load Line

The **dc load line** graphically illustrates $I_{C(sat)}$ and Cutoff for a transistor.



DC load line on a family of collector characteristic curves illustrating the cutoff and saturation conditions.

Ex 3-4 Determine whether or not the transistors in Figure is in saturation. Assume $V_{CE(sat)} = 0.2$ V.



First, determine $I_{C(sat)}$

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

$$= \frac{10V - 0.2V}{1.0k\Omega} = 9.8\,mA$$

Now, see if I_B is large enough to produce $I_{C(sat)}$.

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{3V - 0.7V}{10k\Omega} = \frac{2.3V}{10\,k\Omega} = 0.23\,mA$$

$$I_C = \beta_{DC} I_B = (50)(0.23\,mA) = 11.5\,mA$$

Transistor Characteristics and Parameters – Maximum Transistor Ratings

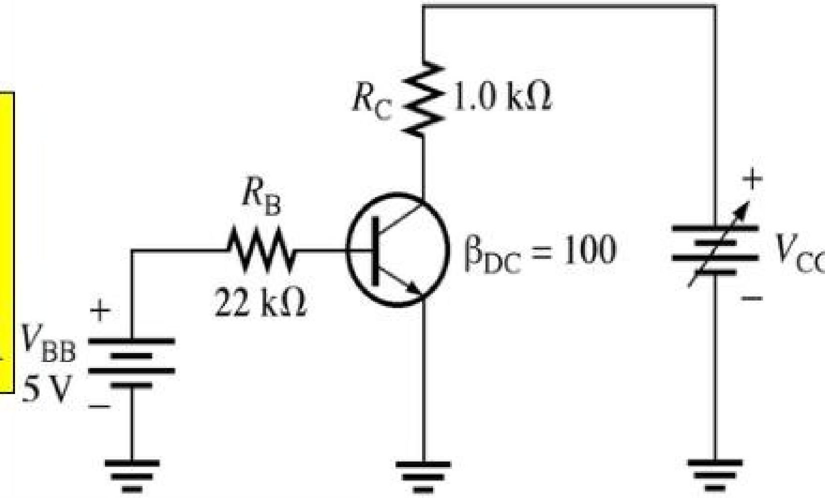
A transistor has limitations on its operation. The product of V_{CE} and I_C cannot be maximum at the same time. If V_{CE} is maximum, I_C can be calculated as

$$I_C = \frac{P_{D(\max)}}{V_{CE}}$$

Ex 4-5 A certain transistor is to be operated with $V_{CE} = 6$ V. If its maximum power rating is 250 mW, what is the most collector current that it can handle?

$$I_C = \frac{P_{D(\max)}}{V_{CE}} = \frac{250\,mW}{6V} = 41.7\,mA$$

Ex 3-5 The transistor in Figure has the following maximum ratings: $P_{D(max)} = 800$ mW, $V_{CE(max)} = 15$ V, and $I_{C(max)} = 100$ mA. Determine the maximum value to which V_{CC} can be adjusted without exceeding a rating. Which rating would be exceeded first?



First, find I_B so that you can determine I_C.

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5V - 0.7V}{22k\Omega} = 195\mu A$$

$$I_C = \beta_{DC} I_B = (100)(195\mu A) = 19.5mA$$

The voltage drop across R_C is.

$V_{Rc} = I_C R_C = (19.5\text{ mA})(1.0\text{ k}\Omega) = 19.5$ V
$V_{Rc} = V_{CC} - V_{CE}$ when $V_{CE} = V_{CE(max)} = 15$ V
$V_{CC(max)} = V_{CE(max)} + V_{Rc} = 15\text{ V} + 19.5\text{ V} = 34.5$ V

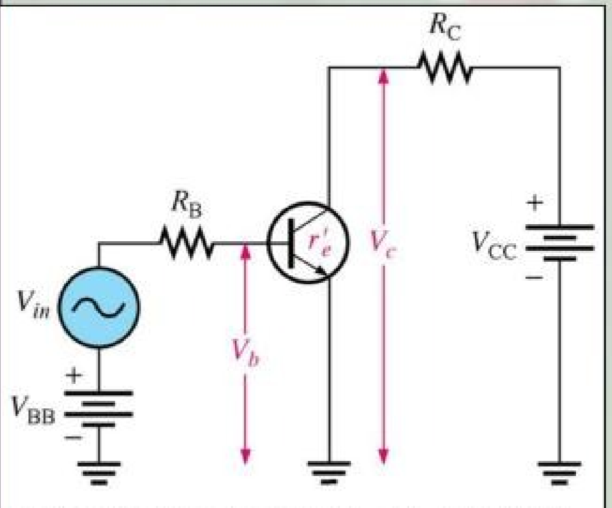
$P_D = V_{CE(max)} I_C = (15V)(19.5mA) = 293$ mW

$V_{CE(max)}$ **will be exceeded first** because the entire supply voltage, V_{CC} will be dropped across the transistor.

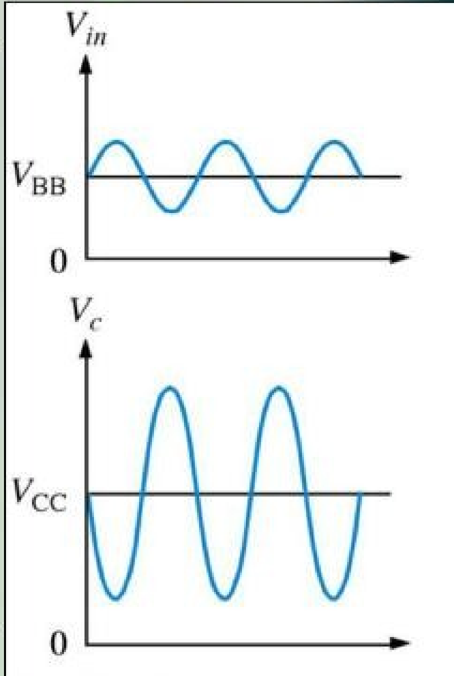
The Transistor as an Amplifier

Amplification of a relatively small ac voltage can be had by placing the ac signal source in the base circuit.

Recall that small changes in the base current circuit causes large changes in collector current circuit.



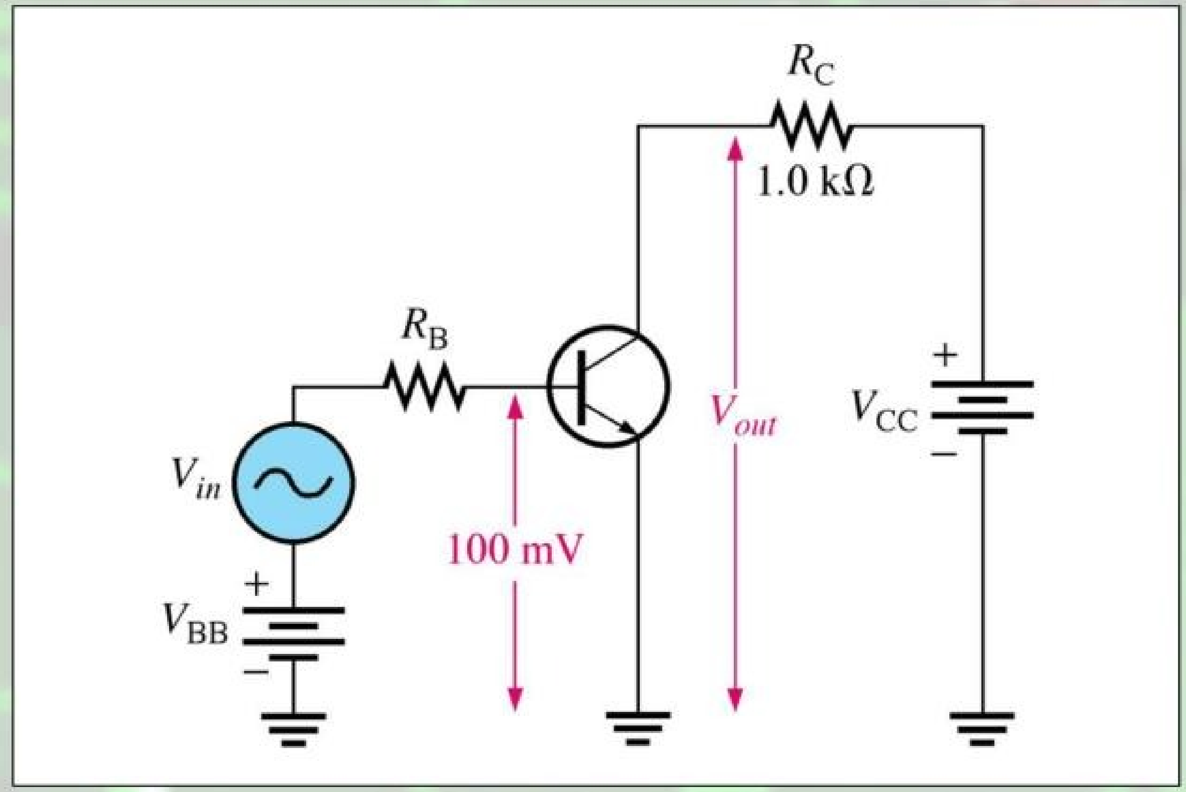
(a) Circuit with ac input voltage V_{in} and dc bias voltage superimposed



(b) Waveforms

The ac emitter current : $I_e \approx I_c = V_b/r'_e$
The ac collector voltage : $V_c = I_cR_c$
Since $I_c \approx I_e$, the ac collector voltage : $V_c \approx I_eR_c$
The ratio of V_c to V_b is the ac voltage gain : $A_v = V_c/V_b$
Substituting I_eR_c for V_c and $I_er'_e$ for V_b : $A_v = V_c/V_b \approx I_cR_c/I_er'_e$
The I_e terms cancel : $A_v \approx R_c/r'_e$

Ex 3-6 Determine the voltage gain and the ac output voltage in Figure if $r'_e = 50\ \Omega$.

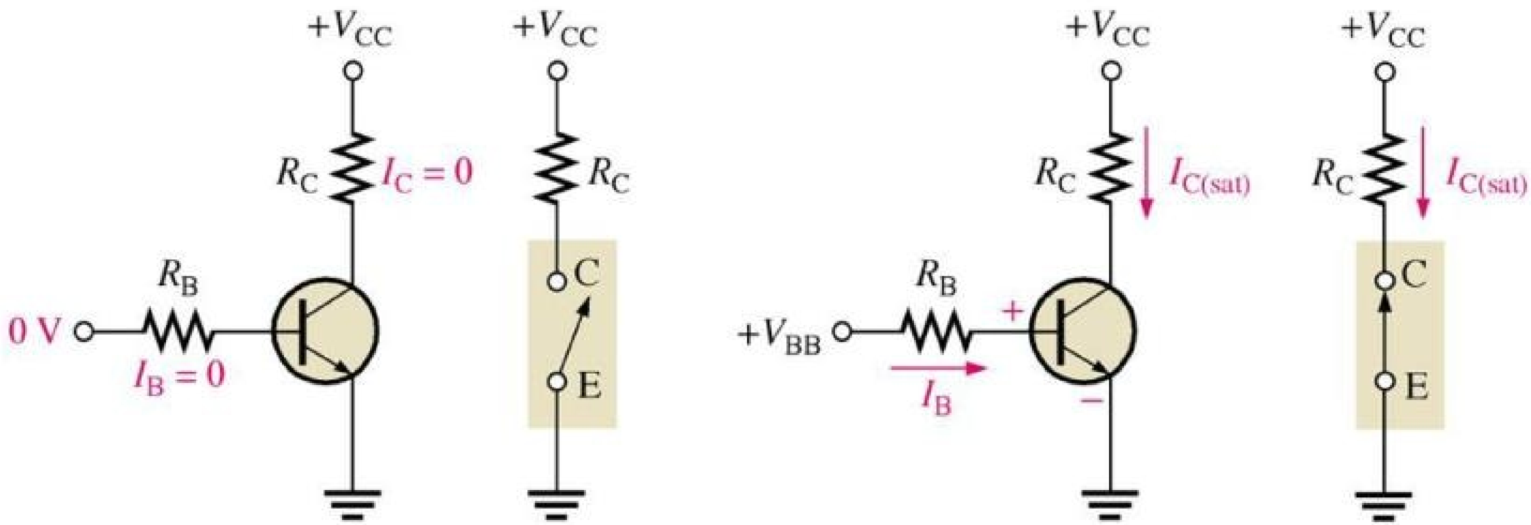


The voltage gain : $A_v \approx R_c/r'_e = 1.0\ k\Omega/50\ \Omega = 20$

The ac output voltage : $A_v V_b = (20)(100\ mV) = 2\ V$

The Transistor as a Switch

A transistor when used as a switch is simply being biased so that it is in **cutoff (switched off)** or **saturation (switched on).** Remember that the V_{CE} in cutoff is V_{CC} and 0V in saturation.



(a) Cutoff — open switch

(b) Saturation — closed switch

Conditions in Cutoff & Saturation

A transistor is in the cutoff region when the base-emitter junction is not forward-biased. All of the current are zero, and V_{CE} is equal to V_{CC}

$$V_{CE(cutoff)} = V_{CC}$$

When the base-emitter junction is forward-biased and there is enough base current to produce a maximum collector current, the transistor is saturated. The formula for collector saturation current is

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

The minimum value of base current needed to produce saturation is

$$I_{B(\min)} = \frac{I_{C(sat)}}{\beta_{DC}}$$

Ex 3-7 (a) For the transistor circuit in Figure, what is V_{CE} when $V_{IN} = 0$ V?
(b) What minimum value of I_B is required to saturate this transistor if β_{DC} is 200? Neglect $V_{CE(sat)}$.
(c) Calculate the maximum value of R_B when $V_{IN} = 5$ V.

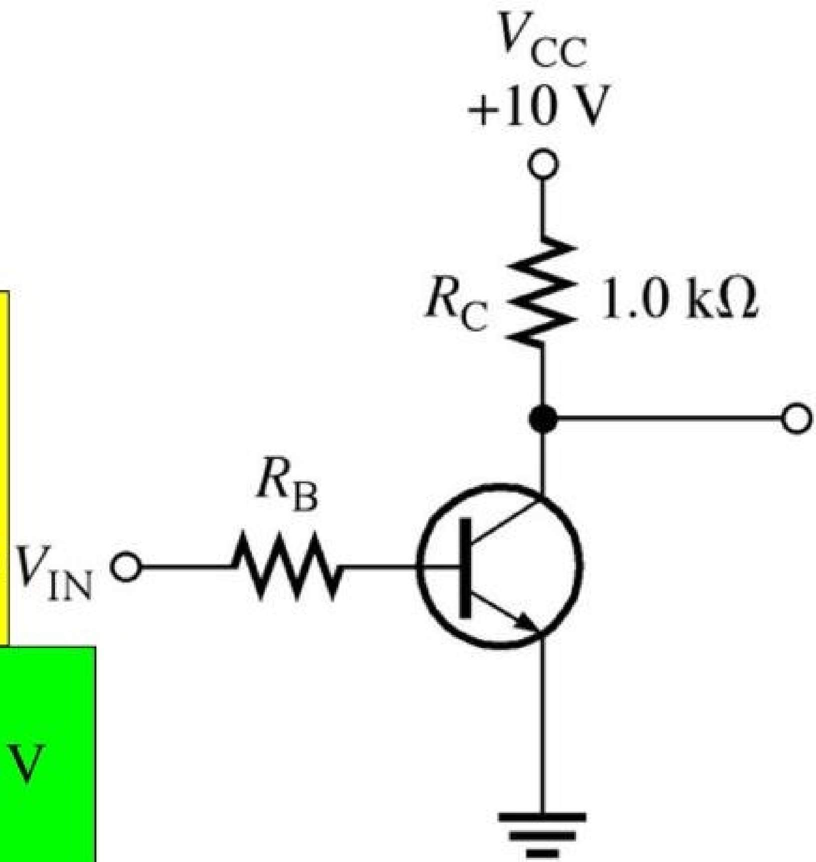
(a) When $V_{IN} = 0$ V

$$V_{CE} = V_{CC} = 10\text{ V}$$

(b) Since $V_{CE(sat)}$ is neglected,

$$I_{C(sat)} = \frac{V_{CC}}{R_C} = \frac{10V}{1.0k\Omega} = 10\ mA$$

$$I_{B(\min)} = \frac{I_{C(sat)}}{\beta_{DC}} = \frac{10\,mA}{200} = 50\ \mu A$$



(c) When the transistor is on, $V_{BE} \approx 0.7$ V.

$$V_{R_B} = V_{IN} - V_{BE} \approx 5\text{ V} - 0.7\text{ V} = 4.3\text{ V}$$

Calculate the maximum value of R_B

$$R_{B(\max)} = \frac{V_{R_B}}{I_{B(\min)}} = \frac{4.3V}{50\ \mu A} = 86\ k\Omega$$

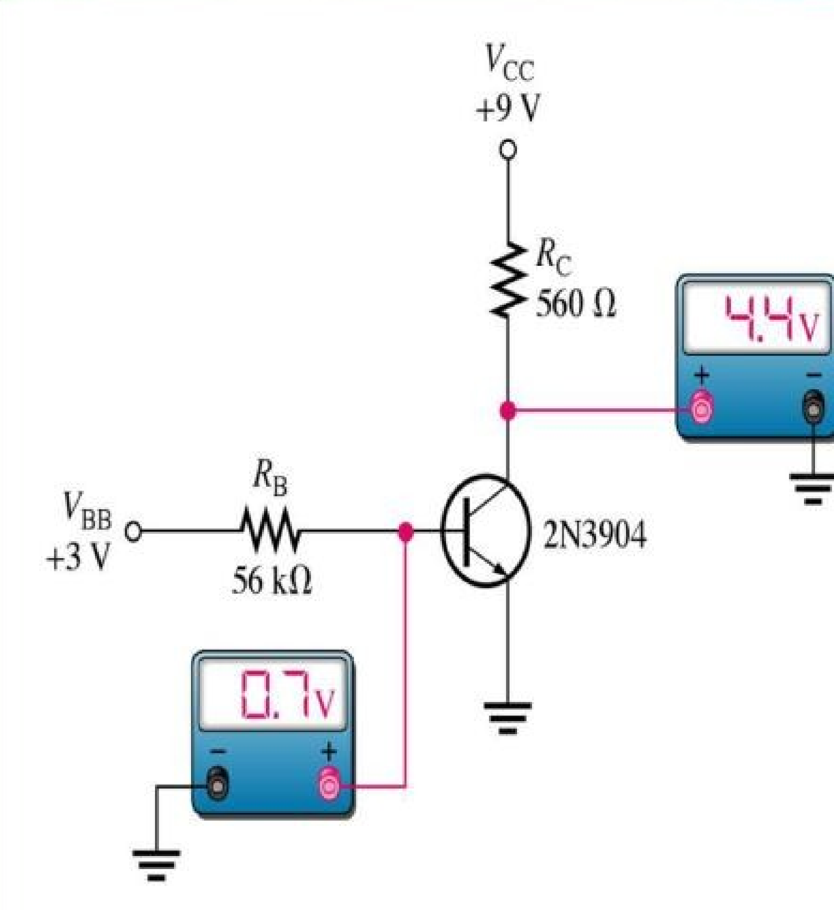
Troubleshooting

Opens in the external resistors or connections of the base or the circuit collector circuit would cause current to cease in the collector and the voltage measurements would indicate this.

Internal opens within the transistor itself could also cause transistor operation to cease.

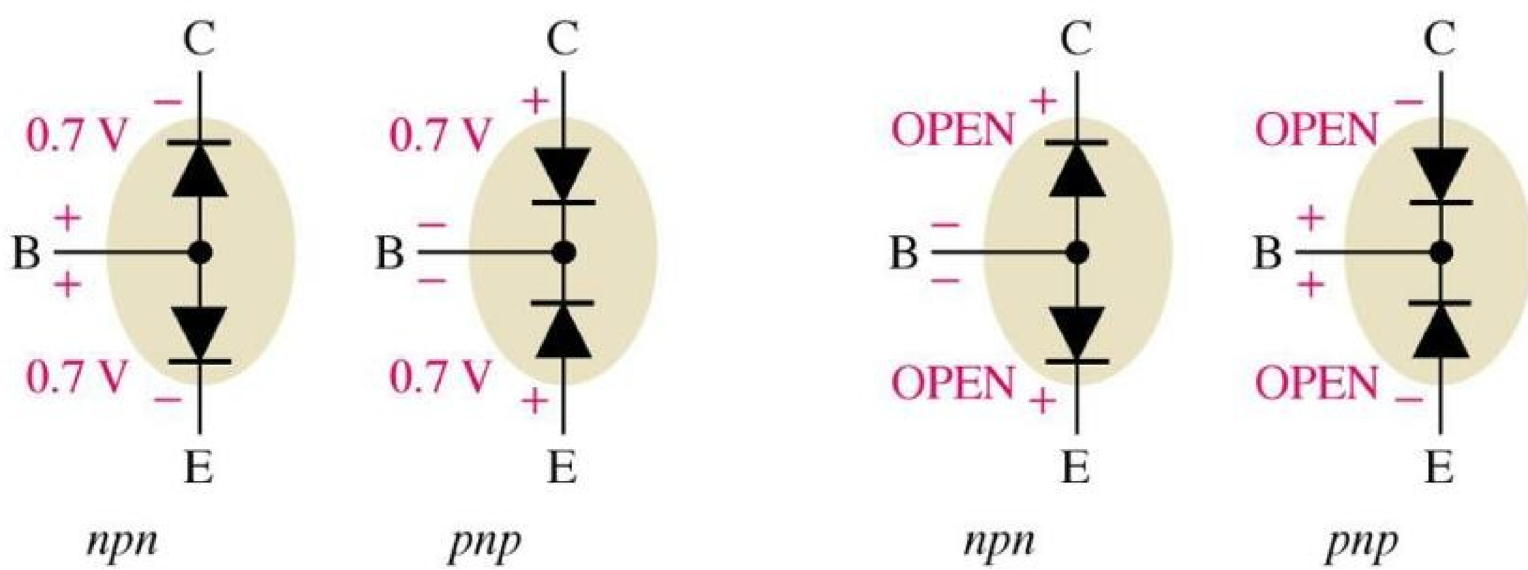
Erroneous voltage measurements that are typically low are a result of point that is not "solidly connected". This called a **floating point**. This is typically indicative of an open.

More in-depth discussion of typical failures are discussed within the textbook.



Troubleshooting

Testing a transistor can be viewed more simply if you view it as testing two diode junctions. Forward bias having low resistance and reverse bias having infinite resistance.



(a) Both junctions should read 0.7 V ± 0.2 V when forward-biased.

(b) Both junctions should ideally read OPEN when reverse-biased.