Bipolar Junction Transistors

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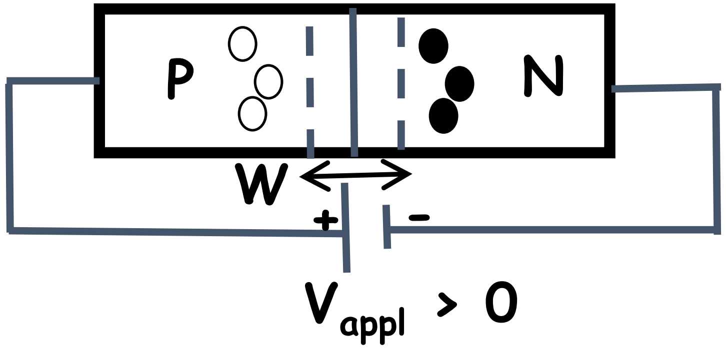
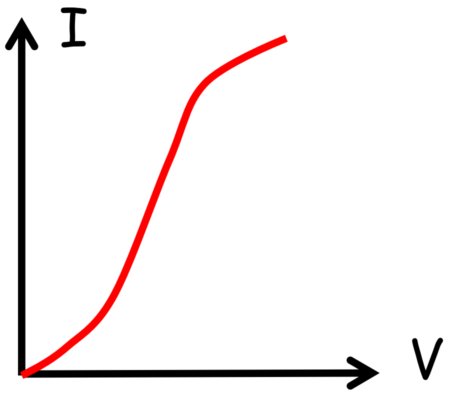
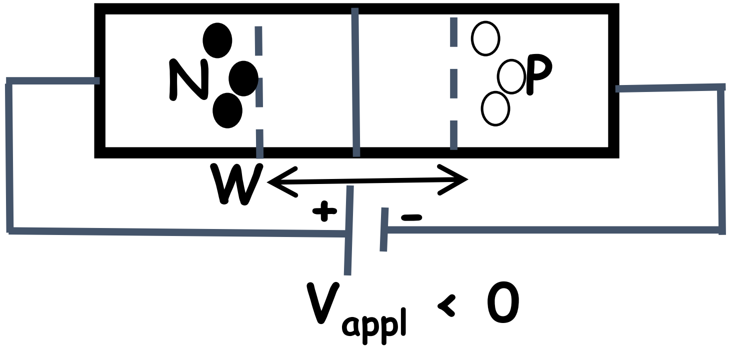
Recall p-n junction



Forward bias, + on P, - on N
(Shrink W, V_{bi})

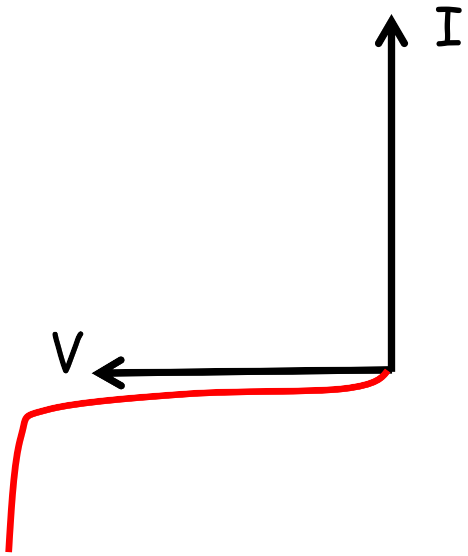
Allow holes to jump over barrier
into N region as minority carriers



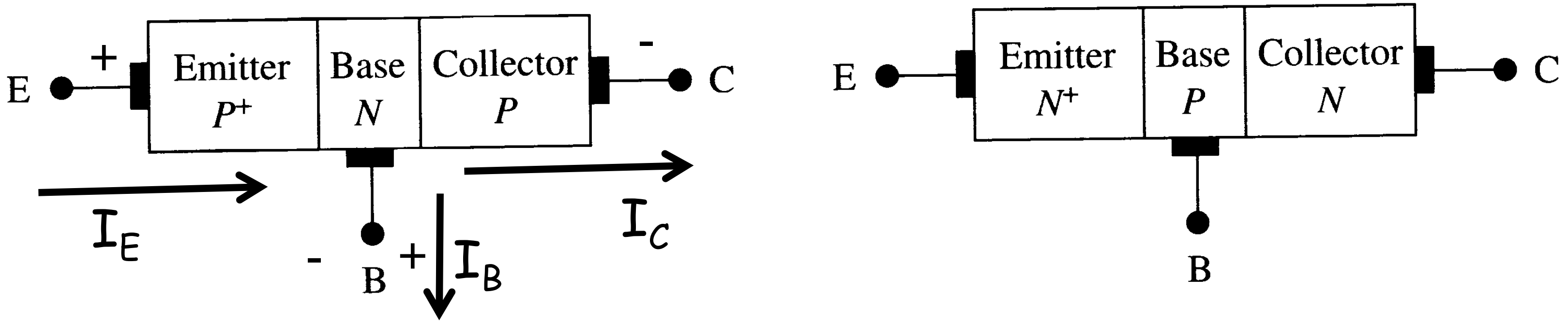


Reverse bias, + on N, - on P
(Expand W, V_{bi})

Remove holes and electrons away
from depletion region



Bipolar Junction Transistors: Basics

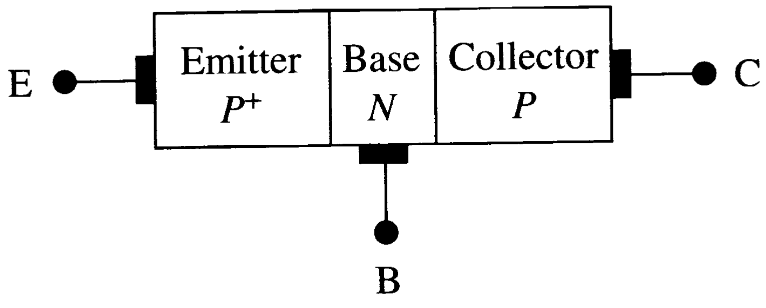


(a) *pnp* (b) *npn*

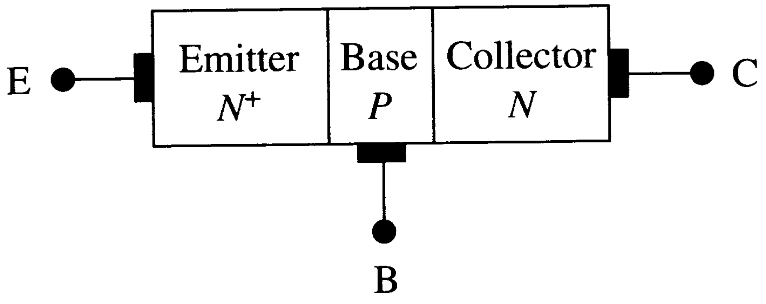
$$I_E = I_B + I_C \quad \text{.........(KCL)}$$

$$V_{EC} = V_{EB} + V_{BC} \quad \text{......... (KVL)}$$

Bipolar Junction Transistors: Basics



(a) *pnp*



(b) *npn*

Bias Mode	*E-B Junction*	*C-B Junction*
Saturation	Forward	Forward
Active	**Forward**	**Reverse**
Inverted	Reverse	Forward
Cutoff	Reverse	Reverse

Saturation And Cut-off

Saturation

With both junctions forward-biased, a BJT is in saturation mode and facilitates high current conduction from the emitter to the collector (or the other direction in the case of NPN, with negatively charged carriers flowing from emitter to collector).

This mode corresponds to a logical "on", or a closed switch.

Cut-off

In cut-off, biasing conditions opposite of saturation (both junctions reverse biased) are present.

There is very little current, which corresponds to a logical "off", or an open switch.

DC Beta (β DC) and DC Alpha (α DC)

- The dc current **gain** of a transistor is the ratio of the dc collector current (*I*C) to the dc base current (*I*B) and is designated dc **beta** (**β** DC).

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

- The ratio of the dc collector current (*I*C) to the dc emitter current (*I*E) is the dc **alpha** (**α** DC). The alpha is a less-used parameter than beta in transistor circuits.

$$\alpha_{DC} = \frac{I_C}{I_E}$$

Example

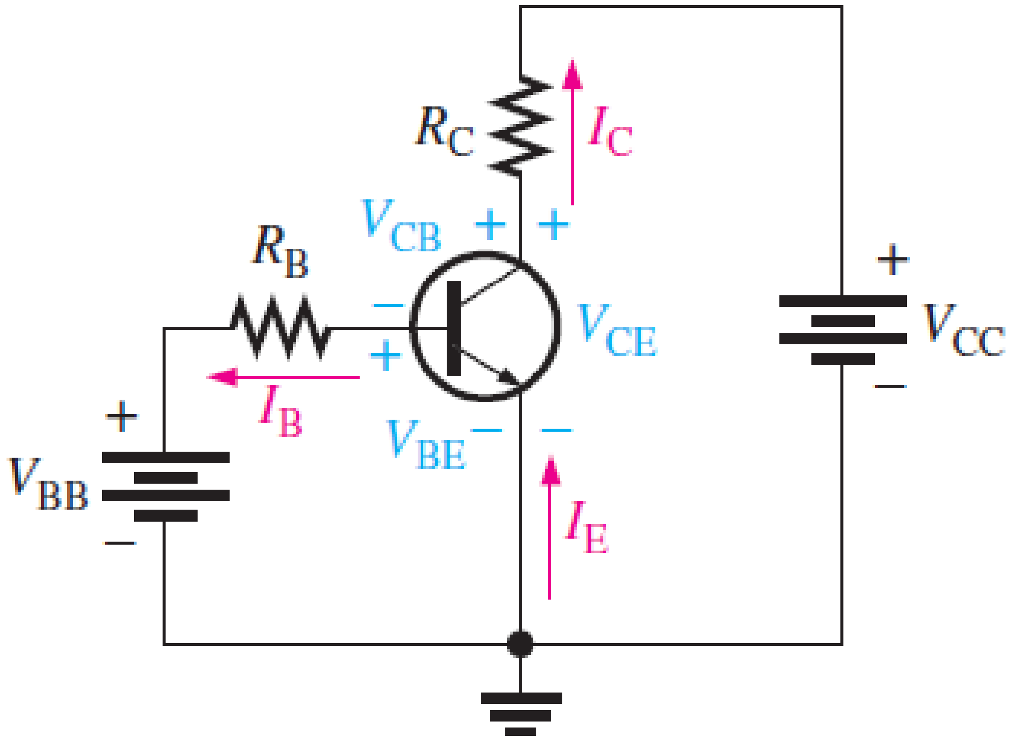
- Determine the dc current gain and the emitter current *I*E for a transistor where I_B 50 microA and I_C 3.65 mA.?

- A certain transistor has a **β** DC of 200. When the base current is 50 microA, determine the collector current.

BJT Circuit Analysis

- Consider the basic transistor bias circuit configuration in Figure 4–8. Three transistor dc
- currents and three dc voltages can be identified.
- I_B: dc base current
- I_E: dc emitter current
- I_C: dc collector current
- V_{BE}: dc voltage at base with respect to emitter
- V_{CB}: dc voltage at collector with respect to base
- V_{CE}: dc voltage at collector with respect to emitter

Diagram



Also, by Ohm's law,

$$V_{R_B} = I_B R_B$$

$$V_{R_B} = V_{BB} - V_{BE}$$

Substituting for V_{R_B} yields

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

Solving for I_B,

$$\boldsymbol{I_B = \frac{V_{BB} - V_{BE}}{R_B}}$$

The voltage at the collector with respect to the grounded emitter is

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

Since the drop across R_C is

$$V_{R_C} = I_C R_C$$

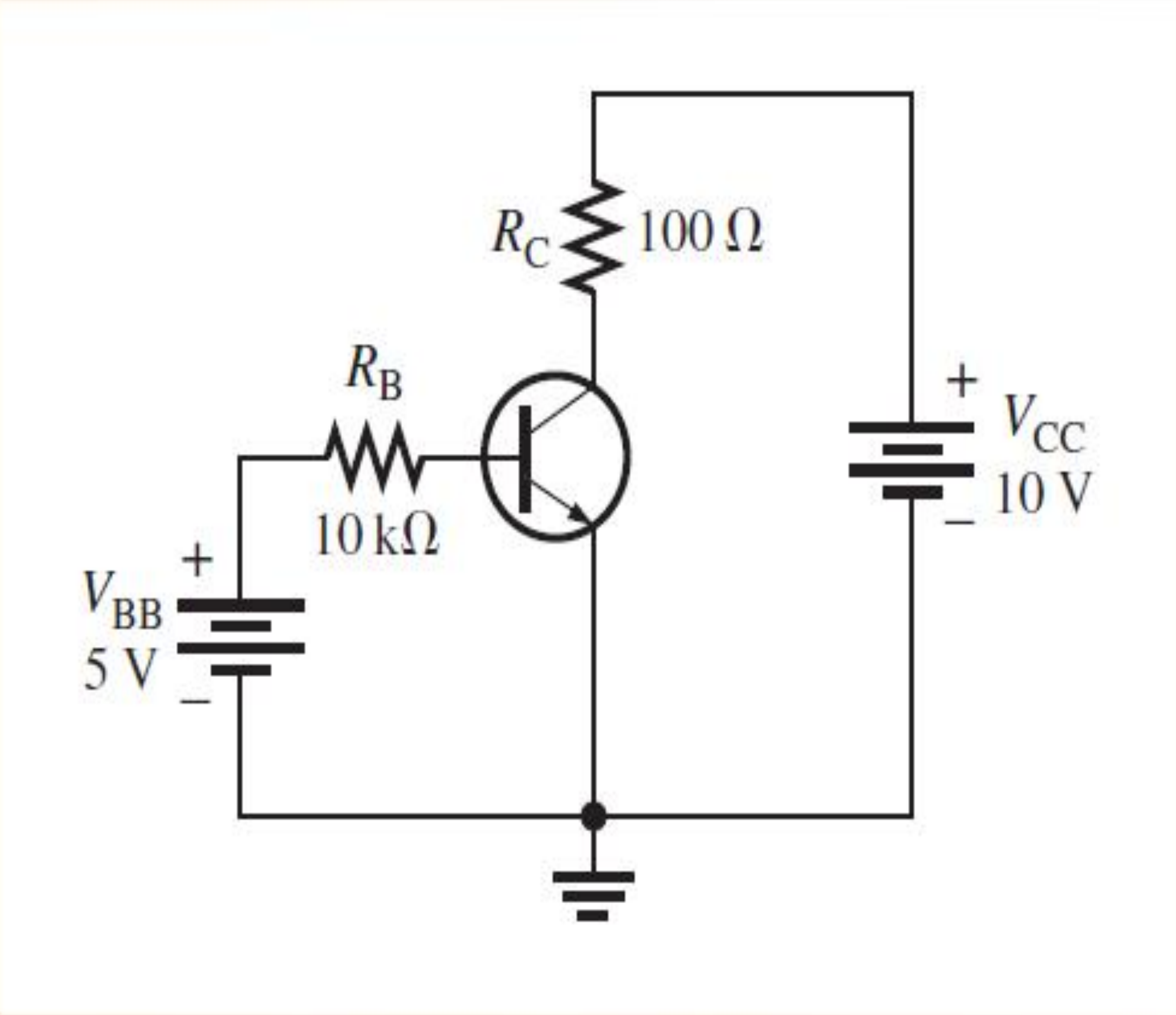
the voltage at the collector with respect to the emitter can be written as

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

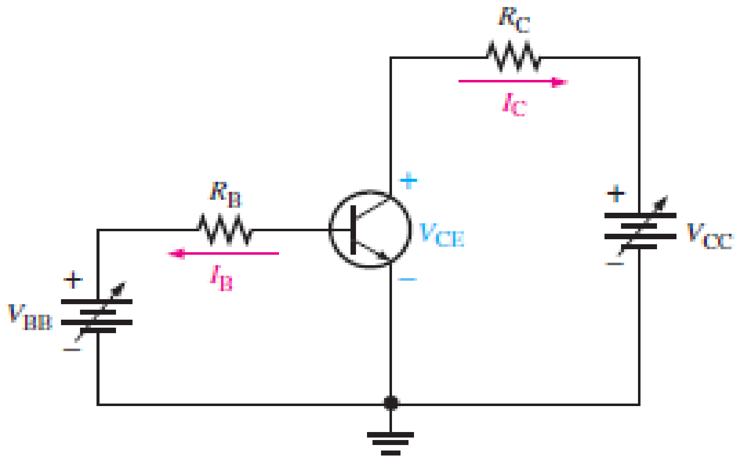
where $I_C = \beta_{DC} I_B$.

Determine I_B, I_C, I_E, V_{BE}, V_{CE}, and V_{CB} in the circuit of Figure 4–9. The transistor has a $\beta_{DC} = 150$.

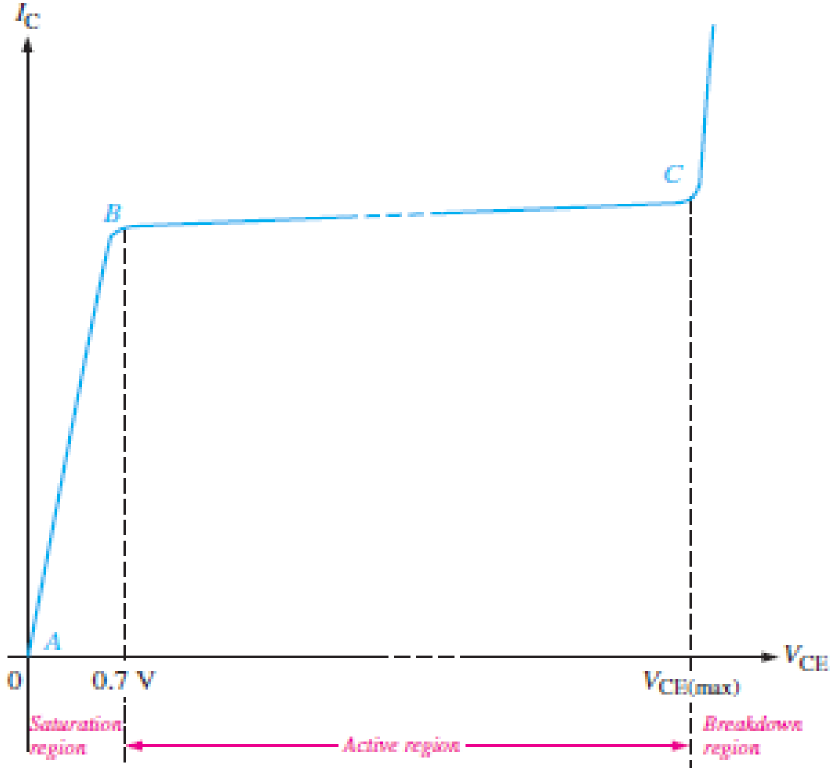
FIGURE 4–9



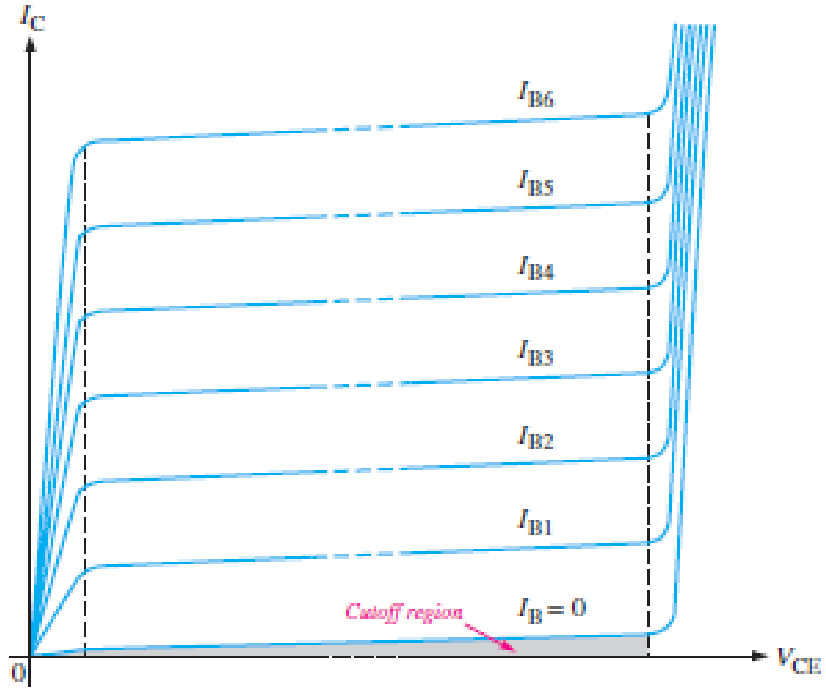
Collector Characteristic Curves



(a) Circuit



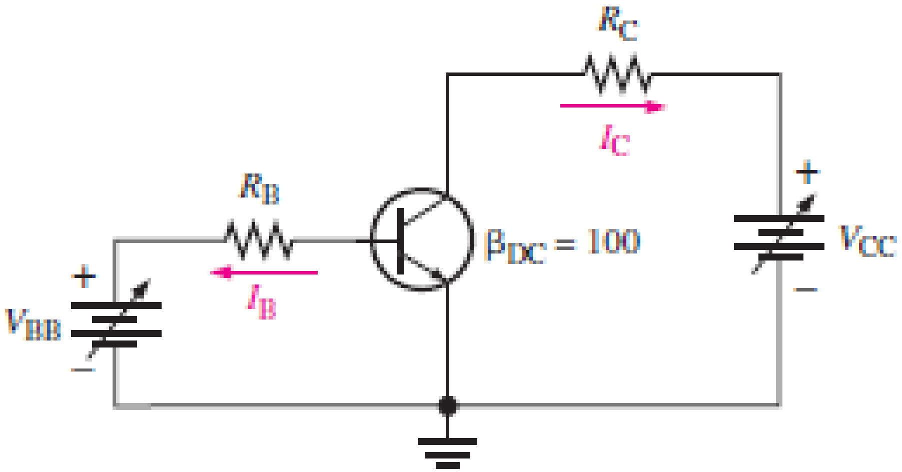
(b) I_C versus V_{CE} curve for one value of I_B



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

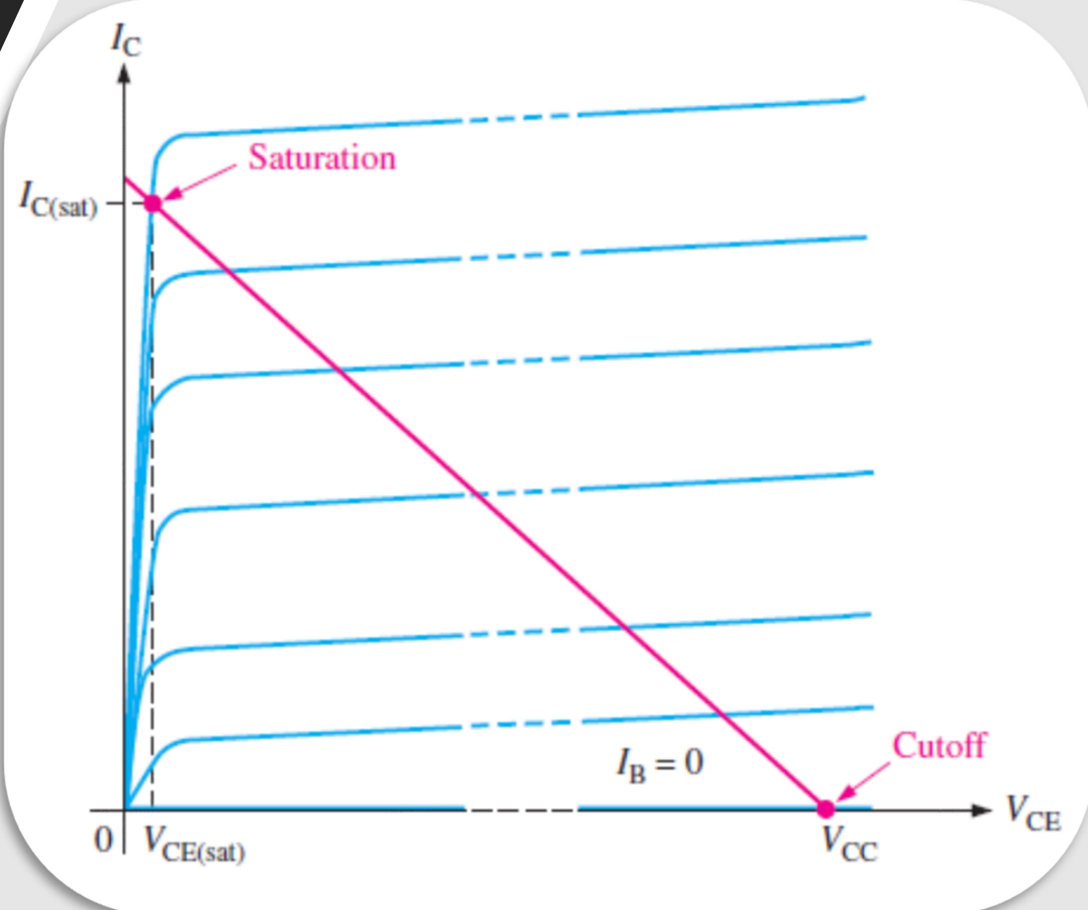
Sketch an ideal family of collector curves for the circuit in Figure 4–11 for I_B 5 mA to 25 mA in 5 mA increments. Assume b_{DC} = 100 and that V_{CE} does not exceed breakdown.

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



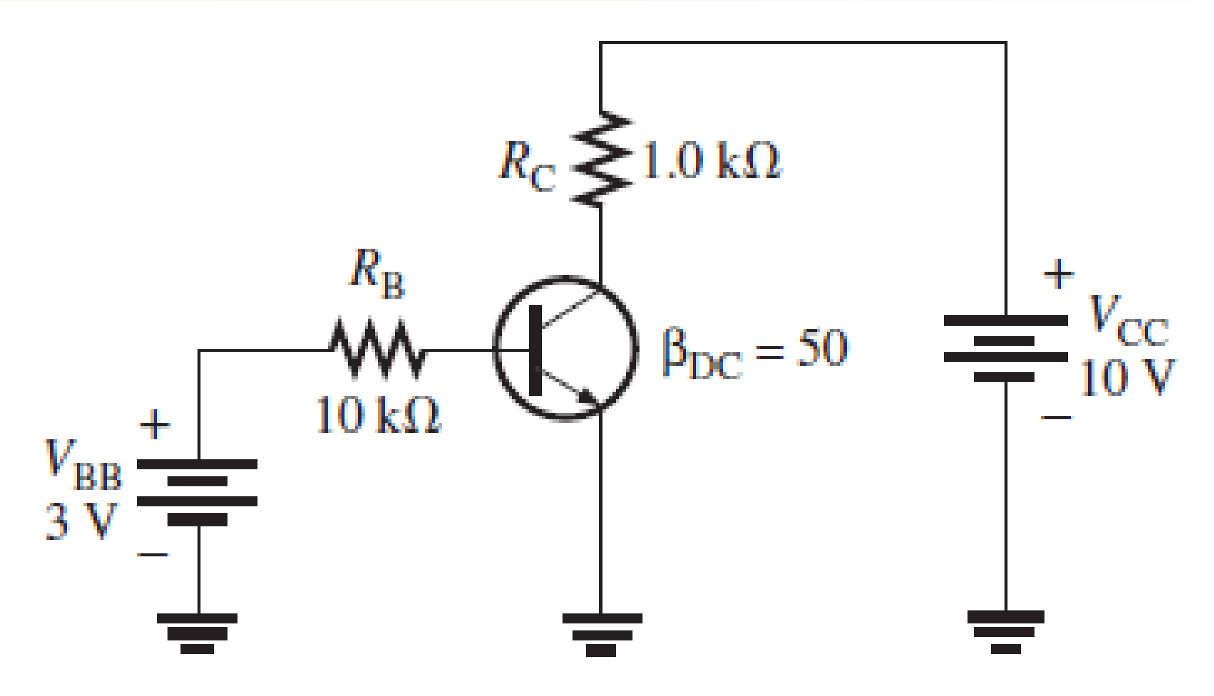
Load Line

- Cutoff and saturation can be illustrated in relation to the collector characteristic curves by the use of a load line. Figure shows a dc load line drawn on a family of curves connecting the cutoff point and the saturation point. The bottom of the load line is at ideal cutoff where *IC* 0 and *VCE VCC*. The top of the load line is at saturation where *IC IC*(sat) and *VCE VCE*(sat). In between cutoff and saturation along the load line is the *active region* of the transistor's operation.

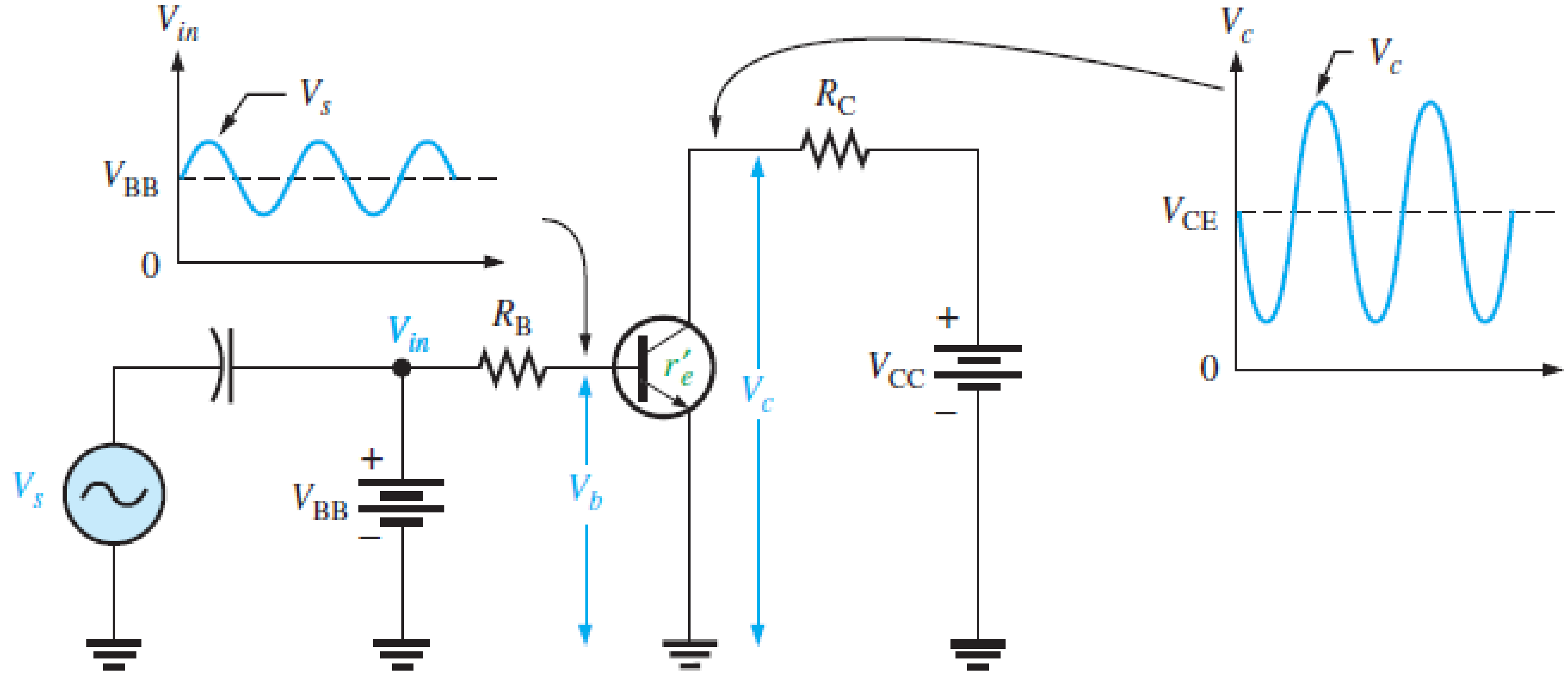


Determine whether or not the transistor in Figure 4–16 is in saturation. Assume $V_{CE(sat)} = 0.2$ V.

▶ FIGURE 4–16



Amplifier



Amplifier

$$V_b = I_e r'_e$$

The ac collector voltage, V_c, equals the ac voltage drop across R_C.

$$V_c = I_c R_C$$

Since $I_c \cong I_e$, the ac collector voltage is

$$V_c \cong I_e R_C$$

V_b can be considered the transistor ac input voltage where $V_b = V_s - I_b R_B$. V_c can be considered the transistor ac output voltage. Since *voltage gain* is defined as the ratio of the output voltage to the input voltage, the ratio of V_c to V_b is the ac voltage gain, A_v, of the transistor.

$$A_v = \frac{V_c}{V_b}$$

Substituting $I_e R_C$ for V_c and $I_e r'_e$ for V_b yields

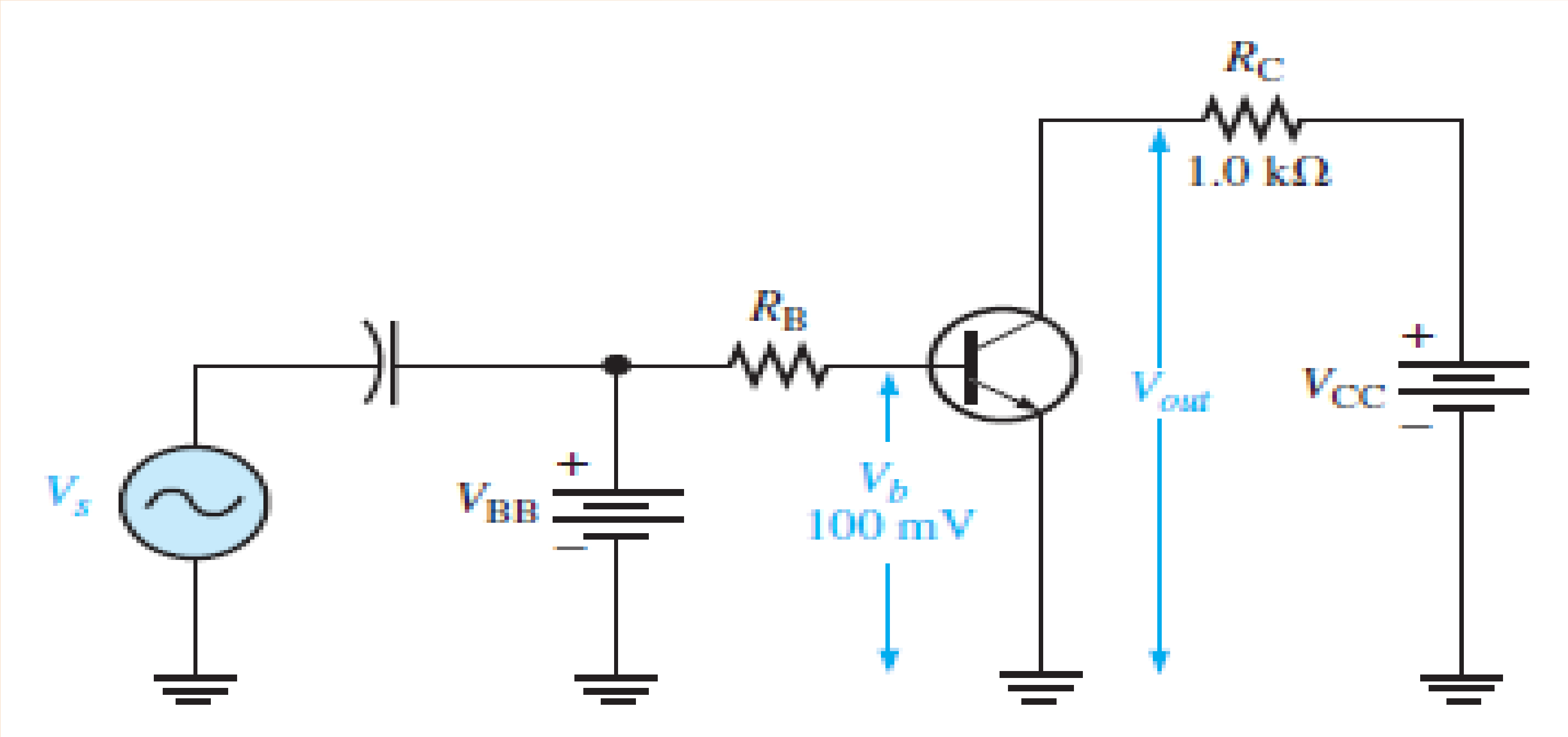
$$A_v = \frac{V_c}{V_b} \cong \frac{I_e R_C}{I_e r'_e}$$

The I_e terms cancel; therefore,

$$A_v \cong \frac{R_C}{r'_e}$$

Equation 4–7 shows that the transistor in Figure 4–21 provides amplification in the form of voltage gain, which is dependent on the values of R_C and r'_e.

Determine the voltage gain and the ac output voltage in Figure 4–22 if $r'_e = 50\ \Omega$.

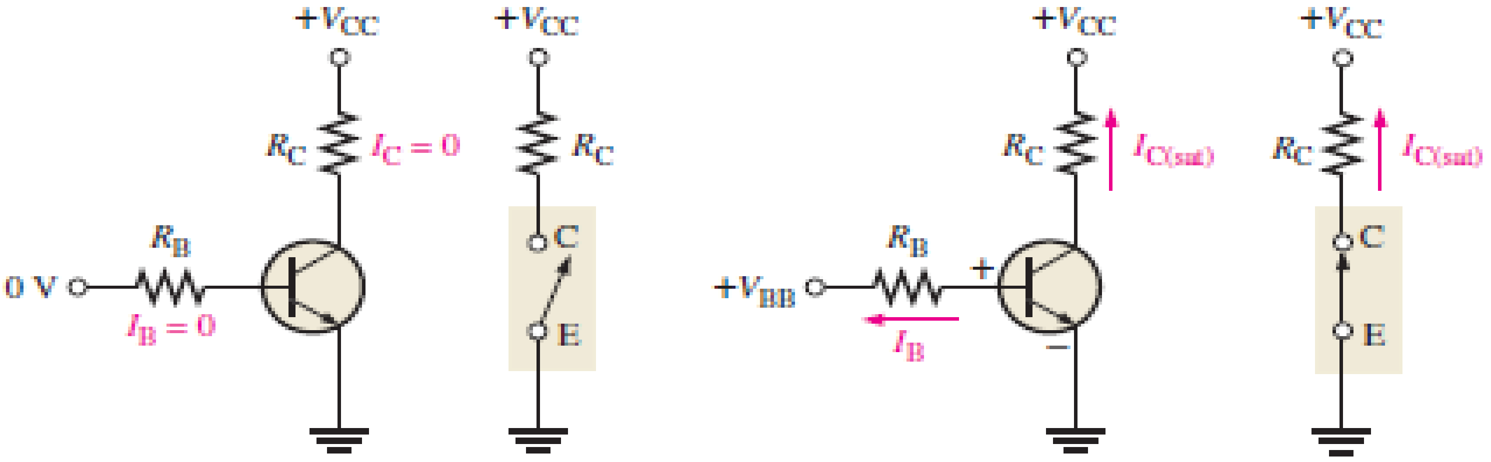


The voltage gain is

$$A_v \cong \frac{R_C}{r'_e} = \frac{1.0\ \text{k}\Omega}{50\ \Omega} = 20$$

Therefore, the ac output voltage is

$$V_{out} = A_v V_b = (20)(100\ \text{mV}) = 2\ \text{V rms}$$



(a) Cutoff — open switch (b) Saturation — closed switch

Conditions in Cutoff As mentioned before, a transistor is in the cutoff region when the base-emitter junction is not forward-biased. Neglecting leakage current, all of the currents are zero, and V_{CE} is equal to V_{CC}.

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

Conditions in Saturation As you have learned, 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

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

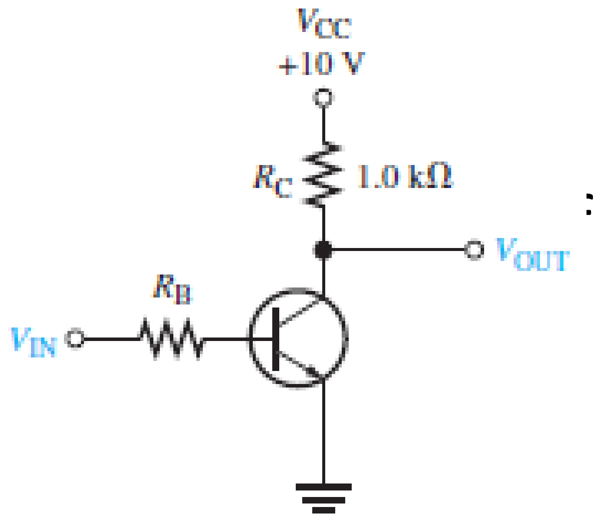
Since $V_{CE(sat)}$ is very small compared to V_{CC}, it can usually be neglected.

The minimum value of base current needed to produce saturation is

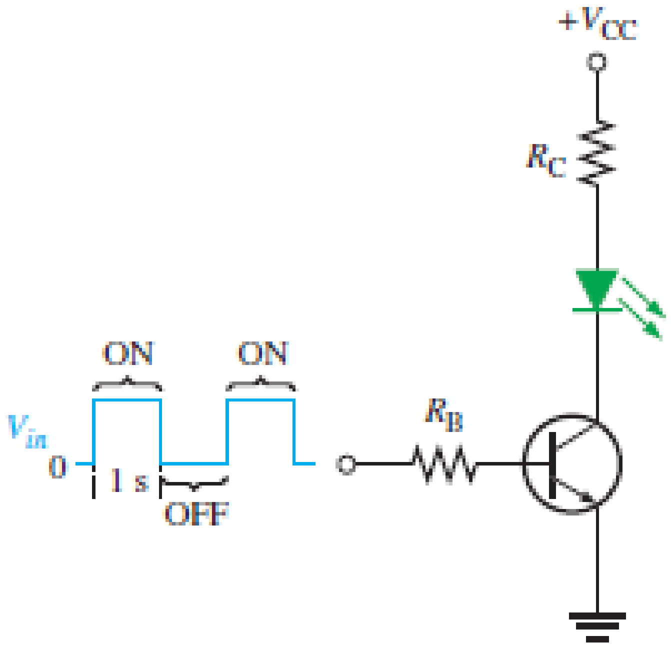
$$I_{B(min)} = \frac{I_{C(sat)}}{\beta_{DC}}$$

Example

- **(a)** For the transistor circuit in Figure 4–24, what V?
- **(b)** What minimum value of *I*B is required to satu bDC is 200? Neglect *V*CE(sat).
- **(c)** Calculate the maximum value of *R*B when *V*IN



Application of Transistor as a Switch



CHECKUP

SECTION 4–4 CHECKUP

1. What is amplification?
2. How is voltage gain defined?
3. Name two factors that determine the voltage gain of an amplifier.
4. What is the voltage gain of a transistor amplifier that has an output of 5 V rms and an input of 250 mV rms?
5. A transistor connected as in Figure 4–22 has an $r'_e = 20\ \Omega$. If R_C is 1200 Ω, what is the voltage gain?

Check Up Questions

- 1. When a transistor is used as a switch, in what two states is it operated?
- 2. When is the collector current maximum?
- 3. When is the collector current approximately zero?
- 4. Under what condition is V_{CE} V_{CC}?
- 5. When is V_{CE} minimum?