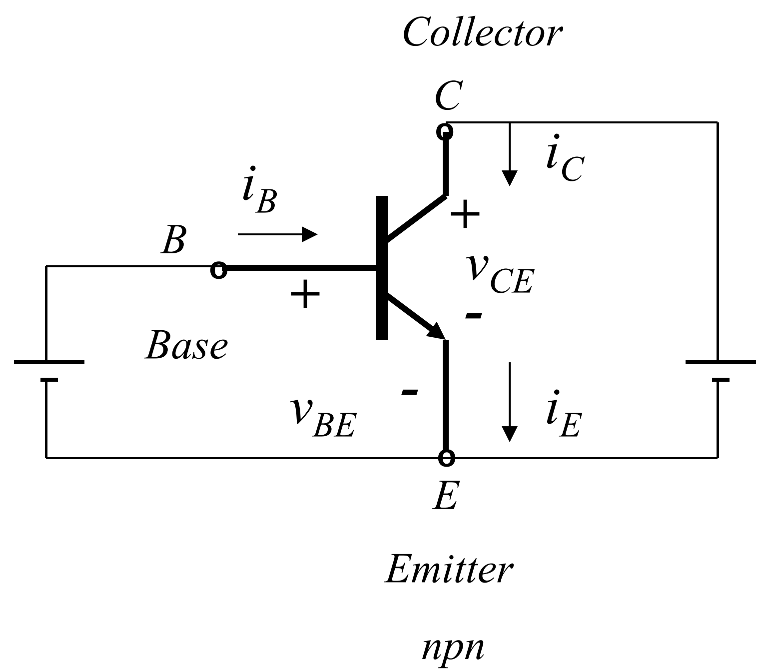
# *Transistors*

# Lesson #8

# Chapter 4

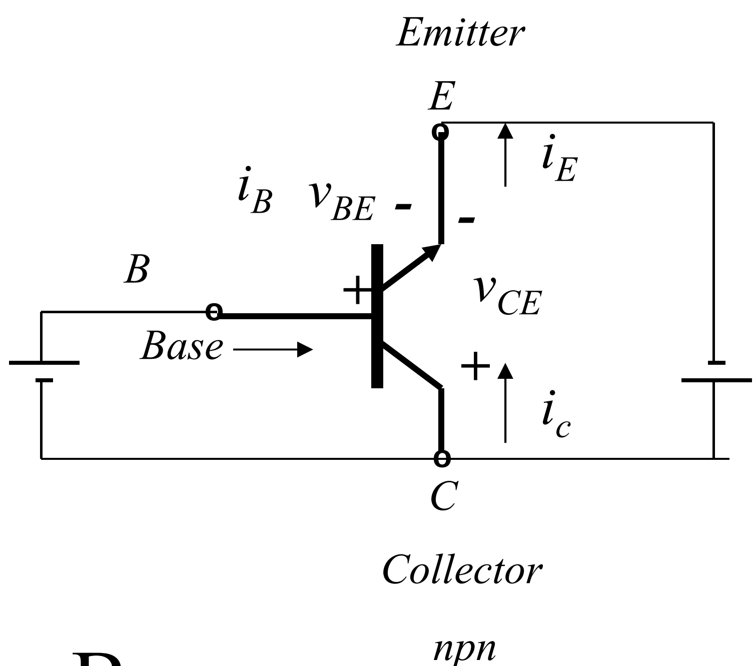
# *Configurations of the BJT*

- Common Emitter and Emitter Follower



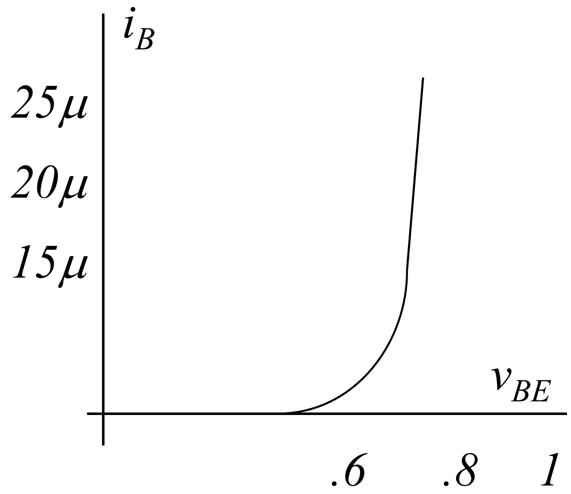
# *Configurations of the BJT*

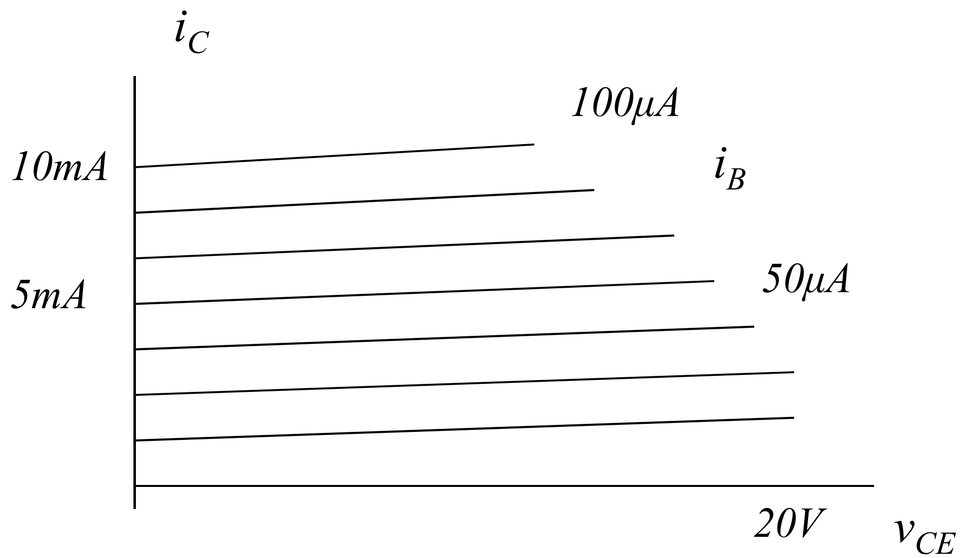
- Common Collector




- Common Base

# *Characteristics of the BJT*
# *npn*
# *Common Emitter Configuration*




**Base-emitter junction looks like a forward biased diode**

**Collector-emitter is a family of curves which are a function of base current**

# *BJT Equations*

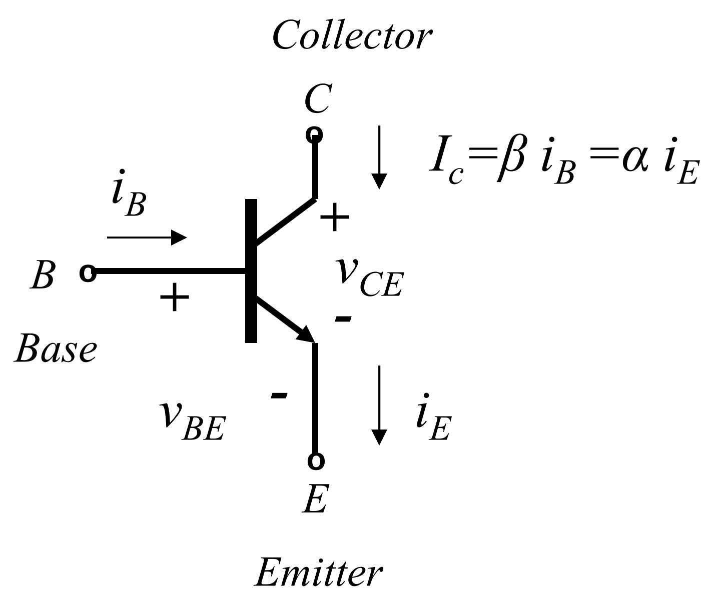
$$i_E = i_C + i_B$$

$$\alpha = \frac{i_C}{i_E}$$

$$i_B = (1-\alpha)i_E$$

$$i_C = \frac{\alpha}{1-\alpha} i_B = \beta i_B$$

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

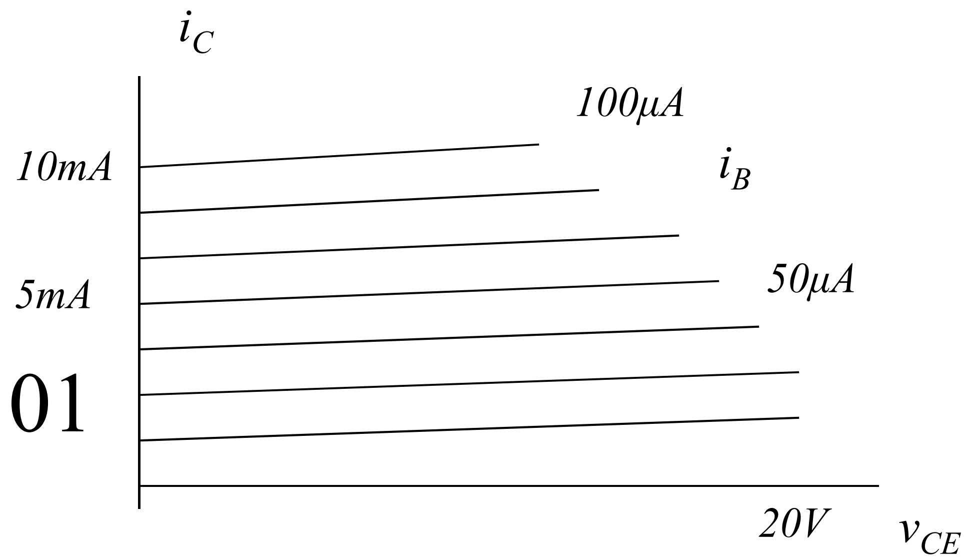



**Since *α* is less than unity then *β* will be greater than unity and there is current gain from base to collector.**

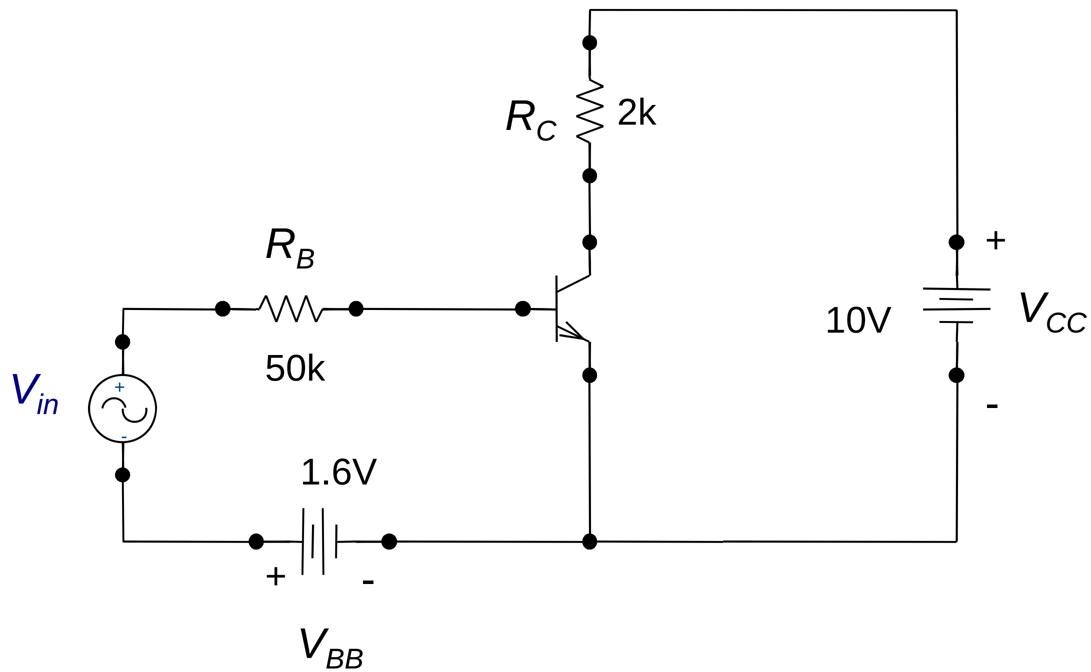
# *Example*

- Calculate the values of $\beta$ and $\alpha$ from the transistor shown in the previous graphs.

$$\beta = i_c / i_b$$
$$= 5m/50\mu = 100$$
$$\alpha = \beta /(\beta+1) = 100/101$$
$$=.99$$



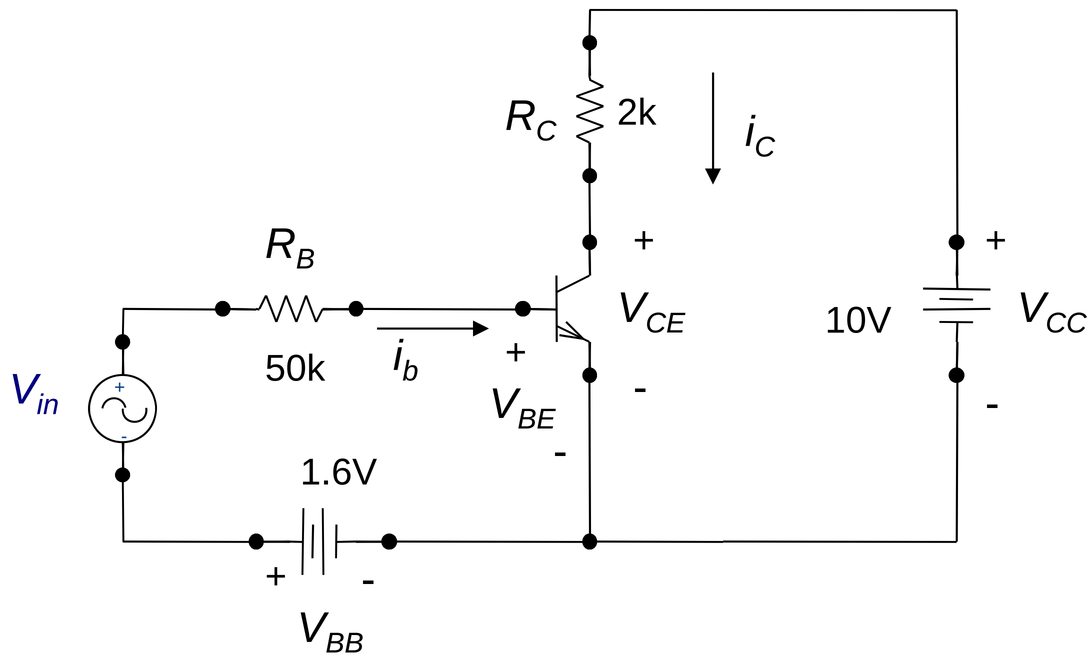
# *BJT Analysis*




**Here is a common emitter BJT amplifier:**

**What are the steps?**

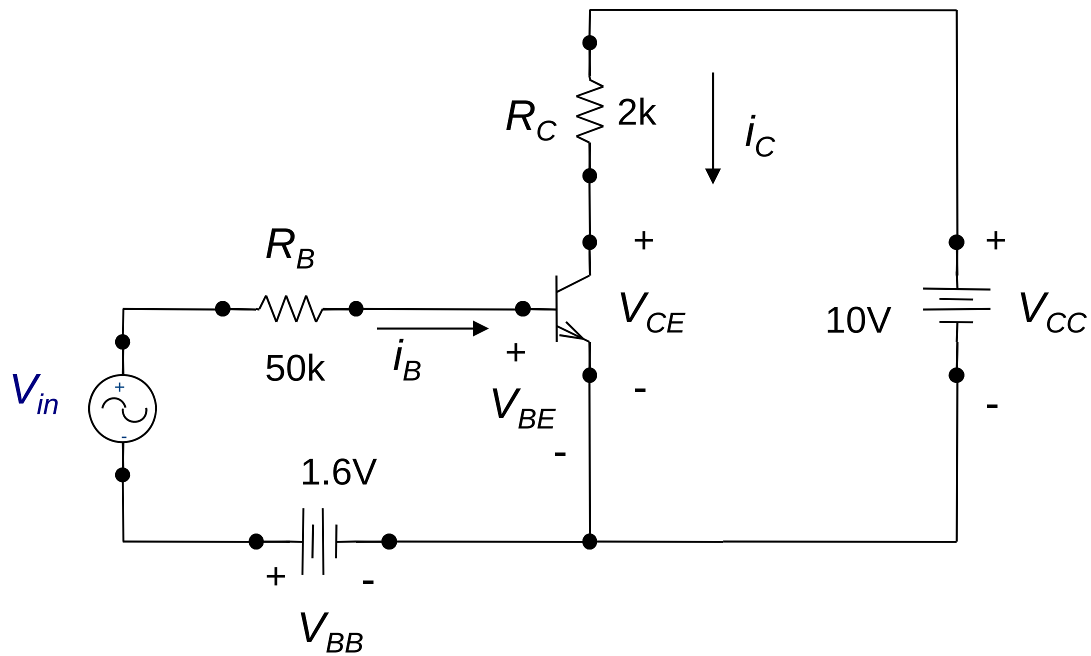
# *BJT Analysis – Inputs and Outputs*




**We would want to know the collector current ($i_c$), collector-emitter voltage ($V_{CE}$), and the voltage across $R_C$.**

**To get this we need to fine the base current ($i_b$) and the base-emitter voltage ($V_{BE}$).**

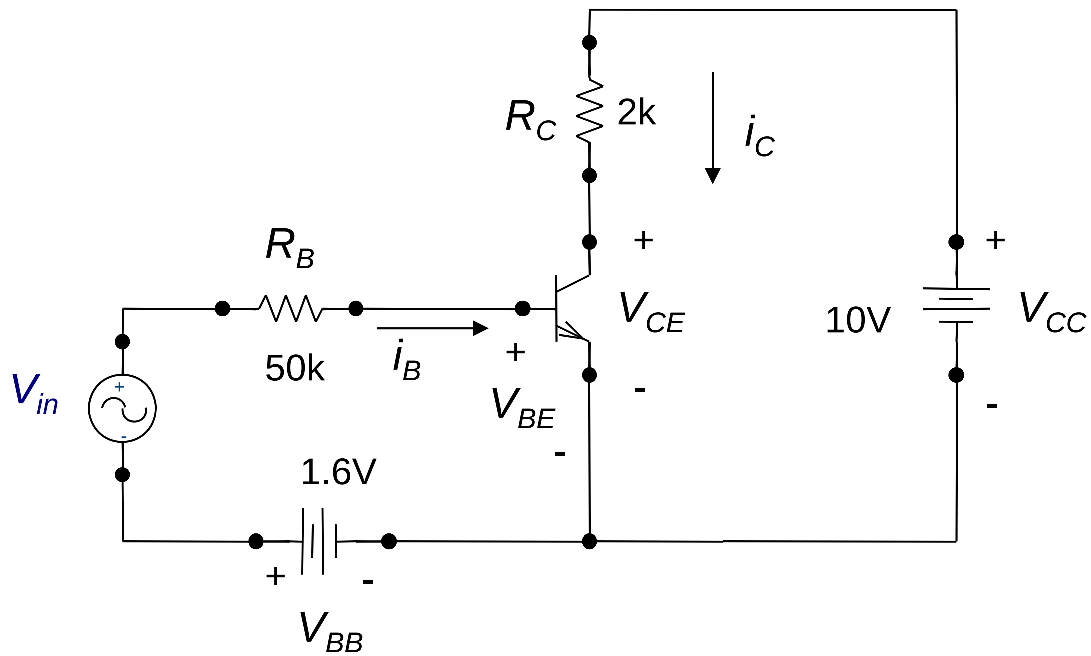
# *BJT Analysis – Input Equation*




**To start, let's write KVL around the base circuit.**

$$V_{in}(t) + V_{BB} = i_B(t)R_B + V_{BE}(t)$$

# *BJT Analysis – Output Equations*




**Likewise, we can write KVL around the collector circuit.**

$$V_{CC} = i_C(t)R_C + V_{CE}(t)$$

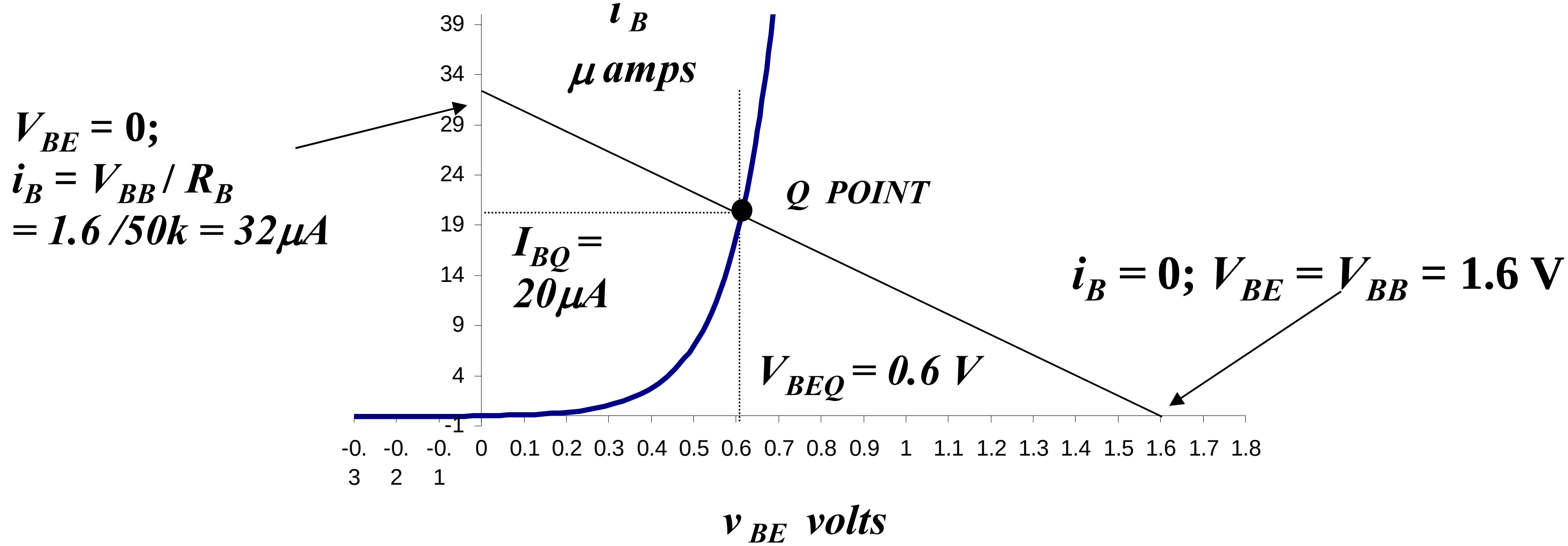
# *BJT Analysis*
# *Use Superposition: DC & AC sources*

- Note that both equations are written so as to calculate the transistor parameters (i.e., base current, base-emitter voltage, collector current, and the collector-emitter voltage) for both the DC signal and the AC signal sources.
- Let's use superposition, calculate the parameters for each separately, and add up the results
  - First, the DC analysis to calculate the DC Q-point
    - Short Circuit any AC voltage sources
    - Open Circuit any AC current sources
  - Next, the AC analysis to calculate gains of the amplifier.
    - Depends on how we perform AC analysis
      - Graphical Method
      - Equivalent circuit method for small AC signals

# *BJT DC Analysis*

- Using KVL for the input and output circuits and the transistor characteristics, the following steps apply:
  1. Draw the load lines on the transistor characteristics
  2. For the input characteristics determine the Q point for the input circuit from the intersection of the load line and the characteristic curve (Note that some transistor do not need an input characteristic curve.)
  3. From the output characteristics, find the intersection of the load line and characteristic curve determined from the Q point found in step 2, determine the Q point for the output circuit.

# *BJT DC Analysis*
# *Base-Emitter Circuit Q point*




**First let's set $V_{in}(t)$ =0 to get the Q-point for the BJT.**

**We start with the base circuit.**

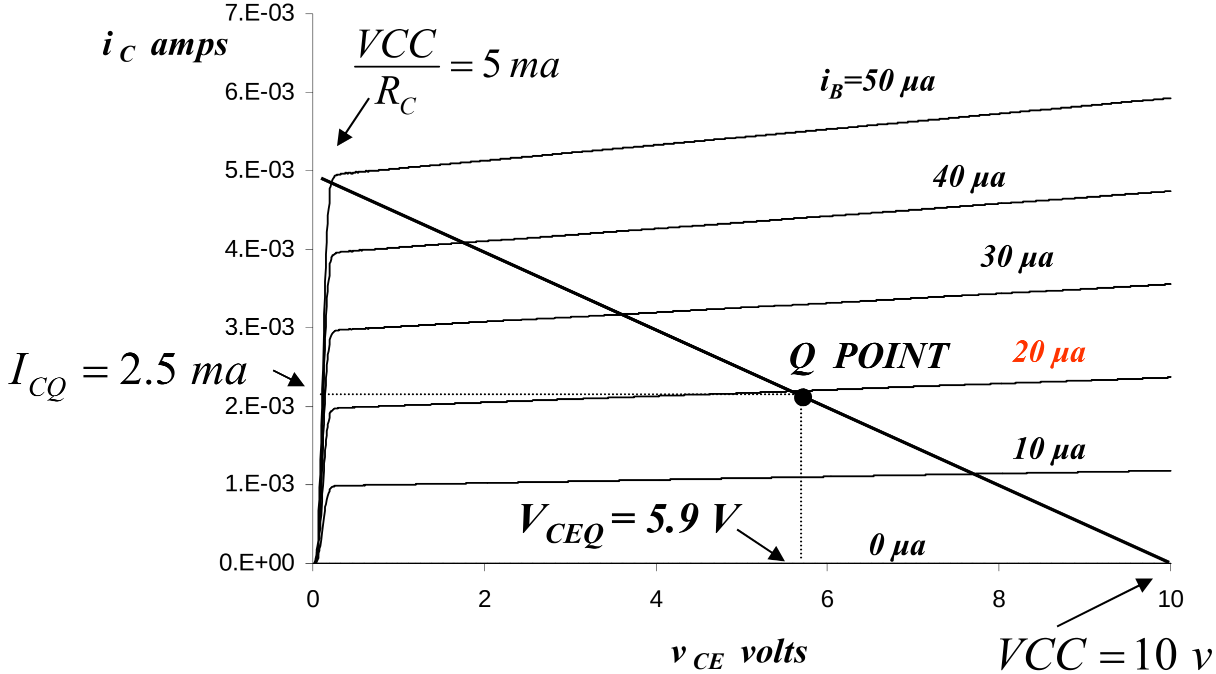
$$V_{BB} = i_B R_B + V_{BE}$$

**And the intercepts occur at $i_B = 0; V_{BE} = V_{BB} = 1.6$ V**

**and at $V_{BE} = 0; i_B = V_{BB} / R_B = 1.6/50k = 32\mu A$**

**The Load Line intersects the Base-emitter characteristics at $V_{BEQ} = 0.6\ V$ and $I_{BQ} = 20\mu A$**

# *BJT DC Analysis*
# *Collector-Emitter Circuit Q point*




**Now that we have the Q-point for the base circuit, let's proceed to the collector circuit.**

$$V_{CC} = i_C R_C + V_{CE}$$

**The intercepts occur at $i_C = 0$; $V_{CE} = V_{CC} = 10$ V; and at $V_{CE} = 0$; $i_C = V_{CC} / R_C = 10/2k = 5mA$**

**The Load Line intersects the Collector-emitter characteristic, $i_B$=20mA at $V_{CEQ} = 5.9\ V$ and $I_{CQ} = 2.5mA$**

$$\beta = 2.5m/20m = 125$$

# *BJT DC Analysis Summary*

- Calculating the Q-point for BJT is the first step in analyzing the circuit
- To summarize:
  - We ignored the AC (variable) source
    - Short circuit the voltage sources
    - Open Circuit the current sources
  - We applied KVL to the base-emitter circuit and using load line analysis on the base-emitter characteristics, we obtained the base current Q-point
  - We then applied KVL to the collector-emitter circuit and using load line analysis on the collector-emitter characteristics, we obtained the collector current and voltage Q-point
- This process is also called DC Analysis
- We now proceed to perform AC Analysis

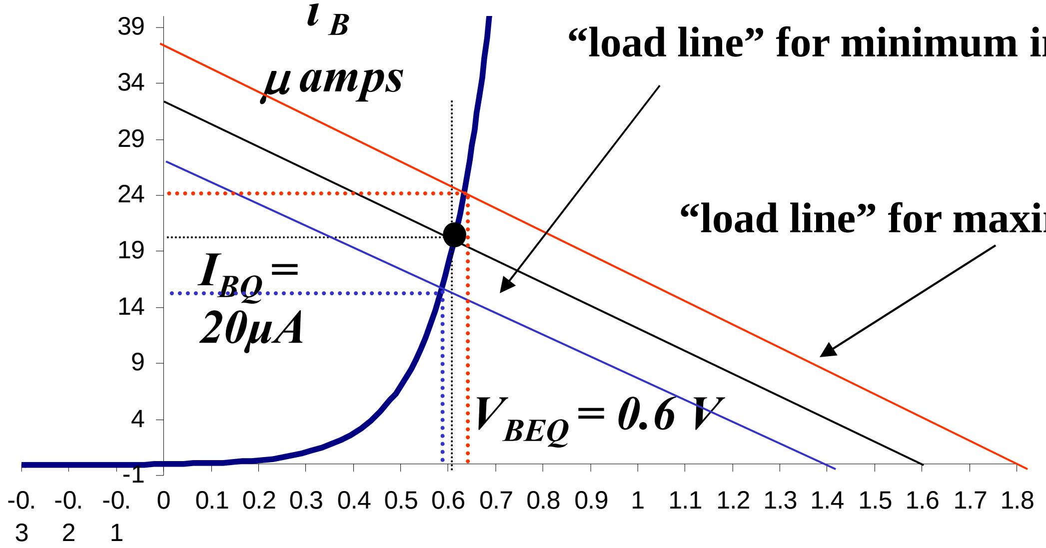
# *BJT AC Analysis*

- How do we handle the variable source $V_{in}(t)$ ?
- When the variations of $V_{in}(t)$ are large we will use the base-emitter and collector-emitter characteristics using a similar graphical technique as we did for obtaining the Q-point
- When the variations of $V_{in}(t)$ are small we will shortly use a linear approach using the BJT small signal equivalent circuit.

# *BJT AC Analysis*

- Let's assume that $V_{in}(t) = 0.2\ \sin(\omega t)$.
- Then the voltage sources at the base vary from a maximum of 1.6 + .2 = 1.8 V to a minimum of 1.6 -.2 = 1.4 V
- We can then draw two "load lines" corresponding the maximum and minimum values of the input sources
- The current intercepts then become for the:
  - Maximum value: 1.8 / 50k = 36 μa
  - Minimum value: 1.4 / 50k = 28 μa

# BJT AC Analysis Base-Emitter Circuit




**From this graph, we find:**

**At Maximum Input Voltage: $V_{BE}$ = 0.63 V, $i_B$ = 24$\mu$a**

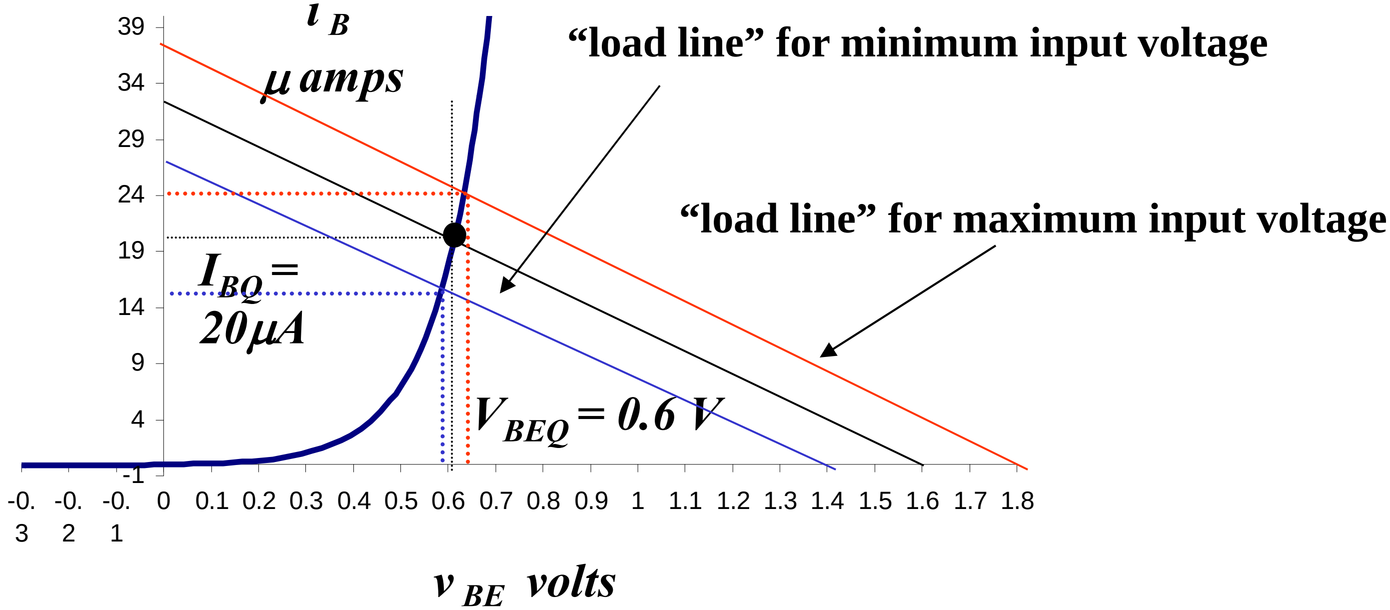
**At Minimum Input Voltage: $V_{BE}$ = 0.59 V, $i_B$ = 15$\mu$a**

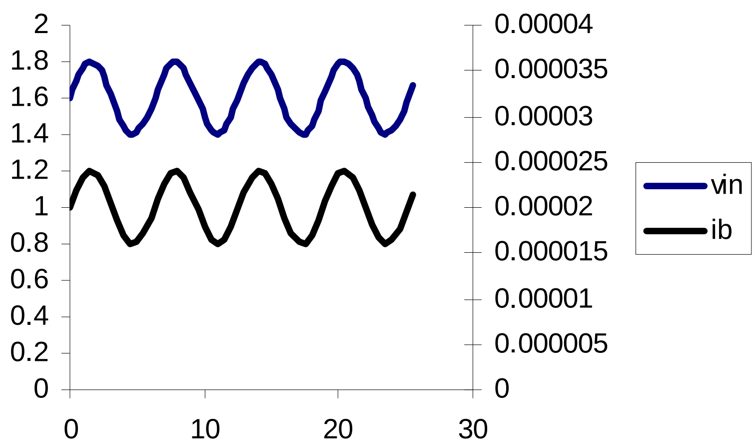
**Recall: At Q-point: $V_{BE}$ = 0.6 V, $i_B$ = 20$\mu$a**

**Note the asymmetry around the Q-point of the Max and Min Values for the base current and voltage which is due to the non-linearity of the base-emitter characteristics**

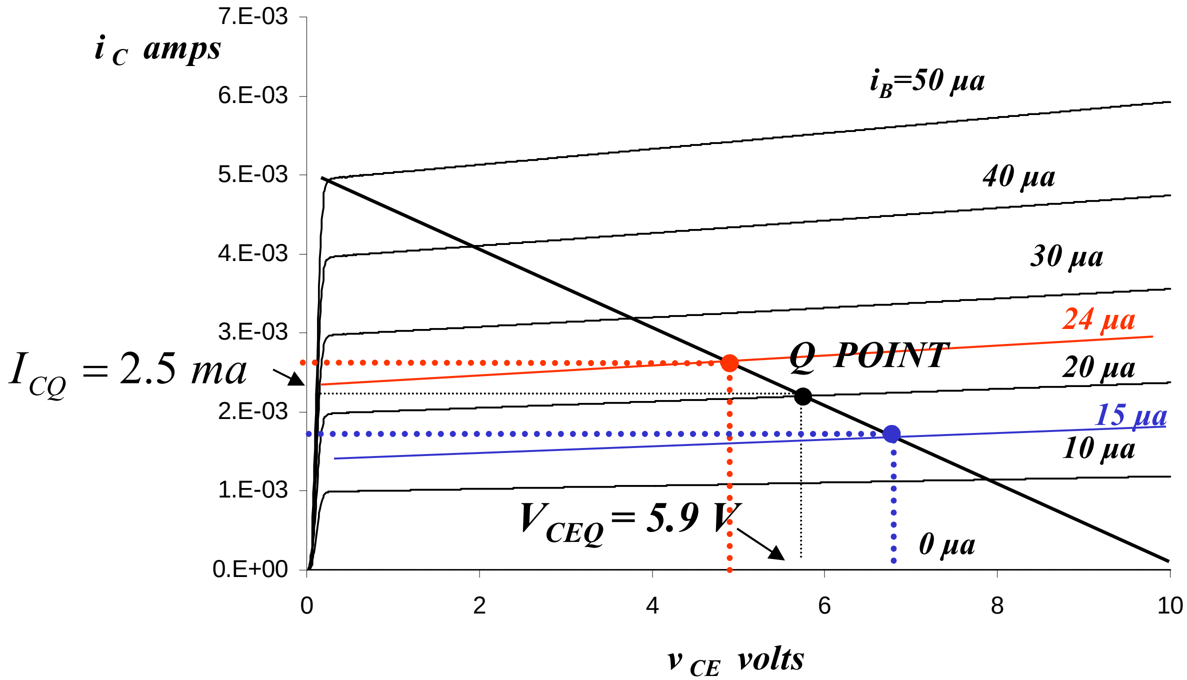
$\Delta i_{Bmax}$=24-20=4$\mu$a; $\Delta i_{Bmin}$=20-15=5$\mu$a

# BJT AC Analysis Base-Emitter Circuit



# BJT Characteristics-Collector Circuit




**Using these maximum and minimum values for the base current on the collect circuit load line, we find:**

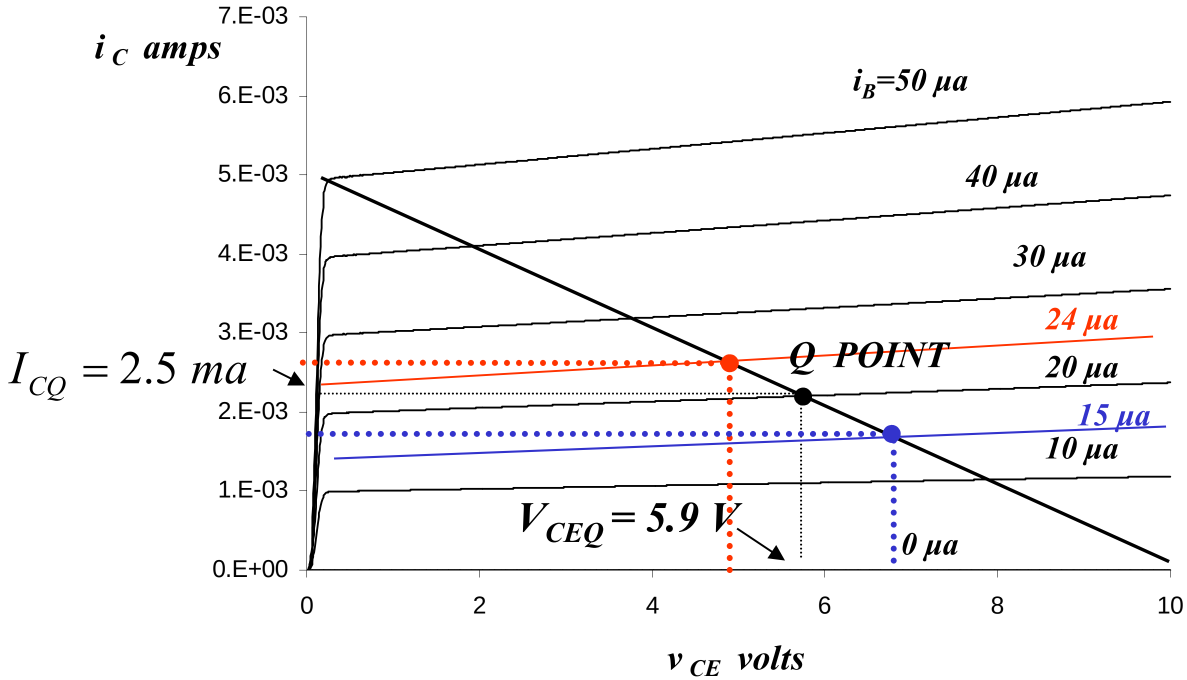
**At Maximum Input Voltage: $V_{CE}$ = 5 V, $i_C$ = 2.7ma**

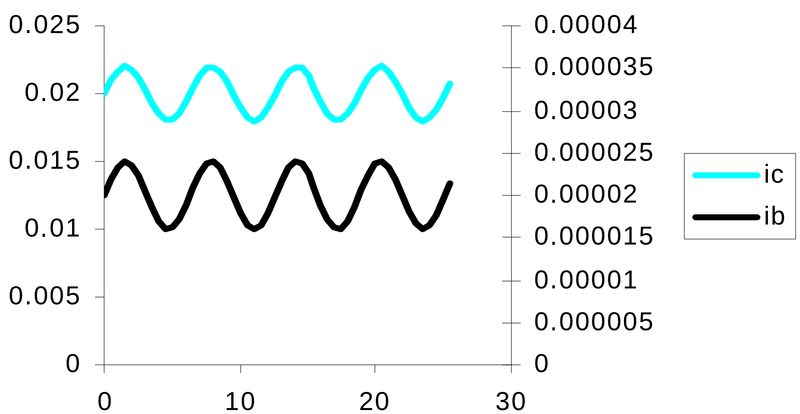
**At Minimum Input Voltage: $V_{CE}$ = 7 V, $i_C$ = 1.9ma**

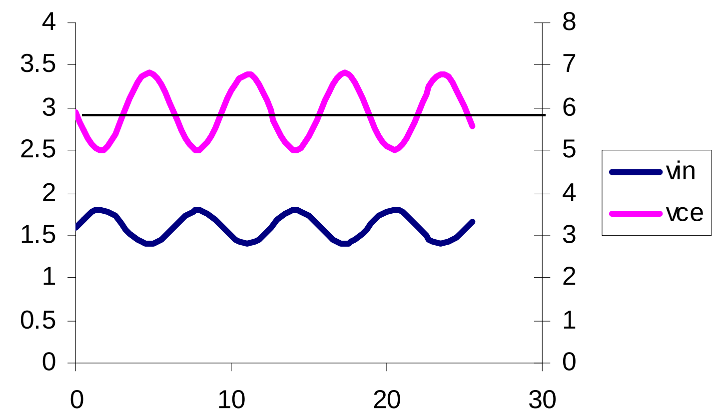
**Recall: At Q-point: $V_{CE}$ = 5.9 V, $i_C$ = 2.5ma**

**Note that in addition to the asymmetry around the Q-point there is an inversion between the input voltage and the collector to emitter voltage**

# *BJT Characteristics-Collector Circuit*



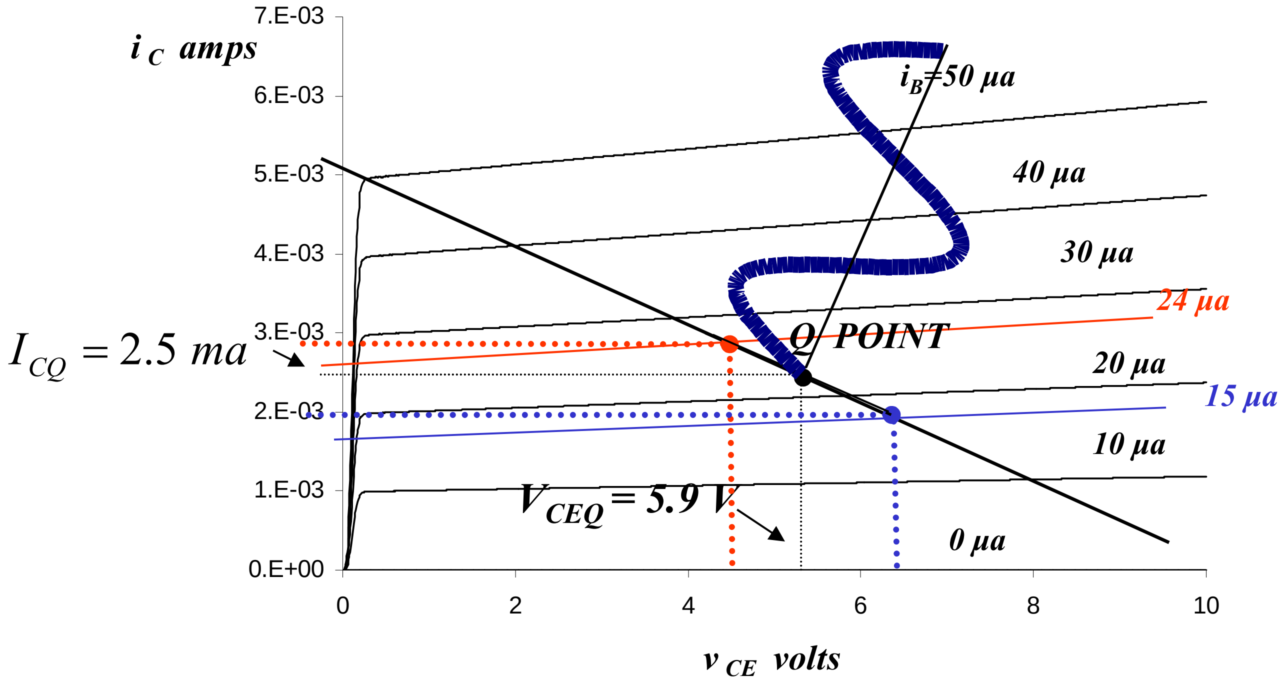
# *BJT AC Analysis*
# *Amplifier Gains*

- From the values calculated from the base and collector circuits we can calculate the amplifier gains:
  - $\beta = 125$
  - Current gain $= \Delta i_c / \Delta i_b = (2.7 - 1.9)\, m / (24 - 15)\, \mu$
    $= 0.8/9 \times 10^3 = 88.9$
  - Voltage gain $= V_o / V_i = \Delta V_{CE} / \Delta V_{BE}$
    $= (5 - 7) / (.63 - .59) = -2/0.04 = -50$
  - Voltage gain $= V_o / V_s = \Delta V_{CE} / \Delta V_{in}$
    $= (5 - 7) / .4 = -2 / .4 = -5$

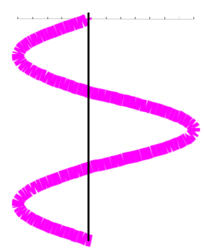
# *BJT AC Analysis Summary*

- Once we complete DC analysis, we analyze the circuit from an AC point of view.
- AC analysis can be performed via a graphical processes
  – Find the maximum and minimum values of the input parameters (e.g., base current for a BJT)
  – Use the transistor characteristics to calculate the output parameters (e.g., collector current for a BJT).
- Calculate the gains for the amplifier

# *BJT Characteristics - Distortion*




**Note that even though the input (base current) is symmetrical about its Q-point, the output voltage is uneven.**



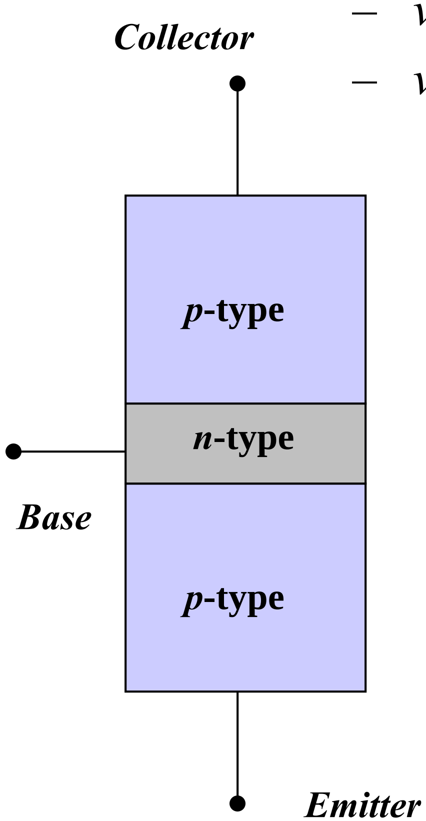
**This is due to the non-linear spacing of the characteristic curves and leads to signal distortion**

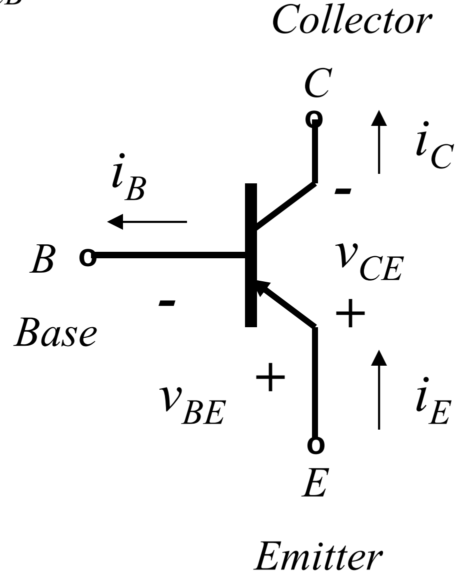
# *The pnp Transistor*

- Basically, the *pnp* transistor is similar to the *npn* except the parameters have the opposite sign.
  - The collector and base currents flows out of the transistor; while the emitter current flows into the transistor
  - The base-emitter and collector-emitter voltages are negative
- Otherwise the analysis is identical to the *npn*

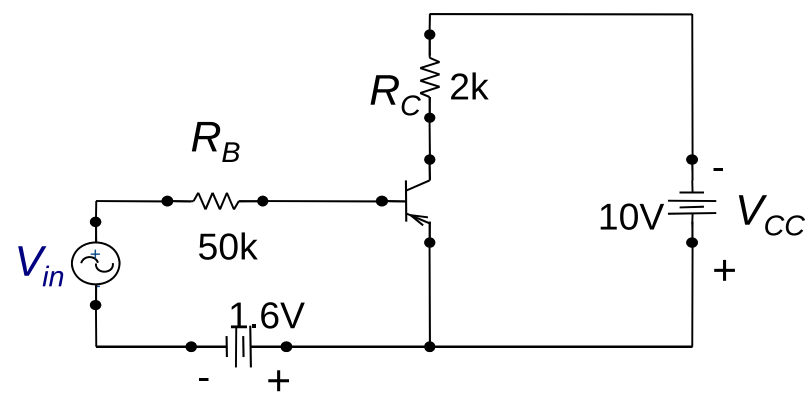
# *PNP Bipolar Junction Transistors*

- Two junctions
  - Collector-Base and Emitter-Base
- Biasing
  - $v_{BE}$ Forward Biased
  - $v_{CB}$ Reverse Biased




*pnp*



## *Homework*

- Probs. 4.4, 4.5, 4.8, 4.10, 4.14, 4.15, 4.19, 4.20, 4.21, 4.22,