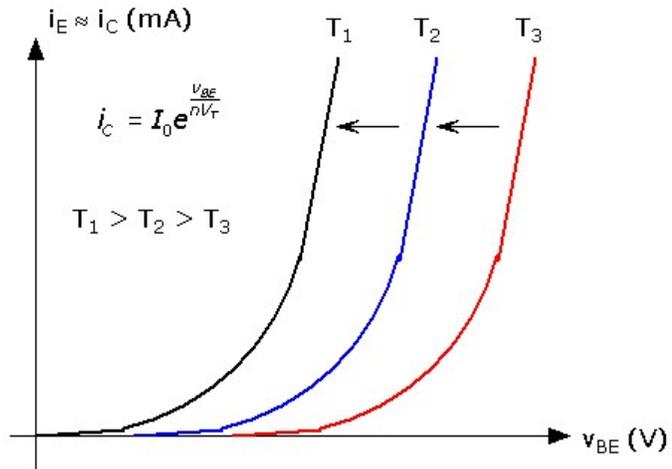


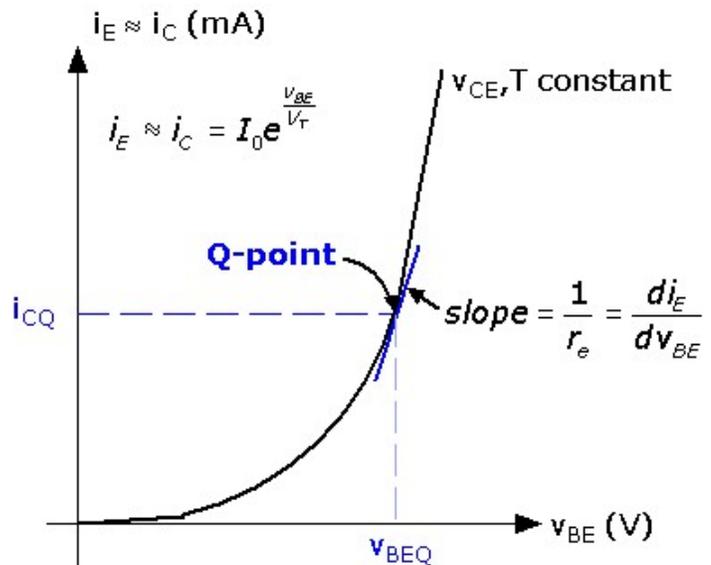
Section C4: BJT Characteristic Curves

It is sometimes helpful to view the characteristic curves of the transistor in graphical form. This is very similar to the graphical approach used with diodes, but now we have three possible points where something could be happening (base, emitter, collector). We're still going to concentrate on normal active mode operation here and talk about the two pn junctions in the BJT separately.

The **forward biased junction** in the BJT follows the same curve as we saw for the forward biased diode. This set of characteristics obeys the same exponential relationship as the diode, has the same turn on voltage (0.7V for Si and 0.2V for Ge at 25°C), and exhibits the same temperature dependence (-2.0 mV/°C for Si and -2.5 mV/°C for Ge).



The general form of the base-emitter characteristics are presented to the right and shows the behavior of the emitter current (i_E) as a function of the voltage between base and emitter (v_{BE}), at a given temperature, when the voltage between the collector and emitter (v_{CE}) is held constant (note that this is a modification of Figure 4.7a in your text). The inverse of the slope of the curve about a specified operating point (Q-point) is the **dynamic resistance** (also referred to as the **emitter resistance**) of the transistor – which is just r_d from our diode days.



By making the following assumptions:

- the collector current is approximately equal to the emitter current (i.e., $\beta \gg 1$),

- the nonideality factor n is equal to one, and
- room temperature operation;

the emitter resistance may be calculated by *(bear with me please, I don't like to have massive quantities of derivations, but I had to go back and prove this to myself again so I decided to write it down):*

$$\frac{1}{r_e} = \frac{di_E}{dv_{BE}} = \frac{I_0}{V_T} e^{\frac{v_{BE}}{V_T}} = \frac{i_E}{V_T}.$$

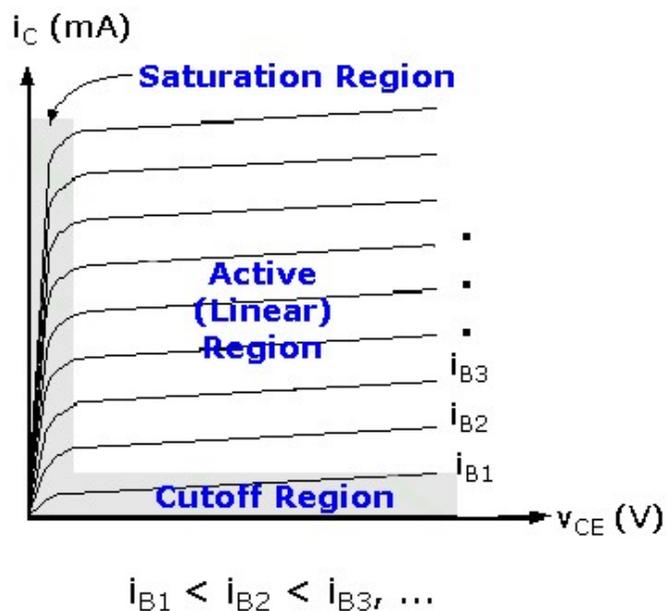
Substituting $V_T=26\text{mV}$ at room temperature, i_E (i_C) at the Q-point, and solving for r_e (r_d), we get

$$r_d = r_e = \frac{26\text{mV}}{I_{CQ}}. \quad \text{(Equation 4.19)}$$

Note that, if the temperature changes, V_T will no longer be 26mV.

The actual i_C - v_{BE} characteristics behave identically to the curve above, but have a scaling factor of α (I_0 in the equation above becomes αI_0). However, since usually $\alpha \approx 1$, this is generally disregarded. Similarly, the i_B - v_{BE} characteristics have the same appearance, but with a scaled current of I_0/β . Finally, the curves for a **pnp transistor** will look the same, but the polarity on the base-emitter voltage will be switched (v_{BE} becomes $-v_{BE}=v_{EB}$).

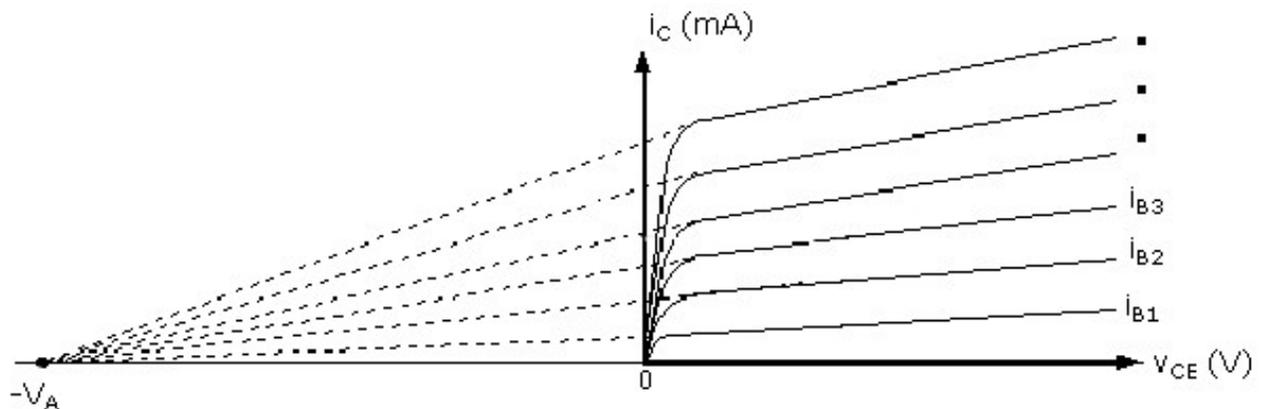
The second set of characteristics we're going to be interested in is illustrated to the right as a family of i_C - v_{CE} curves (note that this is a modified combination of Figures 4.7(b) and 4.8 of your text). Each of the curves in this family illustrates the dependence of the collector current (i_C) on the collector emitter voltage (v_{CE}) when the base current (i_B) has a constant value (i.e., v_{BE} is held constant).



There are three distinct

regions of these characteristics that are of importance:

- As the magnitude of v_{CE} decreases, there comes a point when the collector voltage becomes less than the base voltage. When this happens, the transistor leaves the linear region of operation and enters the **saturation region**, which is highly nonlinear and is not usable for amplification.
- The **cutoff region** of operation occurs for base currents near zero. In the cutoff region, the collector current approaches zero in a nonlinear manner and is also avoided for amplification applications.
- The linear region is where we want to be for amplification. In the **linear** (or **active**) **region** the curves would ideally be horizontal straight lines, indicating that the collector behaves as a constant current source independent of the collector voltage, as illustrated in the hybrid- π model ($i_C = \beta i_B$). Practically, these curves have a slight positive slope. If these curves are extended to the left along the $-v_{CE}$ axis, they will converge to a point known as the **Early voltage**, shown as $-V_A$ in the figure below (a modified version of Figure 4.10 in your text).

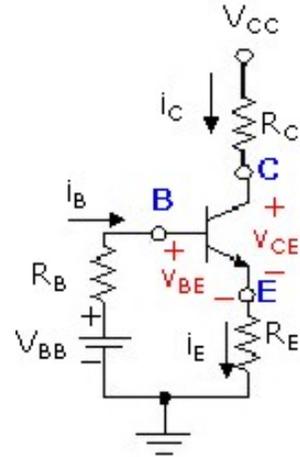


The Early Voltage (note that $V_A > 0$), is a figure of merit that is dependent on the particular transistor and defines how close to ideal the ideal behaves (for an ideal curve, the Early Voltage would be infinity). The magnitude of the Early voltage typically falls in the range of 50 – 100V for practical devices.

Using the value of V_A , we can define the **output resistance** of the transistor (r_o in the hybrid- π model or h_{oe}^{-1} in the h-parameter model) for a specific value of collector current. Although r_o is strictly defined as the inverse of the partial derivative of i_C with respect to v_{CE} at a constant value of i_B (**yikes!**), the same result is achieved by taking the inverse of the slope of the curve and realizing that $V_A \gg V_{CE}$:

$$r_o = \frac{V_A}{I_C} . \quad \text{(Equation 4.21)}$$

The characteristic curves for a transistor provide a powerful tool in the design and analysis of transistor circuits. Figure 4.9, slightly modified and presented to the right, illustrates a simple transistor circuit. By using KVL around the collector to emitter loop (remember that the other side of V_{CC} is tied to ground), by using the approximation that $i_C \approx i_E$, and by restricting ourselves to the dc values of circuit parameters,

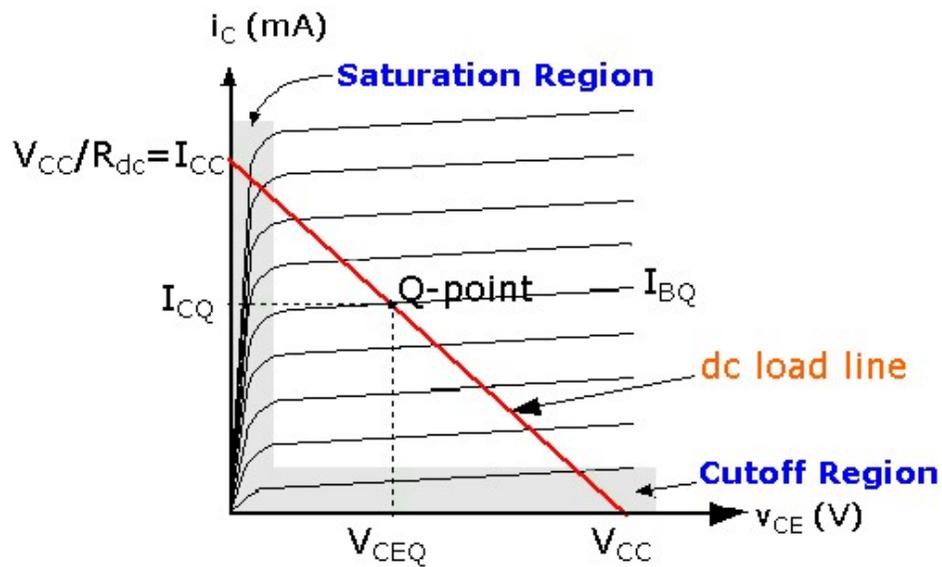


$$V_{CC} = I_C(R_C + R_E) + V_{CE} . \quad \text{(Equation 4.20)}$$

By defining the two extremes in this equation; i.e., when

- $I_C = 0, V_{CE} = V_{CC}$ and
- $V_{CE} = 0, I_C = V_{CC}/(R_E + R_C)$;

the endpoints of the **dc load line** are defined as illustrated in the figure below (Figure 4.8-ish of your text). The dc load line is determined by the resistors R_C and R_E in the circuit, where the quantity $R_E + R_C$ has been given the designation R_{dc} , or dc circuit resistance, in the calculation of I_{CC} . The intersection of the dc load line with a specific i_B curve defines the quiescent point (**Q-point**) for circuit operation in terms of I_{BQ}, I_{CQ} and V_{CEQ} . We're just talking about dc right now, but we'll see that the Q-point represents the **dc bias**, or starting point, for the transistor circuit and that the variations about this point carry the information (ac signals) in the circuit. Also, the R_{dc} designation will make more sense... we'll see that under ac operation we may have a different equivalent circuit resistance that, big surprise, we're going to call R_{ac} !



We've now got enough information in terms of models and characteristics to actually do something with the BJT! In the remainder of this section of our studies, we're going to discuss the general characteristics of single stage BJT amplifiers in terms of configurations, biasing, and power considerations. Hang on!