**First-Order Common-Emitter (CE) Characteristics**

![Graph showing Ic-Vbe characteristic](image)

**Figure 4.18** Ic-Vbe characteristic for an NPN transistor.

**Observations:**

* For \( V_{BE} \leq 0.6 \text{V} \), \( I_c \approx 0 \) therefore in cut-off region.

* As \( V_{BE} \) starts increasing a couple of mV above \( \approx 0.65 \text{V} \), \( I_c \) starts increasing exponentially.

* In other words, as the base current (\( I_B \)) increases, the base-emitter voltage (\( V_{BE} \)) almost remains constant \( \approx 0.7 \text{V} \).
**Figure 4.26** $I_C-V_{CE}$ characteristics for different $I_B$ for a NPN transistor.

* The transistor is in saturation for $V_{CE} \leq 0.2V$.

* The transistor is in cut-off region for $V_{BE} \leq 0.6V$ or $I_B \approx 0$.

* The transistor enters forward active region when $V_{CE} \geq 0.2V$ & $I_B > 0$ ($V_{BE} \approx 0.7V$).

* In this particular graph, the transistor is assumed to have no early effect i.e. $I_C$ does not depend on $V_{CE}$. 
**EARLY VOLTAGE**: 

**Figure 4.3**: Bipolar Transistor Output Characteristic showing the Early Voltage, $V_A$.

\[ I_c = I_s \left( 1 + \frac{V_{CE}}{V_A} \right) \left( \frac{V_{BE}}{V_T} - 1 \right) \]

* For every real transistor, there is a dependency on $V_{CE}$ as shown in the graph.
* It so happens that if you extrapolate the collector current ($I_c$), for all values of $V_{BE}$ ($I_B$), they converge at a point on the $V_{CE}$ axis which is known as the Early Voltage ($V_A$).

* This increase in $I_c$ due to increase in $V_{CE}$ can be accounted for with the correction term \( \left( 1 + \frac{V_{CE}}{V_A} \right) \).
LARGE-SIGNAL DC CIRCUIT MODELS:

In the analysis and design of BJT amplifier design, we often consider the dc-operating point separately from the analysis of the signal. This is done because the BJT is a non-linear device, i.e., the small-signal parameters depend on the operating point. In order to do a dc-operating point analysis, we need to develop some simple models for it.

(a) Large signal model for a npn transistor.

(b) Large-signal model for a pnp transistor.

Figure 4.4: Large signal models for BJT.