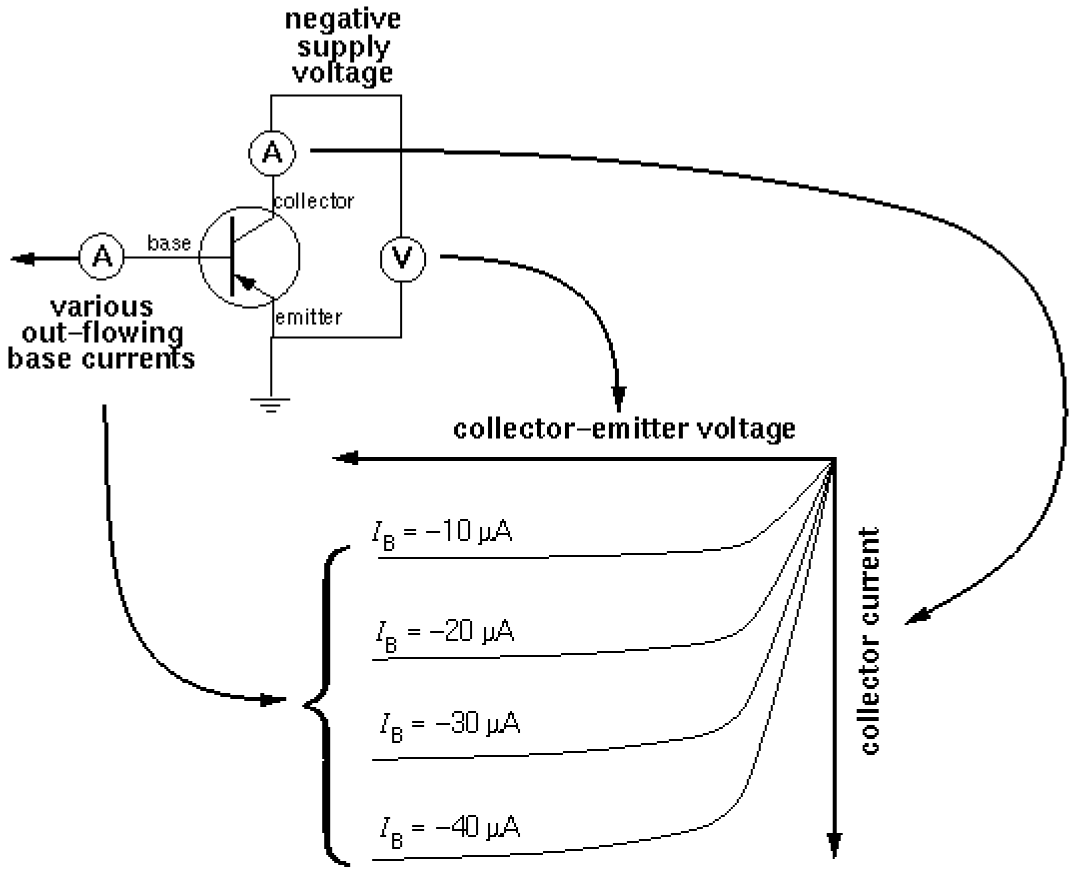
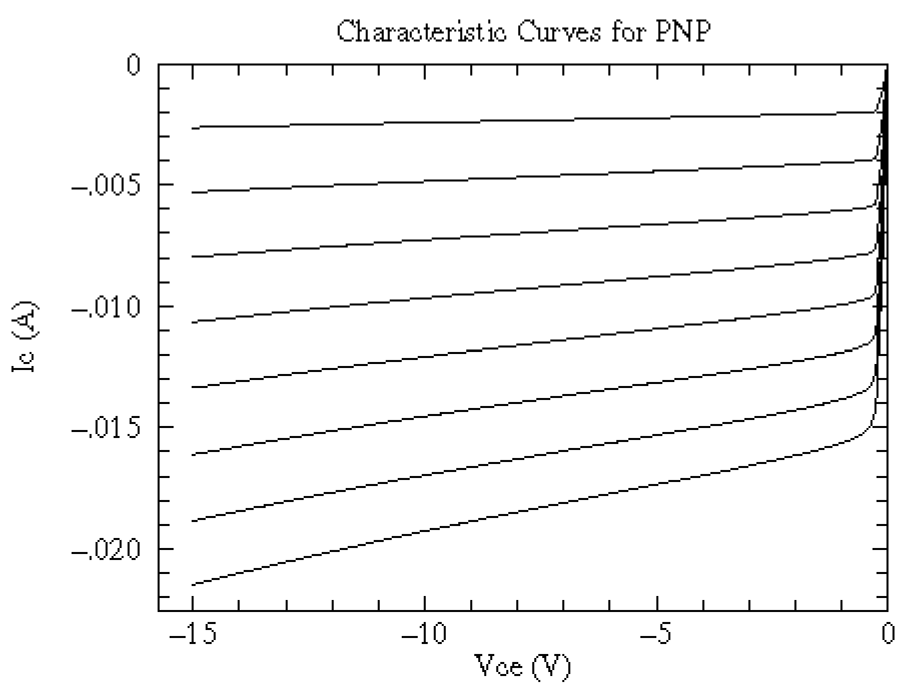
PNP Characteristic Curves



Measured Characteristic Curves for 2N3906



for I_B = -10 µA, -20 µA, -30 µA, ... , -80 µA big data file, smaller data file, postscript plot, pdf plot

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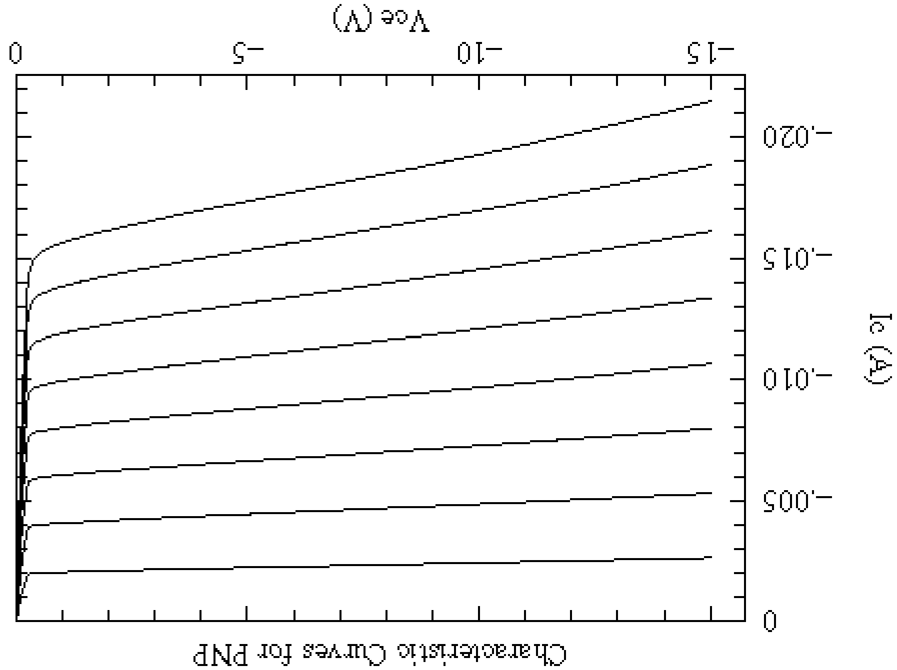
Note that you can make the PNP characteristic curves look like the common NPN curves just by rotating the PNP plot by 180°. In swapping N for P so NPN $\longrightarrow$ PNP, we've reversed the direction of current flows (so currents are negative -- flowing out of the collector and base in a PNP) and the required supply voltage becomes negative for a PNP.

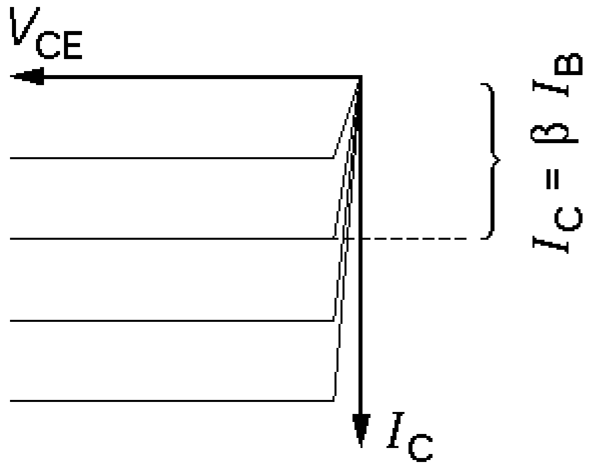


That is to say that the PNP is designed for negative power supplies and out-flowing (negative) base and collector currents -- the opposite of NPNs.

The behavior of a PNP bipolar transistor is largely controlled by the current flowing *out of* the base. For the usual collector-emitter voltage drops (i.e., the active region: negative voltages from a fraction of a volt down to some breakdown voltage) the collector current (I_C) is nearly independent of the collector-emitter voltage (V_{CE}), and instead depends on the base current (I_B). (This is unusual behavior: usually more voltage produces to more current, but here the current only increases slightly with increasingly negative V_{CE}.) The current gain, i.e., the ratio of the collector current to the base current, is often denoted by β or h_{FE}:

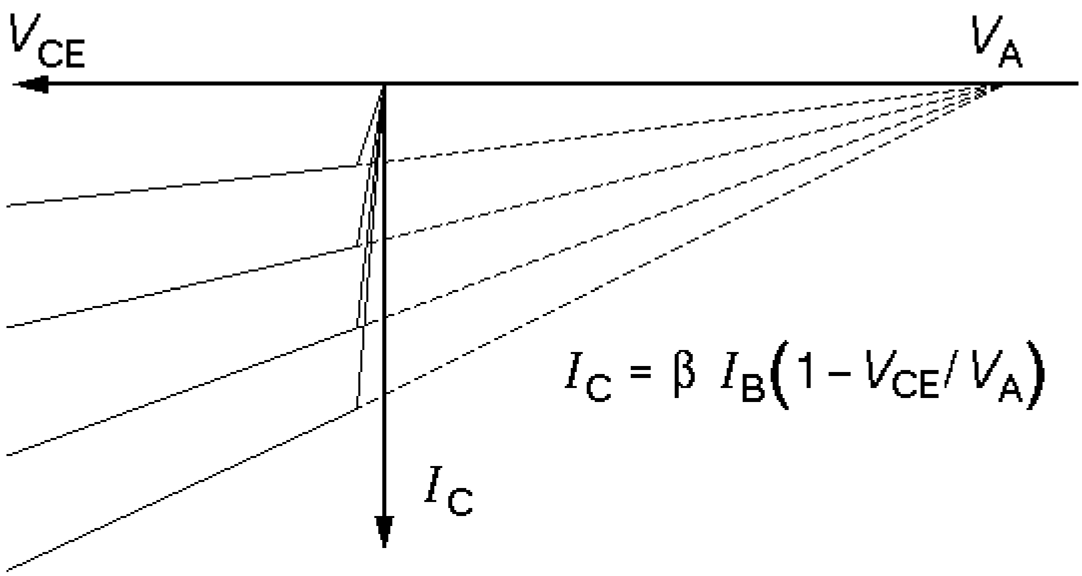
$$\beta = h_{FE} = I_C/I_B$$

Thus in the simplest approximation the characteristic curves of a PNP are a set of flat, evenly spaced, lines:



Each (flat) curve shows that I_C doesn't change with changing V_{CE}. The different levels show that I_C does depend on I_B.

A slightly more complicated approximation takes into account the sloping characteristic curves through a constant Early Voltage (V_A). Here we assume that the characteristic curves all have a common x-axis intercept at the large positive voltage V_A. (The dashed curves are far from the active region and in no way represent the actual behavior of the transistor for positive V_{CE}. In fact, the PNP transistor is not designed to be operated with positive V_{CE}.)



(For the above measured 2N3906, the Early voltage ranges from 40 to 50 V. That is the extrapolated characteristic curves do not intersect at *a* point.)

The actual relationship between the collector current (I_C) and the controlling base current (I_B) and collector-emitter voltage drop (V_{CE}) is some complicated function which we can denote:

$I_C(I_B,V_{CE})$

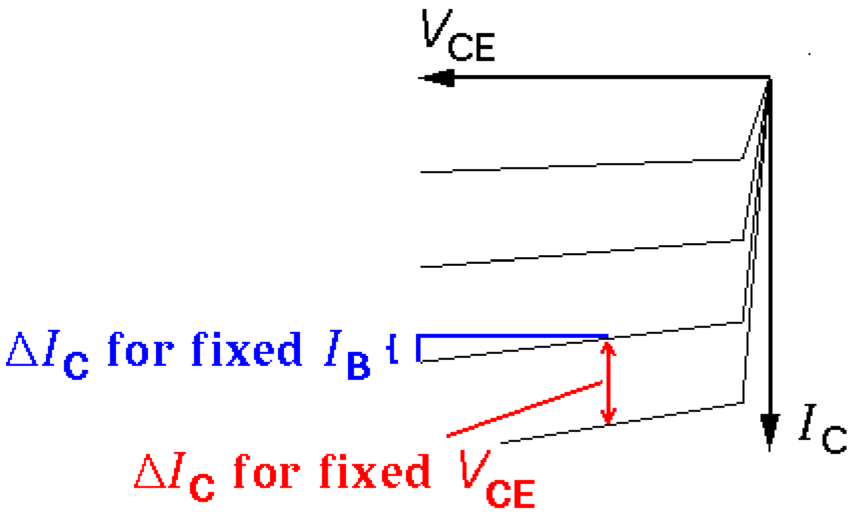
Like any function we can approximate it near a particular point using just the first terms of a Taylors expansion:

$$I_C(I_B, V_{CE}) \quad :$$

$$\Delta I_C \;=\; h_{fe}\Delta I_B + h_{oe}\Delta V_{CE}$$

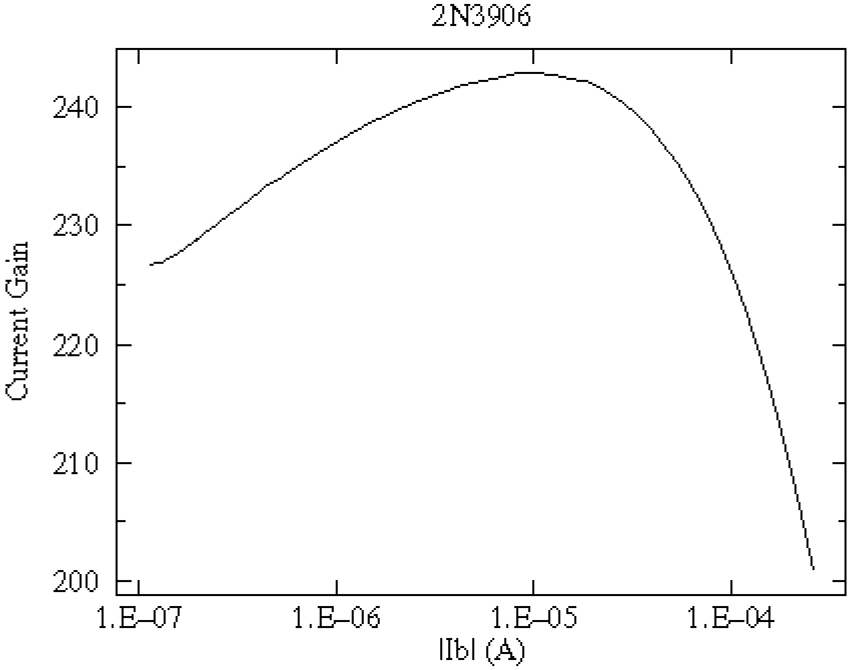
$$h_{fe} \;=\; \left.\frac{\partial I_C}{\partial I_B}\right|_{V_{CE}=\text{const}} \approx \left.\frac{\Delta I_C}{\Delta I_B}\right|_{V_{CE}=\text{const}}$$

$$h_{oe} \;=\; \left.\frac{\partial I_C}{\partial V_{CE}}\right|_{I_B=\text{const}} \approx \left.\frac{\Delta I_C}{\Delta V_{CE}}\right|_{I_B=\text{const}}$$



Clearly these *hybrid (h) parameters* are not constants. For example h_{oe} is the slope of a characteristic curve, which is nearly zero for small $|I_B|$ and increases for more negative I_B. (Note that slope on an *I-V* is basically the inverse of the resistance. Thus $1/h_{oe}$ can be described as the output impedance. A typical value for $1/h_{oe}$ would be 100,000 Ω.)

Even the defining parameter -- the current gain β or h_{FE} -- is not exactly constant and depends on I_B. Here is the measured relationship for the above 2N3906:



The characteristic curves focus on the output of the transistor, but we can also consider the behavior of the input. In the active region the base is a forward biased diode, and so V_B would be about -.7 V, typical for a conducting Si diode. Of course in greater detail the relationship between V_B and I_B would be given by the Shockley diode equation:

$$I = I_s \left[\exp\left(\frac{V}{V_T}\right) - 1\right] \approx I_s e^{V/V_T}$$

where I_s is a constant and the thermal voltage V_T is given by:

$$V_T \approx kT/q = \frac{1}{40} V \quad \text{at room temperature}$$

Because of the exponential relationship between base current and base voltage, the slope of this relationship (which could be called the input conductance, or $1/r_B$, or $1/h_{ie}$) can be approximated by:

$$\frac{1}{r_B} = \left.\frac{\partial I_B}{\partial V_B}\right|_{V_{CE}=\text{const}} \approx \frac{\partial}{\partial V_B} I_s e^{V_B/V_T} = \frac{1}{V_T} I_s e^{V_B/V_T} = \frac{I_B}{V_T}$$

$$r_B = h_{ie} \approx \frac{V_T}{I_B} = \frac{25\ \Omega}{I_B}$$

where in the last equation ($25\ \Omega/I_B$) the absolute value of the base current must be entered in mA.

A desirable characteristic of a transistor is that the outputs have little effect on the inputs, but if we look in detail we find that V_{CE} affects V_B. The actual functional relationship giving the base voltage from the base current (I_B) and collector-emitter voltage drop (V_{CE}) is some complicated function which we can denote:

$V_B(I_B,V_{CE})$

Like any function we can again approximate it near a particular point using just the first terms of Taylors expansion:

$$
\begin{aligned}
V_B(I_B, V_{CE}) &: \\
\Delta V_B &= h_{ie}\Delta I_B + h_{re}\Delta V_{CE} \\
\\
h_{ie} &= \left.\frac{\partial V_B}{\partial I_B}\right|_{V_{CE}=\text{const}} \approx \frac{V_T}{|I_B|} \approx \frac{25\ \Omega}{|I_B|} \\
h_{re} &= \left.\frac{\partial V_B}{\partial V_{CE}}\right|_{I_B=\text{const}} \sim 10^{-4}
\end{aligned}
$$

The small value of h_{re} shows that the input is largely unaffected by the output.

The spec sheet reports the following values for the 2N3906:

Characteristics	**Symbol**	**Min**	**Max**	**Unit**
Input Impedance	h_{ie}	2	12	k Ohms
Voltage Feedback Ratio	h_{re}	0.1	10	$\times 10^{-4}$
Small-Signal Current Gain	h_{fe}	100	400	
Output Admittance	h_{oe}	3.0	60	μ mhos