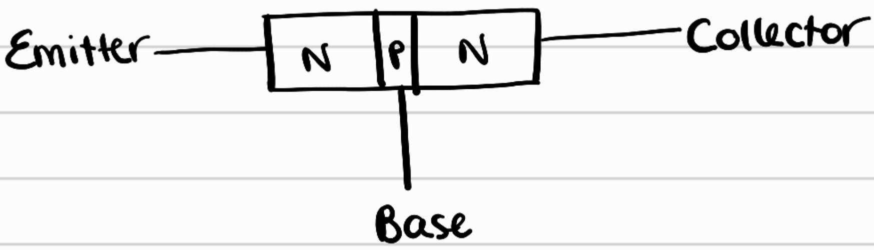
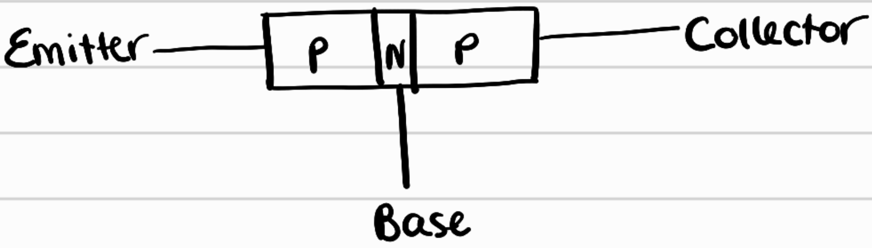
NPN Transistor

* this is a 3 terminal, 3 layer device that can function as an amplifier or electronic switch.

* there are two types of BJTs: NPN and PNP. NPN is the most commonly used one. These two are displayed below:





How do BJTs Work?

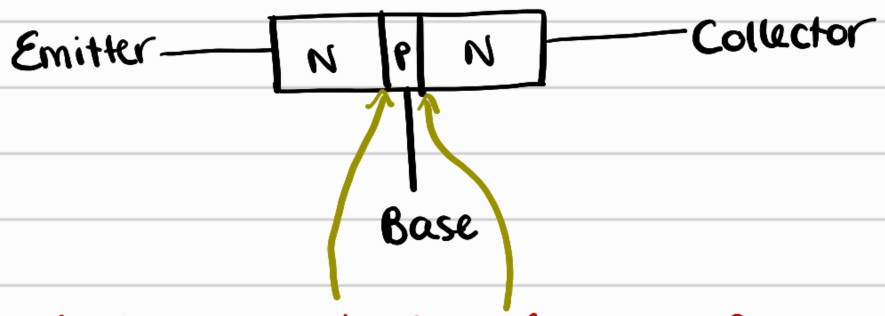
* A BJT consists of 3 separate regions: an emitter, collector and base.

* Each of these regions are doped in some way to allow the BJT to actually work.

    * **N-Type Doping**: impurities like arsenic or phosphorus are injected into a semiconductor to create mobile electrons

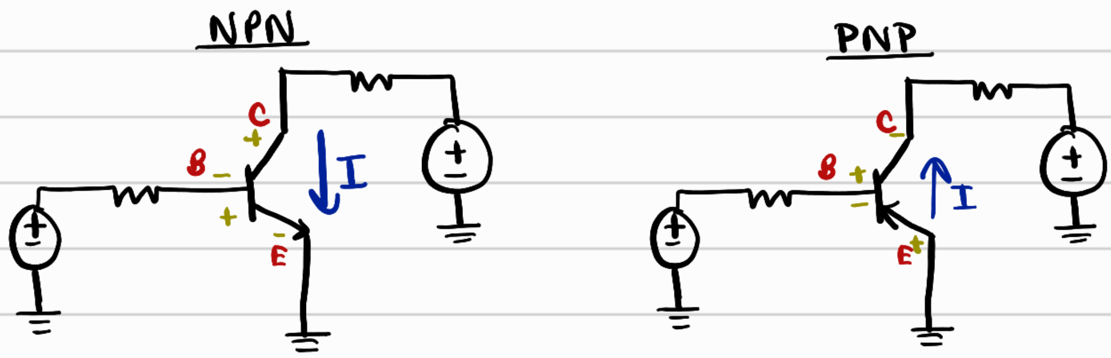
    * **P-Type Doping**: Boron is injected to create holes to accept electrons.

* the emitter has a high doping level, the base has a very low doping level, and the collector has moderate doping.

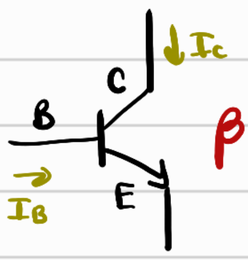


* to allow current to flow from the Collector to the Emitter, the Emitter-Base junction and Base-Collector junction must be biased properly.

* this being said, for npn BJTs the B-C junction must be reversed biased, while the B-E junction is forward biased. Refer to the image below to understand the biasing needed for each junction.



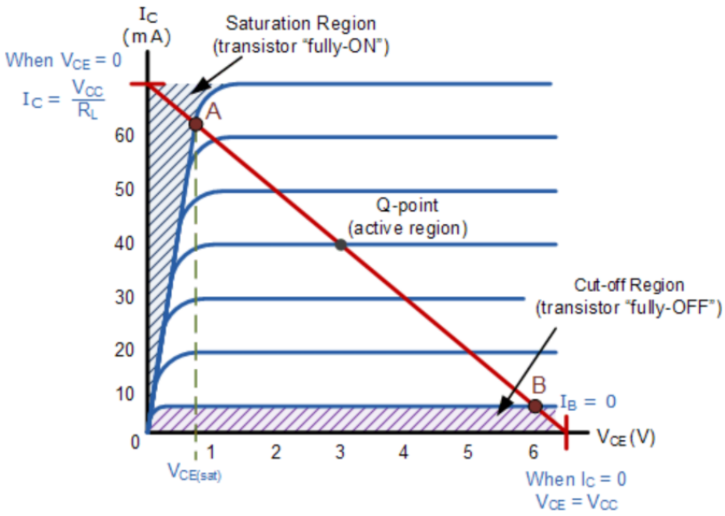
* A current must be supplied to the gate of the BJT b/c it allows for the BJT's conjunctions to be properly biased.



$$\beta = \frac{I_C}{I_B}$$

Note: $I_C = \beta I_B$, so the more current through B, the more current goes through the BJT.

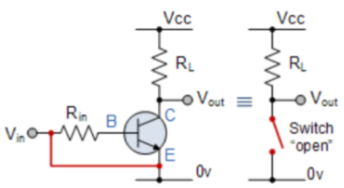
Operating Regions



1. Cut-off Region

Here the operating conditions of the transistor are zero input base current (I_B), zero output collector current (I_C) and maximum collector voltage (V_{CE}) which results in a large depletion layer and no current flowing through the device. Therefore the transistor is switched "Fully-OFF".

Cut-off Characteristics

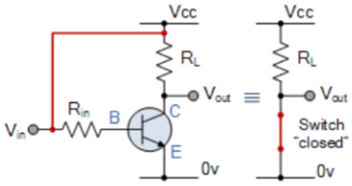


- The input and Base are grounded (0v)
- Base-Emitter voltage V_{BE} < 0.7v
- Base-Emitter junction is reverse biased
- Base-Collector junction is reverse biased
- Transistor is "fully-OFF" (Cut-off region)
- No Collector current flows ($I_C = 0$)
- $V_{OUT} = V_{CE} = V_{CC}$ = "1"
- Transistor operates as an "open switch"

2. Saturation Region

Here the transistor will be biased so that the maximum amount of base current is applied, resulting in maximum collector current resulting in the minimum collector emitter voltage drop which results in the depletion layer being as small as possible and maximum current flowing through the transistor. Therefore the transistor is switched "Fully-ON".

Saturation Characteristics



- The input and Base are connected to V_{CC}
- Base-Emitter voltage V_{BE} > 0.7v
- Base-Emitter junction is forward biased
- Base-Collector junction is forward biased
- Transistor is "fully-ON" (saturation region)
- Max Collector current flows ($I_C = Vcc/R_L$)
- $V_{CE} = 0$ (ideal saturation)
- $V_{OUT} = V_{CE}$ = "0"
- Transistor operates as a "closed switch"

*Note: since we are using the BJT as a switch, we only care about the Cut-off region (off) and saturation regions (on).

* For the npn BJT to turn on, the voltage difference between the base and the emitter must be at least 0.7V. So, $V_{BE} \geq 0.7V$.

* When $V_{BE} = 0.7V$, the BJT is fully on.

We can use this information to calculate what Base resistance is needed to fully saturate (turn on) the BJT. Refer to the image below for this.

Transistor as a Switch Example No1

Using the transistor values from the previous tutorials of: β = 200, Ic = 4mA and Ib = 20uA, find the value of the Base resistor (Rb) required to switch the load fully "ON" when the input terminal voltage exceeds 2.5v.

$$R_B = \frac{V_{in} - V_{BE}}{I_B} = \frac{2.5v - 0.7v}{20x10^{-6}} = 90k\Omega$$