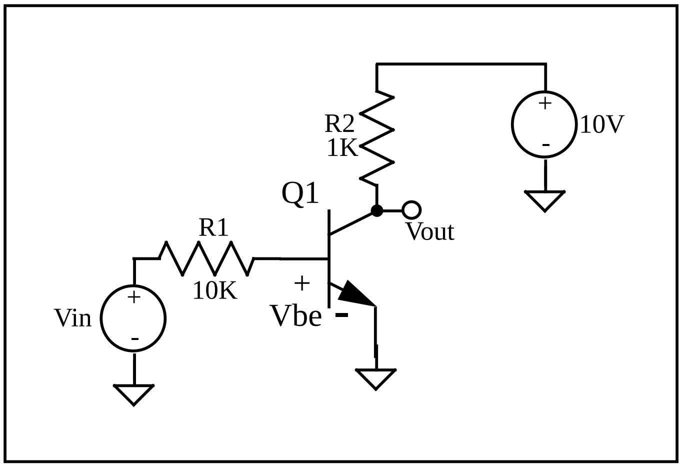
BJT Regions of Operation

To understand the three regions of operation of the transistor, consider the circuit below:



The first region is called “cutoff”. This is the case where the transistor is essentially inactive. In cutoff, the following behavior is noted:

* Ib = 0 (no base current)
* Ic = 0 (no collector current)
* Vbe < 0.7V(emitter-base junction is not forward biased)

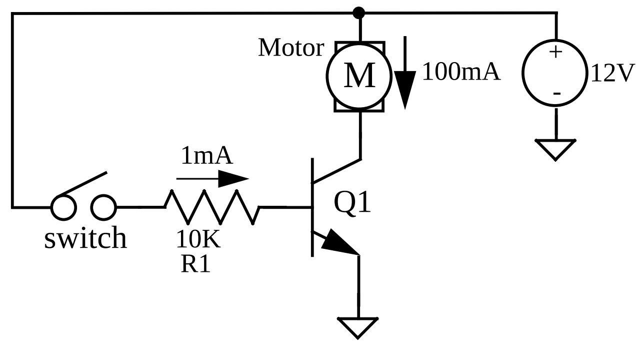
Whenever we observe the terminals of a BJT and see that the emitter-base junction is not at least 0.6-0.7 volts, the transistor is in the cutoff region. In cutoff, the transistor appears as an open circuit between the collector and emitter terminals. In the circuit above, this implies Vout is equal to 10 volts.

The second region is called “saturation”. This is where the base current has increased well beyond the point that the emitter-base junction is forward biased. In fact, the base current has increased beyond the point where it can cause the collector current flow to increase. In saturation, the transistor appears as a near short circuit between the collector and emitter terminals. In the circuit above, this implies Vout is almost 0 volts, but actually about 0.2 volts.

In saturation, the following behavior is noted:

* Vce <= 0.2V. This is known as the saturation voltage, or $Vce_{(sat)}$
* Ib > 0, and Ic > 0
* Vbe >= 0.7V

Using the two states of cutoff and saturation, the transistor may be used as a switch. The collector and emitter form the switch terminals and the base is the switch handle. In other words, the small base current can be made to control a much larger current between the collector and emitter. For example, the circuit above can be modified to control an electric motor. The motor would replace the collector resistor and transistor would act as a switch. See the drawing below.



Transistor Switch - Small Current Controls Large Current

When high current motors are switched on and off, mechanical switch contacts can eventually wear out causing the switch to fail., The BJT can operate as a switch however that has no mechanism that causes it wear out. When it is saturated, the bottom terminal of the motor is essentially connected to ground. When cutoff, the bottom end of the motor is seemingly not connected to anything. Used in this manner, the switch only has to handle 1/100 of the motor current, greatly increasing its life.

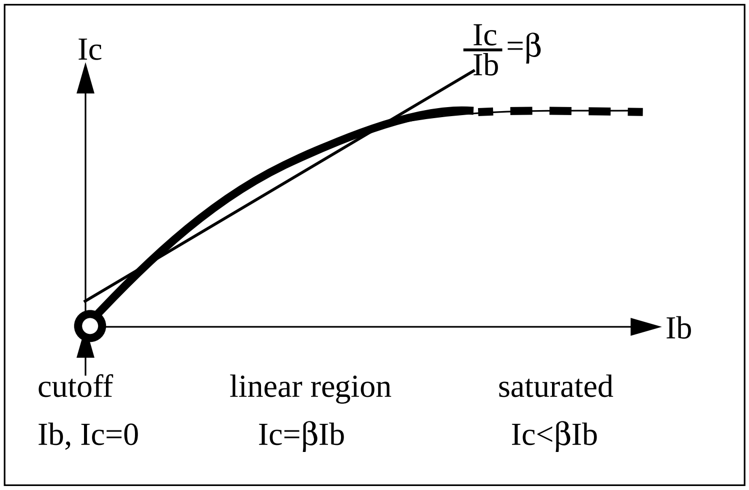
The final region of operation of the BJT is the “forward active” region. It is in this region that the transistor can act as a fairly linear amplifier. In this region, we see that:

* $0.2 < Vce < Vcc$; where Vcc is the supply voltage
* $Ib > 0$ and $Ic > 0$
* $Vbe >= 0.7V$

Thus the transistor is on and the collector to emitter voltage is somewhere between the cutoff and saturated states. In this state, the transistor is able to amplify small variations in the voltage present on the base. The output is extracted at the collector. In the forward active state, the collector current is proportional to the base current by a constant multiplier called “beta”, denoted by the symbol β. Thus in the forward active region we will also observe that:

* $Ic = \beta * Ib$

Another way to think about the different regions of operation is to consider the how collector and base currents are related. In the graph below, we see that at cutoff, Ib and Ic are equal and are zero. In the linear region, Ic = βIb. In the saturated region Ib and Ic are not zero but further increases in Ib barely increase Ic at all.



When we use a BJT as a saturated switch, we usually supply base current well in excess of what is needed to keep the transistor in saturation.