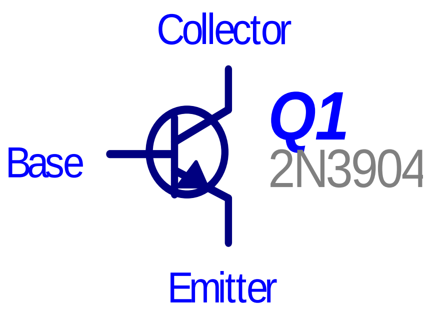
Transistor Basics:



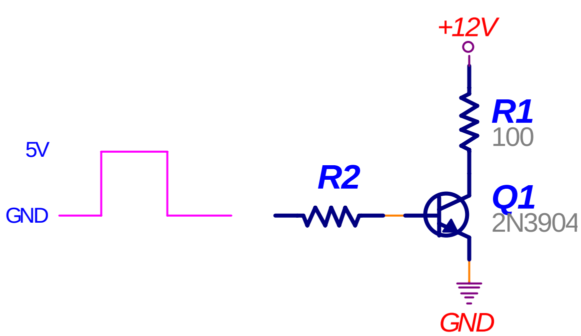
The schematic representation of a transistor is shown to the left. Note the arrow pointing down towards the emitter. This signifies it's an NPN transistor (current flows in the direction of the arrow). See the datasheet at: www.fairchildsemi.com.

A transistor is basically a current amplifier. Say we let 1mA flow into the base. We may get 100mA flowing into the collector. Note: The currents flowing into the base and collector exit through the emitter (the sum off all currents entering or leaving a node must equal zero).

The gain of the transistor will be listed in the datasheet as either β_{DC} or H_{fe}. The gain won't be identical even in transistors with the same part number. The gain also varies with the collector current and temperature. Because of this we will add a safety margin to all our base current calculations (i.e. if we think we need 2mA to turn on the switch we'll use 4mA just to make sure).

Sample circuit and calculations (NPN transistor):

Let's say we want to heat a block of metal. One way to do that is to connect a power resistor to the block and run current through the resistor. The resistor heats up and transfers some of the heat to the block of metal. We will use a transistor as a switch to control when the resistor is heating up and when it's cooling off (i.e. no current flowing in the resistor). In the circuit below R1 is the power resistor that is connected to the object to be heated.



Note: The transistor isn't a perfect switch. When off there is a small current that flows (~50nA for the 2N3904) and when on it has a small voltage drop (~0.2V depending on the collector & base currents).

First calculate the collector current when the switch is on. I = V/R = (12V – 0.2V)/100Ω = 118mA. Now calculate the needed base current required to turn on the transistor. Looking at the datasheet, H_{fe} could be as low as 30 at 100mA. The base current should then be I_C/ H_{fe} = 118mA/30mA = 4mA. We will add a factor of two for safety and use a base current of 8mA (to make sure the transistor turns on fully). Finally calculate the value for R2, the base resistor. Note: When the transistor is turned on there will be about a 0.7V drop across the base emitter junction. Therefore R2 = V/I_b = (5V – 0.75V)/8mA = 531Ω. This value isn't critical so use the closest standard value (560Ω).

That's it. When the input to the base resistor is zero (or less than about 0.65V) no base current flows and the transistor is off (i.e. no current flows through the 100Ω resistor). When the input to the base resistor is 5V the base current is 8mA and turns on the transistor putting 11.8V across the 100Ω resistor. When using a transistor as a switch most of the time it's OK to ignore the 0.2V drop across the collector emitter junction and the 0.7V drop across the base emitter junction in your calculations. Your results will be close enough (especially with the safety margin).

The transistor is a current amplifier. In the previous example it's trying to let $H_{fe} * I_b =$ 240mA flow through the collector. The transistor keeps lowering the voltage drop across the collector emitter junction (increasing the voltage drop across the 100Ω resistor and thus increasing the current) until the transistor saturates (i.e. can't lower the voltage any more) at about 0.2V. Keep in mind we're assuming the worst case H_{fe}. The gain is likely much more than 30.

If you lower the base current enough you can operate the transistor in its linear region (as an amplifier instead of a switch). You can make amplifiers this way but for most low frequency applications it's easier to design amplifiers with op-amps than discrete transistors.

Power dissipation:

When the transistor is in the linear region it may be dissipating enough power to require a heat sink. The power dissipated in the transistor is the voltage drop across the collector emitter junction times the collector current (neglecting the base current times the 0.75V base emitter drop). In the linear range this could be something like 6V@100mA = 600mW (a lot for a little transistor). But when used as a switch very little power is dissipated in the on or off state (0.2V@118mA = 24mW, 12V@50nA = 0.6uW).

PNP transistors:

In the previous example the transistor switch was placed between the load and ground. Sometimes one needs the load tied to ground all the time and has to place the switch between the power supply and the load. In this case a PNP transistor should be used. A explanation of the basics of using transistors as a switch (including PNP transistors) is at: http://www.rason.org/Projects/transwit/transwit.htm

Reading Transistor Datasheets: (refer to the 2N3904 by www.fairchildsemi.com):

V_{CEO}: Maximum voltage the collector emitter junction can handle (40V).

I_C: Maximum collector current (200mA).

Power Dissipation & Thermal Resistance is covered in the voltage regulator section.

H_{fe}: The DC current gain of the transistor (depends on the collector current).

$V_{CE(SAT)}$: The collector to emitter voltage drop when the transistor is saturated (i.e. conducting).

Small Signal Characteristics: Gives you an idea of how well the transistor would work as an amplifier.

Switching Characteristics: Gives you and idea of how fast the transistor can turn on and off when used as a switch. Note: The switching time depends on the base current. The larger the base current the faster the transistor can switch on. The smaller the pull-up resistor the faster the transistor can switch off. See the charts at the bottom of page 7 and top of page 8.