BIPOLAR JUNCTION TRANSISTORS (BJT)

PHYSICAL STRUCTURE AND PRINCIPLE OF OPERATION

The Bipolar Junction Transistor, often referred to simply as " The Transistor" is a three terminal device, which has a multitude of applications, ranging from signal amplifications to the design of digital logic and memory circuits. It consists of two pn junctions constructed in a special way and connected in series. Current is conducted by both electrons and holes, hence the name Bipolar. The basic principle involved is the use of the voltage between two terminals to control the current flowing in the third terminal. In this way a three terminal device can be used to realize a controlled source, which is the basis for amplifier design. The control signal can also be used to cause the current in the third terminal to change from zero to a large value, thus allowing the device to act as a switch. The switch is the basic element of digital circuits.

Below is a simplified structure for a BJT.

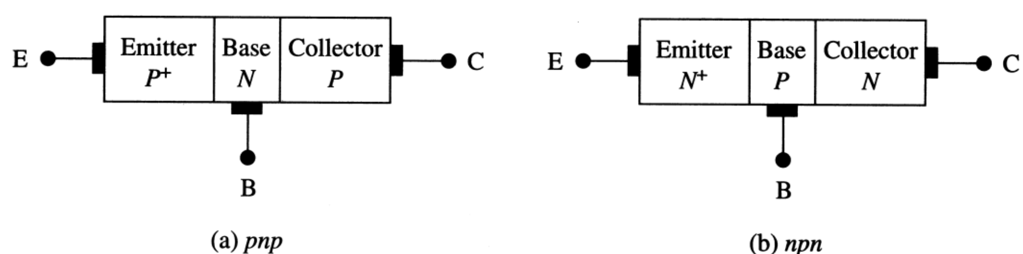


Figure 10.1

The BJT consists of three semiconductor regions: the emitter region (n-type), the base region (p-type) and the collector region (n-type). Such a transistor is referred to as an npn transistor. Another transistor, which has a p-type emitter, an n-type base and a p-type collector, is referred to as a pnp transistor. A transistor consists of two pn junctions, the emitter-base junction (EBJ) and the collector-base junction. Depending on the bias condition (forward or reverse) of each of these junctions, different modes of operation of the BJT are obtained.

BJT MODES OF OPERATION

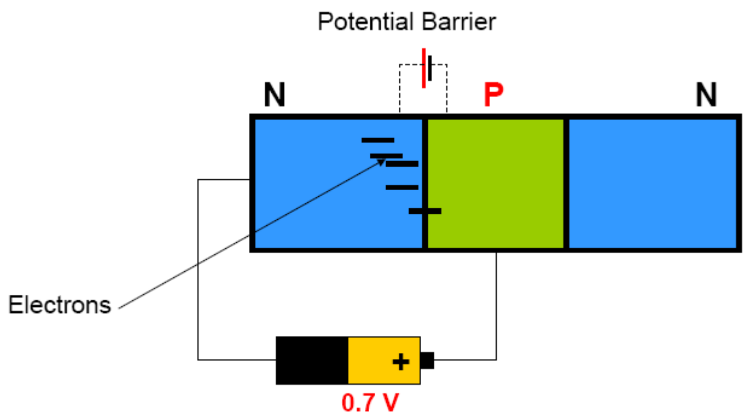
Mode	Emitter Base junction	Collector Base Junction
Cut off	Reverse bias	Reverse bias
Active	Forward bias	Reverse bias
Saturation	Forward bias	Forward bias

The active mode is the one used if the transistor is to operate as an amplifier. Switching applications (for example, logic circuits) utilize both the cutoff and the saturation modes.

OPERATION OF THE NPN TRANSISTOR IN THE ACTIVE MODE

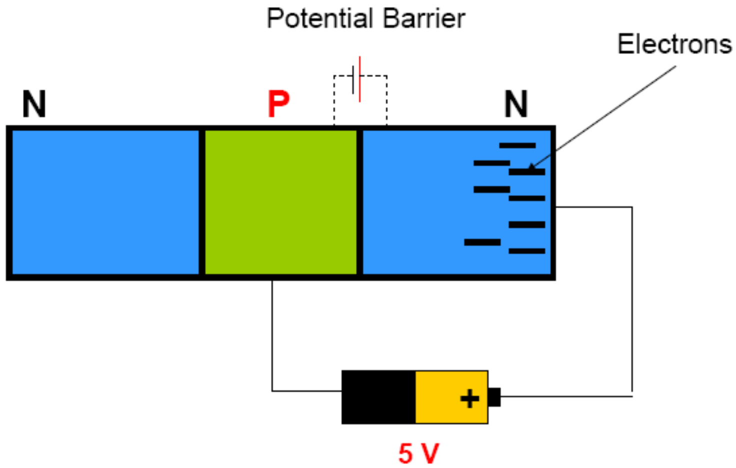
The forward bias on the emitter-base junction will cause electrons to be injected from the emitter into the base. These injected electrons will be minority carriers in the p-type base region. Some of the diffusing electrons will recombine with holes, which are majority carriers in the base. The percentage of electrons lost through recombination is very small since the base is usually very thin and lightly doped. Hence most of the diffusing electrons will reach the boundary on the collector-base depletion region. Because the collector is more positive than the base, these successful electrons will be swept across the CBJ into the collector. They will thus get “collected” to constitute the collector current $I_{C.}$ One important observation to make here is that, the magnitude of Ic is independent of collector-base voltage. I.e. as long as the collector is positive with respect to the base, the electrons that reach the collector side of the base region will be swept into the collector and register as collector current. These actions are illustrated in the following figures.

Transistor Action – Forward bias



Forward bias of the emitter-base junction. The negative potential of the battery drives electrons towards the emitter base-junction.

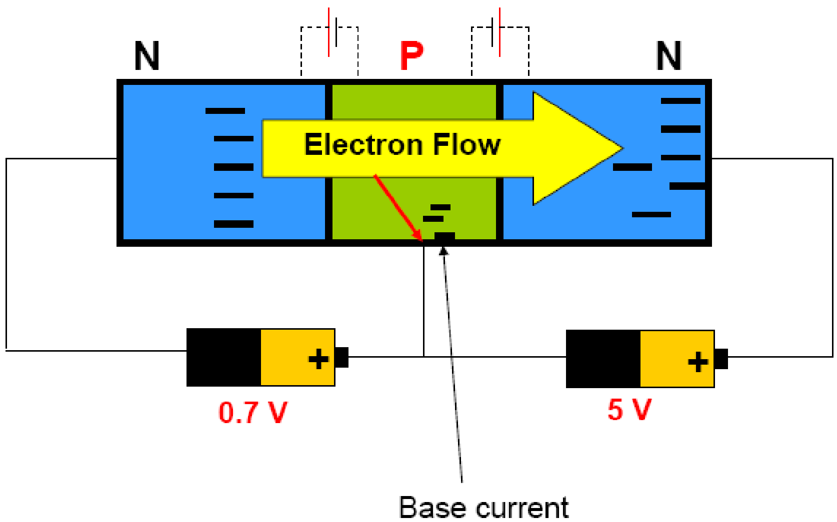
Transistor Action - Reverse bias



Reverse bias of the collector base junction. The positive potential of the battery attracts electrons towards the right hand side of the collector region.

Transistor Action - Current flow in an npn transistor biased to operate in the Active mode operation

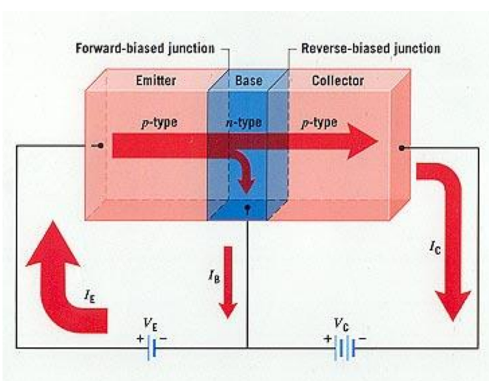
CURRENT FLOW – we consider only the diffusion current, since the drift current due to thermally generated minority carriers are very small and can be neglected.



The forward bias gives a negative ***push*** and the reverse bias a positive ***pull*** to the electrons

Nearly all the electrons injected into the base by the emitter are collected by the collector only a few electrons, 1% to 2% flow out of the base and form the base current.

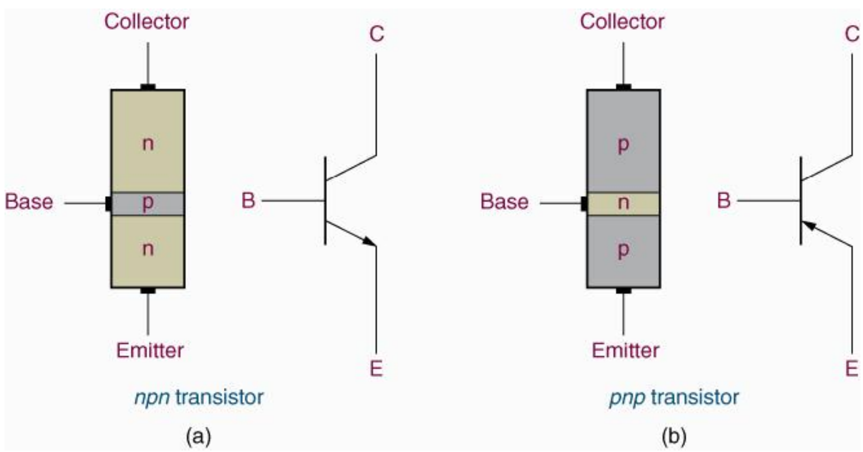
The PNP Transistor



Current flow in a pnp transistor biased to operate in the active mode

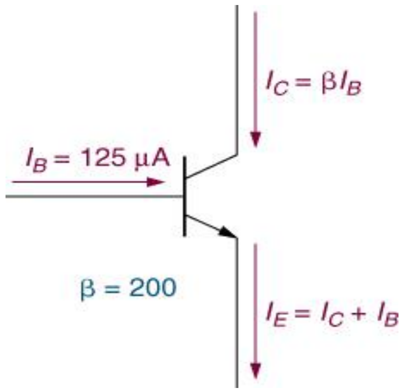
The pnp transistor operates in a manner similar to the npn transistor. The figure above shows the pnp transistor biased to operate in the active mode. The voltage V_E places the p-type emitter at a higher potential than the n-type base thus forward biasing the EBJ. The voltage V_C also reverse biases the CBJ. Unlike the npn transistor, current in the pnp transistor is mainly conducted by holes injected from the emitter into the base by the forward bias voltage V_E. [By keeping the base lightly doped, most of the emitter current will be due to holes] .it can be seen from the above description that the current-voltage relationships of the pnp transistor is the identical to those of the npn transistor.

Circuit symbols for the BJT



In both symbols an arrowhead distinguishes the emitter. The polarity of the device –npn or pnp- is indicated by the direction of the arrowhead on the emitter. This arrowhead points in the direction of the normal current flow in the emitter, which is also the forward direction of the base emitter-junction. This distinction is important because practical BJT's are not symmetric devices. That is, interchanging the emitter and collector will result in a different and much lower value for α (inverse mode of operation).

TRANSISTOR CURRENTS



Kirchoff's current law states that the total current entering a junction must be equal to the total current leaving that junction. Applying this law to the npn transistor shows that the emitter current (I_E) is the sum of the base current (I_B) and collector currents (I_C), expressed as follows:

$$I_E = I_C + I_B \text{ -------- (1)}$$

DC Beta (β_{DC}) or β

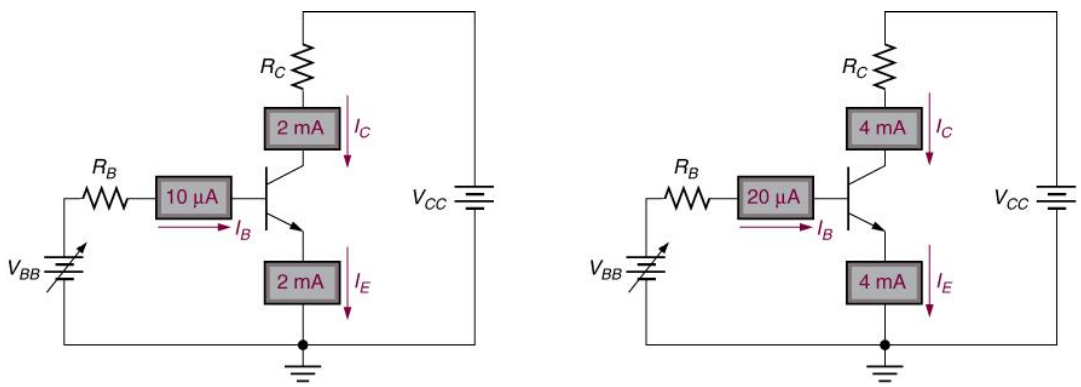
When a transistor is operated within certain limits, the collector current is proportional to the base current.

$$I_C = \beta I_B \text{ ------------(2)}$$

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

Where β is a constant for the particular transistor. The constant β is called the **common-emitter current gain** and it designated as h_{FE} on transistor data sheets**.** It is in the range 100 to 200, but it can be as high as 1000 for special devices.

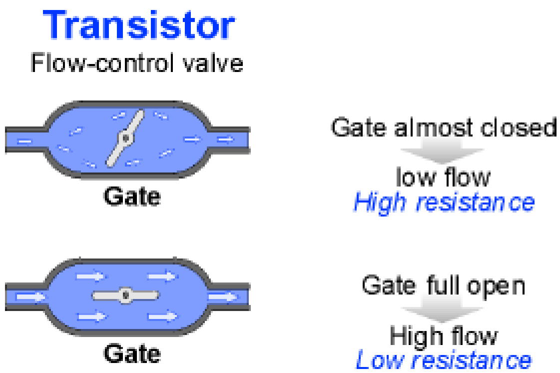
The BJT as a current controlled device



The BJT is a current-controlled device, as shown in the figure above. The small, controlling current is usually referred to simply as the *base current* I_B, because it is the only current that goes through the base wire of the transistor. Conversely, the large, controlled current is referred to as the *collector current* because it is the only current that goes through the collector wire (The value of I_C is normally some multiple of the value of I_B). The emitter current is the sum of the base and collector currents, in compliance with Kirchhoff's Current Law. That is, the *controlling* current and the *controlled* current always mesh together through the emitter wire.

If there is no current through the base of the transistor, it shuts off like an open switch and prevents current through the collector. If there is a base current, then the transistor turns on like a closed switch and allows a proportional amount of current through the collector. Thus, the collector current is primarily limited by the base current, regardless of the amount of voltage available to push it.

A good analogy for a transistor is a pipe with an adjustable gate.



The base controls how much current flows, just like the gate controls the flow of water in the pipe.

[The bottom line is that a small base current can control a larger collector current because of the current gain. Thus the BJT is essentially a current amplifier.]

<u>DC Alpha (α)</u>

From equation 1 and 2;

$$I_E = \left(\frac{\beta + 1}{\beta}\right) I_C$$

Thus,

$$I_C = \alpha I_E$$

$$\alpha = \frac{I_C}{I_E}$$

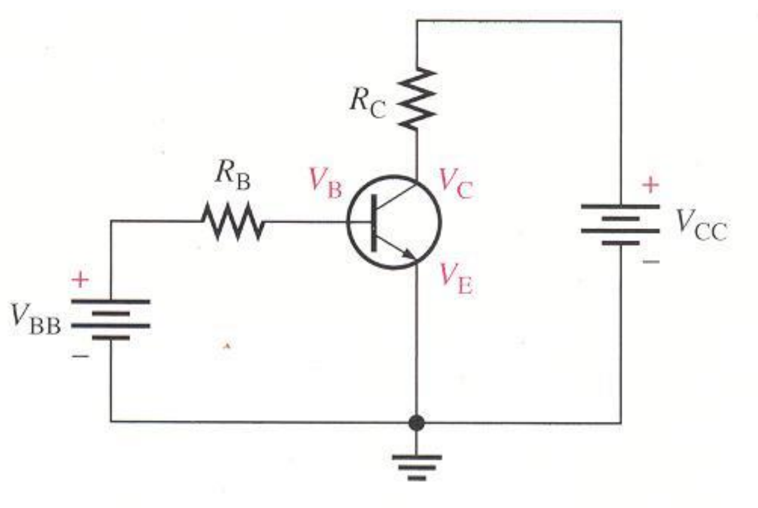
where the constant α is related to β by,

$$\alpha = \frac{\beta}{\beta + 1}$$

α - is a constant (for a particular transistor) less than but very close to unity. It is called the **common-base current gain.**

TRANSISTOR VOLTAGES

The three dc voltages for the biased transistor in figure 3 are the emitter voltage (V_E), the collector voltage (V_C), and the base voltage (V_B). These single-subscript voltages mean that they are referenced to the ground. The collector supply voltage, V_{CC} is shown with repeated subscript letters. The collector voltage is equal to the dc supply voltage V_{CC} less the voltage drop across R_C



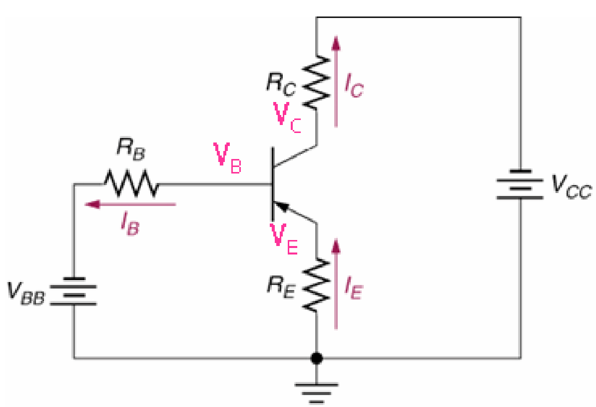
$V_C = V_{CC} – I_C R_C$ – (form Kirchoff's voltage law, note $V_C = V_{CE}$ in this case).

V_{CE}, V_{BE}, and V_{CB} are inter-terminal voltages, each measured from the first identified terminal to the second. (For example, V_{CE} is the voltage measured from the collector terminal to the emitter terminal.)

The primary differences between PNP and NPN circuits are found in the current directions and voltage polarities.

For an npn transistor operating in the active mode, the voltage difference between the base and emitter (V_{BE}) is positive. That is, the base should have a higher voltage than the emitter (by V_{BE}). An npn transistor whose EBJ is forward-biased will operate in the active mode **as long as the collector is higher in potential than the base**. The collector voltage should not be allowed to fall below that of the base if active-mode operation is required

For a pnp transistor operating in the active mode, the emitter should have a higher voltage than the base. That is, V_{EB} is positive. The pnp transistor will operate in the active mode if the potential of the collector is lower than (or equal to) that of the base. The collector voltage should not be allowed to rise above that of the base if active-mode operation is to be maintained



pnp circuit supply voltage and currents in the active mode of operation

- **SUMMARY:**
- Bipolar transistors are so named because the controlled current must go through *two* types of semiconductor material: P and N. The current consists of both electron and hole flow, in different parts of the transistor.
- Bipolar transistors consist of either a P-N-P or an N-P-N semiconductor "sandwich" structure.
- The three leads of a bipolar transistor are called the *Emitter*, *Base*, and *Collector*.
- Transistors function as current regulators by allowing a small current to *control* a larger current. The amount of current allowed between collector and emitter is primarily determined by the amount of current moving between base and emitter.

- In order for a transistor to properly function as a current regulator, the controlling (base) current and the controlled (collector) currents must be going in the proper directions: meshing additively at the emitter and going *against* the emitter arrow symbol.