# Analog Electronics

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1st **semester**

# Chapter 4

# Transistor

# Lecture 9

# Transistor Currents

The conventional current **flows** toward the **arrow** on the **emitter terminal**. The **emitter current** ($I_E$) is the **sum** of the **collector** current ($I_C$) and the small **base current** ($I_B$).

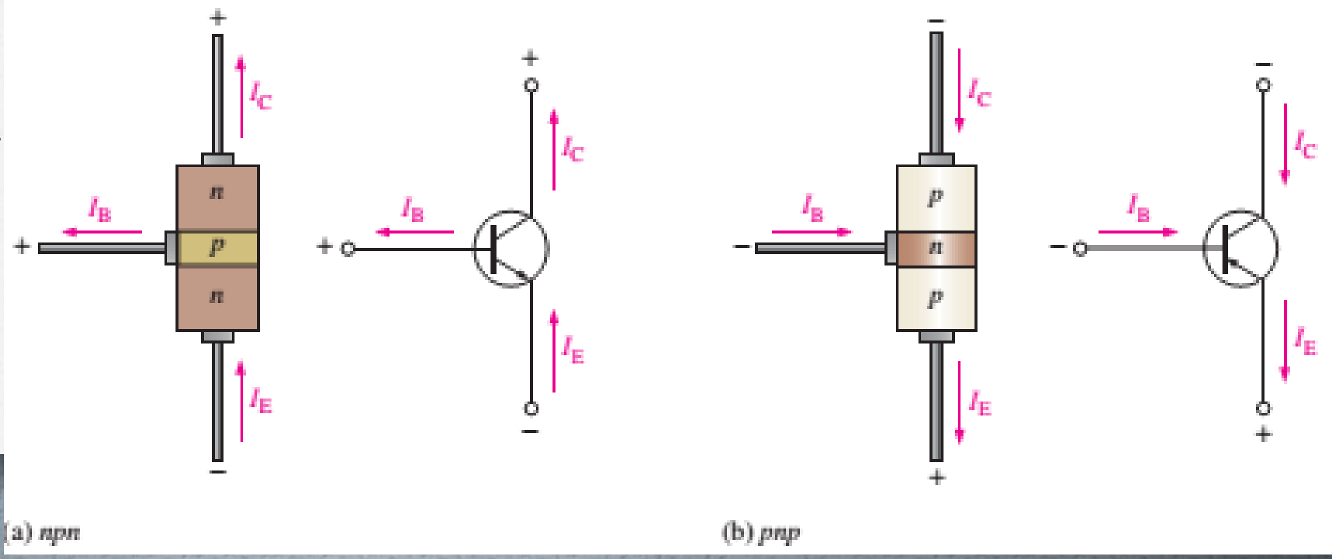
That is, **IE = IC + IB**

**IB** is **very small** compared to **IE or IC**. The capital-letter subscripts indicate DC values.

The voltage drop between the base and emitter is $V_{BE}$, whereas the voltage drop between the **collector and base** is called $V_{CB}$.

Figure:

Transistor currents.

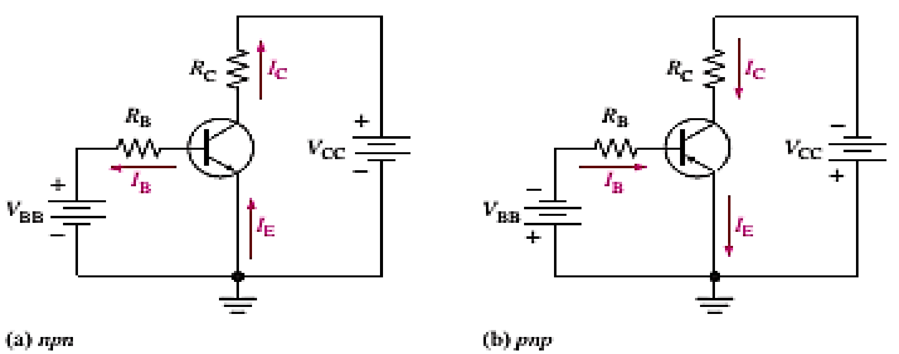


# BJT Characteristics and Parameters

**Two** important **parameters**, $\beta_{DC}$ (**DC current gain**) and $\alpha_{DC}$ are used to analyze a BJT circuit.

When a **transistor is connected** to **DC bias voltages**, as shown in **Figure below** for **both** npn and pnp types,

$V_{BB}$ forward-biases the base-emitter junction, and $V_{CC}$ reverse-biases the base-collector junction.




**Figures of transistor DC bias circuits.**

The **collector current** is directly **proportional** to the **base current**.

$I_C \propto I_B$

The $\beta_{DC}$ of a transistor is the **ratio** of the DC **collector current** ($I_C$) to the **DC base current ($I_B$)**.

$$\beta_{DC} = \frac{I_C}{I_B}$$

This equation explains the amplification of current.

The ratio of the **DC** collector current ($I_C$) to the **DC** emitter current (IE) is the ($\alpha_{DC}$).

$\alpha_{DC}$ is always **less than 1**

$$\alpha_{DC} = \frac{I_C}{I_E}$$

# Example

Determine the dc current gain $\beta_{DC}$ and the emitter current IE for a transistor where $I_B$=50μA and $I_C$= 3.65 mA.

**Solution**

$$\beta_{DC} = \frac{I_C}{I_B} = \frac{3.65\text{ mA}}{50\ \mu\text{A}} = \mathbf{73}$$

$$I_E = I_C + I_B = 3.65\text{ mA} + 50\mu\text{A} = \mathbf{3.70\text{ mA}}$$

# BJT Circuit Analysis

Consider the basic transistor bias circuit configuration in the Figure below. Three transistor DC currents and three DC voltages can be identified.

**$I_B$: DC base current**

**$I_E$: DC emitter current**

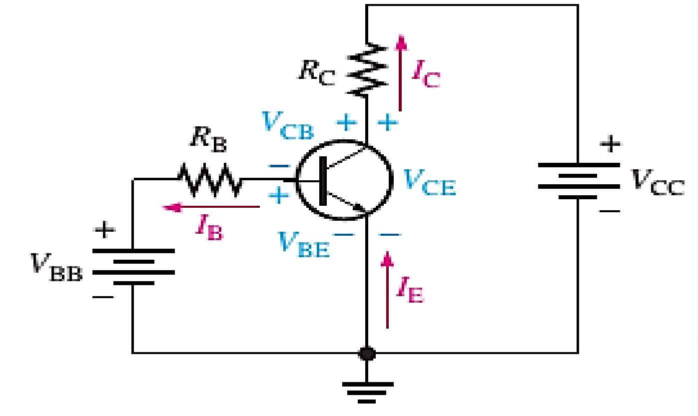
**$I_C$: DC collector current**

**$V_{BE}$: DC voltage across the base-emitter junction**

**$V_{CE}$: DC voltage across collector-emitter junction**

**$V_{CB}$: DC voltage across collector-base junction**

**Figure 4: Transistor currents and voltages.**



When the base-emitter junction is forward-biased,

It is like a forward-biased diode and has a forward voltage drop of $V_{BE} \cong 0.7$ V

The voltage at the collector concerning the grounded emitter is

$V_{CE} = V_{CC} - I_C R_C$ $\qquad (I_C R_C = V_{RC})$

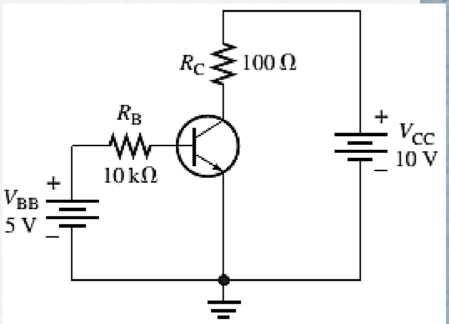
The current across $I_B$ is

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} \qquad (I_B R_B = V_{R_B})$$

The voltage across the reverse-biased collector-base junction is

$$V_{CB} = V_{CE} - V_{BE}$$

**Example: Determine $I_B$, $I_C$, $I_E$, $V_{BE}$, $V_{CE}$, and $V_{CB}$ in the circuit of the following Figure. The transistor has a $\beta_{DC}$ = 150.**




**Solution:**

**VBE≅ 0.7 V, Calculate the base, collector, and emitter currents as follows:**

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5\text{ V} - 0.7\text{ V}}{10\text{ k}\Omega} = \mathbf{430\ \mu A}$$

$$I_C = \beta_{DC} I_B = (150)(430\ \mu\text{A}) = \mathbf{64.5\ mA}$$

$$I_E = I_C + I_B = 64.5\text{ mA} + 430\ \mu\text{A} = \mathbf{64.9\ mA}$$

Solve for $V_{CE}$ and $V_{CB}$.

$$V_{CE} = V_{CC} - I_C R_C = 10\text{ V} - (64.5\text{ mA})(100\ \Omega) = 10\text{ V} - 6.45\text{ V} = \mathbf{3.55\ V}$$

$$V_{CB} = V_{CE} - V_{BE} = 3.55\text{ V} - 0.7\text{ V} = \mathbf{2.85\ V}$$

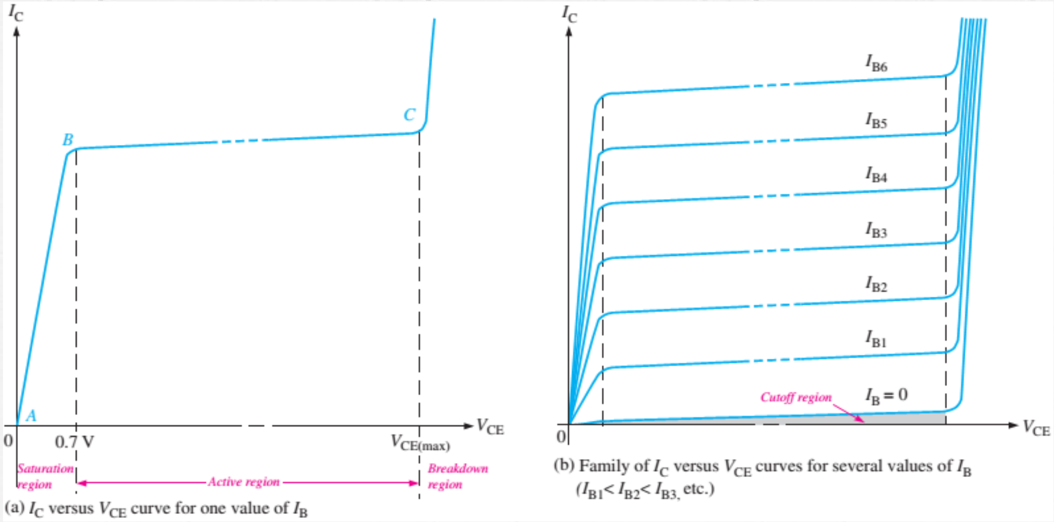
**Since the collector is at a higher voltage than the base, the CB junction is reverse-biased.**

# Collector Characteristic Curves

The collector characteristic curves show three modes of operation of the transistor. The collector current $I_C$ variation varies with the $V_{CE}$ for a specified value of base current $I_B$.

Assume that $V_{BB}$ is set to produce a certain value of $I_B$, $V_{CC}$ **is zero, and** $\mathbf{V_{CE}}$ **is zero.** As $V_{CE}$ is increased, IC increases until $I_B$ becomes constant. When **both BE, and BC junctions** are forward biased, and **the transistor is in the saturation region.**

Figure : Collector characteristic curves.



**In saturation,** an increase in **base current** does not affect the collector current, and the relation $IC=\beta_{DC}I_B$ is no longer valid.

$$I_{C_{(SAT)}} = \frac{V_{CC} - V_{CE_{(SAT)}}}{R_C}$$

The transistor current is maximum, and the voltage across the collector is minimum for a given load.

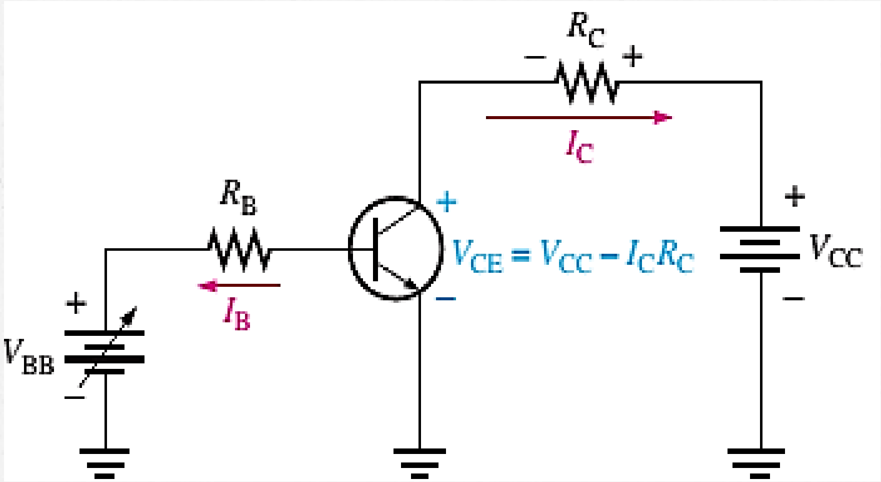



Figure : Base-emitter and base-collector junctions are forward-biased.

When $V_{CE}$ is increased further and exceeds **0.7 V**, the **base-collector junction becomes reverse-biased,** and the transistor goes into its operation's active, or linear, region.

$I_C$ levels off and remains essentially constant for a given value of $I_B$ as $V_{CE}$ continues to increase. The value of $I_C$ is determined only by the relationship expressed as $\mathbf{I_C=\beta_{DC}I_B}$.

A family of collector characteristic curves is produced when $I_C$ versus $V_{CE}$ is plotted for several values of $I_B$, as illustrated in Figure below. It can be read from the curves. The value of $\beta_{DC}$ is nearly the same wherever it is read in the active region. In a **BJT, the cutoff is the condition of no base current ($I_B$=0)**, which results in only an extremely small leakage current ($I_{CEO}$) in the collector circuit.

The subscript CEO represents collector to emitter with the base open. For practical work, this current is assumed to be zero. In **cutoff**, **neither the BE junction nor the BC junction is forward-biased.**

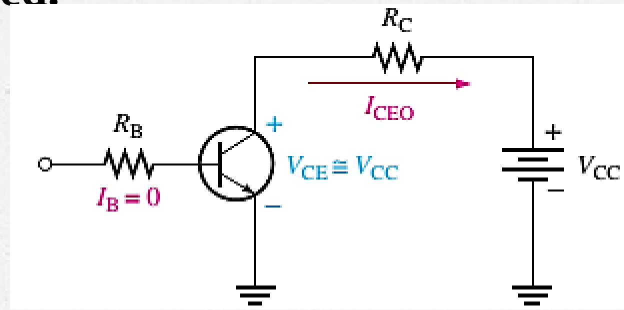
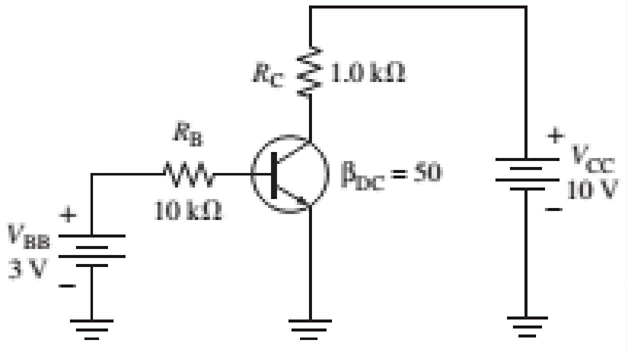



Figure: Cutoff: Base-emitter and base-collector junctions are reverse-biased.

# Example:

Determine whether or not the transistor in the following figure is in saturation. Assume $V_{CE}(sat) = 0.2V$.




**Solution**:

First, determine $I_{C(sat)}$.

$$I_{C(sat)} = \frac{V_{CC} - V_{CE(sat)}}{R_C} = \frac{10\text{ V} - 0.2\text{ V}}{1.0\text{ k}\Omega} = \frac{9.8\text{ V}}{1.0\text{ k}\Omega} = 9.8\text{ mA}$$

Now, see if $I_B$ is large enough to produce $I_{C(sat)}$.

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{3\text{ V} - 0.7\text{ V}}{10\text{ k}\Omega} = \frac{2.3\text{ V}}{10\text{ k}\Omega} = 0.23\text{ mA}$$

$$I_C = \beta_{DC} I_B = (50)(0.23\text{ mA}) = 11.5\text{ mA}$$

**This shows that with the specified $\beta_{DC}$, this base current can produce an $I_C$ greater than $I_C$(sat). Therefore, the transistor is saturated.**

# The BJT as a Switch

A BJT can be used as a switching device in logic circuits to turn on or off the current to a load. As a switch, the transistor is normally in either cutoff (load is OFF) or saturation (load is ON).

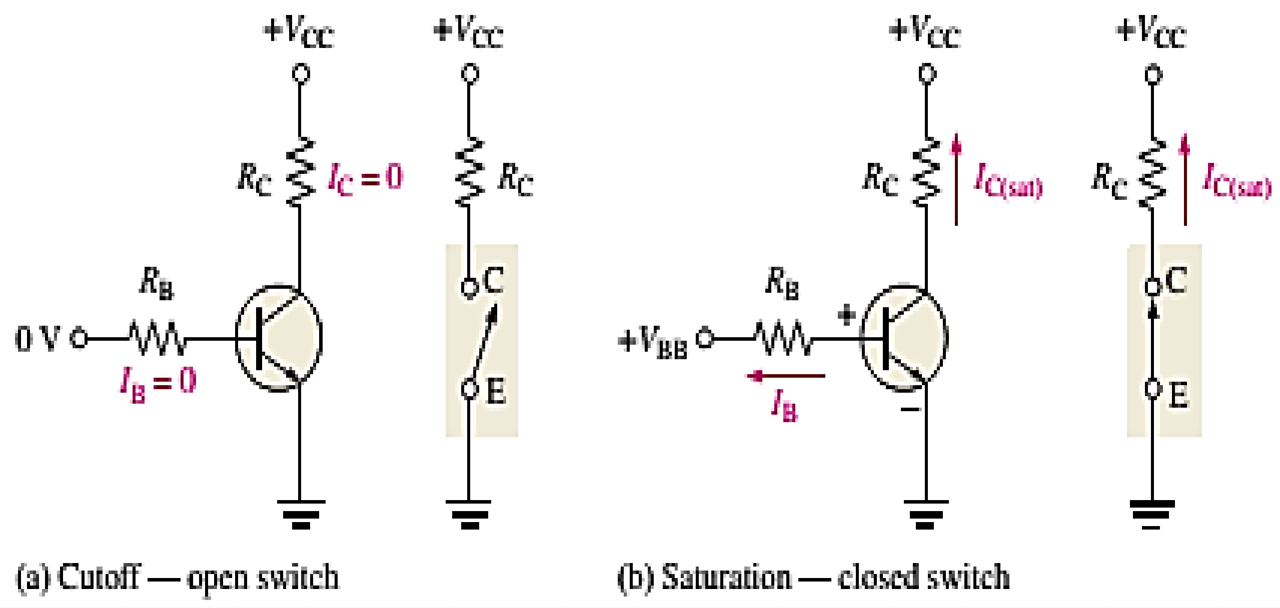



Figure: Switching action of an ideal transistor.