# Bipolar Junction Transistors (BJTs)

## Basic Construction:

The transistor is a three-layer semiconductor device consisting of either two **n-** and one **p-** type layers of material or two p- and one n-type layers of material. The former is called an ***npn transistor***, while the latter is called a ***pnp transistor***. Both (with symbols) are shown in Fig. 8-1. The middle region of each transistor type is called the ***base (B)*** of the transistor. Of the remaining two regions, one is called ***emitter (E)*** and the other is called the ***collector (C)*** of the transistor. For each transistor type, a junction is created at each of the two boundaries where the material changes from one type to the other. Therefore, there are two junctions: ***emitter-base (E-B) junction*** and ***collector-base (C-B) junction***. The outer layers of the transistor are heavily doped semiconductor materials having widths much greater than those of the sandwiched ***p-*** or ***n-***type material.

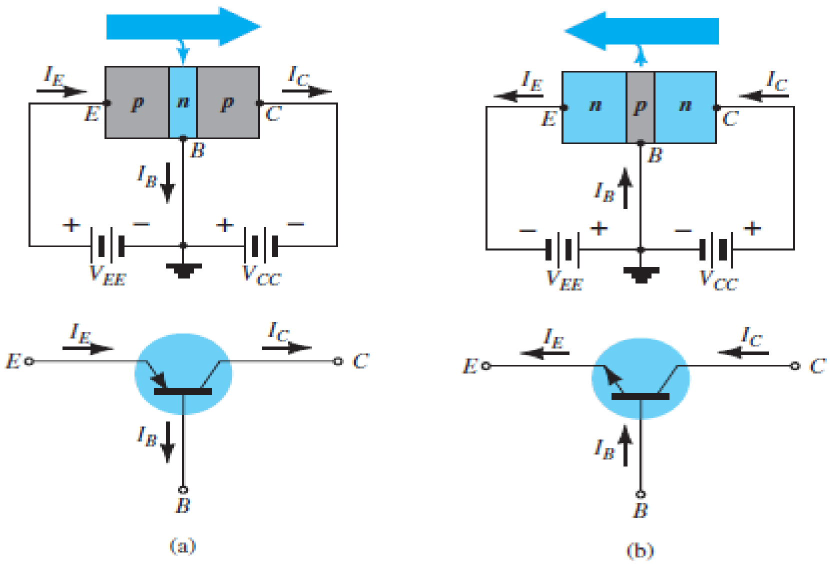


Figure 8-1

The abbreviation ***BJT***, from ***bipolar junction transistor***, is often applied to this three- terminal device. The term ***bipolar*** reflects the fact that holes and electrons participate in the injection process into the oppositely polarized material. If only one carrier is employed (electron or hole), it is considered a ***unipolar*** device. Such a device is the ***field-effect transistor (FET).***

### *Active Region Operation:*

The basic operation of the transistor will now be described using the **pnp** transistor of Fig. 8-2. The operation of the **npn** transistor is exactly the same if the roles played by the electron and hole are interchanged. When the E-B junction is forward-biased, a large number of majority carriers will diffuse across the forward-biased p-n junction into the n-type material (base). Since the base is very thin and has a low conductivity (lightly doping), a very small number of these carriers will take this path of high resistance to the base terminal. The larger number of these majority carriers will diffuse across the reverse-biased C-B junction into the p-type material (collector). The reason for the relative ease with which the majority carriers can cross the reverse- biased C-B junction is easily understood if we consider that for the reverse-biased diode the injected majority carriers will appear as minority carriers in the n-type base region material. Combining this with the fact that all the minority carriers in the depletion region will cross the reverse-biased junction of a diode accounts for the flow indicated in Fig. 8-2.

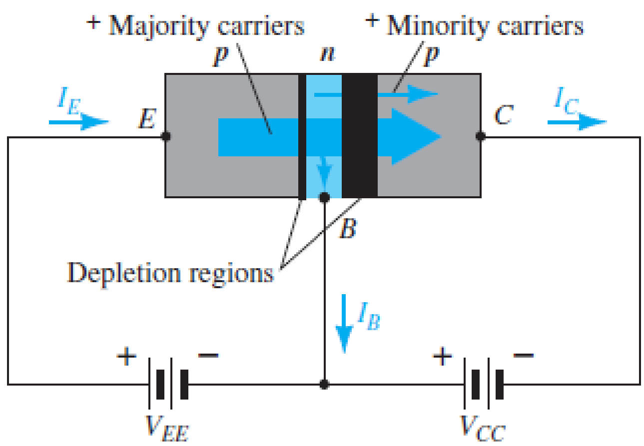


**Figure 8-2**

Applying Kirchhoff's current law to the transistor of Fig. 8-2, we obtain

$$\boxed{I_E = I_C + I_B} \qquad [8.1]$$

# Transistor circuit configurations:

## 1) ***Common-Base (CB) Configuration:***

The common-base configuration with npn and pnp transistors are indicated in Fig. 8-3. The common-base terminology is derived from the fact that the base is common to both input and output sides of the configuration. In addition, the base is usually terminal closest to, or at, the ground potential.

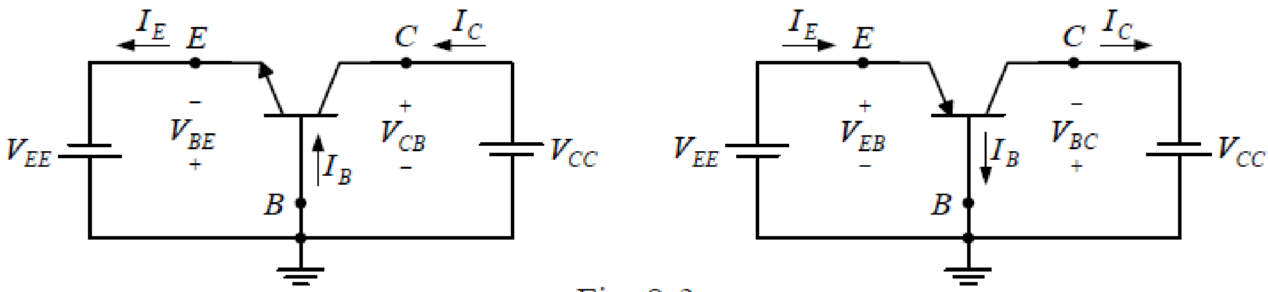


Fig. 8-3

In the dc mode the levels of $I_C$ and $I_E$ due to the majority carriers are related by a quantity called ***alpha*** ($\alpha_{dc}$) and defined by the following equation:

$$\alpha_{dc} = \frac{I_C}{I_E} \qquad \textbf{8.2}$$

Where $I_C$ and $I_E$ are the levels of current at the point of operation and $\alpha_{dc} \approx 1$, or for practical devices: $0.900 \leq \alpha_{dc} \leq 0.998$.

The input (emitter) characteristics for a CB configuration are a plot of the emitter (input) current ($I_E$) versus the base-to-emitter (input) voltage ($V_{BE}$) for a rage of values of the collector-to-base (output) voltage ($V_{CB}$) as shown in Fig. 8-4. Since, the exact shape of this $I_E$-$V_{BE}$ carve will depend on the reverse-biasing output voltage, $V_{CB}$. The reason for this dependency is that the grater the value of $V_{CB}$, the more readily minority carriers in the base are swept through the C-B junction. The increase in emitter- to-collector current resulting from an increase in $V_{CB}$ means the emitter current will be greater for a given value of base-to-emitter voltage ($V_{BE}$).

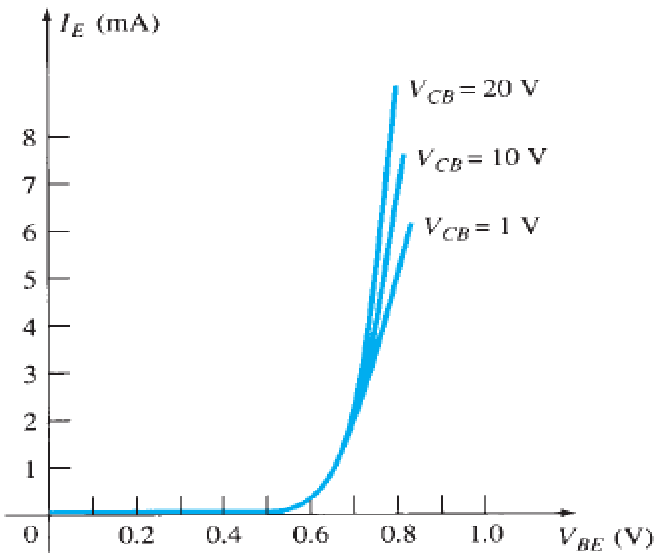


**Figure 8-4**

The output (collector) characteristics for CB configuration will be a plot of the collector (output) current (***$I_C$***) versus collector-to-base (output) voltage (***$V_{CB}$***) for a range of values of emitter (input) current (***$I_E$***) as shown in Fig. 8-5. The collector characteristics have three basic region of interest, as indicated in Fig. 8- 5, the **active**, **cutoff**, and **saturation** regions.

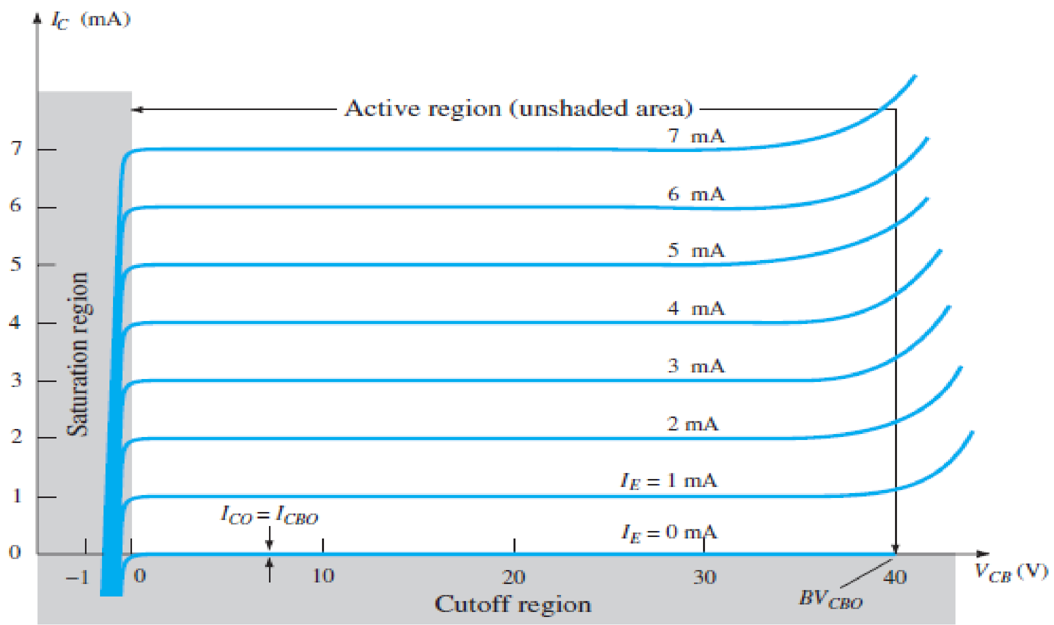


**Figure 8-5**

## 2) Common-Emitter (CE) Configuration:

The common-emitter configuration with npn and pnp transistors are indicated in Fig. 8-6. The external voltage source **VBB** is used to forward bias the E-B junction and the external voltage source **VCC** is used to reverse bias C-B junction. The magnitude of VCC must be greater than VBB to ensure the C-B junction remains reverse biased, since, as can be seen in the Fig.8-6,**VCB=VCC-VBB**.

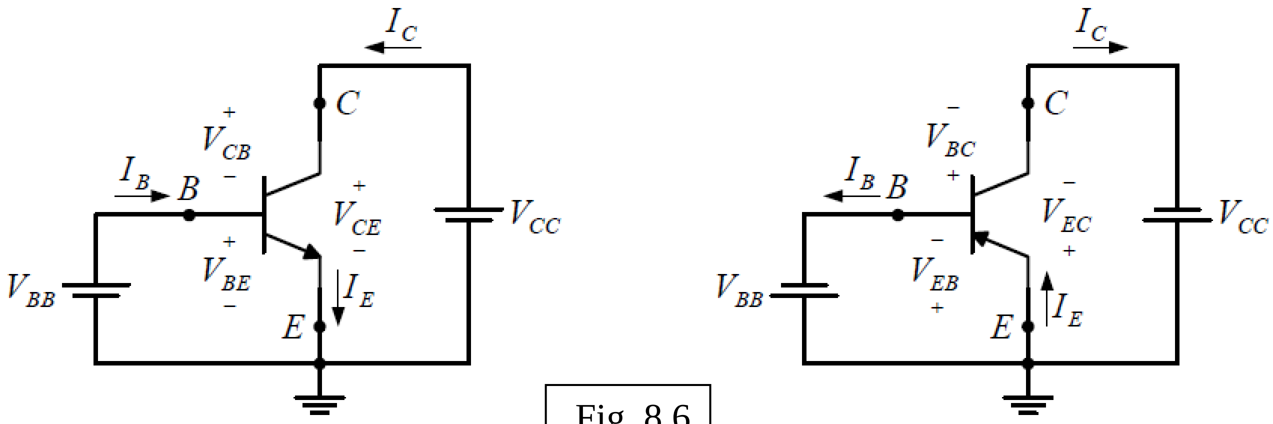


Fig. 8.6

In the dc mode the levels of ***IC*** and ***IB*** are related by a quantity called ***beta*** ($\beta dc$) and defined by the following equation:

$$\beta_{dc} = \frac{I_C}{I_B} \qquad (8.3)$$

Where ***IC*** and ***IB*** are the levels of current at the point of operation. For practical devices the levels of $\beta dc$ typically ranges from about 50 to over 500, with most in the mid-range.

A relationship can be developed between $\beta$ and α using the basic relationships introduced thus far. Using $\beta = I_C / I_B$ we have $I_B = I_C / \beta$, and from $\alpha = I_C / I_E$ we have $I_E = I_C / \alpha$. Substituting into $I_E = I_C + I_B$ we have $I_C / \alpha = I_C + I_C / \beta$ and dividing both sides of the equation by $I_C$ will result in $1/\alpha = 1 + 1/\beta$ or $\beta = \alpha\beta + \alpha = (\beta + 1)\alpha$ so that

$$\alpha = \frac{\beta}{\beta + 1} \quad \text{or} \quad \beta = \frac{\alpha}{1 - \alpha} \qquad 8.4$$

$$I_E = (\beta + 1)\, I_B \qquad [8.5]$$

The input (base) characteristics for the CE configuration are a plot of the base (input) current (***$I_B$***) versus the base-to-emitter (input) voltage (***$V_{BE}$***) for a range of values of collector-to- emitter (output) voltage (***$V_{CE}$***) as shown in Fig. 8-7. Note that ***$I_B$*** increases as ***$V_{CE}$*** decreases, for a fixed value of $V_{BE}$. A large value of ***$V_{CE}$*** results in a large reverse bias of the C-B junction, which widens the depletion region and makes the base smaller. When the base is smaller, there are fewer recombination of injected minority carriers and there is a corresponding reduction in base current (***$I_B$***).

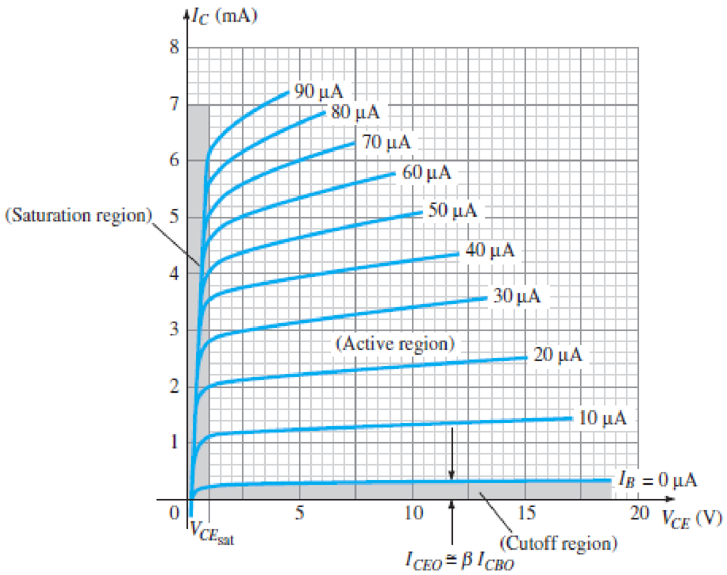


**Figure 8-8**

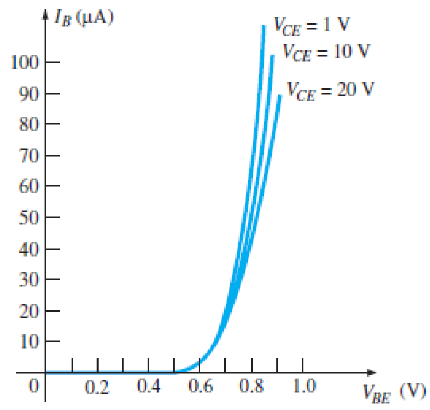


**Figure 8-7**

The output (collector) characteristics for CE configuration are a plot of the collector (output) current ($I_C$) versus collector-to-emitter (output) voltage ($V_{CE}$) for a range of values of base (input) current ($I_B$) as shown in Fig. 8-8. The collector characteristics have three basic region of interest, as indicated in Fig. 8-8, the active, cutoff, and saturation regions.

### 3) Common-Collector (CC) Configuration:

The third and final transistor configuration is the common-collector configuration, shown in Fig. 8-9 with npn and pnp transistors. The CC configuration is used primarily for impedance- matching purposes since it has a high input impedance and low output impedance, opposite to that which is true of the common-base and common-emitter configurations.

From a design viewpoint, there is no need for a set of common-collector characteristics to choose the circuit parameters. The circuit can be designed using the common-emitter characteristics. For all practical purposes, the output characteristics of the CC configuration are the same as for the CE configuration. For the CC configuration the output characteristics are a plot of emitter (output) current (IE) versus collector-to-emitter (output) voltage ($V_{CE}$), for a range of values of base (input) current ($I_B$). The output current, therefore, is the same for both the common-emitter and common-collector characteristics. There is an almost unnoticeable change in the vertical scale of $I_C$ of the common-emitter characteristics if $I_C$ is replaced by $I_E$ for the common- collector characteristics (since $\alpha \cong 1$, $I_E \approx I_C$).

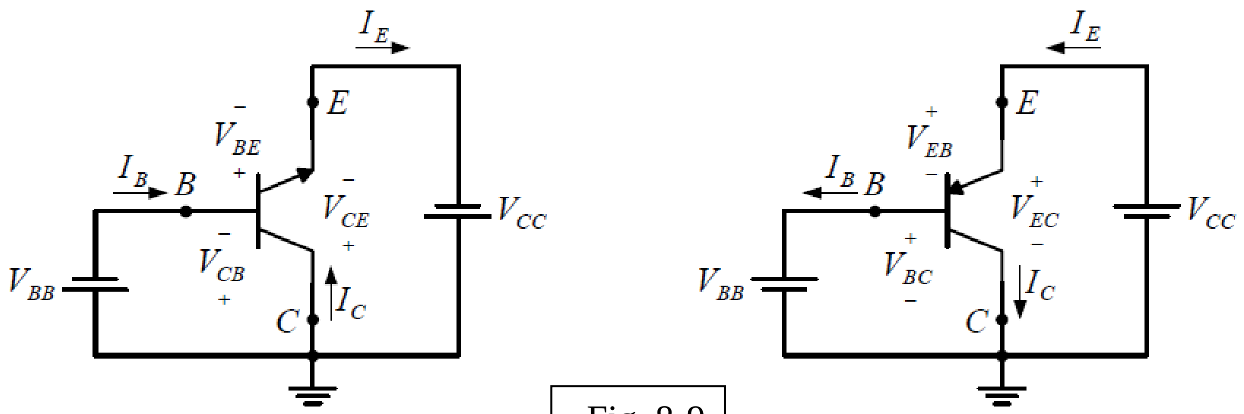


Fig. 8-9

**Ex (1):** Evaluate **α** and **β** when $I_B = 50\ \mu A$ and $I_C = 3.63\ mA$ ?

**Solution:**

$$\beta = \frac{I_C}{I_B} = \frac{3.63\ mA}{50\ \mu A} = 73$$

$$\alpha = \frac{\beta}{\beta + 1} = \frac{73}{73 + 1} = 0.986$$

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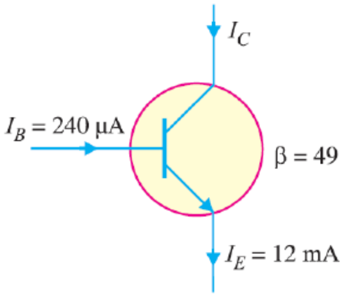
**H.W (1):** Find the value of **β** if (i) α = 0.9 (ii) α = 0.98 (iii) α = 0.99.

**H.W (2):** Find the **α** rating of the transistor shown in Fig below. Hence determine the value of $I_C$ using both α and β rating of the transistor.




**Ex (2):**

A transistor manufacturer produces transistors whose α values vary from 0.992 to 0.995. Find the β range corresponding to this α range.

**Solution:**

- For α = 0.992

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.992}{1-0.992} = 124$$

- For α = 0.995

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.995}{1-0.995} = 199$$

$124 \le \beta \le 199$

## Region of Transistor

Transistors are **used** either as **amplifiers** or as electronic **switches**. The dc biasing is necessary to establish the proper region of operation for ac amplification or switching purposes. **Table 1-1** shows the transistor operation regions and the purpose with respect to the biasing of the B-E and B-C junctions.

*Table 1-1: **NPN transistor** operation regions and junction biasing.*

| Mode | purpose | Junctions biasing | |
|---|---|---|---|
| | | **B-E Junction bias** | **B-C Junction bias** |
| **Active region** | Amplifier | Forward-biased | Reverse-biased |
| **Cutoff region** | Switching | Reverse-biased | Reverse-biased |
| **Saturation region** | | Forward-biased | Forward-biased |

- For PNP transistor reverse the junction biasing only.
- If the transistor in saturation region $V_{CE} = 0.2$ V for (Si) and 0.1 V for (Ge).

**Ex (3):**

Determine the region which transistor NPN operate in junction CE if:

1) $V_B = 0.8$ V and $V_C = 0.2$ V
2) $V_B = -1$ V and $V_C = 10$ V
3) $V_B = 0.7$ V and $V_C = 5$ V

**Solution:**

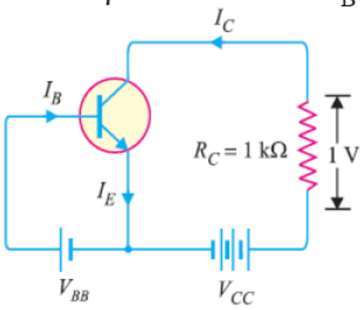
- $V_E = 0$ V ——→ For all cases above.

1) $V_{BE} = V_B - V_E = 0.8 - 0 = 0.8$ V
$V_{BC} = V_B - V_C = 0.8 - 0.2 = 0.6$ V
$V_{BE}$ : Forward , $V_{BC}$ : Forward ——→ Transistor Saturation.

2) $V_{BE} = V_B - V_E = -1 - 0 = -1$ V
$V_{BC} = V_B - V_C = -1 - 10 = -11$ V
$V_{BE}$ : Reverse , $V_{BC}$ : Reverse ——→ Transistor Cutoff.

3) $V_{BE} = V_B - V_E = 0.7 - 0 = 0.7$ V
$V_{BC} = V_B - V_C = 0.7 - 5 = -4.3$ V
$V_{BE}$ : Forward , $V_{BC}$ : Reverse ——→ Transistor Active.

**Ex (4):** In Fig shown below. When β= 45 Find the $I_B$ for CE connection.




**Solution:-**

$$I_C = \frac{1\ \text{v}}{1\ \text{k}\Omega} = 1\ \text{mA}$$

$$\beta = \frac{I_C}{I_B} ==> I_B = \frac{I_C}{\beta} = \frac{1\ \text{mA}}{45} = 0.022\ \text{mA}$$

Summary:

- In **active region**, a transistor acts as an **Amplifier.** Whereas in **cut off** the transistor is **switch OFF ,** and in **saturation** the transistor is **switch ON.**
- One p – n junction of a transistor is **forward-biased** , whereas the other is **reverse biased**.
- The **dc emitter current** is always the largest current of a transistor, whereas the base current is always the smallest .The emitter current is always the sum of the other two.
- In the **active region** of a transistor, the base–emitter junction is forward-biased , whereas the collector–base junction is reverse-biased .
- In the cutoff region the base–emitter and collector–base junctions of a transistor are both reverse-biased.
- In the saturation region the base–emitter and collector–base junctions are forward biased.
- The base-to-emitter voltage of an operating transistor can be assumed to be 0.7V.