Electronics I

LECT 6

Bipolar Junction Transistors BJT

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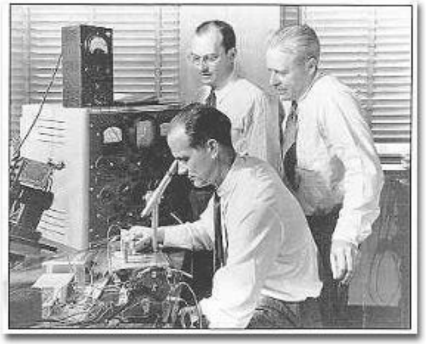
INTRODUCTION

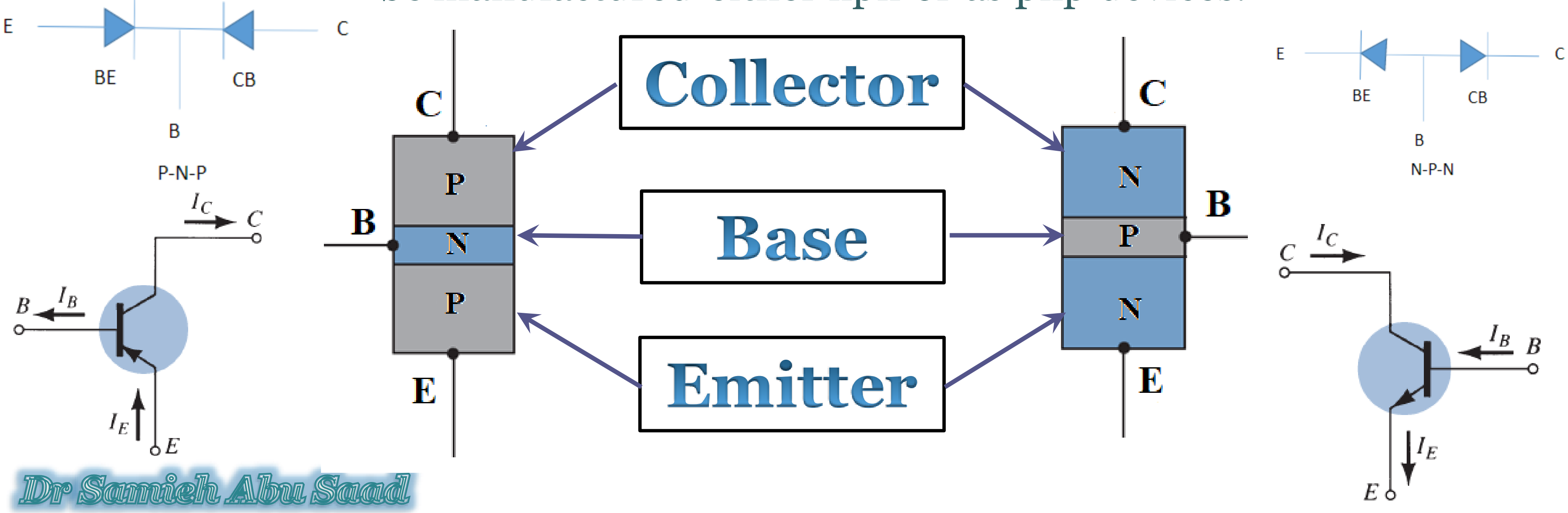
1- Introduction, 1

- The first transistor was adverted On December 23, 1947, by Dr. S. William Shockley, Walter H. Brattain, and John Bardeen.
- They demonstrated the amplifying action of the first transistor at the Bell Telephone Laboratories.
- BJT is an electronic component mainly used for switching and amplification purpose.



➢BASIC CONSTRUCTION OF BJT, 1

- A BJT is a three-terminal semiconductor device.
- BJT are called bipolar because they are consist of two p-n junctions.
- BJT has three doped regions; the bottom region is the emitter, the middle region is the base, and the top region is the collector.
- The base region is much thinner as compared to the other two regions.
- Transistors can be manufactured either npn or as pnp devices.



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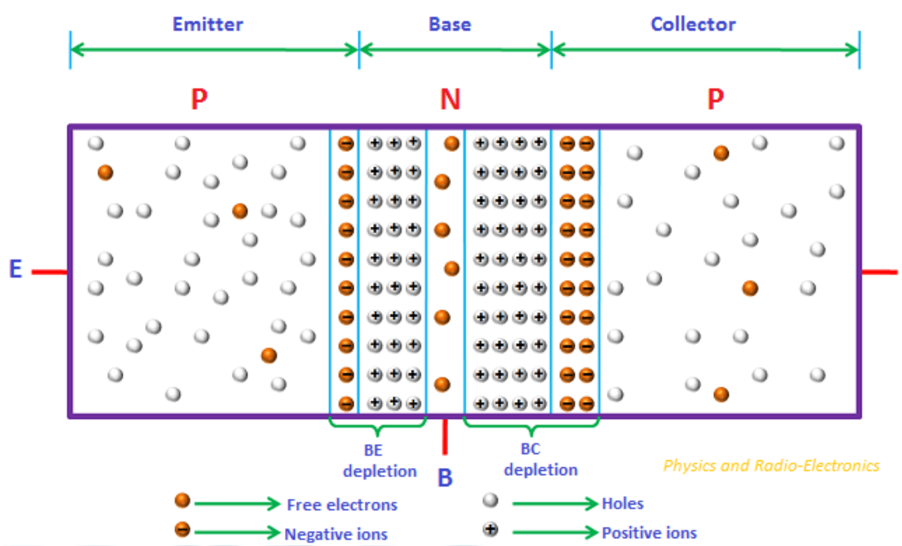
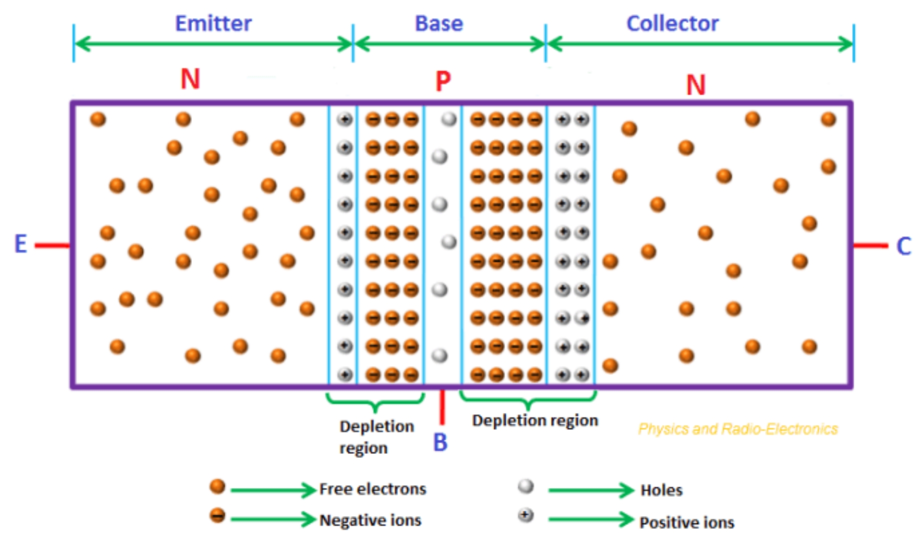
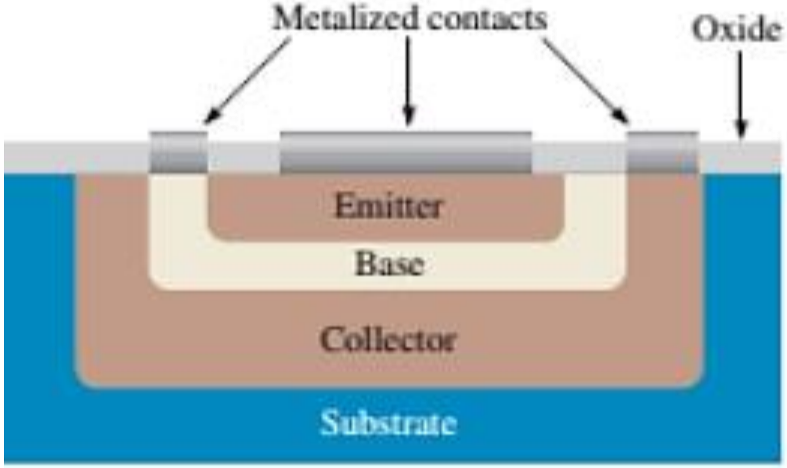
➢BASIC CONSTRUCTION OF BJT, 2

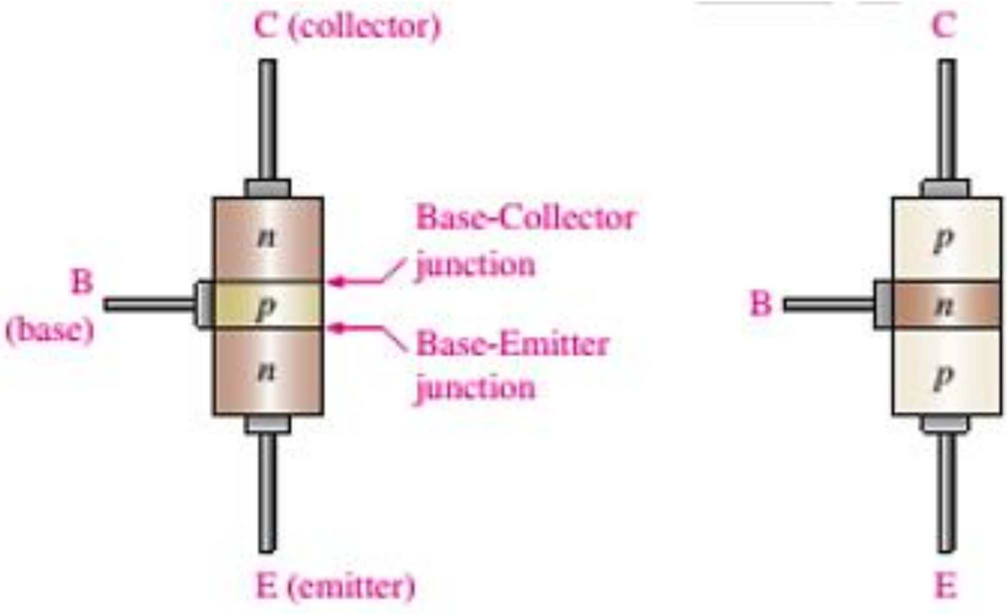
- **Doping Levels**
  - ✓ The emitter is heavily doped. On the other hand, the base is lightly doped. The doping level of the collector is intermediate.
  - ✓ The collector is physically the largest of the three regions.
- The result of combination is two depletion layers, the barrier potential is 0.7 V at 25°C for a Si transistor (0.3 V at 25°C for a Ge transistor).





➢BASIC CONSTRUCTION OF BJT, 3





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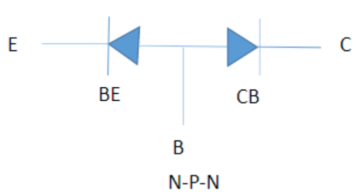
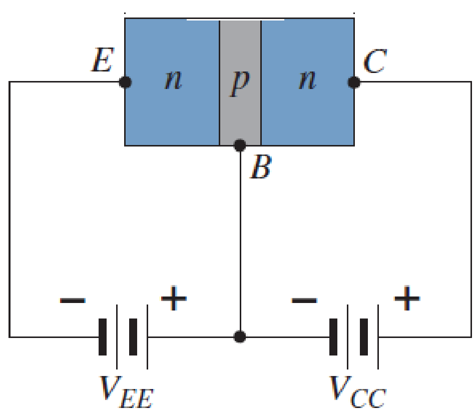
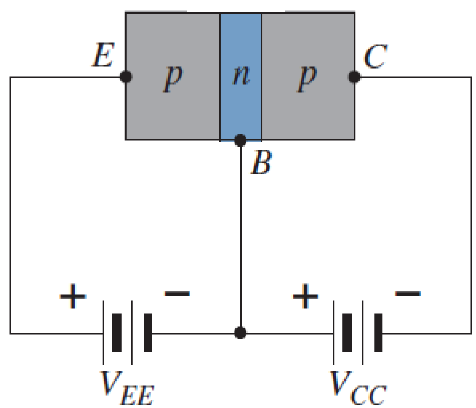
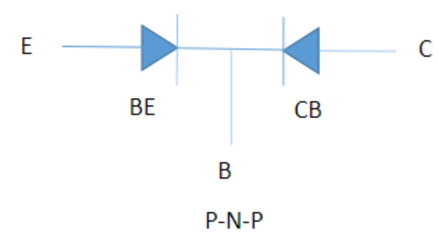
➢ OPERATION PRINCIPLES, 1

- ✓ An unbiased npn transistor is like two back-to-back diodes. Each diode has a barrier potential of approximately 0.7 V.
- ✓ When external voltage sources are connected to the transistor, currents pass through the different parts of the transistor .
- ✓ The transistor is usually biased by connecting sources to its terminals



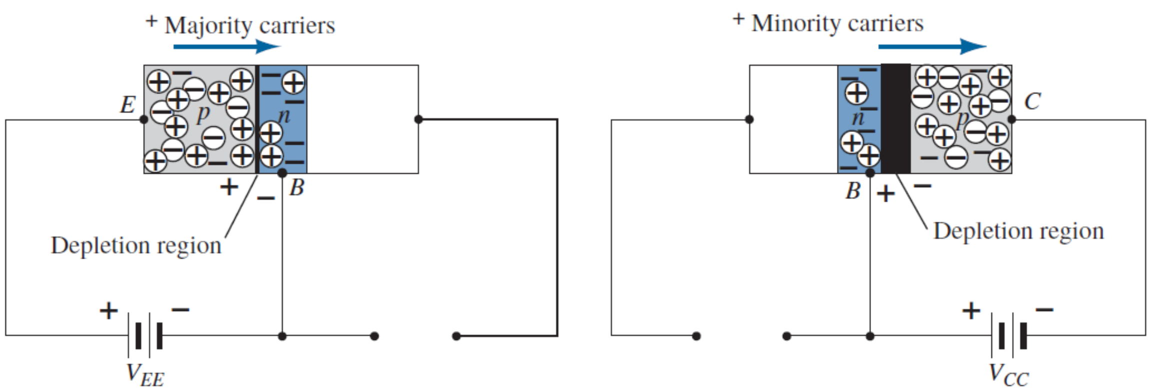






OPERATION PRINCIPLES, 2

- Both pnp and npn transistors have the same basic operation.
- The operation is exactly the same if the roles played by the electron and hole are interchanged.
- If the base-emitter bias circuit only connected, the depletion region is reduced in width due to the applied bias, resulting in a heavy flow of majority carriers from p- to n-type material.
- Now remove the base-emitter bias and back the base-collector bias. The np junction is reverse biased.
- Therefore: One pn junction of a transistor is reverse-biased, whereas the other is forward biased.



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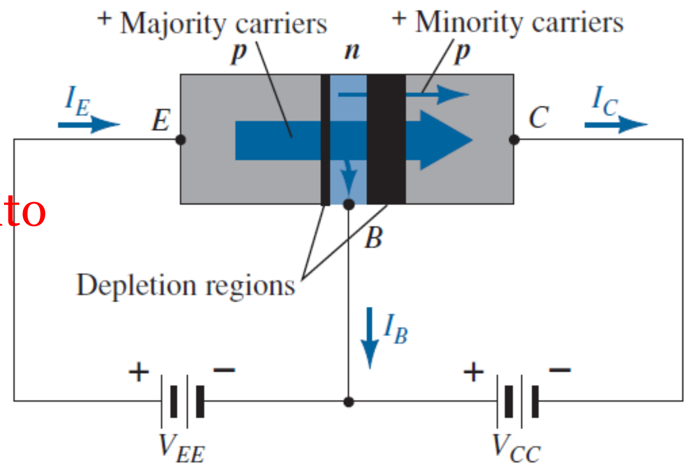
➢ OPERATION PRINCIPLES, 2

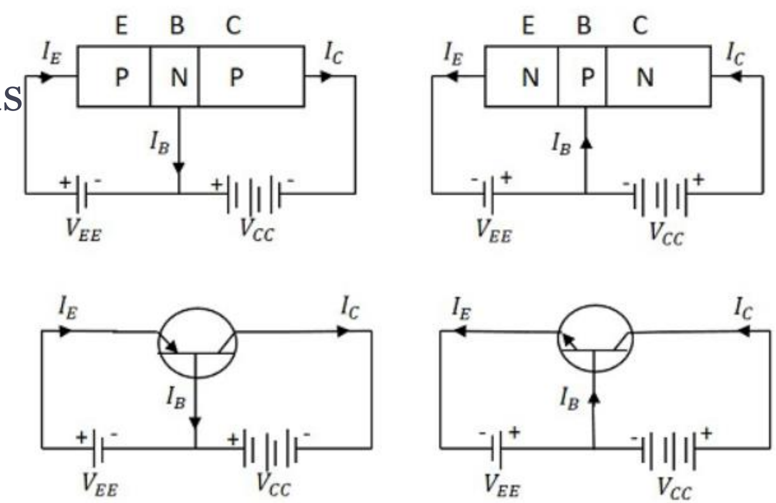
- When both biasing voltages are applied to a pnp transistor, a large number of majority carriers will diffuse across the forward biased p–n junction into the n-type material.
- A very small number of majority carriers (microamperes) will take path to the base terminal.
- The larger number of these majority carriers will diffuse across the reverse-biased junction into the p-type material connected to the collector terminal.

- The reason is that, for the reverse-biased diode, the injected majority carriers will appear as minority carriers in the n-type material.
- It means, there is an injection of minority carriers into the n-type base region material.



➢ OPERATION PRINCIPLES, 3

- The N-type material is provided negative supply and P-type material is given positive supply to make the circuit Forward bias.
- The N-type material is provided positive supply and P-type material is given negative supply to make the circuit Reverse bias.
- By applying the power, the emitter base junction is always forward biased as the emitter resistance is very small.
- The collector base junction is reverse biased and its resistance is a bit higher.
- A small forward bias is sufficient at the emitter junction whereas a high reverse bias has to be applied at the collector junction.
- Conventional Current, is the movement of hole current which is opposite to the electron current.



P-N-P Transistor biasing

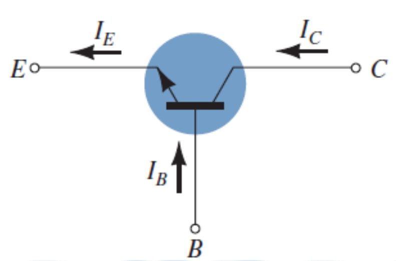
N-P-N Transistor biasing

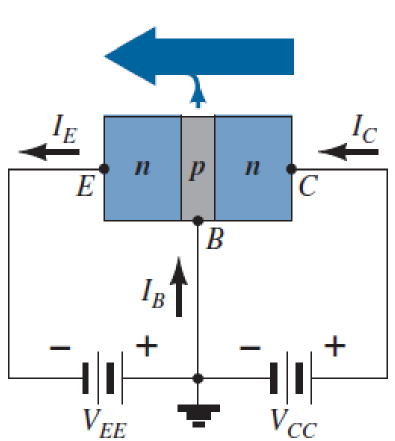
➢ OPERATION PRINCIPLES, 4

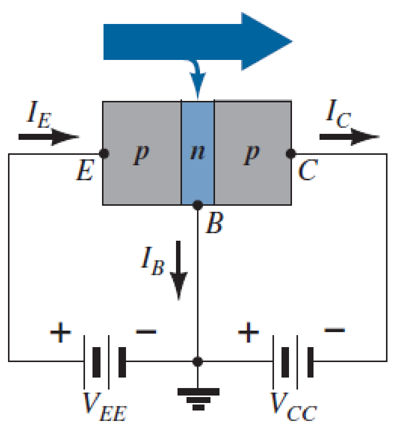
- In short, all the minority carriers in the depletion region will cross the reverse-biased junction.
- Applying KCL to the transistor as if it were a single node, we obtain :

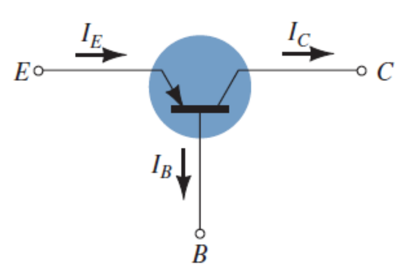
$$I_E = I_C + I_B$$

- That's way the arrow in the graphic symbol of the BJT defines the direction of emitter current (conventional flow) through the device.
- Also, there are three terminal voltages, i.e. V_E, V_C and V_B
- The voltage between each two terminals is indicated to by the letters of the terminals, V_{BE}, V_{CE} and V_{CB}
- The base current is much smaller than the collector current: $I_B << I_C$
- Hence, $I_C \approx I_E$



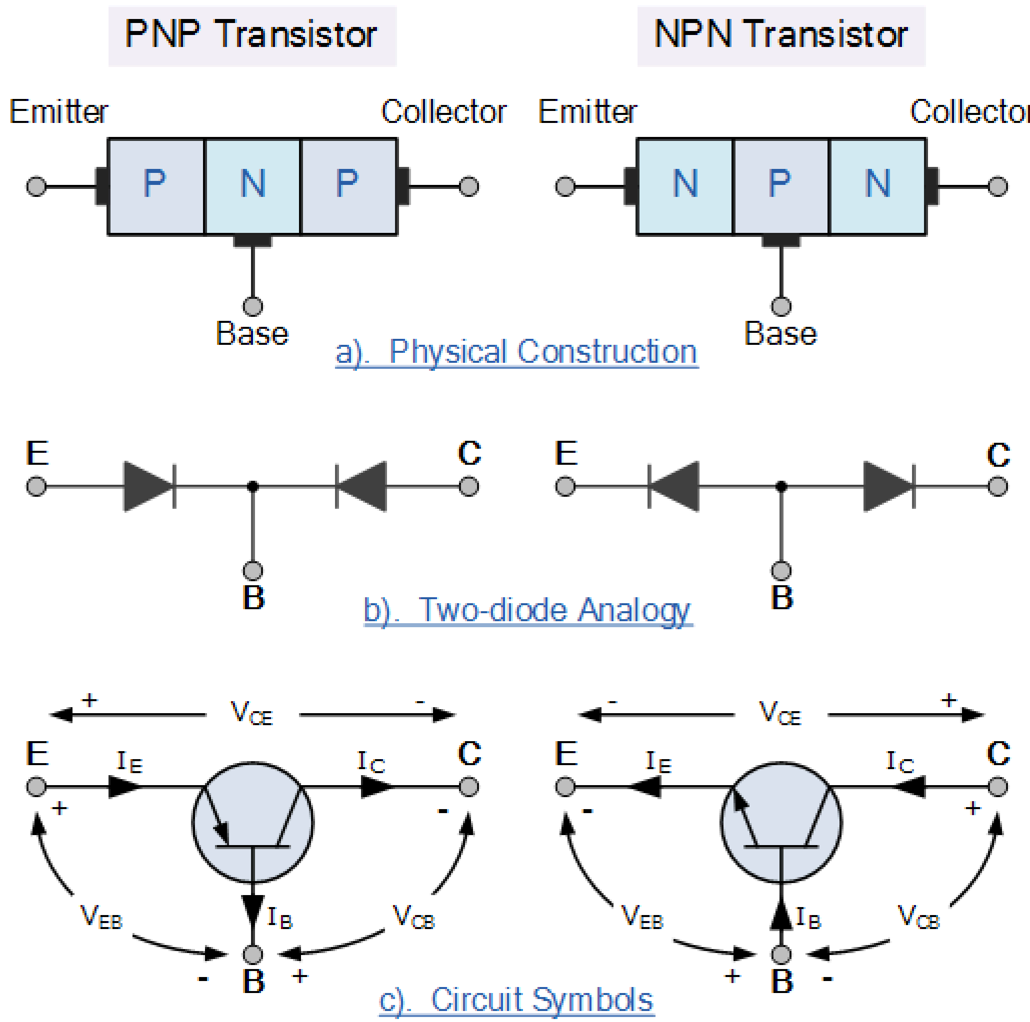






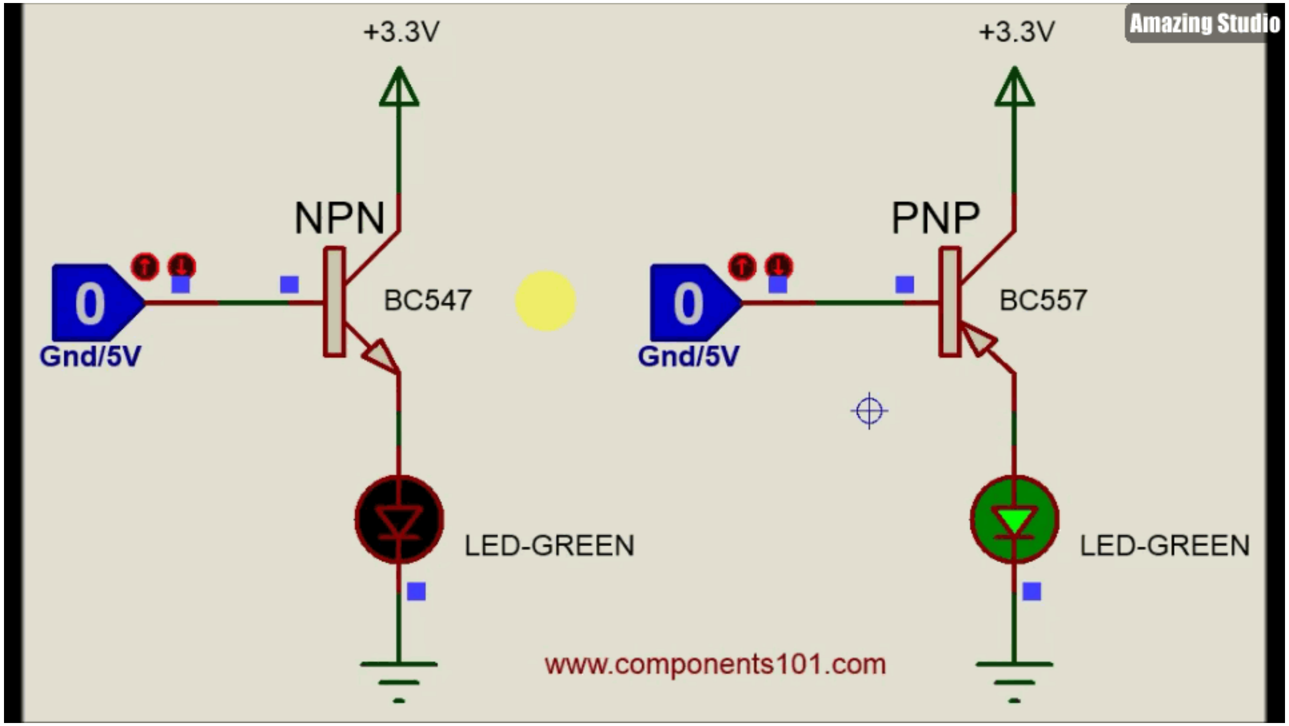
➢ OPERATION PRINCIPLES, 5

- Voltages and Currents are described in the figure.



➢ THE BJT as A SWITCH

- A BJT transistor can be used as an electronic switch as to control devices such as lamps, motors and solenoids etc.
- When a voltage is applied on the base, current passes throughout the transistor via the collector and the emitter into the load.



➢ THE BJT as an AMPLIFIER

➢ DC Alpha

✓ The dc alpha (α_{dc}) is defined as the dc collector current divided by the dc emitter current:

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

✓ Since the collector current almost equals the emitter current, the α_{dc} is slightly less than 1. In a low-power transistor the α_{dc} is typically greater than 0.99.

➢ DC Beta

✓ The dc beta (β_{dc}), also known as the current gain of a transistor, is defined as the ratio of the dc collector current to the dc base current:

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

✓ The β_{dc} is the most important property of a transistor, and normally is given by the manufacturer. For under 1 W transistors, β_{dc} is typically 100 to 300; while it is about 20 to 100 for High-power transistors.

➢ DC OPERATING PONT, 1

➢ **BJT Characteristic Curves**

✓ **The characteristics curves are described for every BJT transistor.**

✓ **The relation between the current and voltage is graphically represented.**

✓ **The BJT has three terminals, so many curves can be obtained based on the voltage supply variations at any terminal.**

✓ **To describe the behavior of a three-terminal device, two sets of characteristics are represented, i.e one for the driving point (input) and the other for the output.**

✓ **However, such curves will highly depending on the way the three terminals are connected (BJT configuration).**

➢ DC OPERATING PONT, 2

➢ **BJT Curve Explanation**

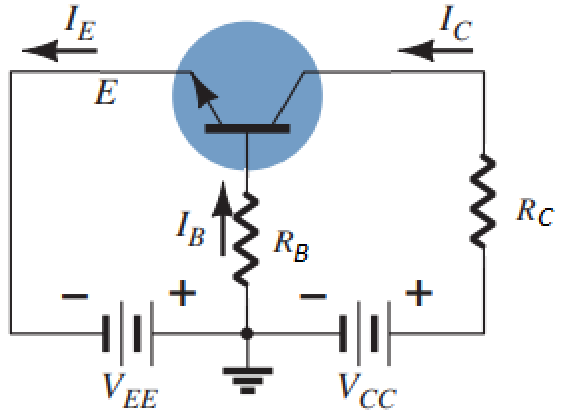
✓ The characteristics curves are graphically described by two sets of characteristics.

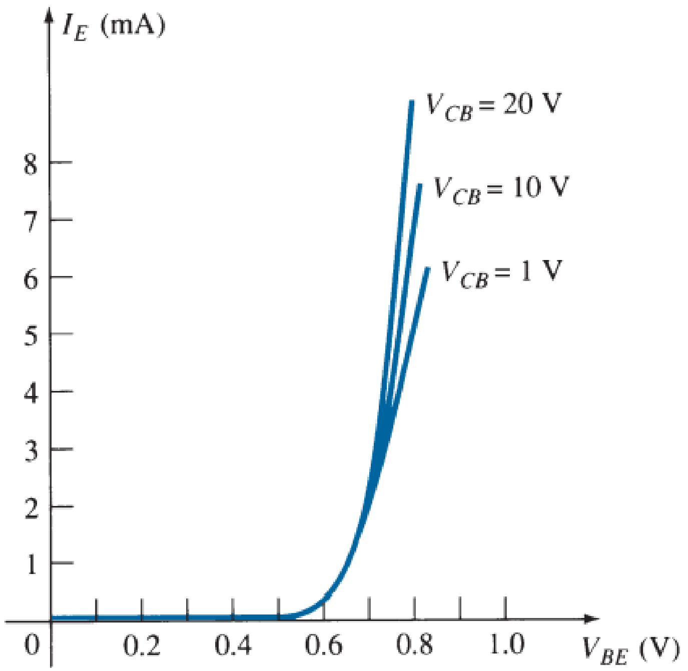
✓ Firstly, by relating the input parameters for various output parameters.

✓ For example, for the circuit shown in the figure, th driving voltage V_{BE} and I_E are drown for various levels of output voltages V_{CB}.

✓ In this case, it looks like the curve of an ordinary diode as shown in following Figure.

✓ It is a forward-biased emitter diode, so it is as the usual diode curve.





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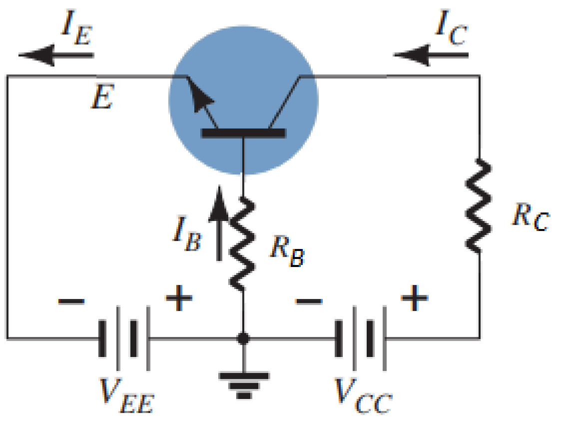
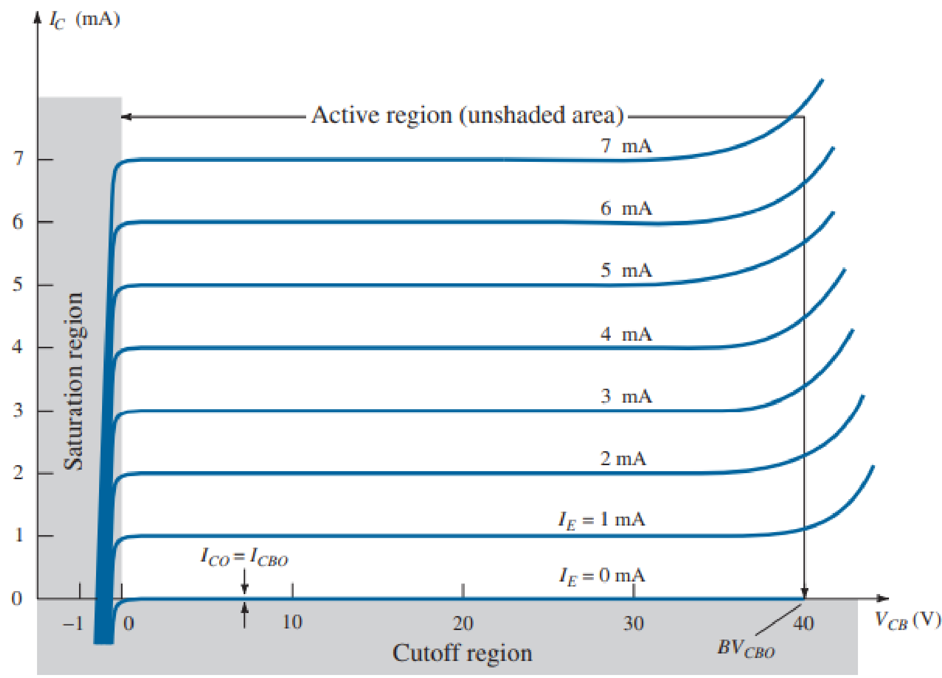
➤ DC OPERATING PONT, 3



➤ BJT Curve Explanation

- ✓ The characteristics curves are graphically described by two sets of characteristics.
- ✓ Second, is the output set that relates the output parameters for various input variables.



- ✓ For example, the current I_C to an output voltage V_{CB} for various levels of input current I_E as shown in the figure.
- ✓ The output or collector set of characteristics has three basic regions.

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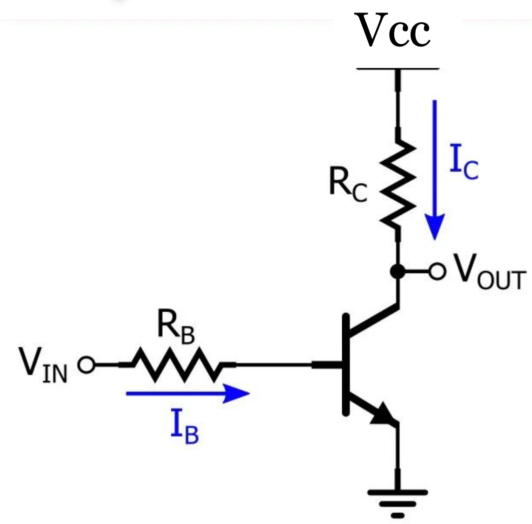
➢ BJT Regions of Operation, 1

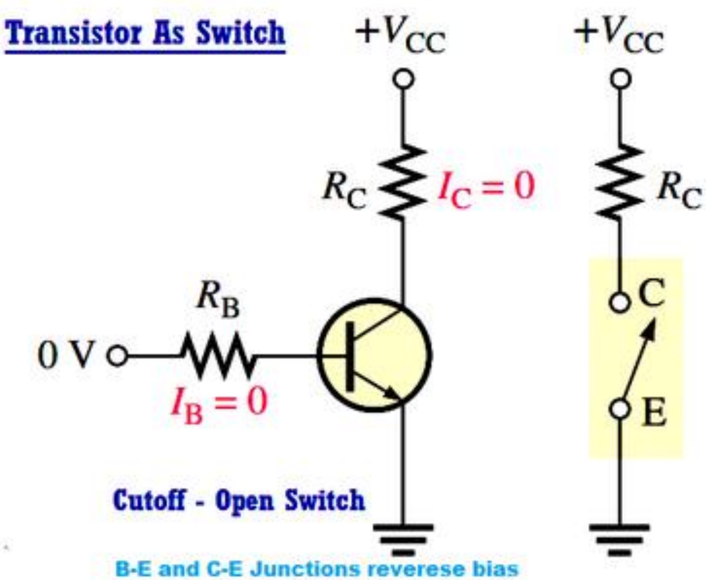
- **The BJT transistors have three basic regions of operation.**
- **The BJT gets into each region of operation based on the DC supply.**
- **The polarity of the supply would make junctions forward or reverse biased.**
- **Therefore, a supply of a dc voltage is called as biasing. Either forward or reverse biasing is done to the emitter and collector junctions of the transistor.**
- **The biasing methods make the transistor circuit to work in three different regions: *Cutoff, Saturation,* and *Active* regions.**
- **All these regions are graphically represented.**

➢ BJT Regions of Operation, 2



➢ The *Cutoff Region*

- ✓ The cutoff region is defined as that region where the collector current is 0 A.
- ✓ In the cutoff region the base–emitter and collector–base junctions of a transistor are both reverse-biased.
- ✓ In this is the region the transistor behaves as an open switch.



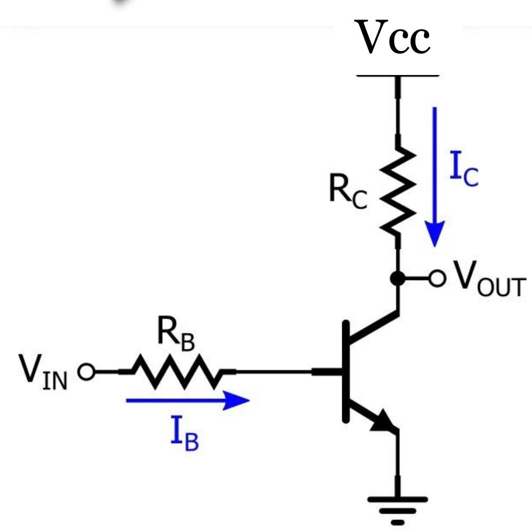
- ✓ However there is a very small collector current called the collector cutoff current.
- ✓ This is because the collector diode has reverse minority-carrier current and surface-leakage current.

$V_{CE} = V_{CC}$, $V_{BE} < 0.7V$ and $I_B = I_C = I_E = 0$

➢ BJT Regions of Operation, 3

➢ The *Saturation Region*

- ✓ In the saturation region , the collector diode has insufficient positive voltage to collect all the free electrons injected into the base.
- ✓ In the saturation region the base–emitter and collector–base junctions are forward-biased.
- ✓ In this is region, the transistor behaves as a closed switch.



- ✓ The transistor has the effect of its collector and emitter being shorted.
- ✓ The collector and emitter currents are maximum.

In this region: $I_C = I_E$ *and* V_{CE} *is very small.*

Transistor As Switch

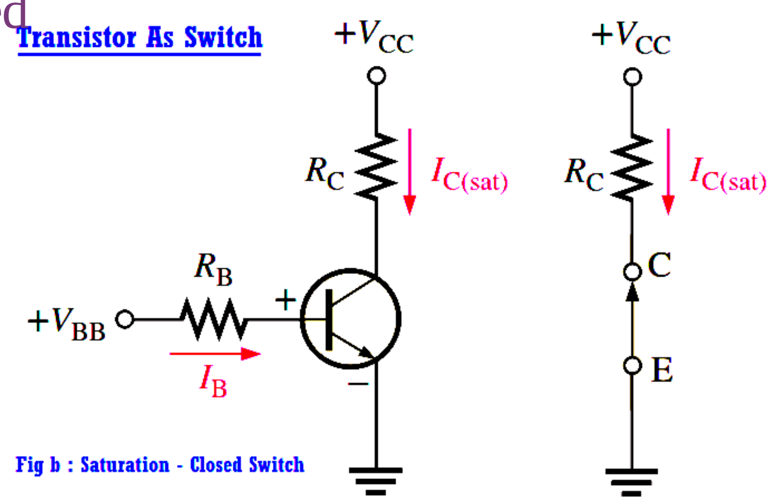
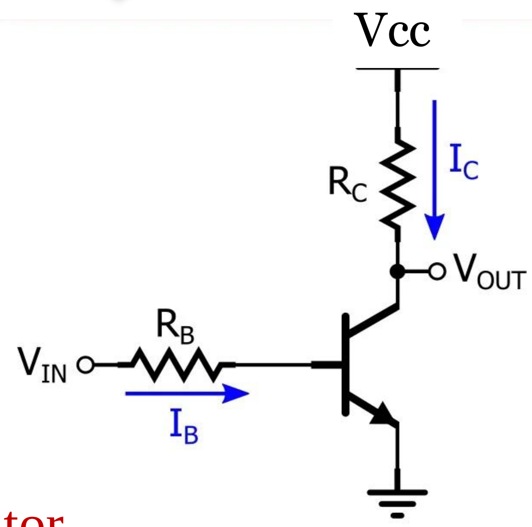


Fig b : Saturation - Closed Switch

➢ BJT Regions of Operation, 4

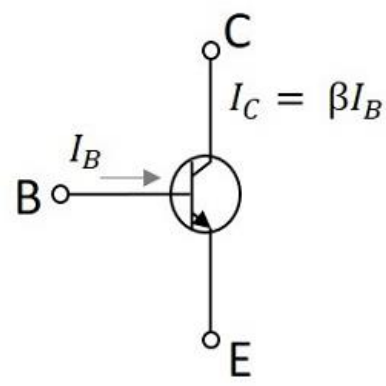


➢ The *Active Region*

- ✓ In the active region, the base–emitter junction is forward-biased, whereas the collector– base junction is reverse-biased.
- ✓ A transistor while in this region, acts as an Amplifier.

- ✓ This region represents the normal operation of a transistor.
- ✓ The collector is gathering almost all the electrons that the emitter has sent into the base.
- ✓ Also, changes in collector voltage have no effect on the collector current.
- ✓ So the collector current is constant in this region.

$$I_C = \beta I_B \quad \text{and} \quad V_{BE} = 0.7V \text{ (as a Si diode)}$$



In Active region

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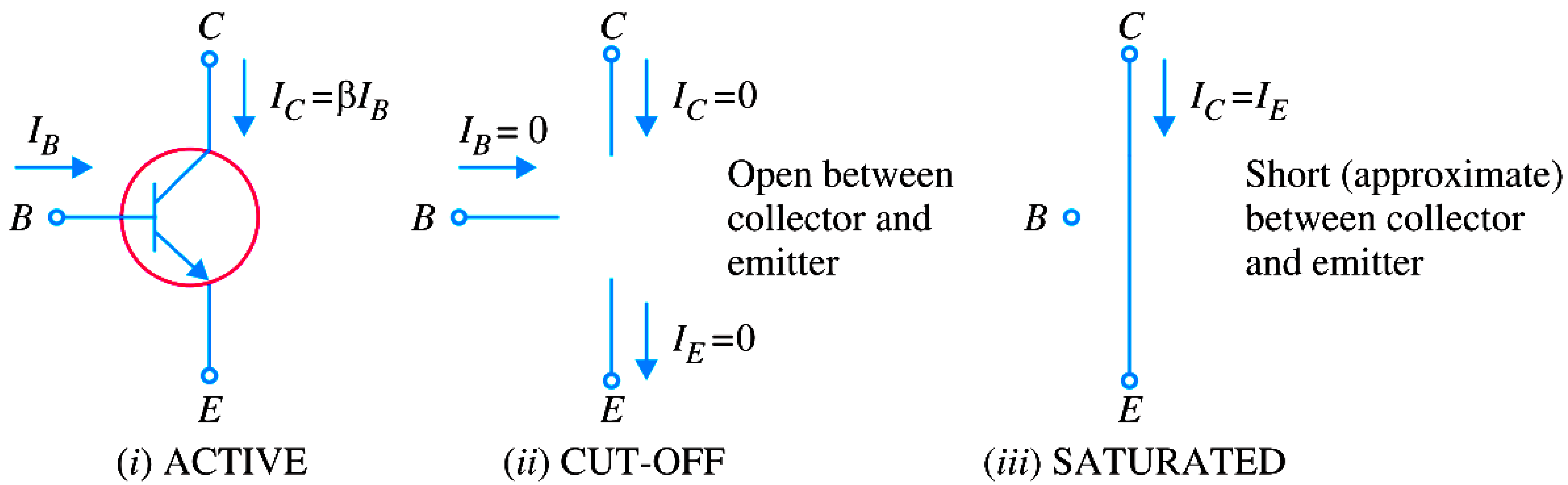
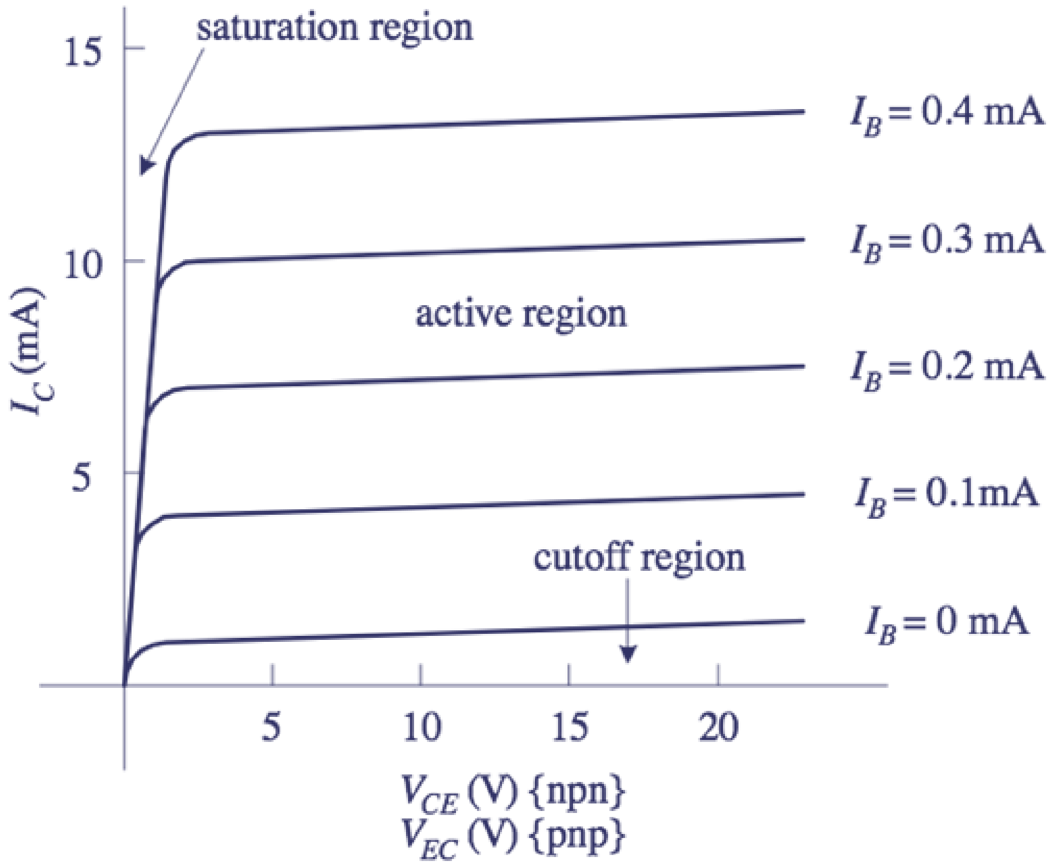
➢ BJT Regions of Operation, 5

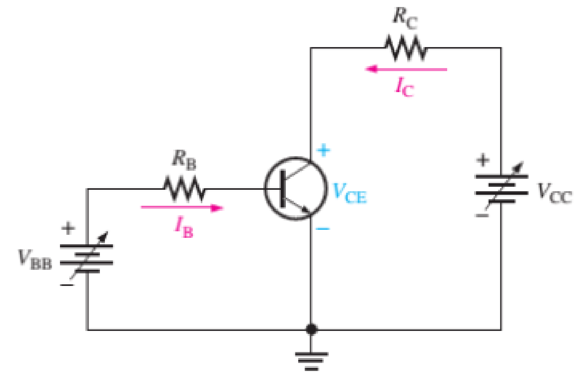
➢ Summary of The Three Regions



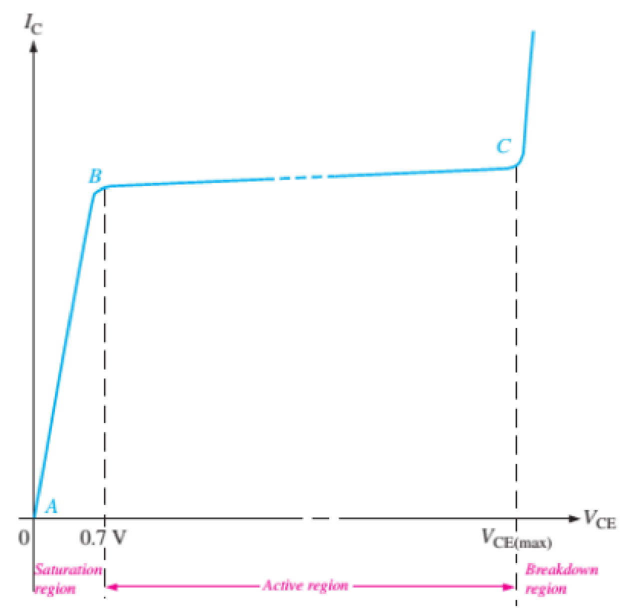
➢ BJT Regions of Operation, 6

- **The Regions of the BJT operation is represented by sketching the device characteristics curve.**





(a) Circuit



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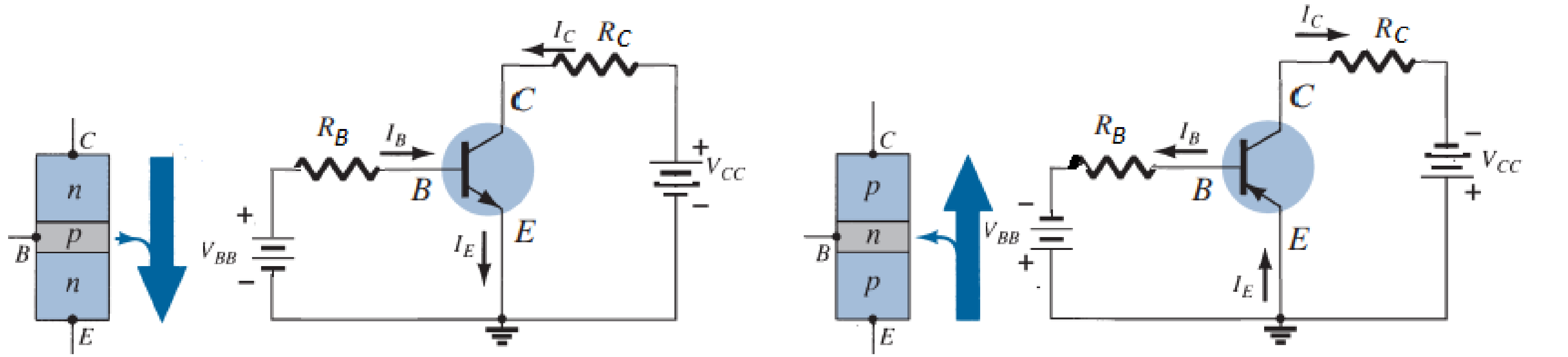
➢ BJT CONFIGURATION, 1

- The BJT configuration refers to the way the three BJT terminals are connected.
- There are three ways to configure (connect) a transistor:
  - ✓ Common Emitter (CE),
  - ✓ Common Collector (CC),
  - ✓ Common Base (CB).
- The term common refers to the fact that ground (common) side of each voltage source is connected to one terminal (both sources share one side ground at one terminal).
- In other words, one terminal of the BJT is common to both the input and output sides of the configuration.

➢ BJT CONFIGURATION, 2

➢ Common Emitter (CE), Circuit Description .

- ✓ In this configuration the emitter is common to both the input and output terminals.
- ✓ This configuration is most widely used configuration.
- ✓ As shown in the figure, this configuration comprises of two loops; the base
- ✓ loop, and the collector loop.
- ✓ In the base loop, the V_{BB} forward biases the emitter diode with R_B limiting the current.
- ✓ The base current controls the collector current. It means that a small base current controls a large collector current.



➢ BJT CONFIGURATION, 3

➢ Common Emitter (CE), Circuit Equations.

✓ The current and voltage relations can be developed for this circuit as follows:

$$I_E = I_C + I_B$$

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

$$V_{R_B} = V_{BB} - V_{BE}$$

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

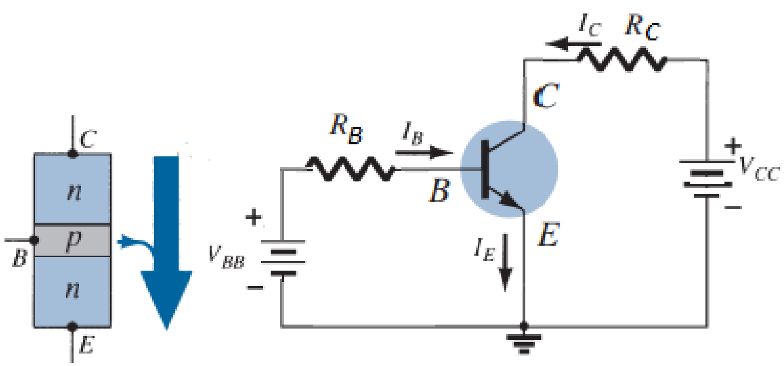
$$V_{CE} = V_{CC} - V_{R_C}$$

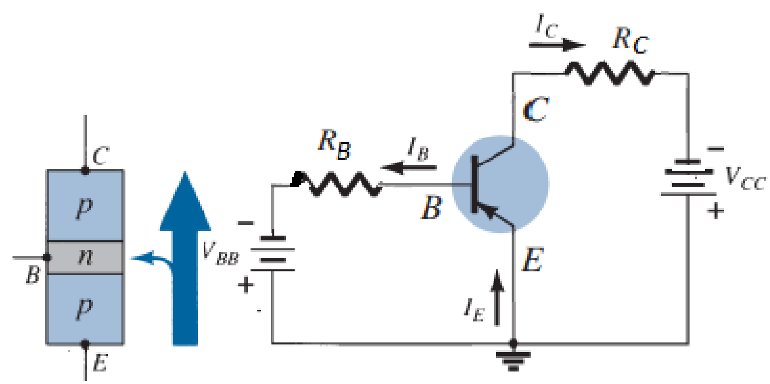
$$V_{R_C} = I_C * R_C$$

$$I_C = I_E\, \alpha_{dc}$$

$$V_{CE} = V_{CC} - I_C * R_C$$

$$P_D = V_{CE} * I_C$$



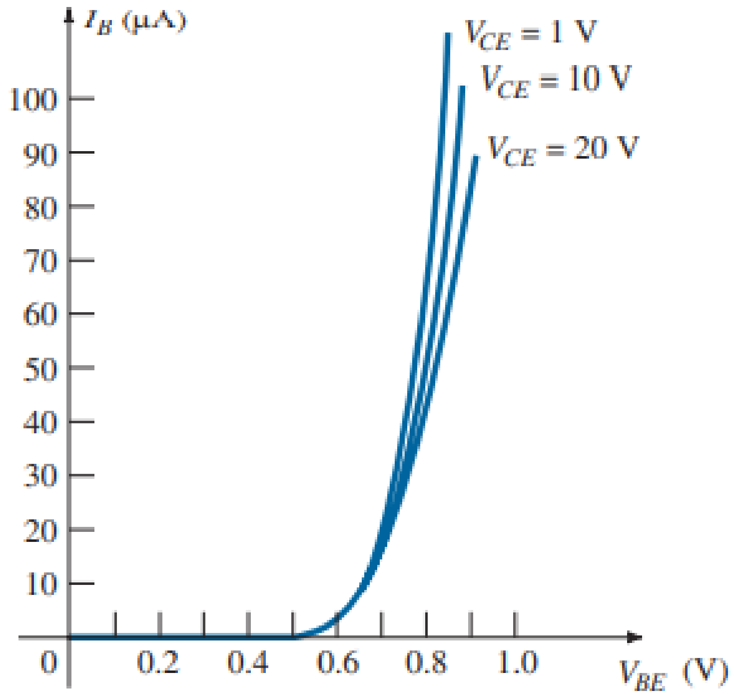


➤ BJT CONFIGURATION, 4

➤ Common Emitter (CE), Characteristic Curves.

➤ Input Circuit Characteristics

- ✓ The input circuit is the base emitter side. Its characteristics are a plot of the input current I_B versus the input voltage V_{BE}.
- ✓ This is done for a range of values of output voltage V_{CE}.
- ✓ As indicated earlier, The curve of the input circuit represents an ordinary diode as illustrated in the Figure.

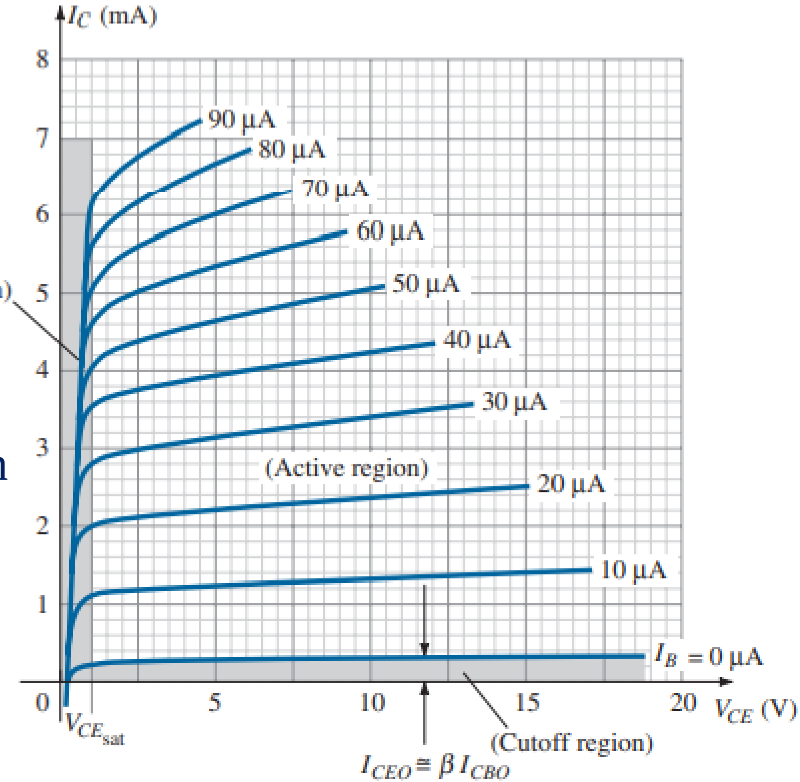


➢ BJT CONFIGURATION, 5

➢ Common Emitter (CE), Characteristic Curves.

➢ Output Circuit Characteristics

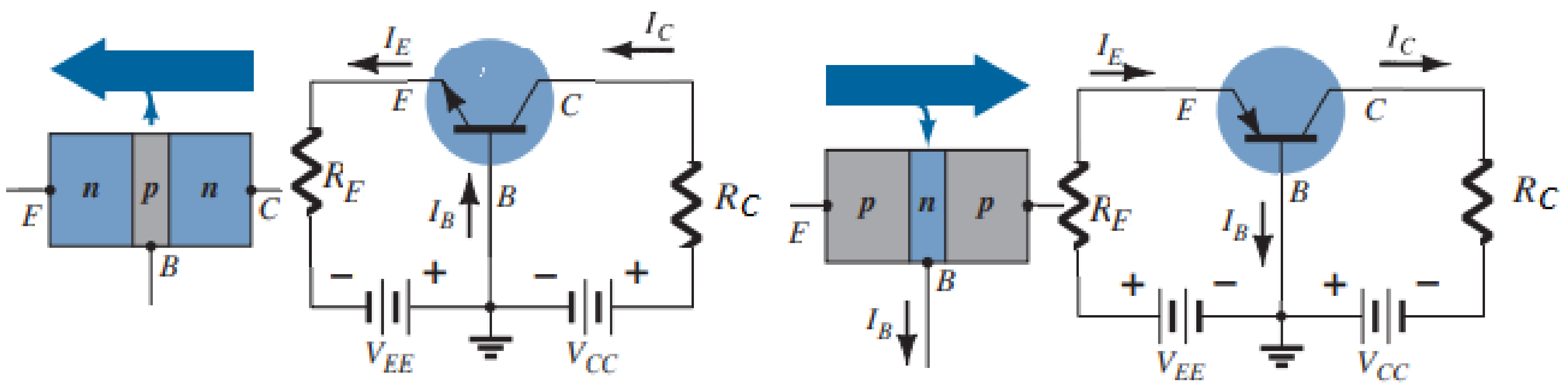
- ✓ The output circuit characteristic is the plot of the output current I_C versus output voltage V_{CE} for a range of values of input current I_B .
- ✓ Varying V_{BB} and V_{CC} to produce different transistor voltages and currents. By measuring I_C and V_{CE}, the graph is plotted.
- ✓ In CE configuration, the active region (V_{CE} is between 1 and 40 V) represents the normal operation of a transistor; the emitter diode is forward biased, and the collector diode is reverse biased.
- ✓ Changes in collector voltage have no effect on the collector current.



➢ BJT CONFIGURATION, 6

➢ Common Base (CB), Circuit Description .

- ✓ In this configuration the Base is common to both the input and output sides.
- ✓ When the transistor in the "on" or active state the voltage from base to emitter will be 0.7 V at any level of emitter current.

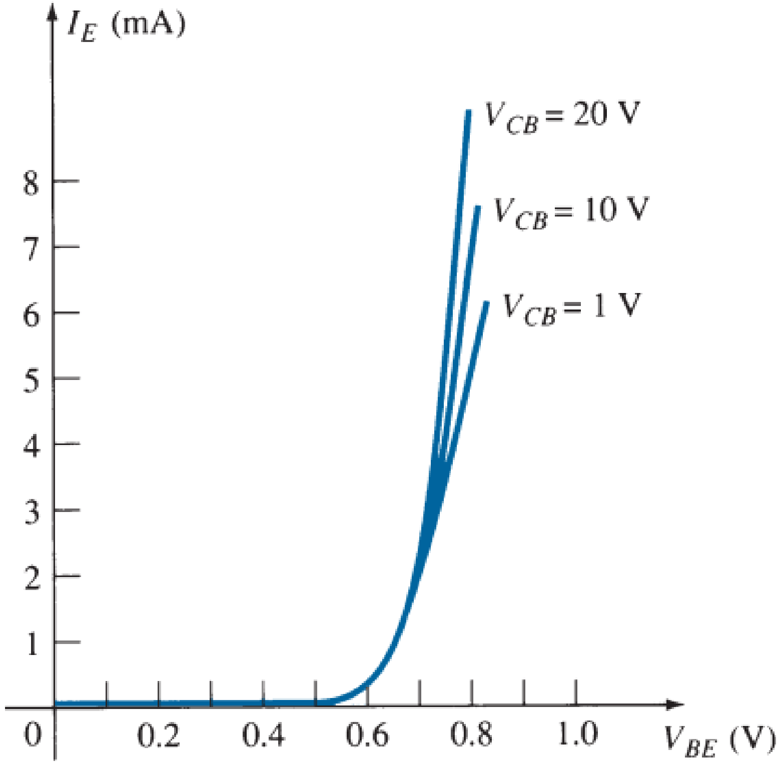


➢ BJT CONFIGURATION, 7

➢ Common Base (CB), Characteristic Curves.

➢ Input Circuit Characteristics

- ✓ The input circuit is the base emitter side. Its characteristics are a plot of the input current I_E versus the input voltage V_{BE}.
- ✓ This is done for a range of values of output voltage V_{CB}.
- ✓ The variation of the collector – base voltage, V_{CB} has a little effect on the characteristic input curve.

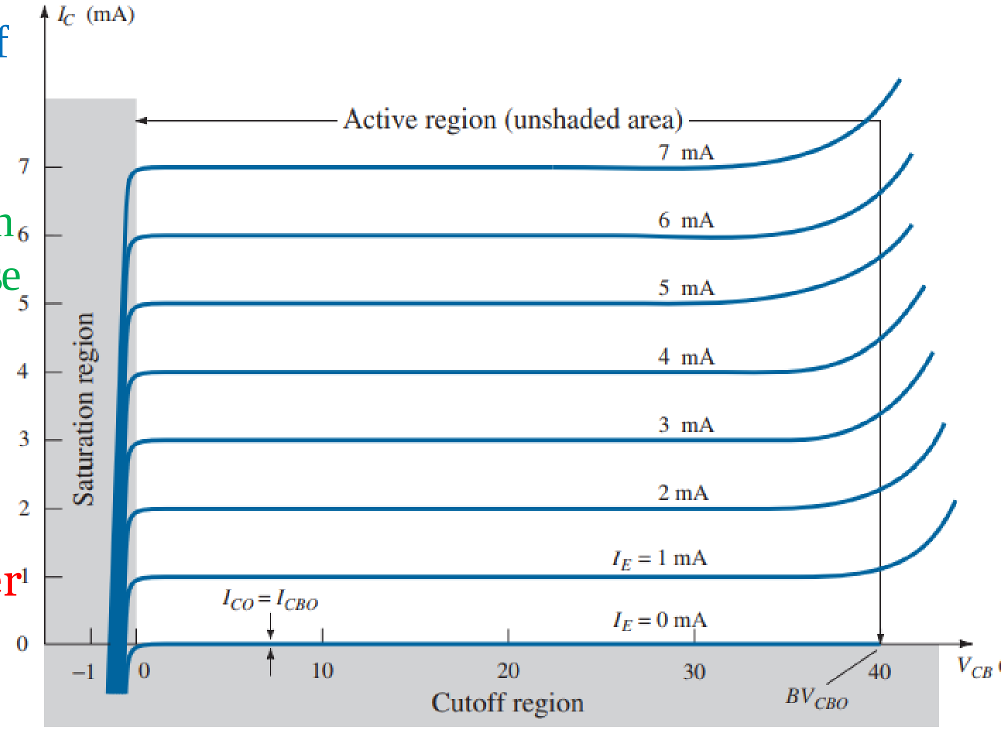


➢ BJT CONFIGURATION, 9

➢ Common Base (CB), Characteristic Curves.

➢ Output Circuit Characteristics

- ✓ The output circuit characteristic is the plot of the output current I_C versus output voltage V_{CB} for a range of values of input current I_E.
- ✓ In the active region 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.



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➢ BJT CONFIGURATION, 10

➢ Common Base(CB), Circuit Equations.

✓ The current and voltage relations can be developed for this circuit as follows:

$$V_{EE} = V_{EB} + V_{R_E}$$

$$V_{R_E} = I_E * R_E$$

$$I_C = \frac{V_{EE} - V_{EB}}{R_E}$$

$$\boldsymbol{V_{CC} = V_{CB} + I_C * R_C}$$

$$\mathbf{I}_C = \frac{\boldsymbol{V_{CC} - V_{CB}}}{\mathbf{R}_C}$$

$$\boldsymbol{V_{R_C} = V_{CC} - V_{CB}}$$

$$\alpha_{dc} = \frac{I_C}{I_E} \rightarrow \boldsymbol{I_C} = \alpha_{dc}\, I_E$$

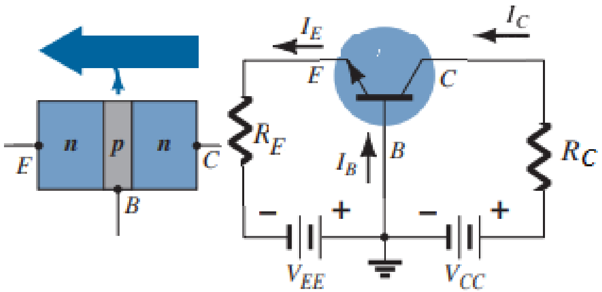
$$\boldsymbol{\beta_{dc} = \frac{I_C}{I_B} \rightarrow I_C = \beta_{dc}\, I_B}$$

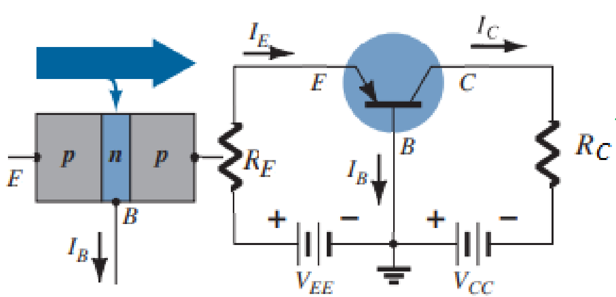
$$\boldsymbol{I_E = I_C + I_B \rightarrow I_E = \beta_{dc}\, I_B + I_B}$$

$$\therefore \boldsymbol{I_E = (\beta_{dc} + 1) I_B = \frac{I_C(\beta_{dc} + 1)}{\beta_{dc}}}$$

$$\boldsymbol{I_E = I_C + I_B} \rightarrow \frac{I_C}{\alpha_{dc}} = \frac{I_C}{\boldsymbol{\beta_{dc}}} + I_C$$

$$\alpha_{dc} = \frac{\boldsymbol{\beta_{dc}}}{\boldsymbol{1+\beta_{dc}}} \text{ and } \qquad \boldsymbol{\beta_{dc}} = \frac{\alpha_{dc}}{\boldsymbol{1-}\alpha_{dc}}$$

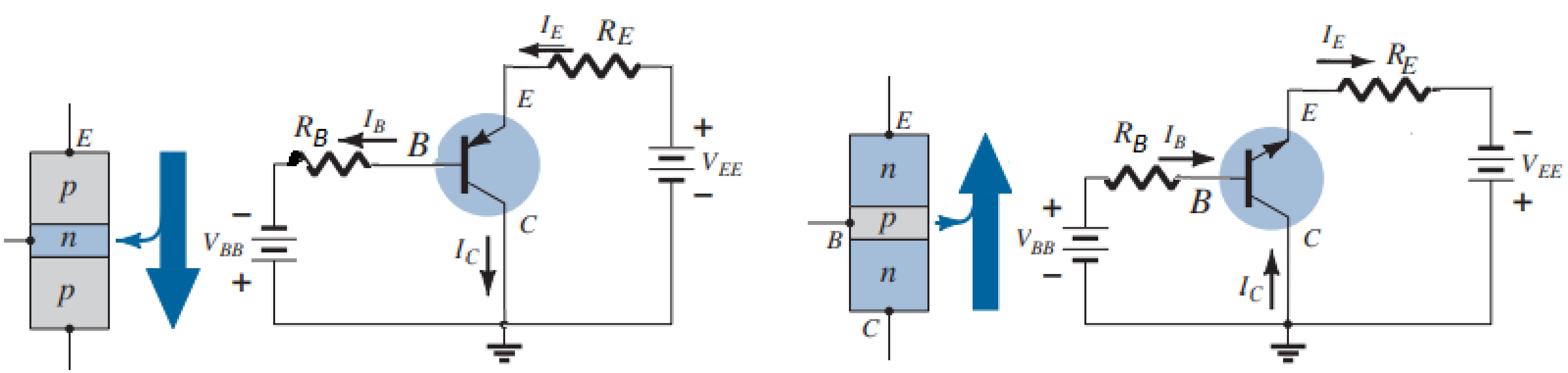




➢ BJT CONFIGURATION, 11

➢ Common Collector (CC), Circuit Description .

- In this configuration the Collector is common to both the input and output sides.
- The CC configuration is used primarily for impedance-matching purposes since it has a high input impedance and low output impedance, opposite to that of other two configurations.
- Its input characteristics is the same as for the CE characteristics.
- Also, its output characteristics are the same as for the CE configuration.



Dr Samieh Abu Saad

➢ EXAMPLES, 1

➢ Example 1

A transistor has a collector current of 10 mA and a base current of 40 A. What is the current gain of the transistor?`

The transistor current gain is $\beta_{dc} = \frac{I_C}{I_B} = \frac{10mA}{40\,000mA} = 250$

➢ Example 2

A transistor has a current gain of 175 and base current 0.1 mA, what is I_C?

The collector current is $I_C = I_B\ \beta_{dc} = 175 * 0.1mA = 17.5mA$

➢ Example 3

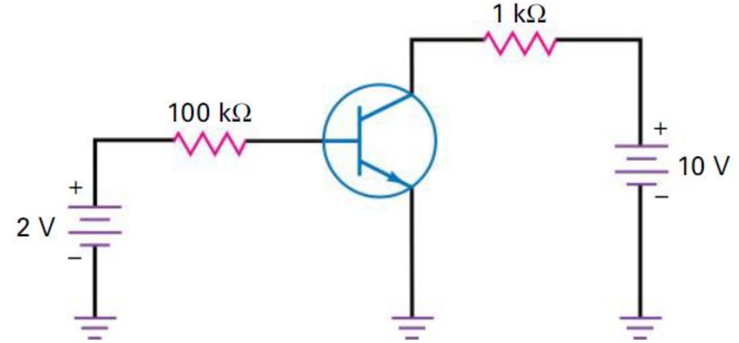
A transistor has a collector current of 2 mA and current gain 135, what is I_B?

The base current is $I_B = \frac{I_C}{\beta_{dc}} = \frac{2mA}{135} = 14.8\mu A$

➤ EXAMPLES, 2

➤Example 4

Calculate the I_B for the circuit. What is the V_{RB} and I_C if β_{dc} = 200?



Applying KVL for the base emmiter loop:

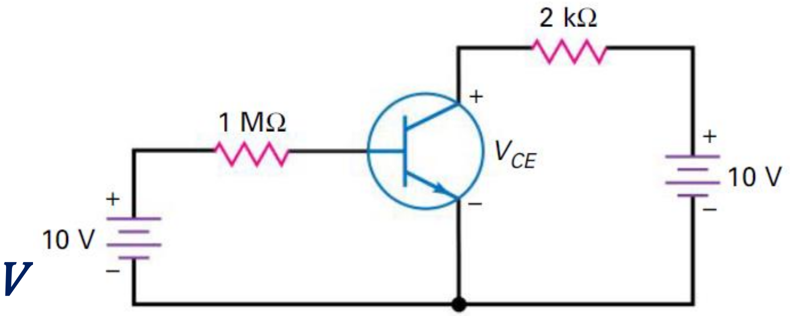
$$V_{RB} = V_{BB} - V_{BE} = 2V - 0.7V = 1.3V$$

$$\therefore I_B = \frac{V_{RB}}{R_B} = \frac{1.3V}{100K\Omega} = 13\mu A$$

$$\therefore I_C = I_B\ \beta_{dc} = 200 * 13\mu A = 2.6mA$$

➤Example 4

The transistor in the figure has β_{dc} = 300. Calculate I_B , I_C, V_{CE}, and P_D?



$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{10V - 0.7V}{1M\Omega} = 9.3\mu A$$

$$I_C = I_B\ \beta_{dc} = 300 * 9.3\mu A = 2.79mA$$

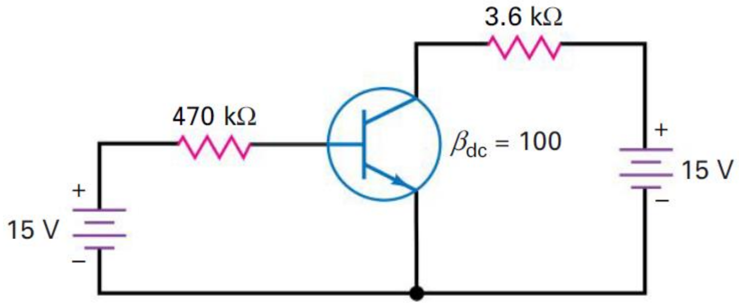
$$V_{CE} = V_{CC} - V_{RC} = 10V - 2K\Omega * 2.79mA = 4.42\ V$$

$$P_D = V_{CE} * I_C = 4.42\ V * 2.79mA = 12.33mW$$

➤ EXAMPLES, 3

➤ Example 5

Calculate the V_{CE} for the following circuit?



$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{15V - 0.7V}{470K\Omega} = 30.4\mu A$$

$$\therefore\ I_C = I_B\ \beta_{dc} = 100 * 30.4\mu A = 3.04mA$$

$$V_{CE} = V_{CC} - V_{RC} = 15V - 3.6K\Omega * 3.04mA = 4.06$$

➤ Example 6

For the previous circuit if V_{BE} is 1V, what is the V_{CE}?

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{15V - 1V}{470K\Omega} = 29.78\mu A$$

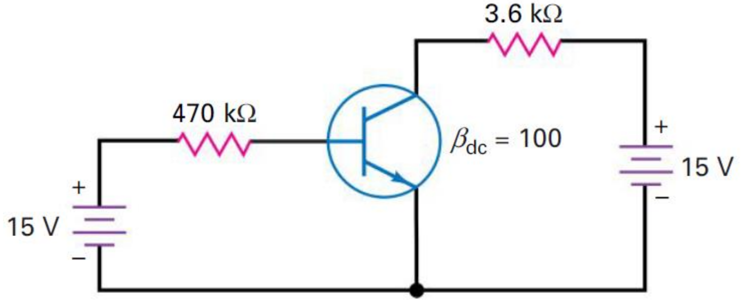
$$I_C = I_B\ \beta_{dc} = 100 * 29.78\mu A = 2.98mA$$

$$V_{CE} = V_{CC} - V_{RC} = 15V - 3.6K\Omega * 2.98mA = 4.27V$$

➢ EXAMPLES, 4

➢ Example 7

Calculate the V_{CE} for the following circuit?



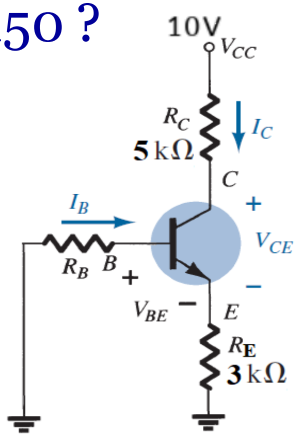
$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{15V - 0.7V}{470K\Omega} = 30.4\mu A$$

$$\therefore\ I_C = I_B\ \beta_{dc} = 100 * 30.4\mu A = 3.04mA$$

$$V_{CE} = V_{CC} - V_{RC} = 15V - 3.6K\Omega * 3.04mA = 4.06$$

➢ Example 8

For the following circuit determine I_E , V_E , I_C , V_C , I_B where β = 150 ?



Bothe base and emitter nodes are grounded, therefore the emitter-base junction is not conducting, so:

V_E = 0V, V_B = 0V , V_{BE} = 0V, I_B = 0mA and I_E = 0mA.

applying KCL we find $I_C = I_E - I_B$ = 0 mA

use KVL to find V_{CE} : $V_{CE} = V_{CC} - I_E * R_E$ = 10V- 0*3K Ω = 10V

The transistor is working in the cutoff region (an open switch).

End of LECT 3