Electronic Circuits for Mechatronics (ELCT 609)

Spring 2021

Lecture 3: BJT Physical Structure & I-V Characteristics

Course Instructor: Dr. Eman Azab

GUC
German University in Cairo
الجامعة الألمانية بالقاهرة

Introduction

- Why we call it Transistor?
  - The name came as an abbreviation of the device job!

Transfer-Resistor

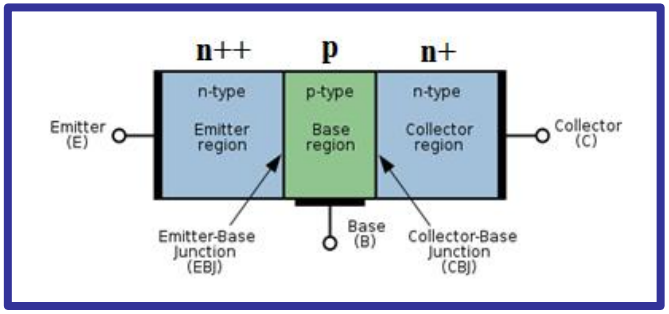
Bipolar Junction Transistor (BJT)

Physical Structure

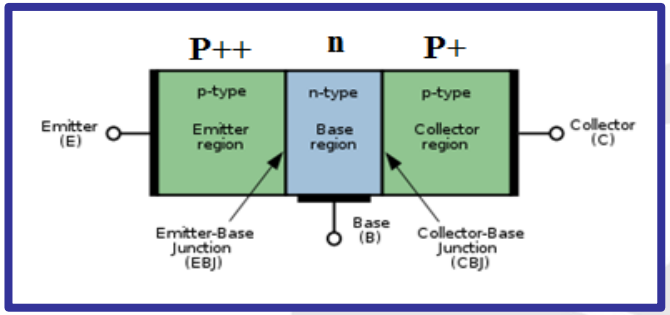
Course Instructor: Dr. Eman Azab
Contact: eman.azab@guc.edu.eg

BJT Physical Structure

- Two back to back PN Junctions
- NPN or PNP Transistor
- Three terminal device, for NPN: Base (**P-Type**), Emitter and Collector (**N-Type**)
  - Base-Emitter Junction (BE-J)
  - Base-Collector Junction (BC-J)
  - Emitter doping is higher than Collector doping



NPN BJT Transistor



PNP BJT Transistor

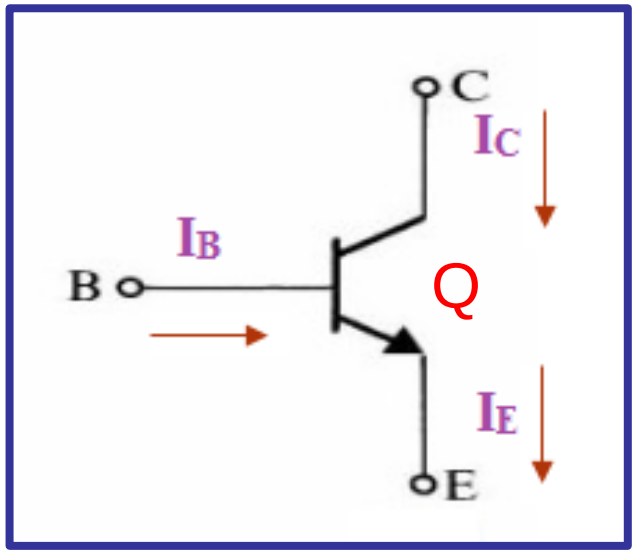
BJT Modes of Operation

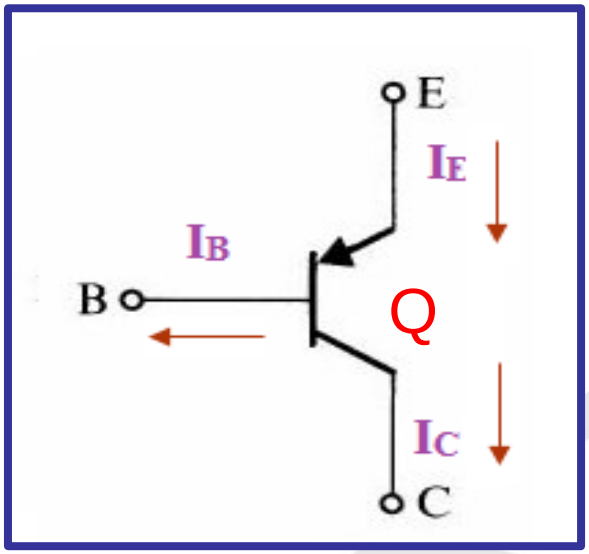
Electrical Equations of BJT: I-V Characteristics

GUC German University in Cairo
الجامعة الألمانية بالقاهرة

Course Instructor: Dr. Eman Azab
Contact: eman.azab@guc.edu.eg

BJT Circuit Symbol and Structure

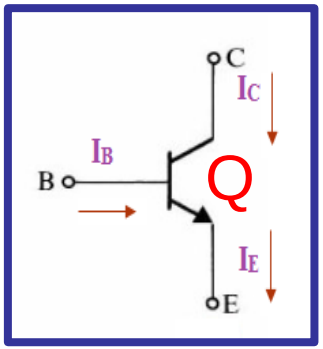




NPN BJT I-V characteristics

1. NPN Transistor in Cutoff Mode

- Base-Emitter Junction is Reverse biased
- Base-Collector Junction is Reverse biased

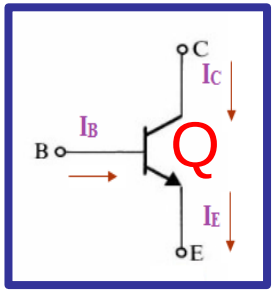


$$I_C = I_B = I_E = 0$$

NPN BJT I-V characteristics

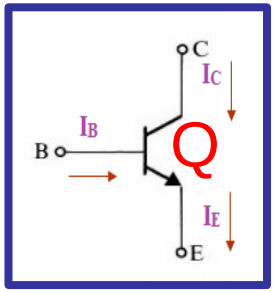
2. NPN Transistor in Forward Active Mode

- BE-J is Forward biased & BC-J is reverse biased
- Electrons pass across Base to the collector due to the Base small area (Electrons from the Emitter are collected at the Collector side)



NPN BJT I-V characteristics

2. NPN Transistor in Forward Active Mode (Cont.)



- BE-J is Forward biased & BC-J is reverse biased
- Electrons pass across Base to the collector due to the Base small area (Electrons from the Emitter are collected at the Collector side)
- The transistor's Collector current can be modeled by a **current/voltage dependent current source**
- I_s depends on doping and width of the Base

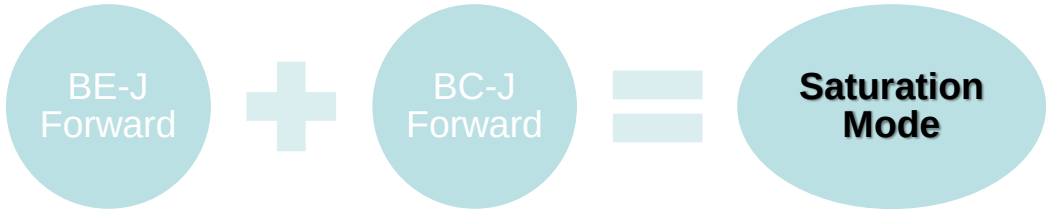
$$I_C = \beta_F I_B$$

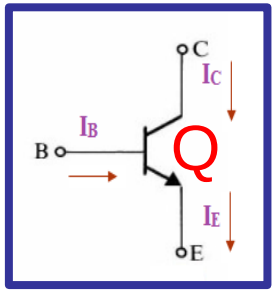
$$I_C = I_s \exp\left(\frac{V_{BE}}{V_T}\right)$$

NPN BJT I-V characteristics

3. NPN Transistor in Saturation Mode

- Both junctions are Forward biased
- The total current is the BE-J diffusion current opposite to BC-J diffusion current





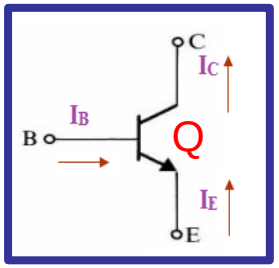
- BJT could be used as a closed switch in Saturation

$$V_{BE} \cong 0.7V \qquad V_{CE} \cong 0.2V$$

$$V_{BC} \cong 0.5V \qquad I_C < \beta_F I_B$$

NPN BJT I-V characteristics

4. NPN Transistor in Reverse Active mode



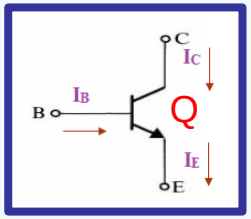
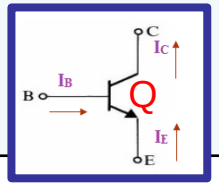
- BC-J is Forward biased
- BE-J Junction is reverse biased
- Emitter and collector reverse their roles
- However, BJT has an asymmetrical physical structure
- The current gain from Base to Emitter is very small

$$V_{BC} \cong 0.5V$$

$$I_E = \beta_R I_B$$

$$\beta_R << \beta_F$$

NPN BJT Modes of Operation

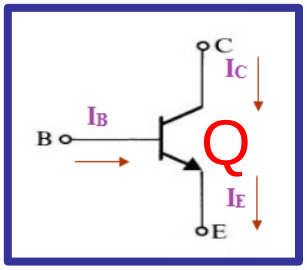
Mode	BEJ	BCJ	Equations	Condition
Cutoff	Reverse	Reverse	$I_C = I_E = I_B$=0	$V_{BE} < 0.7$ $V_{BC} < 0.5$
Active (Forward)	Forward 	Reverse	$V_{BE} \cong 0.7$ $I_E = I_C + I_B$ $I_C = I_s e^{\frac{V_{BE}}{V_T}}$ $I_C = \beta_F I_B = \alpha_F I_E$ $\alpha_F = \frac{\beta_F}{1+\beta_F}$	$V_{BC} < 0.5$ Or $V_{CE} > 0.2$
Saturation		Forward	$V_{BE} \cong 0.7$ $V_{BC} \cong 0.5$ $V_{CE} \cong 0.2$ $I_E = I_C + I_B$	$I_C < \beta_F I_B$
Reverse Active	Reverse 	Forward	$V_{BC} = 0.5$ $I_C = I_E + I_B$ $I_E = \beta_R I_B = \alpha_R I_C$ $\alpha_R = \frac{\beta_R}{1+\beta_R}$	$V_{BE} < 0.7$

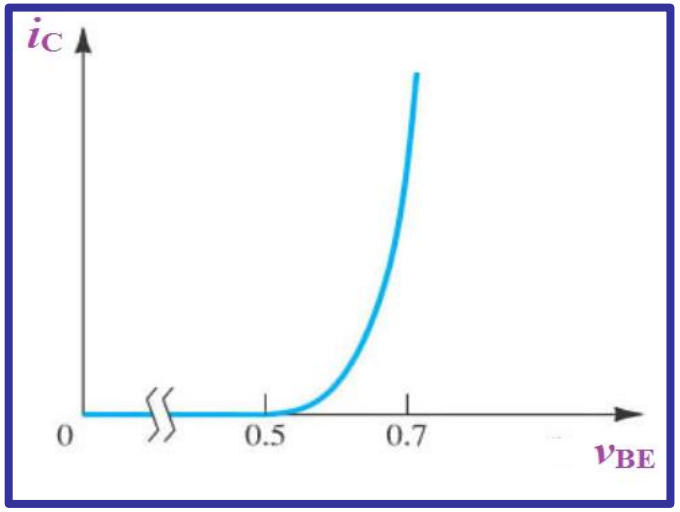
NPN BJT I-V Characteristics

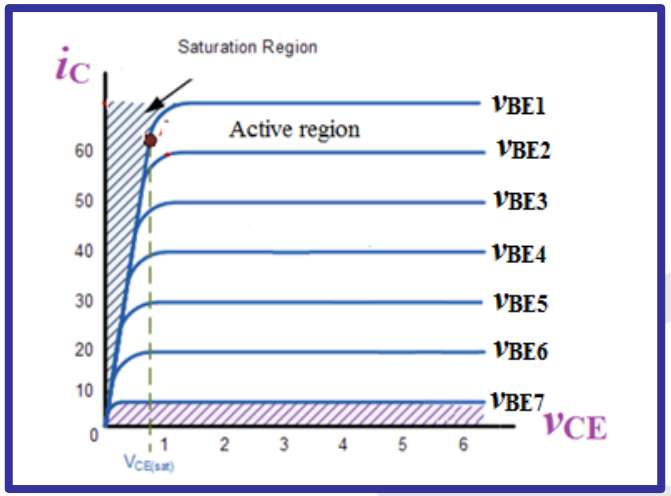
- **I_C versus V_{BE} and V_{CE}**

$$I_C = I_s \exp\left(\frac{V_{BE}}{V_T}\right)$$

For Active ONLY







NPN BJT I-V Characteristics

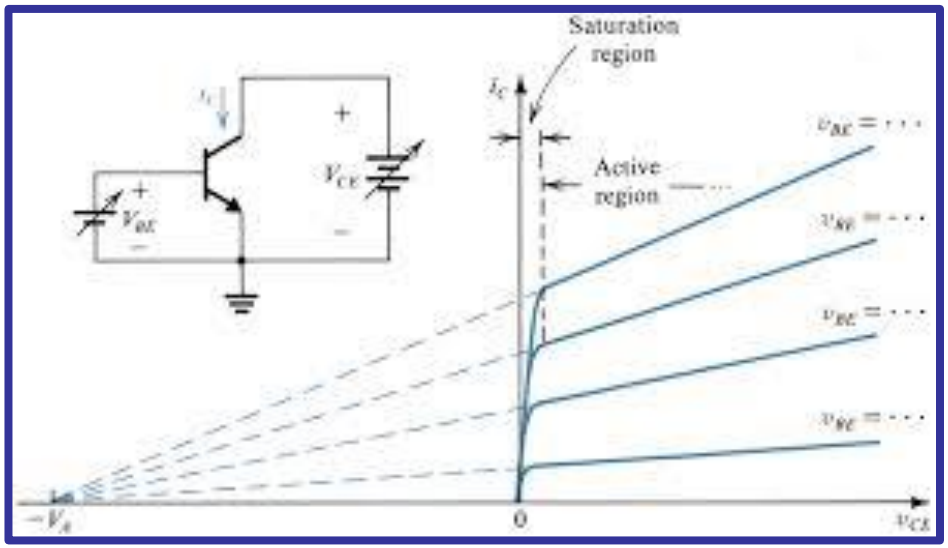
- **I_C versus V_{CE}**
  - The Early effect

NPN BJT I-V Characteristics

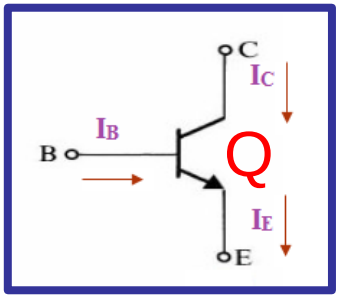
- **I_C versus V_{CE}** (The Early effect)

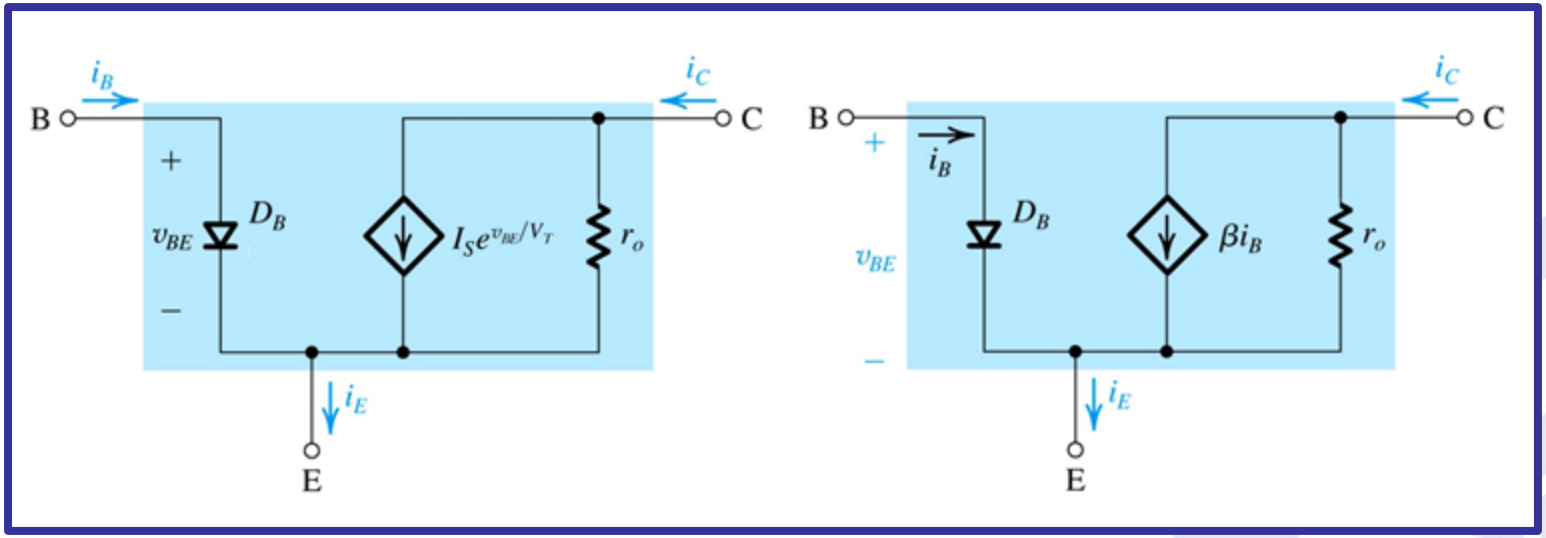
$$i_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right)\left(1+\frac{v_{CE}}{V_A}\right)$$

$$r_o = \left(\frac{\partial i_C}{\partial v_{CE}}\right)^{-1} = \frac{V_A}{I_C}$$



BJT Large Signal Model in Active Mode

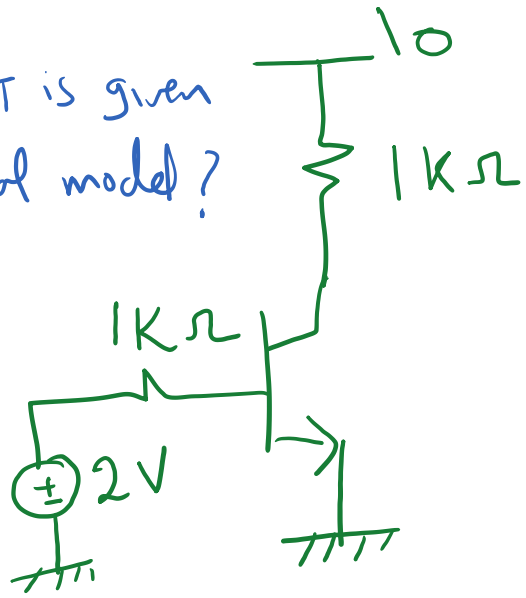




Ex: Find I_C, if Q is active

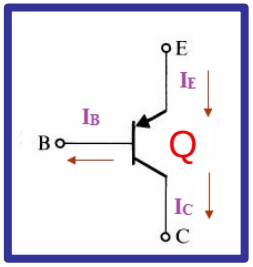
Assume, β_F, V_A, V_T is given

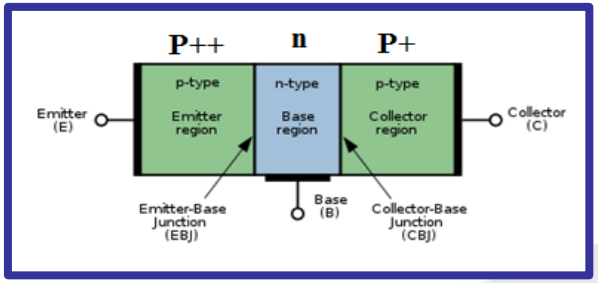
Solve using large signal model?



PNP BJT Physical Structure

- **BJT PNP Transistor**
  - PNP is the NPN Complementary structure
  - Two back to back PN Junctions
  - Three terminal device: Base (**N-type**), Emitter and Collector (**P-type**)
  - Emitter-Base Junction
  - Collector-Base Junction
  - Emitter doping is higher than Collector doping
  - Same modes of operation as NPN Transistor

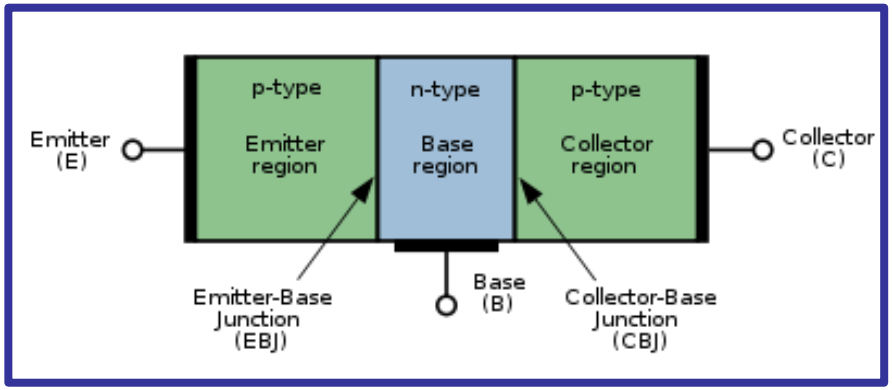


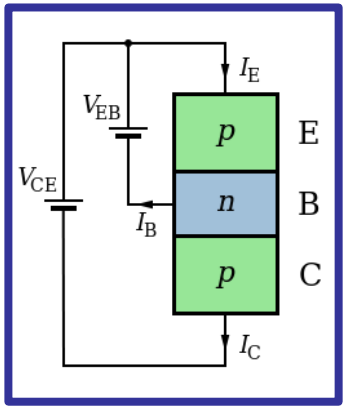


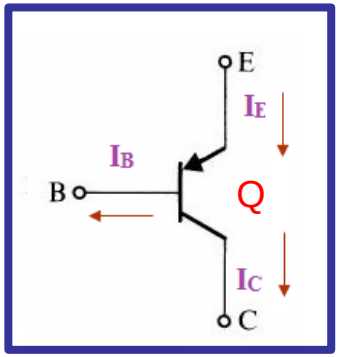
PNP BJT Transistor

BJT PNP Physical Structure

- **BJT PNP Transistor in Forward Active Mode**

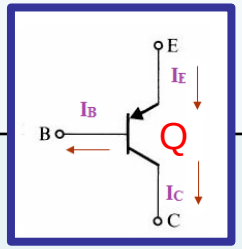
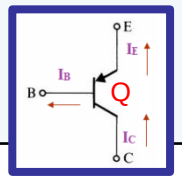






EBJ Forward + CBJ Reverse = **Forward Active Mode**

BJT PNP Modes of Operation

Mode	EB-J	CB-J	Equations	Condition
Cutoff	**Reverse**	**Reverse**	$I_C = I_E = I_B$=0	$V_{EB} < 0.7$ $V_{CB} < 0.5$
Active (Forward)	**Forward**  	**Reverse**	$V_{EB} \cong 0.7$ $I_E = I_C + I_B$ $I_C = \beta_F I_B = \alpha_F I_E$ $\alpha_F = \frac{\beta_F}{1+\beta_F}$	$V_{CB} < 0.5$ Or $V_{EC} > 0.2$
Saturation	**Forward**	**Forward**	$V_{EB} \cong 0.7$ $V_{CB} \cong 0.5$ $V_{EC} \cong 0.2$ $I_E = I_C + I_B$	$I_C < \beta_F I_B$
Reverse Active	**Reverse**  	**Forward**	$V_{CB} = 0.5$ $I_C = I_E + I_B$ $I_E = \beta_R I_B = \alpha_R I_C$ $\alpha_R = \frac{\beta_R}{1+\beta_R}$	$V_{EB} < 0.7$

Calculating DC operating point

Solved Exercise

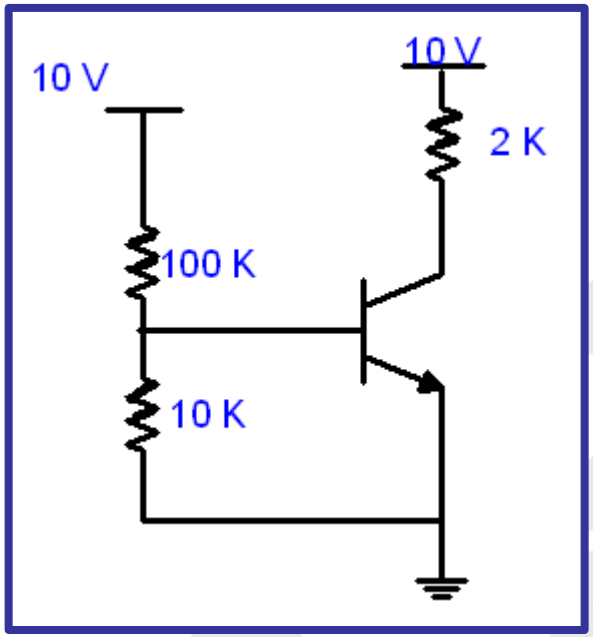
GUC German University in Cairo
الجامعة الألمانية بالقاهرة

Course Instructor: Dr. Eman Azab
Contact: eman.azab@guc.edu.eg

Solved Example

- Find the DC Operating point of the Transistor?
  - Given: V_{BE}=0.7V ,β_F=10

(Ans.: I_B=0.023mA, I_C=0.23mA, I_E=0.253mA, V_{CE}=9.54V, Active)



DC Analysis of BJT Solution Steps:

1. Identify the BJT Type
2. Place the terminals name on the circuit
3. Write a KVL in the INPUT Loop
   - Input loop for BJT is any loop containing V_{BE} OR V_{EB}
4. Assume the BJT mode (most of the time active)
5. Calculate the currents and voltages
6. Write KVL in the OUTPUT loop
   - Output loop for BJT is any loop containing V_{CE} OR V_{EC}
7. **Verify your assumption!**

Example

- Find the DC Operating point of the Transistor?
  - Given: V_{EB}=0.7V ,β=10