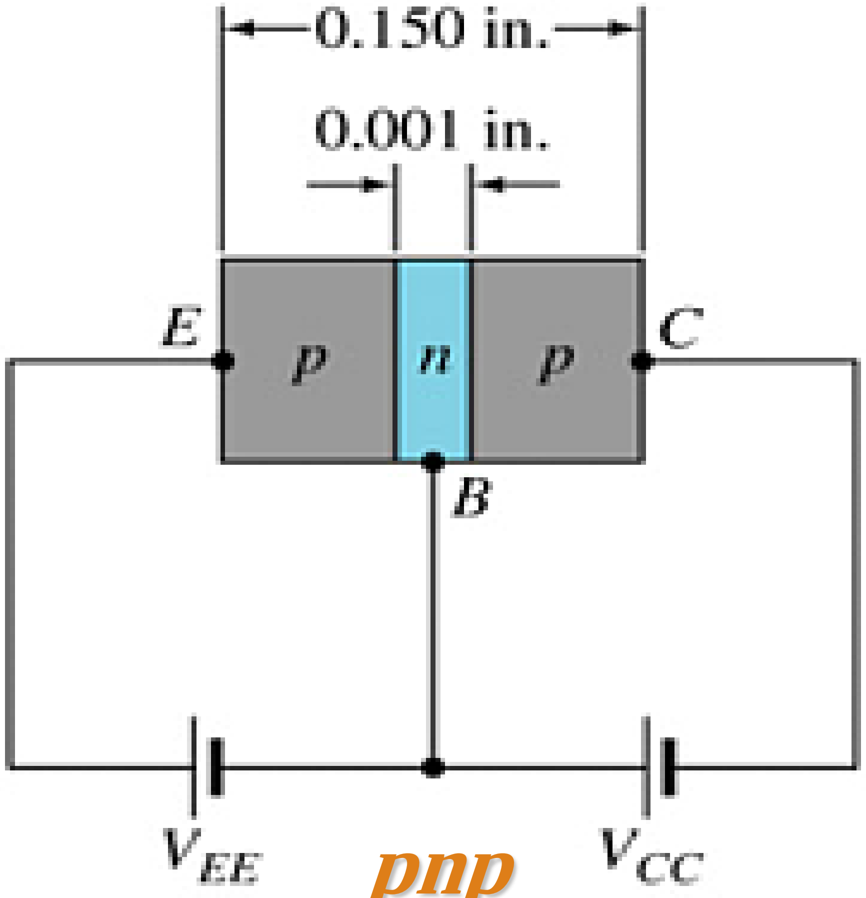
Lecture 5

BJT TRANSISTORS

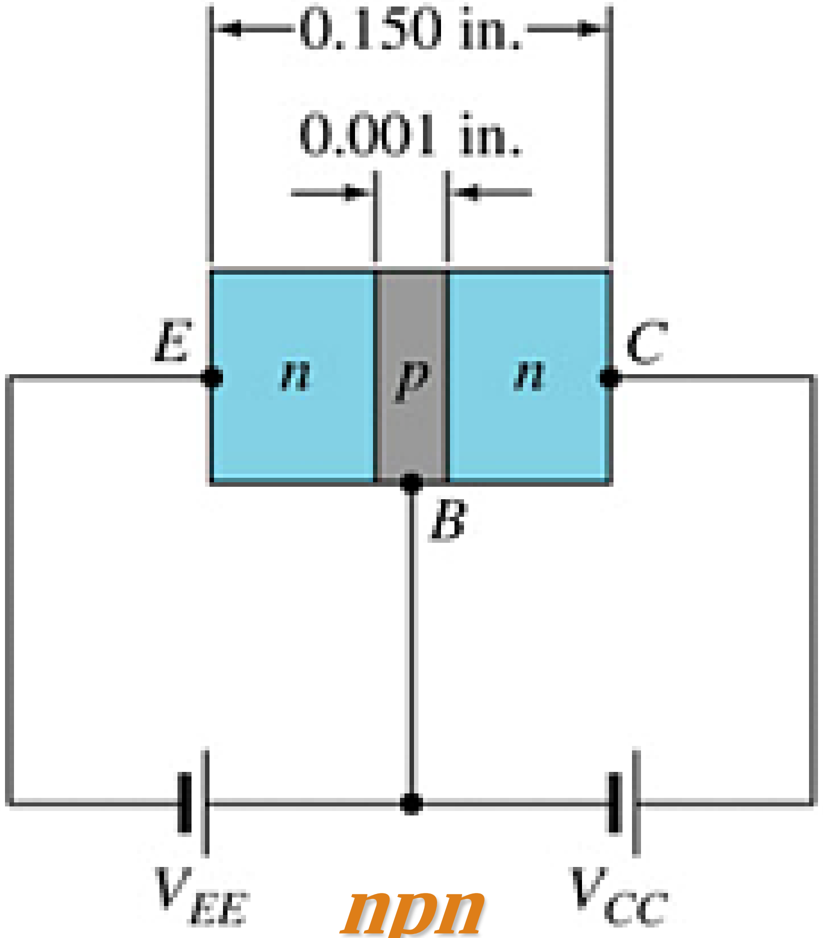
DR. BASSAM ATIEH

Transistor Construction

There are two types of transistors:



pnp



npn

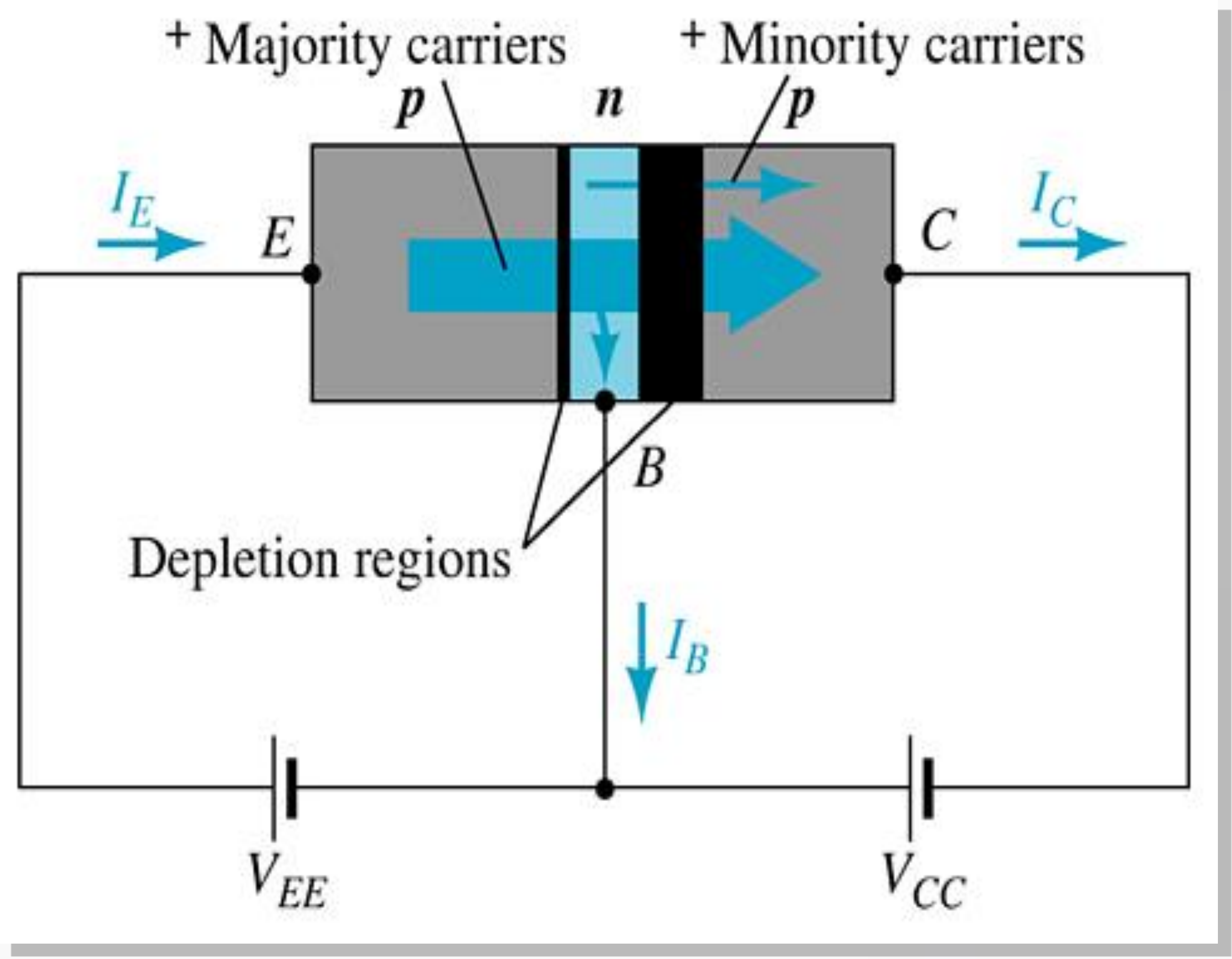
The terminals are labeled:

E – Emitter B – Base - Collector

Transistor Operation

With the external sources, V_{EE} and V_{CC}, connected as shown:

- The emitter-base junction is forward biased
- The base-collector junction is reverse biased



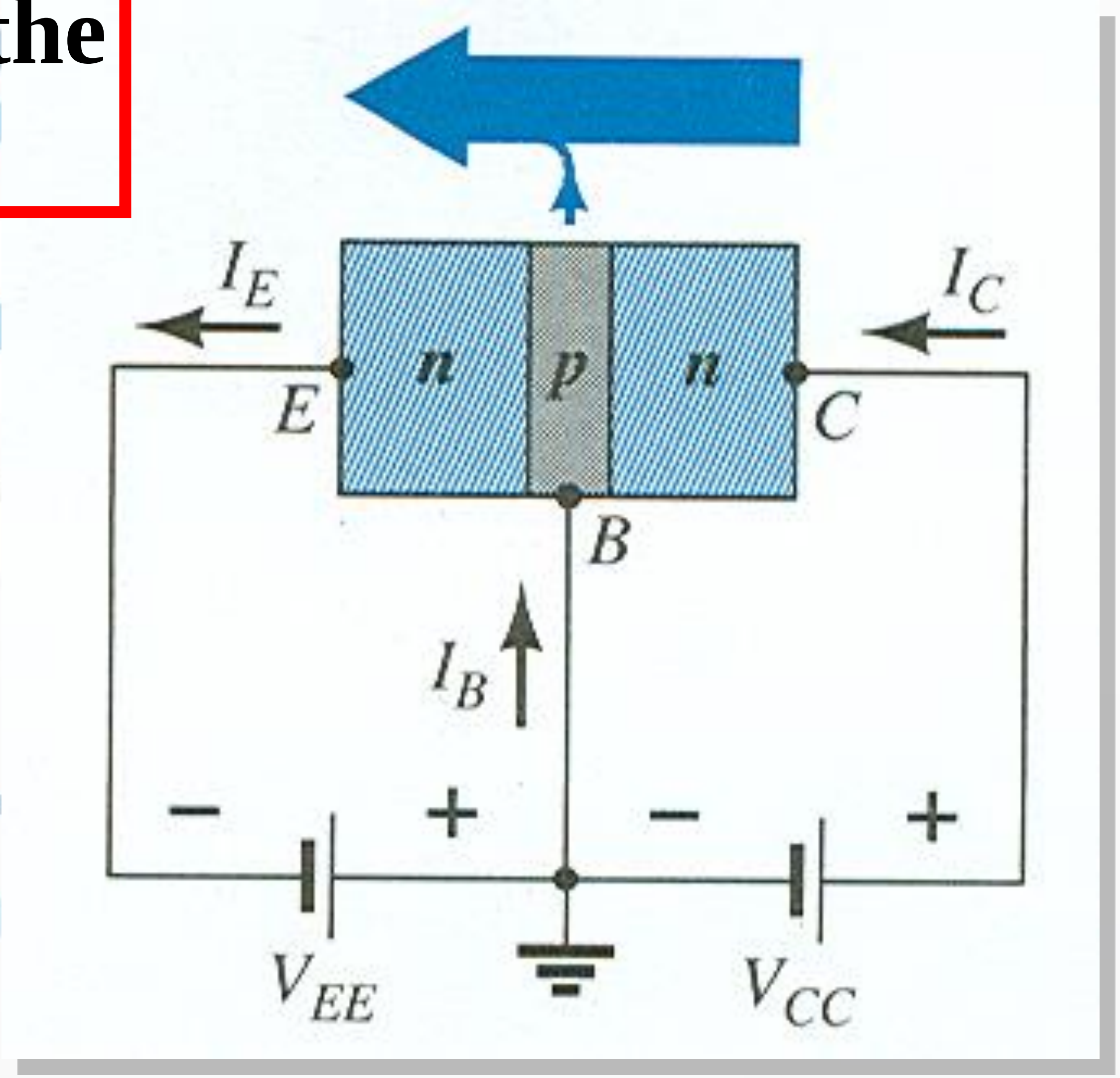
Currents in a Transistor

Emitter current is the sum of the collector and base currents:

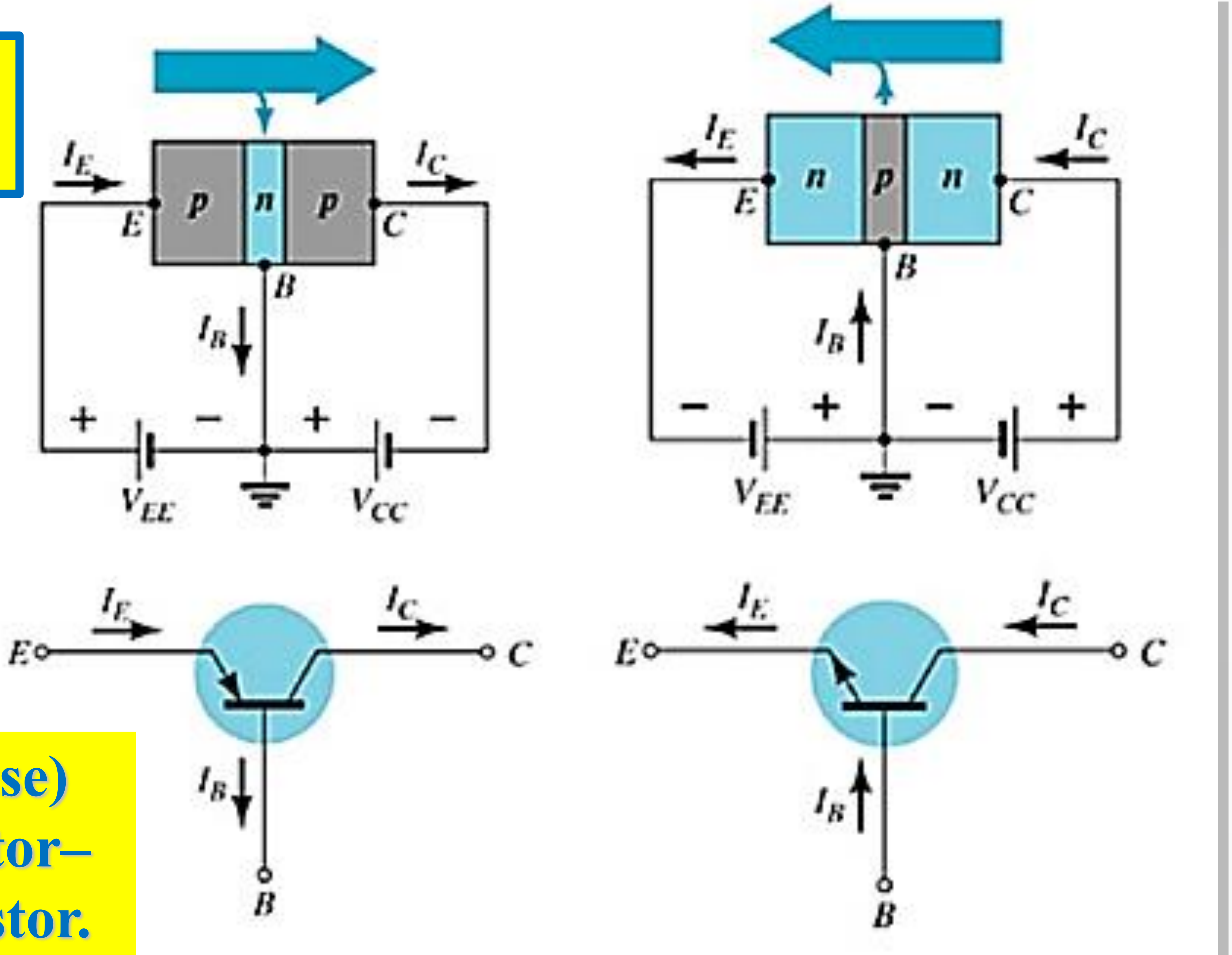
$$I_E = I_C + I_B$$

The collector current is comprised of two currents:

$$I_C = I_{C_{majority}} + I_{CO_{minority}}$$



Common-Base Configuration

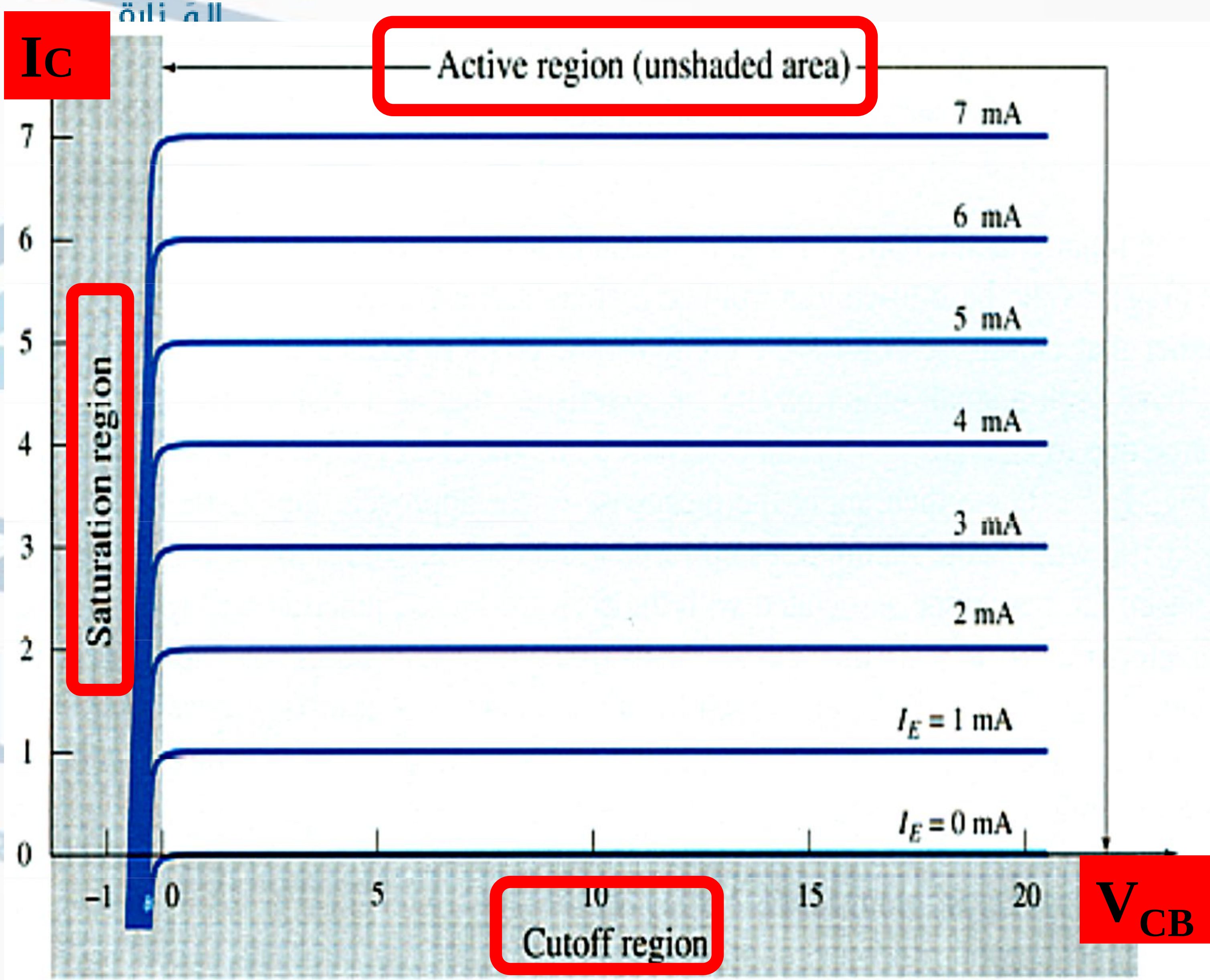


input (emitter–base) and output (collector–base) of the transistor.

Common-Base Amplifier

Output Characteristics

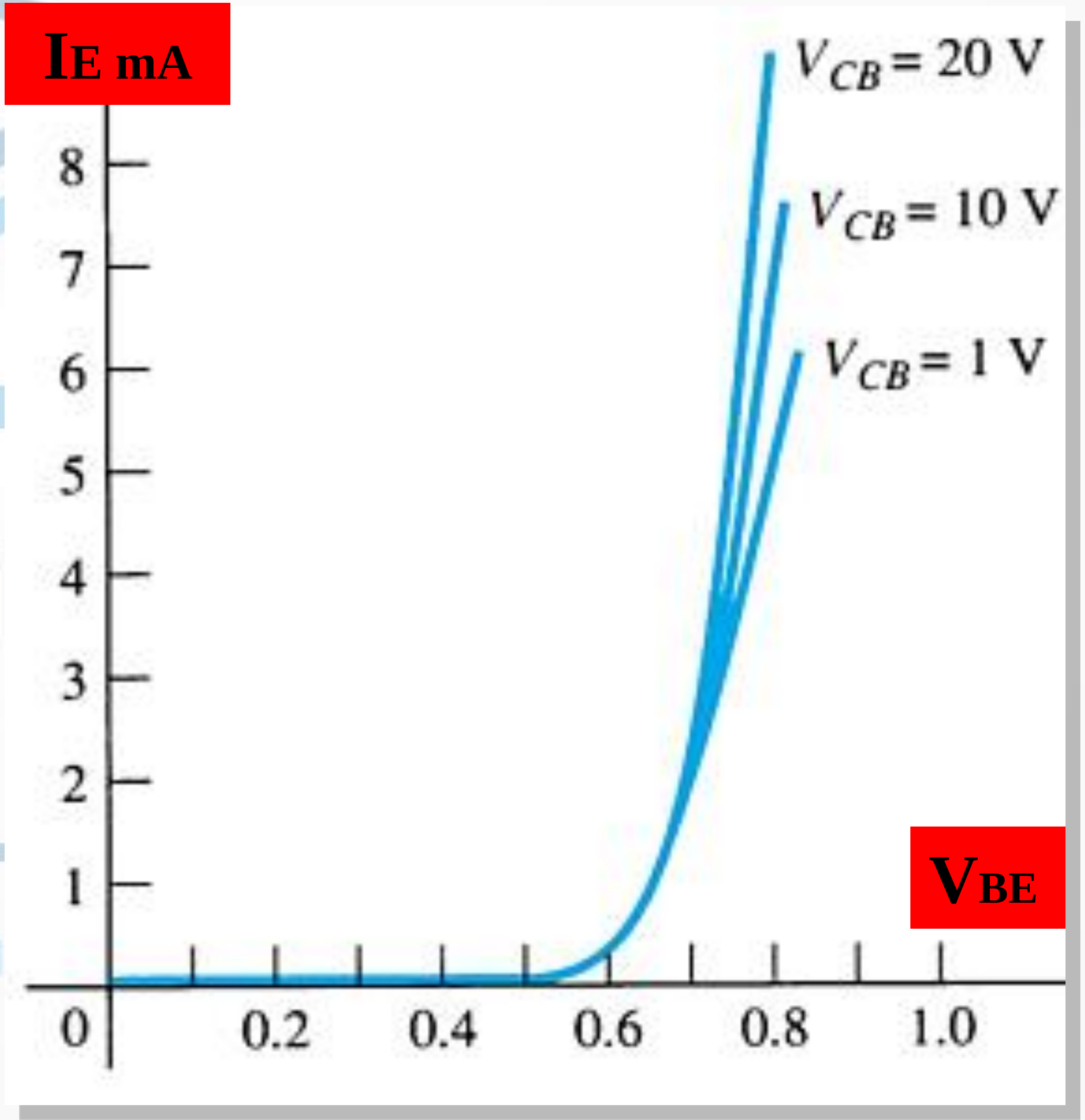
This graph demonstrates the output current (I_C) to an output voltage (V_{CB}) for various levels of input current (I_E).



Common-Base Amplifier

Input Characteristics

This curve shows the relationship between of input current (I_E) to input voltage (V_{BE}) for three output voltage (V_{CB}) levels.



Operating Regions

- **Active** – Operating range of the amplifier.
- **Cutoff** – The amplifier is basically off. There is voltage, but little current.
- **Saturation** – The amplifier is full on. There is current, but little voltage.

Approximations

- Emitter and collector currents:

$$I_C \cong I_E$$

- Base-emitter voltage:

$$V_{BE} = 0.7\text{ V} \quad (\text{for Silicon})$$

Alpha (a)

Alpha (α) is the ratio of I_C to I_E:

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

- Ideally: $\alpha = 1$
- In reality: a is between 0.9 and 0.998

Alpha (α) in the AC mode:

$$\alpha_{ac} = \frac{\Delta I_C}{\Delta I_E}$$

Transistor Amplification

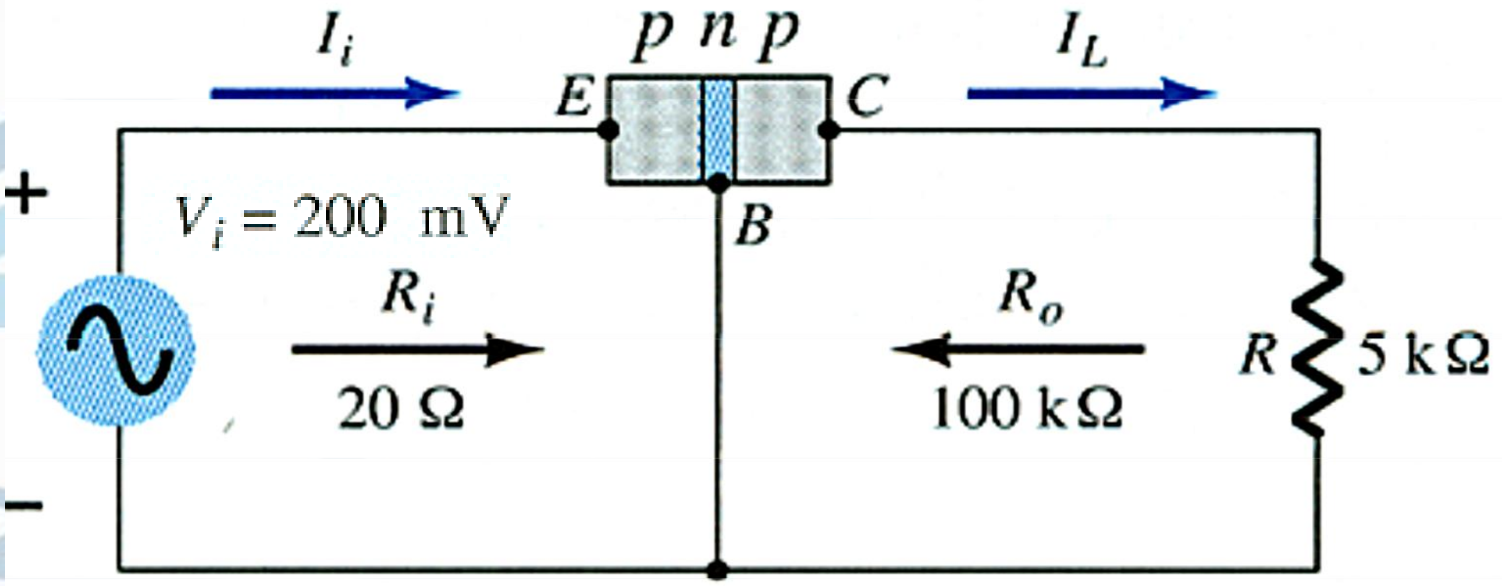
Currents and Voltages:

$$I_E = I_i = \frac{V_i}{R_i} = \frac{200mV}{20\Omega} = 10mA$$

$$I_C \cong I_E$$

$$I_L \cong I_i = 10\,mA$$

$$V_L = I_L R = (10\,mA)(5\,k\Omega) = 50\,V$$

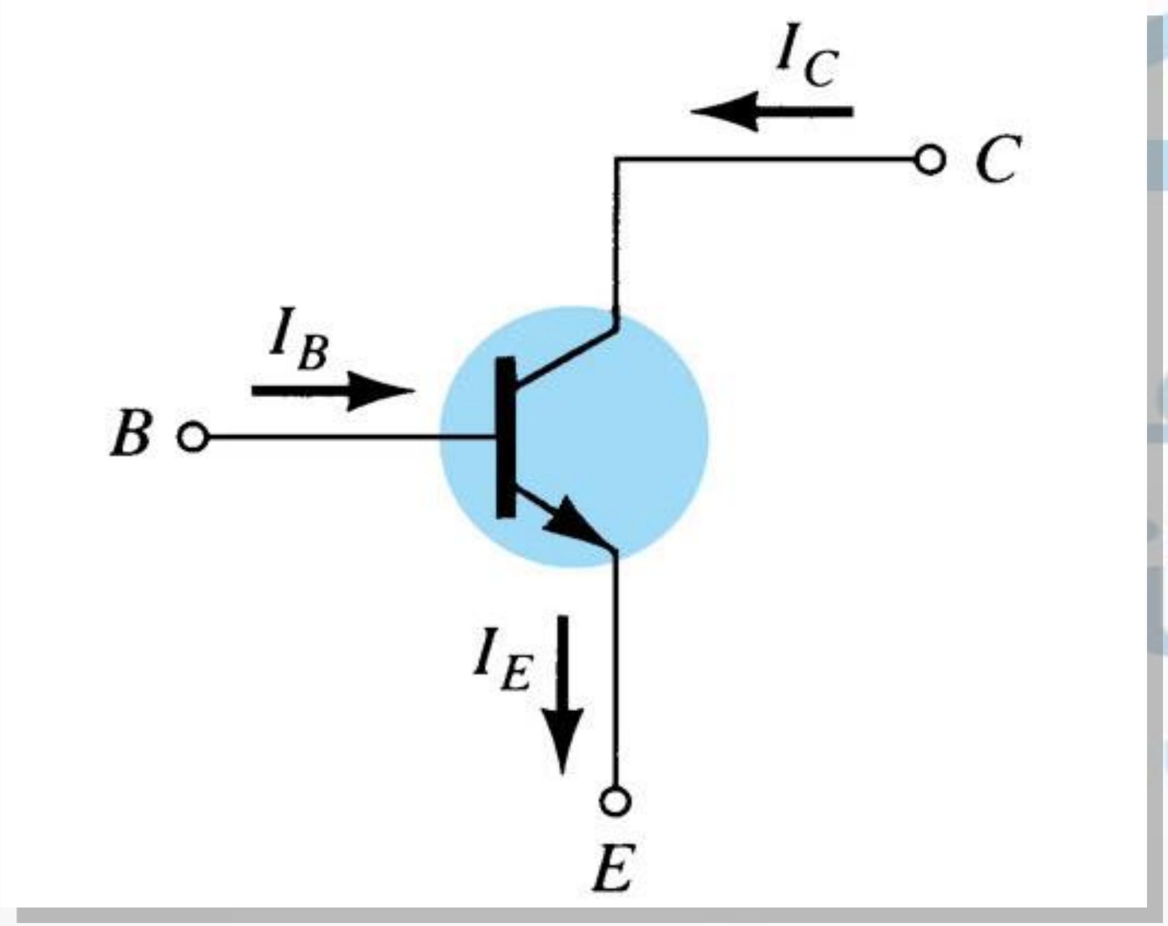


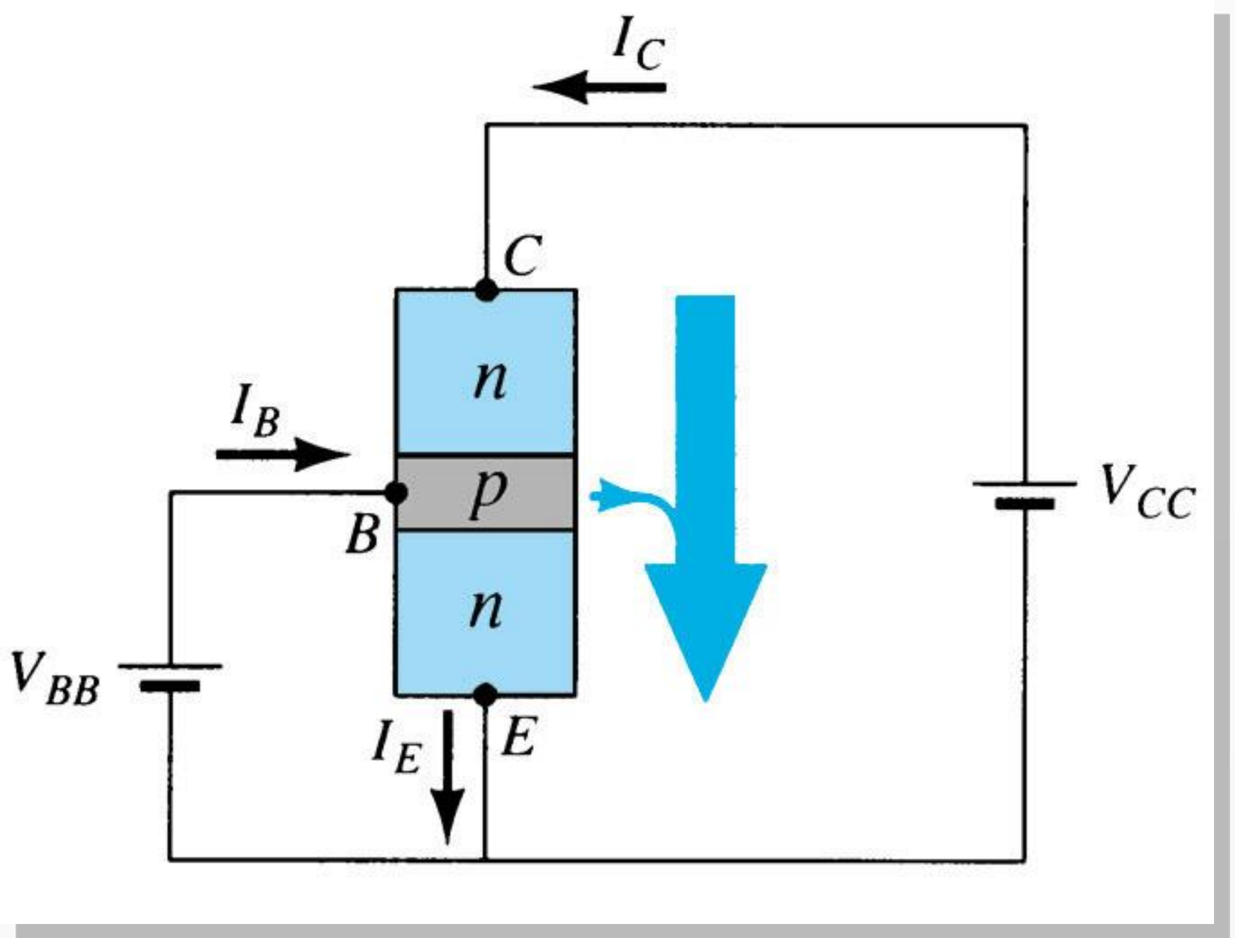
Voltage Gain:

$$A_v = \frac{V_L}{V_i} = \frac{50V}{200mV} = 250$$

Common–Emitter Configuration

- **input (base-emitter) and output (collector-emitter).**

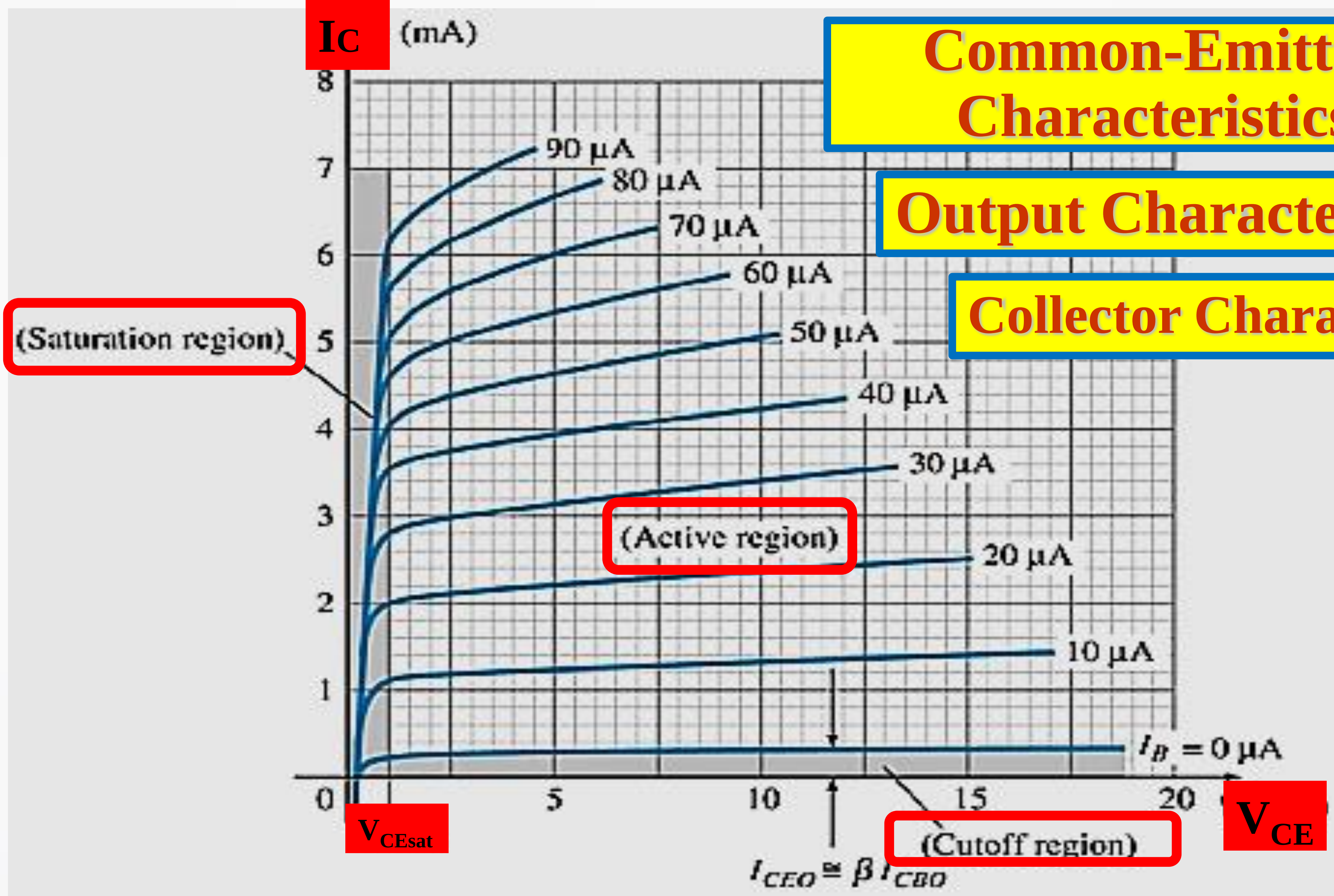




Common-Emitter Characteristics

Output Characteristics

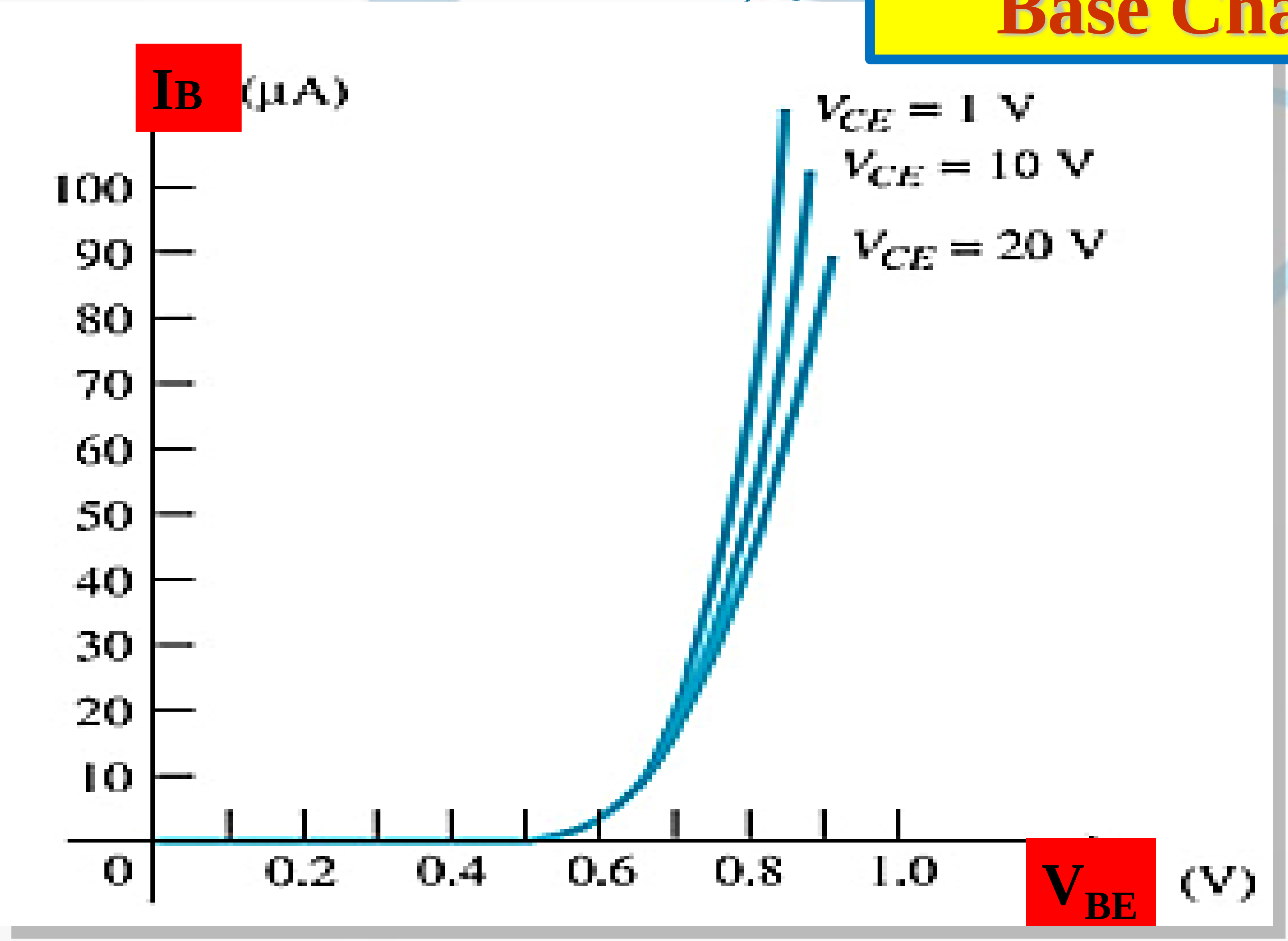
Collector Characteristics



Common-Emitter Characteristics

Input Characteristics

Base Characteristics



Common-Emitter Amplifier Currents

جَامعة
المَنارة
MANARA UNIVERSITY

- **Ideal Currents** $I_E = I_C + I_B$ $I_C = \alpha I_E$
- **Actual Currents** $I_C = \alpha I_E + I_{CBO}$

where I_{CBO} = minority collector current

I_{CBO} :is usually so small that it can be ignored, except in high power transistors and in high temperature environments.

When I_B = 0 μA the transistor is in cutoff, but there is some minority current flowing called I_{CEO}.

$$I_{CEO} = \left.\frac{I_{CBO}}{1-\alpha}\right|_{I_B = 0\,\mu A}$$

Beta (β)

β :represents the amplification factor of a transistor.
(β is sometimes referred to as h_{fe} ; a term used in transistor modeling calculations)

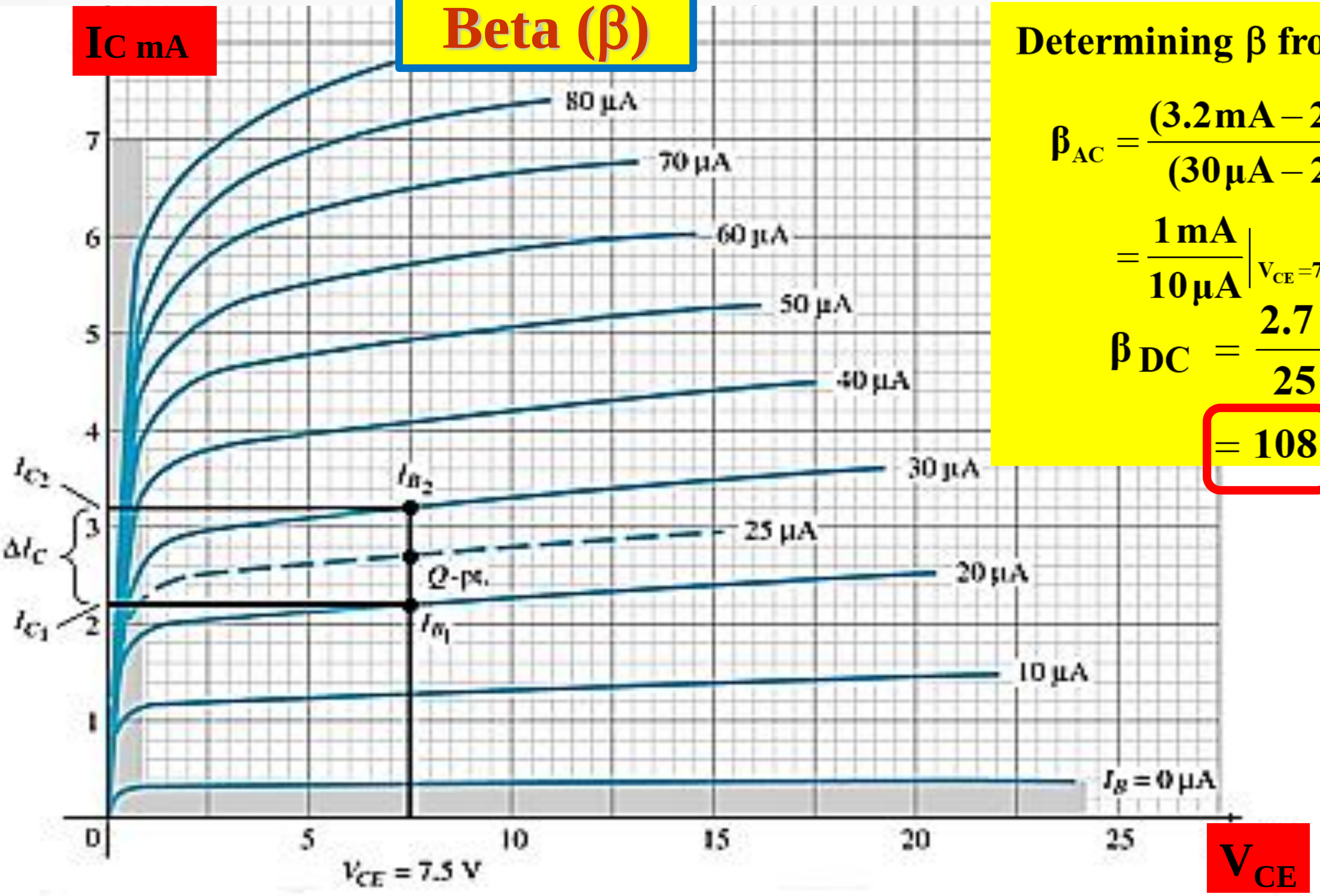
- In DC mode:

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

- In AC mode:

$$\beta_{ac} = \frac{\Delta I_C}{\Delta I_B}\bigg|_{V_{CE}=\text{constant}}$$

Beta (β)



Determining β from a Graph

$$\beta_{AC} = \frac{(3.2\,mA - 2.2\,mA)}{(30\,\mu A - 20\,\mu A)}$$

$$= \frac{1\,mA}{10\,\mu A}\bigg|_{V_{CE}=7.5} = 100$$

$$\beta_{DC} = \frac{2.7\ mA}{25\ \mu A}\bigg|_{V_{CE}=7.5}$$

$$= 108$$

Relationship between amplification factors β and α:

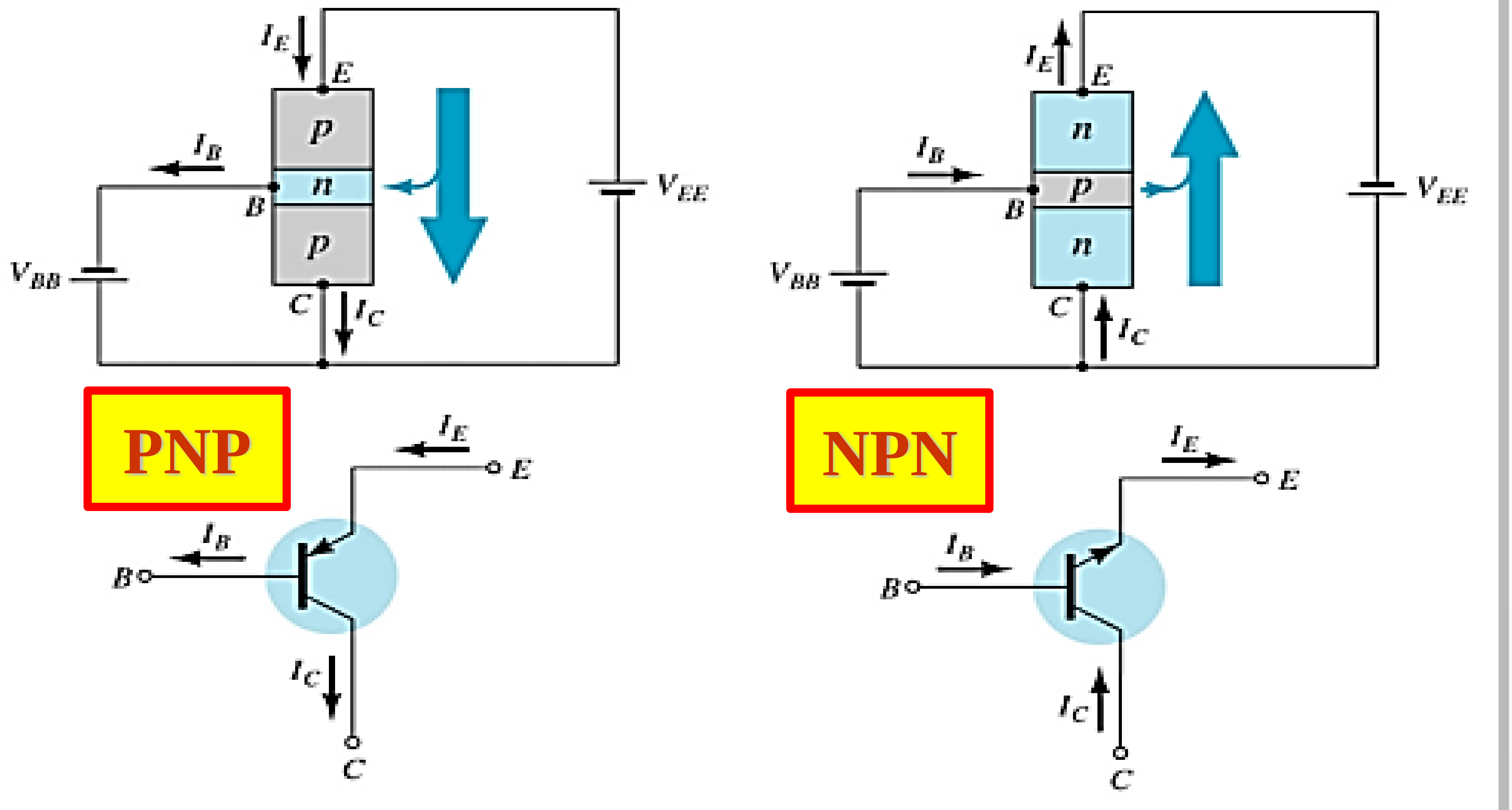
$$\alpha = \frac{\beta}{\beta + 1} \qquad \beta = \frac{\alpha}{\alpha - 1}$$

Relationship Between Currents

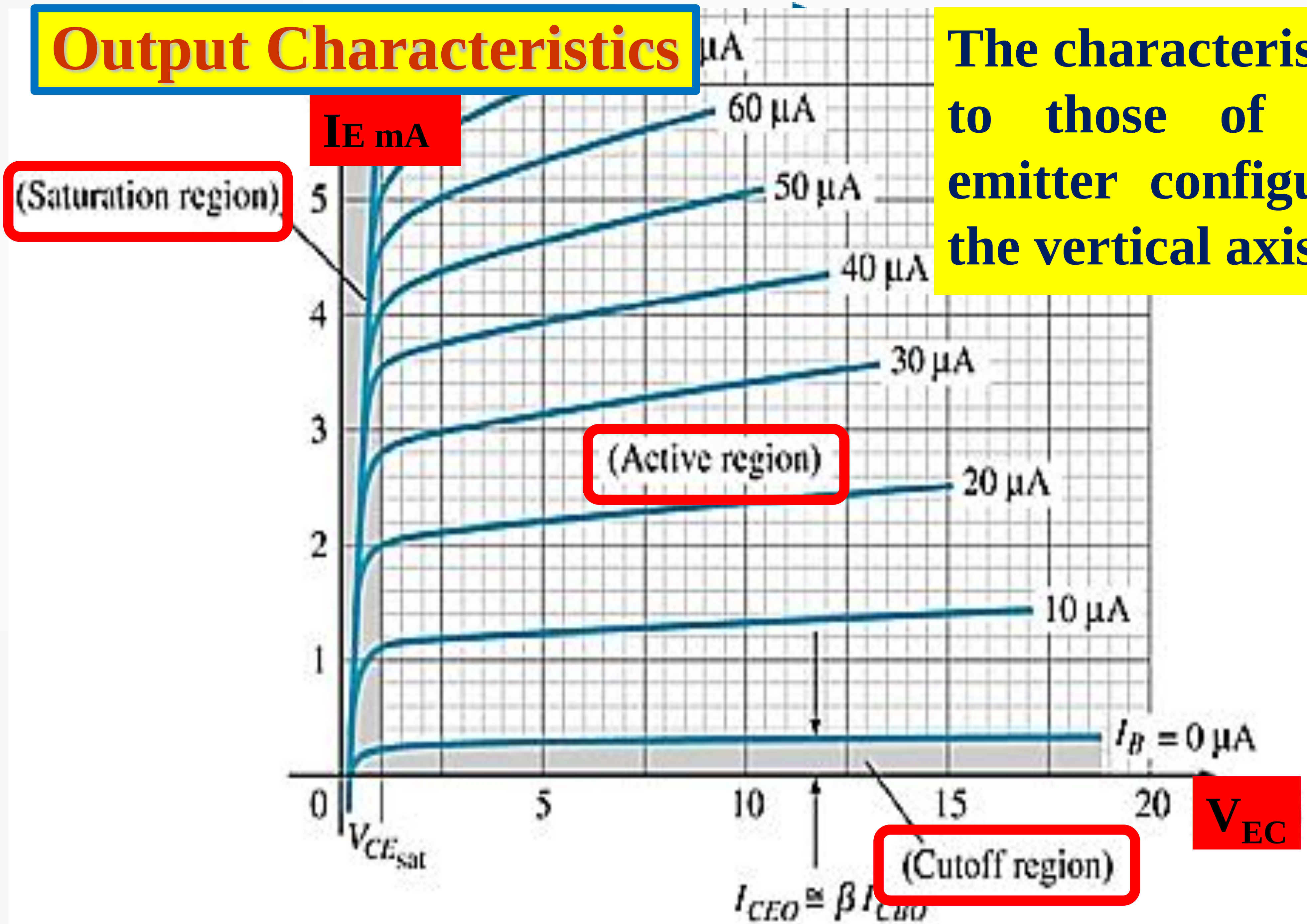
$$I_C = \beta I_B \qquad I_E = (\beta + 1) I_B$$

Common–Collector Configuration

The input is on the base and the output is on the emitter.

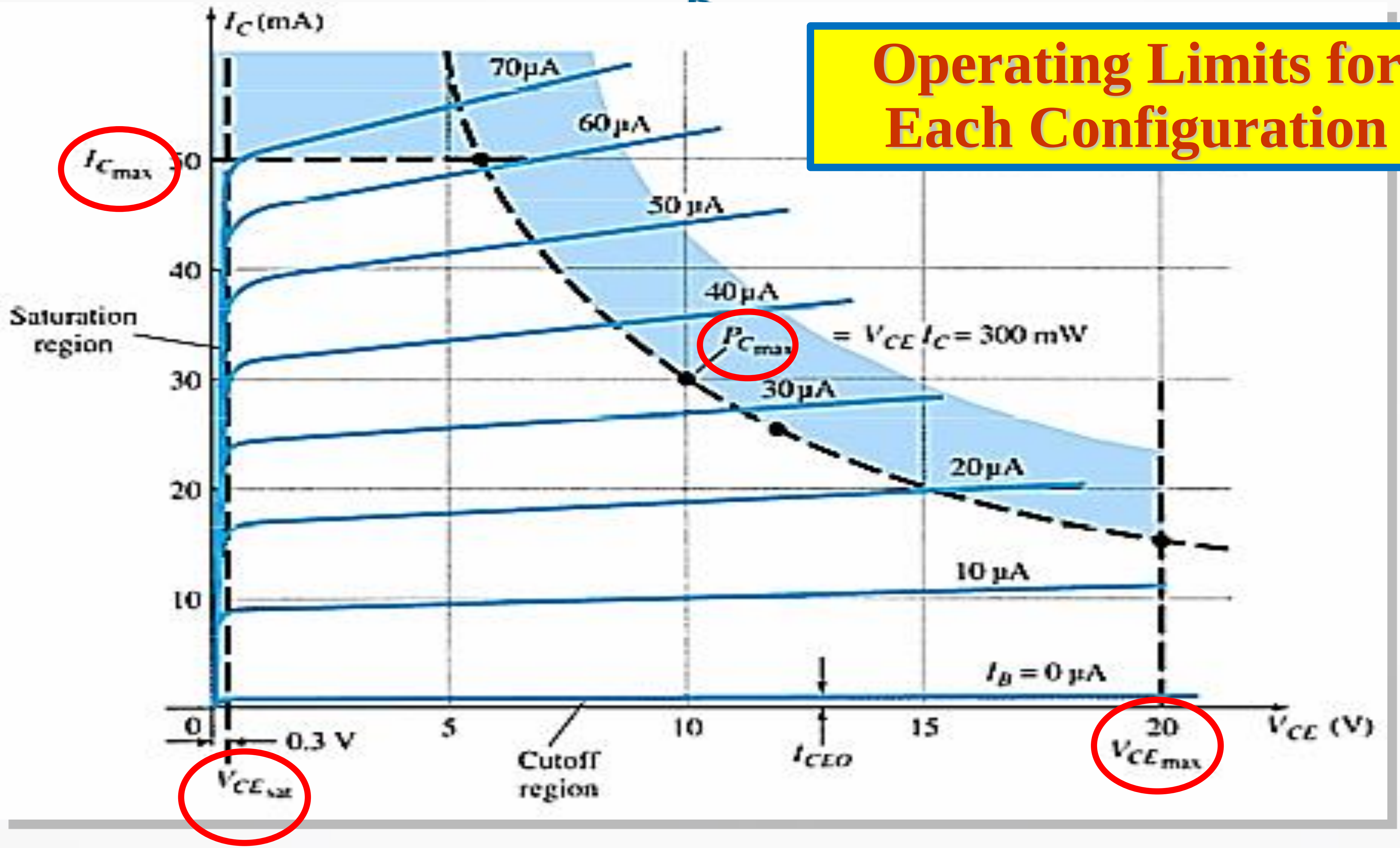


Output Characteristics



The characteristics are similar to those of the common-emitter configuration, except the vertical axis is I_E.

Operating Limits for Each Configuration



Power Dissipation

Common-base: $P_{Cmax} = V_{CB} I_C$

Common-emitter: $P_{Cmax} = V_{CE} I_C$

Common-collector: $P_{Cmax} = V_{CE} I_E$

نظام العمل	المتصل J_E	المتصل J_C	$I_C\,(mA)$	$V_{CE}\,(volt)$
الإشباع	أمامي	أمامي	$I_{C\,sat} \approx \frac{V_{CC}}{R_C}$	$V_{CE} = V_{CE\,sat} \approx 0$
القطع	عكسي	عكسي	$I_C = I_{C\,cut-off} \approx 0$	$V_{CE} = V_{CE\,cut-off} \approx V_{CC}$
الفعّال	أمامي	عكسي	$I_{C\,cut-off} < I_{CQ} < I_{C\,sat}$	$V_{CE\,sat} < V_{CEQ} < V_{CC}$

Transistor Specification Sheet

MAXIMUM RATINGS

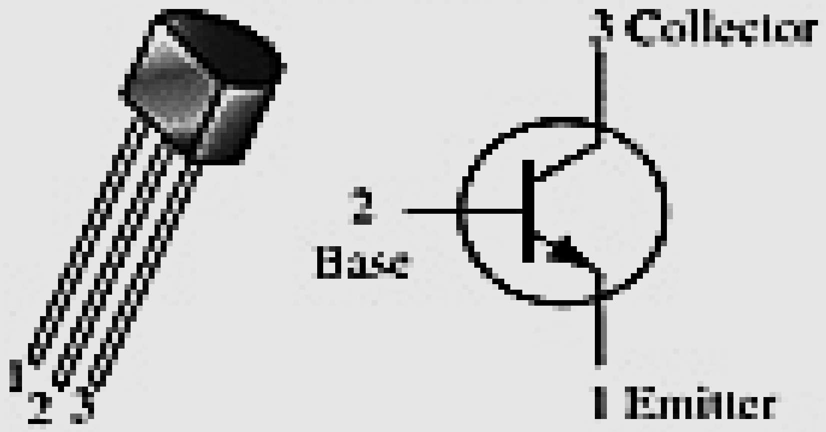
Rating	Symbol	2N4123	Unit
Collector-Emitter Voltage	V_{CEO}	30	Vdc
Collector-Base Voltage	V_{CBO}	40	Vdc
Emitter-Base Voltage	V_{EBO}	5.0	Vdc
Collector Current – Continuous	I_C	200	mAdc
Total Device Dissipation @ $T_A = 25°C$ Derate above 25°C	P_D	625 5.0	mW mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	–55 to +150	°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	83.3	°C/W
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	200	°C/W

2N4123

CASE 29-04, STYLE 1
TO-92 (TO-226AA)



GENERAL PURPOSE TRANSISTOR
NPN SILICON

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Max	Unit
OFF CHARACTERISTICS				
Collector-Emitter Breakdown Voltage (1) (I_C = 1.0 mAdc, I_B = 0)	$V_{(BR)CEO}$	30		Vdc
Collector-Base Breakdown Voltage (I_C = 10 μAdc, I_E = 0)	$V_{(BR)CBO}$	40		Vdc
Emitter-Base Breakdown Voltage (I_E = 10 μAdc, I_C = 0)	$V_{(BR)EBO}$	5.0	–	Vdc
Collector Cutoff Current (V_{CB} = 20 Vdc, I_E = 0)	I_{CBO}	–	50	nAdc
Emitter Cutoff Current (V_{BE} = 3.0 Vdc, I_C = 0)	I_{EBO}	–	50	nAdc
ON CHARACTERISTICS				
DC Current Gain(1)				
(I_C = 2.0 mAdc, V_{CE} = 1.0 Vdc)	h_{FE}	50	150	–
(I_C = 50 mAdc, V_{CE} = 1.0 Vdc)		25	–	
Collector-Emitter Saturation Voltage(1) (I_C = 50 mAdc, I_B = 5.0 mAdc)	$V_{CE(sat)}$	–	0.3	Vdc
Base-Emitter Saturation Voltage(1) (I_C = 50 mAdc, I_B = 5.0 mAdc)	$V_{BE(sat)}$	–	0.95	Vdc

SMALL-SIGNAL CHARACTERISTICS

Current-Gain – Bandwidth Product (I_C = 10 mAdc, V_{CE} = 20 Vdc, f = 100 MHz)	f_T	250		MHz
Output Capacitance (V_{CB} = 5.0 Vdc, I_E = 0, f = 100 MHz)	C_{obo}	-	4.0	pF
Input Capacitance (V_{BE} = 0.5 Vdc, I_C = 0, f = 100 kHz)	C_{ibo}	-	8.0	pF
Collector-Base Capacitance (I_E = 0, V_{CB} = 5.0 V, f = 100 kHz)	C_{cb}	-	4.0	pF
Small-Signal Current Gain (I_C = 2.0 mAdc, V_{CE} = 10 Vdc, f = 1.0 kHz)	h_{fe}	50	200	-
Current Gain – High Frequency (I_C = 10 mAdc, V_{CE} = 20 Vdc, f = 100 MHz) (I_C = 2.0 mAdc, V_{CE} = 10 V, f = 1.0 kHz)	h_{fe}	2.5 50	- 200	-
Noise Figure (I_C = 100 μAdc, V_{CE} = 5.0 Vdc, R_S = 1.0 k ohm, f = 1.0 kHz)	NF	-	6.0	dB

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%

Transistor Testing

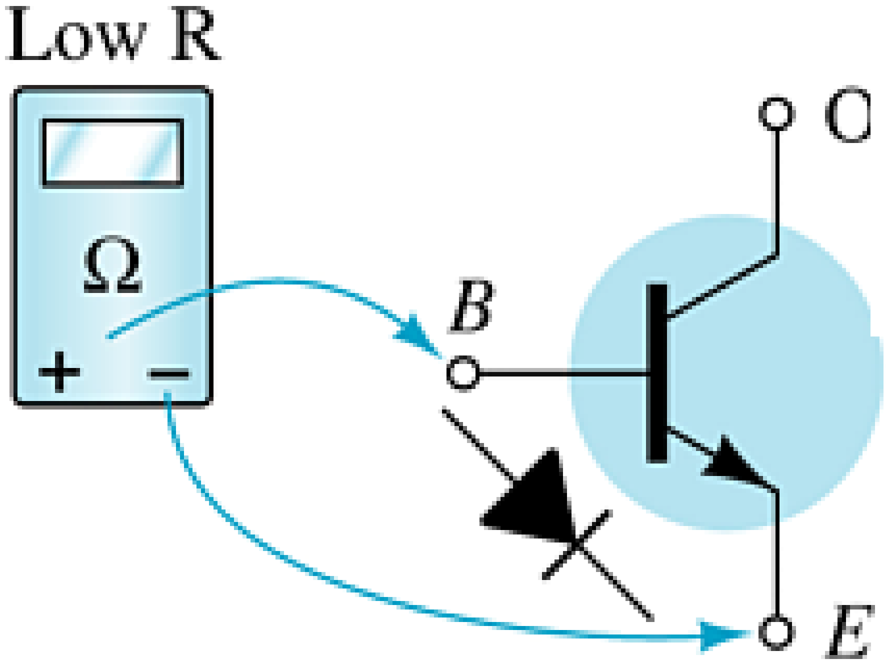
- **Curve Tracer:**

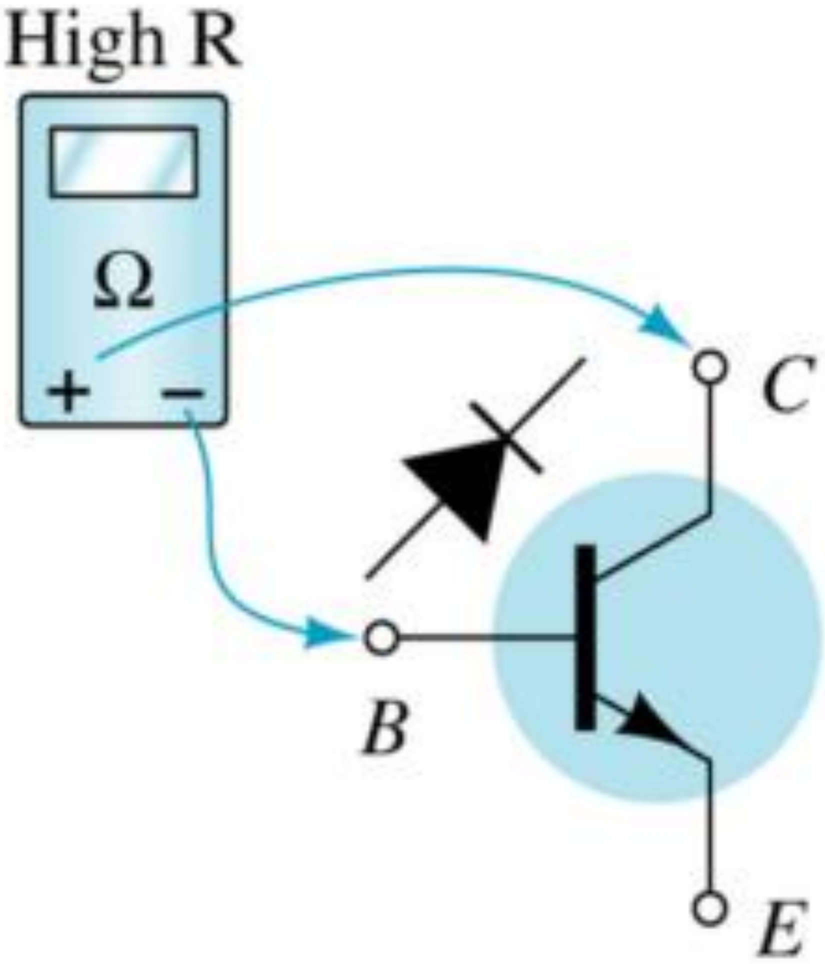
  Provides a graph of the characteristic curves.

- **DMM:**

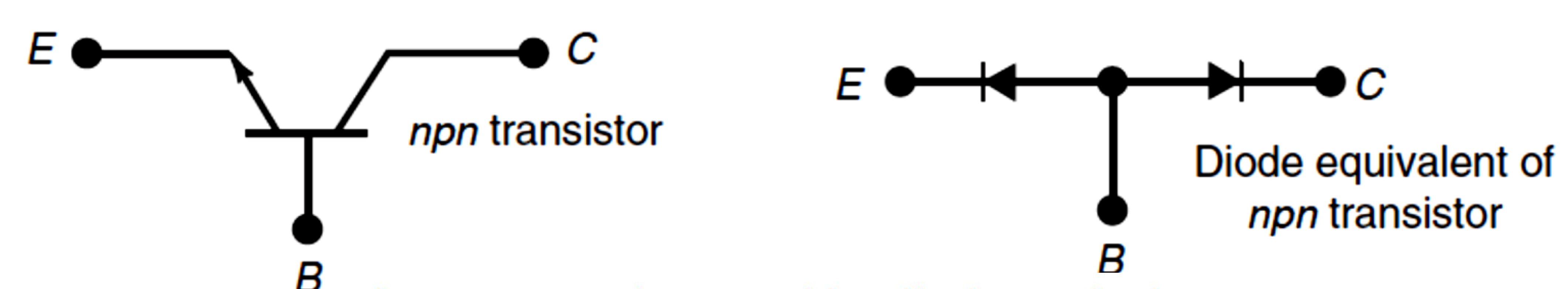
  Some DMMs measure β_{DC} or h_{FE}.

- **Ohmmeter:**

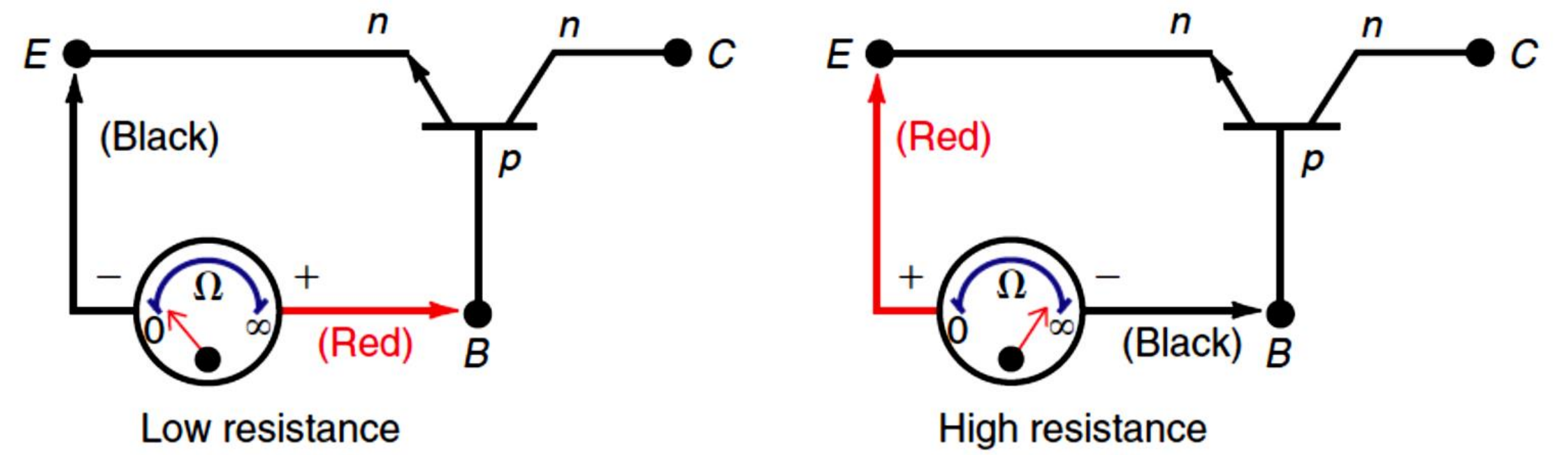


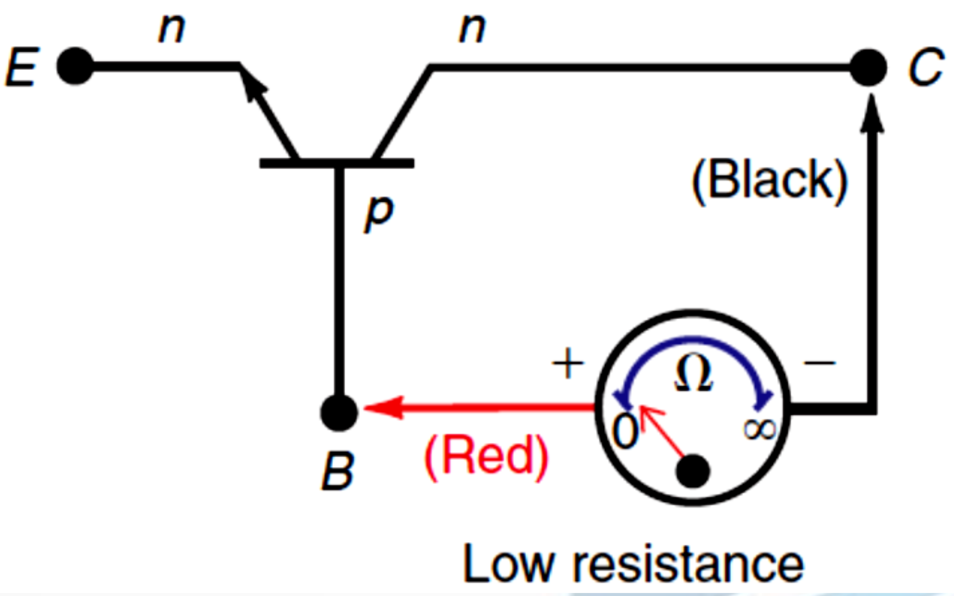


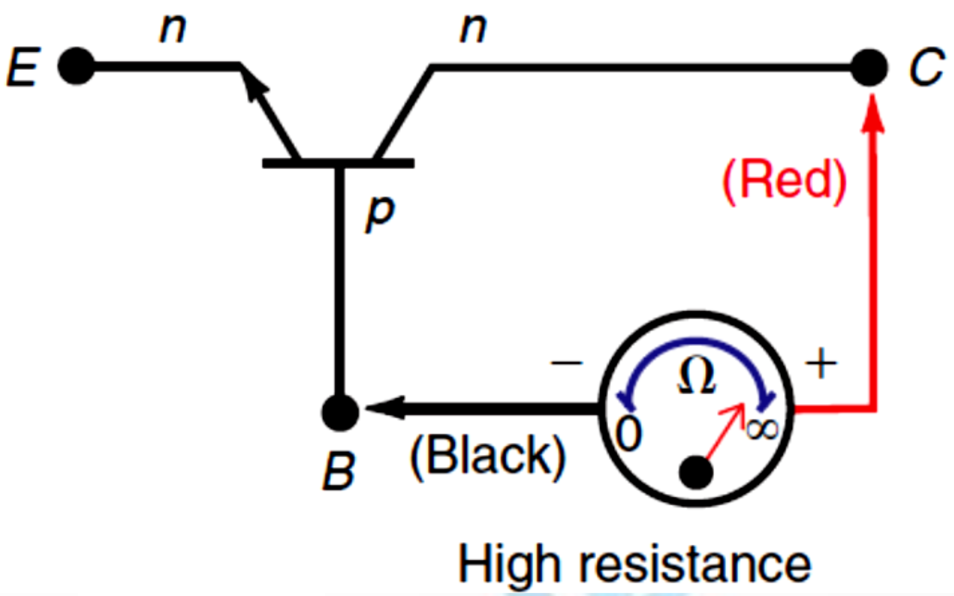
Checking a Transistor with an Ohmmeter



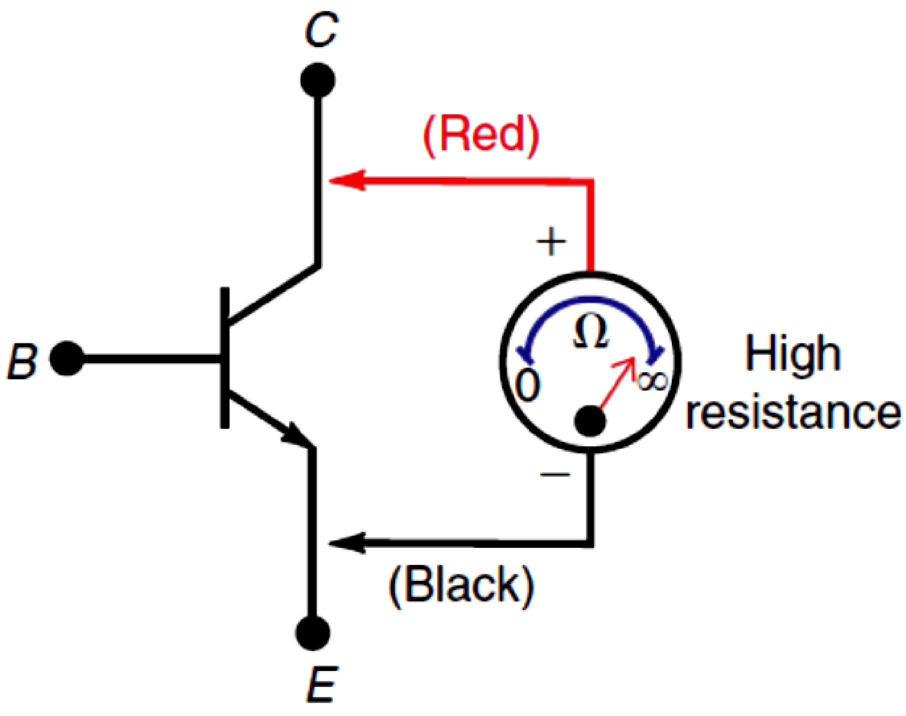
An *npn* transistor and its diode equivalent.

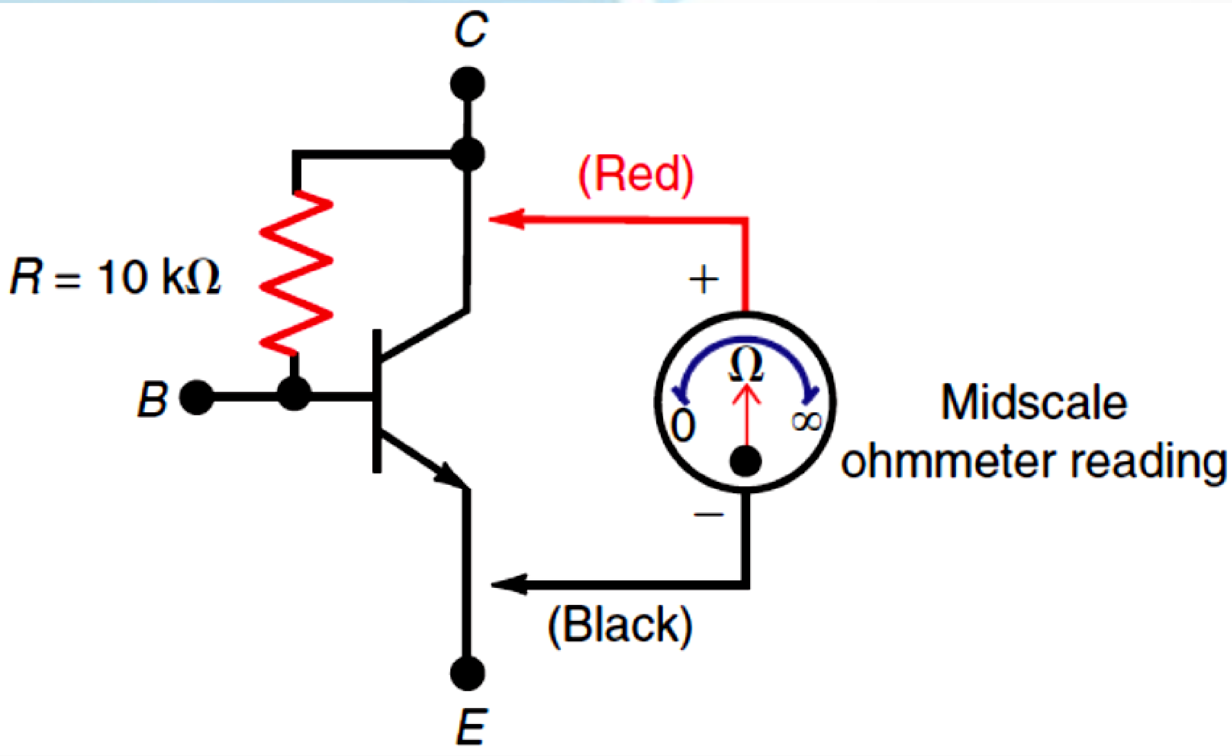






Checking for Proper Transistor Action





Transistor Terminal Identification