Bipolar Junction Transistors

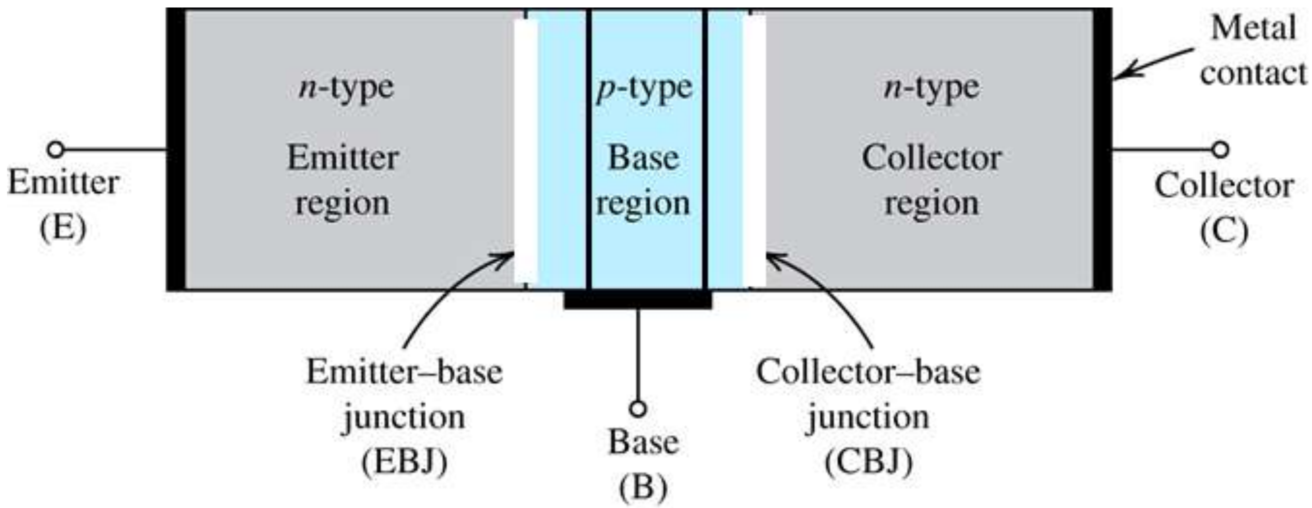
Topic 3 (Chapter 3)

Bipolar Junction Transistor (BJT)

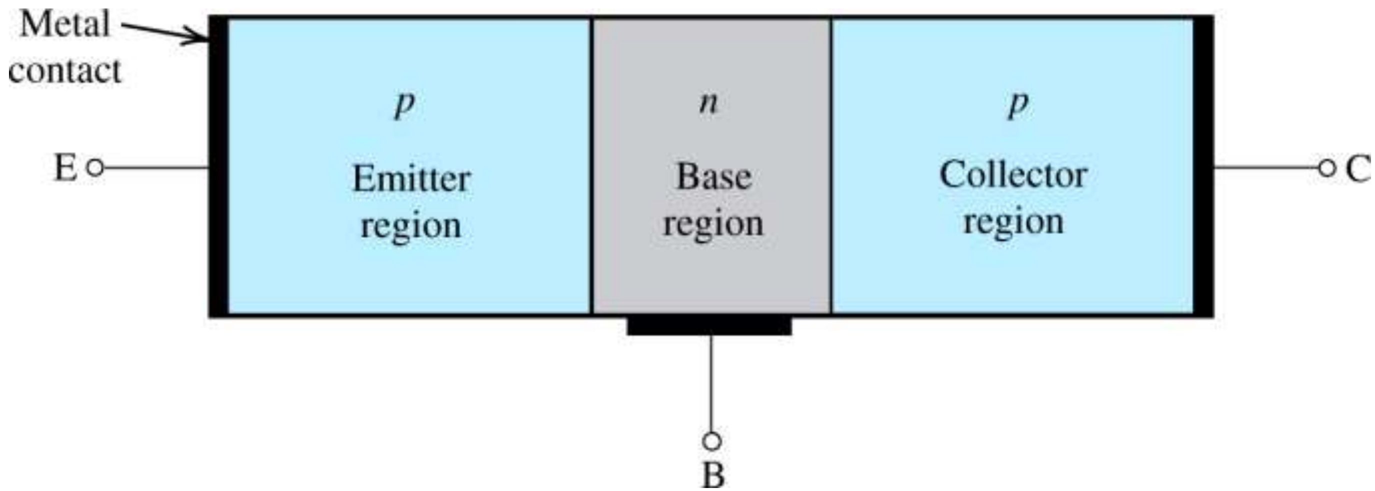
- **A semiconductor device that can amplify (enlarge) electronic signals such as radio and television signals**
- **The transistor has led to many other semiconductor inventions including the integrated circuit (IC)**
  - **Backbone of modern civilization**
- **Bipolar means “two polarities” - electrons and holes**

BJT Device Structure

NPN



PNP



$d_{emitter} > d_{collector} > d_{base}$: Emitter has highest doping

$w_{collectrr} > w_{emitter} > w_{base}$: Collector has highest width

Base has lowest width and doping: Base current is very small. I_{base} very small

The Structure of BJT Transistors in ICs

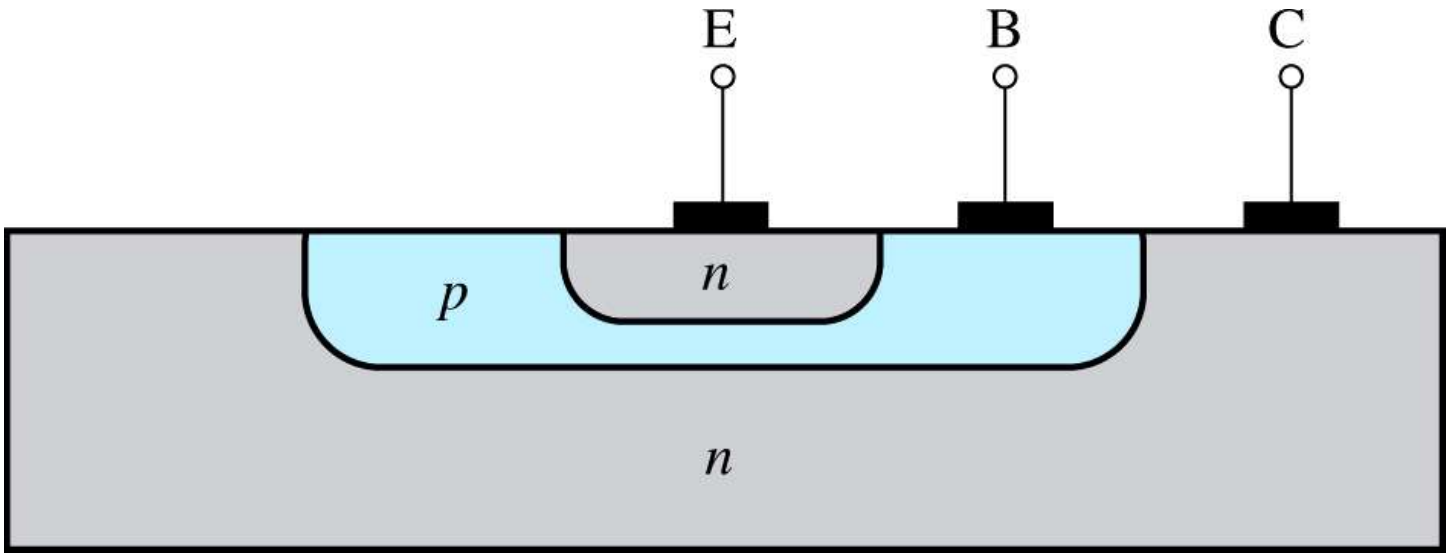
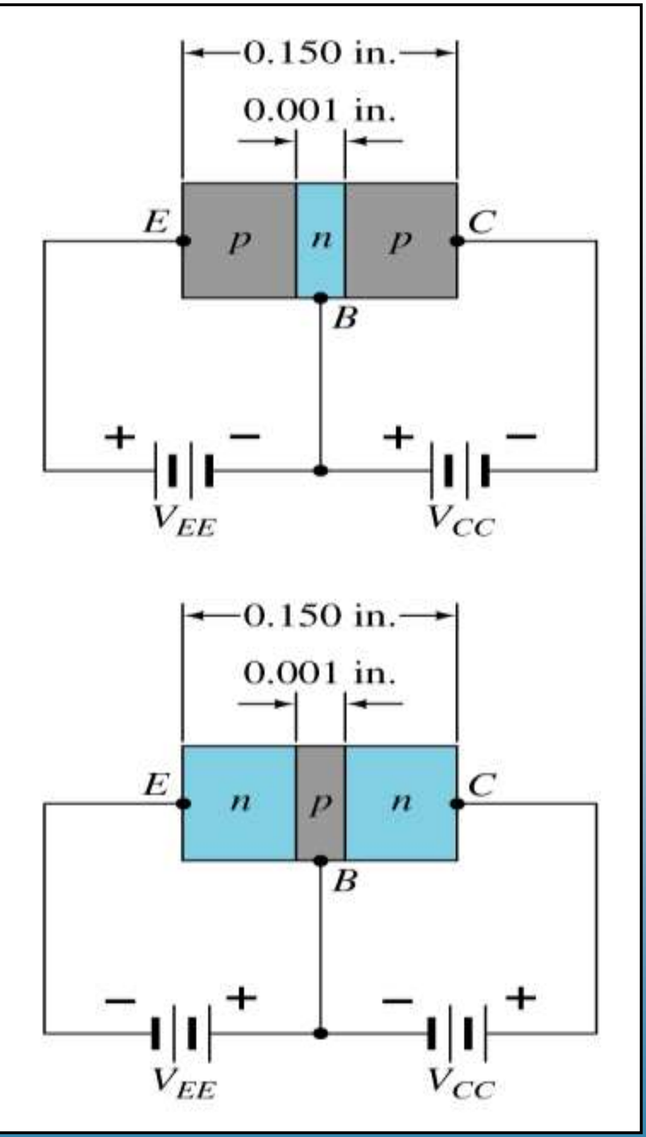


Figure: A more realistic (but still simplified) cross section of an *npn* BJT

- The collector virtually surrounds the emitter region
- The device is *not* symmetrical, and thus the emitter and collector cannot be interchanged.

Discrete Component BJT Construction



pnp

npn

BJT: Three terminals. Emitter, Base, Collector.

BJT: Two Junctions.

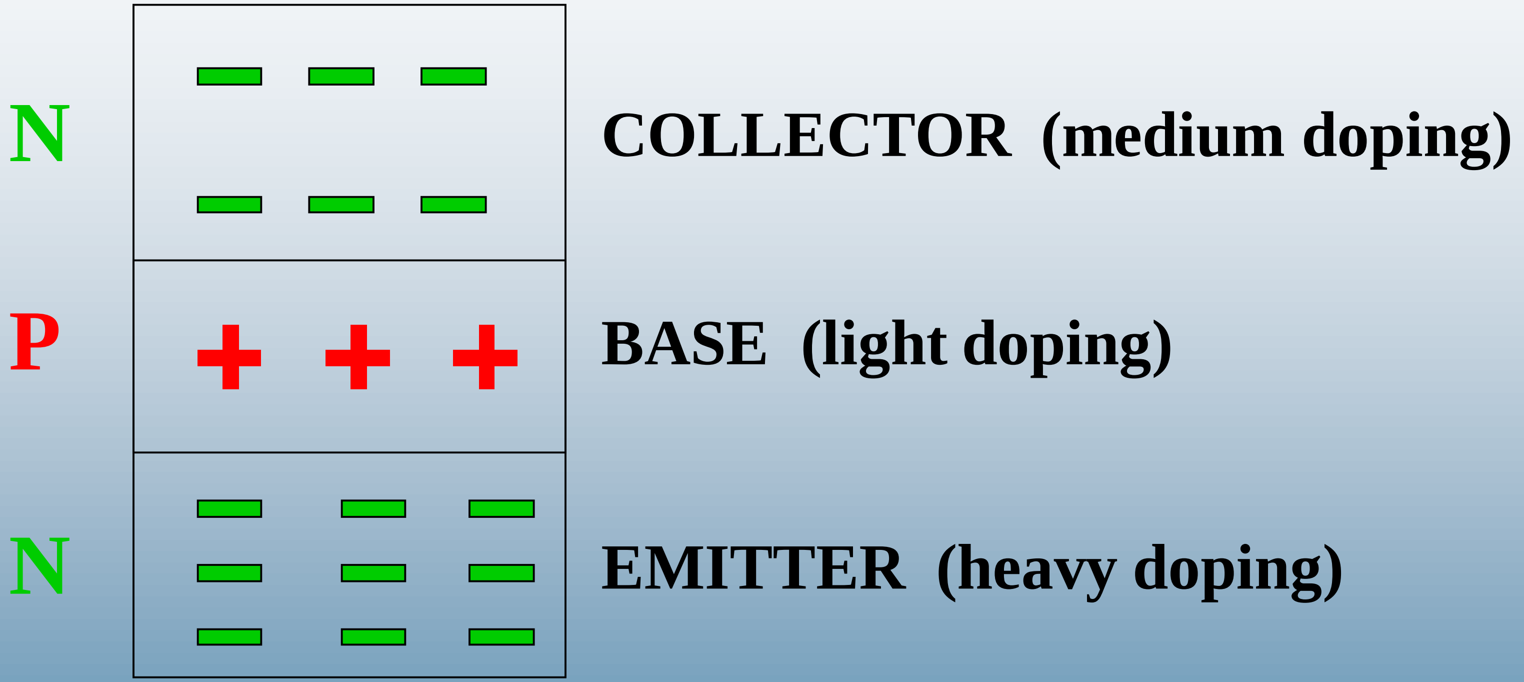
1. Emitter – Base Junction (EB)
2. Collector – Base Junction (CB)

EB	CB	
FB	FB	ON: Saturation mode
FB	RB	Amplifier: Active mode
RB	RB	OFF: Cutoff mode
RB	FB	Inverter

Unbiased transistor

- **Three** doped regions: emitter, base, and collector
- **Two** pn junctions: emitter-base and base-collector
  - Like two back-to-back connected diodes
- Two types: NPN or PNP
- Silicon or germanium

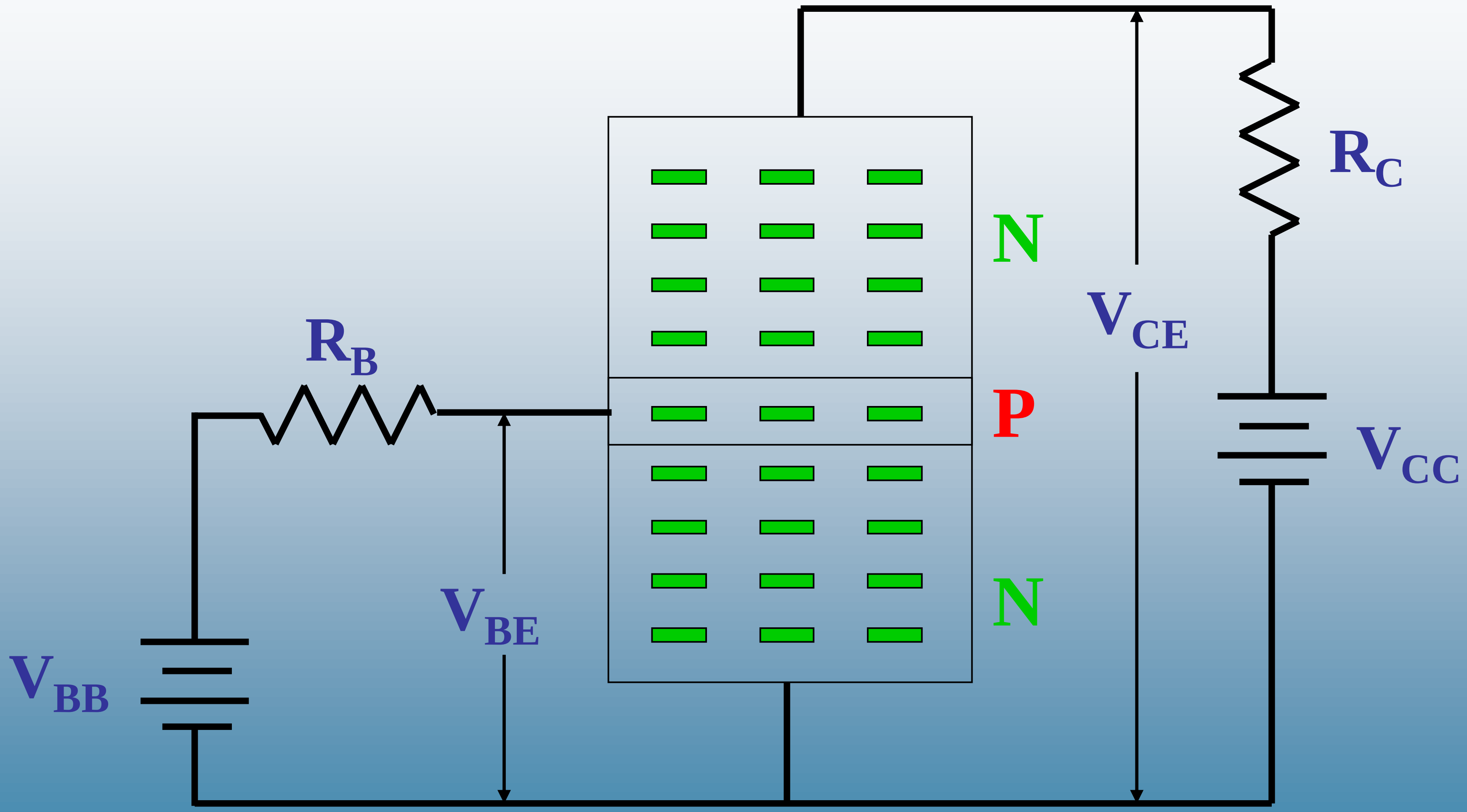
The bipolar junction transistor has 3 doped regions.



Biased transistor

- **BJT in Active mode**
- **Forward bias the emitter diode**
- **Reverse bias the collector diode**
- **BJT works as an Amplifier**

In a properly biased NPN transistor, the emitter electrons diffuse into the base and then go on to the collector.



Purposes of Different Transistor Regions

- The heavily doped emitter emits or injects its free electrons into the base
- The lightly doped base also has a well-defined purpose: to pass emitter-injected electrons on to the collector
- The collector is so named because it collects or gathers most of the electrons from the base

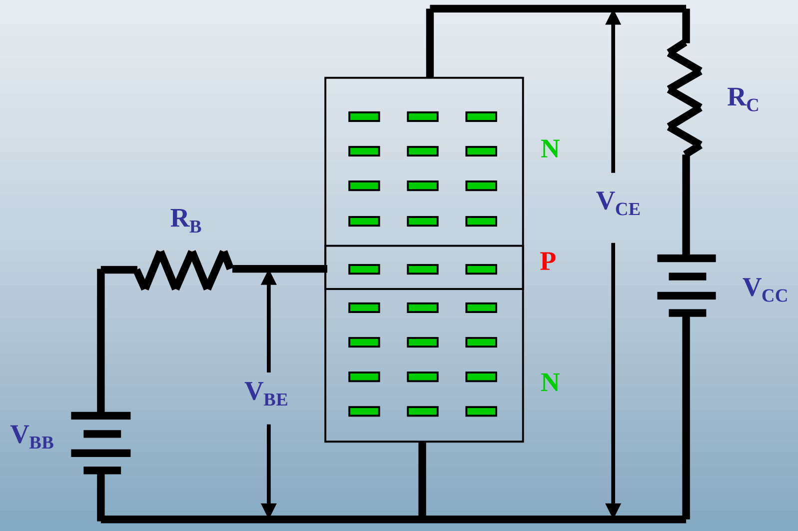
Electron Movement

- If V_{BE} is greater than the emitter-base barrier potential (0.7 V for Si), emitter electrons (I_E) will enter the base region
- These electrons can flow in either of two directions.
  1. They can flow out of the base through the base terminal or Recombination (I_B)
  2. They can flow into the collector (I_C)

Which way the free electrons in the base region go?

- Most continue on to the collector
  - Why?
    - The base is *lightly doped* and *very thin*
    - The light doping means that there are very few majority carriers
    - The very thin base means that the free electrons have only a short distance to go to reach the collector
    - The positive voltage (reverse voltage) applied to the collector pulls them towards the collector
    - For these reasons, almost all the emitter-injected electrons pass through the base to the collector.
  - Only a few free electrons will recombine with holes in the lightly doped base

Summary of Carrier Flow in a Biased NPN Transistor



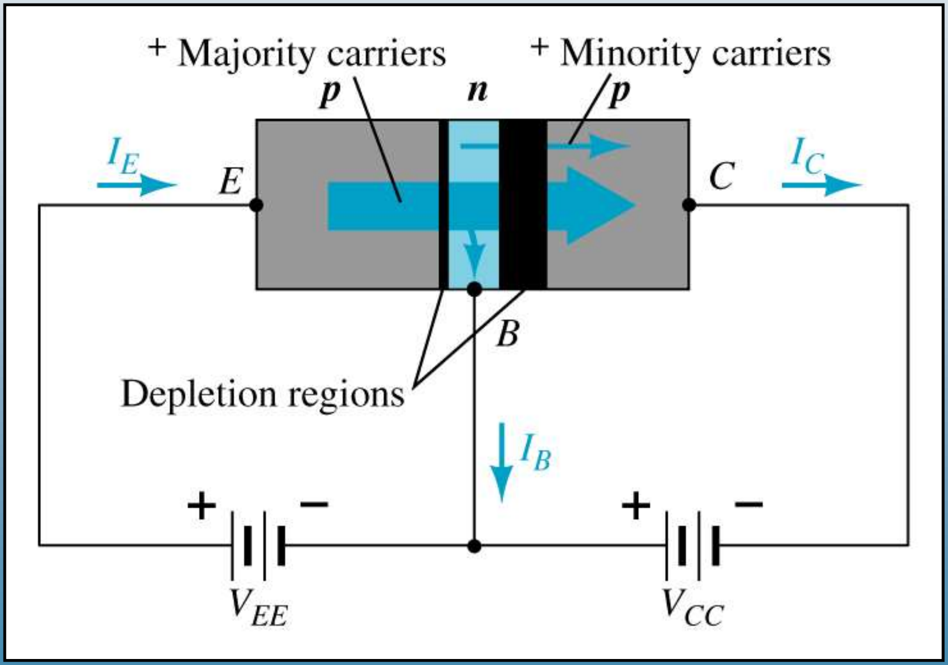
- V_{BB} forward biases the emitter diode
  - Forces the free electrons in the emitter to enter the base
- The thin and lightly doped base gives almost all these electrons enough time to diffuse into the collector
- These electrons flow through the collector, through R_C and into the positive terminal of the V_{CC} voltage source

Transistor Operation

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

The emitter-base junction is forward biased

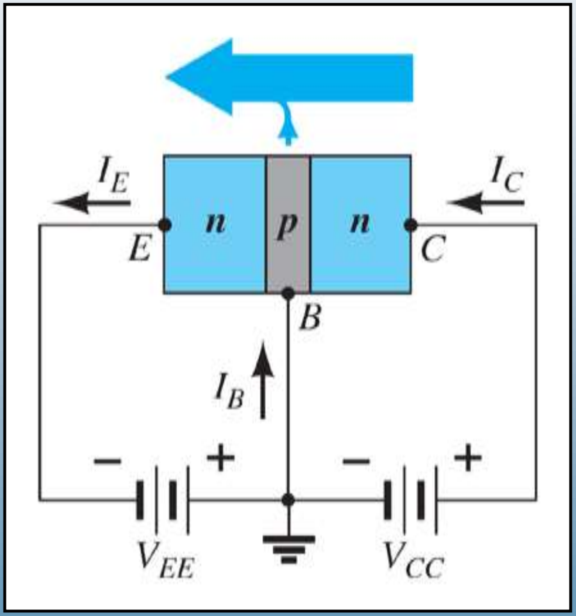
The base-collector junction is reverse biased



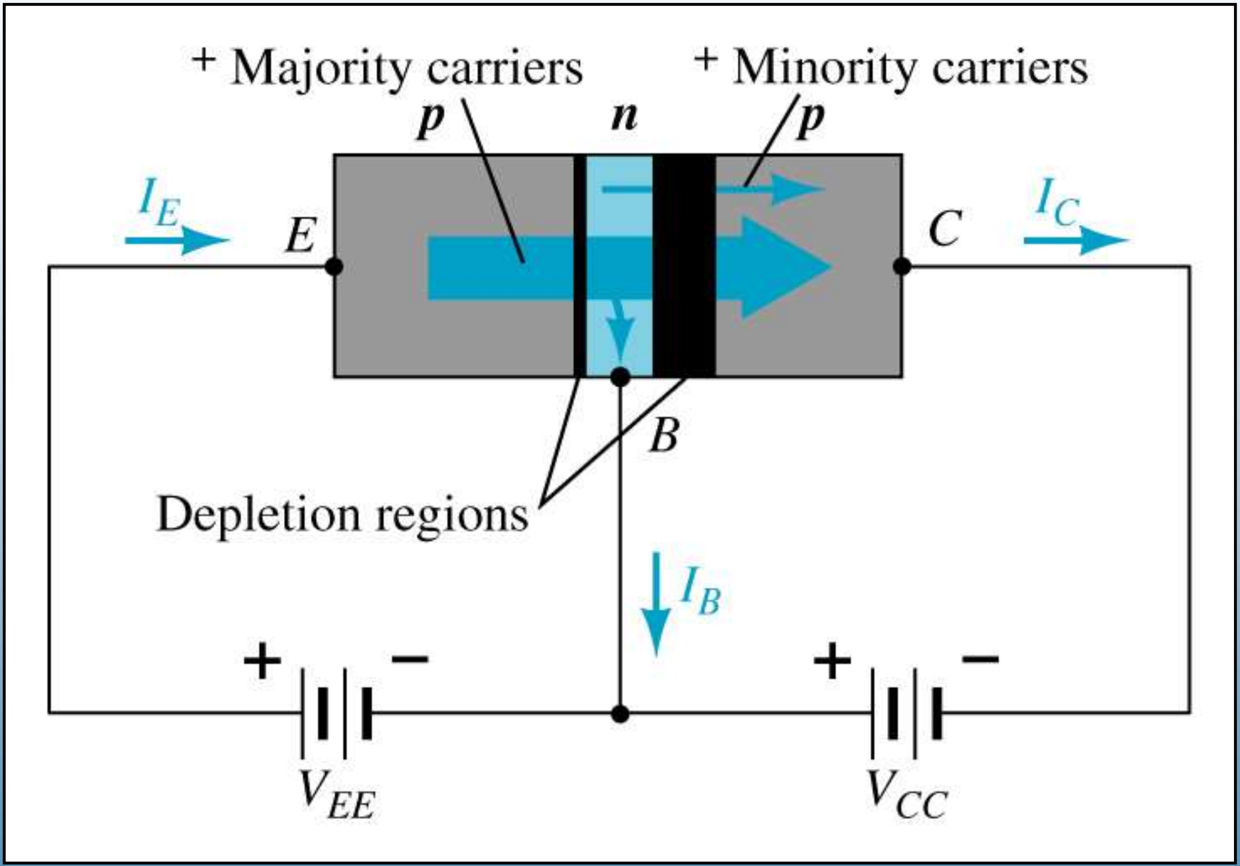
Currents in a Transistor

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

$$I_E = I_C + I_B$$



Carrier flow in a pnp 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:

$$I_C = I_{C\,(majority)} + I_{CO\,(minority)}$$

Transistor Connections

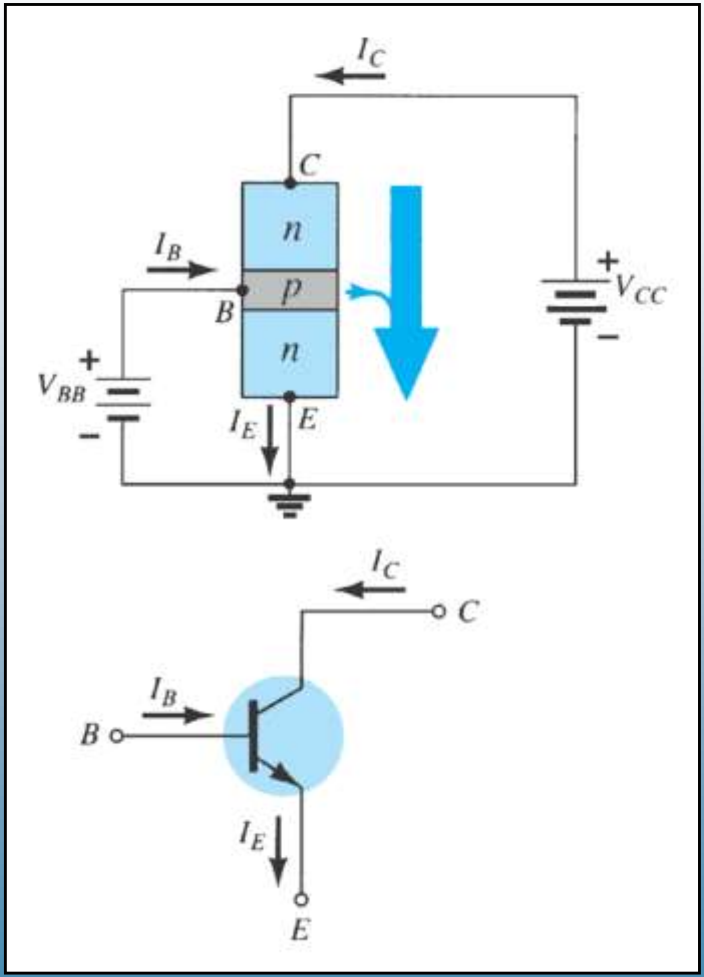
There are three useful way to connect a transistor:

- CE (common emitter) – most widely used
- CC (common collector)
- CB (common base)

Common-Emitter Configuration

The emitter is common to both input (base-emitter) and output (collector-emitter) circuits.

The input is applied to the base and the output is taken from the collector.



Common-Emitter Amplifier Currents

Ideal Currents

$$I_E = I_C + I_B \qquad I_C = \alpha I_E$$

Actual Currents

$$I_C = \alpha I_E + I_{CBO}$$

where I_{CBO} = minority collector current

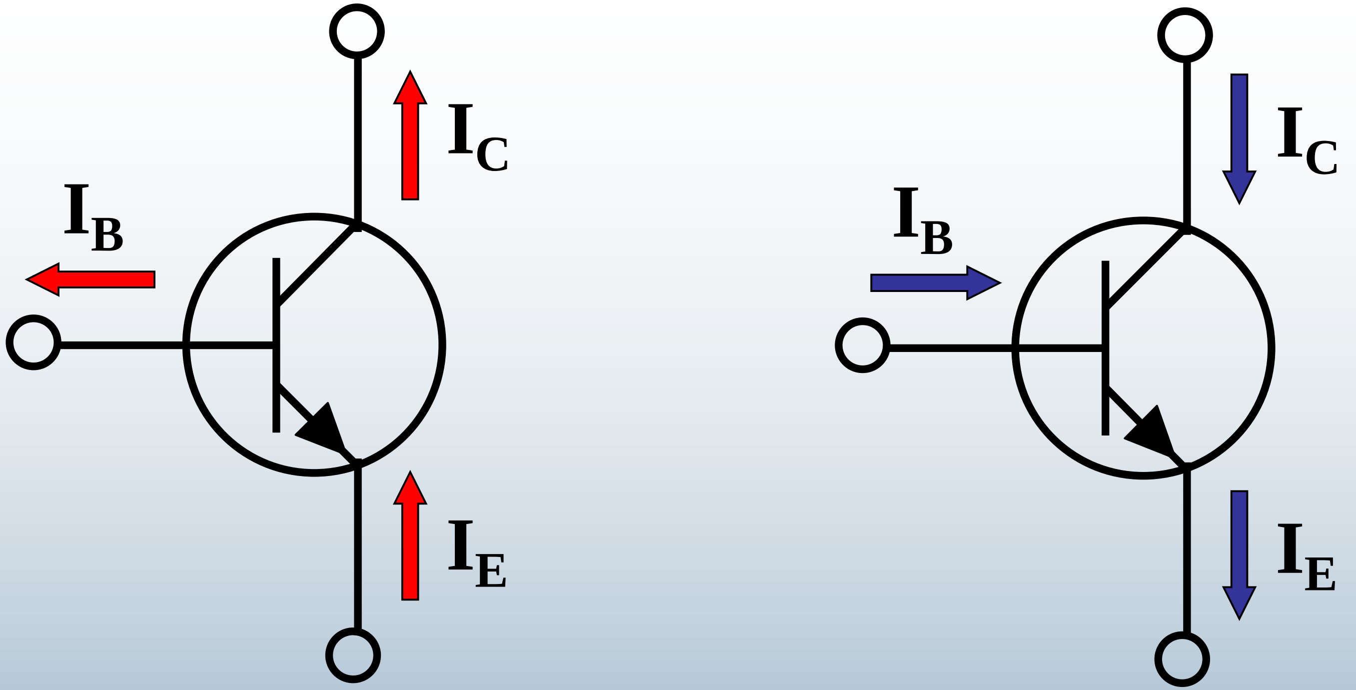
I_{CBO} is usually so small that it can be ignored, except in high power transistors and in high temperature environments.

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

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

Transistor Current Gain

- Current Gain (β) = $\frac{Output\ Current\ (I_C)}{Input\ Current\ (I_B)}$
- The ratio of collector current to base current is **current gain** (β_{dc})
- Current gain is typically **100** to **300**



Electron flow **Conventional flow**

$I_E = I_C + I_B$ $I_C \cong I_E$ $I_B << I_C$

$$\alpha_{dc} = \frac{I_C}{I_E} \qquad \beta_{dc} = \frac{I_C}{I_B}$$

Beta (β)

β **represents the amplification factor of a transistor.**

In DC mode:

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

In AC mode:

$$\beta_{ac} = \left.\frac{\Delta I_C}{\Delta I_B}\right|_{V_{CE}=constant}$$

Beta (β)

Determining β from a Graph

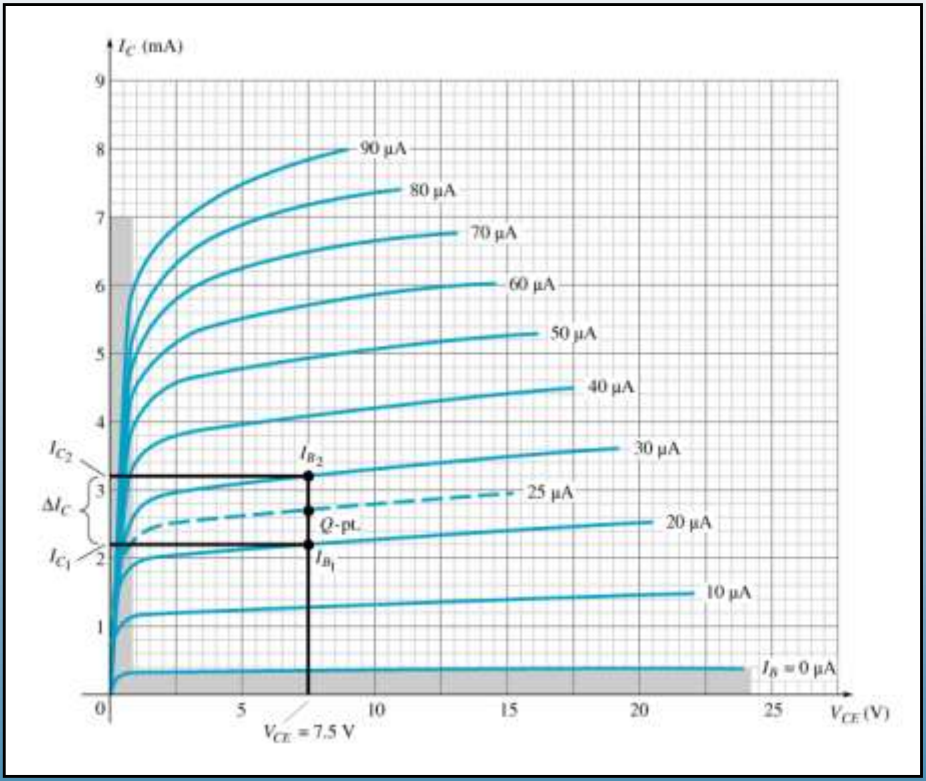
$$\beta_{AC} = \frac{(3.2\ mA - 2.2\ mA)}{(30\ \mu A\ -\ 20\ \mu A)}$$

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

$$= 100$$

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

$$= 108$$



Example 6-1

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

SOLUTION Divide the collector current by the base current to get:

$$\beta_{dc} = \frac{10\text{ mA}}{40\ \mu\text{A}} = 250$$

Example 6-2

A transistor has a current gain of 175. If the base current is 0.1 mA, what is the collector current?

SOLUTION Multiply the current gain by the base current to get:

$$I_C = 175(0.1\ \text{mA}) = 17.5\ \text{mA}$$

Example 6–3

A transistor has a collector current of 2 mA. If the current gain is 135, what is the base current?

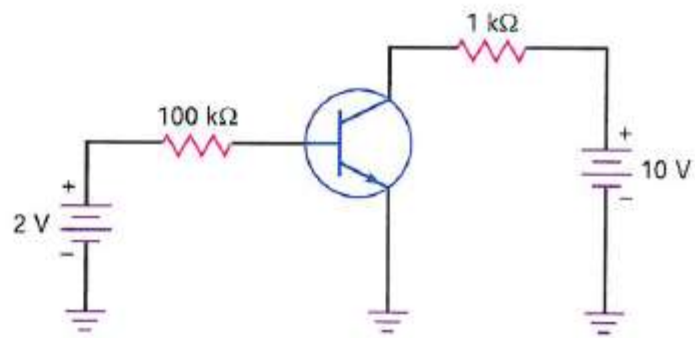
SOLUTION Divide the collector current by the current gain to get:

$$I_B = \frac{2\ \text{mA}}{135} = 14.8\ \mu\text{A}$$

Example 6-4

MultiSim

Use the second approximation to calculate the base current in Fig. 6-8*b*. What is the voltage across the base resistor? The collector current if $\beta_{dc} = 200$?



(*b*)

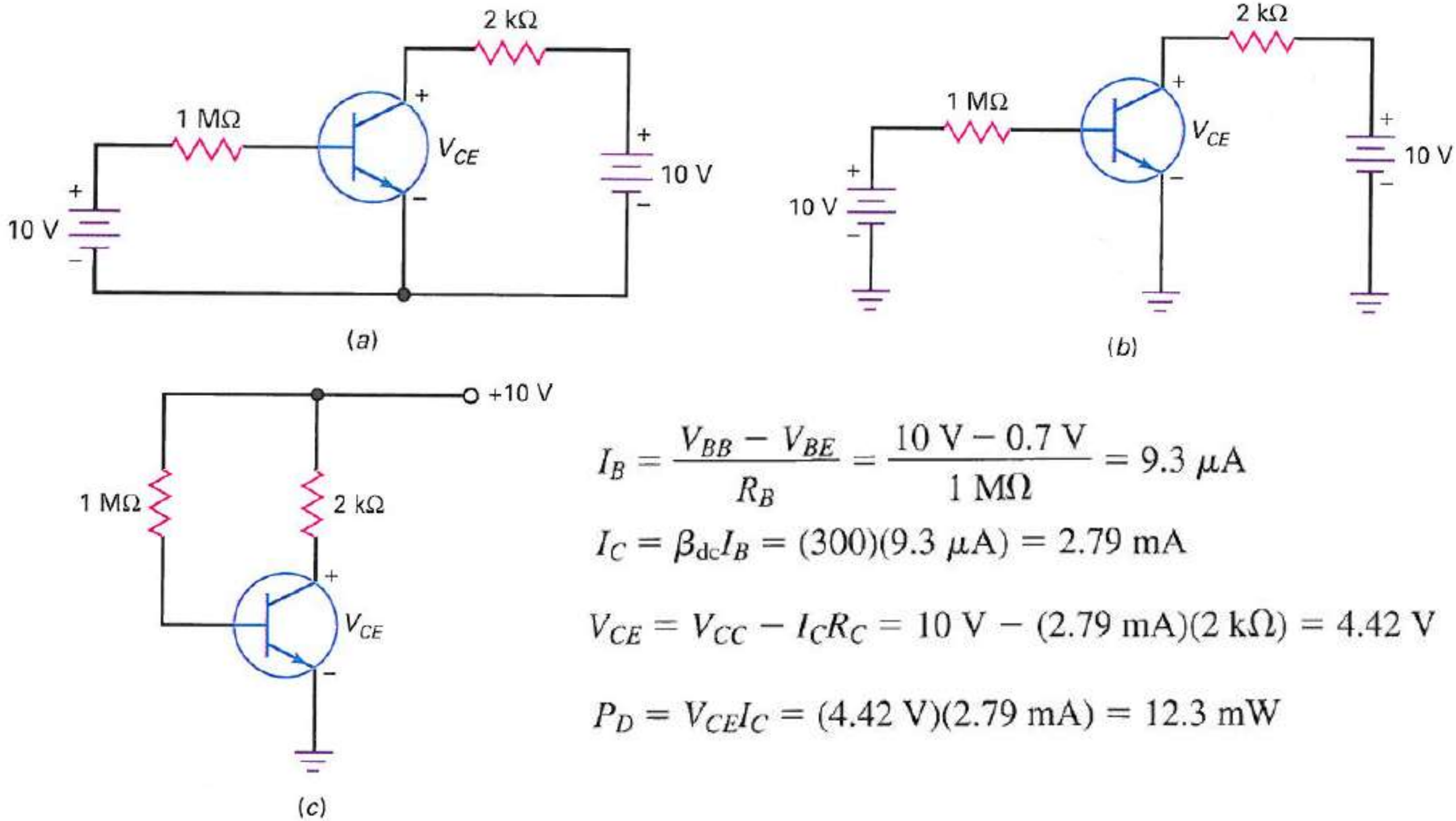
$$V_{BB} - V_{BE} = 2\text{ V} - 0.7\text{ V} = 1.3\text{ V}$$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{1.3\text{ V}}{100\text{ k}\Omega} = 13\ \mu\text{A}$$

$$I_C = \beta_{dc} I_B = (200)(13\ \mu\text{A}) = 2.6\text{ mA}$$

Example 6-5

The transistor of Fig. 6-11a has $\beta_{dc} = 300$. Calculate I_B, I_C, V_{CE}, and P_D.



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

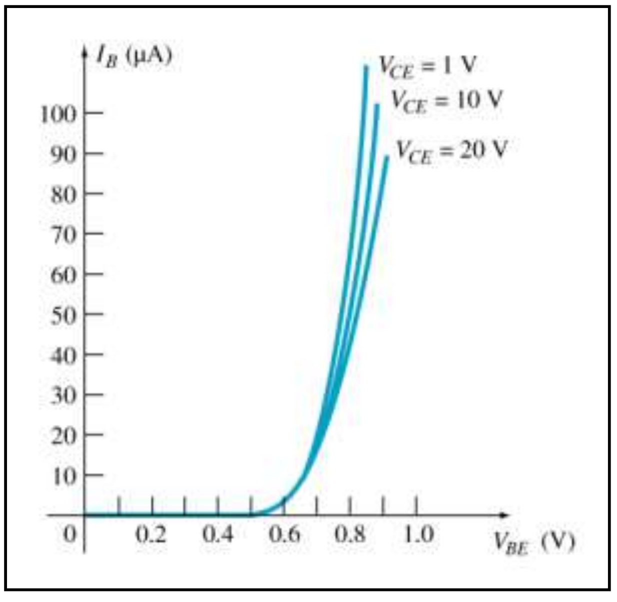
$$I_C = \beta_{dc} I_B = (300)(9.3\ \mu\text{A}) = 2.79\text{ mA}$$

$$V_{CE} = V_{CC} - I_C R_C = 10\text{ V} - (2.79\text{ mA})(2\text{ k}\Omega) = 4.42\text{ V}$$

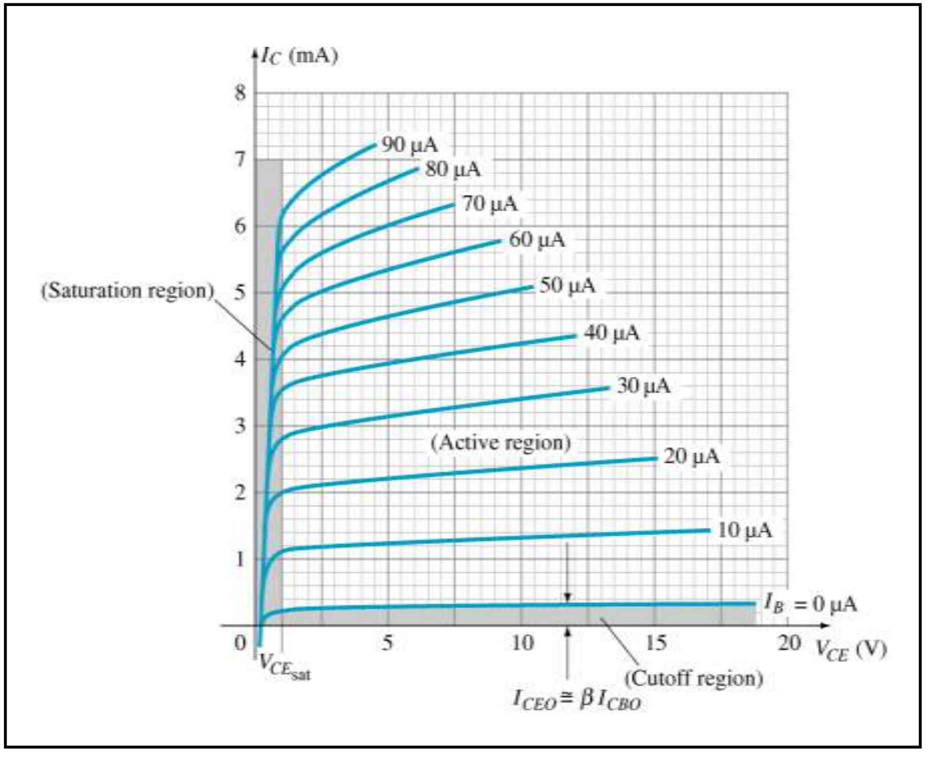
$$P_D = V_{CE} I_C = (4.42\text{ V})(2.79\text{ mA}) = 12.3\text{ mW}$$

CE Transistor Characteristics

- To fully describe the behavior of a BJT, two sets of characteristics are required:
  1. Driving point or input characteristics
  2. Output side or output characteristics

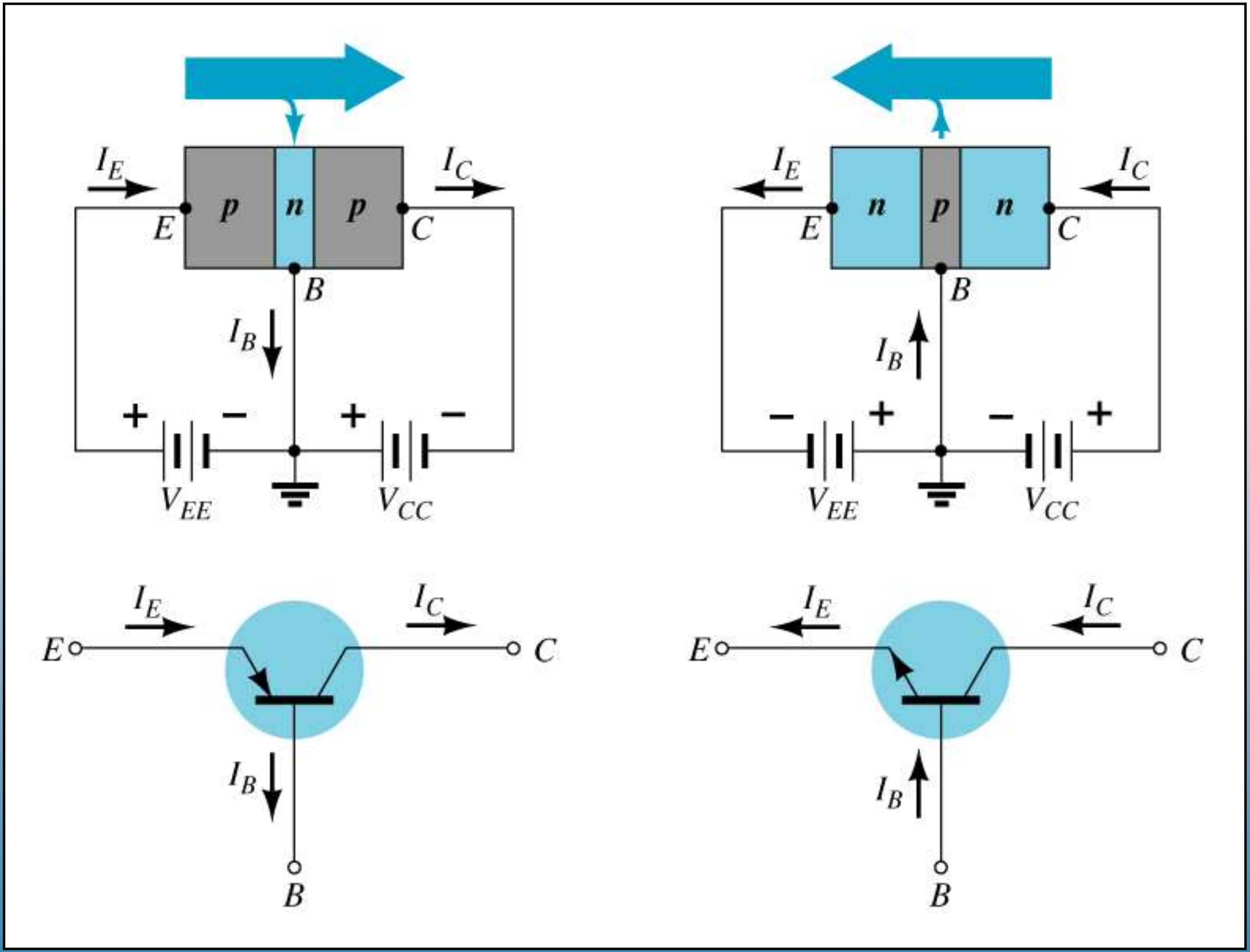


Base or Input Characteristics



Collector or Output Characteristics

Common-Base Configuration



The base is common to both input (emitter–base) junction and output (collector–base) junction of the transistor.

Operating Regions

Active

Operating range of the amplifier.

Cutoff

The amplifier is basically off. There is voltage, but little current.

Saturation

The amplifier is fully on. There is current, but little voltage.