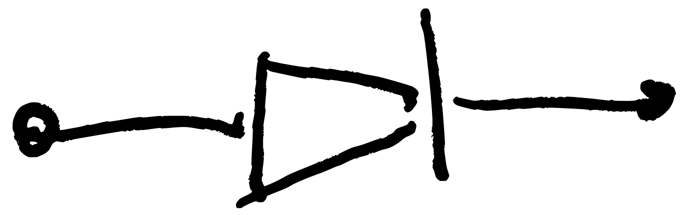
ME133 Lecture 6 1/26/23

Last time:

> diode  on/off behavior

> diode circuits

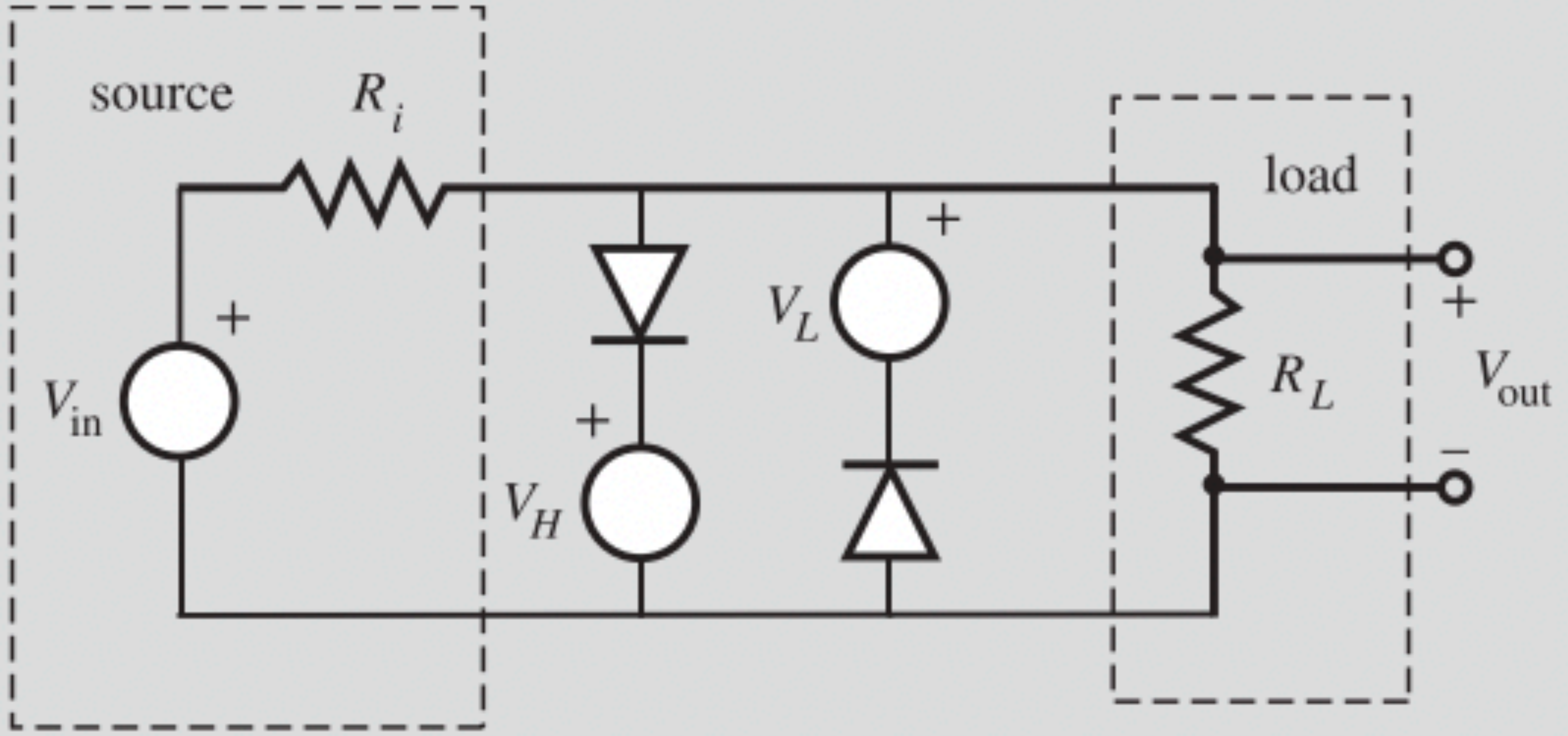
Today:

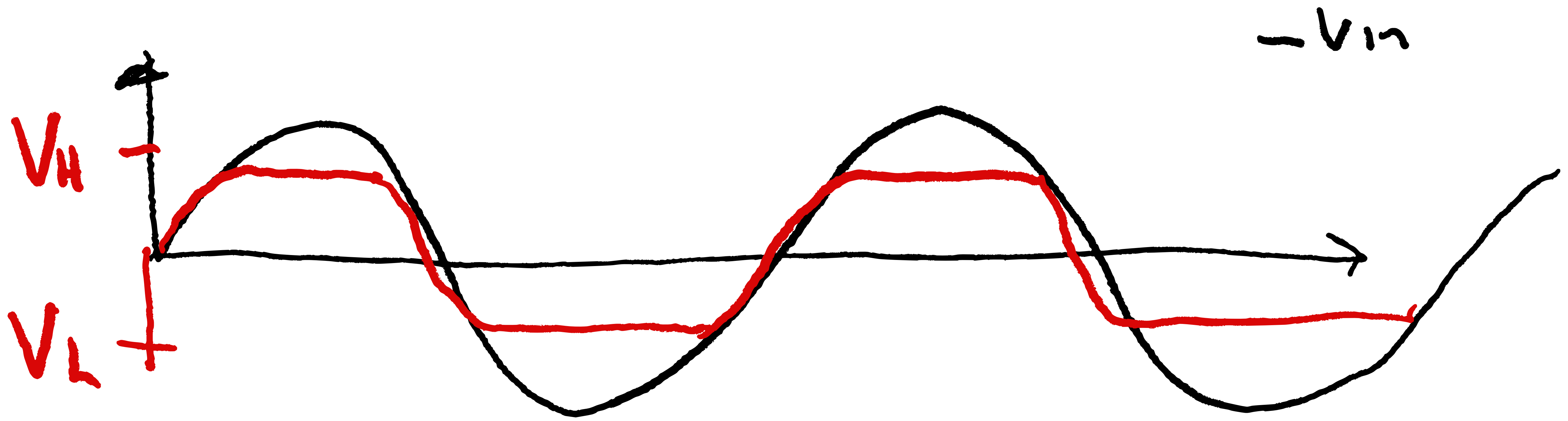
Bipolar Junction Transistor (BJT)

■ CLASS DISCUSSION ITEM 3.4

Voltage Limiter

The diode portion of the following circuit is called a **voltage limiter.** Explain why. Sketch some input and output waveforms that illustrate the circuit's behavior. Note: $V_H > V_L$.





Zener Diode: Voltage regulator

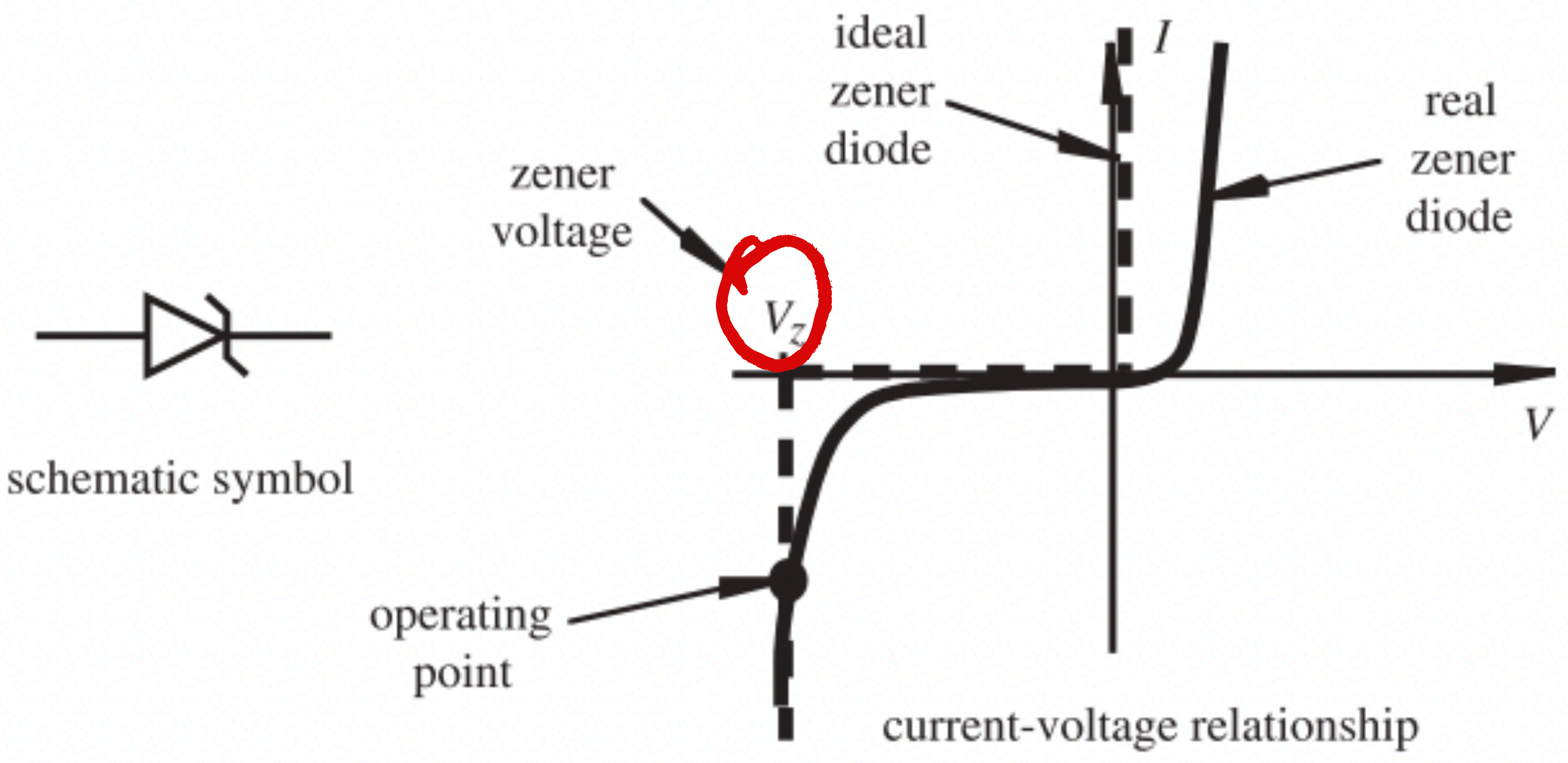


Figure 3.14 Zener diode symbol and current–voltage relationship.

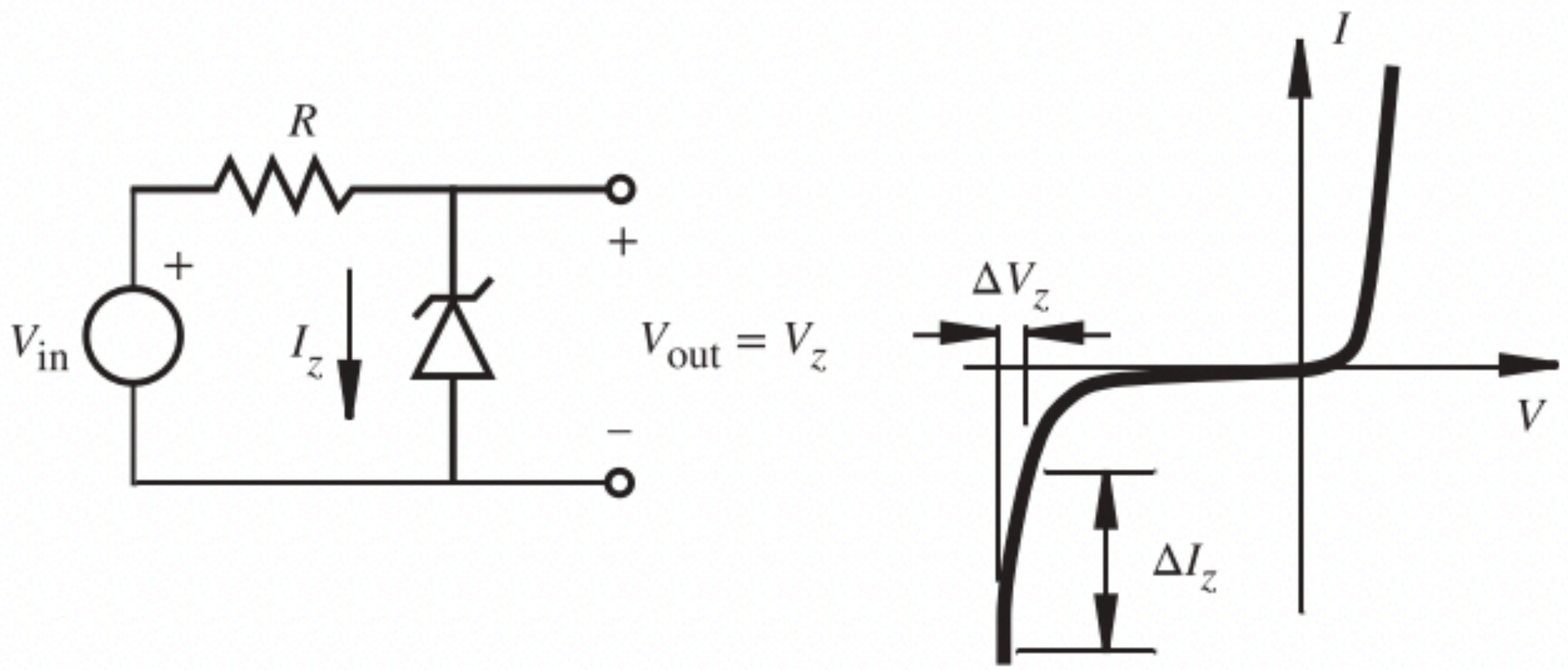
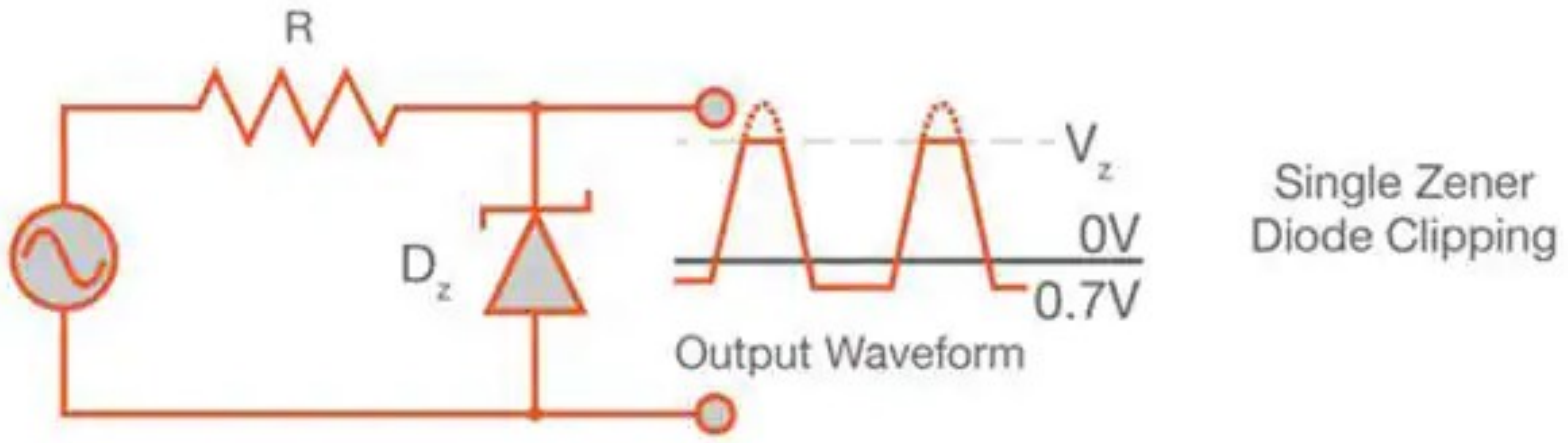
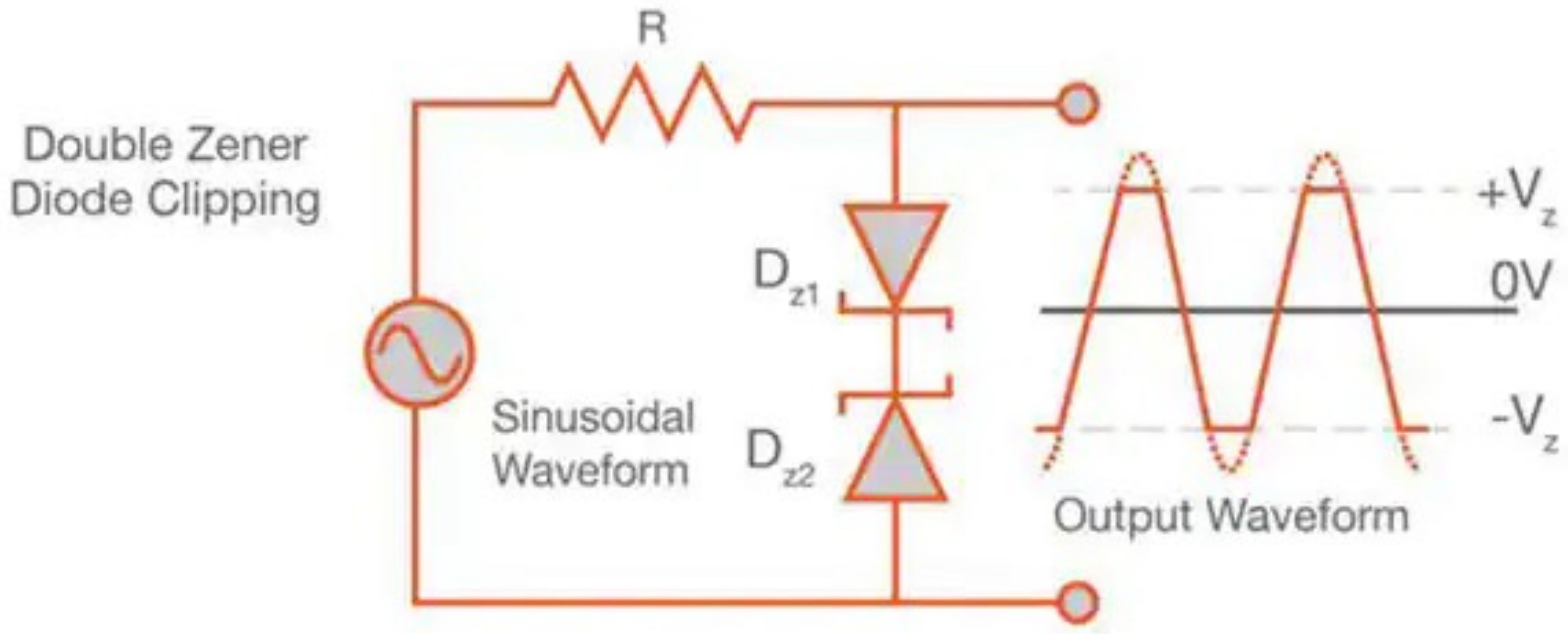


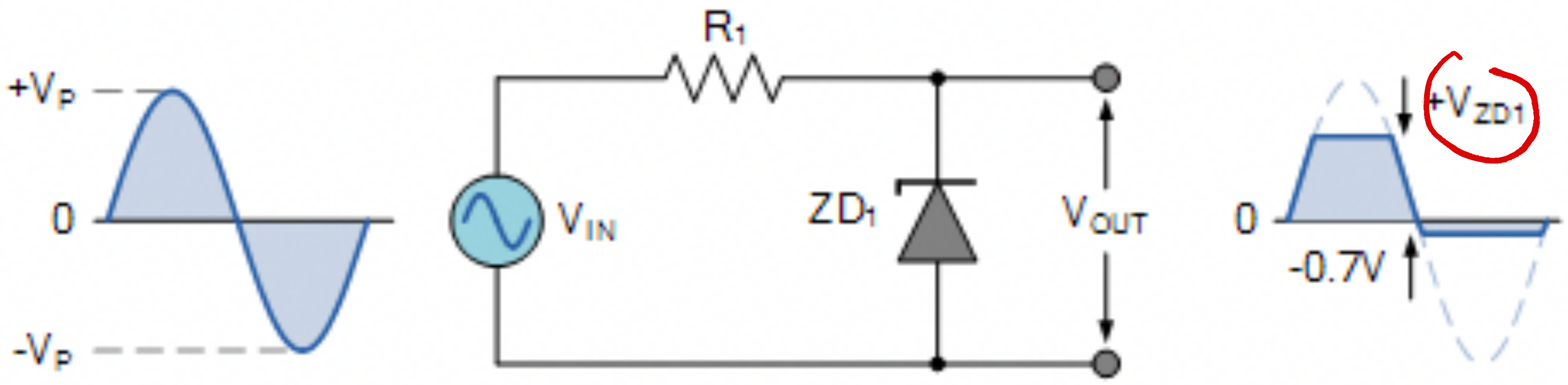
Figure 3.15 Zener diode voltage regulator.

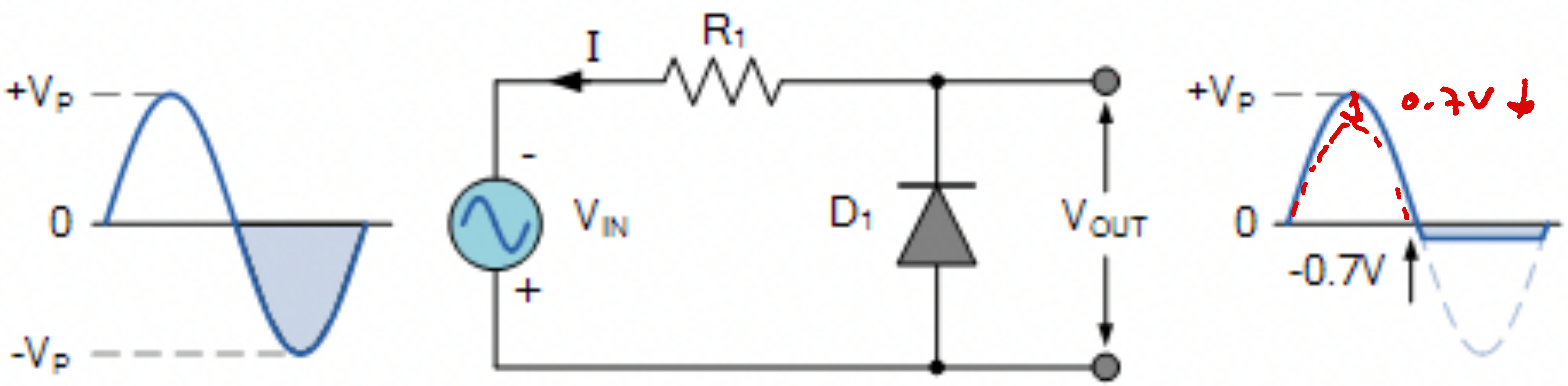
Other Applications





Compare with normal diode





Transistors Overview

- these the heart of nearly every electronic device

  mechatronic devices

- the first transistor, BJT invented in 1948
  - William Shockley, Bell Labs

  → most important tech. innovation in the 20th

Basically two functions

1. Switching : control <u>large</u> voltage/current using small voltage/current

2. Amplification : magnify voltage/current by transfering energy from another source

Main Advantages

① Amplification : transistor tiny signal then amplify

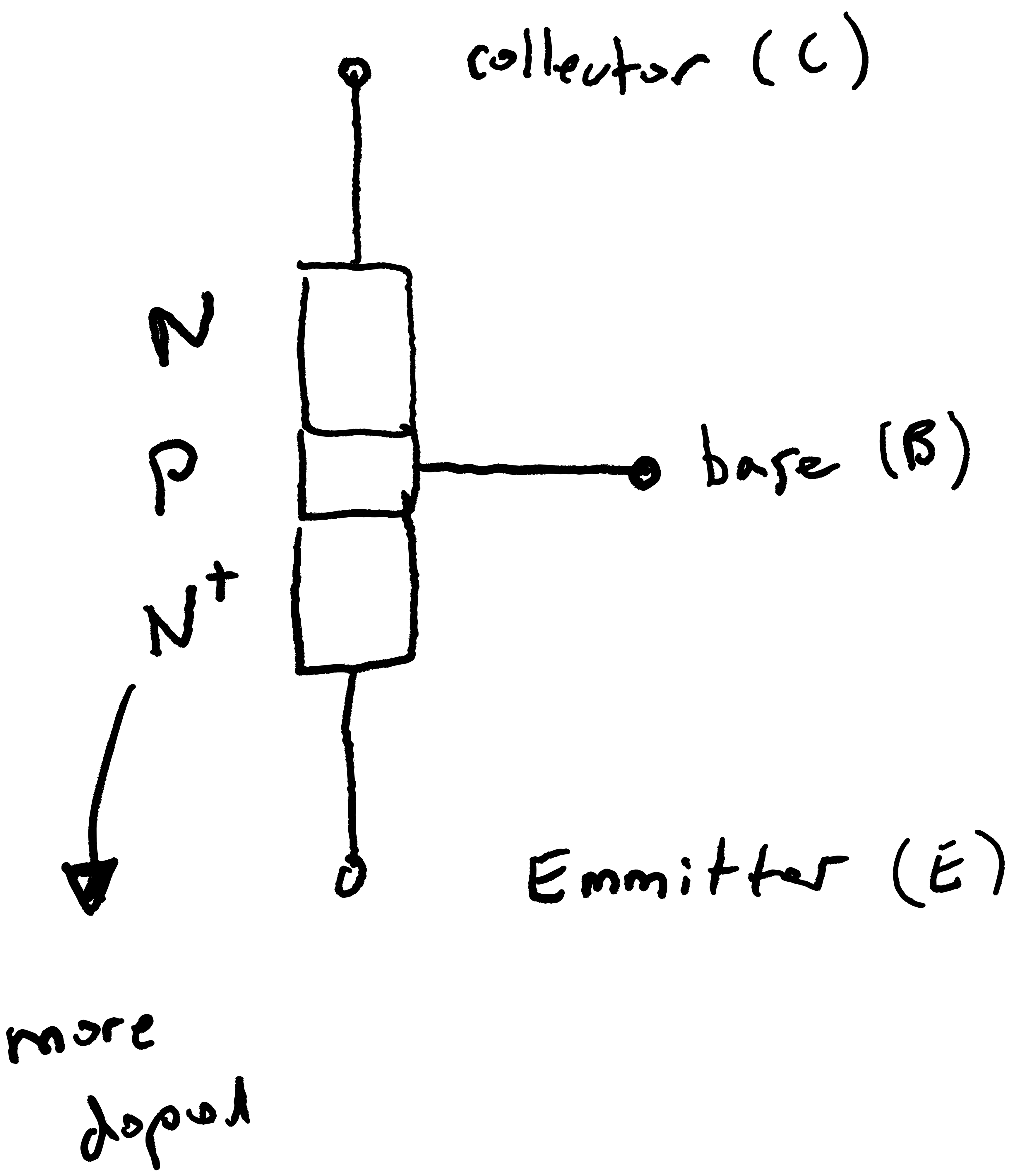
② switching : Build logic circuits

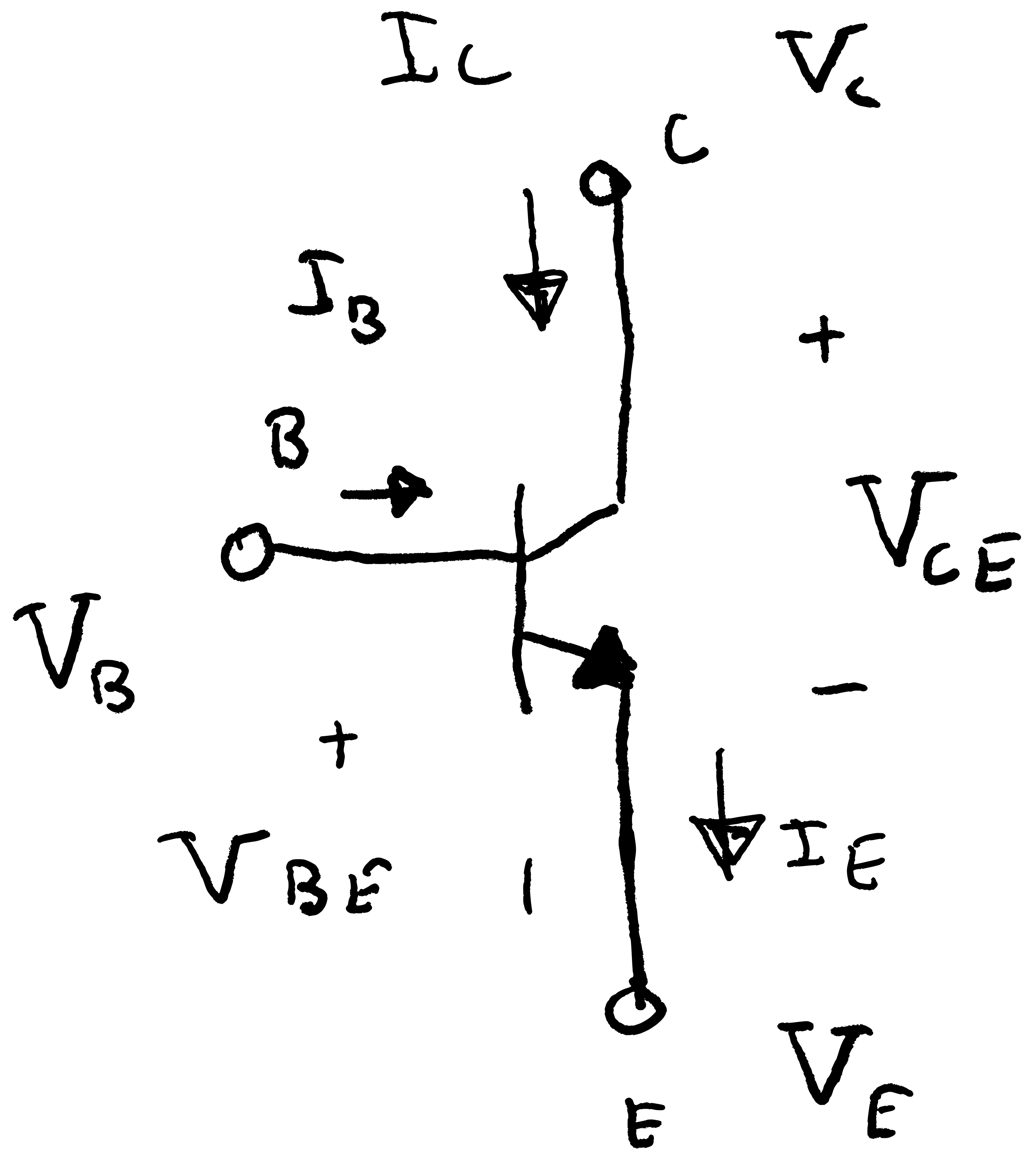
Ch. 6

Most Common Types of Transistors

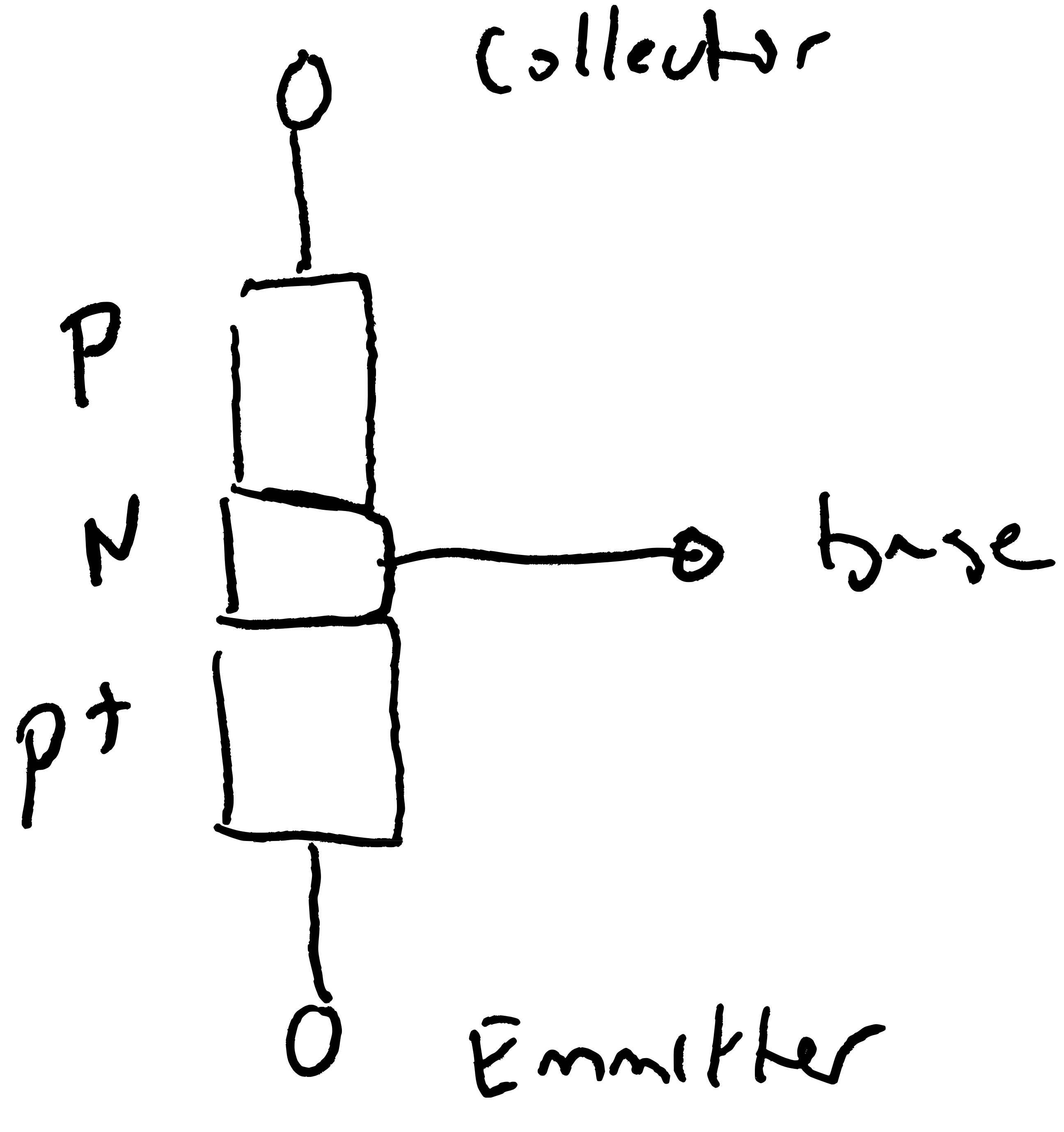
Bipolar Junction	Field Effect
. 3 terminal	. 3 terminal
. Two PN junction	. channel of doped semiconductor → conductivity channel

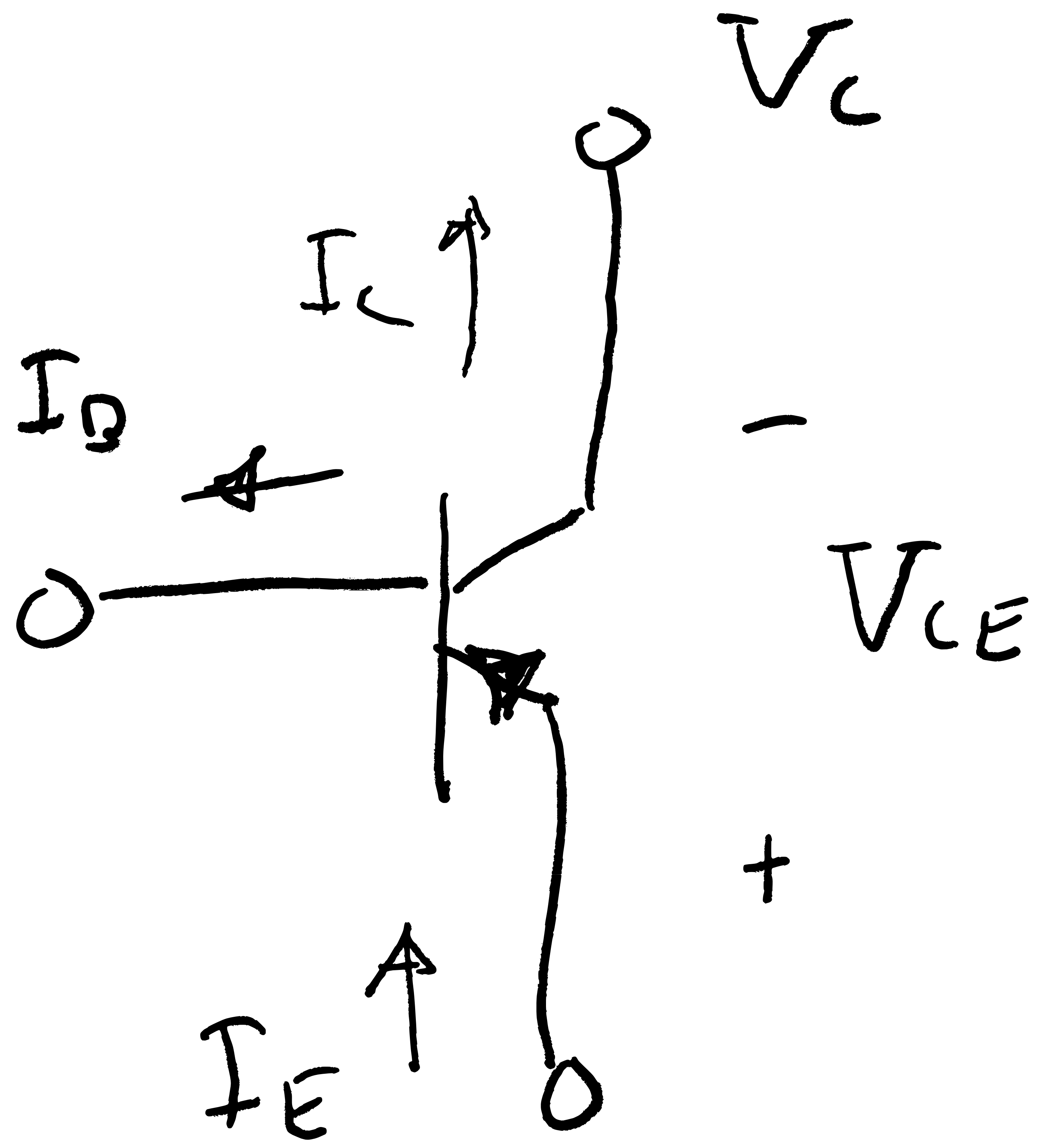
Bipolar Junction NPN transistor



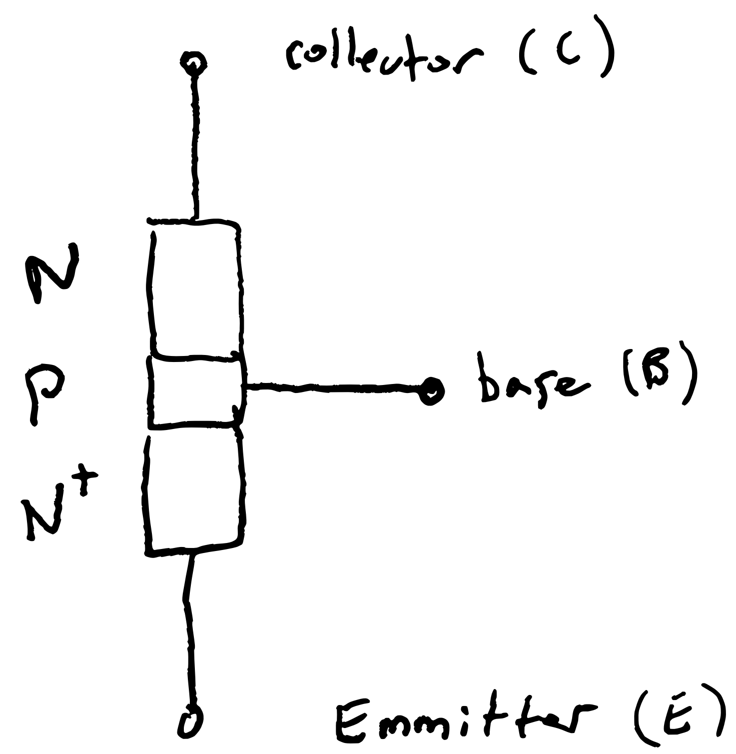


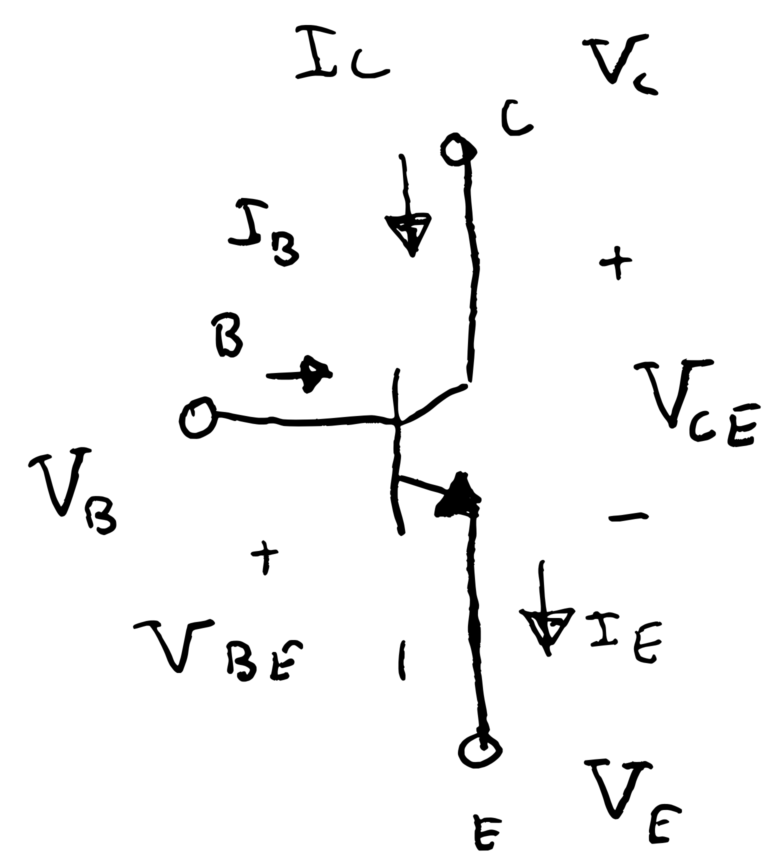
Bipolar Junction PNP transistor





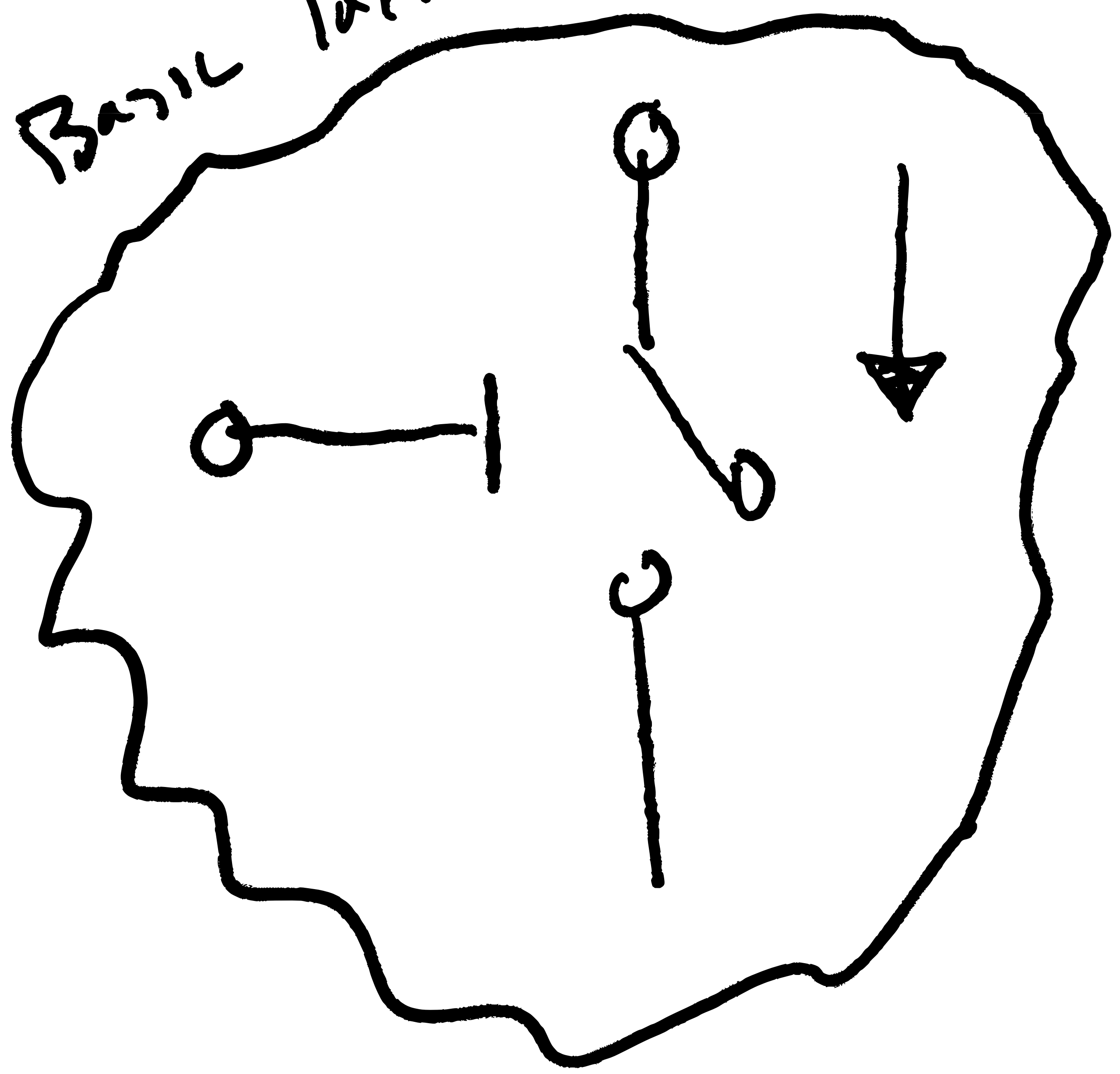
NPN Working Principle





$$
\begin{cases}
I_E = I_C + I_B \\
V_{BE} = V_B - V_E \\
V_{CE} = V_C - V_E
\end{cases}
$$

Basic Idea



$$V_{BE} = 0.7\,V$$

For transistor to be <u>on</u>

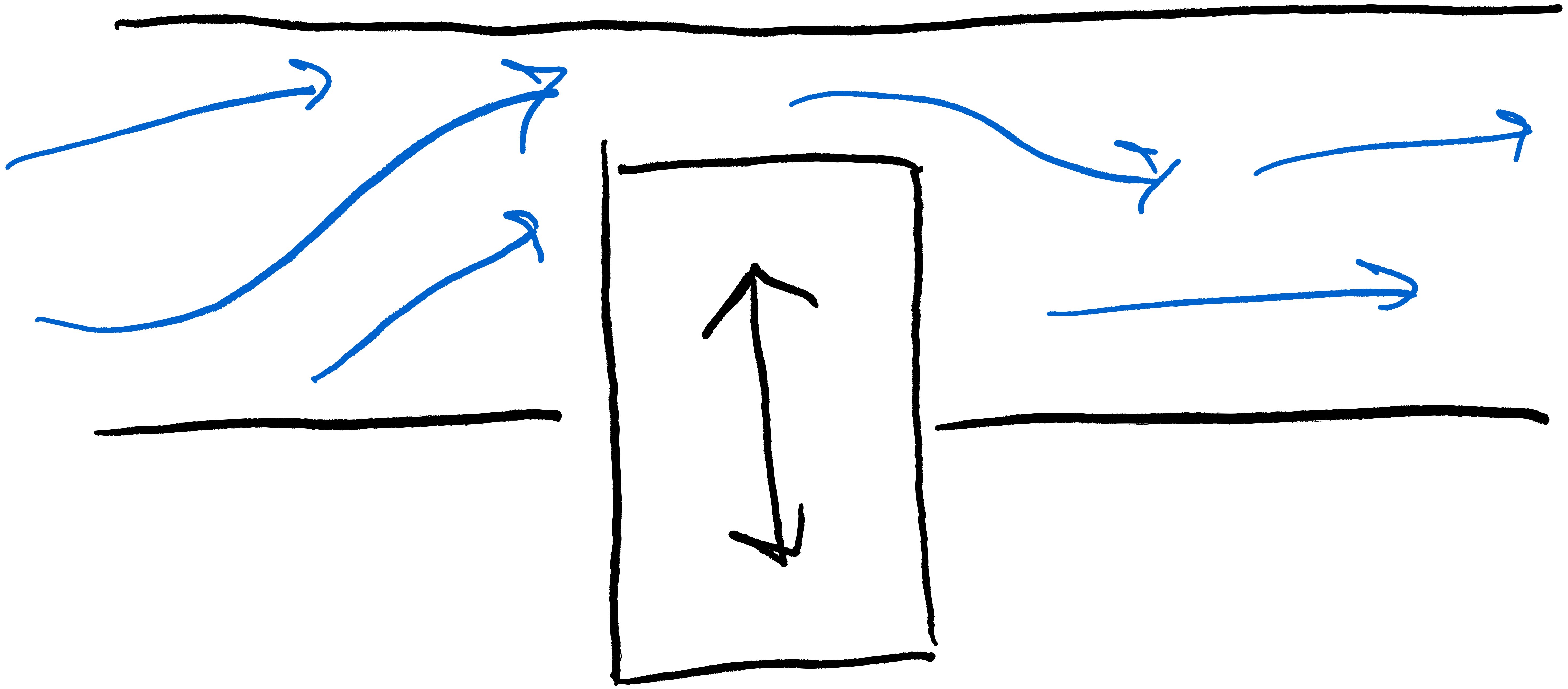
base-to-emitter forward bias

→ large collector current (I_C) flows, with only small (I_B)

$$I_B \ll I_C$$

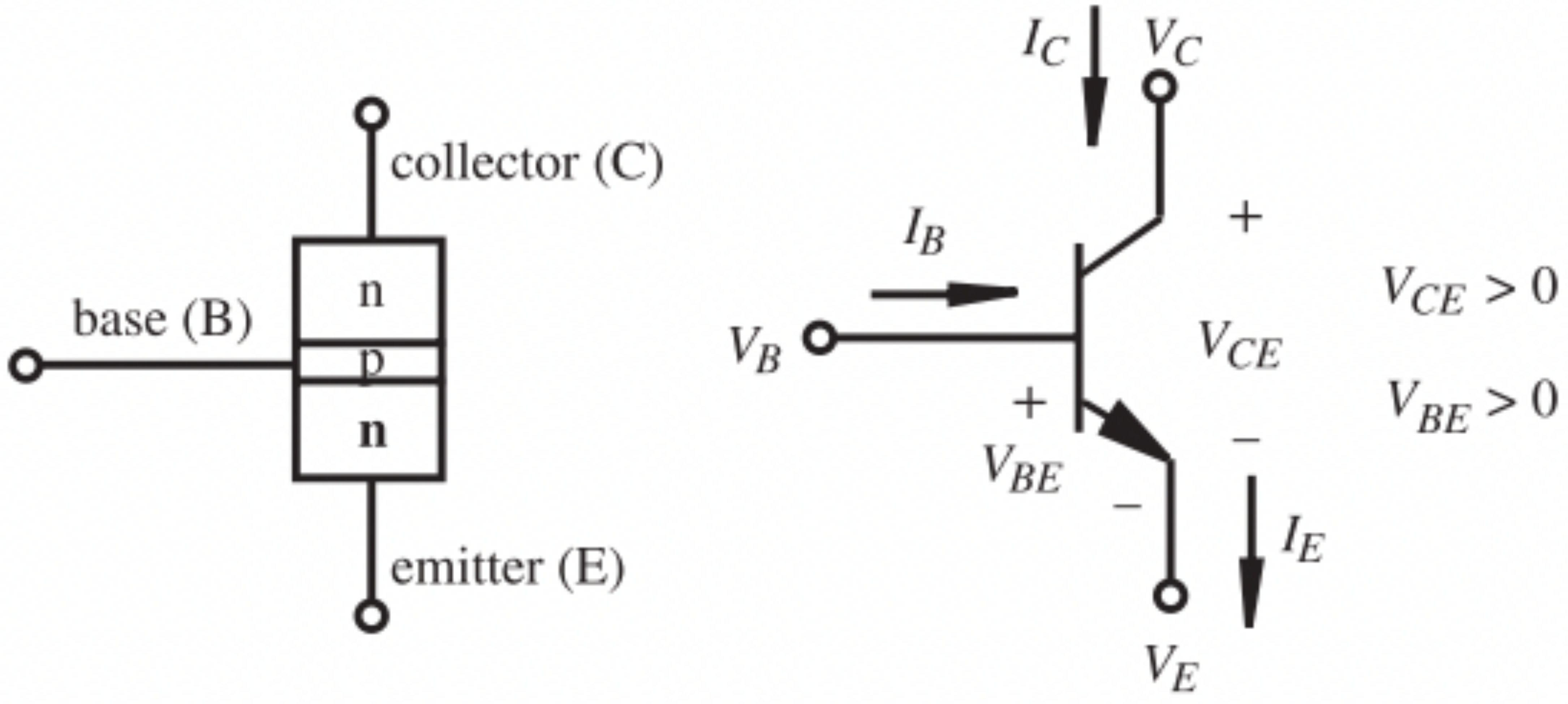
- Voltage drop V_{CE} (0.2 V)

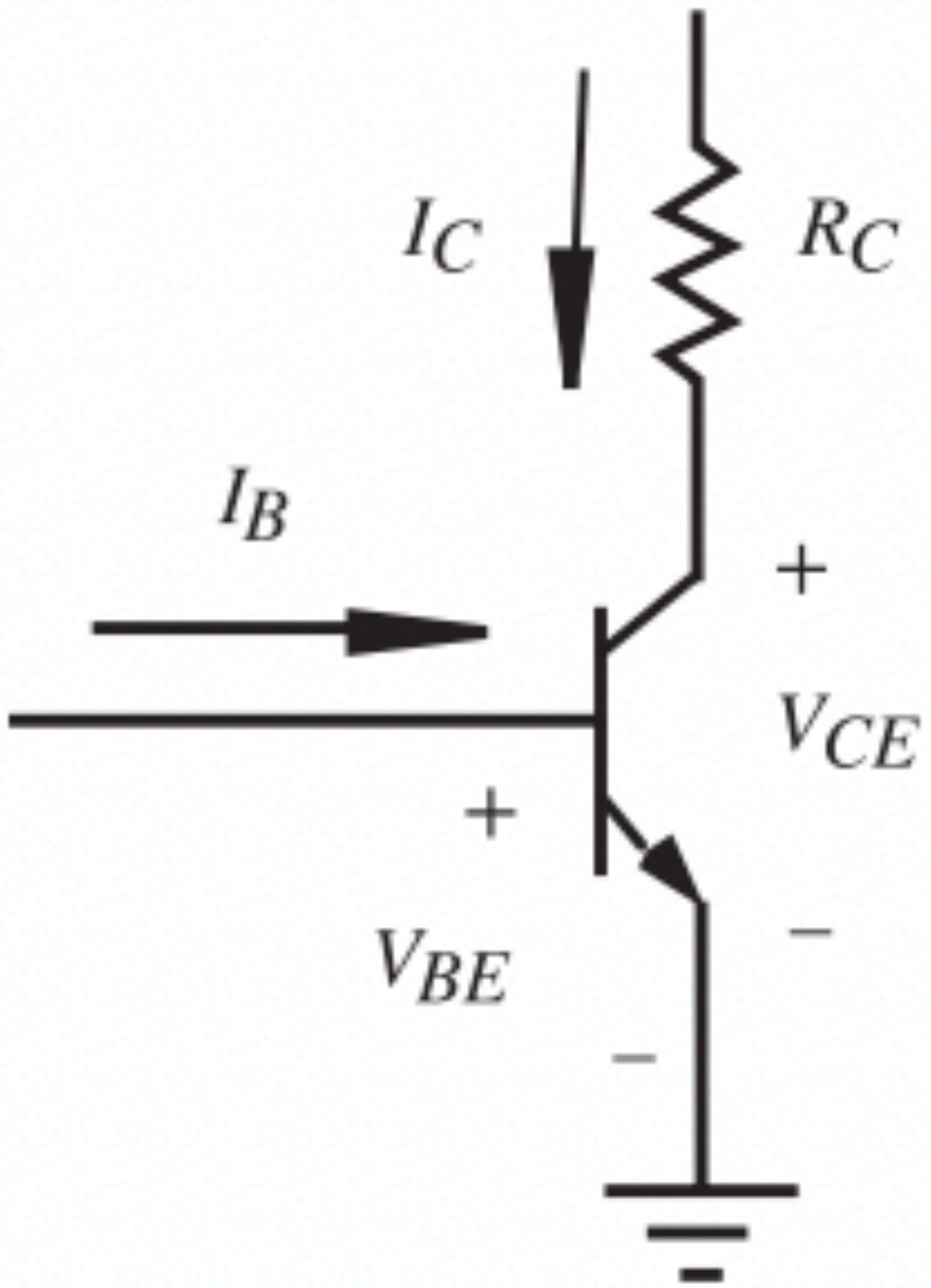
Transistor Water Analogy



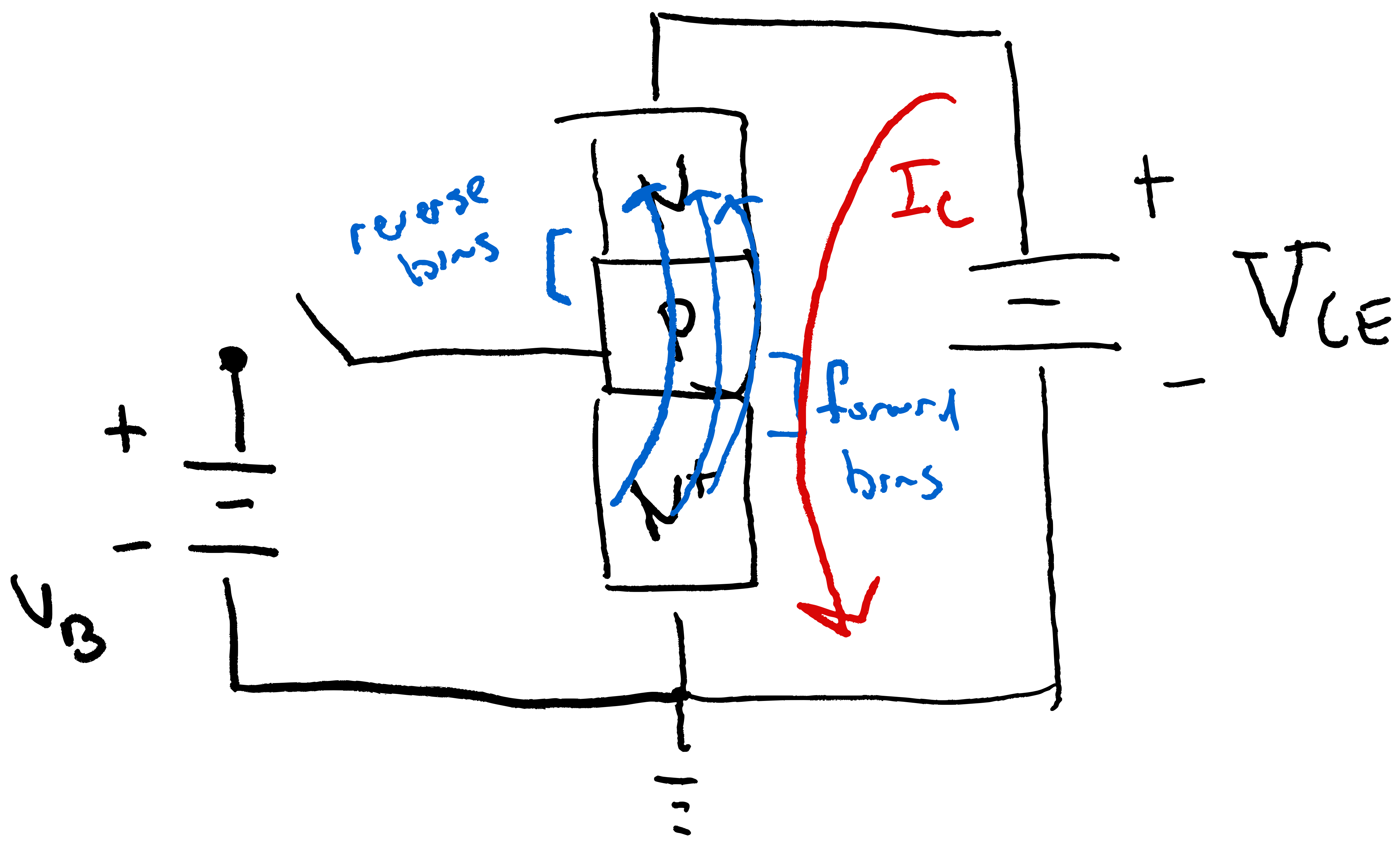
variable valve, controlled by $\underline{I_B}$

Common Emitter Circuit





NPN Working Principle



Collector : collects e^-
emitter : emits e^-
] when transistor is ON

$$V_B = V_E + 0.7\,V$$

P-section is small, e^- have enough momentum to cross over

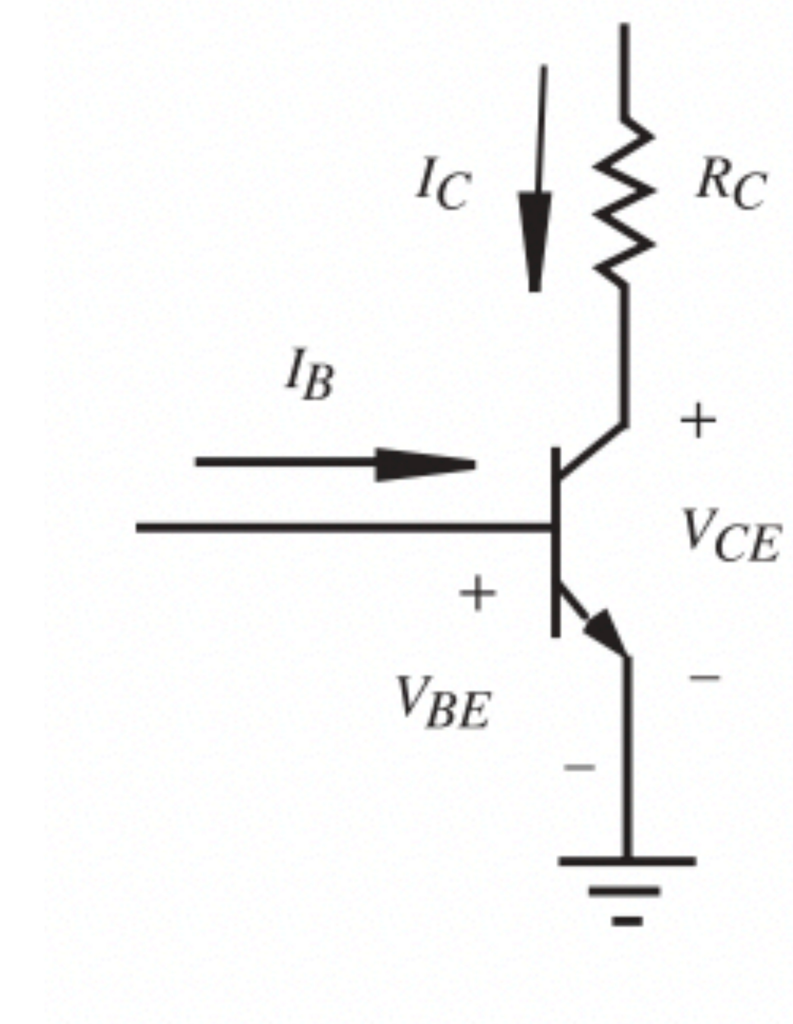
Key idea

$$I_c = \beta I_B$$

β ← 100

h_{fe} => transistor data sheet

BJT Operation Modes Common Emitter



Active:

$\uparrow I_B \rightarrow \uparrow I_C$

- proportional currents

$I_C = \beta I_B$

amplifier

Saturation:

$V_{CE} \approx 0$;

max current flows

- $I_E >> I_B$

$I_B \approx I_C$

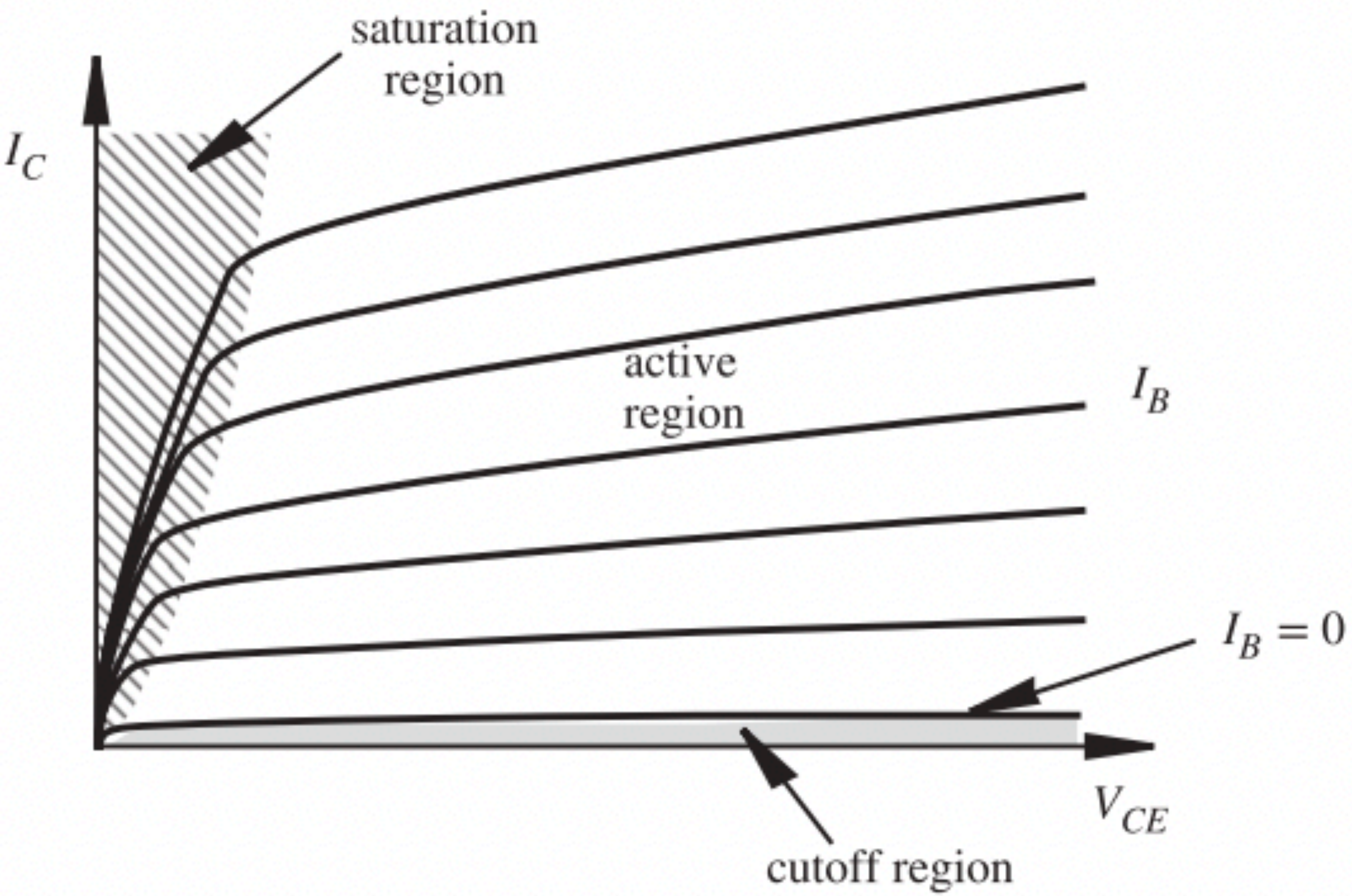
- both junctions become forward
- behaves like short circuit

Cutoff:

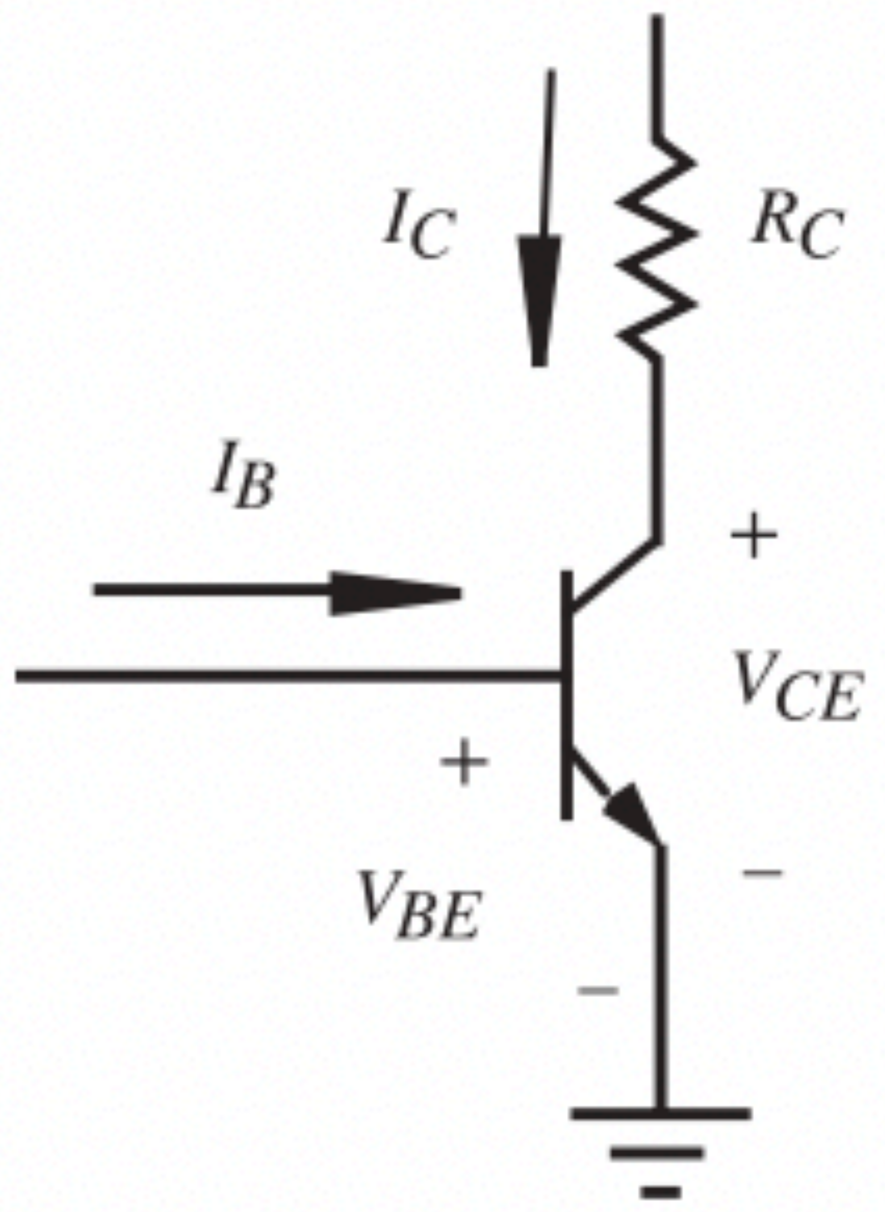
- $V_{BE} << 0.7$

no current flow

open circuit

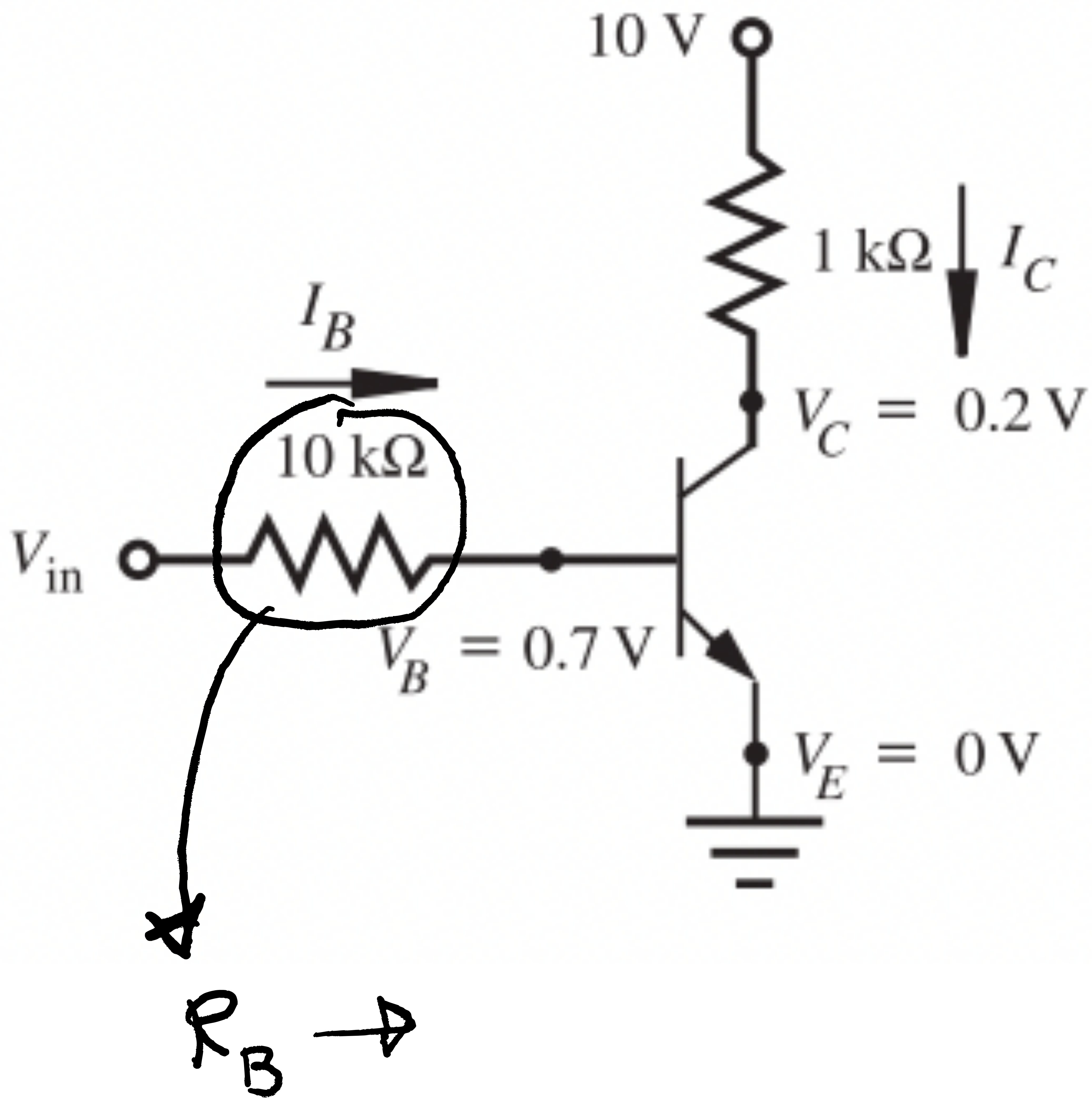


saturation region
I_C
active region
I_B
$I_B = 0$
V_{CE}
cutoff region



I_C
R_C
I_B
+
V_{CE}
+
V_{BE}
−
−

How to ensure saturation? (Example 3.4)



$I_{C,max} = 200$ mA

$V_{CE,max} = 0.2$ V

$h_{FE} = \beta = 100$

$I_C = (10 - 0.2)/1k\Omega = 9.8$ mA

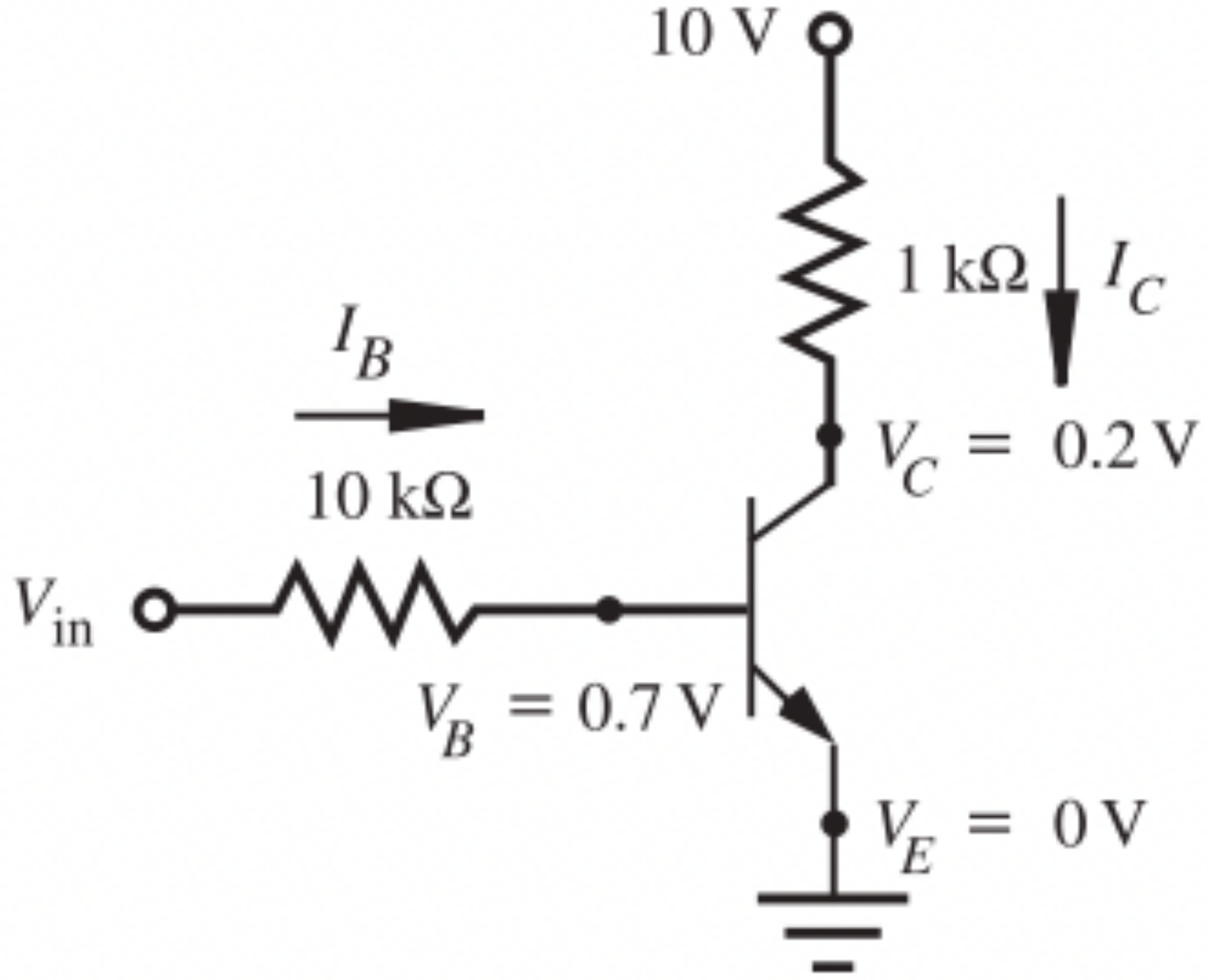
$I_C = \beta I_B \rightarrow I_B = 0.098$ mA

$V_{BE} = 0.7$ V, $I_B = \frac{(V_{in} - V_{BE})}{10k\Omega}$

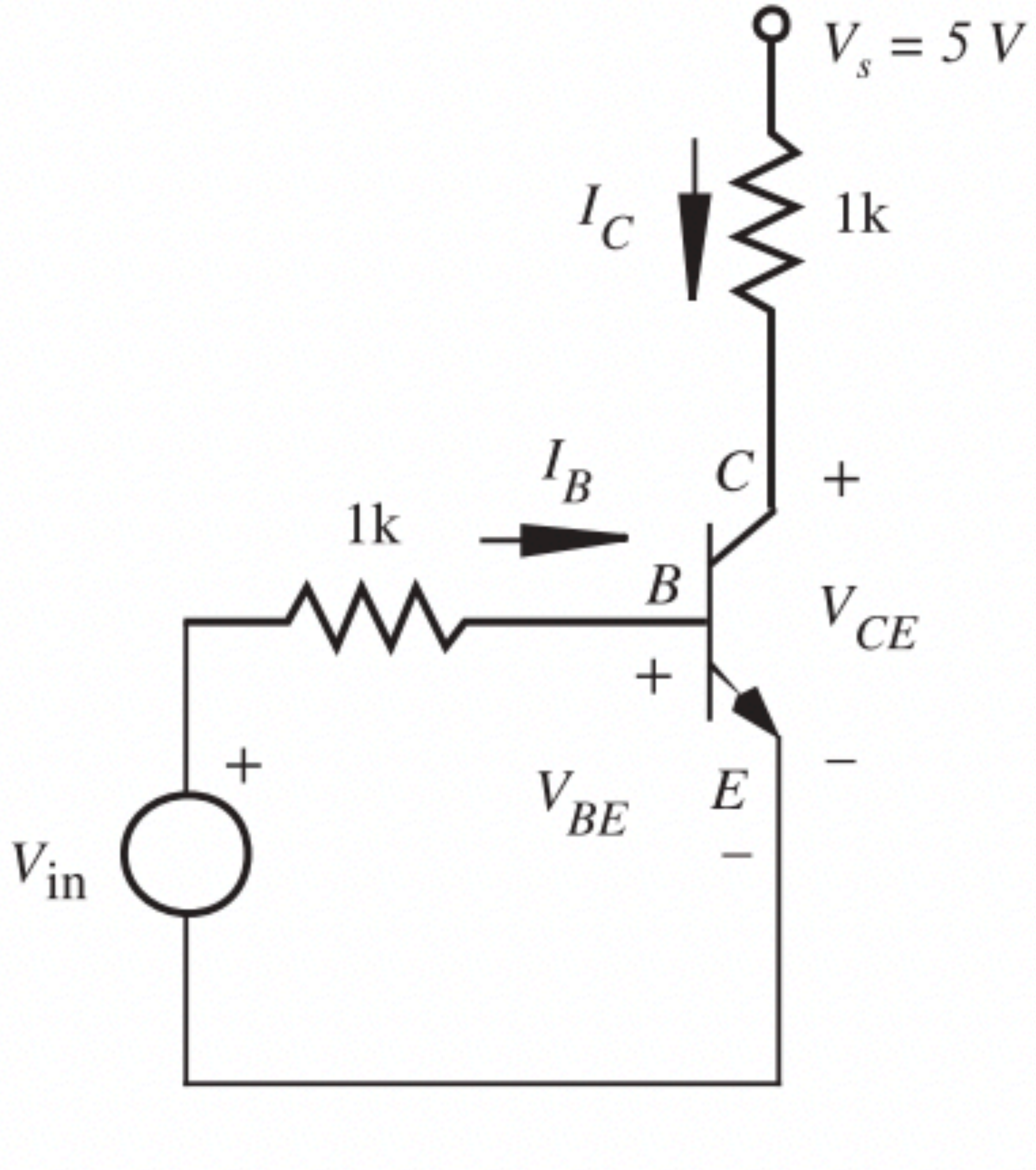
$V_{in} = 0.98V + 0.7V$

$V_{in} = 1.68V$ × 2-5 times

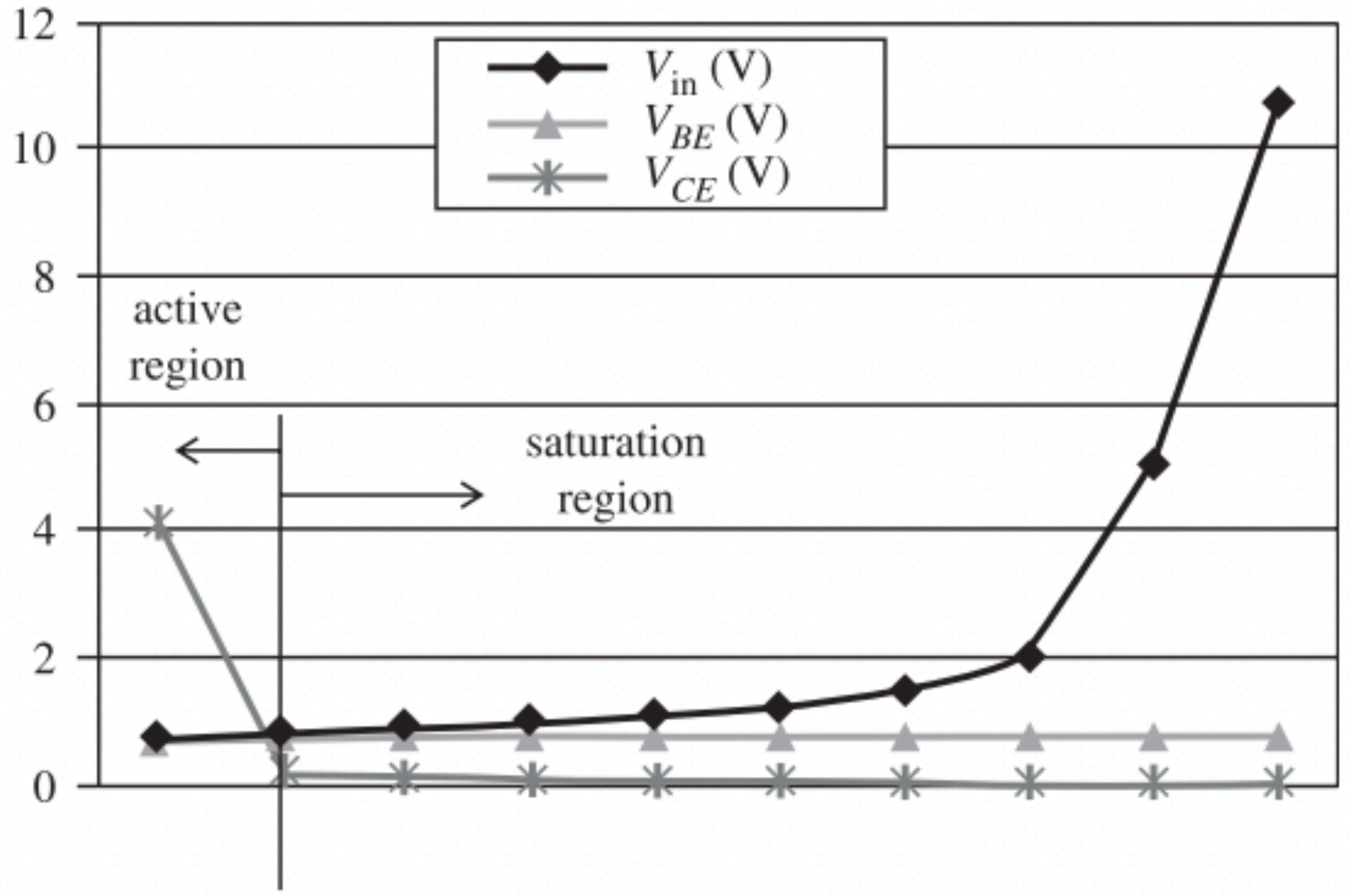
How to ensure saturation? (Example 3.4)



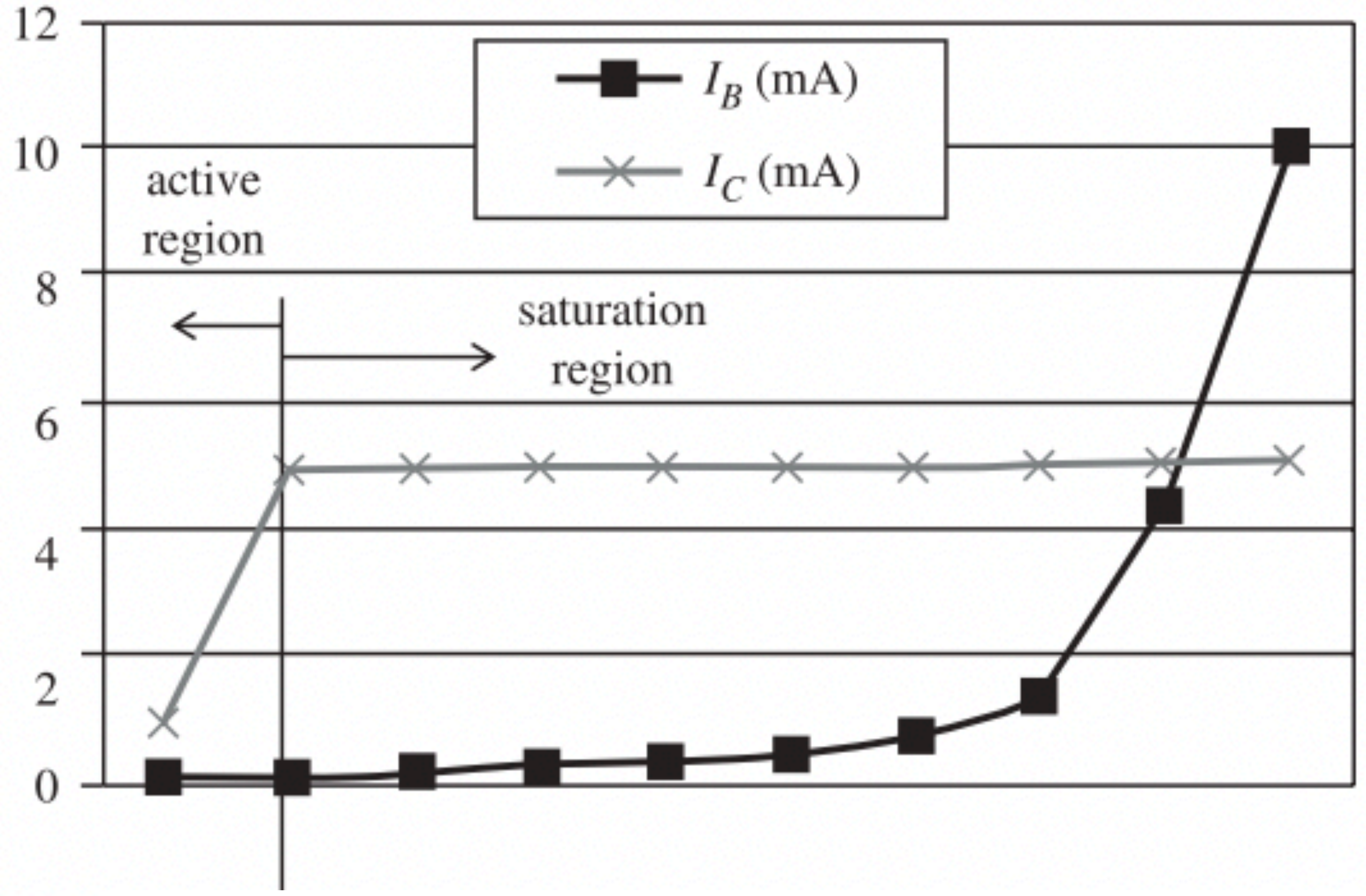
Real Data



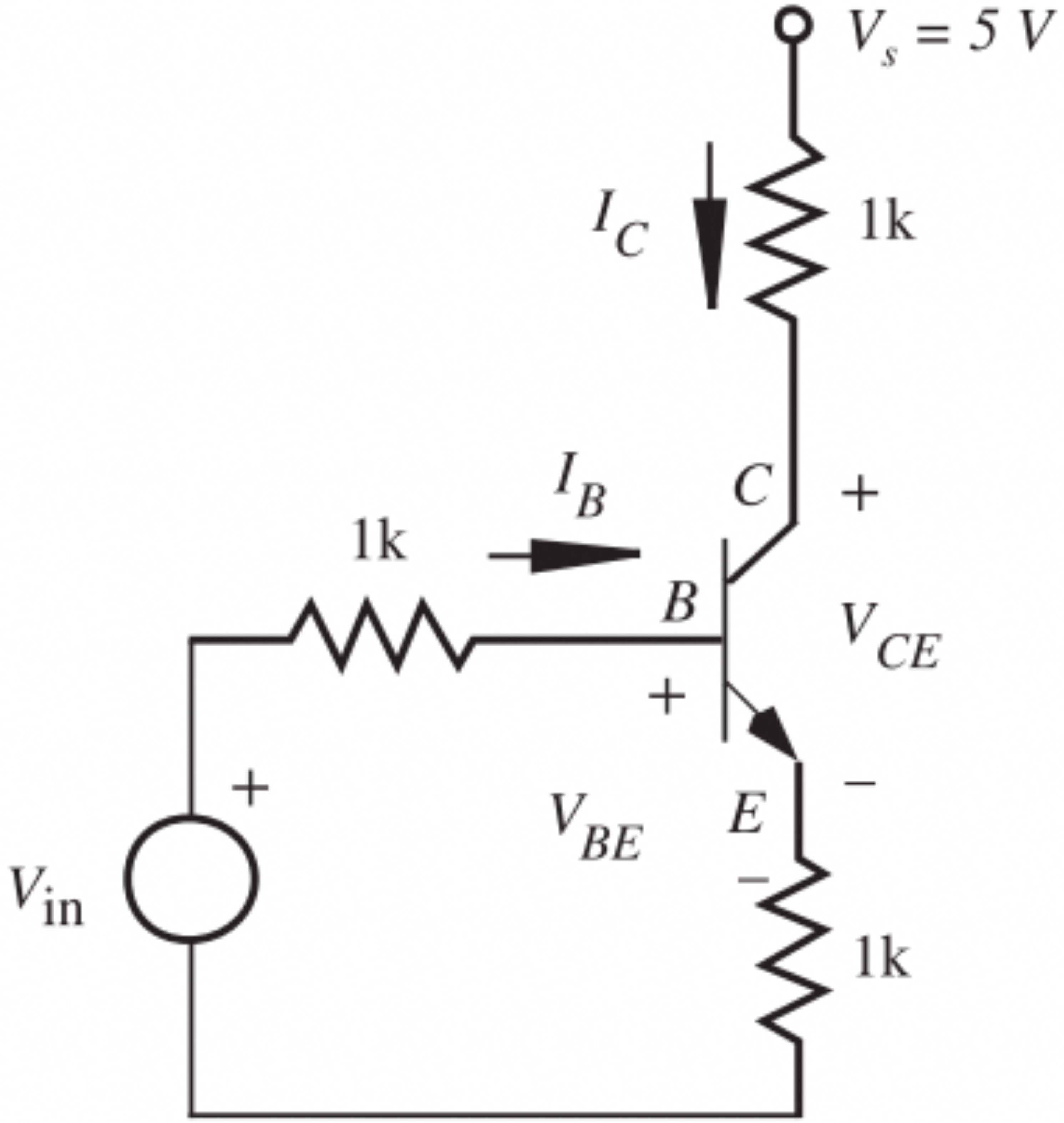
(a) common emitter

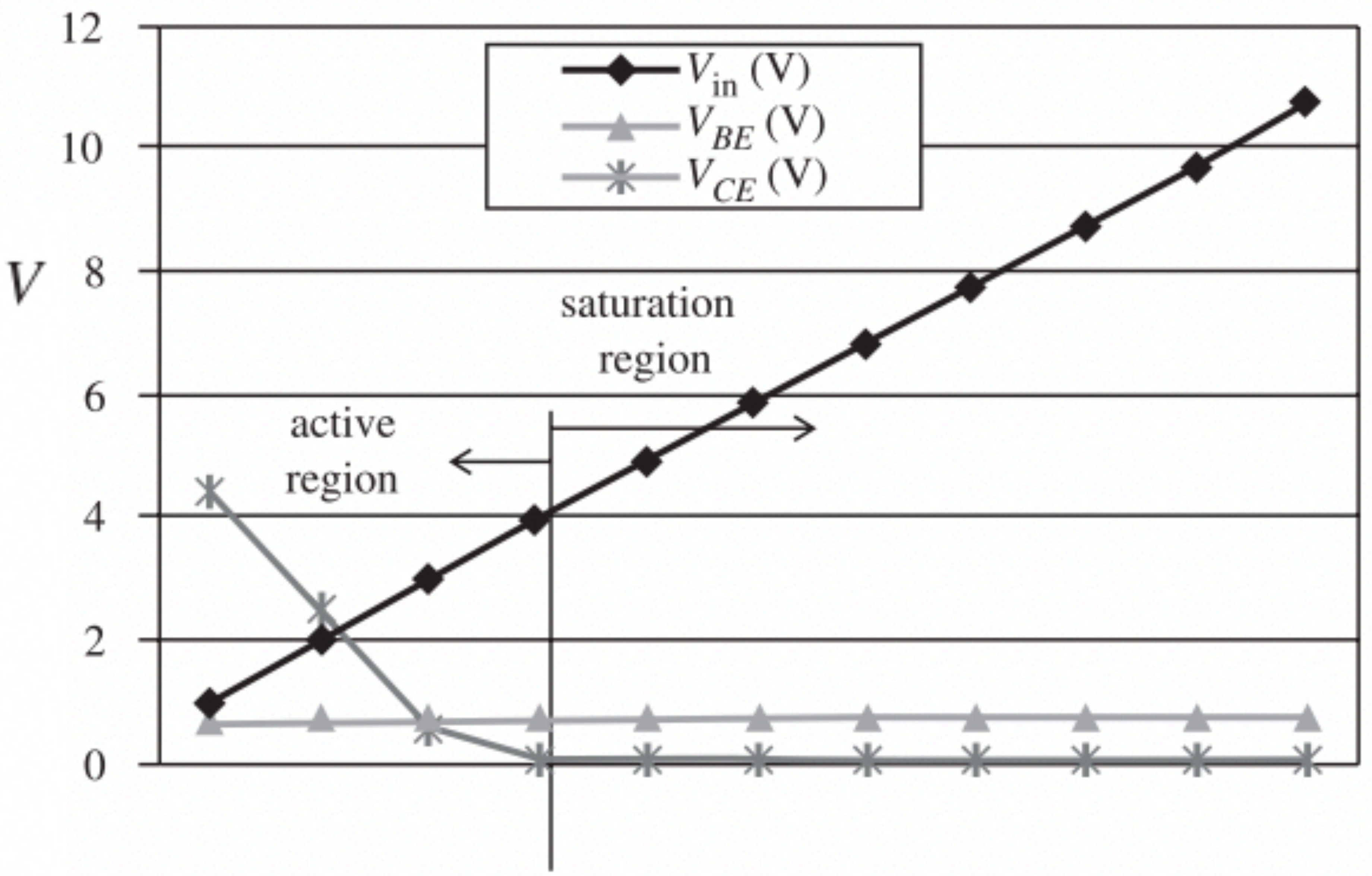


(a) voltages

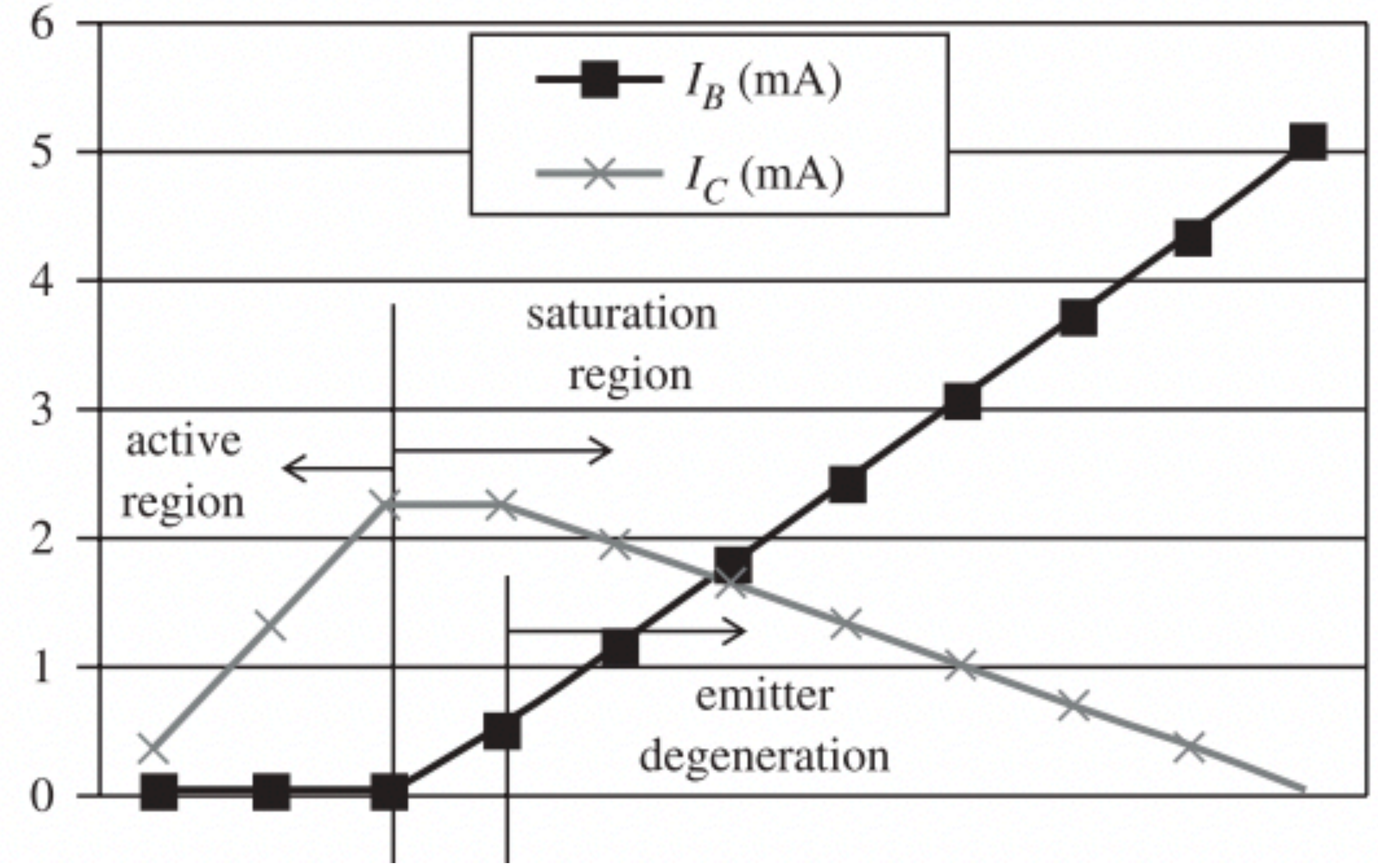


Real Data

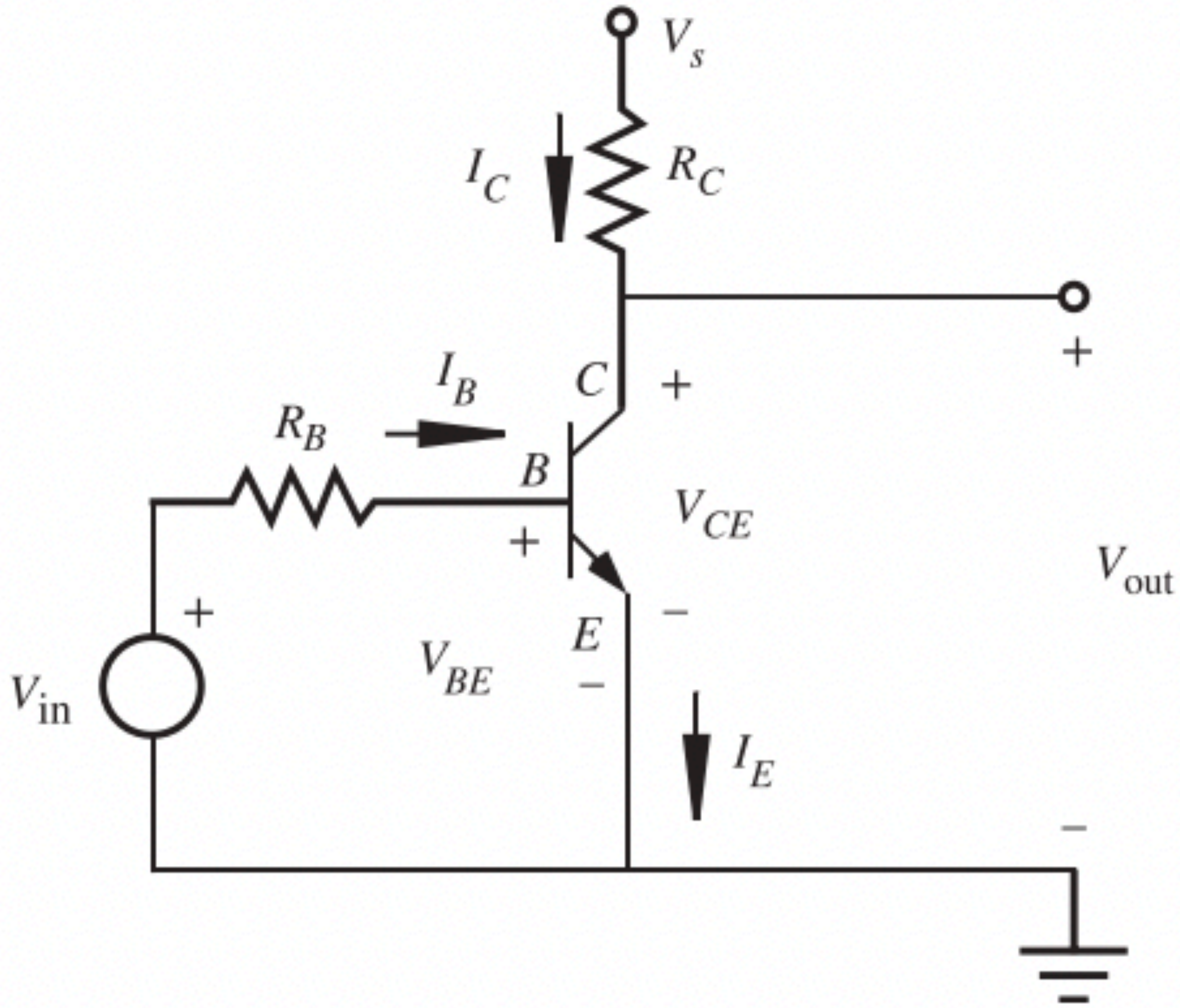


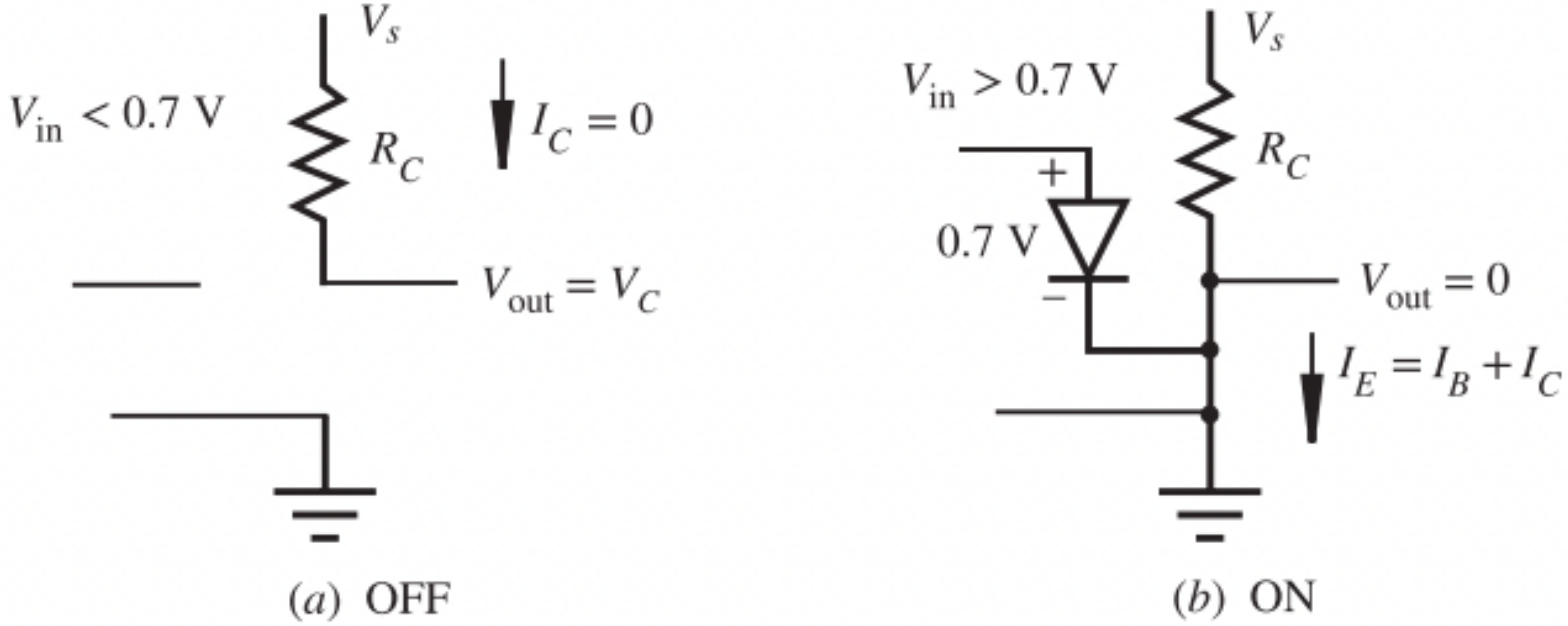


(a) voltages



Summary of BJT Switch





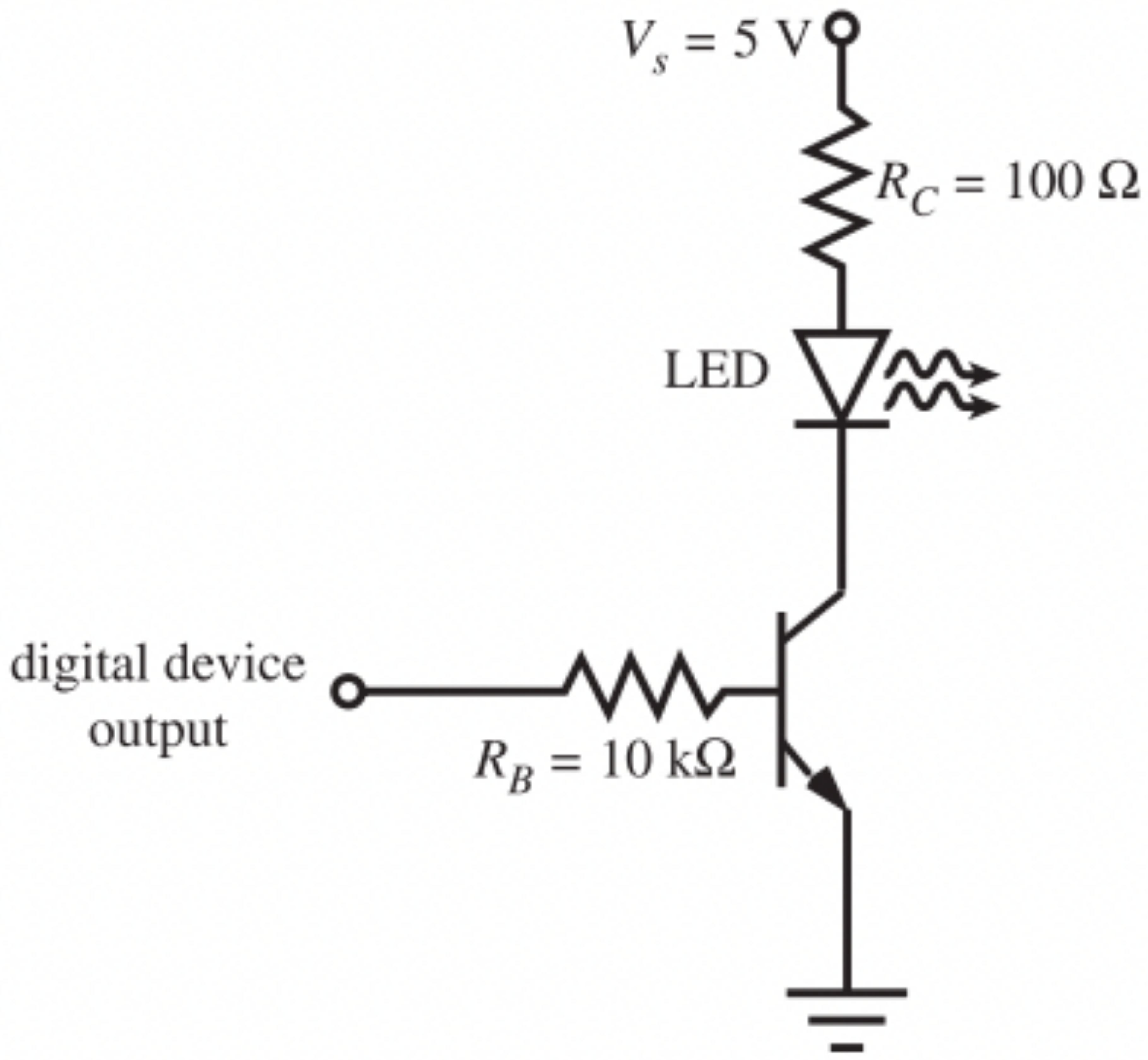
Rb is required

$$I_B = (V_{in} - V_B)/R_B \qquad I_C = (V_s - V_C)/R_C$$

$$V_B = V_{BE} = 0.7\text{ V} \qquad V_C = V_{out} = 0.2\text{V}$$

Summary of BJT Switch

BJT Switch Applications



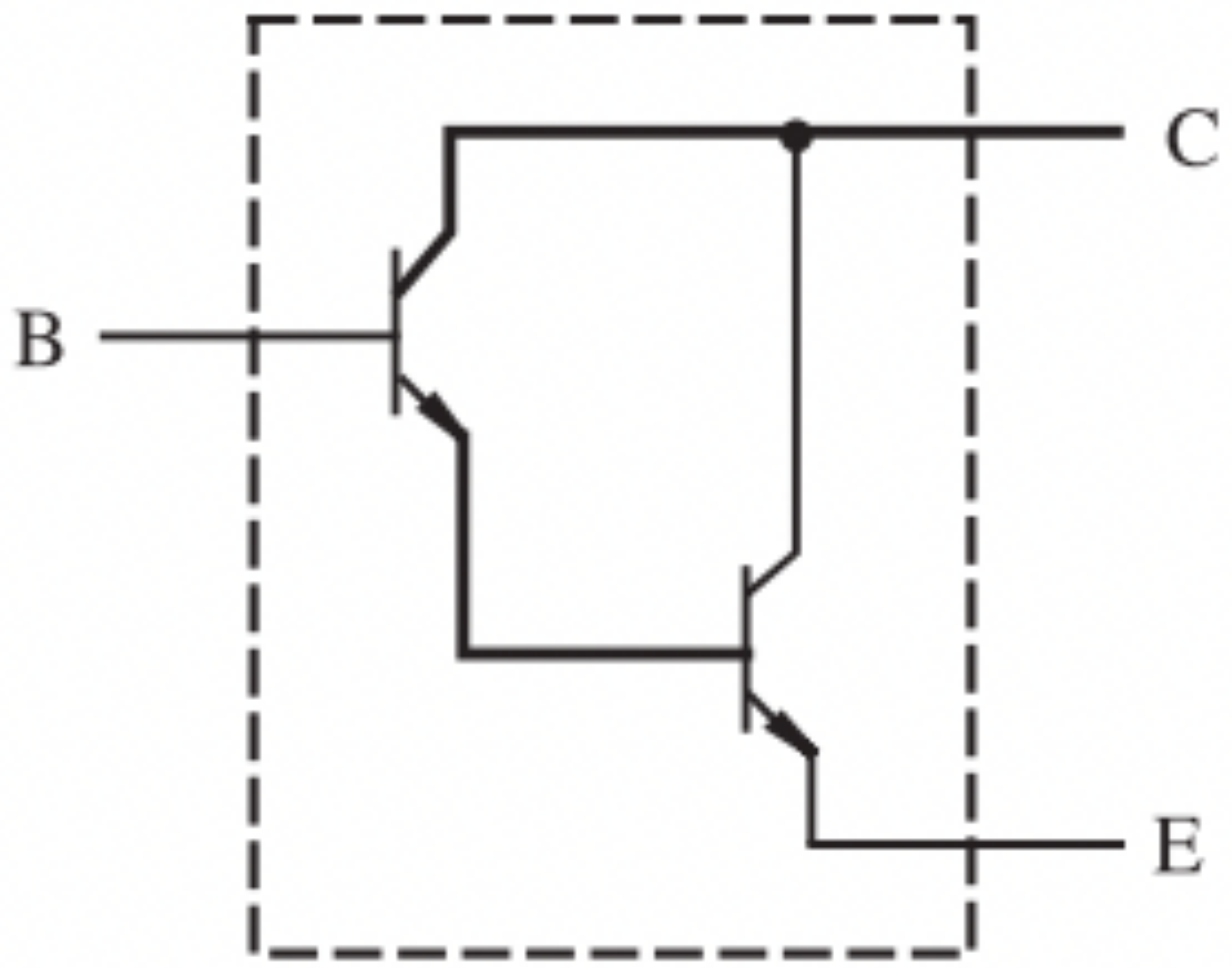


Figure 3.30 Darlington pair.

BJT Switch Applications

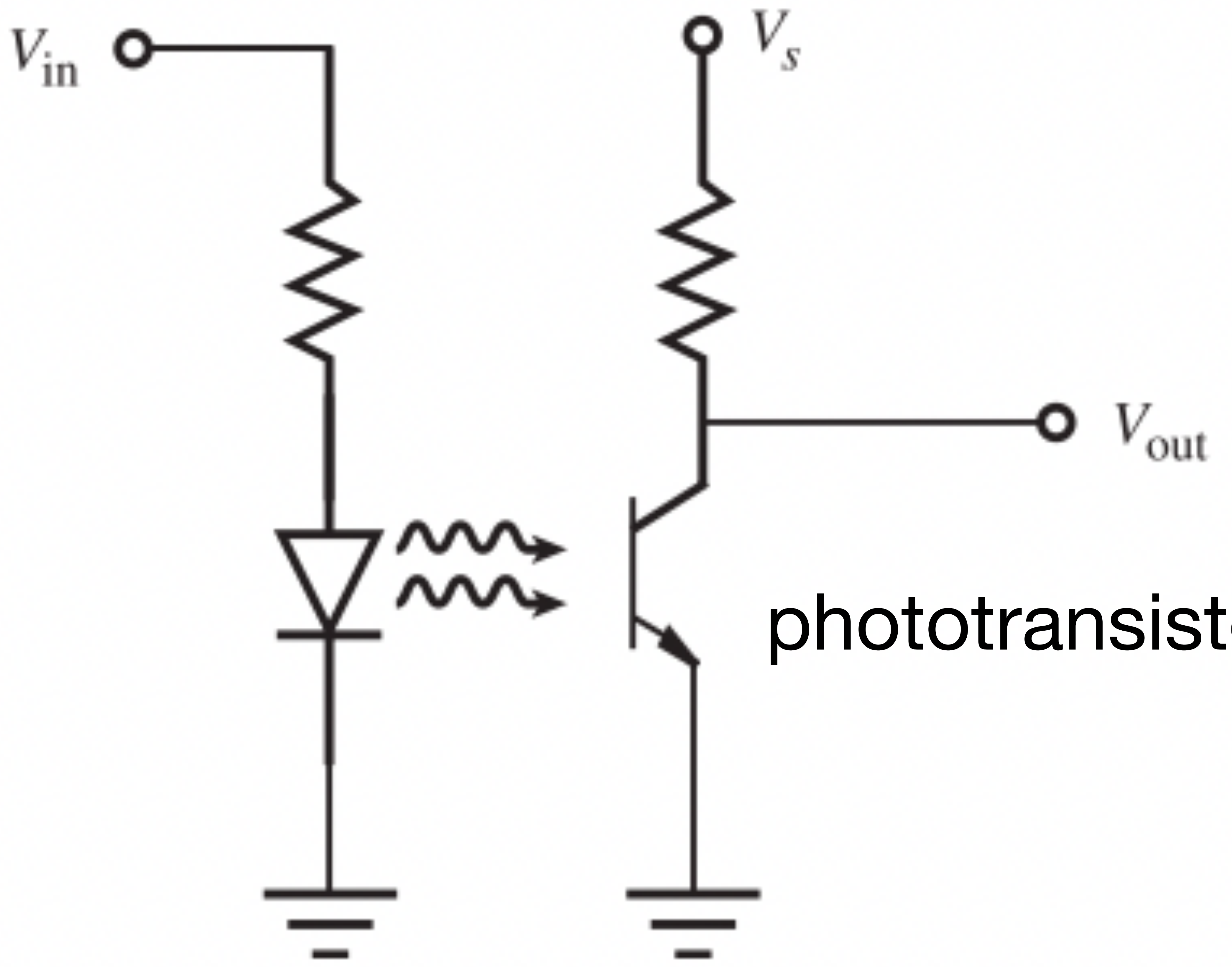
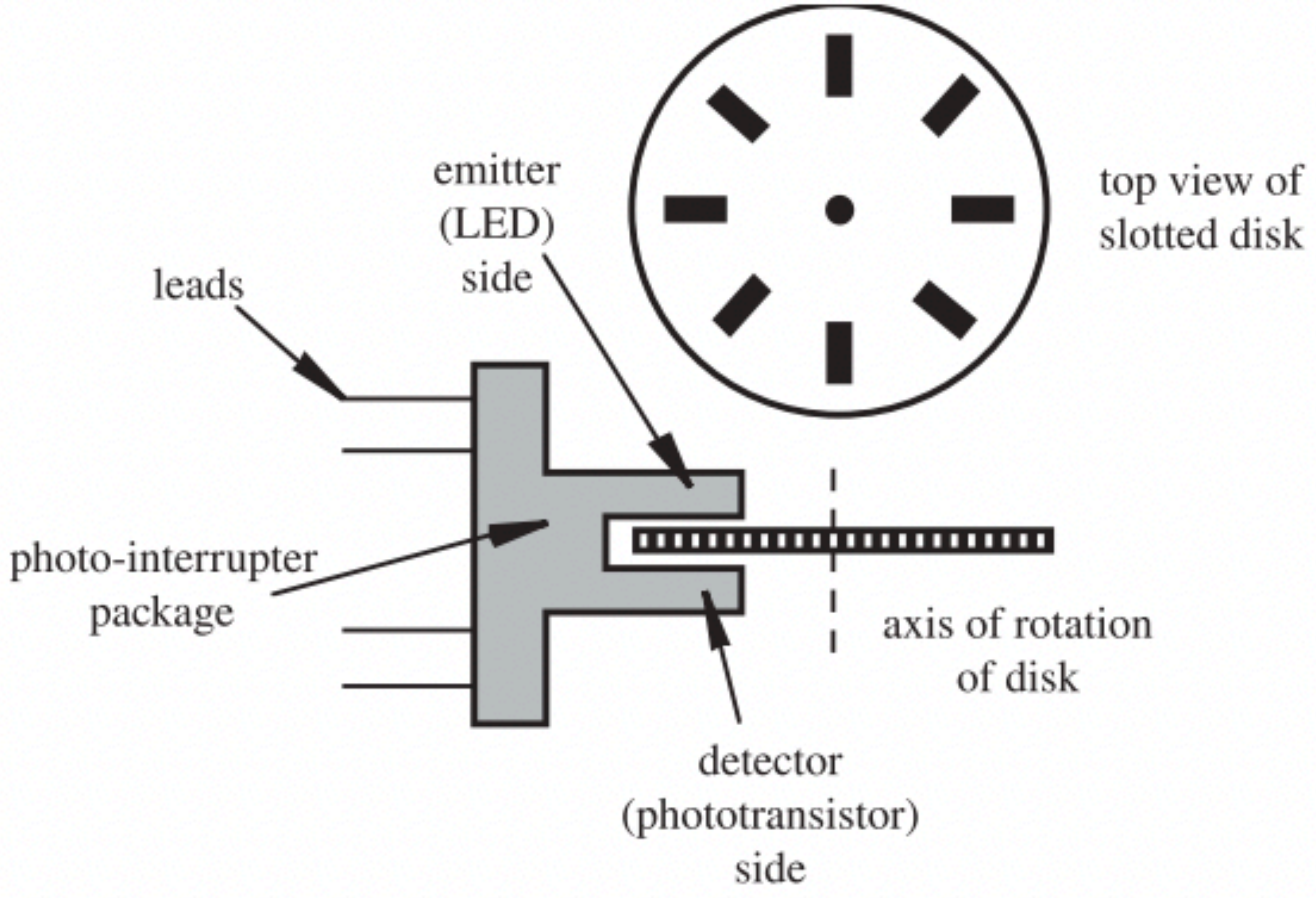


Figure 3.31 Optoisolator.



Types of optoisolators

Device type[note 5]	Source of light[7]	Sensor type[7]	Speed	Current transfer ratio
Resistive opto-isolator (Vactrol)	Incandescent light bulb	CdS or CdSe photoresistor (LDR)	Very low	<100%[note 6]
	Neon lamp		Low	
	GaAs infrared LED		Low	
Diode opto-isolator	GaAs infrared LED	Silicon photodiode	Highest	0.1–0.2%[22]
Transistor opto-isolator	GaAs infrared LED	Bipolar silicon phototransistor	Medium	2–120%[22]
		Darlington phototransistor	Medium	100–600%[22]
Opto-isolated SCR	GaAs infrared LED	Silicon-controlled rectifier	Low to medium	>100%[23]
Opto-isolated triac	GaAs infrared LED	TRIAC	Low to medium	Very high
Solid-state relay	Stack of GaAs infrared LEDs	Stack of photodiodes driving a pair of MOSFETs or an IGBT	Low to high[note 7]	Practically unlimited

BJT Packages