Fundumantal of Electronic I

Second Class

Chapter01: Semiconductor Diodes
Lec01_p1

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2019-2020

Semiconductor Materials: Ge, Si, and GaAs

Semiconductors are a special class of elements having a conductivity between that of a good conductor and that of an insulator.

- They fall into two classes : single crystal and compound
- Single crystal : Germanium (Ge) and silicon (Si).
- Compound : gallium arsenide (GaAs),
  cadmium sulfide (CdS),
  gallium nitride (GaN),
  gallium arsenide phosphide (GaAsP)

The three semiconductors used most frequently in the construction of electronic devices are **Ge**, **Si**, and **GaAs**.

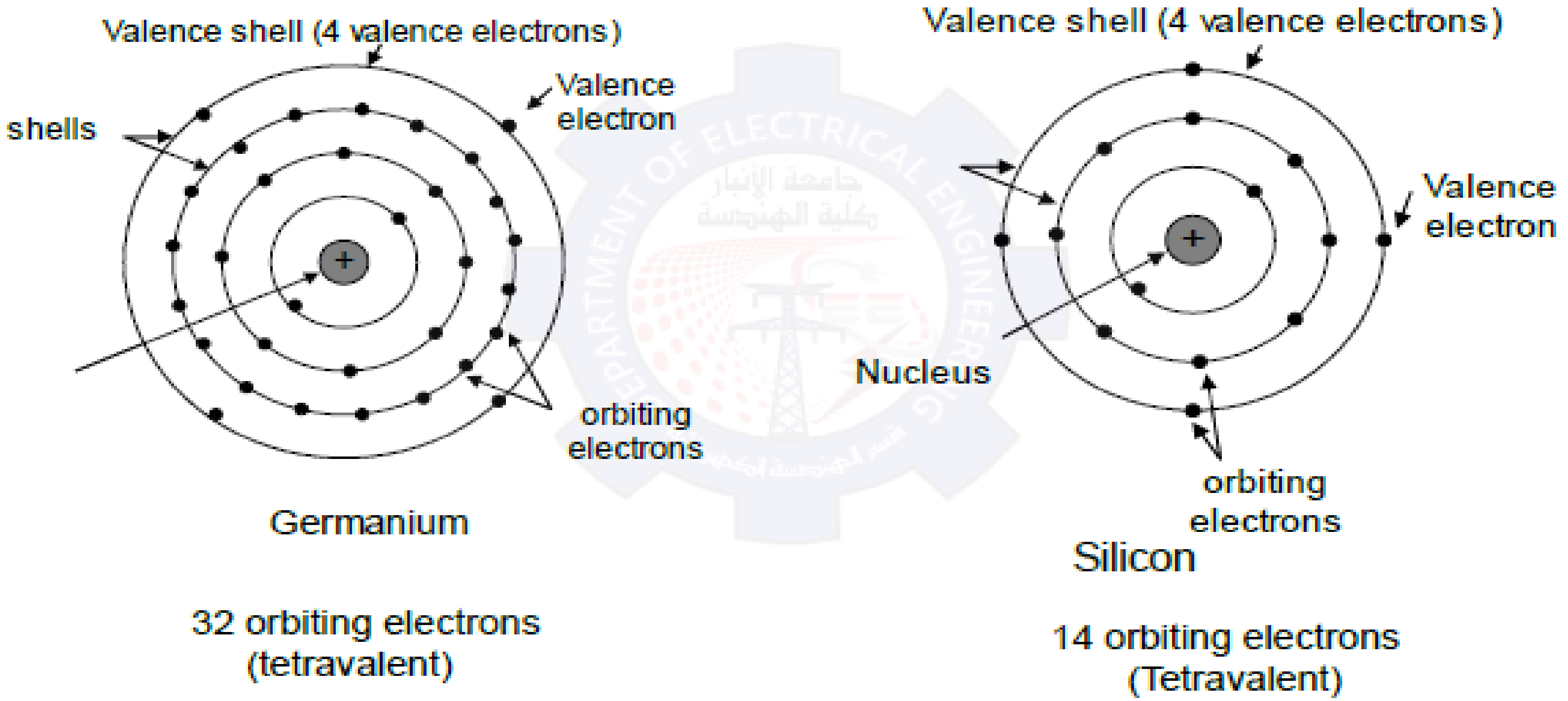
→ Group Period ↓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Uub	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo

* Lanthanides	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides **	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

History

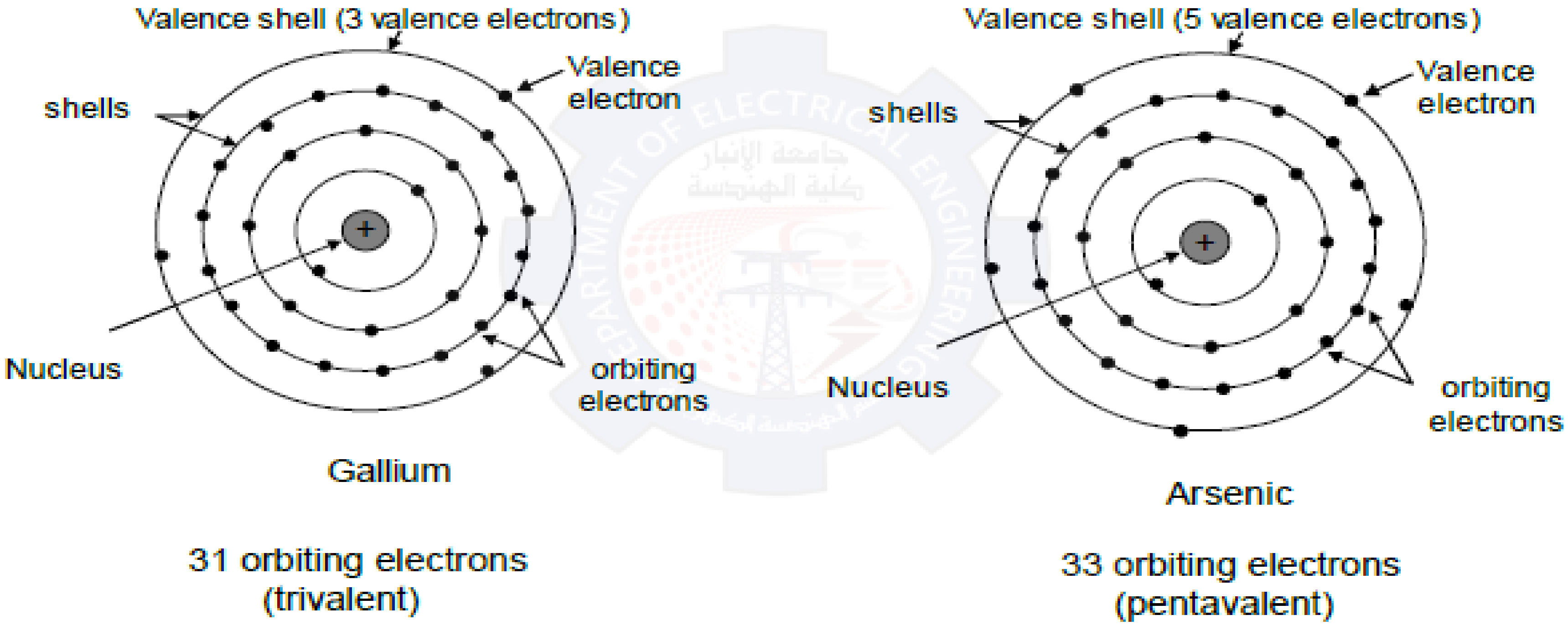
- Diode , in 1939 was using Ge
- Transistor, in 1947 was using Ge
- In1954 Si was used in Transistor because Si is less temperature sensitive and abundantly available.
- High speed transistor was using GaAs in 1970 (which is 5 times faster compared to Si)
- Si, Ge and GaAs are the semiconductor of choice

Atomic Structure



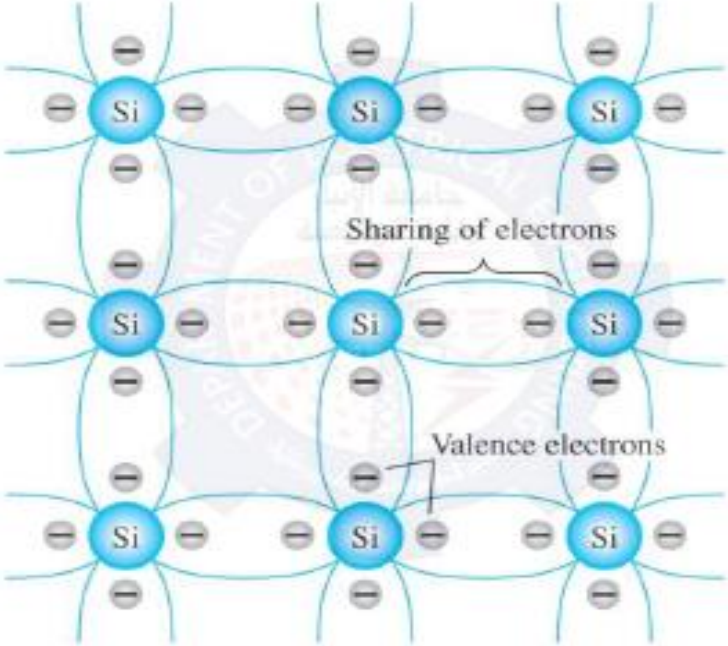
- Valence electrons: electrons in the outermost shell.
- Atoms with four valence electrons are called tetravalent.

Atomic Structure



- Atoms with three valence electrons are called trivalent, and those with five are called pentavalent.

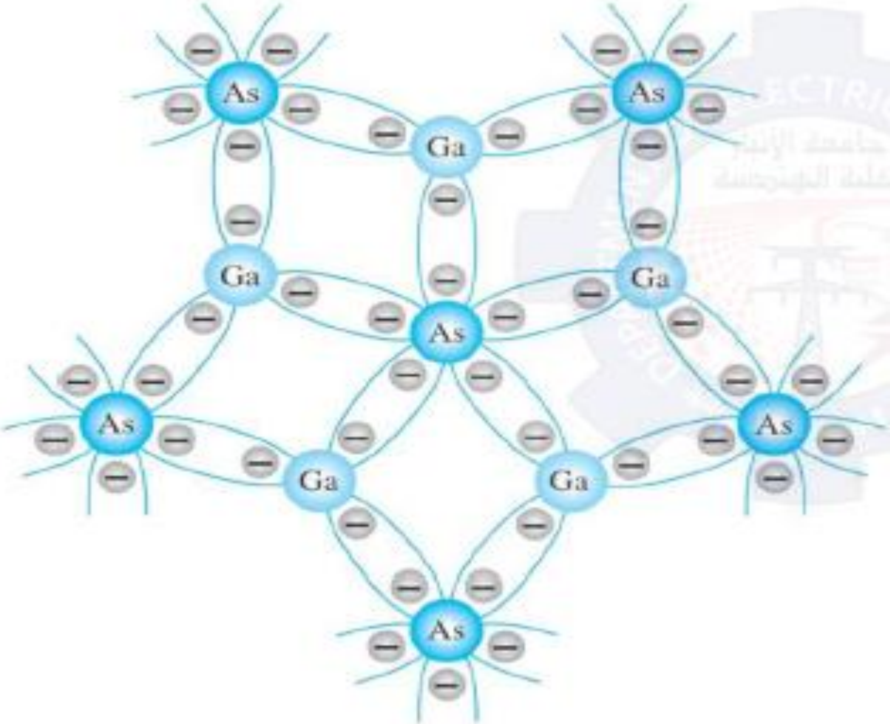
Covalent Bonding



Covalent bonding of Si crystal

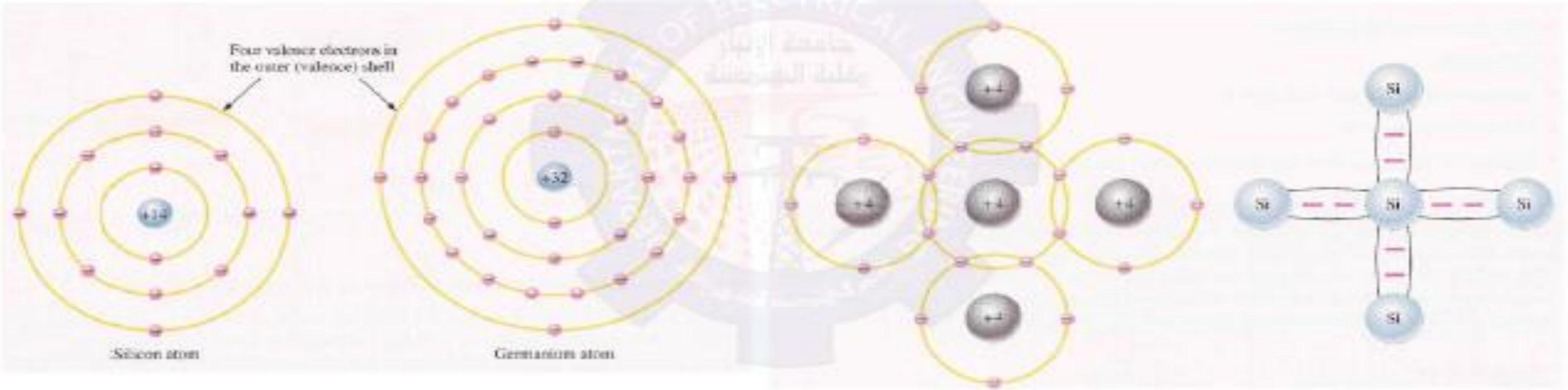
This bonding of atoms, strengthened by the sharing of electrons, is called **covalent bonding**

Covalent Bonding

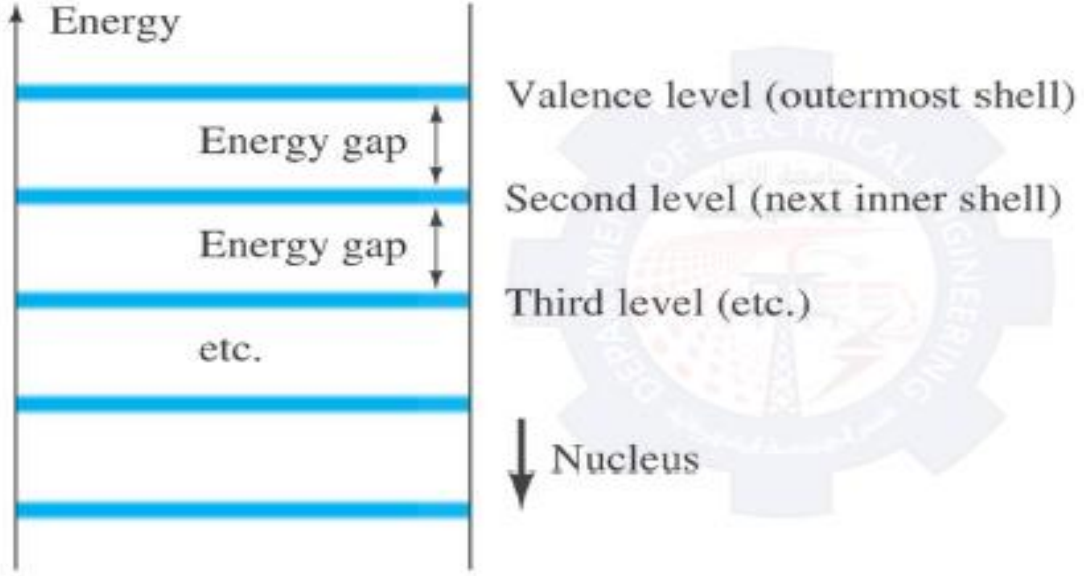


There is sharing of electrons, five electrons provided by As atom and three by the Ga atom.

Covalent bonding of GaAs crystal


Four valence electrons in the outer (valence) shell
+14
+32
Silicon atom
Germanium atom
+4
Si

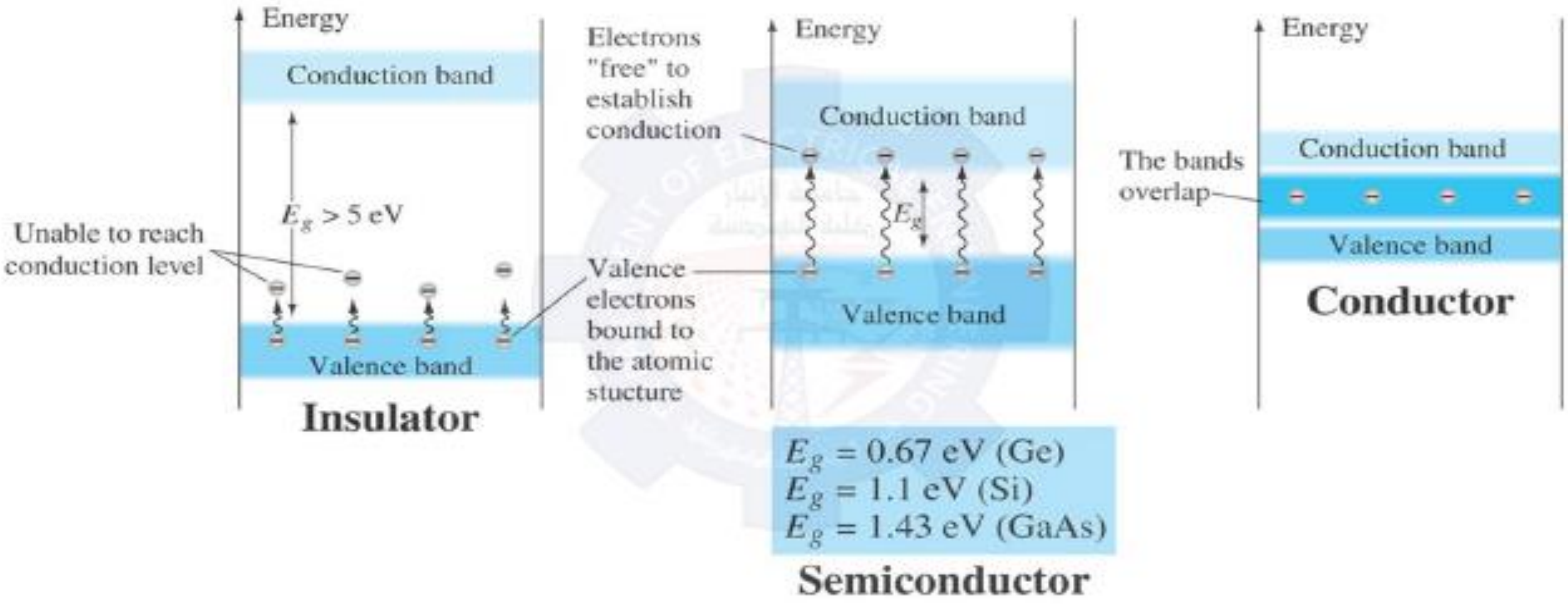
Energy Levels



(a)

The farther an electron is from the nucleus, the higher is the energy state.

Energy Levels



An electron in the valence band of silicon must absorb more energy than one in the valence band of germanium to become a free carrier. [free carriers are free electrons due only to external causes such as applied electric fields established by voltage sources or potential difference.

n-Type and p-Type materials

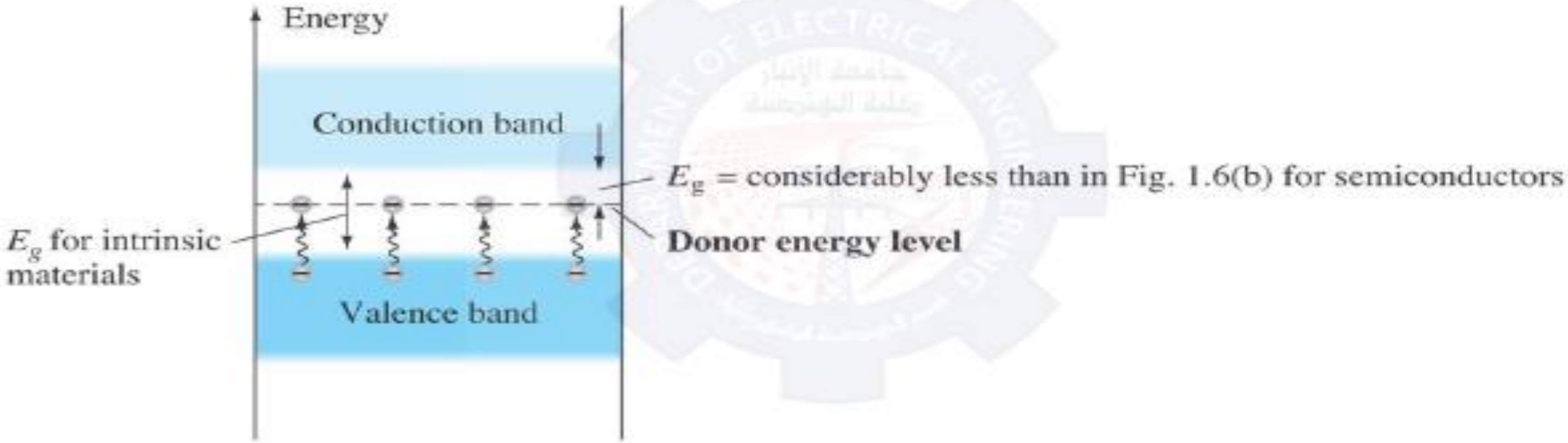
n-Type Material

- n-Type materials are created by adding elements with **five** valence electrons such as antimony, arsenic, and phosphorous.
- There is a fifth electron due to the (Sb) atom that is relatively free to move in the n-Type material.
- The atoms (in this case is antimony (Sb)) are called **donor atoms.**

Doping with Sb. (antimony)

n-Type and p-Type materials

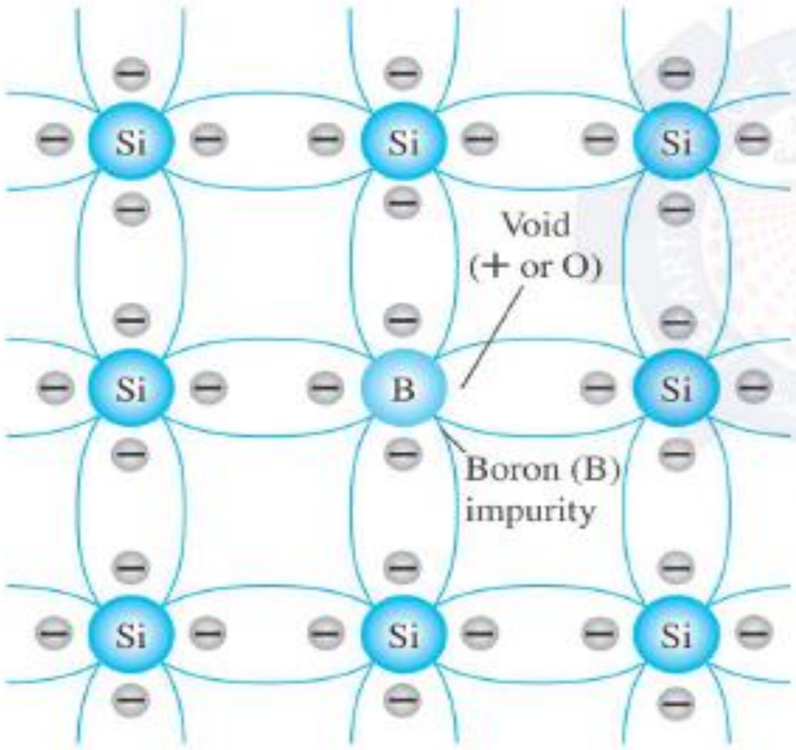
n-Type Material



The free electrons due to the added atoms have higher energy levels and require less energy to move to conduction band.

n-Type and p-Type materials

p-Type Material



Boron (B)

- p-Type materials are created by adding atoms with **three** valence electrons such as boron, gallium, and indium.
- In this case, an insufficient number of electrons to complete the covalent bonds.
- The resulting vacancy is called a "**hole**" represented by small circle or plus sign indicating absence of a negative charge.
- The atoms (in this case boron(B)) are called **acceptor atoms**.

Majority and Minority carriers

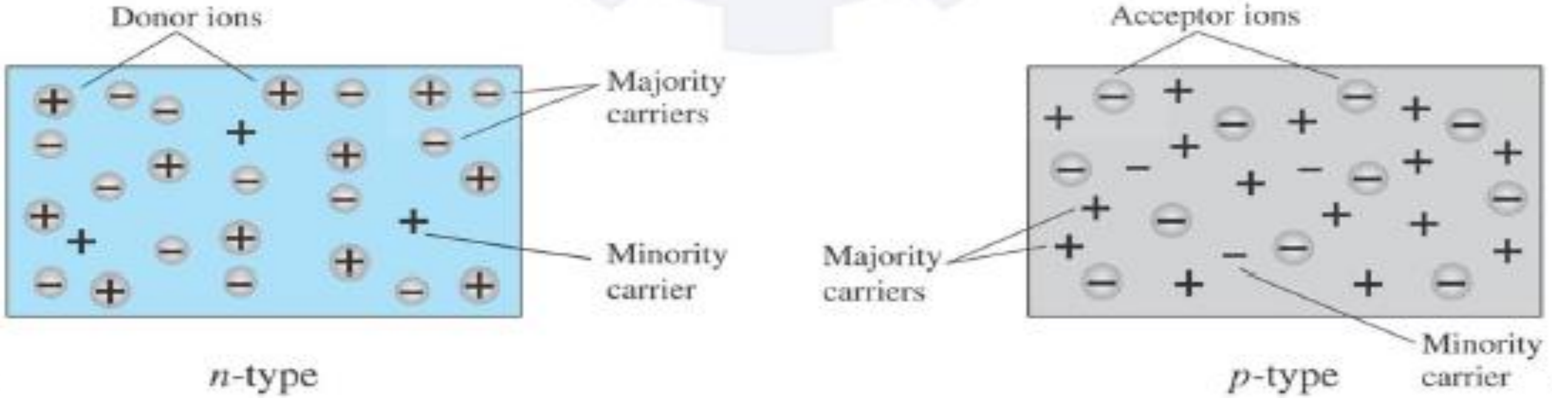
Two currents through a diode:

Majority Carriers

- The majority carriers in n-type materials are electrons.
- The majority carriers in p-type materials are holes.

Minority Carriers

- The minority carriers in n-type materials are holes.
- The minority carriers in p-type materials are electrons.



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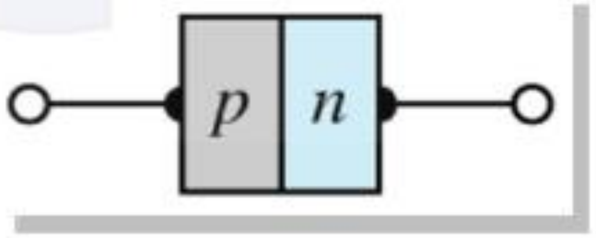
p-n Junctions

One end of a silicon or germanium crystal can be doped as a *p*-type material and the other end as an *n*-type material.

The result is a *p-n* junction.

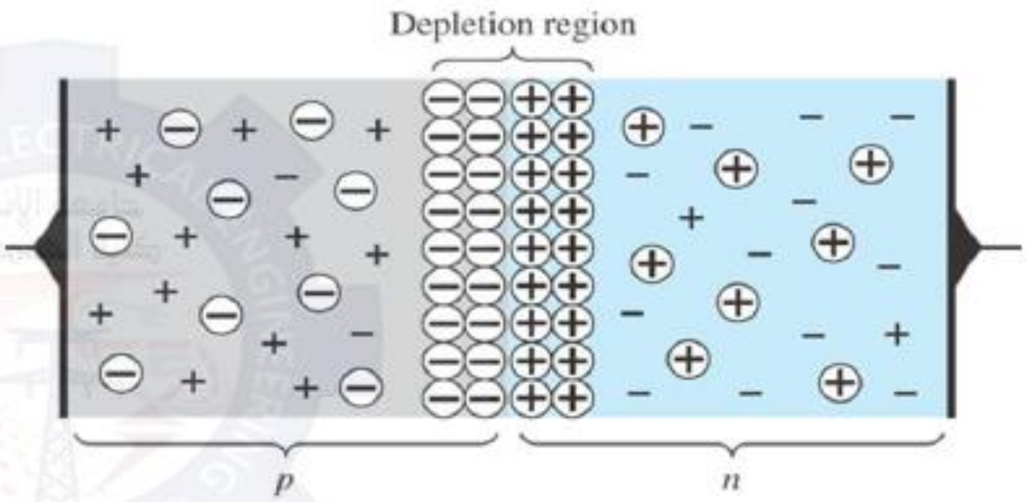


p-n Junctions

At the *p-n* junction, the excess conduction-band electrons on the *n*-type side are attracted to the valence-band holes on the *p*-type side.

The electrons in the *n*-type material migrate across the junction to the *p*-type material (electron flow).

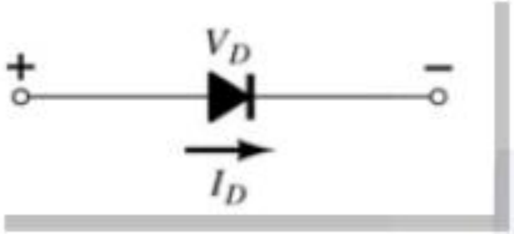
The electron migration results in a negative charge on the p-type side of the junction and a positive charge on the n-type side of the junction.



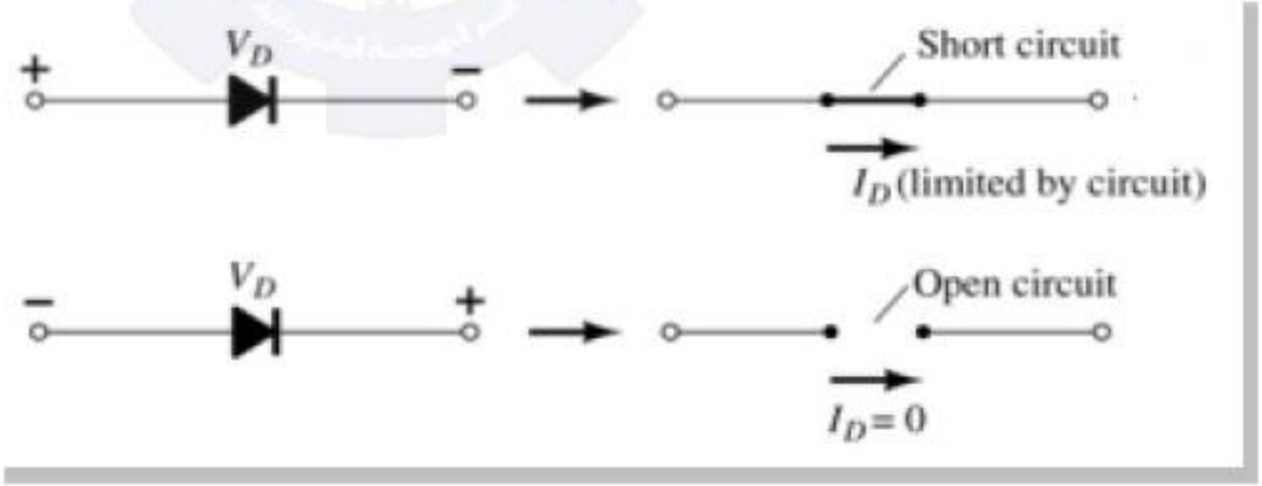
The result is the formation of a depletion region around the junction.

Diodes

The diode is a 2-terminal device.

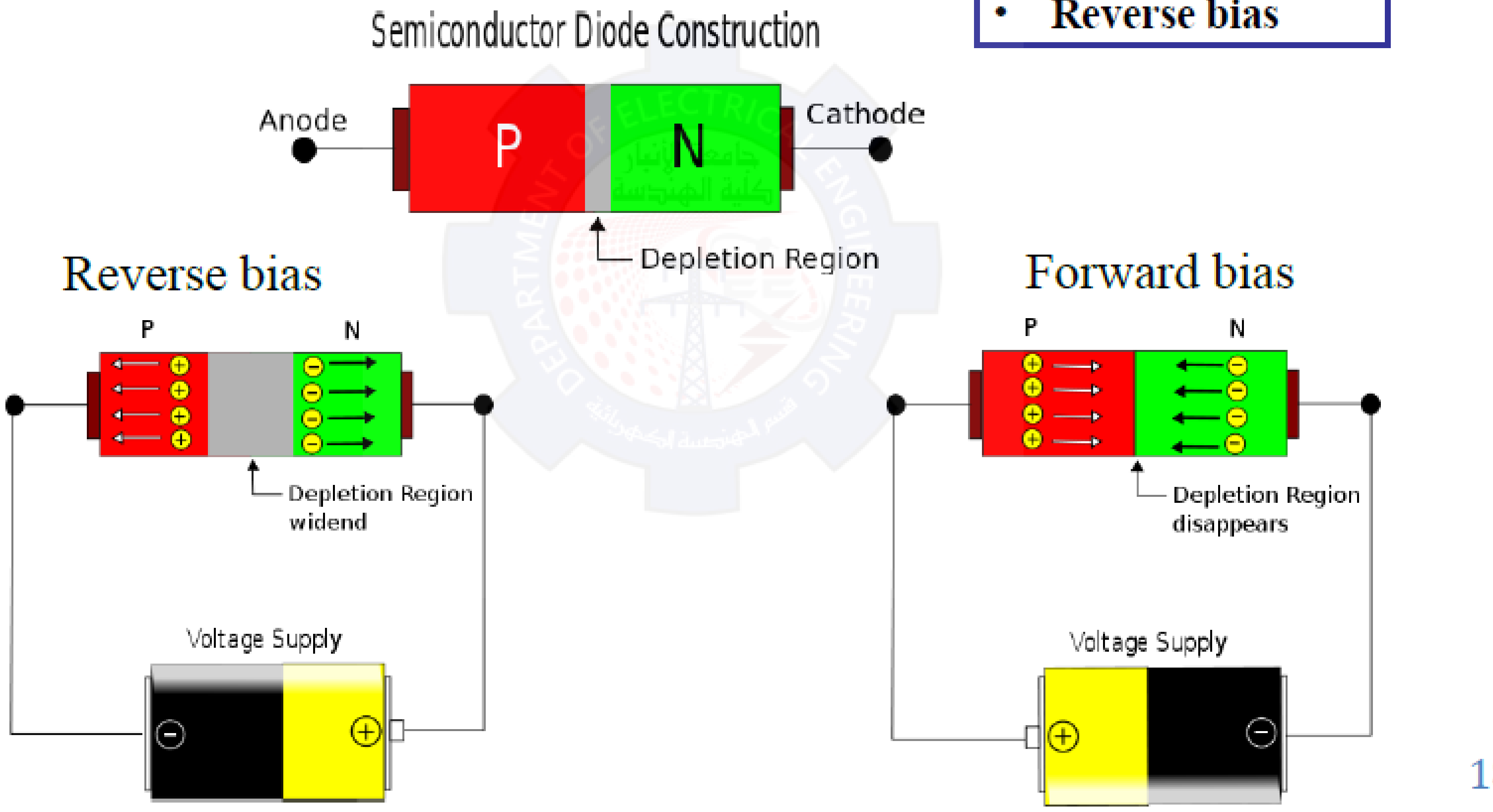


A diode ideally conducts in only one direction.



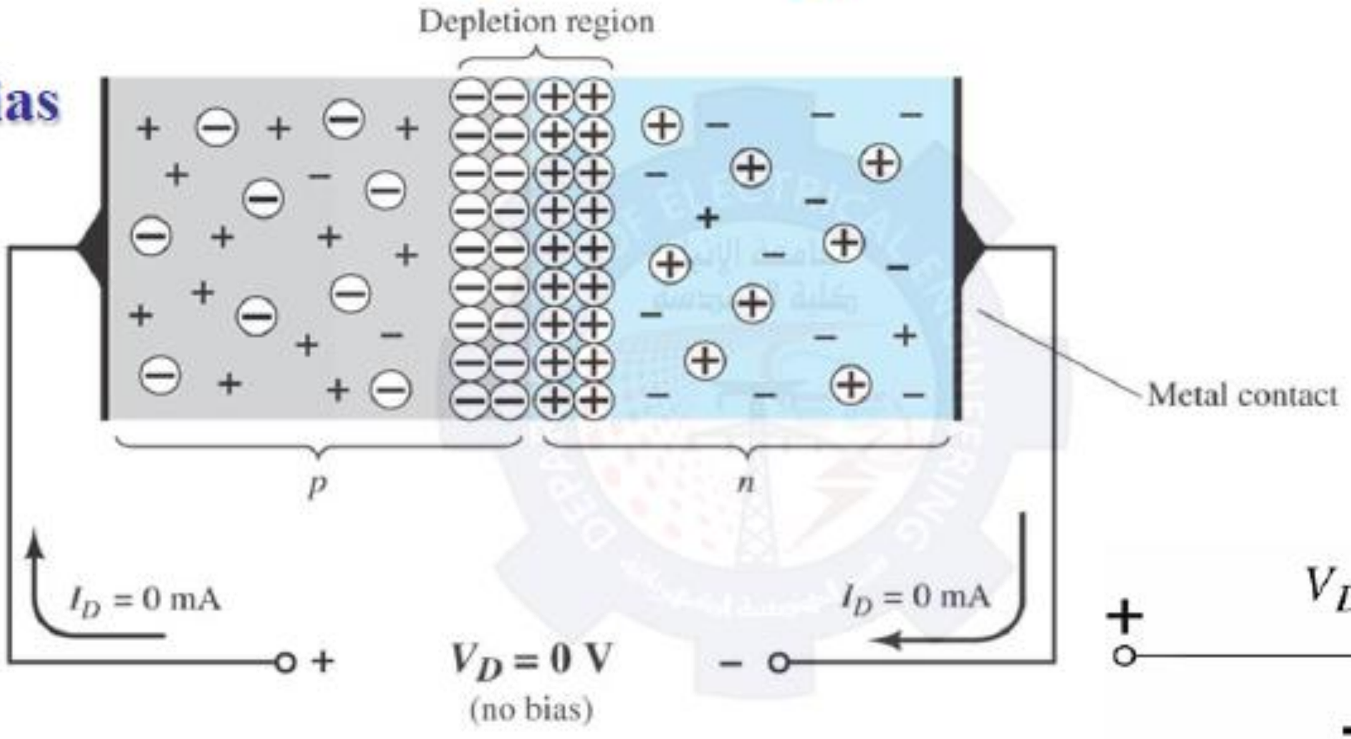
Diode Operating Conditions

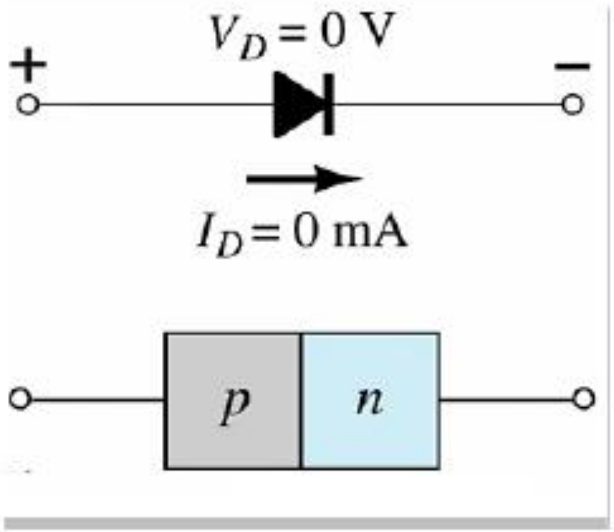
- No bias
- Forward bias
- Reverse bias



Diode Operating Conditions

No Bias





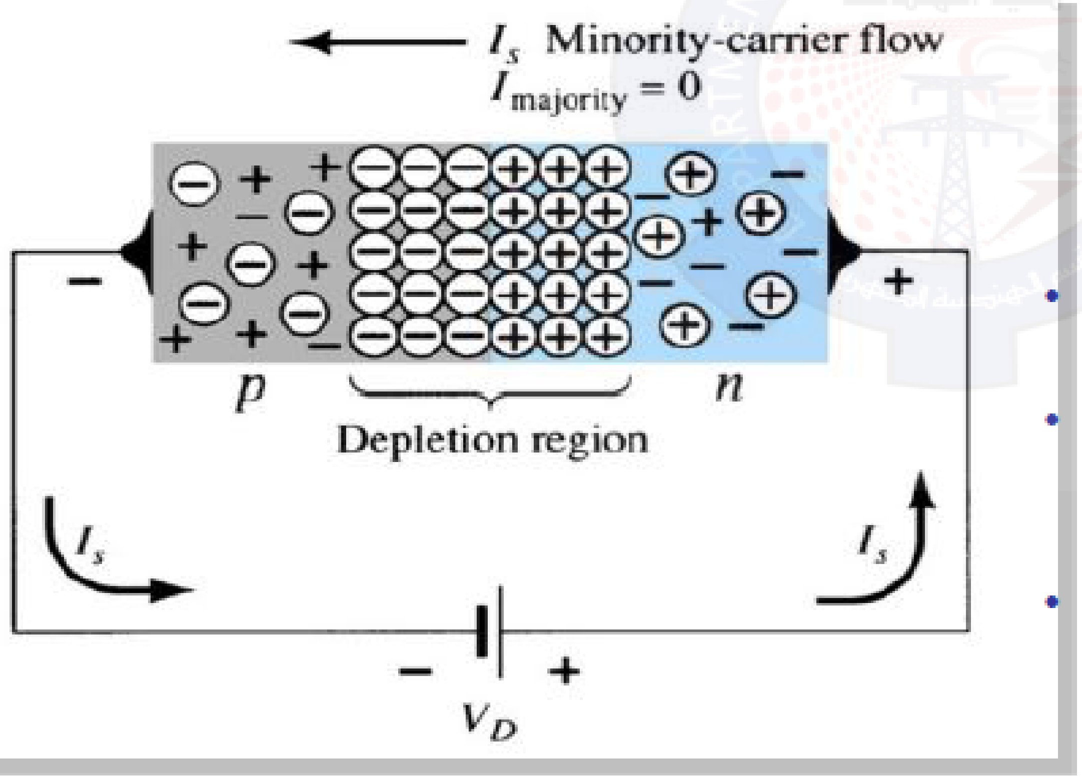
- **No external voltage is applied: $V_D = 0$ V**
- **No current is flowing: $I_D = 0$ A**
- **Only a modest depletion region exists**

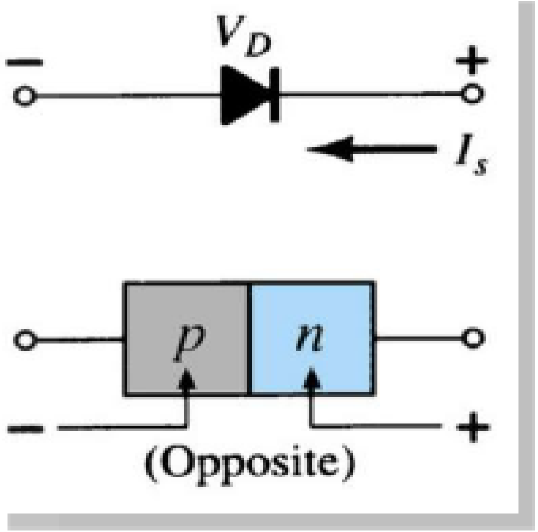
Diode Operating Conditions

Reverse Bias

Reverse Bias

External voltage is applied across the *p-n* junction in the opposite polarity of the *p-* and *n*-type materials.



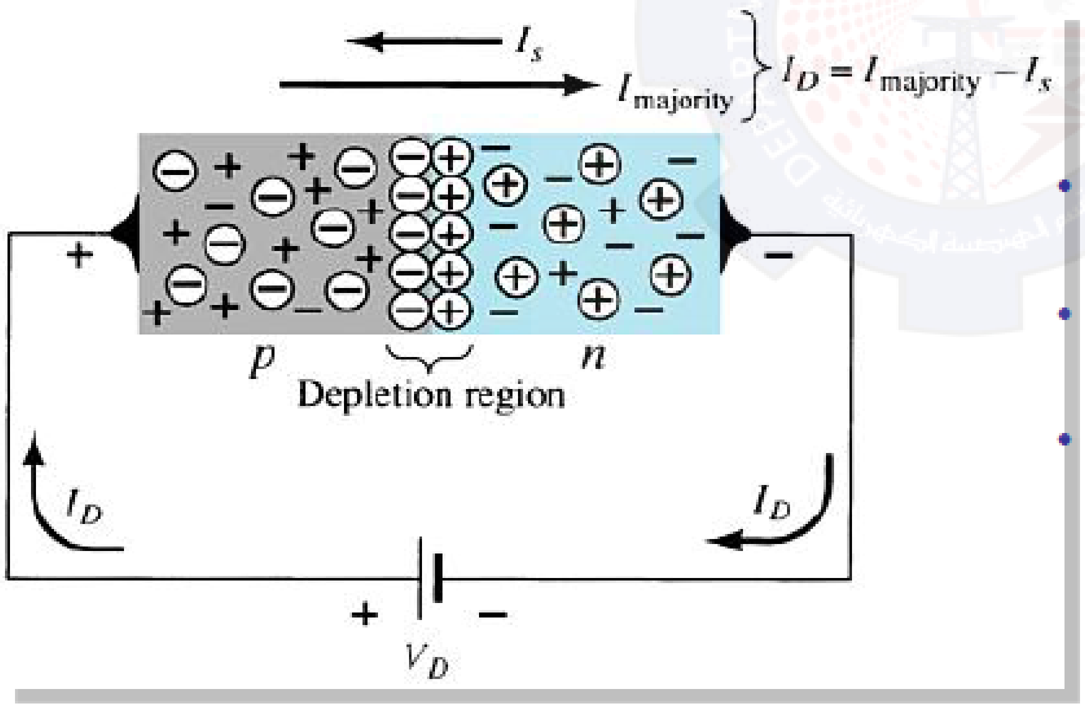


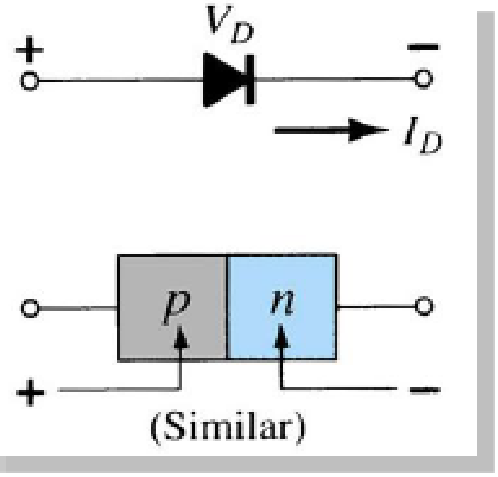
- The reverse voltage causes the depletion region to widen.
- The electrons in the *n*-type material are attracted toward the positive terminal of the voltage source.
- The holes in the *p*-type material are attracted toward the negative terminal of the voltage source.

Diode Operating Conditions

Forward Bias

External voltage is applied across the *p-n* junction in the same polarity as the *p-* and *n-*type materials.





- **The forward voltage causes the depletion region to narrow.**
- **The electrons and holes are pushed toward the *p-n* junction.**
- **The electrons and holes have sufficient energy to cross the *p-n* junction.**

Actual Diode Characteristics

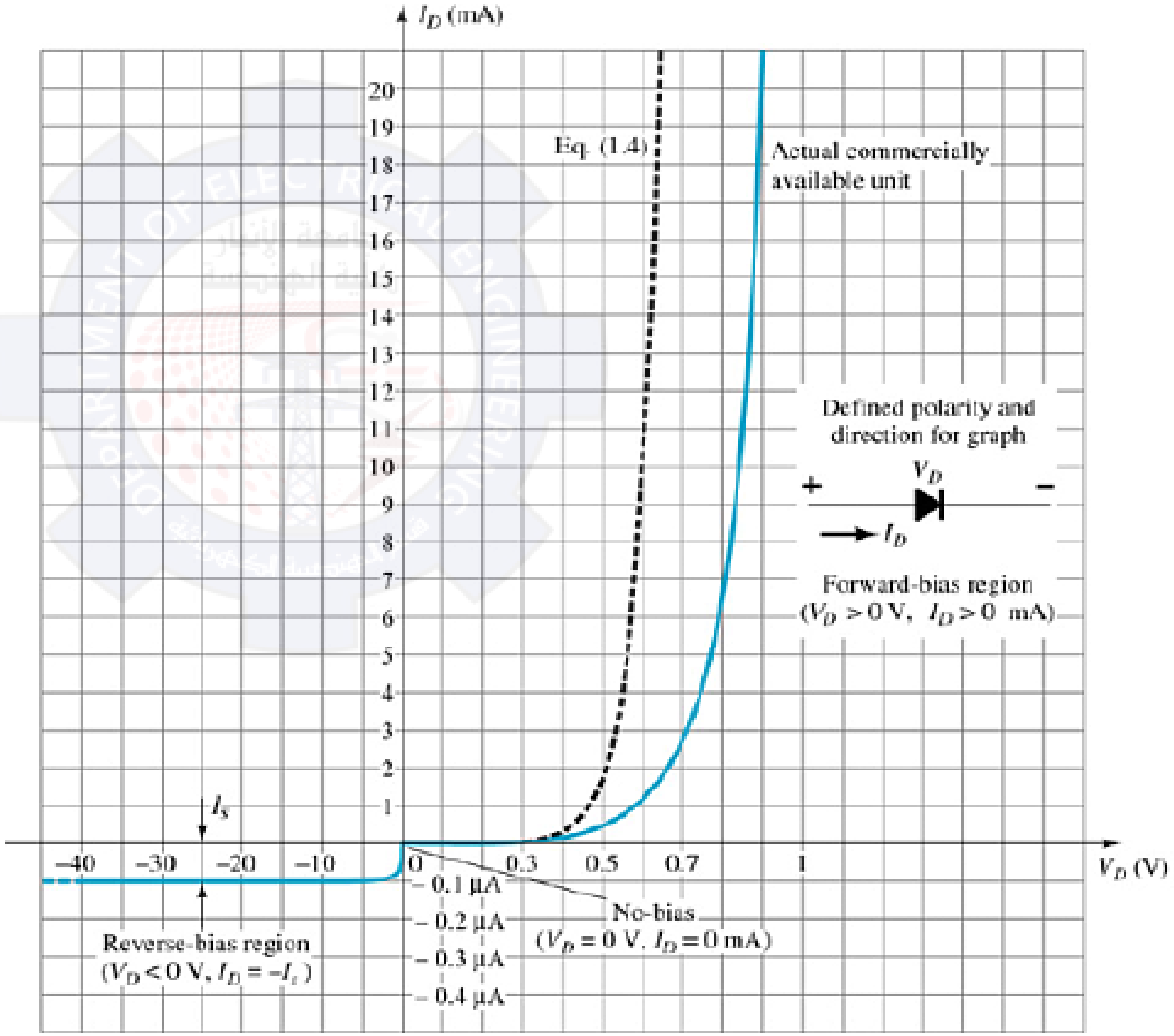
Note the regions for no bias, reverse bias, and forward bias conditions.

Carefully note the scale for each of these conditions.

The reverse saturation current is seldom more than a few microamperes.

$$I_D = I_S\left(e^{V_D/nV_T} - 1\right)$$

$$V_T = \frac{kT}{q}$$



Diode equation

$$I_D = I_S\left(e^{V_D/nV_T} - 1\right)$$

$$V_T = \frac{kT}{q}$$

where

V_T : is called the thermal voltage.

I_s : is the reverse saturation current.

V_D : is the applied forward-bias voltage across the diode.

n : is a factor function of operation conditions and physical construction. It has range between 1 and 2. assume n=1 unless otherwise noted.

K : is Boltzman's constant =1.38 x 10^{-23}

T: is temperature in kelvins = 273+temperature in C.

q : is the magnitude of electron charge = 1.6 x 10^{-19} C.

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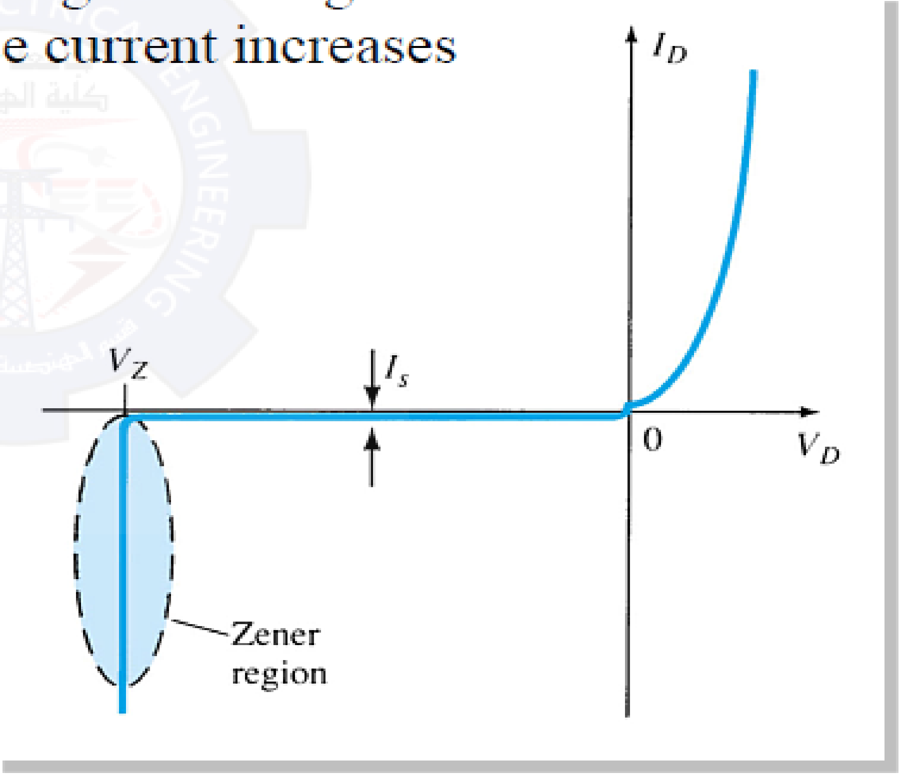
Zener Region

The Zener region is in the diode's reverse-bias region.

At some point the reverse bias voltage is so large the diode breaks down and the reverse current increases dramatically.

- The maximum reverse voltage that won't take a diode into the zener region is called the peak inverse voltage (PIV) or peak reverse voltage (PRV).
- The voltage that causes a diode to enter the zener region of operation is called the zener voltage (V_Z).



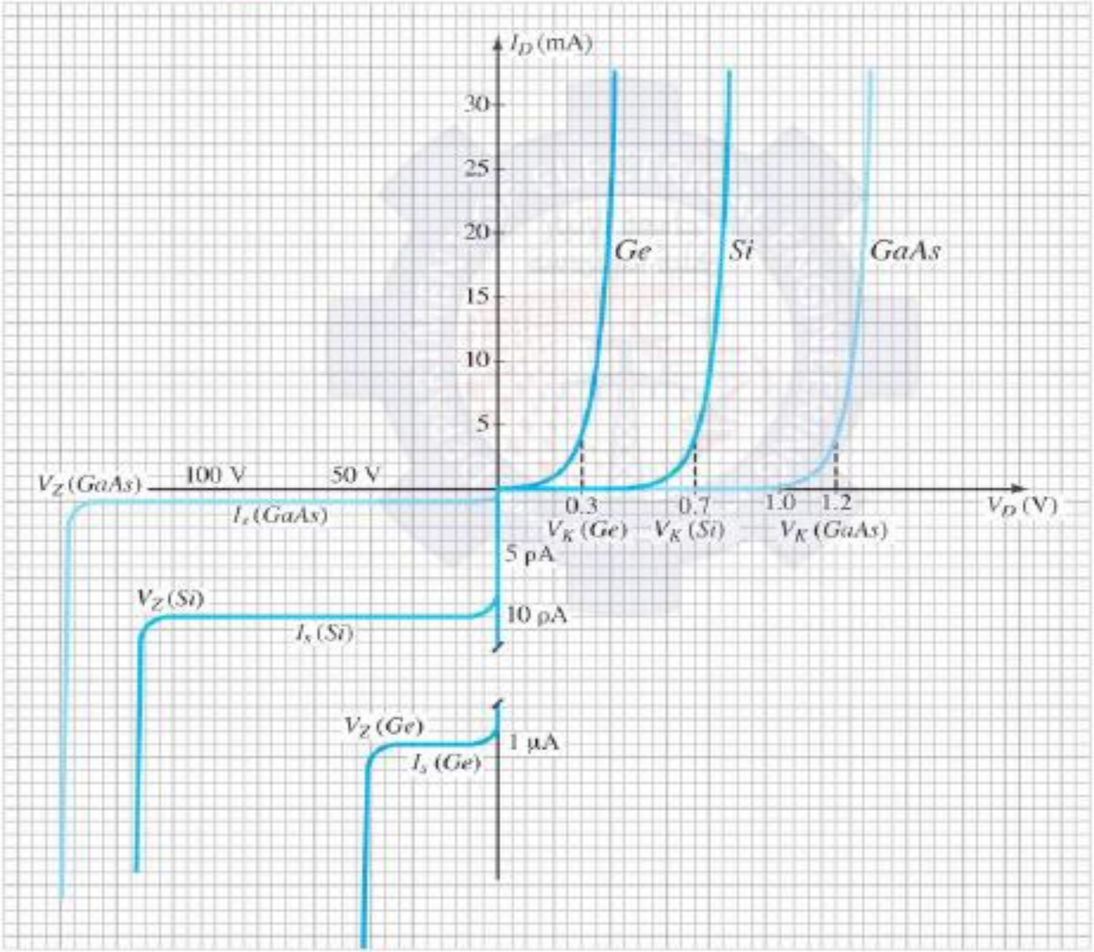
Forward Bias Voltage

The point at which the diode changes from no-bias condition to forward-bias condition occurs when the electrons and holes are given sufficient energy to cross the *p-n* junction. This energy comes from the external voltage applied across the diode.

The forward bias voltage required for a:

- **gallium arsenide diode ≅ 1.2 V**
- **silicon diode ≅ 0.7 V**
- **germanium diode ≅ 0.3 V**

Comparison Ge, Si, GaAs



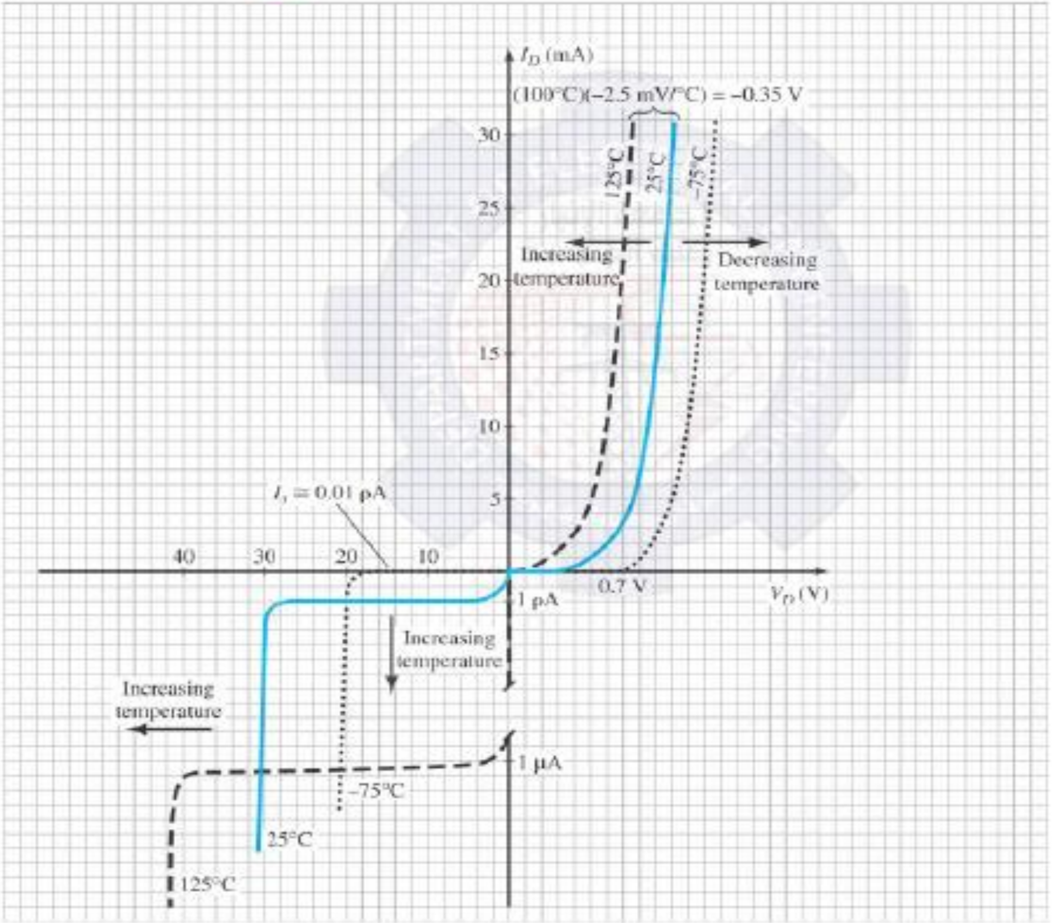
Temperature Effects

As temperature increases it adds energy to the diode.

- It reduces the required forward bias voltage for forward-bias conduction.
- It increases the amount of reverse current in the reverse-bias condition.

Germanium diodes are more sensitive to temperature variations than silicon or gallium arsenide diodes.

Temperature Effects



Resistance Levels

Semiconductors react differently to DC and AC currents.

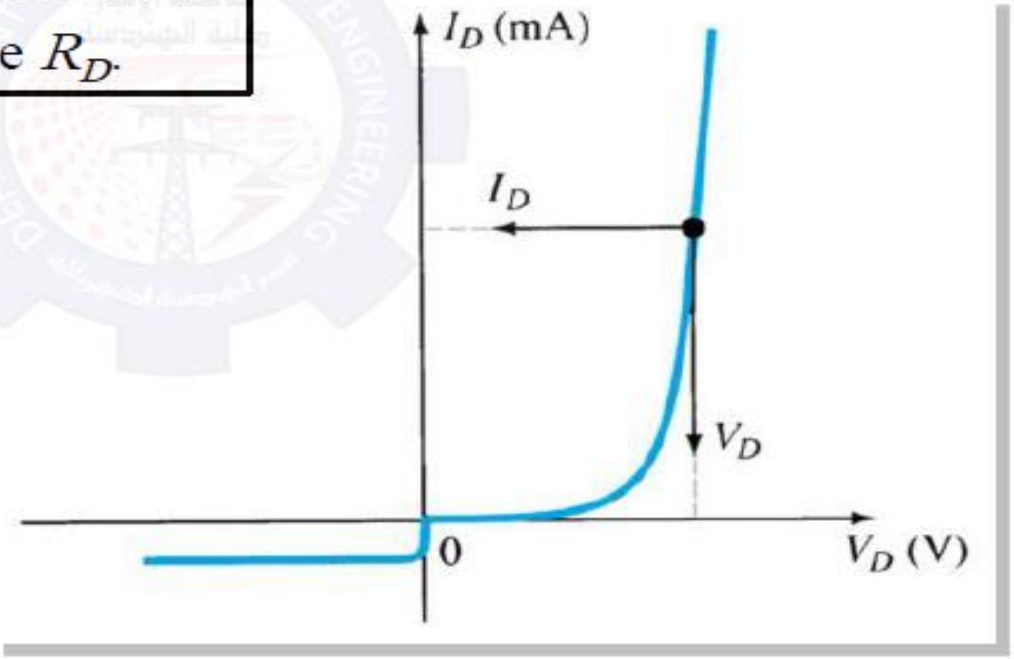
There are three types of resistance:

- **DC (static) resistance**
- **AC (dynamic) resistance**
- **Average AC resistance**

DC (Static) Resistance

For a specific applied DC voltage V_D, the diode has a specific current I_D, and a specific resistance R_D.

$$R_D = \frac{V_D}{I_D}$$



EXAMPLE 1.3 Determine the dc resistance levels for the diode of Fig. 1.24 at

a. $I_D = 2$ mA (low level)
b. $I_D = 20$ mA (high level)
c. $V_D = -10$ V (reverse-biased)

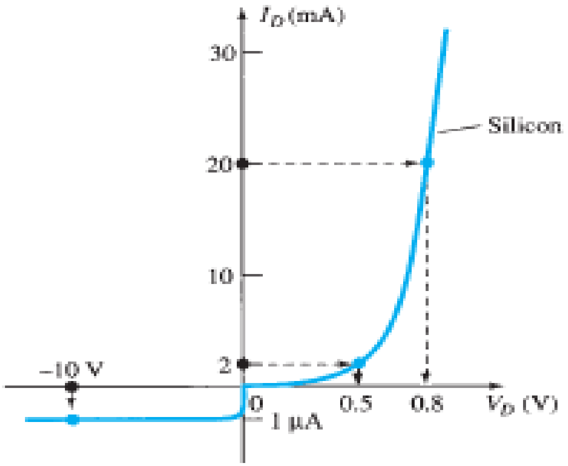


FIG. 1.24
Example 1.3.

Solution:

a. At $I_D = 2$ mA, $V_D = 0.5$ V (from the curve) and

$$R_D = \frac{V_D}{I_D} = \frac{0.5\text{ V}}{2\text{ mA}} = \mathbf{250\ \Omega}$$

b. At $I_D = 20$ mA, $V_D = 0.8$ V (from the curve) and

$$R_D = \frac{V_D}{I_D} = \frac{0.8\text{ V}}{20\text{ mA}} = \mathbf{40\ \Omega}$$

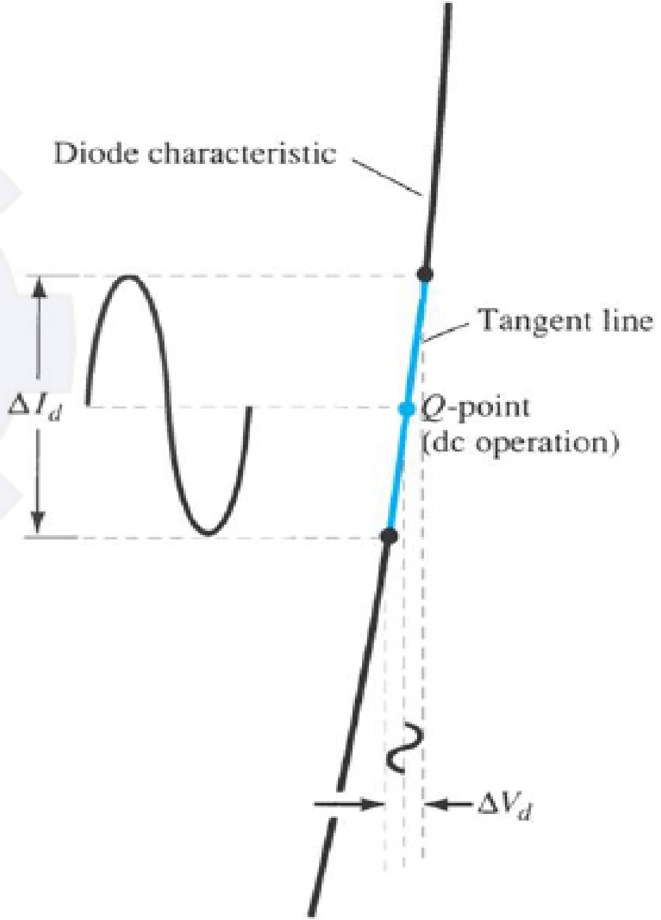
c. At $V_D = -10$ V, $I_D = -I_s = -1\ \mu$A (from the curve) and

$$R_D = \frac{V_D}{I_D} = \frac{10\text{ V}}{1\ \mu\text{A}} = \mathbf{10\ M\Omega}$$

AC (Dynamic) Resistance

The dynamic resistance is the resistance offered by the diode to the AC signal. Is is equal to the slope of the *VI* characteristics (dV/dI or $\Delta V/\Delta I$) ,

$$r_D = \frac{\text{change in voltage}}{\text{resulting change in current}} = \frac{dV}{dI} = \frac{\Delta V}{\Delta I}$$



AC (Dynamic) Resistance

$$\text{since } I_D = I_s\left(e^{V_D/nV_T} - 1\right) \quad , \quad \frac{dI_D}{dV_D} = \frac{I_s}{nV_T} e^{V_D/nV_T}$$

$$\frac{dI_D}{dV_D} = \frac{1}{nV_T}(I_D + I_s) \quad , \quad \text{since } I_D >> I_s \quad , \quad \frac{dI_D}{dV_D} \cong \frac{I_D}{nV_T}$$

$$\frac{dV_D}{dI_D} = r_D = \frac{nV_T}{I_D}$$

for n=1, and at room temperature of 27°C, T=273+27=300K

$$V_T = \frac{KT}{q} = \frac{\left(1.38\times10^{-23}\right)}{1.6\times10^{-19}} \cong 26mV$$

$$\boxed{r_D = \frac{26mV}{I_D}}$$

AC (Dynamic) Resistance

In the forward bias region: $$r'_d = \frac{26\,\text{mV}}{I_D} + r_B$$

- The resistance depends on the amount of current (I_D) in the diode.
- r_D = 26 mV/I_D is the resistance of the p-n junction and does not include the resistance of the semiconductor material itself (the *body* resistance).
- r_B is added to account for body resistance and it ranges from a typical 0.1 Ω to 2 Ω.

In the reverse bias region:

$$r'_d = \infty$$

The resistance is effectively infinite. The diode acts like an open.

EXAMPLE 1.4 For the characteristics of Fig. 1.27:

a. Determine the ac resistance at $I_D = 2$ mA.
b. Determine the ac resistance at $I_D = 25$ mA.
c. Compare the results of parts (a) and (b) to the dc resistances at each current level.

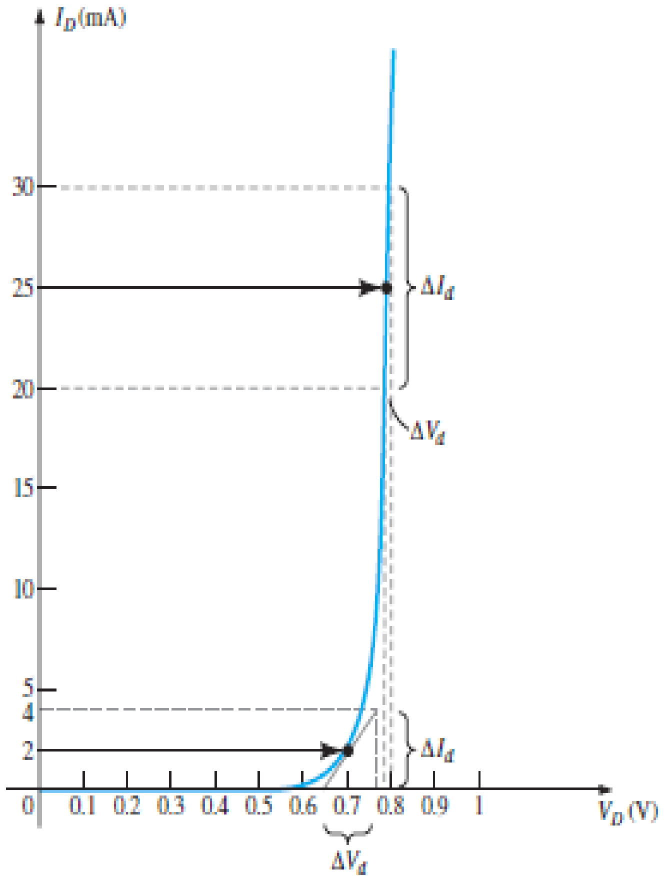


FIG. 1.27
Example 1.4.

Solution:

a. For $I_D = 2$ mA, the tangent line at $I_D = 2$ mA was drawn as shown in Fig. 1.27 and a swing of 2 mA above and below the specified diode current was chosen. At $I_D = 4$ mA, $V_D = 0.76$ V, and at $I_D = 0$ mA, $V_D = 0.65$ V. The resulting changes in current and voltage are, respectively,

$$\Delta I_d = 4 \text{ mA} - 0 \text{ mA} = 4 \text{ mA}$$

and

$$\Delta V_d = 0.76 \text{ V} - 0.65 \text{ V} = 0.11 \text{ V}$$

and the ac resistance is

$$r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{0.11 \text{ V}}{4 \text{ mA}} = \mathbf{27.5\ \Omega}$$

b. For $I_D = 25$ mA, the tangent line at $I_D = 25$ mA was drawn as shown in Fig. 1.27 and a swing of 5 mA above and below the specified diode current was chosen. At $I_D = 30$ mA, $V_D = 0.8$ V, and at $I_D = 20$ mA, $V_D = 0.78$ V. The resulting changes in current and voltage are, respectively,

$$\Delta I_d = 30 \text{ mA} - 20 \text{ mA} = 10 \text{ mA}$$

and

$$\Delta V_d = 0.8 \text{ V} - 0.78 \text{ V} = 0.02 \text{ V}$$

and the ac resistance is

$$r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{0.02 \text{ V}}{10 \text{ mA}} = \mathbf{2\ \Omega}$$

c. For $I_D = 2$ mA, $V_D = 0.7$ V and

$$R_D = \frac{V_D}{I_D} = \frac{0.7 \text{ V}}{2 \text{ mA}} = \mathbf{350\ \Omega}$$

which far exceeds the r_d of 27.5 Ω.

For $I_D = 25$ mA, $V_D = 0.79$ V and

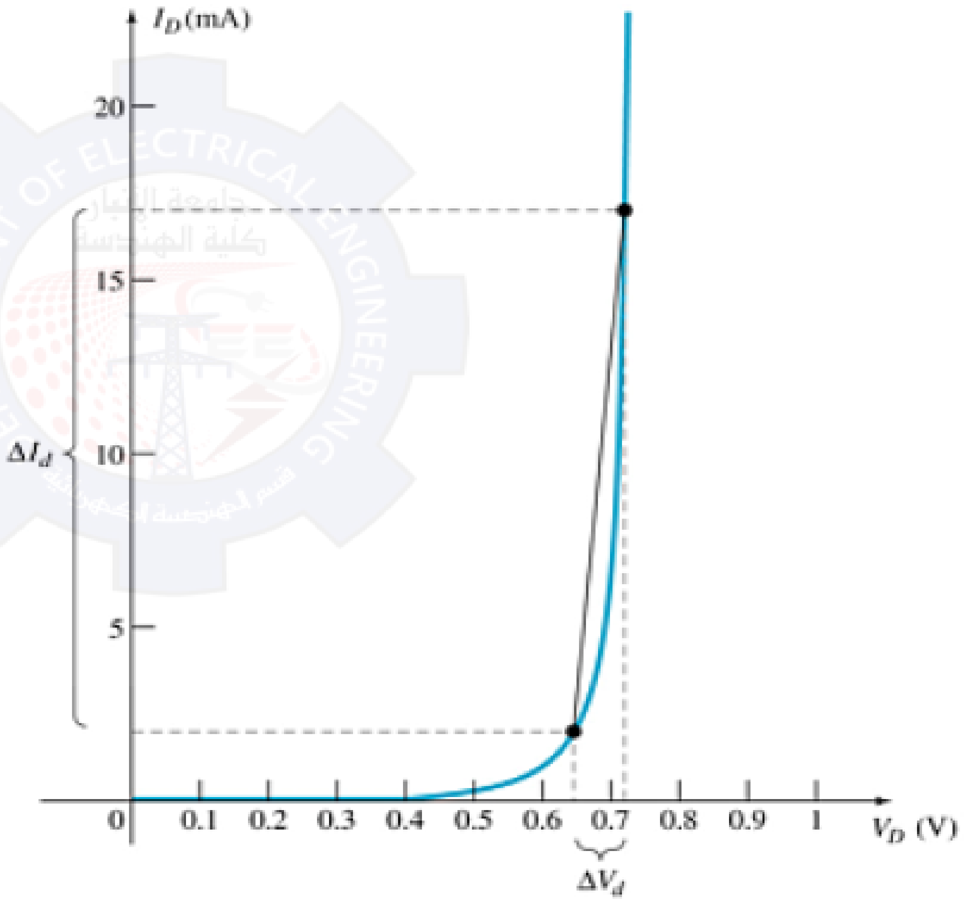
$$R_D = \frac{V_D}{I_D} = \frac{0.79 \text{ V}}{25 \text{ mA}} = \mathbf{31.62\ \Omega}$$

which far exceeds the r_d of 2 Ω.

Average AC Resistance

$$r_{av} = \frac{\Delta V_d}{\Delta I_d} \bigg|_{\text{pt. to pt.}}$$

AC resistance can be calculated using the current and voltage values for two points on the diode characteristic curve.



For the situation indicated by Fig. 1.28,

$$\Delta I_d = 17\text{ mA} - 2\text{ mA} = 15\text{ mA}$$

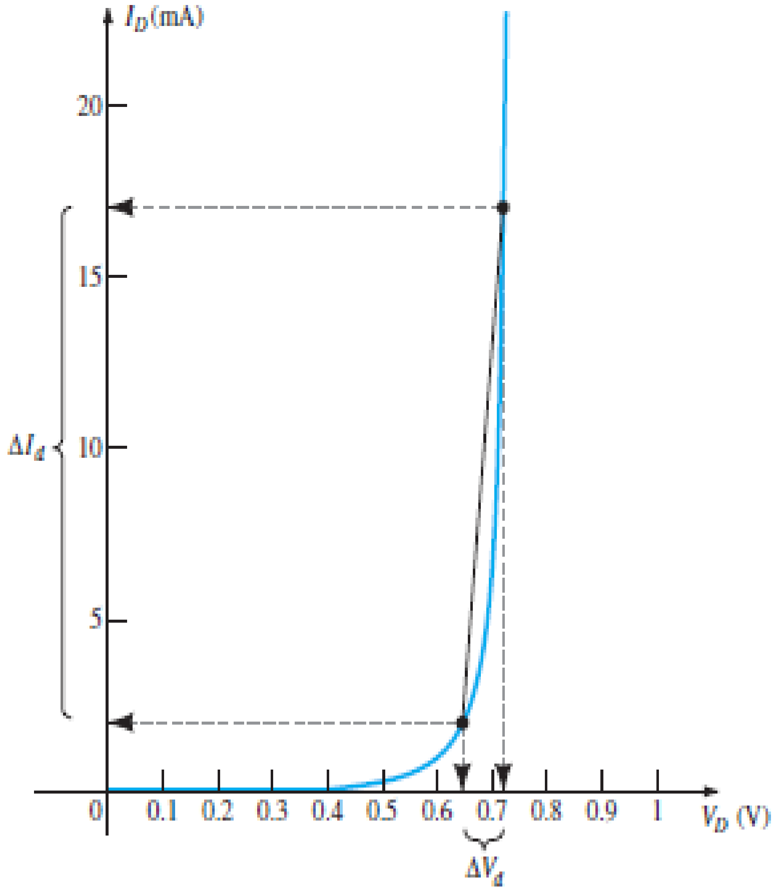


FIG. 1.28

Determining the average ac resistance between indicated limits.

and $$\Delta V_d = 0.725\text{ V} - 0.65\text{ V} = 0.075\text{ V}$$

with $$r_{av} = \frac{\Delta V_d}{\Delta I_d} = \frac{0.075\text{ V}}{15\text{ mA}} = \mathbf{5\ \Omega}$$

If the ac resistance (r_d) were determined at $I_D = 2$ mA, its value would be more than 5 Ω, and if determined at 17 mA, it would be less. In between, the ac resistance would make the transition from the high value at 2 mA to the lower value at 17 mA. Equation (1.7) defines a value that is considered the average of the ac values from 2 mA to 17 mA. The fact that one resistance level can be used for such a wide range of the characteristics will prove quite useful in the definition of equivalent circuits for a diode in a later section.

As with the dc and ac resistance levels, the lower the level of currents used to determine the average resistance, the higher is the resistance level.

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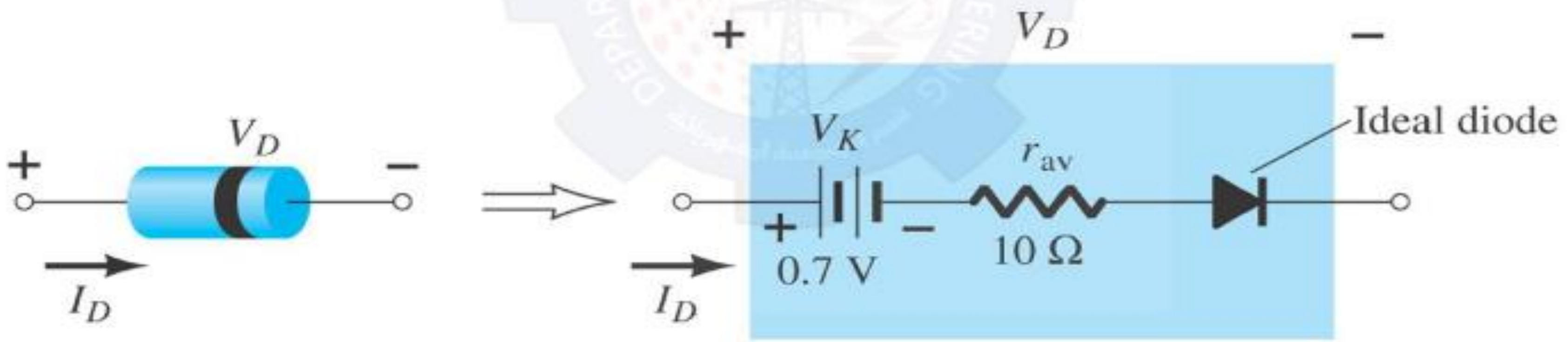
Diode Equivalent Circuit



Diode Specification Sheets

Data about a diode is presented uniformly for many different diodes.

1. **Forward Voltage (V_F) at a specified current and temperature**
2. **Maximum forward current (I_F) at a specified temperature**
3. **Reverse saturation current (I_R) at a specified voltage and temperature**
4. **Reverse voltage rating, PIV or PRV or V(BR), at a specified temperature**
5. **Maximum power dissipation at a specified temperature**
6. **Capacitance levels**
7. **Reverse recovery time, t_{rr}** (is the time required for a diode to stop conducting once it is switched from forward bias to reverse bias)
8. **Operating temperature range**

Diode Specification Sheets

DIFFUSED SILICON PLANAR

A — • BV . . . 125 V (MIN) @ 100 μA (BAY73)

ABSOLUTE MAXIMUM RATINGS (Note 1)

Temperatures

B —

Storage Temperature Range	-65°C to +200°C
Maximum Junction Operating Temperature	+175°C
Lead Temperature	+260°C

Power Dissipation (Note 2)

C —

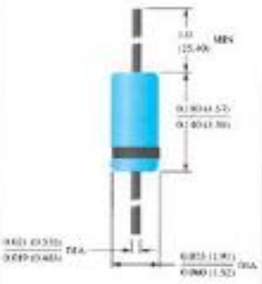
Maximum Total Power Dissipation at 25°C Ambient	500 mW
Linear Power Derating Factor (from 25°C)	3.33 mW/°C

Maximum Voltage and Currents

D —

WIV	Working Inverse Voltage	BAY73	100 V
I_O	Average Rectified Current		200 mA
I_F	Continuous Forward Current		500 mA
i_f	Peak Repetitive Forward Current		600 mA
$i_{f(surge)}$	Peak Forward Surge Current		
	Pulse Width = 1 s		1.0 A
	Pulse Width = 1 μs		4.0 A

DO-35 OUTLINE



NOTES:
Copper clad steel leads, tin plated
Gold plated leads available
Hermetically sealed glass package
Package weight is 0.14 gram

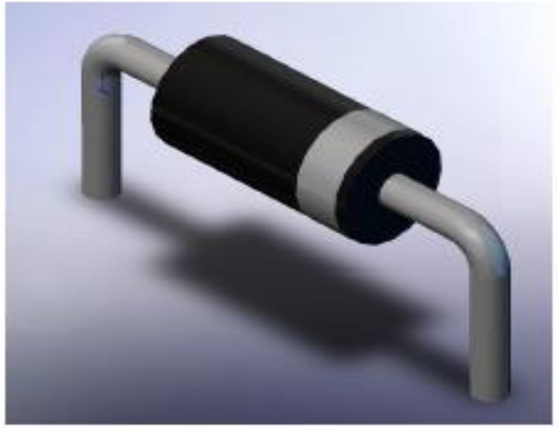
ELECTRICAL CHARACTERISTICS (25°C Ambient Temperature unless otherwise noted)

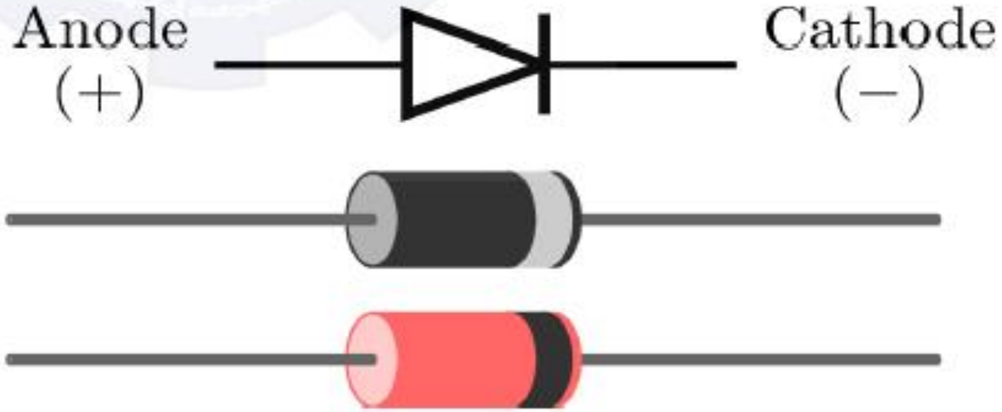
	SYMBOL	CHARACTERISTIC	BAY73 MIN	BAY73 MAX	UNITS	TEST CONDITIONS
E	V_F	Forward Voltage	0.85	1.00	V	$I_F = 200$ mA
			0.81	0.94	V	$I_F = 100$ mA
			0.78	0.88	V	$I_F = 50$ mA
			0.69	0.80	V	$I_F = 10$ mA
			0.67	0.75	V	$I_F = 5.0$ mA
			0.60	0.68	V	$I_F = 1.0$ mA
F	I_R	Reverse Current		500	nA	$V_R = 20$ V, $T_A = 125°C$
				1.0	μA	$V_R = 100$ V, $T_A = 125°C$
				0.2	nA	$V_R = 20$ V, $T_A = 25°C$
				0.5	nA	$V_R = 100$ V, $T_A = 25°C$
	BV	Breakdown Voltage	125		V	$I_R = 100$ μA
G	C	Capacitance		8.0	pF	$V_R = 0$, f = 1.0 MHz
H	t_{rr}	Reverse Recovery Time		3.0	μs	$I_F = 10$ mA, $V_R = 35$ V, $R_L = 1.0$ to 100 kΩ, $C_L = 10$ pF, JAN 256

NOTES
1. These ratings are limiting values above which the serviceability of the diode may be impaired.
2. These are steady state limits. The factory should be consulted on applications involving pulses or low duty-cycle operation.

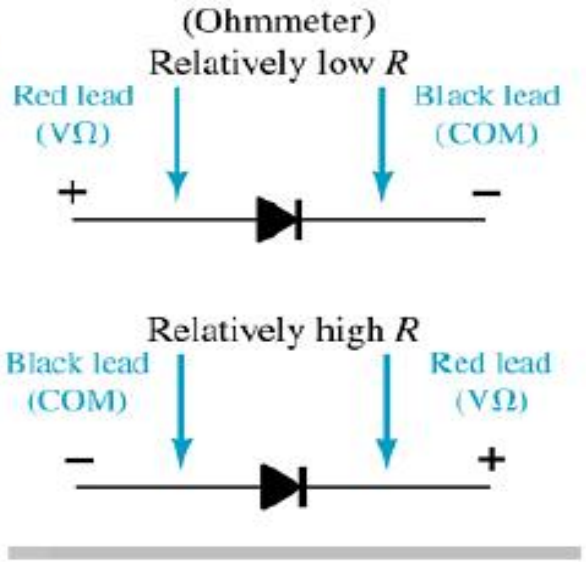
Diode Symbol and Packaging

The anode is abbreviated A
The cathode is abbreviated K

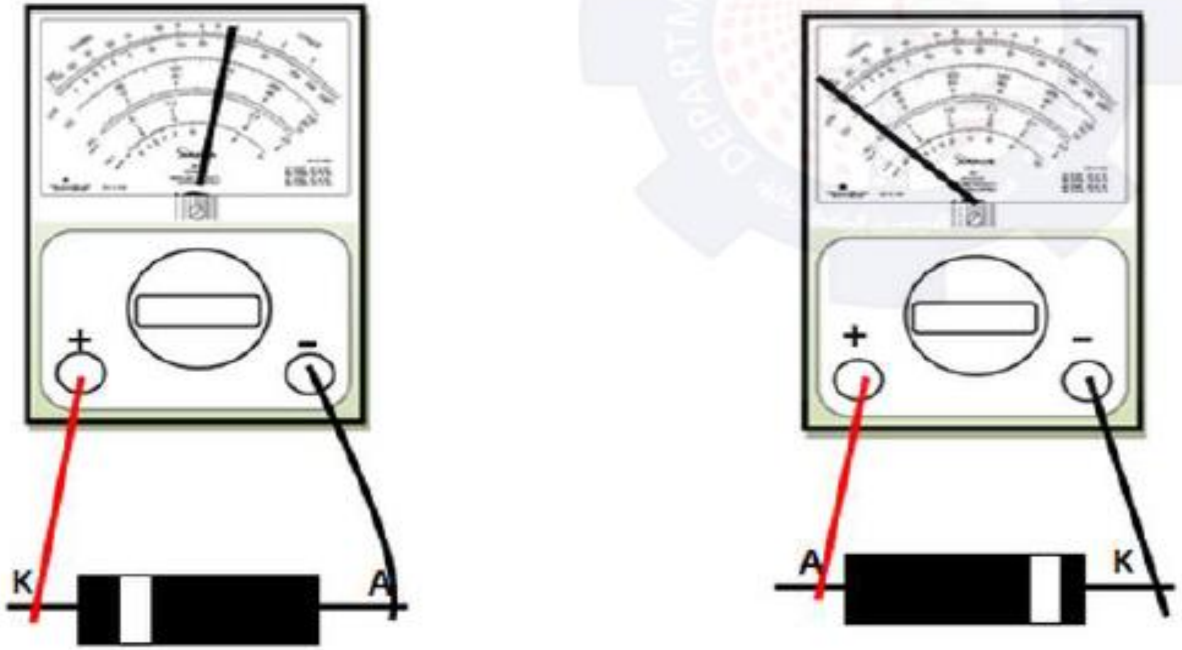




Diode Testing - Ohmmeter



An ohmmeter set on a low Ohms scale can be used to test a diode. The diode should be tested out of circuit.



Other Types of Diodes

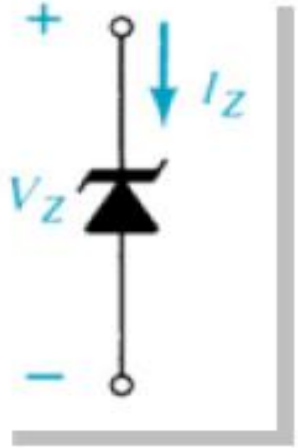
Zener diode
Light-emitting diode
Diode arrays

Zener Diode

•A **Zener diode** is a type of diode that permits current not only in the forward direction like a normal diode, but also in the reverse direction if the voltage is larger than the breakdown voltage known as "Zener voltage" **(V_Z)**.

•Common Zener voltages are between 1.8 V and 200 V.

•Zener diode is used as regulator (circuits will be shown in chapter 2).

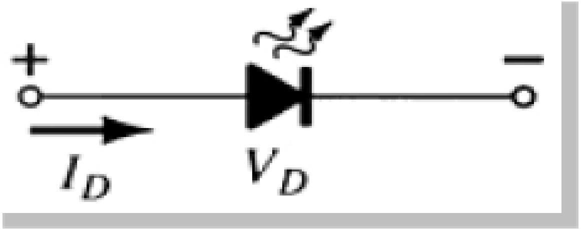


Light-Emitting Diode (LED)

- An LED emits photons when it is forward biased.
- These can be in the infrared or visible spectrum.
- The forward bias voltage is usually in the range of 2 V to 5 V.

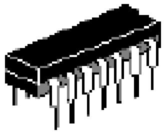
Light-Emitting Diodes

Color	Construction	Typical Forward Voltage (V)
Amber	AlInGaP	2.1
Blue	GaN	5.0
Green	GaP	2.2
Orange	GaAsP	2.0
Red	GaAsP	1.8
White	GaN	4.1
Yellow	AlInGaP	2.1

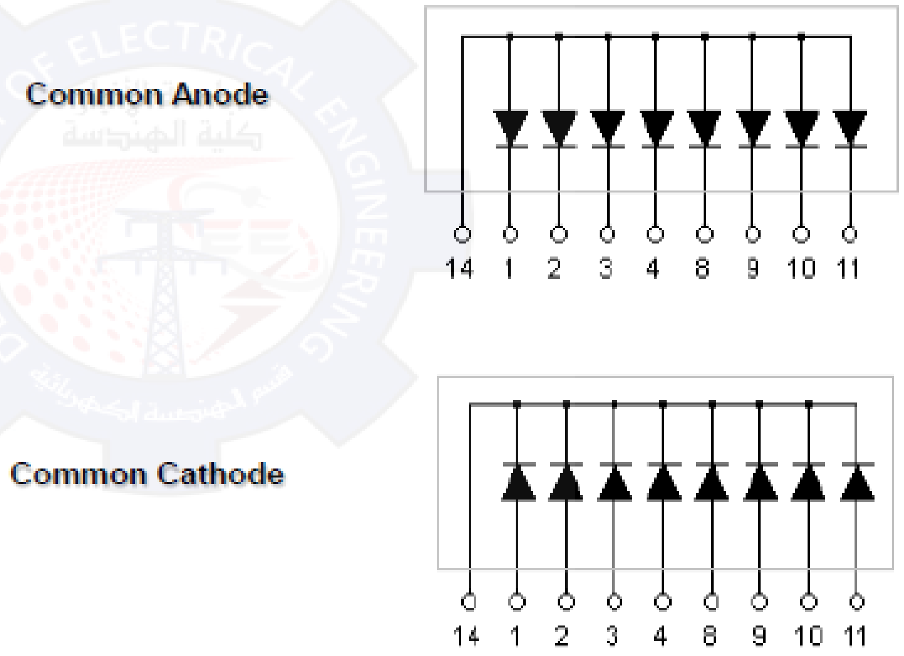


Diode Arrays

Multiple diodes can be packaged together in an integrated circuit (IC).



A variety of combinations exist.



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Second Class

Chapter02: Diode Applications

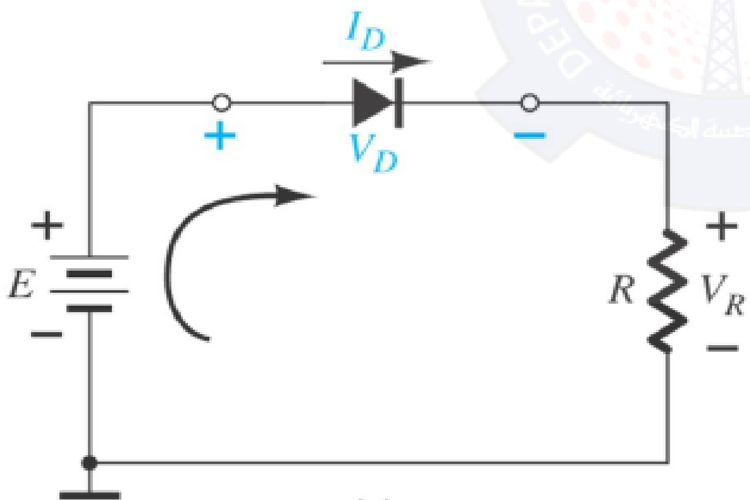
Lec02_p1

Munther N. Thiyab

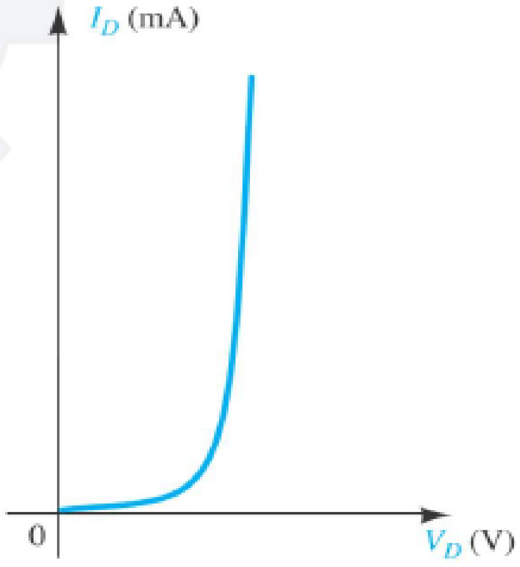
2019-2020

Load-Line Analysis (graphical solution)

- The analysis of diode can follow one of two paths: using the actual characteristics or applying an approximate model for the device.
- Load Line Analysis: is used to analyze diode circuit using its actual characteristics.

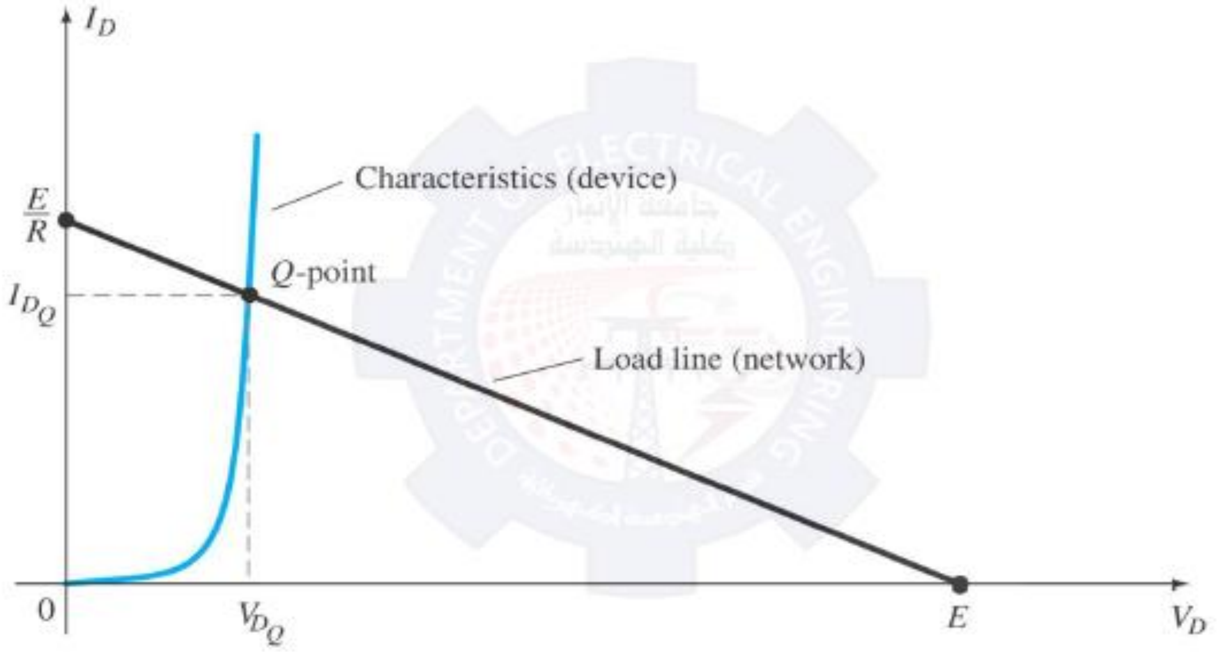


(a)



(b)

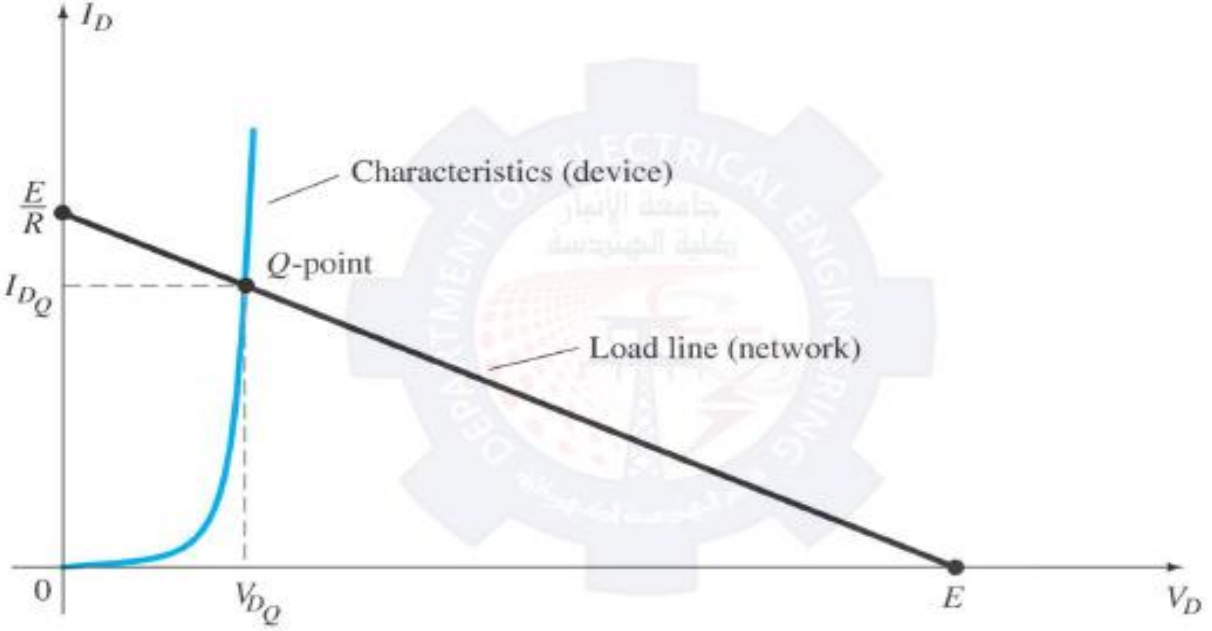
Load-Line Analysis (graphical solution)



•A straight line is defined by the parameters of the network.

•It is called the **load line** because the intersection on the vertical axes is defined by the applied load R.

Load-Line Analysis (graphical solution)

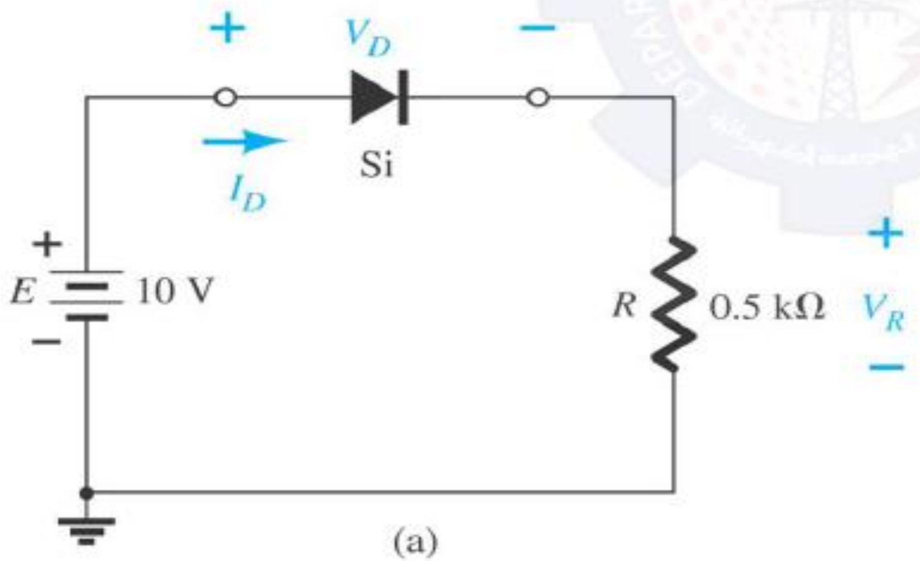


•The maximum I_D equals E/R, and the maximum V_D equals E.

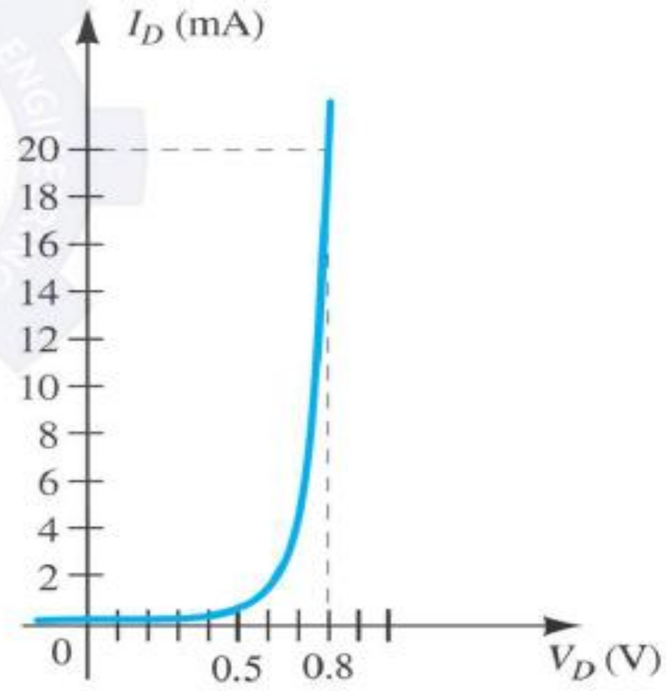
•The point where the load line and the characteristic curve intersect is the Q-point, which identifies I_D and V_D for a particular diode in a given circuit.

Example 2.1

For the given diode configuration and diode characteristics, determine: V_{DO} , I_{DO} and V_R.

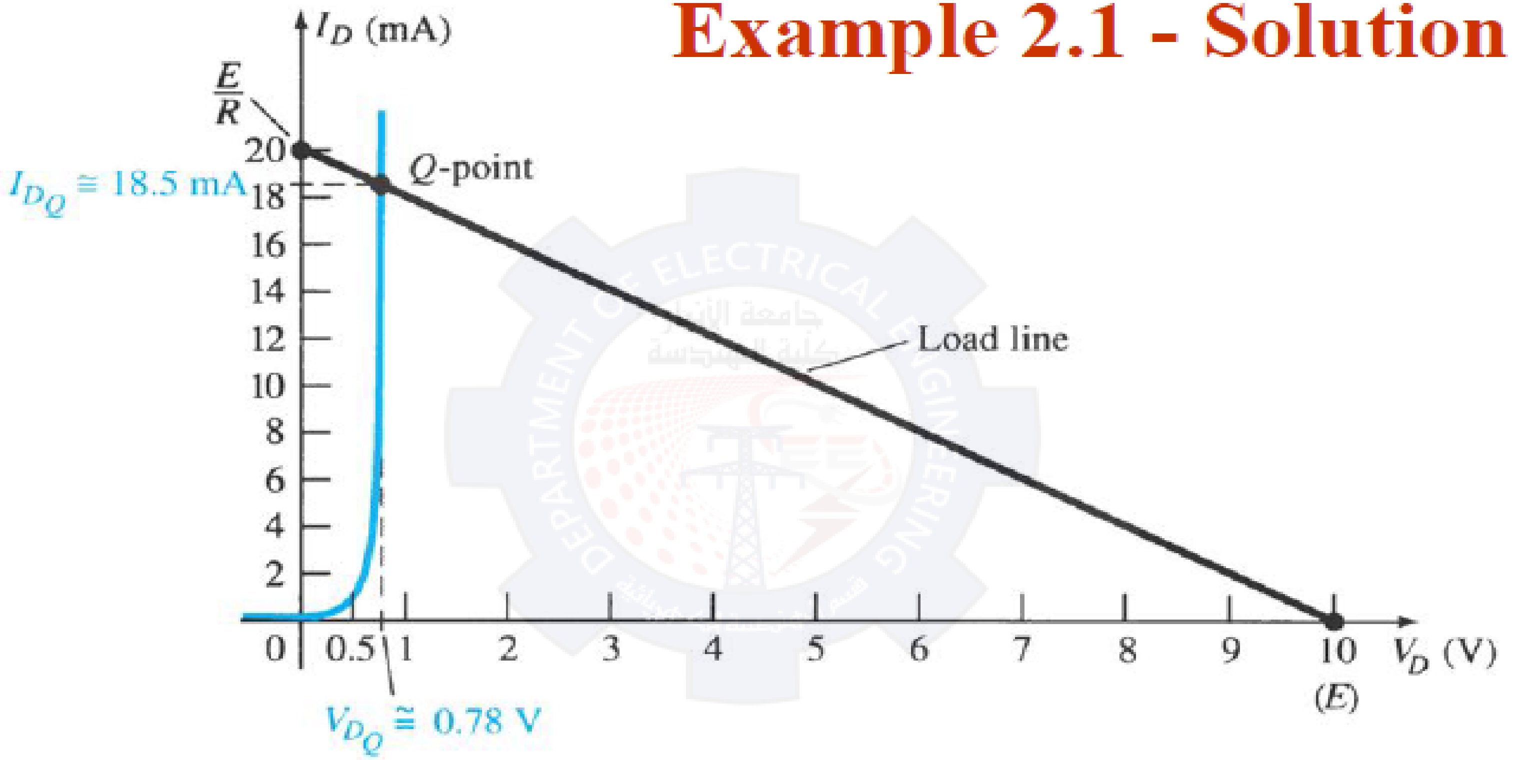


(a)



(b)

Example 2.1 - Solution



- The load line is firstly drawn between V_D=E=10 V and I_D=E/R=10/0.5k=20mA. The intersection between the load line and characteristics defines the Q-point as V_{DQ}=0.78 and I_{DQ}=18.5mA.
- $V_R = I_{DQ}R$=(18.5mA)(1K)=18.5 V

Diode Configurations

- The forward resistance of the diode is usually so small compared to the other series elements of the network that it can be ignored.

- In general, a diode is in the “on” state if the current established by the applied sources is such that its direction matches that of the arrow in the diode symbol, and $V_D \geq 0.7V$ for silicon, $V_D \geq 0.3V$ for germanium, and $V_D \geq 1.2V$ for gallium arsenide.

- You may assume the diode is “on”, and then find the current in the diode. If the current flows into the positive terminal of the diode, then the assumption is right, otherwise, the diode is “off”.

Series Diode Configurations

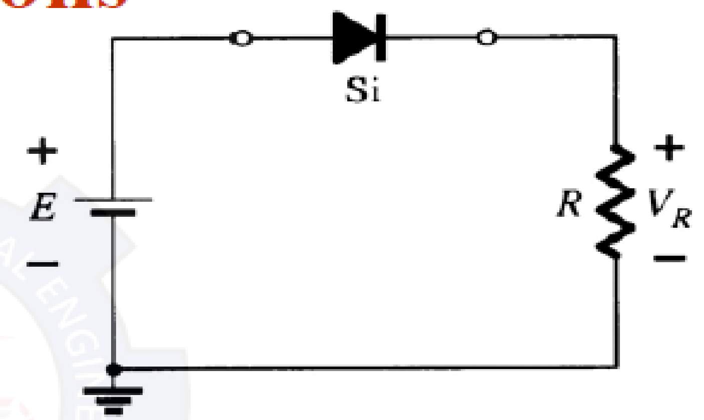
Forward Bias

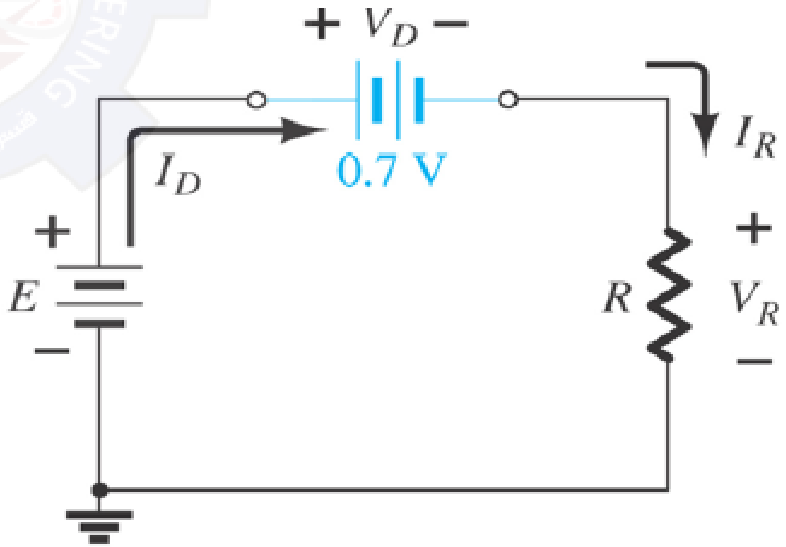
Constants

- **Silicon Diode:** $V_D = 0.7\ V$
- **Germanium Diode:** $V_D = 0.3\ V$

Analysis (for silicon)

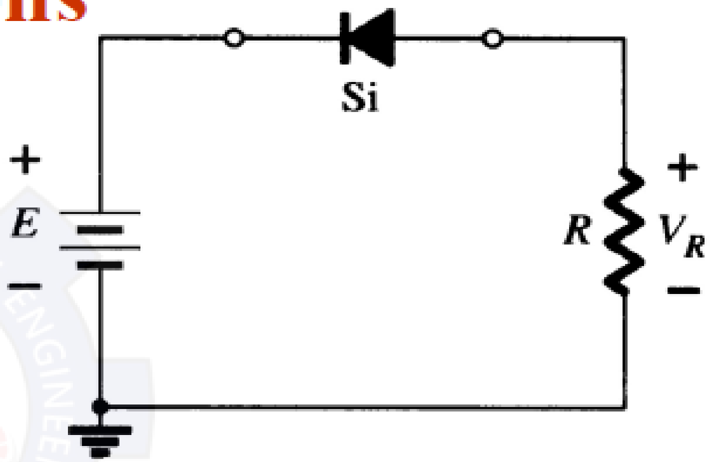
- $V_D = 0.7\ V$ (or $V_D = E$ if $E < 0.7\ V$)
- $V_R = E - V_D$
- $I_D = I_R = I_T = V_R / R = (E - V_D) / R$





Equivalent circuit for the "on" diode

Series Diode Configurations

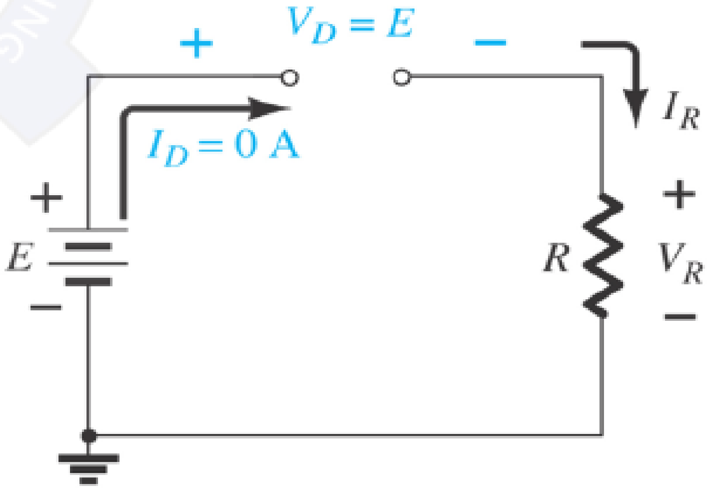


Reverse Bias

Diodes ideally behave as open circuits

Analysis

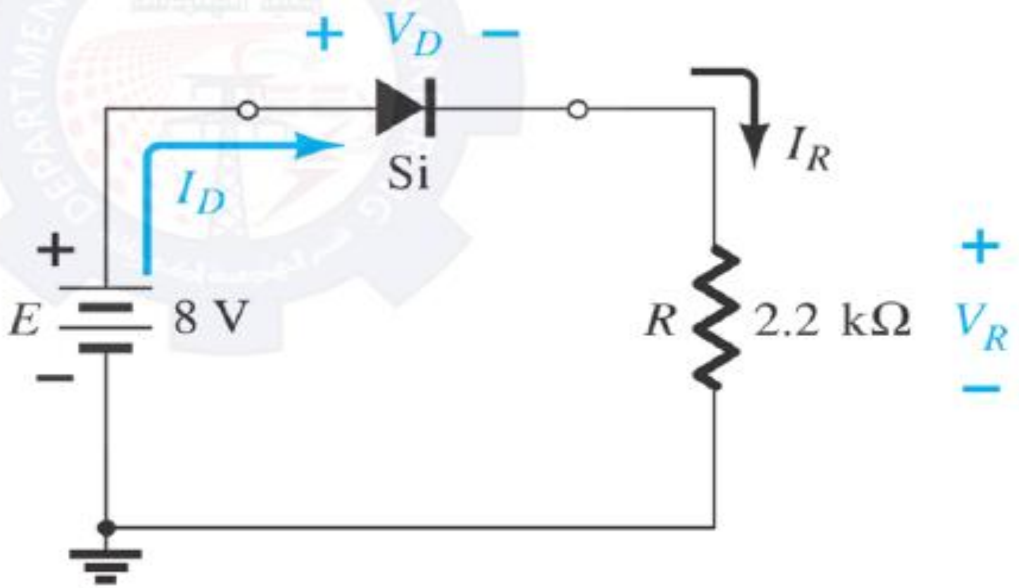
- $V_D = E$
- $V_R = 0\ \text{V}$
- $I_D = 0\ \text{A}$



Equivalent circuit for the “off” diode

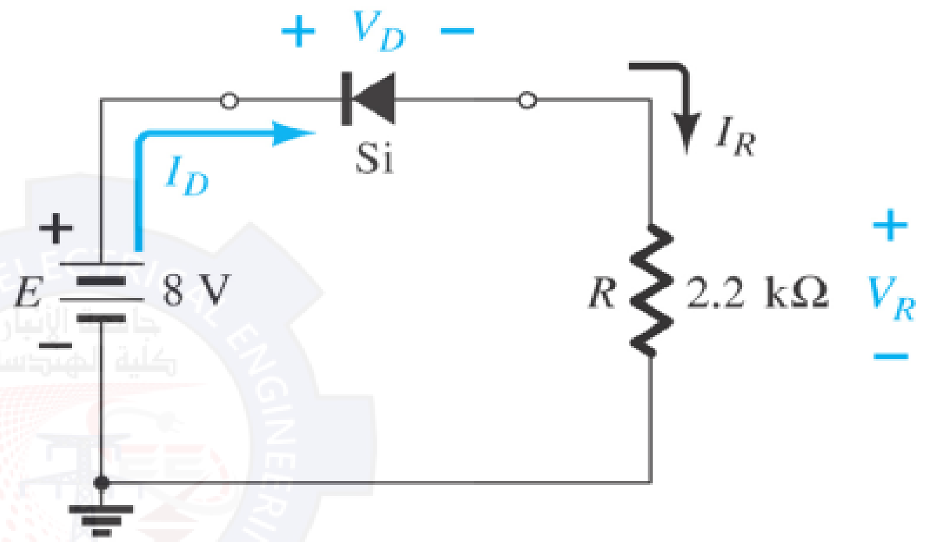
Example 2.4

- Determine V_D, V_R and I_D.

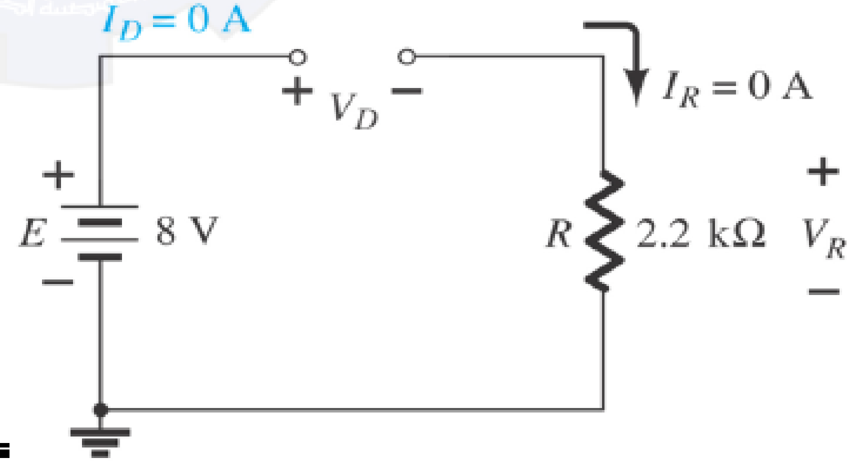


Example 2.5

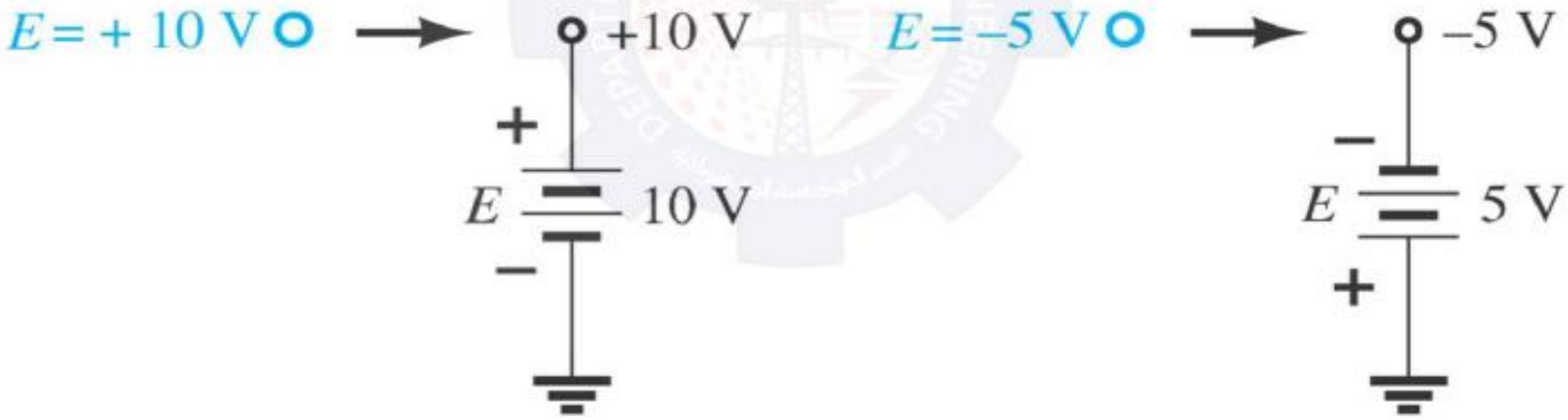
Determine V_D, V_R and I_D.



Solution



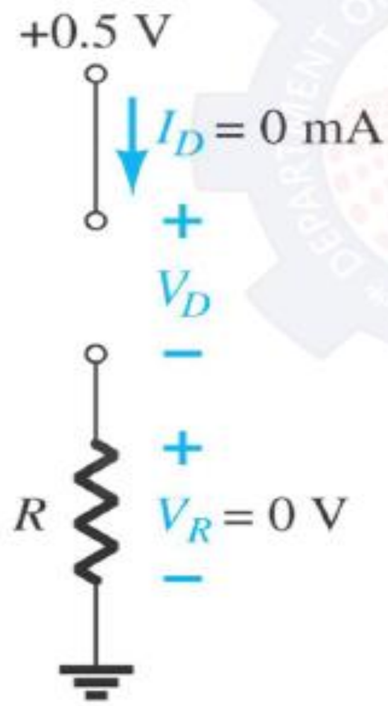
Source Notation

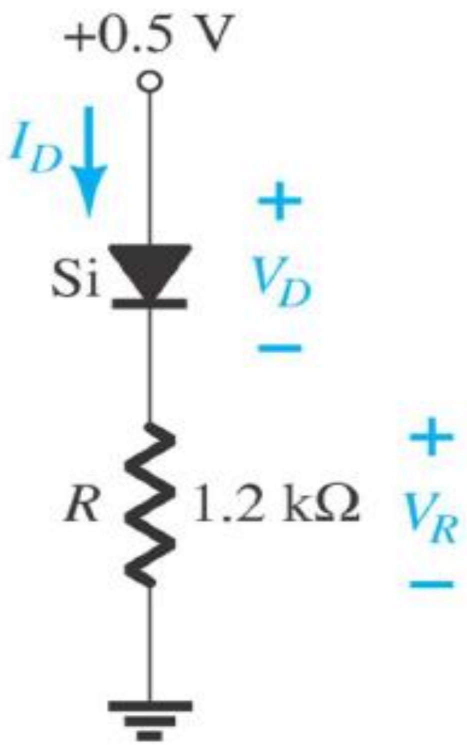


Example 2.6

Determine V_D, V_R and I_D.

Solution

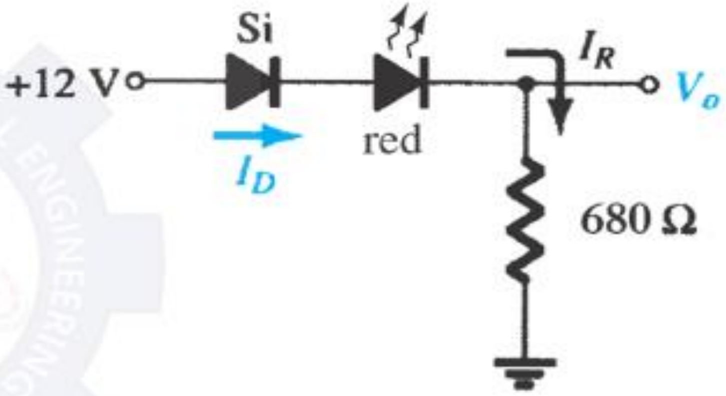


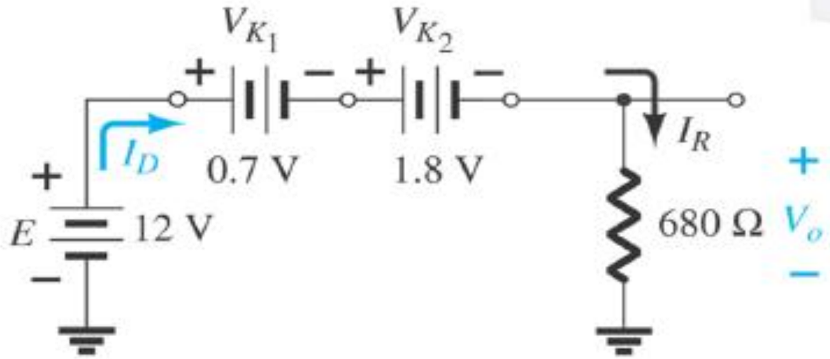


Example 2.7

Determine V_o and I_D. The forward bias voltage for red LED is 1.8 V.

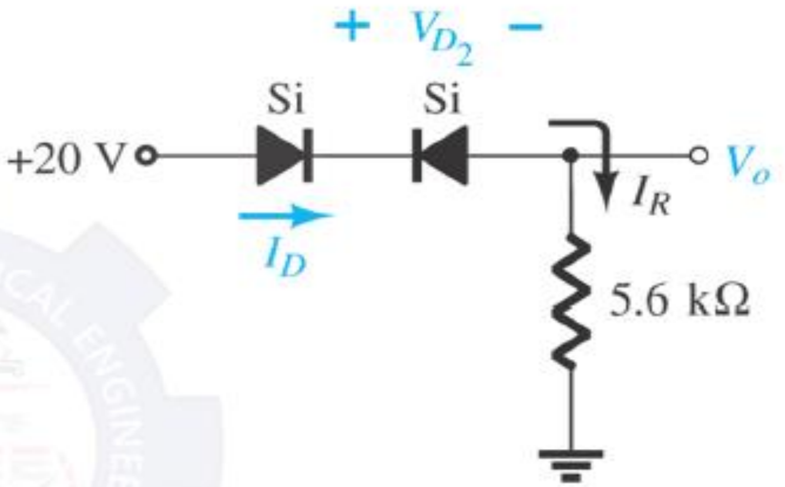
Solution



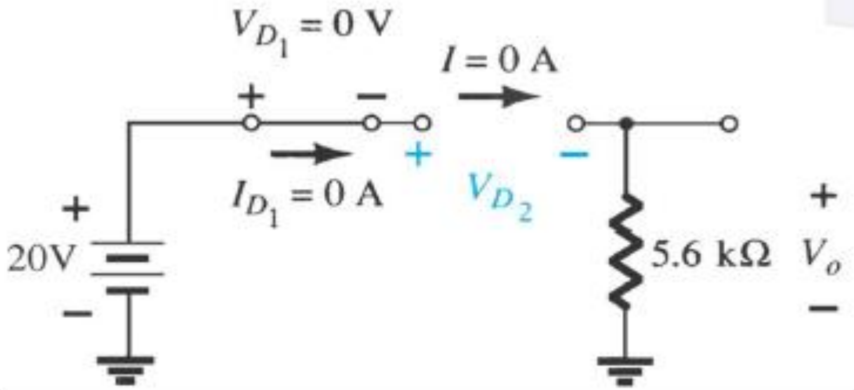


Example 2.8

Determine I_D , V_{D2} and V_o.

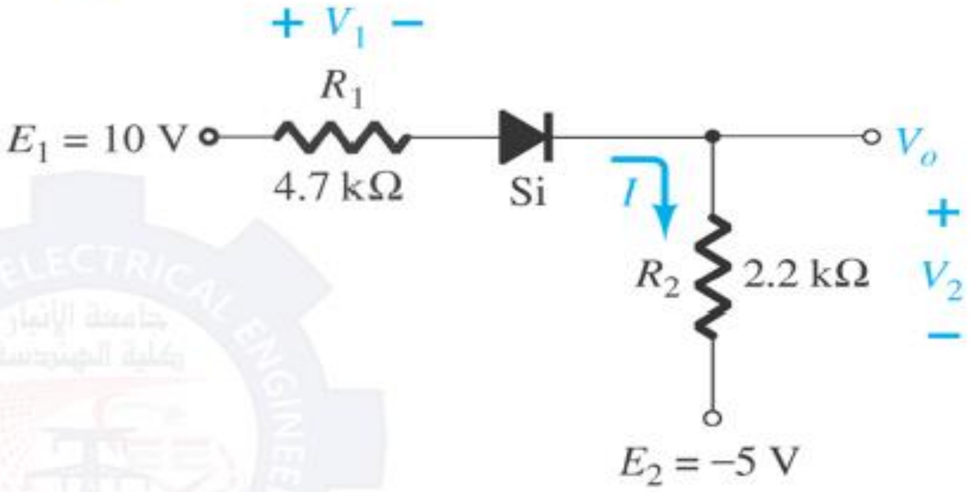


Solution

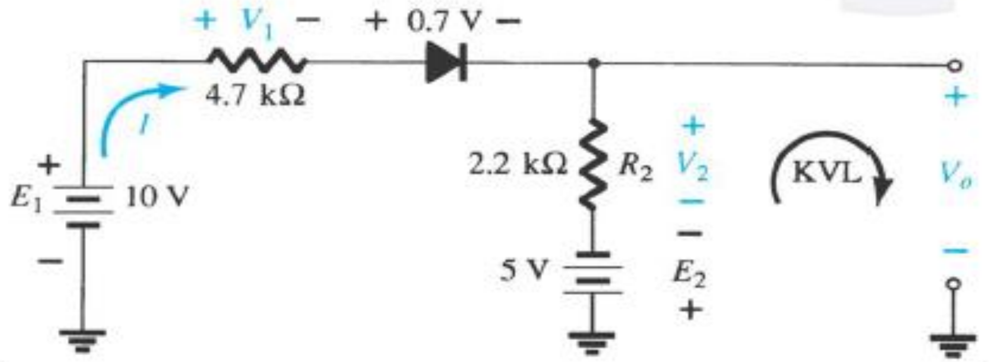


Example 2.9

Determine I , V_1 ,V_2 and V_o

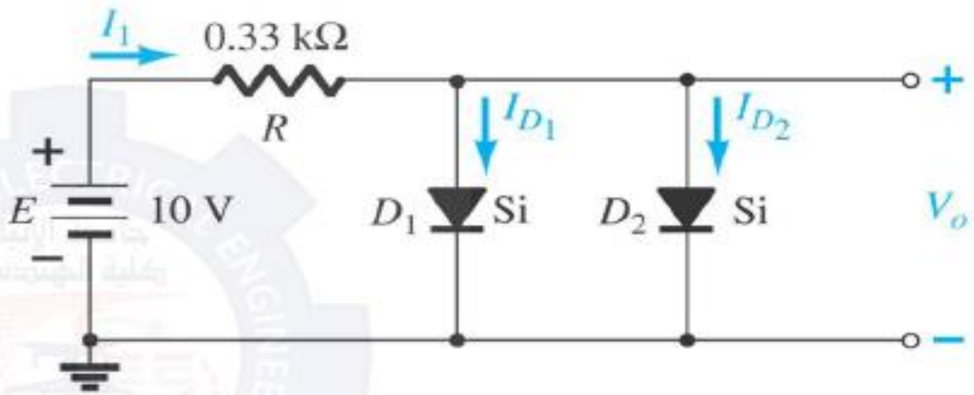


Solution



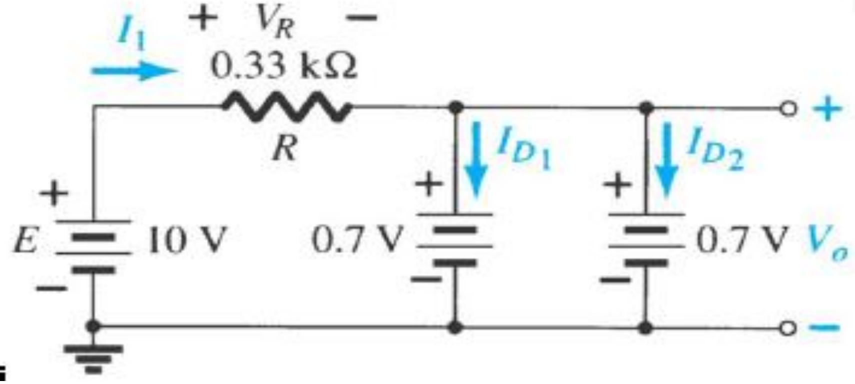
Parallel and Series-Parallel Configurations

Example 2.10



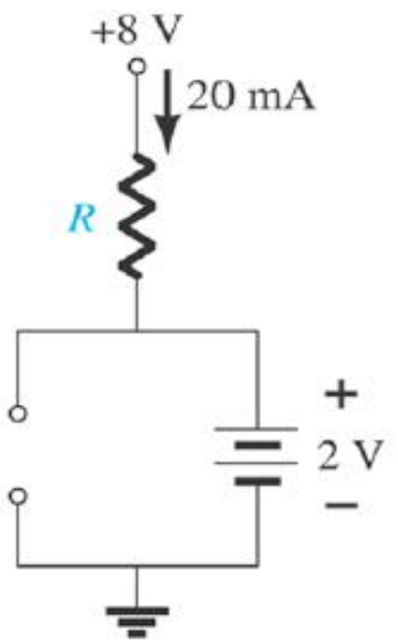
Determine V_O , I_1, I_{D1}, and I_{D2}

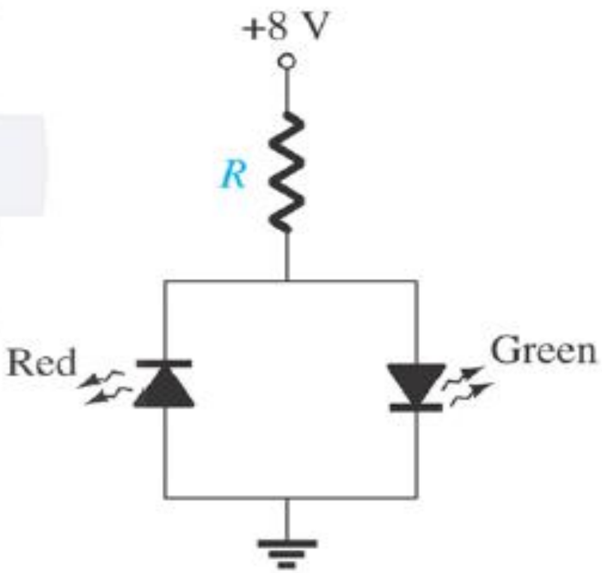
Solution



Example 2.11: Find the resistor R to ensure a current of 20 mA through the "on" diode for the given circuit. Both diodes have reverse breakdown voltage of 3V and average turn-on voltage of 2V.

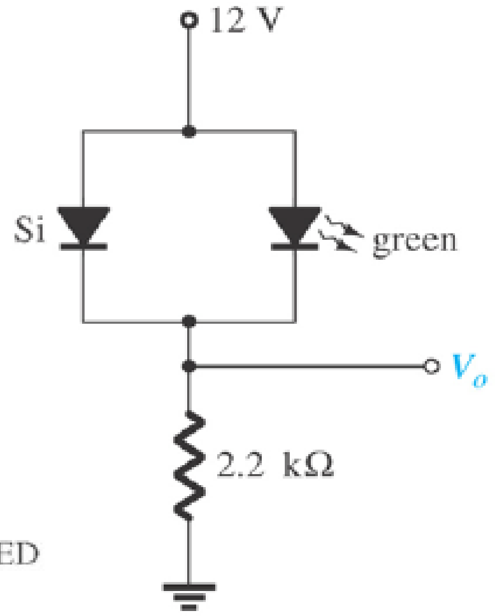
Solution



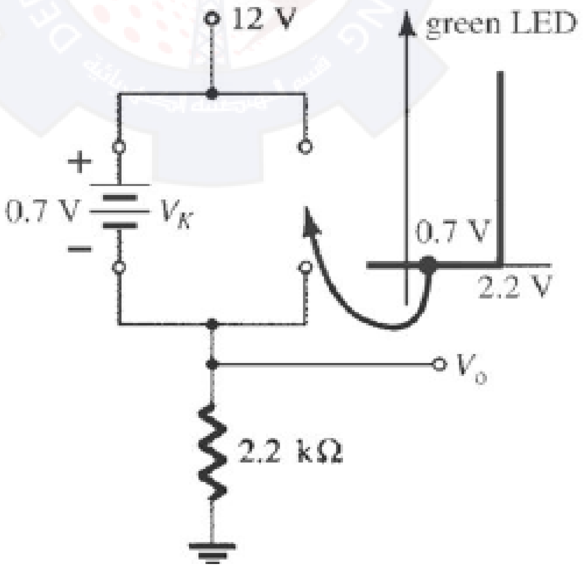


Example 2.12

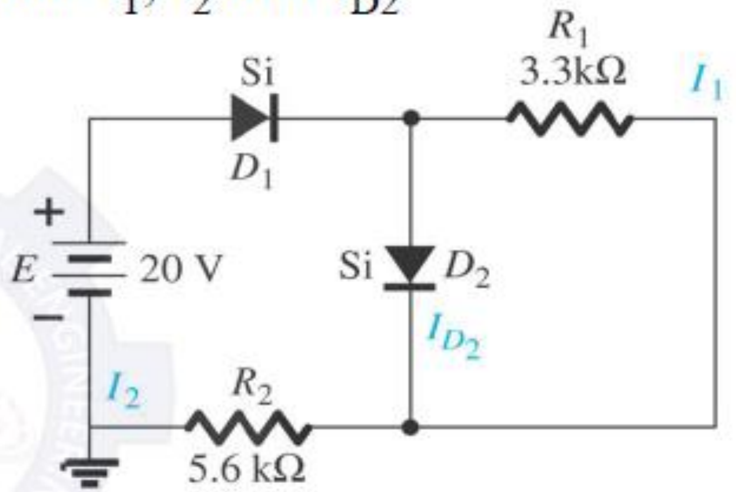
Determine the voltage V_o.



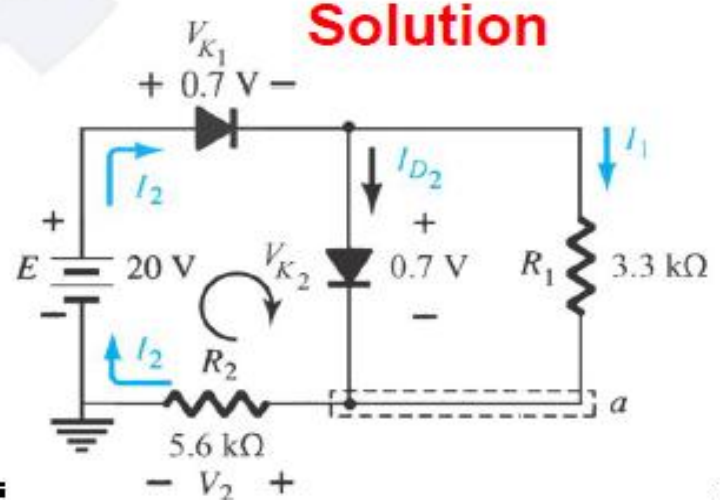
Solution



Example 2.13 Determine the currents I_1, I_2 and I_{D2}

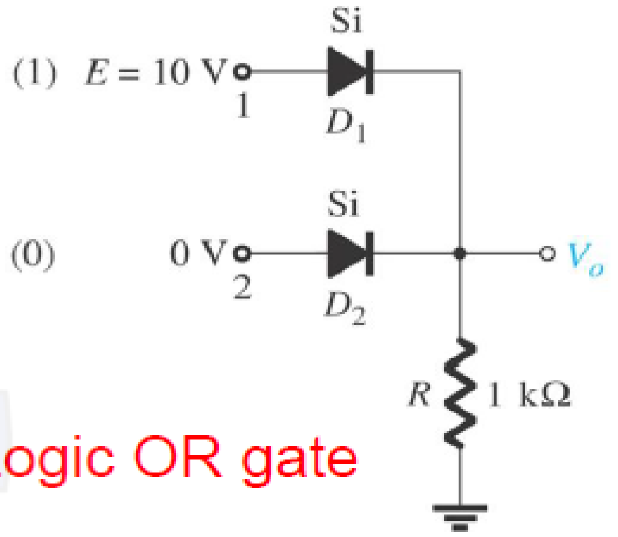


Solution



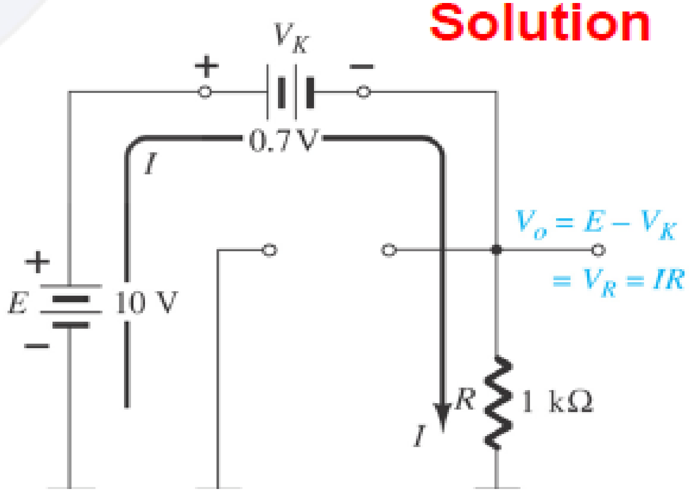
AND/OR Gates

Example 2.14 Determine V_o



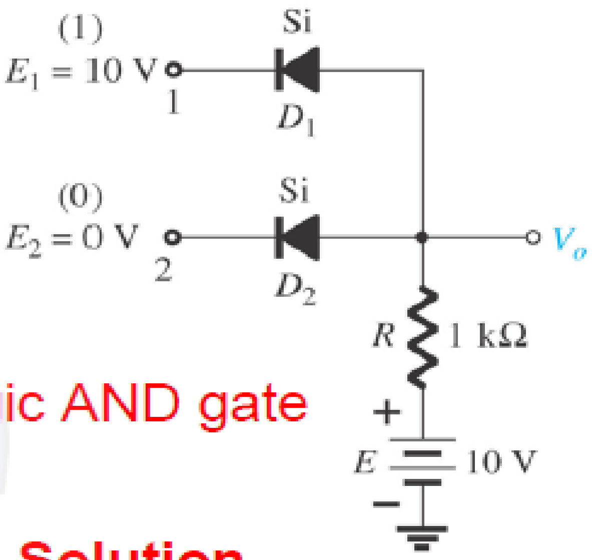
Logic OR gate

Solution



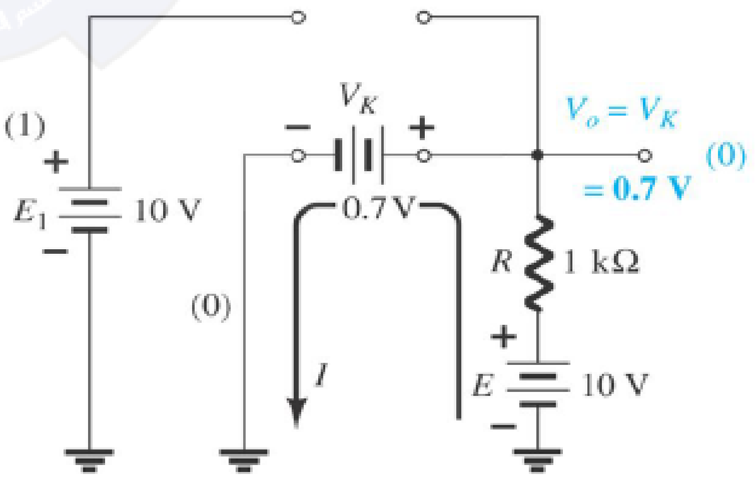
AND/OR Gates: Example 2.15

Determine the output level for the logic AND gate



Logic AND gate

Solution



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Chapter02: Diode Applications

Lec02_p2

Munther N. Thiyab

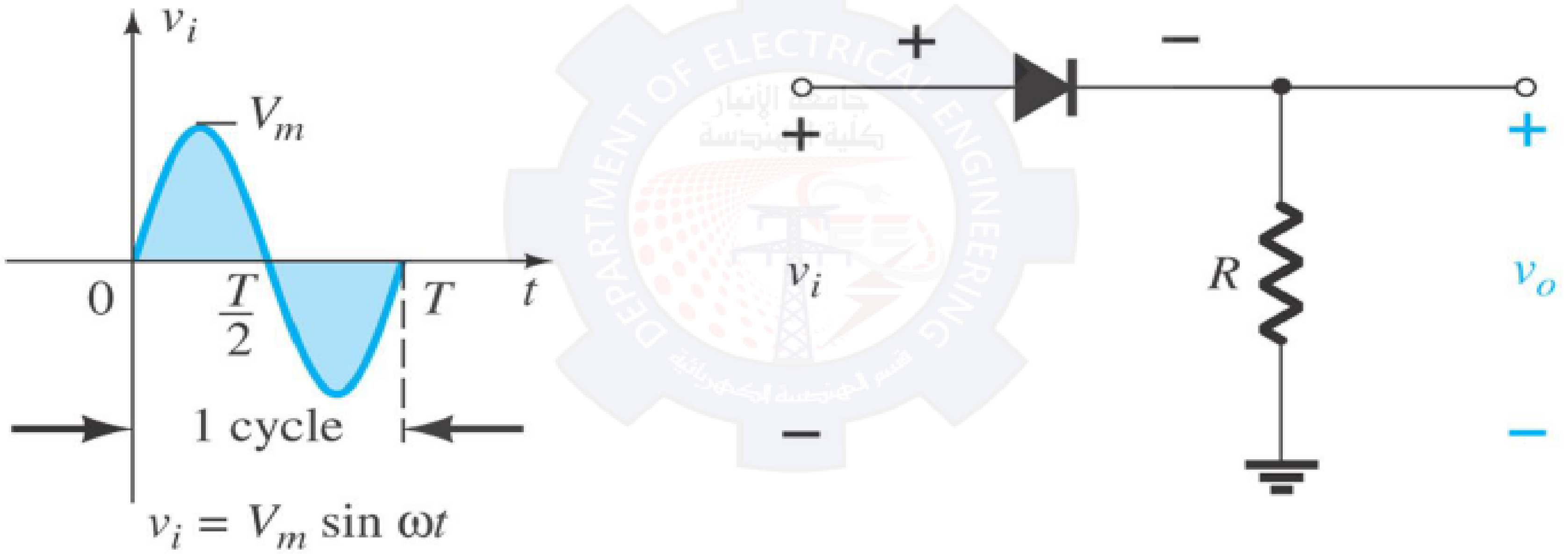
2019-2020

Diode Applications

Diodes are used in many applications:

(a) Rectifiers
(b) Clippers or Limiters
(c) Clampers
(d) Voltage Multipliers

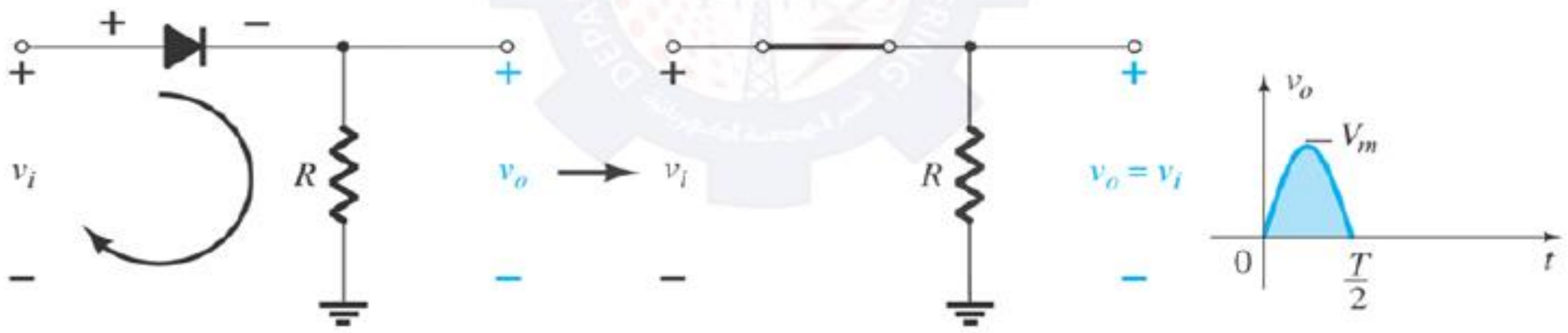
Sinusoidal Inputs: Half-Wave Rectification



Half-wave Rectifier

Sinusoidal Inputs: Half-Wave Rectification

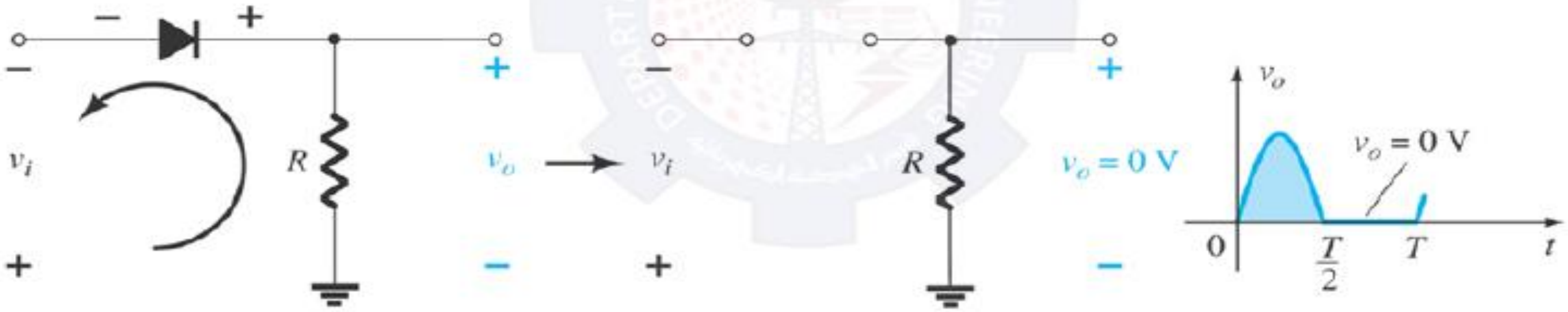
- For t= 0 → T/2, the diode is on.
- Diode is substituted with short-circuit equivalence for ideal diode (reduce complexity).



Conduction region (0 → T/2).

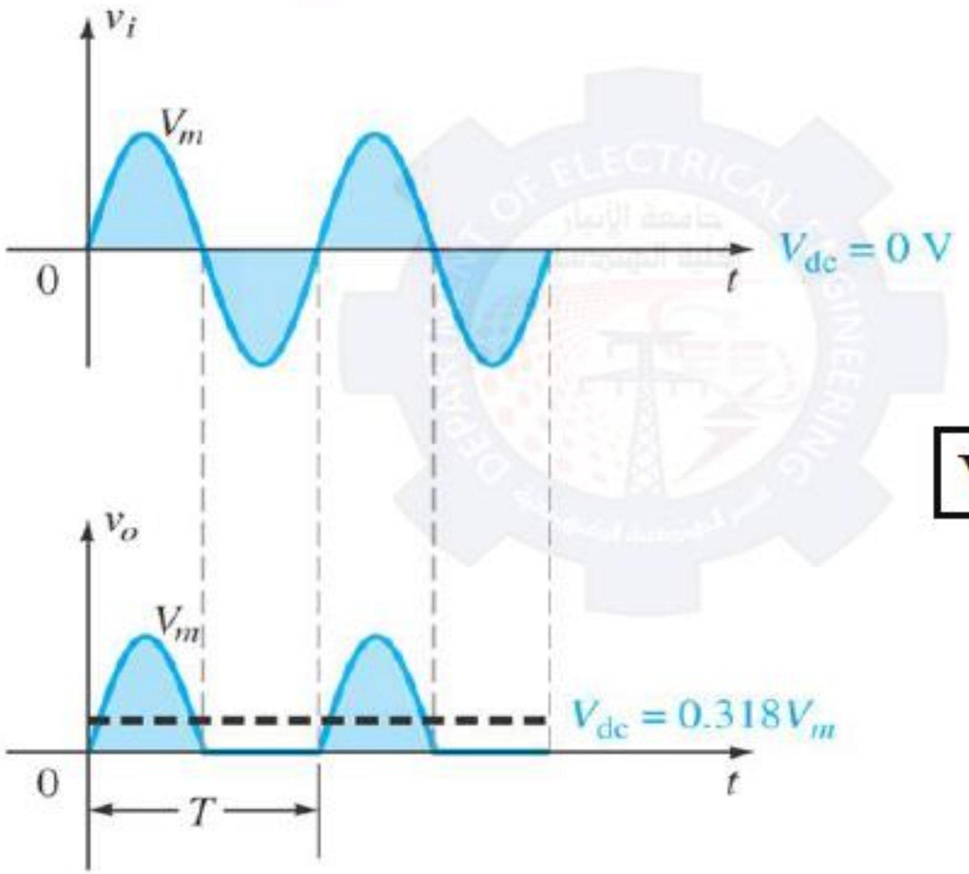
Sinusoidal Inputs: Half-Wave Rectification

- For the period T/2 → T, the diode is off.
- Diode is substituted with an open circuit.



Nonconduction region (T/2 → T).

Sinusoidal Inputs: Half-Wave Rectification

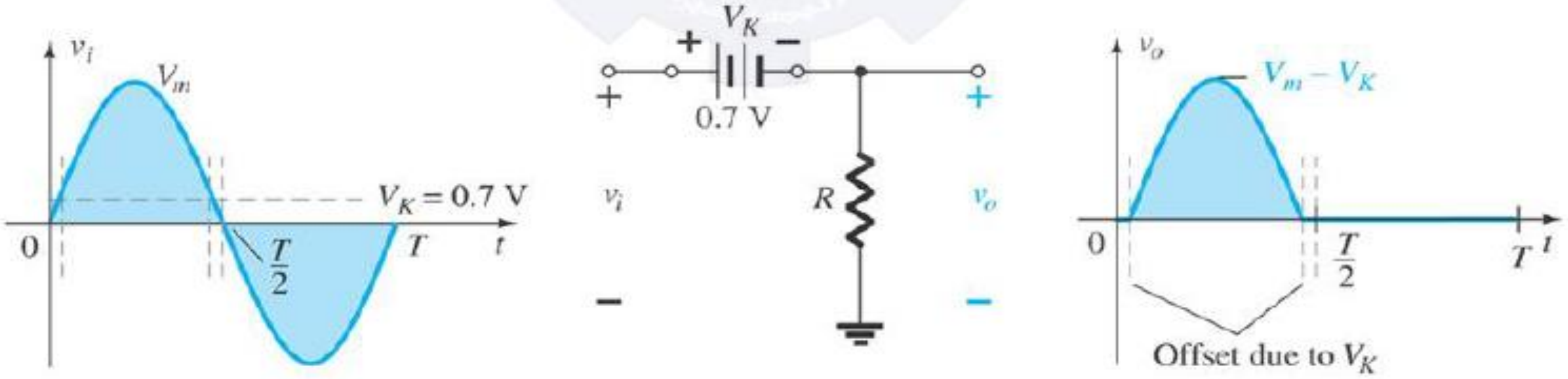


$$V_{DC}=0.318\ V_m$$

The DC output voltage is 0.318 V_m, where V_m = the peak AC voltage.

Sinusoidal Inputs: Half-Wave Rectification

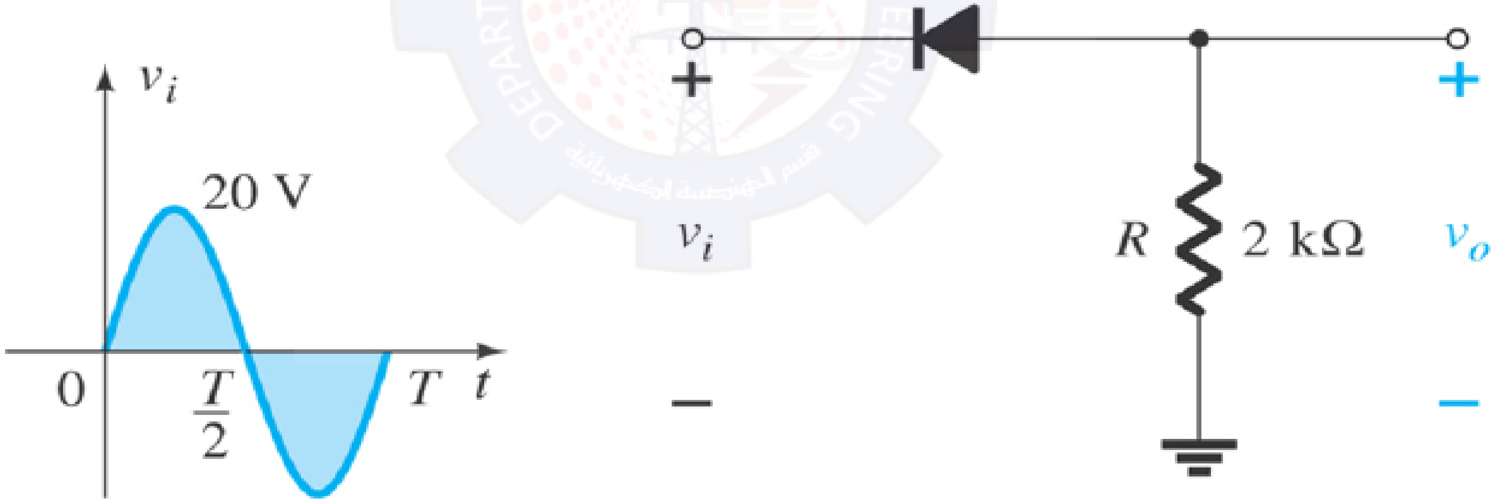
- The effect of using a silicon diode with V_K=0.7 is shown.
- The diode is "**on**" when the applied signal is at least 0.7 V.
- $V_o = V_i - V_K$
- For $V_m >> V_k$: $V_{DC} \approx 0.318\,(V_m - V_K)$



Example 2.16

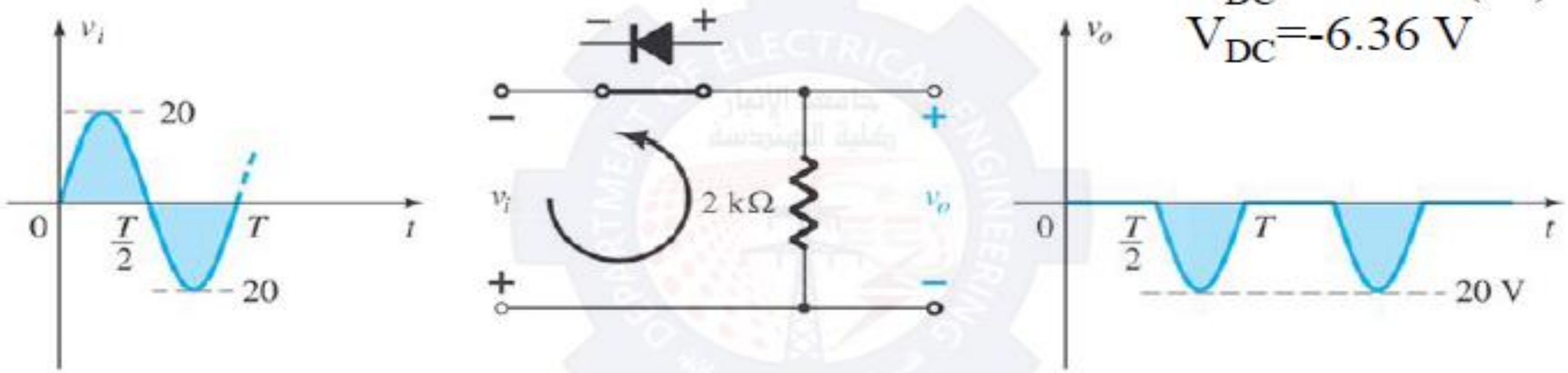
a) Sketch dc output $\mathbf{v_o}$ and determine the dc level of the output.

b) Repeat (a) if the ideal diode is replaced by silicon diode.



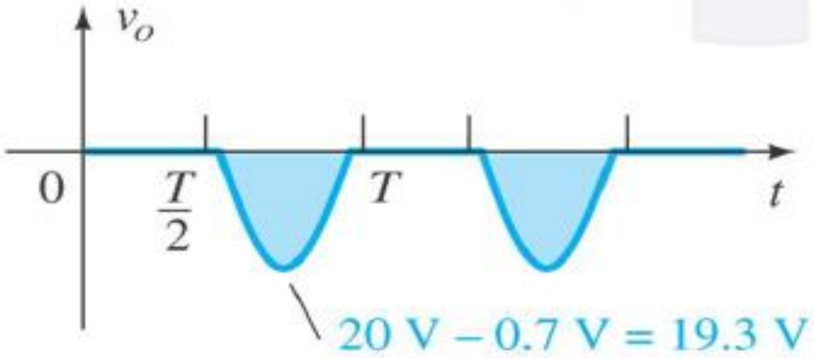
Example 2.16 - Solution

(a)



V_{DC}=-0.318 V_m
V_{DC}=-0.318 (20)
V_{DC}=-6.36 V

(b)



V_{DC}=-0.318 (V_m- 0.7)
V_{DC}=-0.318 (19.3)
V_{DC}=-6.14 V

PIV (PRV)

Because the diode is only forward biased for one-half of the AC cycle, it is also reverse biased for one-half cycle.

It is important that the reverse breakdown voltage rating of the diode be high enough to withstand the peak, reverse-biasing AC voltage and avoid entering the Zener region.

PIV (or PRV) > V_m

- **PIV = Peak inverse voltage**
- **PRV = Peak reverse voltage**
- **V_m = Peak AC voltage**

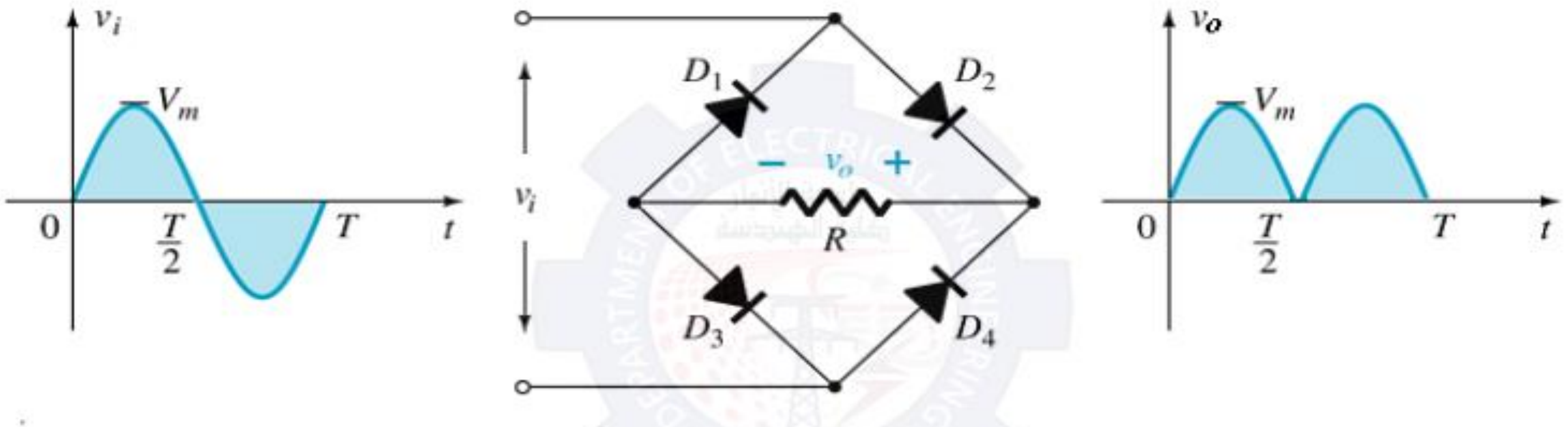
Full-Wave Rectification

❑The rectification process can be improved by using a full-wave rectifier circuit.

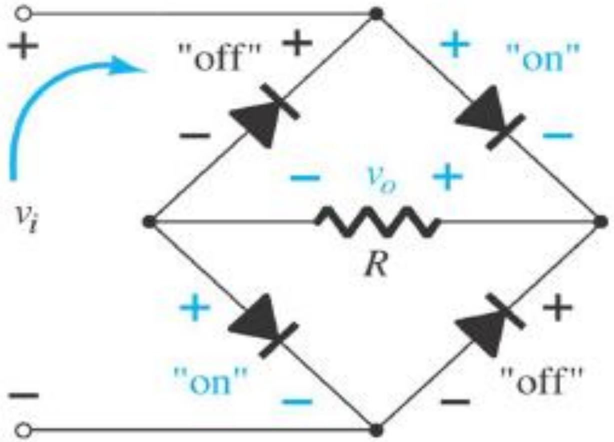
❑Full-wave rectification produces a greater DC output:

- **Half-wave: $V_{dc} = 0.318\,V_m$**
- **Full-wave: $V_{dc} = 0.636\,V_m$**

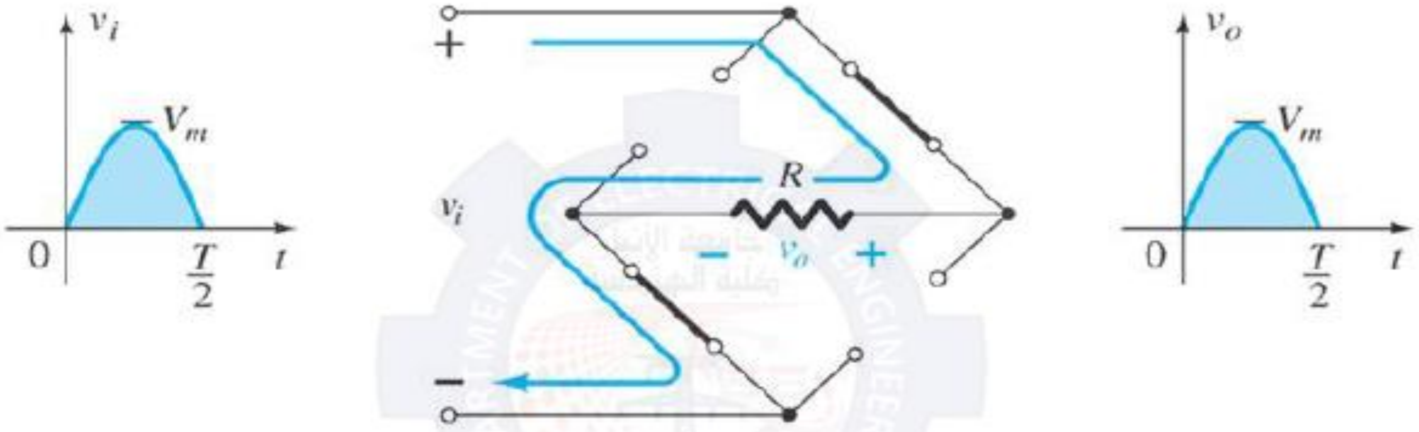
Full-Wave Rectification – Bridge Network



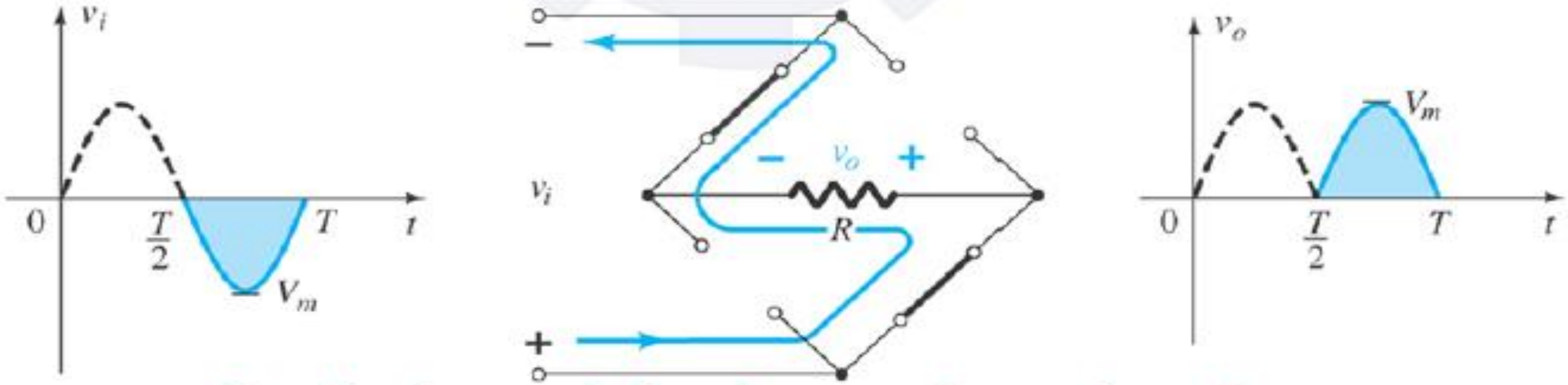
Network for the period 0 → T/2 of the input voltage v_i



Full-Wave Rectification – Bridge Network

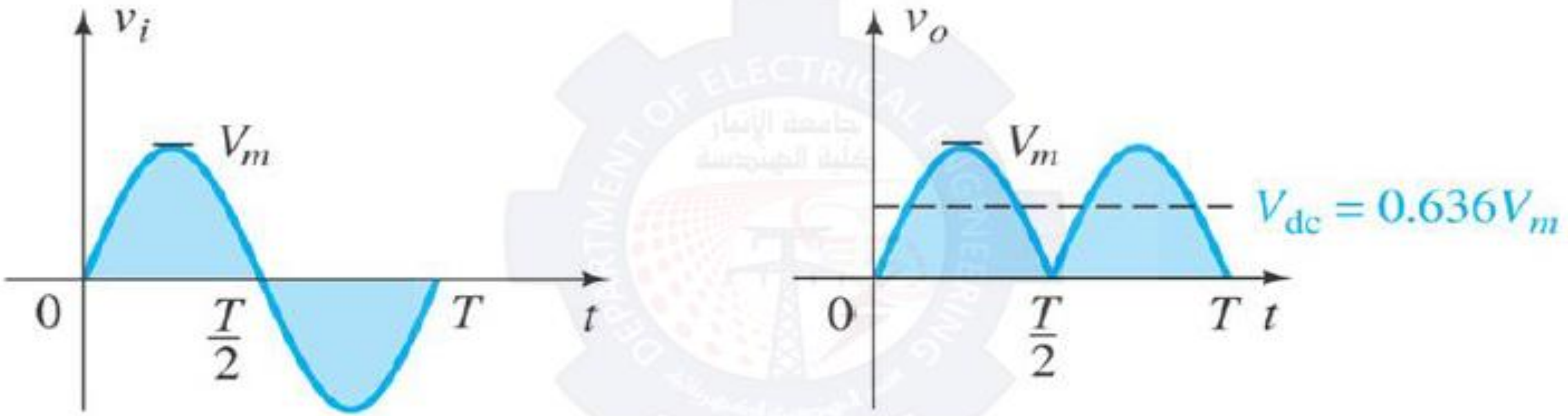


Conduction path for the positive region of v_i



Conduction path for the negative region of v_i

Full-Wave Rectification – Bridge Network



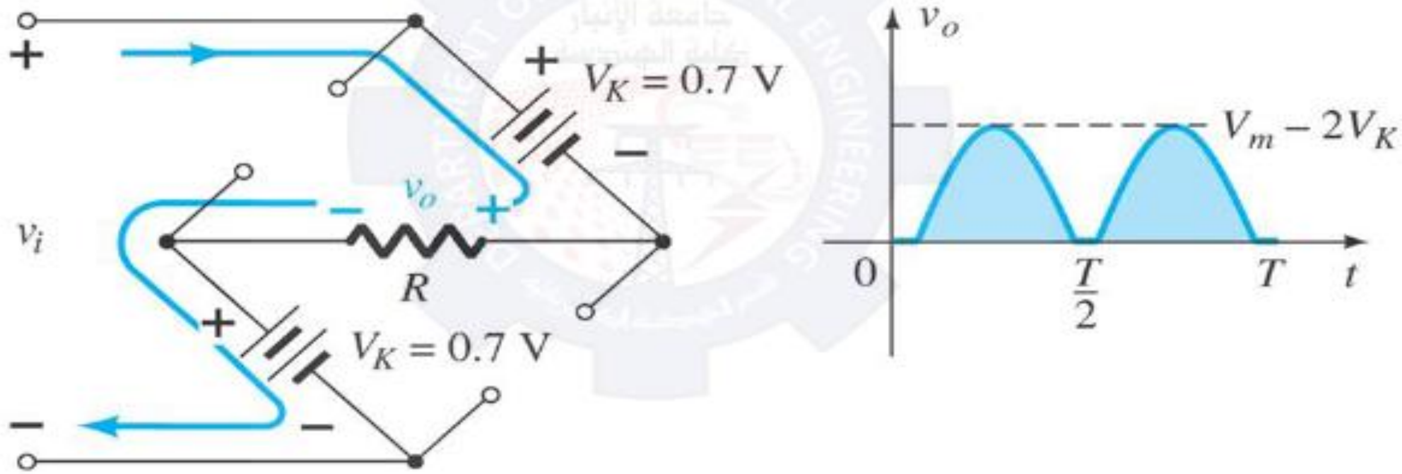
The DC level is now twice that of half wave rectifier=2(0.318V_m)

$$V_{DC}=0.636V_m$$

Full-Wave Rectification – Bridge Network

If silicon diode is used, $v_i - V_K - v_o - V_K = 0$

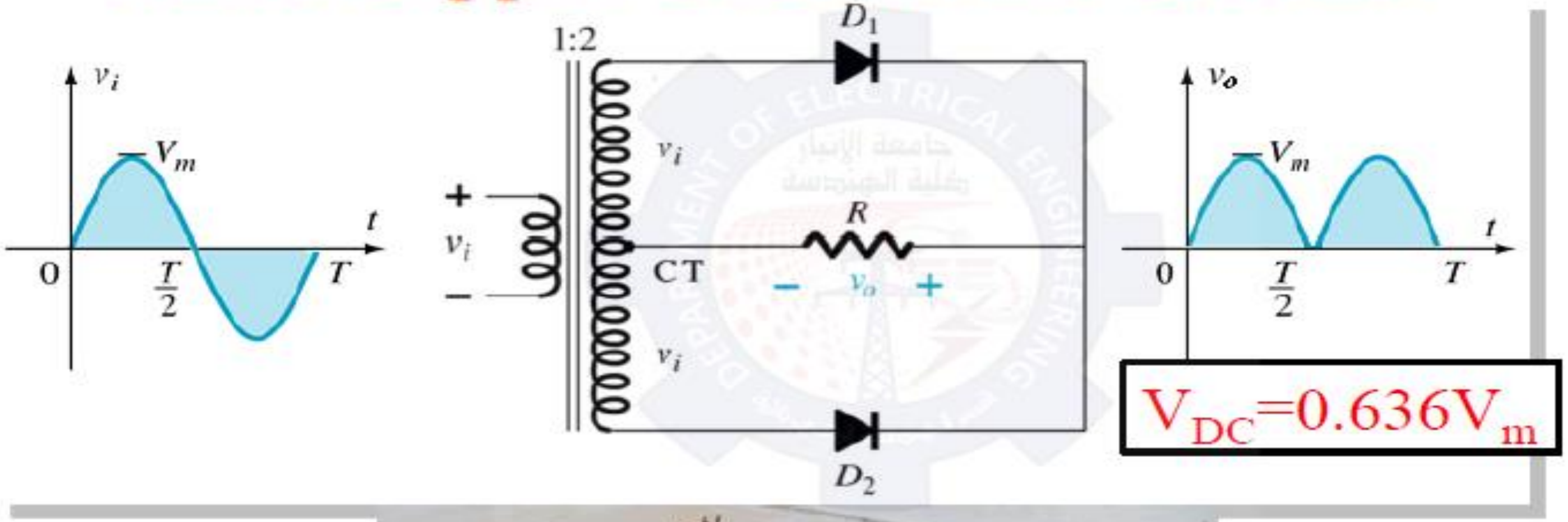
$$v_o = v_i - 2V_K$$



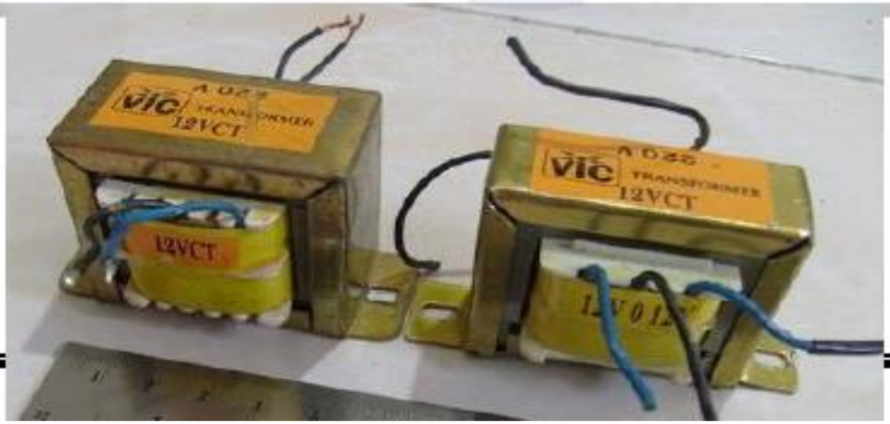
$$V_{o\,max} = V_m - 2V_K$$

For $V_m >> 2V_k$: $V_{DC} \approx 0.636\,(V_m - 2V_K)$

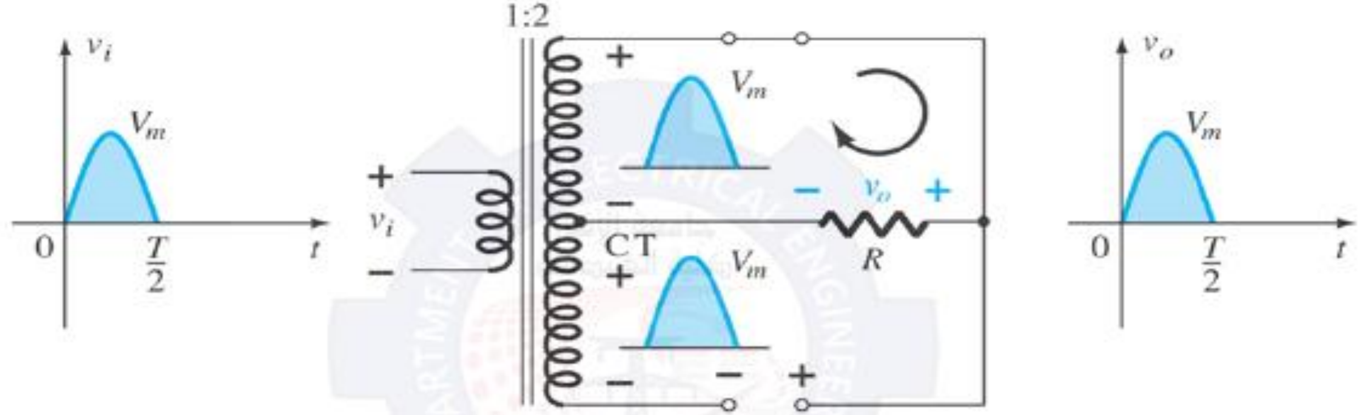
Full-Wave Rectification
Center Tapped Transformer Rectifier



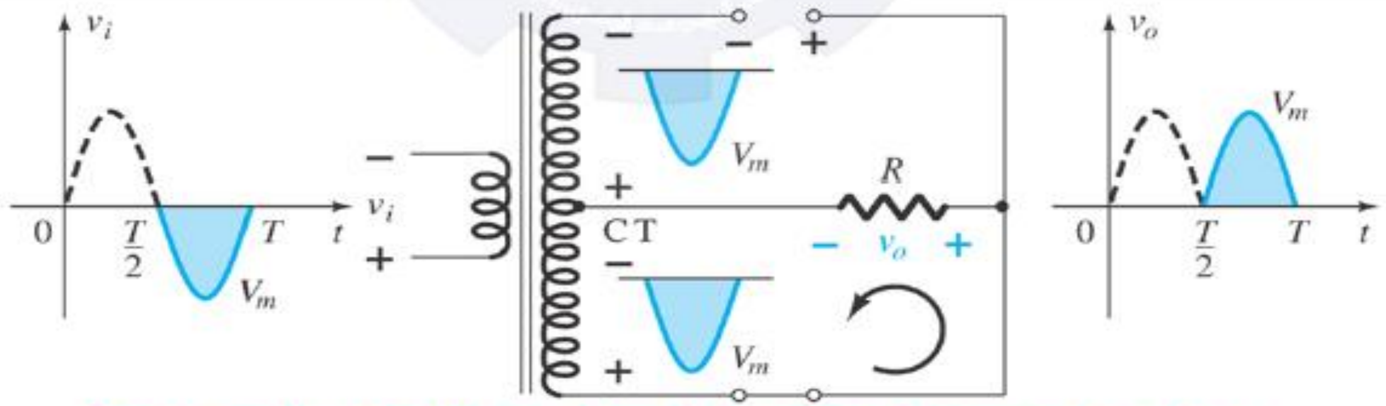
$$V_{DC}=0.636V_m$$



Center Tapped Transformer Rectifier



Network conditions for the positive region of v_i



Network conditions for the negative region of v_i

Summary of Rectifier Circuits

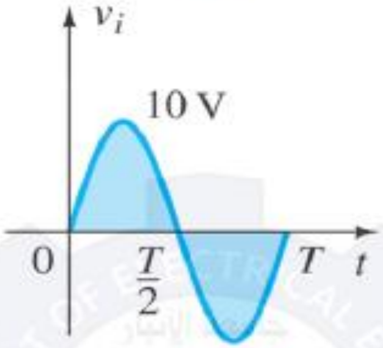
Rectifier	Ideal V_{DC}	Realistic V_{DC}
Half Wave Rectifier	$V_{DC} = 0.318\, V_m$	$V_{DC} = 0.318(V_m - 0.7)$
Bridge Rectifier	$V_{DC} = 0.636\, V_m$	$V_{DC} = 0.636(V_m - 2(0.7))$
Center-Tapped Transformer Rectifier	$V_{DC} = 0.636\, V_m$	$V_{DC} = 0.636(V_m - 0.7)$

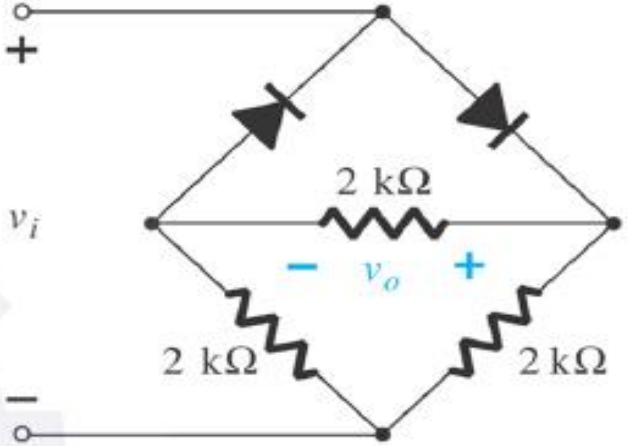
V_m = peak of the AC voltage.

In the center tapped transformer rectifier circuit, the peak AC voltage is the transformer secondary voltage to the tap.

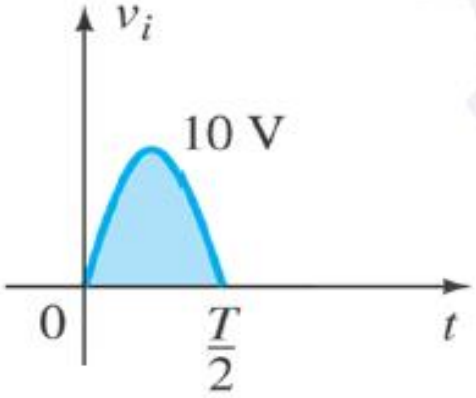
Example 2.17

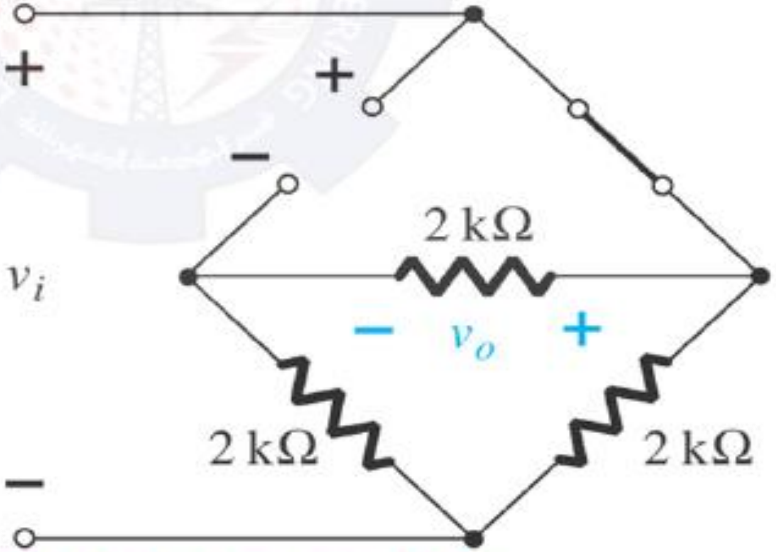
Determine the output waveform for the network and calculate the output dc level.





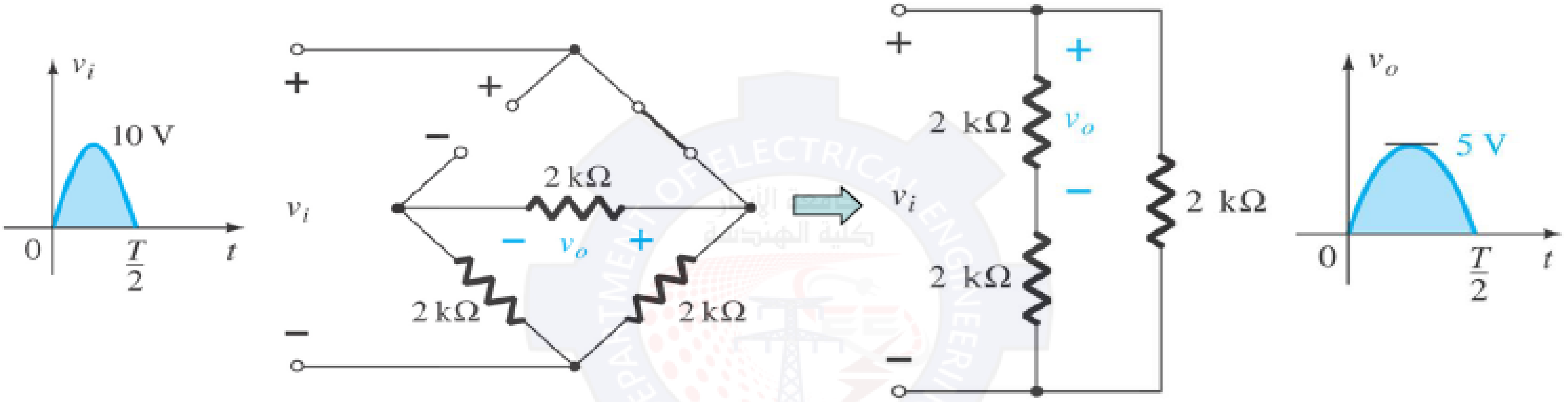
Solution

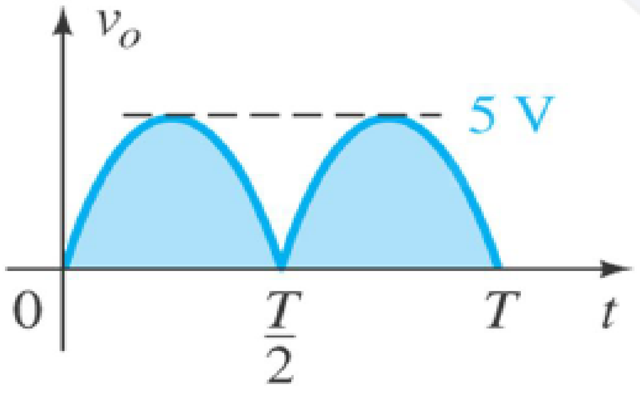




Network for the positive region of v_i

Example 2.17 - Solution





Resulting output

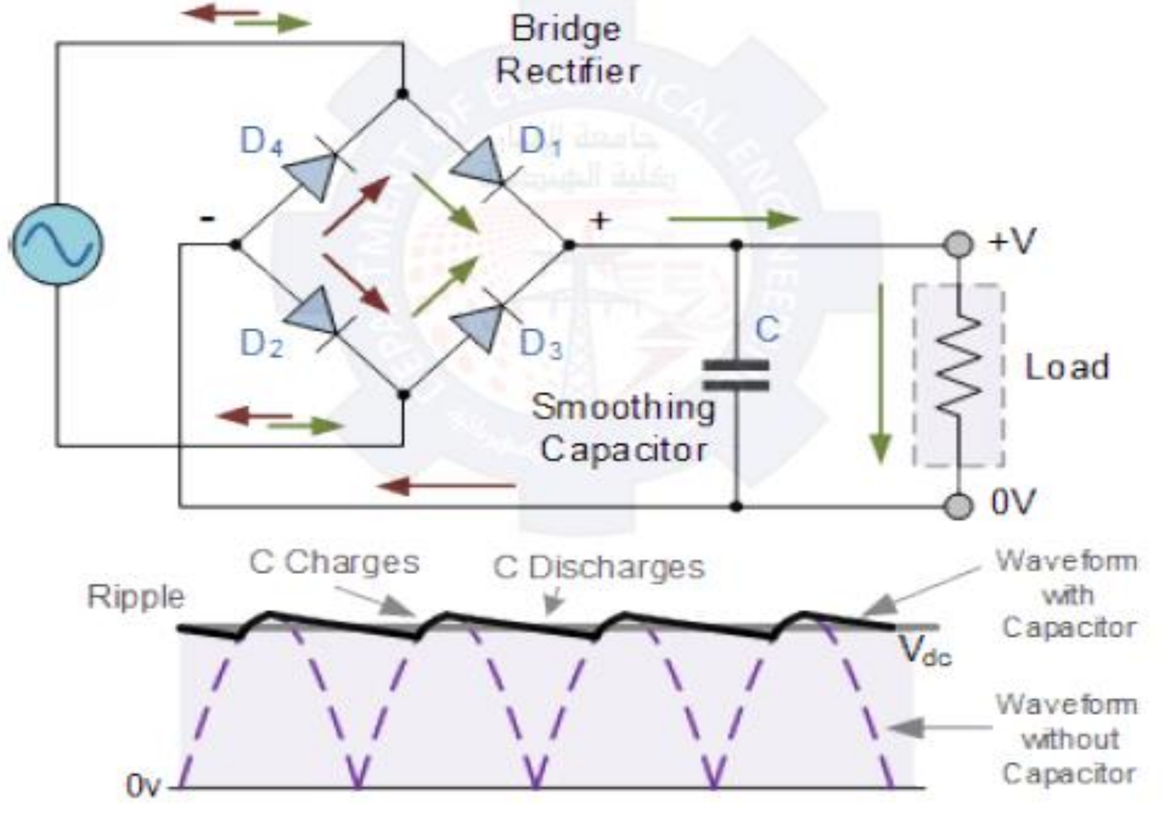
$v_o=(1/2)\ v_i$

$V_{omax}=(1/2)\ V_{imax}=(1/2)\ 10=5V$

$V_{DC}=0.636(5V)=3.18\ V.$

For the negative part the roles of the diodes are interchanged and v_o appears as shown in figure.

Full Wave Rectifier with Smoothing Capacitor (AC to DC Converter)



Resultant Output Waveform

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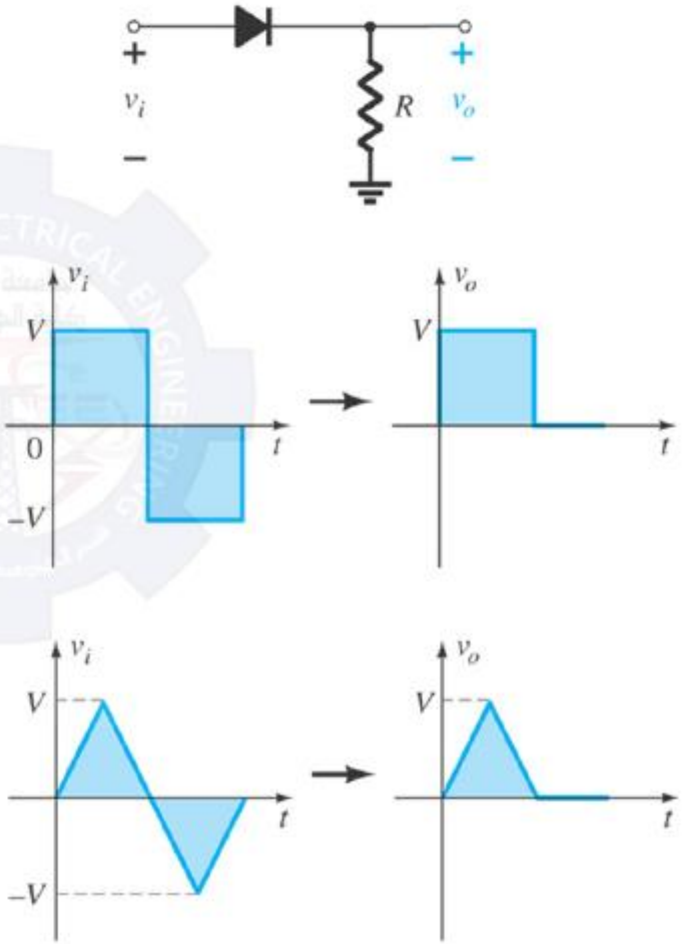
Chapter02: Diode Applications
Lec02_p3

Munther N. Thiyab

2019-2020

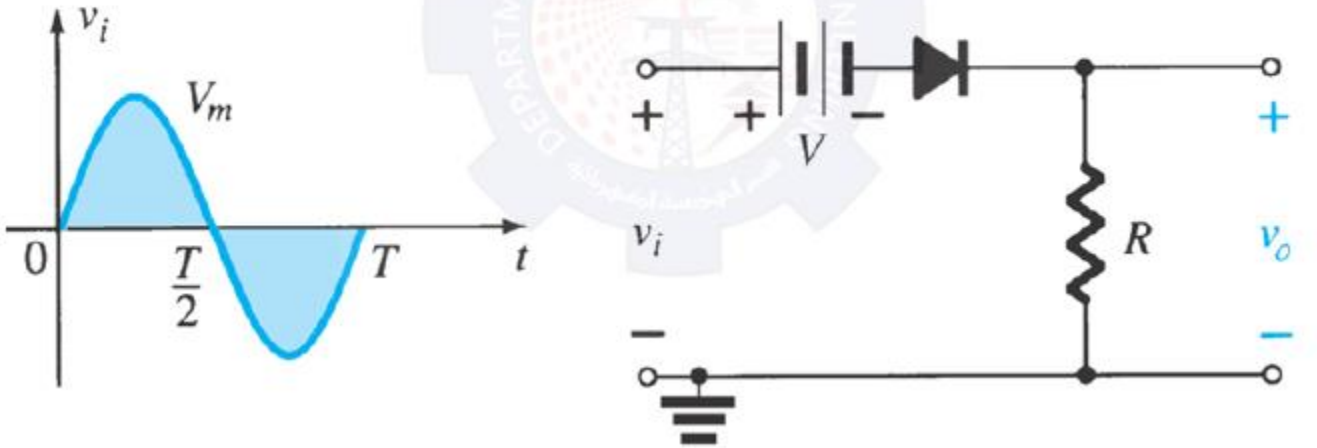
Diode Clippers

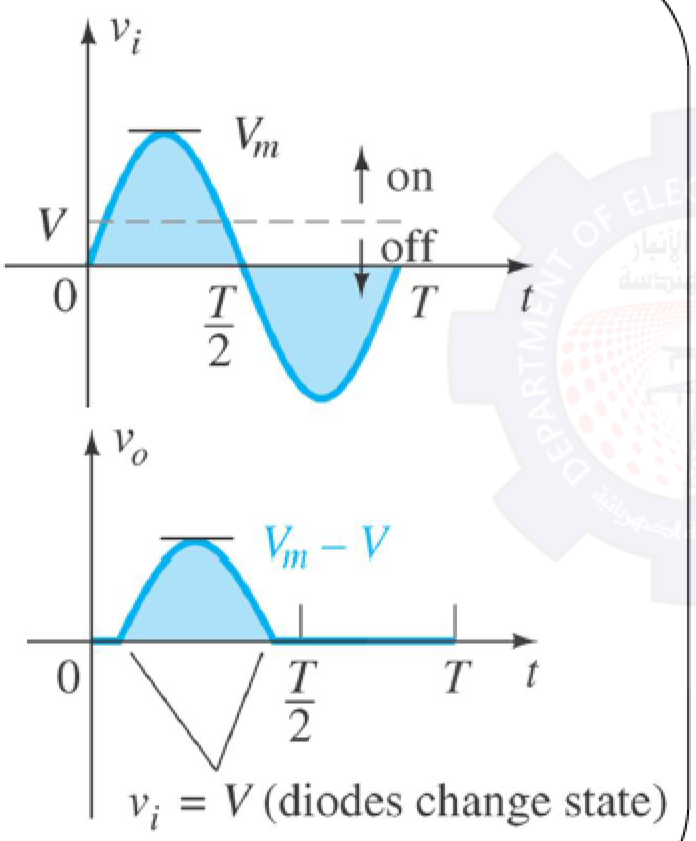


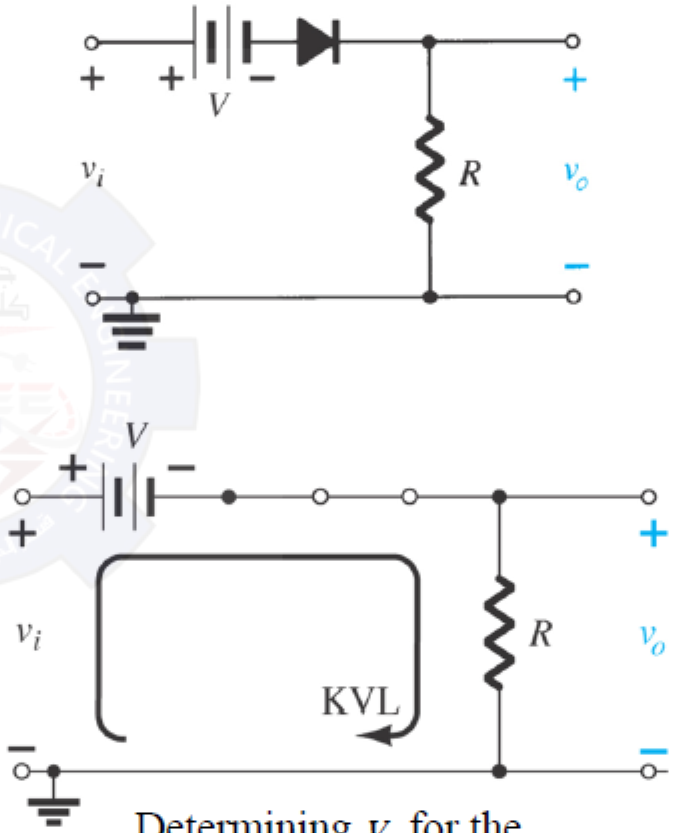
Clippers are networks that employ diodes to "clip" away a portion of an input signal without distorting the remaining part of the applied waveform.

Biased Clippers

Adding a DC source in series with the clipping diode changes the effective forward bias of the diode.

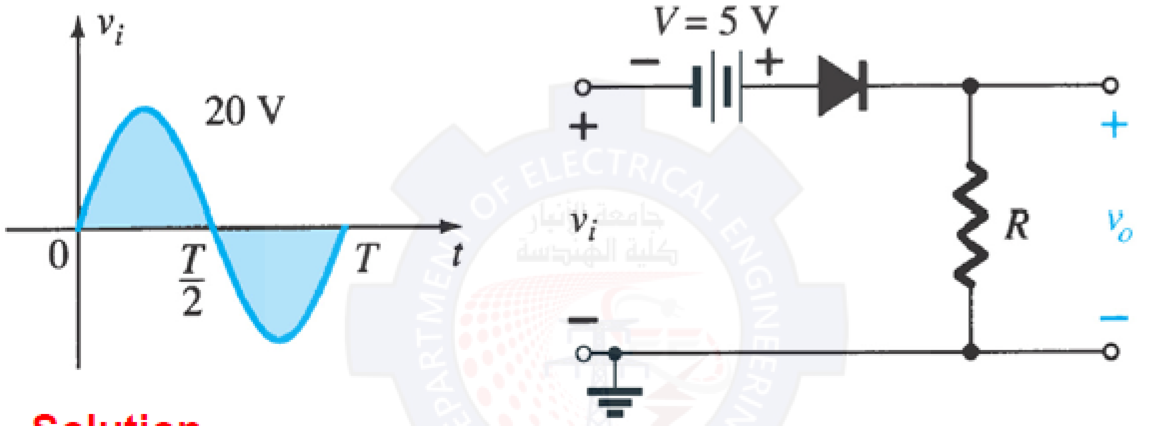




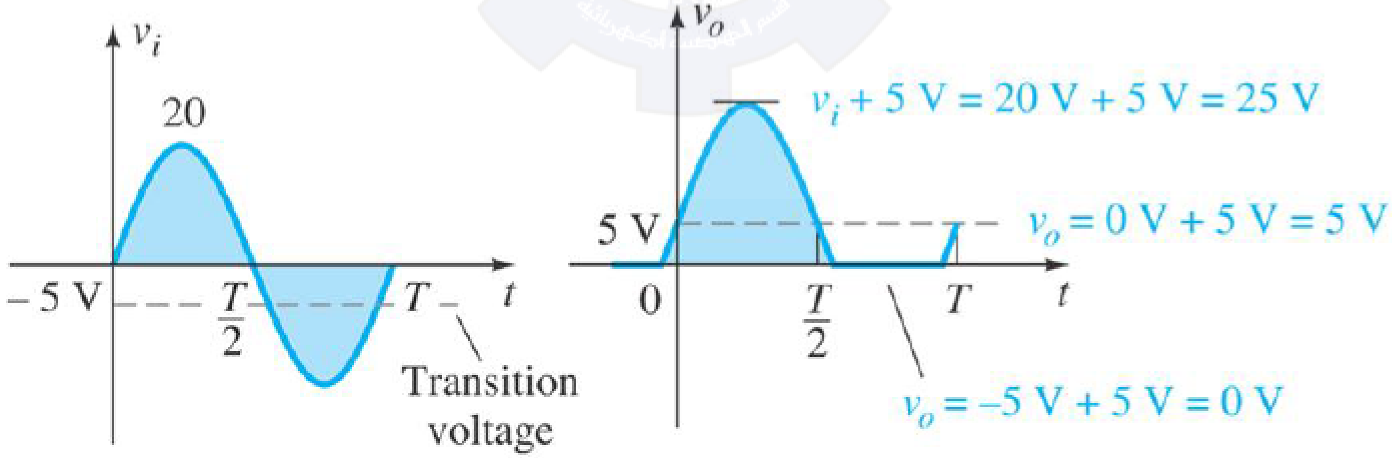


Determining v_o for the diode in the "on" state.

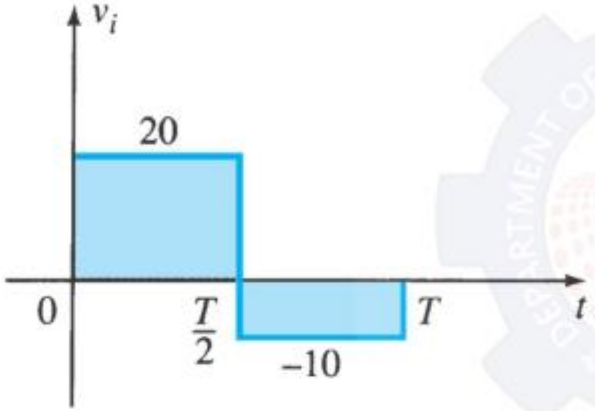
Example 2.18 Determine the output waveform for the network.

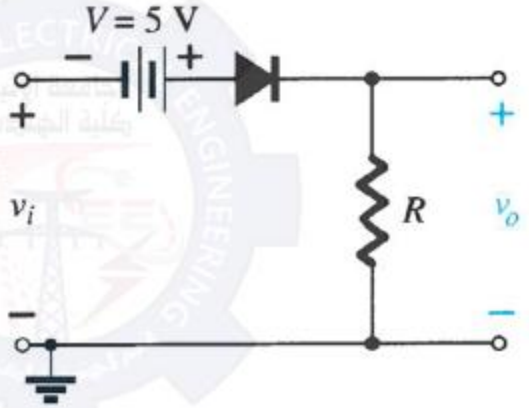


Solution



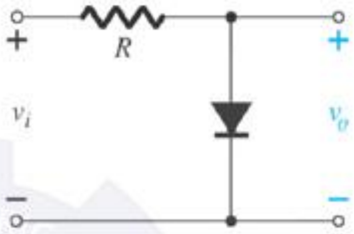
Example 2.19 Determine the output waveform for the network.





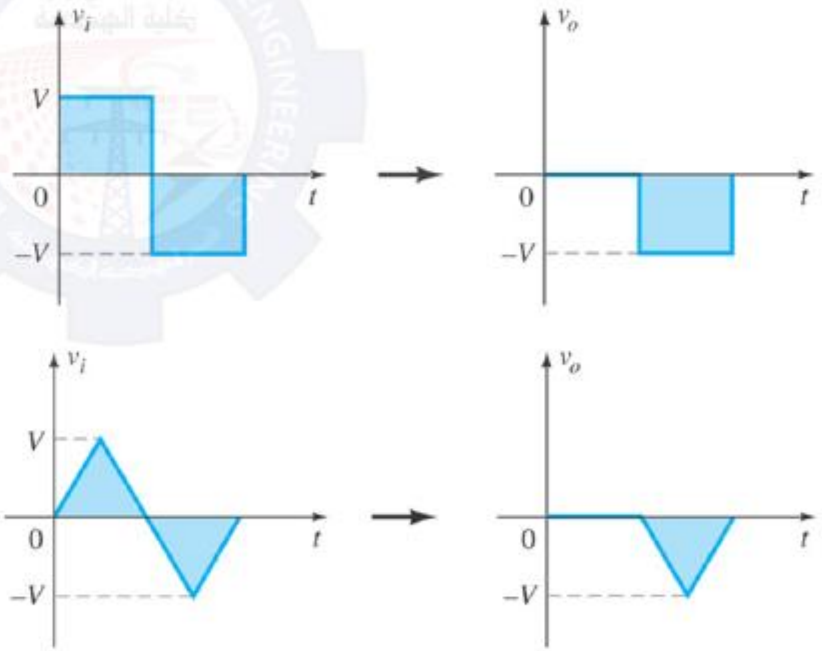
Solution

Parallel Clippers



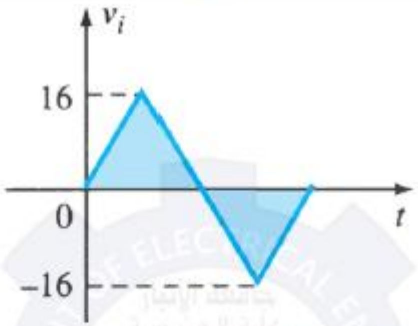
The diode in a **parallel clipper** circuit "clips" any voltage that forward bias it.

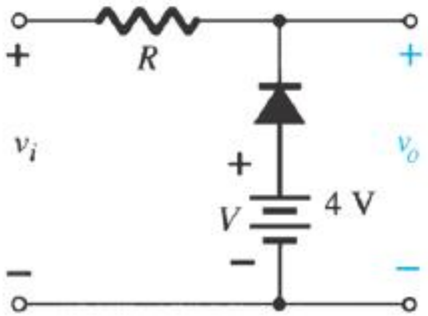
DC biasing can be added in series with the diode to change the clipping level.



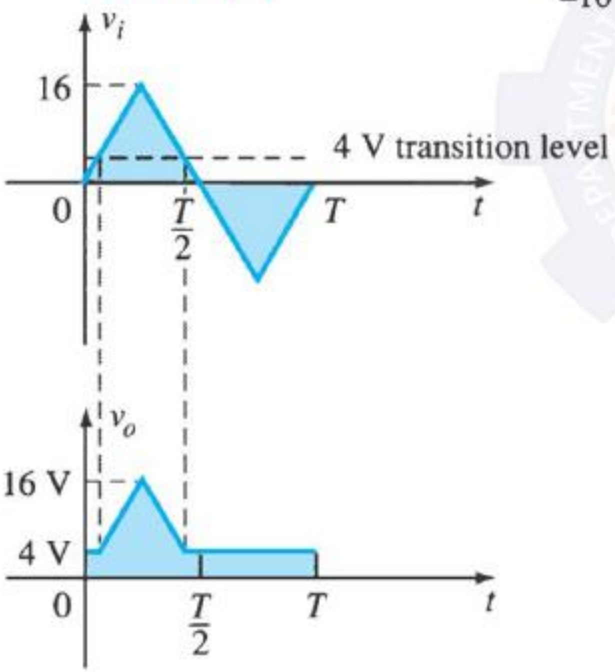
Example 2.20

Determine v_o for the network shown.



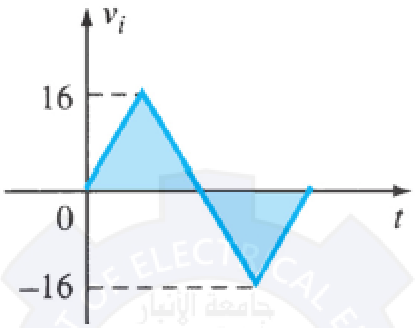


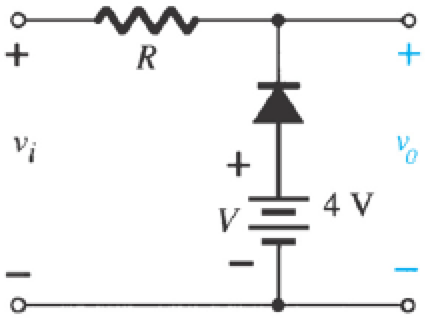
Solution



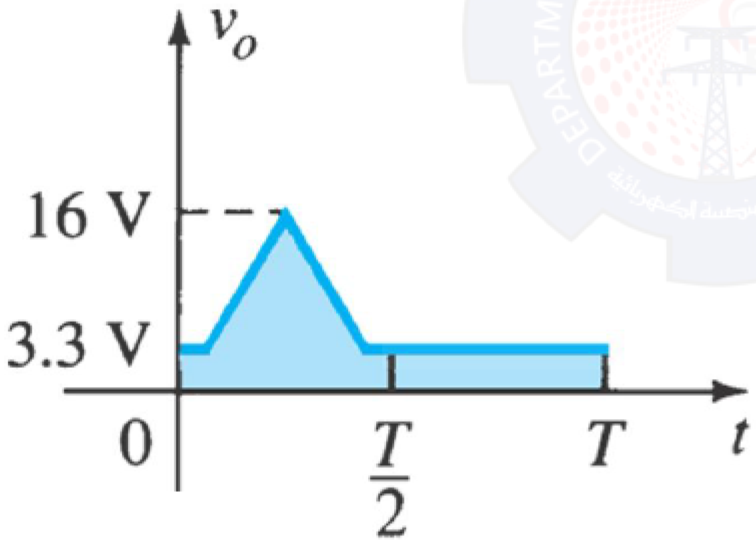
Example 2.21

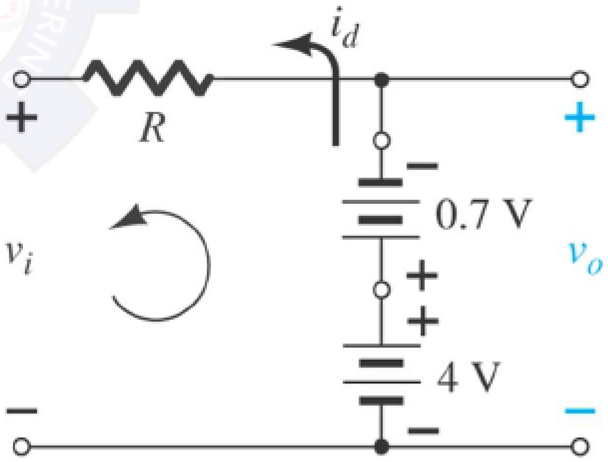
Determine v_o for the network if silicon diode is used.





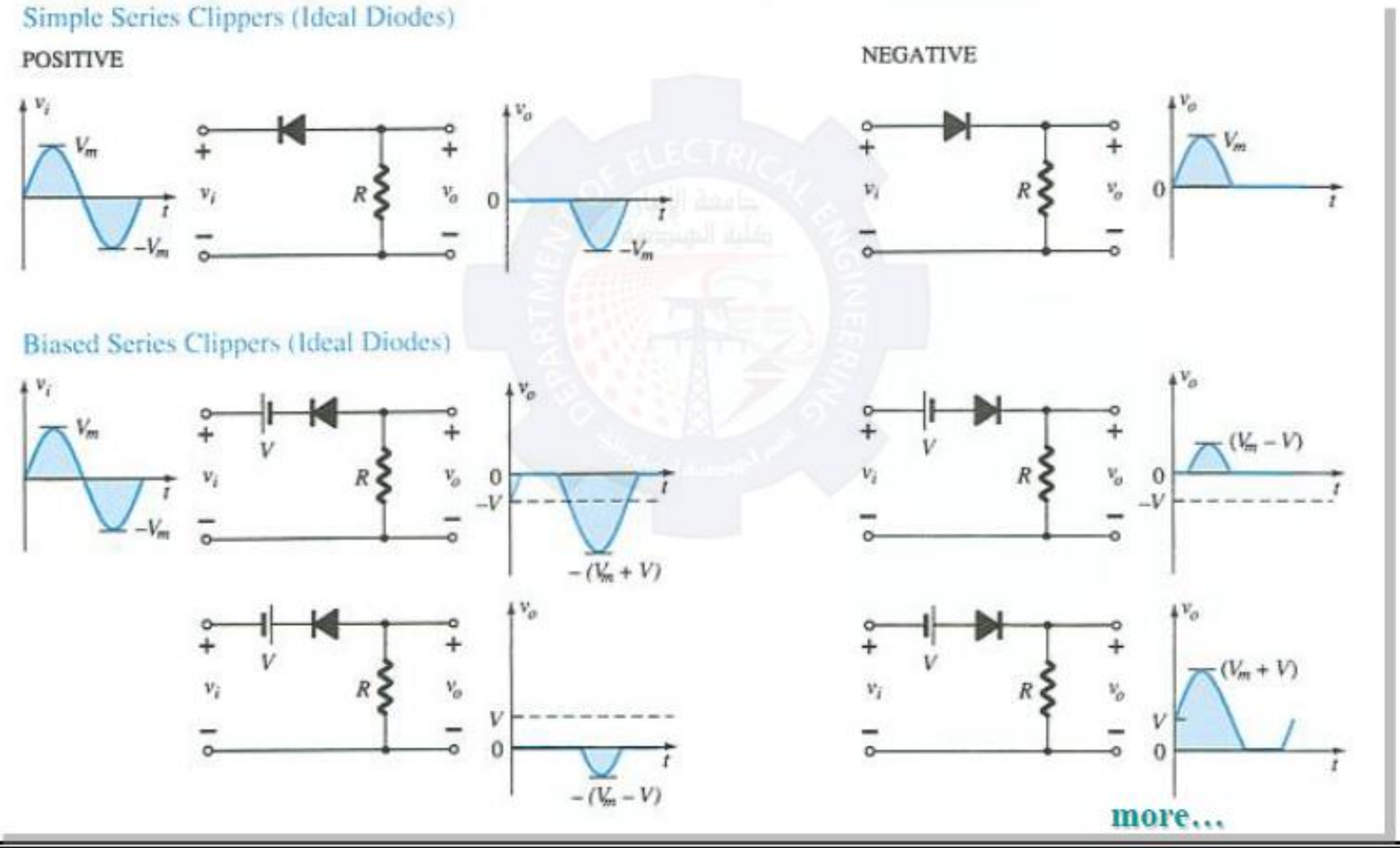
Solution





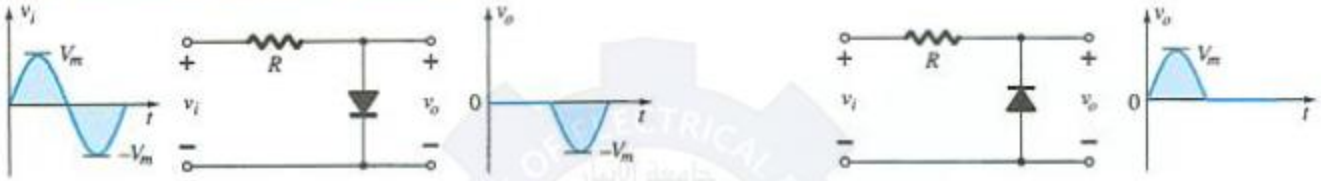
.Determining v_o for the diode in the “on” state

Summary of Clipper Circuits

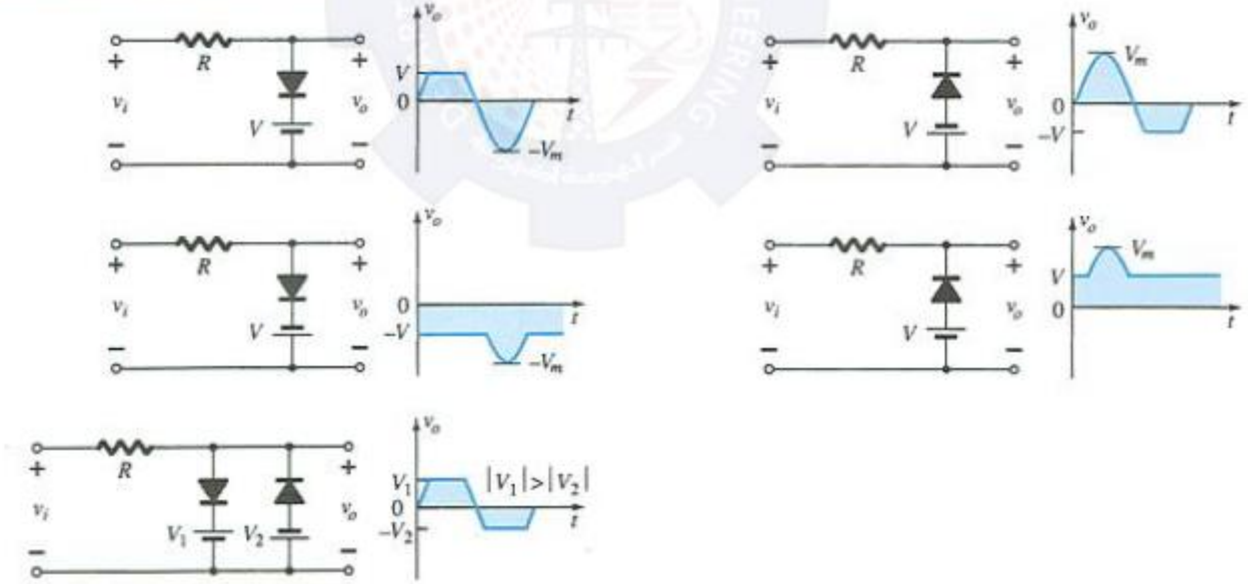


Summary of Clipper Circuits

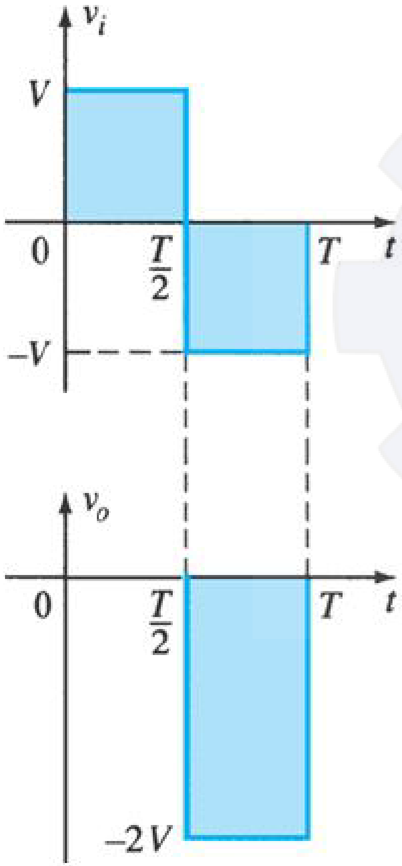
Simple Parallel Clippers (Ideal Diodes)

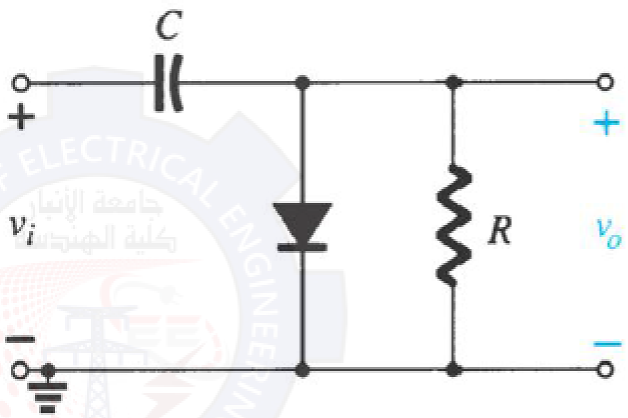


Biased Parallel Clippers (Ideal Diodes)



Clampers

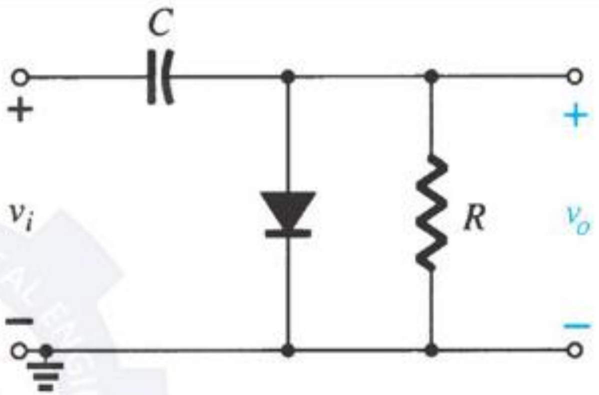


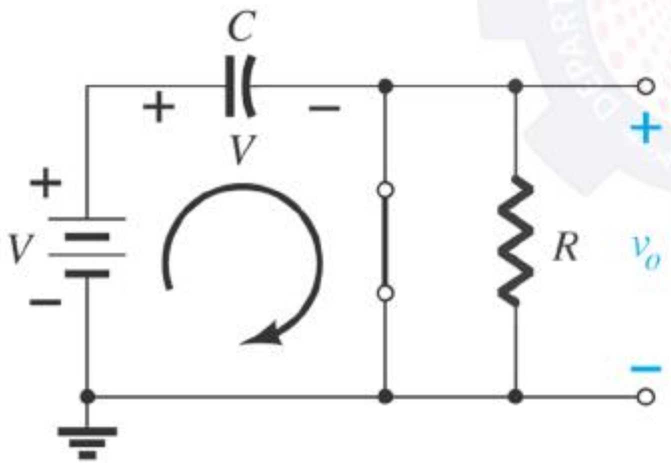


A clamper is a network constructed of a diode, a resistor, and a capacitor that shifts a waveform to a different DC level.

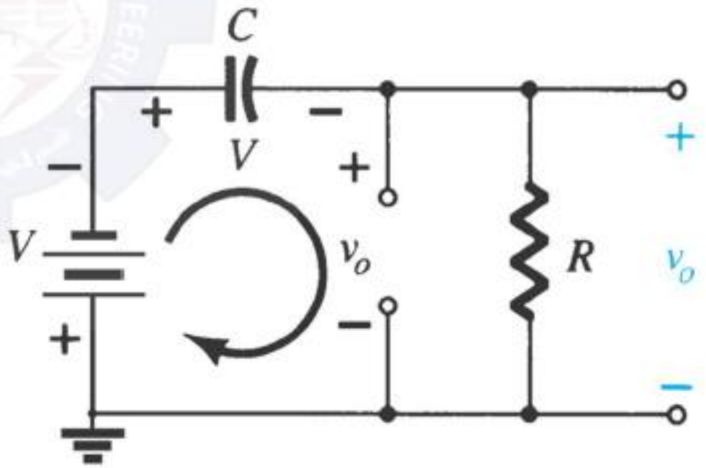
Clampers

R is chosen such that the discharge period 5τ=5RC is much larger than the period T/2→T, and the capacitor is assumed to hold onto all its charge.



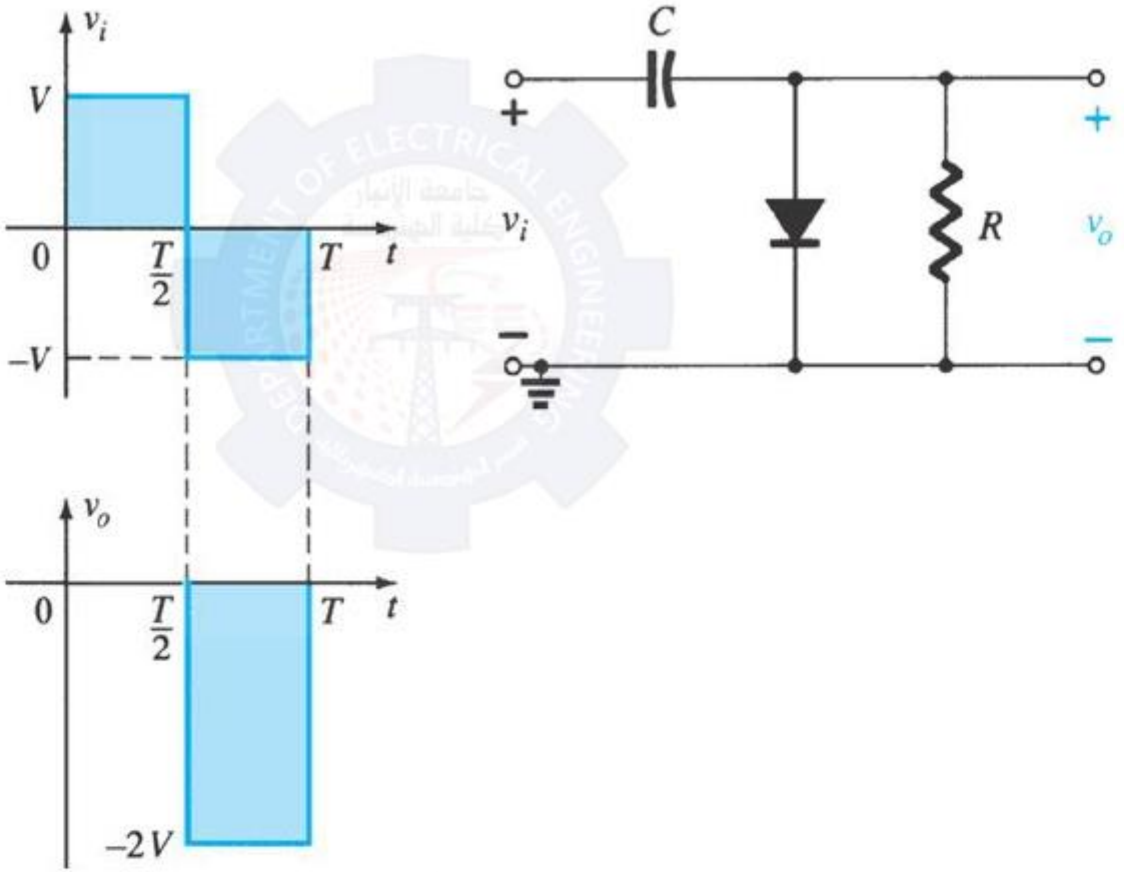


Diode "on" and the capacitor charging to *V* volts.

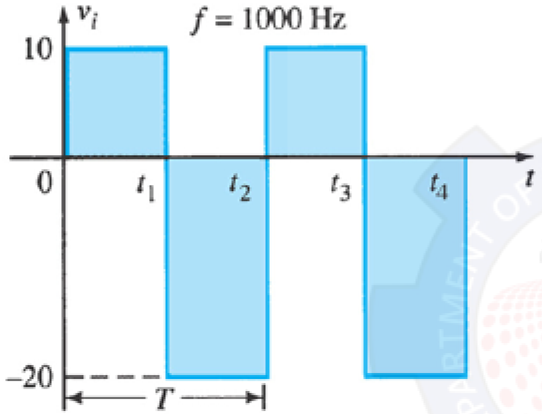


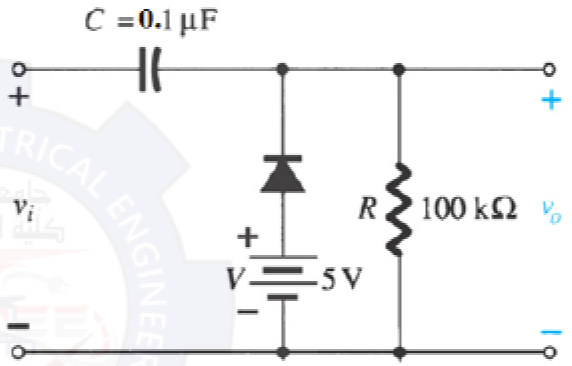
Determining v_o with the diode "off."

Clampers

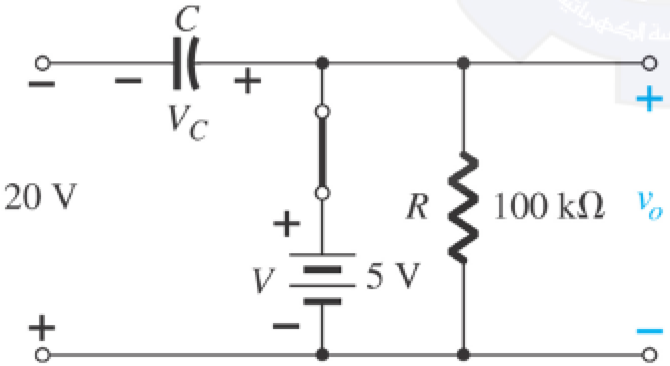


Example 2.22 Determine v_o for the network.

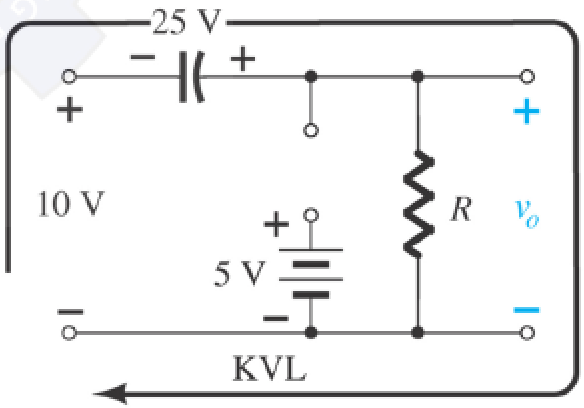




Solution

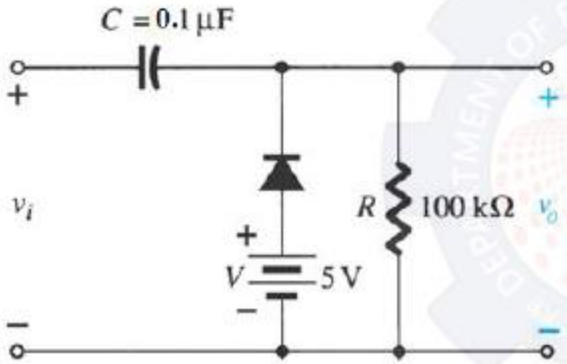


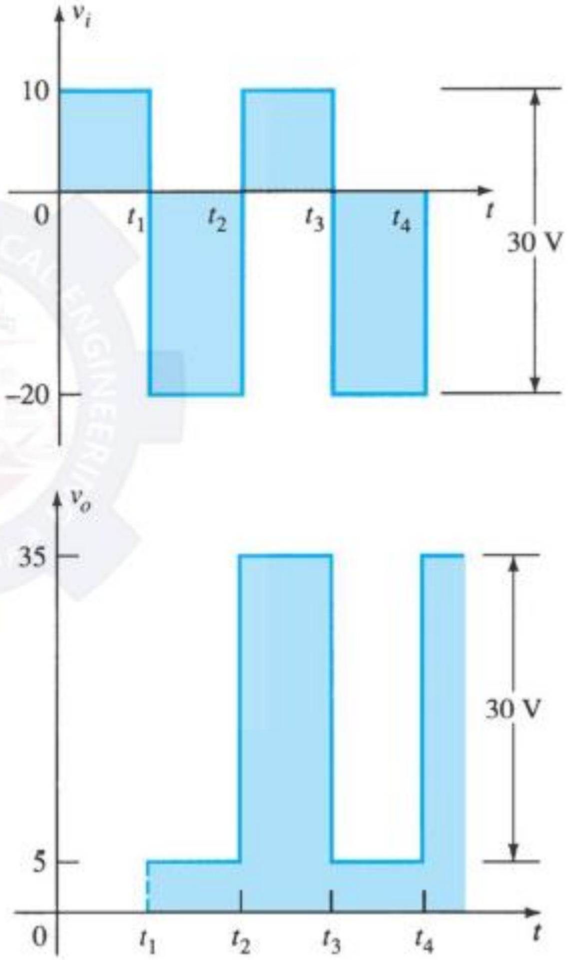
Determining v_o and V_C with the



Determining v_o with the diode

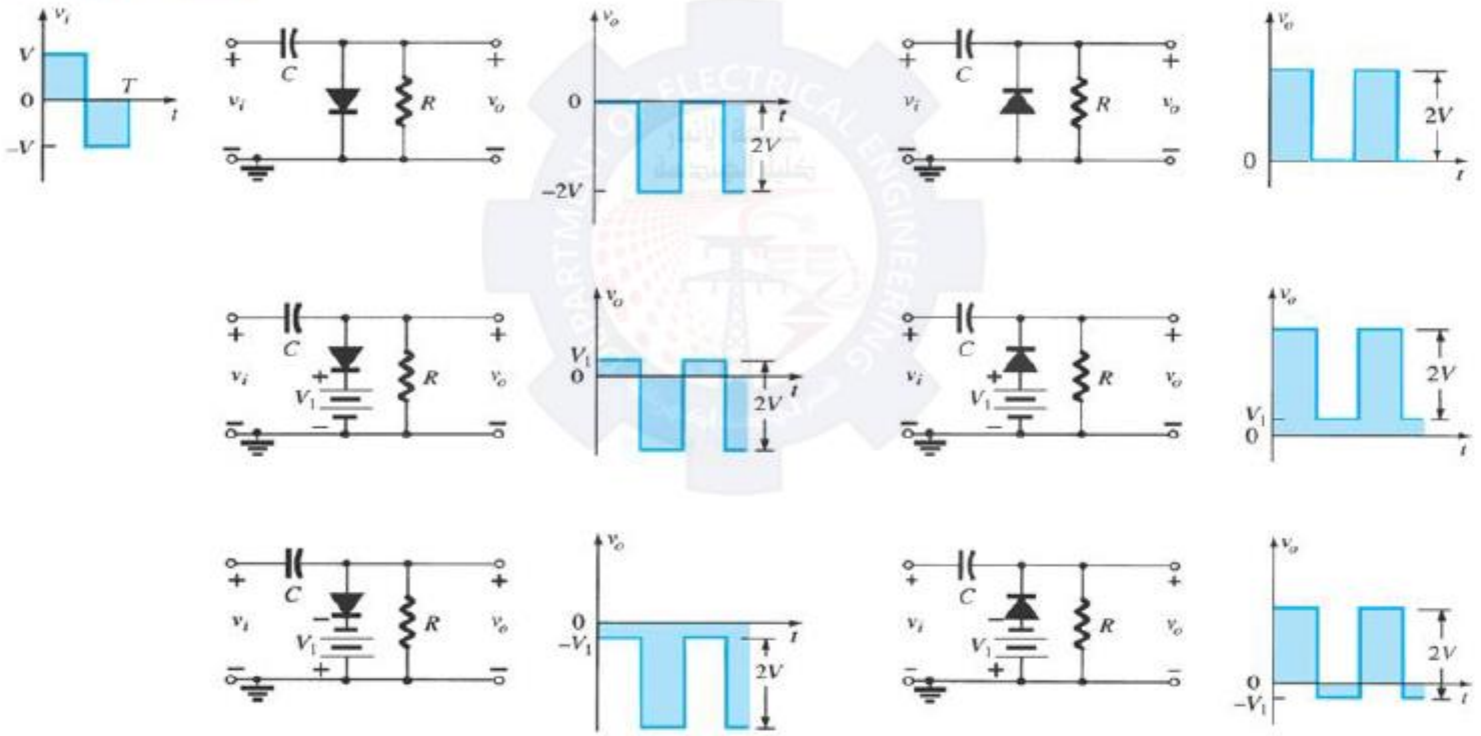
Example 2.22





Summary of Clamper Circuits

Clamping Networks



Clamping circuits with ideal diodes ($5\tau = 5RC \gg T/2$).

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Chapter02: Diode Applications

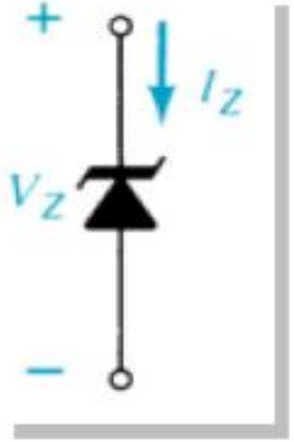
Lec02_p4

Munther N. Thiyab

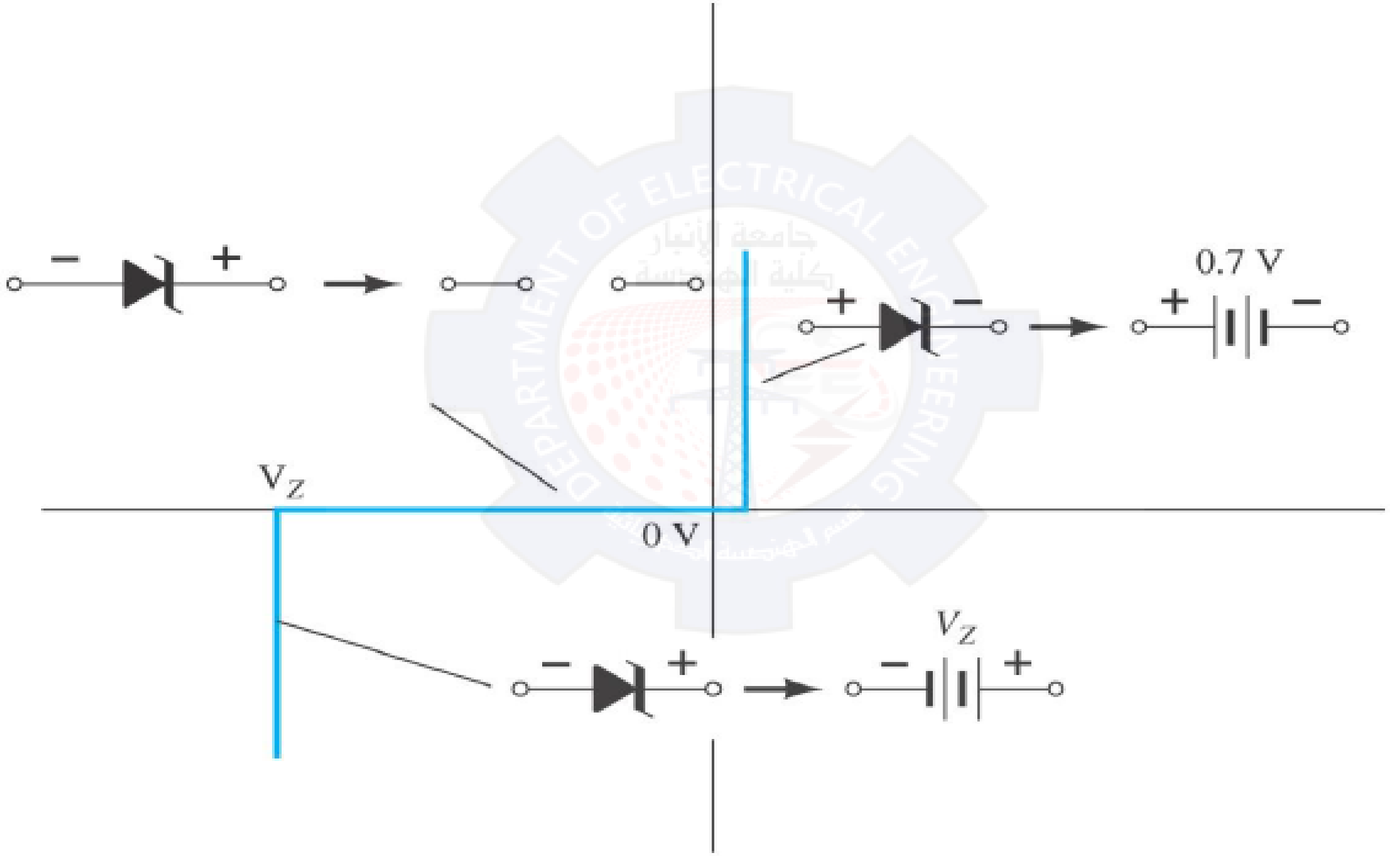
2019-2020

Zener Diodes

- A **Zener diode** is a type of diode that permits current not only in the forward direction like a normal diode, but also in the reverse direction if the voltage is larger than the breakdown voltage known as "Zener voltage" **(V_Z)**.
- Common Zener voltages are between 1.8 V and 200 V.
- Zener diode is used as regulator.

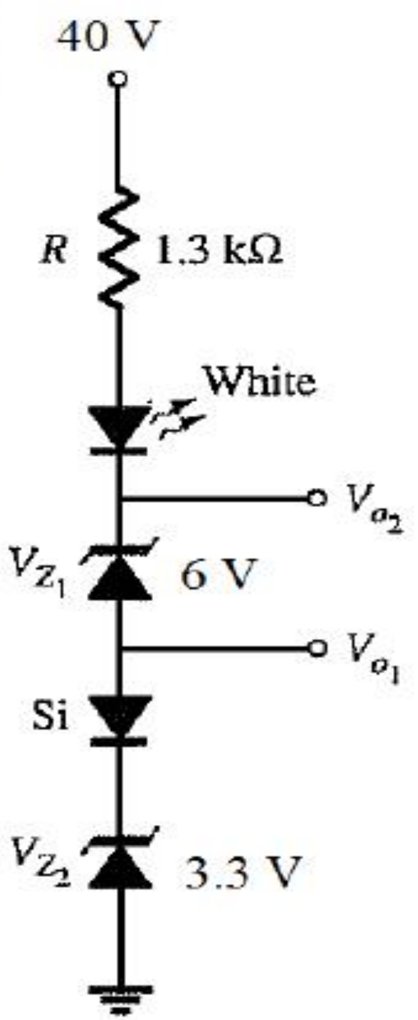


Zener Diodes



Approximate equivalent circuits for the Zener diode in the three possible regions of application.

Example 2.24 Determine the reference voltages provided by the network which uses a white LED (4V) to indicate power is on. What is the power delivered to the LED and to the 6 V Zener diode.



$$V_{o1} = V_{Z2} + V_K = 3.3 + 0.7 = 4V$$

$$V_{o2} = V_{o1} + V_{Z_1} = 4 + 6 = 10V$$

The 4-V across the white LED

$$I_R = I_{LED} = \frac{40 - V_{o2} - V_{LED}}{1.3k} = \frac{40 - 10 - 4}{1.3k} = \frac{26}{1.3k} = 20mA$$

the power delivered by the supply

$$P_S = E \times I_S = E \times I_R = (40V) \times (20mA) = 800mW$$

the power absorbed by the LED

$$P_{LED} = V_{LED} \times I_{LED} = (4V) \times (20mA) = 80mW$$

the power absorbed by 6-V Zener diode

$$P_Z = V_Z \times I_Z = (6V) \times (20mA) = 120mW$$

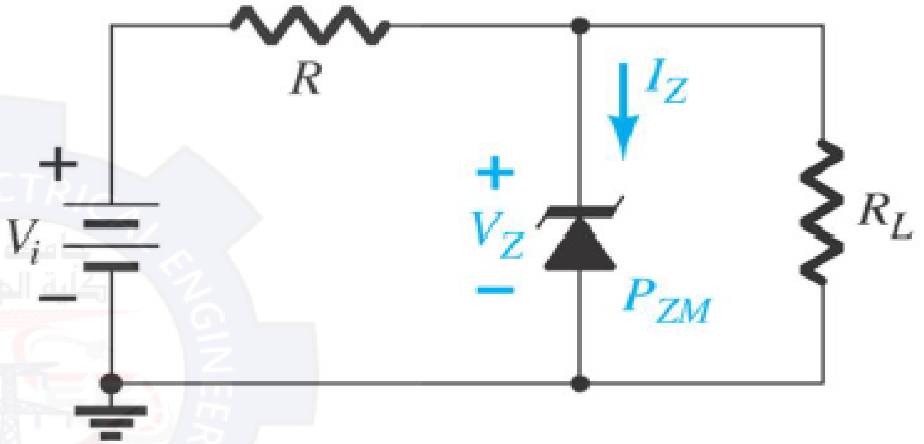
Basic Zener Regulator

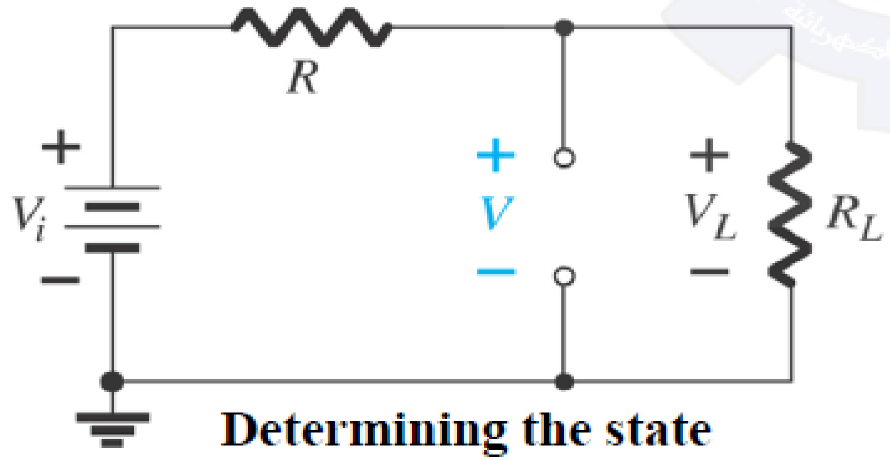
Remove Zener diode from network.

Calculate V across open circuit.

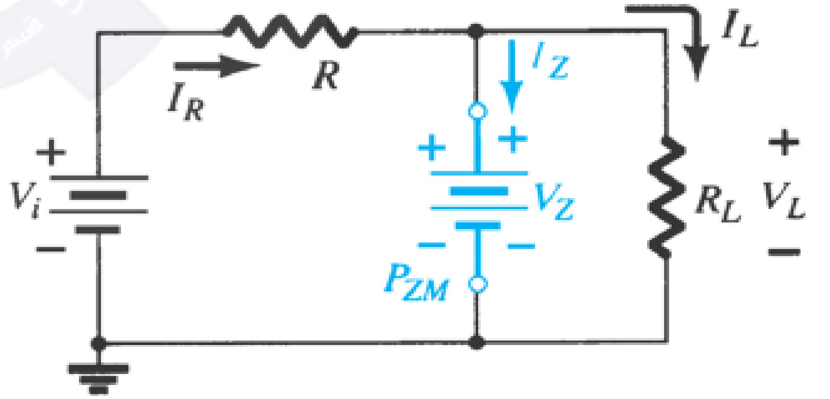
If $V \geq V_z$, Zener diode is on.

If $V < V_z$, Zener diode is off.





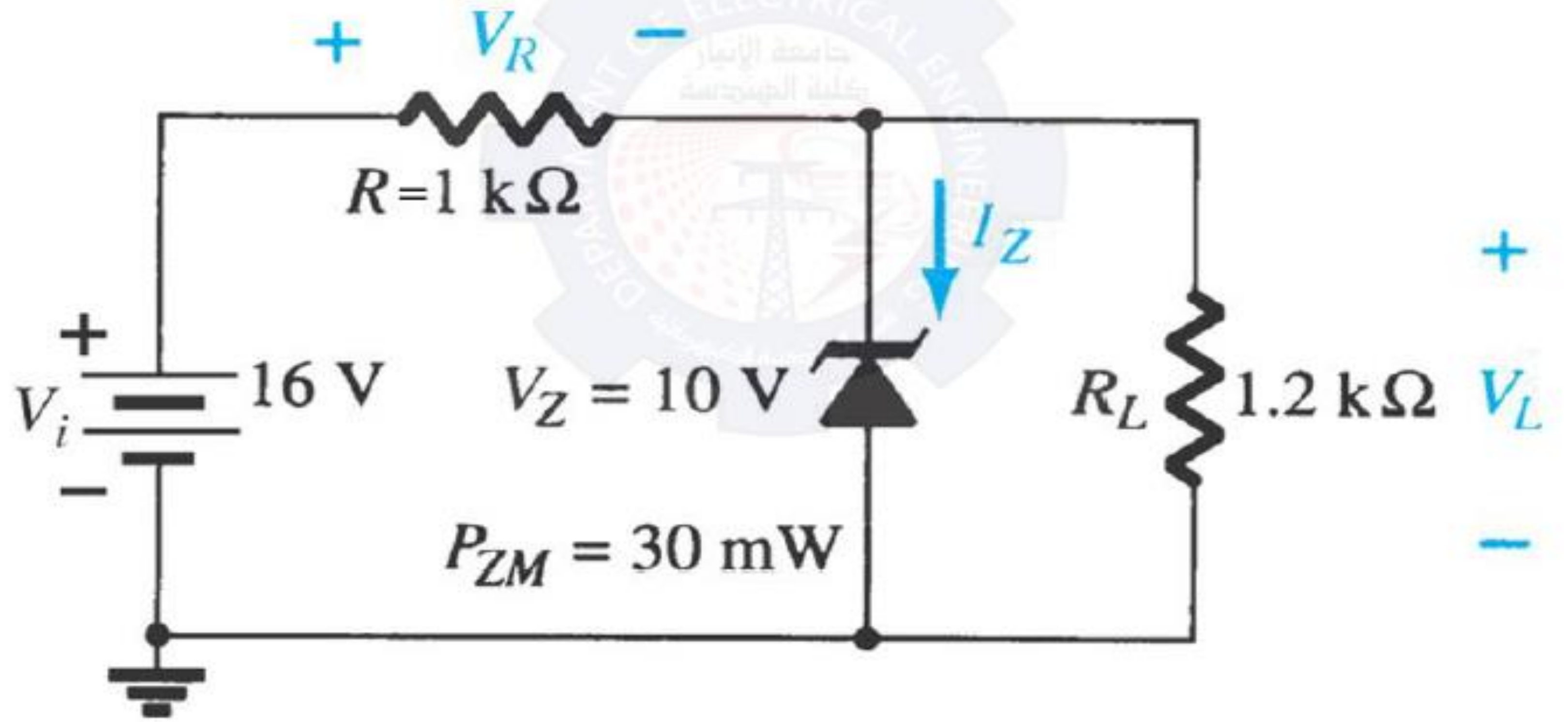
Determining the state of the Zener diode.



Substituting the Zener equivalent for the "on" situation

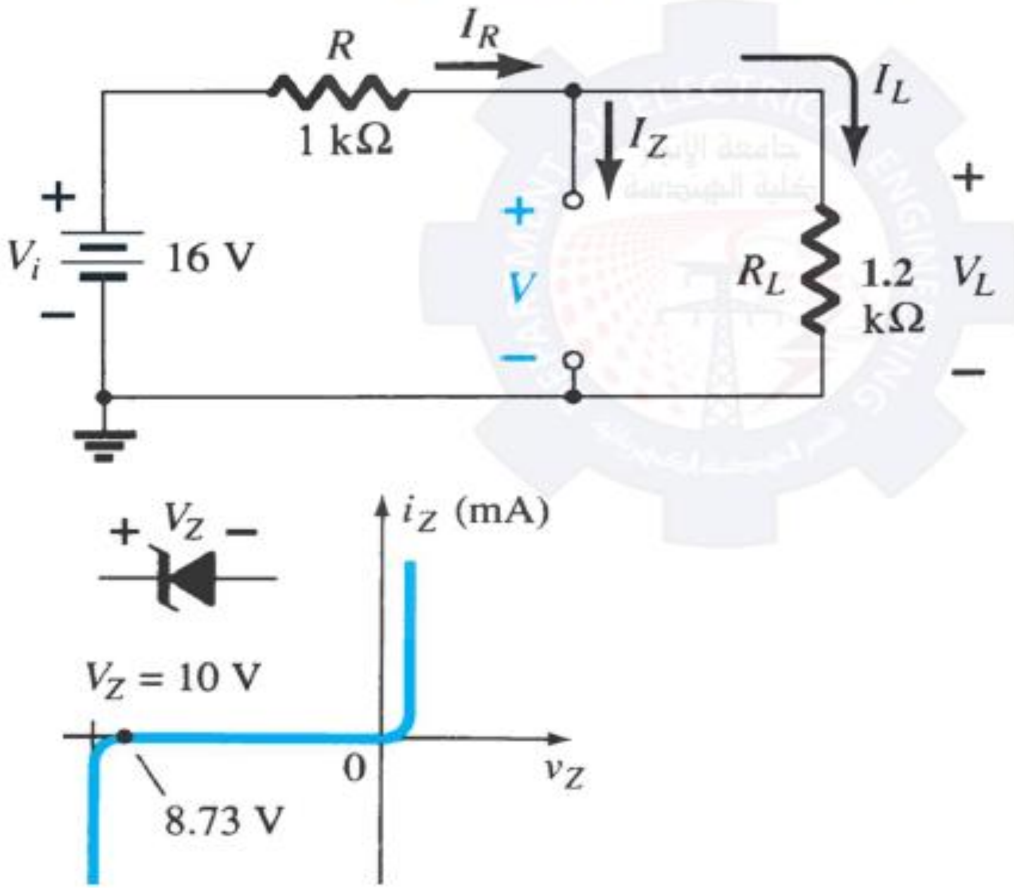
Example 2.26

(a) For the Zener diode network, determine V_L, V_R, I_Z and P_Z.
(b) Repeat part (a) with R_L=3 kΩ.



Example 2.26 - Solution

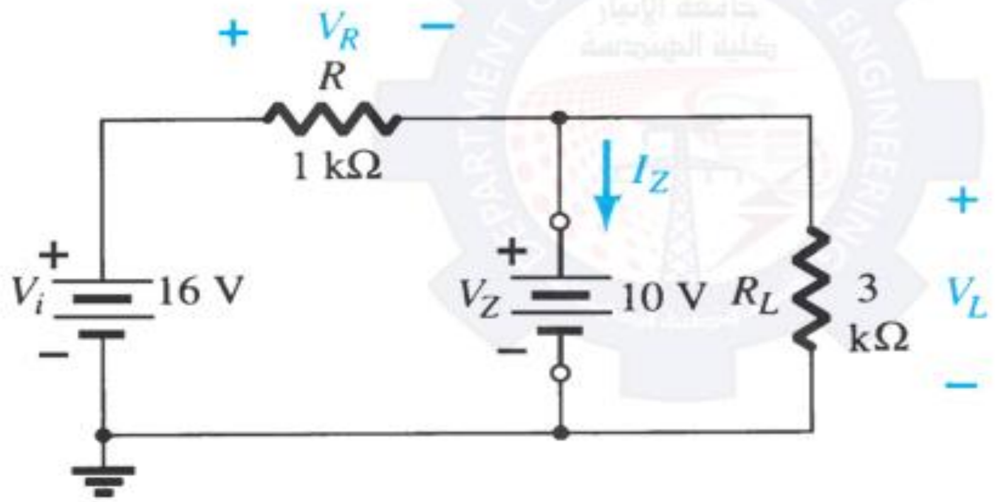
(a) determine V_L, V_R, I_Z and P_Z. (R_L=1.2 kΩ)



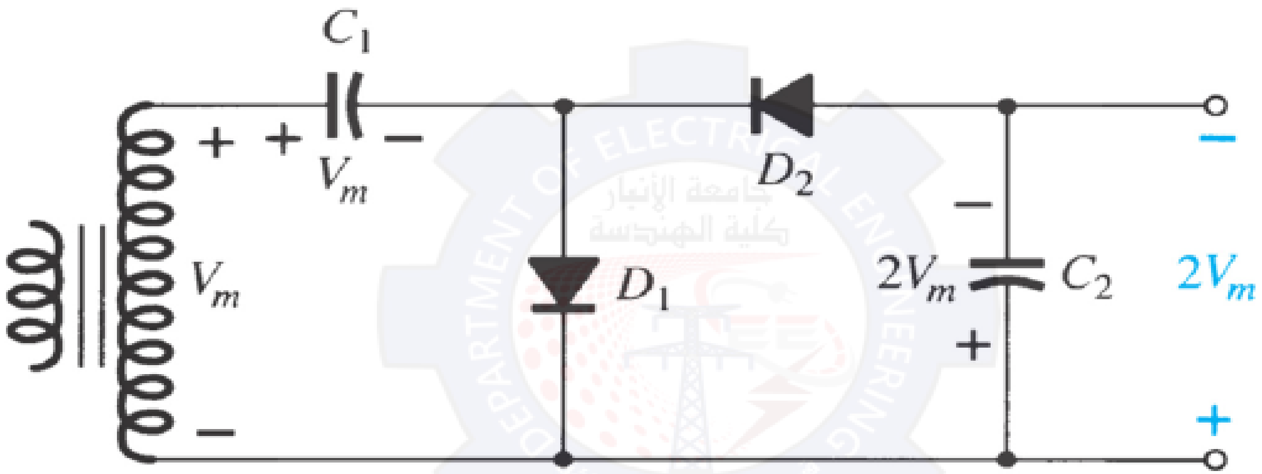
V=8.73 V (<10)
I_Z=0

Example 2.26 - Solution

(b) determine V_L, V_R, I_Z and P_Z. (R_L=3 kΩ)



Voltage Doubler



This half-wave voltage doubler's output can be calculated by:

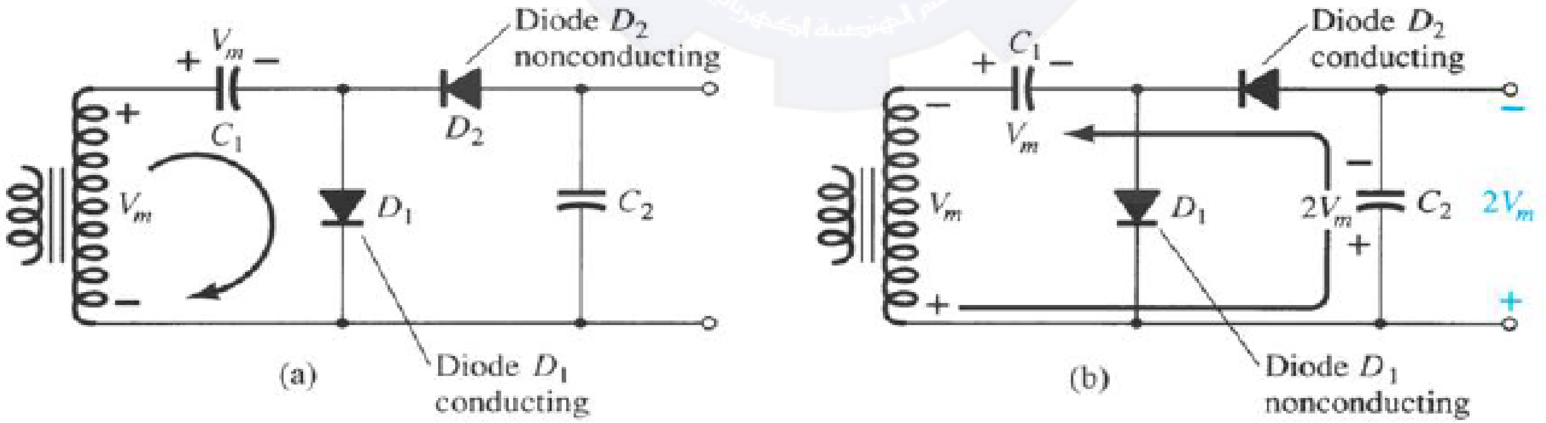
$$V_{out} = V_{C2} = 2V_m$$

where V_m = peak secondary voltage of the transformer

Voltage Doubler

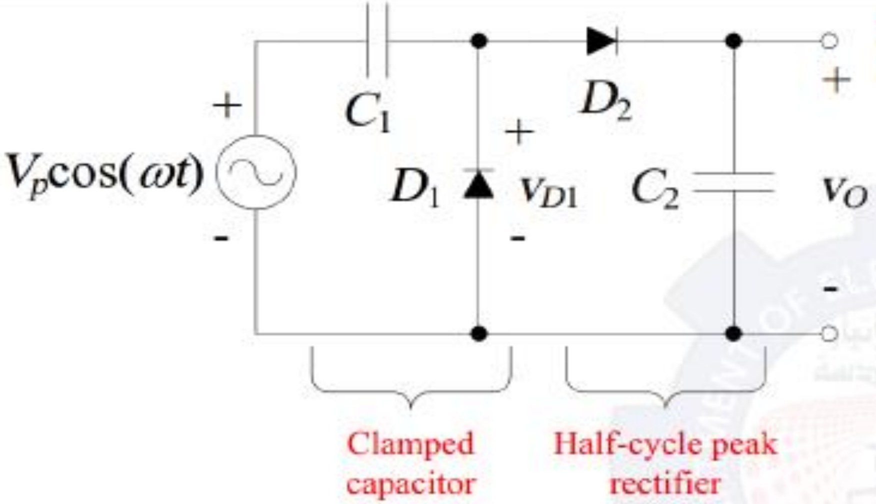
- **Positive Half-Cycle**
  - **D_1 conducts**
  - **D_2 is switched off**
  - **Capacitor C_1 charges to V_m**
- **Negative Half-Cycle**
  - **D_1 is switched off**
  - **D_2 conducts**
  - **Capacitor C_2 charges to $2V_m$**

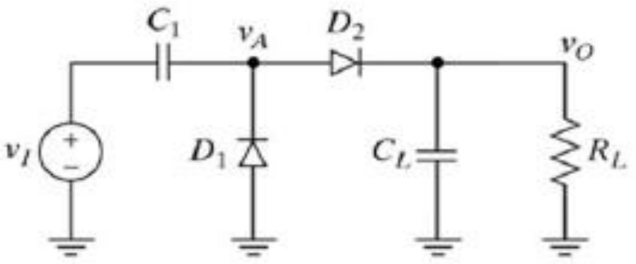
$$V_{out} = V_{C2} = 2V_m$$

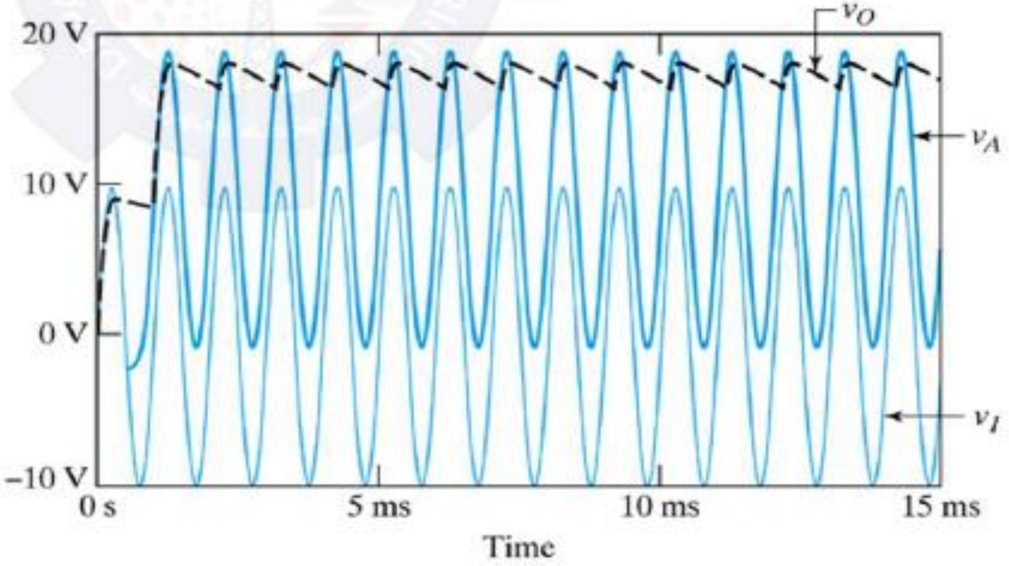


(a) positive half-cycle; (b) negative half-cycle.

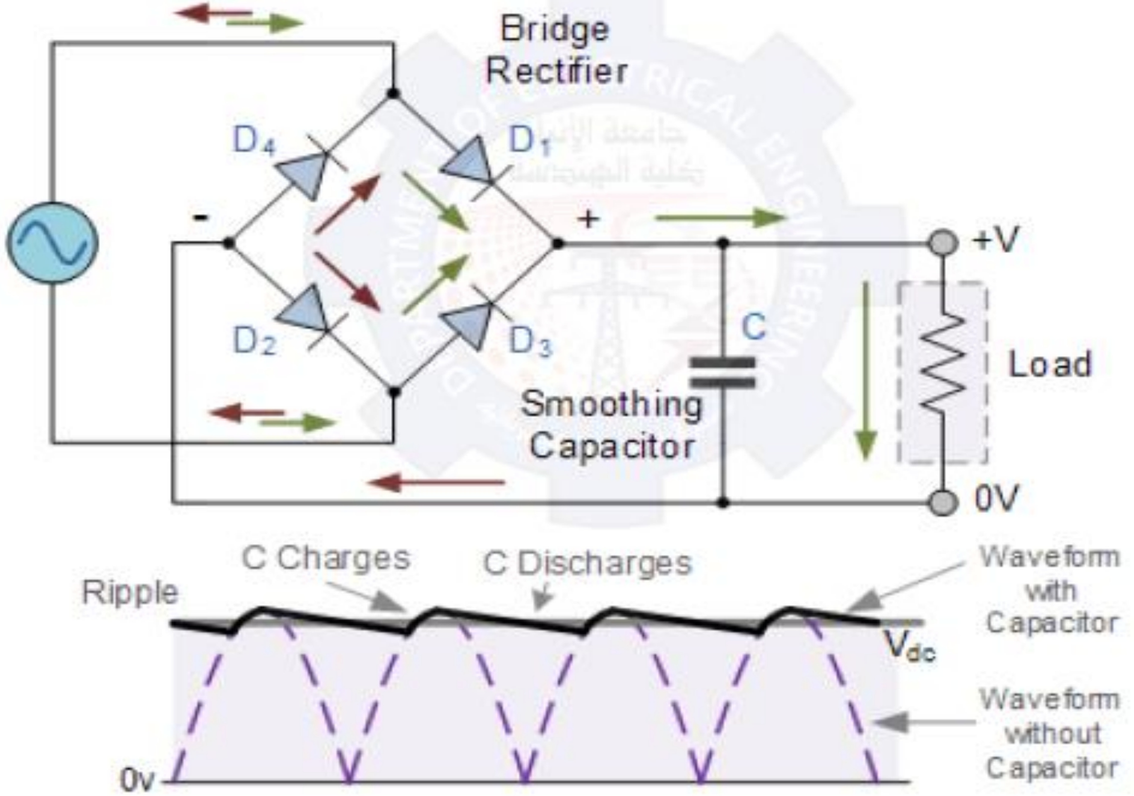
Voltage Doubler







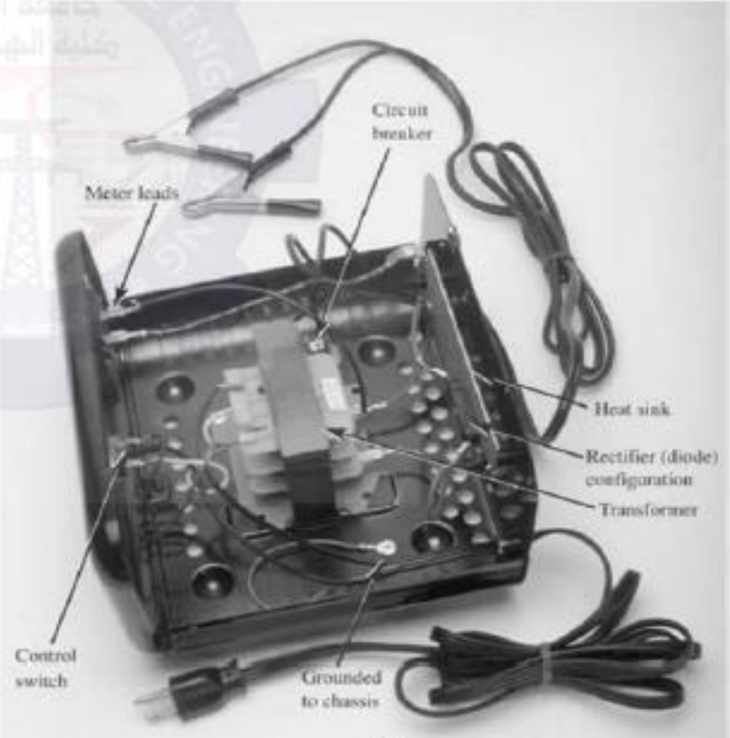
Practical Applications
(AC to DC Converter)



Resultant Output Waveform

Practical Applications
Battery Charger

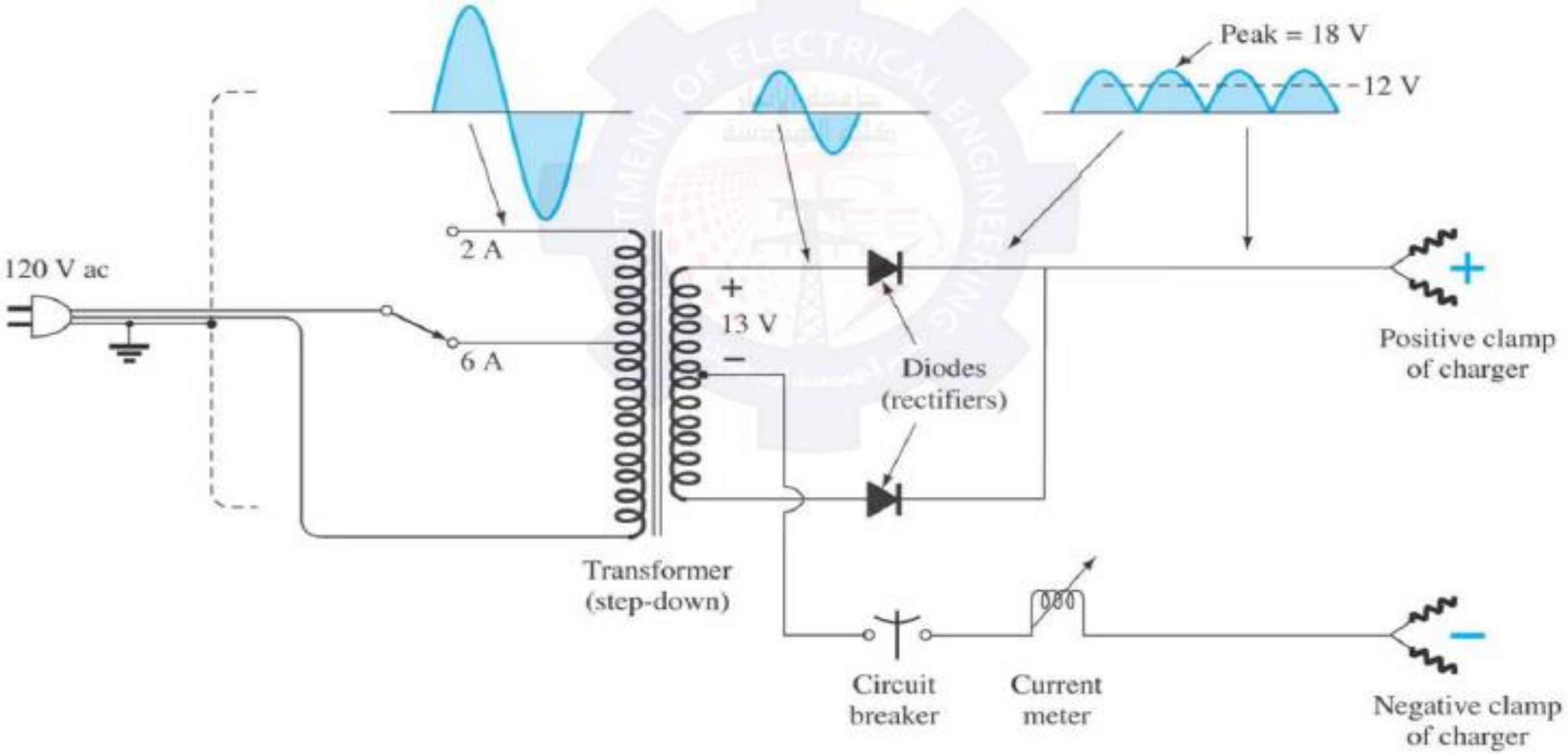
(a)



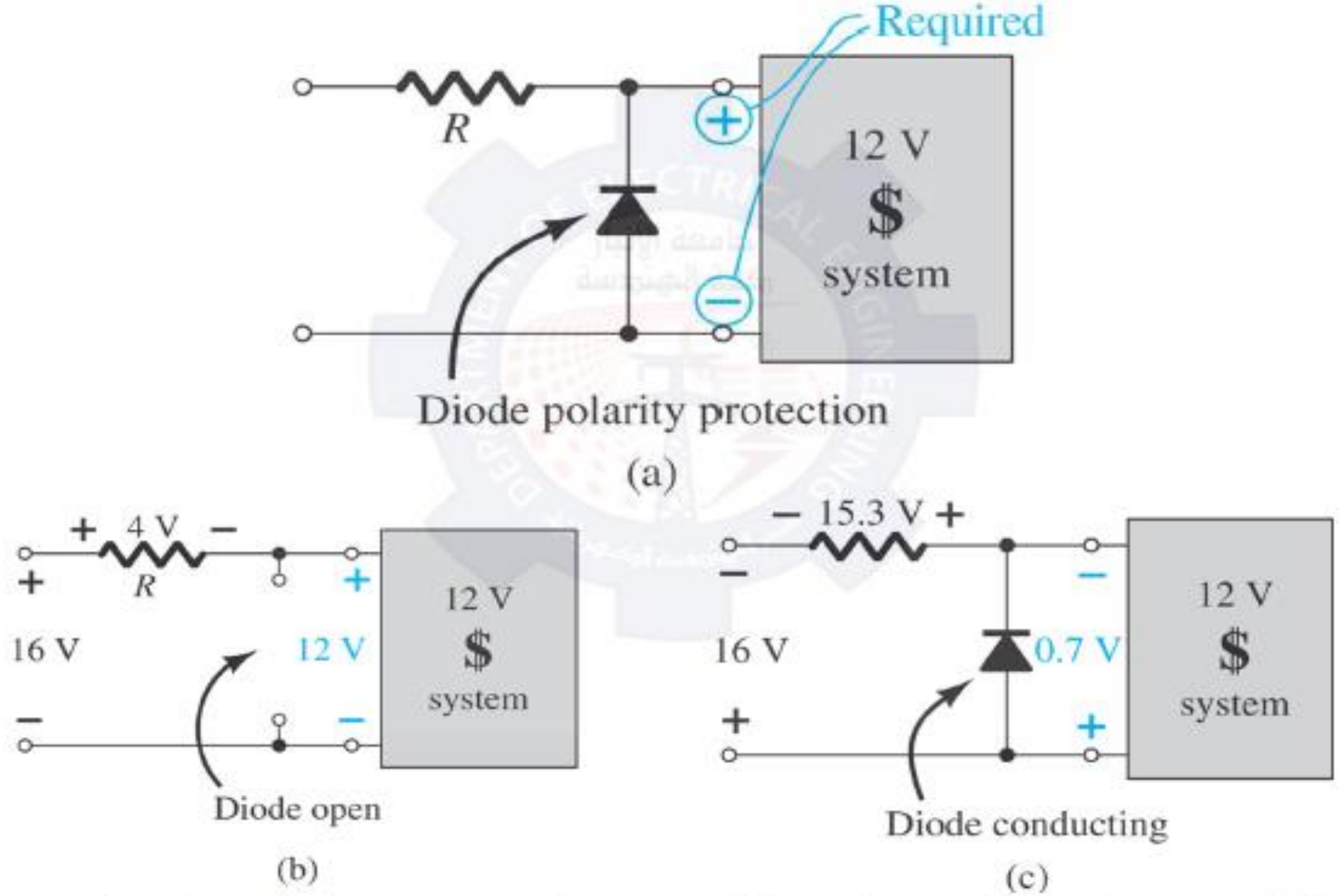
(b)

Practical Applications

Battery Charger

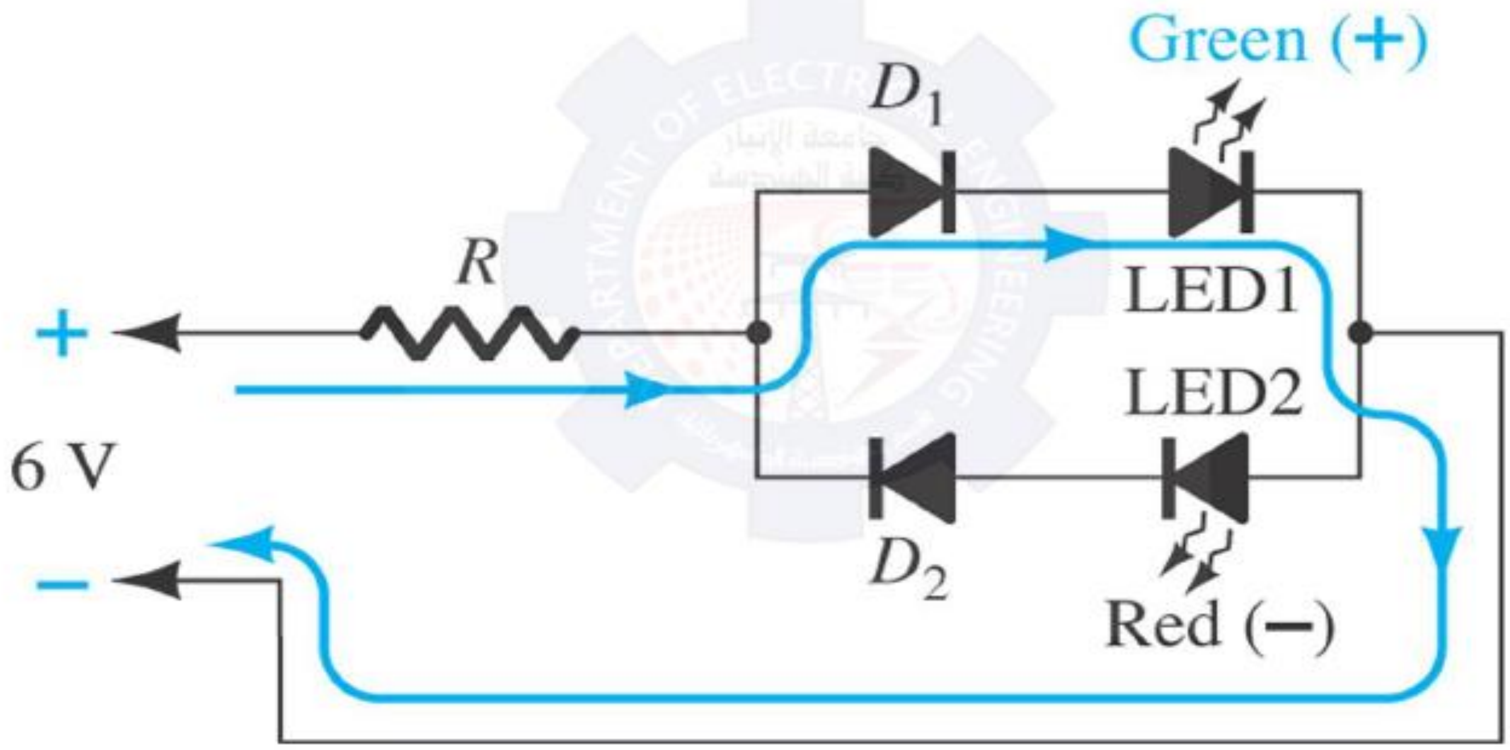


Practical Applications - Polarity insurance



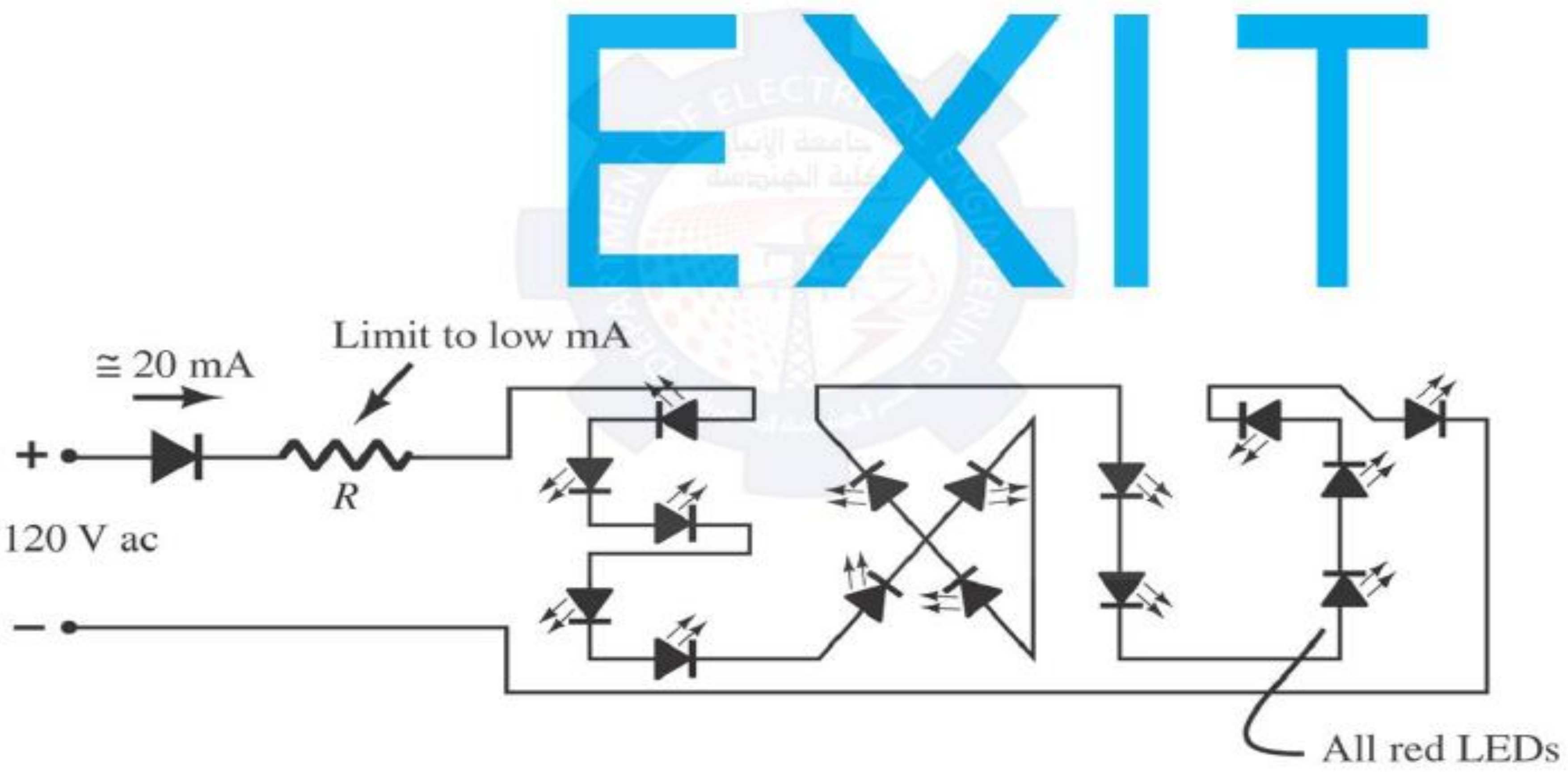
(a) Polarity protection for an expensive, sensitive piece of equipment; (b) correctly applied polarity; (c) application of the wrong polarity.

Practical Applications - Polarity Detector

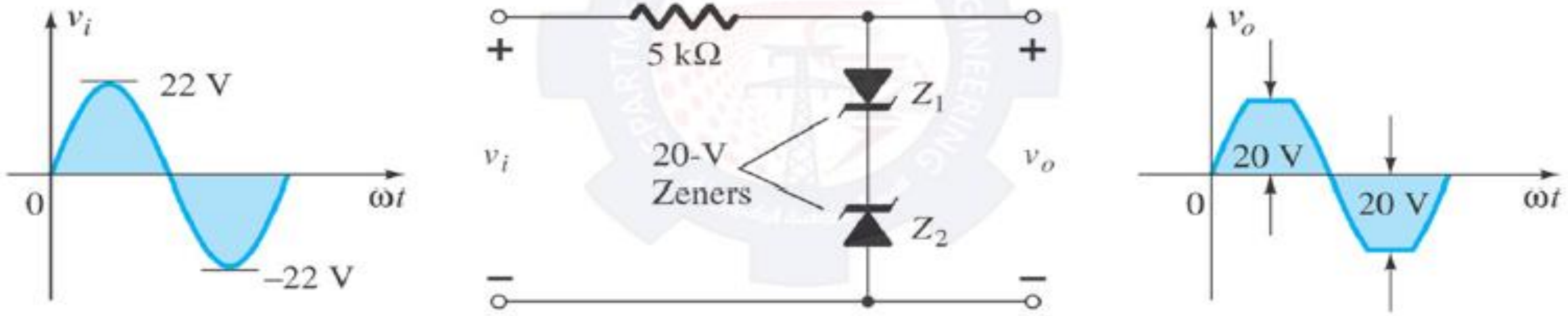


Polarity detector using diodes and LEDs.

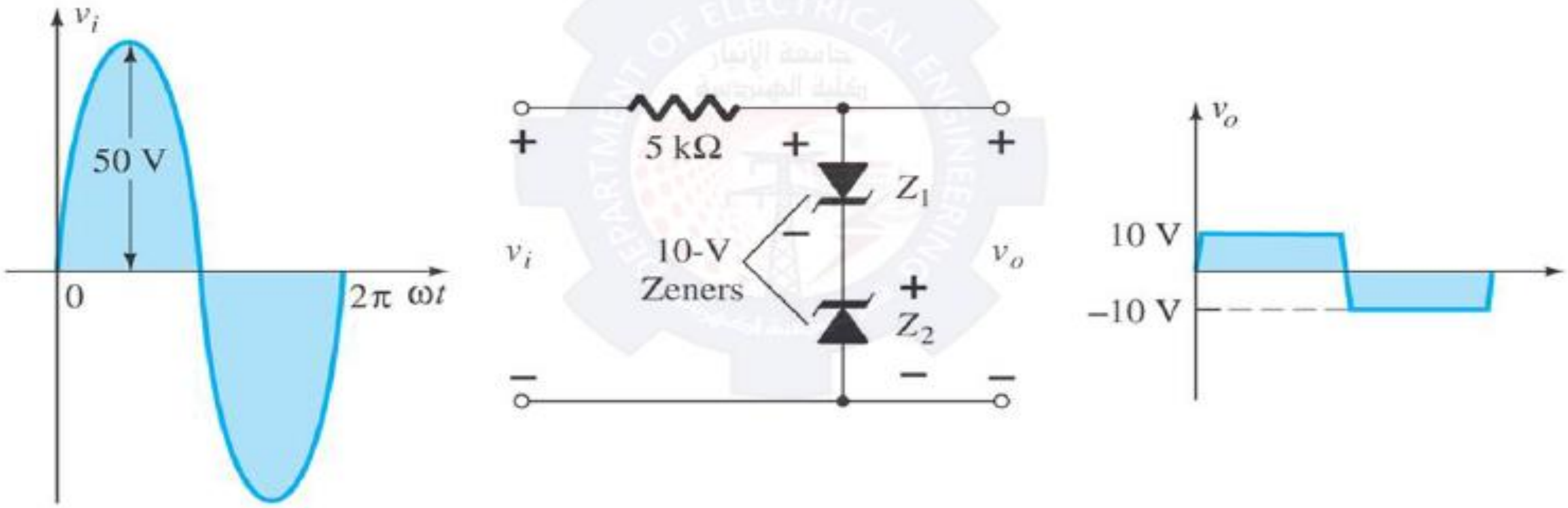
Practical Applications – Exit sign using LEDS



Practical Applications – AC Regulator



Practical Applications – Square-Wave Generator



Fundumantal of Electronic I

Second Class

Chapter 3 : BJT Transistors

Lec03_p1

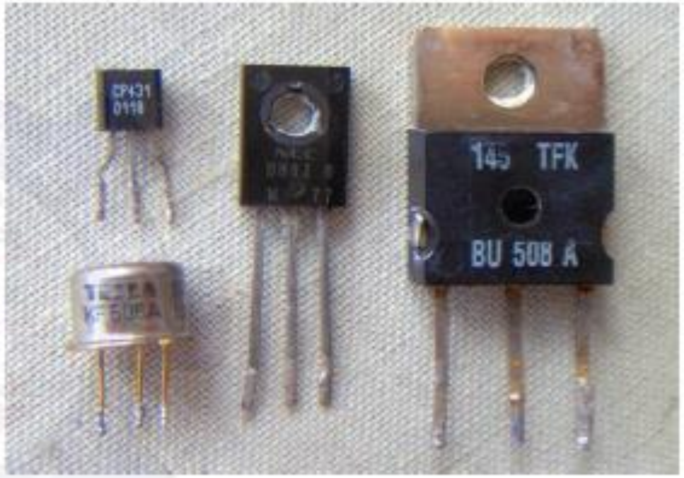
Munther N. Thiyab

2019-2020

Transistor Construction

There are two types of transistors:

- ***pnp***
- ***npn***



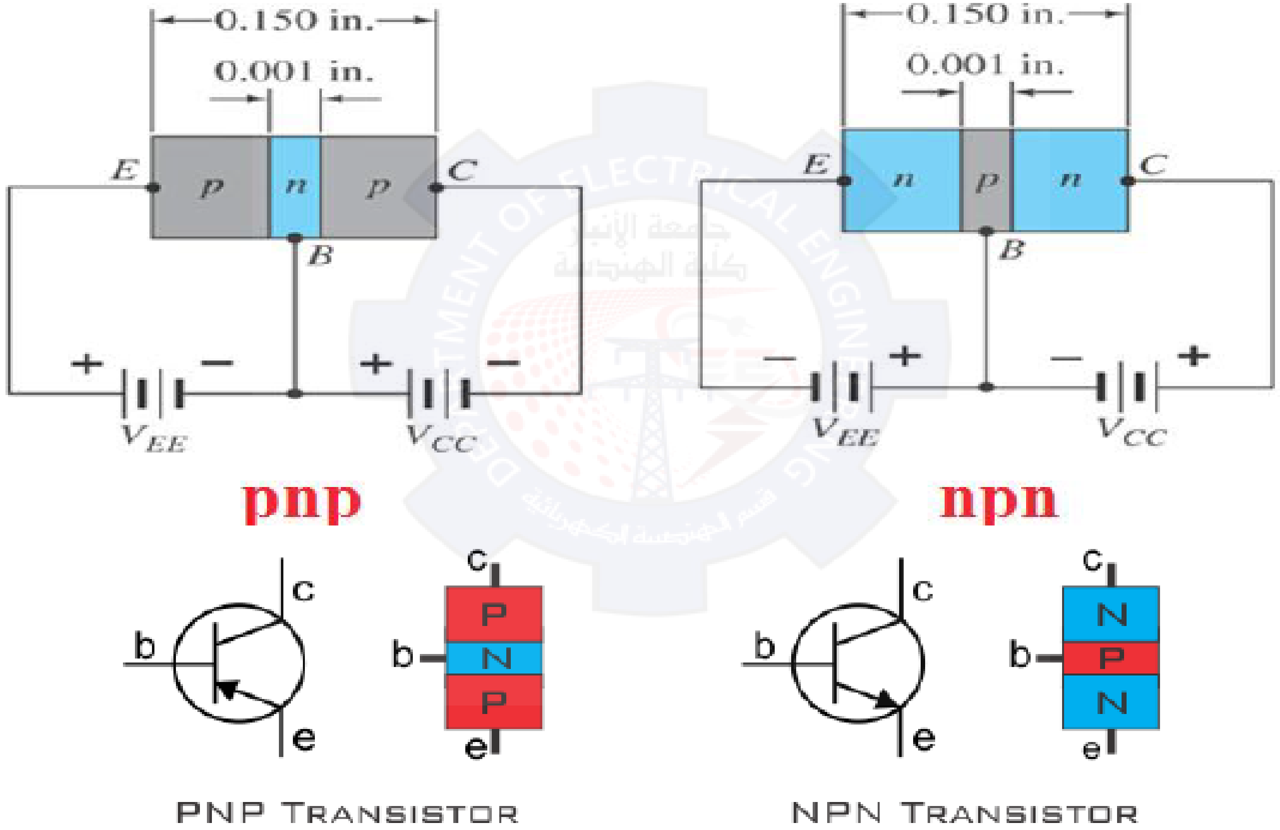
The terminals are labeled:

- **E - Emitter**
- **B - Base**
- **C - Collector**

•The ***npn*** BJT consists of three semiconductor regions: the emitter region (*n type), the* base region (*p type), and the collector region (n type).*

•The ***pnp*** BJT consists of three semiconductor regions: the emitter region (*p type), the* base region (*n type), and the collector region (p type).*

Transistor Construction



The transistor consists of two *pn junctions, the* **emitter–base junction (EBJ) and the collector–base junction (CBJ).**

Transistor Construction

- **Emitter**: The portion on one side of transistor that supplies charge carriers (i.e. electrons or holes) to the other two portions.
- The emitter is a heavily doped region.
- Emitter of PNP transistor supplies hole charges to its junction with the base. Similarly, the emitter of NPN transistor supplies free electrons to its junction with the base.

Transistor Construction

- **Collector** is the portion on the other side of the transistor (i.e. the side opposite to the emitter) that collects the charge carriers (i.e. electrons or holes).
- The doping level of the collector is in between the heavily doping of emitter and the light doping of the base.
- **Base:** The middle portion which forms two PN junctions between the emitter and the collector is called the base.
- The base of transistor is thin, as compared to the emitter and is a lightly doped portion.
- The function of base is to control the flow of charge carrier.

BJT Modes Of Operation

- There are two junctions in bipolar junction transistor.
- Each junction can be forward or reverse biased independently.
- Thus there are different modes of operations:

  Forward Active.

  Cut off.

  Saturation.

Mode	EBJ	CBJ
Cutoff	Reverse	Reverse
Active	Forward	Reverse
Saturation	Forward	Forward

BJT Modes Of Operation

FORWARD ACTIVE

- Emitter-base junction is forward biased and collector-base junction is reverse biased.
- The BJT can be used as an amplifier and in analog circuits.

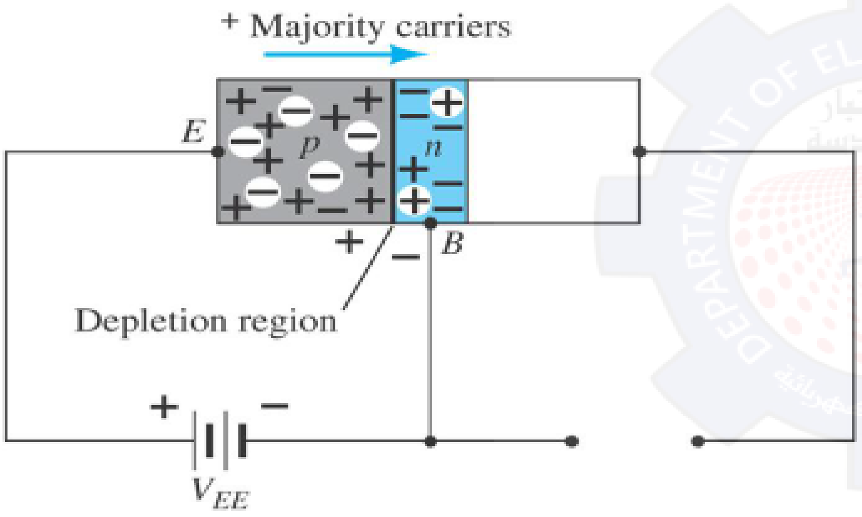
CUTT OFF

- When both junctions are reverse biased it is called cut off mode.
- In this situation there is nearly zero current and transistor behaves as an open switch.

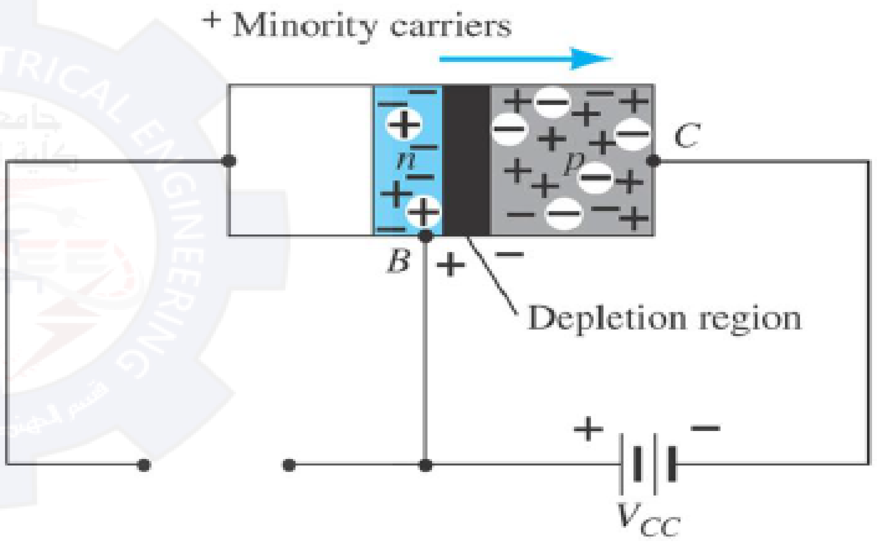
SATURATION

- In saturation mode both junctions are forward biased.
- Large collector current flows with a small voltage across collector base junction.
- Transistor behaves as an closed switch.

Operation of pnp transistor in active mode



Forward-biased junction of a pnp transistor.

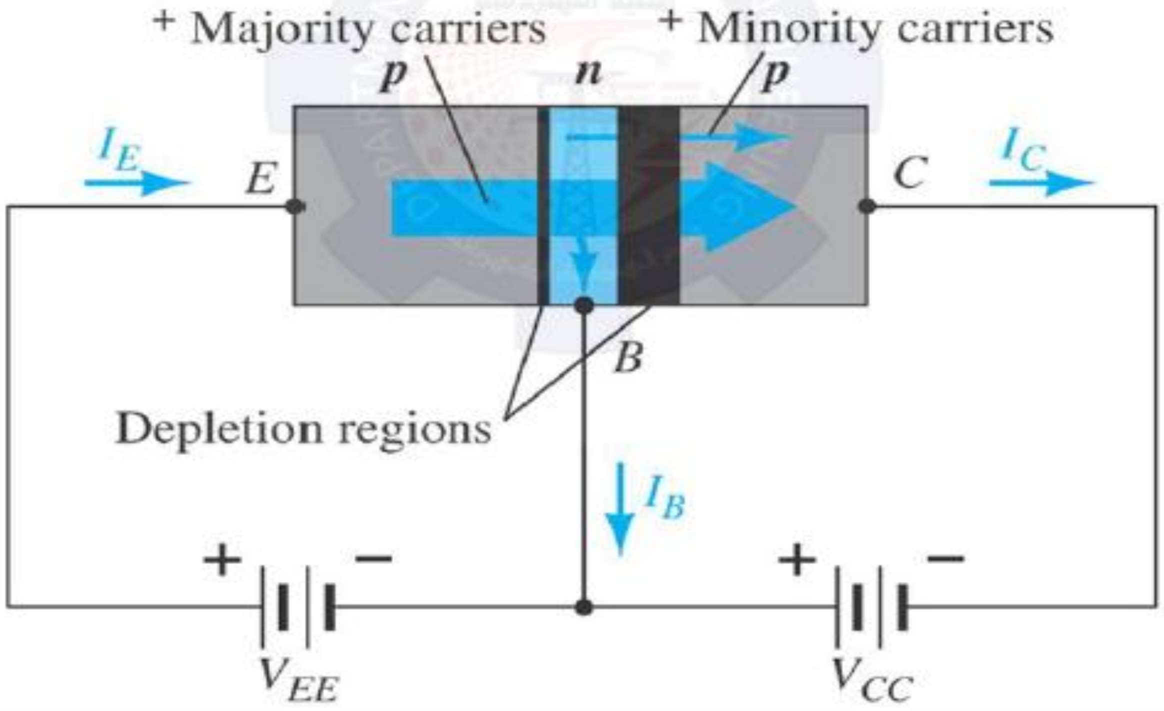


Reverse-biased junction of a pnp transistor

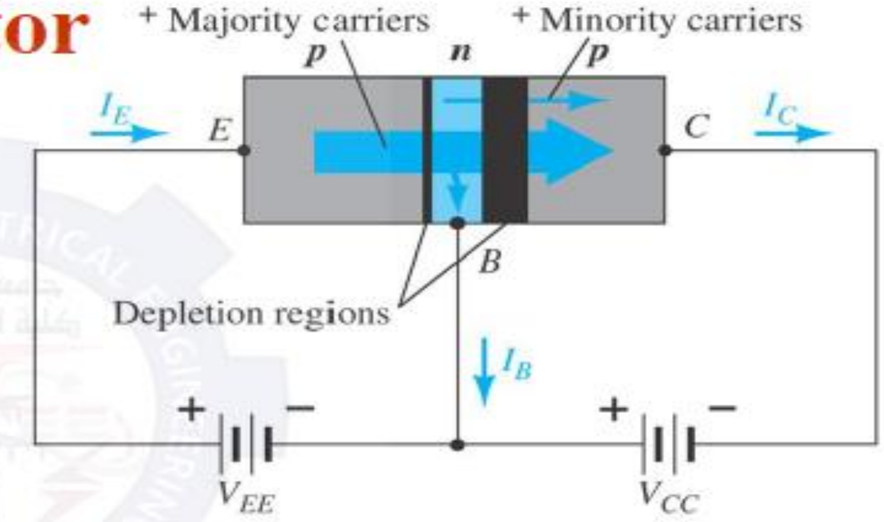
Operation of pnp transistor in active mode

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:

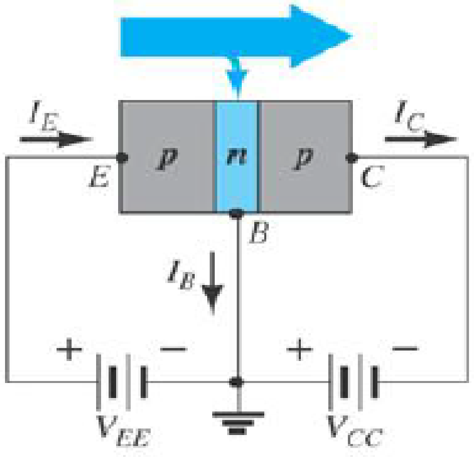
$$I_E = I_C + I_B$$

The collector current is comprised of two currents:

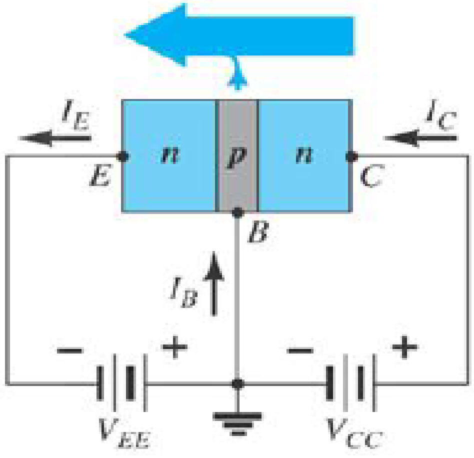
$$I_C = I_{C_{majority}} + I_{CO_{minority}}$$

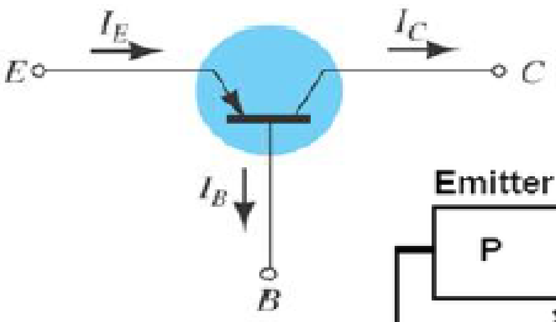
The minority current is called the leakage current and is given by the symbol I_{CO} (I_C current with emitter terminal *O*pen).

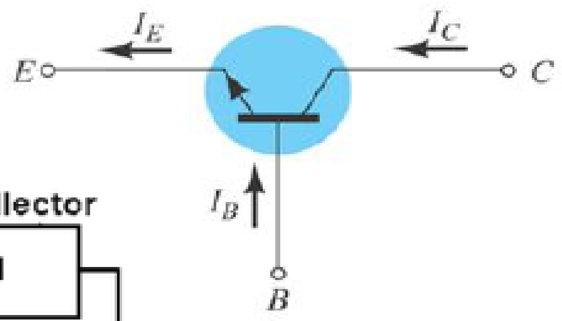
Common Base Configuration

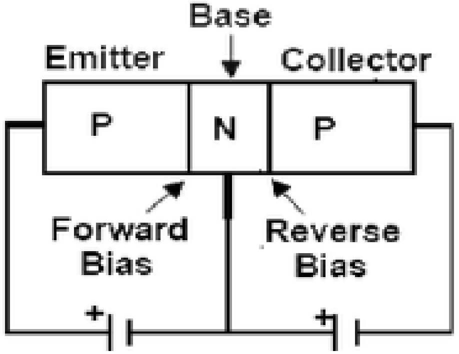


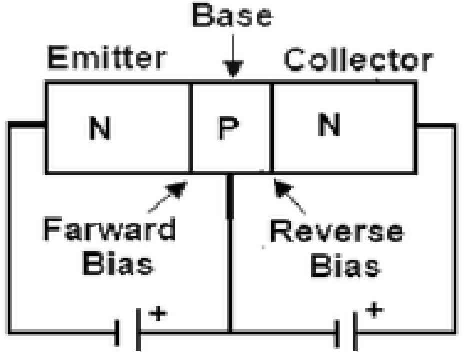
The base is common to both input (emitter–base) and output (collector–base) of the transistor.



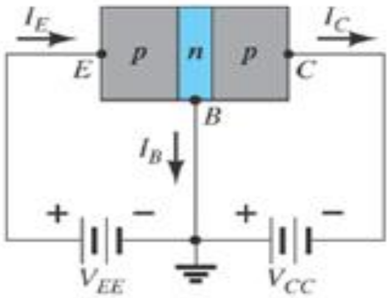






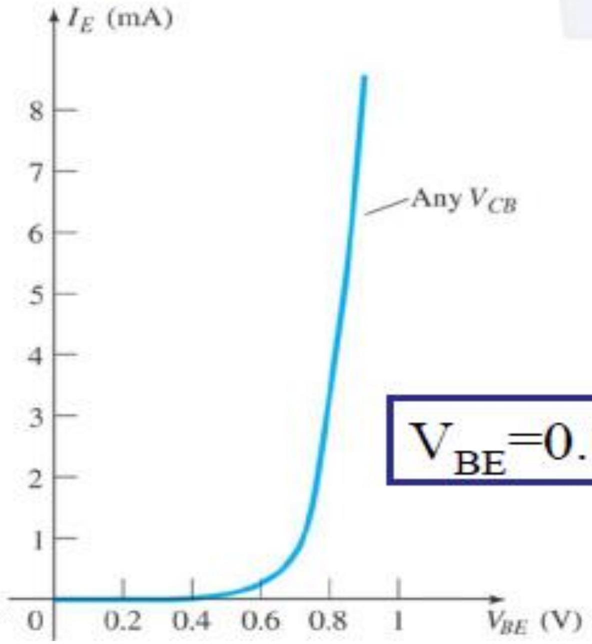


Common-Base Configuration

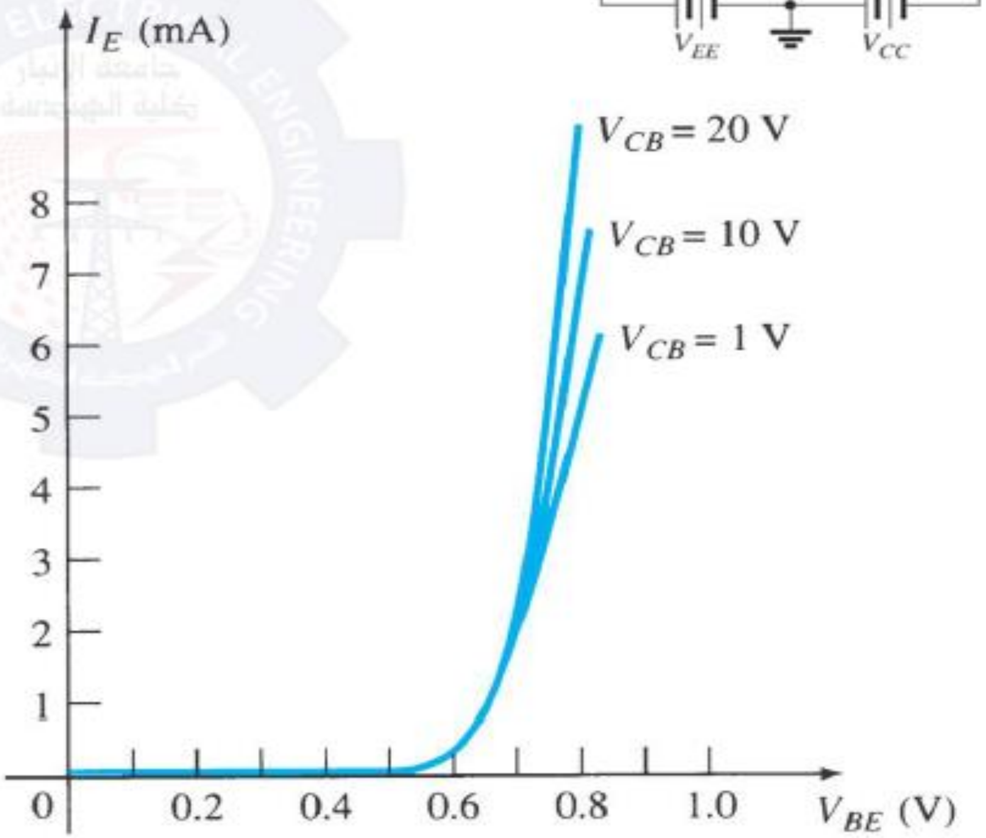


Input Characteristics

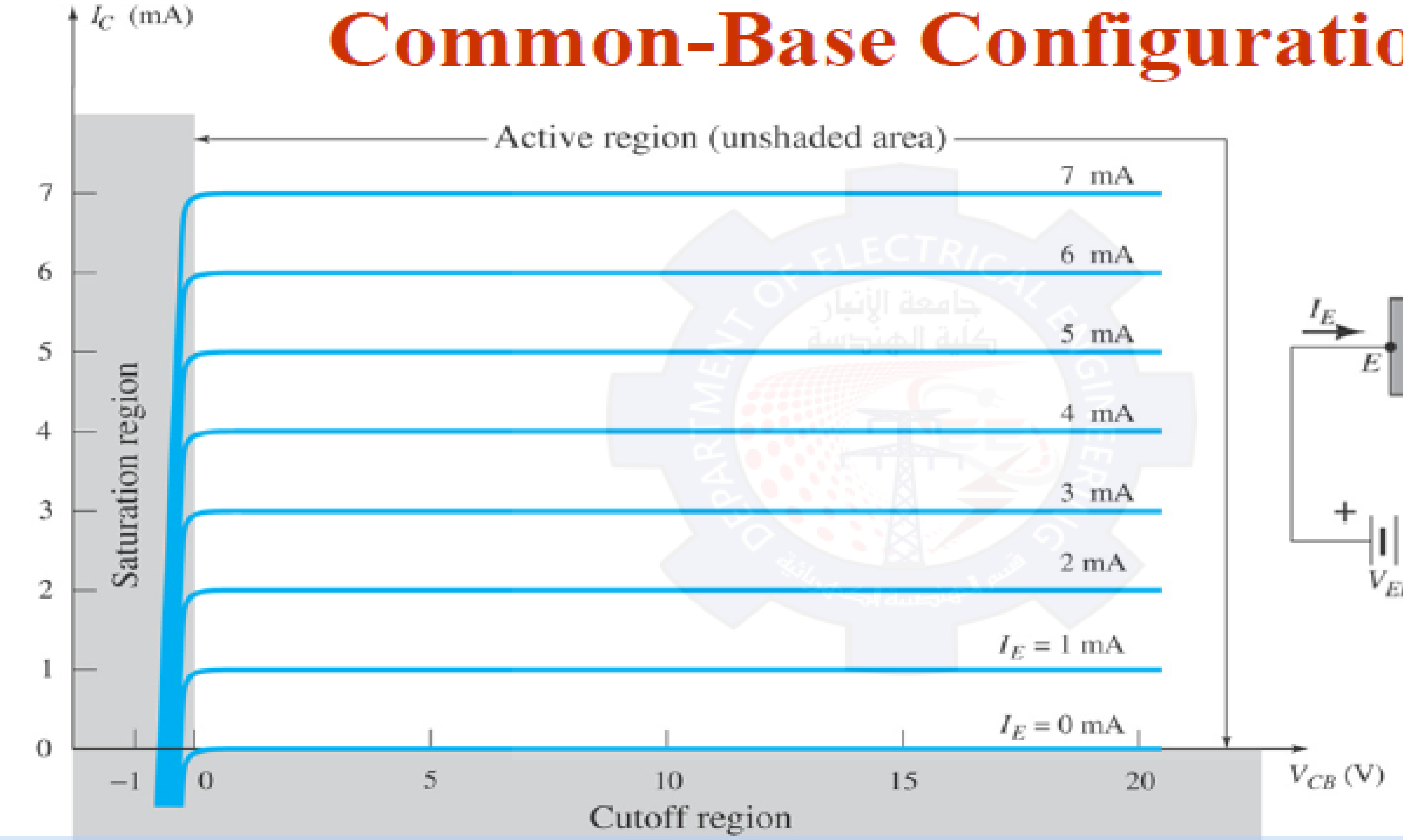
This curve shows the relationship between of input current (I_E) to input voltage (V_{BE}) for three output voltage (V_{CB}) levels.

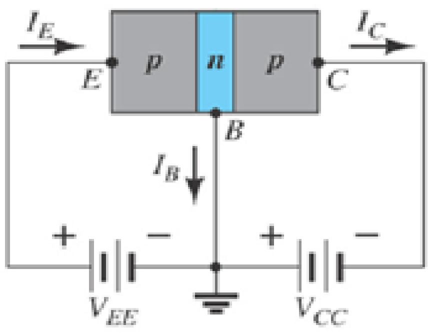


V_{BE}=0.7 V



Common-Base Configuration





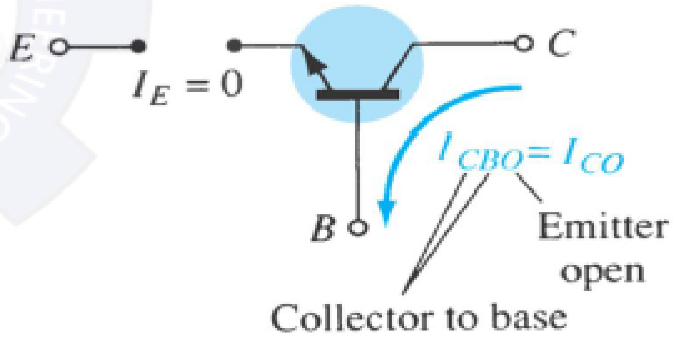
Output Characteristics

Output Characteristics

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

Operating Regions

- **Active** – Operating range of the amplifier. It is noticed that I_E is approximately equal to I_C ($I_C \approx I_E$).
- **Cutoff** – the region where the collector current is approximately 0A ($I_C = I_{CBO}$). The amplifier is basically off. There is voltage, but little current.



- **Saturation** – Region to the left of V_{CB}=0. Note the exponential increase in collector current as the voltage V_{CB} increases toward 0 V. There is current but little voltage.

Approximations

Emitter and collector currents:

$$I_C \cong I_E$$

Base-emitter voltage:

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

Alpha (α)

Alpha (α) is the ratio of I_C to I_E:

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

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

Ideally: α = 1
In reality: α is between 0.9 and 0.998

Alpha (α) in the AC mode:

$$\alpha_{ac} = \left.\frac{\Delta I_C}{\Delta I_E}\right|_{V_{CB} = \text{constant}}$$

Fundumantal of Electronic I

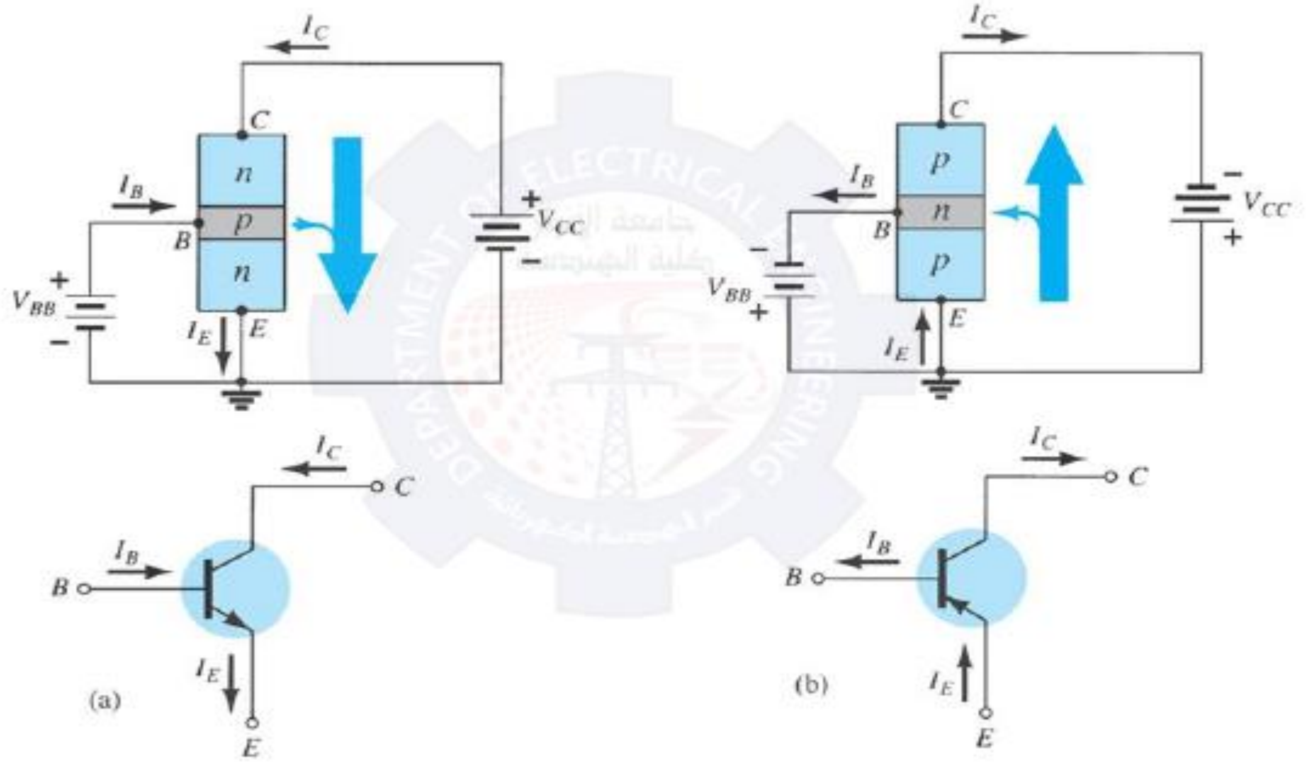
Second Class

Chapter 3 : BJT Transistors
Lec03_p2

Munther N. Thiyab

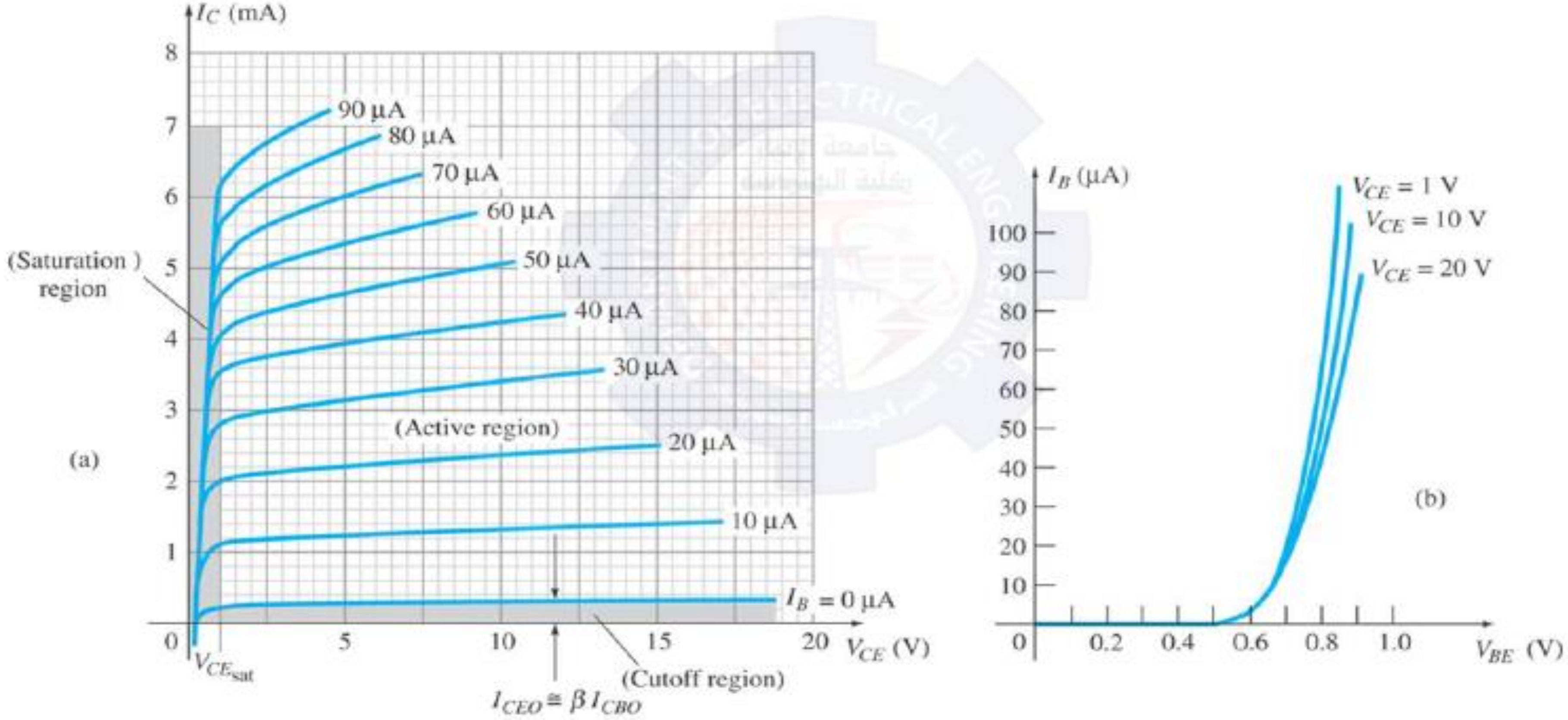
2019-2020

Common–Emitter Configuration



•The emitter is common to both input (base-emitter) and output (collector-emitter).
•The input is on the base and the output is on the collector.

Common-Emitter Characteristics



(a) collector characteristics; (b) base characteristics.

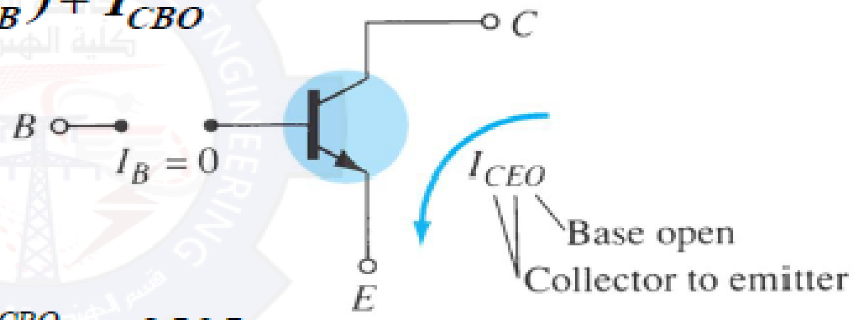
Common-Emitter Amplifier Currents

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

Since $I_E = I_C + I_B$, $I_C = \alpha (I_C + I_B) + I_{CBO}$

$$I_C = \frac{\alpha I_B}{1-\alpha} + \frac{I_{CBO}}{1-\alpha}$$



For I_B=0, and take $\alpha = 0.996$,

$$I_C = \frac{\alpha(0\ \text{A})}{1-\alpha} + \frac{I_{CBO}}{1-0.996} = \frac{I_{CBO}}{1-0.996} = \frac{I_{CBO}}{0.004} = 250 I_{CBO}$$

If I_{CBO} were 1 μA, the resulting collector current with I_B=0 A would be 250(1 μA) =0.25 mA, as reflected in the characterestics.

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

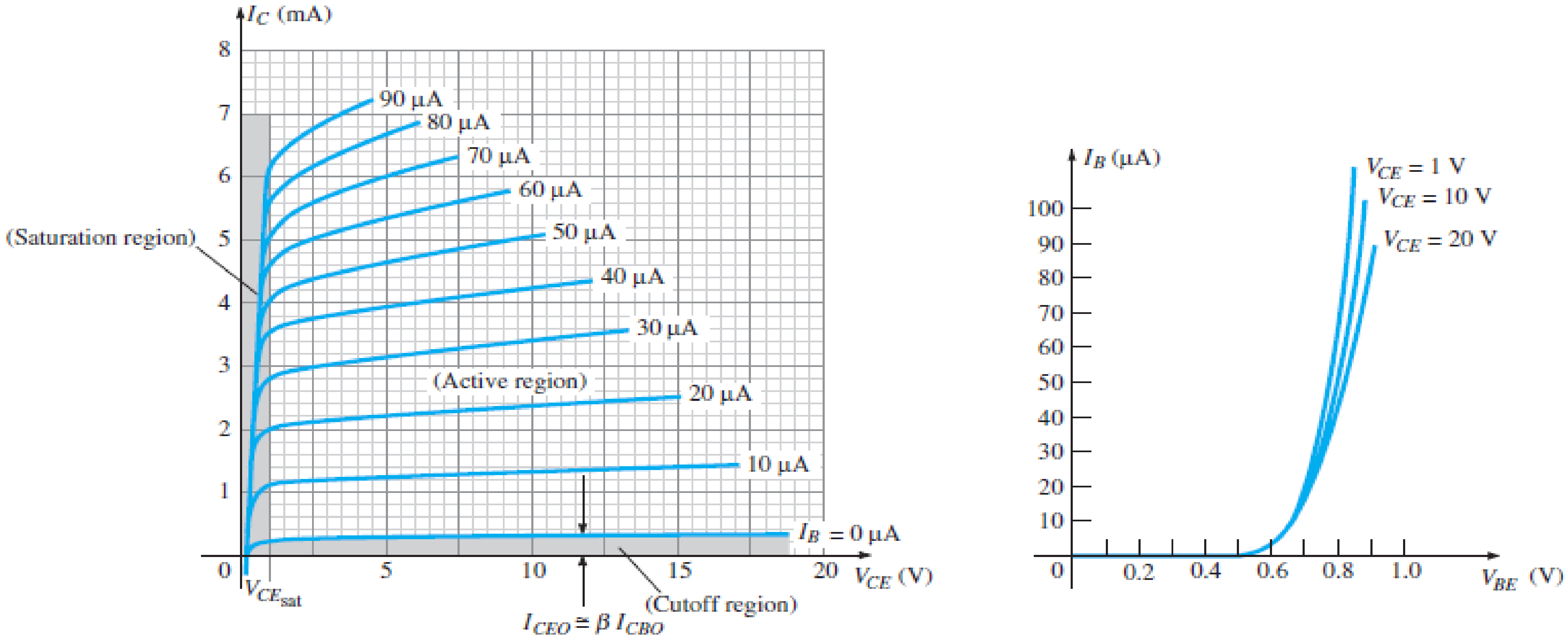
$$I_{CEO} = \frac{I_{CBO}}{1-\alpha}\bigg|_{I_B = 0\ \mu\text{A}}$$

EXAMPLE 3.2

a. Using the characteristics of Fig. 3.13, determine I_C at $I_B = 30\ \mu A$ and $V_{CE} = 10$ V.
b. Using the characteristics of Fig. 3.13, determine I_C at $V_{BE} = 0.7$ V and $V_{CE} = 15$ V.

Solution:

a. At the intersection of $I_B = 30\ \mu A$ and $V_{CE} = 10$ V, $I_C =$ **3.4 mA**.
b. Using Fig. 3.13b, we obtain $I_B = 20\ \mu A$ at the intersection of $V_{BE} = 0.7$ V and $V_{CE} =$ 15 V (between $V_{CE} = 10$ V and 20 V). From Fig. 3.13a we find that $I_C =$ **2.5 mA** at the intersection of $I_B = 20\ \mu A$ and $V_{CE} = 15$ V.



(a) (b)

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:

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

For practical devices β is typically 50 to over 400.

In AC mode:

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

Beta (β)

Determining β from a Graph

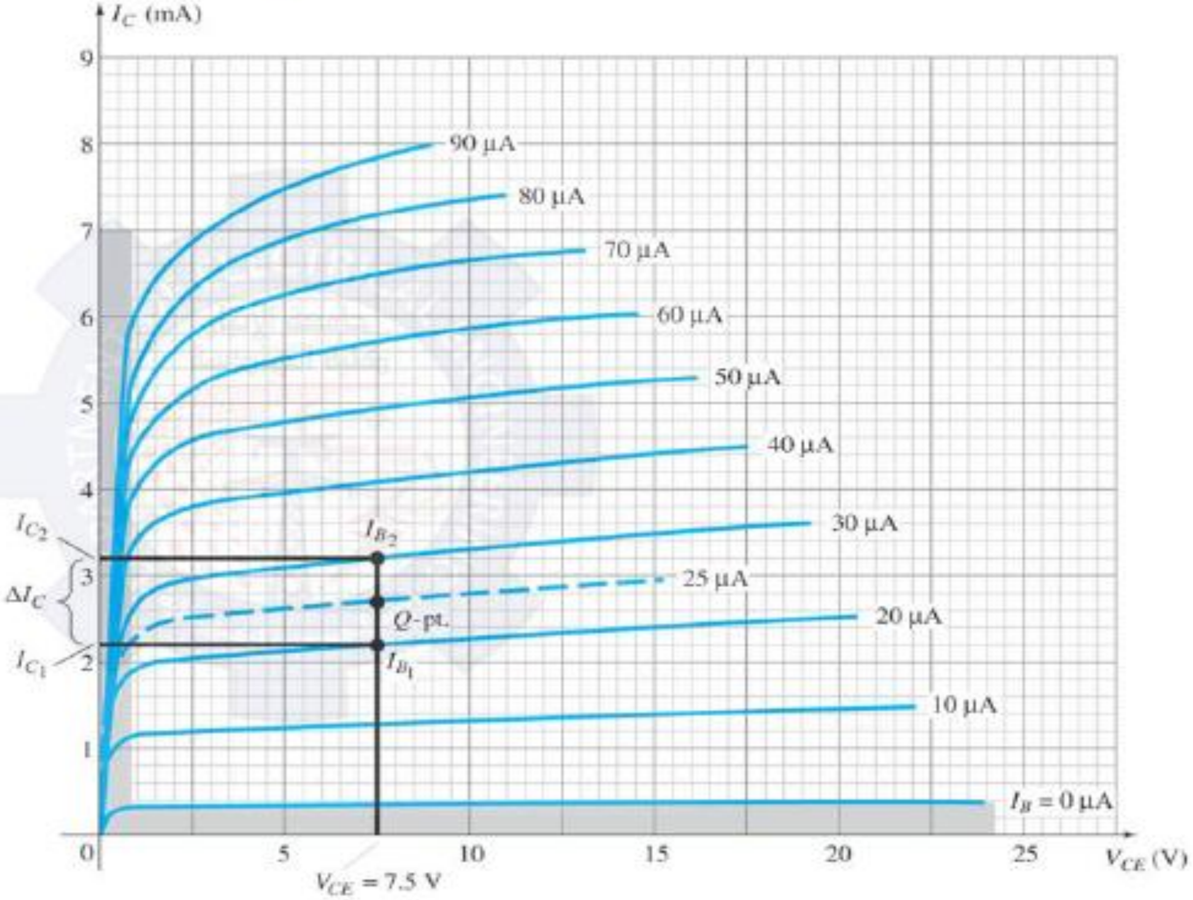
$$\beta_{AC} = \frac{(3.2\,\text{mA} - 2.2\,\text{mA})}{(30\,\mu\text{A} - 20\,\mu\text{A})}$$

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

$$= 100$$

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

$$= 108$$



β_{ac} and β_{dc} are usually reasonably close and are often used interchangeably.

Beta (β)

Relationship between amplification factors β and α :-

using $\beta = \frac{I_C}{I_B}$, $\alpha = \frac{I_C}{I_E}$

and $I_E = I_C + I_B$

$$\frac{I_C}{\alpha} = I_C + \frac{I}{\beta} \rightarrow \frac{1}{\alpha} = 1 + \frac{1}{\beta}$$

$$\beta = \alpha\beta + \alpha = (\beta + 1)\alpha$$

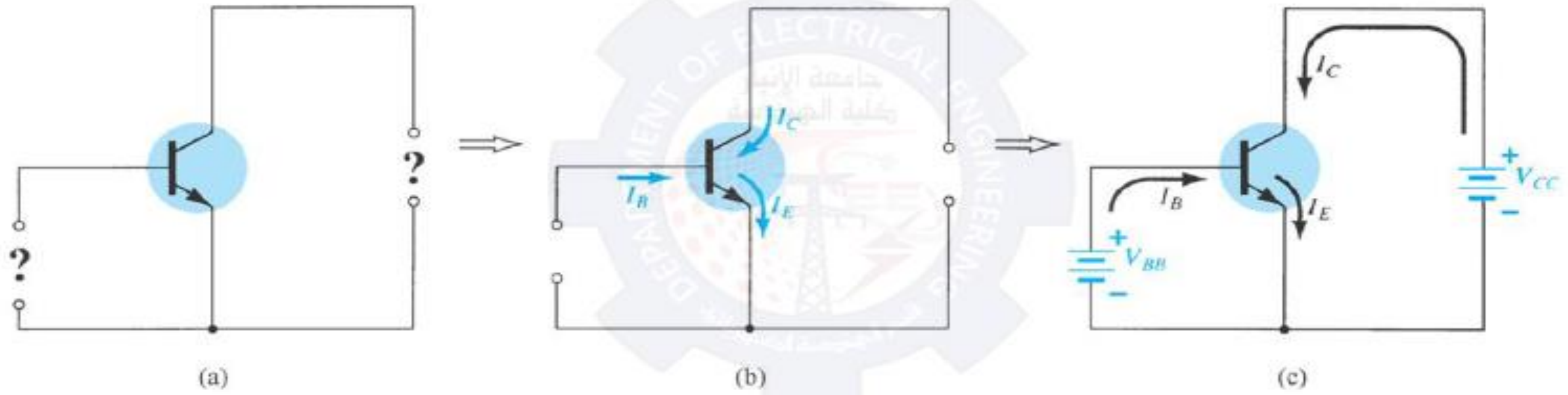
$$\boldsymbol{\alpha = \frac{\beta}{\beta + 1}}$$

$$\boldsymbol{\beta = \frac{\alpha}{\alpha - 1}}$$

Relationship Between Currents

$\mathbf{I_C = \beta I_B}$, $I_E = I_C + I_B = \beta I_B + I_B$, $\mathbf{I_E = (\beta + 1) I_B}$

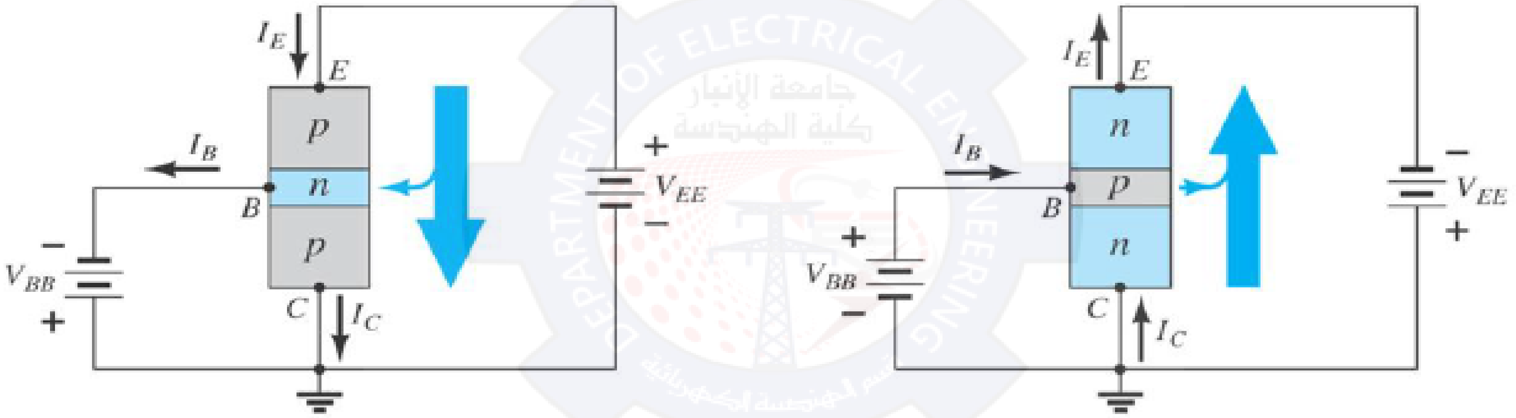
Biasing

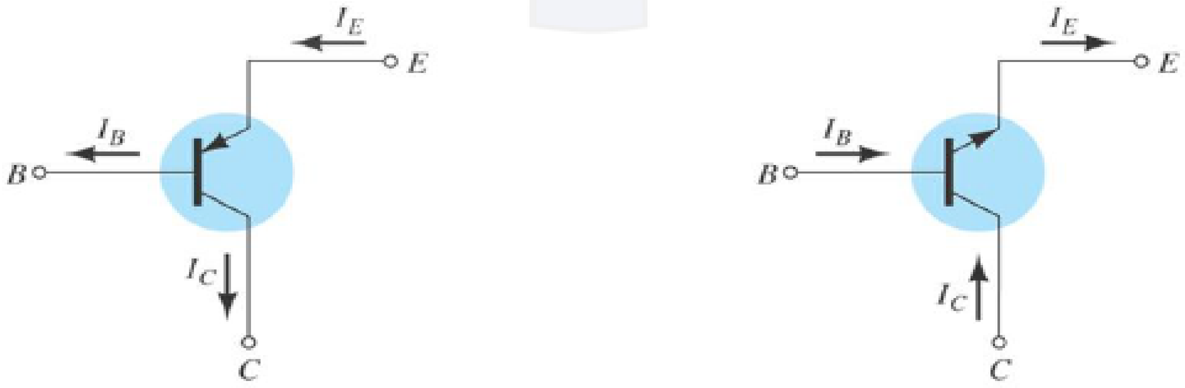


Determining the proper biasing arrangement for a common-emitter ***npn*** transistor configuration.

Common–Collector Configuration

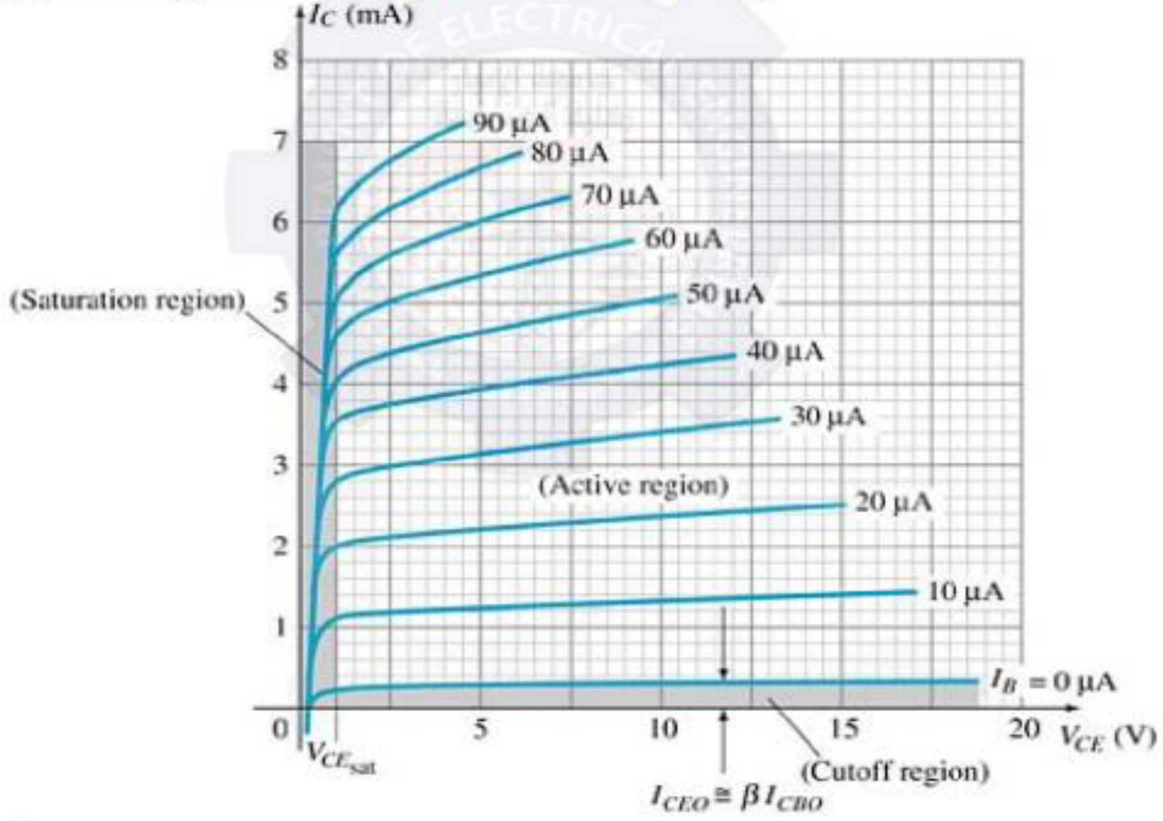
The input is on the base and the output is on the emitter.





Common–Collector Configuration

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

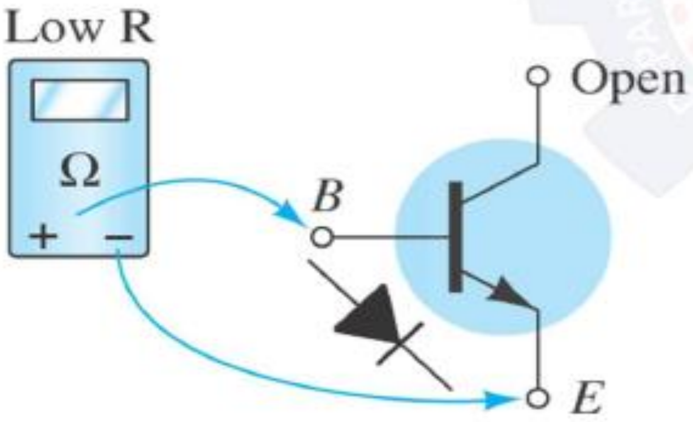


Transistor Testing

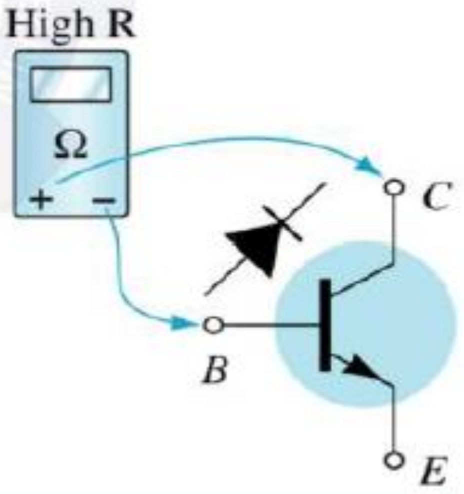
- DMM

  Some DMMs measure β_{DC} or h_{FE}.

- Ohmmeter



Checking the forward-biased base-to-emitter junction of an npn transistor.



Checking the reverse-biased base-to-collector junction of an npn transistor.

(a) (b) (c)

Various types of general-purpose or switching transistors:
(a) low power; (b) medium power; (c) medium to high power.

University of Anbar
College of Engineering
Dept. of Electrical Engineering

Fundumantal of Electronic I

Second Class

Chapter 4 : DC Biasing – BJTs
Lec04_p1

Munther N. Thiyab

2019-2020

Biasing

Biasing: **The DC voltages applied to a transistor in order to turn it on so that it can amplify the AC signal.**

Recall the following basic relationships for a transistor:

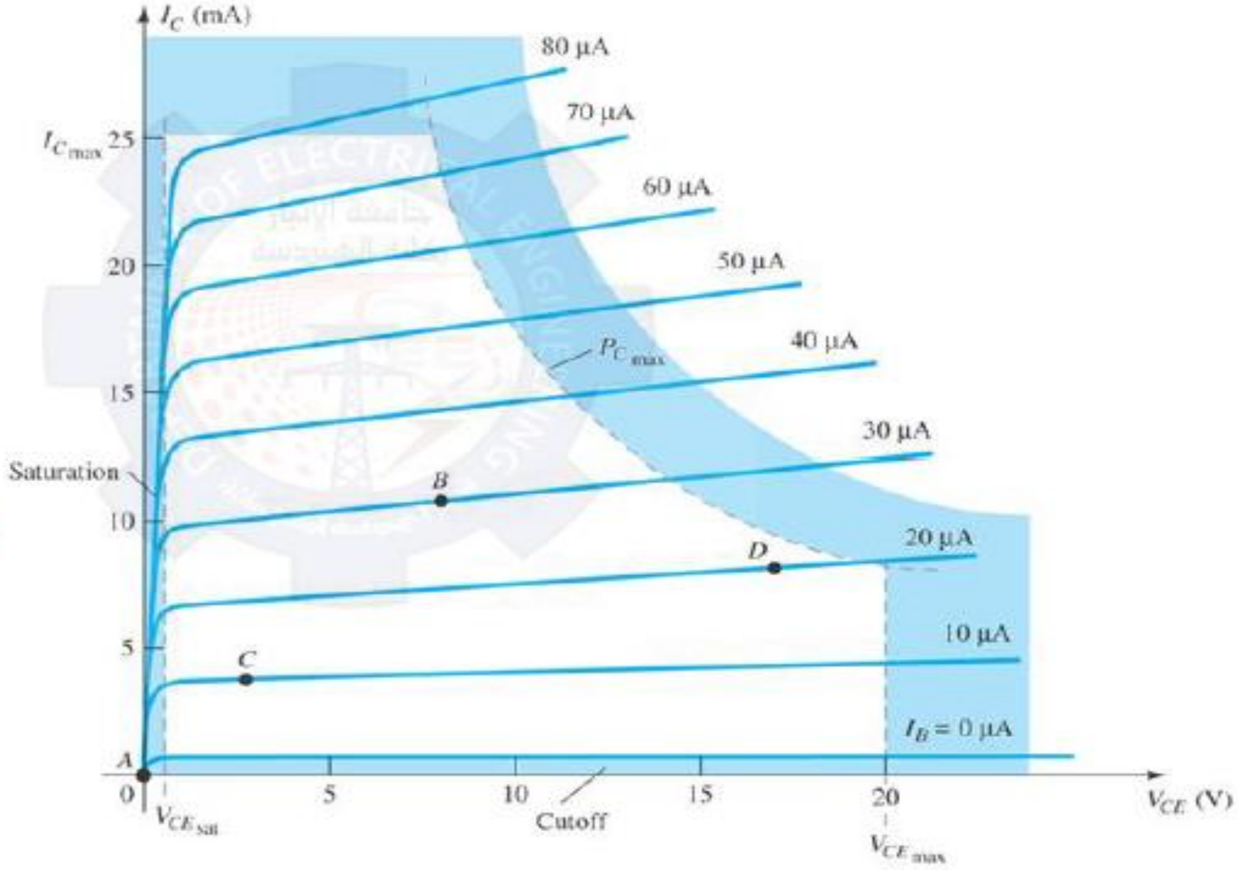
$$V_{BE} = 0.7 \text{ V}$$

$$I_E \quad (\beta + 1) I_\beta$$

$$I_C = \beta I_\beta$$

Operating Point

The DC input establishes an operating or *quiescent point* called the *Q-point*.



Various operating points within the limits of operation of a transistor.

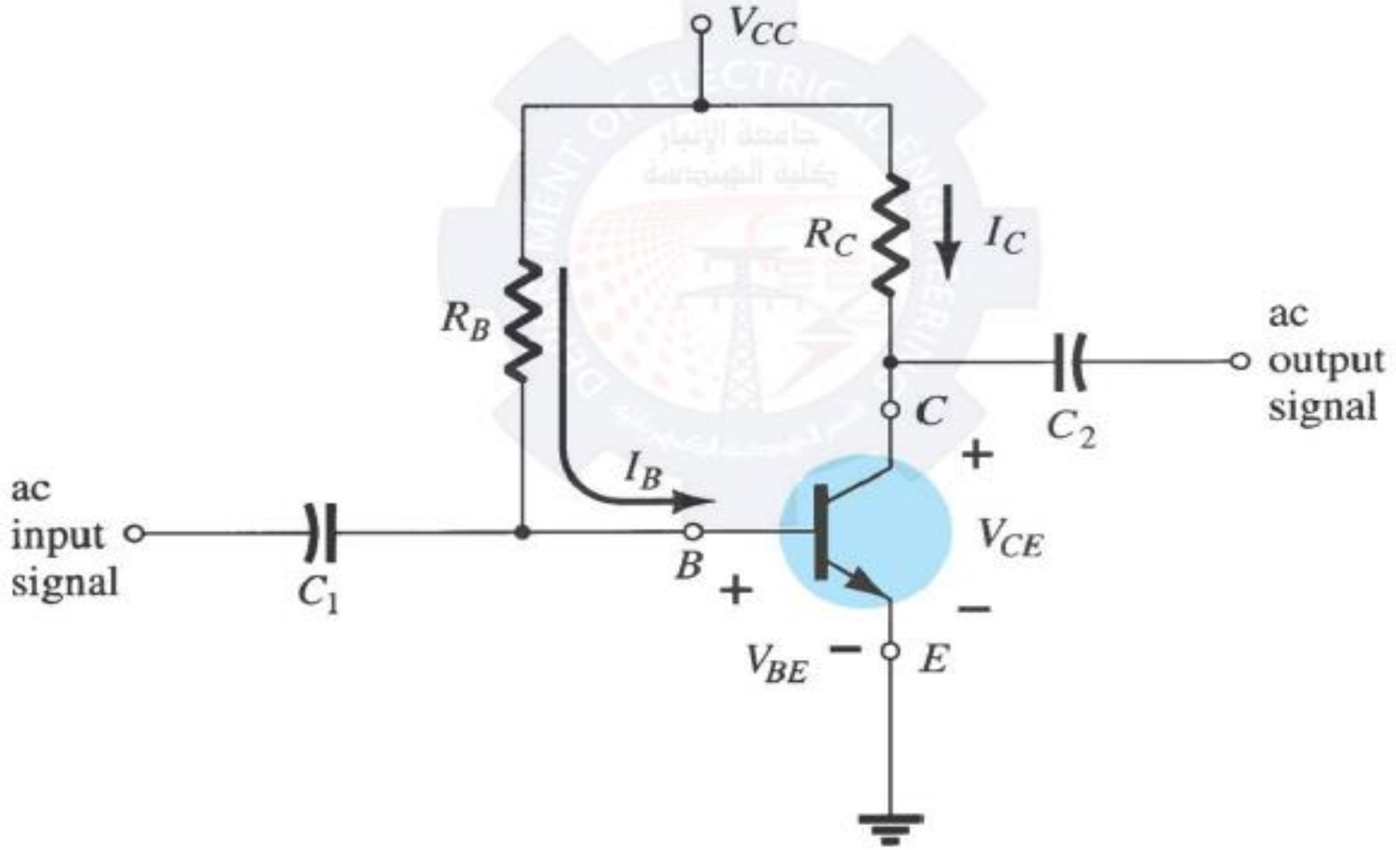
The Three States of Operation

- **Active or Linear Region Operation**
  - Base–Emitter junction is forward biased
  - Base–Collector junction is reverse biased
- **Cutoff Region Operation**
  - Base–Emitter junction is reverse biased
- **Saturation Region Operation**
  - Base–Emitter junction is forward biased
  - Base–Collector junction is forward biased

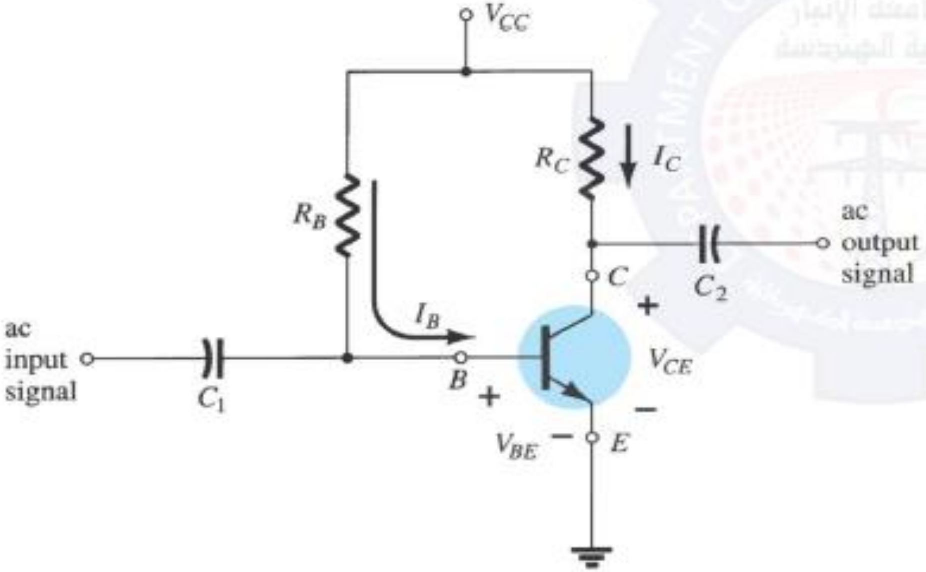
DC Biasing Circuits

- Fixed-bias circuit
- Emitter-stabilized bias circuit
- Collector-emitter loop
- Voltage divider bias circuit
- DC bias with voltage feedback

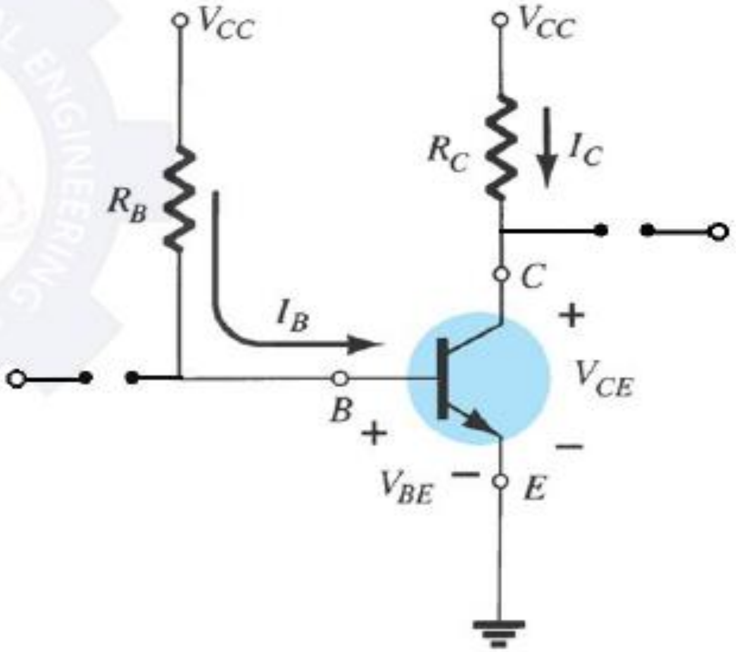
Fixed Bias configuration



Fixed Bias configuration



Fixed bias circuit



DC equivalent

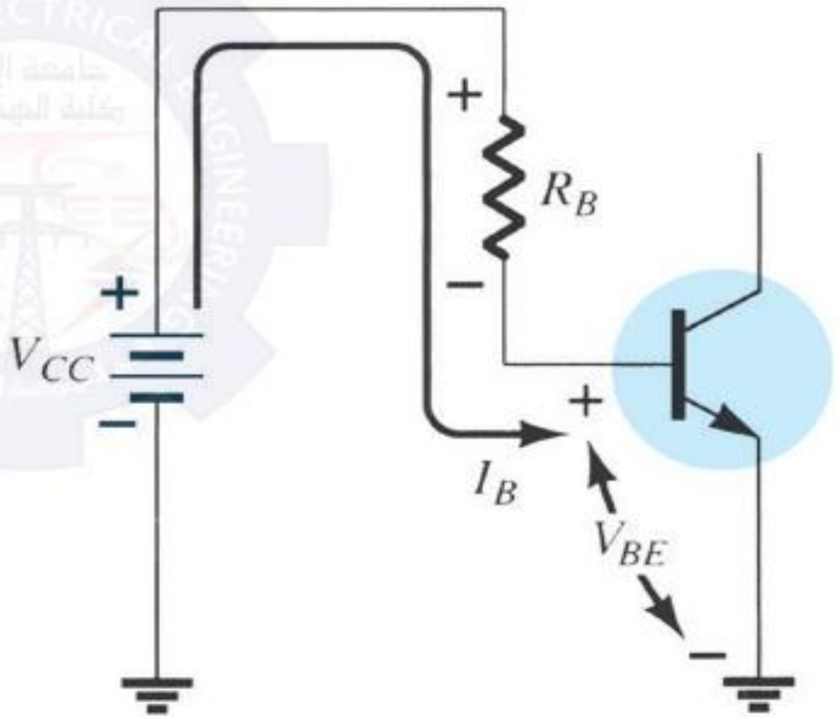
The Base-Emitter Loop

From Kirchhoff's voltage law:

$$+V_{CC} - I_B R_B - V_{BE} = 0$$

Solving for base current:

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



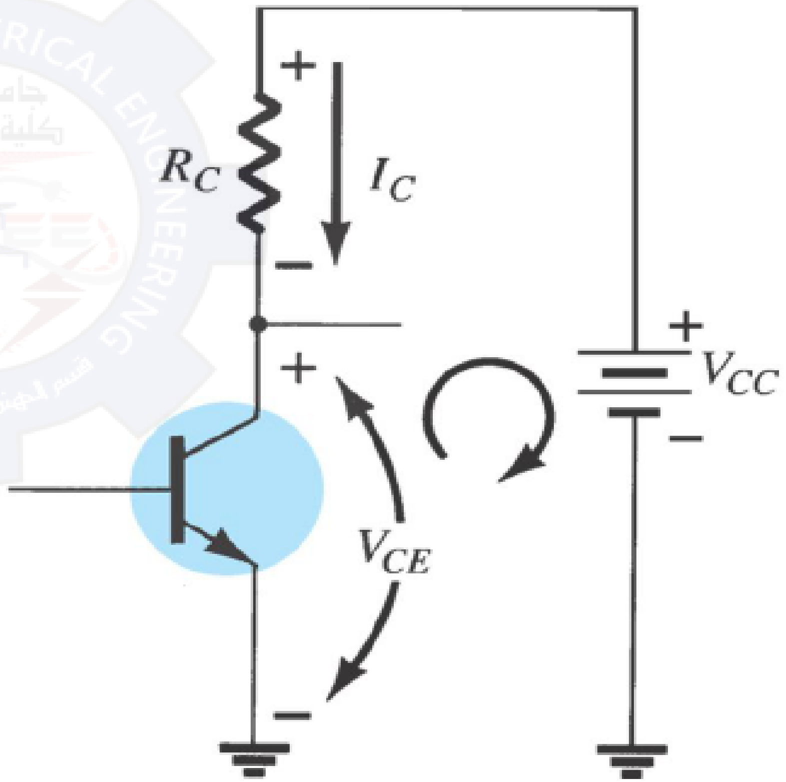
Collector-Emitter Loop

Collector current:

$$I_C = \beta I_B$$

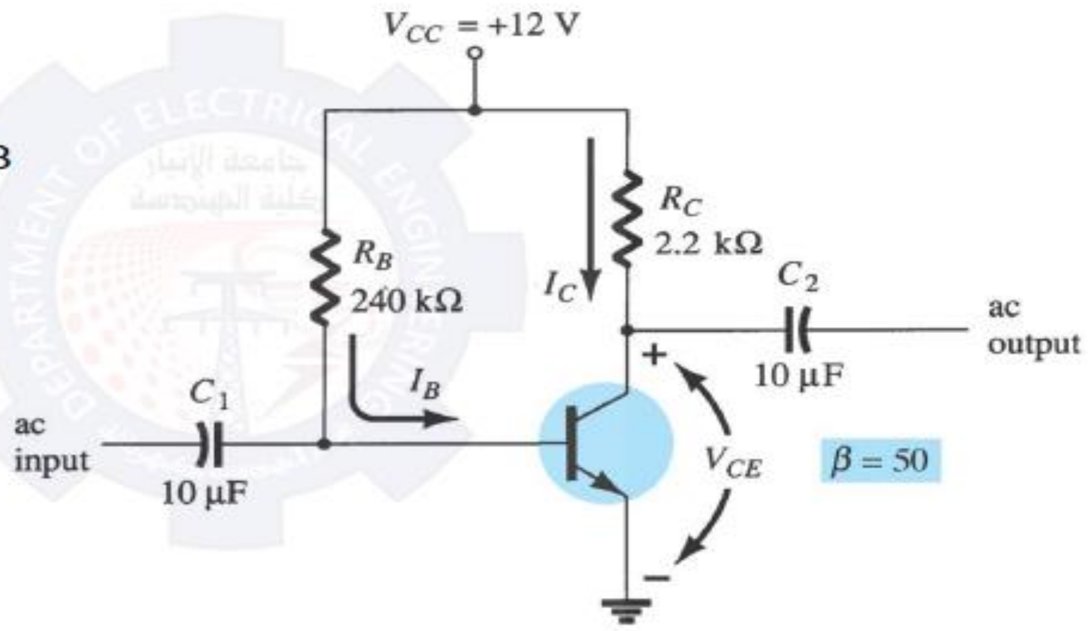
From Kirchhoff's voltage law:

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

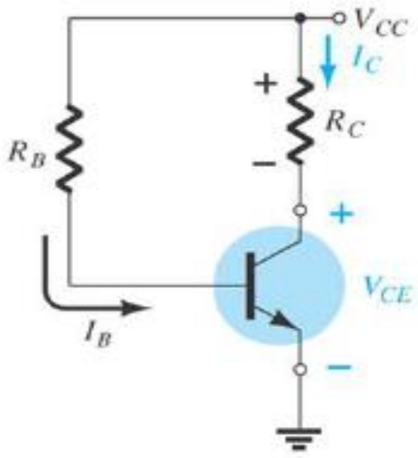


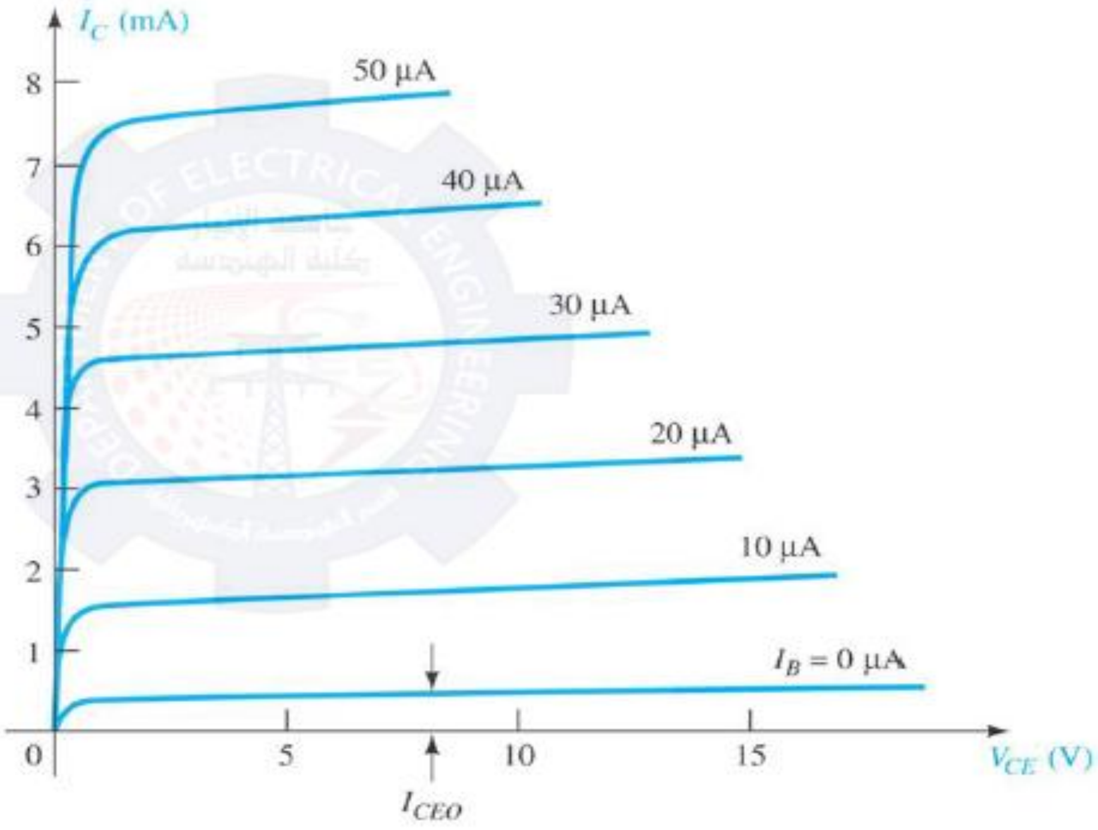
Example 4.1

Find I_{BQ} , I_{CQ} , V_{CEQ} , V_B , V_C , V_{BC}.



Load Line Analysis





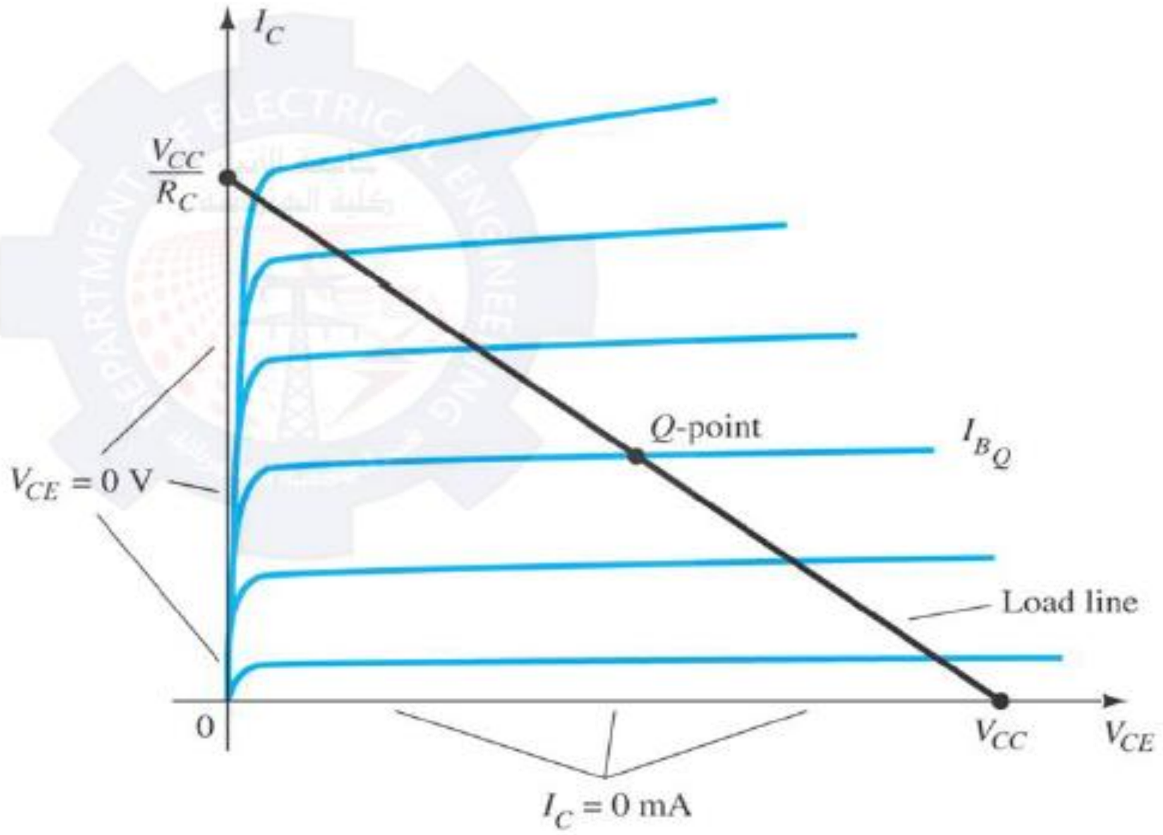
$$V_{CE} = V_{CC} - I_C R_C$$

Load Line Analysis

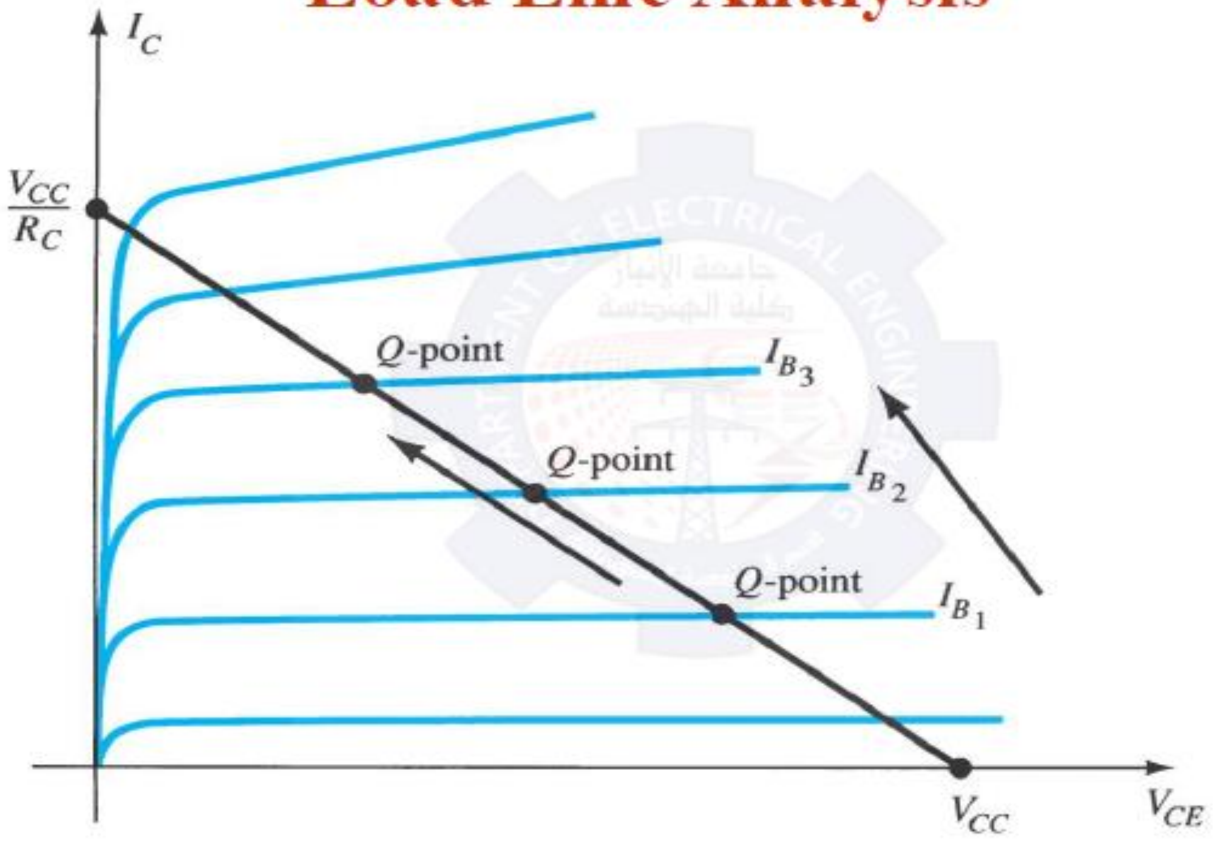
$$V_{CE} = V_{CC} - I_C R_C$$

$$V_{CE} = V_{CC} \Big|_{I_C = 0mA}$$

$$I_C = \frac{V_{CC}}{R_C} \Big|_{V_{CE} = 0V}$$

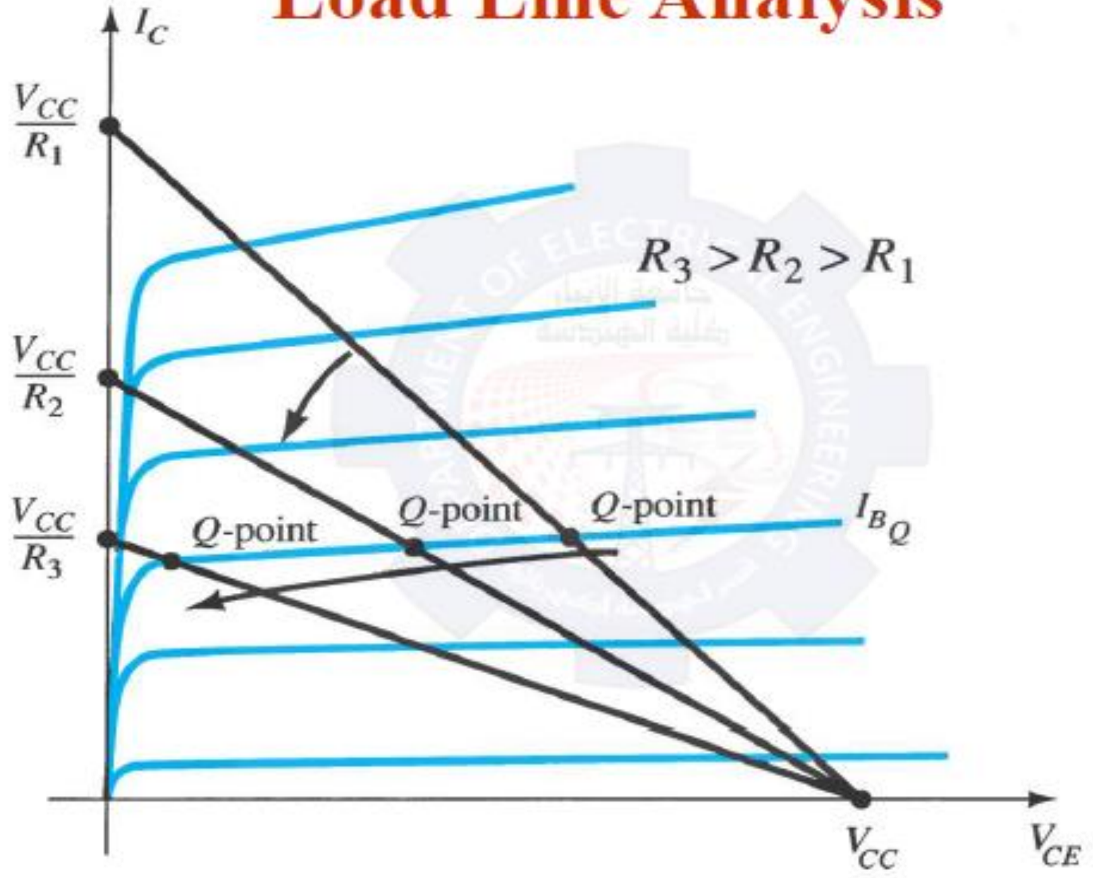


Load Line Analysis



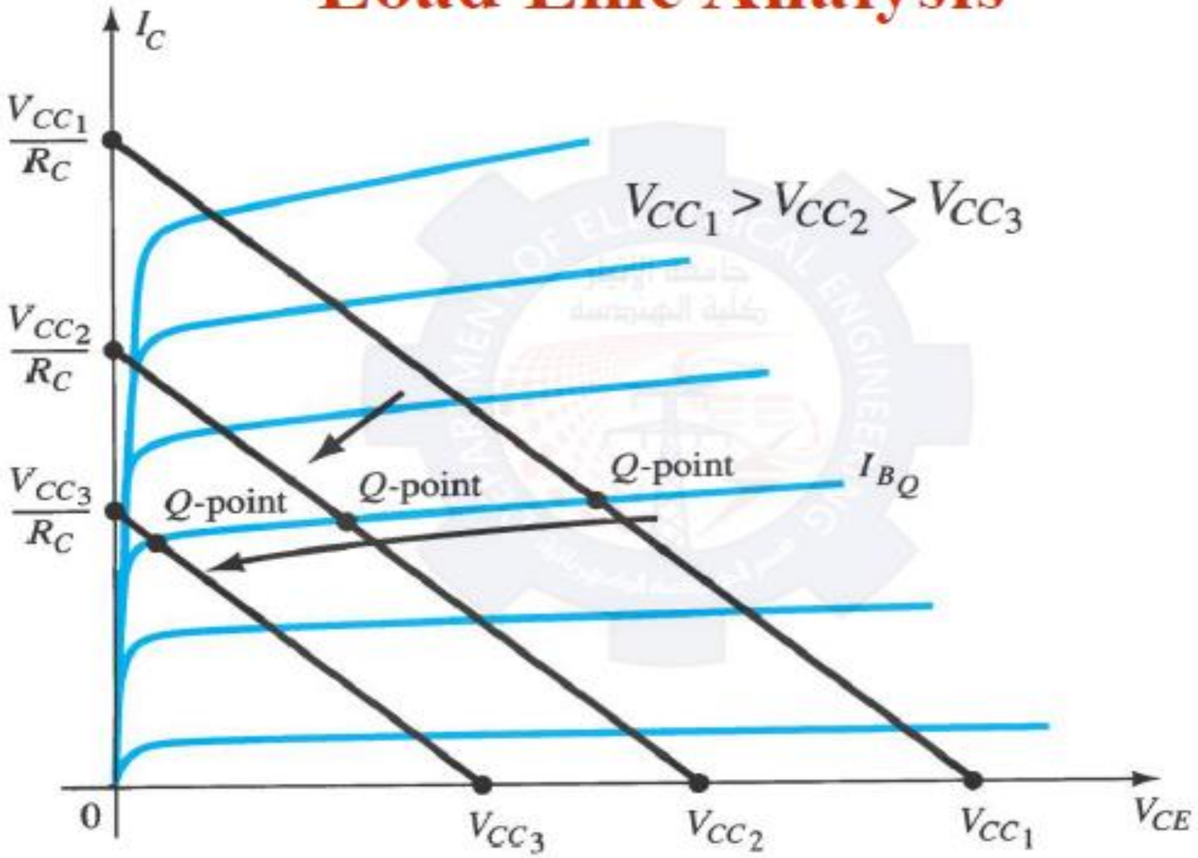
Movement of the *Q*-point with increasing level of I_B.
(The level of I_B is changed by varying the value of R_B)

Load Line Analysis



Effect of an increasing level of R_C on the load line and the Q-point. (V_{CC} fixed)

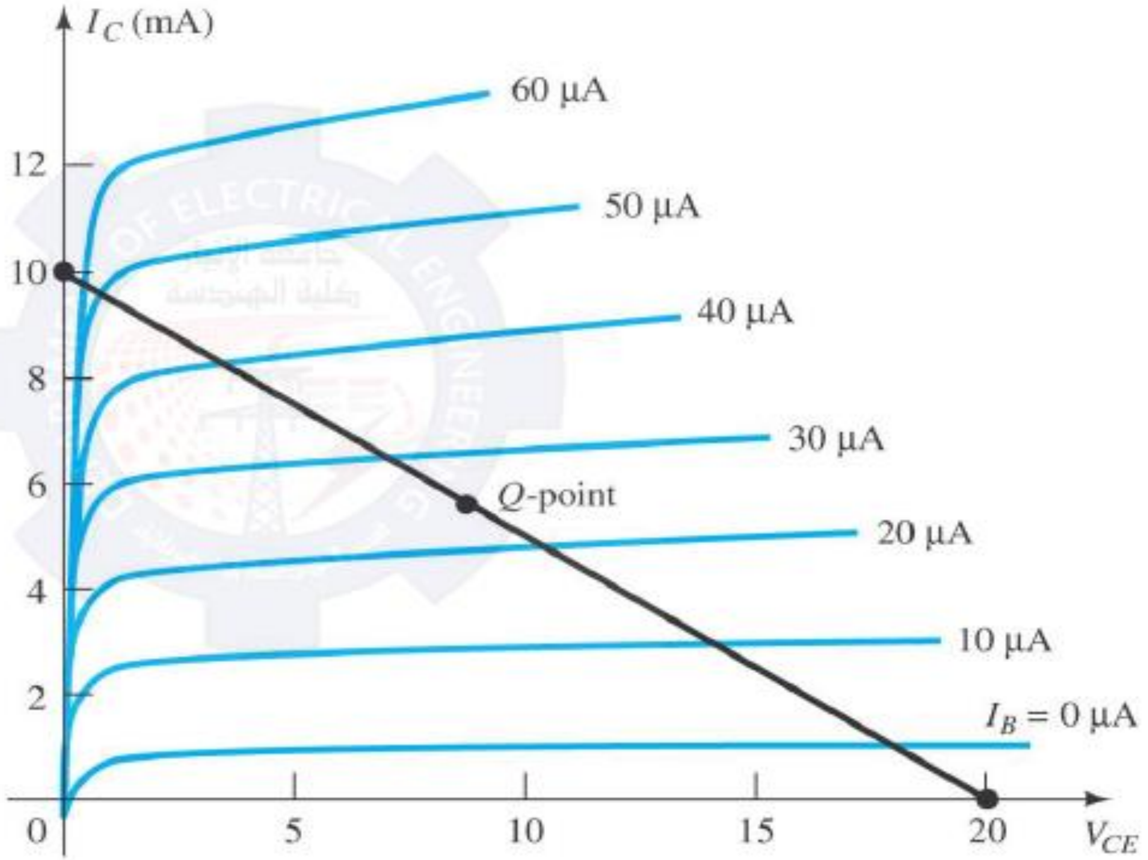
Load Line Analysis



Effect of lower values of V_{CC} on the load line and the Q-point.

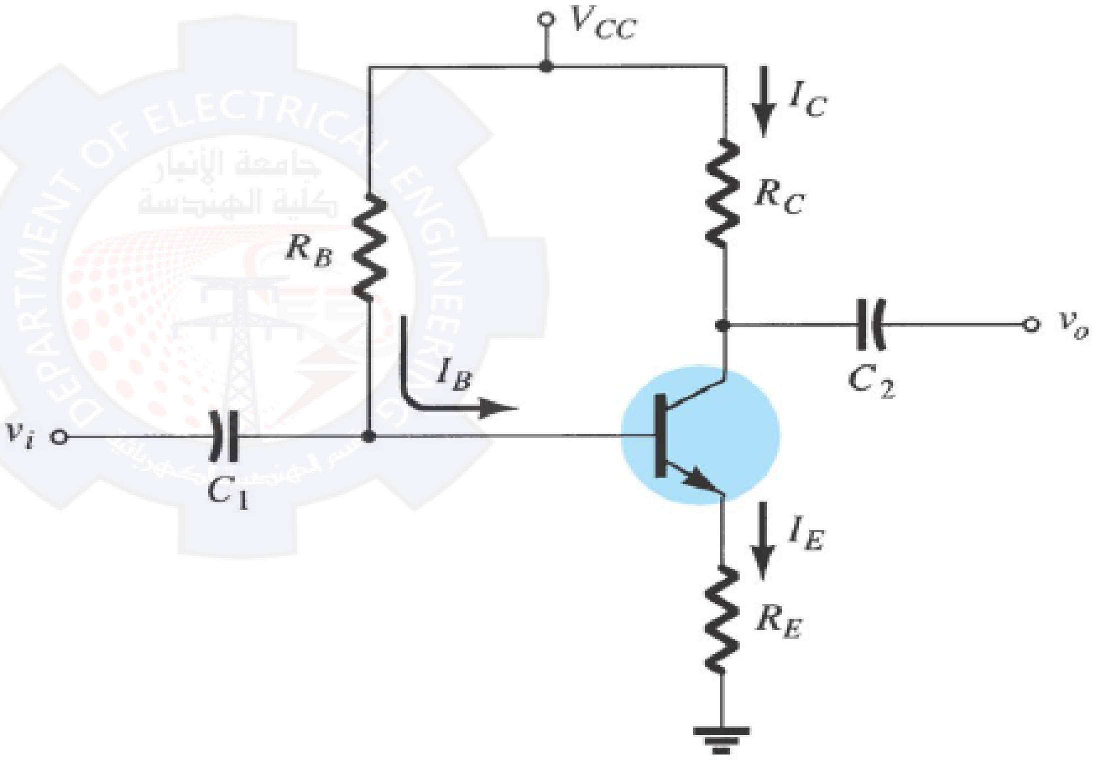
Example 4.3

Find V_{CC}, R_C, R_B for the fixed biasing configuration

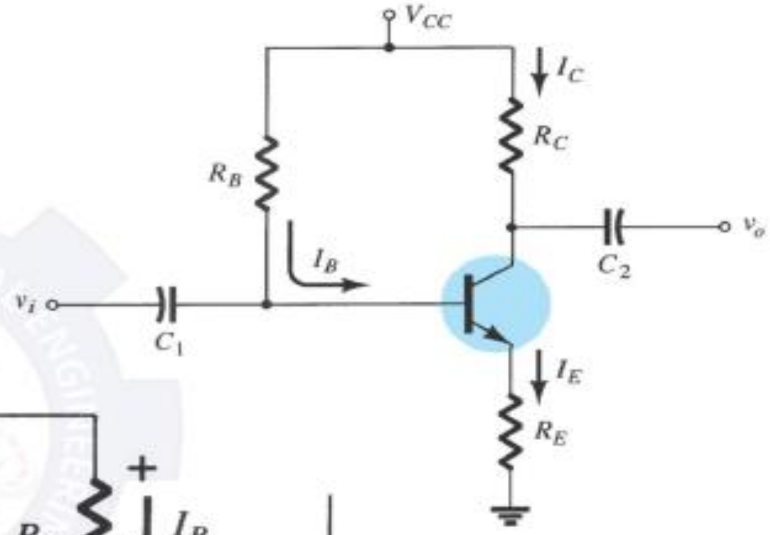


Emitter-Stabilized Bias Circuit

Adding a resistor (R_E) to the emitter circuit stabilizes the bias circuit.



Base-Emitter Loop



From Kirchhoff's voltage law:

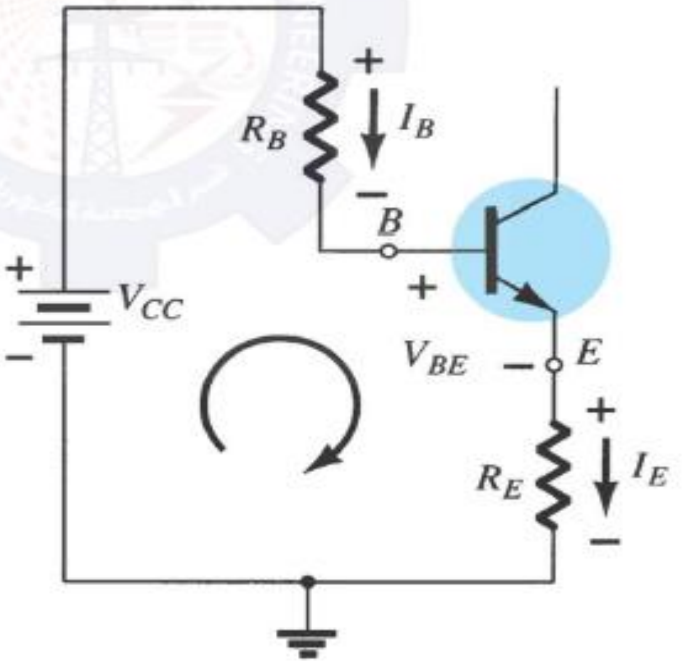
$$+V_{CC} - I_E R_E - V_{BE} - I_E R_E = 0$$

Since $I_E = (\beta + 1) I_B$:

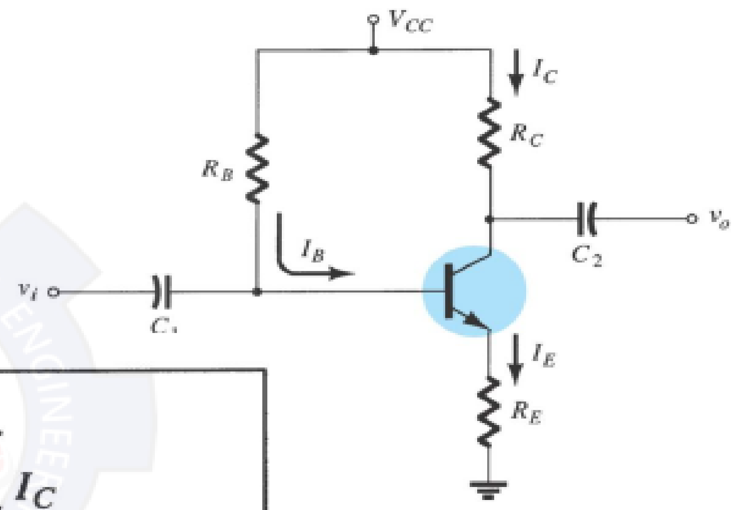
$$V_{CC} - I_B R_B - (\beta + 1) I_B R_E = 0$$

Solving for I_B:

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1) R_E}$$



Collector-Emitter Loop



From Kirchhoff's voltage law:

$$I_E R_E + V_{CE} + I_C R_C - V_{CC} = 0$$

Since $I_E \cong I_C$:

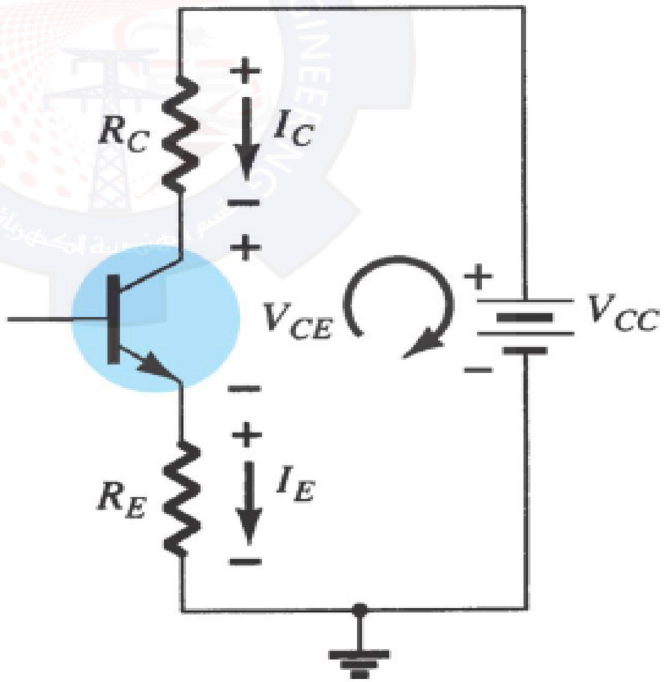
$$V_{CE} = V_{CC} - I_C(R_C + R_E)$$

Also:

$$V_E = I_E R_E$$

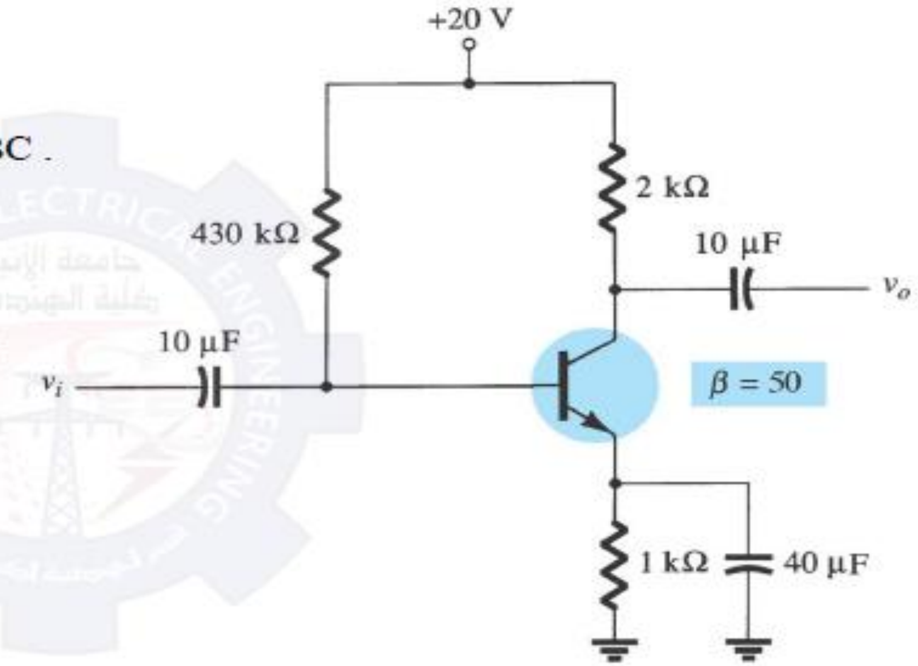
$$V_C = V_{CE} + V_E = V_{CC} - I_C R_C$$

$$V_B = V_{CC} - I_R R_B = V_{BE} + V_E$$



Example 4.4

Find I_B, I_C, V_{CE}, V_C, V_E, V_B, V_{BC}.

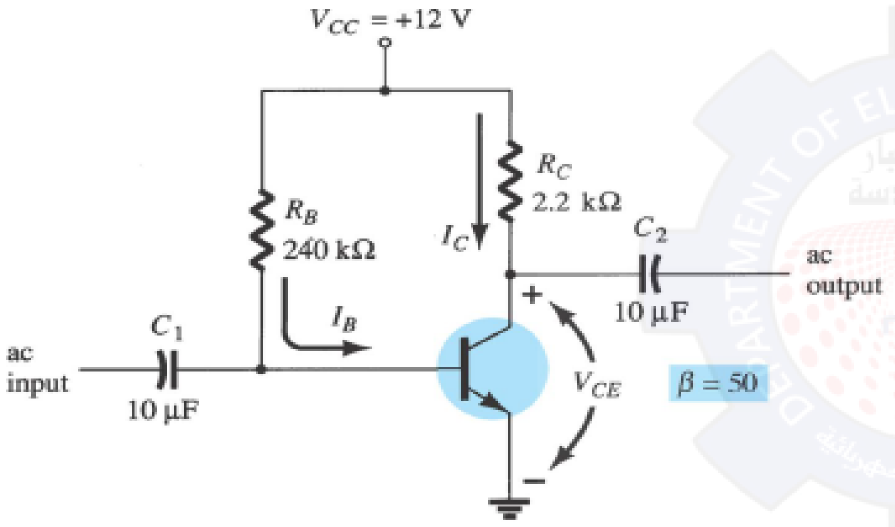


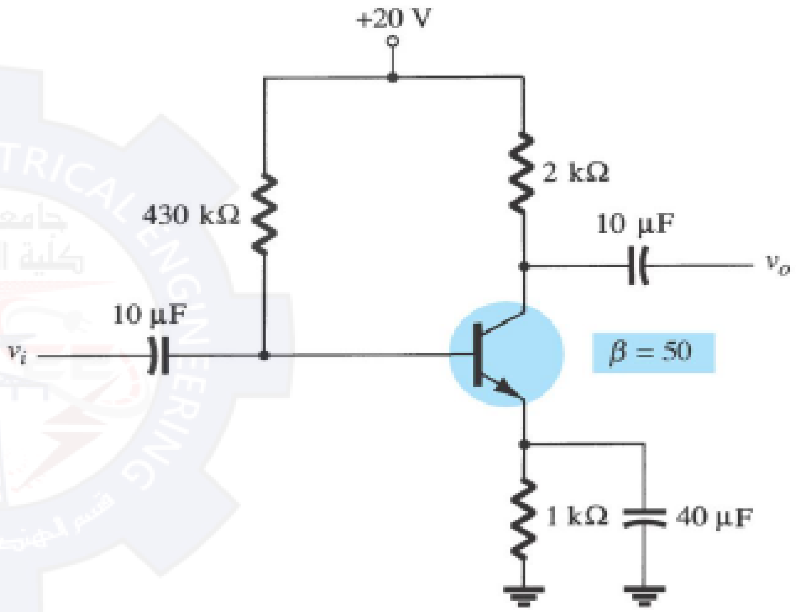
Improved Biased Stability

Stability refers to a circuit condition in which the currents and voltages will remain fairly constant over a wide range of temperatures and transistor Beta (β) values.

Adding R_E to the emitter improves the stability of a transistor.

Improved Biased Stability





β	I_B (μA)	I_C (mA)	V_{CE} (V)
50	47.08	2.35	6.83
100	47.08	4.71	1.64

β	I_B (μA)	I_C (mA)	V_{CE} (V)
50	40.1	2.01	13.97
100	36.3	3.63	9.11

Saturation Level

The collector saturation level or maximum collector current for an emitter-bias design can be determined using the same approach applied to the fixed-bias configuration: Apply a short circuit between the collector–emitter terminals as shown in Fig. 4.24 and calculate the resulting collector current. For Fig. 4.24

$$I_{C_{sat}} = \frac{V_{CC}}{R_C + R_E} \tag{4.25}$$

The addition of the emitter resistor reduces the collector saturation level below that obtained with a fixed-bias configuration using the same collector resistor.

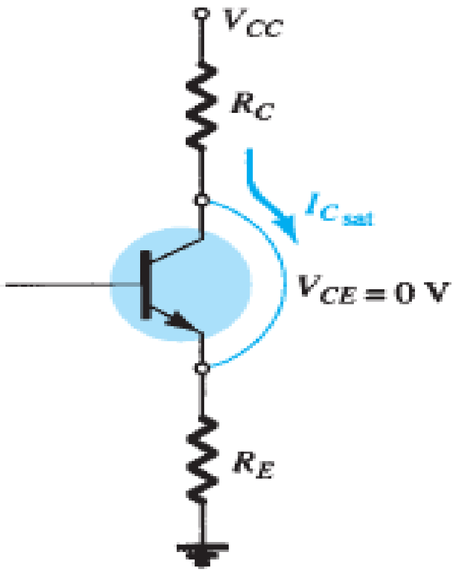


FIG. 4.24
Determining $I_{C_{sat}}$ for the emitter-stabilized bias circuit.

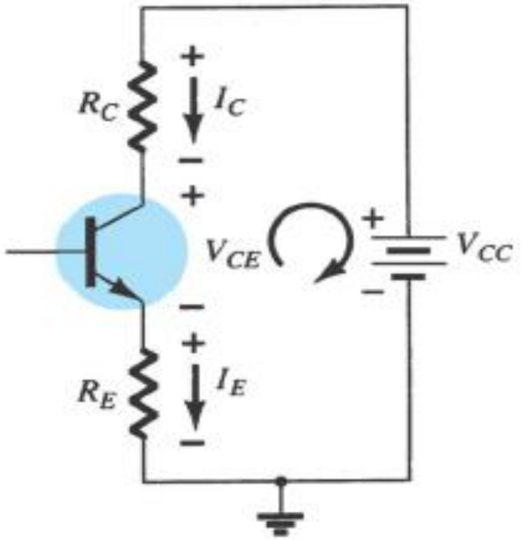
EXAMPLE 4.6 Determine the saturation current for the network of Example 4.4.

Solution:

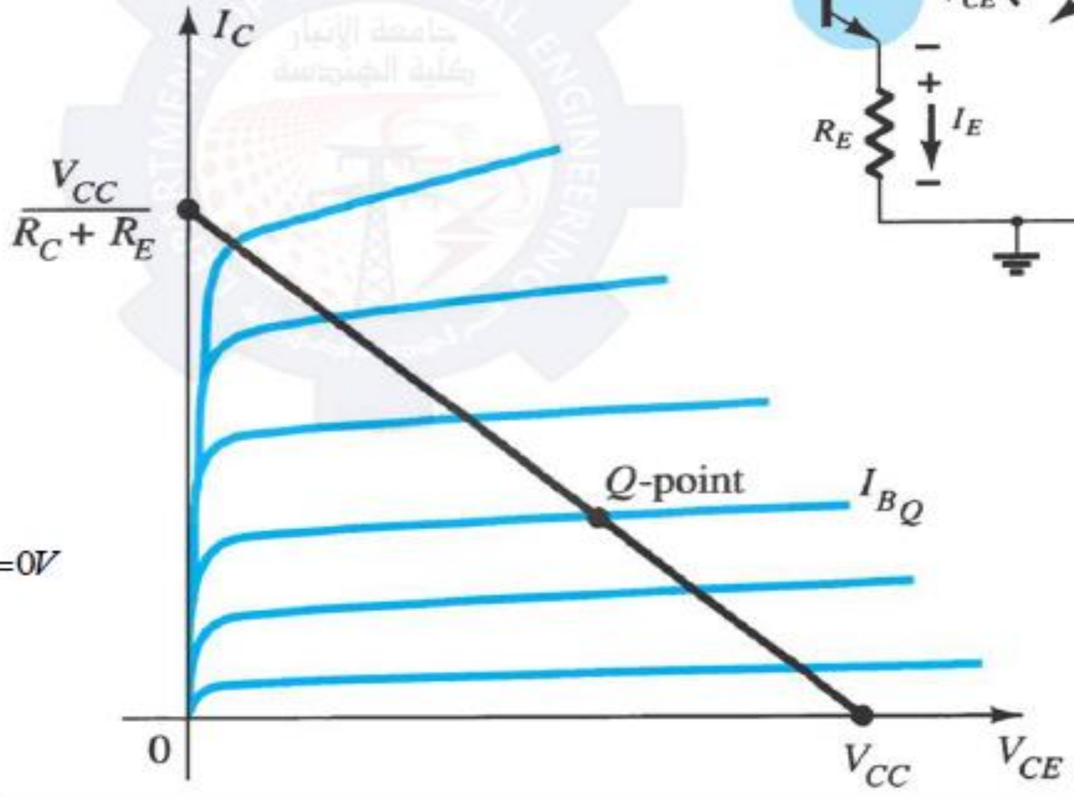
$$\begin{aligned} I_{C_{sat}} &= \frac{V_{CC}}{R_C + R_E} \\ &= \frac{20\text{ V}}{2\text{ k}\Omega + 1\text{ k}\Omega} = \frac{20\text{ V}}{3\text{ k}\Omega} \\ &= \mathbf{6.67\text{ mA}} \end{aligned}$$

which is about three times the level of I_{C_Q} for Example 4.4.

Load Line Analysis



$$V_{CE} = V_{CC} - I_C (R_C + R_E$$



$$V_{CE} = V_{CC} \Big|_{I_C = 0mA}$$

$$I_C = \frac{V_{CC}}{R \quad + R_E} \Bigg|_{V_{CE} = 0V}$$

Choosing $I_C = 0$ mA gives

$$\boxed{V_{CE} = V_{CC}\big|_{I_C = 0\,\text{mA}}} \tag{4.26}$$

as obtained for the fixed-bias configuration. Choosing $V_{CE} = 0$ V gives

$$\boxed{I_C = \frac{V_{CC}}{R_C + R_E}\bigg|_{V_{CE} = 0\,\text{V}}} \tag{4.27}$$

as shown in Fig. 4.25. Different levels of I_{B_Q} will, of course, move the Q-point up or down the load line.

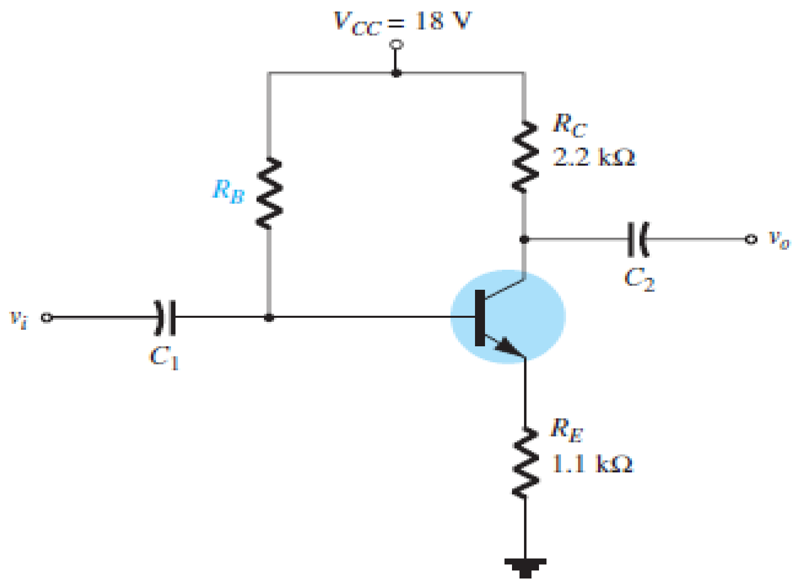


FIG. 4.26a
Network for Example 4.7.

EXAMPLE 4.7

a. Draw the load line for the network of Fig. 4.26a on the characteristics for the transistor appearing in Fig. 4.26b.
b. For a Q-point at the intersection of the load line with a base current of 15 μA, find the values of I_{C_Q} and V_{CE_Q}.
c. Determine the dc beta at the Q-point.
d. Using the beta for the network determined in part c, calculate the required value of R_B and suggest a possible standard value.

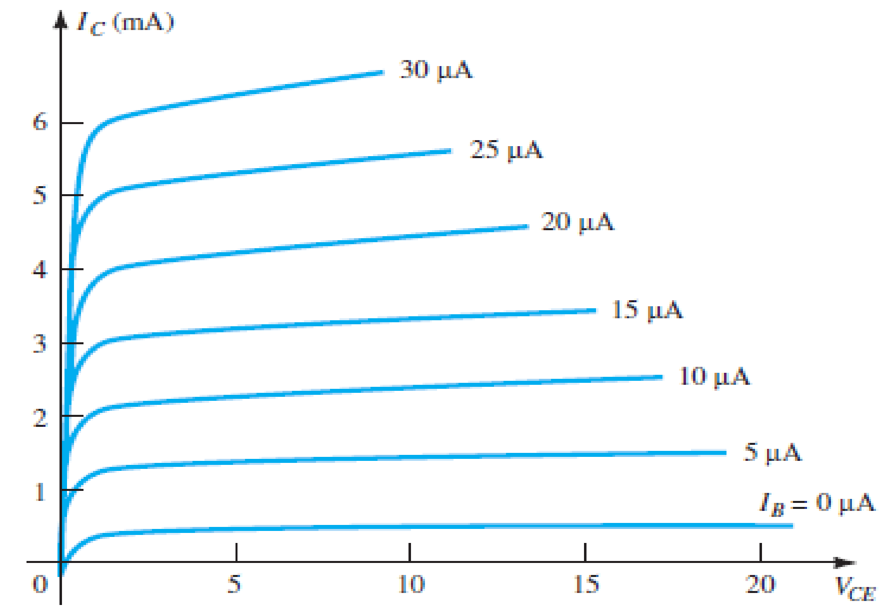


FIG. 4.26b
Example 4.7.

Solution:

a. Two points on the characteristics are required to draw the load line.

At $V_{CE} = 0$ V: $I_C = \dfrac{V_{CC}}{R_C + R_E} = \dfrac{18\text{ V}}{2.2\text{ k}\Omega + 1.1\text{ k}\Omega} = \dfrac{18\text{ V}}{3.3\text{ k}\Omega} = 5.45\text{ mA}$

At $I_C = 0$ mA: $V_{CE} = V_{CC} = 18$ V

The resulting load line appears in Fig. 4.27.

b. From the characteristics of Fig. 4.27 we find

$V_{CE_Q} \cong$ **7.5 V**, $I_{C_Q} \cong$ **3.3 mA**

c. The resulting dc beta is:

$$\beta = \frac{I_{C_Q}}{I_{B_Q}} = \frac{3.3\text{ mA}}{15\ \mu\text{A}} = \mathbf{220}$$

d. Applying Eq. 4.17:

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E} = \frac{18\text{ V} - 0.7\text{ V}}{R_B + (220 + 1)(1.1\text{ k}\Omega)}$$

and $15\ \mu\text{A} = \dfrac{17.3\text{ V}}{R_B + (221)(1.1\text{ k}\Omega)} = \dfrac{17.3\text{ V}}{R_B + 243.1\text{ k}\Omega}$

so that $(15\ \mu\text{A})(R_B) + (15\ \mu\text{A})(243.1\text{ k}\Omega) = 17.3\text{ V}$

and $(15\ \mu\text{A})(R_B) = 17.3\text{ V} - 3.65\text{ V} = 13.65\text{ V}$

resulting in $R_B + \dfrac{13.65\text{ V}}{15\ \mu\text{A}} = \mathbf{910\ k\Omega}$

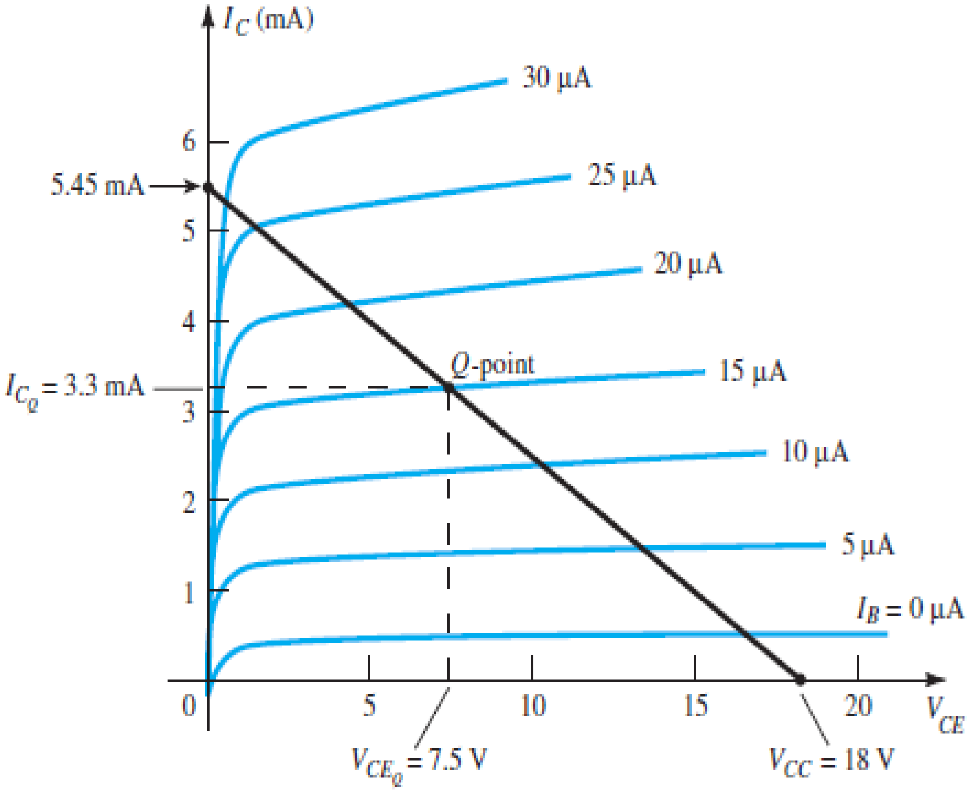


FIG. 4.27
Example 4.7.

THE END