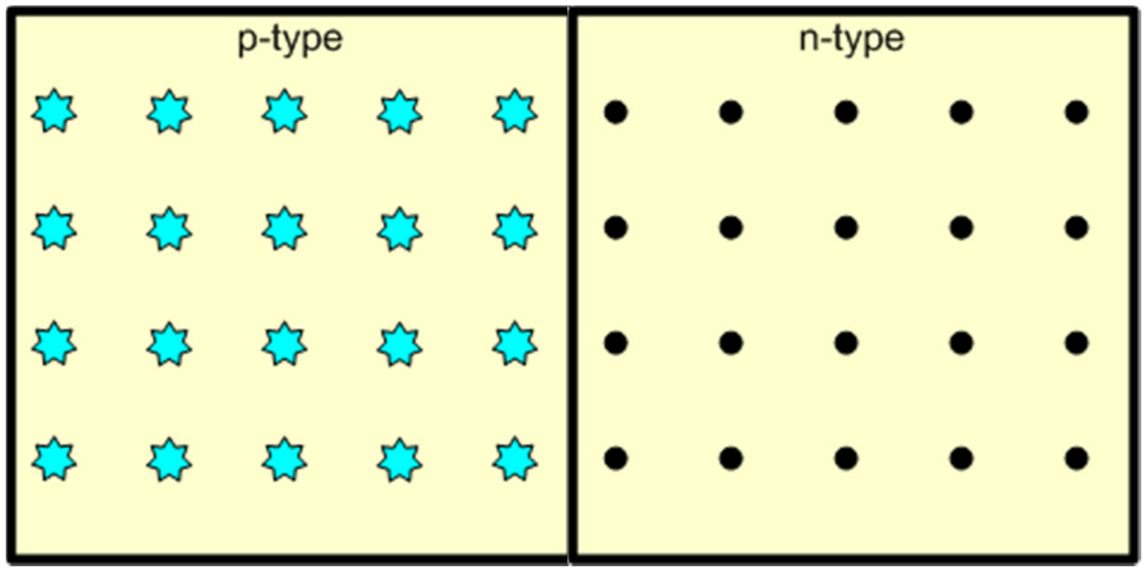
The p-n junction   تكوين الوصلة p-n

Suppose we join a piece of p-type silicon to a piece of n-type silicon



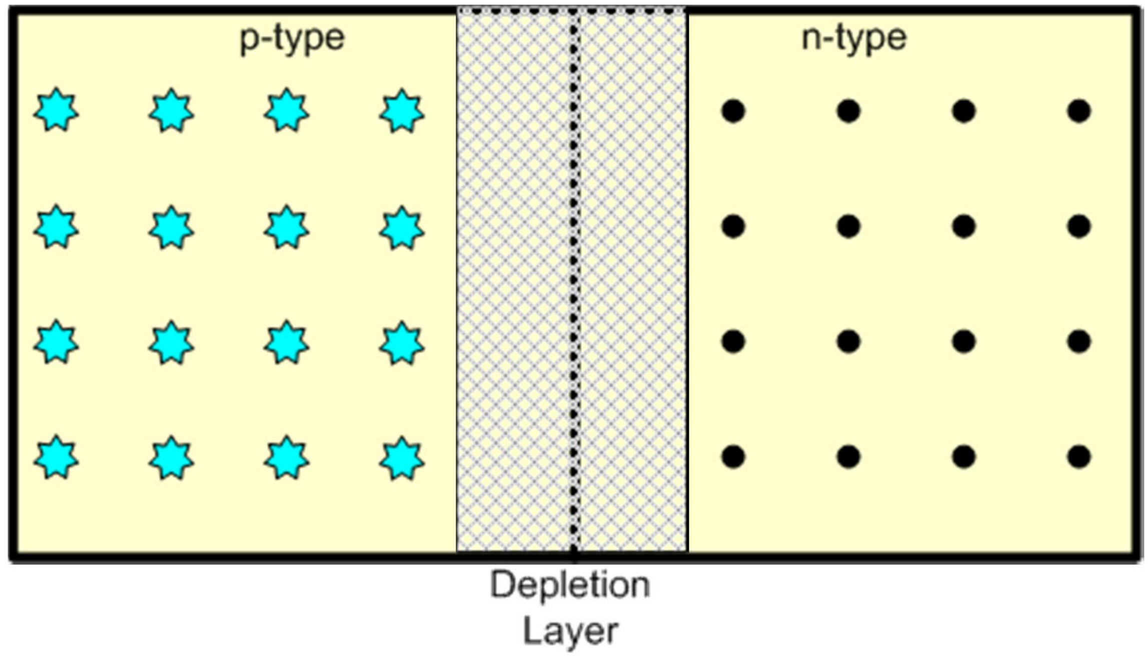
We get what is called a p-n junction

Remember – both pieces are electrically neutral

The p-n Junction

When initially joined electrons from the n-type migrate into the p-type

When an electron fills a hole – both the electron and hole disappear



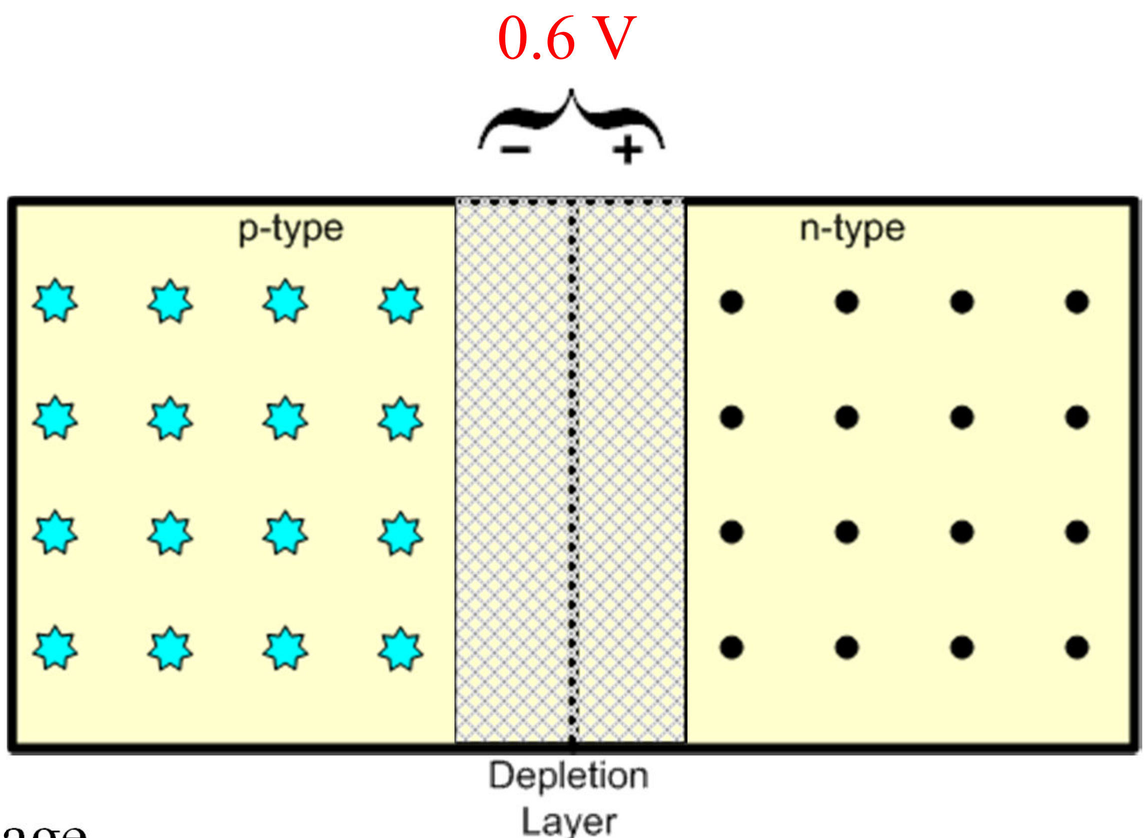
This leaves a region with no free charge carriers – the depletion layer – this layer acts as an insulator

The p-n Junction

As the p-type has gained electrons – it is left with an overall negative charge…

As the n-type has lost electrons – it is left with an overall positive charge…

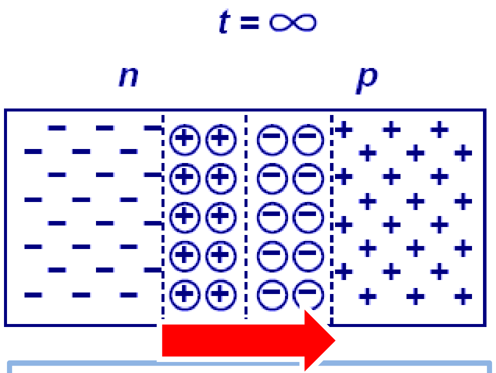
Therefore there is a voltage across the junction – the junction voltage – for silicon this is approximately 0.6 V



يسمى الجهد المتكون بين جانبي منطقة النضوب:

جهد الوصلة the junction voltage

offset voltage أو Built-In voltage V_B.



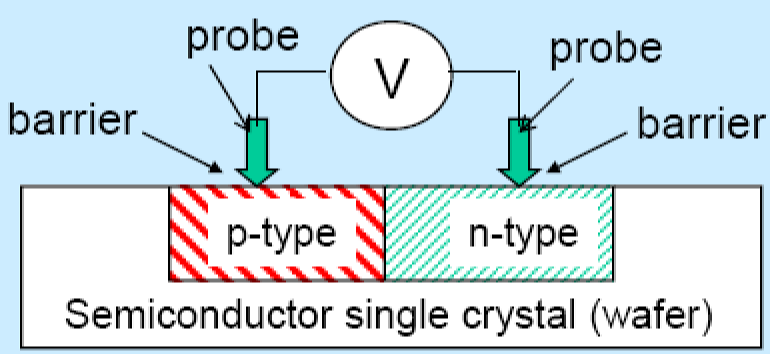
يتكون مجال كهربي.

تصبح هذه المنطقة كحاجز يعيق مرور الشحنات.

هل يقاس جهد بين طرفي الوصلة؟؟؟

Built-in Potential Barrier or Built-in Voltage (Vbi) across the depletion region can not be measured by a voltmeter because new potetial barriers form between the probes of the voltmeter and the semiconductor, canceling the effects of Vbi.

Therefore, it only can be determined or predicted from the calculation using previous equation.



The depletion region of a p−n junction is what gives diodes, transistors, and all other semiconductors their useful properties.

The p-n junction   تكوين الوصلة p-n

Built-in Potential Barrier or Built-in Voltage (Vbi)

$$V_{bi} = \frac{kT}{e}\ln\left(\frac{N_a N_d}{n_i^2}\right) = V_T \ln\left(\frac{N_a N_d}{n_i^2}\right)$$

V_T: Thermal voltage
k: Boltzman's constant
T: absolute temperature(K)
e: electronic charge
N_a: acceptor concentration
N_d: donor concentration

$V_T = kT/e$; $V_T = 0.026\text{V}$ at $300K$

Example: Calculate the V_B of a p-n junction.

Consider a silicon p-n junction at T=300 K, doped at $N_a = 10^{16}$ cm^{-3} in the p-region and $N_d = 10^{17}$ cm^{-3} in the n-region.
Here, $n_i = 1.5\times10^{10}$ cm^{-3}.

Answer: $V_B = 0.757$ V

The current in the junction التيار المار في الوصلة

ما هو تيار الانتشار Diffusion current؟

هو التيار الناتج عن انتشار حاملات الشحنة من المنطقة الأكثر تركيز إلى الأقل تركيز.

ينتج عن حركة شحنات الأغلبية.

ما هي الشحنات الأغلبية majority carriers؟

ما هو تيار الدفع Drift current؟

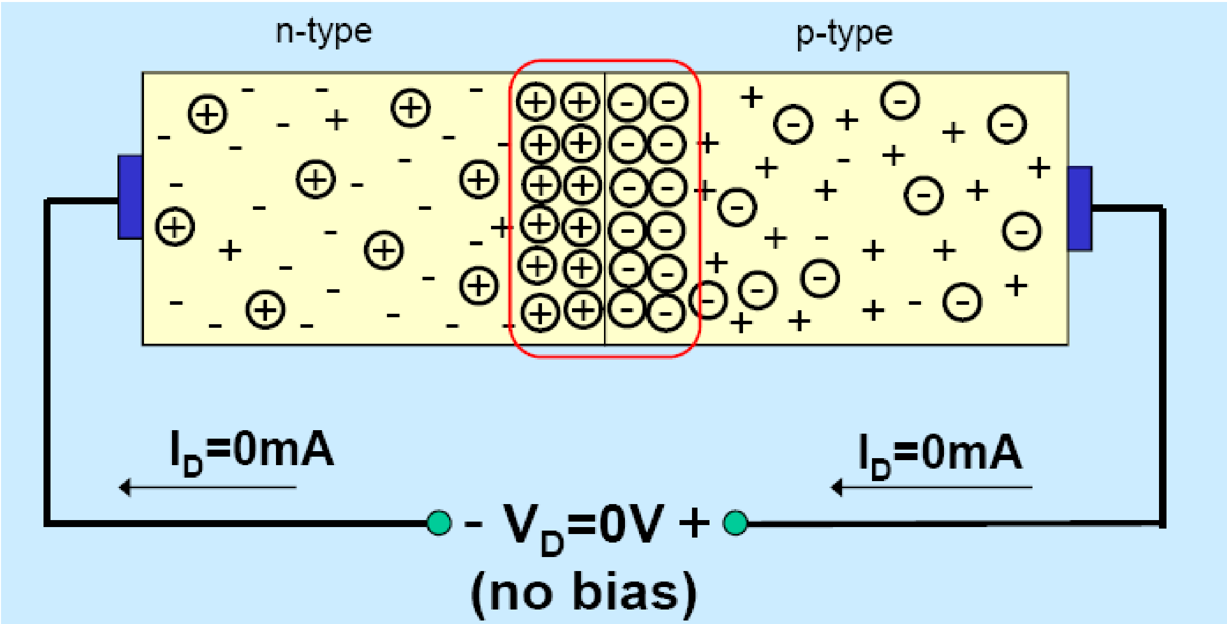
هو التيار الناتج عن حركة حاملات الشحنة نتيجة الجهد المطبق.

ينتج عن حركة شحنات الأقلية.

ما هي الشحنات الأقلية minority carriers؟

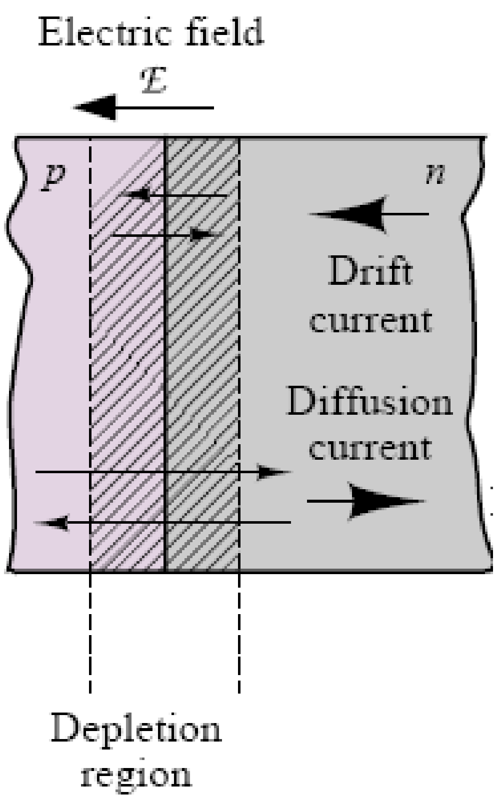
The current in the junction التيار المار في الوصلة

هل يمر تيار بين طرفي الوصلة pn؟



In the absence of an applied bias voltage, the net flow of charge in any one direction for a p-n junction is zero.

The current in the junction التيار المار في الوصلة

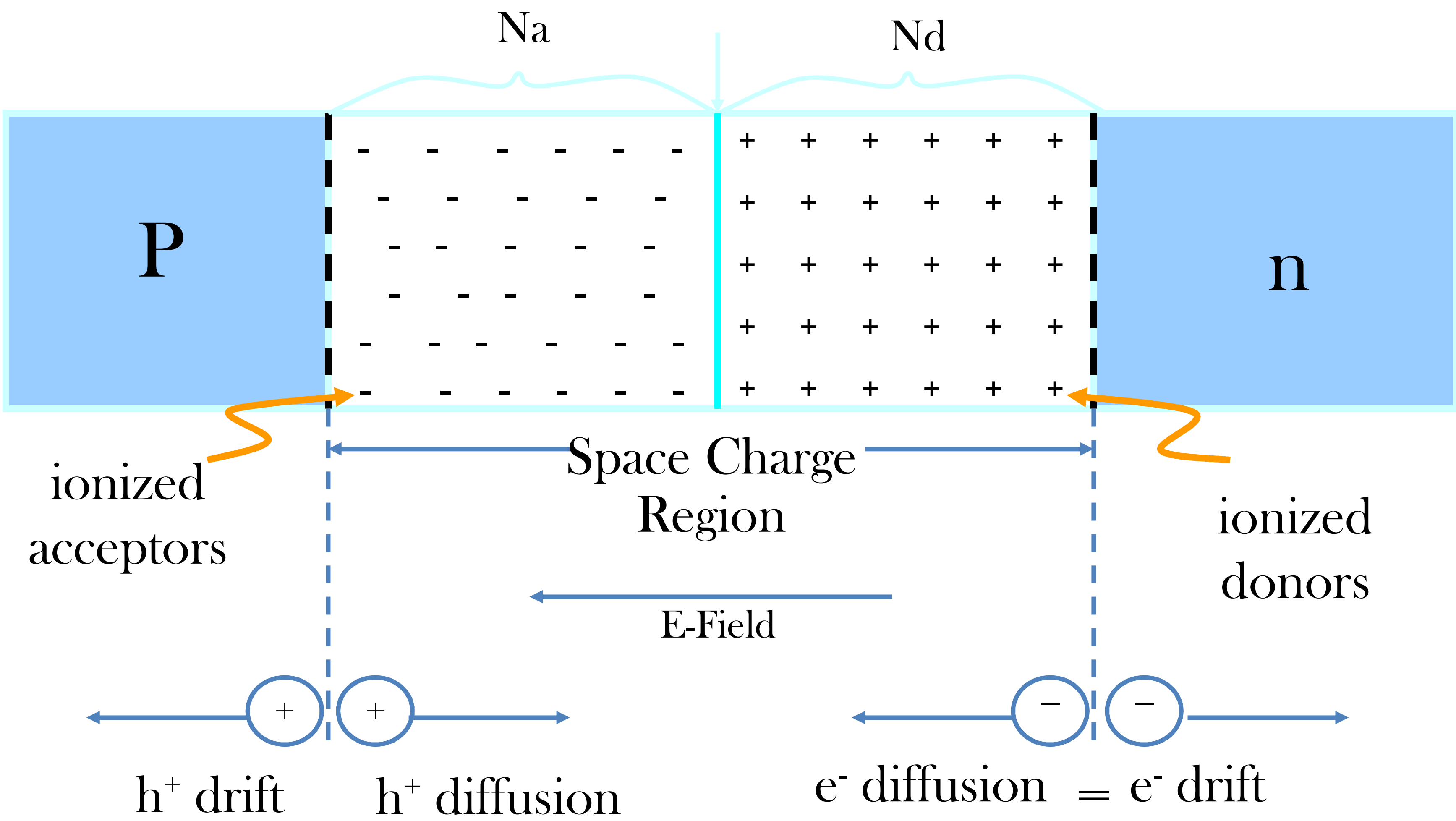


1- يمر تيار يسمى تيار الانتشار I_D (Diffusion current) ينتج من انتشار بعض شحنات الأكثرية (الكترونات في الجانب n وثقوب في الجانب p).

2- يمر تيار يسمى تيار الدفع I_S (Drift current) ينتج من اندفاع بعض شحنات الأقلية (الكترونات في الجانب p وثقوب في الجانب n) التي تملك طاقة حرارية كلا باتجاه الجهد المعاكس له.

reverse saturation current I_0

The current in the junction التيار المار في الوصلة



The current in the junction التيار المار في الوصلة

PN Junction in Equilibrium

In equilibrium, the drift and diffusion components of current are balanced; therefore the net current flowing across the junction is zero.

$$J_{p,drift} = -J_{p,diff}$$

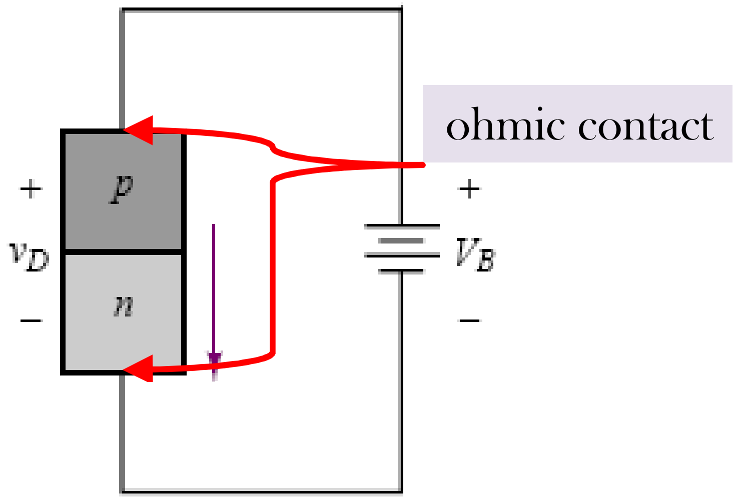
$$J_{n,drift} = -J_{n,diff}$$

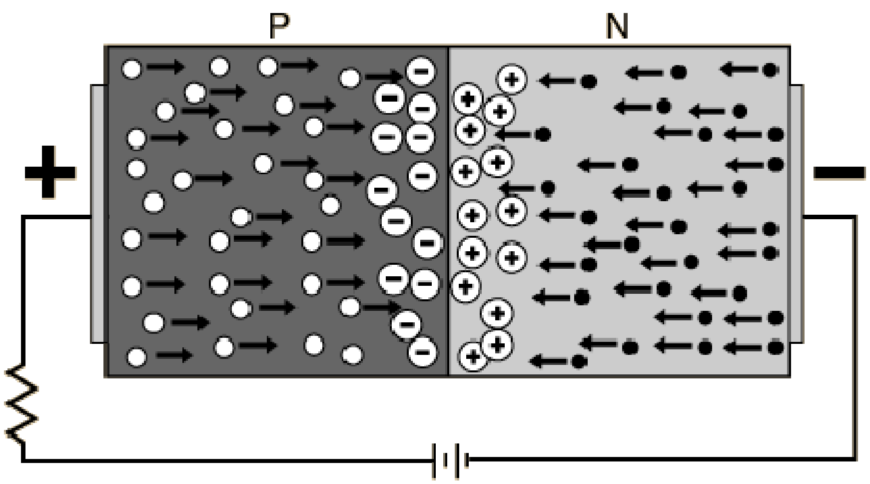
$$J_{tot} = J_{p,drift} + J_{n,drift} + J_{p,diff} + J_{n,diff} = 0$$

The current in the junction التيار المار في الوصلة

pn junction with applied bias الوصلة pn عند تطبيق جهد انحياز

forward bias الانحياز الأمامي



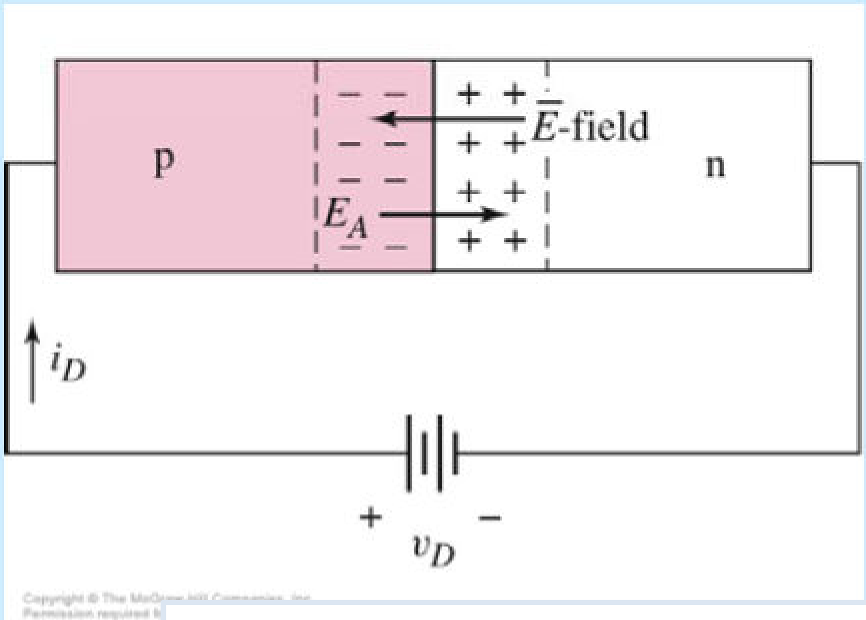


- both electrons and holes are repelled toward the depletion region.
- As a result, the depletion region gets smaller.
- Once the depletion region is gone, electrons are free to carry current across the junction and the semiconductor becomes a conductor.

The current in the junction التيار المار في الوصلة

Forward Bias condition ($V_D > 0V$)

Electric Field



The net electric field is always from the n- to the p-region.

$\vec{E} > E_A$

E_A: المجال الكهربي الناتج عن الجهد المطبق V_D

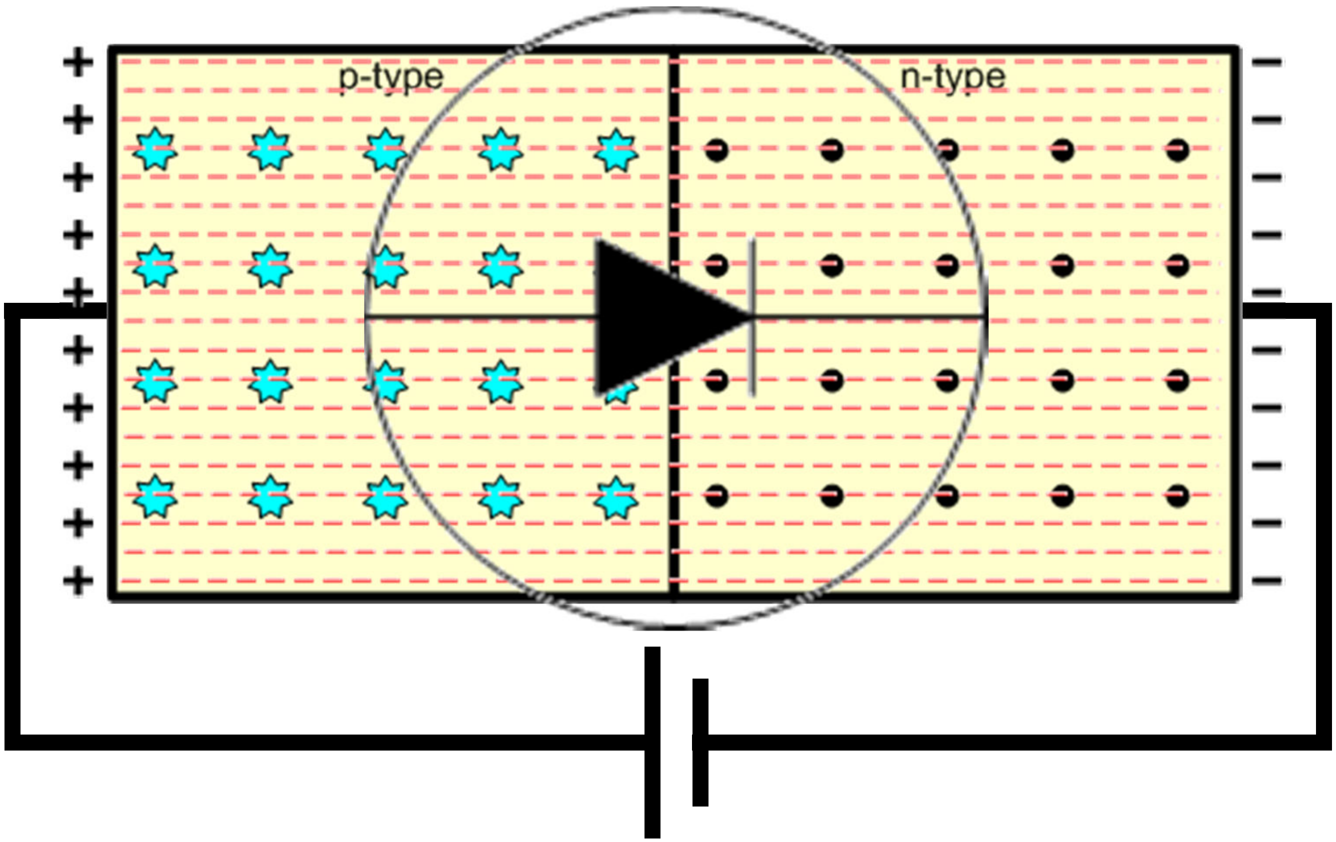
$\vec{E}$: المجال الكهربي لمنطقة النضوب

The Forward Biased P-N Junction

If we apply a higher voltage…

The electrons feel a greater force and move faster

The current will be greater and will look like this….



The p-n junction is called a DIODE and is represented by the symbol…

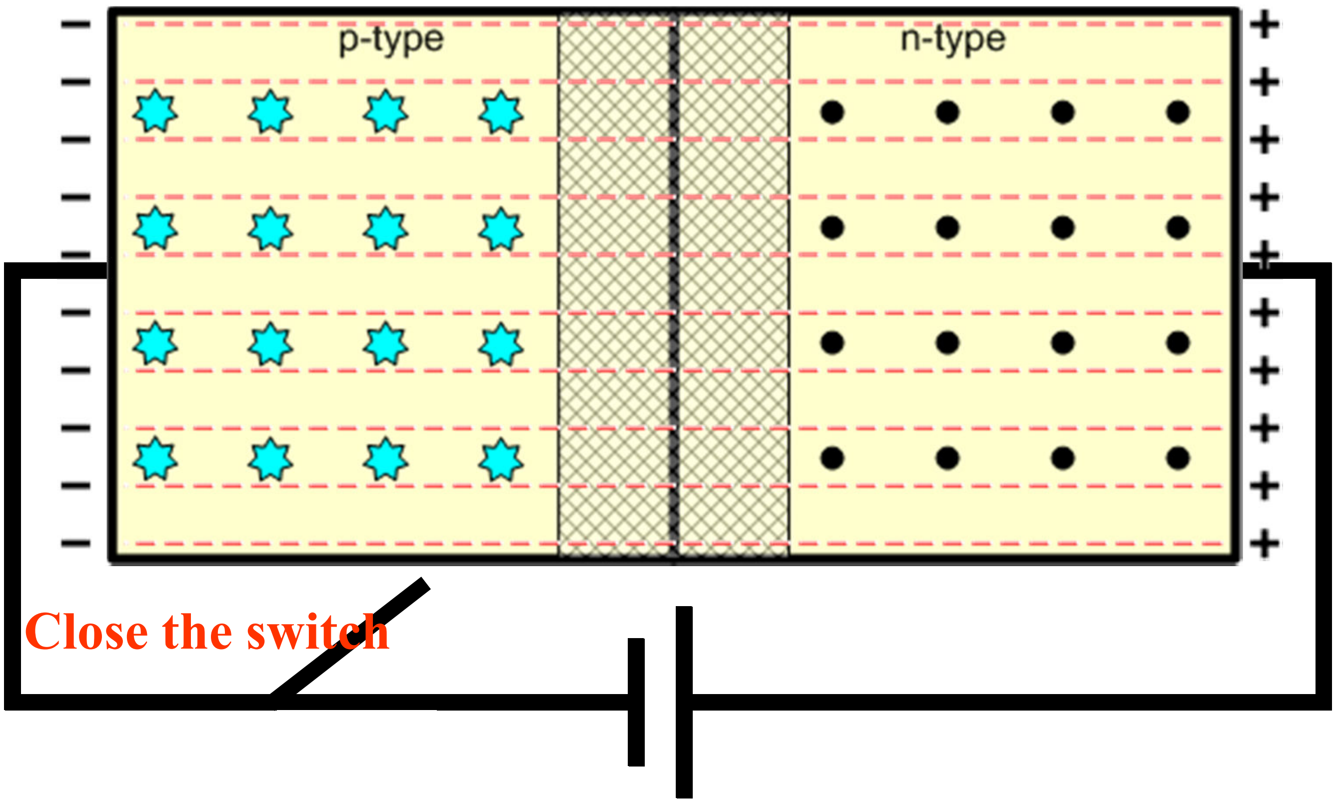
The arrow shows the direction in which it conducts current

The Reverse Biased P-N Junction

Apply a voltage across it with the

p-type negative

n-type positive

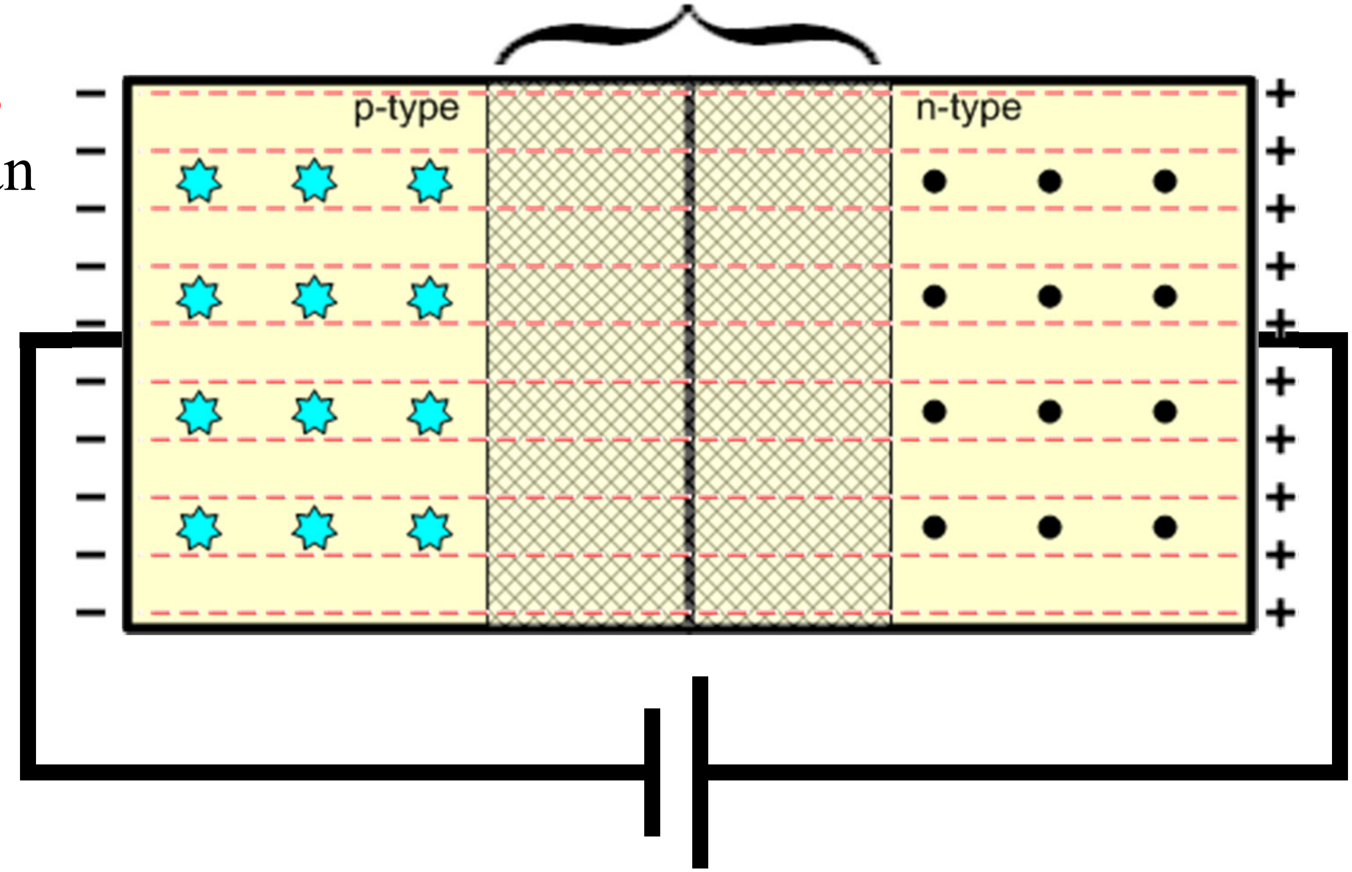


The voltage sets up an electric field throughout the junction

The junction is said to be reverse – biased

The Reverse Biased P-N Junction

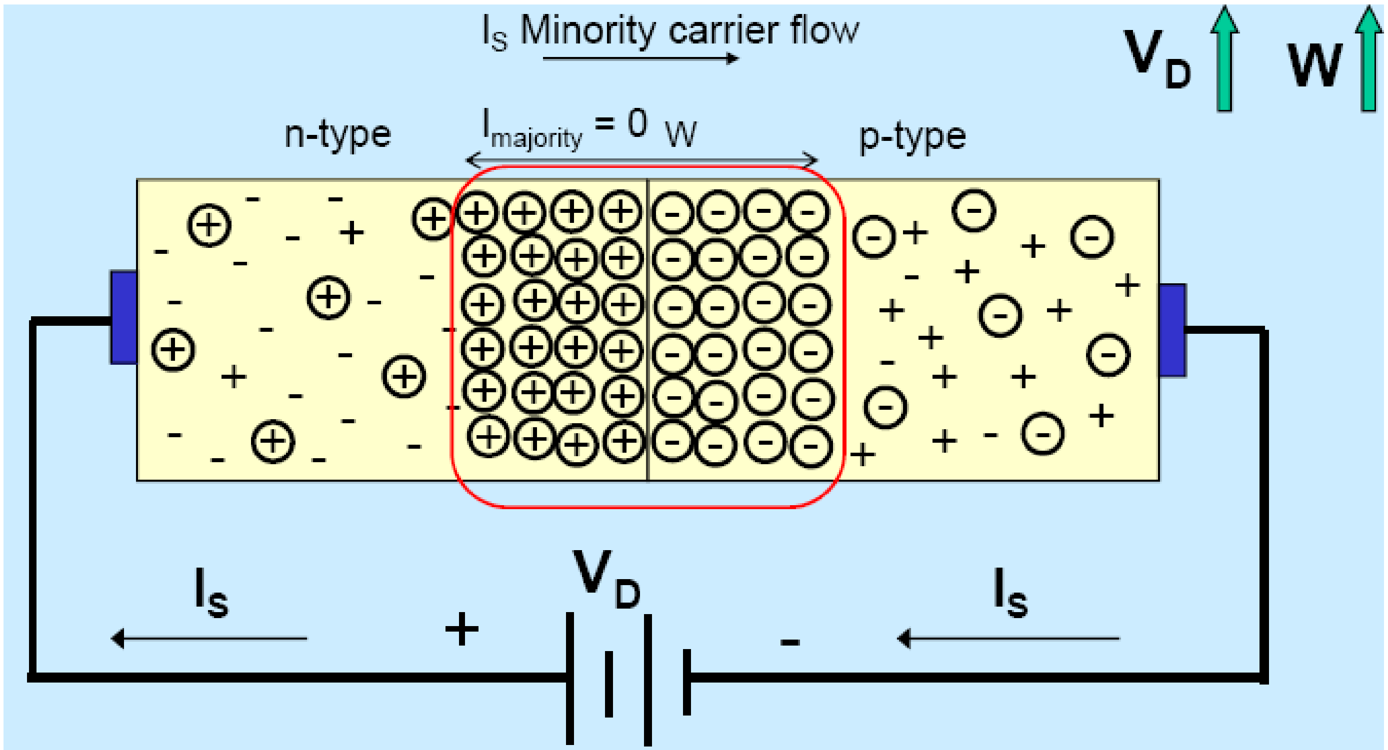
Negative electrons in the n-type feel an attractive force which pulls them away from the depletion layer



Positive holes in the p-type also experience an attractive force which pulls them away from the depletion layer

Thus, the depletion layer (INSULATOR) is widened and no current flows through the p-n junction

backward bias الانحياز العكسي

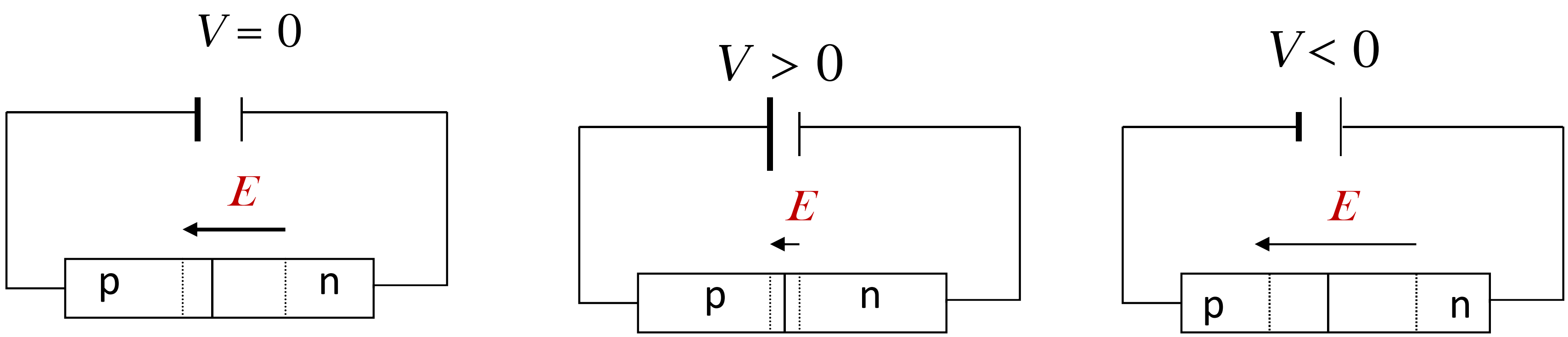


- يرفع الانحياز العكسي الجهد عبر الوصلة.
- يزداد المجال الكهربي المتكون.
- يزداد عرض منطقة النضوب.

A reverse bias increases the potential drop across the junction.

As a result, the magnitude of the electric field increases and the width of the depletion region widens.

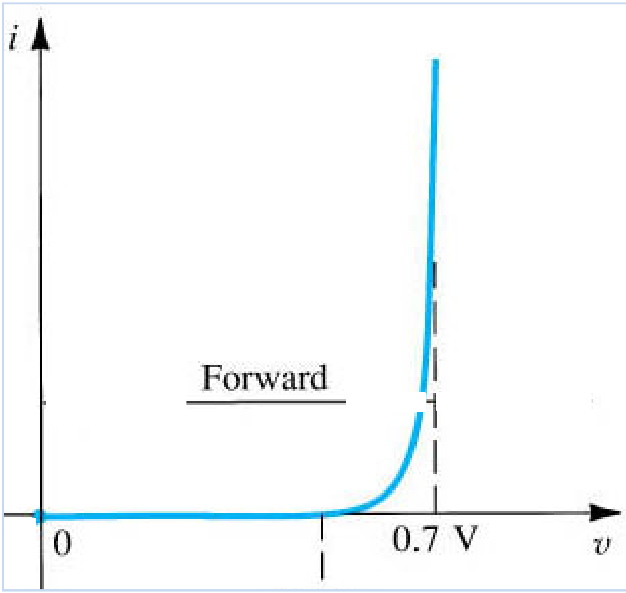
الوصلة pn تحت حالات انحياز مختلفة



Hole diffusion current	Hole diffusion current	Hole diffusion current
Hole drift current	Hole drift current	Hole drift current
Electron diffusion current	Electron diffusion current	Electron diffusion current
Electron drift current	Electron drift current	Electron drift current

The current in the junction التيار المار في الوصلة

forward bias الانحياز الأمامي



$$I_d = I_s \left[e^{\frac{v_d}{V_T}} - 1 \right]$$

$$I_d = I_s \ e^{\frac{v_d}{V_T}}$$

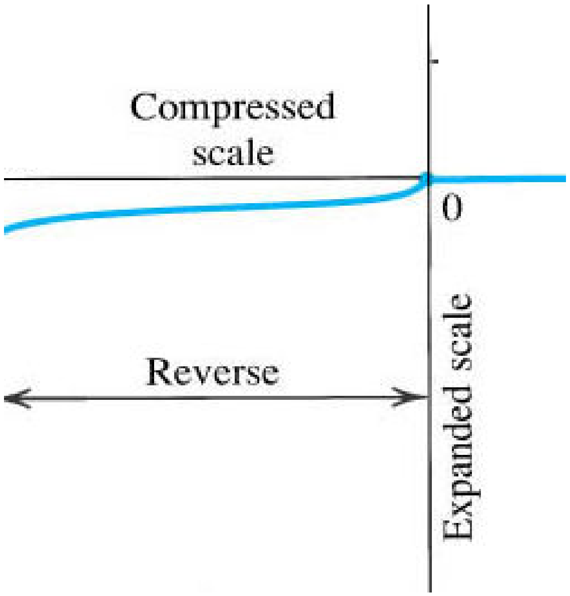
saturation current ثابت. ويسمى تيار التشبع I_S

thermal voltage ثابت. ويسمى الجهد الحراري $V_T = \frac{kT}{q}$

k = 1.38 x 10^{-23} J/K T = temperature in Kelvin q = 1.6 x 10^{-19} C

The current in the junction التيار المار في الوصلة

backward bias الانحياز العكسي



$$I_d = I_S\left[e^{\frac{v_d}{V_T}} - 1\right]$$

$$I_d = -I_S$$

يزيد التيار في الانحياز العكسي مع زيادة جهد الانحياز

يتناسب التيار العكسي طردياً مع مساحة مقطع الوصلة

بسبب صغر قيمة التيار، يرسم بقياس رسم مختلف عن الانحياز الأمامي

The current in the junction التيار المار في الوصلة

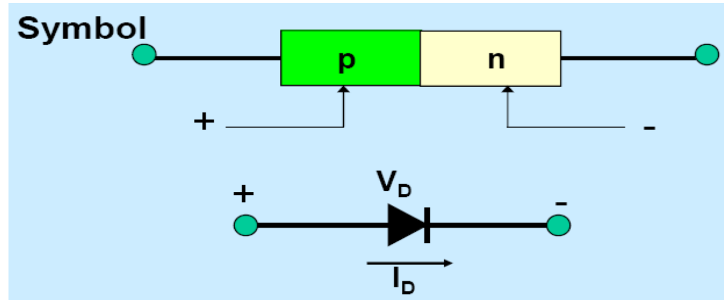
Example:Determine the current in a p-n junction diode.

Consider a p-n junction at T=300K in which I_S =10^{-14} A
Find the diode current for V_D=0.7V and V_D = -0.7V

Determine the diode current at 20°C for a silicon diode with I_s= 50 nA and an applied forward bias of 0.6 V.

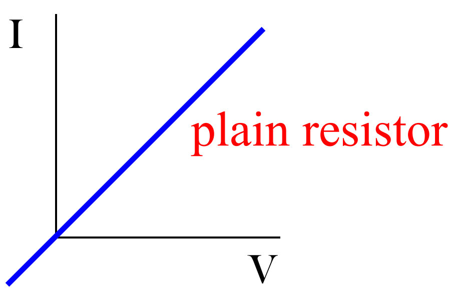
Diodes الثنائي

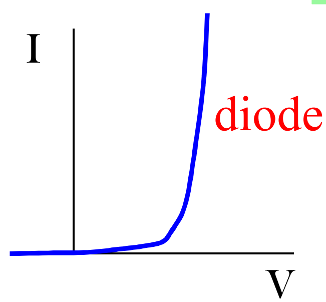
- The simplest and most fundamental nonlinear circuit element .
- Symbolized by:



- Has two terminals.
- the direction the arrow points in the diode symbol is the direction that current *will* flow.
- Diodes are essentially one-way current gates.
- Has nonlinear i-v characteristic.

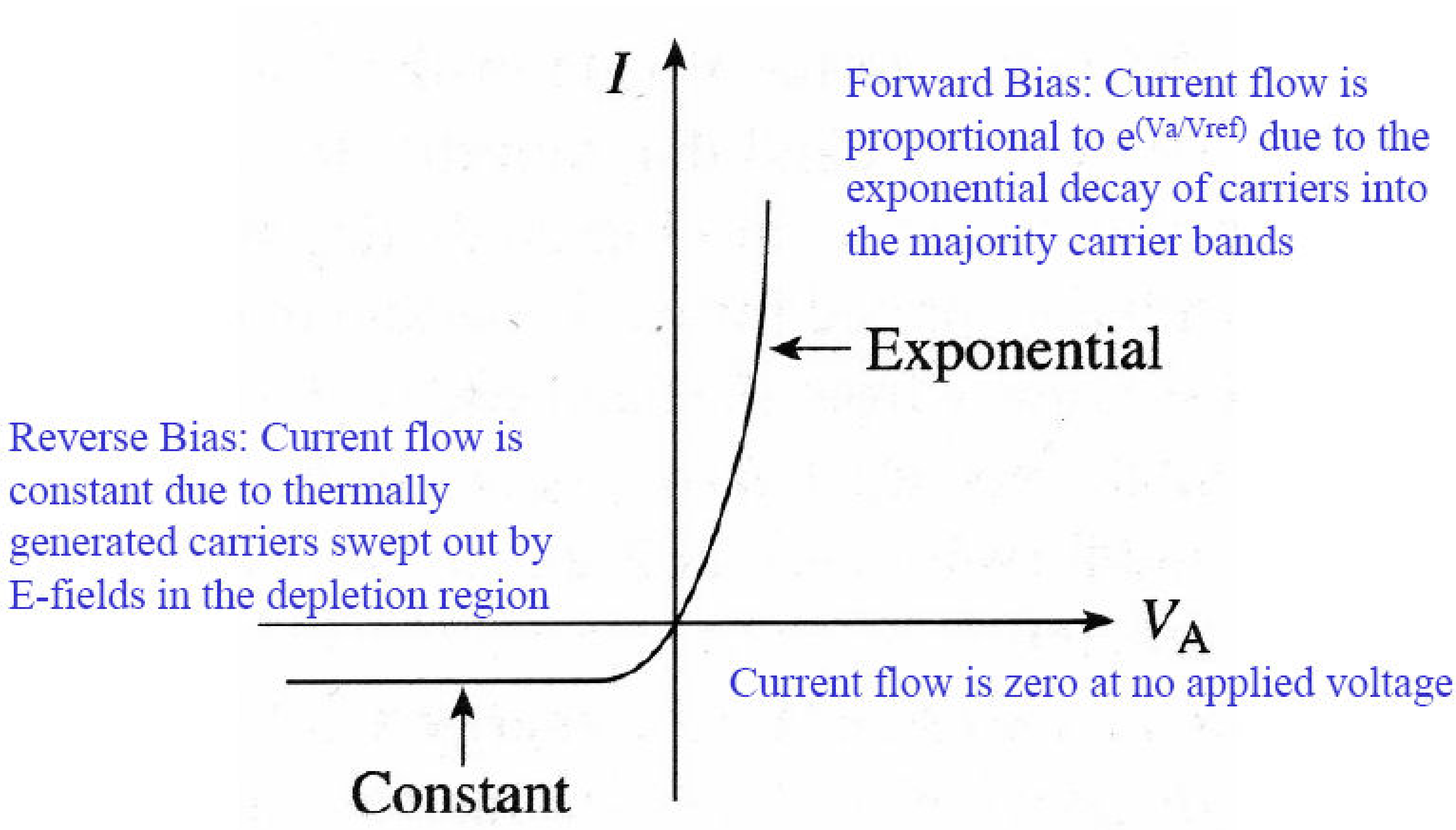
ماذا يعني أن العلاقة لا خطية؟





The diode characteristics المنحنى المميز للثنائي

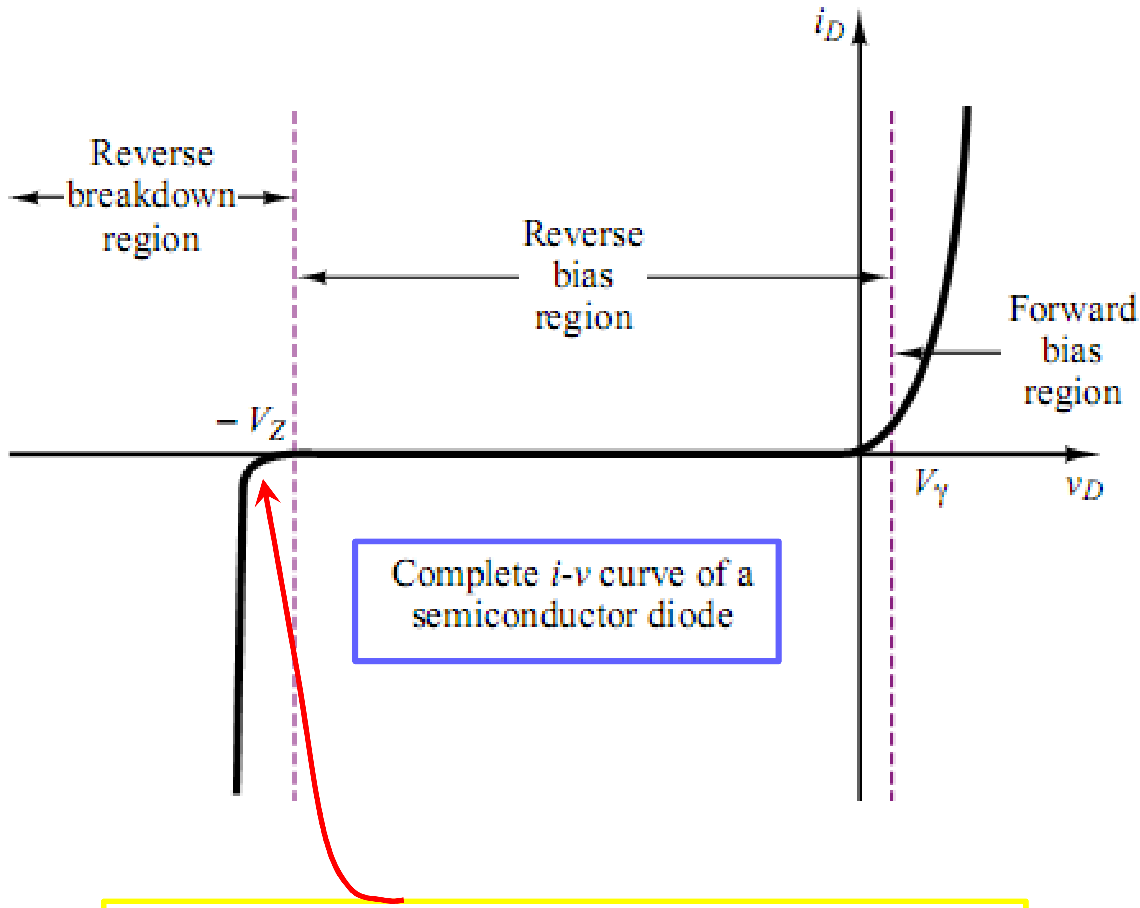
P-n Junction I-V Characteristics
Putting it all together



$$I=I_o(e^{Va/Vref}-1)$$

The diode characteristics المنحنى المميز للثنائي

*The maximum reverse-bias potential that can be applied before entering the Zener region is called the **peak inverse voltage** (referred to simply as the PIV rating) or the peak reverse voltage (denoted by PRV rating).*



ما هو انهيار زينر Zener breakdown ؟؟

ما هو انهيار زينر Zener breakdown ؟؟

Avalanche effect: The increase of the reverse-biased voltage over the specified value will cause a rapid strengthening of current. That is called a breakdown voltage. Once it is reached, a large number of the carriers appear in the depletion layer causing the junction to conduct heavily. Each free electron liberates one valence electron to get two free electrons. These two free electrons then free two more electrons to get four free electrons and so on until the reverse current becomes huge.

The process when the free electrons are accelerated to such high speed that they can dislodge valence electrons is called an avalanche breakdown and the current is called a reverse breakdown current.

Operation of a pn junction in the breakdown region must be avoided. In general, pn junctions are never operated in the breakdown region except for some special-purpose devices, such as the Zener diode.

ما هو انهيار زينر Zener breakdown ؟؟

- When the reverse voltage across diode reaches breakdown voltage these electrons will get sufficient energy to collide and dislodge other electrons

- The number of high energy electrons increases in geometric progression leading to an avalanche effect causing heavy current and ultimately destruction of diode

Silicon versus Germanium

Silicon diodes have, in general, higher PIV and current rating and wider temperature ranges than germanium diodes.

The disadvantage of silicon, however, as compared to germanium, as indicated in Fig. 1.23, is the higher forward-bias voltage required to reach the region of upward swing.

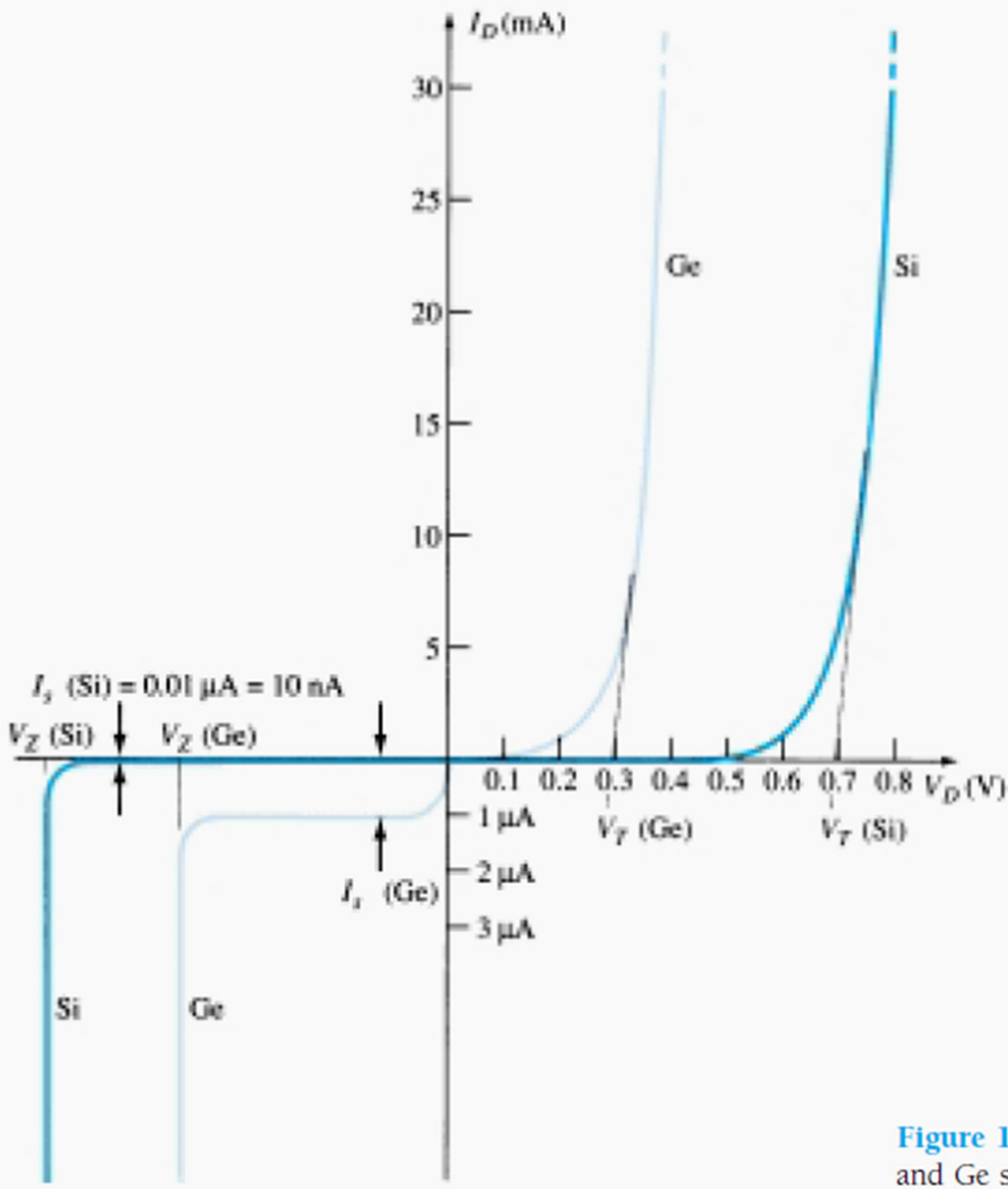
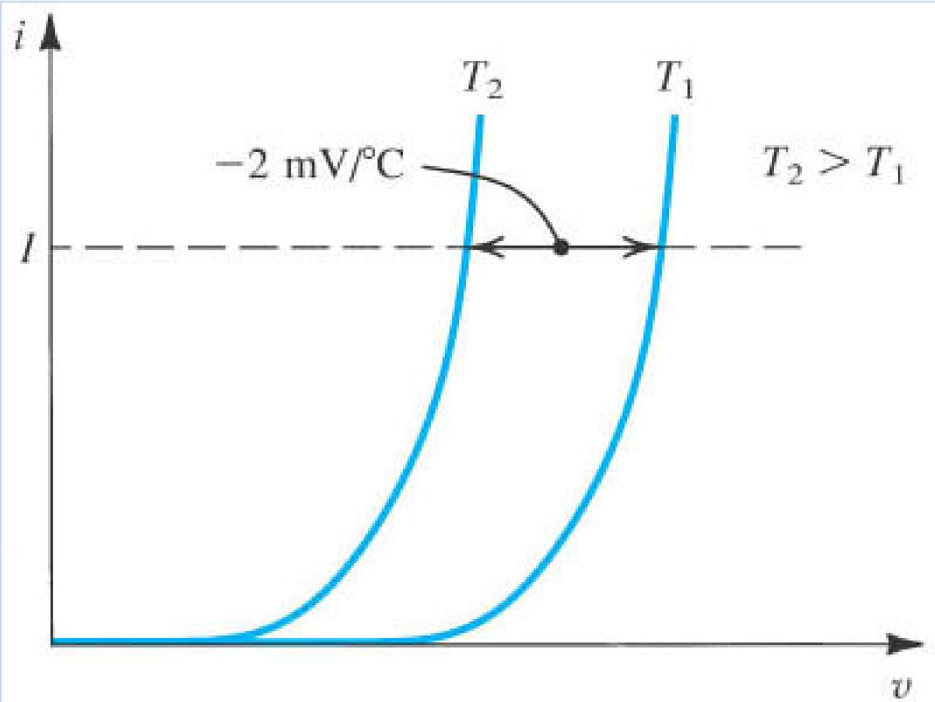


Figure 1.23 Comparison of Si and Ge semiconductor diodes.

تغير التيار الأمامي مع درجة الحرارة



عند قيمة معينة للتيار، يقل الجهد بمقدار 2mV عند زيادة درجة الحرارة بمقدار درجة واحدة.

1.7 RESISTANCE LEVELS

As the operating point of a diode moves from one region to another the resistance of the diode will also change due to the nonlinear shape of the characteristic curve.

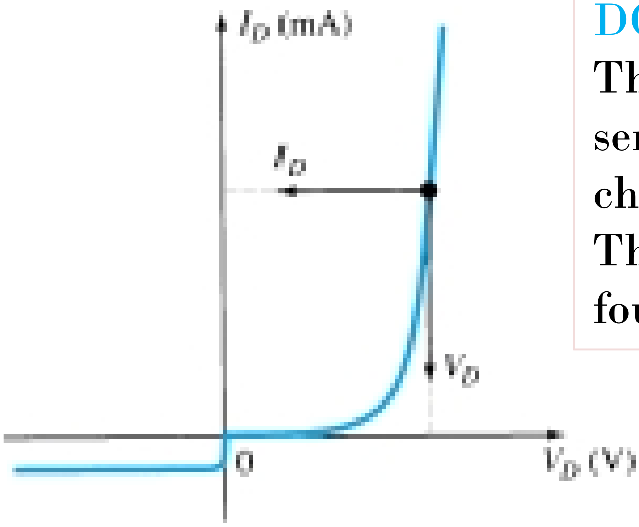


Figure 1.25 Determining the dc resistance of a diode at a particular operating point.

DC or Static Resistance

The application of a dc voltage to a circuit containing a semiconductor diode will result in an operating point on the characteristic curve that will <u>not change with time</u>.

The resistance of the diode at the operating point can be found simply by applying the following equation:

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

The dc resistance levels at the knee and below will be greater than the resistance levels obtained for the vertical rise section of the characteristics. The resistance levels in the reverse-bias region will naturally be quite high

In general, therefore, the lower the current through a diode the higher the dc resistance level.

مقاومة الثنائي

AC or Dynamic Resistance:

It is obvious from Eq. 1.5 that the dc resistance of a diode is independent of the shape of the characteristic in the region surrounding the point of interest.

If a sinusoidal rather than dc input is applied, the situation will change completely.

The varying input will move the instantaneous operating point up and down a region of the characteristics and thus defines a specific change in current and voltage.

The designation Q-point is derived from the word quiescent, which means "still or unvarying."

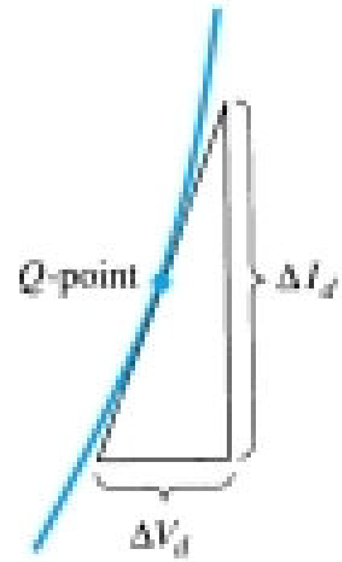


Figure 1.28 Determining the ac resistance at a Q-point.

$$r_d = \frac{\Delta V_d}{\Delta I_d}$$

$$r_d = \frac{26\text{ mV}}{I_D}$$

Ge,Si

Worksheet:4

Determine the dc resistance levels for the diode of Fig. 1.26 at

(a) $I_D = 2$ mA

(b) $I_D = 20$ mA

(c) $V_D = -10$ V

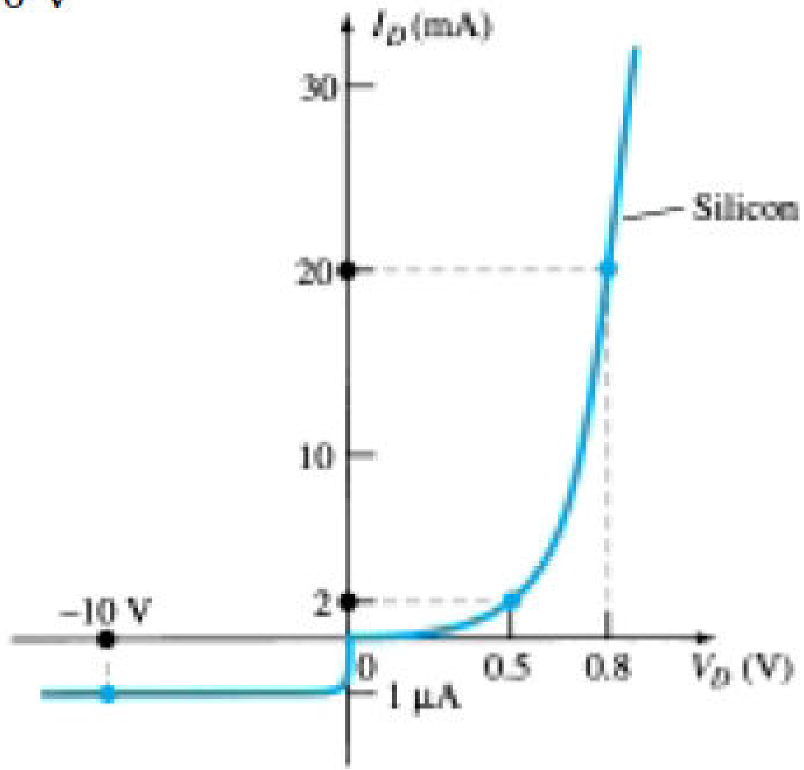
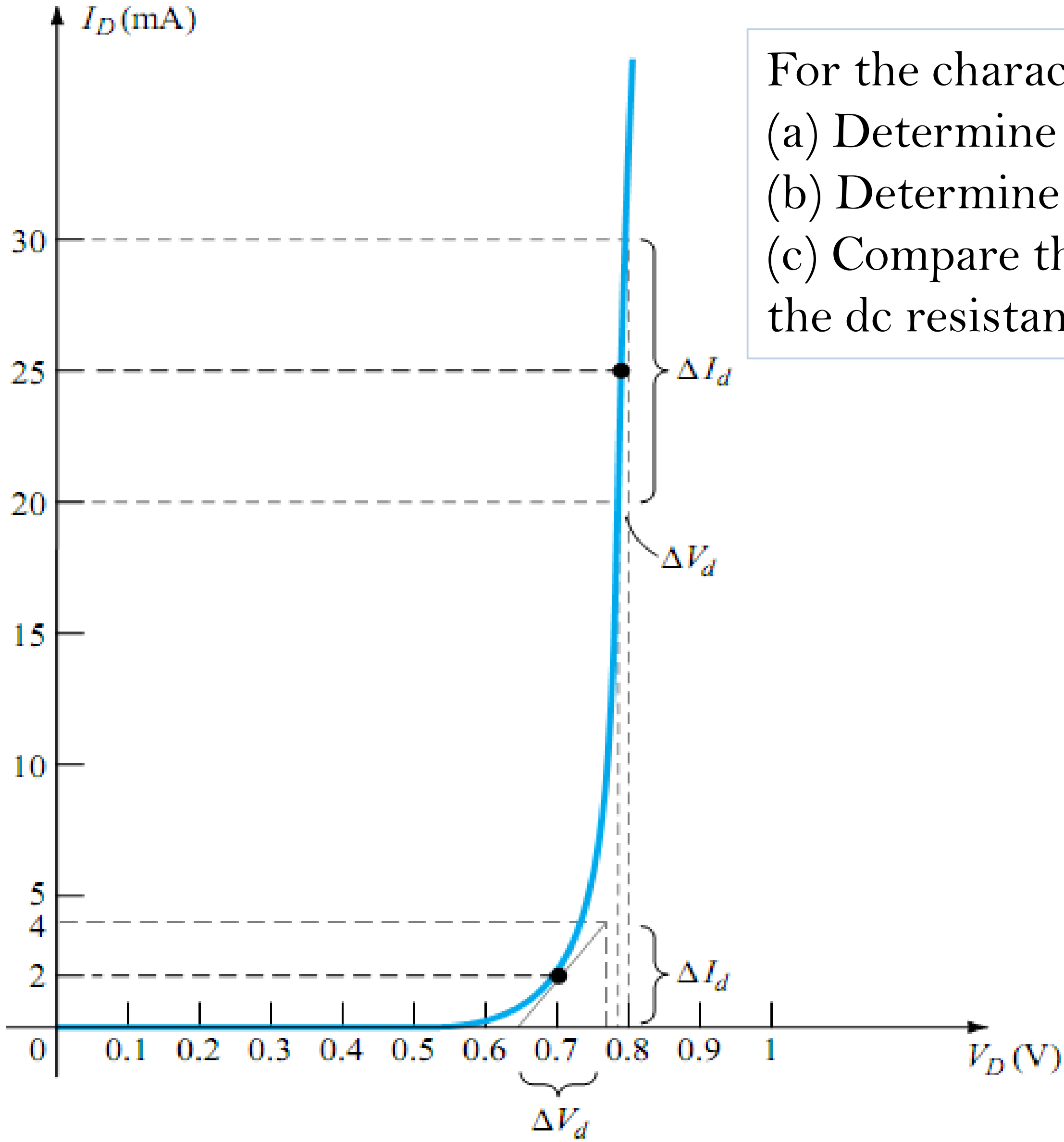


Figure 1.26

مقاومة الثنائي



For the characteristics of Fig. 1.29:

(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.

مقاومة الثنائي

Average AC Resistance

If the input signal is sufficiently large as indicated in Fig. 1.30, the resistance for this region is called the *average ac resistance. The average ac resistance is, by definition, the resistance determined by* a straight line drawn between the two intersections established by the maximum and minimum values of input voltage.

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

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

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

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

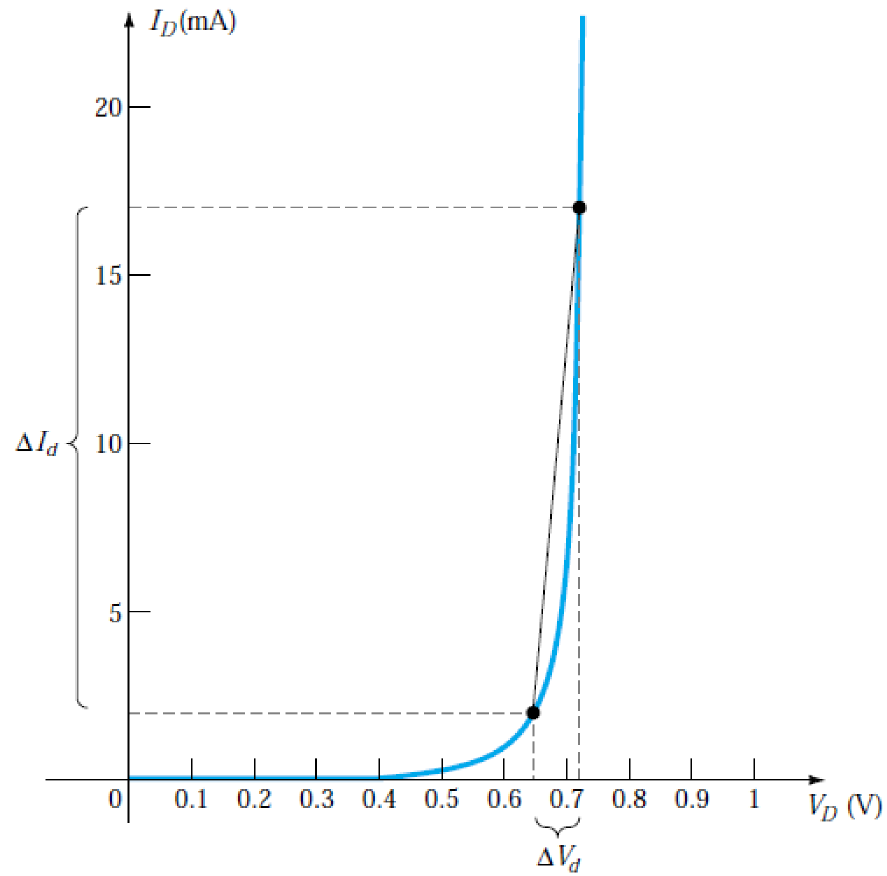
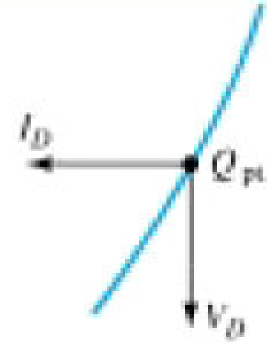
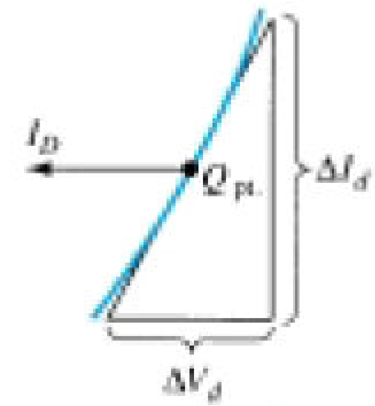
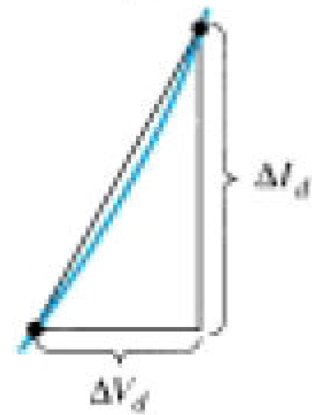


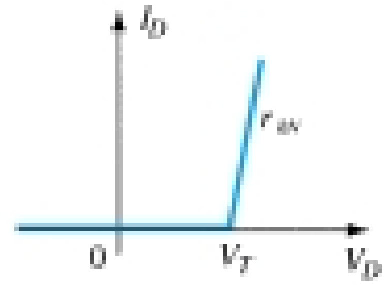
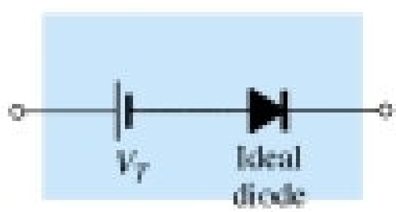
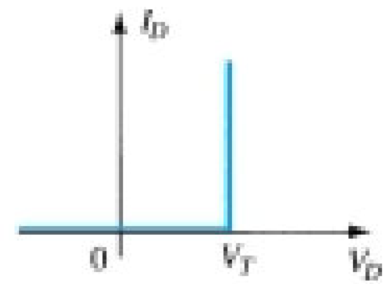
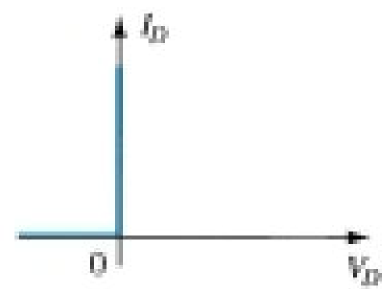
Figure 1.30 Determining the average ac resistance between indicated limits.

TABLE 1.2 Resistance Levels

Type	*Equation*	*Special Characteristics*	*Graphical Determination*
DC or static	$R_D = \frac{V_D}{I_D}$	Defined as a *point* on the characteristics	
AC or dynamic	$r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{26\text{ mV}}{I_D}$	Defined by a tangent line at the *Q*-point	
Average ac	$r_{av} = \frac{\Delta V_d}{\Delta I_d}\Big\vert_{\text{pt. to pt.}}$	Defined by a straight line between limits of operation	

DIODE EQUIVALENT CIRCUITS النماذج المكافئة للثنائي

An equivalent circuit is a combination of elements properly chosen to best represent the actual terminal characteristics of a device, system, or such in a particular operating region.

Type	*Conditions*	*Model*	*Characteristics*
Piecewise-linear model			
Simplified model	$R_{network} \gg r_{av}$		
Ideal device	$R_{network} \gg r_{av}$ $E_{network} \gg V_T$		

DIODE SPECIFICATION SHEET ورقة مواصفات الثنائي

A — • BV . . . 125 V (MIN) @ 100 µA

ABSOLUTE MAXIMUM RATINGS (Note 1)

Temperatures

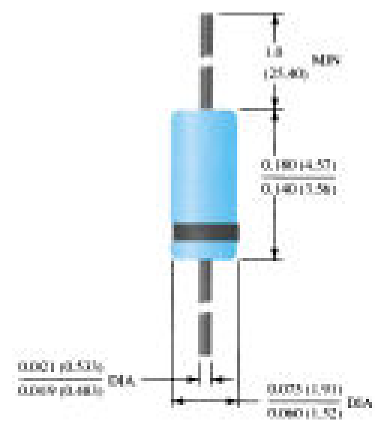
	Storage Temperature Range	-65°C to +200°C
B	Maximum Junction Operating Temperature	+175°C
	Lead Temperature	+260°C

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

	WIV	Working Inverse Voltage	100 V
	I_O	Average Rectified Current	200 mA
D	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



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	MIN	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
F			0.60	0.68	V	I_F = 1.0 mA
					V	I_F = 0.1 mA
G	I_R	Reverse Current		500	nA	V_R = 20 V, T_A = 125°C
				5.0	nA	V_R = 100 V
				1.0	µA	V_R = 100 V, T_A = 125°C
					nA	V_R = 180 V
					µA	V_R = 180 V, T_A = 100°C
	BV	Breakdown Voltage	125		V	I_R = 100 µA
H	C	Capacitance		8.0	pF	V_R = 0, f = 1.0 MHz
I	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

DIODE SPECIFICATION SHEET ورقة مواصفات الثنائي

Specific areas of the specification sheet have been highlighted in blue with a letter identification corresponding with the following description:

A: The *minimum* reverse-bias voltage (PIVs) for a diode at a specified reverse saturation current.

B: Temperature characteristics as indicated. Note the use of the Celsius scale and the wide range of utilization [recall that 32°F = 0°C = freezing (H_2O) and 212°F = 100°C = boiling (H_2O)].

C: Maximum power dissipation level $P_D = V_D I_D = 500$ mW. The maximum power rating decreases at a rate of 3.33 mW per degree increase in temperature above room temperature (25°C), as clearly indicated by the *power derating curve* of Fig. 1.36.

D: Maximum continuous forward current $I_{F_{max}} = 500$ mA (note I_F versus temperature in Fig. 1.36).

E: Range of values of V_F at $I_F = 200$ mA. Note that it exceeds $V_T = 0.7$ V for both devices.

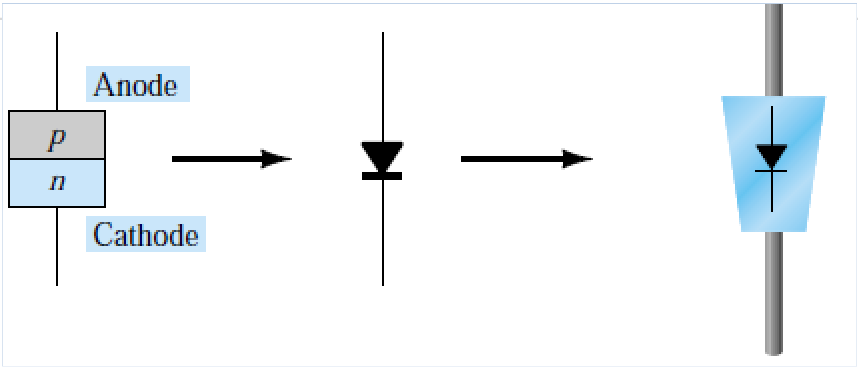
F: Range of values of V_F at $I_F = 1.0$ mA. Note in this case how the upper limits surround 0.7 V.

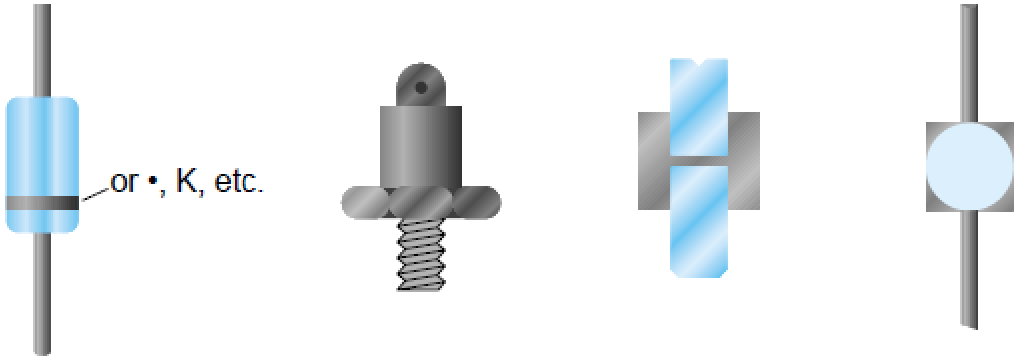
G: At $V_R = 20$ V and a typical operating temperature $I_R = 500$ nA $= 0.5$ μA, while at a higher reverse voltage I_R drops to 5 nA $= 0.005$ μA.

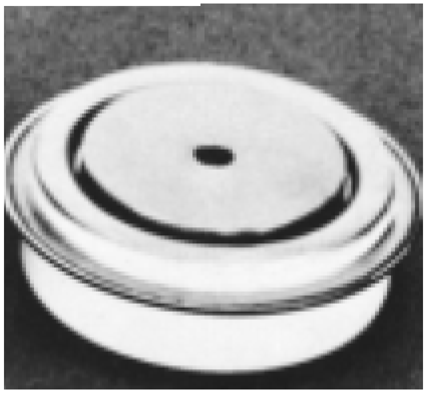
H: The capacitance level between terminals is about 8 pF for the diode at $V_R = V_D = 0$ V (no-bias) and an applied frequency of 1 MHz.

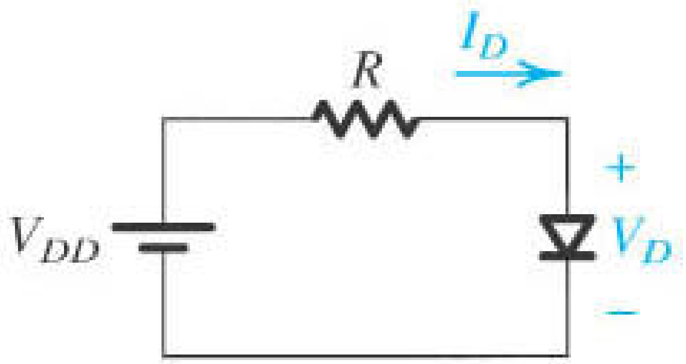
I: The reverse recovery time is 3 μs for the list of operating conditions.

SEMICONDUCTOR DIODE NOTATION









تعيين التيار I_D والجهد V_D

يعطى التيار I_D بالمعادلة

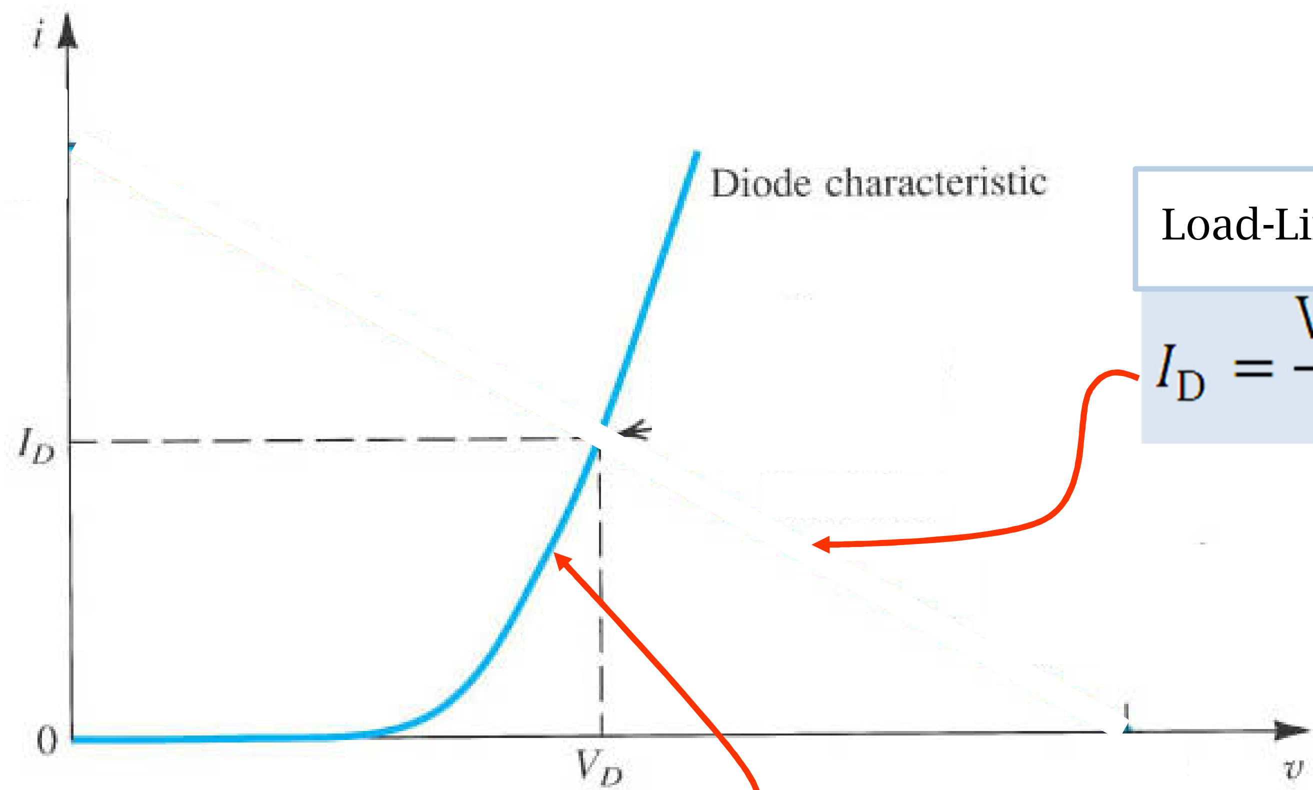
$$I_d = I_s \, e^{\frac{v_d}{V_T}}$$

بتطبيق قانون كيرشوف KVL في دائرة الثنائي

$$I_D = \frac{V_{DD} - V_D}{R}$$

يمكن إيجاد قيمة التيار I_D والجهد V_D
بحل المعادلتين أو من الرسم البياني

الحل هو احاثيي نقطة تقاطع المنحنيين الممثلين للمعادلتين



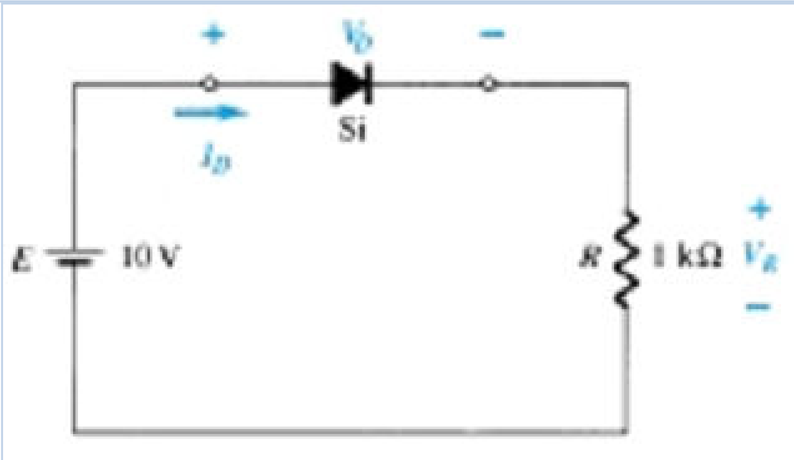
Load-Line Equation

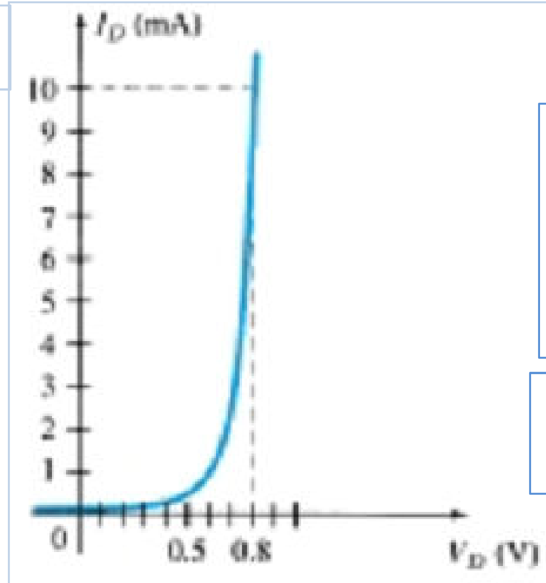
$$I_D = \frac{V_{DD} - V_D}{R}$$

$$I_D = I_S e^{\frac{V_D}{V_T}}$$

Example 2.1

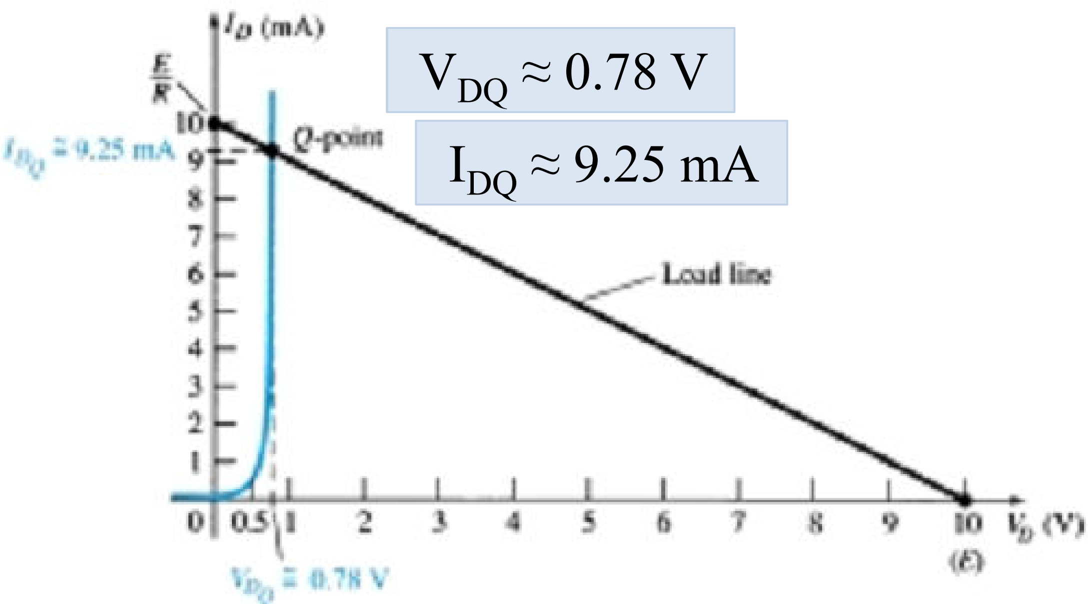
determine: (a) V_{DQ} and I_{DQ}. (b) V_R





$$I_D = \frac{E}{R}\bigg|_{V_D=0V} = \frac{10\ V}{1\ k\Omega} = 10\ mA$$

$$V_D = E\Big|_{I_D=0A} = 10\ V$$



$V_{DQ} \approx 0.78$ V

$I_{DQ} \approx 9.25$ mA

$V_R = I_R\,R = I_D\,R =$ (9.25 mA)(1 kΩ) = 9.25 V

$V_R = E - V_D =$ 10 V – 0.78 V = 9.22 V

2.4 SERIES DIODE CONFIGURATIONS WITH DC INPUTS

EXAMPLE 2.6

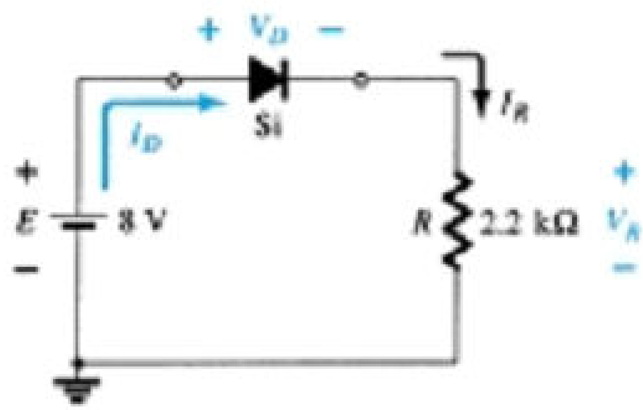


Figure 2.16 Circuit for Example

For the series diode configuration of Fig. 2.16, determine V_D, V_R, and I_D.

Solution

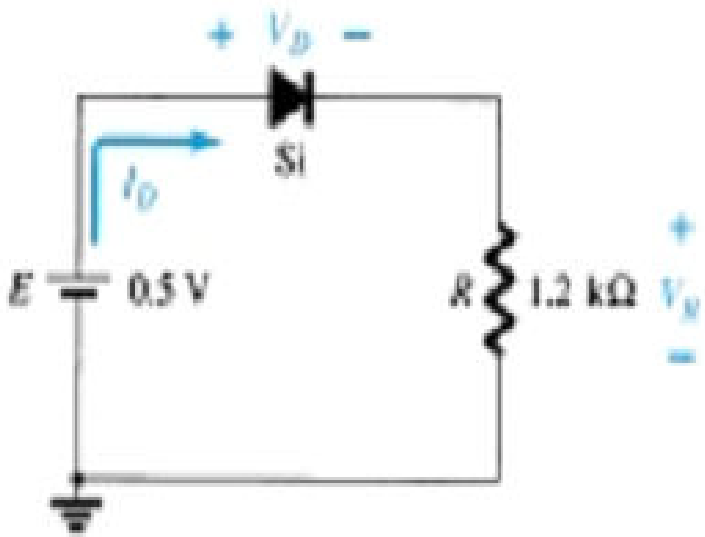
Since the applied voltage establishes a current in the clockwise direction to match the arrow of the symbol and the diode is in the "on" state,

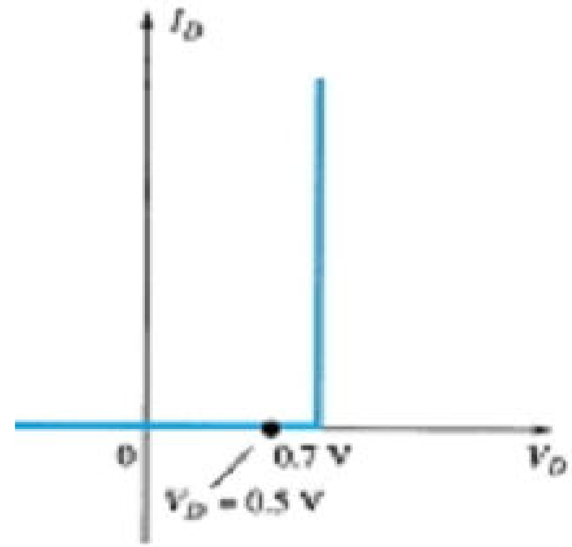
$$V_D = \mathbf{0.7\ V}$$

$$V_R = E - V_D = 8\text{ V} - 0.7\text{ V} = \mathbf{7.3\ V}$$

$$I_D = I_R = \frac{V_R}{R} = \frac{7.3\text{ V}}{2.2\text{ k}\Omega} \cong \mathbf{3.32\ mA}$$

For the series diode configuration of Fig. 2.19, determine : V_D, V_R, and I_D.





Solution

Although the "pressure" establishes a current with the same direction as the arrow symbol, the level of applied voltage is insufficient to turn the silicon diode "on." The point of operation on the characteristics is shown in Fig. 2.20, establishing the open-circuit equivalent as the appropriate approximation. The resulting voltage and current levels are therefore the following:

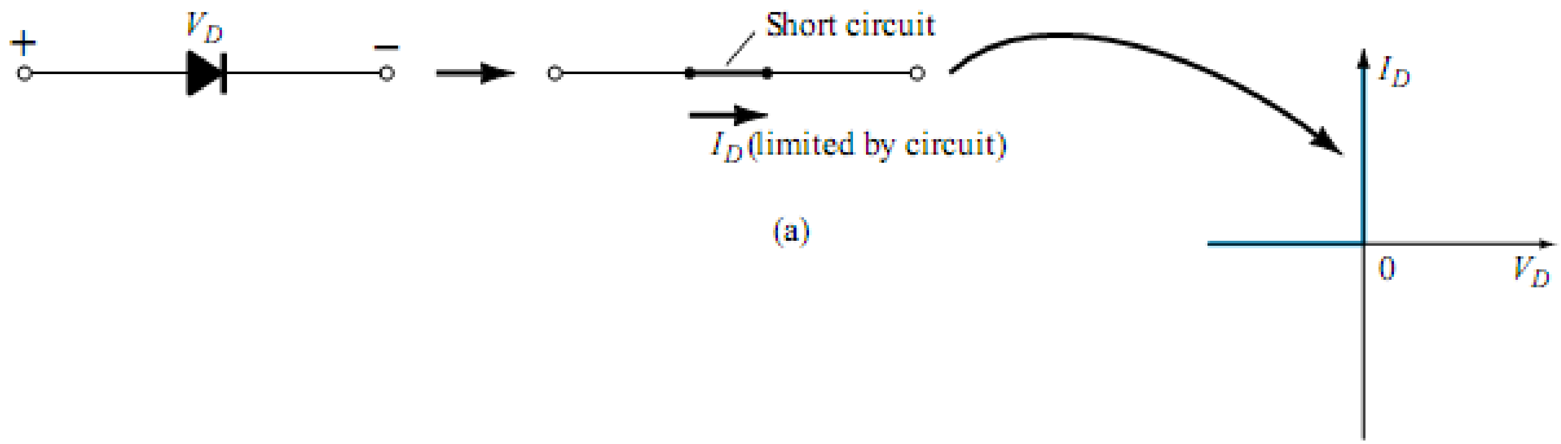
$$I_D = 0 \text{ A}$$

$$V_R = I_R R = I_D R = (0 \text{ A}) 1.2 \text{ k}\Omega = 0 \text{ V}$$

and

$$V_D = E = 0.5 \text{ V}$$

الدائرة المكافئة للثنائي



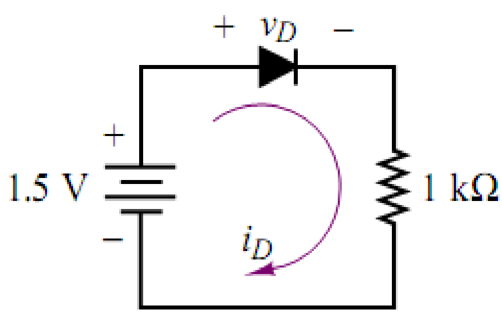


Figure 8.12 Circuit containing ideal diode

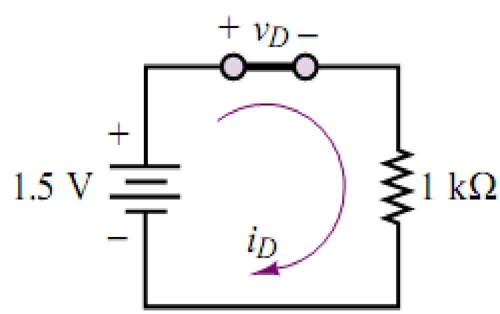


Figure 8.13 Circuit of Figure 8.12, assuming that the ideal diode conducts

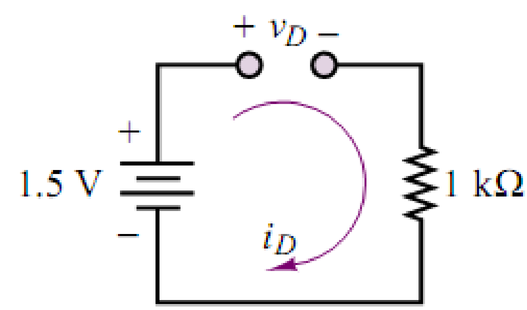
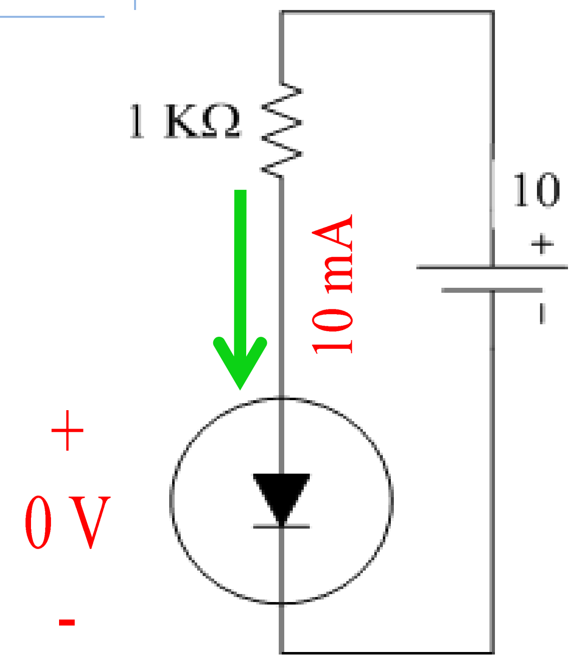


Figure 8.14 Circuit of Figure 8.12, assuming that the ideal diode does not conduct

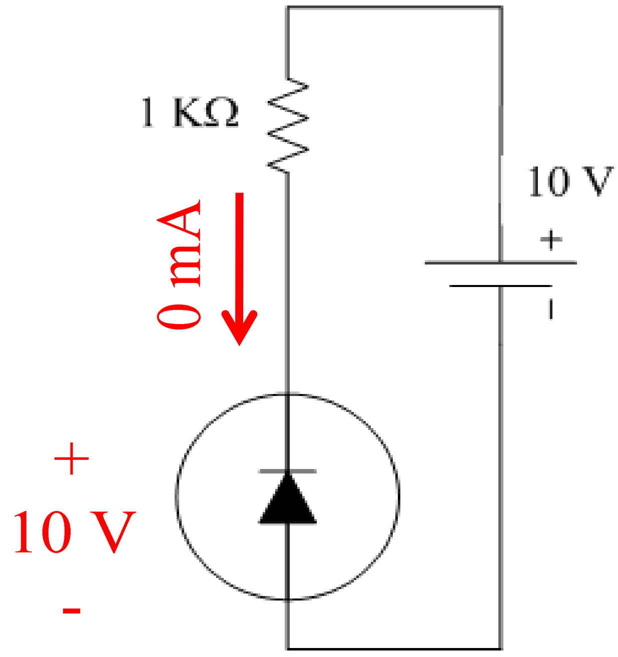
توصيل الثنائي في الدوائر

The external circuit must be designed so as to limit:

1-the forward current through a conducting diode.



2- the reverse voltage across a cutoff

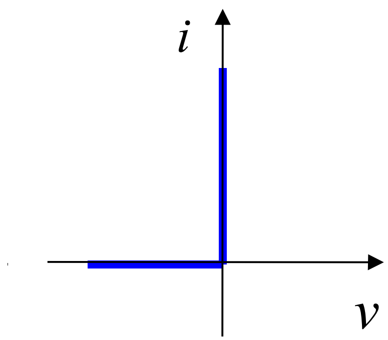


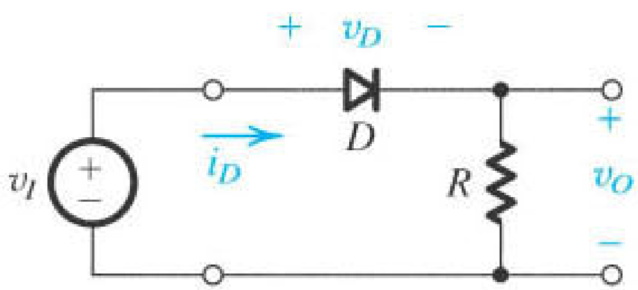
Diode Applications تطبيقات الثنائي

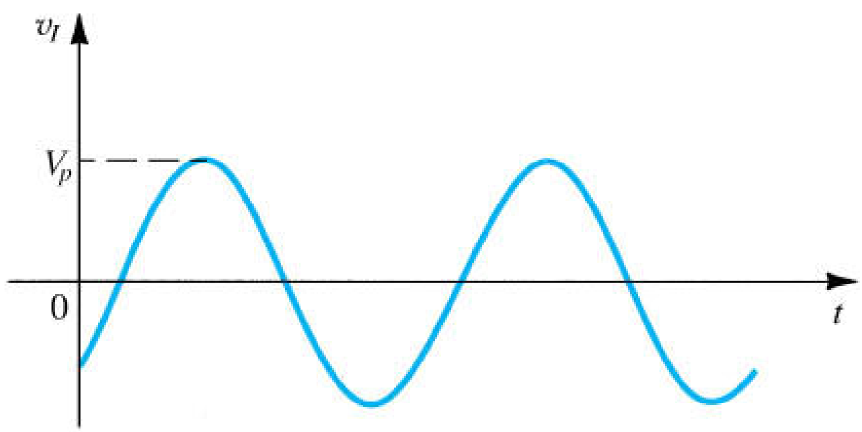
Logic gates. البوابات المنطقية

The Rectifier. مقوم التيار

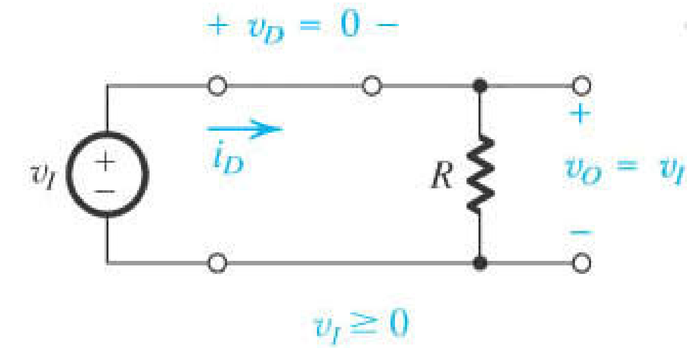
The half-wave Rectifier. مقوم نصف الموجة



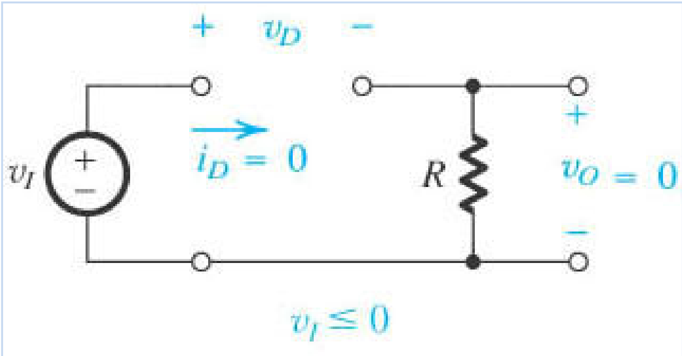


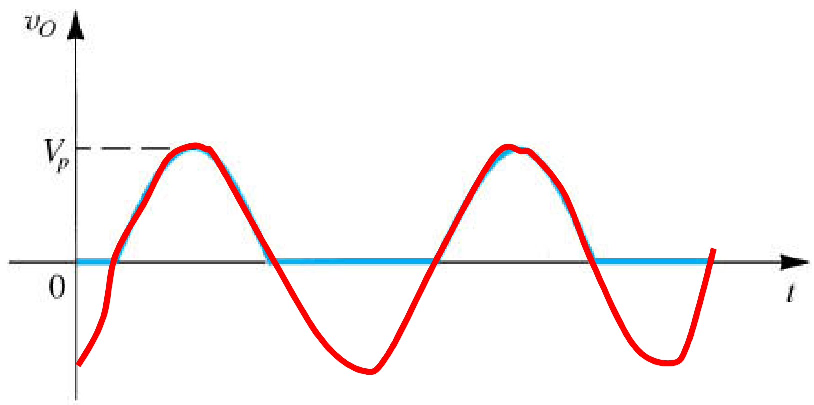


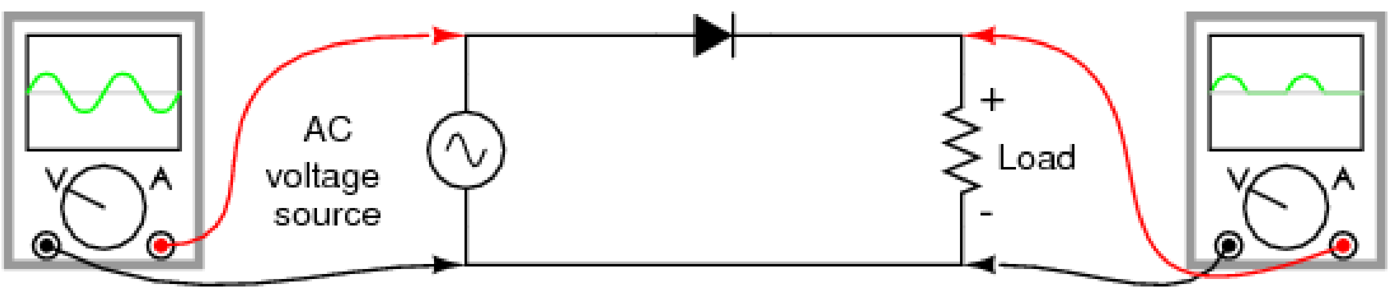
خلال نصف الدورة الموجبة للموجة



خلال نصف الدورة السالبة للموجة

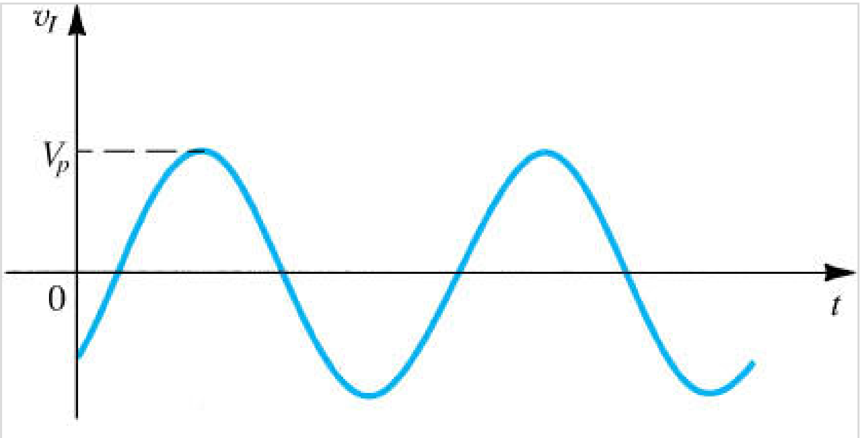


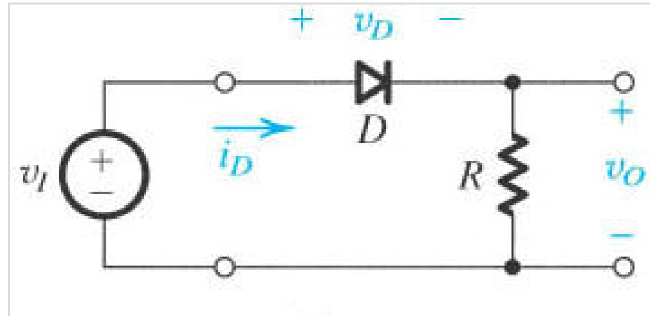




تدريب

من الدائرة ارسمي شكل الموجة المقاسة على الثنائي V_D، إذا كان شكل الموجة من المصدر كما في الشكل.





* **26.** For the network of Fig. 2.150, sketch v_o and i_R.

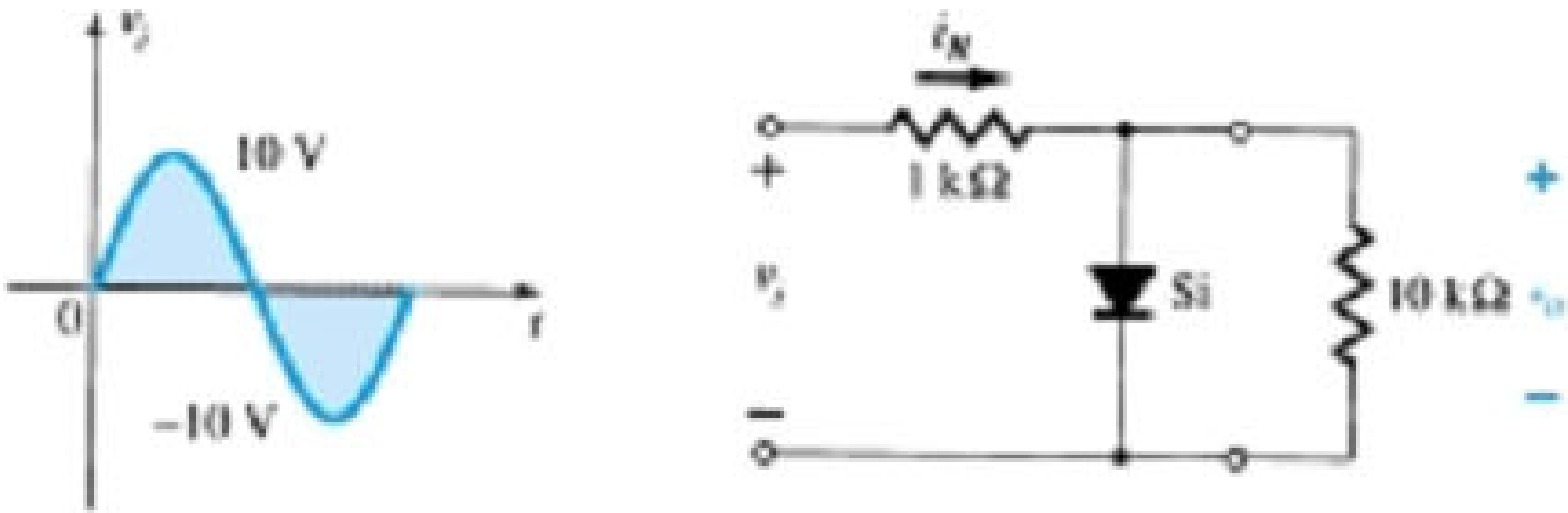
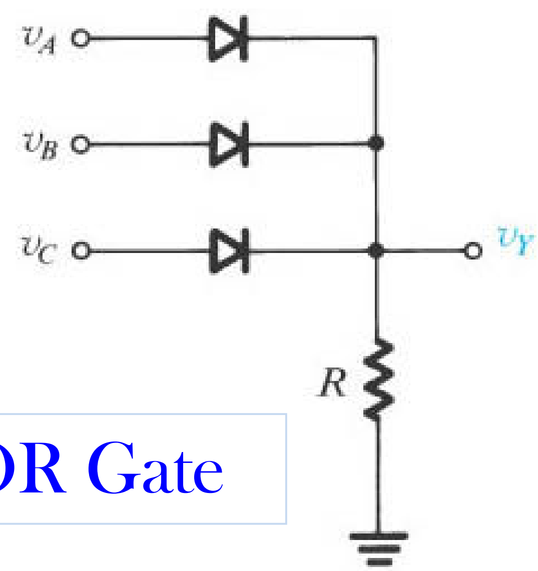


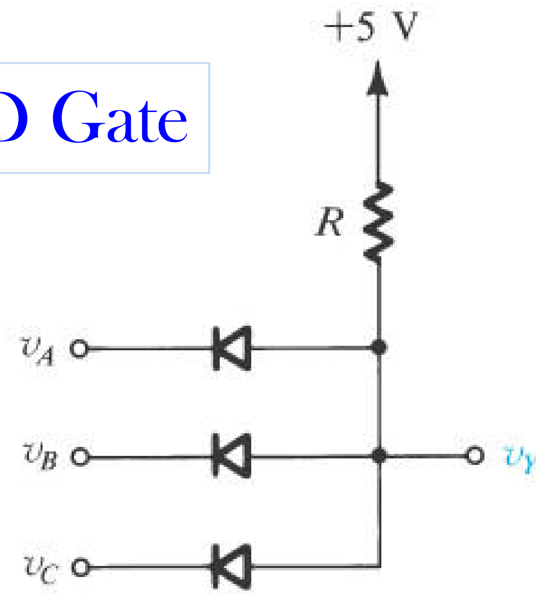
Figure 2.150 Problem 26

Logic gates. البوابات المنطقية



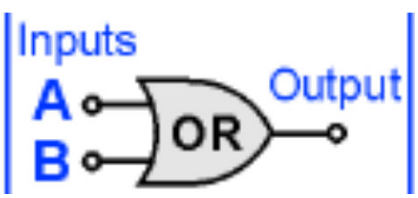
OR Gate

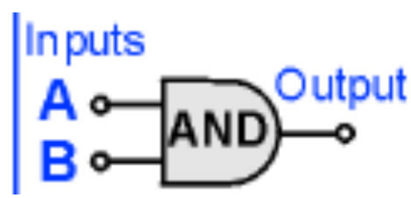
AND Gate

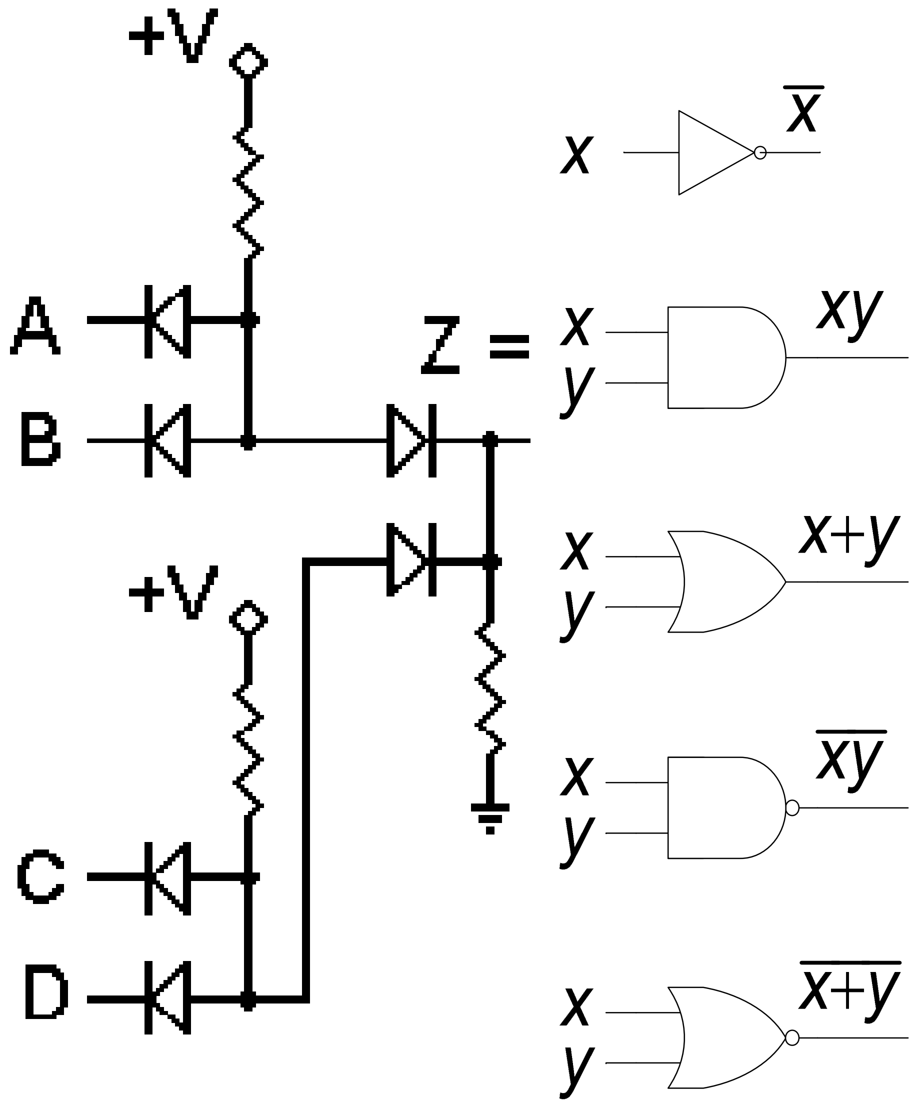


Y= A+B+C

Y= A.B.C







+V
A
B
+V
C
D
Z =
x
$\overline{x}$
x
y
xy
x
y
x+y
x
y
$\overline{xy}$
x
y
$\overline{x+y}$