المملكة العربية السعودية

كلية الاتصالات والمعلومات بالرياض

مقرر الالكترونيات

ELECTRONICS

نظري

SR: 30

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STUDENT GUIDE
ELECTRONICS
COURSE CODE: COM-121

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Course Information

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Course Code :	COM-121
Course Title :	Electronics
Duration :	14 weeks (L : 3 Hours/Week, P : 2 Hours/Week)
Course Description :	This course is intended to cover an overview of various semiconductor devices such as: diodes, transistors and op-amps, then to use them in a large number of practical electronic circuits.
Target Group :	This course is designed for Saudi Technicians, Engineers and in general people who are involved in any of the Telecommunication fields and like to improve their background or those who are interested and/or may be involved in various Telecommunications systems and Technologies.
Prerequisite :	1. English Language 2. Basics of Electrical Engineering and Circuits 3. Minimum Secondary School Diploma or Equivalent
Global Objectives :	At the end of this course, the trainee will be able to understand the basic features of various electronic devices and their operation in different applications.
Course Objectives :	Upon the completion of this course, the trainee will be able to : 1. understand the principle of each semiconductor and how to use it safely. 2. Identify various semiconductor devices and use them in many practical circuits and systems. 3. Identify the main features, characteristics and parameters of each device and how to deal with them properly in design or maintenance for example. 4. Describe the operation of a given device in a given application both in theory and practice. 5. Use and deal with circuits and systems based on semiconductors devices through referring to their technical data sheets.

UNIT 0

INTRODUCTION TO ELECTRONICS

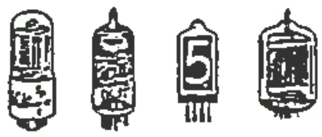
THE HISTORY OF ELECTRONICS

We live at the end of the first *Electronics Century* (OK, we made that term up, but it fits). From the moment our clock radios wake us in the morning, to our last waking moment in the glow of late night TV, electronics is an integral part of our daily life.

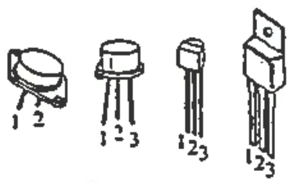
As Figure 1–1 shows, our Electronics Century began with the invention of the first vacuum tube. The vacuum tube allowed us to amplify weak telephone signals, to construct radio transmitters and receivers, and to build the first computers. The vacuum tube was later replaced with the smaller and more energy-efficient transistor. Today, we can place thousands of transistors on a single small chip to produce an integrated circuit.

FIGURE 1–1
Electronics timeline

1890s	Cathode Ray Tube (oscilloscope)
1900s	Vacuum Tube Diode (radio detection)
	Vacuum Tube Triode (amplification)
1910s	Superheterodyne Reciver
1920s	Commercial AM Radio
	Kinescope (TV cathode ray tube)
	FM Radio
1930s	Commercial FM Radio
	Radar
	Electron Microscope
	Radio Telescope
	Analog Computer
1940s	Inertial Navigation
	Commercial TV
	Commercial Stereo
	Digital Computer
	Transistor
1950s	Video Recorder
	Color TV
	Industrial Robot
	Transistorized Hearing Aid
	Transistorized Computer (Mainframe)
	Compact Pacemaker
	Sputnik
1960s	Minicomputer
	Music Synthesizer
	Light Emitting Diode (LED)
	Laser
	Integrated Circuit
	Communication Satellite
	Electronic Watches
1970s	Microcomputer
	Personal Computer
	Pocket Calculator
	Fiber Optics
	Microchip
	Video Games
1980s	Laser Printer
	VHS and BETA VCRs
	Portable Video Camera
	Home Video Games
	CD Player
	Satellite TV

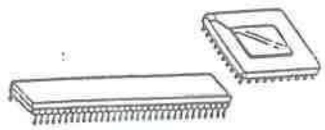


Tubes



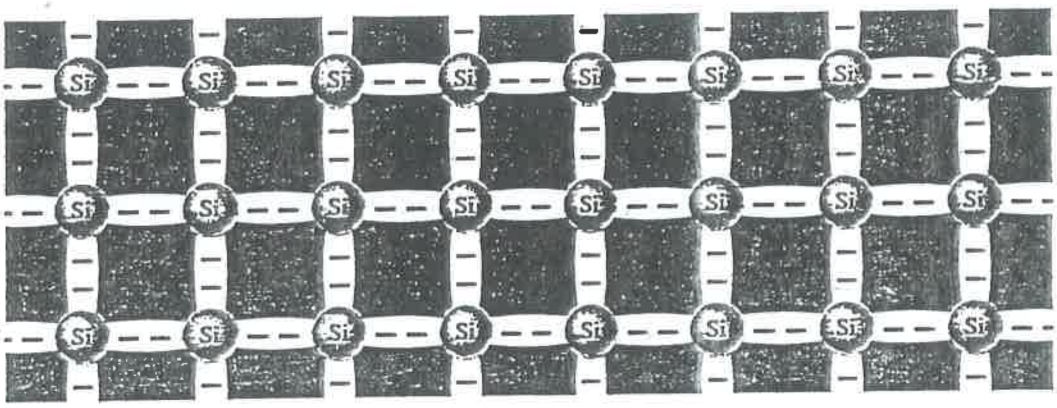
Transistors


Integrated circuits

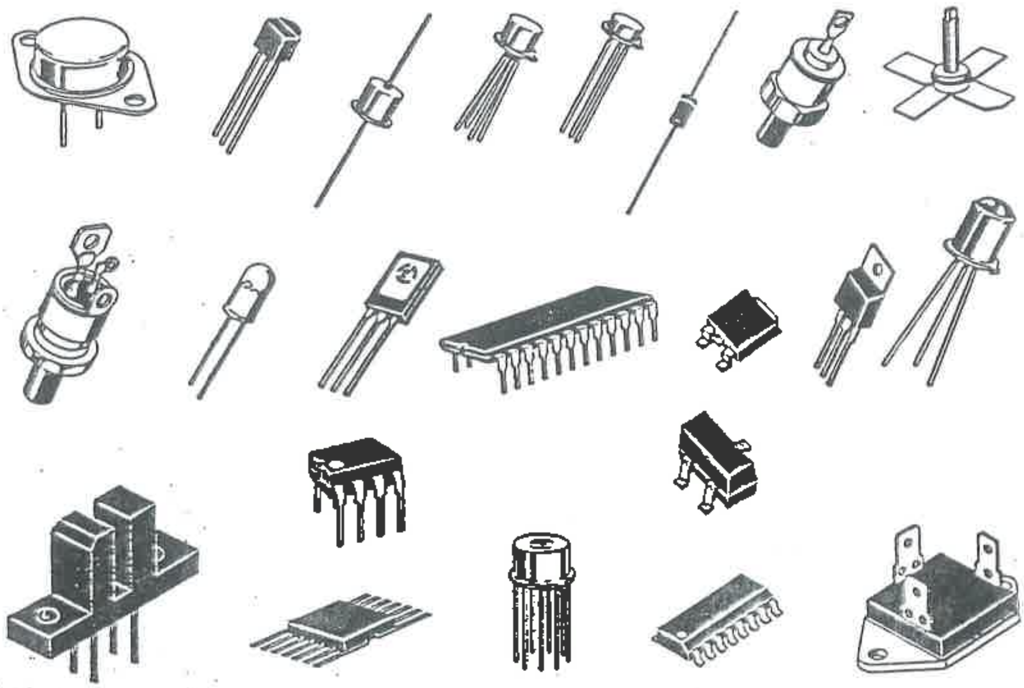

μ processors

UNIT 1

INTRODUCTION TO SEMICONDUCTORS



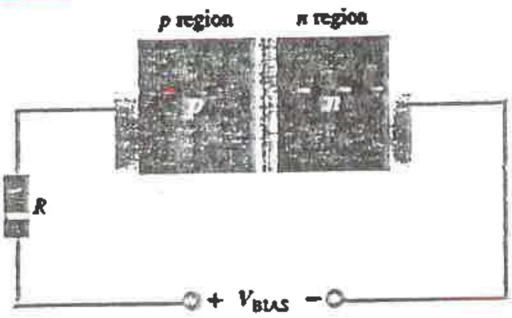
Electronic devices such as diodes, transistors, and integrated circuits are made of a semiconductor material. To understand how these devices work, you need a basic knowledge of the structure of atoms and the interaction of atomic particles. An important concept introduced in this chapter is that of the *pn* junction that is formed when two different types of semiconductor material are joined. The *pn* junction is fundamental to the operation of devices such as the diode and certain types of transistors. Also, the function of the *pn* junction is an essential factor in making electronic circuits operate properly.



BIASING THE PN JUNCTION

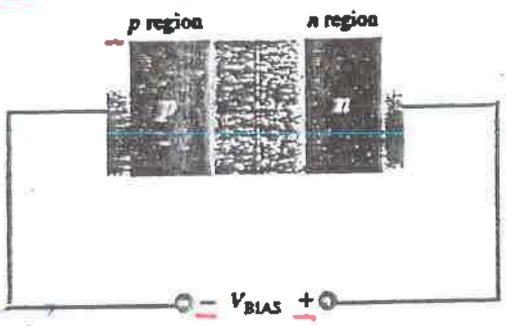
SUMMARY OF *PN* JUNCTION BIAS

FORWARD BIAS: PERMITS CURRENT



- Bias voltage connections: positive to *p* region; negative to *n* region.
- The bias voltage must be greater than the barrier potential.
- Barrier potential: 0.7 V for silicon; 0.3 V for germanium.
- Majority carriers provide the forward current.
- Majority carriers flow toward the *pn* junction.
- The depletion region narrows.

REVERSE BIAS: PREVENTS CURRENT



- Bias voltage connections: positive to *n* region; negative to *p* region.
- The bias voltage must be less than the breakdown voltage.
- Minority carriers provide the small reverse current.
- Majority carriers flow away from the *pn* junction during short transition time.
- There is no majority carrier current after transition time.
- The depletion region widens.

1–8 ▪ CURRENT-VOLTAGE CHARACTERISTIC OF A *PN* JUNCTION

As you have learned, forward bias produces current through a pn junction and reverse bias prevents current except for a negligible reverse current. Reverse bias prevents current as long as the reverse-bias voltage does not equal or exceed the breakdown voltage of the junction. In this section, we will examine more closely the relationship between the voltage and the current in a pn junction on a graphical basis.

After completing this section, you should be able to

- Analyze the current-voltage (*I-V*) characteristic curve of a *pn* junction
  - ☐ Explain the forward-bias portion of the *I-V* characteristic curve
  - ☐ Explain the reverse-bias portion of the *I-V* characteristic curve
  - ☐ Identify the barrier potential
  - ☐ Identify the breakdown voltage
  - ☐ Discuss temperature effects on a *pn* junction

I-V Characteristic for Forward Bias

As you have learned, when a forward-bias voltage is applied across a silicon *pn* junction, there is current through the junction. This current is called the *forward current* and is designated I_F. Figure 1–27 illustrates what happens as the forward-bias voltage is increased positively from 0 V. The resistor is used to limit the forward current to a value that will not overheat the *pn* junction and cause damage.

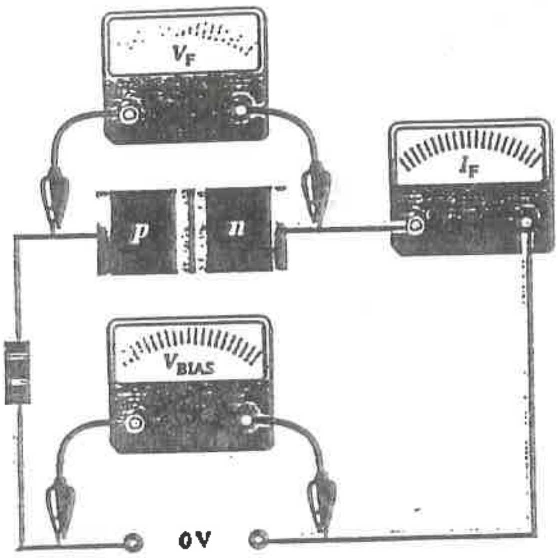
With 0 V across the *pn* junction, there is no forward current, as indicated in Figure 1–27(a). As you gradually increase the bias voltage, the forward current *and* the voltage across the *pn* junction gradually increase, as shown in part (b). A portion of the applied bias voltage is dropped across the limiting resistor. When the applied bias voltage is increased to a value where the voltage across the *pn* junction reaches approximately 0.7 V (barrier potential), the forward current begins to increase rapidly.

As you continue to increase the bias voltage, the current continues to increase very rapidly, but the voltage across the *pn* junction increases very gradually above 0.7 V, as illustrated in Figure 1–27(c). This small increase in the *pn* junction voltage above the barrier potential is due to the voltage drop across the dynamic resistance of the semiconductive material.

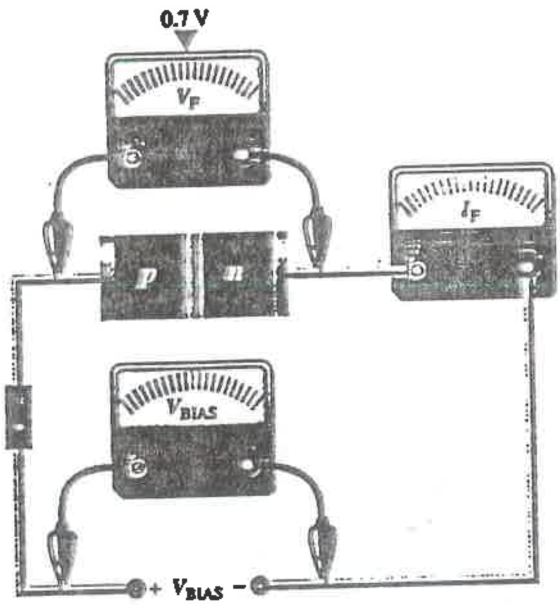
Graphing the I-V Curve If you plot the results of the type of measurements shown in Figure 1–27 on a graph, you get the *I-V* characteristic curve for a forward-biased *pn* junction, as shown in Figure 1–28(a). The forward current (I_F) increases upward along the vertical axis and the *pn* junction forward voltage (V_F) increases to the right along the horizontal axis.

As you can see in Figure 1–28(a), the forward current increases very little until the forward voltage across the junction reaches approximately 0.7 V at the knee of the curve. After this point, the forward voltage remains at approximately 0.7 V, but I_F increases rapidly. As previously mentioned, there is a slight increase in V_F above 0.7 V as the current increases due mainly to the voltage drop across the dynamic resistance. *Normal operation for a forward-biased pn junction is above the knee of the curve.* The I_F scale is typically in mA, as indicated.

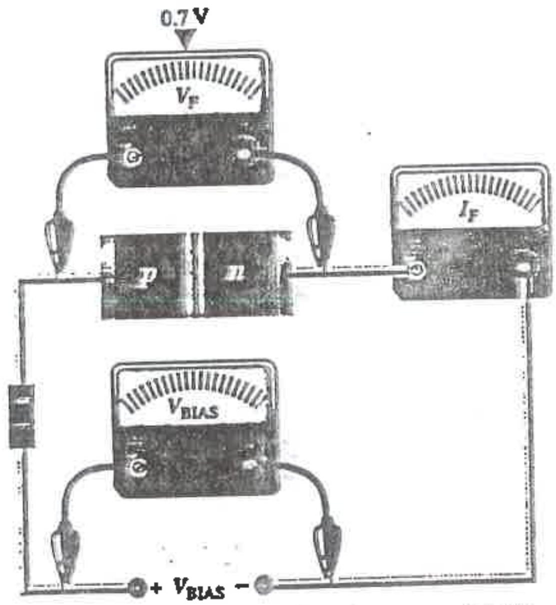
The three points *A*, *B*, and *C* shown on the curve in Figure 1–28(a) can be related to the measurements in Figure 1–27. Point *A* corresponds to Figure 1–27(a), which is a zero-bias condition. Point *B* corresponds to Figure 1–27(b) where the forward voltage is less than the barrier potential of 0.7 V. Point *C* corresponds to Figure 1–27(c) where the



(a) No bias voltage. *PN* junction is at equilibrium.



(b) Small forward-bias voltage ($V_F < 0.7$ V), very small forward current.



(c) Forward voltage reaches and remains at approximately 0.7 V. Forward current continues to increase as the bias voltage is increased.

FIGURE 1–27
Forward-bias measurements show general changes in V_F and I_F as V_{BIAS} is increased.

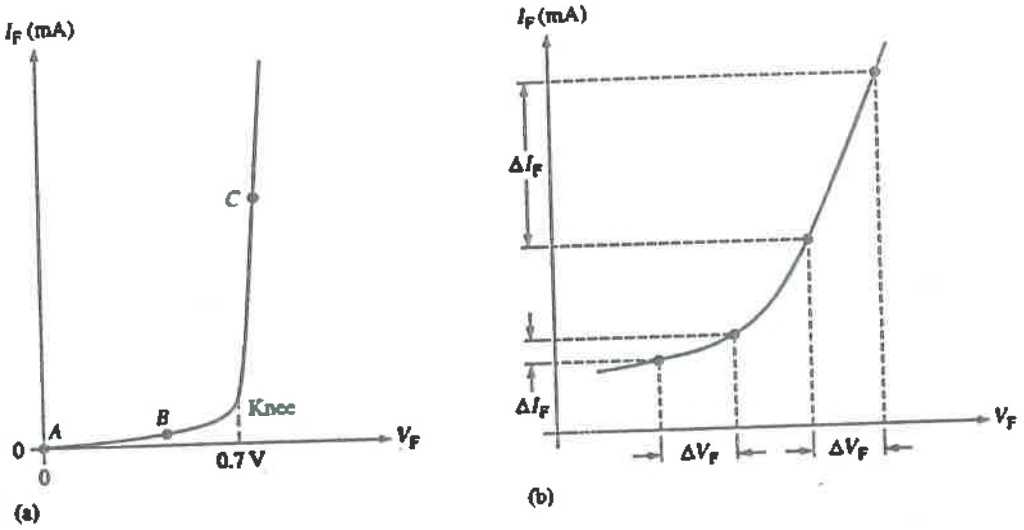


FIGURE 1–28
I-V characteristic curve for forward bias. Part (b) illustrates how the dynamic resistance decreases as you move up the curve ($r'_d = \Delta V_F/\Delta I_F$).

forward voltage V_F *approximately* equals the barrier potential. As the external bias voltage and forward current continue to increase above the knee, the forward voltage will increase slightly above 0.7 V. In reality, the forward voltage can be as much as 0.90 V, depending on the forward current.

Dynamic Resistance Unlike a linear resistance, the resistance of the forward-biased *pn* material is not constant over the entire curve. Because the resistance changes as you move along the *I-V* curve, it is called *dynamic* or *ac resistance.* Internal resistances of electronic devices are usually designated by lowercase italic *r* with a prime, instead of the standard *R*. The dynamic resistance of a diode is designated r'_d.

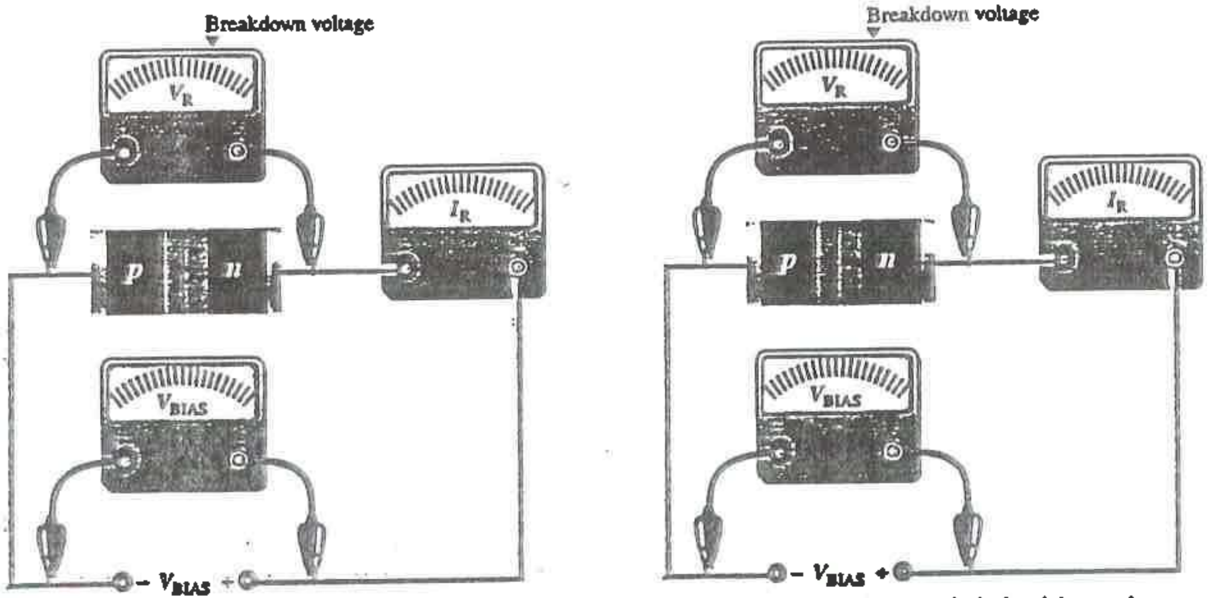
Below the knee of the curve the resistance is greatest because the current increases very little for a given change in voltage ($r'_d = \Delta V_F/\Delta I_F$). The resistance begins to decrease in the region of the knee of the curve and becomes smallest above the knee where there is a large change in current for a given change in voltage. This characteristic is illustrated in Figure 1–28(b) for equal changes in V_F (ΔV_F) on a magnified segment of the *I-V* curve below and above the knee.

I-V Characteristic for Reverse Bias

When a reverse-bias voltage is applied across a *pn* junction, there is only an extremely small reverse current (I_R) through the junction. Figure 1–29 illustrates what happens as the reverse-bias voltage is increased negatively from 0 V.

With 0 V across the *pn* junction, there is no reverse current. As you gradually increase the reverse-bias voltage, there is a very small reverse current and the voltage across the *pn* junction increases, as shown in Figure 1–29(a). When the applied bias voltage is increased to a value where the reverse voltage across the *pn* junction (V_R) reaches the breakdown value (V_{BR}), the reverse current begins to increase rapidly.

As you continue to increase the bias voltage, the current continues to increase very rapidly, but the voltage across the *pn* junction increases very little above V_{BR}, as illustrated in Figure 1–29(b). *Breakdown, with exceptions, is not a normal mode of operation for most pn junction devices.*



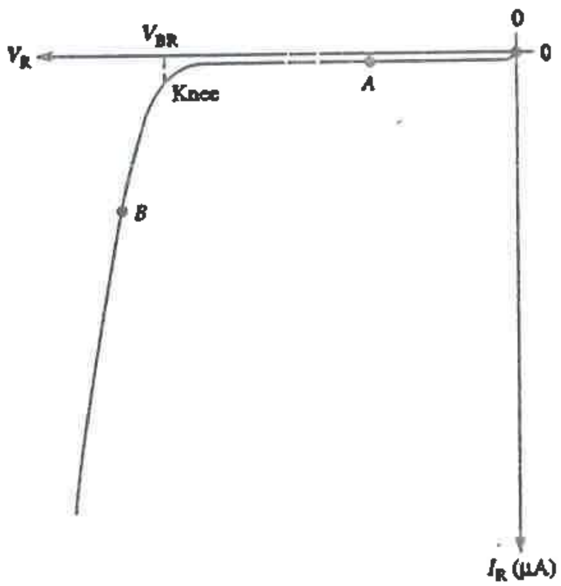
(a) A reverse-bias voltage less than breakdown value produces an extremely small reverse current.

(b) When the bias voltage exceeds the breakdown value, the reverse current rapidly increases and damage from excessive heat can destroy the *pn* material.

FIGURE 1–29
Current and voltage in a reverse-biased pn junction.

Graphing the I-V Curve If you plot the results of the type of measurements shown in Figure 1–29 on a graph, you get the *I-V* characteristic curve for a reverse-biased *pn* junction. A typical curve is shown in Figure 1–30. The reverse current (I_R) increases downward along the vertical axis and the *pn* junction reverse voltage (V_R) increases to the left along the horizontal axis. Point *A* on the curve corresponds to the measurements in Figure 1–29(a), and point *B* corresponds to the measurements in Figure 1–29(b).

FIGURE 1–30
I-V characteristic curve for reverse bias.



As you can see, there is very little reverse current (usually µA or nA) until the reverse voltage across the junction reaches approximately the breakdown value (V_{BR}) at the knee of the curve. After this point, the reverse voltage remains at approximately V_{BR}, but I_R increases very rapidly resulting in overheating and possible damage. The breakdown voltage for a typical silicon *pn* junction can vary, but a minimum value of 50 V is not unusual.

The Complete *I-V* Characteristic Curve

Combine the curves for both forward bias and reverse bias, and you have the complete *I-V* characteristic curve for a *pn* junction, as shown in Figure 1–31. Notice that the I_F scale is in mA compared to the I_R scale in µA.

Temperature Effects on the *I-V* Characteristic

For a forward-biased *pn* junction, as temperature is increased, the forward current increases for a given value of forward voltage. Also, for a given value of forward current, the forward voltage decreases. This is shown with the *I-V* characteristic curves in Figure 1–32. The blue curve is at room temperature (25°C) and the red curve is at an elevated temperature (25°C + Δ*T*). Notice that the barrier potential decreases as temperature increases.

For a reverse-biased *pn* junction, as temperature is increased, the reverse current increases. The difference in the two curves is exaggerated on the graph in Figure 1–32 for illustration. Keep in mind that the reverse current remains extremely small.

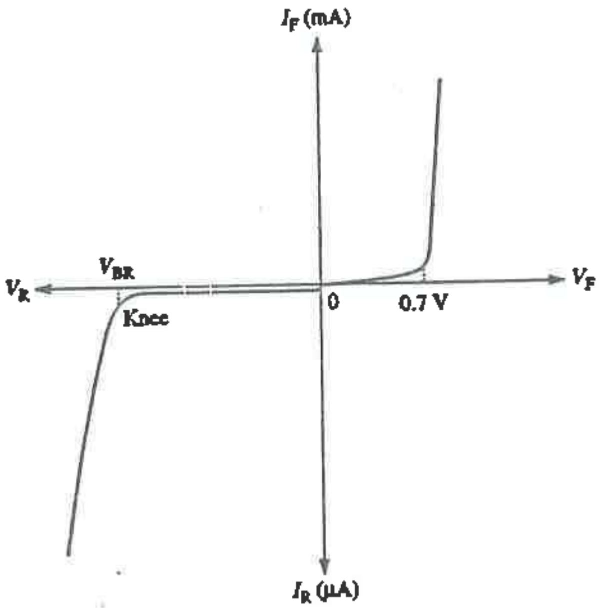


FIGURE 1–31
The complete I-V characteristic curve for a pn junction.

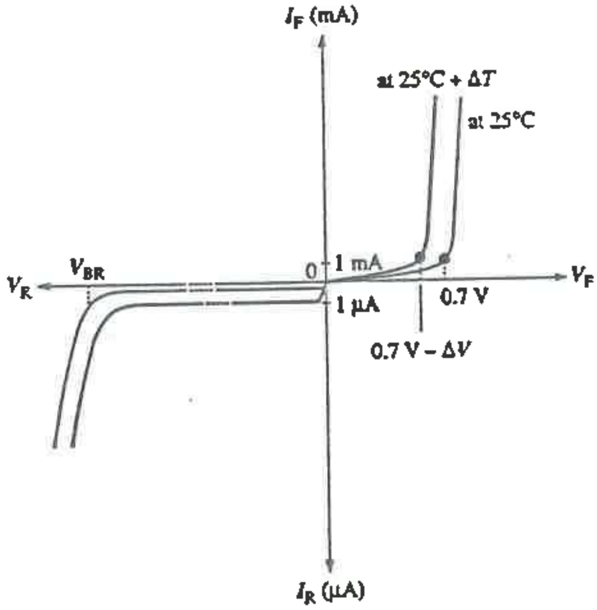


FIGURE 1–32
Temperature effect on the I-V characteristic of a pn junction. The 1 mA and 1 µA marks on the vertical axis are given as a basis for a relative comparison of the current scales.

SECTION 1–8 REVIEW

1. Discuss the significance of the knee of the characteristic curve in forward bias.
2. On what part of the curve is a forward-biased *pn* junction normally operated?
3. Which is greater, the breakdown voltage or the barrier potential?
4. On what part of the curve is a reverse-biased *pn* junction normally operated?
5. What happens to the barrier potential when the temperature increases?

1–9 ■ THE DIODE

In this section, you will see that the diode is a pn junction device and learn its electrical symbol. You will also learn how the diode can be modeled for circuit applications using three levels of complexity.

After completing this section, you should be able to

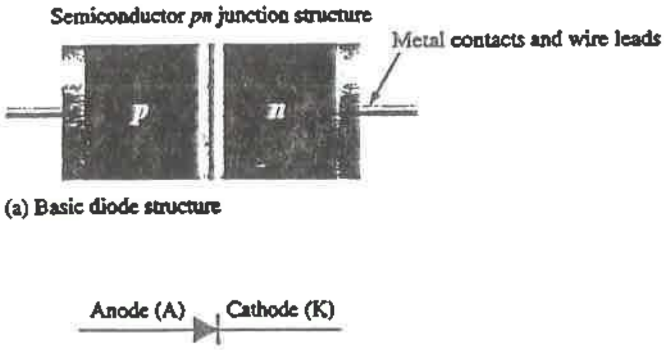
- Discuss the operation of diodes and explain the three diode models
  - ☐ Explain the relation of the *pn* junction to a diode
  - ☐ Recognize a diode symbol and indentify the diode terminals
  - ☐ Recognize diodes in various physical configurations
  - ☐ Explain the ideal diode model
  - ☐ Explain the practical diode model
  - ☐ Explain the complex diode model

Diode Structure and Symbol

The general-purpose or rectifier diode is a single *pn* junction device with conductive contacts and wire leads connected to each region, as shown in Figure 1–33(a). One-half of the diode is an *n*-type semiconductor and the other half is a *p*-type semiconductor. You should recognize this as the *pn* junction device that was discussed in the preceding sections.

The schematic symbol for a general-purpose or rectifier diode is shown in Figure 1–33(b). The *n* region is called the **cathode** and the *p* region is called the **anode**. The "arrow" in the symbol points in the direction of conventional current (opposite to electron flow).

FIGURE 1–33
Diode structure and schematic symbol.



(b) Schematic symbol

Forward and Reverse Bias of a Diode

The previous coverage of biasing with relation to a *pn* junction applies to the diode because the diode is a *pn* junction device.

Forward-Bias Connection A diode is forward-biased when a voltage source is connected as shown in Figure 1–34(a). The positive terminal of the source is connected to the anode through a current-limiting resistor. The negative terminal of the source is connected to the cathode. The forward current (I_F) is from cathode to anode as indicated. The forward voltage drop (V_F) due to the barrier potential is from positive at the anode to negative at the cathode.

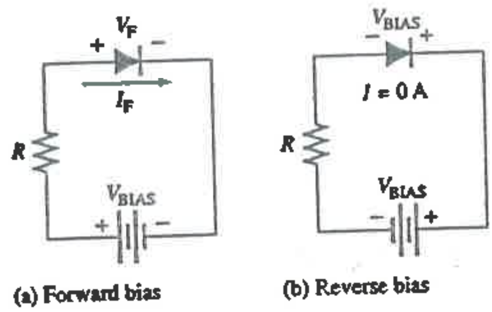


FIGURE 1–34
Forward-bias and reverse-bias connections for a diode.

Reverse-Bias Connection A diode is reverse-biased when a voltage source is connected as shown in Figure 1–34(b). The negative terminal is connected to the anode, and the positive terminal is connected to the cathode. A resistor is not necessary in reverse bias but it is shown for circuit consistency. The current is zero (neglecting the small reverse current). Notice that the entire bias voltage (V_{BIAS}) appears across the diode.

Typical Diodes

Several common physical configurations of diodes are illustrated in Figure 1–35. The anode and cathode are indicated on a diode in several ways, depending on the type of package. The cathode is usually marked by a band, a tab, or some other feature. On those packages where one lead is connected to the case, the case is the cathode. Always check the data sheet, which will be introduced in Chapter 2, for the pin configuration, if there is uncertainty.

The Ideal Diode Model

The ideal model of a diode is a simple switch. When the diode is forward-biased, it acts like a closed (on) switch, as shown in Figure 1–36(a). When the diode is reverse-biased, it acts like an open (off) switch, as shown in part (b). The barrier potential, the forward dynamic resistance, and the reverse current are all neglected.

In Figure 1–36(c), the ideal diode characteristic curve graphically depicts the ideal diode operation. Since the barrier potential and the forward dynamic resistance are neglected, the diode is assumed to have a zero voltage across it when forward-biased, as indicated by the portion of the curve on the positive vertical axis.

$$V_F = 0\text{ V}$$

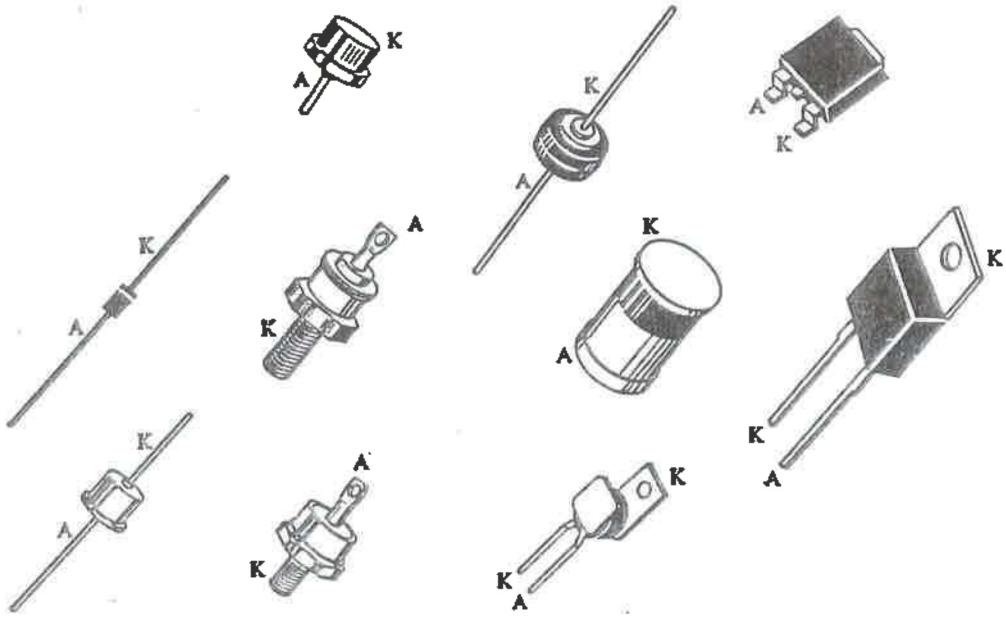
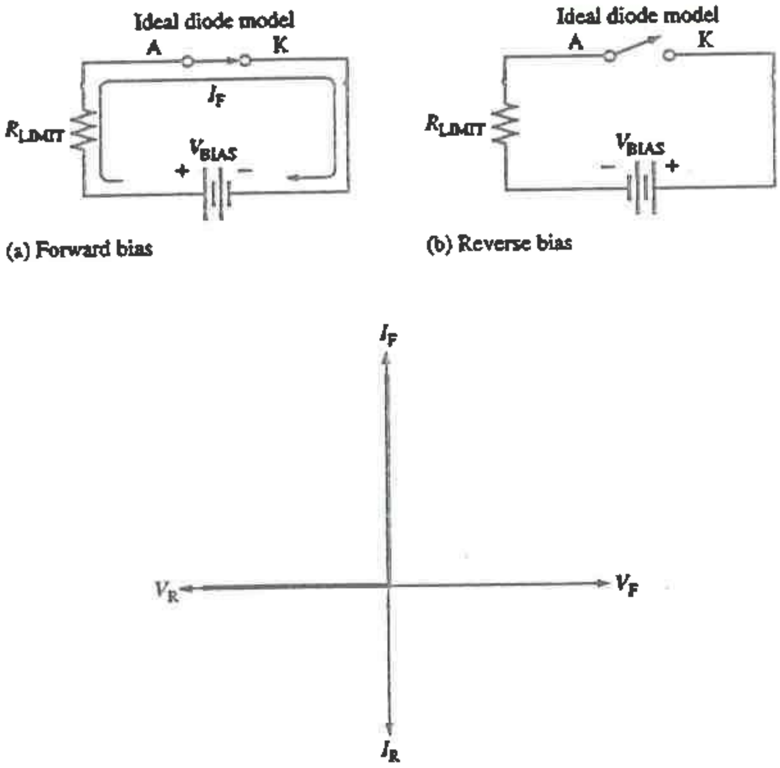


FIGURE 1–35
Typical diode packages and terminal identification.



(c) Ideal characteristic curve (blue)

FIGURE 1–36
The ideal model of a diode.

The forward current is determined by the bias voltage and the limiting resistor.

$$I_F = \frac{V_{BIAS}}{R_{LIMIT}} \qquad (1\text{–}2)$$

Since the reverse current is neglected, its value is assumed to be zero, as indicated in Figure 1–36(c) by the portion of the curve on the negative horizontal axis.

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

The reverse voltage equals the bias voltage.

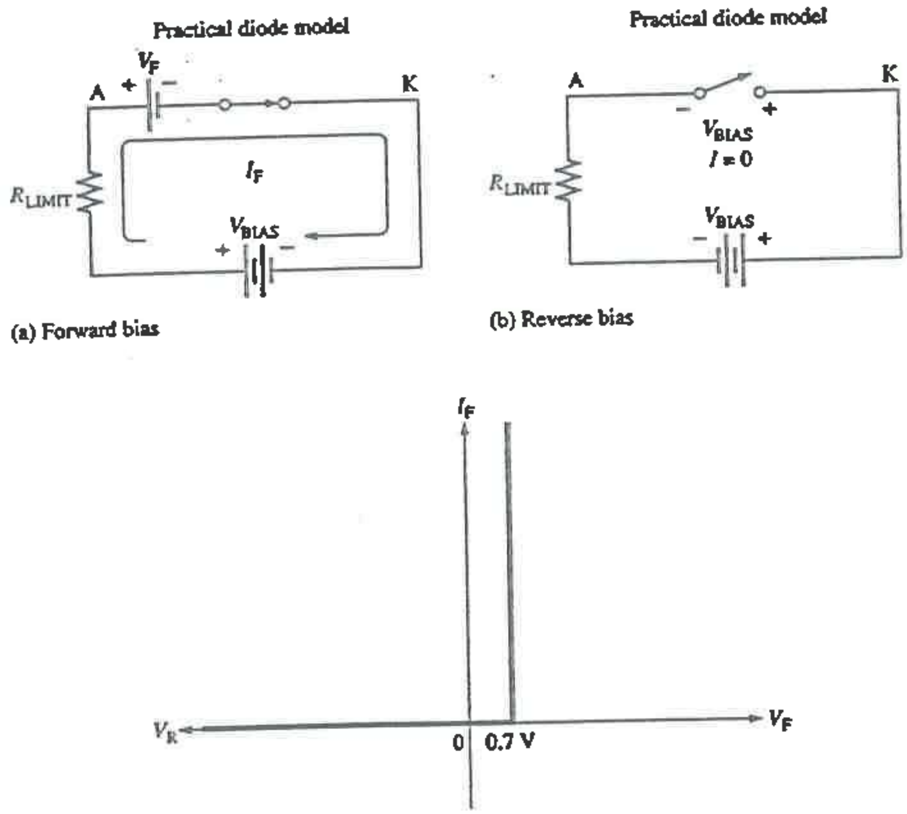
$$V_R = V_{BIAS}$$

You may want to use the ideal model when you are troubleshooting or trying to figure out the operation of a circuit and are not concerned with more exact values of voltage or current.

The Practical Diode Model

The practical model, the one we will use most often, adds the barrier potential to the ideal switch model. When the diode is forward-biased, it acts as a closed switch in series with a small voltage (assumed to be 0.7 V for silicon) equal to the barrier potential with the positive side toward the anode, as indicated in Figure 1–37(a). The barrier potential voltage

FIGURE 1–37
The practical model of a diode.



(c) Characteristic curve (silicon)

source represents the fixed voltage drop (V_F) produced across the forward-biased *pn* junction of the diode and is not an active source of voltage.

When the diode is reverse-biased, it acts as an open switch just as in the ideal model, as shown in Figure 1–37(b). The barrier potential does not affect reverse bias, so it is not a factor.

The characteristic curve for the practical silicon diode model is shown in Figure 1–37(c). Since the barrier potential is included and the forward dynamic resistance is neglected, the diode is assumed to have a voltage across it when forward-biased, as indicated by the portion of the curve to the right of the origin.

$$V_F = 0.7\ \text{V} \qquad \text{(silicon)}$$
$$V_F = 0.3\ \text{V} \qquad \text{(germanium)}$$

The forward current is determined with the following formula:

$$I_F = \frac{V_{BIAS} - V_F}{R_{LIMIT}} \qquad (1\text{–}3)$$

Since the reverse current is neglected, the diode is assumed to have zero reverse current, as indicated by the portion of the curve on the negative horizontal axis.

$$I_R = 0\ \text{A}$$
$$V_R = V_{BIAS}$$

EXAMPLE 1–1

(a) Determine the forward voltage and forward current for the diode in Figure 1–39(a) for each of the diode models. Also find the voltage across the limiting resistor in each case. Assume $r'_d = 10\ \Omega$ at the determined value of forward current.

(b) Determine the reverse voltage and reverse current for the diode in Figure 1–39(b) for each of the diode models. Also find the voltage across the limiting resistor in each case. Assume $I_R = 1\ \mu A$.

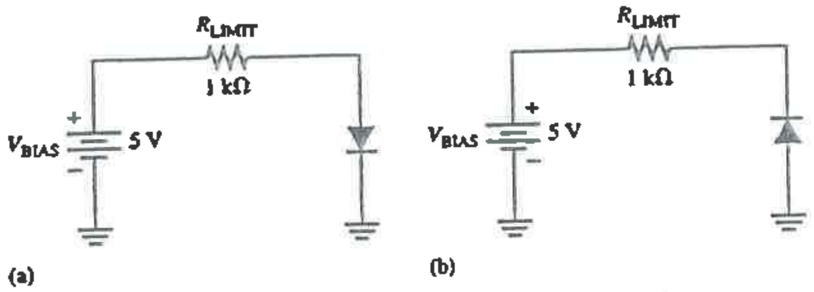


FIGURE 1–39

Solution

(a) Ideal model:

$$V_F = 0\ V$$

$$I_F = \frac{V_{BIAS}}{R_{LIMIT}} = \frac{5\ V}{1\ k\Omega} = 5\ mA$$

$$V_{LIMIT} = I_F R_{LIMIT} = (5\ mA)(1\ k\Omega) = 5\ V$$

Practical model:

$$V_F = 0.7\ V$$

$$I_F = \frac{V_{BIAS} - V_F}{R_{LIMIT}} = \frac{5\ V - 0.7\ V}{1\ k\Omega} = \frac{4.3\ V}{1\ k\Omega} = 4.3\ mA$$

$$V_{LIMIT} = I_F R_{LIMIT} = (4.3\ mA)(1\ k\Omega) = 4.3\ V$$

Complex model:

$$I_F = \frac{V_{BIAS} - 0.7\ V}{R_{LIMIT} + r'_d} = \frac{5\ V - 0.7\ V}{1\ k\Omega + 10\ \Omega} = \frac{4.3\ V}{1010\ \Omega} \cong 4.26\ mA$$

$$V_F = 0.7\ V + I_F r'_d = 0.7\ V + (4.26\ mA)(10\ \Omega) = 743\ mV$$

$$V_{LIMIT} = I_F R_{LIMIT} = (4.26\ mA)(1\ k\Omega) = 4.26\ V$$

(b) Ideal model:

$$I_R = 0\ A$$

$$V_R = V_{BIAS} = 5\ V$$

$$V_{LIMIT} = 0\ V$$

Practical model:

$$I_R = 0\ A$$

$$V_R = V_{BIAS} = 5\ V$$

$$V_{LIMIT} = 0\ V$$

Complex model:

$$I_R = 1\ \mu A$$

$$V_{LIMIT} = I_R R_{LIMIT} = (1\ \mu A)(1\ k\Omega) = 1\ mV$$

$$V_R = V_{BIAS} - V_{LIMIT} = 5\ V - 1\ mV = 4.999\ V$$

Related Exercise Assume that the diode in Figure 1–39(a) fails open. What is the voltage across the diode and the voltage across the limiting resistor?

Testing a Diode

A multimeter can be used as a fast and simple way to check a diode. As you know, a good diode will show an extremely high resistance (or open) with reverse bias and a very low resistance with forward bias. A defective open diode will show an extremely high resistance (or open) for both forward and reverse bias. A defective shorted or resistive diode will show zero or a low resistance for both forward and reverse bias. An open diode is the most common type of failure.

The DMM Diode Test Position Many digital multimeters (DMMs) have a diode test position which provides a convenient way to test a diode. A typical DMM, as shown in Figure 1–40, has a small diode symbol to mark the position of the function switch. When set to *diode test*, the meter provides an internal voltage sufficient to forward bias and reverse bias a diode. This internal voltage may vary among different makes of DMM, but 2.5 V to 3.5 V is a typical range of values. The meter provides a voltage reading or other indication to show the condition of the diode under test.

When the Diode Is Working In Figure 1–40(a), the red (positive) lead of the meter is connected to the anode and the black (negative) lead is connected to the cathode to forward bias the diode. If the diode is good, you will get a reading of between 0.5 V and 0.9 V, with 0.7 V being typical for forward bias.

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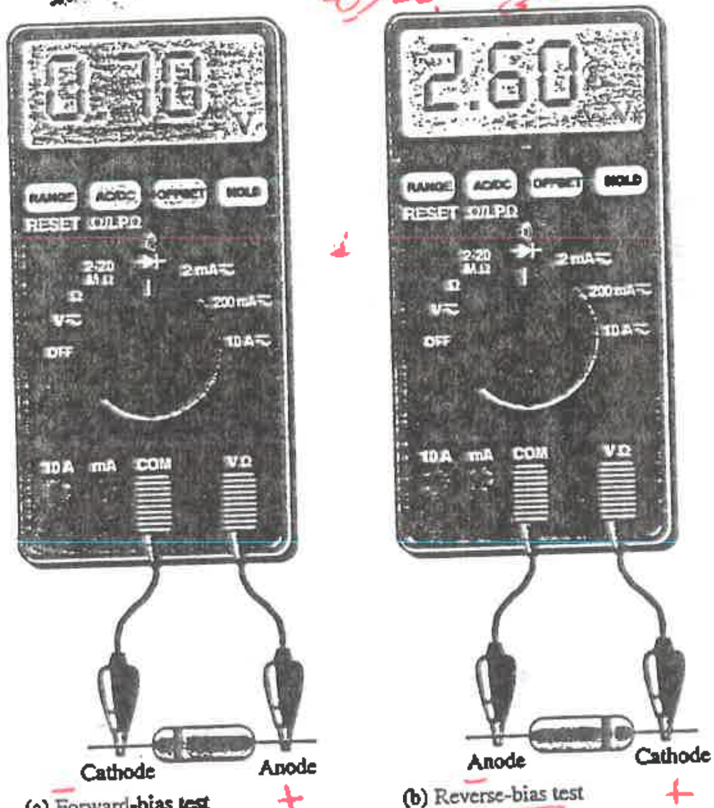


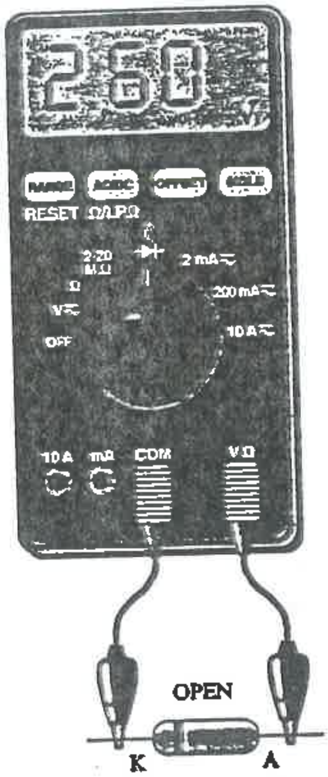
(a) Forward-bias test

(b) Reverse-bias test

FIGURE 1–40
DMM diode test on a properly functioning diode.

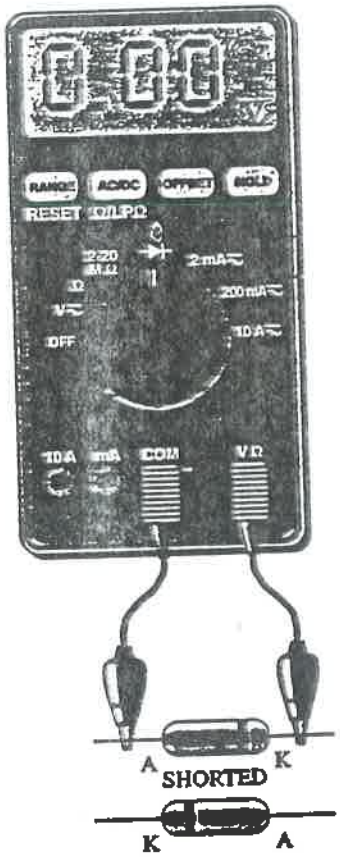
In Figure 1–40(b), the diode is turned around to reverse bias the diode as shown. If the diode is working properly, you will get a voltage reading based on the meter's internal voltage source. The 2.6 V shown in the figure represents a typical value and indicates that the diode has an extremely high reverse resistance with essentially all of the internal voltage appearing across it.

When the Diode Is Defective When a diode has failed open, you get an open circuit voltage reading (2.6 V is typical) for both the forward-bias and the reverse-bias condition, as illustrated in Figure 1–41(a) and (b). If a diode is shorted, the meter reads 0 V in both forward- and reverse-bias tests, as indicated in part (c). Sometimes, a failed diode may exhibit a small resistance for both bias conditions rather than a pure short. In this case, the meter will show a small voltage much less than the correct open voltage. For example, a resistive diode may result in a reading of 1.1 V in both directions rather than the correct readings of 0.7 V forward and 2.6 V reverse.



(a) Forward-bias test, open diode

(b) Reverse-bias test, open diode



(c) Forward- and reverse-bias tests for a shorted diode give same 0 V reading. If the diode is resistive rather than a pure short, the reading is less than 2.6 V.

FIGURE 1–41
Testing a defective diode.

Checking a Diode with the OHMs Function DMMs that do not have a diode test position can be used to check a diode by setting the function switch on an OHMs range. For a forward-bias check of a good diode, you will get a resistance reading that can vary depending on the meter's internal battery. Many meters do not have sufficient voltage on the OHMs setting to fully forward-bias a diode and you may get a reading of from several hundred to several thousand ohms. For the reverse-bias check of a good diode, you will get some type of out-of-range indication such as "OL" on most DMMs because the reverse resistance is too high for the meter to measure.

Even though you may not get accurate forward- and reverse-resistance readings on a DMM, the relative readings indicate that a diode is functioning properly, and that is usually all you need to know. The out-of-range indication shows that the reverse resistance is extremely high, as you expect. The reading of a few hundred to a few thousand ohms for forward bias is relatively small compared to the reverse resistance, indicating that the diode is working properly. The actual resistance of a forward-biased diode is typically much less than 100 Ω.