Optoelectronic Devices

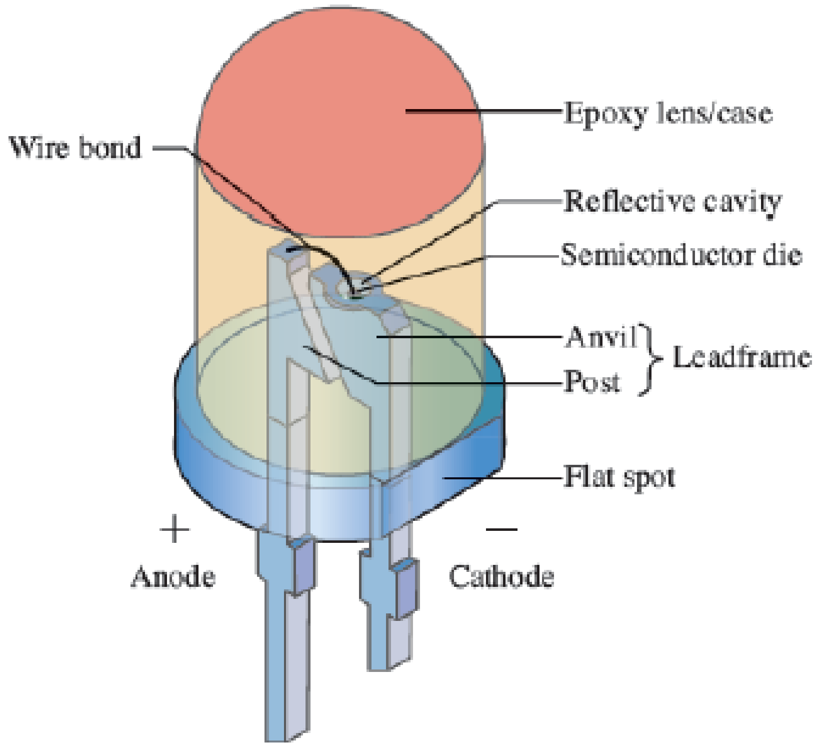
OPTOELECTRONICS

- It is the technology that combines optics and electronics.
- This field includes many devices based on the action of a pn junction.
- Examples of optoelectronics devices are light-emitting diodes (LEDs), photodiodes, optocouplers, and laser diodes.

Light-Emitting Diodes (LEDs)

- LEDs have replaced incandescent lamps in many applications because of the LED's lower energy consumption, smaller size, faster switching and longer lifetime.
- Figure 5-1 shows the parts of a standard low-power LED.

FIGURE 5-1 Parts of an LED.

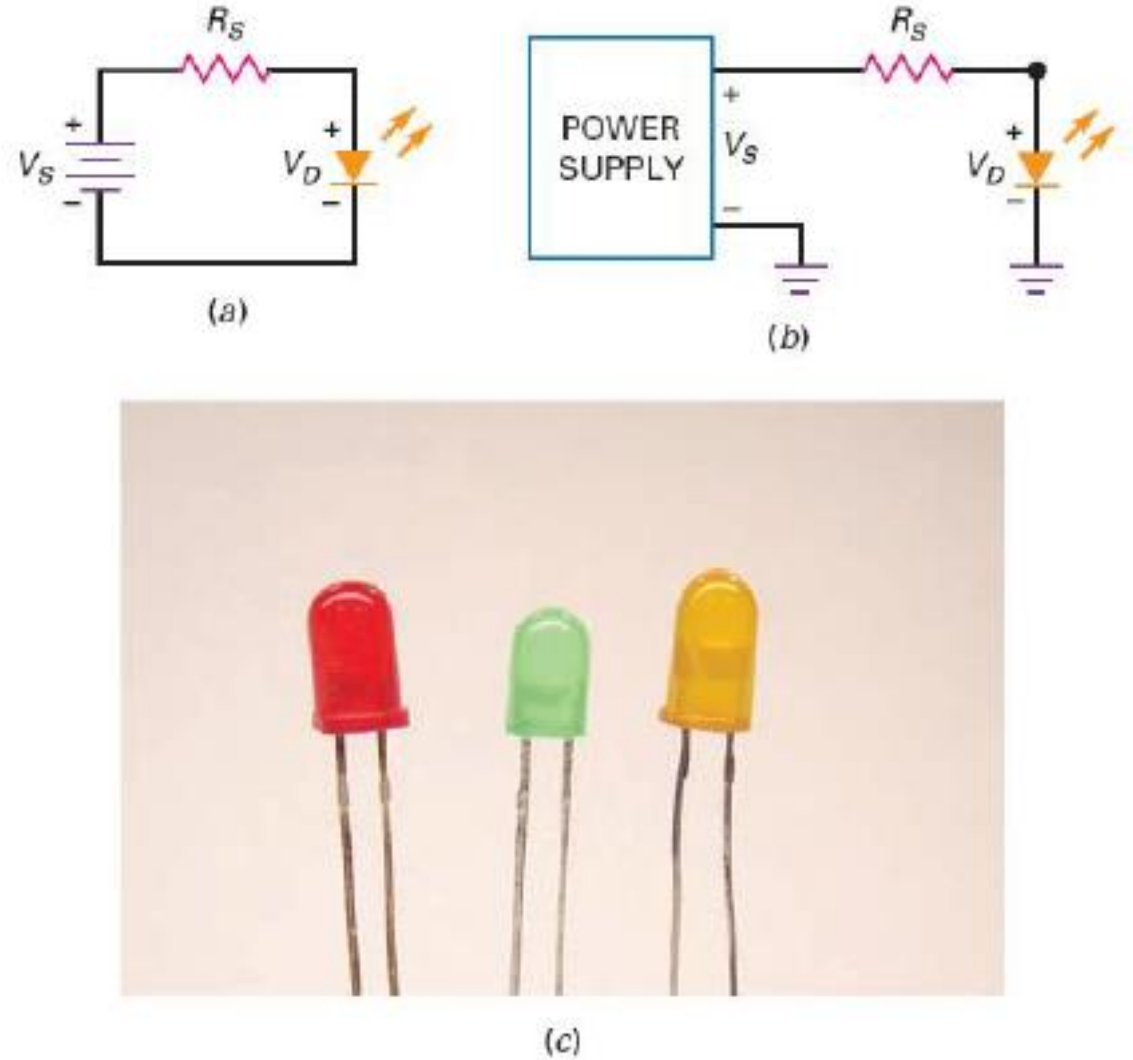


Light-Emitting Diodes (LEDs)

- Just as in an ordinary diode, the LED has an anode and a cathode that must be properly biased.
- The outside of the plastic case typically has a flat spot on one side which indicates the cathode side of the LED.
- The material used for the semiconductor will determine the LED’s characteristics.
- Figure 5-2a shows a source connected to a resistor and an LED.
- The outward arrows symbolize the radiated light.
- In a forward-biased LED, free electrons cross the pn junction and fall into holes. As these electrons fall from a higher to a lower energy level, they radiate energy in the form of photons.
- In ordinary diodes, this energy is radiated in the form of heat. But in an LED, the energy is radiated as light.
- This effect is referred to as **electroluminescence**.

Light-Emitting Diodes (LEDs)

FIGURE 5-2 LED indicator. (*a*) Basic circuit; (*b*) practical circuit; (*c*) typical LEDs.



Light-Emitting Diodes (LEDs)

- The color of the light, which corresponds to the *wavelength energy of the photons*, is primarily determined by the energy band gap of the semiconductor materials that are used.
- By using elements like gallium, arsenic, and phosphorus, a manufacturer can produce LEDs that radiate red, green, yellow, blue, orange, white or infrared (invisible) light.
- LEDs that produce visible radiation are useful as indicators in applications such as instrumentation panels, internet routers, and so on.
- The infrared LED finds applications in security systems, remote controls, industrial control systems, and other areas requiring invisible radiation.

LED Voltage and Current

- The resistor of Fig. 5-2b is the usual current-limiting resistor that prevents the current from exceeding the maximum current rating of the diode.
- Since the resistor has a node voltage of VS on the left and a node voltage of VD on the right, the voltage across the resistor is the difference between the two voltages.
- With Ohm’s law, the series current is:

$$I_S = \frac{V_S - V_D}{R_S}$$

LED Voltage and Current

- For most commercially available low-power LEDs, the typical voltage drop is from 1.5 to 2.5 V for currents between 10 and 50 mA.
- The exact voltage drop depends on the LED current, color, tolerance, along with other factors.
- Unless otherwise specified, we will use a nominal drop of 2 V when troubleshooting or analyzing lowpower LED circuits in this book.
- Figure 5-2c shows typical low-power LEDs with housings made to help radiate the respective color.

LED Voltage and Current

Colour	Approx. Forward Voltage Vf (V)
Red	1.7
HE Red*	2.0
Bright Red	2.3
Orange	2.0
Yellow	2.1
Green	2.2
Blue	3.2
White	3.2

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

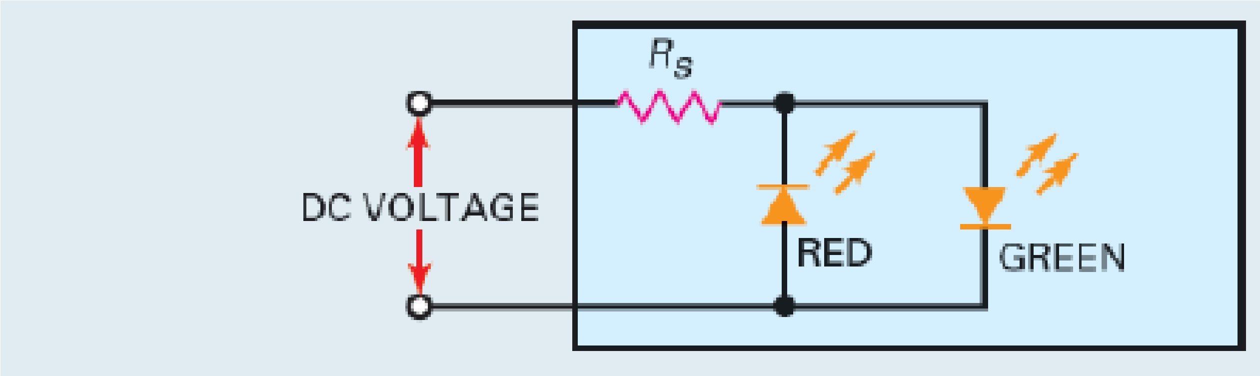
LED Brightness

- The brightness of an LED depends on the current. The amount of light emitted is often specified as its luminous intensity IV and is rated in candelas (cd).
- Low-power LEDs generally have their ratings given in millicandelas (mcd). For instance, a TLDR5400 is a red LED with a forward voltage drop of 1.8 V and an IV rating of 70 mcd at 20 mA. The luminous intensity drops to 3 mcd at a current of 1 mA.
- When VS is much greater than VD in Eq. (5-1), the brightness of the LED is approximately constant. If a circuit like Fig. 5-2b is mass-produced using a TLDR5400, the brightness of the LED will be almost constant if VS is much greater than VD.
- If VS is only slightly more than VD, the LED brightness will vary noticeably from one circuit to the next. The best way to control the brightness is by driving the LED with a current source. This way, the brightness is constant because the current is constant.

Applications of LEDs

Voltage-polarity Tester

- Figure 5-3*a* shows a voltage-polarity tester. It can be used to test a dc voltage of unknown polarity. When the dc voltage is positive, the green LED lights up. When the dc voltage is negative, the red LED lights up.



(*a*)

Voltage-polarity Tester

- What is the approximate LED current if the dc input voltage is 50 V and the series resistance is 2.2 kΩ?

Solution:

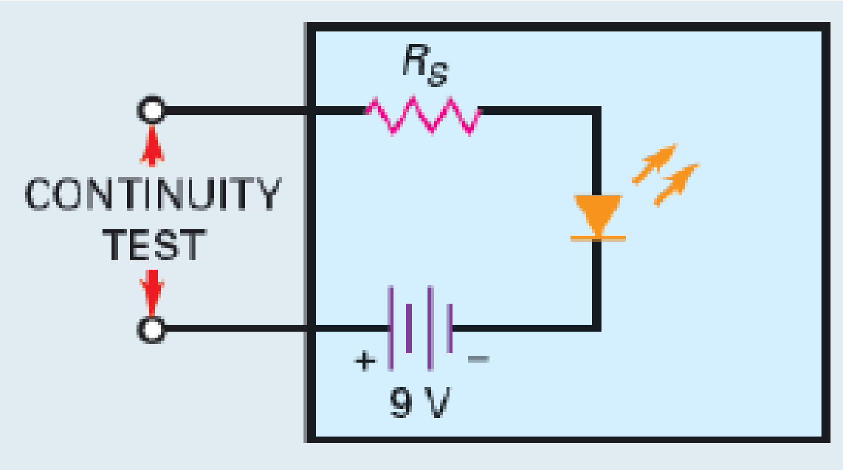
We will use a forward voltage of approximately 2 V for either LED.

With Eq. (5-1):

$$I_S = \frac{50\text{V} - 2\text{V}}{2.2\ \text{k}\Omega} = 21.8\ \text{mA}$$

Continuity Tester

- Figure 5-3*b* is a continuity tester. After you turn off all the power in a circuit under test, you can use this circuit to check for the continuity of cables, connectors, and switches.



(*b*)

Continuity Tester

- How much LED current is there if the series resistance is 470 V?

Solution:

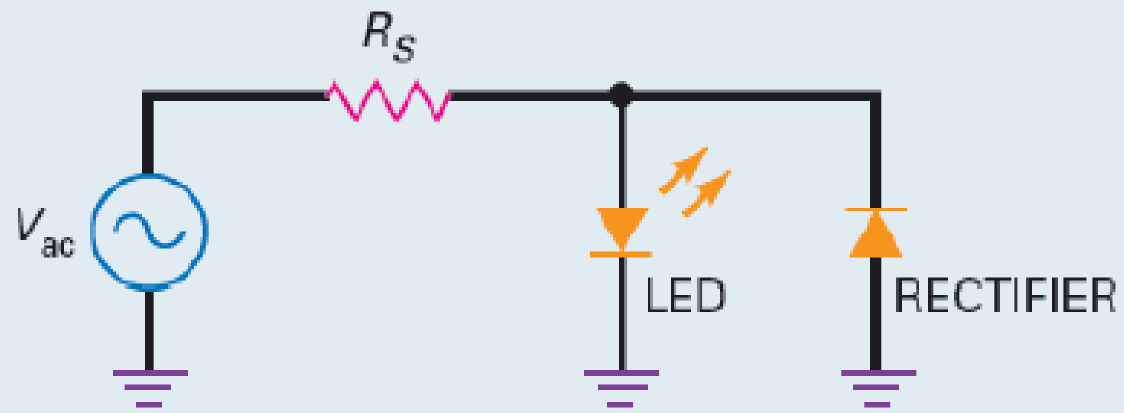
When the input terminals are shorted (continuity), the internal 9-V battery produces an LED current of:

$$I_S = \frac{9V - 2V}{470\ \Omega} = 14.9\ \text{mA}$$

AC Voltage Indicator

- LEDs are often used to indicate the existence of ac voltages.
- Figure 5-4 shows an ac voltage source driving an LED indicator.
- When there is ac voltage, there is LED current on the positive half-cycles. On the negative half-cycles, the rectifier diode turns on and protects the LED from too much reverse voltage.

FIGURE 5-4 Low ac voltage indicator.



AC Indicator

- If the ac source voltage is 20 Vrms and the series resistance is 680 Ω, what is the average LED current? Also, calculate the approximate power dissipation in the series resistor.

Solution:

The LED current is a rectified half-wave signal. The peak source voltage is $1.414 * 20\ V$, which is approximately 28 V. Ignoring the LED voltage drop, the approximate peak current is:

$$\mathrm{I_S} = \frac{28\mathrm{V}}{680\ \Omega} = 41.2\ \mathrm{mA}$$

The average of the half-wave current through the LED is:

$$\mathrm{I_S} = \frac{41.2\ \mathrm{mA}}{\pi} = 13.1\ \mathrm{mA}$$

AC Indicator

- Ignore the diode drops in Figure 5-4; this is equivalent to saying that there is a short to ground on the right end of the series resistor.
- Then the power dissipation in the series resistor equals the square of the source voltage divided by the resistance:

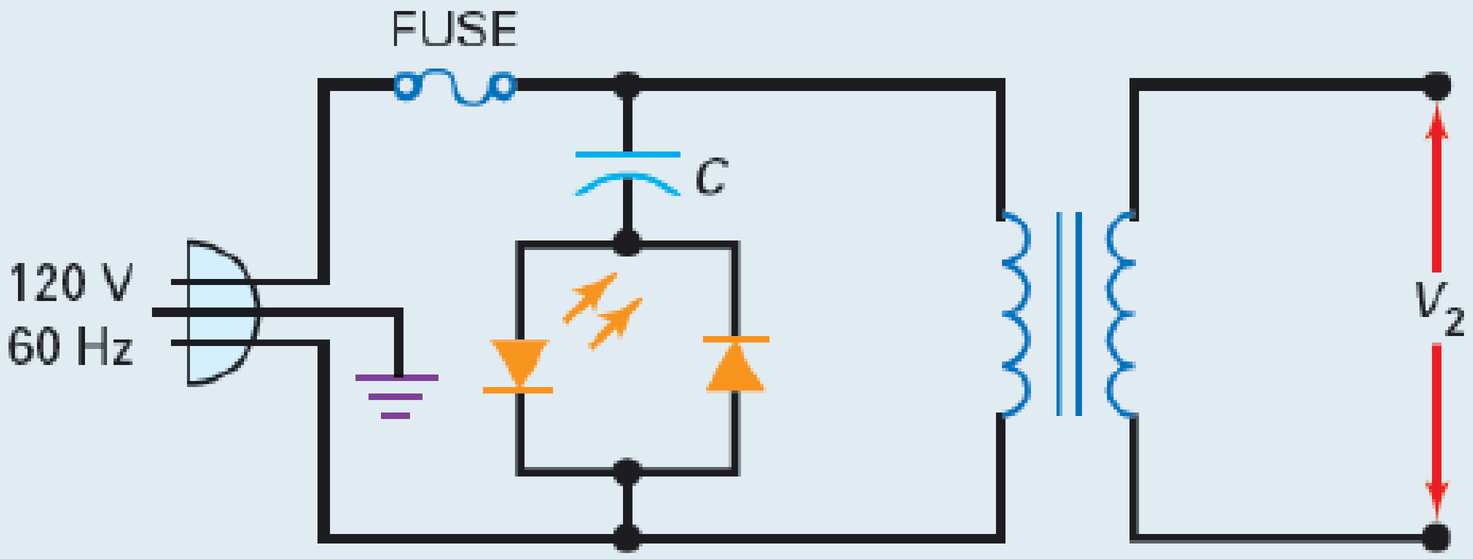
$$P = \frac{(20\ \mathrm{V})^2}{680\ \Omega} = 0.588\ \mathrm{W}$$

- As the source voltage in Figure 5-4 increases, the power dissipation in the series resistor may increase to several watts. This is a disadvantage because a high-wattage resistor is *too bulky* and *wasteful* for most applications.

AC Power Line Indicator

- The circuit of Figure 5-5 shows an LED indicator for the ac power line. The idea is basically the same as in Figure 5-4, except that we use a capacitor instead of a resistor.

FIGURE 5-5 High ac voltage indicator.



AC Power Line Indicator

- If the capacitance is 0.68 μF, what is the average LED current?

Solution:

Calculate the capacitive reactance:

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(60\ \text{Hz})(0.68\ \mu\text{F})} = 3.9\ \text{k}\Omega$$

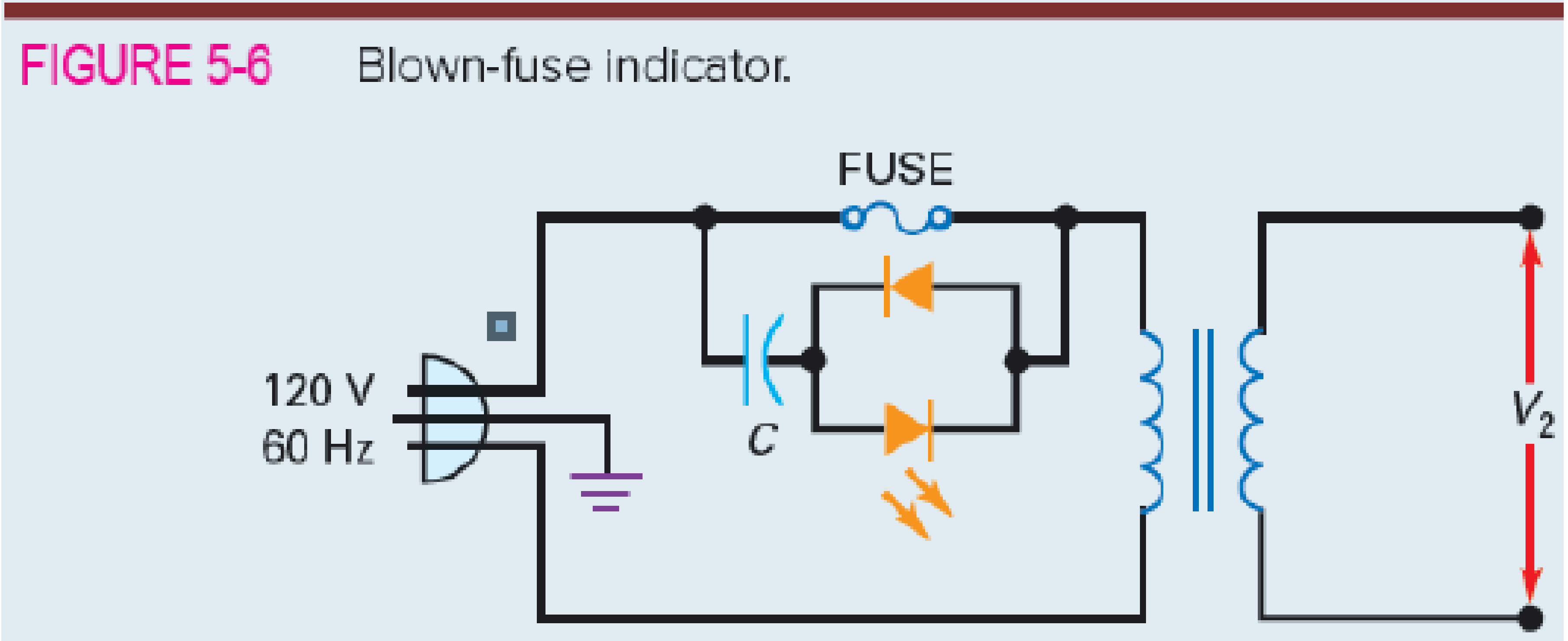
Ignoring the LED voltage drop, the approximate peak LED current is:

$$I_S = \frac{170\ \text{V}}{3.9\ \text{k}\Omega} = 43.6\ \text{mA}$$

The average LED current is:

$$I_S = \frac{43.6\ \text{mA}}{\pi} = 13.9\ \text{mA}$$

Blown-fuse Indicator



- This is a blown-fuse indicator. If the fuse is OK, the LED is off because there is approximately zero voltage across the LED indicator.
- On the other hand, if the fuse is open, some of the line voltage appears across the LED indicator and the LED lights up.

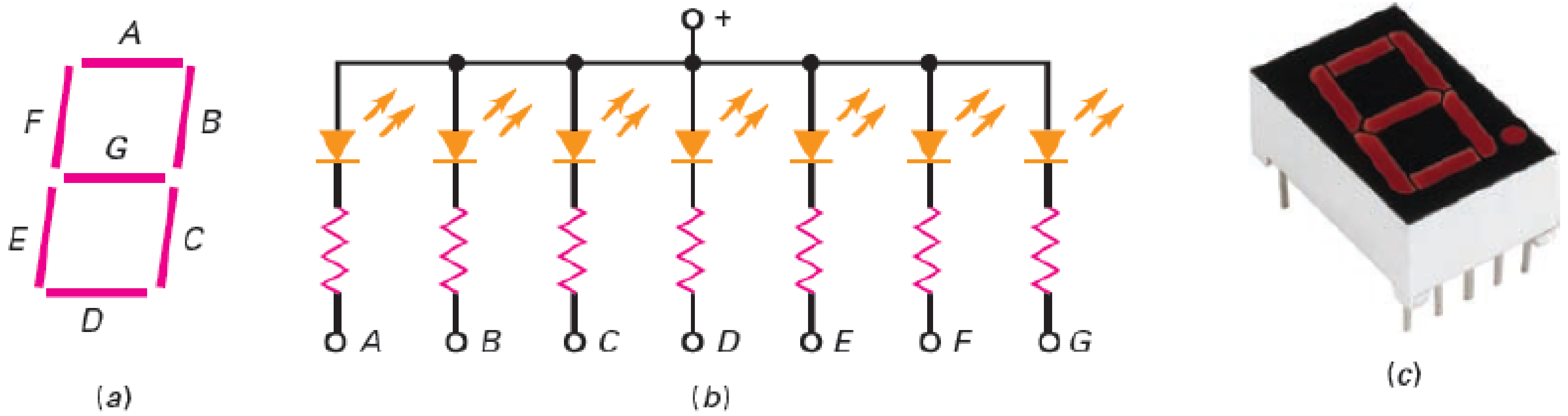
Other Optoelectronic Devices

- Besides standard low-power through high-power LEDs, there are many other optoelectronic devices which are based on the photonic action of a pn junction.
- These devices are used to source, detect and control light in an enormous variety of electronic applications

Seven-Segment Display

- Figure 5-7*a* shows a **seven-segment display.**

FIGURE 5-7 Seven-segment indicator. (*a*) Physical layout of segments; (*b*) schematic diagram; (c) Actual display with decimal point. Courtesy of Fairchild Semiconductor.



Seven-Segment Display

- It contains seven rectangular LEDs (A through G).
- Each LED is called a **segment** because it forms part of the character being displayed.
- Figure 5-7b is a schematic diagram of the seven-segment display. External series resistors are included to limit the currents to safe levels.
- By grounding one or more resistors, we can form any digit from 0 through 9. For instance, by grounding A, B, and C, we get a 7. Grounding A, B, C, D, and G produces a 3.
- A seven-segment display can also display capital letters A, C, E, and F, plus lowercase letters b and d. Microprocessor trainers often use seven-segment displays that show all digits from 0 through 9, plus A, b, C, d, E, and F.

Seven-Segment Display

- The seven-segment indicator of Fig. 5-7b is referred to as the common-anode type because all anodes are connected together.
- Also available is the common-cathode type, in which all cathodes are connected together. Figure 5-7c shows an actual seven-segment display with pins for fitting into a socket or for soldering to a printed-circuit board. Notice the extra dot segment used for a decimal point.

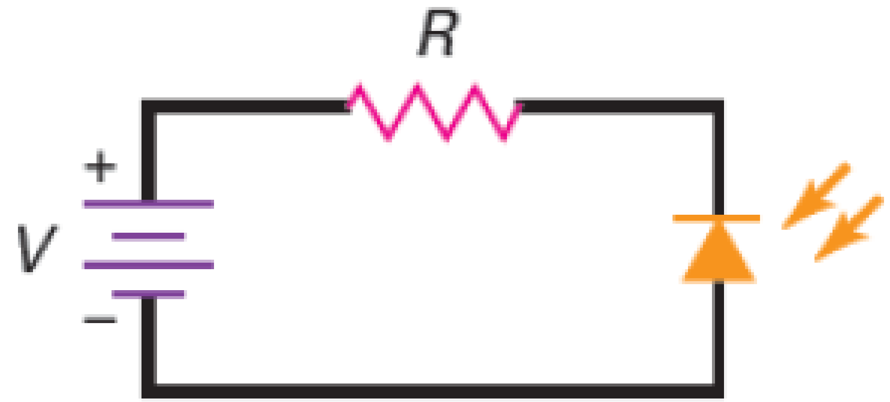
Photodiode

- As previously discussed, one component of reverse current in a diode is the flow of minority carriers. These carriers exist because thermal energy keeps dislodging valence electrons from their orbits, producing free electrons and holes in the process.
- The lifetime of the minority carriers is short, but while they exist, they can contribute to the reverse current.
- When light energy bombards a pn junction, it can dislodge valence electrons. The more light striking the junction, the larger the reverse current in a diode.
- A **photodiode** has been optimized for its sensitivity to light.
- In this diode, a window lets light pass through the package to the junction. The incoming light produces free electrons and holes.
- The stronger the light, the greater the number of minority carriers and the larger the reverse current.

Photodiode

- Figure 5-8 shows the schematic symbol of a photodiode. The arrows represent the incoming light. Especially important, the source and the series resistor reverse-bias the photodiode. As the light becomes brighter, the reverse current increases. With typical photodiodes, the reverse current is in the tens of microamperes.

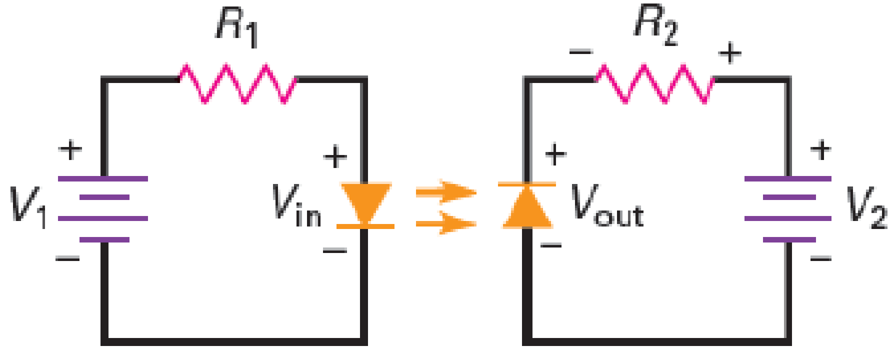
FIGURE 5-8 Incoming light increases reverse current in photodiode.



Optocoupler

- An optocoupler (also called an optoisolator) combines an LED and a photodiode in a single package.
- It has an LED on the input side and a photodiode on the output side. The left source voltage and the series resistor set up a current through the LED.
- Then the light from the LED hits the photodiode, and this sets up a reverse current in the output circuit. This reverse current produces a voltage across the output resistor. The output voltage then equals the output supply voltage minus the voltage across the resistor.
- Figure 5-9 shows an optocoupler.

FIGURE 5-9 Optocoupler combines an LED and a photodiode.



Optocoupler

- When the input voltage is varying, the amount of light is fluctuating.
- This means that the output voltage is varying in step with the input voltage. This is why the combination of an LED and a photodiode is called an **optocoupler**.
- The device can couple an input signal to the output circuit. Other types of optocouplers use phototransistors, photothyristors, and other photo devices in their output circuit side. These devices will be discussed in later chapters.
- The key advantage of an optocoupler is the **electrical isolation** between the input and output circuits.
- With an optocoupler, the only contact between the input and the output is a beam of light. Because of this, it is possible to have an insulation resistance between the two circuits in the thousands of megohms.
- Isolation like this is useful in high-voltage applications in which the potentials of the two circuits may differ by several thousand volts.

Laser Diode

- In an LED, free electrons radiate light *when falling from higher energy levels to lower ones*. The free electrons fall randomly and continuously, resulting in light waves that have every phase between 0 and 360°.
- Light that has many different phases is called noncoherent light. An LED produces noncoherent light.
- **Noncoherent lights**
  - The amplitude and phase of the emitted light waves fluctuate randomly in space and time.
  - Light emitted by normal means such as a flashlight or a bulb, is incoherent or the photons of the many wave frequencies of light are oscillating in different directions.
- A laser diode is different. It produces a **coherent light**. This means that all the light waves are in phase with each other.
- **Coherent light** is a beam of photons (almost like particles of light waves) that have the same frequency and are all at the same frequency.

Laser Diode

- The basic idea of a laser diode is to use a mirrored resonant chamber that reinforces the emission of light waves at a single frequency of the same phase.
- Because of the resonance, a laser diode produces a narrow beam of light that is very intense, focused, and pure.
- Laser diodes are also known as ***semiconductor lasers***. These diodes can produce visible light (red, green, or blue) and invisible light (infrared).

Laser Diode Applications

- Laser diodes are used in a large variety of applications. They are used in telecommunications, data communications, broadband access, industrial, aerospace, test and measurement, and medical and defense industries.
- They are also used in laser printers and consumer products requiring large-capacity optical disk systems, such as compact disk (CD) and digital video disk (DVD) players.
- In broadband communication, they are used with fiber-optic cables to increase the speed of the Internet. A fiber-optic cable is analogous to a stranded wire cable, except that the strands are thin flexible fibers of glass or plastic that transmit light beams instead of free electrons. The advantage is that much more information can be sent through a fiber-optic cable than through a copper cable.
- New applications are being found as the lasing wavelength is pushed lower into the visible spectrum with visible laser diodes (VLDs). Also, near infrared diodes are being used in machine vision systems, sensors, and security systems.

LED Displays

- LEDs are widely used in large and small signs and message boards for both indoor and outdoor uses, including large-screen television.
- Signs can be single-color, multicolor, or full-color. Full-color screens use a tiny grouping of high-intensity red, green, and blue LEDs to form a pixel. A typical screen is made of thousands of RGB pixels with the exact number determined by the sizes of the screen and the pixel.
- Red, green, and blue (RGB) are primary colors and when mixed together in varying amounts, can be used to produce any color in the visible spectrum.
- A basic pixel formed by three LEDs is shown in Figure 5 –10. The light emission from each of the three diodes can be varied independently by varying the amount of forward current. Yellow is added to the three primary colors (RGBY) in some TV screen applications.

LED Displays

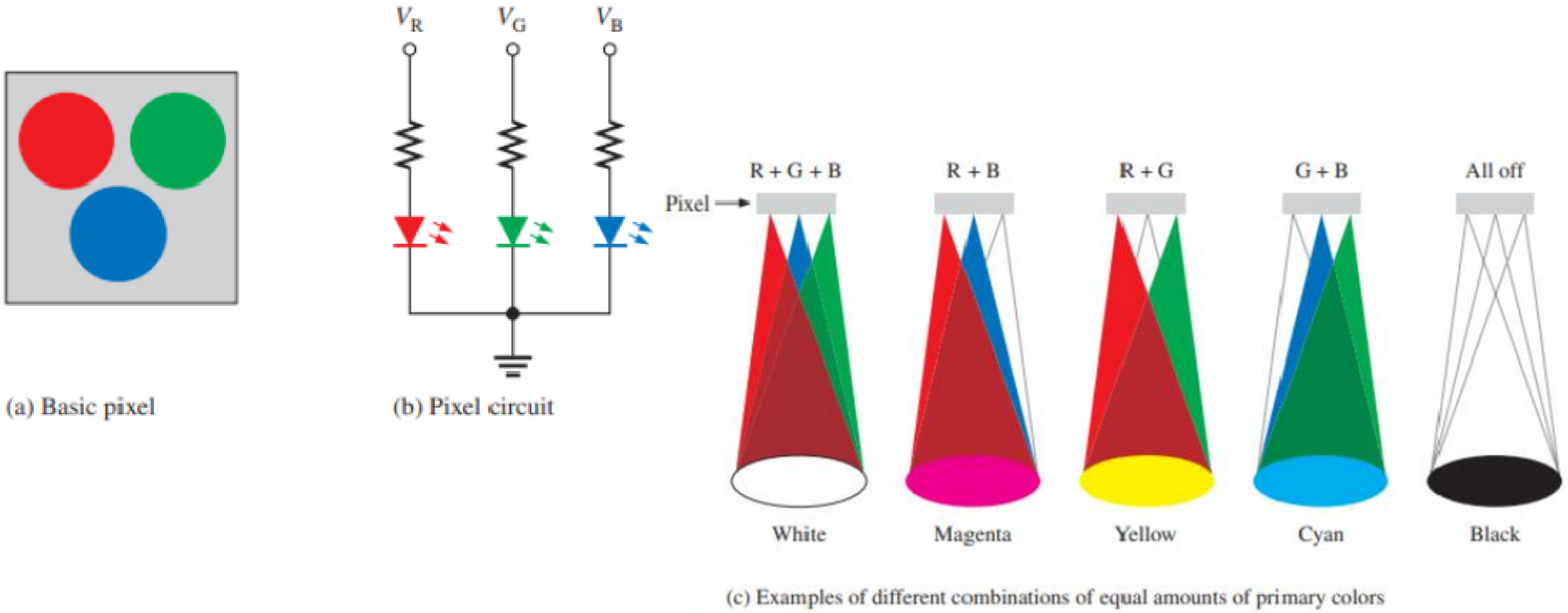


FIGURE 5-10

The concept of an RGB pixel used in LED display screens.

Organic LED (OLED)

- An OLED is a device that consists of two or three layers of materials composed of organic molecules or polymers that emit light with the application of voltage.
- OLEDs produce light through the process of **electrophosphorescence**.
- Electrophosphorescence is a form of *phosphorescence*, especially in doped LEDs, that is triggered by an electric charge.
- Phosphorescence is emission of light from triplet-excited states, in which the electron in the excited orbital has the same spin orientation as the ground-state electron. Transitions to the ground state are spin-forbidden, and the emission rates are relatively slow (10^3 to 100 s^{-1}).
- The color of the light depends on the type of organic molecule in the emissive layer. The basic structure of a 2-layer OLED is shown in Figure 5–11.

Organic LED (OLED)

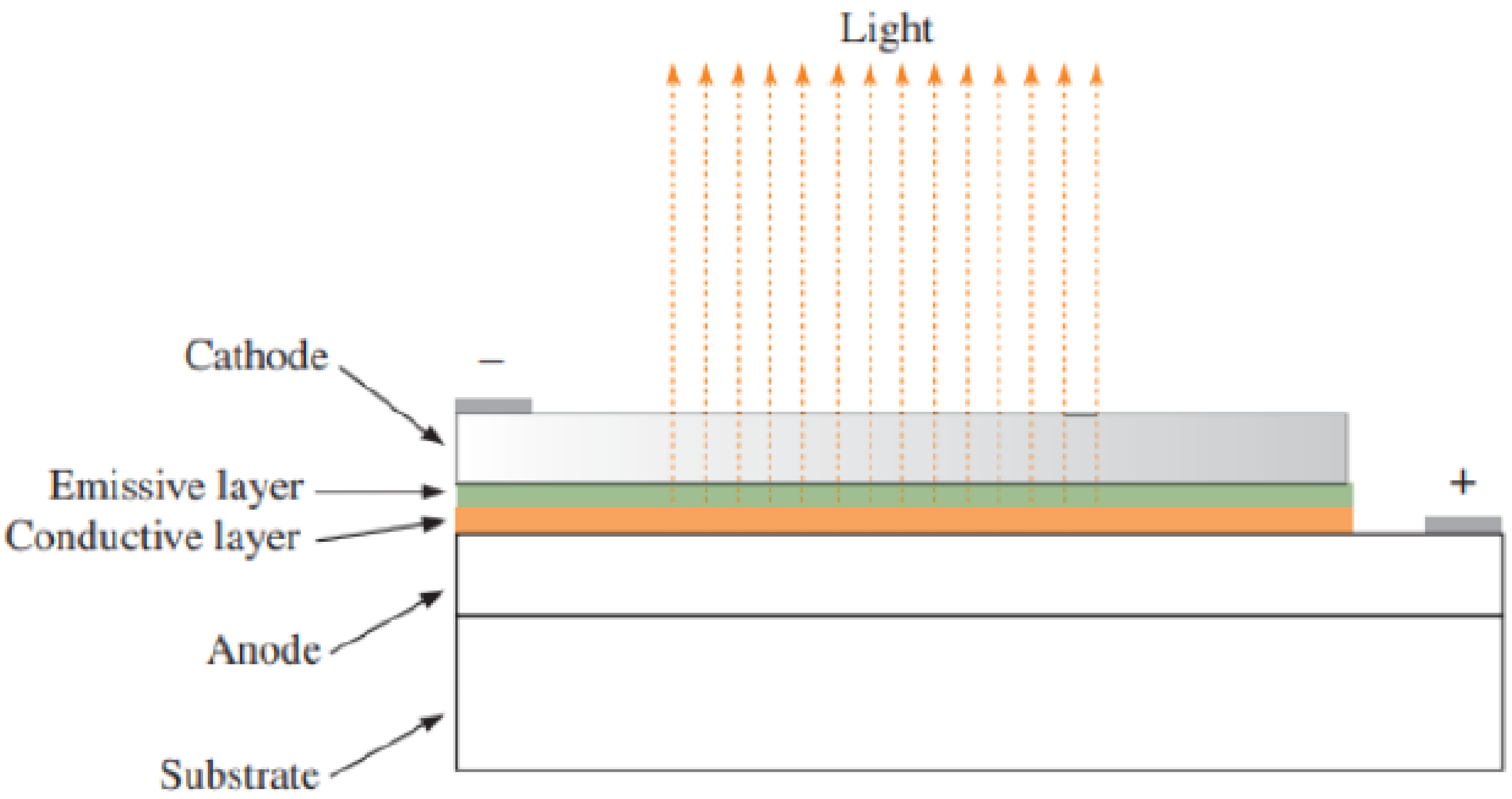


FIGURE 5-11

Basic structure of a top-emitting 2-layer OLED.

Organic LED (OLED)

- Electrons are provided to the emissive layer and removed from the conductive layer when there is current between the cathode and anode. This removal of electrons from the conductive layer leaves holes.
- The electrons from the emissive layer recombine with the holes from the conductive layer near the junction of the two layers.
- When this recombination occurs, energy is released in the form of light that passes through the transparent cathode material.
- If the anode and substrate are also made from transparent materials, light is emitted in both directions, making the OLED useful in applications such as heads-up displays.
- OLEDs can be sprayed onto substrates just like inks are sprayed onto paper during printing. Inkjet technology greatly reduces the cost of OLED manufacturing and allows OLEDs to be printed onto very large films for large displays like 80-inch TV screens or electronic billboards.

Sample Problems

Problem#1

- What happens to the light emission of an LED as the forward current increases?

Ans.

Problem#2

- When the intensity of the incident light (irradiance) on a photodiode increases, what happens to its internal reverse resistance?

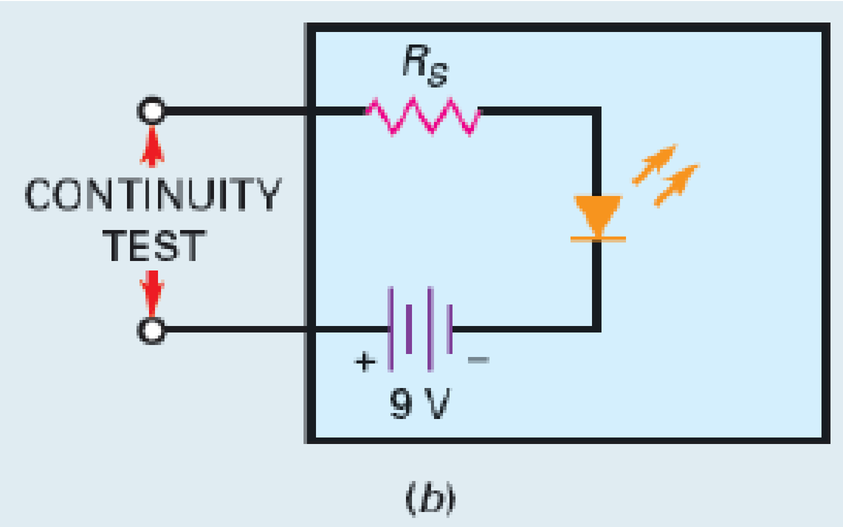
Ans.

Problem#3

- When the intensity of the incident light (irradiance) on a photodiode increases, what happens to its internal reverse resistance?

Ans.

- Using the Figure below, what value series resistor should be used to produce 21 mA of LED current?



Ans.