SEMICONDUCTOR DIODE

No Applied Bias (V = 0 V)

This region of uncovered positive and negative ions is called the depletion region due to the "depletion" of free carriers in the region.

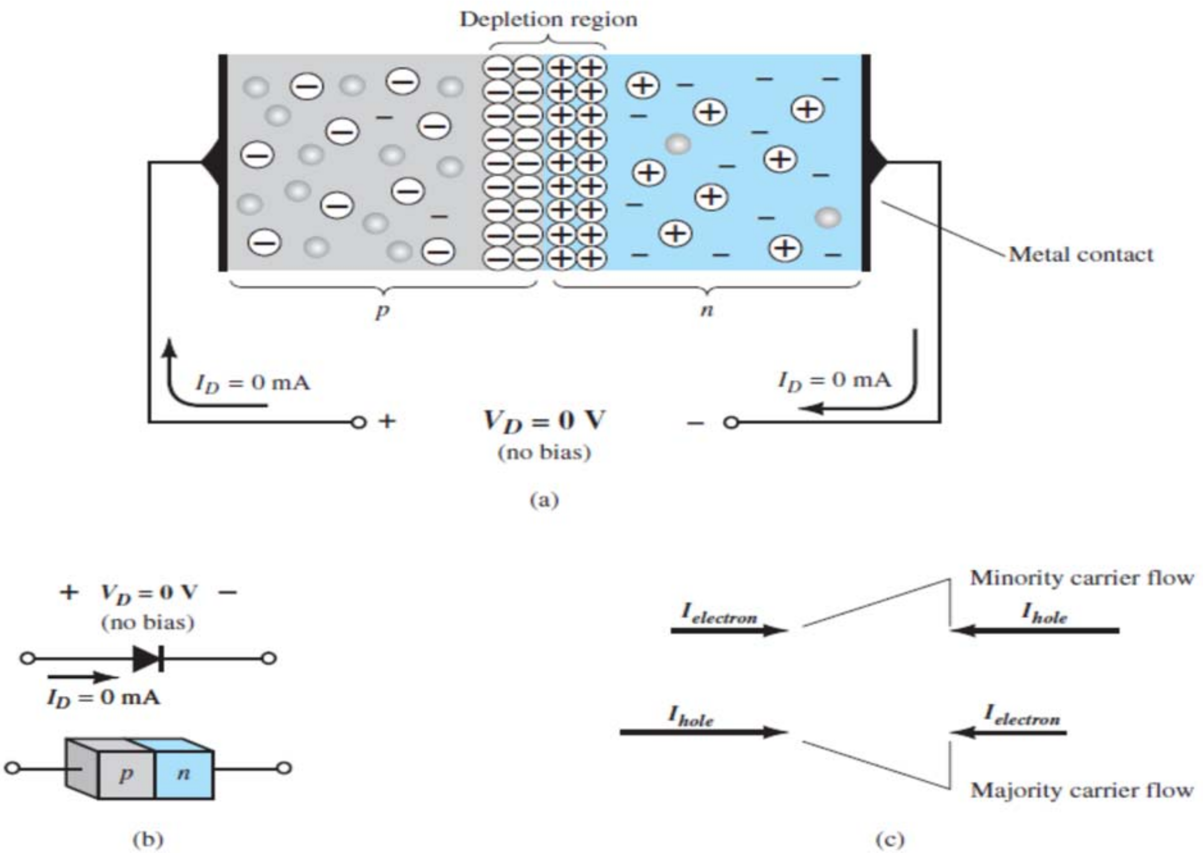

FIG. 1.12
A p–n junction with no external bias: (a) an internal distribution of charge; (b) a diode symbol, with the defined polarity and the current direction; (c) demonstration that the net carrier flow is zero at the external terminal of the device when $V_D = 0$ V.

In the absence of an applied bias across a semiconductor diode, the net flow of charge in one direction is zero.

Reverse-Bias Condition ($V_D < 0$ V)

If an external potential of V volts is applied across the p – n junction such that the positive terminal is connected to the n -type material and the negative terminal is connected to the p -type material as shown in Fig. 1.13 , the number of uncovered positive ions in the depletion region of the n -type material will increase due to the large number of free electrons drawn to the positive potential of the applied voltage. For similar reasons, the number of uncovered negative ions will increase in the p -type material. The net effect, therefore, is a widening of the depletion region. This widening of the depletion region will establish too great a barrier for the majority carriers to overcome, effectively reducing the majority carrier flow to zero, as shown in Fig. 1.13a .

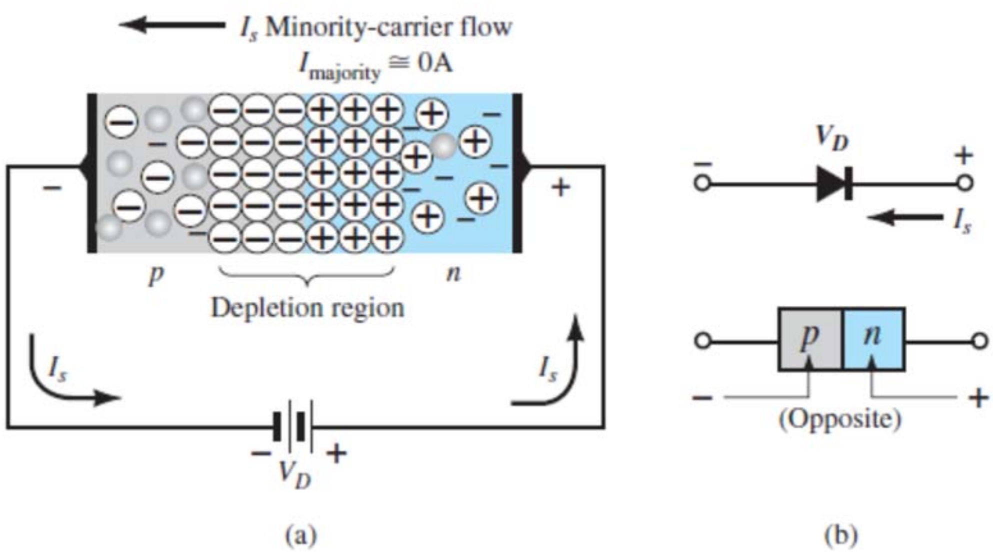

FIG. 1.13

Reverse-biased p–n junction: (a) internal distribution of charge under reverse-bias conditions; (b) reverse-bias polarity and direction of reverse saturation current.

Forward-Bias Condition ($V_D > 0$ V)

A *forward-bias* or “on” condition is established by applying the positive potential to the *p* -type material and the negative potential to the *n* -type material as shown in Fig. 1.14 .

The application of a forward-bias potential V_D will “pressure” electrons in the *n* -type material and holes in the *p* -type material to recombine with the ions near the boundary and reduce the width of the depletion region as shown in Fig. 1.14a. The resulting minority-carrier flow of electrons from the *p* -type material to the *n* -type material (and of holes from the *n* -type material to the *p* -type material) has not changed in magnitude (since the conduction level is controlled primarily by the limited number of impurities in the material), but the reduction in the width of the depletion region has resulted in a heavy majority flow across the junction.

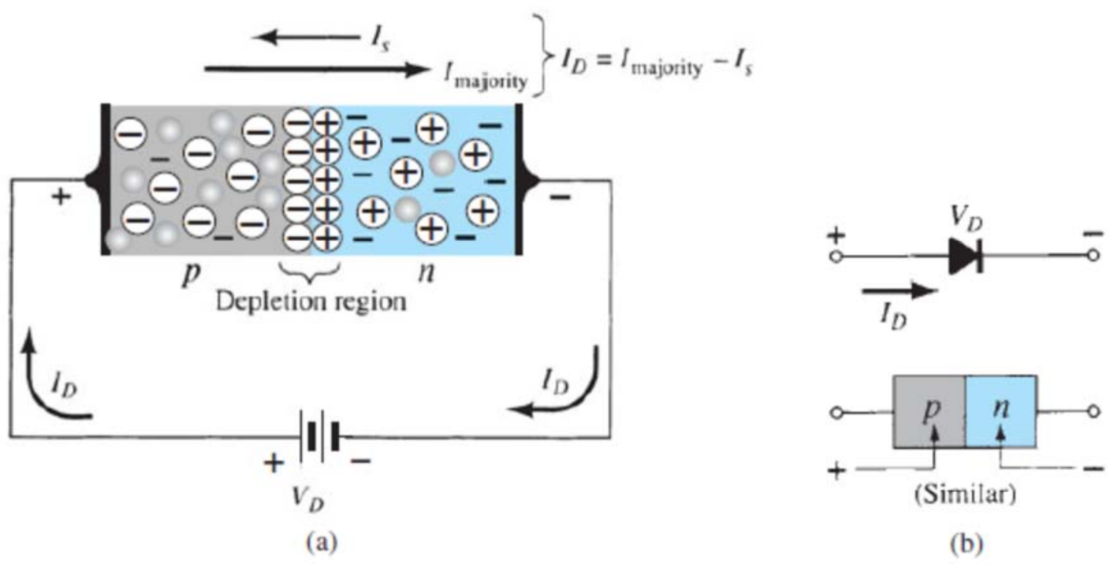

FIG. 1.14
Forward-biased p–n junction: (a) internal distribution of charge under forward-bias conditions; (b) forward-bias polarity and direction of resulting current.

It can be demonstrated through the use of solid-state physics that the general characteristics of a semiconductor diode can be defined by the following equation, referred to as Shockley's equation, for the forward- and reverse-bias regions:

$$I_D = I_s(e^{V_D/nV_T} - 1) \quad \text{(A)} \tag{1.2}$$

where I_s is the reverse saturation current
V_D is the applied forward-bias voltage across the diode
n is an ideality factor, which is a function of the operating conditions and physical construction; it has a range between 1 and 2 depending on a wide variety of factors ($n = 1$ will be assumed throughout this text unless otherwise noted).

The voltage V_T in Eq. (1.1) is called the *thermal voltage* and is determined by

$$V_T = \frac{kT_K}{q} \quad \text{(V)} \tag{1.3}$$

where k is Boltzmann's constant $= 1.38 \times 10^{-23}$ J/K
T_K is the absolute temperature in kelvins $= 273 +$ the temperature in °C
q is the magnitude of electronic charge $= 1.6 \times 10^{-19}$ C

EXAMPLE 1.1 At a temperature of 27°C (common temperature for components in an enclosed operating system), determine the thermal voltage V_T.

Solution: Substituting into Eq. (1.3), we obtain

$$T = 273 + {}^\circ\text{C} = 273 + 27 = 300\text{ K}$$

$$V_T = \frac{kT_K}{q} = \frac{(1.38 \times 10^{-23}\text{ J/K})(30\text{ K})}{1.6 \times 10^{-19}\text{ C}}$$

$$= 25.875\text{ mV} \cong 26\text{ mV}$$

The thermal voltage will become an important parameter in the analysis to follow in this chapter and a number of those to follow.