PN JUNCTION DIODE

Muhammad Adeel

M.Sc. Electronics (KU)

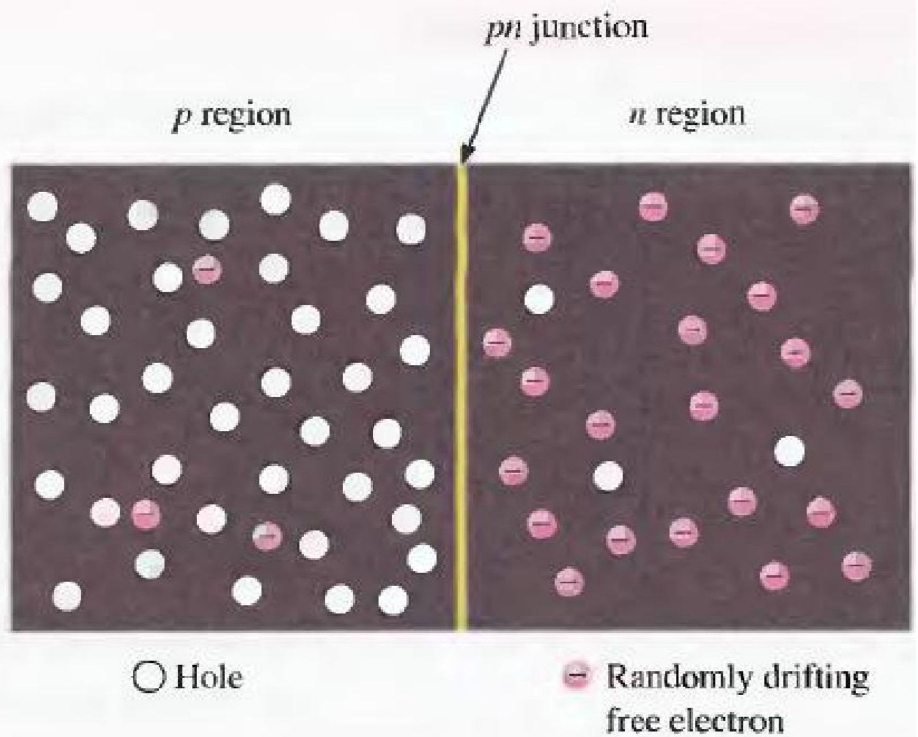
M.Phil. ISPA (KU)

THE PN JUNCTION DIODE:

If a piece of intrinsic silicon is doped so that part is *n*-type and the other part is *p*-type, a *pn* junction forms at the boundary between the two regions and a diode is created, as indicated in Figure 1–17. The *p* region has many holes (majority carriers) from the impurity atoms and only a few thermally generated free electrons (minority carriers). The *n* region has many free electrons (majority carriers) from the impurity atoms and only a few thermally generated holes (minority carriers).

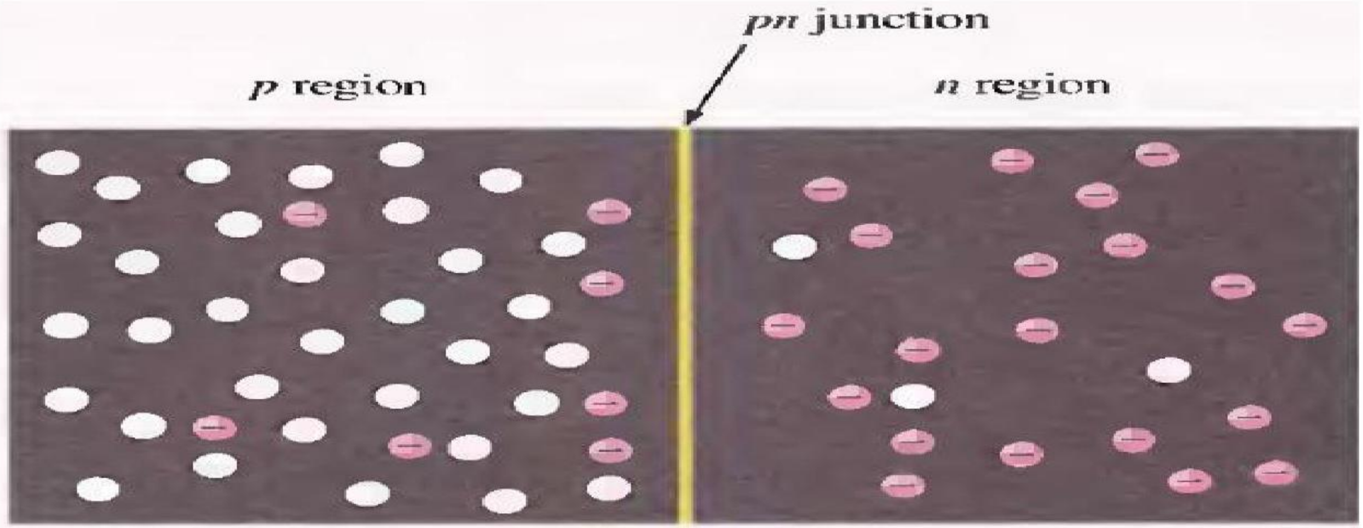
FIGURE 1–17

The basic diode structure at the instant of junction formation showing only the majority and minority carriers.



Formation of the Depletion Region

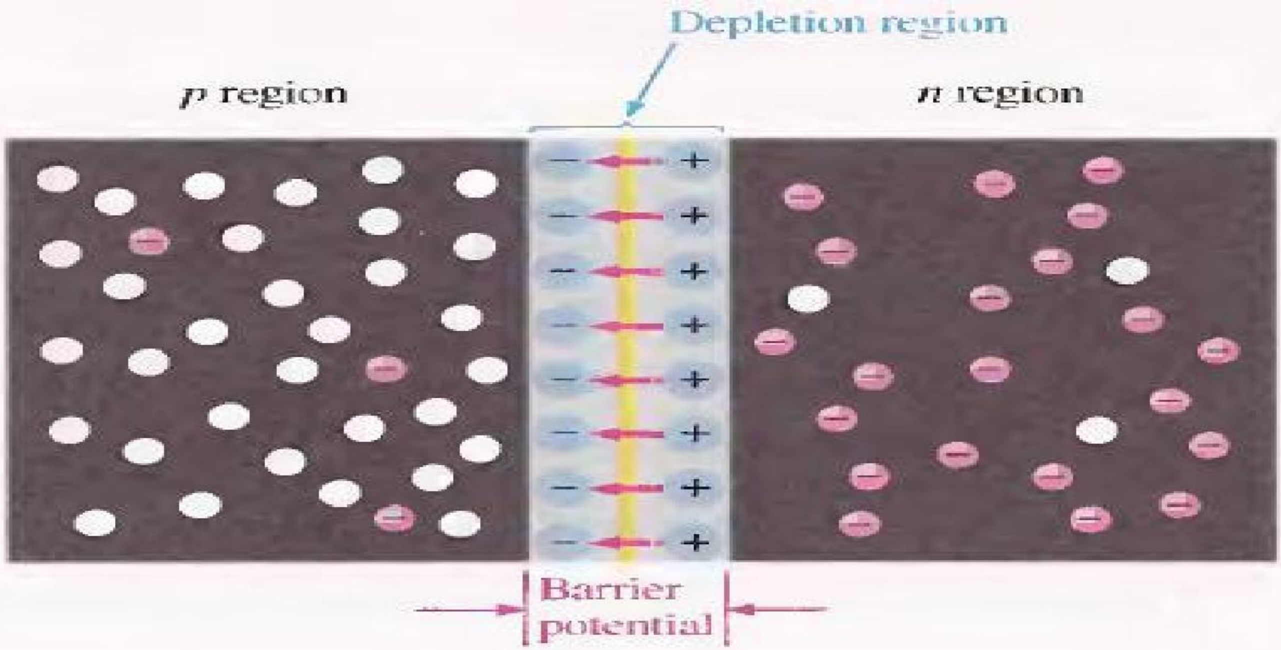
As you have seen, the free electrons in the *n* region are randomly drifting in all directions. At the instant of the *pn* junction formation, the free electrons near the junction in the *n* region begin to diffuse across the junction into the *p* region where they combine with holes near the junction, as shown in Figure 1–18(a).



(a) At the instant of junction formation, free electrons in the *n* region near the *pn* junction begin to diffuse across the junction and fall into holes near the junction in the *p* region

FIGURE 1–18

Formation of the depletion region. The width of the depletion region is exaggerated for illustration purposes.



(b) For every electron that diffuses across the junction and combines with a hole, a positive charge is left in the n region and a negative charge is created in the p region, forming a barrier potential. This action continues until the voltage of the barrier repels further diffusion.

FIGURE 1–18

Formation of the depletion region. The width of the depletion region is exaggerated for illustration purposes.

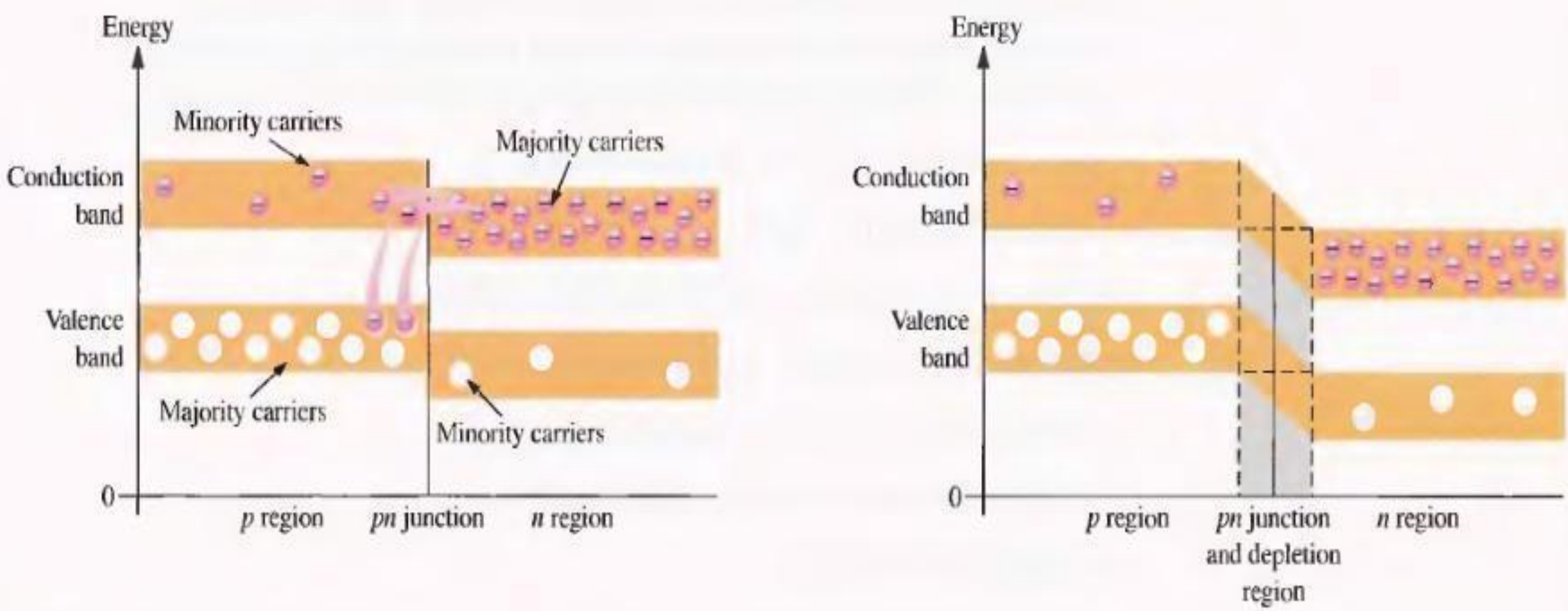
Barrier Potential:

The potential difference of the electric field across the depletion region is the amount of voltage required to move electrons through the electric field. This potential difference is called the **barrier potential** and is expressed in volts. Stated another way, a certain amount of voltage equal to the barrier potential and with the proper polarity must be applied across a *pn* junction before electrons will begin to flow across the junction. You will learn more about this when we discuss *biasing* in Section 1–7.

Energy Diagrams of the *PN* Junction and Depletion Region

The valence and conduction bands in an *n*-type material are at slightly lower energy levels than the valence and conduction bands in a *p*-type material. This is due to differences in the atomic characteristics of the pentavalent and the trivalent impurity atoms.

An energy diagram for a *pn* junction at the instant of formation is shown in Figure 1–19(a). As you can see, the valence and conduction bands in the *n* region are at lower energy levels than those in the *p* region, but there is a significant amount of overlapping.



(a) At the instant of junction formation

(b) At equilibrium

FIGURE 1–19

Energy diagrams illustrating the formation of the *pn* junction and depletion region.

BIASING THE DIODE:

Generally the term *bias* refers to the use of a dc voltage to establish certain operating conditions for an electronic device. In relation to a diode, there are two bias conditions: forward and reverse. Either of these bias conditions is established by connecting a sufficient dc voltage of the proper polarity across the *pn* junction.

FORWARD BIAS:

- Negative terminal of biasing source is connected to N region of the diode, and Positive terminal of biasing source is connected to P region of the diode.
- Depletion region becomes narrower.
- Forward Bias allows current through the PN junction.

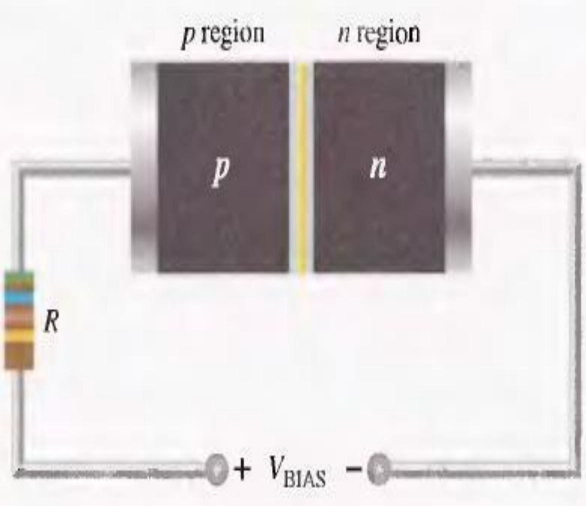


FIGURE 1–20

A diode connected for forward bias.

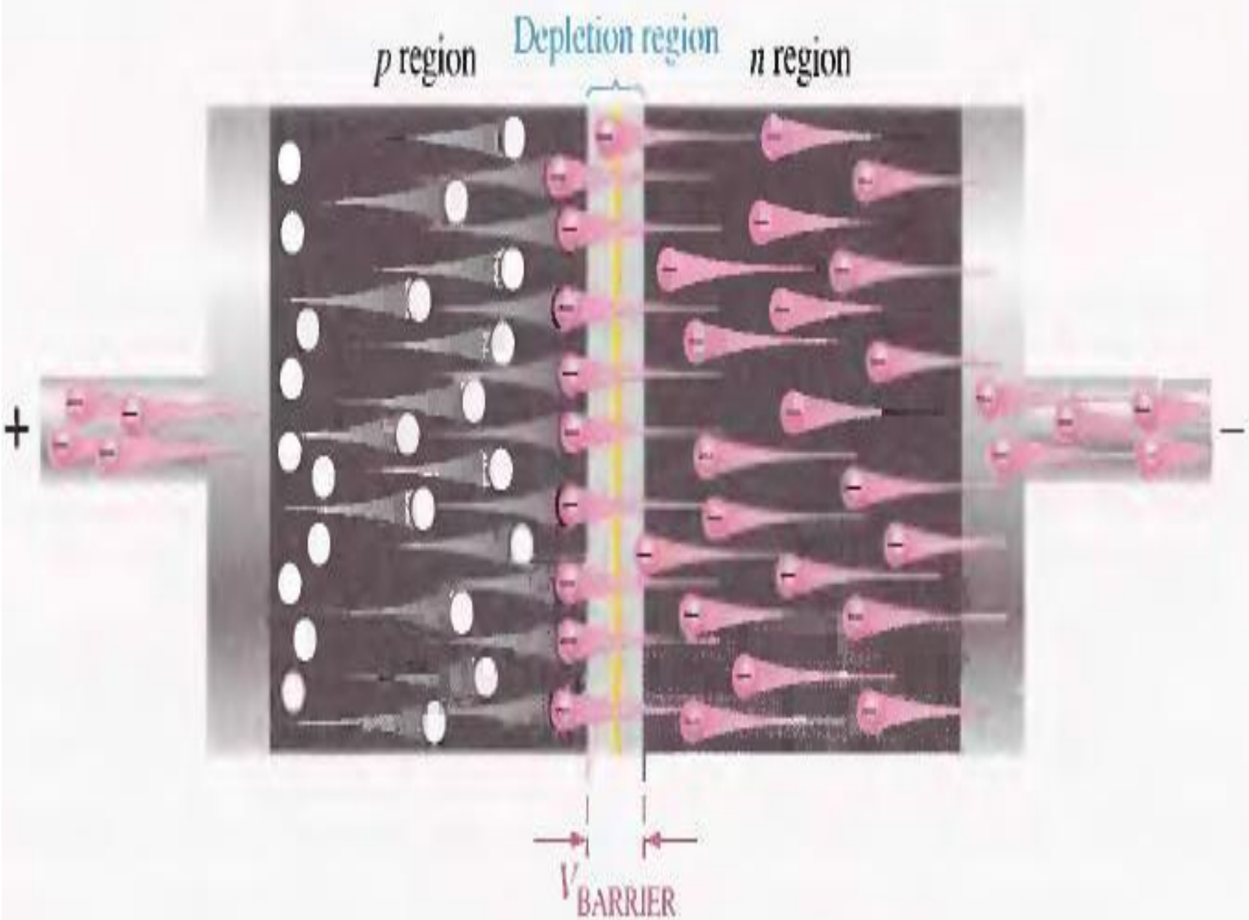
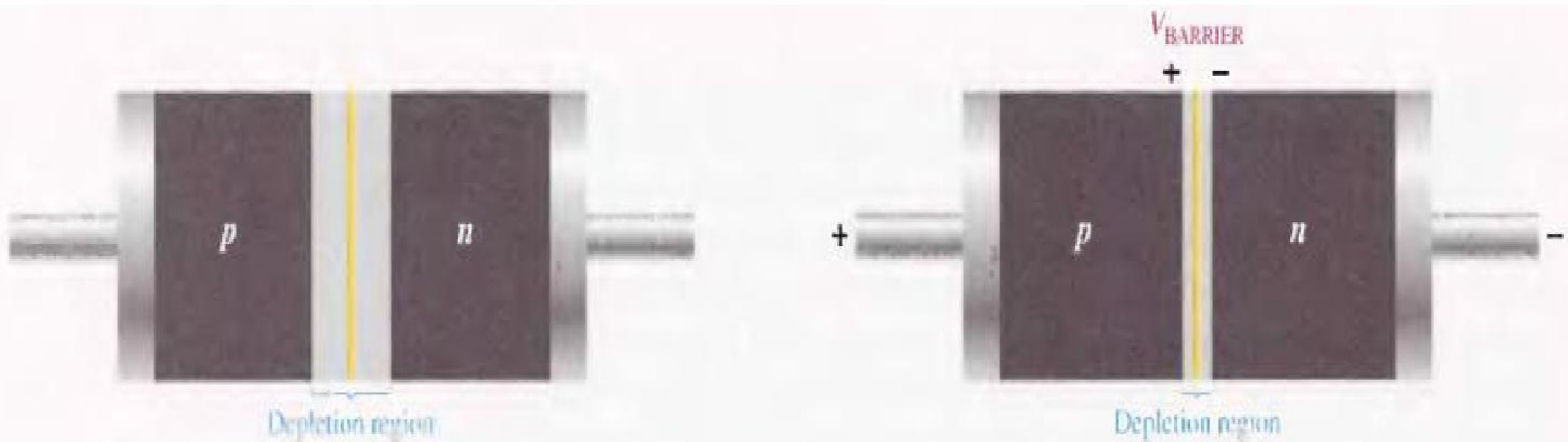


FIGURE 1–21

A forward-biased diode showing the flow of majority carriers and the voltage due to the barrier potential across the depletion region.

The Effect of Forward Bias on the Depletion Region As more electrons flow into the depletion region, the number of positive ions is reduced. As more holes effectively flow into the depletion region on the other side of the *pn* junction, the number of negative ions is reduced. This reduction in positive and negative ions during forward bias causes the depletion region to narrow, as indicated in Figure 1–22.



(a) At equilibrium (no bias)

(b) Forward bias narrows the depletion region and produces a voltage drop across the *pn* junction equal to the barrier potential.

FIGURE 1–22

The depletion region narrows and a voltage drop is produced across the *pn* junction when the diode is forward-biased.

The Effect of the Barrier Potential During Forward Bias Recall that the electric field between the positive and negative ions in the depletion region on either side of the junction creates an "energy hill" that prevents free electrons from diffusing across the junction at equilibrium (see Figure 1–19(b)). This is known as the *barrier potential*.

When forward bias is applied, the free electrons are provided with enough energy from the bias-voltage source to overcome the barrier potential and effectively "climb the energy hill" and cross the depletion region. The energy that the electrons require in order to pass through the depletion region is equal to the barrier potential. In other words, the electrons give up an amount of energy equivalent to the barrier potential when they cross the depletion region. This energy loss results in a voltage drop across the *pn* junction equal to the barrier potential (0.7 V), as indicated in Figure 1–22(b). An additional small voltage drop occurs across the *p* and *n* regions due to the internal resistance of the material. For doped semiconductive material, this resistance, called the **dynamic resistance**, is very small and can usually be neglected. This is discussed in more detail in

REVERSE BIAS:

- Reverse Bias prevents current through the PN junction.

- Positive terminal of biasing source is connected to N region of the diode, and Negative terminal of biasing source is connected to P region of the diode.

- Depletion region becomes wider.

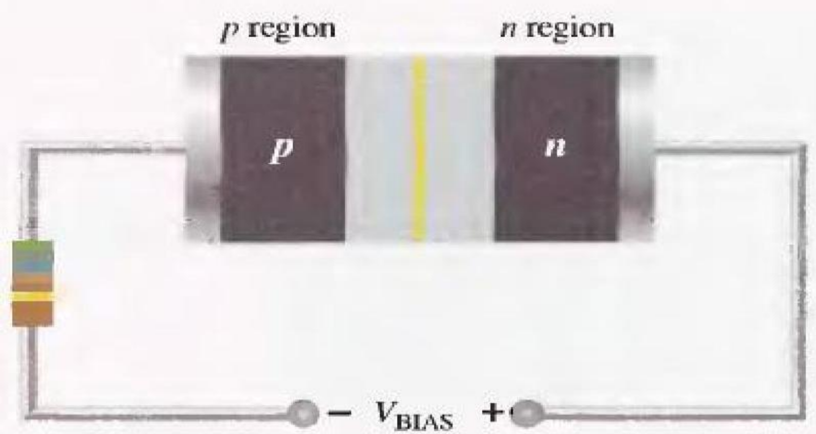


FIGURE 1–23

A diode connected for reverse bias. A limiting resistor is shown although it is not important in reverse bias because there is essentially no current.

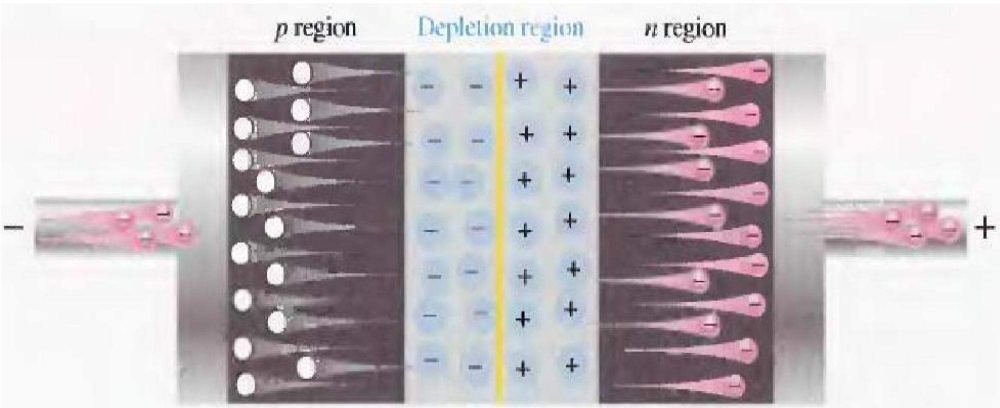


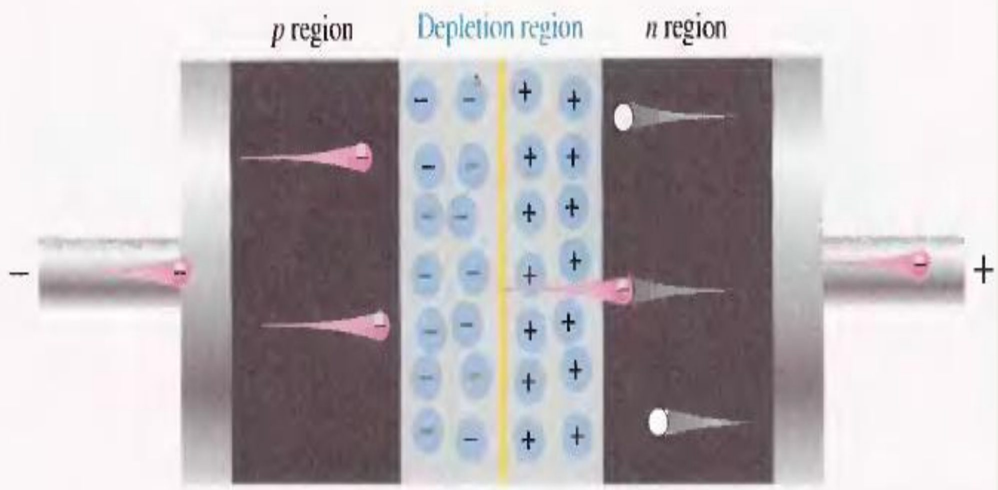
FIGURE 1–24

The diode during the short transition time immediately after reverse-bias voltage is applied.

Reverse Current The extremely small current that exists in reverse bias after the transition current dies out is caused by the minority carriers in the *n* and *p* regions that are produced by thermally generated electron-hole pairs. The small number of free minority electrons in the *p* region are "pushed" toward the *pn* junction by the negative bias voltage. When these electrons reach the wide depletion region, they "fall down the energy hill" and combine with the minority holes in the *n* region as valence electrons and flow toward the positive bias voltage, creating a small hole current.

FIGURE 1-25

The extremely small reverse current in a reverse-biased diode is due to the minority carriers from thermally generated electron-hole pairs.



Reverse Breakdown Normally, the reverse current is so small that it can be neglected. However, if the external reverse-bias voltage is increased to a value called the *breakdown voltage*, the reverse current will drastically increase.