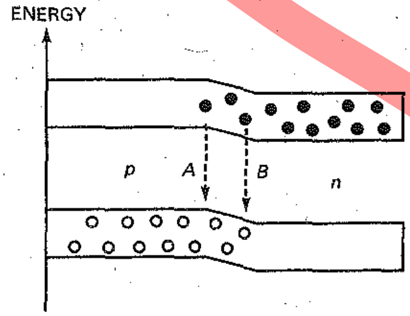
Figure 2-26 Forward bias gives free electrons more energy, equivalent to higher energy level.



hill as a "physical" hill. Instead, think of it as the necessary higher energy level for the valence electrons to "rise" to before they can cross the depletion layer.

Forward Bias

Forward bias lowers the energy hill (see Fig. 2-26). In other words, the battery increases the energy level of the free electrons; this is equivalent to forcing the *n* band upward. Because of this, free electrons have enough energy to enter the *p* region. Soon after entering the *p* region, they fall into holes (path *A*). As valence electrons, they continue moving toward the left end of the crystal; this is equivalent to holes moving toward the junction.

Some holes penetrate the *n* region as shown in Fig. 2-26. In this case, conduction-band electrons can follow recombination path *B*. Regardless of where the recombination takes place, the result is the same. A steady stream of free electrons moves toward the junction and falls into holes near the junction. The captured electrons (now valence electrons) move left in a steady stream through the holes in the *p* region. In this way, we get a continuous flow of electrons through the diode.

Incidentally, when free electrons fall from the conduction band to the valence band, they radiate their excess energy in the form of heat and light. With an ordinary diode, the radiation is heat energy, which serves no useful purpose. But with an LED, the radiation can be light such as red, green, blue, or orange. LEDs are widely used as visual indicators on electronic instruments, computer keyboards, and consumer equipment.

2-14 Barrier Potential and Temperature

The **junction temperature** is the temperature inside a diode, right at the *pn* junction. The *ambient temperature* is different. It is the temperature of the air outside the diode, the air that surrounds the diode. When the diode is conducting, the junction temperature is higher than the ambient temperature because of the heat created by recombination.

The barrier potential depends on the junction temperature. An increase in junction temperature creates more free electrons and holes in the doped regions. As these charges diffuse into the depletion layer, it becomes narrower. This means that there is *less barrier potential at higher junction temperatures.*

Before continuing, we need to define a symbol:

$$\Delta = \text{the change in} \tag{2-2}$$

The Greek letter Δ (delta) stands for "the change in." For instance, ΔV means the change in voltage, and ΔT means the change in temperature. The ratio $\Delta V/\Delta T$ stands for the change in voltage divided by the change in temperature.

Now we can state a rule for estimating the change in barrier potential: *The barrier potential of a silicon diode decreases by 2 mV for each degree Celsius rise.*

As a derivation:

$$\frac{\Delta V}{\Delta T} = -2 \text{ mV/°C} \tag{2-3}$$

By rearranging:

$$\Delta V = (-2 \text{ mV/°C})\,\Delta T \tag{2-4}$$

With this, we can calculate the barrier potential at any junction temperature.

Example 2-5

Assuming a barrier potential of 0.7 V at an ambient temperature of 25°C, what is the barrier potential of a silicon diode when the junction temperature is 100°C? At 0°C?

SOLUTION When the junction temperature is 100°C, the change in barrier potential is:

$$\Delta V = (-2 \text{ mV/°C})\,\Delta T = (-2 \text{ mV/°C})(100°\text{C} - 25°\text{C}) = -150 \text{ mV}$$

This tells us that the barrier potential decreases 150 mV from its room temperature value. So, it equals:

$$V_B = 0.7 \text{ V} - 0.15 \text{ V} = 0.55 \text{ V}$$

When the junction temperature is 0°C, the change in barrier potential is:

$$\Delta V = (-2 \text{ mV/°C})\,\Delta T = (-2 \text{ mV/°C})(0°\text{C} - 25°\text{C}) = 50 \text{ mV}$$

This tells us that the barrier potential increases 50 mV from its room temperature value. So, it equals:

$$V_B = 0.7 \text{ V} + 0.05 \text{ V} = 0.75 \text{ V}$$

PRACTICE PROBLEM 2-5 What would be the barrier potential in Example 2-5 when the junction temperature is 50°C?