3-1 Basic Ideas

An ordinary resistor is a **linear device** because the graph of its current versus voltage is a straight line. A diode is different. It is a **nonlinear device** because the graph of its current versus voltage is not a straight line. The reason is the barrier potential. When the diode voltage is less than the barrier potential, the diode current is small. When the diode voltage exceeds the barrier potential, the diode current increases rapidly.

The Schematic Symbol and Case Styles

Figure 3-1*a* shows the schematic symbol of a diode. The *p* side is called the **anode,** and the *n* side the **cathode.** The diode symbol looks like an arrow that points from the *p* side to the *n* side, from the anode to the cathode. Figure 3-1*b* shows some of the many typical diode case styles. Many, but not all, diodes have the cathode lead (K) identified by a colored band.

Basic Diode Circuit

Figure 3-1*c* shows a diode circuit. In this circuit, the diode is forward biased. How do we know? Because the positive battery terminal drives the *p* side through a resistor, and the negative battery terminal is connected to the *n* side. With this connection, the circuit is trying to push holes and free electrons toward the junction.

In more complicated circuits, it may be difficult to decide whether the diode is forward biased. Here is a guideline. Ask yourself this question: Is the external circuit pushing current in the *easy direction* of flow? If the answer is yes, the diode is forward biased.

What is the easy direction of flow? If you use conventional current, the easy direction is the same direction as the diode arrow. If you prefer electron flow, the easy direction is the other way.

Figure 3-1 Diode. (*a*) Schematic symbol; (*b*) diode case styles; (*c*) forward bias.

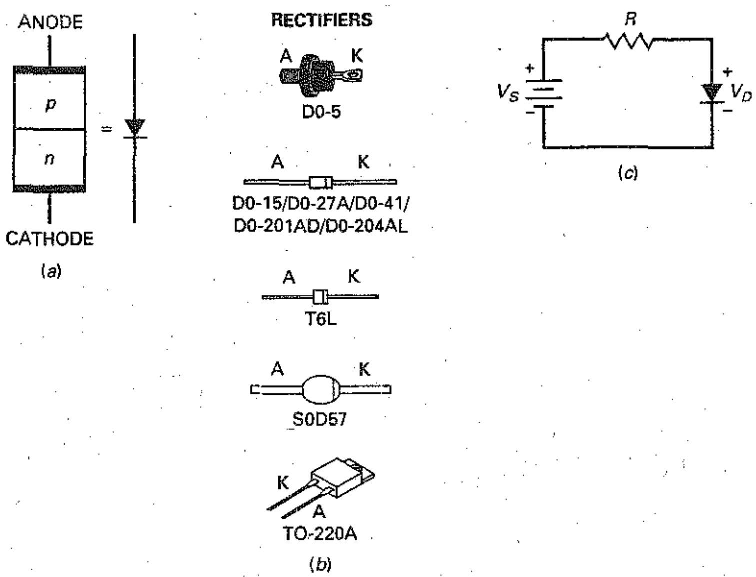
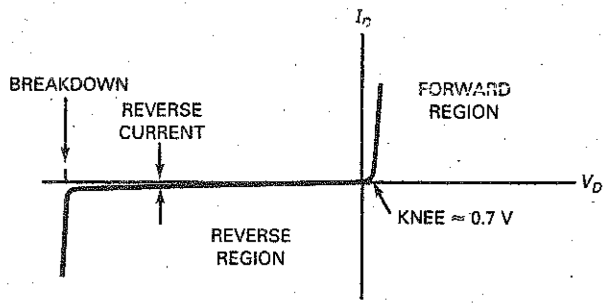


Figure 3-2 Diode curve.



When the diode is part of a complicated circuit, we also can use Thevenin's theorem to determine whether it is forward biased. For instance, assume that we have reduced a complicated circuit with Thevenin's theorem to get Fig. 3-1*c*. We would know that the diode is forward biased.

The Forward Region

Figure 3-1*c* is a circuit that you can set up in the laboratory. After you connect this circuit, you can measure the diode current and voltage. You can also reverse the polarity of the dc source and measure diode current and voltage for reverse bias. If you plot the diode current versus the diode voltage, you will get a graph that looks like Fig. 3-2.

This is a visual summary of the ideas discussed in the preceding chapter. For instance, when the diode is forward biased, there is no significant current until the diode voltage is greater than the barrier potential. On the other hand, when the diode is reverse biased, there is almost no reverse current until the diode voltage reaches the breakdown voltage. Then, avalanche produces a large reverse current, destroying the diode.

Knee Voltage

In the forward region, the voltage at which the current starts to increase rapidly is called the **knee voltage** of the diode. The knee voltage equals the barrier potential. Analysis of diode circuits usually comes down to determining whether the diode voltage is more or less than the knee voltage. If it's more, the diode conducts easily. If it's less, the diode conducts poorly. We define the knee voltage of a silicon diode as:

$$V_K \approx 0.7 \text{ V} \tag{3-1}$$

(*Note:* The symbol ≈ means "approximately equal to.")

Even though germanium diodes are rarely used in new designs, you may still encounter germanium diodes in special circuits or in older equipment. For this reason, remember that the knee voltage of a germanium diode is approximately 0.3 V. This lower knee voltage is an advantage and accounts for the use of a germanium diode in certain applications.

Bulk Resistance

Above the knee voltage, the diode current increases rapidly. This means that small increases in the diode voltage cause large increases in diode current. After the barrier potential is overcome, all that impedes the current is the **ohmic resistance** of the p and n regions. In other words, if the p and n regions were two separate pieces of semiconductor, each would have a resistance that you could measure with an ohmmeter, the same as an ordinary resistor.

The sum of the ohmic resistances is called the **bulk resistance** of the diode. It is defined as:

$$R_B = R_P + R_N \tag{3-2}$$

The bulk resistance depends on the size of the p and n regions, and how heavily doped they are. Often, the bulk resistance is less than 1 Ω.

Maximum DC Forward Current

If the current in a diode is too large, the excessive heat can destroy the diode. For this reason, a manufacturer's data sheet specifies the maximum current a diode can safely handle without shortening its life or degrading its characteristics.

The **maximum forward current** is one of the maximum ratings given on a data sheet. This current may be listed as I_{max}, $I_{F(max)}$, I_O, etc., depending on the manufacturer. For instance, a 1N456 has a maximum forward current rating of 135 mA. This means that it can safely handle a continuous forward current of 135 mA.

Power Dissipation

You can calculate the power dissipation of a diode the same way as you do for a resistor. It equals the product of diode voltage and current. As a formula:

$$P_D = V_D I_D \tag{3-3}$$

The **power rating** is the maximum power the diode can safely dissipate without shortening its life or degrading its properties. In symbols, the definition is:

$$P_{max} = V_{max} I_{max} \tag{3-4}$$

where V_{max} is the voltage corresponding to I_{max}. For instance, if a diode has a maximum voltage and current of 1 V and 2 A, its power rating is 2 W.

Example 3-1

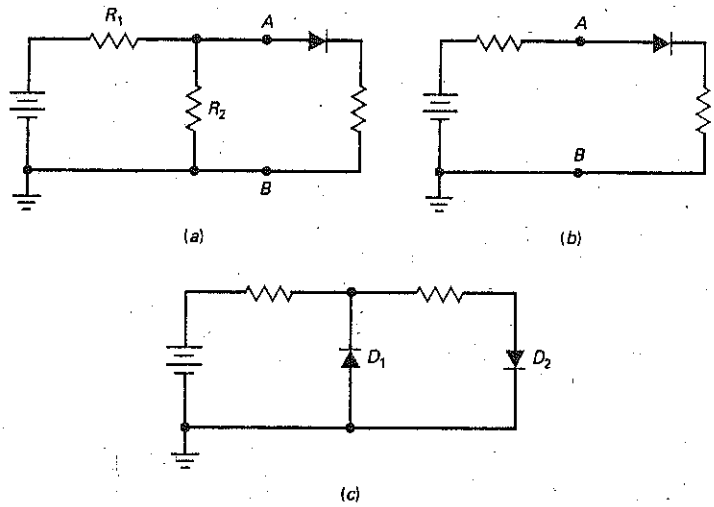
MultiSim

Is the diode of Fig. 3-3*a* forward biased or reverse biased?

SOLUTION The voltage across R_2 is positive; therefore, the circuit is trying to push current in the easy direction of flow. If this is not clear, visualize the Thevenin circuit facing the diode as shown in Fig. 3-3*b*. In this series circuit, you can see that the dc source is trying to push current in the easy direction of flow. Therefore, the diode is forward biased.

Whenever in doubt, reduce the circuit to a series circuit. Then, it will be clear whether the dc source is trying to push current in the easy direction or not.

Figure 3-3



PRACTICE PROBLEM 3-1 Are the diodes of Fig. 3-3c forward biased or reverse biased?

Example 3-2

A diode has a power rating of 5 W. If the diode voltage is 1.2 V and the diode current is 1.75 A, what is the power dissipation? Will the diode be destroyed?

SOLUTION

$$P_D = (1.2\ \text{V})(1.75\ \text{A}) = 2.1\ \text{W}$$

This is less than the power rating, so the diode will not be destroyed.

PRACTICE PROBLEM 3-2 Referring to Example 3-2, what is the diode's power dissipation if the diode voltage is 1.1 V and the diode current is 2 A?

3-2 The Ideal Diode

Figure 3-4 shows a detailed graph of the forward region of a diode. Here you see the diode current I_D versus diode voltage V_D. Notice how the current is approximately zero until the diode voltage approaches the barrier potential. Somewhere in the vicinity of 0.6 to 0.7 V, the diode current increases. When the diode voltage is greater than 0.8 V, the diode current is significant and the graph is almost linear.

Depending on how a diode is doped and its physical size, it may differ from other diodes in its maximum forward current, power rating, and other characteristics. If we need an exact solution, we would have to use the graph of