where V_1 and I_1 are the voltage and current at some point at or above the knee voltage; V_2 and I_2 are the voltage and current at some higher point on the diode curve.

For instance, the data sheet of a 1N4001 gives a forward voltage of 0.93 V for a current of 1 A. Since this is a silicon diode, it has a knee voltage of approximately 0.7 V and a current of approximately zero. Therefore, the values to use are: $V_2 = 0.93$ V, $I_2 = 1$ A, $V_1 = 0.7$ V, and $I_1 = 0$. Substituting these values into equation, we get a bulk resistance of:

$$R_B = \frac{V_2 - V_1}{I_2 - I_1} = \frac{0.93\text{V} - 0.7\text{ V}}{1\text{ A} - 0\text{ A}} = \frac{0.23\text{ V}}{1\text{ A}} = 0.23\ \Omega$$

Incidentally, the diode curve is a graph of current versus voltage. The bulk resistance equals the inverse of the slope above the knee. The greater the slope of the diode curve, the smaller the bulk resistance. In other words, the more vertical the diode curve is above the knee, the lower the bulk resistance.

3-9 DC Resistance of a Diode

If you take the ratio of total diode voltage to total diode current, you get the *dc resistance* of the diode. In the forward direction, this dc resistance is symbolized by R_F; in the reverse direction, it is designated R_R.

Forward Resistance

Because the diode is a nonlinear device, its dc resistance varies with the current through it. For example, here are some pairs of forward current and voltage for a 1N914: 10 mA at 0.65 V, 30 mA at 0.75 V, and 50 mA at 0.85 V. At the first point, the dc resistance is:

$$R_F = \frac{0.65\text{ V}}{10\text{ mA}} = 65\ \Omega$$

At the second point:

$$R_F = \frac{0.75\text{ V}}{30\text{ mA}} = 25\ \Omega$$

And at the third point:

$$R_F = \frac{0.85\text{ mV}}{50\text{ mA}} = 17\ \Omega$$

Notice how the dc resistance decreases as the current increases. In any case, the forward resistance is low compared to the reverse resistance.

Reverse Resistance

Similarly, here are two sets of reverse current and voltage for a 1N914: 25 nA at 20 V; 5 μA at 75 V. At the first point, the dc resistance is:

$$R_R = \frac{20\text{ V}}{25\text{ nA}} = 800\text{ M}\Omega$$

At the second point:

$$R_R = \frac{75\text{ V}}{5\ \mu\text{A}} = 15\text{ M}\Omega$$

Notice how the dc resistance decreases as we approach the breakdown voltage (75 V).

DC Resistance versus Bulk Resistance

The dc resistance of a diode is different from the bulk resistance. The dc resistance of a diode equals the bulk resistance *plus* the effect of the barrier potential. In other words, the dc resistance of a diode is its total resistance, whereas the bulk resistance is the resistance of only the p and n regions. For this reason, the dc resistance of a diode is always greater than bulk resistance.

3-10 Load Lines

This section is about the **load line,** a tool used to find the exact value of diode current and voltage. Load lines are useful with transistors, so a detailed explanation will be given later in the transistor discussions.

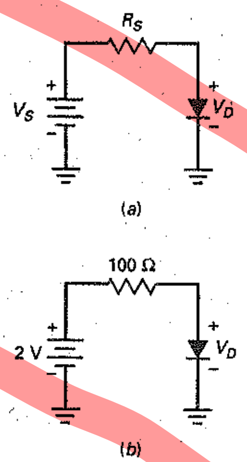
Equation for the Load Line

How can we find the exact diode current and voltage in Fig. 3-17*a*? The current through the resistor is:

$$I_D = \frac{V_S - V_D}{R_s} \tag{3-8}$$

Because of the series circuit, this current is the same through the diode.

Figure 3-17 Load-line analysis.



An Example

If the source voltage is 2 V and the resistance is 100 Ω as shown in Fig. 3-17*b*, then Eq. (3-8) becomes:

$$I_D = \frac{2 - V_D}{100} \tag{3-9}$$

Equation (3-9) is a linear relationship between current and voltage. If we plot this equation, we will get a straight line. For instance, let V_D equal zero. Then:

$$I_D = \frac{2\text{ V} - 0\text{ V}}{100\ \Omega} = 20\text{ mA}$$

Plotting this point ($I_D = 20$ mA, $V_D = 0$) gives the point on the vertical axis of Fig. 3-18. This point is called *saturation* because it represents maximum current with 2 V across 100 Ω.

Here's how to get another point. Let V_D equal 2 V. Then Eq. (3-9) gives:

$$I_D = \frac{2\text{ V} - 2\text{ V}}{100\ \Omega} = 0$$

When we plot this point ($I_D = 0$, $V_D = 2$ V), we get the point shown on the horizontal axis (Fig. 3-18). This point is called *cutoff* because it represents minimum current.

By selecting other voltages, we can calculate and plot additional points. Because Eq. (3-9) is linear, all points will lie on the straight line shown in Fig. 3-18. The straight line is called the *load line.*

The *Q* Point

Figure 3-18 shows the load line and a diode curve. The point of intersection, known as the Q point, represents a simultaneous solution between the diode curve and the load line. In other words, the Q point is the only point on the graph that works for both the diode and the circuit. By reading the coordinates of the Q point, we get a current of 12.5 mA and a diode voltage of 0.75 V.