forward current when the diode burns out because of excessive power dissipation. On other data sheets, the average current may be designated as I_o.

Again, a designer looks upon 1 A as the absolute maximum rating of the 1N4001, a level of forward current that should not even be approached. This is why a safety factor would be included—possibly a factor of 2. In other words, a reliable design would ensure that the forward current is less than 0.5 A under all operating conditions. Failure studies of devices show that the lifetime of a device decreases the closer you get to the maximum rating. This is why some designers use a safety factor of as much as 10:1. A really conservative design would keep the maximum forward current of the 1N4001 at 0.1 A or less.

Forward Voltage Drop

Under "Electrical Characteristics" in Fig. 3-16, the first entry shown gives you these data:

Characteristic and Conditions	Symbol	Maximum Value
Forward Voltage Drop (i_F) = 1.0 A, T_A = 25°C	v_F	1.1 V

As shown in Fig. 3-16 on the chart titled "Forward Characteristics," the typical 1N4001 has a forward voltage drop of 0.93 V when the current is 1 A and the junction temperature is 25°C. If you test thousands of 1N4001s, you will find that a few will have as much as 1.1 V across them when the current is 1 A.

Maximum Reverse Current

Another entry on the data sheet that is worth discussing is this one:

Characteristic and Conditions	Symbol	Typical Value	Maximum Value
Reverse Current	I_R		
T_A = 25°C		0.05 μA	10 μA
T_A = 100°C		1.0 μA	50 μA

This is the reverse current at the maximum reverse dc rated voltage (50 V for a 1N4001). At 25°C, the typical 1N4001 has a maximum reverse current of 5.0 μA. But notice how it increases to 500 μA at 100°C. Remember that this reverse current includes thermally produced saturation current and surface-leakage current. You can see from these numbers that temperature is important. A design that requires a reverse current of less than 5.0 μA will work fine at 25°C with a typical 1N4001, but will fail in mass production if the junction temperature reaches 100°C.

3-8 How to Calculate Bulk Resistance

When you are trying to analyze a diode circuit accurately, you will need to know the bulk resistance of the diode. Manufacturers' data sheets do not usually list the bulk resistance separately, but they do give enough information to allow you to calculate it. Here is the derivation for bulk resistance:

$$R_B = \frac{V_2 - V_1}{I_2 - I_1} \tag{3-7}$$

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).