Lab 1 - The Diode

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ECE 3110

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1 Introduction

In this lab we build a simple circuit utilizing a diode and a resistor to measure and analyze the performance of the diode under different condiditions. Before we take measurements of the circuit, we solve for the voltages and current through the circuit in a few different ways and then compare our results. We will test our circuit with a few different voltages to see how the components respond.

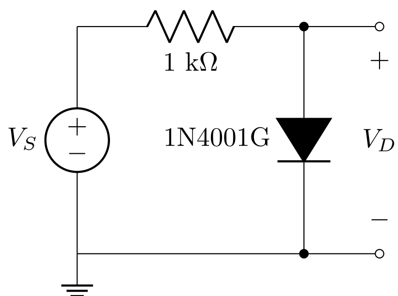

Figure 1: The circuit we used in the lab.

2 Theory

To analyze the circuit we will make use of three ways to model a diode, known as the *ideal model*, *constant drop model*, and the *exponential model*. For each model we will calculate the current through the circuit, and the voltages present around the resistor and the diode for 10 V, 1.2 V, and 0.75 V (a voltage where we found the current to drop off significantly).

2.1 Ideal Model

In the ideal model we assume that a diode is simply a short circuit when forward biased, which leaves us with a circuit as shown in Fig. 2.

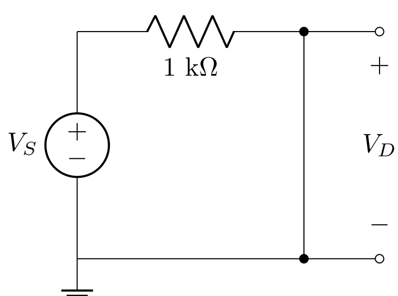

Figure 2: The circuit when using the ideal model.

Without a diode present, the current through the circuit is shown with $I = \frac{V}{R}$, and the voltage over the diode is always 0 V.

For 10 V: $I = \frac{10 \text{ V}}{1 \text{ k}\Omega} = 10$ mA
For 1.2 V: $I = \frac{1.2 \text{ V}}{1 \text{ k}\Omega} = 1.2$ mA
For 0.75 V: $I = \frac{0.75 \text{ V}}{1 \text{ k}\Omega} = 0.75$ mA

2.2 Constant Drop

The constant drop model for a diode suggests that a diode can be replaced by a voltage source equalling 0.7 V with the positive terminal aligned with the cathode of the diode. See Fig. 3

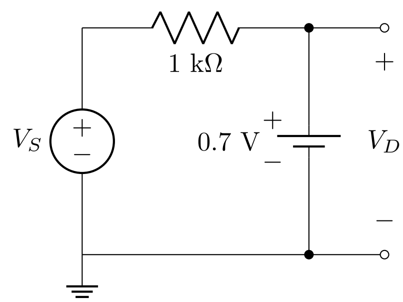

Figure 3: The circuit when usint the constant drop model.

With a supposed battery supplying voltage to the circuit, the resulting voltage over that resistor is then reduced to $V - 0.7$ V. This means that the current through the circuit is shown by $I = \frac{V-0.7 \text{ V}}{R}$.

For 10 V: $I = \frac{9.3 \text{ V}}{1 \text{ k}\Omega} = 9.3$ mA
For 1.2 V: $I = \frac{0.5 \text{ V}}{1 \text{ k}\Omega} = 0.5$ mA
For 0.75 V: $I = \frac{0.05 \text{ V}}{1 \text{ k}\Omega} = 0.05$ mA

2.3 Exponential Model

When using the exponential model, we use Eq. 1 to show the relationship between the current and the voltage through a diode.

$$I = I_S e^{V/V_{TH}} \tag{1}$$

We are using a value of $V_{TH} = 25.9$ mV for the thermal voltage. I_S is calculated by using an operating point given from a datasheet in Eq. 1. Rearranging the equation yields the following:

$$I_S = \frac{I}{e^{V/V_{TH}}}$$

Plugging in our values we find:

$$I_S = \frac{1 \text{ A}}{e^{0.93 \text{ V}/25.9 \text{ mV}}} = 2.545 \times 10^{-16} \text{A}$$

Now, with a satisfactory I_S value we can use the iterative method to solve for the current and voltage in the diode. Using the following two equations we can iterate on the values of I and V_D until we have sufficiently accurate values.

$$I_D = \frac{V_S - V_D}{R} \tag{2}$$

$$V_2 - V_1 = V_{TH} \ln\left(\frac{I_2}{I_1}\right) \tag{3}$$

One iteration is shown below:

$$I_D = \frac{10\text{ V} - 0.93\text{ V}}{1\text{ k}\Omega} = 9.07\text{ mA}$$

$$V_2 = 0.93\text{ V} + 25.9\text{ mV} \cdot \ln\left(\frac{9.07\text{ mA}}{1\text{ A}}\right) = 0.8082\text{ V}$$

Inserting 0.8082 V into Eq. 2 will provide another V-I pair that can once again be used to calculate a more accurate approximation of I and V_D. After two iterations we found that the values were sufficiently accurate for our needs. We used the iterative method to solve for the current and voltages of the circuit for both $V_S = 10$ V and $V_S = 1.2$ V, and the results are shown along with the results from the other models in Table 1.

	Ideal			Constant Drop			Exponential		
V_S	V_D	V_R	I	V_D	V_R	I	V_D	V_R	I
10 V	0 V	10 V	10 mA	0.7 V	9.3 V	9.3 mA	0.8085 V	9.192 V	9.192 mA
1.2 V	0 V	1.2 V	1.2 mA	0.7 V	0.5 V	0.5 mA	0.7314 V	0.4686 V	0.4686 mA
0.75 V	0 V	0.75 V	0.75 mA	0.7 V	0.05 V	0.05 mA			

Table 1: Calculations for all three models of the circuit.

3 Graphical Analysis

We can achieve the same result from the exponential model if we graph both the current through the resistor and the diode as a function of voltage. Doing so shows an intersection on the graph showing the operating point of the circuit for a given V_S. For $V_S = 10$ V we may examine Fig. 4.

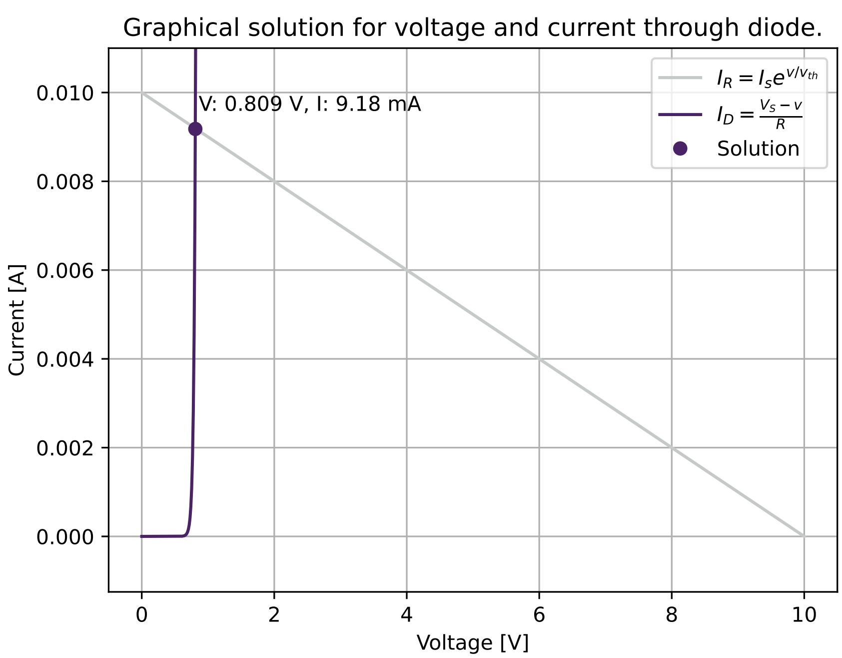

Figure 4: Graphical solution for the circuit at 10 V.

Similarly, the same was done for a voltage of 1.2 V, as seen in Fig. 5

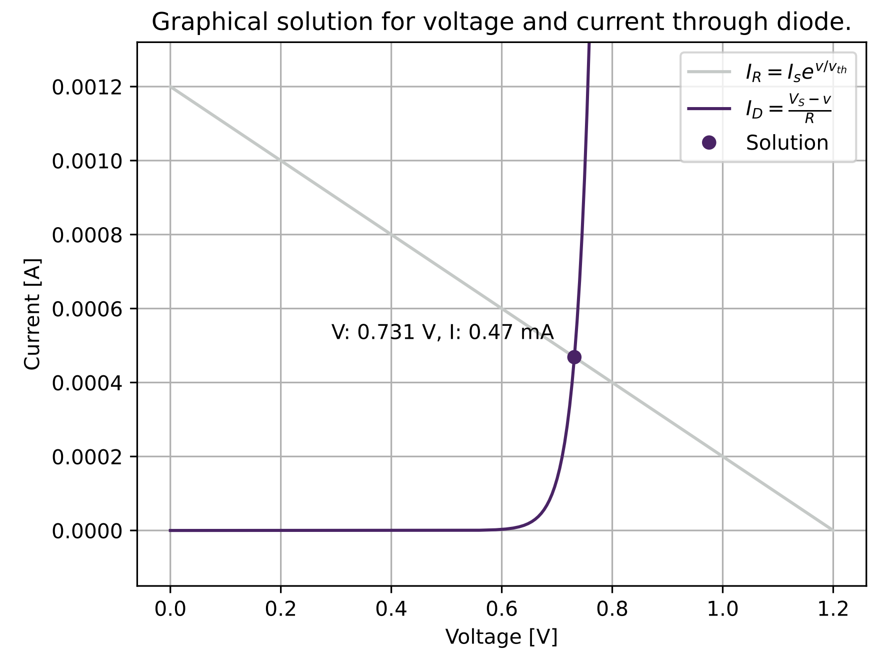

Figure 5: Graphical solution for the circuit at 1.2 V.

4 Results

Table 2 contains the results from the circuit. Notice that the voltages across the diode are higher when the supplied voltage is higher. Also, we found that at $V_S = 0.75$ V the current through the circuit was sufficiently low that we could consider the diode as shut off.

Voltage	V_S	V_D	V_R	I
10 V	10.0004 V	0.6856 V	9.317 V	9.484 mA
1.2 V	1.204 V	0.5563 V	0.6477 V	0.6384 mA
0.75 V	0.7545 V	0.5097 V	0.2443 V	0.2409 mA

Table 2: Results from measuring the circuit.

5 Conclusion

As you can see, the voltages that were calculated for the diode were a bit higher than what we measured when we built the circuit. Tolerances for these semiconductor devices are usually around 20%, which falls within the error we found. For V_D @ 10 V, the error is calculated at $\frac{0.8085-0.6856}{0.6856} = 17.93\%$, and the other error values were consistently $\sim 16 - 18\%$.

It is also notable that the voltage over the diode did slightly increase as the supplied voltage in both the expontential model and the recorded results. The exponential model was the best at approximating the behavior of the circuit, but the constant drop model ended up getting closer to the real value of V_D.

6 Extra Thoughts

During the lab we spent some time considering whether the characteristic point revealed in the datasheet was accurate to our hardware. We decided to measure our own characteristic point by setting a specific voltage and measuring the current through it. We found that at a voltage of 0.600 V the current was 1.42 mA. These values were used to calculate a new I_S, which was $I_S = 1.246 \times 10^{-13}$A.

We solved the circuit once again graphically using the new characteristic point and the results matched much more closely with our results from Table 2, as shown in Fig. 6 and 7.

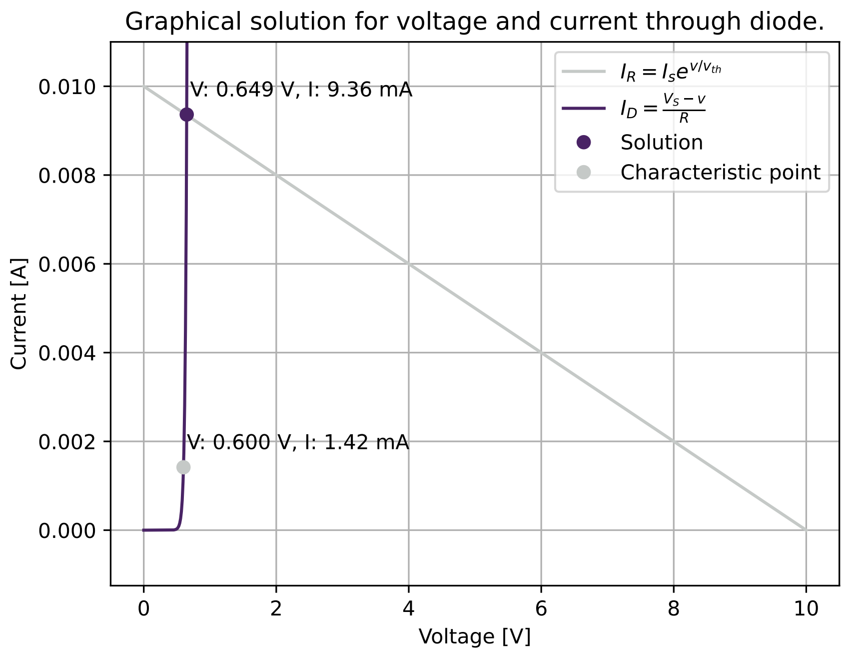

Figure 6: Calculated I and V_D at 10 V with the new characteristic point.

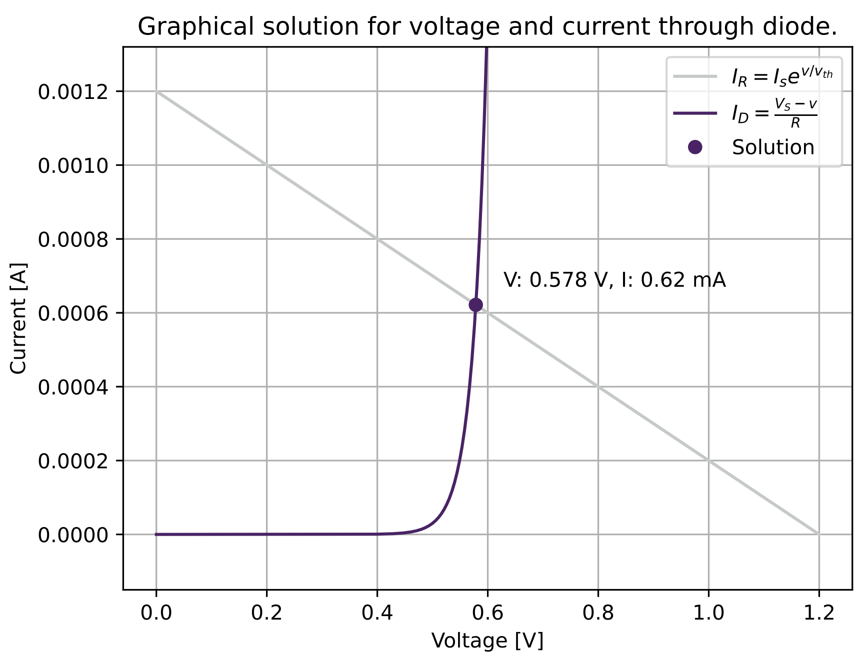

Figure 7: Calculated I and V_D at 1.2 V with the new characteristic point.