# ECE 310L: Microelectronic Circuits Lab

**Lab 2: *I—V* Characteristics of Diode**

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## Objectives

(1) Experimentally determine the forward and reverse *I–V* characteristics for a standard PN diode and a Zener diode, then compare them to predicted values.

(2) Plot load lines to determine diode operating points.

## Background

The ideal diode operates such that if the anode terminal is at a lower potential than the cathode terminal no current ($I_D$) will flow. If the anode terminal is at a higher potential than the cathode terminal, then the diode will conduct with no voltage drop. A real diode, such as 1N4004 and 1N5230B, will not conduct until a small forward bias is present and then exhibits an increasing forward voltage-drop as the diode current increases. The 1N4004 is a common power diode with a 400 V reverse voltage (PIV) rating, and should only have a small leakage current in the reverse bias mode. The 1N5230B Zener diode will exhibit a small leakage current in the reverse bias condition until the Zener voltage (~4.7 V) is reached, and then the current will increase rapidly as voltage increases.

To measure the *I–V* characteristics, we will use the DC power supply with a resistor in series with the diode under test as shown in Figures 1a and 1b. The resistor allows us to produce and measure a small current that is controlled by the power supply output voltage. We cannot easily control the power supply voltage to the degree needed to with a very nonlinear device like the diode. The resistor also limits the maximum current to an acceptable value.

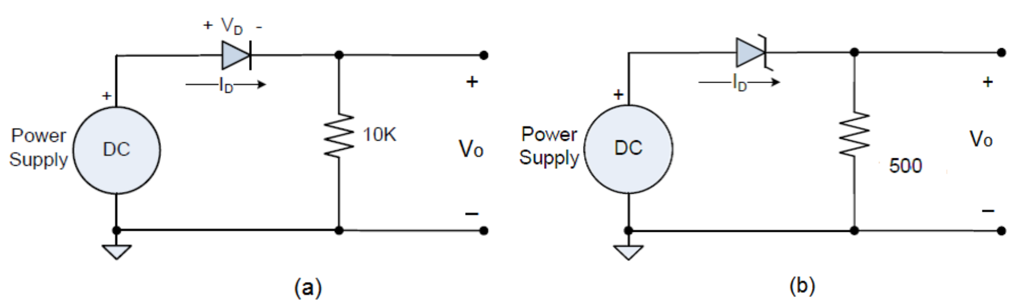



Figure 1. *I-V* characteristic circuit for (a) 1N4004 and (b) Zener diode 1N5230B.

Once you have collected the empirical data, you will compare it to the theoretical values. The forward current in the diode can be modeled as

$$i_D = I_S(e^{\frac{v_D}{n v_T}} - 1)$$

where $i_D$ = diode current (A)
$v_D$ = diode voltage (V)
$I_S$ = reverse saturation current (A)
$v_T$ = thermal voltage (V)
$n$ = non-ideality constant (unitless, $1 \leq n < 2$)

## Materials

- DC power supply, HP E3631A
- DMM, Agilent E3631A
- Oscilloscope, Agilent DSO5014A
- Solderless breadboad
- Hookup wires
- Resistors: 10 Ω, 500 Ω, and 10 KΩ
- 1N4004 diode
- 1N5230B Zener diode

## Pre-Lab Assignments

Question 1. The $I$–$V$ relations of a non-ideal diode ($n > 1$) was measured at two points: (a) $I_D = 0.6$ mA for $V_D = 0.7$ V and (b) $I_D = 2.3$ mA for $V_D = 0.74$ V at the room temperature. Calculate:

(1) The emission coefficient n and saturation current $I_S$;
(2) The current $I_D$ at $V_D = 0.72$ V.

Question 2. The SPICE parameters of a non-ideal diode ($n > 1$) is

$$I_D = I_S \exp(V_{D0}/nV_t)$$

where $V_{D0}$ is the voltage drop across the $p$-$n$ junction. $V_{D0}$ differs from the voltage drop between the terminals, $V_D$, by the voltage drop across the parasitic resistance $r_S$.

$$V_{D0} = V_D - r_S I_D$$

For the diode in the circuit shown below, the SPICE parameters are $I_S = 10^{-12}$ A, $n = 1.4$, and $r_S = 10$ Ω. The current flowing through the circuit is found to be $I_D = 3.5$ mA. Knowing that the thermal voltage is $V_T = 26$ mV, determine the voltage between the diode terminals, $V_D$.

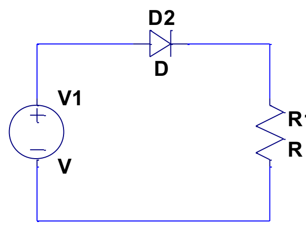



Figure 2. Circuit for pre-lab question 2.

Question 3. In a circuit shown below, can one correctly measure the voltage across the diode $D_1$ and the resistor $R_1$ using an oscilloscope probe as shown in Fig. 3? Explain. How to arrange circuit components so that you can properly measure the voltage. Show the schematic (clearly label the ground and the probe).

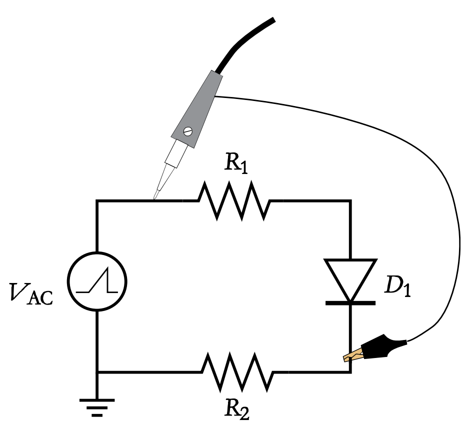



Figure 3. Circuit for pre-lab question 3.

Question 4. The Zener diode in the circuit shown in Fig. 4 has an *I*–*V* characteristic shown in the textbox. Graph the load line on the *I*–*V* curve.

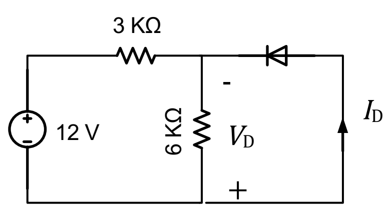



Figure 4. Circuit for question 4

A load line is used in graphical analysis of electronic circuits, representing the constraint other parts of the circuit place on a non-linear device such as diodes or transistors. It is drawn on a graph of the *I*–*V* relationship in the nonlinear device, called the device's characteristic curve such as the one shown in the textbox below. A load line represents the response of the linear part of the circuit as shown in Fig. 5, connected to the nonlinear device in question. It's usually a straight line.

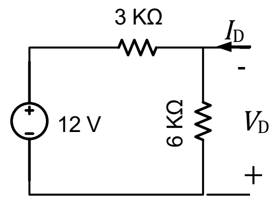
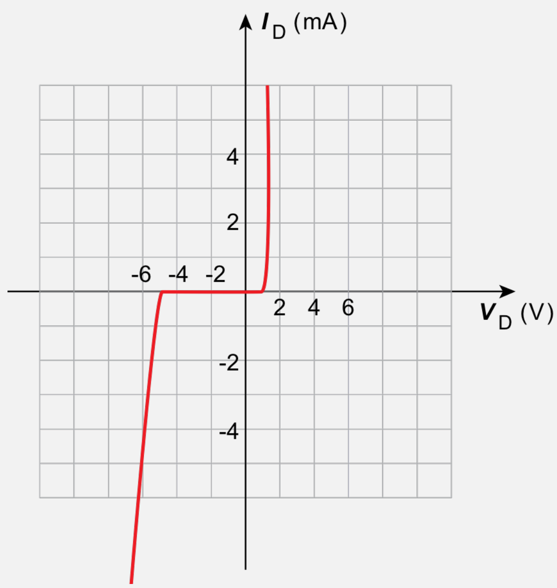



Figure 5. Linear circuit for question 4

The points where the characteristic curve and the load line intersect are the operating point(s) (Q points) of the circuit; at these points the current and voltage parameters of both parts of the circuit match.

In this exercise, analyze the circuit shown in Fig. 5 and determine the $I_D - V_D$ relationship. Plot $I_D - V_D$ on the same figure below and determine the intersection.



## Setup

Turn on DC power supply and the DMM. Set the current limit on the power supply +25 V output to 100 mA. You will only need to use the +25 V output in this experiment. Obtain the resistors and diodes needed for the experiment.

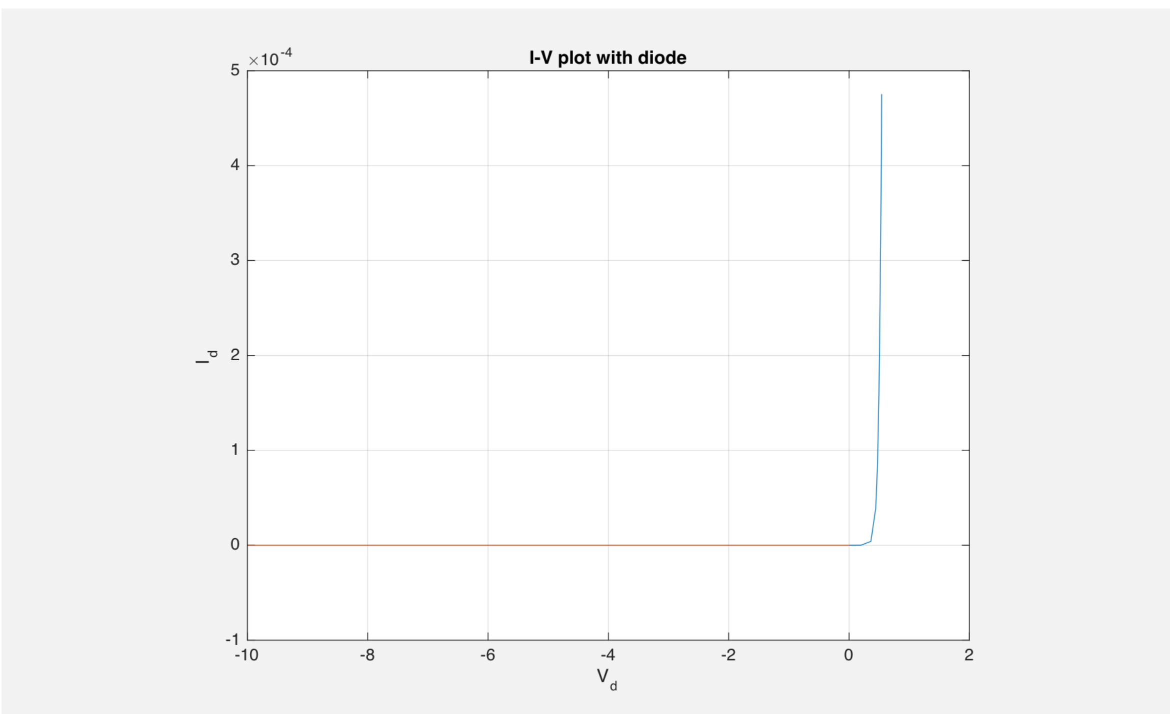
## Lab Assignments

1. Use the DMM to measure the values of the 10 KΩ and 500 Ω resistors. Used the measured resistor values in your calculations.

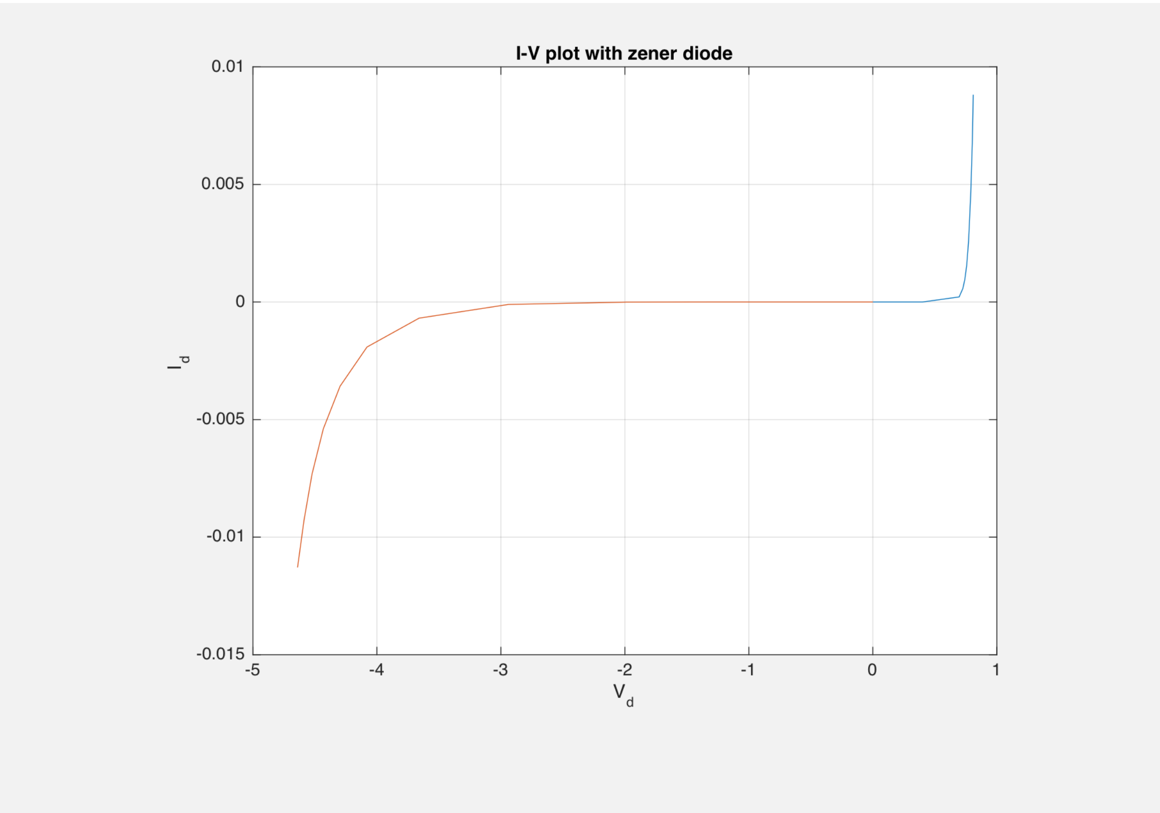
Table 1: Measured Resistance for Diode Circuits

| Expected Resistance | $R_1 = 10$ KΩ | $R_2 = 500$ Ω | $R_3 = 10$ Ω |
|---|---|---|---|
| Measured Resistance | 9.383 KΩ | 474.95 Ω | 11.05 |

2. Connect the diode circuit shown in Figure 1a with a 10 KΩ resistor. The positive supply voltage should be connected to the anode of the diode. The diode will be forward biased in this configuration. Ensure the supply voltage is set to 0 V prior to applying the source to the circuit. Record the voltage drop across both the diode and resistor as the supply voltage is increased in the following steps: 0.0, 0.2, 0.4, 0.8, 1.0, 1.2, 1.5, 2.0, 3.0, 4.0, and 5.0 V. Set the supply back to 0 V. Calculate and record the diode current for each voltage using the voltage drop across the resistor and its measured resistance.
3. Reverse the diode so the positive supply voltage is connected to the cathode. The diode will be in the reversed biased condition. Repeat the measurements as in step 2 plus additional measurements at 6 V, 7 V, 8 V, 9 V, and 10 V. Record the diode and resistor voltage drops and calculate the diode current as before. Set the supply back to 0 V.
4. Create a plot for each diode showing your measured *I*–*V* data. Remember that your reverse bias data was obtained by reversing the diode, so you must account for that in the sign of your measurements. Plot the *I*–*V* curve using MATLAB for the forward and reverse bias in one figure.



5. Connect the circuit shown in Figure 1b with a 500 Ω resistor and perform the same measurements as in Step 2. The positive supply voltage should be connected to the anode of the diode. These measurements will provide the forward bias curve of the Zener diode. Repeat the measurements and calculations in Step 2. Set the supply back to 0 V.
6. Reverse the Zener diode and repeat the measurements and calculations in Step 3.
7. Create a plot for each diode showing your measured *I–V* data. Remember that your reverse bias data was obtained by reversing the diode, so you must account for that in the sign of your measurements. Plot the *I–V* curve using MATLAB for the forward and reverse bias in one figure.



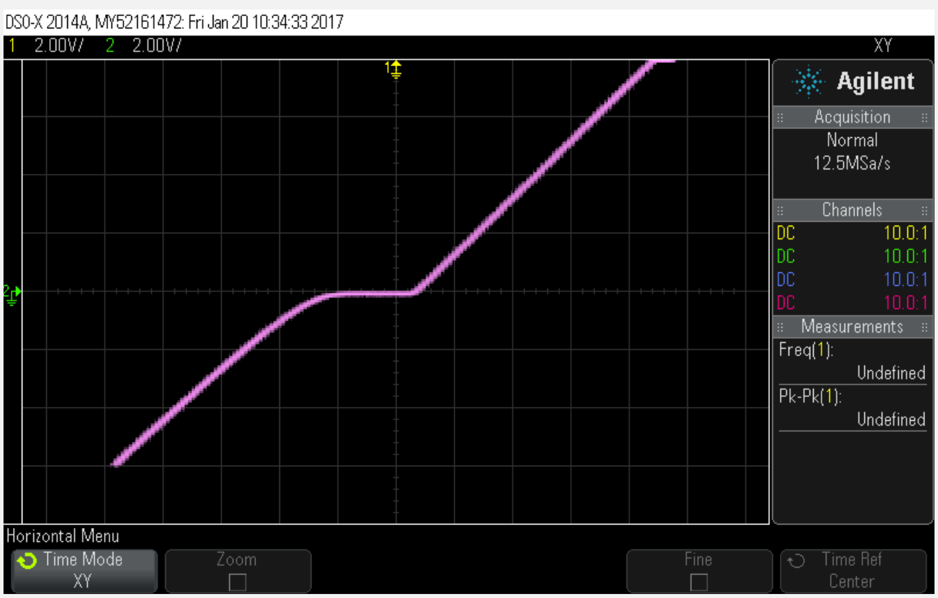

> Device *I-V* curve can also be measured directly with most modern oscilloscope using the "XY mode" or "versus" math function. For Agilent DSO 5014A oscilloscope, probe the voltage across the terminals of interest with channel 1 (the X input) and the current through the terminal of interest with channel 2 (the Y input). Access the "XY mode" by Main button in the Horizontal pane.

It is often more convenient to measure the current through a semiconductor device by probing the voltage across a resistor connected in series with the device. As long as the resistance is sufficiently small, its impact to the circuit can be ignored. However, resistance needs to be large enough so that voltage across the resistor can be reliably measured.

In this experiment, we will add a 10 Ω resistor in series with the diode so that the current through the diode is given by the voltage drop across a resistor, $I_D = V_R$ / 10 Ω. The voltage across the 10 Ω resistor is negligibly small so that we will consider the voltage drop of diode and 10 Ω resistor as $V_D$.

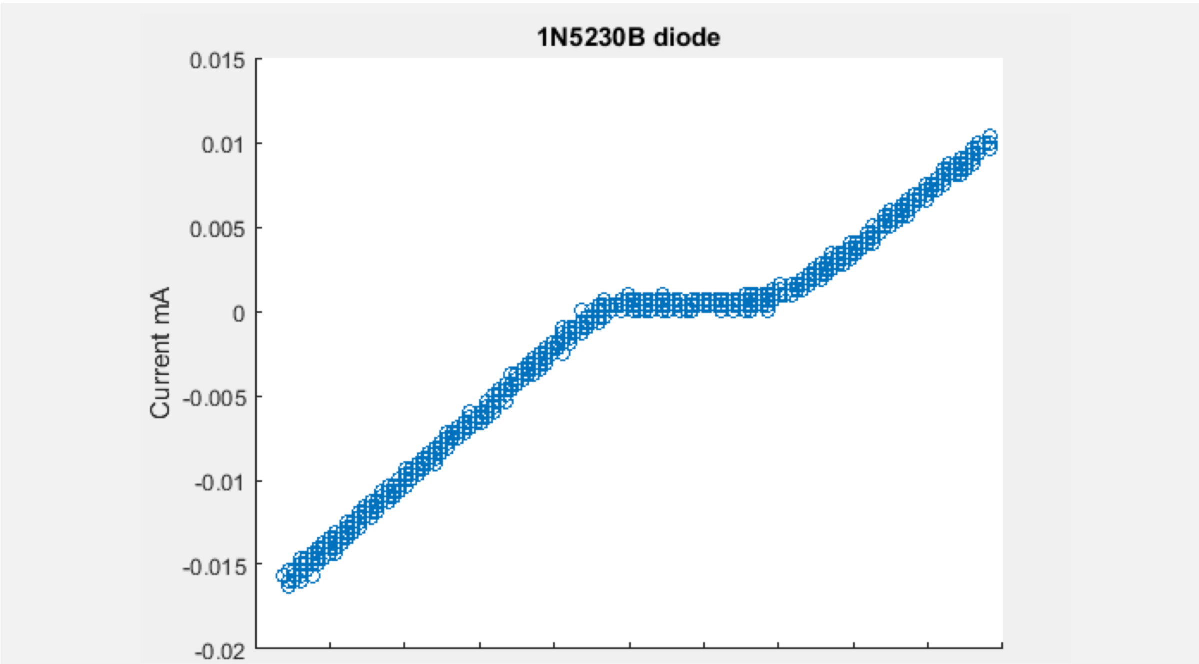
Since all equipment shares the same grounding, circuit components needs to be rearranged so that the probe will not cause shorting of any circuit components. How to do that?

8. Use the signal generator as the power source for the circuit in Fig. 1b. Confirm that the internal impedance of the signal generator is set to High-Z. Set the output to a sawtooth function with a voltage from −10 V to +10 V and frequency to 100 Hz. Verify the output with oscilloscope.
9. Setup the circuit in Fig. 1b and add a 10 Ω resistor in series with the diode. Probe the voltage across the diode and 10 Ω resistor for channel 1. Probe the voltage across 10 Ω resistor for channel 2. Make sure that the oscilloscope probes do not cause shorting of the circuit. Create an XY plot on the oscilloscope showing the *I*–*V* characteristics of the 1N5230B diode.
10. The current through the circuit can be calculated from the voltage across 10 Ω resistor. Use the measured resistance in your calculations.




> To record the data points from the oscilloscope, switch oscilloscope back from the X-Y mode to the normal mode. Save data either as an ASCII or CSV file. The voltage across the diode and the sensing resistor are in two separate columns.

11. Compare the $I$–$V$ characteristics of the 1N5230B diode measured from step 5 - 7 and 8 – 10. Does the two measurements match? If they don't match, why?




12. Set the supply back to 0 V and return the components.

## Discussion

Answer the following questions regarding the diodes:

(1) What is the input impedance of the DMM we are using? Does it have a significant loading effect in the experiment? Justify your answer.

The DMM uses a very high input impedance, for the one we used it was 10 M Ω – using such a large impedance ensures that when the circuit components are probed there is negligible impact on the circuit as the current will take the path of least resistance.

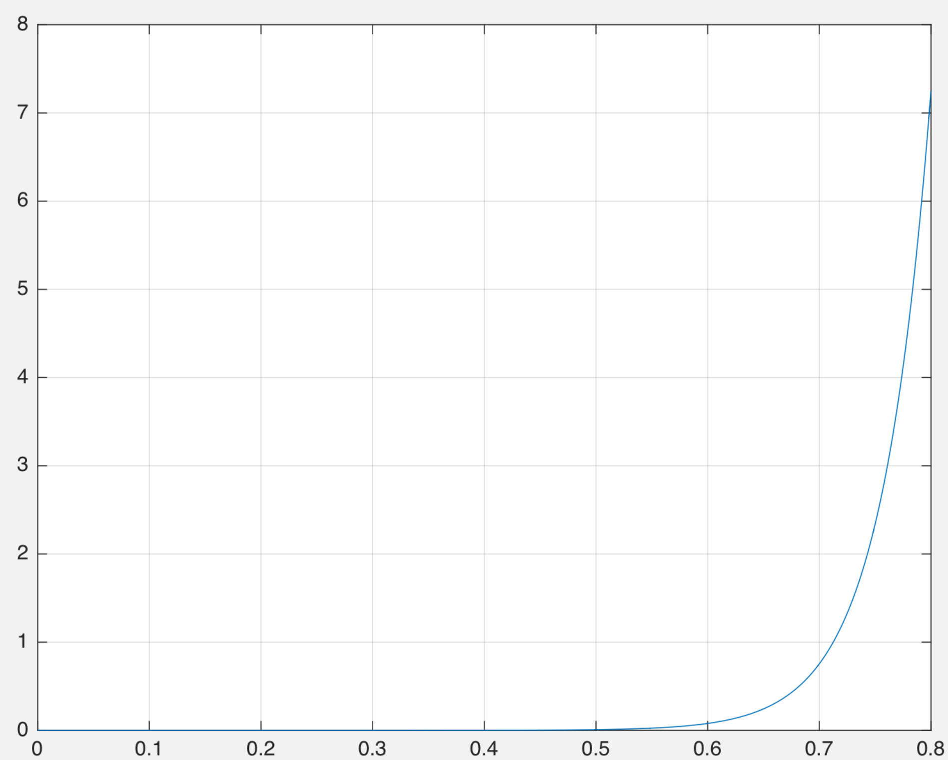
(2) From the measured *I*–*V* data, using the diode equation, create an *I*–*V* plot (forward bias only) for each diode. Use $n = 1$, with $I_S = 10$ nA for the 1N4004, and $I_S = 2$ μA for the 1N5230B as starting points. Vary $I_S$ and $n$ to try to match the diode equation plots to the measured data for each diode. What values of $I_S$ and $n$ gave the best fit?

We got the best results around n=1.7 and Is=$10^{-7}$

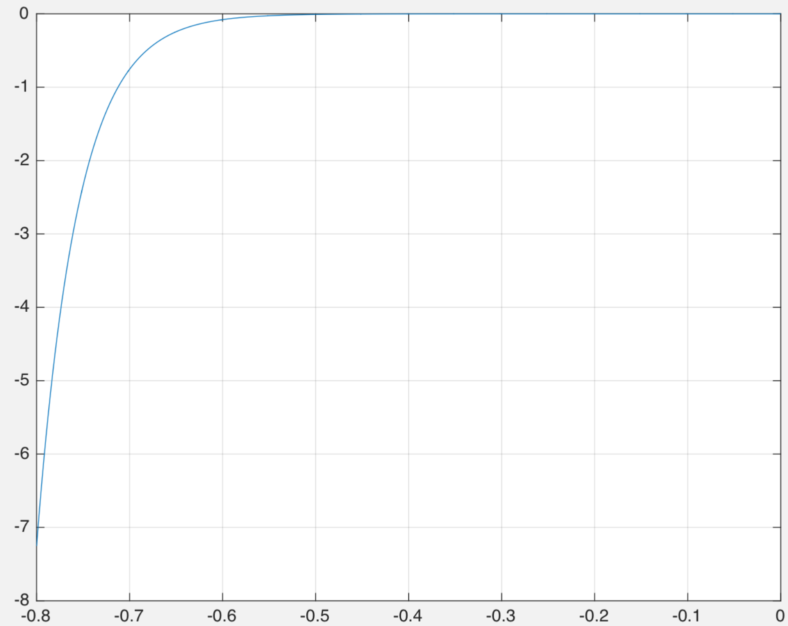
(3) Compare $I_S$ and $n$ from the previous question to the specifications given in diode datasheets. How well does it agree?

It was pretty close

(4) Plot the load line for the 1N4004 forward biased mode when $V_S$ is 3 V (i.e., diode in forward bias) on the measured $I$–$V$ data you obtained in the lab.



(5) Plot the load line for the 1N5230B reverse biased mode when $V_S$ is -6 V (i.e., diode in reverse bias) on the measured *I*–*V* data you obtained in the lab.




## Reference


1. March 2010 - By Richard Jaeger, Travis Blalock - McGraw-Hill Education - 2010.03.01 - Hardback - 1,334 pages - ISBN 0073380458

2. On Semiconductor TDS for 1N4004 diode. Semiconductor Components Industries, LLC, 2013. http://www.onsemi.com/pub_link/Collateral/1N4001-D.PDF

3. Fairchild Semiconductor TDS for 1N5230B Zener diode. http://www.fairchildsemi.com/ds/1N/1N5221B.pdf

## Appendix

Attach your MATLAB code used for lab assignments and discussions

```
%% scope data
%forward 10k
filename = 'Lab2.xlsx';
sheet = 1;

figure
vr1 = xlsread(filename,sheet,'B2:L2');
vd1 = xlsread(filename,sheet,'B3:L3');
ir1 = vr1./9383;
plot(vd1,ir1);
hold on;

%reverse 10k
vrr1 = xlsread(filename,sheet,'B7:Q7');
vdr1 = xlsread(filename,sheet,'B8:Q8');
vdr1 = vdr1.*(-1);
irr1 = vrr1./9383;
irr1 = irr1.*(-1);
subplot(2,1,1)
plot(vdr1,irr1), grid on
xlabel('V_d')
ylabel('I_d')
title('I-V plot with diode')

%forward 500
subplot(2,1,2)
figure
vr2 = xlsread(filename,sheet,'B12:L12');
vd2 = xlsread(filename,sheet,'B13:L13');
ir2 = vr2./474.95;
plot(vd2,ir2);
hold on;

%reverse 500
vrr2 = xlsread(filename,sheet,'B17:Q17');
vdr2 = xlsread(filename,sheet,'B18:Q18');
vdr2 = vdr2.*(-1);
irr2 = vrr2./474.95;
```