LABORATORY 3

Diode

Guide

Diodes Overview

Diodes are mostly used in practice for emitting light (as Light Emitting Diodes, LEDs) or controlling voltages in various circuits. The best way to think about diodes is to first understand what happens with an ideal diode and then to extend it to the practical case. An ideal diode has an infinite resistance when the voltage across it is less than its "threshold voltage" (or $v_{threshold}$) and zero resistance when the voltage is greater than the threshold. The threshold voltage is just a characteristic of each individual diode i.e. every 1N4148 diode should have the same threshold voltage (around 0.6 volts) whereas an LED may have a different threshold voltage. This threshold voltage concept comes from the fact that a diode is just a p-n junction. Don't feel bad if you haven't studied p-n junctions before, it is not required for this lab. The I-V graph for an ideal diode looks like that in Figure 1.

In Figure 1, the threshold voltage (i.e. the voltage when the slope of the line changes from 0 to ∞) is at 0. This will not be the case for the real diodes we use in lab. For the diodes we will use in this lab, all threshold voltages will be positive (Zener diodes have a low reverse threshold - you will deal with them later). We will see shortly that the behavior of diodes is actually somewhat like a switch, and so there are some easy ways to analyze circuits with diodes in them.

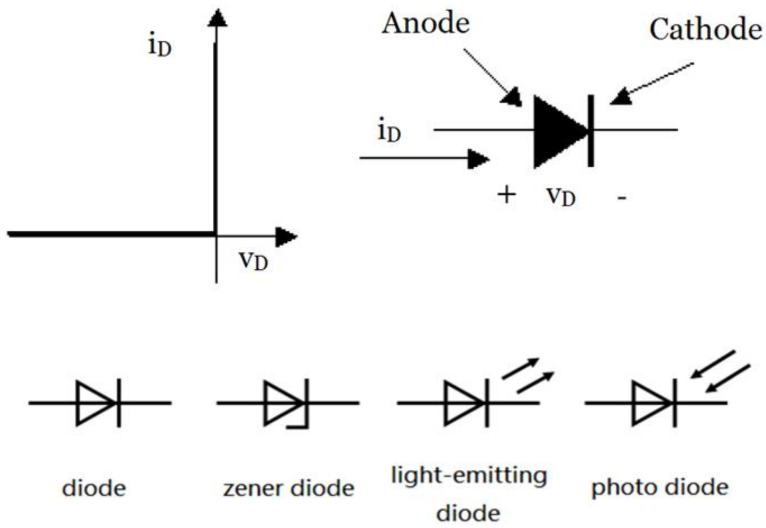


Figure 1. Ideal Diode I-V Curve and Symbols of different types of diodes.

Diode I-V characteristics

The I-V graph for a non-ideal diode is shown in Figure 2, along with an ideal approximation to accommodate the non-zero threshold voltage. The diode will be easier to understand if we compare the diode to another two terminal device we know (and love) - the resistor.

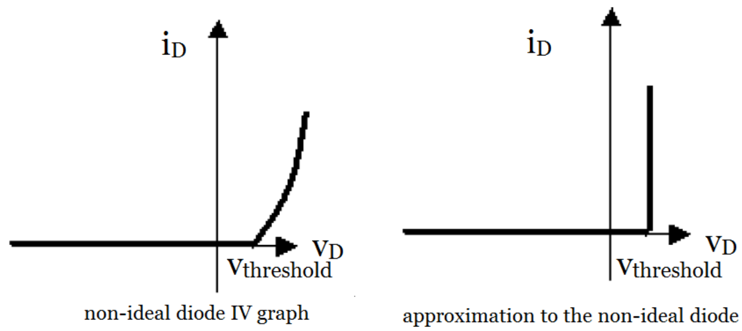


Figure 2. Non-Ideal Diode I-V Curve and an approximation to the non-ideal diode.

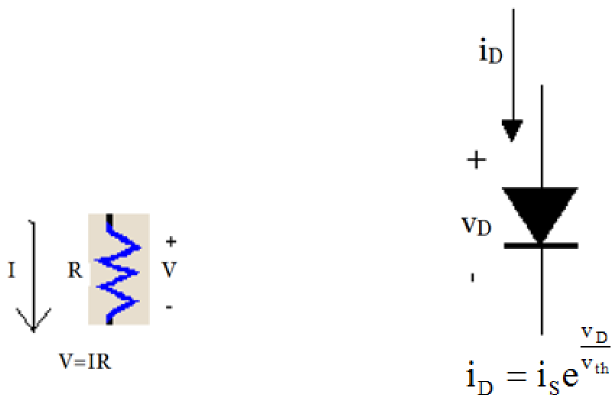


Figure 3. The resistor vs. the diode. v_{th} is the threshold voltage.

From Figure 3, we see that both diodes and resistors are two terminal devices. However, their I-V characteristics are very different. An equation that models the I-V characteristic of a non-ideal diode is shown below.

$$i_D = I_S e^{\frac{v_D}{v_{th}}} \quad \text{if } v_D \geq v_{th}$$
$$i_D = 0 \quad \text{if } v_D \leq v_{th}$$

If v_D is greater than v_{th}, then the diode is said to be forward-biased or it is said to be in the forward-biased region. If not, the diode is said to be operating in reverse-bias. Also, in the equation above:

- I_S is a constant called the reverse bias saturation current and is approximately equal to 1×10^{-11} A.
- V_{th} is a constant called the thermal voltage (this is different from the threshold voltage) and is approximately equal to 26 mV at room temperature.

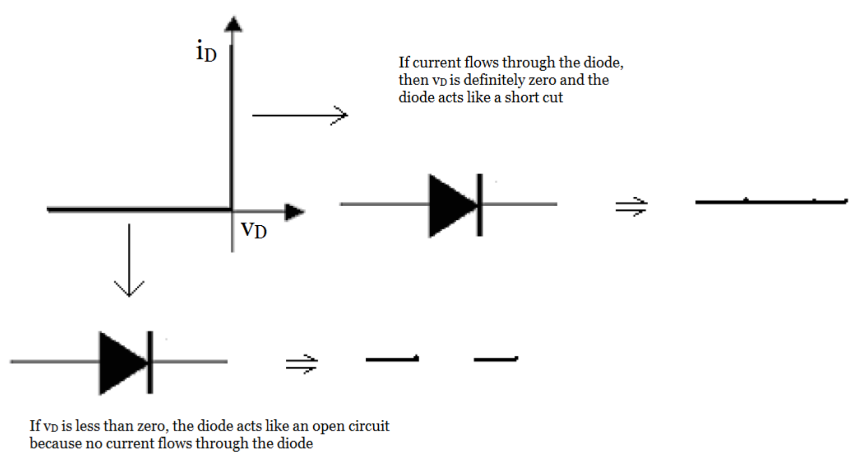


Figure 4. Ideal diode model without threshold voltage.

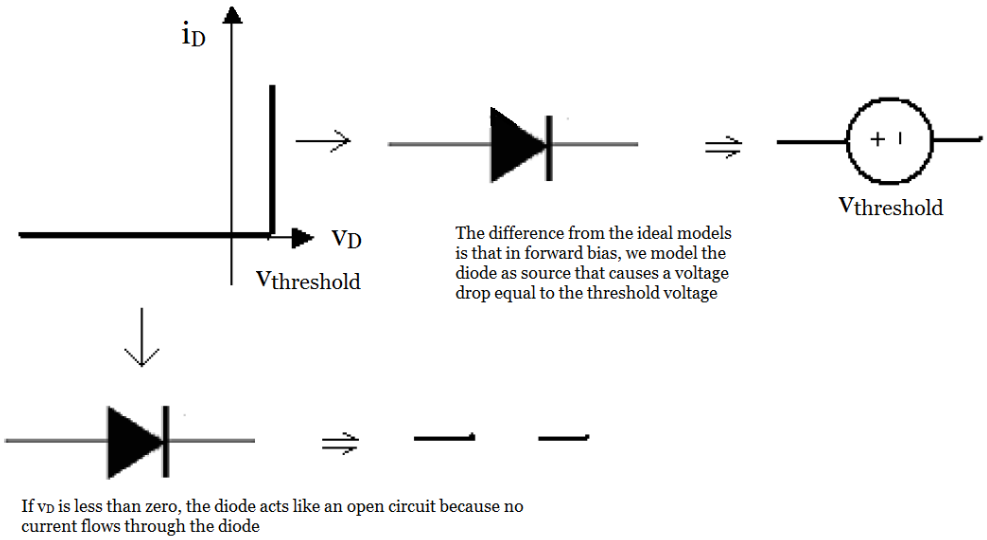


Figure 5. Ideal diode model with threshold voltage.

One more property of the diode - looking at Figures 4 and 5, if you think about the diode symbol as an arrow - you can infer that current can flow through the diode only in the direction of the arrow. Let us apply these two models and study the very practical diode circuit shown in Figure 6 - the half-wave rectifier.

Half-Wave Rectifier

The half-wave rectifier is a circuit that allows only part of an input signal to pass. The circuit is simply the combination of a single diode in series with a resistor, where the resistor is acting as a load (see Figure 6 below).

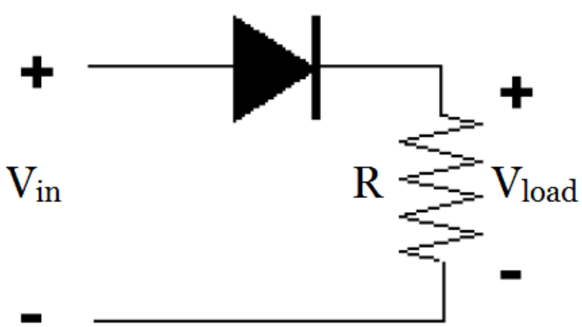


Figure 6. Half-Wave Rectifier Schematic.

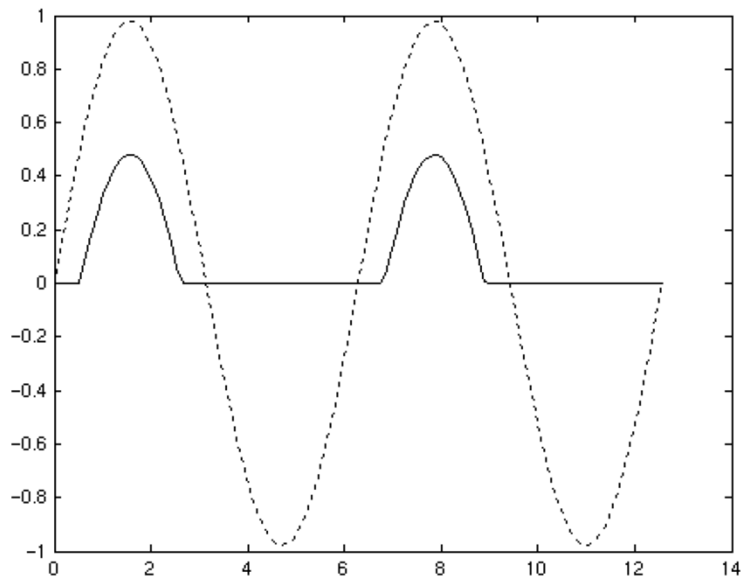


Figure 7. Half-Wave Rectifier, Voltage vs Time, V_{load} and V_{in} from Figure 4 are plotted. The dotted line is the input sinusoid (V_{in}).

The output from the half-wave rectifier is shown in Figure 7. We can see that if the V_{in} is greater than zero (corresponding to a positive half-cycle on the sinusoid), the diode is forward biased. Using the threshold voltage model from Figure 5, we can redraw the circuit in Figure 6 as:

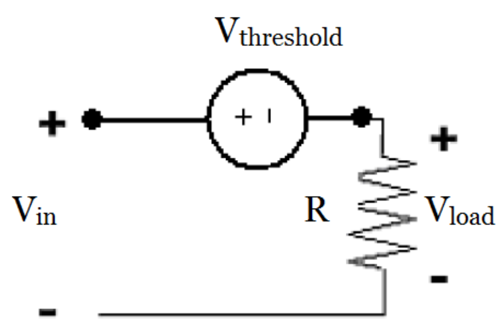


Figure 8. Half-Wave Rectifier with threshold voltage model when the diode is forward biased.

Hence, the effect of the diode is to drop a voltage of $v_{threshold}$ from the input. You can see this effect in Figure 7, the peak V_{load} voltage is less than V_{in} by $v_{threshold}$. When the diode is reverse-biased, that is when the V_{in} is the negative half-cycle of the sine wave, the diode is off and hence it is modeled as an open circuit. Thus, the current flowing through the circuit is zero and $V_{load} = 0$. This explains what happens during the negative half-cycles of the sinusoid in Figure 7.

Bridge Rectifiers

Bridge rectifier is the most common circuit, which uses diode to single connectivity, is used to convert AC to DC. The bridge rectifier is composed by four diodes. And when input is the positive half of sine wave, two diodes are breakover getting positive output voltage. When input is the negative half of sine wave, another two turn on, as the diodes are reverse, so the output is to be positive. Figure 9 is a bridge rectifier circuit.

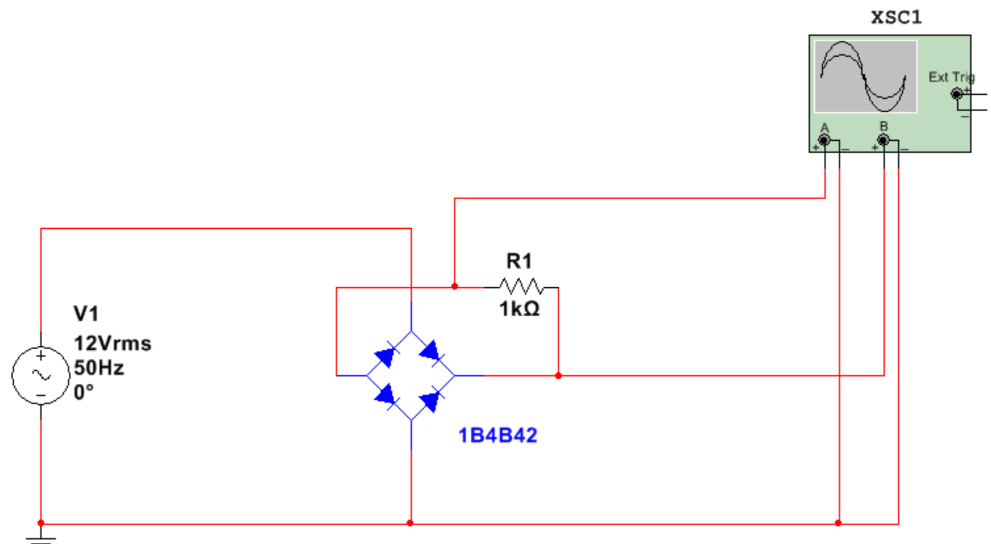


Figure 9. Bridge rectifier circuit.

AC-to-DC converter

What is the use of the rectifier above? We can use it to convert AC voltage to DC voltage. In fact, most of the power supplies that plug into your wall outlet (like computers, blenders, microwave ovens etc.) do exactly this. A simple AC-to-DC (AC-DC) converter is shown below. Of course, the converters in computers and blenders are much more complex, but the fundamental circuit is still the same:

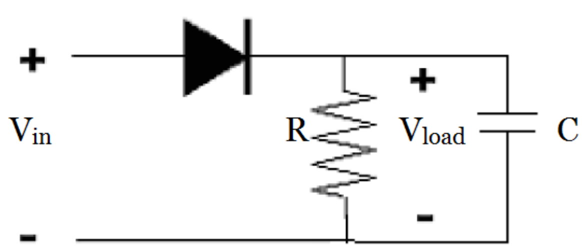


Figure 10. AC-DC converter.

When the diode is forward biased, it just drops a $V_{threshold}$ from V_{in}. Hence, the capacitor charges and V_{load} increases. When the diode is reverse biased (during the negative half cycle of the input sinusoid), the diode is open. Hence, the capacitor discharges through the resistor. The trick in the AC-DC converter is to have a very large time constant (RC value) as compared to the period of the input sinusoid. This ensures the capacitor does not lose any voltage before the next charging cycle.

Reference

[1]UC Berkeley, course EE-100, Spring 2004.
[2]UC Berkeley, course EE-40, Spring 2008.

Lab3 Prelab

Name ________________________ Student ID _________________________

1. Look at the circuit below. Suppose V_{in} is a sine wave that has amplitude voltage 1V, frequency f, and offset = 0V. Suppose the threshold voltage of the diode is $V_{threshold}$ = 500mV. Describe and draw what you will see at the output. Make sure to include the amplitude, frequency, and offset in terms of the input and V_{th}. **__/8pt**

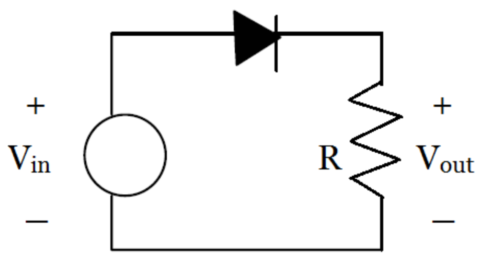


Figure 11

2. In the circuit below, assuming all diodes are ideal (threshold voltage is 700mV), find V_a and then explain why. **__/8pt**

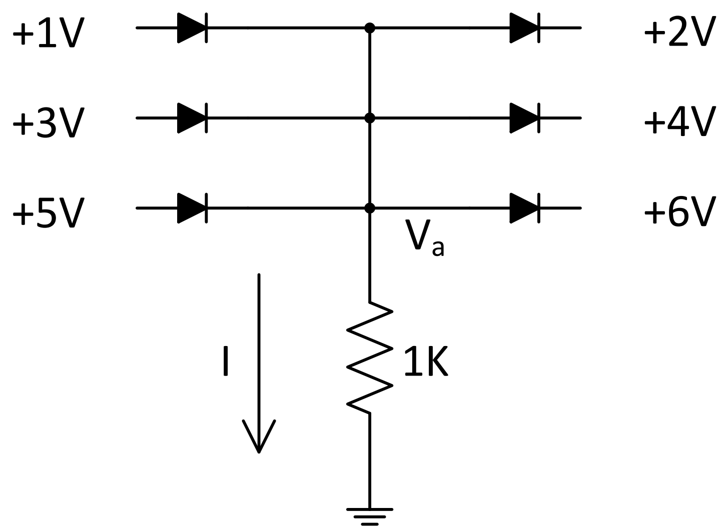


Figure 12

HINT: Each diode can be on or off. Since you are using the ideal diode model, the diode can be modeled as a short circuit if it is on and open circuit if it is off. However, there are 6 diodes and thus there are 64 possibilities.

Obviously, only one of the 64 is correct. You could try all 64, but think: what values can V_a take? Obviously, it cannot be greater than the largest voltage in the circuit and it cannot be smaller than the least value. Can you use this fact to guess which diode is on and which is off?

3. Using the non-ideal exponential diode equation from the lab guide, solve for V_a and I in the circuit above. Compare with the values from question 2. **__/8pt**

4. In boost converter circuit, an ideal switch and a non-ideal diode could be used to realize the single-pole double throw switch. The operating situations of boost converter while the switch is on and off are shown in Figure. 13 (a) and (b) respectively. Please compete your design using an ideal switch and a diode in the dotted box. **__/6pt**

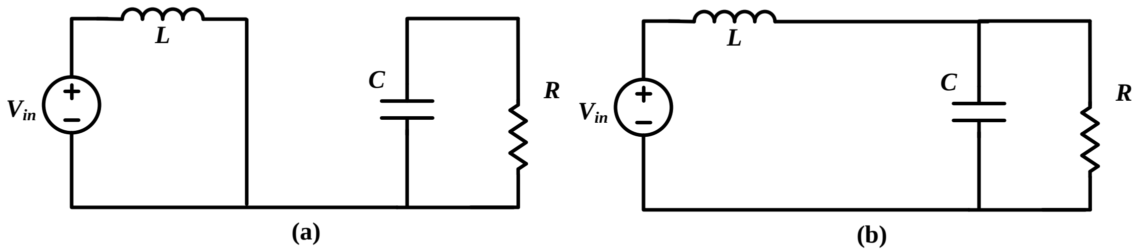
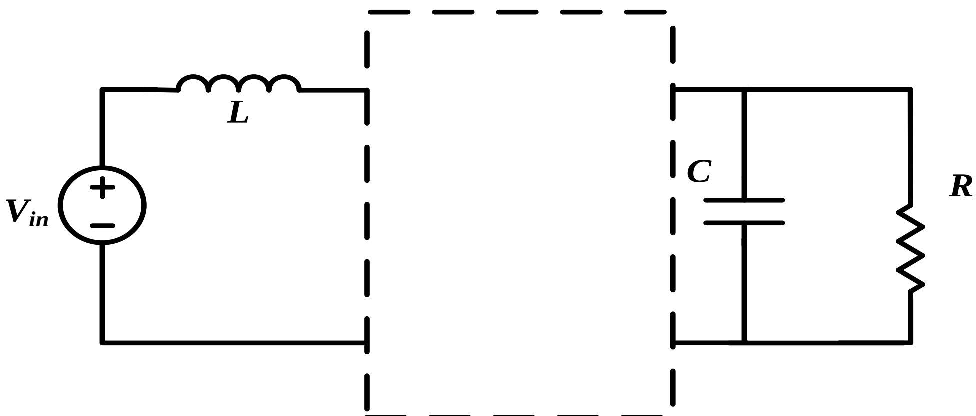


Figure 13 (a) while the switch is on (b) while the switch is off.



TA checkoff ______________________________

Question1: ____of 8 Pt.

Question2: ____of 8 Pt.

Question3: ____of 8 Pt.

Question4: ____of 6 Pt.

Lab3 Report

Name ______________________ TA Checkoff ______________________

Teammate ______________________ Score ______________________

Part One: Half-Wave Rectifier __/20pt

1. Build the half-wave rectifier circuit drawn in Figure 6. Use a 120 Hz, 2 Vpp input signal with no offset. Let R=1kΩ. Note: You must be very careful with the function generator settings. If you have the output too high with a low resistance resistor (or if you have no resistance connected), you risk burning out the diode. Show the completed circuit to your TA for check off.

Working half-wave rectifier circuit (TA checkoff) : ________________________

2.

a) Figure out how to use the multimeter to measure the threshold voltage of the diode.
b) Measure the threshold voltage of the diode from the scope by measuring the voltage difference between the peak of the input signal and the peak of the output signal.
c) Calculate the error between the multimeter value and your measured value. Explain to your TA how you are able to measure the threshold voltage of the diode from the scope.

Threshold voltage from the multimeter: _________ volts

Measured threshold voltage from the scope: _________ volts

% error: __________

Change the current through diode, does threshold voltage vary? ___________

TA checkoff: ___________

d. Rebuild the half-rectifier, but use a 10M resistor for R. Look at the output waveform on the scope. What changes can you see? Describe the difference and briefly explain why.

TA checkoff: ____________

Part Two: Bridge Rectifier __/20pt

1. Build the bridge rectifier circuit drawn in figure 9, R=300Ω, 10 Vpp input signal with no offset. Draw the input waveform and output waveform (use function **A-B** on the oscilloscope) in following box.

2. Determine the DC output voltage with the multimeter ________________
3. Comparison of bridge rectifiers and half-wave rectifiers, what's the difference of output waveform?

TA checkoff: ___________

Part Three: AC-DC converter __/20pt

1. Build the AC-DC converter shown in figure 10. Use R=510KΩ and use C=22uF. Input signal V_{pp}=5V. Calculate the time constant of the circuit. Ask your TA to check your working circuit off. The curve will turn to sawtooth wave when frequency is too small. Then, find a smallest possible frequency that doesn't make sawtooth wave ($V_{pp} \leqslant 5mV$ and one frequency will be enough).

   Time constant of the circuit: ________________seconds

   TA checkoff for working AC-DC converter : ________________

   Smallest possible frequency ________________

   Explain the sawtooth wave

TA checkoff: ___________

Part Four: Extra Credit __/10pt

Design a circuit with diodes, resistors and voltage sources to show the wave like the full line in the figure below. ($v_{threshold} \approx 0.7V$) This may be a little difficult for you, so it is ok if you can't finish it.

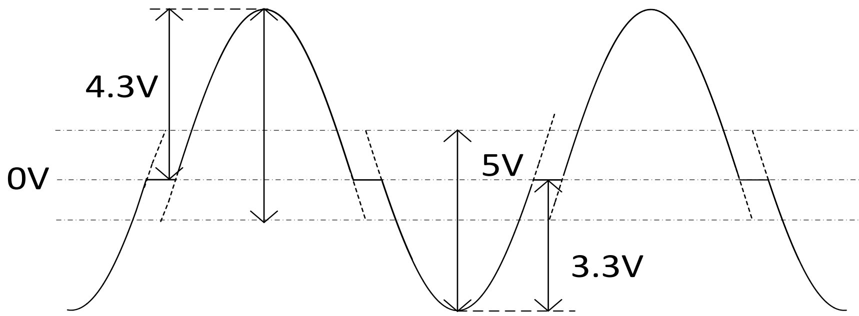


Figure 14.

Draw the schematic

Working circuit (TA checkoff) ______________________________

TA:	______________________________
Part One :	____of 20 Pt.
Part Two :	____of 20 Pt.
Part Three:	____of 20 Pt.
Part Four:	____of 10 Pt.
Prelab :	____of 30 Pt.
Total :	____of 100 Pt.