Lab 8
Diodes and Transistors

Objectives

- *concepts*

  1. nonlinearity
  2. ideal diode and transistor models
  3. forward and reverse bias

- *skills*

  1. measuring i-v curves
  2. measuring the current gain of a transistor
  3. building a transistor amplifier

Key Prerequisites

Diodes
- overview and applications: https://learn.sparkfun.com/tutorials/diodes/all
- solving current in: https://www.youtube.com/watch?v=ihVIpIqWajs
- physics of: http://www.electronics-tutorials.ws/diode/diode_1.html

Transistors
- overview and apps: http://www.electronics-tutorials.ws/transistor/tran_1.html
- comprehensive: http://www.sentex.ca/~mec1995/tutorial/xtor/xtor.html

Required Resources

- Circuit Kits, DMM
- Laptop

Diodes and transistors are the simplest semiconductor devices we can work with. They consist of 2 layers (diodes) or 3 layers (transistors) of differently doped semiconductor material (N and P). The electrical properties of these materials provide simple "soild state" (no moving parts) switching behavior, and can be used in a myriad of ways. Unlike all the other components we've worked with so far, they are also inherently *non*-linear.

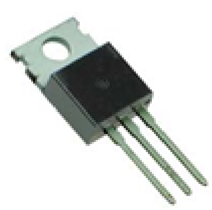
Diodes find their way into power supplies as rectifiers or simple voltage regulators. They also protect sensitive components from voltage spikes that happen when inductors are switched on or off, and can also be used to construct digital logic gates such as AND and OR gates.

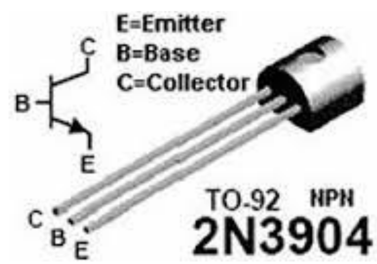
Transistors are often used as switches, since a low current flowing into the base from a microcontroller, for example, can switch on and switch off a much larger current driving, say, a motor. They are also used in sophisticated amplifier circuits such as the LM741 we worked with last week, although it is possible to construct an amplifier with just a single transistor.

In this lab you will build and analyze circuits using diodes and transistors. Two different types of diodes will be used, including a regular general purpose diode, and a red or green light-emitting diode (LED). You will also be introduced to a commonly-used NPN transistor, the 2N3904, and use it in several circuit configurations, including switching and amplifying signals.

Parts List

- LM7805 5V Reg
- 1N4007 diode
- 2N3904 Transistor
- Push-button switch





- Red or Green LED (Light Emitting Diode) (2)
- Resistors (1K, 10K, 100K, 1M)

Discussion and Procedure

Part 1. The Diode

A diode acts like a valve, allowing current to flow in one direction and blocking current in the other (to a point). The current is allowed to flow in the direction the triangle shape is pointing, and blocked in the reverse direction. A typical diode turns "on" when the voltage exceeds 0.6 or 0.7 volts, and turns off below that. The i-v curve below shows a typical curve for a diode.

You will be measuring the curve in Fig 1 below using the 1N4007 in the following steps.

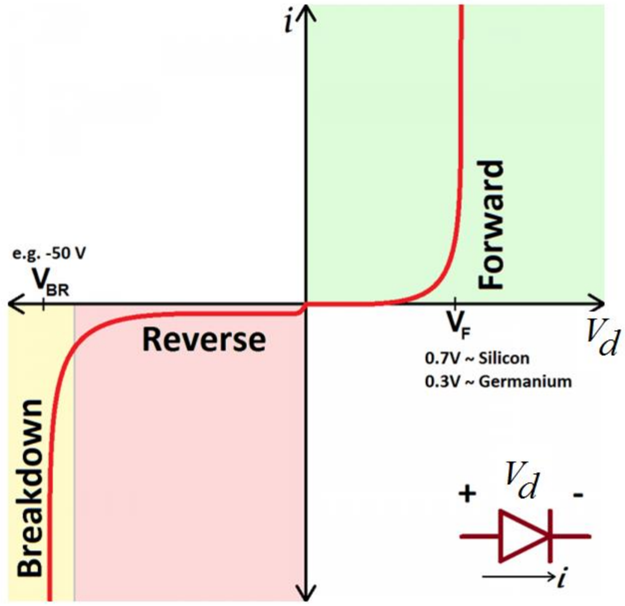


Fig 1. I-V curve for a diode

We will explore the current varying properties of the diode using the 1N4007 diode in your kit.

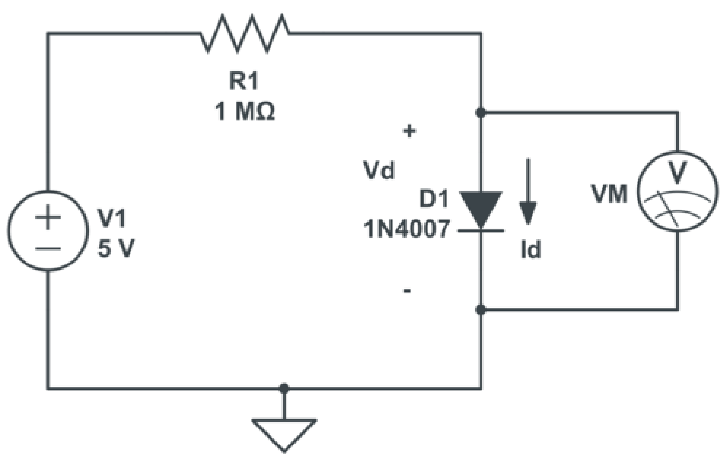


Fig 2. Diode Measurement Circuit: 5V supplied by LM7805 (see breadboard below)

> **Caution: Connecting 5V directly across a diode will destroy it!** A resistor is needed to keep the current flow within the range tolerated by the diode. Start with R = 1 MΩ
>
> In your datasheet, explain why this is so (hint: look at the i-v curve above).

1. Build the circuit above, taking note of the location of the voltmeter, and the forward biased direction of the diode. The line across the diode is the cathode or (-) end.

We will be using the LM7805 voltage regulator to provide 5V on our breadboard. This chip takes 12V and ground on the first two pins and produces 5V on the third pin. These chips have a metal heat sink which needs to be facing away from you when you place the chip in the breadboard. *Make sure to press the three prongs of the chip firmly into the breadboard sockets* – they need to go in about ¼" to engage the clips properly. Figure 3 below shows the wiring of the LM7805.

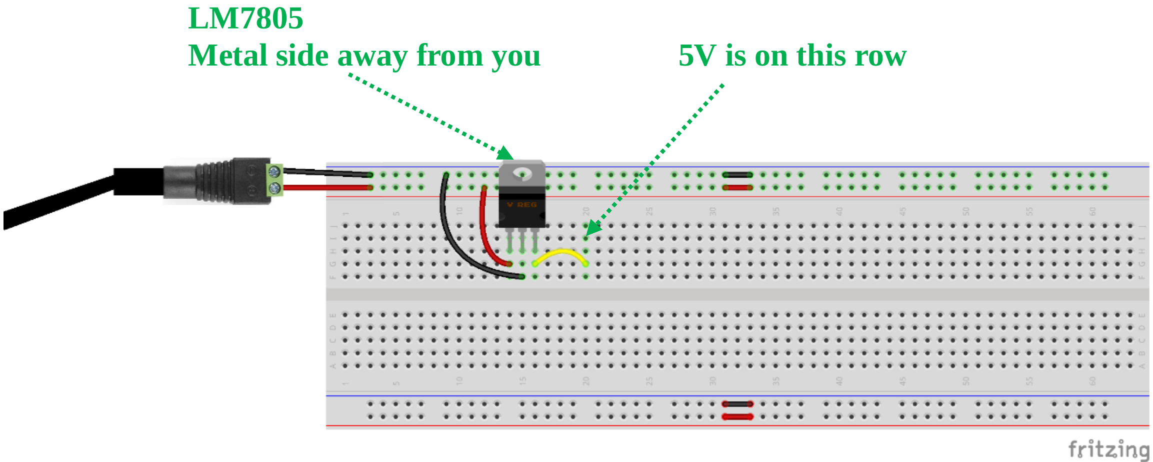


Fig 3. Wiring for the LM7805 voltage regulator to provide 5V to your diode test circuit. Build the rest of the diode test circuit in the blank area of the breadboard. If you are stuck in your wiring, you can view the completed breadboard here.

Because the diode is so sensitive to small changes in voltage near the "turn on" voltage, we will need to sample the i-v curve by using a range of resistor values to control the current. For each resistor, you will measure the voltage across the diode, and (without moving the voltmeter) *calculate* the current through the diode, using resistors with values 1 MΩ, 100 KΩ, 10 KΩ, and 1 KΩ, or as close as you can get to those.

2. In your datasheet, work out a formula to calculate the diode current given: a) the diode voltage, b) the resistor value R, and c) the 5 volt drop across the series combination. Hint: since the current going into the voltmeter is essentially zero, the current through the resistor is the same as the diode current. Using nodal analysis, if you determine the voltage coming out of the 5V regulator AND the voltage across the diode, you can calculate the voltage drop across the resistor and divide by R to find I_d.

3. Record your measurements and calculations in Table 1 in your datasheet.

4. Reverse the diode's direction in your circuit and measure the current and voltage again, using a 1k resistor. Since the diode is now reversed with respect to the voltmeter, the positive voltmeter reading should be negative when you enter it into Table 2 of the datasheet, and the calculated current should be negative as well.

However, use the positive voltmeter reading in your formula when calculating the current.

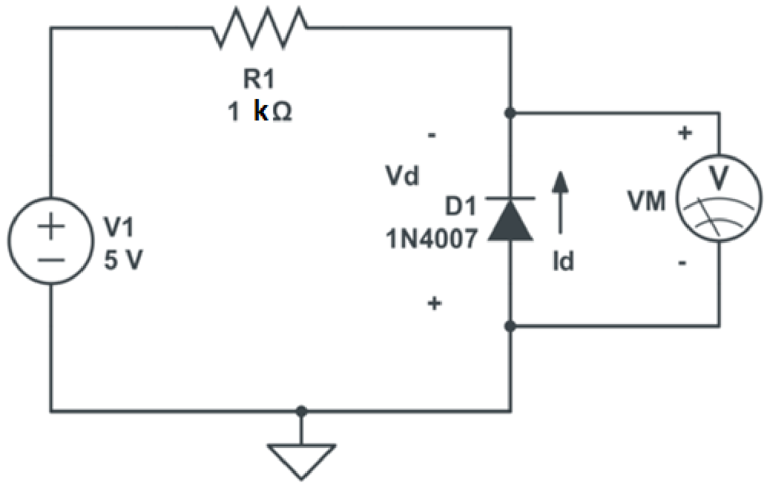


Fig 4. Reverse bias measurement of diode. Positive Voltmeter (VM) reading is used to calculate current Id as before. However, the value entered for Vd in Table 2 is negative due to reversed polarity between VM and Vd.

5. Use MATLAB or Freemat to Graph diode current vs. voltage and copy/paste your plot here. Define your vectors with the **reverse bias** (negative voltage and current) data points first, then the others in order of increasing value. Plot voltage on the x-axis, current on the y-axis, add labels and a title (using xlabel('voltage'), etc), and copy paste into your datasheet.

   The shape of your plot should look something like this (**only it should have x and y labels and a title**), which shows the characteristic exponential curve of a diode current vs voltage:

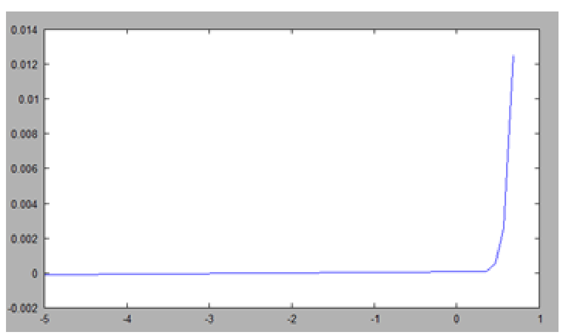


Fig 5 Approximate shape of your plot for step 6.
Please add xlabel, ylabel and title to your plot

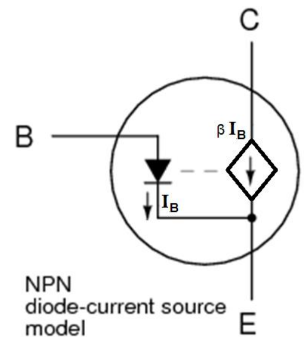
6. Repeat the entire procedure with a red Light Emitting Diode (LED) with the same resistors as with the 1N4007. **Note the flat bevel is on the side of the LED with the (-) lead, and the (+) lead is longer than the (-) lead.** Start with the LED inserted backwards (will not light up) to measure the reverse bias values first. Then reverse

the diode's direction and continue measuring forward bias values. Enter your data into Table 3 in your datasheet.

7. **Plot the new data on the same graph as the 1N4007 diode with an overlay plot,** using the command `plot(v1,i1,v2,i2)`, where `v1,i1` are the data for the 1N4007 and `v2,i2` are the data for the red LED. Add xlabels, ylabels and a title, and also add a legend to the plot with the command `legend('1N4007','Red LED');`

Part 2. The Transistor

A transistor is a 3-wire device that acts like an electronic switch. It can be modeled as a diode combined with a dependent current source.



The current flowing into the diode's "base" (B) controls the current flowing into the "collector" (C) and leaving the "emitter" (E).

Since the base is essentially a diode, current flowing into the base has to be constrained with a resistor.

Caution: the B-E junction acts like a diode, so connecting 5V directly across it will destroy it, as before with the diode.

Common-Emitter Circuit

We will now explore some simple circuits using a bipolar transistor. The pin-out for the 2N3904 NPN transistor is shown below right, with the Emitter (E), Base (B), and Collector (C) labeled from the top view.

8. Construct the common-emitter circuit shown below. Refer to the diagram at right for pin layout – the flat side of the transistor should face the bottom of page for proper alignment of pins.

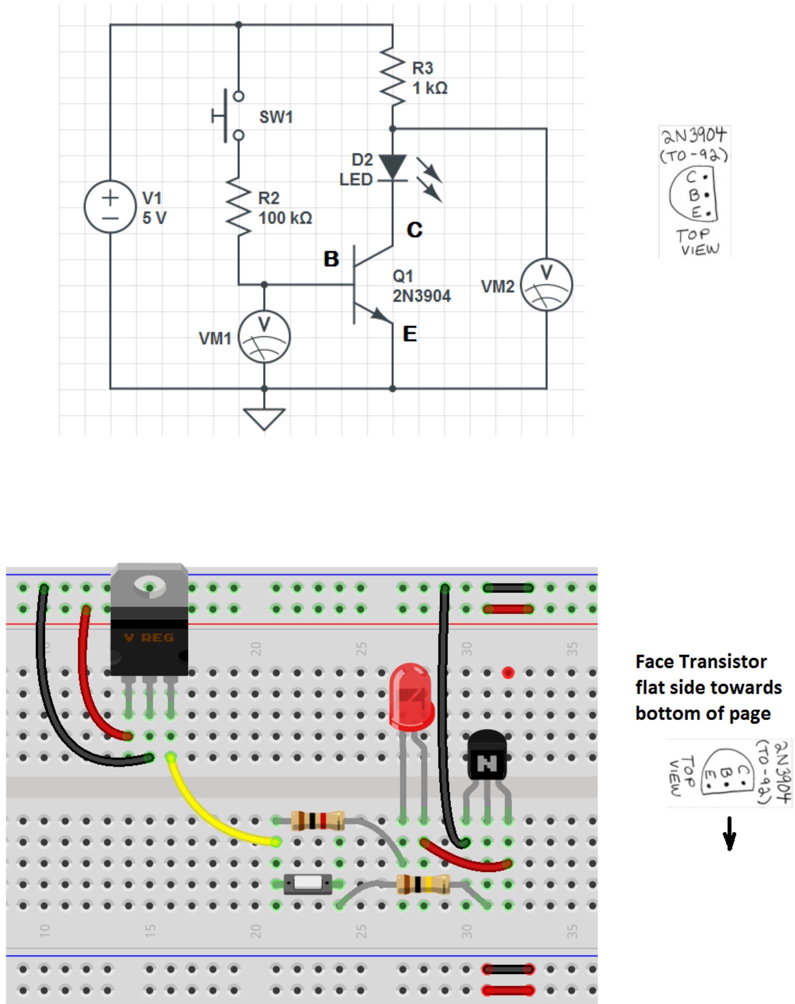


Fig 4. Common Emmiter Transistor Schematic and Wiring Diagrams
***Flat side of transistor should be facing page bottom*.**

9. Pushing the button should light the LED. When the circuit works, record the transistor base voltage (VM1) and diode anode voltage (VM2) while the LED is illuminated. From these measurements, calculate the voltage across each of the two resistors. Then calculate I_C and I_B, and determine the β (hFE or current gain) of the 2N3904 transistor, which is the ratio of I_C to I_B. Correct values of β can range from the 20's to low 100's.

10. How does this demonstrate the transistor's ability to control a relatively large current with a relatively small current? If you are stuck on this question, you might consider the "water flow" analogies of a transistor available here.

Part 3. Application

Your kit comes with two photoresistors, also known as photocells or Light Dependent Resistors (LDR). These devices, shown below in Fig 5, can be used, along with a transistor and an LED, to build a dusk-to-dawn lighting circuit, as

Fig 5. Photoresistors (Light Dependent Resistors)

shown in Fig 6. The circuit to the left of the transistor forms a voltage divider, which allows changing light levels to affect the value of Vb.

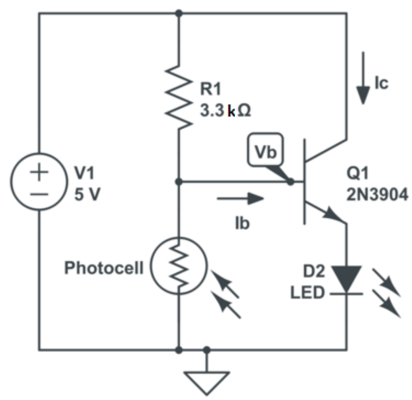


Fig 6. A Photocell controls turn-on state of LED via transistor

Before building the circuit, measure the resistance of your photoresistors using a voltmeter under bright illumination coming from a flashlight or other light source, and again under darkness by covering the surface with a finger or other opaque material and record these values in Table 5 of your datasheet.

Use the voltage divider formula (we can assume Ib = 0 so the two resistors are essentially in series) to estimate the value of Vb under darkness and bright light. Then measure these values and record all in Table 7 of your datasheet.

If the LED in your circuit never comes on, you will probably need to swap a smaller resistor, such as 1KΩ, in place of R1. If the LED never goes off, you will probably need to swap in a larger resistor for R1, such as 10 KΩ.

Take a couple photos or videos of your circuit in operation and paste into your datasheet.