Lab #0: This Little Light of Mine: Exploring semiconductor operation with an LED
ENGN/PHYS 207—Fall 2020 (September 23, 2020)

Stuff You'll Learn

The point of this exercise is to get hands-on to understand the main operational principle of diodes. We'll learn soon about the amazing pn junction and semiconductor physics inside.

1 Classic LED circuit

In circuits we always interested in the current–voltage relation. How much stuff charge flows vs. how hard we push (voltage difference from point a to b). We know from our previous studies, that for a resistor the relationship is linear: $v_R = i_R R$. For a (constant) capacitor we know we can write $i_C(t) = C dV_C/dt$. How about for a diode? Let's find out—empirically!

Figure 1 is a beautiful little circuit. Elegant in its simplicity, exploring this humble little circuit can give us profound insights into the physics governing semiconductor devices.

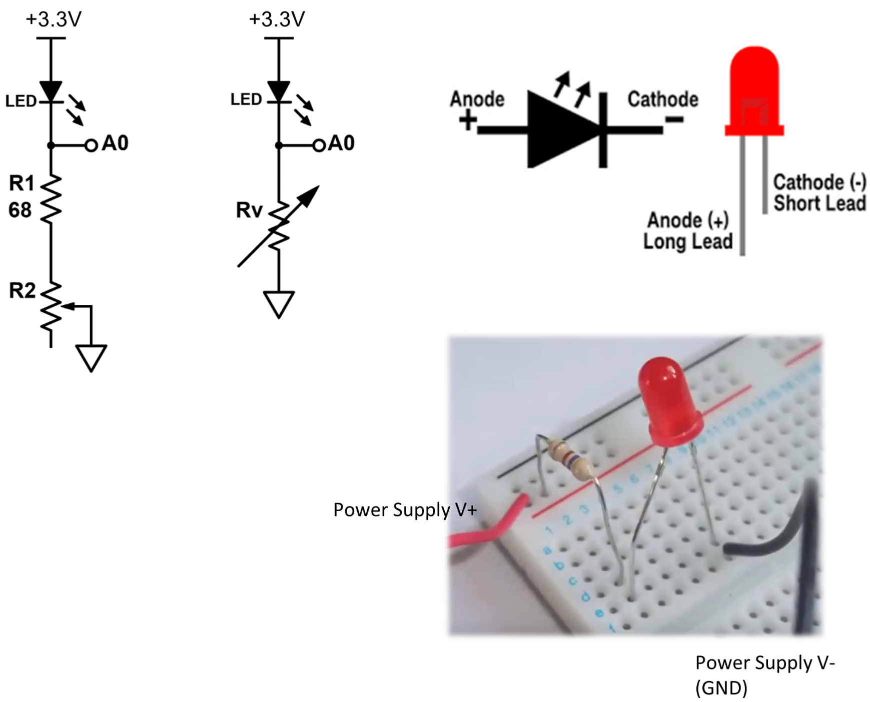

Figure 1: Basic LED circuit. Left: LED circuit with circuit limiting resistor. The small (68Ω) resistor is in parallel with a potentiometer. Middle: Same circuit as on left, but with series combination of $R1$ and $R2$ indicated as a single variable resistance. Right: Polarity of LED: cartoon illustrates Anode/cathode and long/short leg relation of typical LEDs. Image credit: `make-it.ca`. Bottom right: Actual LED + current limiting resistor circuit on a breadboard

1.1 Build and Measure: The I-V characteristic curve

1. Build the circuit shown in Figure 1.
   - Start with a ***red*** LED. The instructor will provide one to you–please do NOT use the the clear-cased red LED in your circuits kit. Carefully note the polarity.
   - For $R1$ use a small valued resistor: 68 Ω is suggested, but anything in the range of 50-100 Ω will work too.
   - For $R2$, use a potentiometer in the kΩ range. A 10 kΩ pot will do, but it may be a bit touchy as you make relatively small changes in resistance moving from about 0 to ≈, 1 kΩ worth of series resistance. Grab a 5k or 2k pot from the lab, if it makes life easier.
   - Analog input: The voltage across the series resistance will be measured by the Feather board at analog input A0. You already know how to read analog input and convert to voltage and print it out to the serial monitor. In case you need a refresher, just look back at your old code!
   - Power supply. Use your feather board's +3.3V and GND, per usual.
2. Get a quick feel for how the circuit works by varying the pot's resistance. How does the brightness of the LED vary as the resistance varies? Stop and think: Why should this be so?
3. Now time to get quantitative and make careful measurements. The table below will help organize your thoughts/measurements:

V_{Rv} (V)	V_{LED} (V)	Pot resistance Ω	Series resistance Ω	I_{LED} (mA)

Table 1: Data table to help derive current-voltage relation for LED

   (a) Start with your LED fairly brightly illuminated. Turn the pot to a value so that this is actually the case. You will progressively increase the pot's resistance until the LED is fully off (beyond the faintest visual perceptible hint it is on), taking measurement of voltage and resistance—hence current—along the way.

   (b) Specifically: for each pot position, be sure to record the following:
   - Voltage across measured across the series resistance (across $R_v = R1 + R_{pot}$.)
   - Compute voltage across the LED: (Hint 1: use KVL. Hint 2: you can ask your feather board to do the math for you and print out the result!)
   - Pot resistance value—remember to remove it from your board before making the measurement with a Fluke multi-meter
   - Series resistance $R_v = R1 + R_{pot}$.
   - Current through LED. Hint: apply KCL....and you know Ohm's law for the series resistance
   - Plot as you go the ***characteristic curve*** showing I_{LED} (mA) vs. V_{LED} (V). That is, current goes on the vertical axis, voltage on the horizontal. Post your data file with plot to circuits class box folder:
   `https://wlu.box.com/s/eqhjd8oi474uap0h7wn4jrk13kobxyyr`

(c) What was the diode voltage when the current really started to shoot up? This is typically referred to as the ***turn-on voltage***.

(d) Now reverse the polarity of your diode, try turning the pot knob. Do you ever see the light go on? Hint: hopefully not! This should convince you that essentially no current flows when the diode is in "***reverse bias***". That is, the major lesson is that, for normal diode operation, ***current can only flow in one direction***! Stop and think: is a resistor polarized in the same way?

2 Different strokes for different folks: Diode turn-on voltage

Now let's look at different diodes and how their turn-on voltage differs. We'll do a quick experiment here. Later, we'll discuss the theory of why red, green, blue, silicon, germanium diodes all have different turn-on voltages. Hint: depends on what they are made of.

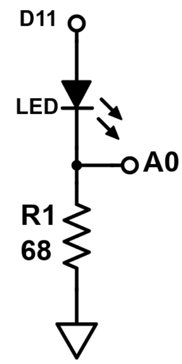

Figure 2: Toggling an LED on/off with a digital output.

1. Build the LED + current limiting resistor circuit shown in Figure 2. Note: you can just modify your previous circuit. For now, start with the red LED you already had.

   (a) Note that you are now toggling the power to the circuit using one of the Feather's digital outputs (D11 suggested here, or choose any one you like).

   (b) The resistor should be in the range of 50-330 Ω, the exact value isn't critical so long as it is in this range.

   (c) You are still measuring resistor using analog input A0. Be sure to make that connection.

   (d) Program your feather to toggle the digital output approximately every 1 s. Need help? Load the classic "blink" sketch (File...Examples...Basic...Blink). Program it to print out the voltage across the resistor and across the diode. Record the value of V_{LED} when the diode is on. Write this number down and keep track of what LED it pertains to. If you want to get extra fancy, you can plot V_{LED} vs. time, just like you plotted the temperature vs. time in the Wheatstone bridge lab.

   (e) Then swap out the red LED for a blue one. Again, write down $VLED$ for when the diode is on. Repeat using other colors of LEDs: green, orange, anything you can find.

(f) Do the same, but now use a standard silicon diode (1N914) that is part of your circuit pack. need help orienting it properly? Check out the data sheet here `https://www.vishay.com/docs/85622/1n914.pdf` or see below Figure 3. Note the black band matches the cathode.

(g) Lastly, make a table of diode type vs. turn on voltages. Are they the same? Different? Why might this be?

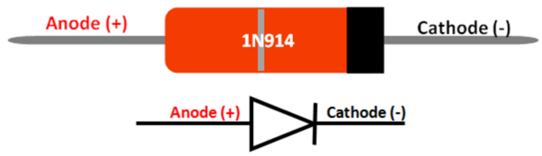

Figure 3: 1N914 polarity and orientation. Image credit: `https://components101.com/diodes/1n914-datasheet-pinout-equivalent`