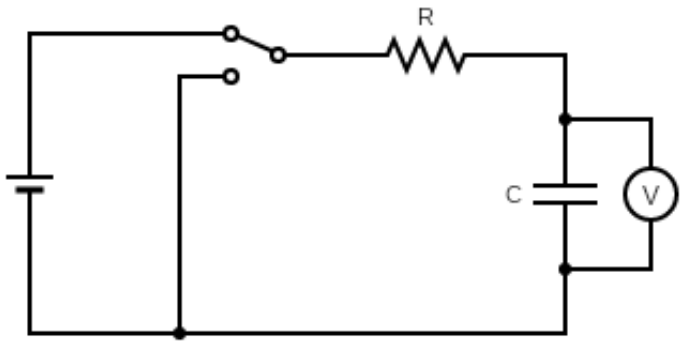
Lab 4: RC Circuits

The charge *q* on a capacitor's plate is proportional to the potential difference *V* across the capacitor. We express this relationship with:

$$V = \frac{q}{C}$$

where *C* is a proportionality constant known as the *capacitance*. *C* is measured in the unit of the farad, F, (1 farad = 1 coulomb/volt).

If a capacitor of capacitance *C* (in farads), initially charged to a potential V_0 (volts) is connected across a resistor *R* (in ohms), a time-dependent current will flow according to Ohm's law. This situation is shown by the RC (resistor-capacitor) circuit below when the switch is closed.



As the current flows, the charge *q* is depleted, reducing the potential across the capacitor, which in turn reduces the current. This process creates an exponentially decreasing current, modeled by

$$V(t) = V_0 e^{-\frac{t}{RC}}$$

The product RC, known as the time constant of the circuit, determines the rate of the decrease. A large time constant means that the capacitor will discharge slowly.

When the capacitor is charged, the potential across it approaches the final value exponentially, modeled by

$$V(t) = V_0(1 - e^{-\frac{t}{RC}})$$

The same time constant *RC* describes the rate of charging as well as the rate of discharging.

PROCEDURE

1. Using your multimeter, verify the function of the "dual throw" switch you're using for this experiment. Which legs are connected when the switch is in each position. Draw a schematic sketch of the switch's functionality in your lab notebook.

   After verifying the function of the switch, connect the circuit as shown in Figure 1 above with a ~10 μF capacitor and a ~100 kΩ resistor. Record the values of your resistor and capacitor in your data table, as well as any tolerance values marked on them.

2. Connect the Voltage Probe to Channel 1 of the computer interface, as well as across the capacitor.

3. Open the file in the "24 Capacitors" file in the *Physics with Vernier* folder.

4. Charge the capacitor until the potential is roughly constant.

5. Click to begin data collection. As soon as graphing starts, throw the switch to its other position to discharge the capacitor. Your data should show a constant value initially, then decreasing function.

6. Select the range of your data that corresponds to the discharge of the capacitor and fit your data with the Natural Exponent function, A*exp(–Ct) + B. Note: You will need to allow for a "time offset" in the fit. This allows for the zero-point of the fit to be something different than the t=0 point on the x-axis.

7. Record the value of the fit parameters in your data table. Notice that the C used in the curve fit is not the same as the C used to stand for capacitance. Compare the fit equation to the mathematical model for a capacitor discharge proposed in the introduction,

$$V(t) = V_0 e^{-\frac{t}{RC}}$$

How is fit constant C related to the time constant of the circuit, which was defined in the introduction?

8. Print the graph of potential *vs*. time. **Choose Store Latest Run from the Experiment menu to store your data. You will need these data for later analysis.**

9. The capacitor is now discharged. To monitor the charging process, click Collect. As soon as data collection begins, throw the switch the other way. Allow the data collection to run to completion.

10. This time you will compare your data to the mathematical model for a capacitor charging,

$$V(t) = V_0(1 - e^{-\frac{t}{RC}})$$

Select the range of data that corresponds to the charging of the capacitor and fit your data with the Inverse Exponent function, A*(1 – exp(–Ct)) + B. Again, you will need to allow for a "time offset" in the fit.

11. Record the value of the fit parameters in your data table. Compare the fit equation to the mathematical model for a charging capacitor.

12. Hide your first runs by choosing Hide Data Set from the Data menu. Remove any remaining fit information by clicking the upper left corner in the floating boxes.

13. Now repeat the experiment with a resistor of lower value. How do you think this change will affect the way the capacitor discharges? Rebuild your circuit using the 47 kΩ resistor and repeat Steps 4–11.

DATA TABLE

	Fit parameters				Resistor	Capacitor	Time constant
Trial	A	B	C	1/C	R (Ω)	C (F)	RC (s)
Discharge 1							
Charge 1							
Discharge 2							
Charge 2							

ANALYSIS

1. In the data table, calculate the time constant of the circuit used; that is, the product of resistance in ohms and capacitance in farads. (Note that 1 Ω F = 1s)

2. Calculate and enter in the data table the inverse of the fit constant *C* for each trial. Now compare each of these values to the time constant of your circuit. How is the fit parameter A related to your experiment?

3. Resistors and capacitors are not marked with their exact values, but only approximate values with a tolerance. Determine the tolerance of the resistors and capacitors you are using. If there is a discrepancy between the two quantities compared in Question 2, can the tolerance values explain the difference?

4. How does the discharge rate of the capacitor change when you lower the resistance in the circuit?

5. How would the graphs of your discharge graph look if you plotted the natural logarithm of the potential across the capacitor *vs*. time? Sketch a prediction. Show Run 1 (the first discharge of the capacitor) and hide the remaining runs. Click on the *y*-axis label and select ln(*V*). Click OK to see the new plot.

Lab 5: Light Emitting Diodes[1]

Introduction

The light-emitting diode commonly referred to as LED is a special type of diode with characteristics similar to that of a normal diode. The LED is a device that converts electrical energy into light energy. The LED is a current-driven semiconductor device and when forward-biased emits light of narrow bandwidth depending on the construction of the LED. The emitted light may either be in the visible or non-visible spectrum. LEDs can be categorized as the most widely used semiconductor devices and are mostly used in televisions, colored displays and in road lights, etc. LEDs are replacing conventional light bulbs because of their efficiency and construction size. The conventional light sources dissipate heat and losses much of the energy whilst LEDs do not heat up producing minimum voltage drop across them. Being an electrostatic device, the LED can be constructed into very small sizes and shapes depending on the application requirements.

LEDs with monochromatic light have two legs – an anode (+) and cathode (-). There are different ways to represent the anodes and cathodes of LEDs, but one of the common ways (which are true for the LEDs we are using for this lab) is that the cathode of an LED can be identified by a shorter lead.

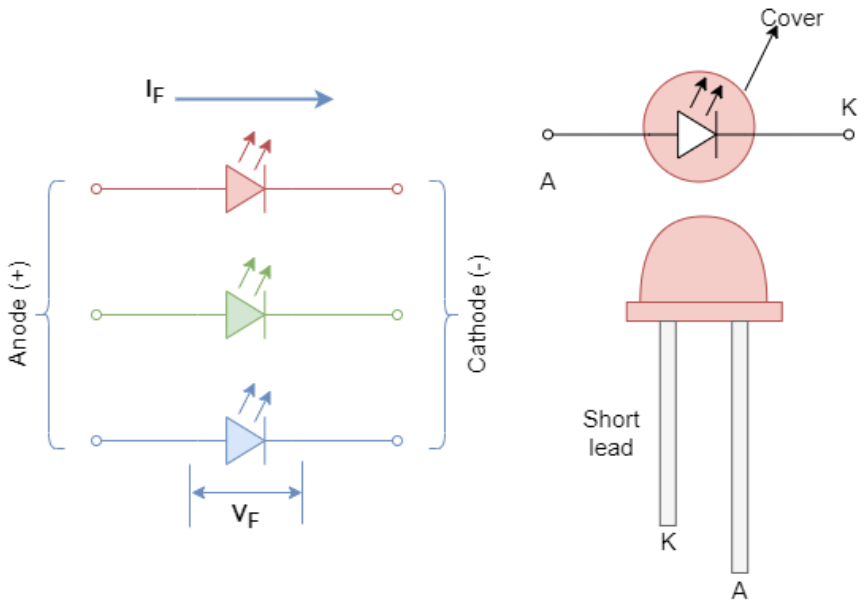


Figure 1: The LED symbol and typical shape

The most common and cheaply available colors are Red, Green, and Blue which are the primary colors easily produced by semiconductor compounds. Other colors are expensive and are produced by mixing the primary colors.

[1] Parts of this lab have been adapted from https://www.electronics-lab.com/article/light-emitting-diode/

Voltage Drop and Series Resistance

Similar to conventional diode, the LED is current driven and a certain voltage drop occurs when put in forward-biased mode. The forward voltage drop (V_F) usually ranges from 1.2V to 4.0V and is dependent on the type of compound material used in the LED (lab foreshadowing: be very skeptical of any voltage drop you read that's not in this range). The LED emits a light when a voltage greater than the forward voltage drop is applied and the current flows through it. Excessive current flow can damage the sensitive PN junction of LED and as such requires that a proper resistor be inserted in series between the LED and voltage source. The value of series resistance should be such that it does not permit more than 80% of the rated current of the LED and should permit a sufficient amount of current to significantly brighten the LED.

A Single LED Example

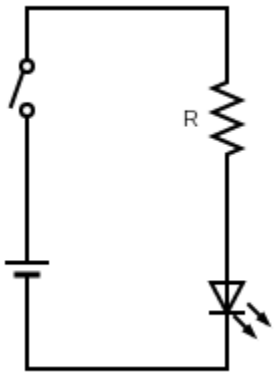


Figure 2: Single LED in series with the resistor and switch

The circuit above has an LED wired in series with a resistor. You will be building this circuit, but first, you must calculate the value of the resistor to put in this circuit. In order to do this, you must know the forward voltage drop (V_F) and forward current (I_F) of the LED in addition to the supply voltage (V_S) of your power supply. **We will use a power supply voltage of 5V for this part of the lab.**

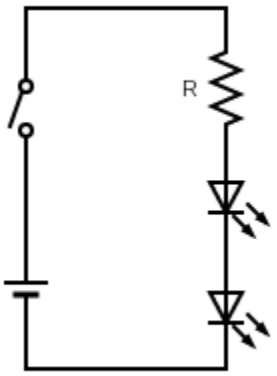
1. Pick an LED from the box of LEDs. Note (and write down in your lab notebook), the forward current (I_F) and forward voltage drop (V_F) for the specific LED you choose.
2. We will be using V_S=5V for this experiment. Given that, calculate the value of resistance for the current-limiting resistor R that you need for this experiment. To do this:
    a. Given the value of V_F for the LED you chose, what will be the voltage drop across the current limiting resistor?
    b. Given that voltage drop and Ohm's law, what resistance should your resistor have?
    c. Why is it important that the resistor is *in series* rather than *in parallel* with the LED?
3. Get a resistor that has a resistance close to the resistance you calculated. You will likely be unable to find a resistor that has the exact resistance you calculated in Step 3. You can either:
    a. Combine resistors in series or parallel to get a resistor of equivalent resistance OR
    b. Just choose a resistor close (but a little higher) than your calculated resistance. Your LED won't be quite at its maximum brightness, but you also won't fry your LED.

4. Build the circuit above with your chosen LED and resistor. Take particular care to ensure that you are wiring the circuit *in series* and that your LED is oriented correctly. Push the switch and verify that the LED lights up.
5. With the switch depressed, use your multimeter to verify the voltage drop across the LED.
6. What do you think will happen if you decrease the supply voltage? Try it and record the results.
7. What do you think will happen if you reverse the direction of the LED? Try it and record the results.
8. What do you think will happen if you replace the resistor with one of larger resistance? Try it and record the results.

Multiple LEDs

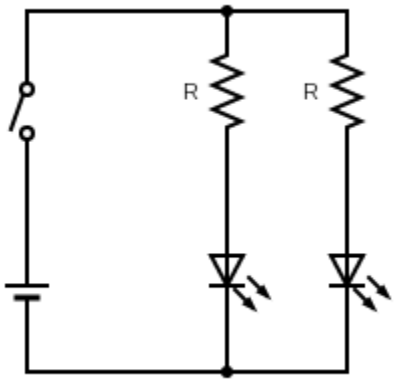
Multiple LEDs can be connected in series and the current will be the same for the LEDs in series (as it always is for circuit elements in series). However, you do have to consider the voltage drop (V_F) across *each* of the two LEDs. For example, if you have two LEDs, each with a voltage drop of 1.8V, the total voltage drop of the LEDs combined will be 2 x 1.8 = 3.6V.

Add a second LED to the circuit you built initially:



1. Given the voltage drop across the two LEDs you are using (i.e. check the specs), you will likely need to adjust the power supply appropriately so that it can supply sufficient voltage across the two LEDs.
2. As you did for the single LED, calculate the voltage drop across the current limiting resistor and, using Ohm's law, calculate the resistance you need for the current limiting resistor in this circuit. Show your work in your lab notebook.
3. Replace the resistor with a new appropriately-sized one and push the switch.
4. How does the brightness of the two LEDs compare to one another?
5. With the switch depressed, use your multimeter to verify the voltage drop across each of the two LEDs.

Revise the circuit so that you have the two LEDs in *parallel* rather than in series:



The current in each branch will be determined by the resistors and LEDs used – if you use the same resistors and LEDs in each branch, the current will be the same (although the supply current will have to double).

1. Calculate the voltage needed and resistors needed to adequately power the circuit above.
    a. What will be the voltage drop across each of the two legs of the circuit?
    b. For each leg of the circuit:
        i. What will be the voltage drop across the LED?
        ii. Given that, what will be the voltage drop across the resistor?
        iii. Given that (and Ohm's law), what should be the size of the current-limiting resistor?
2. Wire the circuit and test it by pushing the button.
3. With the switch depressed, use your multimeter to verify the voltage drop across each of the two LEDs.
4. Next, wire the circuit so that each LED is controlled by its own switch. Draw the circuit diagram in your lab notebook. Will you need to change the resistors or LEDs here? Why or why not? ***Think carefully because this is a case where you could fry an LED*** 🙂 **.** Once you have it wired, what happens when you push both buttons at the same time? One at a time? Do you notice any differences in the LEDs in these situations?

Multi-colored LEDs

The single-color LEDs are most commonly used for indications purposes or in seven-segment displays (see the next section). They are low cost due to simple construction and are available in different sizes & shapes. Besides single-color LEDs, the bi-color and tri-color LEDs are also most commonly used to display different states such as power or battery level, etc. A multi-colored LED comprises different color LEDs which are connected in parallel to each other. The color emitted by the compound LED is dependent on the driving current of the individual LEDs.

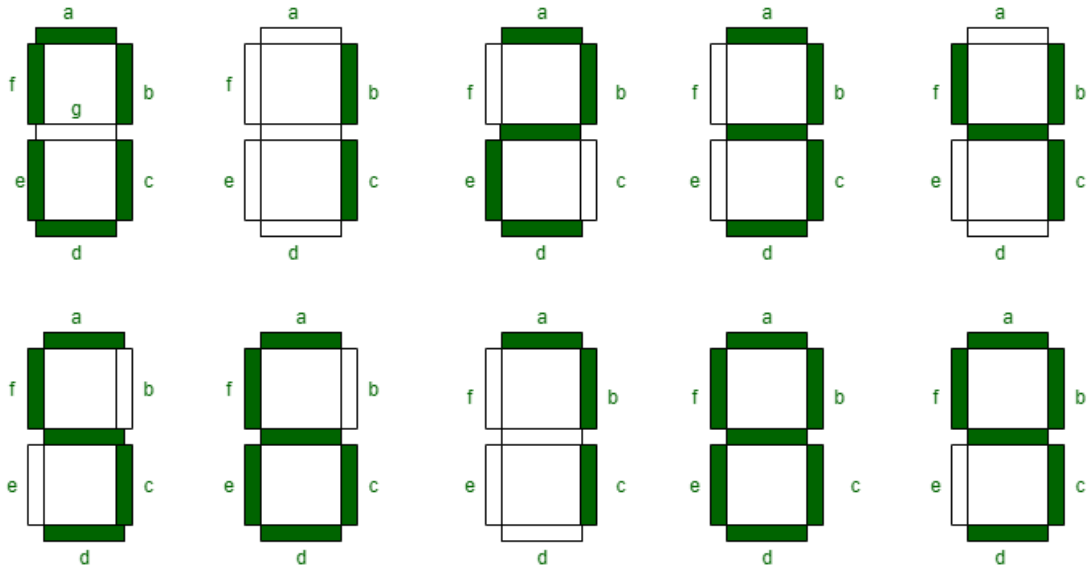
1. Retrieve a 3-color LED from the back table. Note the information on the bag as it will be important for building a circuit. In particular:

a. make sure to record the voltage drop across the LED (V_F), the maximum current for each of the three colors of the LEDs (*Hint:* these are not necessarily the same for all three LEDs).
b. To save space, multi-color LEDs usually share either an anode or cathode wire. Both types of LEDs exist, so you cannot assume that all LEDs are the same. Note whether these LEDs are “common anode” or “common cathode” LEDs from the information on the bag.

2. Design a circuit where you can individually switch on all three of these LEDs independently – you should be able to turn on the R, G, and B lights individually or all together. Sketch this circuit in your lab notebook. Note that you will need to calculate the resistance of each of the three current-limiting resistors. I recommend using a voltage of ~5V as your supply voltage, but you can use whatever you like as long as you adjust your resistors appropriately.
3. By playing with the size of the current-limiting resistors, you can make custom colors for your RGB LED. Based on what you observe with the color of your resistor from the first part, adjust the color curve – make the light “warmer” or “cooler” or just change the color. Describe what you changed in your lab notebook and record the results.

Seven-Segment Displays

Seven-segment displays are a common way to display a number in a digital display. However, at their heart, they are 7 linear LEDs arranged in such a way that they can represent the digit. They are called seven segment displays because there are seven LEDs packaged together (labeled a-g in the below diagram):

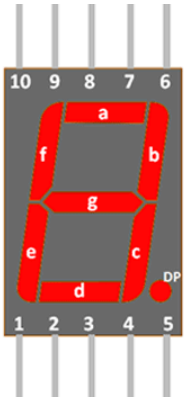


More complicated electronic components such as this have “data sheets.” There are copies of the data sheet for these seven segment displays provided to you next to the displays themselves.

- Using Google, see if you can find where I located these data sheets – *Hint*: try googling the part number stamped on the side of the displays.

Given the serial number on the side of the specific ones we're using, read the relevant information (and record in your lab notebooks) from the data sheet. This should include:

- The maximum allowed current for each of the LEDs in the display.
- The forward voltage **(WARNING: I am very suspicious of the quoted forward voltage on this data sheet. For safety, I recommend starting with a much lower forward voltage – something on the order of 2V). If you feel adventurous, you can increase the forward voltage up to what it says on the data sheet, but don't do it until after you've done the rest of this lab, because I have some concern that you might fry part of the seven segment display).**
- Note whether this is a seven segment display with a "common anode" or "common cathode."
- Note the "pin out" for each of the LEDs in the seven segment display. Note that, in addition to each of the seven segments, these displays also have an eighth LED for the decimal point in addition to two "common" pins that serve to complete the circuit (whether they are anodes or cathodes depends on the design of the LED package). The numbering scheme for the pins follows the common convention of starting from the bottom left (when viewed from the front of the display) and proceeding counterclockwise:



On your breadboard, wire your seven segment display so that the bottom LED (labelled "d" on the above diagram) lights up. Because of the physical size of the seven-segment display, you can likely only wire half of it up at once. If you want to power the whole seven segment display, use a second breadboard to make the other half of the connections. Remember all of the things you have to do before you power on:

1. Is the package common anode or common cathode?
2. What does the resistance of each of the current-limiting resistors need to be?
3. What should the supply voltage be?

Power on and check. Make sure to record a circuit diagram of your working circuit along with any calculations used in your lab notebook.