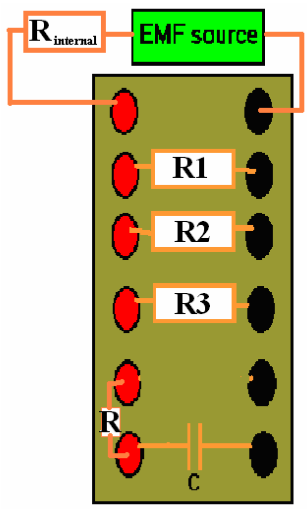
Measurement of the EMF from a source,
Parallel and Series Capacitances.
And the RC time constant of a series RC circuit.
Revised 2013



In this lab, you will explore aspects of the EMF from a battery and you will also investigate the time dependence of the series RC circuit and also parallel and series capacitances.

Part 1: Measurement of the internal resistance of a battery.
The first part of this lab is intended to help you gain an understanding of the difference between an emf and an potential source. For this experiment, I have provided you with the circuit shown below. The emf source here is a battery which has some internal resistance, which I have added to the normal resistance from a battery. The idea is this: when you place your voltmeter across the open leads of a source of emf, if the voltmeter is ideal, you will not have a current through your circuit. In this configuration, you will measure the emf of your battery, but not the internal resistance that goes along with your battery. Of course, there may be some transient behavior that occurs so the voltmeter reading may slowly build up to a final steady reading for the emf.

You will want to measure and record the values of R1, R2, R3, R and C for future reference at the beginning. You may do this with the voltmeter directly here. (note the placement of R varies slightly from the picture above). Nominally, the values for the resistors are about 10, 100, 1K and 1Meg although variations may occur. Also the capacitor is about 470 μf although significant variations may be seen. You ought to measure and record these values for future reference at the beginning of lab.

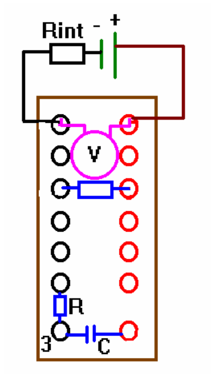


Figure 2

Now, connect your circuit as shown to the left. This configuration allows you to measure the emf (or open-circuit voltage) from your battery. Make this measurement now and record it. It won't be too surprising that the result is around 7 volts (or less, as the batteries age). This is, then, the emf from your source.

All batteries have some internal resistance. In addition, I have placed an external resistance on the battery to add to this internal resistance. Let's see how to measure this and what effect it is going to have on your circuit.
The first connection is shown in figure 2. It consists of the voltmeter measuring directly the emf across the battery. Record this emf below.

EMF from the battery: _____________ volts
While you are at it, you may want to measure the capacitance which is going to be 470μf (you have the option to make this measurement or accept this value).

Capacitance value: ____________ μf
Now we are going to measure the internal resistance. This will be done by measurements of potential drops across the battery when various known resistances are placed in the circuit.

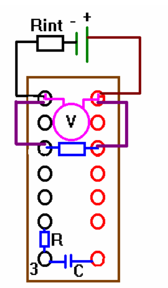


Figure 3

Make the additional connection shown in Figure 3 and observe what happens to the reading on the voltmeter when the final connection is made.
Answer: *the voltage will drop. Why?*

The internal resistance emf and terminal voltage (the terminal voltage is the voltage measured across the terminals of the battery) are related by:

$$V = \mathcal{E} - IR_i$$

When I is zero, you measure directly the emf of the battery. However, you will experience a potential drop due to the internal resistance of the battery once a current is established. Just how this allows a measurement of the internal resistance is worth looking at. You have the emf from your “open circuit” voltage measurement. Now if you make connections that include the ammeter as shown in Figure 4, you will additionally be making a measurement of I. Assuming the emf does not change, you can then solve for the internal resistance:

$$R_{int} = \frac{V - emf}{I}$$

I do advise connecting the voltmeter directly across the resistor as I have shown here.

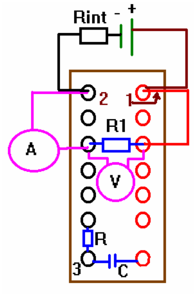


Figure 4

	Voltage [V]	Current [A]	Resistance [Ohms]
1			
2			
3			
4			

Now that we have two very high impedance instruments we are able to make internal resistance measurements directly. The purpose of R1, R2, R3 and R4 will be simply to vary the current output from the battery. Make your 4 measurements of V and I for each resistor and record the values in the table below. You will want to measure resistance values (particularly for R). This is easily done at the end of your experiment by removing all wire connections, placing the voltmeter across the particular resistor and recording the value. You will need to switch the voltmeter to the "ohms" setting for it to read the resistance. Plot your values in the spreadsheet helper and provide a copy of the helper in your report today.

You'll want to look at the analysis in the spreadsheet which is included as a spreadsheet. By finding the intercept of your dependence of the internal resistance upon I, you have the internal resistance at I=0 which you can compare to the value of the resistance which is attached to your battery. I am presently not aware of any theory that explains for a given battery the logarithmic dependence upon the current that the internal resistance seems to have: you can regard this as one of those experimental niceties. It might be something that you might want to look more deeply into sometime. It is obtainable in this lab because of the high quality meters that we now have.

To conclude what you have done for the first part of this experiment, you have measured the emf, you measured the terminal voltage and you measured the current for 4 resistors. The internal resistance is related to the terminal voltage by:

$$V = \mathcal{E} - IR_i \Rightarrow R_i = \frac{\mathcal{E} - V}{I}.$$

This permits us to solve for the internal resistance which is done on the spreadsheet.

Part II: The series RC Circuit

Connections for discharge/charge measurements from the RC circuit

(1) You will want to begin by connecting the mx55 which is configured as a voltmeter across the capacitor.

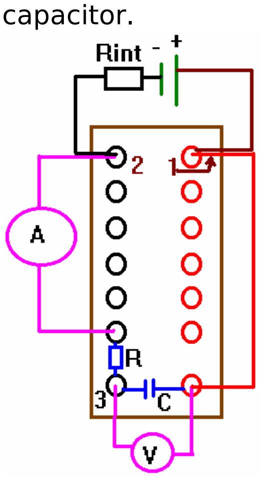


Figure5

(2) Then connect the mx55 which is configured as an ammeter between the unconnected side of the resistor and the black terminal (or green terminal) connected to the battery.

(3) Then connect the red terminal connected to the capacitor to the red terminal across from the black terminal of the battery.

You will need to make sure other connections exist (i.e. from the battery, etc). Never-the-less, when I set up this circuit I usually follow exactly this thought process.

This shows the circuit connection when charging. To make the fully charged circuit discharge, connect the lead marked "1" to the hole marked "2". I have attached an additional black lead to the hole marked "3" so that you are able to fully charge or discharge the capacitor rapidly. You will probably want to try the circuit connections a few times to insure you know how to charge / discharge the circuit.

In making these measurements, make sure your meters are using the 1000 MΩ input impedance, and, of course, the RS232 interface needs to be initialized.

The running of the data acquisition program should be straight forward. You'll name your file, press s to start and t to terminate. The computer will collect data about every 1/3 sec or so. After you press t for terminate, the program will write the data to the data file on the I drive. This may take a few minutes depending upon factors beyond my control. In any event, let the program close itself out ... don't close it out prematurely since you may not get all your data written properly. At the present time, the helper is limited to a maximum acquisition of 300 data tuples although the program can take 3500 tuples.

After you know how to charge and discharge your circuit, you should, with a fully charged capacitor acquire data out to about 500 seconds or so. The program will automatically stop after 3500 measurements. You might just want to start it and then (slowly) move away and take a break for about 3 minutes but ... 300 measurements is a lot of data to work with. You do not want to mess with the circuit while measurements are going on.

Next, you'll acquire data on the charging capacitor (write this to a different data file than the discharging system).

Procedure for analyzing discharge data

Paste your data into the RC discharge helper. You will want to use paste special, choose the option to detect special numbers, and paste it column by column**. It is not essential to paste beginning at t=0 and in fact, I don't recommend it. You might start after say t=10 s. However do paste 300 data tuples here total.**

The discharge potential across the capacitor should vary as

$$V = V_0 e^{-\frac{t}{\tau}}$$

While the discharge current measured should vary as

$$I = I_0 e^{-\frac{t}{\tau}}$$

At each point throughout time, we can thus find the resistance as:

$$R = \frac{V}{I}$$

which, of course, you know since this is the definition of resistance.

A plot of V vs I, together with the trendline is shown. Additionally the resistance calculation is provided by the openoffice slope function. Since the slope is linear, this means that the resistance is Ohmatic. Since the intercept is nearly zero, the implication is that the voltmeters supply little current to the circuit and also that the time dependence of V and I are identical.

We can measure the time constant by looking at the logarithm of the discharge current through:

$$\ln(I) = \ln(I_0) - \frac{t}{\tau}$$

A plot of this will show a slope with an absolute value of $\text{slope} = \frac{1}{\tau}$.

Since theoretically the time constant is RC, and since we have already obtained the resistance, the capacitance can now be determined as:

$$\frac{1}{\text{SLOPE}} = RC \Rightarrow C = \frac{1}{R(\text{slope})}$$

You will want to compare the value of C obtained with the value of C which you measured earlier with the meter by using the %deviation:

$$\%\text{dev} = \frac{\text{measure\#2} - \text{measure\#1}}{\frac{1}{2}(\text{measure\#2} + \text{measure\#1})} \text{x}100$$

You will need to do this calculation by hand and report it in your report.

Procedure for analyzing charge data

Paste your data into the RC discharge helper. You will want to use paste special, choose the option to detect special numbers, and paste it column by column, again starting after say 10s of data to a maximum of 300 data tuples.

The charging potential across the capacitor should vary as

$$V = \text{emf}\left(1 - e^{-\frac{t}{\tau}}\right) = \text{emf} - \text{emf}\, e^{-\frac{t}{\tau}}$$

While the charging current measured should vary as

$$I = \frac{emf}{R} e^{-\frac{t}{\tau}} \Rightarrow RI = emf\, e^{-\frac{t}{\tau}}$$

So, at each point throughout time, we can thus find the resistance and emf through time as:

$$v = emf - IR$$

A plot of this will then give an intercept whose absolute value is the emf and the absolute value of the slope will be the resistance.

The calculation of this is provided on the helper for you by the slope and intercept functions.

Now that you have R, you can calculate the time constant and thus the capacitance from the discharge current. As before, look at the logarithm:

$$I = \frac{emf}{R} e^{-\frac{t}{\tau}} \Rightarrow \ln(I) = \ln\left(\frac{emf}{R}\right) - \frac{t}{\tau}$$

The slope will provide the time constant from which the capacitance is calculated. This is provided also on the spreadsheet. You will want to compare the value of C obtained with the value of C which you measured earlier by the meter by using the %deviation. You will need to do this calculation by hand and report it in your report.

parallel vs. series capacitances

I have provided you with millimeters capable of measuring capacitance and I have several decade capacitances boxes that you can use here. First, measure each of the capacitances and try to get some rough agreement between the meter reading and what is printed on the side of the capacitor. After you have done this, use the clip provided to connect one leg of the capacitances in series. Measure this capacitance. Then, place both of the capacitances into the slot of the meter and then measure the parallel capacitance. Determine the percentage error in each of the measurements. You will probably find that the error is higher than it was for the resistance. Part of the reason for this is that it is simply harder to measure capacitance than resistance.

You may have noticed that the capacitor has markings on its side. There is not really only one standard for capacitance rating through markings. If you are diligent enough, you will find that there are some systems in wide use today but my absolute best advice to you is if you are going to use a capacitor, either measure the capacitance or get one that has the values printed on the side. While I am at it, I need to mention something about the polarity of capacitors. Modern capacitances require you to respect polarity, keeping + sides with the higher potentials. If you fail to connect your capacitor in many circuits properly, you will sooner or later get a big surprise. The surprise will be the failure of the capacitor. This is accompanied by an enormous pop and a release of energy. More annoying, however, is that it will scare you without warning. The moral to this story is to get your capacitor polarities correct.

You may have also noticed that many resistors have color bands marked on them. There is a standard method for marking resistances (and some resistances must have polarity respected if they are very high). The color coding is useful if you are looking at a resistance in a circuit and want to know its value. However, for my time, I would much rather use an Ohmmeter to measure the resistance and leave the color bands up to someone else with more time on their hands. Although the bands are useful in circuits, you are usually looking at a burned out resistor and the color bands are usually already burned off of these things. Your mileage may vary and you should feel free to learn the color coding for resistances if you like.

You are required to perform a calculation of the equivalent capacitance for 2 dissimilar capacitances, in series and in parallel (which you measured) today (by hand, with paper) and to show that you can do this calculation. You are required to show it to me so that I can confirm that you have done this.