Objective: To observe the behavior of a capacitor charging and discharging through a resistor; to determine the effective capacitance when capacitors are connected in series or parallel.

Apparatus: RC (Resistor-Capacitor) circuit box, voltmeter, power supply, cables

Introduction:

You may have seen this schematic in lecture; it represents a charging/discharging circuit in which a capacitor and resistor are connected in series with a battery:

![Diagram of a RC circuit]

When the switch S is placed in position A, the battery charges the circuit – charge flows from the battery into the capacitor, until the capacitor is fully charged. When the switch
is placed in position B, the capacitor (which stores charge and energy) discharges through the resistor (which dissipates charge energy). You will investigate how quickly this charge enters and leaves the capacitor by measuring the voltage across it as a function of time and analyzing the data. You will also connect capacitors in series (end to end) and parallel to measure the equivalent capacitance. Capacitance is the capacity to store charge, measured in Farads, defined by:

\[ C = \frac{Q}{V} \]

where \( Q \) (Coulombs) is the charge on the capacitor and \( V \) (Volts) is the voltage across it. The electrical energy stored in the capacitor is given by \( E = \frac{1}{2} CV^2 \).

**Exponential Function**

An exponential (base e) function is of the form \( y = A e^{-Cx} + B \). Note that for positive \( C \), the exponential term \( e^{-Cx} \) always decreases (termed “exponential decay”) with increasing \( x \) and approaches zero asymptotically as \( x \) gets very large. However, depending on the signs of the coefficients \( A \) (maximum value of exponential term) and \( B \) (offset), the function \( y = y(x) \) can either approach \( A \) or \( B \) as \( x \) gets very large. The coefficient \( C \) controls the rate at which the function \( y = y(x) \) increases or decreases; it is often called the decay constant and is defined as the value of \( x \) required for the exponential term to fall to \( 1/e \) of its original value.

The equation describing the voltage across a capacitor that is discharging through a resistor as a function of time is:

\[ V = V_0 e^{-\frac{t}{\tau}} ; \quad \tau = RC \]

In this experiment, you will be plotting the voltage across the capacitor \( V \) as a function of time \( t \). You will then try to fit the curve with an exponential of the form \( y = A e^{-Cx} + B \). Here the coefficient \( A \) represents the maximum voltage \( V_0 \), \( B \) represents the offset (very close to zero for this experiment), and \( C \) represents the quantity \( \frac{1}{\tau} \), where \( \tau = RC \), also called the time constant and is the product of the resistance and capacitance values. Note that the higher \( \tau \) is, the slower the discharge occurs.

For the voltage across a capacitor **charging** through a resistor, the equation is:

\[ V = V_0 \left( 1 - e^{-\frac{t}{\tau}} \right) \]

**IMPORTANT:** There are two variable \( C \)'s here – one is for Capacitance, and one is the fit coefficient in the exponential; you should distinguish between the two when writing them; it is suggested you use \( C_{\text{cap}} \) and \( C_{\text{coef}} \).
Capacitors in Series and Parallel

$N$ Capacitors connected in series have their equivalent capacitance calculated as follows:

$$\frac{1}{C_e} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots + \frac{1}{C_N}$$

$N$ Capacitors in parallel have their equivalent capacitance calculated as follows:

$$C_e = C_1 + C_2 + \ldots + C_N$$

How to connect the RC circuit

Two capacitors and one resistor are already wired into a single box with connection jacks. You need only connect the box to the power supply (which acts as the battery in the circuit) and the voltmeter.

The capacitors in the box are *polarized* and will only work if connected in one direction; Ground (black) on the power supply should only be connected to black on the box, red on the power supply should only be connected to red on the box.

By connecting to different jacks (which are labeled A, B, C, etc) using the supplied cables, you can create various circuits as shown below:

**Single capacitor discharge through a resistor:**
Parallel Capacitors discharging through a resistor:

Power Supply

Plug into +20V to Charge Capacitor

Unplug from +20V to Discharge Capacitor

Voltmeter

Single capacitor charging through a resistor:

Power Supply

Plug "A" into +20V to Charge Capacitor

Plug "A" into "E" to Discharge Capacitor

Voltmeter

Activities

Remember that for all the following activities, capacitor charging or discharging occurs through the resistor so make sure it is part of your circuit. If you are not sure with your connections, consult with your TA before turning on the power supply.

Capacitor charging or discharge takes place over a period of a couple of minutes; you can either use the second hand of your watch or stopwatch.exe, an application you will find on your lab PC (Desktop --> Lab Softwares --> Stopwatch.exe).

How many data points should you take, and how often? This is a question you'll have to determine for yourself. It is true that more data points reduces uncertainty, but you have a constraint in this experiment – you are limited by how quickly you can continuously record Voltage data as it drops quickly over the span of a couple of minutes.

NOTE 1: Although many of the diagrams refer to 20V as the maximum voltage that
the power supply will produce, you may only be able to get 18V or 19V out of yours.

**NOTE 2:** It is NOT necessary that a red cable be plugged into a red jack, nor a black cable be plugged into a black jack! The cables are identical other than color.

**A. Single capacitor discharge**

<For this, and for the remaining three activities, try drawing out your circuit first before connecting it.>

Do an experiment to find out how the voltage through a discharging capacitor varies with time. Analyze the data using Graphical Analysis to perform a curve-fit to the V vs. t graph. From the curve-fit equation, find the maximum voltage \( V_0 \) and the time constant \( \tau \). Print out the curve and show calculations on it; attach to hand-in sheet.

**B. Parallel capacitors discharge**

Do an experiment to find out how the voltage through two parallel discharging capacitor varies with time. Analyze the data using Graphical Analysis to perform a curve-fit to the V vs. t graph. From the curve-fit equation, find the maximum voltage \( V_0 \) and the time constant \( \tau \). Print out the curve and show calculations on it; attach to hand-in sheet.

**C. Series capacitors discharge**

Do an experiment to find out how the voltage through two series discharging capacitor varies with time. **Note that there is no diagram for two capacitors in series; hook up the cables according to what you think the circuit should be connected but have your instructor check the connection before performing the experiment.** Analyze the data using Graphical Analysis to perform a curve-fit to the V vs. t graph. From the curve-fit equation, find the maximum voltage \( V_0 \) and the time constant \( \tau \). Print, hand in.

**D. Single capacitor charge**

Do an experiment to find out how the voltage through a single charging capacitor varies with time. **Remember that the capacitor needs to be charged through the resistor, in series with it.** Analyze the data using Graphical Analysis to perform a curve-fit to the V vs. t graph. From the curve-fit equation, find the maximum voltage \( V_0 \) and the time constant \( \tau \). Print out the curve and show calculations on it; attach to hand-in sheet.

**Questions**

1. From your values for \( \tau \), calculate the values of C for all four parts above. How do these values compare to the values as labeled on the capacitors?

2. For multiple capacitors, which arrangement would result in the maximum equivalent capacitance – series or parallel?