CAPACITANCE IN A RC CIRCUIT

PURPOSE: To observe the behavior of resistor-capacitor circuit, to measure the RC time constant and to understand how it is related to the time dependence of the voltage in this circuit.

APPARATUS: RC circuit box, assorted wires, function generator, oscilloscope.

INTRODUCTION: A capacitor is a device consisting of two very closely spaced conducting plates that are insulated from each other. When a charge +Q flows onto one of the capacitor plates an equal and opposite amount of charge -Q from away from the other plate, and a voltage V develops across the two plates. The capacitance C is the constant of proportionality between C and V; Q = C V.

In this experiment you will study a simple circuit consisting of a capacitor in series with a resistor and a voltage source such as a function generator. The resistor acts to limit the rate at which current flows on or off the capacitor, which means that the voltage across the capacitor cannot instantly respond to a change in the voltage source.

SQUARE WAVE RESPONSE: We want to study the transient behavior of the RC circuit when we suddenly change the voltage across the circuit. In order to do this we generate a square wave and observe the response of the voltage across the capacitor using an oscilloscope.

The circuit shown in Fig. 1 allows the capacitor to be charged through the resistor when the function generator changes from the low state of the square wave to the high state. The oscilloscope measures the voltage across the capacitor as a function of time. Care must be exercised to keep the grounds of the function generator and oscilloscope together.

![Circuit Diagram](image)

**FIGURE 1.**

To understand the behavior of the circuit, suppose the function generator output has been at ground for a long time so the capacitor is uncharged. Then when the function generator changes to it high state, the entire voltage $V_f$ will appear across the resistor (because the capacitor is uncharged) and a current $V_f/R$ will flow. But as this charge flows it will accumulate on the capacitor, a voltage drop $V(t)$ will build up across the
Capacitor and the amount of current flowing will decrease (because the voltage across the resistor, $V_f - V(t)$, will decrease). Eventually all current will stop flowing when $V(t)$ reaches $V_f$. Mathematically the behavior of the voltage across the leads of the capacitor is given by:

$$V(t) = V_f(1 - e^{-t/\tau})$$

while charging, \hspace{1cm} (1)

Where $\tau = RC$, the **characteristic time constant** and $e$ is the base of the natural logarithms, $e = 2.71828...$. It is called the characteristic time because it determines (characterizes) how quickly or slowly the RC circuit responds.

When the function generator changes back to its low state (ground), the voltage across the capacitor will exponentially decrease as the positive charge on the one plate flows backward through the resistor to neutralize the negative charge on the other plate. Mathematically,

$$V(t) = V_f(e^{-t/\tau})$$

while discharging. \hspace{1cm} (2)

When discharging at $t = \tau$, $V(\tau) = V_f/e$. That is, $V$ is about one third of the initial voltage ($1/e = 0.368$). During the charging process the time constant is the time it takes for the capacitor to charge to about two thirds of its final value. The equations are graphed in Fig. 2 on the next page. Study the graphs to be sure you understand the physics.

In this lab you will measure the discharge of a RC circuit by digitizing ($t,V$) pairs of numbers measured from the oscilloscope face. You will then use “OroginPro” to plot your data and fit for the time constant, $\tau$, then compare with your calculated value of RC. From the uncertainty in the resistance and capacitance used, and the scale reading uncertainty of the oscilloscope calculate your measurement uncertainties. In other words, from the scale reading uncertainty you can calculate the uncertainty in $\tau$. From the resistor and capacitor values and specifications you can calculate the value and uncertainty in your expected answer, the product RC. Compare your measured answer to your expected answer. What is their ratio, with uncertainties included?

The resistor-capacitor box gives you two capacitors. You will first measure RC using a single capacitor, then using the two capacitors connected in parallel and finally the two capacitors in series. To calculate RC you will need to use the equations for the total capacitance of two capacitors in parallel and series:

$$\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2}$$

series connection \hspace{1cm} (3)

$$C_{total} = C_1 + C_2$$

parallel connection \hspace{1cm} (4)
Fitting The Data Using Origin Pro

After collecting the data and plotting it, click “Analysis” and from the drop down menu select “Fitting” and “Non linear Curve fit” and then select “Open Dialogue”. A window appears where you can select the Category of functions. Select “exponential”. For the charging plot select the function “BoxLucas1” and for the discharging plot select “Exp2PMod1” to perform fitting.

FIGURE 2
CAPACITANCE IN AN RC CIRCUIT

Name: ____________________________________________________ Section: _______
Partners: _________________________________________________ Date: __________

PART ONE:

Determine the behavior of the voltage across the capacitor as the circuit discharges.

\[ R = \quad \text{C} = \quad \]

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Expected value of RC:_____________________________ (include uncertainty)
Fitted value of \( \tau \):_____________________________(include uncertainty)
\( \tau / RC \):_____________________________(include uncertainty)
PART TWO:

Now repeat the steps in Part One for the two capacitors connected in parallel and then in series and determine τ for both cases.

Compare the theoretical and experimental values of τ.

**Capacitors in parallel:** C1 = _____________  C2 = _____________

R = ________  C (Total) = ________

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τ exp _____________  τ theory _____________

**Capacitors in series:** C1 = _____________  C2 = _____________

R = ________  C (Total) = ________

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