

RC Circuits

Experiment PH06_Todd

OBJECTIVE

- To investigate how the voltage across a capacitor varies as it charges.
- To find the capacitive time constant.

EQUIPMENT NEEDED

Computer: Personal Computer with the Pasco Scientific *DataStudio*TM Program installed.

Interface Unit: Pasco Scientific *Science Workshop*TM (Model 500, 700 or 750.)

Power Amplifier: PascoTM Power Amplifier II (CI-6552A.)

Experiment Software File(s): PH06_RC Circuits.ds

Experiment Apparatus:

PascoTM RLC Circuit Network (CI-6512)

Wire Lead, Banana-Banana (2) (1 red, 1 black)

PascoTM Voltage Sensor (CI-6503)

THEORY

When a DC voltage source is connected across an uncharged capacitor in a RC circuit, the rate at which the capacitor charges actually decreases as time passes because the resistance in the circuit slows the charging process.

At first, the capacitor is easy to charge because there is very little charge on the plates. But as charge accumulates on the plates, the voltage source must do more work to move additional charges onto the plates because the plates already have charge of the same sign on them. As a result, **the capacitor charges exponentially**, quickly at the beginning and more slowly as the capacitor nears full charge. The **charge on the plates at any time is given by:**

$$q = q_0 \left(1 - e^{-t/\tau} \right) \quad (1)$$

where q_0 is the maximum charge on the plates and τ is the **capacitive time constant** ($\tau = RC$, where R is resistance and C is capacitance). When $t = 0$, $q = 0$, there is no charge on the plates initially. When t goes to infinity (∞), q goes to q_0 , it takes an infinite amount of time to completely charge the capacitor.

The **charge on the capacitor** where C is capacitance and V is voltage is given by:

$$q = CV \quad (2)$$

The time it takes to charge the capacitor to half the maximum charge is called the half-life and is related to the time constant in the following way:

$$t_{1/2} = \tau \ln 2 = t_{1/2} = \tau 0.693 \quad (3)$$


$$\tau = RC \quad (4)$$

PROCEDURE

In this experiment the Power Amplifier produces a low frequency square wave (0 to 4 V). This waveform imitates the action of charging and then discharging a capacitor by connecting and then disconnecting a DC voltage source. The Voltage Sensor measures the voltage across the capacitor as it charges and discharges.

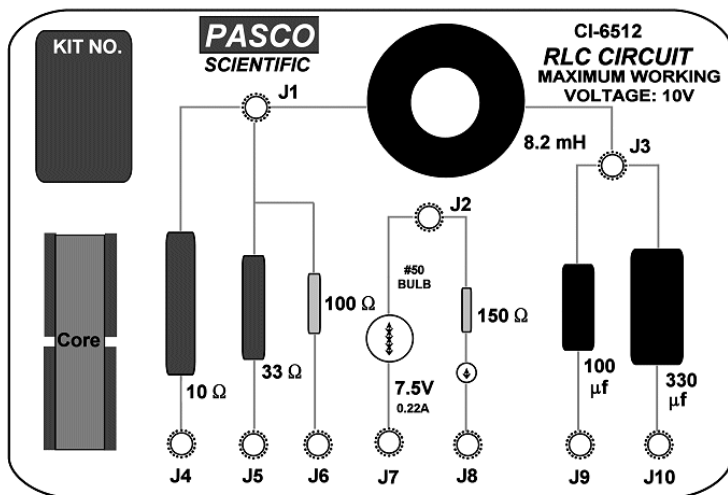
The Pasco *DataStudio*TM program records and displays the data. You will measure the time for the capacitor to charge to the “half-maximum” voltage. Using the half-max time and the known value of the resistor, you can calculate the capacitance of the capacitor.

● Computer Setup

1. Connect the **Voltage Sensor** DIN plug to **Analog Channel A**. Connect the **Power Amplifier** DIN plug to **Analog Channel B**.
2. Open experiment file **Ph06_RC Circuits**.
3. The default **Signal Generator** output is a **4.00 V**, “**positive square wave**” waveform, at **0.400 Hz**, with a sample rate of **1000 Hz**. It is set to **Auto** so it will start automatically when you click the  **Start** button on the the *DataStudio*TM program **main toolbar**.

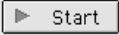

● Equipment Setup

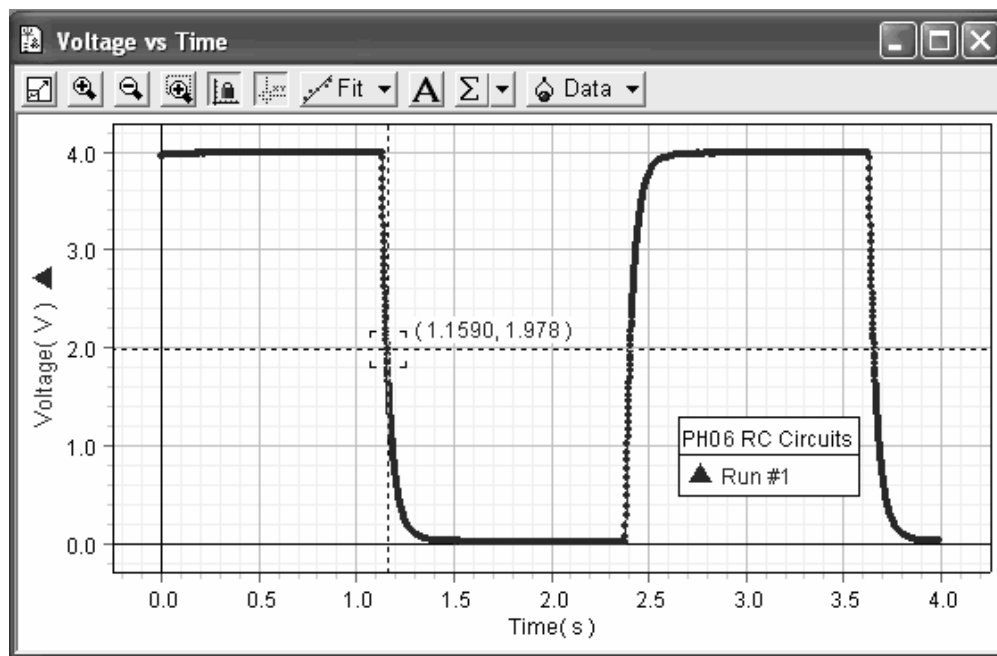
1. The **Pasco RLC Circuit board (RLC)** contains hard-mounted electrical components for use in experiments and is configured by plugging test leads into the board. **RLC Jack points (J1 – J10)** are used to connect banana plug connector test leads to the board. **Note: The RLC jack points are not directly numbered on the board; refer to the figure below to locate the proper jack points used in the experiment.**





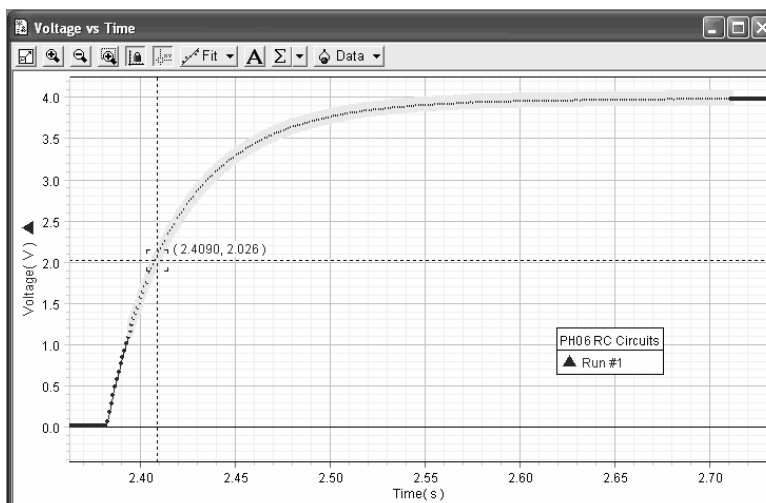
2. Locate the **100-Ohm (Ω)** resistor and **330 microfarad (μF)** capacitor mounted on the RLC Circuit board. In this experiment, you will be connecting these components in a *series* configuration.
3. Connect the **Voltage Sensor (Analog Channel “A”)** stackable *red* lead to RLC **jack J3**. Connect the Voltage Sensor stackable *black* lead to RLC jack **J10**.
4. Using wire leads with *banana plugs* at opposite ends, connect one end of a *red* wire lead to the *red* connection jack on the **Power Amplifier** and plug the other end into RLC jack **J6**.
5. Connect a *black* wire lead to the *black* connection jack on the **Power Amplifier** and plug the other end *into the top* of the stackable Voltage Sensor lead in RLC jack **J10**.
6. Because of the physical layout of the RLC Circuit board, the coil is also schematically included in this configuration. However, for the purposes of this experiment, the coil has no effect except to add an additional **5 Ω** resistance to the circuit. Thus, **the total resistance in the circuit is 105 Ω** .

● **Data Collection**

1. **Turn on the Power Amplifier.** Click the  **Start** *button* in the *DataStudio™* program **main toolbar** to begin collecting data.
2. Data recording will continue for four seconds and then automatically stop.
3. **Run #1** will appear in the **Data List** on the graph display.
4. When data recording is complete, **turn off the Power Amplifier.**
5. Click the graph to make it active. Click the  **Scale to Fit** *button* on the **graph toolbar** to fully display the collected data on the graph. See figure below.



6. Click the  **Zoom Select Magnifier** *button* on the **graph toolbar**. Use the cursor to click-and-draw a rectangle over a region of the plot of Voltage vs Time that shows the voltage rising from **zero volts** to the **maximum volts**. This will give you an expanded view of the Voltage vs Time plot for that region. See Figure PH06.3.
7. Click the  **Smart Tool** *button* on the **graph toolbar**. The cursor changes to a crosshair when you move it into the display area of the graph. The numbers next to the crosshair's position on the graph represents the Time and Voltage.
 - The **y-coordinate** of the cross-hair represents the voltage.
 - The **x-coordinate** of the cross-hair represents the time.



8. Move the **Smart Tool crosshair** to the point on the plot where the voltage begins to rise. Record in Data Table 1, as the **beginning time**, the time that is shown in the area below the horizontal axis.
9. Move the **Smart Tool crosshair** to the point where the voltage is approximately **2.00 volts**. (See figure above). Record in Data Table 1, as the **ending time**, the time that is shown in the area below the horizontal axis.
10. **Save the magnified graph display** for inclusion in your laboratory report. Connect an USB storage device to the computer. Click on the graph to make it active. Click on **Display** in the *DataStudio*TM **upper main toolbar**. Select **Export Picture** from the drop-down menu. A **Save As** box will open. Name the file **PH06_graph** and use the **Save in drop down arrow** to select your USB storage device. Click the **Save button** to save the file.
11. Find the difference between the beginning and ending times, and record it in Data Table 1 as the **time to “half-max”, or $t_{1/2}$** . Show your work in the data section of your lab report.
12. Use Equations (3) and (4) to calculate the **experimental capacitance (C) of the capacitor**. Record the calculated value in Data Table 1. Show your work in the data section of your lab report.
13. Determine the *percent difference* between the stated value of the capacitor ($330 \mu F$) and the experimental value of capacitance. Record the calculated value in Data Table 1. Show your work in the data section of your lab report.

$$\% \text{ difference} = \left| \frac{\text{stated value} - \text{experimental value}}{\text{stated value}} \right| \times 100$$

ENDING THE EXPERIMENT

1. **Close the PH06_RC Circuits** experiment file. **Do NOT save the file.**
2. **Disassemble the equipment.**
 - ▶ Disconnect all wire leads and sensors from the RLC Circuit board, Power Amplifier and Interface unit.
 - ▶ Return the RLC Circuit board to its storage bag.
 - ▶ Return the voltage sensor and wire leads to the wire lead storage locker.
 - ▶ Turn off the Power Amplifier.
 - ▶ Disconnect the Power Amplifier from the Interface unit.
3. **Complete analysis questions.**

DATA ATTACHMENTS

- Experiment PH06 Data Table 1.

ANALYSIS QUESTIONS

- (5 pts). The time to half-maximum voltage is how long it takes the capacitor to charge halfway. Based on your experimental results, how long does it take for the capacitor to charge to 75% of its maximum? Show your work.

- (5 pts). The stated value of a capacitor may vary by as much as $\pm 20\%$ from the actual measured value. What are some physical experimental uncertainties that could account for the percent difference between the stated and experimental values? (*Hint*: consider the design of a parallel plate capacitor which you investigated in lab earlier this semester.)

DATA TABLES – Experiment PH06

Lab Instructor Signature and Date: _____

Data Table 1: RC Circuits

| | | | |
|--|---|-------------------------------------|-------------|
| Beginning time | s | Stated Capacitance (C) | 330 μF |
| Ending time | s | Experimental Capacitance (C) | μF |
| Time to half-max ($t_{1/2}$) | s | Percent difference | % |