RC TIME CONSTANT

Objectives

The purpose of this lab is to give the student an understanding of basic RC circuit.
In this lab you will determine the charge across the capacitor as it charges and discharges, and measure the time constant of the RC circuit.

Equipment

- Science workshop interface with power source
- Charge sensor
- Computer
- (4) Patch cords
- Capacitor (22 µF)
- Resistors (5-6 different values, use tens or hundreds of KΩ)
- Switch
- Voltage source

Introduction

When a capacitor (C) is connected to a dc voltage source like a battery, charge builds upon its plates and the voltage across the plate increases until it equals the voltage (V) of the battery. At any time (t), the charge (Q) on the capacitor plates is given by $Q = CV$. The rate of voltage rise depends on the value of the capacitance and the resistance in the circuit. Similarly, when a capacitor is discharged, the rate of voltage decay depends on the same parameters. Both charging and discharging of a capacitor are characterized by a quantity called the ***time constant, τ***, which is the product of the capacitance (C) and the resistance (R), i.e., $\boldsymbol{\tau = RC}$
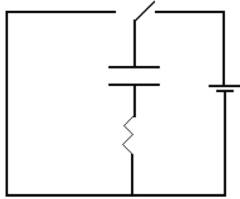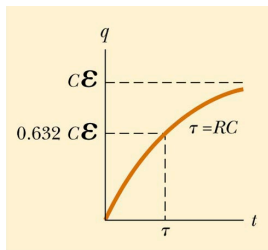

Figure 1. Simple RC circuit. The switch can connect the RC elements to the battery (right side) and charge the capacitor. After the capacitor is charged, the switch can be shifted toward left side and discharge the capacitor.

Theory

A. Charging a capacitor (Fig. 2)

The charge on a capacitor varies with time as:

$$q(t) = Q_{max}(1 - e^{-t/RC}) = C\,E\,(1 - e^{-t/\tau}),$$

where the maximum charge $Q_{max} = C\,E$ and the *time constant* $\tau = RC$

Figure 2. Charging the capacitor. The time constant τ represents the time required for the charge to increase from zero to 63.2% of its maximum value.

B. Discharging capacitor (Fig. 3)

When a charged capacitor is placed in a circuit, it can be discharged
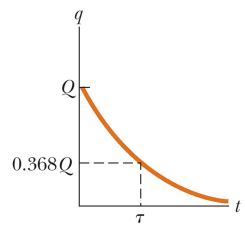
$$q(t) = Q\,e^{-t/RC}$$

Figure 3. Discharging a capacitor. The time constant is the time it takes to reduce the electric charge to 36.8% of its initial value Q. In a circuit with a large time constant, the capacitor charges very slowly. The capacitor charges very quickly if there is a small time constant.

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Procedure:
To measure electric properties (electric charge, voltage, current, etc.) we use appropriate meters, or sensors, attached to a computer via an interface. In this lab, we will use a *charge sensor* connected in parallel to a capacitor to measure its electric charge.

1. Connecting the charge sensor and working with Data Studio software
2. Connect the power source to PASCO interface and turn the interface on.
3. Connect the USB cable from the interface to the computer and turn the computer on.
4. Connect the charge sensor to channel A of the interface and attach it across the capacitor with the red wire (+) connected to the plus mark on the capacitor and the black wire (-) connected to minus.
5. Open "Data Studio" software
6. Click on "Create new experiment" icon to start your lab experiment. At this time you should see three separate panels:
   a. "Experimental setup" containing a picture of the interface
   b. "Data" window that will collect your experimental
   c. "Displays" panel that will allow you to visualize experimental data
7. In order read properly the sensor, you must tell the interface what kind of sensor is physically attached. For this purpose, click on the "Add Sensors and Instruments" button shown in "Experimental setup" panel. Select the charge sensor from the drop-down menu and double-click on it in order to automatically connect the sensor to the interface.
8. Drag with the mouse the data icon called charge Q from "Data" window and releases it on top of the "Graph" icon under the "Displays" menu.

Performing the experiment
1. Build the RC circuit shown in Fig. 1 using selected capacitor and resistors.
2. Click "Start" button in DataStudio to start recording the electric charge across the capacitor.
3. Close the switch to connect the RC circuit across the power source in order to charge the capacitor. Hold the switch closed until the electric charge levels to a maximum value (see Fig. 1).
4. Disconnect the power source and shortcut the RC circuit (not the power source!) in order to discharge the capacitor (see Fig. 1).
5. Press the "Stop" button in DataStudio after the electric charge significantly decreased (more than 90% discharged).
6. From the plot of the electric charge versus time curve obtain the time constant of the circuit during
   a. charging (Fig. 2) measure τ_{up} , which is the time it takes for the electric charge to rise from 0 to 63.2% of its maximum value $Q_{max} = CE$,
   b. discharging (Fig. 3) measure τ_{down}, which is the time it takes to reduce the electric charge to 36.8% of the initial value.

   Recorded the two measured time constants (τ_{up}, τ_{down}) in Table 1. Compute the experimental time constant $\tau_{exp} = (\tau_{up} + \tau_{down})/2$.
7. Save the graph, send it to the printer, and attach one copy to your lab report.

8. Calculate the theoretical value of the time constant ($\tau = RC$) from the known values of resistance and capacitor and record this value in the table. Calculate % errors of the time constant $\%err = \dfrac{|\tau_{exp} - \tau_{theory}|}{\tau_{theory}} 100\%$

9. Repeat the experiment for different values of R by combining given resistors in series, parallel, etc.

Table 1.   RC time constant

	R (Ω)	C (F)	Charging τ_{up} (s)	Discharging τ_{down} (s)	τ_{exp} (s)	τ_{theory}(s)	%err
1							
2							
3							
4							
5							
6							

10. Plot the experimental time constant τ_{exp} versus the electric resistance R and attach a copy to your lab report.

What is the value of the slope from your graph? _____

What is the value of the expected slope? Why?

What is the value of the intercept from your graph? _____

What is the expected intercept? Why?

Question:

What is the time constant of the circuit shown below? Take C=22μF and R=10M Ω