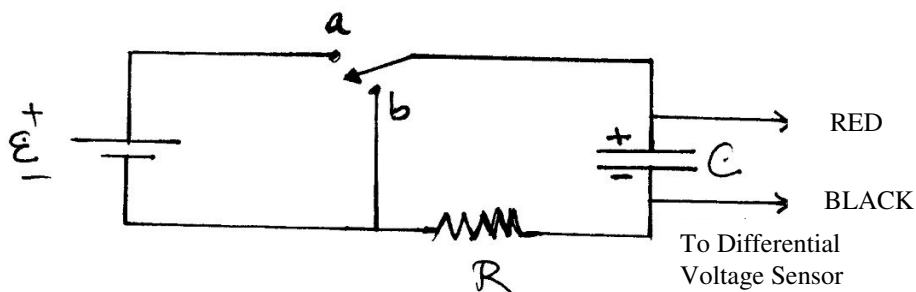


PHYS 2426
Engineering Physics II
EXPERIMENT 5
CAPACITOR CHARGING AND DISCHARGING

I. OBJECTIVE:

The objective of this experiment is the study of charging and discharging of a capacitor by measuring the potential difference (voltage) across the capacitor as a function of time. From this measurement the student will use the Logger Pro software to calculate the charge and the current as functions of time. The student will also measure the experimental time constant and use it to determine the experimental value of the capacitance of the capacitor.



II. APPARATUS:

Pasco AC/DC Electronics Lab
Lab Pro Interface
Computer with Logger Pro
Vernier Differential Voltage Sensor
Resistor (decade box)

Capacitor, about $1000/\mu\text{F}$
Batteries, 1.5 volt D-cell, two (2)
Ohmmeter (DMM)
Connecting wires

III. THEORY:

A capacitor consists of two conducting objects (plates) separated by a non-conducting medium (dielectric). The capacitance of a capacitor is defined as the ratio of the charge on the one of the conductors to the potential difference between them,

$$C = Q/V \quad (1)$$

When a capacitor is connected to a power supply (battery), it begins to charge up. During this process, both the charge Q and the potential difference, V , are increasing while the electric current is decreasing. This will continue until both Q and V reach their maximum values and the electric current goes to zero indicating that the charging process has stopped.

The characteristic time that indicates how fast or slow a capacitor charges or discharges is called the time constant. It is the time it takes the potential difference (or the charge) to

increase from zero to 0.632 (or 63.2%) of its maximum value. The time constant “TC” depends on the values of the capacitance and the resistance in the circuit and is given by the equation

$$TC = RC \quad (2)$$

A capacitor needs a time period equal to 5 time constants to charge up to 0.993 (or 99.3%) of maximum value. When this happens, we can assume for practical purposes that the capacitor is fully charged.

Further analysis shows (see your favorite physics textbook) that the potential difference increases with time according to

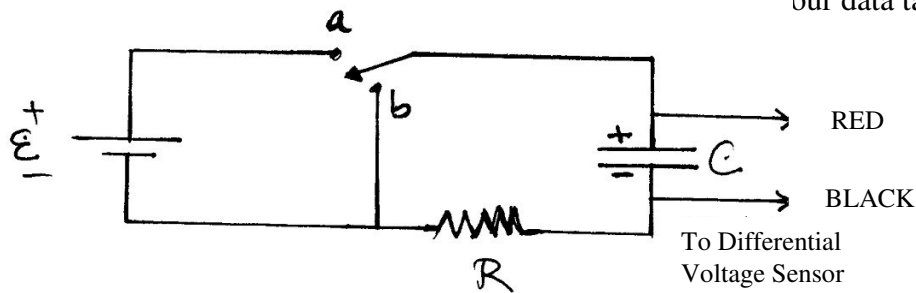
$$V_C(t) = E (1 - \exp(-t/RC)) \quad (3)$$

where E is the battery Emf. The charge increases similarly since $Q(t) = CV_C(t)$.

During the discharging process, both the charge and the potential difference decrease with time until they reach zero.

IV. EXPERIMENTAL PROCEDURE:

1. Record the nominal value of the capacitance, written on the capacitor, in your data table.
2. Choose a value for R to give a time constant value of $RC = 2$ sec. This is the nominal value of the time constant, T. Dial in the value of R on the decade resistance box and use the ohmmeter to check the value of R. Record the value of R in your data table.



3. Wire the circuit as shown in the figure above.
 - a. Make sure the capacitor is completely discharged.
 - b. Clip the Differential Voltage Probe to the capacitor observing the correct polarity (RED lead to positive, BLACK lead to negative).
 - c. Plug the other end of the cable into Analog Channel 1 in the LabPro interface.
 - d. Next, follow the procedure described below on how to use Logger Pro to collect data for the capacitor charging and discharging. The only data collected are the capacitor potential difference, V_C and the battery Emf, E. We will use Logger Pro to calculate the charge, the electric current and the time constant using this potential difference data. The computer and the LabPro should be on. If they are not, turn them on.

4. Double click on the Logger Pro icon
 - a. The application should automatically display 2 data columns for “Time” and “Potential” and a graph of Potential vs Time.
 - b. A box in the lower left hand corner should display the current value of the voltage being measured by the Differential Voltage Sensor. This should be just about zero because the capacitor has been discharged at this point.

5. Measure the battery Emf
 - a. Open the circuit prior to measuring the battery Emf. The circuit should not be connected to either point “a” or point “b.”
 - b. Observing the correct polarity, use the Differential Voltage sensor to measure the battery Emf, E . Record the value in your data table.
 - c. By using the Differential Voltage Sensor to measure the capacitor voltage difference, V_C and the battery Emf, E we can avoid the calibration issue in the voltage measurements. The reason for this is that only the ratio of V_C/E will be used to determine the experimental value of the time constant and hence the value of C .

V. DATA COLLECTION

1. Collect the CHARGING Data
 - a. Click on COLLECT button and connect your “switch wire” to the circuit point "a".
 - b. The capacitor will start to charge and you will see the capacitor potential difference increase.
 - c. Practice this timing process to ensure that the capacitor starts charging during the first 1 or 2 seconds after pressing the COLLECT button.

2. Collect the DISCHARGING Data
 - a. When the time reaches 12 seconds (about 6 time constants) move your “switch wire” to the point in the circuit designated as "b".
 - b. The capacitor starts to discharge and the capacitor potential difference decreases to zero over the next 12 seconds.
 - c. The potential difference vs. time data is stored in a data table and will be used to calculate the charge, the current and the time constant.

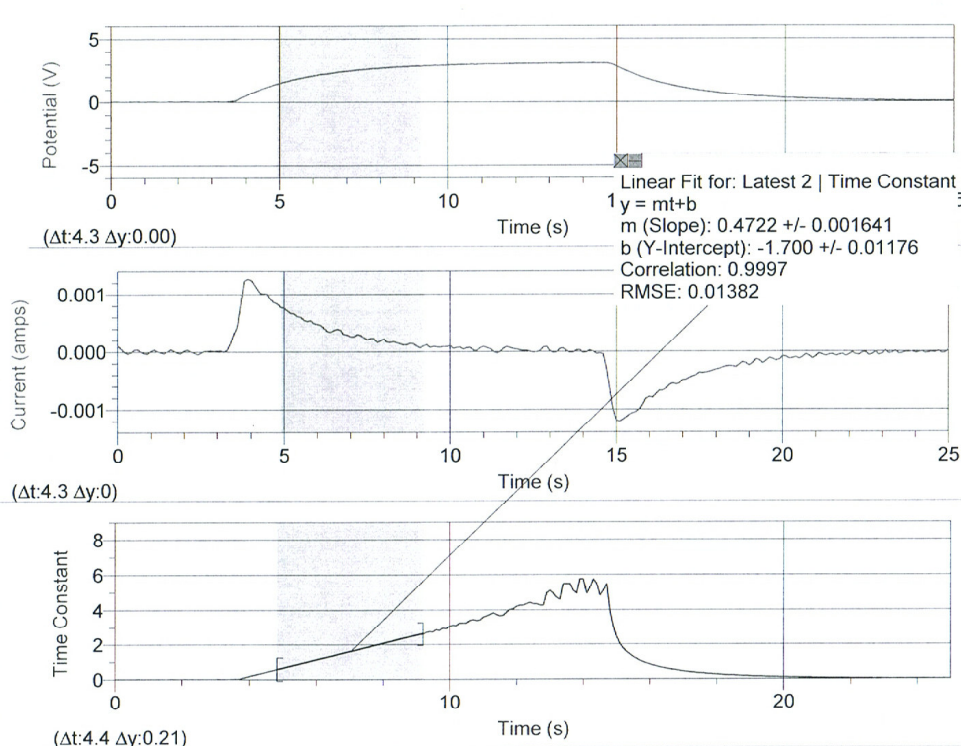
3. Constructing the New Data Columns

The first step in creating a new column is to go to **Data** on the main menu, click on **New Calculated Column**.

 - a. The first column will contain the ELECTRIC CHARGE data.
 1. Click on options and call the new column “Charge” (Q) and give it units.
 2. Change the precision from 3 to 5 digits. Click OK.
 3. Click on definition and enter $C \cdot V$ for Q . Enter the numerical value of C as a decimal number and drag to "Potential" under variables to get the value of V . Click try new column.
 4. You do not need to graph the Charge since it's graph looks exactly the same as that of the capacitor voltage. Next you will calculate the electric current

- b. The second column will contain the CURRENT data.
1. Proceed as before in creating a new Calculated Column
 2. Click on options and call the new column "Current" (I) and give it units.
 3. Change the precision from 3 to 5 digits. Click OK.
 4. Click on definition and from "functions" choose derivative and from variables choose "Charge" (Q). This calculates the derivative of the charge that is the current.
 5. Create a new graph for the "Current" in the second graph slot.
- c. The third column will contain function values - TIME CONSTANT
1. Proceed as before in creating a new Calculated Column
 2. Enter the formula:

$$-\ln(1.0 - ("Potential" / E))$$
 3. In the above formula, enter the numerical value for **E**.
 4. Get the natural log function Ln from functions and "Potential" from variables.
 5. This will give a straight line graph whose slope is the reciprocal of the time constant.
 6. Graph this function for the third graph and calculate the slope of the straight line and the uncertainty in the slope value. Skip the first second and don't go past 4 seconds.
4. Now you are ready to begin the taking of multiple Data Sets. Run the Charging-Discharging cycle six (6) times and record the slope values and their corresponding uncertainties in your data table.



Your three graphs should look something like the above

VI. ANALYSIS:

SAVE YOUR LAST DATA SET - you will need it for calculations in this part of the lab.

1. From the average of your values of the slope calculate the experimental time constant $(RC)_{\text{exp}}$ and calculate the percent difference between this time constant and the time constant calculated from the product RC .
2. Calculate an experimental value of the capacitance C_{exp} from your experimental value of the time constant $(RC)_{\text{exp}}$. Calculate the % Difference between the nominal value and the experimental values of C .
3. Use the theoretical expression for the charging capacitor potential difference and your experimental time constant value $(RC)_{\text{exp}}$

$$V_C(t) = E (1 - \exp(-t/(RC)_{\text{exp}})) \quad (3)$$

to calculate V_C at time $t_1 - t_{\text{charge}} = 3 \text{ sec}$.

$$V_C(t = 3 \text{ sec}).$$

4. Use the theoretical expression for the capacitor potential difference (discharging) and your experimental time constant value $(RC)_{\text{exp}}$.

$$V_C(t = 3 \text{ sec}) = E \exp(-(t_2 - t_{\text{disch}})/(RC)_{\text{exp}}) \quad (4)$$

and calculate V_C at time $t_2 - t_{\text{disch}} = 3 \text{ sec}$ where t_{disch} is the time you switched to discharging. Use the value of $(RC)_{\text{exp}}$ calculated above.

5. Compare the values of the capacitor potential difference you calculated above to their corresponding values in the data table "Potential" data column at times $t_1 = t_{\text{charge}} + 3 \text{ sec}$ (charging) and $t_2 = t_{\text{disch}} + 3 \text{ sec}$ (discharging), by finding percent differences.
6. Use the theoretical expression for the electric current. This function is used for both charging and discharging - only the direction of the current is different.

$$I(t) = (E/R)\exp(-t/(RC)_{\text{exp}}) \quad (5)$$

and calculate the current at times $t_1 - t_{\text{charge}} = 3 \text{ sec}$ and $t_2 - t_{\text{disch}} = 3 \text{ sec}$ where t_{disch} is the time you switched to discharging. Compare these values (by finding percent differences) to the values of the "Current" in the data table at these two times, t_1 and t_2 .

VII. DATA TABLE

Name	Nominal	Experimental	% Difference
C (μF)			
R (Ω)			
RC (sec)			
E (V)			

Data Set	Slope (s^{-1})	Uncertainty (s^{-1})	% (Unc./Slope)
1			
2			
3			
4			
5			
6			

Average Slope		$(\text{RC})_{\text{exp}} \text{ (s)}$	
Std Dev (SD)		$C_{\text{exp}} \text{ (}\mu\text{F)} = (\text{RC})_{\text{exp}}/\text{R}$	
$(\text{SD}/\text{Avg})*100$			

VOLTAGE	$V_C \text{ (V)}$	$V_{C_{\text{exp}}} \text{ (V)}$	% Diff
Charging time			
Discharging time			

CURRENT	$I_C \text{ (V)}$	$I_{C_{\text{exp}}} \text{ (V)}$	% Diff
Charging time			
Discharging time			