Capacitance and the RC Circuit

Your Name _____

Partners' Names _____

_____

TA's signature allowing you
to take the quiz or leave _____

Obtained reasonable experimental results?	yes ☐
Answered questions?	yes ☐
Cleaned your table?	yes ☐

Introduction

Unlike resistors you experimented previously, capacitors have a different property. A capacitor has capability to store charges whose parameter is called capacitance, C. The unit of the capacitance is farads (F). The charges stored in a capacitor, Q, can be determined by the voltage provided by the power supply, V, and the capacitance, C, which indicates the capacity to store charges in the capacitor:

$$Q = CV$$

A circuit to put a resistor and a capacitor gives more variety of applications. This is called an RC circuit which gives the processes of charging and discharging in the capacitor. When you turn on the power, the capacitor will be charged with certain time. Then, after the power is switched off, the charges will be released out from the capacitor gradually. The process of how the charges are stored in the capacitor is given by:

$$Q = Q_0\left(1 - e^{-\frac{t}{RC}}\right)$$

where Q_0 is the possible maximum charges to be stored in the capacitor, and t is the time elapsed for this process. Inside the exponential function, RC characterizes the how fast the charges can be stored, which is called time constant, τ. The discharging process will not be discussed in this lab, but it is expressed as $Q=Q_0(e^{-t/RC})$, which is a decaying process. The RC circuit can control timing due to the time constant, so one of the applications is a heart defibrillator and other timing devices.


Objectives:
- To find capacitance of capacitors experimentally
- To test the charging and discharging properties of an RC (resistor and capacitor) circuit

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1. The definition of capacitance and confirmation of the relationship, $V=(1/C)Q$:

A capacitor is an open circuit (spacious separation) capable of storing charges. The capacitance is defined as charge per voltage, $C = Q/V$. The SI unit of capacitance is Farads (F). For the other SI units, charge is (C); voltage is (V); resistance is (Ω); and the time constant is (s).

Procedure

① Start up DataStudio, select a voltage sensor, and display a graph (voltage vs. time).

② Use the capacitor module, and implement a following series RC circuit.

③ The default setting is: Switch 1 is off; Switch 2 is flipped to "discharge", Switch 3 is placed in R_0, which has no resistor. <u>To reset the experiment, come back to this setting</u>.
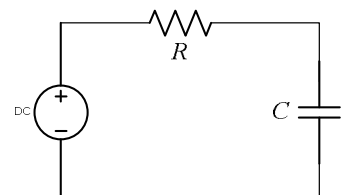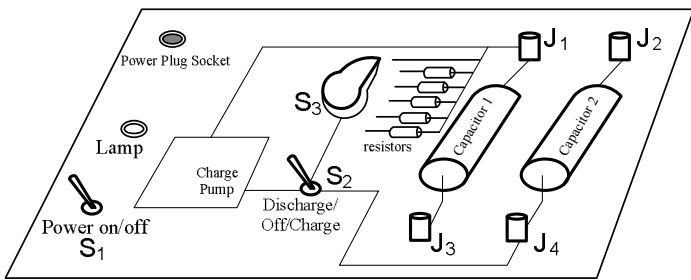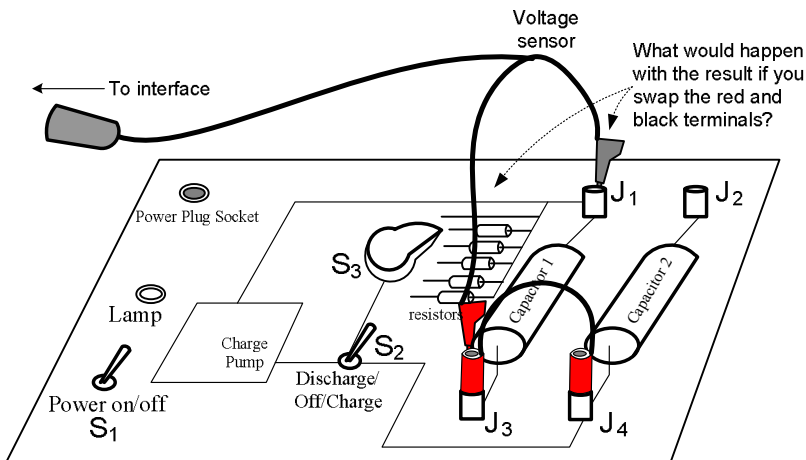
④ Note that you will not use capacitor 2 in this lab. To implement the above circuit, junctions J_3 and J_4 will be connected with a wire as shown.
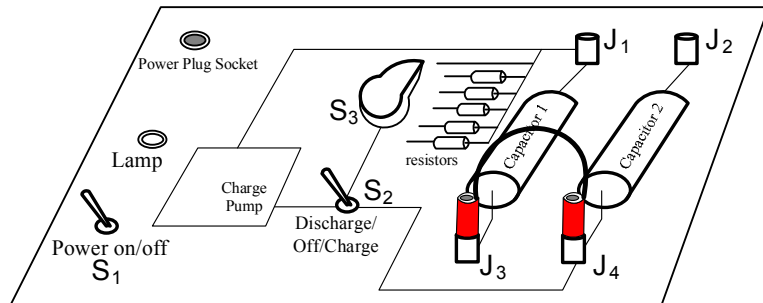
⑤ You will measure the voltage across capacitor 1. Thus a voltage sensor has to be connected with J_1 and J_3.

⑥ For switch 3, <u>select R_1</u>. Be ready to click start on DataStudio. First, turn the power on (S_1). Then, start charging (S_2) and recording the data.

⑦ The graph is voltage vs. time. The charge pump provides a steady current, 1.0×10^{-3} A. Namely, from $I = \frac{\Delta Q}{\Delta t}$, $\Delta Q = 1.0 \times 10^{-3}$ C with respect to time. The slope is obtained by $\Delta V/\Delta Q$.

From the formula, C=Q/V. Therefore, the slope is 1/C. We now have C=1/(slope)=Q/V=(1.0×10^{-3})/V. Hence, C=1/(slope $\times 10^3$) (F) [Note that when it is expressed as μF, C=$\{1/(\text{slope} \times 10^3)\} \times 10^6$. Thus, C=1000/slope (μF).]
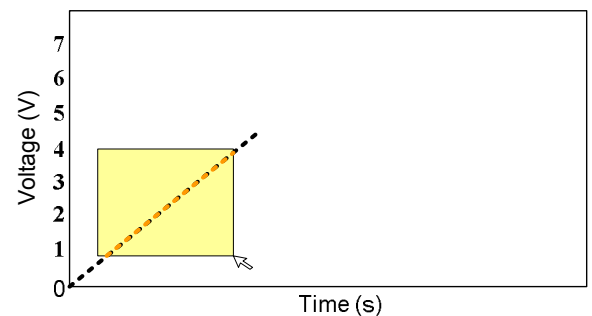
⑧ Click stop when the voltage reaches around 4 or 5 voltages. Select proper range of the line and use the "Fit" tool to obtain the linear fit. **Print out** the graph and its slope.

Calculation of the capacitance (Put the unit next to the value you obtain.)

1	2	3
Slope from the graph $\times 10^3$	Capacitance in (F) [1 ÷ Column 1]	Capacitance in (μF) [Column 2 $\times 10^6$]
		This will be used to confirm in the last part.

Conceptual question: How do you explain "capacitance" to your friends who do not know physics? Namely, what is the significance of "capacitance"?

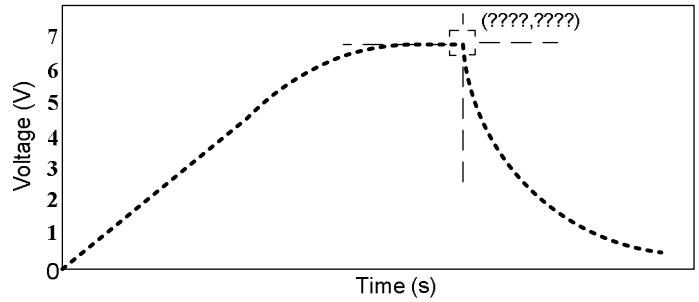## 2. Charging process in the RC circuit:

① Reset the previous trial. (For switch 2, flip the toggle to "discharge.") Wait for a while, and then repeat the same; <u>however, you record the voltage change more than a few minutes for this time.</u>

② The voltage will be saturated after certain time.

③ When it look almost flat (likely after 2 minutes), switch the S_2 into "discharge."

④ It starts the discharging process as shown. When it approaches almost zero voltage, it is time to stop the measurement.

⑤ Use the smart tool to identify the peak value of the charging process. **Print this out.**

The Peak values

| Time (s) [Max.]	Maximum voltage (V)

3. Discharging process in the RC circuit:

① After you complete the voltage measurement (including the discharging process), calculate the 37 % ($\times$ 0.37) of the maximum voltage that you obtained the above. (Put the unit next to the value you obtain. <u>Before you simply ask your TA about what the unit is, look for it from this manual.</u>)

Max. voltage from the previous measurement	$0.37 \times$ The max. voltage	Time [37%]
(　　)←unit	(　　)←unit	(　　)←unit

② Seek the calculated voltage from the graph with the smart tool as shown:

③ The time at the maximum voltage and the time at the 37% of the maximum voltage are recorded in the above table.

④ The time between the maximum and the 37% is called the time constant. Calculate the following:
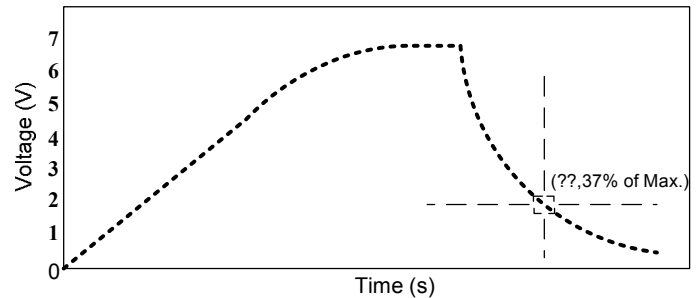
1	2	3
Time [Max.] from the above table	Time [37%] from the above table	τ (time constant) = The difference b/w column 1 and column 2 [Note: Time should be a positive value.]
( )←unit	( )←unit	( )←unit

Conceptual question: Rephrase "time constant" in your word from what you did in the experiment.

⑤ The time constant is also equal to the resistance of the resistor times the capacitor, $\tau = RC$. Measure the resistance of the resistor R_1 with a multimeter. (Be careful with the units expressed in the multimeter. Note that kilo (k) is $\times 10^3$.)

The resistance of R_1 with a multimeter
(   )←unit
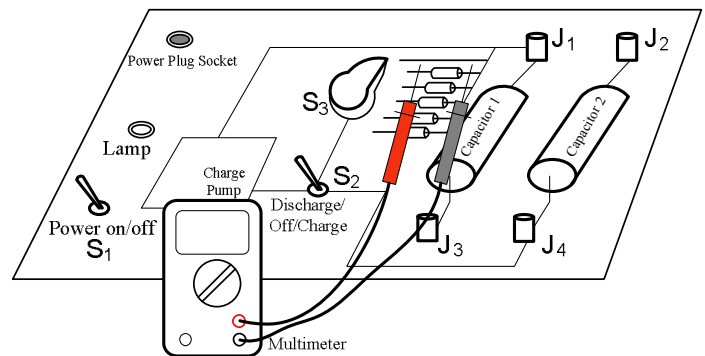
⑥ The capacitor to be compared is calculated by time constant divided by the resistance of the resistor. (Before you simply ask your TA about what the unit is, look for it from this manual.)

τ (time constant) from the above table	Resistance, R_1, from the above table	C (capacitance) = $\tau \div R_1$
( )←unit	( )←unit	( )←unit

Convert the units: The capacitance you obtain above table should be (F) if you use (s) and (Ω). Let's convert it into μF. (Do you want to multiply or divide? Let us give you an example. One dollar will be converted into 100 cents, so it is that 1 times 100. When you convert from a larger unit to a smaller one, the number will be larger. Farad (F) is larger than micro farad (μF). Now what will you do? Discus this with your partner.)

_____ (μF)

Question 1:
Are the capacitances you obtained close each other? Calculate the percent difference.

% difference = $\dfrac{|\text{ the first result - the second result }|}{\frac{1}{2}(\text{the first + the second})}$ = _____ (   ) ← units

Question 2:

Find the saturation voltage by using $Q = Q_0\left(1 - e^{-\frac{t}{RC}}\right)$, which expresses the charging process in an RC circuit. Q is the charge at time, t. Q_0 is the maximum possible charge to be stored in the capacitor. Use $Q = CV$, and it will be $CV = CV_0\left(1 - e^{-\frac{t}{RC}}\right) \Rightarrow V = V_0\left(1 - e^{-\frac{t}{RC}}\right)$. To solve for the saturation voltage, divide both sides by $1 - e^{-\frac{t}{RC}}$:

$$V_0 = \frac{V}{1 - e^{-\frac{t}{RC}}}$$

Use V and t as the measured maximum voltage and time respectively from part 2. The RC can be the time constant from part 3. Calculate the maximum possible voltage of the capacitor.

V_0 = _____ (   ) ← units

What is the ratio between the maximum possible voltage, V_0, **and** the voltage you obtained by the previous experiment, V?

(**Check your answer by yourself!** The voltage you experimentally obtained is almost the maximum as you can see in the graph. Thus, the ratio must be close to 100%; however, it is not 100% yet. Discuss how to calculate this with your partner before just plugging in the numbers.)

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