Experiment #: 04

Experiment Title: Charging curve of a capacitor / charging and discharging of a capacitor

Objectives:

1. The objective of this experiment is to verify the exponential behavior of capacitors during charging and discharging processes.

Theory:

Capacitors are devices that can store electric charge and energy. Capacitors have several uses, such as filters in DC power supplies and as energy storage banks for pulsed lasers. Capacitors pass AC current, but not DC current, so they are used to block the DC component of a signal so that the AC component can be measured. **Plasma physics** makes use of the energy storing ability of capacitors. In plasma physics short pulses of energy at extremely high voltages and currents are frequently needed. A capacitor can be slowly charged to the necessary voltage and then discharged quickly to provide the energy needed. It is even possible to charge several capacitors to a certain voltage and then discharge them in such a way as to get more voltage (but not more energy) out of the system than was put in.
This experiment features an *RC* circuit, which is one of the simplest circuits that uses a capacitor. You will study this circuit and ways to change its effective capacitance by combining capacitors in series and parallel arrangements.

DISCUSSION OF PRINCIPLES

A capacitor consists of two conductors separated by a small distance. When the conductors are connected to a charging device (for example, a battery), charge is transferred from one conductor to the other until the difference in potential between the conductors due to their equal but opposite charge becomes equal to the potential difference between the terminals of the charging device. The amount of charge stored on either conductor is directly proportional to the voltage, and the constant of proportionality is known as the ***capacitance***. This is written algebraically as
$Q = C\Delta V$.
The charge *C* is measured in units of *coulomb* (C), the voltage
ΔV in *volts* (V), and the capacitance *C* in units of *farads* (F). *Capacitors* are physical devices; *capacitance* is a property of devices.

Charging and Discharging

In a simple **RC circuit**, a resistor and a capacitor are connected in series with a battery and a switch. See Fig. 1.

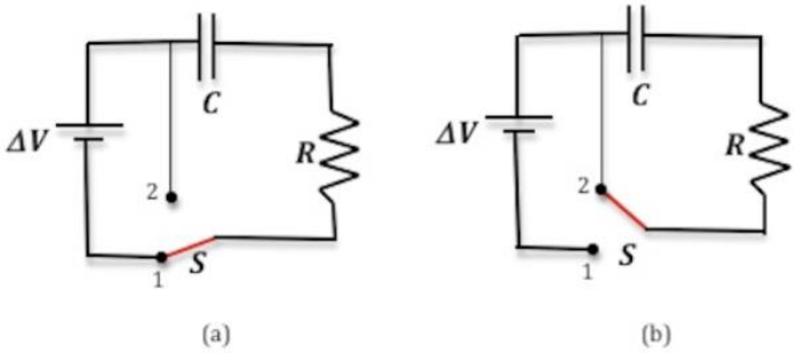

Figure 1: A simple RC circuit

When the switch is in position 1 as shown in Fig. 1(a), charge on the conductors builds to a maximum value after some time. When the switch is thrown to position 2 as in Fig. 1(b), the battery is no longer part of the circuit and, therefore, the charge on the capacitor cannot be replenished. As a result the capacitor discharges through the resistor. If we wish to examine the charging and discharging of the capacitor, we are interested in what happens *immediately* after the switch is moved to position 1 or position 2, not the later behavior of the circuit in its steady state.

For the circuit shown in Fig. 1(a), Kirchhoff's loop equation can be written as

$$\Delta V - \frac{Q}{C} - R\frac{dQ}{dt} = 0. \qquad (2)$$

The solution to is **Eq. (2)** is

$$Q = Q_f\left[1 - e^{(-t/RC)}\right] \qquad (3)$$

Where Q_f represents the *final* charge on the capacitor that accumulates after an infinite length of time, *R* is the circuit resistance, and *C* is the capacitance of the capacitor. From this expression you can see that charge builds up exponentially during the charging process. See Fig. 2(a).

When the switch is moved to position 2, for the circuit shown in Fig. 1(b), Kirchhoff's loop equation is now given by

$$\frac{Q}{C} - R\frac{dQ}{dt} = 0. \qquad (4)$$

The solution to **Eq. (4)** is

$$Q = Q_0 e^{(-t/RC)} \qquad (5)$$

Where Q_0 represents the *initial* charge on the capacitor at the beginning of the discharge, i.e., at $t = 0$. You can see from this expression that the charge decays exponentially when the capacitor discharges, and that it takes an infinite amount of time to fully discharge. See Fig. 2(b).

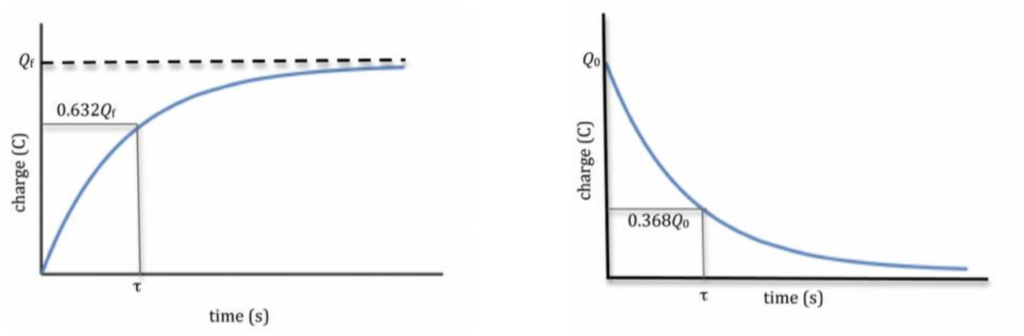

Figure 2: Change versus time graphs

Time Constant τ

The product RC (having units of time) has a special significance; it is called the time constant of the circuit. The time constant is the amount of time required for the charge on a charging capacitor to rise to 63% of its final value. In other words, when

$t = RC$ (6)

$Q = Q_f\,(1 - e^{-1})$

and

$1 - e^{-1} = 0.632.$ (7)

Another way to describe the time constant is to say that it is the number of seconds required for the charge on a *discharging* capacitor to fall to 36.8% ($e^{-1} = 0.368$) of its initial value.

We can use the definition($I = dQ/dt$) of current through the resistor and **Eq. (3)** and **Eq. (5)** to get an expression for the current during the charging and discharging processes.

charging: $I = +I_0 e^{-t/RC}$ (8)

discharging: $I = -I_0 e^{-t/RC}$ (9)

where $I_0 = \Delta V_0/R$

in **Eq. (8)** and **Eq. (9)** is the maximum current in the circuit at time $t = 0$.

Then the potential difference across the resistor will be given by the following.

charging: $\Delta V = +\,\Delta V_f e^{-t/RC}$ (10)

discharging: $\Delta V = -\,\Delta V_0 e^{-t/RC}$ (11)

List of Equipment:

Apparatus

1. A capacitor,
2. A resistance box,
3. 2 multi-meters,
4. connecting wires,
5. A watch,
6. A dc power source,
7. A 2-way switch
8. 2 Resistor

Circuit Diagram:

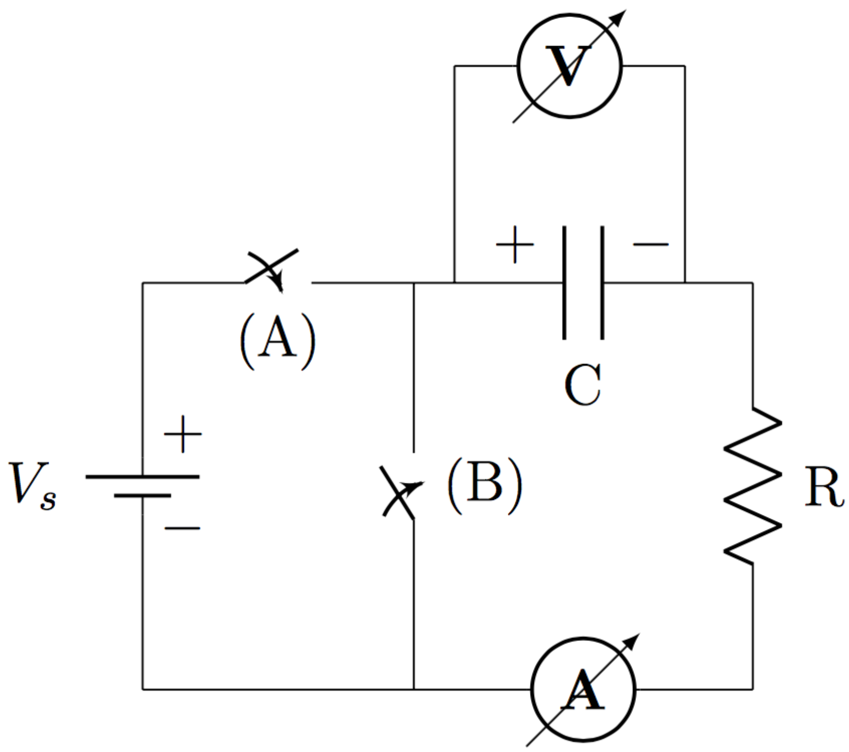

Figure 3 Circuit diagram

The experimental setup is shown in Figure 3. The internal resistance of the digital multimeter and the setting time can be disregarded. R is a protective resistor that limits the current while discharging (Switch setting B) the capacitor.

Procedure:

1. Ensure that the capacitor and resistance are working properly. Check with multimeter.
2. Adjust the voltage source to the desired value precisely and ensure that it works correctly using a digital multimeter.

3. Build the circuit shown in Figure 3 but be careful the minus part of the capacitor should be plugged in the correct direction of the current. If it is plugged in a wrong way the circuit does not work as requested.
4. Part I
5. By using the multimeter and the chronometer, record the experimental voltage value of the capacitor and current passing through the circuit as a function of time using the capacitor $C_1 = 1000$ μF and resistance R = 10 kΩ. Set the voltage source to $V_s = 10$V. (In the case of charging that means switch A is closed when switch B is opened).
6. NOTE: First, ensure that the capacitor is fully discharged by changing the switch to the position of II (position II corresponds to the closure of switch B in Figure 3).

Part I

Time (s)	Iexp (mA)	Vc (Volt)	Time (s)	Iexp (mA)	Vc (Volt)	Time (s)	Iexp (mA)	Vc (Volt)
5			115			225		
10			120			230		
15			125			235		
20			130			240		
25			135			245		
30			140			250		
35			145			255		
40			150			260		
45			155			265		
50			160			270		
55			165			275		
60			170			280		
65			175			285		
70			180			290		
75			185			295		
80			190			300		
85			195			305		
90			200			310		
95			205			315		
100			210			320		
105			215			325		
110			220			330		

Part II

Repeat the same procedure in Part I when switch B is closed and switch A is opened. It is called as discharging of the capacitor.

Time (s)	Iexp (mA)	Vc (Volt)	Time (s)	Iexp (mA)	Vc (Volt)	Time (s)	Iexp (mA)	Vc (Volt)
5			115			225		
10			120			230		
15			125			235		
20			130			240		
25			135			245		
30			140			250		
35			145			255		
40			150			260		
45			155			265		
50			160			270		
55			165			275		
60			170			280		
65			175			285		
70			180			290		
75			185			295		
80			190			300		
85			195			305		
90			200			310		
95			205			315		
100			210			320		
105			215			325		
110			220			330		

Part III

By using the multimeter and the chronometer, record the experimental voltage value of the capacitor and current passing through the circuit as a function of time using the capacitor C_2 = 2200 μF or make parallel connection of two capacitors of 1000 μF where the equivalent capacitance will doubled as 2000 μF and the resistance R = 10 kΩ. Set the voltage source to V_s = 10V. (In the case of charging that means switch A is closed when switch B is opened)

Time (s)	Iexp (mA)	Vc (Volt)	Time (s)	Iexp (mA)	Vc (Volt)	Time (s)	Iexp (mA)	Vc (Volt)
5			115			225		
10			120			230		
15			125			235		
20			130			240		
25			135			245		
30			140			250		
35			145			255		
40			150			260		
45			155			265		
50			160			270		
55			165			275		

60			170			280		
65			175			285		
70			180			290		
75			185			295		
80			190			300		
85			195			305		
90			200			310		
95			205			315		
100			210			320		
105			215			325		
110			220			330		

Part IV

By using the multimeter and the chronometer, record the experimental voltage value of the capacitor and current passing through the circuit as a function of time using the capacitor C_1 = 1000 μF and the resistance R = 10 kΩ. Set the voltage source to V_s = 5V. (In the case of charging that means switch A is closed when switch B is opened)

Time (s)	Iexp (mA)	Vc (Volt)	Time (s)	Iexp (mA)	Vc (Volt)	Time (s)	Iexp (mA)	Vc (Volt)
5			115			225		
10			120			230		
15			125			235		
20			130			240		
25			135			245		
30			140			250		
35			145			255		
40			150			260		
45			155			265		
50			160			270		
55			165			275		
60			170			280		
65			175			285		
70			180			290		
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4. Plot voltage vs time graph. How does the volage across the capacitor change with the time for all cases?
5. Plot (I_{exp}) vs time graph. How does the current change with the time for all cases?
6. Calculate the theoretical values of the time constants (RC) for all cases. Determine the experimental values of the time constants by drawing the ln (I_{exp}) vs time graph. In order to do that, calculate the ln() values with calculator first. The slope of the graph will be (-1/RC) which is shown in Equation 5. After mathematical manipulation, determine the percentage error in time constant.

graph paper

Time constant for		Theoretical	Experimental
C_1	:	....	....
C_2	:	....	....

% percentage error for		
	C_1	....
	C_2	....

7. How does the time constant change as the capacitance in the circuit increases?

Data Collection:

Calculation:

In this experiment, you will record the voltage across the capacitor and current passing through the circuit as a function of time for various capacitance and voltage source values. To observe the theoretical relation given in Eq. 1, it is best to graph natural logarithm of the current as a function of time. In that case, the theoretical expression can be written as

$$\ln I = \ln\left(\frac{V}{R}\right) - \frac{1}{RC}t$$

Result: