E&M Lab
Charging and discharging a capacitor

1. Objective:

- To observe the charging and discharging of a capacitor through a resistor.
- To measure the time constant of a series RC circuit.
- To acquire data using the science workshop interface.
- To transform data in order to make the graph linear.

2. Material:

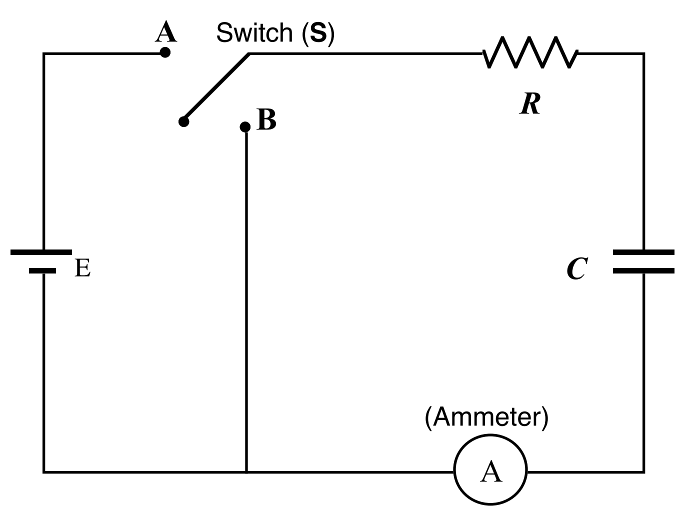
- Circuit board, power supply, 2 × multimeters, variable resistance box, capacitor, switch, science workshop interface, USB adaptor, 1 × voltage sensors.

3. Theory:

What is a capacitor?

A capacitor is a device than can store electric charge and energy. A capacitor is one type of circuit element that we can combine with others to make an electric circuit. When a capacitor is connected to a power supply, it will accumulate charge until the potential across the capacitor equals the supplied potential. In principle the charge remains on the capacitor until it is allowed to discharged through an electric circuit.

The amount of charge a capacitor can store is determined by its capacitance $C \equiv \dfrac{Q}{\Delta V}$. The capacitance is therefore the ratio of charge stored on the capacitor to the potential difference across the capacitor. The following equations will be derived in class, your job here will be to show experimentally that they are correct.



(fig.1)

a) Charging a capacitor

Consider the RC circuit shown in ***fig.1***. At t = 0 s, the capacitor (C) is completely uncharged. If the switch ***S*** is closed at position ***A***, the capacitor will eventually become fully charged. The current I in the circuit at any time t, is given by:

$$I(t) = I_{\max}\, e^{-t/\tau},$$

where $I_{\max} = \varepsilon/R$, in which ε represents the potential difference applied by the power supply, $\tau = RC$, in which R is the resistance of the circuit and C is the capacitance of the circuit. τ is called the time constant and is a measure of how much time is required to charge the capacitor.

As the capacitor charges, the potential across the device increases until it reaches the potential provided by the power supply:

$$V(t) = \varepsilon \left(1 - e^{-t/\tau}\right).$$

The charge q on the capacitor at any given time t after the switch is closed is given by:

$$q(t) = C\ V(t).$$

b) Discharging a capacitor

Consider again the RC circuit in ***fig.1***. In this case, at t = 0 s, the capacitor is fully charged. When the switch ***S*** is placed at position ***B***, the capacitor will discharge, eventually become completely uncharged. The current I in the circuit at any time t after the switch is closed is given by:

$$I(t) = I_{\max}\, e^{-t/\tau}.$$

As the capacitor discharges, the potential across the device will decreases until it reaches zero:

$$V(t) = V_0\ e^{-t/\tau}.$$

The initial value of the potential (V_0) does not need to be the same as the power supply, as you could start discharging the device before it is fully charged.

The charge q on the capacitor at any given time t after the switch is closed is given by:

$$q(t) = C\ V(t).$$

4. Procedure

Connect the circuit as shown in ***fig.1***. Leave the switch ***S*** open. Set the voltage ε of the power supply at 10 V, R at 50 kΩ. Measure ε and R with the multimeter. Your teacher will measure the capacitance C with the capacitor tester to obtain a precise value.

From these values, you will be able to calculate the expected values of I_{max} and of the time constant τ.

Keep a voltmeter connected to the power supply to make sure the potential remains constant at 10 V.

Make sure the capacitor is ***fully discharged*** before you place the switch in position ***A***. To make sure the capacitor has no charge on it, short-circuit the capacitor with a wire. This will make the potential difference across the capacitor exactly zero.

Potential across the capacitor while charging: Use the voltage sensor and the science workshop interface to measure the potential ***across the capacitor*** at a frequency of 10 Hz as it is charging. Let the capacitor charge for 300 s. At a rate of 10 points/second, this will represent 3000 points. During data acquisition, leave the computer alone! Doing anything else, like changing the axes scale of the graph, checking your emails or updating your Facebook status may result in loss of data.

When data acquisition is completed, export your data in a text file. The file should have 2 columns (time; ΔV across the capacitor), and about 3000 rows. The name you give to the text file must have less than 8 characters.

Potential across the capacitor while discharging: Before starting the discharging phase, make sure the capacitor is fully charged. In order to do so, with the switch in position ***A***, short-circuit the resistance. This will charge the capacitor almost instantly.

Once the capacitor is fully charged, place the switch in position ***B***. Record again the potential across the capacitor at a rate of 10 Hz for 300 s. Export your data in another text file.

Potential across the resistor while charging: Move the voltage sensor to measure the potential across the resistor in the circuit. Using ohm's law ($\Delta V = RI$) across the resistor, you will then be able to calculate the current flowing through the resistor as a function of time. Make sure to note how the voltage sensor is connected in the circuit. This will allow you to find the direction of the current in the circuit.

Make sure the capacitor is ***fully discharged*** before you place the switch in position ***A***.

Potential across the resistor while discharging: Before starting the discharging phase, make sure the capacitor is fully charged. In order to do so, with the switch in position ***A***, short-circuit the resistance. This will charge the capacitor almost instantly.

Once the capacitor is fully charged, place the switch in position ***B***. Record again the potential across the resistor at a rate of 10 Hz for 300 s. Export your data in another text file.

You should have now 4 text files each containing 3000 points of data.

5. Data Analysis

a) Charging phase:

- Using the data across the resistor, plot a graph of I versus t. This should be an exponential function as seen in the theory. Add an exponential trendline on your data.
- Using Excel, transform the data so it gives you a straight line: plot a graph of $\ln(I)$ versus t. Use LINEST to find the slope and intercepts of this line.
- From these parameters determine the values of I_{max} and the time constant τ, including uncertainties. Compare them to the expected values.
- Plot a graph of ΔV across the capacitor versus t.
- This graph does not follow a simple exponential function. Indeed, Excel does not let you fit an exponential trendline on this graph. Do not fit any other type of function.
- Explain if this graph is consistent with the theory.

b) Discharging phase:

- Using the data across the resistor, plot a graph of I versus t. Explain how this is consistent with theory. Make it linear.
- Plot a graph of ΔV across the capacitor versus t. Transform the data, so you can plot it as a straight line. Use Excel to determine the parameters of this line.
- From these parameters determine the voltage ε of the power supply and the time constant, and compare the experimental results to the expected values.

6. Report

- You should present seven (7) graphs:
  - ***charging phase***:
    - I vs t,
    - $\ln(I)$ vs t,
    - ΔV vs t,
  - ***discharging phase***:
    - I vs t,
    - transformed(I) vs t, so it is linear.
    - ΔV vs t,
    - transformed(ΔV) vs t, so it is linear.
- Your data should use approximately 80% of the area of the graph, and the graph should be no smaller than 1/2 a page. All axes should be labeled correctly and show the units of the scales. You must place a descriptive title at the top of the graph.
- In your conclusion, discuss why it is useful to transform the data to plot it as a straight line.