EXPERIMENT II

THE RC TIME CONSTANT

Objective

- Investigate the discharge behavior of a capacitor in an RC circuit.
- Measure the voltage as a function of time and determine the RC time constant.
- Compare the experimental time constant with the theoretical value $\tau = RC$.
- Practice plotting and analyzing exponential decay data.

Experimental Materials

- DC power supply, digital voltmeter or multimeter, capacitor, switch, stopwatch or timer, connecting wires, breadboard or circuit board

Theoretical Background

An RC circuit consists of a resistor R, a capacitor C, and a source of emf ε. The circuit behavior depends on how the capacitor is connected through the switch. In the configuration shown in Figure 1, the switch allows the capacitor either to be connected to the power supply (position A) or to be disconnected from it and discharge through the resistor (position B).

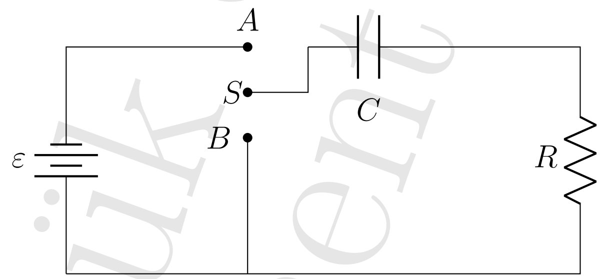

Figure 1: RC circuit with a switch selecting charging at A or discharging at B.

If the switch is placed at position A at time $t = 0$, the capacitor begins to charge through the resistor. Initially, the capacitor is uncharged, so the current has its maximum value $I_0 = \varepsilon/R$. As charge accumulates on the capacitor plates, the voltage across the capacitor increases and opposes the source. As a result, the current decreases exponentially with time, while the charge on the capacitor increases toward its maximum value $C\varepsilon$. The time dependence of the charge and current is given by

$$Q(t) = C\varepsilon\left(1 - e^{-t/RC}\right), \qquad I(t) = \frac{\varepsilon}{R}e^{-t/RC}.$$

After a sufficiently long time, the capacitor becomes fully charged, and the current in the circuit approaches zero. If the switch is then moved to position B, the power supply is removed from the circuit, and the capacitor discharges through the resistor. During this process, both the charge on the capacitor and the current decrease exponentially:

$$Q(t) = Q_0 e^{-t/RC}, \qquad I(t) = \frac{Q_0}{RC}e^{-t/RC}.$$

The quantity RC is called the time constant of the circuit and determines how fast the capacitor charges or discharges. It has units of seconds, and it represents the characteristic time scale over which significant changes occur in the circuit. For example, during discharge, the voltage or charge drops to about 37% of its initial value after a time equal to RC.
In practical measurements, the voltage across the capacitor is often recorded as a function of time while it discharges through a resistance. In many laboratory setups, the internal resistance of the measuring device (voltmeter) acts as the effective resistance through which the capacitor discharges. This situation is illustrated in Figure 2.

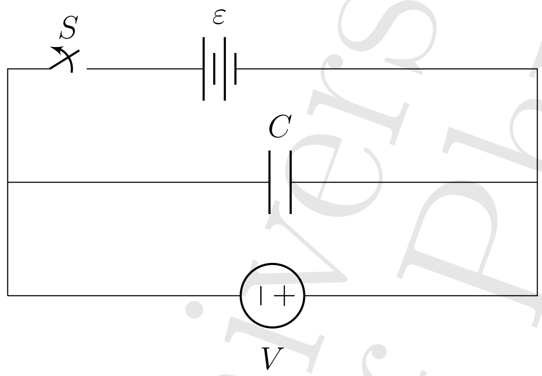

Figure 2: RC circuit in which the voltmeter input resistance acts as the discharge resistance.

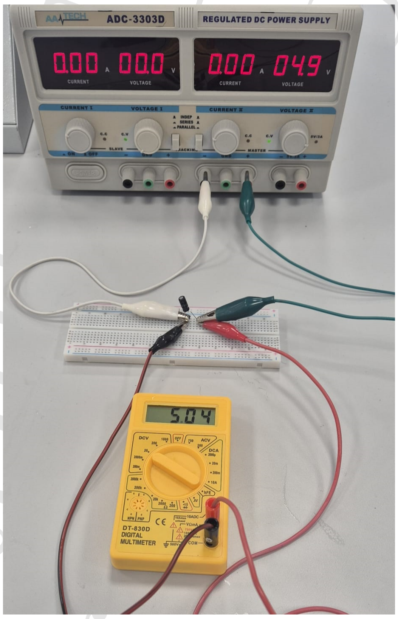

Figure 3: RC circuit experimental setup.

When the switch is opened, the capacitor discharges through the effective resistance R_v, and the voltage across the capacitor follows

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

Taking the natural logarithm of both sides gives

$$\ln V = \ln V_0 - \frac{t}{RC}.$$

Thus, a plot of $\ln V$ versus time t yields a straight line with slope $-1/RC$. From this slope, the time constant of the circuit can be determined experimentally. If the resistance is known, the capacitance can be calculated, and vice versa.

Procedure

1. Construct the circuit shown in Figure 2 using the capacitor, the voltmeter, the switch, and the DC power supply. Before applying power, have the circuit checked by the instructor. Record the input resistance of the voltmeter in the data table as R.

2. Close the switch and adjust the power supply until the capacitor is fully charged to the selected initial voltage V_0. Record this initial voltage in the data table.

3. Open the switch and simultaneously start the timer. As soon as the discharge begins, record the capacitor voltage at predetermined time intervals. As a reference, the following time values may be used:

$$t = 0,\ 10,\ 20,\ 30,\ 40,\ 50,\ 60,\ 80,\ 100,\ 120,\ 140 \text{ s}.$$

   If different time intervals are specified by the instructor, follow those values instead. The initial voltage V_0 should be measured immediately before opening the switch. This value is used in calculating $\ln(V_0/V)$. Unless otherwise instructed, the linear least-squares fit should be applied only to the discharge data points with $t > 0$.

4. Enter the measured voltage $V(t)$ corresponding to each time value in the data table.

5. Using the voltage values, calculate

$$\ln\left(\frac{V_0}{V}\right)$$

   for each measurement time and record the results in the table.

6. Perform a linear least-squares fit to the graph and determine the slope of the best-fit line.

7. Use the relation

$$\text{slope} = \frac{1}{RC}$$

   to calculate the experimental value of the time constant RC.

8. Using the measured value of RC and the known resistance R, calculate the capacitance C of the capacitor.

Graphs

1. Using the measured data, plot the voltage V as a function of time t. Place t on the horizontal axis and V on the vertical axis. The graph should display an exponential decay behavior.

2. Draw a smooth curve through the data points to represent the overall trend of the exponential decrease.

3. Using the calculated values, plot $\ln(V_0/V)$ as a function of time t. Place t on the horizontal axis and $\ln(V_0/V)$ on the vertical axis.

4. On the $\ln(V_0/V)$ versus t graph, draw the straight line obtained from the linear least-squares fit to the data.

THE RC TIME CONSTANT EXPERIMENT REPORT

Name: **Surname:**
Student ID: **Group:** **Date:**

Experimental Data: Present the measured data in tables or figures where appropriate.

Table: Time and voltage measurements for verification of the RC time constant

t **(s)**	V **(V)**	ΔV **(V)**	$\ln(V_0/V)$	$\Delta[\ln(V_0/V)]$

V_0 (V)	
R (Ω)	
Slope (s^{-1})	
RC (s)	
C (F)	

Measurement Analysis: Show the calculations performed using the experimental data, including relevant formulas.

Conclusion / Discussion: Summarize the results, discuss their physical meaning, and compare them with theoretical expectations.

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