Determining the capacitor charging curve

The aim of the exercise is to examine the course of the capacitor charging process and to determine the time constant of the serial RC system.

Objectives

- capacitor capacity,
- Ohm's law for an electric circuit,
- Kirchhoff's laws,
- series and parallel connection of capacitors,
- series and parallel connection of resistors,
- Joule-Lenz law,
- capacitor charging / discharging,
- least squares method.

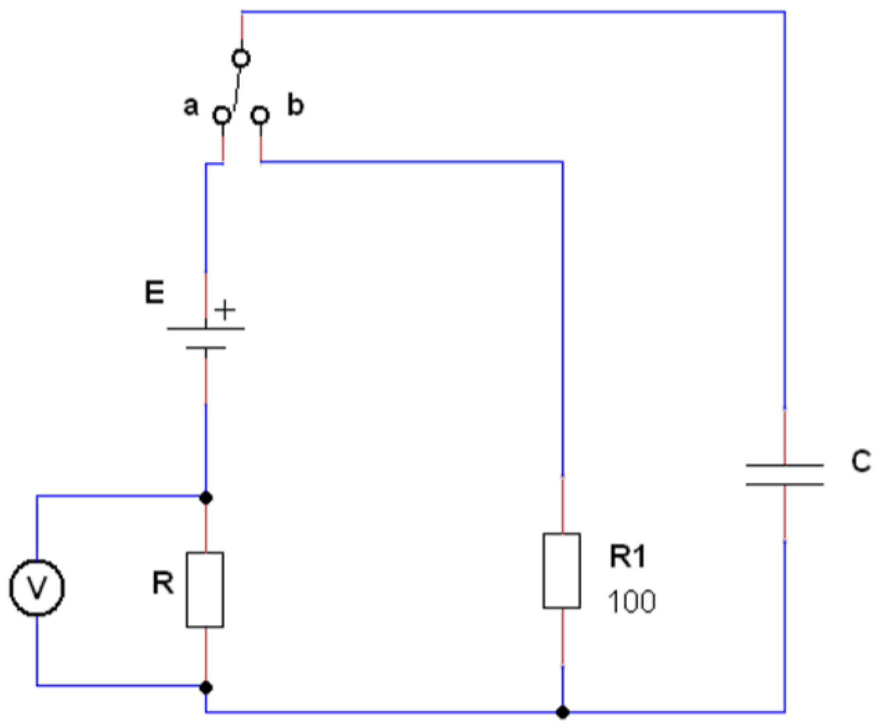

Figure 1: The scheme of the measuring system

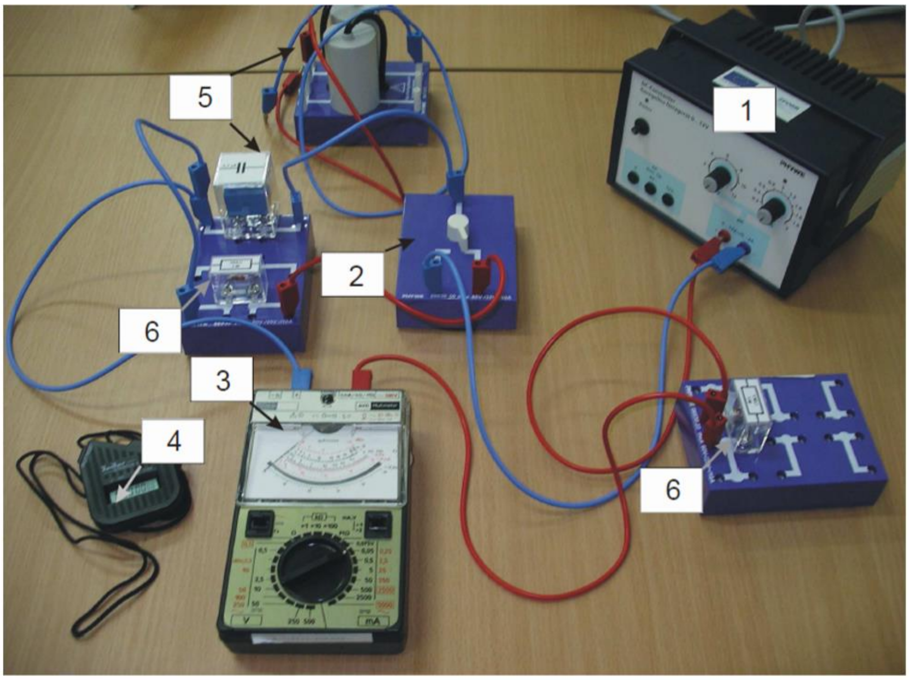

Figure 2: A photo presents elements of the of the measuring system. It includes: 1 - power supply, 2 - switch, 3 - universal meter, 4 - stopwatch, 5 - capacitors, 6 - resistors.

Realization of the experiment

1. Connect the system according to the diagram in Figure 1.
2. Set switch (2) in position b.
3. Turn on the power supply (1) and set it to $\epsilon = 12V$.
4. Execution the process of charging the capacitor (5): simultaneously with switching the switch (2) to position a, start the stopwatch (4) and write the voltage value from the meter (3) every 10 seconds. The experiment must be carried out by two people. Depending on the system tested, the measurement should be carried out for $150 - 300$ s.
5. After completing the measurements, discharge the capacitor: switch (2) in position b. The discharge current will flow through the R_1resistor.
6. After discharging the capacitor, an additional capacitor can be connected in parallel or an additional resistor can be connected in series to the R resistor, thus changing the time constant of the system.
7. After changing the C or R value, carry out additional measurements in the same way, i.e. repeat steps 4-5.

Problems

1. Measure the voltage change at the resistance R while charging the capacitor for $\epsilon = 12V$, $R = 1M\Omega$ i $C = 30\mu F$.
2. Measure the voltage change at the resistance R when charging the capacitor for larger values of C (at constant values of ϵ and R). Plot and discuss the relationship $\tau = f(C)$.
3. Measure the voltage change at the resistance R when charging the capacitor for larger R values (at constant values of τ and C). Plot and discuss the relationship $\tau = f(R)$.

Information:

Connecting the capacitor (C) to the source of the electromotive force (ϵ) leads to its charging with the charge $q = C\epsilon$. The speed of charging a capacitor is determined by the series electrical resistance (R) through which the capacitor is connected to the source ϵ. The speed of the capacitor charging process is determined by a parameter called the time constant.

During charging, the work done by the electromotive force (ϵdQ) must be equal to the sum of energy released in the form of heat on the resistance (I^2Rdt) and the increase in energy stored in the condenser:

$$\epsilon dQ = I^2Rdt + \frac{Q}{C}dQ\,,$$

where $dQ = Idt$ is the charge flowing in the time interval dt. Using this relationship we get:

$$\epsilon = R\frac{dQ}{dt} + \frac{Q}{C}$$

The solution of this equation, with $Q = 0$ at $t = 0$, has the following form:

$$Q = C\epsilon\left[1 - exp\left(-\frac{t}{RC}\right)\right]$$

This equation shows how the charge on the capacitor changes when it is being charged (since the switch (2) is set to position a). Time derivative of the above equation, determine how the capacitor charging current changes over time:

$$I = \frac{\epsilon}{R} exp\left(-\frac{t}{RC}\right).$$

This current decreases e-times after time $\tau = RC$, hence the value τ is called the time constant of the system.

For technical reasons, we do not measure the change in the charging current. Instead we measure the voltage changes over time across the resistance R. This method of testing can be carried out with a multimeter - there is no need to measure microamp current values. From relationship $I(t)$, we get that during the charging of the capacitor C, the voltage at the resistance R changes over time as follows:

$$U = \epsilon exp\left(-\frac{t}{RC}\right).$$

The results obtained from the measurement should therefore be plotted in the form $\ln(U) = f(t)$. This relationship should be linear. The parameters of the obtained linear relation should be determined directly from the graph or the method of least squares. Then the time constant of the system should be calculated. Finally, compare the experimentally obtained τ value with the value that can be expected considering the nominal R and C values.

Error analysis

We evaluate the uncertainty of U and t measurement during measurements based on the scale, range and class of measuring instruments used. The calculated uncertainty values should be put on the chart. We estimate the uncertainty of the parameters of the linear function from the graph or calculate a standard uncertainties using the appropriate least squares method formulas. The uncertainty of determination τ is defined as the uncertainty of the composite quantity, expressed by the direction factor of the linear relationship.