Experiment 14

Charging curves of a Capacitor

Apparatus:
Connection box, two-way switch (single pole), capacitors, resistors, power supply, stopwatch, multimeter, connecting cords.
Purpose of the Experiment
In this experiment we study the transient behavior of an RC circuit. The concept of time constant of an RC circuit is demonstrated.
Basic Methodology:
A capacitor, in series with a resistor, is charged by a battery. The current in the circuit is measured as a function of time. The time constant is estimated from the current Vs time graph.

I Theory:

The basic circuit for charging/discharging a capacitor is shown in the figure on the next page. If switch a is closed (see figure), the battery charges the capacitor and current flows though resistor R and the micro-ammeter until the capacitor C is fully charged. If the charge on the capacitor at time t is $q(t)$, then the voltage across the capacitor C is q/C and the current through R is $dq/dt = I$.

By applying Kirchoff's second law,

$$IR + \frac{q}{C} = U \quad \Longrightarrow \quad R\frac{dq}{dt} + \frac{q}{C} = U. \tag{1}$$

With the initial condition $q = 0$ at $t = 0$, this has the solution

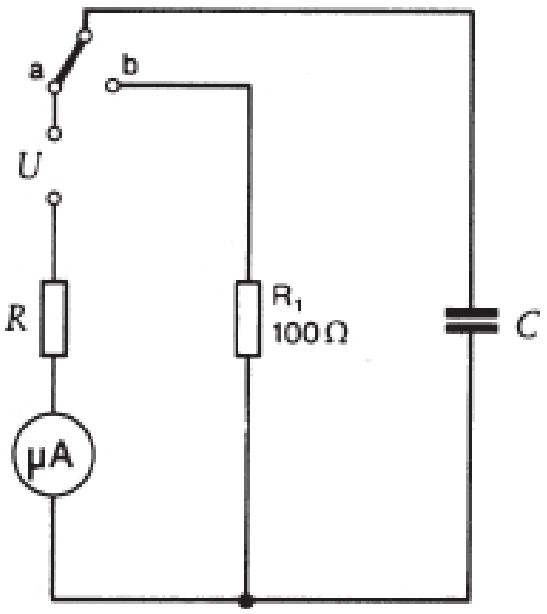
$$q(t) = CU(1 - e^{-t/RC}) = q_0(1 - e^{-t/\tau}). \tag{2}$$

where $q_0 = CU$ and $\tau = RC$. The quantity $\tau = RC$ is the **time constant** which characterizes the rate at which charge is deposited on the capacitor. In particular, at $t = \tau$, the capacitor charges to $q_0(1-e^{-1}) = 0.632q_0$. It charges to the maximum value q_0 ultimately at $t \to \infty$. Once the capacitor is fully charged then the current I through the resistor becomes zero. Equation (2) also implies that the instantaneous current in the circuit is given by

$$I \equiv \left|\frac{dq}{dt}\right| = \frac{U}{R}\exp(-t/(RC)).$$

II Set-up and Procedure:

1. Connect the circuit as shown in the figure.
2. Put the circuit in discharge mode. Set the voltage in the dc supply to the recommended value.
3. Switch to charging mode and start recording the current in the circuit every five seconds.
4. Plot a graph of current versus time.
5. Calcuate the time constant from graphical analysis and compare it with time constant based on component values.



Capacitor charging circuit
a) charging b) discharging

III Exercises and Viva Questions:

1. Plot qualitatively the curves $q(t)$ describing charging and discharging of a capacitor and explain these curves physically.
2. What is the physical meaning of the time constant $\tau = RC$? Explain for both the cases of charging and discharging. Verify that RC has the dimensions of time.
3. By what percentage (with respect to the maximum charge on the capacitor C), does the capacitor charge/discharge in a time interval $t = \tau, t = 2\tau$?
4. What kind of capacitors are used in this experiment?
5. As the capacitor discharges it loses energy. Verify by calculation that this is equal to the energy dissipated through the resistor.
6. Explain how the RC circuit can be used to measure a large unknown resistance.
7. Suggest a mechanical analogy for the electrical process of charging and discharging.

References:

1. *Physics*, M. Alonso and E.J. Finn, Addison Wesley 1992.
2. *Fundamentals of Physics*, R. Resnick, D. Halliday and J. Walker, John Wiley and Sons, New York 2001.