Charging curve of a capacitor (Item No.: P2420201)

Curricular Relevance

Area of Expertise:	Education Level:	Topic:	Subtopic:	Experiment:
Physics	Univerity	Electricity and Magnetism	Capacitors, Dielectric, Electric Energy, Storage	Charging curve of a capacitor / charging and discharging of a capacitor

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Easy	20 Minutes	30 Minutes	2 Students

Additional Requirements:

Experiment Variations:

Keywords:

Overview

Short description

Related topics

Charging, discharging, time constant, exponential function, half life.

Principle

A capacitor is charged by way of a resistor. The current is measured as a function of time and the effects of capacitance, resistance and the voltage applied are determined.

Fig. 1: Experimental set-up for measuring the current when a capacitor is being charged.

Equipment

Position No.	Material	Order No.	Quantity
1	Connection box	06030-23	2
2	Two-way switch, single pole	06030-00	1
3	Capacitor,2x30 micro-F	06219-32	1
4	Resistor 100 Ohm, 1W, G1	39104-63	1
5	Resistor 1 MOhm, 1W, G1	39104-52	4
6	Short-circuit plug, white	06027-06	2
7	Capacitor 1 microF/ 100V, G2	39113-01	1
8	Capacitor 4,7microF/ 100V, G2	39113-03	1
9	PHYWE power supply DC: 0...12 V, 2 A / AC: 6 V, 12 V, 5 A	13506-93	1
10	Stopwatch, digital, 1/100 s	03071-01	1
11	DMM, auto range, NiCr-Ni thermocouple	07123-00	1
12	Connecting cord, 32 A, 250 mm, red	07360-01	3
13	Connecting cord, 32 A, 250 mm, blue	07360-04	4

Tasks

To measure the charging current over time:

1. using different capacitance values C, with constant voltage U and constant resistance R
2. using different resistance values (C and U constant)
3. using different voltages (R and C constant).

To determine the equation representing the current when a capacitor is being charged, from the values measured.

Set-up and procedure

Set up the experiment as shown in Fig. 1 and Fig. 2.

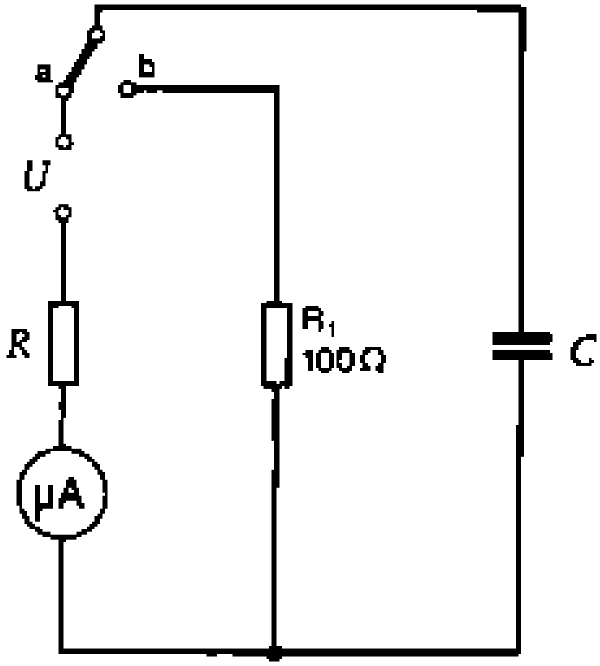

Fig. 2: Capacitor charging circuit a) charging b) discharging

Various resistance values R are established by series connection. The internal resistance of the digital multimeter and the setting time can be disregarded.

R_1 is a protective resistor which limits the current when discharging (switch setting b).

Theory and evaluation

The course of current with time, $I(t)$, when a capacitor C is charged through a resistor R at a fixed voltage U (Fig. 2) is determined from Kirchhoff 's laws:

$I(t) = \frac{U}{R} e^{\frac{t}{RC}}$ (1)

The dependence of the current on the capacitance, the resistance and the voltage should be worked out from the measured values obtained by systematically varying the parameters.

1. First plot the measured values direct (Fig. 3) and then semilogarithmically (Fig. 4).

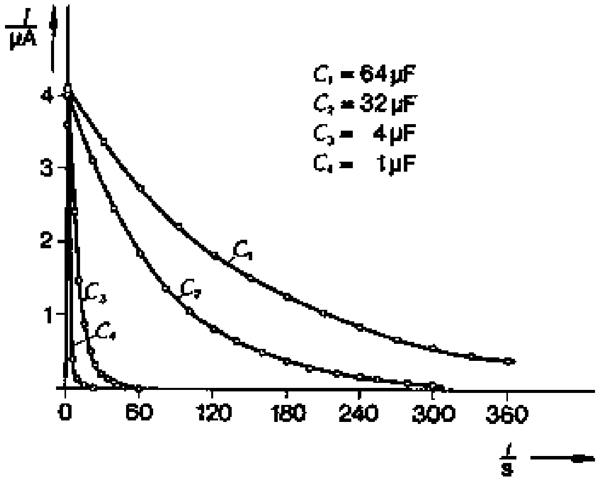

Fig. 3: Course of current with time at different capacitance values; voltage and resistance are constant ($U = 9V$, $R = 2.2 M\Omega$).

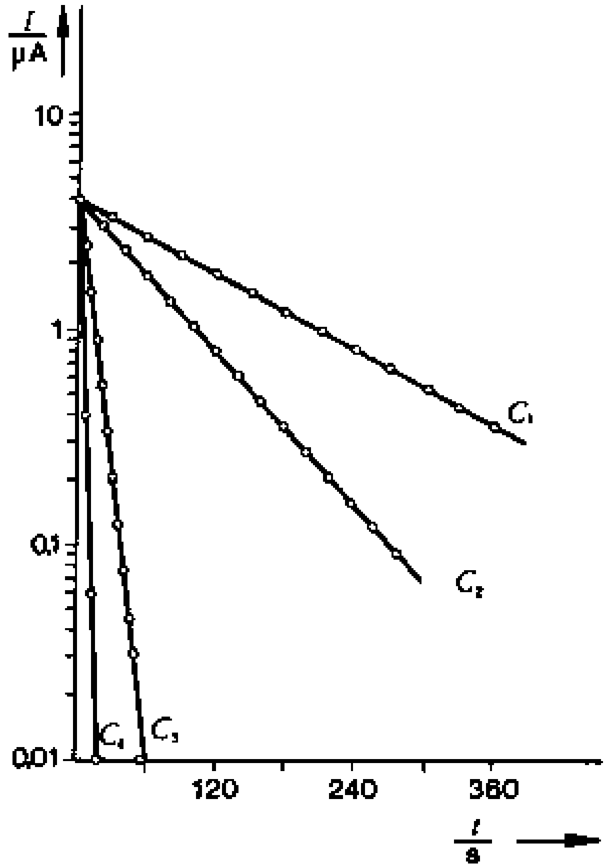

Fig. 4: as Fig. 3, but plotted semi-logarithmically.

According to Figs. 3 and 4; the function takes the general form

$I(t) = I_0(U,R) e^{\alpha(U,R,C)) \cdot t}$

I_0 is not dependent on C as all curves begin at the same current values.

To investigate the dependence of the exponent on the capacitance, the slopes of the straight lines in Fig. 4 are plotted against capacitance, on a log-log basis.

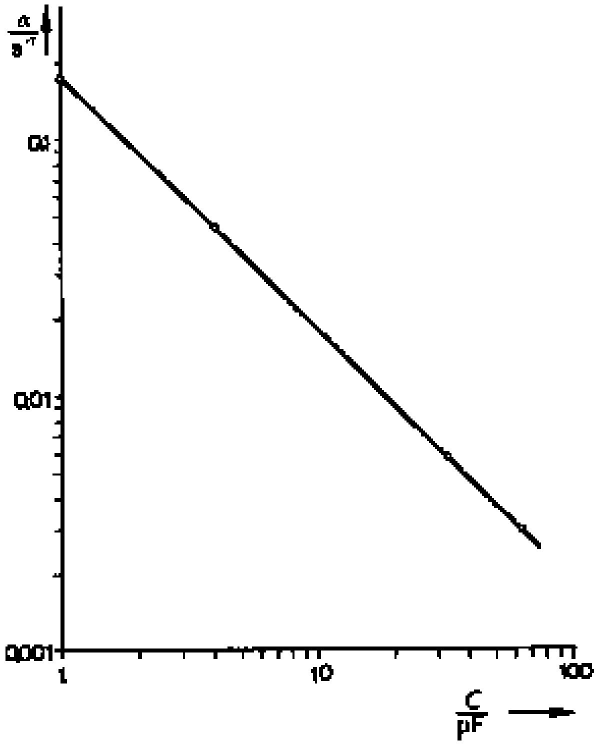

Fig. 5: Exponent α as a function of capacitance C .

A straight line with the slope $-0.98 \approx -1$ is obtained, so that

$$I(t) = I_0(U,R)e^{\frac{\alpha'(U,R)}{C}t}$$

2. Straight lines with different slopes and different starting points are obtained. The dependence of the exponent on R is determined by plotting the log-log of the straight lines in Fig. 6.

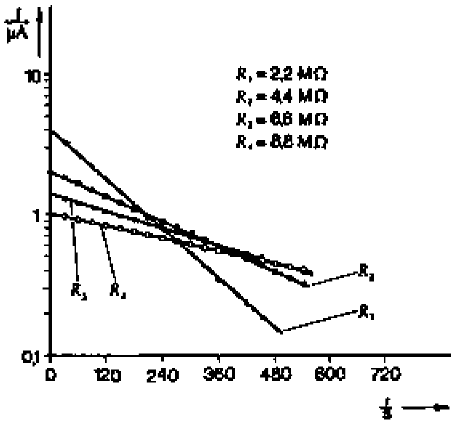

Fig. 6: Course of current with time at different resistance values; capacitance and voltage are constant at $64\mu F$ and 9 V respectively.

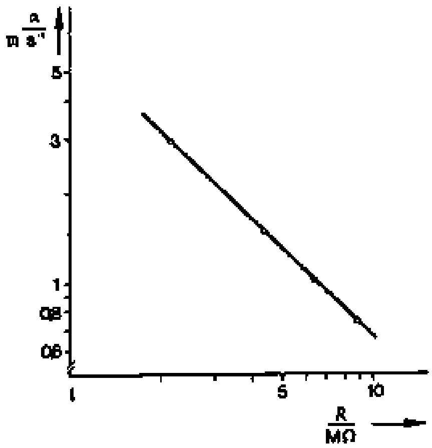

Fig. 7: Exponent α as a function of resistance R.

A straight line with the slope –1.00 is obtained, so that

$$I(t) = I_0(U,R)e^{\frac{\alpha''(U)}{RC}\cdot t}$$

The straight line in Fig. 8 has a slope of $-0.99 \approx -1$, i.e.

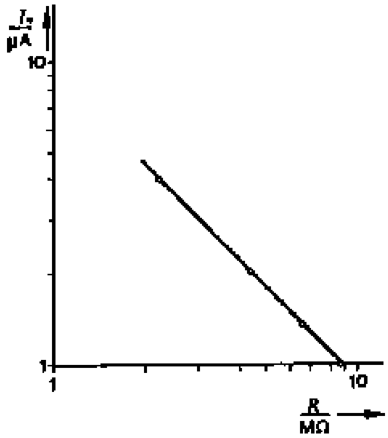

Fig. 8: Starting current I_0 of the measured values in Fig. 6 as a function of the resistance.

$$I_0 = \frac{\beta(U)}{R}$$

3. All the straight lines in Fig. 9 have the same slope. The exponent is thus independent of the voltage U (this statement can also be made on the basis of dimensions). The slope of the straight line is

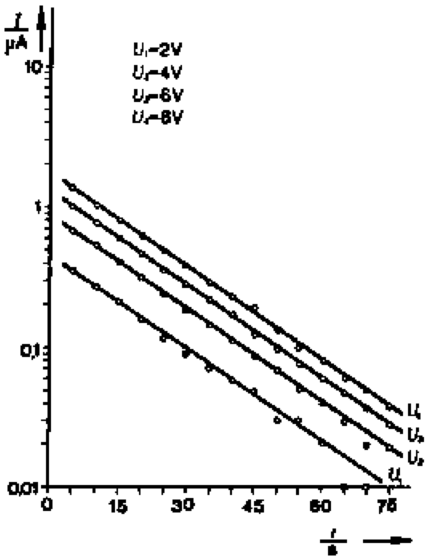

Fig. 9: Course of current with time at various voltages $R = 4.4\ M\Omega$, $C = 4\ \mu F$).

$$0.058\ \mathrm{s}^{-1} = \frac{1}{RC} \rightarrow RC = 17.24\ \mathrm{s}$$

The starting current values I_0 for the measured values in Fig. 9 are plotted directly against the voltage values U in this case (Fig. 10).

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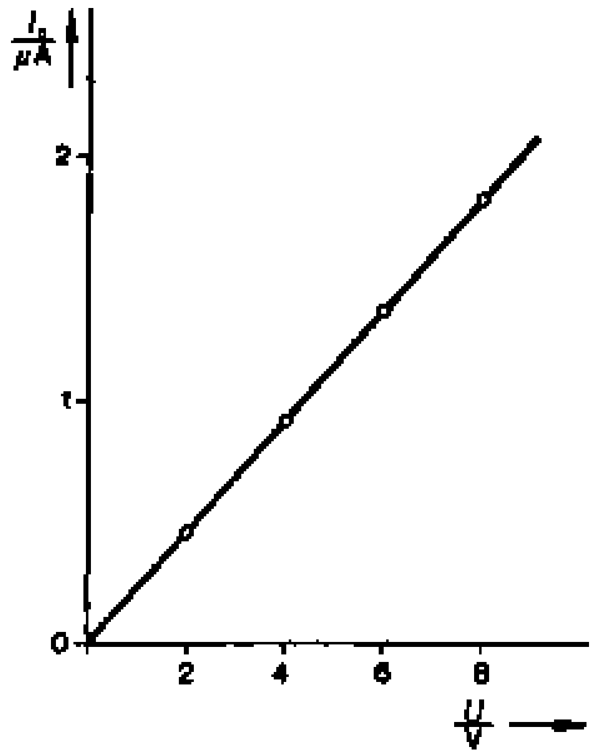

Fig. 10: Starting current as a function of the applied voltage ($R = 4.4$ MΩ, $C = 4\ \mu F$).

A straight line with the slope

$$0.227 \frac{\mu A}{V} = \frac{1}{R} \rightarrow R = 4.41 M\Omega$$

is obtained.

Taken together, therefore, all the measured values give equation (1).

Note

If discharging curves are to be measured as well, the circuit as shown in Fig. 11 will be used.

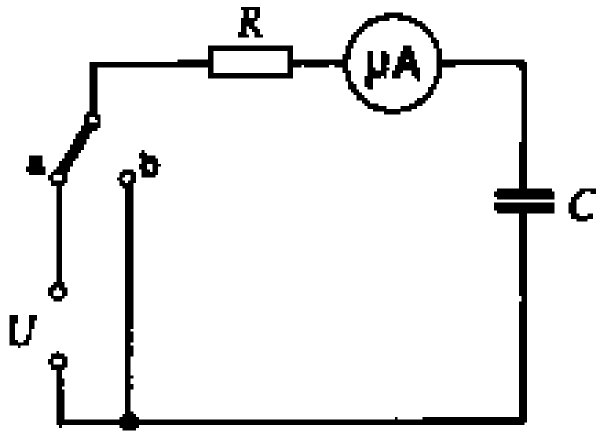

Fig. 11: Circuit for recording charging and discharging curves.

Another experiment which could be carried out would be to determine unknown capacitance values from the charging and discharging curves with known resistance and charging function, or conversely to determine large resistance values at known capacitance.