GDYNIA MARITIME UNIVERSITY
FACULTY OF MECHANICAL

PHYSICS LABORATORY
DEPARTMENT OF PHYSICS

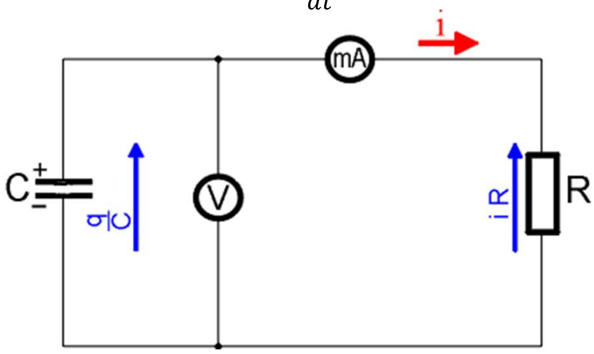
Theoretical Introduction

Experiment "C A P A C I T O R"

Capacitor Discharge

In the capacitor discharge circuit, the current intensity is defined as the rate of capacitor discharge, that is, the rate of decrease of charge on the capacitor:

$$i = \frac{dq}{dt}$$



From Kirchhoff's law for a closed circuit, applied to the discharge circuit, the following differential equation is obtained:

$$\frac{q}{C} - iR = 0 \qquad \rightarrow \qquad \frac{q}{C} - \frac{dq}{dt} \cdot R = 0$$

After separating the variables, we obtain:

$$\frac{dq}{q} = \frac{1}{RC} dt$$

After integrating both sides:

$$\ln q = \frac{1}{RC} t + const$$

where the integration constant is identified as: *const* = ln q_o therefore:

$$\ln \frac{q}{q_0} = \frac{1}{RC} t$$

The charge $q$flowing from the capacitor is:

$$q = q_0 e^{-\frac{t}{RC}}$$

Since: $i = \frac{dq}{dt}$, we obtain:

$$i = i_0 e^{-\frac{t}{RC}}$$

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Preparation Questions:

1. What is a capacitor? Describe the construction of a parallel-plate capacitor.
2. What is the capacitance of a capacitor? Give the definition and unit.
3. What does the capacitance of a parallel-plate capacitor depend on?
4. Discuss series and parallel connection of capacitors.
5. What is the difference between a battery and a capacitor?
6. What is a time constant?
7. What does the time constant of a capacitor depend on?
8. What is the number e? Give its definition and value.
9. What is the unit of electric permittivity of a medium, for example air?
10. What is a conductor and what is a dielectric?
11. What is the equivalent capacitance of three identical capacitors, each with a capacitance of $2\mu F$, connected in series?
12. Calculate the equivalent capacitance of a system of five identical capacitors, each with a capacitance of $2\mu F$, connected in parallel.
13. Capacitance of a parallel-plate capacitor. Calculate the capacitance of a parallel-plate capacitor whose rectangular plates have dimensions 1 cm $\times$ 2 cmand are separated by a distance of 0.5 cm.
14. Capacitance of a parallel-plate capacitor. Calculate the capacitance of a parallel-plate capacitor whose rectangular plates have dimensions 1 cm $\times$ 2 cmand are separated by a distance of 0.5 cm. Calculate the capacitance of this capacitor filled with a dielectric with a dielectric constant equal to 5.
15. What does the energy stored in a capacitor depend on?

Course of Activities:

1. With the instructor’s permission, switch on the power supply of the system and set the proposed voltage value.
2. Switch on capacitor charging.
3. Read the current value on the microammeter, the initial current value.
4. After the capacitor has been charged, disconnect it from the power supply using the charging switch, while simultaneously starting the time measurement.
5. At selected current or time values, read the values of time $t$and current i, until ten values of each parameter are obtained, so that the last current measurement $i$has a value of at least $1\mu A$.
6. After completing the measurements, tidy up the workstation.
7. Perform the calculations according to the instruction and prepare a trial graph in a spreadsheet. In the calculations, remember to use the basic SI units for current and time.
8. Prepare a measurement protocol and measurement uncertainties.

NOTE:

- The capacitor charging voltage must not exceed the value specified by the instructor.
- The value of the time constant can be determined on the basis of the capacitance value of the discharged capacitor and the resistance value through which the discharge takes place.

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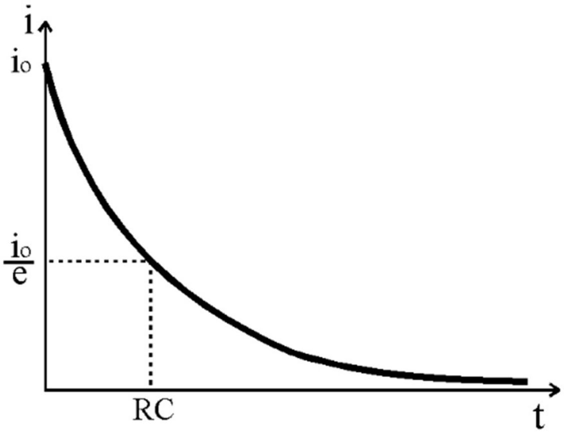
Methodological Template

Student 1: Determination of the time constant of the capacitor discharge circuit.
Student 2: Verification of the dependence of current intensity in the capacitor discharge circuit on time.

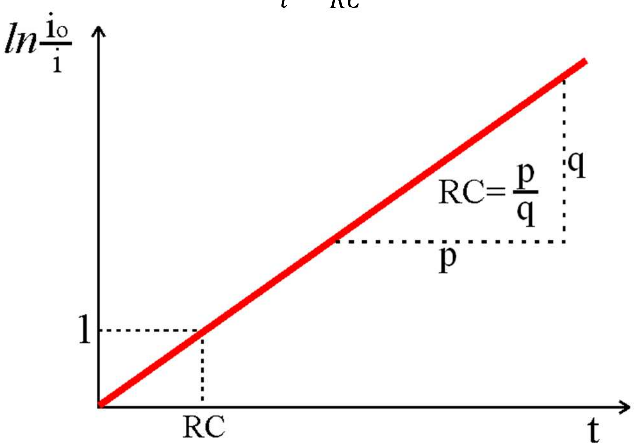
Theoretical Basis

$$i(t) = i_0 \cdot e^{-\frac{t}{RC}}$$

Time constant: the time after which the capacitor is discharged e-times.



$$\ln\frac{i_0}{i} = \frac{1}{RC} \cdot t$$

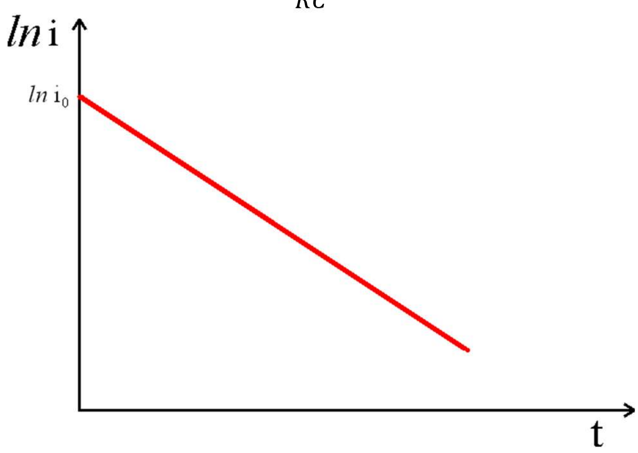


Therefore, in order to determine the time constant RC of the capacitor discharge circuit, one should:

- perform measurements of the dependence of the discharge current intensity on time,
- prepare a graph of the dependence:

  $\ln\frac{i_0}{i}$ as a function of: t
- read the value of the time constant RC.

$$\ln i = -\frac{1}{RC} \cdot t + \ln i_0$$



Therefore, in order to verify the dependence of the discharge current intensity on time, one should:

- perform measurements of the dependence of the discharge current intensity on time,
- prepare a graph of the dependence:

  $\ln i$ as a function of: t
- analyse its linearity.

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Report Guidelines – Determination

Student 1: Determination of the time constant of the capacitor discharge circuit.

I. Methodology (conceptual plan of the exercise)
II. Course of the exercise
II.1. Course of activities
II.2. Sketch of the measurement setup
II.1. Results
II.2. Measurement results

		1	2	3	4	5	6	7	8	9	10
t	[s]										
i	[...]										

Δt = ...
Δi = ...

2. Calculations (example calculations - referring, for example, to measurement no. 3)

$$\ln\frac{i_0}{i} = \dots$$

$$\Delta\left(\ln\frac{i_0}{i}\right) = \frac{\Delta i_0}{i_0} + \frac{\Delta i}{i} = \dots$$

3. Calculation results

		1	2	3	4	5	6	7	8	9	10
$\ln\frac{i_o}{i}$	[-]										
t	[...]										
$\triangle \ln\frac{i_o}{i}$	[-]										

Δt = ...

4. Graph

- *calculation of RC, the reciprocal of the slope of the “best-fit” straight line*
- *calculation of RC', the reciprocal of the slope of the deviated straight line*
- *calculation of the accuracy of the method:* $\Delta RC = |RC - RC'|$

5. Summary

The determined value of … is …
Accuracy of the method: …
Additional conclusions, observations, causes of measurement uncertainties.

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Report Guidelines – Verification

Student 2: Verification of the dependence of current intensity in the capacitor discharge circuit on time.

III. Methodology (conceptual plan of the exercise)
IV. Course of the exercise
II.1. Course of activities
II.2. Sketch of the measurement setup
IV.1. Results
IV.2. Measurement results

		1	2	3	4	5	6	7	8	9	10
t	[s]										
i	[...]										

Δt = ...
Δi = ...

2. Calculations (example calculations - referring, for example, to measurement no. 3)

$\ln(i)$ = ...

$\Delta \ln i = |\ln(i) - \ln(i + \Delta i)|$ = ...

3. Calculation results

		1	2	3	4	5	6	7	8	9	10
t	[s]										
ln *i*	[ln A]										
Δ ln *i*	[ln A]										

4. Graph

5. Summary

Since on the graph … it is possible to draw a straight line passing through all measurement uncertainty rectangles, there are no grounds to conclude a deviation from …
Alternatively:
The deviation from linearity in the range … may result from …
Additional conclusions, observations, causes of measurement uncertainties.