GDYNIA MARITIME UNIVERSITY
FACULTY OF MECHANICAL ENGINEERING

PHYSICS LABORATORY
DEPARTMENT OF PHYSICS

Theoretical Introduction

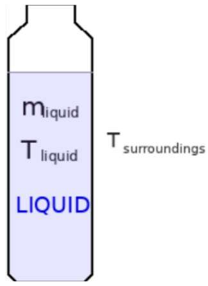
Experiment "C O O L I N G"

The rate of heat energy transfer is proportional to the temperature difference between the cooling material and the surroundings:

$$-\frac{dQ}{dt} \sim (T_{Liquid} - T_{Surroundings})$$

Specific heat, specific heat capacity, determines the amount of energy that must be exchanged with a body in order to change its temperature by one degree, per unit mass.

$$c = \frac{Q}{m \cdot \Delta T} \left[\frac{J}{kg \cdot K}\right]$$



Differential definition of specific heat: dQ=mcdT

The law of cooling therefore takes the following differential form:

$$-mc\frac{dQ}{dt} \sim \mathrm{k}(T_{Liquid} - T_{Surroundings})$$

where:
k- a constant related to the cooling conditions.

After separating the variables, with T- temperature on the left side and t- time on the right side:

$$-\frac{dT}{T_{Liquid} - T_{Surroundings}} = -\frac{k}{mc}dt$$

and after integrating both sides:

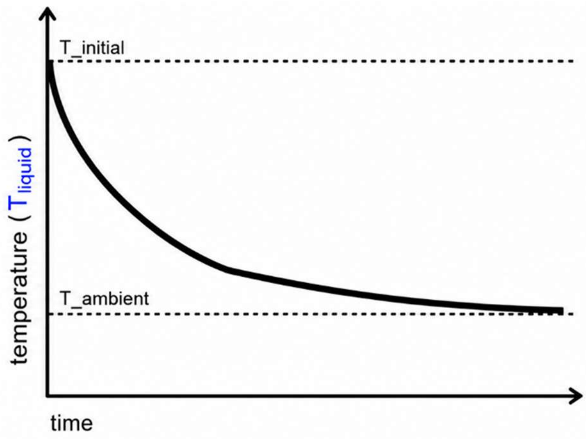
$$\ln(T_{CIECZY} - T_{OTOCZENIA}) = -\frac{k}{mc}t + const$$

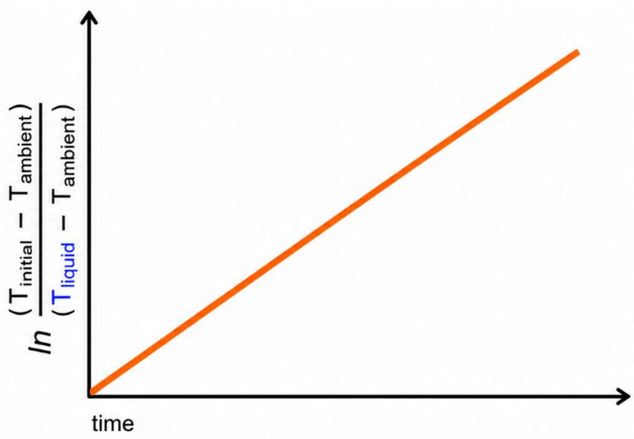
The integration constant $const$ is identified as $\ln(T_{Initial\ liquid} - T_{Surroundings})$ and after substitution we obtain:

$$\ln\frac{T_{\text{INITIAL LIQUID}} - T_{\text{SURROUNDINGS}}}{T_{\text{LIQUID}} - T_{\text{SURROUNDINGS}}} = \frac{k}{mc}t$$

Using the definition of the logarithm, the integral form of the law of cooling is obtained:

$$T_{\text{LIQUID}}(t) = (T_{\text{INITIAL LIQUID}} - T_{\text{SURROUNDINGS}})e^{-\frac{k}{mc}t} + T_{\text{SURROUNDINGS}}$$





“C O O L I N G”

Preparation Questions:

1. Give the definition of heat and its unit.
2. Give the definition of specific heat and its unit.
3. Give the approximate value of the specific heat of water and oil.
4. How much heat energy must be supplied to heat one kilogram of water by 10 K?
5. Explain what temperature is and give its SI unit.
6. Discuss the Kelvin and Celsius temperature scales.
7. What is the boiling point of water on the Celsius scale and on the Kelvin scale?
8. What is the freezing point of water on the Celsius scale and on the Kelvin scale?
9. Discuss the Fahrenheit temperature scale.
10. Discuss the dependence of the temperature of a cooling body on time and give the mathematical function that describes it.
11. What are the methods of energy transfer?
12. What is a thermometer? Discuss the types of thermometers.
13. Discuss the zeroth law of thermodynamics.
14. Discuss the operating principle of a thermocouple.
15. Discuss the construction of a thermos flask.

Instructions for Performing the Measurements

1. Determine the mass of the empty vessel for distilled water and the tested liquid.
2. Remove the stopper and weigh the vessel with water and the vessel with oil one after another.
3. Determine the masses of water m_{water} and oil m_{oil}.
4. Record the air temperature in the room:

$$T_{\text{SURROUNDINGS}}$$

5. Heat both vessels with water and oil to a temperature above $70°C$.
6. Remove the vessels from the water bath and leave them to cool.
7. After the samples have cooled by at least $2°C$, start the stopwatch and record the initial temperatures:

$$T_{\text{INITIAL WATER}} \text{ and: } T_{\text{INITIAL OIL}}$$

8. At equal time intervals, that is every 30 or 60 seconds, record the subsequent temperatures of water T_{WATER} and oil T_{OIL}.
9. Calculate the values of the natural logarithms:

$$A(t) = \ln\left(\frac{T_{\text{INITIAL WATER}} - T_{\text{SURROUNDINGS}}}{T_{\text{WATER}}(t) - T_{\text{SURROUNDINGS}}}\right)$$

and:

$$B(t) = \ln\left(\frac{T_{\text{INITIAL OIL}} - T_{\text{SURROUNDINGS}}}{T_{\text{OIL}}(t) - T_{\text{SURROUNDINGS}}}\right)$$

10. Prepare a time graph of the logarithms and calculate the values of the slope coefficients for water a_{water} and for oil a_{oil}.
11. Calculate the specific heat from the relationship:

$$c_{\text{oil}} = \frac{m_{\text{water}} \cdot a_{\text{water}}}{m_{\text{oil}} \cdot a_{\text{oil}}} c_{\text{water}}$$

using the tabular value of the specific heat of water c_{water}.

“C O O L I N G”

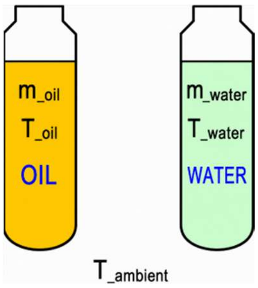
Methodological Template

Student 1: Determination of specific heat by the cooling method.

Student 2: Verification of the dependence of the temperature of a cooling body on time.

Theoretical Basis

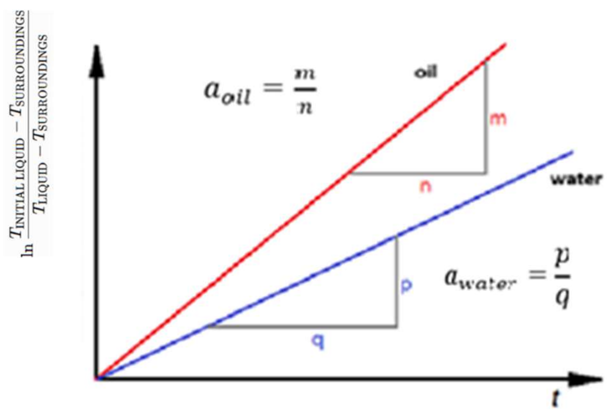
The dependence of the body temperature on its cooling time is expressed by the relationship:



$$T_{\text{LIQUID}}(t) = (T_{\text{INITIAL LIQUID}} - T_{\text{SURROUNDINGS}})e^{-\frac{k}{mc}t} + T_{\text{SURROUNDINGS}}$$

which can be transformed into a linearized form:

$$\ln\frac{T_{\text{INITIAL LIQUID}} - T_{\text{SURROUNDINGS}}}{T_{\text{LIQUID}} - T_{\text{SURROUNDINGS}}} = \frac{k}{mc}t$$



$a_{water} = \frac{k}{m_{water} \cdot c_{wate}}$ and $a_{oil} = \frac{k}{m_{oil} \cdot c_{oil}}$

therefore $c_{oil} = \frac{a_{wate} \cdot m_{wate} \cdot c_{wate}}{a_{oil} \cdot m_{oil}}$

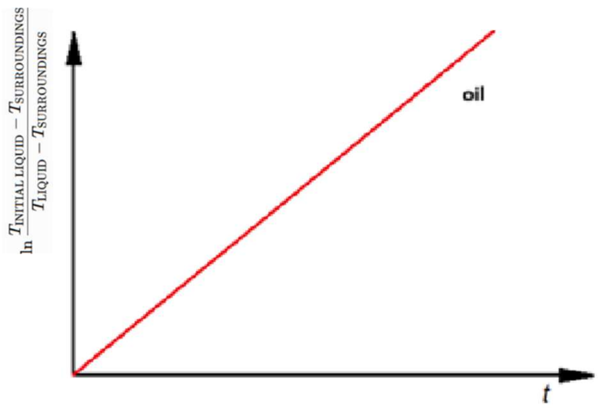
Therefore, in order to determine the specific heat of oil, one should:

- perform measurements of the mass of oil and water,
- perform measurements of the dependence of the temperature of cooling liquids on time,
- prepare, on one sheet, graphs of the dependence:

$$\ln\frac{T_{\text{INITIAL LIQUID}} - T_{\text{SURROUNDINGS}}}{T_{\text{LIQUID}} - T_{\text{SURROUNDINGS}}}$$

as a function of time t,

- read the values of the slopes of both graphs, a_{water} and a_{oil}, and calculate the value of the specific heat of oil c_{oil} using the tabular value c_{water}.



Therefore, in order to verify the dependence of the temperature of a cooling body, oil, on time, one should:

- perform measurements of the dependence of the temperature of cooling oil on time,
- prepare a graph:

$$\ln\frac{T_{\text{INITIAL LIQUID}} - T_{\text{SURROUNDINGS}}}{T_{\text{LIQUID}} - T_{\text{SURROUNDINGS}}}$$

as a function of time t,

- analyse its linearity.

"C O O L I N G"

Report Guidelines – Determination

Student 1: Determination of specific heat by the cooling method.

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]										
T_{Water}	[°C]										
T_{Oil}	[°C]										

m_{oil} = ... m_{water} = ... $T_{Surroundings}$ = ...
Δt = ... $\Delta T_{Water} = \Delta T_{Oil}$ = ... $\Delta T_{Surroundings}$ = ...

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

$$A(t) = \ln\left(\frac{T_{Initial\ water} - T_{Surroundings}}{T_{Water}(t) - T_{Surroundings}}\right) =..$$
$$B(t) = \ln\left(\frac{T_{PInitial\ oil} - T_{Surroundings}}{T_{Oi}\ (t) - T_{Surroundings}}\right) =..$$
$$\Delta A(t) = \frac{\Delta T_{Water} + \Delta T_{Surroundings}}{T_{Initial\ water} - T_{Surroundings}} + \frac{\Delta T_{Water} + \Delta T_{Surroundings}}{T_{Wate}\ (t) - T_{Surroundings}} =..$$
$$\Delta B(t) = \frac{\Delta T_{Oil} + \Delta T_{Surroundings}}{T_{Initial\ oil} - T_{Surroundings}} + \frac{\Delta T_{Oi}\ + \Delta T_{Surroundings}}{T_{Oil}(t) - T_{Surroundings}} =..$$

III.3. Calculation results

		1	2	3	4	5	6	7	8	9	10
t	[s]										
A	[...]										
B	[...]										
ΔA	[...]										
ΔB	[...]										

Δt = ...

III.4. Graph

- calculation of a_{water} and a_{oil}, the slopes of the "best-fit" straight lines
- calculation of a'_{water} and a'_{oil}, the slopes of the deviated straight lines, one upwards and the other downwards
- using the tabular value of c_{water}, calculation of:

$c_{oil} = \frac{m_{water} \cdot a_{water}}{m_{oil} \cdot a_{oil}} \cdot c_{water}$ and: $c'_{oil} = \frac{m_{water} \cdot a'_{water}}{m_{oil} \cdot a'_{oil}} \cdot c_{water}$ and the accuracy of the method: $\Delta c_{oil} = |\, c_{oil} - c'_{oil}|$

IV. Summary

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

"C O O L I N G"

Report Guidelines – Verification

Student 2: Verification of the dependence of the temperature of a cooling body on time.

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]										
T_{Oil}	[°C]										

Δt = ... $T_{Surroundings}$ = ...
ΔT_{Oil} = ... $\Delta T_{Surroundings}$ = ...

III.2. Calculations (example calculations - referring, for example, to measurement no. 12)

$$B(t) = \ln\left(\frac{T_{Initial\ oil} - T_{\mathrm{Surroundings}}}{T_{Oil}(t) - T_{\mathrm{Surroundings}}}\right) =..$$

$$\Delta B(t) = \frac{\Delta T_{Oil} + \Delta T_{\mathrm{Surroundings}}}{T_{Initial\ oil} - T_{\mathrm{Surroundings}}} + \frac{\Delta T_{Oi}\ + \Delta T_{\mathrm{Surroundings}}}{T_{Oil}(t) - T_{\mathrm{Surroundings}}} =..$$

III.3. Calculation results

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

Δt = ...

III.4. Graph

IV. 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.