Exercise 215

Measurement of specific heat for a liquid by means of calorimeter with electric heater and determination of efficiency of the heater

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1. Theory

1. Temperature and internal energy in terms of kinetic-molecular theory of matter. [1]
2. Specific heat and molar heat, their units. [1]
3. Method of measurement. Principle of heat balance. [2]
4. Work and power of electric current. Heat emission in the electrical circuit. Joule-Lenz law. [3]
5. Definition of efficiency. [1]

2. Devices

1. Calorimeter with electric heater
2. Magnetic stirrer
3. DC power supply
4. Thermometer
5. Clock or stopwatch

3. Method

Conversion of electric current work into thermal energy is used. A known mass of liquid contained in a calorimeter is heated by an electric heater. Joule-Lenz heat is emitted during flow of the electric current in the heater. It is given by the formula

$$Q_0 = U\,I\,t\,, \qquad (1)$$

where U - voltage applied to the heater, I - intensity of the current flowing in the heater, t - time of the current flow. Emitted heat is absorbed by the liquid in the calorimeter, by the calorimeter and by the stirring bar. The increase of temperature of the whole system depends on the specific heat of the liquid, which allows to calculate its value. However one should take into account that the heat absorbed by the liquid and the calorimeter is smaller than the heat emitted by the heater due to unavoidable losses. This means that one has two unknown quantities: the specific heat and the efficiency coefficient of the heater. This coefficient is defined as the ratio of the heat absorbed by the system to the total heat yielded by the heater:

$$\eta = \frac{Q}{Q_0}. \tag{2}$$

In order to determine both unknown quantities, the experiment is carried out in two stages. At the first stage, the calorimeter contains water, i.e. the liquid of known specific heat. Therefore the efficiency coefficient η is the only unknown and can be determined. At the second stage, the calorimeter contains oil. The efficiency coefficient calculated earlier can be used for calculation of the specific heat of the oil which is the only unknown value at the second stage.

At the first stage, the heat absorbed by the water, calorimeter and the stirring bar is given by the formula

$$Q = c_w m_w (T_2 - T_1) + c_k m_k (T_2 - T_1) + C (T_2 - T_1), \tag{3}$$

where c_w - specific heat of water, c_k - specific heat of acid-resistant steel of which the calorimeter is made, m_w , m_k - masses of water and calorimeter, C - heat absorbed by the stirring bar, T_1, T_2 - initial and final temperatures. Using eqs. (1) - (3) one can determine the efficiency coefficient of the heater:

$$\eta = \frac{(c_w m_w + c_k m_k + C)(T_2 - T_1)}{UI\ t}. \tag{4}$$

At the second stage of the exercise, one heats the oil from temperature T_1' to T_2'. Applying the heat balance principle

$$\eta\, U I t = (c_o m_o + c_k m_k + C)(T_2' - T_1') \tag{5}$$

one can determine the specific heat of the oil c_o:

$$c_o = \frac{\eta U I t - (c_k m_k + C)(T_2' - T_1')}{m_o (T_2' - T_1')}. \tag{6}$$

4. Course of experiment

The experimental setup is shown schematically in figure 1. The heater is put into the calorimeter. Water is heated at first. Magnetic stirrer ensures the uniform temperature in the whole volume. After switching on the heater, one should wait c. 5 minutes before the main experiment. Then the temperature should be determined and taken as initial. After heating for c. 15 minutes the heater should be switched off and the final temperature should be read. (Please notice that the temperature increases still for some time due to thermal inertia; its maximum value is important.) The same procedure obeys for the oil. Since the specific heat of water is known, the results of the first stage

of the experiment yield the efficiency coefficient from eq. (5). The calculated value of η can be used in formula (7) which allows to determine the specific heat of the oil by use of data obtained at the second stage of the experiment.

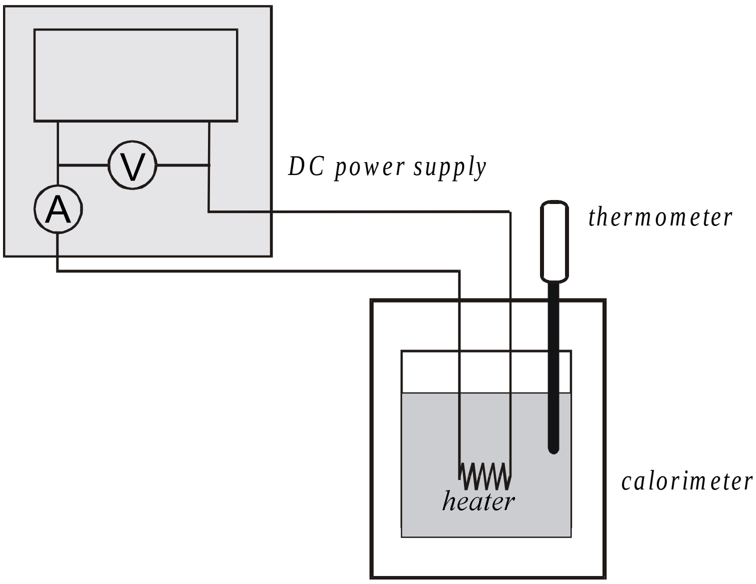

Fig. 1. Experimental setup

5. Experimental procedure

1. Weigh the mass m_k of empty calorimeter (its inner vessel).
2. Fill the calorimeter vessel with distilled water to c. 3/4 of its volume and weigh it. Calculate mass of water m_w.
3. Put the stirrer bar into the calorimeter vessel.
4. Put the calorimeter vessel into the calorimeter, put the heater and thermometer. Turn left the voltage regulation knobs. After permission from the teacher switch on the dc supply. The voltage should ensure the power of the heater equal to 6-7 W. **Attention! Do not exceed 10 W!**
5. Switch on the heater and wait c. 5 minutes.
6. Read the water temperature and the values of voltage and current intensity.
7. Heat the water by c. 15 minutes.
8. Read the final temperature of water and the detailed time of heating.
9. Pour out the water from the calorimeter, dry it and fill with the oil to c. 3/4 of its volume.

10. Repeat the measurements with the oil.
11. Estimate the absolute uncertainties of mass Δm, temperature ΔT and time Δt.
12. Adopt the uncertainties of voltage ΔU and current intensity ΔI as the unit at the last digit on the display.
14. Wash the calorimeter, thermometer and the heater.

6. Preparation of the report

The report should contain:

1. Short description of the principle of measurement.
2. Tables with results of measurements.
3. Calculations of efficiency coefficient and of the specific heat of oil. Use the thermal capacitance of the stirrer bar $C = (1,0 \pm 0,1)$ J/K.
4. Estimation of absolute uncertainties of efficiency coefficient and of the specific heat of oil.

   Absolute uncertainty of efficiency coefficient η is calculated by means of the formula:

$$\Delta\eta = \Delta\eta_m + \Delta\eta_T + \Delta\eta_{UIt}. \quad (7)$$

where

$$\Delta\eta_{\mathrm{m}} = \frac{(T_2 - T_1)}{UIt}[(c_{\mathrm{w}} + c_{\mathrm{k}})\Delta m + \Delta C], \qquad (8)$$

$$\Delta\eta_{\mathrm{T}} = \frac{2\eta}{T_2 - T_1}\Delta T\ , \qquad (9)$$

$$\Delta\eta_{\mathrm{UIt}} = \eta\left(\frac{\Delta U}{U} + \frac{\Delta I}{I} + \frac{\Delta t}{t}\right). \qquad (10)$$

Absolute uncertainty of the specific heat of oil is

$$\Delta c_{\mathrm{o}} = \Delta c_{\eta\mathrm{UIt}} + \Delta c_{\mathrm{T}} + \Delta c_{\mathrm{C}} + \Delta c_{\mathrm{mk}} + \Delta c_{\mathrm{mo}}. \qquad (11)$$

The corresponding formulae are as follows:

$$\Delta c_{\eta\mathrm{UIt}} = \frac{1}{m_{\mathrm{o}}(T_2' - T_1')}(UIt\Delta\eta + It\eta\Delta U + \eta Ut\Delta I + \eta UI\Delta t), \qquad (12)$$

$$\Delta c_T = \frac{2\eta UIt}{m_{\mathrm{o}}\left(T_2' - T_1'\right)^2}\Delta T\ , \qquad (13)$$

$$\Delta c_C = \frac{1}{m_{\mathrm{o}}}\Delta C\ , \qquad (14)$$

$$\Delta c_{\mathrm{mk}} = \frac{c_{\mathrm{k}}}{m_{\mathrm{o}}}\Delta m\ , \qquad (15)$$

$$\Delta c_{\mathrm{mo}} = \frac{c_{\mathrm{o}}}{m_{\mathrm{o}}}\Delta m\ . \qquad (16)$$

5. Final results written in the form

$$\eta = \eta_{\mathrm{cal}} \pm \Delta\eta,$$

$$c_{\mathrm{o}} = c_{\mathrm{o\ cal}} \pm \Delta c_{\mathrm{o}},$$

where η_{cal} i $c_{\mathrm{o\ cal}}$ are calculated from eqs. (4) and (6).

6. Comparison of the obtained value of c_o with data given in tables of physical quantities. Discussion of the phenomena which can cause experimental errors.

7. References

[1] I. W. Sawieliew, *Wykłady z fizyki*, t. 1, PWN, Warszawa, 2002
[2] J. Karniewicz, T. Sokołowski, *Podstawy fizyki laboratoryjnej*, skrypt PŁ, Łódź, 1996.
[3] I. W. Sawieliew, *Wykłady z fizyki*, t. 2, PWN, Warszawa, 2002