Experiment Nr. 16

DETERMINATION OF THE HEAT CAPACITY OF METAL MASS BODY

Theoretical part

Heat capacity or thermal capacity is a physical quantity equal to the ratio of the heat added to (or removed from) an object resulting in its temperature change:

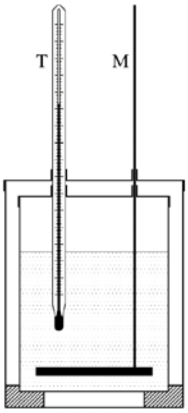
$$C = \frac{dQ}{dT}$$

The unit of heat capacity is joule per kelvin ($J.K^{-1}$). Heat capacity is an extensive property of matter, meaning it to be proportional to the size of the system. When expressing the same phenomenon as an intensive property, the heat capacity is divided by the amount of substance, mass, or volume, thus the quantity is independent of the size or extent of the sample. The **molar heat capacity** is the heat capacity per mole of a pure substance and the **specific heat capacity**, often called simply as specific heat, is the heat capacity per unit mass of a material.

$$c = \frac{1}{m}\frac{dQ}{dT}$$

The unit of specific heat capacity is joule per kilogram and kelvin ($J.kg^{-1}.K^{-1}$). Nonetheless some authors use the term specific heat to refer to the ratio of the specific heat capacity of a substance at any given temperature, to the specific heat capacity of another substance at a reference temperature, much in the fashion of specific gravity. In some engineering contexts, the volumetric heat capacity is used.

Specific heat and other thermodynamic parameters describing the heat interchange are usually studied by **calorimetry**. Calorimetry is the science or act of measuring changes in state variables of a body for the purpose of deriving the heat transfer associated with changes of its state due, for example, to chemical reactions, physical changes, or phase transitions under specified constraints. Calorimetry is performed with a calorimeter. A **calorimeter** is an object used for calorimetry, or the process of measuring the heat of chemical reactions or physical changes as well as heat capacity. Differential scanning calorimeters, isothermal microcalorimeters, titration calorimeters and accelerated rate calorimeters are among the most common types. A simple calorimeter just consists of a thermometer attached to a metal container filled with water. An **adiabatic calorimeter** is a calorimeter used to examine a runaway thermodynamic reaction.



Since the calorimeter runs in an adiabatic environment, any heat generated by the material sample under test causes the sample to increase in temperature, thus fuelling the reaction. No adiabatic calorimeter is fully adiabatic - some heat will be lost by the sample to the sample holder. A mathematical correction factor, known as the phi-factor, can be used to adjust the calorimetric result to account for these heat losses. The phi-factor is the ratio of the thermal mass of the sample and sample holder to the thermal mass of the sample alone.

Determination of the specific heat capacity of the metal sample

The measurement is performed considering the adiabatic calorimetry. The calorimeter with a heat capacity K_K is filled by a specific amount of cold water (temperature $t_{1,}$ mass m_1 and specific heat capacity c_V). The pre-heated metal sample (temperature $t_{2,}$ mass m and specific heat capacity c) is immersed into the calorimeter and the temperature change is observed. After some time, the temperature reached a steady value t. We can consider that the heat transferred from the hot metal sample to the calorimeter is equal to the heat absorbed by the calorimeter filled with water. In this case, the calorimetry formula could be defined as follows:

$$mc(t_2 - t) = (m_! c_! + K_K)(t - t_!)$$

Thus, the specific heat capacity c of the metal could be calculated by following formula:

$$c = \frac{m_V c_V + K_K}{m} \frac{t - t_1}{t_2 - t}$$

Measurement objective

1. Determine the specific heat capacity of two metal samples.
2. Calculate the specific heat capacity uncertainty.

Measurement procedure

First determine the heat capacity of the calorimeter K_K. The value can be calculated by

$$K_K = (m_b + m_s)c_b + K_T,$$

where m_b is the mass of the dry calorimeter bin, m_s is the mass of the stirrer, c_b is the specific heat capacity of the calorimeter material (brass) and K_T is the heat capacity of the thermometer (see the constants). The calorimeter cover can be neglected, thus, the cover mass is not taken into account. The important constants are listed below.

The metal samples has to be warmed up in a thermostat tank. The temperature of the metal samples is 80 °C. After immersing the samples into hot water, wait about 5 minutes till the samples are fully heated up.

The calorimeter is filled with water and its temperature is below room temperature. The mass of the water has to be determined by the subtraction of the water-filled and empty calorimeter masses. After immersing the hot metal sample, the temperature of the calorimeter will increase. After some time, the temperature reaches its steady value. Note that the value of the room temperature should be approximately the mid point of the range (t_1;t_2) due to the balance of the heat transfer between the calorimeter and the ambient environment.

Please note that for the second sample measurement the calorimeter should be filled with new cold water and its mass should be determined again.

Important constants

The water specific heat capacity as a function of temperature:

t [°C]	**c [J·kg^{-1}·K^{-1}]**	**t [°C]**	**c [J·kg^{-1}·K^{-1}]**	**t [°C]**	**c [J·kg^{-1}·K^{-1}]**
0	4217,8	35	4178,1	70	4189,7
5	4201,3	40	4178,4	75	4192,9
10	4192,2	45	4179,3	80	4196,4
15	4186,3	50	4180,5	85	4200,5
20	4181,8	55	4182,2	90	4205,2
25	4179,5	60	4184,3	95	4210,4
30	4178,4	65	4186,7	100	4216,0

Specific heat capacity values of selected materials

Material	**c [J·kg^{-1}·K^{-1}]**
Aluminium	896
Copper	393
Brass	395
Platinum	133
silver	235
zinc	385
iron	450

The specific heat of the brass is c_b = (385±10) J·kg^{-1}·K^{-1}.
The heat capacity of the thermometer is K_T = 4 J·K^{-1}.

Uncertainty calculation notes

The evaluation of the uncertainty of the specific heat capacity is more complicated. Let's consider the existence of Type B uncertainty only. Secondly, some of the sub uncertainties can be neglected due to low effect on the result of the heat capacity uncertainty. Using the law of summation we can obtain

$$u_{rcB} = \sqrt{\frac{u_{K_K B}^2}{\left(m_V c_V + K_K\right)^2} + \frac{u_{tB}^2 + u_{t_1 B}^2}{\left(t - t_1\right)^2} + \frac{u_{t_2 B}^2}{\left(t_2 - t\right)^2}} \; ,$$

The relative uncertainty of the calorimeter capacity can be determined from the relative uncertainty of the brass, thus

$$u_{rK_K B} = u_{rc_b B}.$$