

# SPECIFIC HEAT OF METALS

## 1 Introduction

Heat energy is the energy of disordered motion, rotation and oscillation of the atoms and molecules of a solid, fluid or gas. This energy is larger for higher temperatures of the body. Ordered motion does not contribute to but can be transformed into heat energy.

## 2 Specific Heat

The heat capacity  $C$  of a body is defined as the ratio of added heat energy  $\Delta Q$  to the resulting change in temperature  $\Delta T$ :

$$C = \frac{\Delta Q}{\Delta T}, \quad [C] = 1 \frac{J}{K}$$

The heat capacity in general strongly depends on the temperature but in metals around room temperature it can be treated as constant to good approximation according to the law of Dulong-Petit.

The molar heat capacity depends on the mass/particle number. Therefore one defines:

i) the specific heat (capacity):

$$c = \frac{C}{m} = \frac{1}{m} \frac{\Delta Q}{\Delta T}, \quad [c] = 1 \frac{J}{kg \cdot K}$$

ii) the molar heat capacity:

$$c_{\text{molar}} = \frac{C}{n} = \frac{1}{n} \frac{\Delta Q}{\Delta T}, \quad [c_{\text{molar}}] = 1 \frac{J}{mol \cdot K}$$

### 2.1 Specific heat of water:

$$c_{\text{Water}} = 4187 \frac{J}{kg \cdot K}$$

The specific heat of water is almost independent of the temperature.

### 2.2 Calorie

The calorie is still in use as the unit of heat energy.

### 2.3 Definition:

A calorie is the amount of heat energy which at atmospheric pressure  $p_n=1033.25$  mbar heats up 1 Kilogram of water from 14.5°C to 15.5°C.

$$\Rightarrow \quad 1 \text{ kcal} = 4.187 \cdot 10^3 \text{ J}$$

## 2.4 Dulong-Petit-Law

According to the law of Dulong-Petit the molar heat capacity of solids for not too small temperatures (i.e. Room temperature or higher) is independent of the substance:

$$c_{\text{molar}} = 3R \approx 24.94 \frac{\text{J}}{\text{mol K}},$$

where R is the ideal gas constant. Of course Dulong-Petit's law is an approximation but it is well fulfilled for metals under the given conditions. The goal of this experiment is to verify this law.

## 2.5 Measurement

The absolute and specific heat capacity of a body can be determined by addition of the heat energy  $\Delta Q$  and measurement of the resulting increase in temperature  $\Delta T$ . However the heat energy  $\Delta Q$  will not be measured directly but is determined by a mixing experiment. In a mixing experiment the probe body (at a temperature  $T_1$  and with unknown heat capacity  $C_1$ ) is brought into thermal contact with a second body (at temperature  $T_2$  and with known heat capacity  $C_2$ ). The body with higher temperature will transfer heat energy to the other and both will assume a temperature  $\bar{T}$  in between.

Then (for  $T_1 > T_2$ ):

$$\text{Body 1: } C_1 = \frac{\Delta Q_1}{\Delta T_1} = \frac{\Delta Q_1}{T_1 - \bar{T}}$$

Body 2:

Assuming that there is no heat loss to the environment energy conservation implies:

$$\Delta Q_1 = \Delta Q_2$$

Therefore:

$$C_1 = C_2 \frac{\bar{T} - T_2}{T_1 - \bar{T}}$$

## 3 Estimation of the mixing temperature

Estimating the mixing temperature  $\bar{T}$  is the hardest part of the experiment. Since the equilibration is not instantaneous and heat is lost even before the maximal temperature is reached, the theoretical mixing temperature  $\bar{T}$  is never assumed. To extrapolate  $\bar{T}$  we therefore estimate the temperature in the calorimeter as a function of time (fig. 1). It can be shown that the instantaneous transfer of heat can be approximated by elongating the lines AB and CD and drawing a line EF such that the areas BEG and CFG are of the same size. It is usually sufficient to do this manually. The temperatures at points

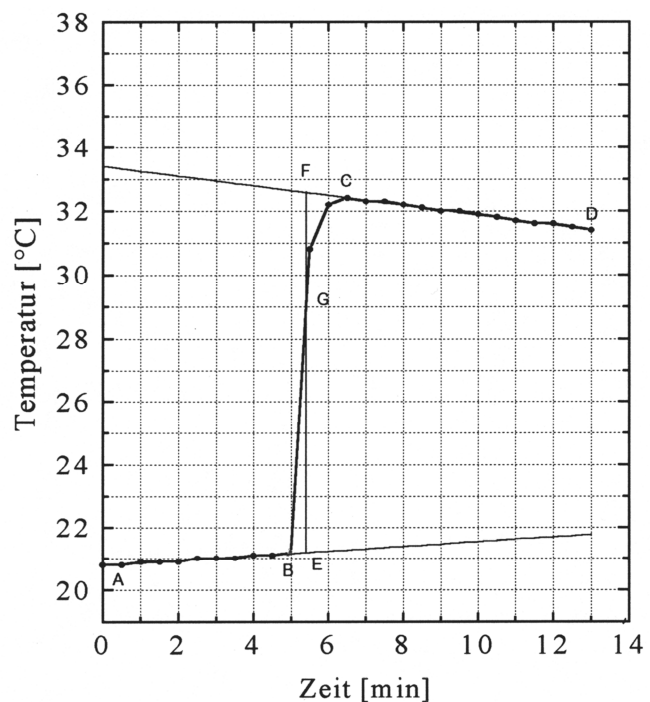


Abb. 1: Temperaturverlauf im Kalorimeter

E and F,  $T_1$  and  $\bar{T}$ , correspond to the temperatures in case of instantaneous equilibration.

## 4 Recording the data

To record the data, a PC with a temperature sensor is provided. To start the experiment, press the following button, invoking a widget for the measurements (fig. 2)

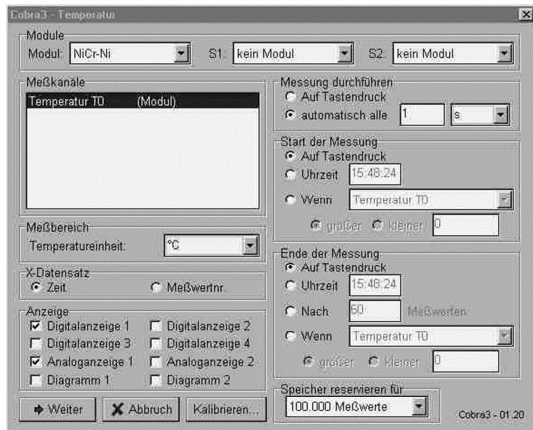


Fig. 3: Calibration

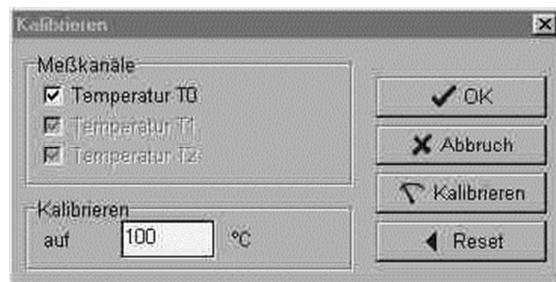
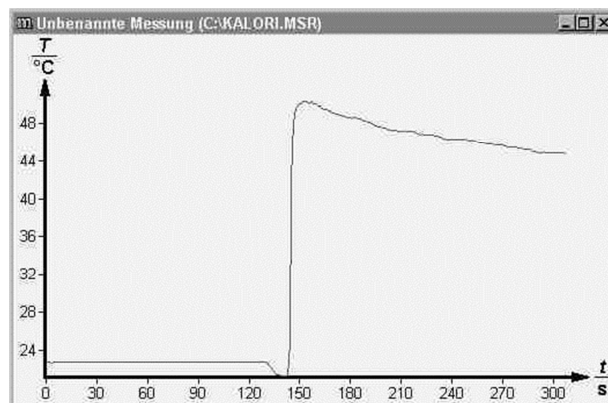


Fig 2: Measurements



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Before recording the data, the temperature sensor has to be calibrated. To do this, click the calibration button. This opens the calibration window (fig. 3). Put the temperature to 100°C and wield the sensor in boiling water for a few seconds. **Under no circumstances let the sensor touch the ground of the plate since it may be damaged permanently!** Then click the calibration button. Click the button 'Weiter' to display the temperature. Now the recording of data can be started. Once the collection of data is stopped, the temperature curve is displayed as in fig. 4. This graph shall be printed and the evaluation can be performed.



**Fig. 4:**  
Measured temperature curve

## 5 Performing the experiment

The execution of the experiment consists of two parts. In the first part the heat capacity of the calorimeter is estimated by a mixing experiment. In the second part the heat capacities of the metals will be measured.

### Part 1: Estimation of the heat capacity of the calorimeter

1. Calibrate the heat sensor as described in section 3.
2. Heat up 100ml of water to 50°C.
3. The thermometer has to be attached to its stand such that its tip touches the inner face of the calorimeter and is 0.5 cm above the expected level of water.
4. The measurement is performed as described in section 3 and the temperature of the calorimeter is recorded 1-2min. Then pour the 100ml of 50°C water into the calorimeter **-the thermometer should now not be in the water!**- continue the measurement for 8min.
5. Now stop the measurement and print the graph. Save the data as: Group Nr., - , Month , Year , a (e.g.: For group 17 in Aril 2015: 17-0415a.msr).
6. **Weigh the water!** If you tip away the water without weighing its mass you have to start again from 1.

In the first part the group has printed a graph and weighed the mass of the water.

### Teil 2: Estimation of the heat capacity of metals

1. Choose three probe bodies and weigh them. One of them should be made of aluminium or copper.
2. Fill 200ml of cold water into the calorimeter.
3. Attach the thermometer such that its tip is in the water.
4. Heat up the three probes to 100°C by putting them into boiling water for 10min.. They must not touch the floor or walls of the basin.
5. Start the measurements as described in section 3 and measure the temperature of calimeter+water for 1-2min.
6. Put the first probe body into the calorimeter, it should be fully submerged. Now record the temperature for 8min., then take the body out of the calorimeter without stopping the data recording.  
Repeat with the remaining two probe bodies.
7. Stop the measurements when all three probe bodies have been examined. Plot the graph and save the data under Group Nr., - , Month , Year , a (e.g.: For group 17 in Aril 2015: 17-0415b.msr) .

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### 8. Weigh the water in the calorimeter!

In the second part the group should have weighed the three probe bodies and the mass of the water and have printed a graph.

## 6 Analysis

1. As described in section 3, estimate  $\bar{T}$  and  $T_2$  from the graphs, draw the necessary extrapolation lines by hand.
2. To estimate the heat capacity of the metals, the heat capacity of the calorimeter has to be accounted for as well. Derive the respective formula.
3. Calculate the specific and molar heat capacities and compare with the literature value and Dulong-Petit's law.
4. Estimate errors.

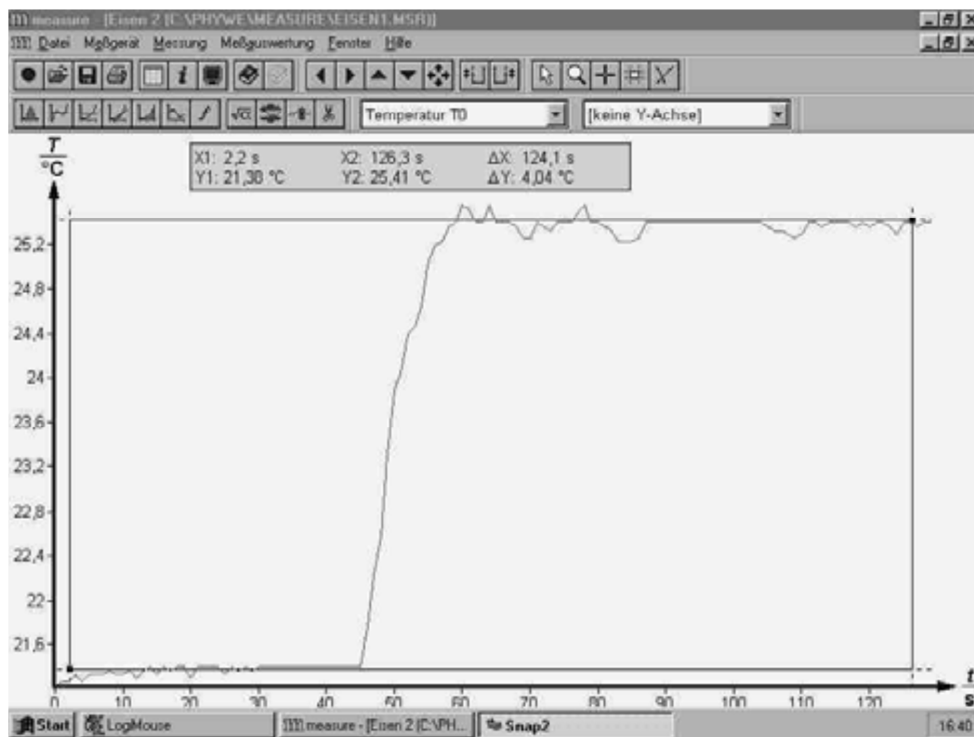


Abb. 5: Analysis of the temperature curve