Musterbericht/Exemplary Report

General requirements

- The report should be concise, short, and contain the important things only: **What** did we measure? **How** did we measure? Every student has to hand in his own, personal, original report!
- **Sectioning** helps to properly structure the report and facilitates the reading/reviewing.
- Gross carelessness like omitting the error calculus or data tables leads to rejection of the report. If such faults are not corrected for immediately the whole experiment must be replaced/repeated.
- **Numbers** have to be given in scientific notatio using only a minimum number of digits. As a rule of thumb: the last digit should correspond to the order of magnitude of the measurement error. Ergo:

$$\begin{aligned} \text{NOT:} \quad W &= 128364.456 \ \pm 468 \text{ J}, \\ \text{correct:} \quad W &= 1.283 \times 10^5 \pm 4.7 \times 10^2 \text{ J} \\ \text{correct:} \quad W &= (1.283 \ \pm 0.005) \times 10^5 \text{ J} \end{aligned}$$

- Electronic reports made by computer have to fulfill the same requirements than hand-written reports: the axes of graphs must be properly labeled, all units must be given, fitting results like slopes etc. must be provided. Formulas have to be written by hand or a suitable formula editor, not in text mode using plenty of brackets! Software like Excel can be used for analyzing and plotting data but not for the text! We do not provide any software.

Data tables

During the experiment, the measurement data should be taken and compiled in tables. Every student is requested to make his own data sheet. An example is given in part (2) of this report. The experiment is carried out once the data tables are controlled for completliness by the assistant. The data tables must contain the units (μA or A or whatever) and the measurement uncertainty, e.g. 1 m $\pm$0.01 m.

Report part 1: Introduction

- Do not forget your name, e-mail address and the date of the experiment! It is recommended to note the name of the assistant, too.
- Use page numbering and number equations and graphs.

Name(s): Niels Bohr, Albert Einstein 16.8.2001

Specific heat of solids (SW)

In this experiment, the specific heat of copper and aluminum are measured and compared to literature values.

Introduction and methods

The specific heat c (capacity per kg) is the constant of proprtionality between the quantity of heat supplied Q and the resulting temperature rise:

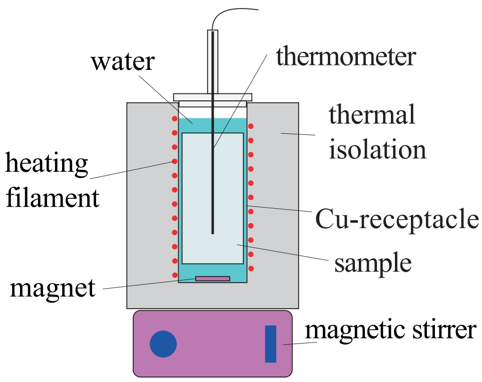
$$Q = c \cdot m \cdot \Delta T \quad \text{with } m = \text{mass of the sample.} \tag{1}$$

For the solids the molar heat capacity is given by the law of Dulong-Petit:

$$c_p \approx c_V = 3R, \tag{2}$$

where $R = 8.31$ J/(K mol) denotes the universal gas constant. ...

Setup:



In a vessel, which is thermally isolated and which possesses a small heat capacity W, the metallic sample is heated in a water bath. Electric energy is provided by an external power supply ...

Part 2: data table

- Provide the raw data in a clearly arranged table.
- Note the units and the corresponding measurement uncertainties! You will not remember them once you write the report at home!

<u>Measurements</u>

determination of W:
water $m_W = (296.4 \pm 0.1) \times 10^{-3}$ kg

determination of c_{Cu}:
water $m_W = (114.4 \pm 0.1) \times 10^{-3}$ kg
water $m_{\mathrm{Cu}} = 1.628 \pm 0.005$ kg
...
current $I = 2.9 \pm 0.05$ A
voltage $U = 25.0 \pm 0.5$ V
etc.

time		temperature (°C)		
min	sec	T_W	T_{Cu}	T_{Al}
0		26.6	26.2	26.8
0	30	28.0	26.4	28.2
1		29.6	26.8	30.1
1	30	31.2	28.0	33.3
2		33.0	28.2	34.8
2	30	34.7	29.2	36.0
...				
8		(*) 53.6	55.5	62.4
9		53.9	58.8	66.4
10		53.8	61.9	(*) 68.3
11		53.7	63.9.	67.8
12		53.6	(*) 66.7	67.6
usw.				

error on temperature reading: ±0.1°C

duration of the measurements:
(with current)
W: 510 ± 1 s
Cu: 720 ± 1 s
Al: 600 ± 1 s

(*)=current switched off.

Part 3: results

- Give results and errors with units in scientific notation.
- Round off to a reasonable number of digits. Usually, 2-3 digits are sufficient. The order of magnitude of the measurement error is a good guideline.
- Compare your results to values from literature if available.
- Make a comment in a concluding sentence.

result

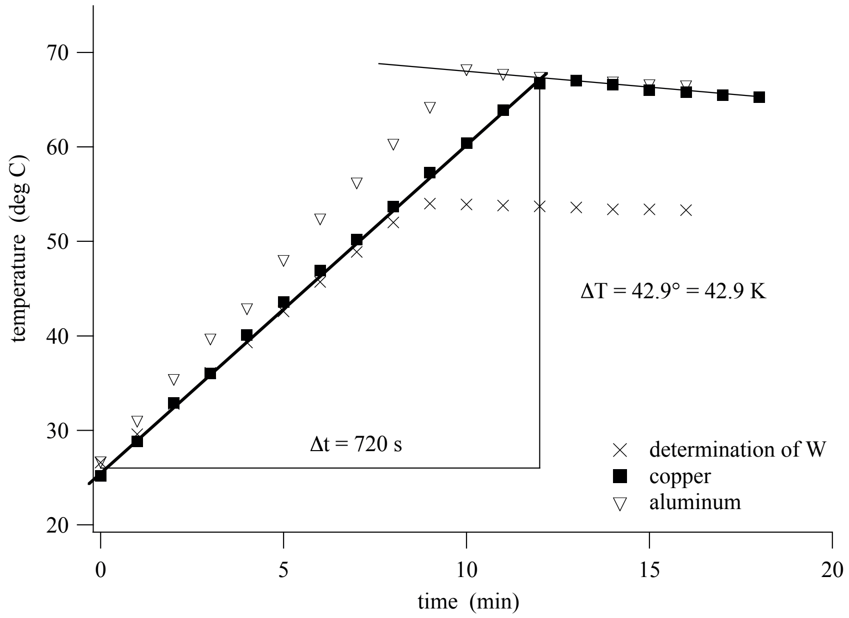
$$c_{\mathrm{Cu}} = 24.8 \pm 1.9 \ \frac{\mathrm{J}}{\mathrm{K.mol}}$$
$$c_{\mathrm{Al}} = 24.2 \pm 2.0 \ \frac{\mathrm{J}}{\mathrm{K.mol}}$$

Value according to equation (2): $c = 24.94 \frac{\mathrm{J}}{\mathrm{K.mol}}$
Literature values:
copper: $c_{\mathrm{Cu}} = 24.51 \ \frac{\mathrm{J}}{\mathrm{K.mol}}$
aluminum: $c_{\mathrm{Al}} = 24.18 \ \frac{\mathrm{J}}{\mathrm{K.mol}}$
Within the error bars, our results are in good agreement with values from literature and with the theoretical value obtained from the law of Dulong-Petit.

Part 4: graphics

- Draw as long axes as possible. the axis range should correspond to the range of data values. Label the axes properly and do not forget the units.
- Plot data using symbols, not lines! use different symbols/colors for different data ses plotted in the same graph.
- Always give error bars, if not stated otherwise. If the error bars are to small to be drawn, you may omit them; in this case make a note and give numbers!
- Calculate the slope from the best fit using a triangle as large as posible. The error on the slope is obtained by half the difference of slopes of the steepest and least steep lines which can be drawn passing through the error bars.

Data plots



Note: the error bars are too small to be represented in this graph (±0.1°C and ±1 s).
Calculation of the slope for copper:

$$\text{slope } \alpha = \frac{\Delta T}{\Delta t} = \frac{42.9 \text{ K}}{720 \text{ s}} = 5.96 \times 10^{-2} \text{ K/s}.$$

etc.

Part 5: data analysis

- Note all steps of your calculations. This facilitates the reviewing and finding errors.
- For convenience, note again the measurement data. Do not forget to check the units of your results.
- Hint: make a rough order-of-magnitude estimate for cross-checking your results!

<u>Calculations</u>

Calculation of W:

$$W = \frac{Q}{\Delta T_W} - m_W \cdot c_W$$

$$\begin{aligned} Q &= U \cdot I \cdot \Delta t = 2.9\,\mathrm{A} \cdot 25\,\mathrm{V} \cdot 510\,\mathrm{s} = 3.7 \times 10^4\,\mathrm{J} \\ \Delta T_W &= 27.5\,\mathrm{K} \\ m_W &= 0.296\,\mathrm{kg} \\ c_W &= 4.182 \times 10^3\,\mathrm{J/(kg.K)} \end{aligned}$$

$$W = \frac{3.7 \times 10^4\,\mathrm{J}}{27.5\,\mathrm{K}} - 0.296\,\mathrm{kg} \cdot 4.182 \times 10^3\,(\mathrm{kg.K}) = 108\,\mathrm{J/K}.$$

Specific heat capacity of copper c_{Cu}:

$$\begin{aligned} c &= \left(\frac{Q}{\Delta T_{\mathrm{Cu}}} - m_W c_W - W\right) \cdot \frac{1}{n_{\mathrm{Cu}}} \text{ mit} \\ \frac{Q}{\Delta T_{\mathrm{Cu}}} &= \frac{U \cdot I \cdot \Delta t}{\Delta T_{\mathrm{Cu}}} = \frac{U \cdot I}{\alpha} \text{ where } \alpha\text{=slope} = 5.96 \times 10^{-2}\ \mathrm{K/s} \\ m_W \cdot c_W &= 0.114 \cdot 4.182 \times 10^3\ \mathrm{J/K} = 477\ \mathrm{J/K} \\ n_{\mathrm{Cu}} &= \frac{m_{\mathrm{Cu}}}{M_{\mathrm{Cu}}} = \frac{1.63\ \mathrm{kg}}{0.064\ \mathrm{kg/mol}} \end{aligned}$$

This yields: $c_{\mathrm{Cu}} = \left(\frac{25 \cdot 2.9}{5.96 \times 10^{-2}} - 477 - 108\right)\ \mathrm{J/(kg.K)} \cdot 0.019\ \mathrm{kg/mol} = 24.8\ \mathrm{J/(mol.K)}.$

...

Part 6: error calculus

- Give again the relevant measurement data here. This is for convenience...
- Give all formulas need and *all* partial derivatives required (not only generic formulas)!
- At the beginning, make an estimate which errors (if any) can be neglected. These contributions may be omitted, but their omission has to be rationalized in the report (including numbers).
- Hint: for functions containing solely multiplications (only sums), the squares of the relative (absolute) errors can by summed up instead of lengthy calculations using the partial derivatives (see Appendix on error calculus).

<u>Error calculus</u>
(example for copper)

$$c = \left(\underbrace{\frac{U \cdot I}{\alpha}}_{A} - \underbrace{m_W c_W}_{B} - W \right) \cdot \frac{1}{n_{\mathrm{Cu}}},$$

where n_{Cu} = mass/molar mass of Cu: $r_n = \frac{0.2}{1628.2} \approx 10^{-4}$ negligible.
Generic equation:

$$m_c = \sqrt{\left(\frac{\partial c}{\partial A}\right)^2 m_A^2 + \left(\frac{\partial c}{\partial B}\right)^2 m_B^2 + \left(\frac{\partial c}{\partial W}\right)^2 m_W^2} = \frac{1}{n_{\mathrm{Cu}}} \sqrt{m_A^2 + m_B^2 + m_W^2}$$

where the partial derivatives with respect to A, B, and W are given by:

$$\frac{\partial c}{\partial A} = \left|\frac{\partial c}{\partial B}\right| = \left|\frac{\partial c}{\partial W}\right| = \frac{1}{n_{\mathrm{Cu}}}.$$

The errors on A, B, and W are given by:

$$r_A = \sqrt{r_U^2 + r_I^2 + r_\alpha^2} = \sqrt{\left(\frac{0.5}{25}\right)^2 + \left(\frac{0.05}{2.9}\right)^2 + \left(\frac{0.03 \times 10^{-2}}{5.96 \times 10^{-2}}\right)^2} = 2.6 \times 10^{-2}$$

$$m_A = A \cdot r_A = \frac{25 \cdot 2.9}{5.96 \times 10^{-2}} \text{ J/K} \cdot 2.6 \times 10^{-2} = 31.6 \text{ J/K}$$

...

$$\rightarrow m_c = 1.9 \text{ J/(K.mol)}.$$