28.2.05

Experiment

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Devices:

Mass of Calorymeter: 373,3 g (with cover)

251,9 g

Preexperiment: (specific heat capacity of the calorymeter)

~~mass of calorymeter with water: 442,0 g~~ experiment failed!

measurement:

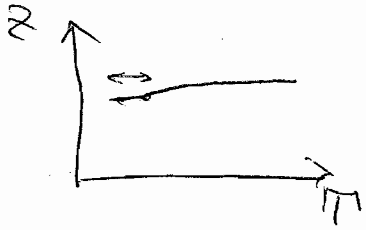
~~start initial temperature: 0,00 1,0 °C~~

initial temperature of calorymeter: 18,6 °C

initial temperature of water: 0,0 °C

temperature development:

time	temperature
30 s	1,3 °C
60 s	1,3 °C
90 s	1,4 °C
120 s	1,5 °C
150 s	2,1 °C ← water mixed!



mass of calorymeter with water: 579,0 g

Additional Devices:

Amperemeter: ~~Error~~: 3 % and 2d

Voltmeter: Error: 3 % and 2d

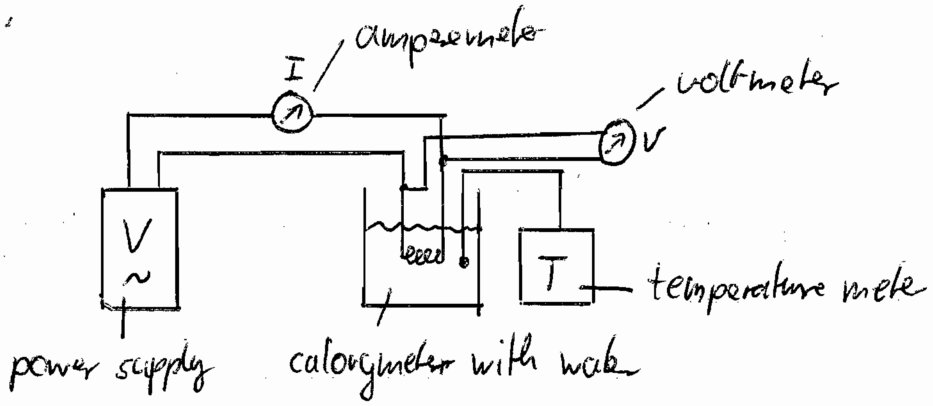
On Assignment 1: (specific heat capacity of water)

mass of calorymeter: 550,5 g   after the experiment: 544,1 g
room temperature: 22,7 °C

mesurement:

time [min]	voltage [V]	current [A]	temperature [°C]
0	0	0	12,7
1	6,15	2,42	13,4
2	6,15	2,42	14,1
3	6,14	2,42	14,8
4	6,04	2,39	15,5
5	6,04	2,38	16,2
6	6,06	2,39	16,9
7	6,04	2,39	17,6
8	6,04	2,39	18,3
9	6,04	2,39	19,0
10	6,04	2,39	19,6
11	6,04	2,39	20,4
12	6,04	2,38	21,1
13	6,03	2,39	21,7
14	6,03	2,38	22,3
15	6,02	2,38	22,9

mesurement setup:



additional mesurements:

time [min]	voltage [V]	current [A]	temperature [°C]
16	6,12	2,42	23,6
17	6,11	2,41	24,2
18	6,10	2,41	24,9
19	6,11	2,41	25,5
20	6,10	2,42	26,2
21	6,09	2,40	26,8
22	6,10	2,39	27,4
23	6,10	2,44	28,0
24	6,10	2,39	28,6
25	6,11	2,38	29,3
26	6,00	2,37	29,9
27	6,00	2,39	30,5

time [min]	voltage [V]	current [A]	temperature [°C]
28	6,00	2,39	31,1
29	5,98	2,39	31,7
30	5,98	2,37	32,2
31	5,98	2,37	32,8

Assignment 3:

~~mass of the calorymeter: 474,7 g~~
~~initial temperature: 31,6°C~~
~~min. temperature: 29,9°C~~
~~mass of the calorymeter with ice: 478,3 g~~

mesurement failed, because of wrong device usage!

second mesurement:

mass of calorymeter: 478,3 g
initial temperature: 29,4°C
min temperature: 28,3°C
mass of calorymeter with ice: 480,5 g

Assignment 2:
weight of the metals:

iron: 946,6 ± 0,5 g
copper: ~~88~~ 833,8 ± 0,5 g
aluminium: 313,4 g ± 0,5 g
plexiglas: 129,9 g ± 0,5 g

room temperature: 23,2°C
weight of the calorymeter: 490,9 g at the beginning

mesurement for iron:

t [s]	temperature [°C]
15	2,1
30	3,6
45	4,5
60	4,4
75	4,6
90	5,5
105	4,8
120	5,8
135	6,1
150	6,3

initial temperature:
water: 0,4 °C
iron: 23,2 °C

weight of the calorymeter:
490,9 g

mesurement for coppe:

t [s]	temperature [°C]
15	2,8
30	3,9
45	4,8
60	5,3
75	5,5
90	5,6
105	5,7
120	5,8
135	5,8
150	5,8

initial temperature:
water: 0,4 °C
coppe: 23,2 °C

weight of the calorymeter:
518,4 g

mesurement for aluminium:

t [s]	temperature [°C]
15	3,0
30	4,6
45	4,4
60	4,5
75	4,7
90	4,7
105	4,8
120	4,8
135	4,9
150	4,9

initial temperatures:
aluminium : 23,2 °C
water : 0,3 °C

weight of the calorymeter:
502,6 g

mesurement for plexiglas:

t [s]	temperature [°C]
15	0,7
30	1,1
45	1,3
60	1,7
75	1,7
90	1,9
105	2,1
120	2,2
135	2,3
150	2,4

initial temperatures:
plexiglas : 23,2 °C
water : 0,1 °C

weight of the calorymeter:
486,2 g

Analysis

Heat capacity of the colorymeter:
In the preexperiment we examinde the mixure temperature of water (cold) and the colorymeter (nearly room temperature). This mesurement ledds to a value for the specific heat capacity of the colorymeter. One problem is the unknown parameter c_w (specific heat capacity of water) which will be determined later on. Therefore we are only able to determine a equivalent mass which will replace the mass of water in further experiments.
First we know, that the rate of change of heat is zero:

$$dQ = 0$$

From the definition of heat capacity we get:

$$dQ = c \cdot m \cdot \Delta T$$

From this follows:

$$c_w \cdot m_w \cdot (T_m - T_w) = + c_c \cdot m_c \cdot (T_c - T_m)$$

$$\Leftrightarrow \quad \frac{c_c}{c_w} m_c = m_w \frac{T_m - T_w}{T_c - T_m} = m_e$$

$$\Rightarrow \quad m_e = \frac{C_c}{c_w} = m_w \frac{T_m - T_w}{T_c - T_m}$$

During the expeiment we found a stabilized mixure temperature at 1,3 °C ± 0,1 °C. $\rightarrow$ $T_m = 1{,}3\,°C \pm 0{,}1\,°C$
The other values are: $T_w = 0{,}0\,°C \pm 0{,}1\,°C$ and
$T_c = 18{,}6\,°C \pm 0{,}1\,°C$

The mass was mesured as follows: $m_w = 579{,}0 \pm 0{,}1\,g - 251{,}9 \pm 0{,}1\,g$
$= 327{,}1 \pm 0{,}2\,g$

$$\Rightarrow \quad m_e = (327{,}1 \pm 0{,}2\ g) \cdot \frac{1{,}3 \pm 0{,}2\ K}{17{,}3 \pm 0{,}2\ K}$$

$$= (327{,}1 \pm 0{,}2\ g) \cdot (0{,}075 \pm 0{,}012)$$

$$= \underline{\underline{24{,}5 \pm 4{,}0\ g}}$$

This means, that we need $24{,}5 \pm 4{,}0\ g$ water to "simulate" the heat capacity of the calorymeter.

Assignment 1: Specific Heat Capacity of Water:

From the equations in the introduction we get:

$$\Delta Q = U \cdot I \cdot \Delta t$$

and $\Delta Q = c_w \cdot m_w' \Delta T$ where $m_w' = m_w + m_e$

from this follows:

$$U \cdot I \cdot \Delta t = c_w \cdot (m_w + m_e) \cdot (T_2 - T_i)$$

T_i beeing the initial temperature with respect to an area of constant current and voltage.

$$\Rightarrow \quad c_w = \frac{U \cdot I \cdot \Delta t}{(m_w + m_e)(T_2 - T_i)}$$

Mesured values: $m_w = -(251{,}9 \pm 0{,}1\ g) + (550{,}5 \pm 6{,}5\ g)$
$= 298{,}6 \pm 6{,}5\ g$

The error of this mass regards the loss of water during the experiment with ~~replace~~ respect to the measured values before and after the experiment.

$$\Rightarrow \quad m_w' = (298{,}6 \pm 6{,}5)\ g + (24{,}5 \pm 4{,}0)\ g$$
$$= \underline{\underline{323{,}1 \pm 7{,}7\ g}}$$

The error of voltage- and amperemeter are 3% of the value and 2 d, which means that all mesured values ~~for~~ of the current are ~~between~~ in that error area of 2 digits and can't be distinguished.

The voltage is ~~class~~ characterized by 4 areas:

$$U_1 = 6{,}15 \pm 0{,}02\ V$$
$$U_2 = 6{,}10 \pm 0{,}02\ V$$
$$U_3 = 6{,}04 \pm 0{,}02\ V$$
$$U_4 = 5{,}98 \pm 0{,}02\ V$$

U_1:

~~error 6,15 ± 0,02~~

$$c_W = (6{,}15 \pm 0{,}21\ V) \cdot (2{,}40 \pm 0{,}08\ A) \cdot \frac{180\,s}{(2{,}1 \pm 0{,}2\ K)(323{,}1 \pm 7{,}7\,g)}$$
$$= 3{,}92 \pm 0{,}44\ \frac{KJ}{K \cdot kg}$$

The error ~~of~~ in time can be ignored, because of the slow rate of change of the mesured temperature.

U_3:

$$c_W = (6{,}04 \pm 0{,}21\ V) \cdot (2{,}40 \pm 0{,}08\ A) \cdot \frac{660\,s}{(7{,}4 \pm 0{,}2\ K)(323{,}1 \pm 7{,}7\,g)}$$
$$= 4{,}00 \pm 0{,}24\ \frac{KJ}{K \cdot kg}$$

U_2:

$$c_W = (6{,}10 \pm 0{,}21\ V) \cdot (2{,}40 \pm 0{,}08\ A) \cdot \frac{540\,s}{(5{,}7 \pm 0{,}2\ K)(323{,}1 \pm 7{,}7\,g)}$$
$$= 4{,}29 \pm 0{,}26\ \frac{KJ}{K \cdot kg}$$

U_4:

$$c_w = (5{,}98 \pm 0{,}20\ V) \cdot (2{,}40 \pm 0{,}08\ A) \cdot \frac{300s}{(2{,}9 \pm 0{,}2\ K) \cdot (323{,}1 \pm 7{,}7\ g)}$$

$$= 4{,}60 \pm 0{,}42\ \frac{kJ}{K \cdot kg}$$

We get an average value for this four mesurements:

$$\underline{\underline{c_w = 4{,}20 \pm 0{,}21\ \frac{kJ}{K \cdot kg}}}$$

This value is equal to the literature value of the specific heat capacity for water ($c_w = 4{,}18\ \frac{kJ}{K \cdot kg}$).

<u>Assignment 2:</u> Specific and Molar Heat Capacity of Aluminium, Copper, Iron and Plexiglas

The ~~mixture temperature~~ experiment analysis in this case is very close to the analysis in the preexperiment. Again we have the following equation:

$$c_w\ m_w'\ \Delta T_w = m_M \cdot c_M \cdot \Delta T_M$$

$$\Leftrightarrow \quad c_M = \frac{c_w\ (m_w + m_e)\ (T_m - T_w)}{m_M\ (T_M - T_m)}$$

Iron:

$$m_w' = (490{,}9 \pm 0{,}1\ g - 251{,}9 \pm 0{,}1\ g) + \overset{24{,}5 \pm 4{,}0\ g}{\cancel{24{,}5 \pm 4{,}0\ g}}\ m_e$$

$$\cancel{= 263{,}5 \pm 4{,}0\ g} \qquad \cancel{= 239 \pm 0{,}2\ g + 17{,}9 \pm 2{,}9\ g}$$

$$= 263{,}5 \pm 4{,}0\ g \qquad \cancel{= 256{,}9 \pm 2{,}9\ g}$$

$T_M = 23{,}2 \pm 0{,}1\ °C$

$T_w = 0{,}4 \pm 0{,}1\ °C$

The stabilized mixture temperature was $4{,}5 \pm 0{,}1\ °C$

$m_M = 946{,}6 \pm 0{,}5\ g$

From this we get:

$$c_m = 4{,}20 \pm 0{,}21 \ \frac{kJ}{K \cdot kg} \cdot \frac{\cancel{280{,}9 \pm 2{,}9\,g}}{\cancel{263{,}5 \pm 4{,}0\,g}} \, 263{,}5 \pm 4{,}0\,g \cdot 4{,}1 \pm 0{,}2\ K \cdot \frac{1}{946{,}6 \pm 0{,}5\,g \cdot 18{,}7 \pm 0{,}2\,K}$$

$$\cancel{= 0{,}26 \pm 0{,}02 \ \frac{kJ}{K\,kg}} \quad = 0{,}26 \pm 0{,}02 \ \frac{kJ}{K \cdot kg}$$

$$\cancel{= 0{,}27 \pm 0{,}02 \ \frac{kJ}{K\,kg}}$$

This value is significant different from the literature value ($0{,}46 \frac{kJ}{K \cdot kg}$). The error will be discussed later on.

The molar heat capacity can be ~~determinated~~ determined as follows.
The amount of substance is given as the quotient of mass (kg) and atomic weight (u):

$$\nu_E = \frac{m_E}{m_a} \qquad \text{where } m_E = 0{,}9466 \pm 0{,}0005\ kg$$

The literature value of m_a for iron is $55{,}8\ u$ $\Rightarrow \nu_E = 1{,}70 \cdot 10^{-2}$

$$\Rightarrow C = \frac{c_m \cdot m_E}{\nu_E} = \frac{0{,}26 \pm 0{,}02 \cdot 0{,}9466 \pm 0{,}0005}{1{,}7 \cdot 10^{-2}} \ \frac{J}{K \cdot mol}$$

$$= 14{,}5 \pm 1{,}2 \ \frac{J}{K \cdot mol}$$

As expected, this value is again significant different from the literature value and does not follow the law of Dulong-Petit.

Copper:

mesured values:

$$m_w = (518{,}4 \pm 0{,}1\,g - 251{,}9 \pm 0{,}1\,g) + 24{,}5 \pm 4{,}0\,g$$
$$= 291{,}0 \pm 4{,}0\,g$$
$$T_M = 23{,}2 \pm 0{,}1\,°C$$
$$T_w = 0{,}4 \pm 0{,}1\,°C$$

mixure temperature: $5{,}5 \pm 0{,}1\,°C$

$$m_M = 833{,}5 \pm 0{,}5\,g$$

From this we get:

$$c_M = 4{,}20 \pm 0{,}21 \frac{kJ}{K \cdot kg} \cdot 291{,}0 \pm 4{,}0\,g \cdot \frac{5{,}1 \pm 0{,}2\,K}{833{,}5 \pm 0{,}5\,g \cdot 17{,}7 \pm 0{,}21}$$

$$= \underline{\underline{0{,}42 \pm 0{,}03 \frac{kJ}{K \cdot kg}}}$$

This value is in correspondence to the literature value of $0{,}386 \frac{kJ}{K \cdot kg}$

The molar heat capacity is: $C = \frac{c_M \cdot m_M}{\nu_c}$

$$\Rightarrow C = \frac{0{,}42 \pm 0{,}03 \cdot 0{,}8335 \pm 0{,}0005}{1{,}3 \cdot 10^{-2}} \frac{J}{K \cdot mol}$$

$$= \underline{\underline{26{,}9 \pm 2{,}2 \frac{J}{K \cdot mol}}}$$

This value is also in correspondence to the literature value and follows the rule of Dulong-Petit by beeing approximately $25 \frac{J}{K \cdot mol}$

Aluminium:

mesured values:

$m_w' = (502{,}6 \pm 0{,}1\,g - 251{,}9 \pm 0{,}1\,g) + 24{,}5 \pm 4{,}0\,g = 275{,}2 \pm 4{,}0\,g$

$T_M = 23{,}2 \pm 0{,}1\ °C$; $T_W = 0{,}3 \pm 0{,}1\ °C$

mixture temperature: $4{,}5 \pm 0{,}1\ °C$

$m_M = 313{,}4 \pm 0{,}5\ g$

Again we get:

$$c_M = 4{,}20 \pm 0{,}21 \frac{KJ}{K \cdot kg} \cdot 275{,}2 \pm 4{,}0\,g \cdot \frac{4{,}2 \pm 0{,}2\ K}{313{,}4 \pm 0{,}5\ g \cdot 18{,}8 \pm 0{,}2\ K}$$

$$= \underline{\underline{0{,}82 \pm 0{,}07 \frac{KJ}{K \cdot kg}}}$$

This value is in correspondence to the literature value of $0{,}9 \frac{KJ}{K \cdot kg}$

molar heat capacity: $C = \frac{0{,}82 \pm 0{,}07 \cdot 0{,}3134 \pm 0{,}0005}{1{,}2 \cdot 10^{-2}} \frac{J}{K \cdot mol}$

$$= \underline{\underline{22{,}1 \pm 2{,}0 \frac{J}{K \cdot mol}}}$$

This value is also in correspondence to the literature value and the law of Dulong-Petit.

Plexiglas:

mesured values:

$m_w' = (486{,}7 \pm 0{,}1\,g - 251{,}9 \pm 0{,}1\,g) + 24{,}5 \pm 4{,}0\,g = 259{,}3 \pm 4{,}0\,g$

$T_M = 23{,}2\ °C \pm 0{,}1\ °C$; $T_W = 0{,}1 \pm 0{,}1\ °C$

mixture temperature: $1{,}5 \pm 0{,}2\ °C$ (hard to determine, therefore the high error)

$m_M = 129{,}9 \pm 0{,}5\,g$

Specific heat capacity:

$$c_M = 4{,}20 \pm 0{,}21 \frac{KJ}{K \cdot kg} \cdot 259{,}3 \pm 4{,}0\,g \cdot \frac{1{,}4 \pm 0{,}3\ K}{129{,}9 \pm 0{,}5\,g \cdot 21{,}7 \pm 0{,}3\,K}$$

$$= \underline{\underline{0{,}54 \pm 0{,}13 \frac{KJ}{K \cdot kg}}}$$

Because, the molecular weight of plexiglas is unknown, I can't find a value for the molar heat capacity.

Assignment 3: Specific Heat of Fusion of Ice

The equations mentioned in the introduction lead us to the following relationship:

$$\underbrace{(m_a + m_w)}_{m_w'} \cdot c_w \left(T_{mixed} - T_{water}\right) \overset{!}{=} m_{ice} \cdot c_w \left(T_{mixed} + \underbrace{T_{ice}}_{=0}\right) + \gamma_{ice} \cdot m_{ice}$$

$$\Rightarrow \quad \gamma_{ice} = \frac{c_w\, m_w' \left(T_{water} - T_{mixed}\right) - m_{ice}\, c_w\, T_{mixed}}{m_{ice}}$$

measured values:

$$m_w' = (478{,}3 \pm 0{,}1\,g - 251{,}9 \pm 0{,}1\,g) + 24{,}5 \pm 4{,}0\,g$$
$$= 250{,}9 \pm 4{,}0\,g$$

$$m_{ice} = 480{,}5 \pm 0{,}1\,g - 478{,}3 \pm 0{,}1\,g = 2{,}2 \pm 0{,}2\,g$$

$T_{water} = 29{,}4\,°C \pm 0{,}1\,°C$; $T_{ice} = 0{,}0$ ~~±0,0°C~~ $°C$

$T_{mixed} = 28{,}3 \pm 0{,}1\,°C$

$$\Rightarrow \gamma_{ice} = \frac{4{,}20 \pm 0{,}21\,\frac{kJ}{K \cdot kg} \cdot 250{,}9 \pm 4{,}0\,g \cdot 1{,}1 \pm 0{,}2\,K \;-\; 2{,}2 \pm 0{,}2\,g \cdot 4{,}20 \pm 0{,}21\,\frac{kJ}{K \cdot kg}}{2{,}2 \pm 0{,}2\,g}$$

$$= \underline{\underline{408{,}0\,\frac{kJ}{kg} \pm 86{,}0\,\frac{kJ}{kg}}}$$

This value is in correspondance to the literature value.

Conclusion

The purpose of this experiment was to determine the specific and molar heat capacity of different materials. Considering the large influence of systematic errors (described later on), it is suprizing how close the results are to the literature values, except of the specific and molar heat capacity of iron. Most of this systematic errors can be found in the experiment setup itself. The calorymeter for example hasn't got sufficent isolation to avoid heat exchange during a mesurement. In case of the heater the loss of electric energy in the cables is another source of systematic error. The second part of this error analysis should have a closer look for the specific experiments:

On Assignment 1:

As I already mentioned we have a loss of electric energy. ~~Additiona~~ Additional errors occured, when we ~~mixed the wate~~ heat up the wate whic causes a loss of water during the time of 30 min.

On Assignment 2:

$\boxed{28{,}3 \pm 0{,}1\ K}$

The errors made during this experiment, ~~specifically~~ specifically in the mesurement with iron can be explained with an insufficient distribution of the water in the calorymeter. Therefore significant different values of the "stabilized" temperature could be mesured.

On Assignment 3:

The small amout of ice used, results into a high relative error of the mesured values, which ~~explained~~ explains the high error of the final value.

In general this experiment is useful for compare the different specific heat capacities of the materials, ~~both should not~~ But another setup should be used for determin more accurate values for the quantities.