Heat capacity of metals with Cobra4 (Item No.: P2330160)

Curricular Relevance

Area of Expertise: Physics
Education Level: University
Topic: Thermodynamics
Subtopic: Heat, Work, and the First Law of Thermodynamics
Experiment: Heat capacity of metals with Cobra4

Difficulty
Difficult

Preparation Time
10 Minutes

Execution Time
30 Minutes

Recommended Group Size
2 Students

Additional Requirements:

- PC with USB interface, Windows XP or higher

Experiment Variations:

Keywords:

Mixture temperature, Boiling point, Dulong Petit’s law, Lattice vibration, Internal energy, Debye temperature

Overview

Short description

Principle

Heated specimens are placed in a calorimeter filled with water at low temperature. The heat capacity of the specimen is determined from the rise in the temperature of the water.

Fig. 1: Experimental setup

Safety instructions


Equipment

Position No.	Material	Order No.	Quantity
1	Cobra4 Wireless/USB-Link incl. USB cable	12601-10	1
2	Cobra4 Sensor-Unit 2 x Temperature, NiCr-Ni	12641-00	1
3	USB charger for Cobra4 Mobile-Link 2 and Wireless/USB-Link	07932-99	1
4	curricuLAB measureLAB	14580-61	1
5	Immersion probe NiCr-Ni, steel, -50...400 °C	13615-03	1
6	Support base DEMO	02007-55	1
7	Support rod, stainless steel, l = 600 mm, d = 10 mm	02037-00	2
8	Right angle boss-head clamp	37697-00	2
9	Universal clamp	37715-00	2
10	Ring with boss head, i. d. = 10 cm	37701-01	1
11	Wire gauze with ceramic, 160 x 160 mm	33287-01	1
12	Metal bodies, set of 3	04406-00	2
13	Butane burner, Labogaz 206 type	32178-00	1
14	Butane cartridge C206, without valve, 190 g	47535-01	1
15	Fish line, l. 100m	02090-00	1
16	Calorimeter vessel, 500 ml	04401-10	1
17	Beaker, low, BORO 3.3, 400 ml	46055-00	1
18	Beaker, low, BORO 3.3, 600 ml	46056-00	1
19	Agitator rod	04404-10	1
20	Pipette with rubber bulb	64701-00	1
21	Boiling beads, 200 g	36937-20	1

Tasks

1. Determine the specific heat capacity of aluminium, iron and brass.
2. To verify Dulong Petit’s law with the results of these experiments.

Set-up and procedure

Setup

The experimental setup is shown in Fig.1.
Fill a 600 ml glass beaker with water at room temperature as a reserve vessel for the calorimeter. Connect the Cobra4 Wireless/USB Link with your computer (either with a USB socket or wireless connection), plug the Cobra4 Sensor-Unit 2 x Temperature NiCr-Ni on the Cobra4 Wireless Link and connect the thermoelement.
Fill 200 g of water at room temperature (m1) in the calorimeter. Tie two aluminium test pieces together with fishing line and do the same with two iron and three brass pieces. Fill a 400 ml glass beaker with about 300 ml of water. Immerse all the metallic bodies in this water bath using a universal clamp to avoid that the metallic bodies touch the bottom of the beaker.
Note: The different metallic bodies have to be removable separately.

Procedure

- Bring the water with the metallic bodies to boil.
- Start the software “measureLAB” on your computer and choose the experiment from the start screen ("PHYWE experiments", search for "P2330160", and click on the folder that contains this experiment). All necessary presettings will be loaded.
- Calibrate the temperature sensor as follows:
- In this experiment the immersion probe should show 100 °C in boiling water. Hence for calibrating, the probe is kept in the glass beaker with the boiling water.
- Go to and then click on Sensors/Channels and select the immersion probe. To perform 1-point calibration, click on Calibrate sensor and enter 100 °C as corrected value (Fig. 2).

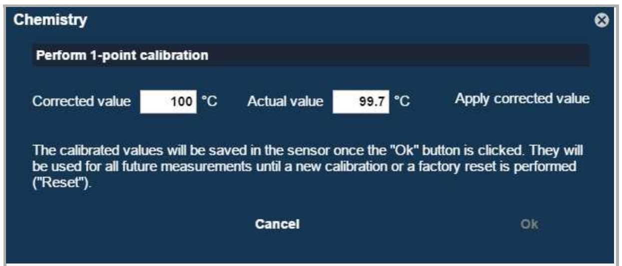

Fig. 2: Sensor calibration.

- Cool the immersion probe very carefully and then immerse it in the cold water in the calorimeter vessel. Click on in the record button to start the measurement and measure the temperature of the water in the calorimeter for about 5 seconds.
- Take the metallic bodies of one type (e.g. Aluminium) out of the the boiling water, dry them quickly, put them in the calorimeter vessel and stir vigorously.
- End measurement after 60 seconds by pressing the stop button .
- Save your project by clicking on the button in the top bar.
- The measured temperatures are displayed as a function of time immediately (see Fig. 3). Repeat the procedure for the other metallic bodies (Figs. 4 and 5).
- Before doing so, wash the calorimeter with cold water, dry it and fill it with water again.

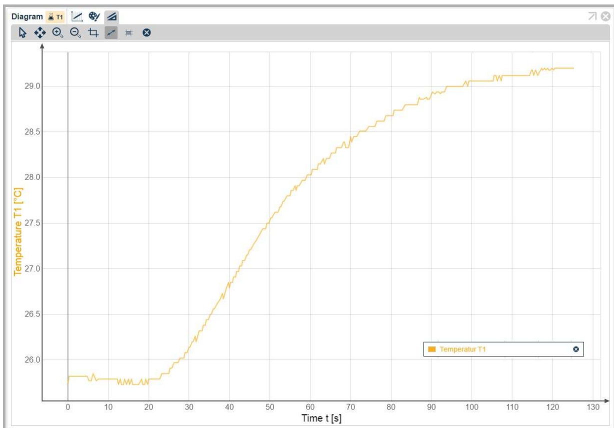

Fig. 3: Course of temperature in the calorimeter for 120 g Aluminium (100 °C) and 200 g water (room-temperature).

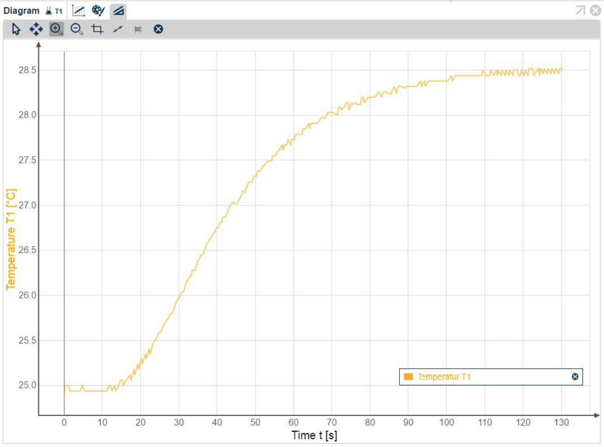

Fig. 4: Course of temperature in the calorimeter for 120 g Iron (100 °C) and 200 g water (room-temperature).

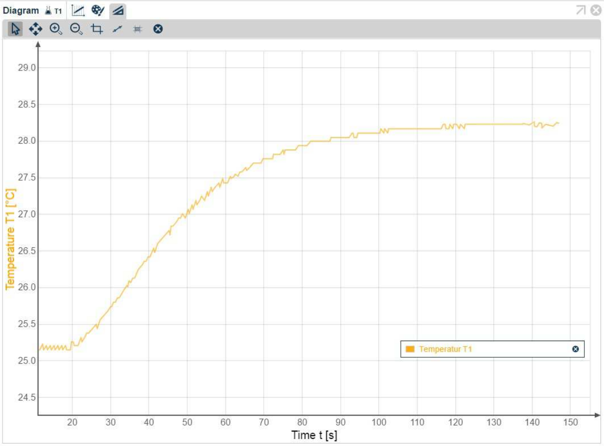

Fig. 5: Course of temperature in the calorimeter for 120 g Brass (100 °C) and 200 g water (room-temperature).

Theory and evaluation

The heat capacity *C* of a substance is defined as the quotient of the quantity of heat absorbed δQ and the change in temperature d*T*.

$$C = \frac{\delta Q}{\mathrm{d}T} \quad (1)$$

and is proportional to the mass of the heated substance.

$$c = \frac{C}{m} \quad (2)$$

is the specific heat capacity.

The quantity of heat absorbed δQ depends on the conditions prevailing as the temperature rises, and a differentiation is made in particular between heat capacity C_V at constant volume *V* and heat capacity C_p at constant pressure *p*.

In accordance with the First Law of Thermodynamics (*U* = internal energy),

$$\delta Q = \mathrm{d}U + p\mathrm{d}V \quad (3)$$

C_p is always greater than C_V. In the case of solids, the change in volume is so small that we can write

$$C_\mathrm{p} \simeq C_\mathrm{V}$$

C_V can be calculated from the change in internal energy with temperature in accordance with (1) and (3):

$$C_\mathrm{V} = \left(\frac{\partial U}{\partial T}\right)_\mathrm{V} \quad (4)$$

The internal energy *U* in a solid is essentially the result of lattice vibrations caused by heat.

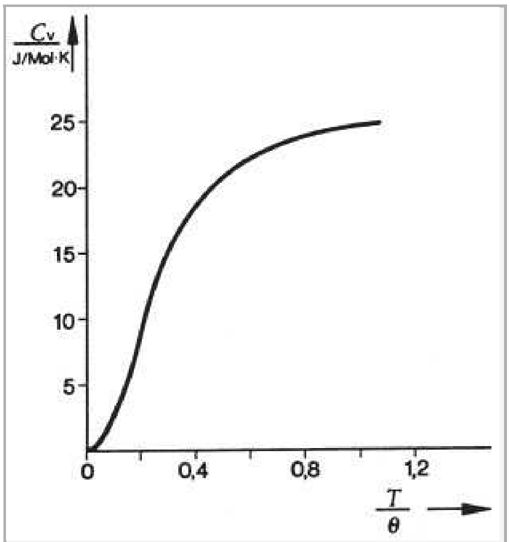

Fig. 7: Molar heat capacity of a solid in accordance with Debye's approximation.

According to Debye's theory, which considers lattice vibrations up to a limiting frequency ν_D , the heat capacity is given by

$C_V(T) = 3\,Nk\left(\frac{T}{\Theta}\right)^3 \cdot 3\int_0^{\Theta/T}\left(\frac{z^4\,e^z d_z}{(e^z-1)^2}\right) = 3Nk\cdot D\left(\frac{T}{\Theta}\right)$ (5)

where

$z = h\,/kT$,

$0 = h\nu_D/k$, called the Debye temperature

h = Planck's constant,

k = Boltzmann constant,

N = number of atoms in the volume considered.

$D(T/\Theta)$ is called the Debye function.

For large values of T/Θ the upper integration limit is small, the integrand can be expanded and we obtain the law of Dulong and Petit:

$C_V = 3Nk$

We thus obtain the molar heat capacity

$C_m = 3N_L\cdot k = 3R = 24.94\ \text{J/K}$ (6)

where N_L is the Loschmidt number and *R* the gas constant.

Debye temperature:

Aluminium: 419 K

Copper: 335 K

Iron: 462 K

Zinc: 100 K

For the evaluation, the heat capacity is assumed to be constant in the temperature range considered.

After the metallic bodies at temperature T_2 (=100 °C) are put in the cold water at temperature T_1, the mixture in the calorimeter has a temperature T_m which results from the energy balance.
The temperatures before and after heat sharing are not constant because of the exchange of heat with the surroundings. For the evaluation select the appropriate scale for the temperature axis by adapting the "display options" in the "measurement" menu. Enlarge the graph to full screen size and use the function "survey" to determine the start temperature T_1 and the mixture temperature T_m with the help of the cursor lines (Figs. 4-6).
The difference in temperature is also available.

The specific heat capacity of the material from which the test pieces are made is obtained from the energy balance as:

$C_2 = \frac{(C+c_1 m_1)\cdot(T_1 - T_m)}{m_2\cdot(T_m - T_2}$

where

C = 80 J/K = heat capacity of the calorimeter

c_1 = 4.19 J/K = specific heat capacity of water

m_1 = 200 g = mass of water

m_2 =120 g = mass of the metal bodies

	Aluminium	Iron	Brass
T_1 [°C]	22.23	22.60	21.82
T_m [°C]	30.17	26.78	25.41
$T_m - T_1$ [K]	7.94	4.18	3.59
$T_2 - T_m$ [K]	69.83	73.22	74.59
C [J/K]	0.870	0.437	0.368
c_{lit} [J/K]	0.896	0.452	0.385
C_m [J/K]	23.46	24.41	23.72

Tab. 1: Typical measurement example of the heat capacity

The measured values (Tab. 1) of the heat capacity correspond to the values found in literature.
The values of molar heat capacity as measured in the experiment also agree well with the theoretical values from Dulong and Petit`s law (24.94 J/(Mol K)).