Specific heat capacity of metals with SMARTsense

(Item No.: P1044269)

Curricular Relevance

Area of Expertise:	Education Level:	Topic:	Subtopic:	Experiment:
Physics	Age 16-19	Thermodynamics	Calorimetry	Specific heat capacity of metals with SMARTsense

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Intermediate	10 Minutes	10 Minutes	2 Students

Additional Requirements:

- Tablet PC with measureAPP

Experiment Variations:

Keywords:

Calorimetry, Mixture temperature, Specific heat capacity

Task and equipment

Information for teachers

A choice can be made as to whether the measured values are to be used to determine the heat capacity of the metal bodies or to determine the water equivalent of the calorimeter that is described under additional tasks.
Initially the calorimeter should be filled with water at room temperaute. This ensures that the contents of it are all at an almost uniform temperature.
A boiling water bath is used as a constant temperature reservoir for the metal bodies. This keeps the temperature constant in a simple way, but has the disadvantage that the temperature is relatively high so that the metal bodies can easily lose heat on their way to the calorimeter.
The water equivalent values found depend on how rapidly the experiment is is carried out.

Notes on setup and procedure

The metal bodies should not touch the bottom of the Erlenmeyer flask when they are heated up, as it is hotter than the rest of the water bath.

Setup

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Task and equipment

Task

Application

The calorimeter can be used to determine the heat content of a piece of metal. The heat content can be calculated from the mixing temperature that is reached in the calorimeter.

Why is the hot-water-bottle filled with water and not with metal? Besides the weight, there is another important reason, that will be revealed in this experiment.

Long-lasting heat from a hot-water-bottle is possible, because of the water inside. Would this be possible with metal, too?

Task

How much heat can be stored in metals?

Heat up metal bodies of the same mass but different metals to the same temperature in a water bath. Bring them separately into a calorimeter that is filled with water having a known initial temperature and measure the mixing temperature that is reached. Calculate the specific heat capacities of the various metals from your results.

Equipment

Position No.	Material	Order No.	Quantity
1	Cobra SMARTsense - Temperature, - 40 ... 120 °C	12903-00	1
2	Support base, variable	02001-00	1
3	Support rod, l = 600 mm, d = 10 mm, split in 2 rods with screw threads	02035-00	1
4	Universal clamp	37715-00	1
5	Boss head	02043-00	1
6	Ring with boss head, i. d. = 10 cm	37701-01	1
7	Wire gauze with ceramic, 160 x 160 mm	33287-01	1
8	Metal bodies, set of 3	04406-00	1
9	Lid for student calorimeter	04404-01	1
10	Agitator rod	04404-10	1
11	Felt sheet, 100 x 100 mm	04404-20	2
12	Erlenmeyer wide neck,boro.,250ml	46152-00	1
13	Beaker, low form, plastic, 100 ml	36011-01	1
14	Beaker, low, BORO 3.3, 250 ml	46054-00	1
15	Beaker, low, BORO 3.3, 400 ml	46055-00	1
16	Graduated cylinder 100 ml, PP transparent	36629-01	1
17	Fishing line, l. 20m	02089-00	1
18	Pipette with rubber bulb	64701-00	1
19	Butane burner, Labogaz 206 type	32178-00	1
20	Butane cartridge C206, without valve, 190 g	47535-01	1
21	Boiling beads, 200 g	36937-20	1

Position No.	Material	Order No.	Quantity
22	Tablet		1
23	PHYWE measure App		1

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Setup and procedure

Setup

Fig. 1: Setup

- Set the stand up as in Fig. 1.
- Fill at least 250 ml of water in the Erlenmeyer flask and add two boiling chips.
- Thread a 40 cm length of fishing line through each of the three metal bodies and knot it to make a loop.
- Hang all of the metal bodies on the universal clamp. They should not touch the bottom of the Erlenmeyer flask and it must be possible to take them out individually.
- Make up a thermally insulating vessel (calorimeter) using two glass beakers (250 ml und 400 ml) and two felt sheets.
- Fill 150 ml of water, either cold or at room temperature, in the calorimeter. Measure the water out exactly from the plastic beaker using the graduated flask and the pipette.
- Ease the agitator rod through the appropriate hole in the calorimeter lid from below and fit the lid on the calorimeter.

Procedure

Caution!

The support ring and the wire gauze get very hot during the heating of the water!
Take care! Do not let the sensor cable touch the wire gauze!

- Bring the water in the Erlenmeyer flask to the boil. When the water boils, adjust the flame so small that it just continues to boil.
- Switch the Cobra SMARTsense-Temperature on.
- Open the PHYWE measure App and select the sensor "temperature".
- Set the sampling rate to 1 Hz for this experiment.
- Insert the temperature sensor through a hole in the lid of the calorimeter so that it dips into the water but does not touch the bottom.
- Start measurement recording in measureApp, a measured temperature value is now recorded every second.
- Stir and wait until the temperature display remains constant, at least 100 s.
- Take a metal body and rapidly transfer it to the calorimeter, immediately put the lid back on.
- Carefullly stir the water in the calorimeter so that the heat in the water is uniformly distributed.
- End measurement with, when the temperature remains constant or when it slowly decreases. Save it afterwards.
- Pour away the water in the calorimeter, dry the calorimeter beaker. Fill 150 ml of water into it.
- Repeat the experiment in the same way with each of the two other metal bodies. Also save those measurements.
- Finally measure the temperature of the boiling water before you turn the burner off, holding the temperature sensor in the universal clamp.

Evaluation

All metal bodies have the same mass m_{metal} = 60 g.
All metal bodies have the same initial temperature in boiling water $\vartheta_{\mathrm{metal,1}}$.
The mass of the water in the calorimeter was for each experiment m_{water} = 150 g.
The specific heat capacity of water is c_{water} = 4,2 J/(g·°C)
After transfer of the metal bodies into the calorimeter, the temperatures of the water in the calorimeter and of the metal bodies come to a common temperature of $\vartheta_{\mathrm{cal,2}}$.

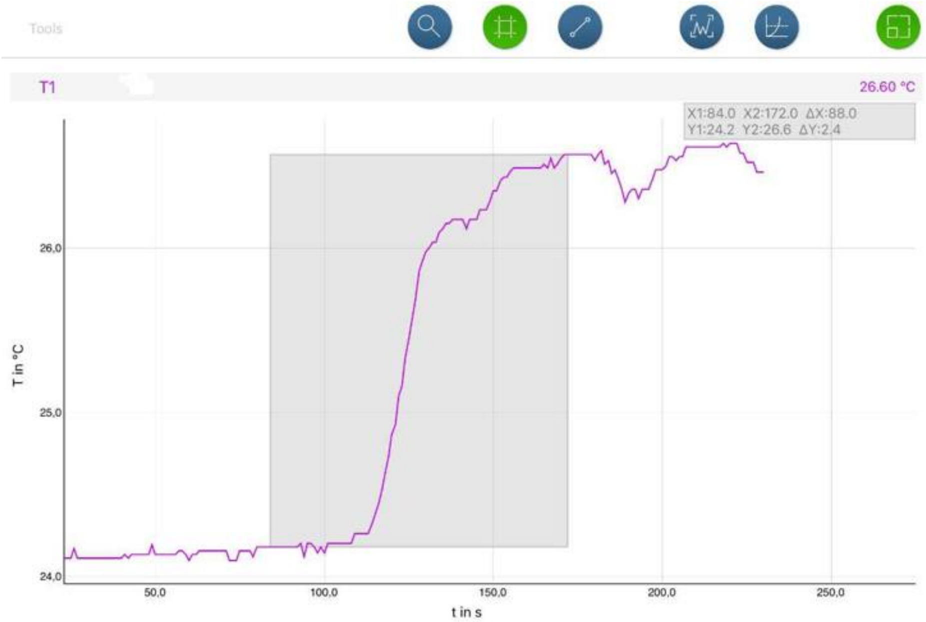

Fig. 2: Behaviour of the temperate display over time, with the measureApp "Survey" tool switched on. Example for brass.

Report: Specific heat capacity of metals with SMARTsense

Evaluation - Question 1 (13 points)

Select the “Survey“ tool in the measureApp to determine the initial temperature in the calorimeter $\vartheta_{\text{cal,1}}$ and the mixture temperature in the calorimeter $\vartheta_{\text{cal,2}}$ for each of the three measurement curves. Enter the values in Table 1.

Also enter the temperature of the boiling water, which depends on the atmospheric pressure and the salt content (mainly lime) of the water, in Table 1. Calculate the temperature differences between the temperatures of the metal sample $\Delta\vartheta_{\text{metal}} = \vartheta_{\text{metal,1}} - \vartheta_{\text{cal,2}}$ and the temperatures of the water in the calorimeter $\Delta\vartheta_{\text{water}} = \vartheta_{\text{cal,2}} - \vartheta_{\text{cal,1}}$ before and after transferring the metal sample into the calorimeter. Enter the values in Table 1:

Brass	$\vartheta_{cal,1}$ / °C	1 ±10	$\Delta\vartheta_{water}$ / °C	1 ±1	$\Delta\vartheta_{brass}$ / °C	1 ±5
	$\vartheta_{cal,2}$ / °C	1 ±10				
Iron	$\vartheta_{cal,1}$ / °C	1 ±10	$\Delta\vartheta_{water}$ / °C	1 ±1	$\Delta\vartheta_{iron}$ / °C	1 ±5
	$\vartheta_{cal,2}$ / °C	1 ±10				
Aluminium	$\vartheta_{cal,1}$ / °C	1 ±10	$\Delta\vartheta_{water}$ / °C	1 ±1	$\Delta\vartheta_{aluminium}$ / °C	1 ±5
	$\vartheta_{cal,2}$ / °C	1 ±10				
Initial temperature of the metals $\vartheta_{metal,1}$	1 ±6					

Evaluation - Question 2 (3 points)

Under the assumption that no heat is released into nor gathered from the environment and also that no other source of heat is active, the following is valid:

The metal sample gives an amount of heat up in the calorimeter $\Delta Q_{\text{metal}} = c_{\text{metal}} \cdot m_{\text{metal}} \cdot \Delta\vartheta_{\text{metal}}$
And the water takes on the amount of heat $\Delta Q_{\text{water}} = c_{\text{water}} \cdot m_{\text{water}} \cdot \Delta\vartheta_{\text{water}}$.

The two amounts of heat must be equal. The specific heat capacity c_{metal} is hereby the only unknown, the other quantities were either measured or are assumed to be known. We therefore have:

$\Delta Q_{\text{metal}} = \Delta Q_{\text{water}}$

$c_{\text{metal}} \cdot m_{\text{metal}} \cdot \Delta\vartheta_{\text{metal}} = c_{\text{water}} \cdot m_{\text{water}} \cdot \Delta\vartheta_{\text{water}}$ (1)

$c_{\text{metal}} = c_{\text{water}} \cdot \frac{m_{\text{water}}}{m_{\text{metal}}} \cdot \frac{\Delta\vartheta_{\text{water}}}{\Delta\vartheta_{\text{metal}}}$ (2)

When the values obtained in the experiment are entered, we have the following:

$c_{\text{metal}} = 4,2 J/(^{\circ}C \cdot g) \cdot \frac{150g}{60g} \cdot \frac{\Delta\vartheta_{\text{water}}}{\Delta\vartheta_{\text{metal}}}$

$c_{\text{metal}} = 10,5 J/(^{\circ}C \cdot g) \cdot \frac{\Delta\vartheta_{\text{water}}}{\Delta\vartheta_{\text{metal}}}$ (3)

Calculate the heat capacities of the metal samples using the measured values from Table 1 and using equation (3). Supplement Table 2:

Table 3: Literature values		
Brass	c_{brass} / J/(°C·g)	0.385
Iron	c_{iron} / J/(°C·g)	0.450
Aluminium	$c_{aluminium}$ / J/(°C·g)	0.896

Evaluation - Question 3 (1 point)

Compare your results with the literature values in Table 3. Why does equation (3) lead to values that are too low? Which heat capacity was not taken into consideration?

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Additional Question 1 (12 points)

Now assume that the heat capacities of the metal bodies are known and are given in Table 3 and take the amount of water in the calorimeter as being the unknown. The difference between the calculated value for the amount of water and the actual amount of water is called the water equivalent of the calorimeter.
After solving in terms of mwater , equation (1) gives:

$m_{\text{water}} = m_{\text{metal}} \cdot \frac{c_{\text{metal}}}{c_{\text{water}}} \cdot \frac{\Delta\vartheta_{\text{metal}}}{\Delta\vartheta_{\text{water}}}$ (4)

In each case, calculate the amount of water acc. to (4) and from that, the water equivalent of the calorimeter with the known amount of water of 150 g.
The water equivalent of the calorimeter corresponds to a heat capacity C in J/°C. (Reminder: $C = c_{\text{water}} \cdot m_{\text{water}}, c_{\text{water}} =$ 4,2 J/(g·°C)). Also calculate the average values for the three experiments.
Supplement Table 4

	m_{water} / g	Water equivalent / g	C / J/°C
Brass	1 ±10	1 ±3	1 ±10
Iron	1 ±10	1 ±3	1 ±10
Aluminiu	1 ±10	1 ±3	1 ±10
Average	1 ±10	1 ±3	1 ±10

Additional Question 2 (1 point)

Where are the greatest measurement uncertainties?

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