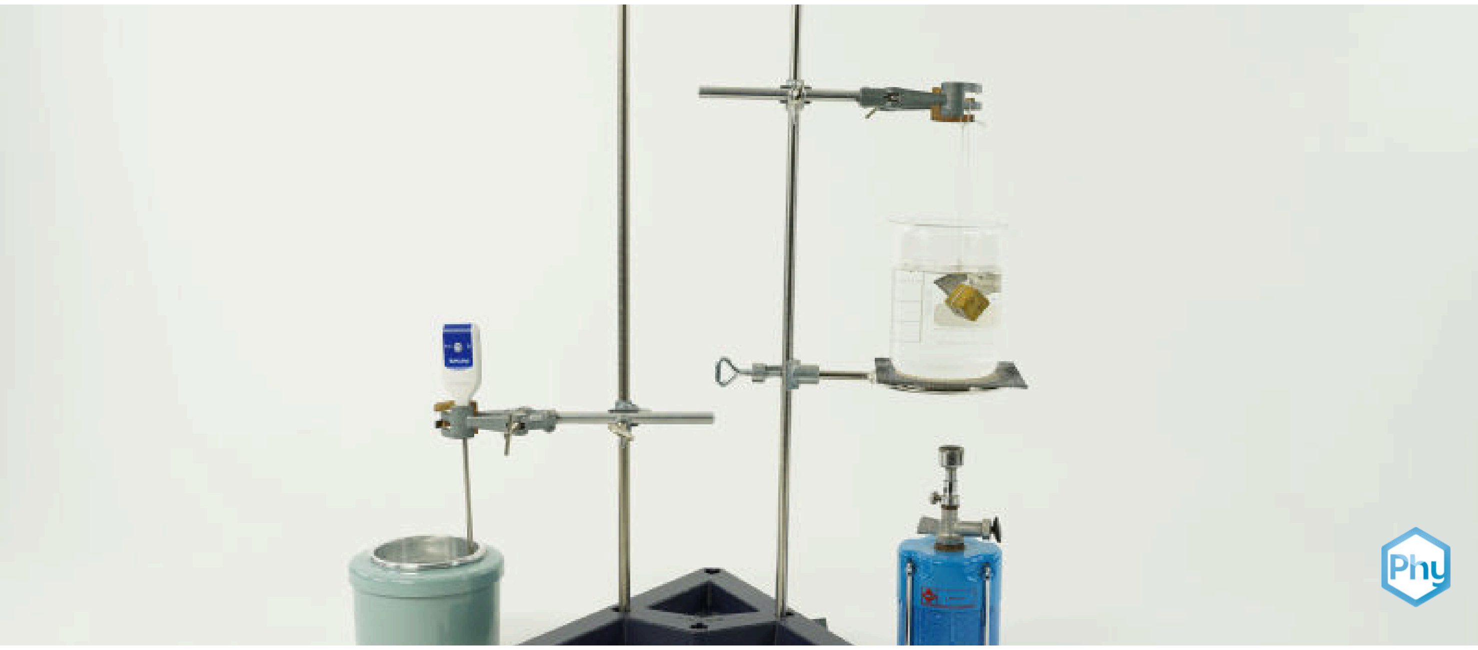
Heat capacity of metals with Cobra SMARTsense



Physics | Thermodynamics | Temperature & Heat

Difficulty level	Group size	Preparation time	Execution time
hard	2	10 minutes	30 minutes

This content can also be found online at:

http://localhost:1337/c/5f0ec807b6127b00030447da

General information

Application

Experiment setup

The specific heat capacity of solids is a characteristic property. In order to determine the heat capacity of solids (e.g. metals), we heat them in a water bath. The metal takes on the temperature of the boiling water.

The heated metal is placed in a calorimeter with cold water. The heated metal transfer heat to the cold water until a mixing temperature has been reached.

The mass of the metal and the temperature of the cold water are known and the mixture temperature is measurable. With the help of this measured variables the heat capacity of the metals can be determined.

Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Other information (1/2)

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Prior knowledge

The calorimeter should be filled with water at room temperature. A boiling water bath is used as a constant temperature reservoir for the metal blocks. The measured water values depend on how quickly you bring the metals into the calorimeter.

Scientific principle

- Calorimetry can be used to determine the heat content of a piece of metal. With the mixing temperature, which is set in the calorimeter, the specific heat can be calculated.
- Heated metals are placed in a calorimeter filled with water at low temperature. The heat capacity of the metal is determined from the rise in the temperature of the water.

Other information (2/2)

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Learning objective

Putting a metal in a water bath with different temperatures, a mixture of temperatures will result. This temperature is used to calculate the specific heat of the metal. Dulong Petit's law states that for high Debye temperatures, the thermal capacity of metals is 24.94 J/(K·mol)

Tasks

Bring a metal probe into a water-filled calorimeter with a known starting temperature and measure the mixing temperature. Use this to calculate the specific heat capacity of the individual metal samples.Determine the specific heat capacity of aluminum, iron and brass. Review of Dulong Petit's law based on the results of this experiment.

For large values of T we obtain the molar heat capacity based on Dulong Petit :

$$C_m = 3 \cdot N \cdot k = 3 \cdot R = 24.94 J/(K \cdot mol)$$

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Safety instructions

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For this experiment the general instructions for safe experimentation in science lessons apply.

For H- and P-phrases please consult the safety data sheet of the respective chemical.

Theory (1/2)

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The heat capacity C of a substance is defined as the quotient of the quantity of heat absorbed ΔQ and the change in temperature ΔT we obtain (1)

$$C = \frac{\Delta Q}{\Delta T}$$

and is proportional to the mass of the heated substance . The specific heat capacity is (2)

$$c = \frac{C}{m}$$

The quantity of heat absorbed 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.

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Equipment

Position	Material	Item No.	Quantity
1	Cobra SMARTsense - Thermocouple, -200 ... +1200 °C (Bluetooth + USB)	12938-01	1
2	Holder for Cobra SMARTsense	12960-00	1
3	USB charger for Cobra SMARTsense and Cobra4	07938-99	1
4	measureLAB, multi-user license	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	37715-01	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, Borosilicate, low-form, 400 ml	46055-00	1
18	Beaker, Borosilicate, low form, 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

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11	Wire gauze with ceramic, 160 x 160 mm	33287-01	1

Additional equipment

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Position	Material	Quantity
1	measureApp	1
2	mobile Device (Tablet, Smartphone)	1

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Setup and procedure

Setup (1/2)

Experiment setup

- Fill 200 g of water at room temperature (mass m1) in the calorimeter.
- Tie aluminium test pieces together with fishing line and do the same with iron and brass pieces.
- Fill a 600 ml glass beaker with about 400 ml of water. Immerse all the metallic bodies in this water bath using an universal clamp to avoid that the metallic bodies touch the bottom of the beaker.
- Put the Cobra SMARTsense Temperature Sensor in the calorimeter.

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Setup (2/2)

The Cobra SMARTsense sensor and the measureApp are required to measure the Temperature. Check whether "Bluetooth" is activated on your device (tablet, smartphone) (the app can be downloaded free of charge from the App Store - QR codes below). Now open the measureApp on your device.

measureApp for Android

(Google Play Store)

measureApp for iOS

(App Store)

Procedure (1/2)

Connect Temperature Sensor

- Switch on the Cobra SMARTsense Temperature sensor by a long press on the power button.
- Connect the sensor in the measureAPP under the item "Measure" to the device, as shown in the figure on the left.
- The Cobra SMARTsense Temperature is now displayed in the app.

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Procedure (1/2)

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- Bring the water with the metallic bodies to boil. Use a gas burner to heat the water. Start the measurement in the measureApp by putting the "Start" button.
- 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
- The measured temperatures are displayed as a function of time immediately. Repeat the procedure for the other metals. Before doing so, wash the calorimeter with cold water, dry it and fill it with water again.

Evaluation (1/8)

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Determination of mixing temperature

After the metals at temperature (=100 °C) are put in the cold water, the mixture in the calorimeter reaches a mixing temperature. Determine the start temperature and the mixture temperature and calculate the specific heat of the metals:

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

C = 80 J/K = heat capacity of the calorimeter and c_1 = 4.19 J/K = specific heat capacity of water and m_1 = 200 g = mass of water and m_2 =120 g = mass of the metal bodies and T_m = mixing temperature and T_2 = 373 K (= 100°C), the boiling point of water

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Evaluation (2/8)

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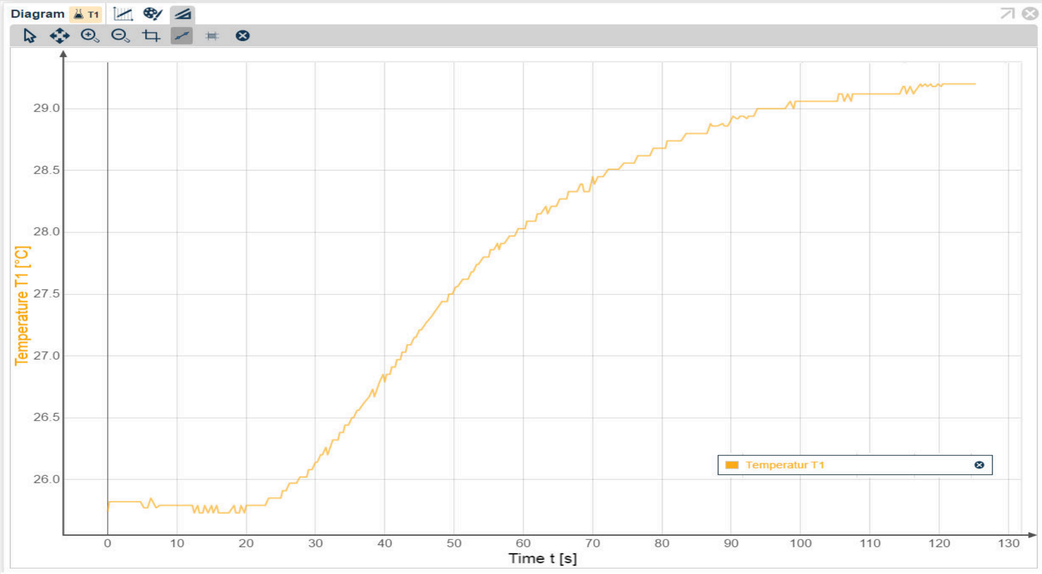
Diagramm of temperature in the calorimeter for 120 g Aluminium (100 °C) and 200 g water (room-temperature).



Evaluation (3/8)

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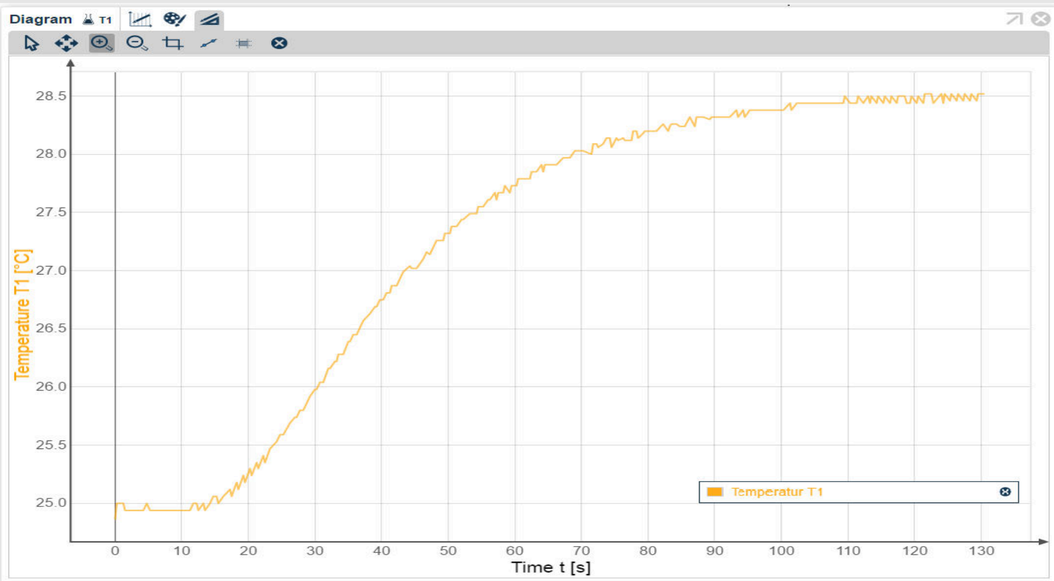
Diagramm of temperature in the calorimeter for 120 g Iron (100 °C) and 200 g water (room-temperature).



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Evaluation (4/8)

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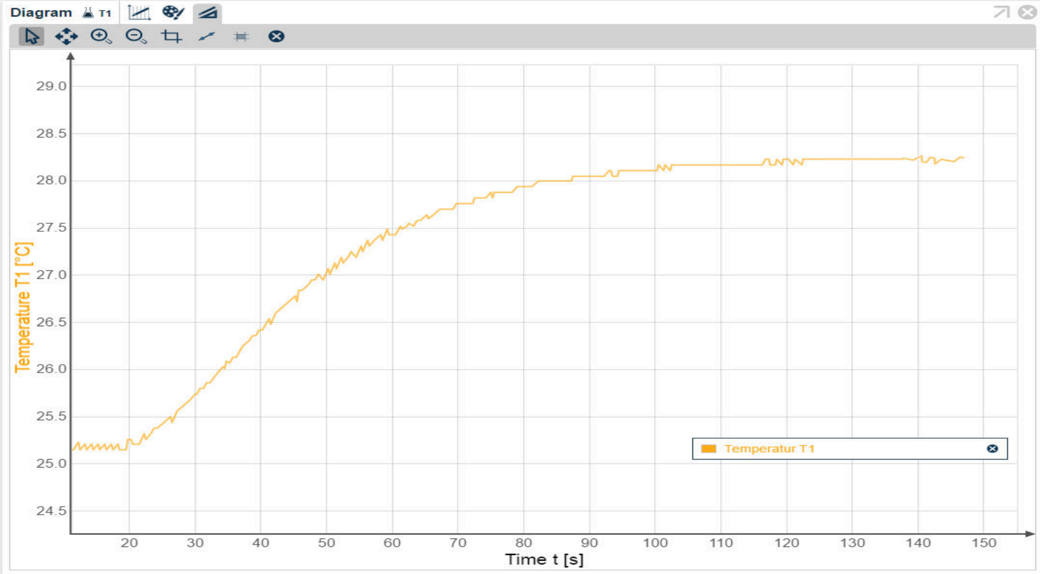
Diagramm of temperature in the calorimeter for 120 g Brass (100 °C) and 200 g water (room-temperature).



Evaluation (5/8)

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Experiment setup

Paramater	materal: Aluminium	material: Iron	material: Brass
cold water T_1			
mixing temperature T_m			
T_m - T_1			
T_2 - T_m			

Type in measurement results

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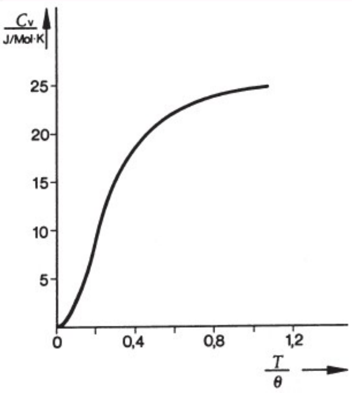
Evaluation (5/8)

Experiment setup

Paramater	Aluminium	Iron	Brass
T_1	22.23 °C	22.60 °C	21.82 °C
T_m	30.17 °C	26.78 °C	25.41 °C
T_m - T_1	7.94 °K	4.18 K	3.59 K
T_2 - T_m	69.83 K	73.22 K	74.59 K
C	0.870 J/K	0.437 J/K	0.368 J/K
C_{Lit}	0.896 J/K	0.452 J/K	0.385 J/K
C_m	23.46 [J/(K·mol)]	24.41 J/(K·mol)	23.72 J/(K/mol)

Typical measurement results

Evaluation (6/8)



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 the heat capacity is given by

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

For large values of T the upper integration limit is small, the integrand can be expanded and we obtain the law of Dulong and Petit: $C_v(T) = 3 \cdot N \cdot k$

We thus obtain the molar heat capacity :

$C_m = 3 \cdot N \cdot k = 3 \cdot R = 24.94 J/(K \cdot mol)$

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Evaluation (8/8)

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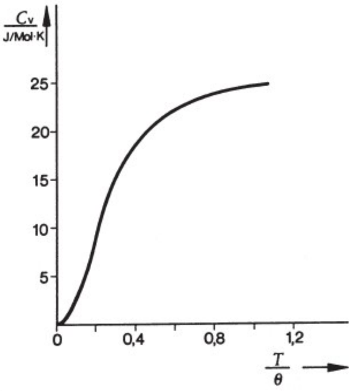

Molar heat capacity of a solid in accordance with Debye's approximation

For large values of T we obtain the molar heat capacity (Dulong Petit law) :

$$C_m = 3 \cdot N \cdot k = 3 \cdot R = 24.94 J/(K \cdot mol)$$

Debye temperature for used materials

- Aluminium: 419 K
- Copper: 335 K
- Iron: 462 K

Therefore the heat capacity of the measure metals should be about 24.94 J/K. The results of the experiment prove the Dullong Petit law, e.g 24.41 J/(K·mol) for Iron.

Question 1

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Principle of thermodynamics

If the volume of the measures system is constant, you can use the first principle of thermodynamics which states that the thermal energy ΔQ supplied to a metall corresponds to the ______ in internal energy ΔU. The increase of internal energy causes a temperature increase, which is directly proportional: ______.
The specific heat capacity of solid substances is ______. At higher temperatures, however, the molar heat capacity is approximately ______ (Rule of Dulong and Petit)

- $\Delta T \sim \Delta U$
- increase
- temperature-dependent
- c = 3R

Check

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
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Question 2

What is the molar heat capacity of Lead (Pb)?

- about 50 J/(K·mol)
- about 25 J/(K·mol)
- about 250 J/(K·mol)

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Diffent metalls

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
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info@phywe.de
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