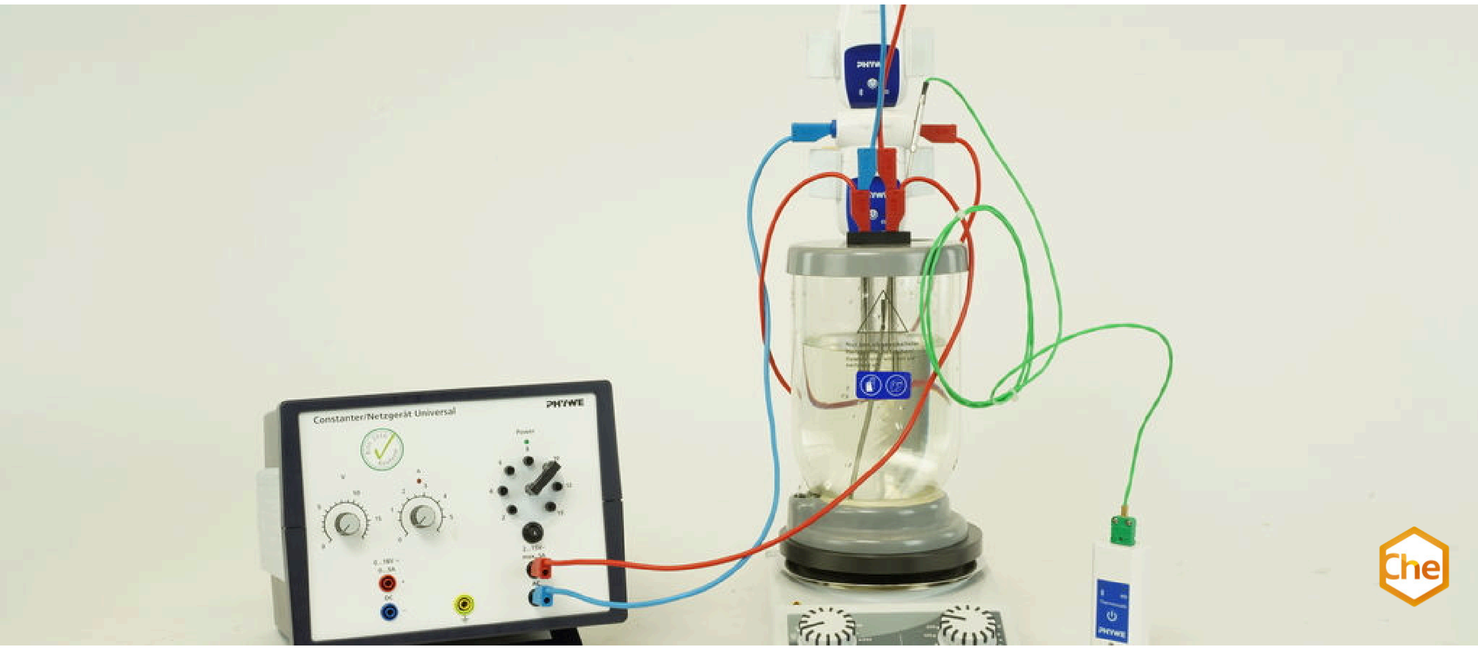
Determination of the hydration enthalpy of an electrolyte (solution enthalpy) with Cobra SMARTsense



When a solid electrolyte dissolves in water, a positive or negative heat effect occurs as a result of the destruction of the crystal lattice and the formation of hydrated ions. The enthalpy of hydration of copper sulphate can be calculated from the different heats of reaction measured when anhydrous and hydrated copper sulphate are separately dissolved in water.

Chemistry > Physical chemistry > Thermochemistry, calorimetry

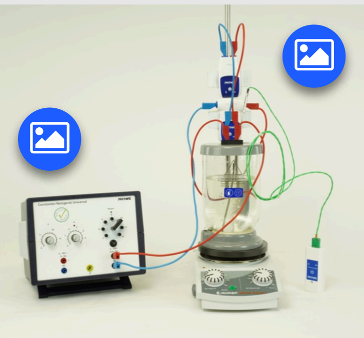
Difficulty level	Group size	Preparation time	Execution time
medium	2	40 minutes	20 minutes

This content can also be found online at:

http://localhost:1337/c/60f3d231aa73180004678e56

General information

Application



The experimental setup

The enthalpy of hydration or enthalpy of solutions addresses fundamental thermodynamic processes during the dissolution of substances in a solvent. The energetic ratios are of particular importance for understanding the dissolution process.

The enthalpy of hydration is released when an ion crystal dissolves. On the other hand, energy is also consumed to dissolve the crystal lattice. The energy to be expended corresponds to the amount of lattice energy of the salt. Lattice energy and hydration enthalpy determine the enthalpy of dissolution, thus qualitatively whether the dissolution process is exothermic or endothermic overall. If the amount of the lattice energy is greater than that of the hydration enthalpy, the dissolution process consumes energy. Conversely, if the hydration enthalpy is greater than the lattice energy, the dissolution process is exothermic and the solution heats up.

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Other information (1/2)

Prior knowledge

The students should be familiar with the method of electrolysis, the basics of thermochemistry, thermodynamics and specifically the principle of enthalpy. Furthermore, students should be familiar working autonomously with chemical agents and be familiar with good laboratory practice.

Scientific principle

When a solid electrolyte dissolves in water, a positive or negative heat effect occurs as a result of the destruction of the crystal lattice and the formation of hydrated ions.
The enthalpy of hydration of copper sulphate can be calculated from the different heats of reaction measured when anhydrous and hydrated copper sulphate are separately dissolved in water.

Other information (2/2)

Learning objective

The students learn to determine the hydration enthalpy of a dissolved electrolyte by recording a temperature-time curve and calculating the enthalpy.

Tasks

1. Record temperature-time curves for the dissolution of anhydrous copper sulphate and hydrated copper sulphate in water.

2. Calculate the hydration enthalpy of anhydrous copper(II)sulphate.

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Safety instructions

- 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

The dissolving of a solid electrolyte in water is primarily determined by two simultaneously occurring processes: the destruction of the crystal lattice and the hydration of the ions. The destruction of the crystal lattice is an endothermic process because energy is required to break down the chemical bonds, whereas the hydration of the ions is exothermic.

Depending on the type of lattice, and on both the radius and the charge of the ions (charge density), the resulting enthalpy of solution can be either endothermic or exothermic.

When a salt exists in both hydrated and dehydrated forms, and on assuming that when the hydrated salt dissolves only the degradation of the crystal lattice occurs, the enthalpy of hydration can be calculated using Hess’s theorem.

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Equipment

Position	Material	Item No.	Quantity
1	Cobra SMARTsense - Voltage, ± 30 V (Bluetooth + USB)	12901-01	1
2	Cobra SMARTsense - High Current, ± 10 A (Bluetooth + USB)	12925-00	1
3	Cobra SMARTsense - Thermocouple, -200 ... +1200 °C (Bluetooth + USB)	12938-01	1
4	measureLAB, multi-user license	14580-61	1
5	Calorimeter, transparent, 1200 ml	04402-00	1
6	Heating coil with sockets	04450-00	1
7	PHYWE Power supply, universal DC: 0...18 V, 0...5 A / AC: 2/4/6/8/10/12/15 V, 5 A	13504-93	1
8	Connecting cord, 32 A, 500 mm, black	07361-05	4
9	Magnetic stirrer with heater MR Hei-Standard	35751-93	1
10	Magnetic stirring bar 30 mm, oval	35680-04	1
11	Separator for magnetic bars	35680-03	1
12	Supp.rod stainl.st.,50cm,M10-thr.	02022-20	1
13	Right angle boss-head clamp	37697-00	1
14	Universal clamp	37715-01	1
15	Mortar with pestle, 150 ml, porcelain	32604-00	1
16	Powder funnel, upper dia. 65mm	34472-00	1
17	Beaker, Borosilicate, tall form, 50 ml	46025-00	2
18	Spoon, special steel	33398-00	1
19	Porcelain dish 140ml, d 100mm	32518-00	1
20	Crucible tongs, 200 mm, stainless steel	33600-00	1
21	Tripod,ring d=140 mm, h=240 mm	33302-00	1
22	Wire gauze with ceramic, 160 x 160 mm	33287-01	1
23	Butane burner, Labogaz 206 type	32178-00	1
24	Butane cartridge C206, without valve, 190 g	47535-01	1
25	Desiccator, vacuum, diam. 150 mm	34126-00	1
26	Porcelain plate f.desiccator150mm	32474-00	1
27	Silicon grease Molykote, 50 g	31863-05	1
28	Silica gel, orange, granular, 500 g	30224-50	1
29	Wash bottle, plastic, 500 ml	33931-00	1
30	Copper-II sulphate, anhydr. 250 g	31495-25	1
31	Copper-II sulphate,cryst. 250 g	30126-25	1
32	Water, distilled 5 l	31246-81	1
33	Sheath Thermocouple, NiCr-Ni, Type K, -40°C ... +1000°C	13615-06	1
34	Holder for Cobra SMARTsense	12960-00	2

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Setup and procedure

Setup

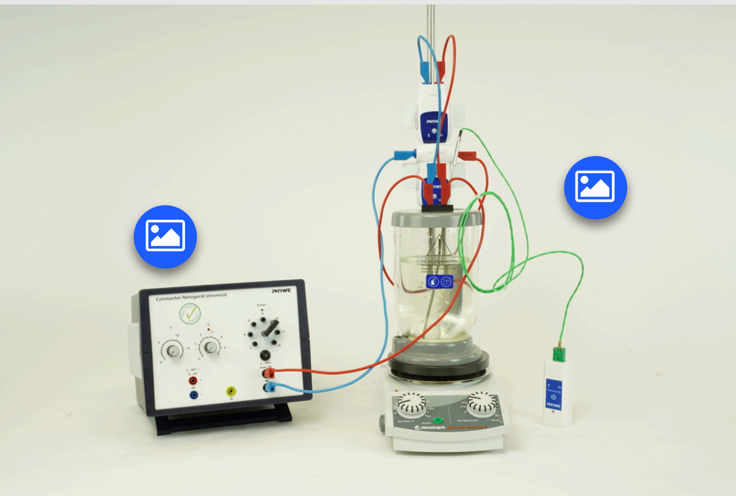

Fig. 1

1. Connect the SMARTSense High Current to the power supply unit and connect it in series with the heating coil. Close the circuit by connecting the heating coil with the power supply.

2. Connect the SMARTSense Voltage to the heating coil to build a parallel curcuit.

3. Place the calorimeter on the magnetic-stir heater and place the temperature sensor and the heating coil into the respective holes.

4. Setup shown in Fig. 1

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Procedure (1/3)

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1. Start the PC and start the software "measureLAB" . Choose the experiment from the start screen. All necessary presettings will be loaded. The Thermocouple, High Current and Voltage sensor will be connected already.

2. Prepare the two copper salts by grinding each of them separately to a fine powder in a mortar. Make sure that the anhydrous copper sulphate really is anhydrous by heating it in a porcelain dish over a butane burner until it is completely white and allowing it to cool in a desiccator.

3. Weigh 24.97 g (0.1 mol) of copper(II) sulphate and 15.96 g (0.1 mol) of anhydrous copper(II) sulphate in two separate beakers (weighing accuracy 0.01 g). Fill the calorimeter with 900 g of distilled water (weighing accuracy 0.1 g).

4. Put the oval magnetic stirrer bar into the calorimeter and switch on the magnetic stirrer (Caution: Do not mistakenly switch on the heating unit!).

Procedure (2/3)

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5. Wait until temperature equilibrium has been reached (approximately 10 min). Start the measurement with a click on in the icon strip. Wait 3 to 4 minutes, then add the first copper salt to the water by pouring it through the powder funnel which has been inserted in the opening of the lid.

6. Continue to measure until a new equilibrium has been reached. To do this, supply 10 V AC to the SMARTSense High Current for the electric heating. The system is now continuously heated and the supplied quantity of energy is measured. When approximately 4000 Ws are transferred, switch off the heating. Continue to measure for another three minutes, then stop temperature recording with a click on in the icon strip.

7. Repeat the experiment to determine the enthalpy of solution of the second copper salt. At least two measurements for each salt should be performed to avoid errors and to calculate a mean value.

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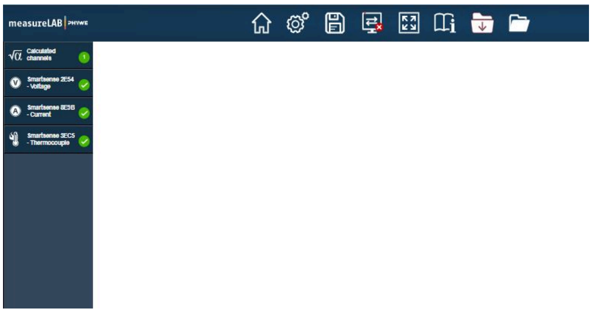
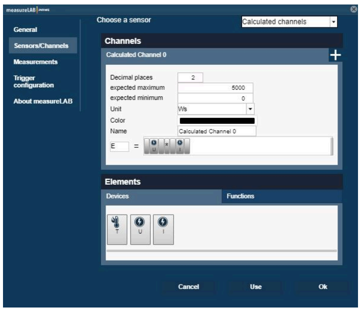
Procedure (3/3)

Note: All necessary measuring channels will be given, but in case there is a need all measuring channels can be further customized by entering the settings (gear symbol in the menu bar). Please select the menu option for Sensors /Channels and modify them according to your needs.

For more details please consult the user manual (book icon) in the menu bar.





Evaluation (1/5)

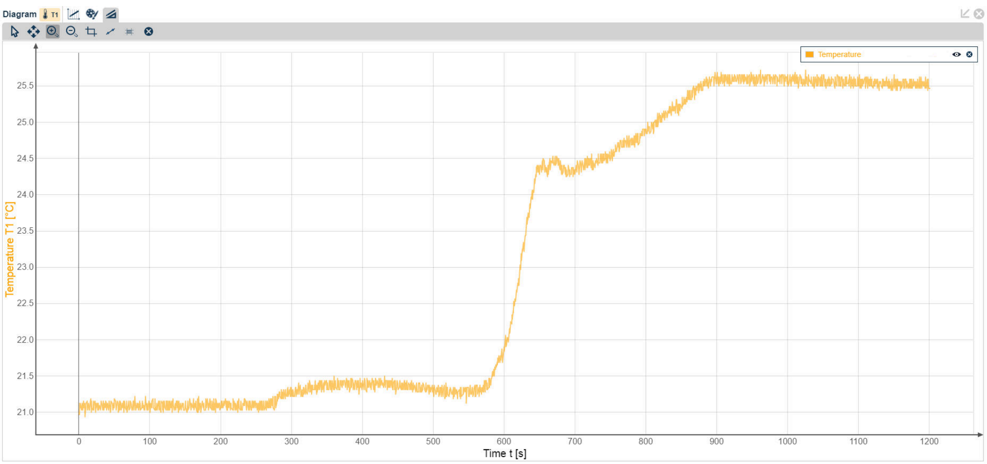


Fig. 2: Examplary measurement: Temperature-time curve of solution of anhydrous copper (II) sulphate and determining the heat capacity of the system.

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Evaluation (2/5)

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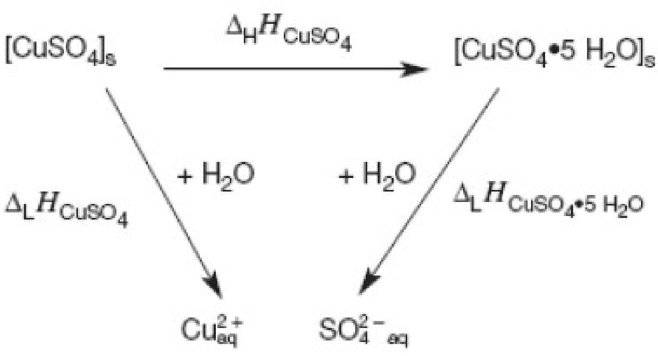

Fig. 3: Schematic representation of the processes taking place

Evaluation (3/5)

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Using Fig. 3 we conclude:

$$\Delta_{\mathrm{L}}H = \frac{\Delta_{\mathrm{L}}h}{n}$$

$$\text{and } \Delta_{\mathrm{H}}H_{\mathrm{CuSO_4}} = \Delta_{\mathrm{L}}H_{\mathrm{CuSO_4}} - \Delta_{\mathrm{L}}H_{\mathrm{CuSO_4 \cdot 5\,H_2O}}$$

$\Delta_{\mathrm{H}}H =$ Enthalpy of hydration

$\Delta_{\mathrm{L}}H =$ Molar enthalpy of solution

$\Delta_{\mathrm{L}}h =$ Integral enthalpy of solution

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Evaluation (4/5)

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$$\Delta_L H = \frac{Q_{exp}}{n} \ (1)$$

$$\text{and } Q_{exp} = Q_{cal} \cdot (\frac{\Delta T_{exp}}{\Delta T_{cal}}) \ (2)$$

Q_{exp} = Heat of solution of a salt, Q_{cal} = Electrical work for calibration

ΔT_{exp} = Temperature difference during the dissolution of the salt

ΔT_{cal} = Temperature difference during the dissolution of the salt

n = Quantity of salt

The integral enthalpy of solution can be calculated according to equation (2)

Evaluation (5/5)

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Data and results

$M_{CuSO_4} = 159.6 \text{ g/mol}$

$M_{CuSO_4 \cdot 5 H_2O} = 249.68 \text{ g/mol}$

$\Delta_L H_{CuSO_4} = -66.2 \text{ kJ/mol}$

$\Delta_L H_{CuSO_4 \cdot 5 H_2O} = +11.5 \text{ kJ/mol}$

$\Delta_H H_{CuSO_4} = -77.7 \text{ kJ/mol}$

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