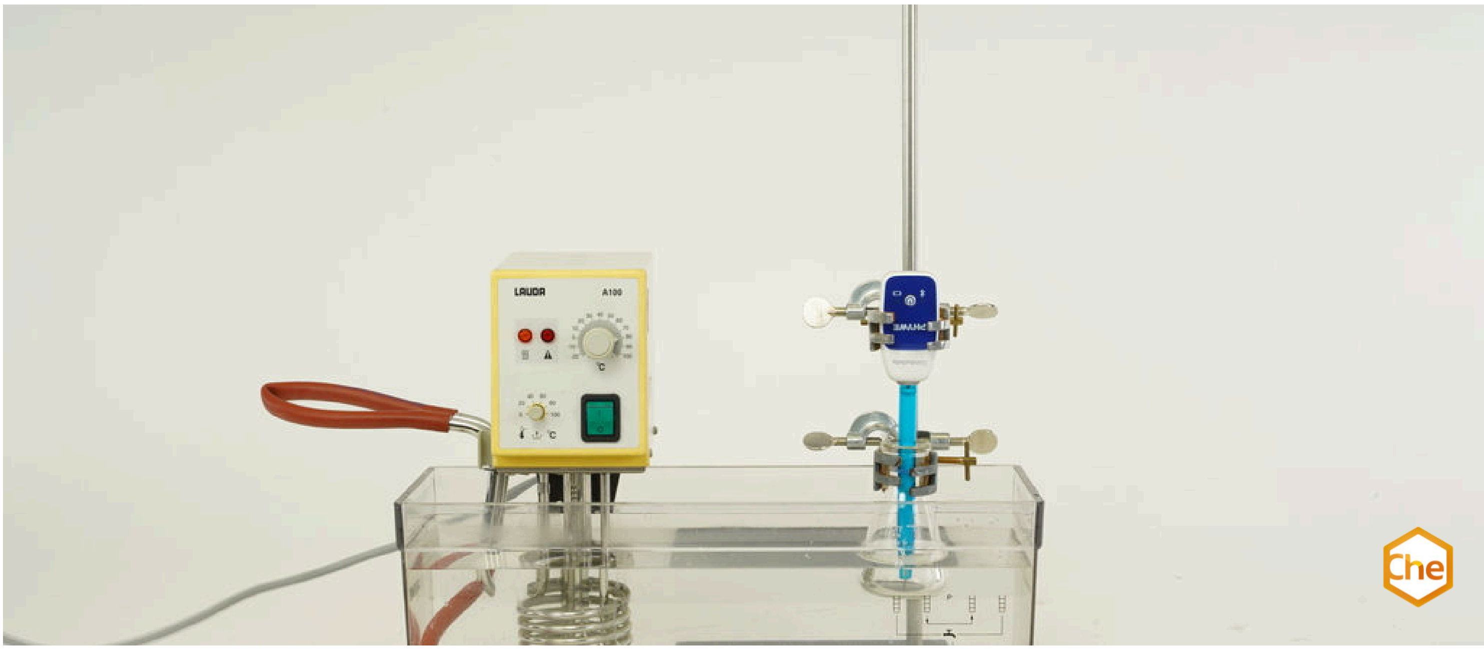
Solubility product with Cobra SMARTsense



The solubility of poorly soluble salts is expressed as the solubility product, i.e. the product of the concentration of cations and anions in the solution which are in equilibrium with the solid salt. These concentrations can be determined via conductivity measurements.

Chemistry > General Chemistry > Substances mixtures & separation

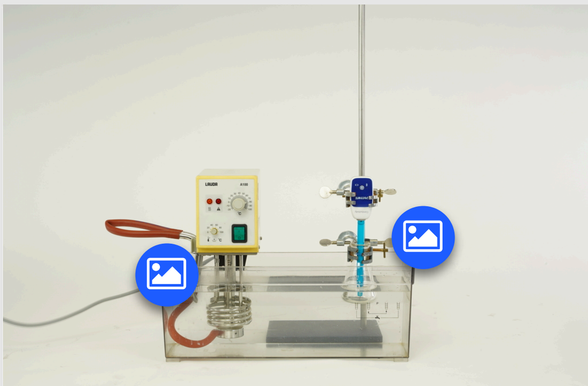
Difficulty level	Group size	Preparation time	Execution time
medium	2	40 minutes	30 minutes

This content can also be found online at:

http://localhost:1337/c/60f45361aa73180004678ee7

General information

Application



The experimental setup

The solubility and insolubility of the material in a solvent is very important. In fact, it is the fundamental phenomenon for the generation of life on earth and the continuation of life. There are various chemical and physical interactions for a substance to be soluble, poorly soluble and insoluble. Unfortunately, the classification of salts into poorly soluble and easily soluble salts cannot be made on the basis of a simple rule. The determination of the solubility product allows the classification of salts into soluble, poorly soluble and insoluble. The following applies:

- Solubility product large → easily soluble salt
- Solubility product small → poorly soluble salt

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Other information (1/2)

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Prior knowledge

The students should be familiar with salts, ions, solubility and its units. Furthermore, students should be familiar working autonomously with chemical agents and be familiar with good laboratory practice.

Scientific principle

The solubility of poorly soluble salts is expressed as the solubility product, i.e. the product of the concentration of cations and anions in the solution which are in equilibrium with the solid salt. These concentrations can be determined via conductivity measurements.

Other information (2/2)

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Learning objective

The students learn how to determine the solubility product and by contrasting different solutions and their conductivity the students learn about the underlying regularities and correlations in regards to the solubility product.

Tasks

1. Measure the conductivities of saturated aqueous solutions of the salts calcium fluoride and calcium carbonate at 25 °C.

2. With the aid of tabulated ionic conductivities, calculate the solubility products of the salts from their conductivities.

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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 (1/3)

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A poorly soluble salt with the general form $M_{v+}^{z+}X_{v-}^{z-}$ (z+ and z- are the charge numbers of the ions) forms anions and cations in aqueous solution according to:

$$M_{v_+}^{Z_+}X_{v_-}^{Z_-} \rightleftharpoons v_+M^{Z_+} + v_-X^{Z-} \ (1)$$

Due to the extreme dilution, the equilibrium constant Ks can be replaced by the solubility product L:

$$K_S \approx (C_M^{Z_+})^{v_+} \cdot (C_X^{Z_-})^{v_-} = L \ (2)$$

In contrast to the equilibrium constant, the solubility product is a function of the concentration (salting-out effect). The saturation concentration c_S of a dissolved salt is as follows:

$$c_S = \frac{c_M^{Z_+}}{v_+} = \frac{c_M^{Z_-}}{v_-} \ (3)$$

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Theory (2/3)

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Substitution in equation (2) results in:

$$L = v_+^{v_+} v_-^{v_-} c_S (v_+ + v_-)\ (4)$$

Table 1: Ionic conductivities at infinite dilution

Ion	Ionic conductivity in $S \cdot cm^2 \cdot mol^{-1}$
Ca^{2+}	119.0
F^-	55.4
CO_{-3}^2	138.6

Theory (3/3)

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The saturation concentration can be determined conductiometrically. To do so, the ionic conductivities for infinite dilution ΛM , ΛX are used (Table 1):

$$\chi = c_S (v_+ \Lambda_M + v_- \Lambda_X)\ (5)$$

$\chi =$ Specific conductance of the electrolyte solution

Transposing according to c_S, the following is obtained:

$$c_S = \frac{\chi}{v_+ \Lambda_M + v_- \Lambda_X}\ (6)$$

Substituting in equation (4), the solubility product can now be calculated.

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Equipment

Position	Material	Item No.	Quantity
1	Cobra SMARTsense - Conductivity, 0...20000 µS/cm, 0...100°C (Bluetooth)	12922-00	1
2	Immersion thermostat Alpha A, 230 V	08493-93	1
3	External circulation set for thermostat Alpha A	08493-02	1
4	Bath for thermostat, makrolon	08487-02	1
5	Rubber tubing, i.d. 6 mm	39282-00	3
6	Hose clip, diam. 8-16 mm, 1 pc.	40996-02	4
7	Retort stand, h = 750 mm	37694-00	2
8	Right angle boss-head clamp	37697-00	3
9	Universal clamp	37715-01	3
10	Magnetic stirrer without heating, 3 ltr., 230 V	35761-99	1
11	Magnetic stirring bar 30 mm, cylindrical	46299-02	2
12	Erlenmeyer flask, Borosilicate, narrow neck,100ml	46141-00	4
13	Powder funnel, upper dia. 65mm	34472-00	1
14	Spoon, special steel	33398-00	1
15	Mortar w. pestle, 70ml, porcelain	32603-00	2
16	Weighing dishes, square shape, 84 x 84 x 24 mm, 500 pcs.	45019-50	1
17	Wash bottle, plastic, 500 ml	33931-00	1
18	Calcium carbonate 500 g	30052-50	1
19	Calcium fluoride, powder, purum, 100 g	31175-10	1
20	Standard solution 1413µS/cm(25°C), 460ml	47070-02	1
21	Water, distilled 5 l	31246-81	1
22	Tubing connector, ID 6-10mm	47516-01	2
23	measureLAB, multi-user license	14580-61	1

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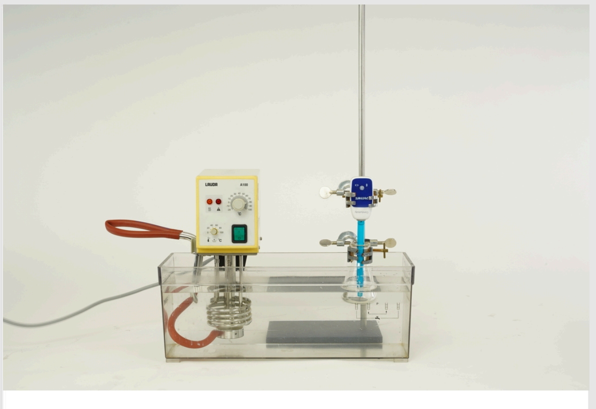
Setup and procedure

Setup (1/2)



Final experimental setup

1. Fill the waterbath with water. Attach the SmartSense Conductivity to the stand using clamps. Prepare another clamp for an Erlenmeyer flask so that the sensor can be immersed in the solution.

2. Place the thermostat into the water and connect it with the external circulation set.

3. Dissolve 2 g of CaF_2 and 2 g of $CaCO_3$ each in 50 ml of distilled water in separate Erlenmeyer flasks (pulverise the salts with the mortar and pestle before weighing).

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Setup (2/2)

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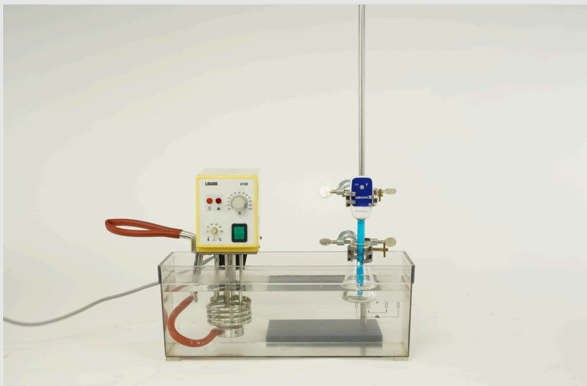

Final experimental setup

4. Prepare a third Erlenmeyer flask with 50 ml of distilled water and a further one with 50 ml of calibration standard solution.

5. Control the calibration of the Cobra SMARTsense Conductivity and, if required, calibrate it according to the manual.

Procedure

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1. Put magnetic stirrer bars in the two flasks with the salts, heat them to approximately 60 °C in the water bath, and subsequently stir them for 30 minutes at room temperature on a magnetic stirrer. To perform the measurements, set the temperature-controlled bath to exactly 25 °C and temperature equilibrate the four Erlenmeyer flasks.

2. Use the calibration solution to calibrate the conductivity probe. Measure the conductivities of the distilled water and the salt solutions, whereby the measuring probe should only be immersed in the clear solutions without stirring up the solid phase.

3. Thoroughly rinse the conductivity probe before each new measurement. Substract the conductance value of the distilled water from that of the salt solutions.

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Evaluation

Data and results

Perform the calculation for both salts from the "Theory" section.

An example (experimental results may vary):

$$CaF_2:\ 4.43 \cdot 10^{-11} (\text{lit.: } 3.4 \cdot 10^{-}11)\ \text{mol}^3 \cdot l^{-3}$$

$$CaCO_3:\ 6.82 \cdot 10^{-8} (\text{lit.: } 4.96 \cdot 10^{-}9)\ \text{mol}^3 \cdot l^{-3}$$

Note:

The conductivity of solutions is strongly affected by even minute traces of contaminants and temperature. Thus, for the measurement of the solubility product of calcium carbonate, the measured value is falsified by dissolved carbon dioxide from the air. As a result of the formation of hydrogen carbonate, the solubility increases and consequently the conductivity also.

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