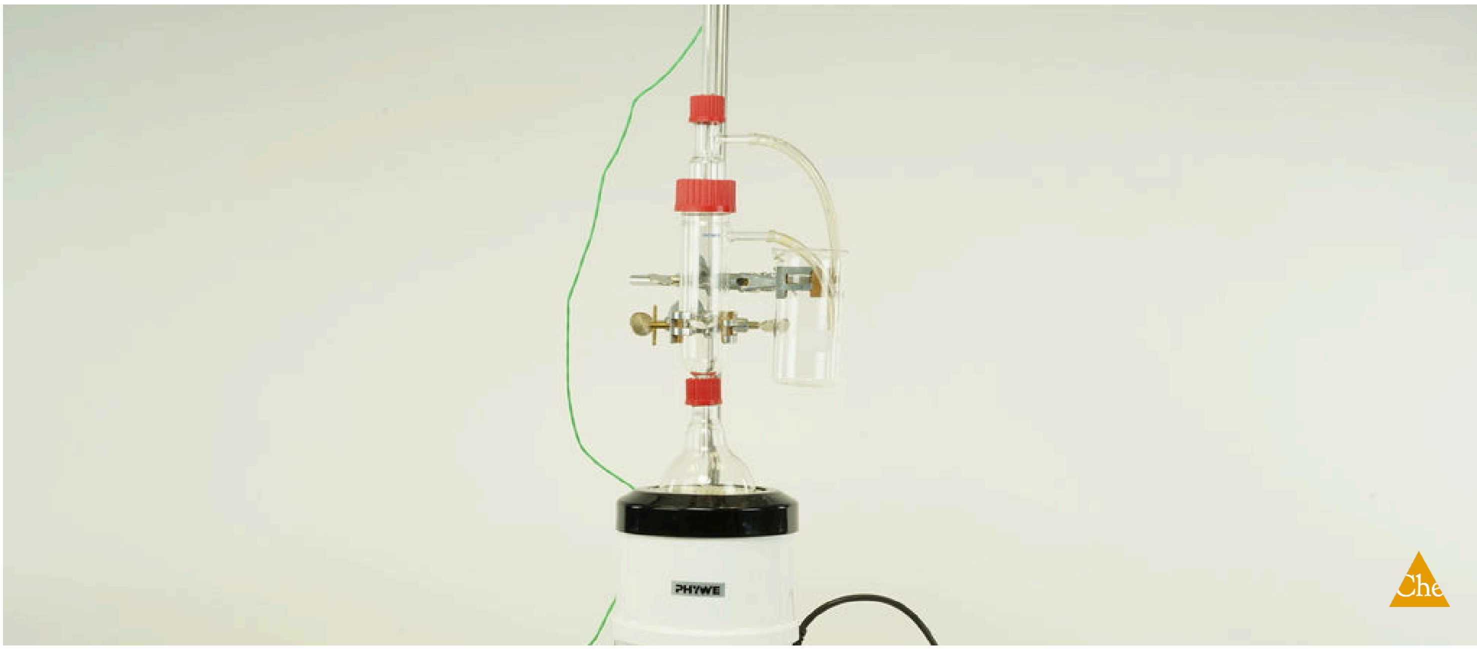
Determination of molar masses via a measurement of the boiling point elevation (ebullioscopy)



This didactic setup to train and demonstrate the determination of molar masses by way of a measurement of the boiling point elevation. The boiling point elevation of aqueous solutions of different substances is determined using a temperature meter. The ebullioscopic constant of water is calculated from the experimental results.

Chemistry → General Chemistry → Stoichiometry

Difficulty level	Group size	Preparation time	Execution time
hard	2	20 minutes	30 minutes

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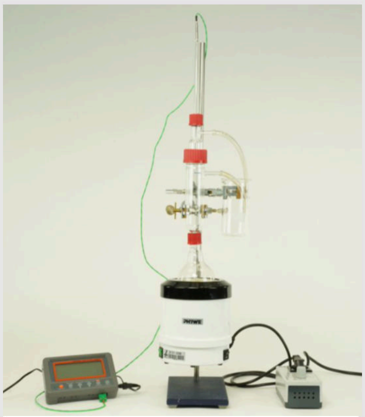
General information

Application



The experimental setup

Ebullioscopy is a method for determining the molar mass of a dissolved substance B with the aid of the boiling point increase ΔT of the solvent A. Furthermore, ebullioscopy can be used in thermal analysis for testing the purity of liquids. This didactic setup to train and demonstrate the determination of molar masses by way of a measurement of the boiling point elevation. The boiling point elevation of aqueous solutions of different substances is determined using a temperature meter. The ebullioscopic constant of water is calculated from the experimental results. The dissolution of a nonvolatile substance in a volatile solvent leads to a boiling point increase. The increase is proportional to the ebullioscopic constant of the solvent and the amount of dissolved substance. By dissolving different copper sulphates in water and measuring the resulting temperature changes over time, the students can now calculate the hydration enthalpy of the observed chemical compunds.

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Other information (1/4)

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Prior knowledge

The students should be familiar with the basics of thermodynamics and molar masses. Furthermore, students should be familiar working autonomously with chemical agents and be familiar with good laboratory practice.

Scientific principle

The measuring solution (solution or solvent) is in the inner vessel. Solvent is brought to boiling point in a round-bottomed flask. The solvent vapour flows first through the outer and then through the inner vessel and thus heats the solution that is in the inner vessel.

Other information (2/4)

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Learning objective

The students learn to determine the molar mass of a substance in solution and to calculate the ebullioscopic constant of a solvent.

Tasks

1. Determine the boiling point elevation of aqueous solutions of different substances
2. Calculate the ebullioscopic constant of water from the experimental results

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Other information (3/4)

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Notes
In order to train and demonstrate the determination of molar masses by way of a measurement of the boiling point elevation, water is absolutely sufficient as the solvent and urea or hydroquinone as the test substance. Of course, it must be ensured that the solid substances are dry when they are used. Dry them for at least 24 hours in a desiccator. When using other substances, determine the most suitable solvent that can be used. The ebullioscopic constants that are specific for every individual solvent can be found in the literature.

Other information (4/4)

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Variation
If other solvents are used in the place of water, do not let the resulting solvent vapour flow into a beaker. Instead, guide them via a V-connector into a flask with a reflux cooler. For this purpose, the following additional equipment is required:

1	Round bottom flask, 100 ml, 2 necks, GL 25/12, GL 18/8	35842-15
1	Condenser, Dimroth type, GL 25/12	MAU-27223500
2	Hose clips, d = 8...12 mm, 2 pcs.	40996-00
1	Tubing connector,Y-shape, ID 8-9mm	47518-03
1	Retort stand, h = 750 mm	37694-00
2	Right angle boss-head clamp	37697-00
2	Universal clamp	37715-00

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Safety instructions

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

If solvents other than water are used for the experiment, ensure proper handling and disposal.

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

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Equipment

Position	Material	Item No.	Quantity
1	Retort stand, h = 750 mm	37694-00	1
2	Right angle boss-head clamp	37697-00	3
3	Universal clamp	37715-01	3
4	Apparatus for elevation of boiling point	36820-00	1
5	Temperature meter digital, 4-2	13618-00	1
6	Universal power supply, 600mA 3/4.5/5/6/7.5/9/12V, incl. 9 adaptors	11078-99	1
7	Sheath Thermocouple, NiCr-Ni, Type K, -40°C ... +1000°C	13615-06	1
8	Protective sleeves f.temp.probe,2	11762-05	1
9	Round-bottom flask, 250 ml, GL 25	MAU-27220002	1
10	Beaker, Borosilicate, tall form, 250 ml	46027-00	1
11	Gasket for GL25, 8mm hole, 10 pcs	41242-03	1
12	Silicone tubing i.d. 7mm, 1 m	39296-00	1
13	Mortar with pestle, 150 ml, porcelain	32604-00	1
14	Pinchcock, width 15 mm	43631-15	1
15	Microspoon, steel	33393-00	1
16	Wash bottle, plastic, 500 ml	33931-00	1
17	Pellet press for calorimeter	04403-04	1
18	Heating mantle f. roundbottom flask, 250ml	49542-93	1
19	Clamp for heating mantle	49557-01	1
20	Power regulator	32288-93	1
21	Weighing dishes, square shape, 84 x 84 x 24 mm, 500 pcs.	45019-50	1
22	Funnel, glass, top dia. 80 mm	34459-00	1
23	Pasteur pipettes, 250 pcs	36590-00	1
24	Rubber caps, 10 pcs	39275-03	1
25	Boiling beads, 200 g	36937-20	1
26	Desiccator, vacuum, diam. 150 mm	34126-00	1
27	Porcelain plate f.desiccator150mm	32474-00	1
28	Watch glass, dia.80mm	34572-00	1
29	Glycerol, 250 ml	30084-25	1
30	Urea, 250 g	30086-25	1
31	Hydroquinone 250 g	30089-25	1
32	Water, distilled 5 l	31246-81	1

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Setup and procedure

Setup (1/4)

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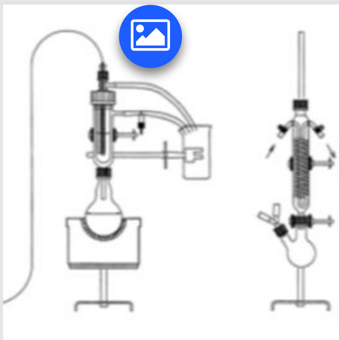

Fig. 1: Schematic illustration

1. The apparatus for measuring the boiling point elevation consists of two cylindrical glass vessels that are placed with one inside the other. At its bottom and just below the GL 45 thread, the outer vessel is equipped with a glass tube connector (d = 8 mm).

2. Apart from a GL 25 threaded connector and a lateral glass tube connector, the inner vessel has a narrow glass tube inside. The inlet opening of this glass tube commences in the wall of the vessel. When assembling the two vessels, the inlet opening must be below the gasket (see Fig. 1).

Setup (2/4)

3. Prior to assembling and screwing the two vessels together, determine the exact mass of the dry inner vessel by weighing it (=$m1$). Note down the result. Connect the assembled apparatus via the lower glass tube connector of the outer vessel to the 250 ml round bottom flask. Tighten the screw connection tightly.

4. Prior to doing so, replace the gasket of the screw connection cap with a gasket with an 8 mm hole. Fill the flask with 150 to 200 ml of the solvent to be used as well as with several boiling beads. Place the flask in a heating mantle.

5. Connect short pieces of silicone tubing to the lateral glass tube connectors. If water is used as the solvent, lay the tubings simply into a beaker but ensure that they do not reach down to the bottom. Instead, they should end approximately in the middle of the beaker. If organic solvents are used, connect these tubings via a Y-shaped connecting tube to a double-neck flask (100 ml) that is equipped with a reflux condenser (Dimroth condenser). Attach a pinchcock to the tubing that is connected to the outer vessel but leave the pinchcock open for the time being.

Setup (3/4)

6. Fill approximately 40 ml of solvent into the inner vessel and seal the vessel with a protective sleeve for the temperature sensor. To do so, replace the gasket of the screw connector with the gasket with the 12 mm hole that was removed from the round bottom flask beforehand. Apply two to three drops of glycerol to the protective sleeve for better heat transfer and insert the temperature probe. Connect the temperature probe to the digital temperature meter.

7. The substance whose molar mass is to be determined must be provided in the form of pellets. A simple pellet press can be used for the production of the pellets.

It works as follows: Grind the substance finely in a mortar. Place the small steel die into the hole of the press cylinder. It seals the bottom of the hole. Then, fill the finely ground substance into the hole.

Place the longer die from the top onto the hole, thereby compressing the substance slightly.

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Setup (4/4)

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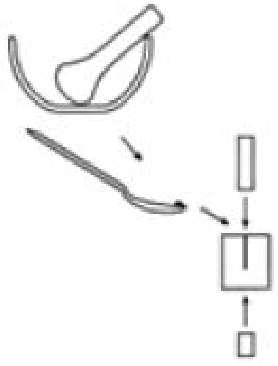

Fig. 3

8. After that, clamp the press into a vice as shown in Fig. 3, thereby pressing against the dies so that the substance is pressed into a compressed pellet.

After the pressing process, push the pellet out of the cylinder by way of the long die.

The measurement requires 1 to 2 pellets with a thickness of approximately 5 to 7 mm. Determine their mass (ms) by weighing with an accuracy of at least 1 mg.

Procedure (1/2)

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1. Heat the solvent in the flask up to its boiling temperature. The resulting vapour rises into the outer vessel and heats the inner vessel. In doing so, part of the vapour condenses; the other part escapes via the tubing with the pinchcock into the beaker or into the flask with a reflux cooler.

2. After a few minutes of boiling, lower the heating mantle for a few seconds so that the boiling stops briefly and the solvent that has condensed in the outer vessel flows back into the flask.

3. When this has happened, raise the heating mantle once again against the flask and continue boiling. When vapour rises once again, close the pinchcock so that the vapour now flows via the inner glass tube into the inner vessel and there through the solvent.

4. Once the boiling temperature is reached and remains constant, measure both temperatures and determine ΔT (please refer to the operating instructions of the measuring instrument to use the data-logging function, if so desired).

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Procedure (2/2)

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5. Open the inner vessel, lift the protective sleeve with the temperature probe up, add a substance pellet to the solvent as quickly as possible, and close the apparatus again. Now, the boiling point of the solution in the inner vessel is determined.

6. Track or record the changes in temperature and (ΔT) with regard to the boiling temperature of the pure solvent. Then, open the pinchcock (Important! This is to ensure that the liquid in the inner vessel cannot be sucked into the flask when the heating apparatus is switched off.).

7. It is only then that the heating mantle can be switched off and lowered so that the boiling in the flask stops quickly. In order to determine the mass of the solvent (= mS), remove the thermometer.

8. Remove the inner vessel carefully (Attention! It is still very hot.) and weigh it together with the solution inside. Note down the mass thus determined (= $m2$).

Evaluation (1/3)

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Evaluation

The following values were measured:

- Mass of the empty vessel $m1$
- Mass of the vessel containing the solution $m2$
- Mass of the dissolved substance ms
- Mass of the solvent $mS = m2 - m1 - ms$
- Boiling temperature of the solvent $T1$
- Boiling temperature of the solution $T2$
- Boiling point elevation $\Delta T = T2 - T1$

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Evaluation (2/3)

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Since the boiling point elevation is proportional to the molar concentration (= mol on 1000 g of solvent), the following applies:

$$M = (ms - 1000 - K)/(mS - \Delta T)$$

$M =$ molar mass

$K =$ ebullioscopic constant

If the ebullioscopic constants of solvents are determined based on known substances, K results from:

$$K = \frac{M \cdot \Delta T \cdot mL}{ms \cdot 1000}$$

Evaluation (3/3)

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Example of a measurement (urea/water):

ms = 0.685 g
ΔT = 0.13 K
mS = 45.0 g
K = 0.515 g/mol * K
(for water as the solvent)

$$M = \frac{0.685g \cdot 1000 \cdot 0.515 \frac{g}{mol \cdot K}}{45.0g \cdot 0.13K} = 60.35 \frac{g}{mol}$$ (Urea = 60.06 g/mol)

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