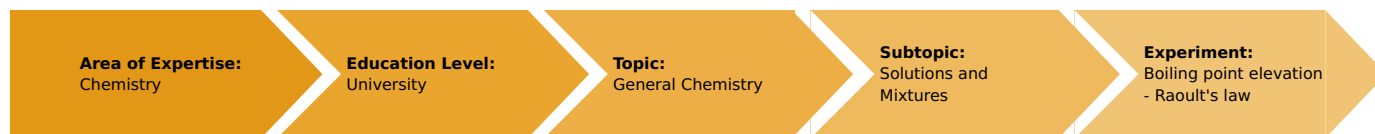


Boiling point elevation - Raoult's law (Item No.: P3021001)

Curricular Relevance



Difficulty



Difficult

Preparation Time



1 Hour

Execution Time



2 Hours

Recommended Group Size



2 Students

Additional Requirements:

- Precision balance, 620 g / 0.001 g

Experiment Variations:

Keywords:

Raoult's law, Henry's law, ebullioscopic constants, chemical potential, Gibbs-Helmholtz equation, concentration ratio, degree of dissociation

Overview

Short description

Principle

The boiling point of a solution is always higher than that of the pure solvent. The dependence of the temperature difference (elevated boiling point) on the concentration of the solute can be determined using a suitable apparatus.



Fig. 1: Experimental set-up

Safety instructions



Hydroquinone

H302: Harmful if swallowed

H341: Suspected of causing genetic defects

H351: Suspected of causing cancer

P201: Obtain special instructions before use

P273: Avoid release to the environment

P280: Wear protective gloves/protective clothing/eye protection/face protection

Equipment

Position No.	Material	Order No.	Quantity
1	Retort stand, h = 750 mm	37694-00	1
2	Right angle boss-head clamp	37697-00	3
3	Universal clamp	37715-00	3
4	Apparatus for elevation of boiling point	36820-00	1
5	Temperature meter digital, 4-2	13617-93	1
6	Temp.probe, imm., PT100, -20...+300°C	11759-04	1
7	Flask,round,1-neck,250ml,GL25/13	35812-15	1
8	Beaker, high, BORO 3.3, 250 ml	46027-00	1
9	Gasket for GL25, 8mm hole, 10 pcs	41242-03	1
10	Silicone tubing i.d. 7mm, 1 m	39296-00	1
11	Mortar with pestle, 150 ml, porcelain	32604-00	3
12	Pinchcock, width 15 mm	43631-15	1
13	Microspoon, steel	33393-00	1
14	Wash bottle, plastic, 500 ml	33931-00	1
15	Pellet press for calorimeter	04403-04	1
16	Heating mantle f. roundbottom flask, 250ml	49542-93	1
17	Clamp for heating mantle	49557-01	1
18	Power regulator	32288-93	1
19	Weighing dishes, square shape, 84 x 84 x 24 mm, 25 pcs.	45019-25	1
20	Funnel, glass, top dia. 80 mm	34459-00	1
21	Pasteur pipettes, 250 pcs	36590-00	1
22	Rubber caps, 10 pcs	39275-03	1
23	Boiling beads, 200 g	36937-20	1
24	Sodium chloride, 500 g	30155-50	1
25	Urea, 250 g	30086-25	1
26	Hydroquinone 250 g	30089-25	1
27	Glycerol, 250 ml	30084-25	1
28	Water, distilled 5 l	31246-81	1

Tasks

1. Measure the increase in the boiling point of water as a function of the concentration of table salt, urea and hydroquinone.
2. Investigate the relationship between the increase in boiling point and the number of pellets.
3. Determine the molar mass of the solute from the relationship between the increase in boiling point and the concentration.

Set-up and procedure



Set up the experiment as shown in Fig. 1.

Weigh the dry inner vessel of the boiling point apparatus and note the exact mass ($= m_1$). Fit the inner vessel into the outer vessel so that its inlet opening is located below the silicone rubber seal of the connecting cap. During measurement, steam is to enter the inner vessel through the lateral aperture, so pay attention that it is not covered. Fill the round flask with 150 ml to 200 ml of water and connect it to the assembled apparatus. Slip two short pieces of silicone tubing onto the two gas outlets of the outer vessel and place the lengths in a 250 ml glass beaker with the free ends at about the middle of the beaker. Attach a pinchclip to the lower of the two tubes coming from the outer vessel, but for the time being leave it open. Pour approximately 40 ml of water into the inner vessel. Close the vessel at the top by fixing the temperature probe in position.

The substances to be tested must be pressed into pellets in order to prevent any particles of them from sticking to the walls of the vessel while being added. Weigh out five portions of each substance (NaCl, urea, hydroquinone), each of approximately 700 mg. It is advisable to first pulverise the substances with a mortar and pestle.

Use the pellet press as follows:

Place it in a vertical position and put the small steel rod in the cylinder to close the bottom end of the borehole.

Fill one portion of the substance into the hole using a funnel.

Next insert the large rod from above and compress the substance a little.

Fit the assembled press in a vice and apply pressure on it, so that a solid pellet is formed from the substance.

Press the pellet out of the borehole with the longer rod.

Weigh the pellets to an accuracy of 1 mg. The dependence of the boiling point elevation of water on the concentration can be demonstrated for each substance in a single experiment by successively adding known amounts of the same substance. Heat the solvent in the flask to boiling. The vapour evolved rises up into the outer vessel and heats up the inner vessel. Control the heating rate with the power control. The temperature in the inner vessel is displayed on the digital temperature meter in degrees Celsius. After some minutes, when the temperature in the inner vessel has nearly reached the boiling point and no longer increases, lower the heating hood for a few seconds until boiling stops and the condensate on the outer vessel returns to the round flask. Then raise the heating hood again.

When boiling recommences, close the pinchcock. The (slightly superheated) steam now flows through the water in the inner vessel. Set the digital temperature meter to measure the change in temperature ΔT over time with the tare function <SET 0.00>. In this mode of operation, the resolution is tenfold better (0.01 K). Wait until the value displayed remains constant.

Now carefully open the inner vessel (screw cap), add the first substance pellet, and close the opening immediately. The temperature first drops slightly and then rises again while the pellet dissolves. When the value has again become constant, record it and repeat this procedure for the next portion of the substance.

After five concentration steps have been measured, first open the pinchcock and then switch off the heating. This is important to avoid solution being sucked from the inner vessel into the flask containing water while cooling down. Remove the inner vessel, dry its outer surface, remove the temperature probe and re-weigh it. The mass of the water is now equal to the last measured value less the mass of the empty vessel and the masses of the five substance pellets. Plot the increase in boiling point against the quotient of the mass of the dissolved substance and the mass of water for each substance as shown in Fig. 2.

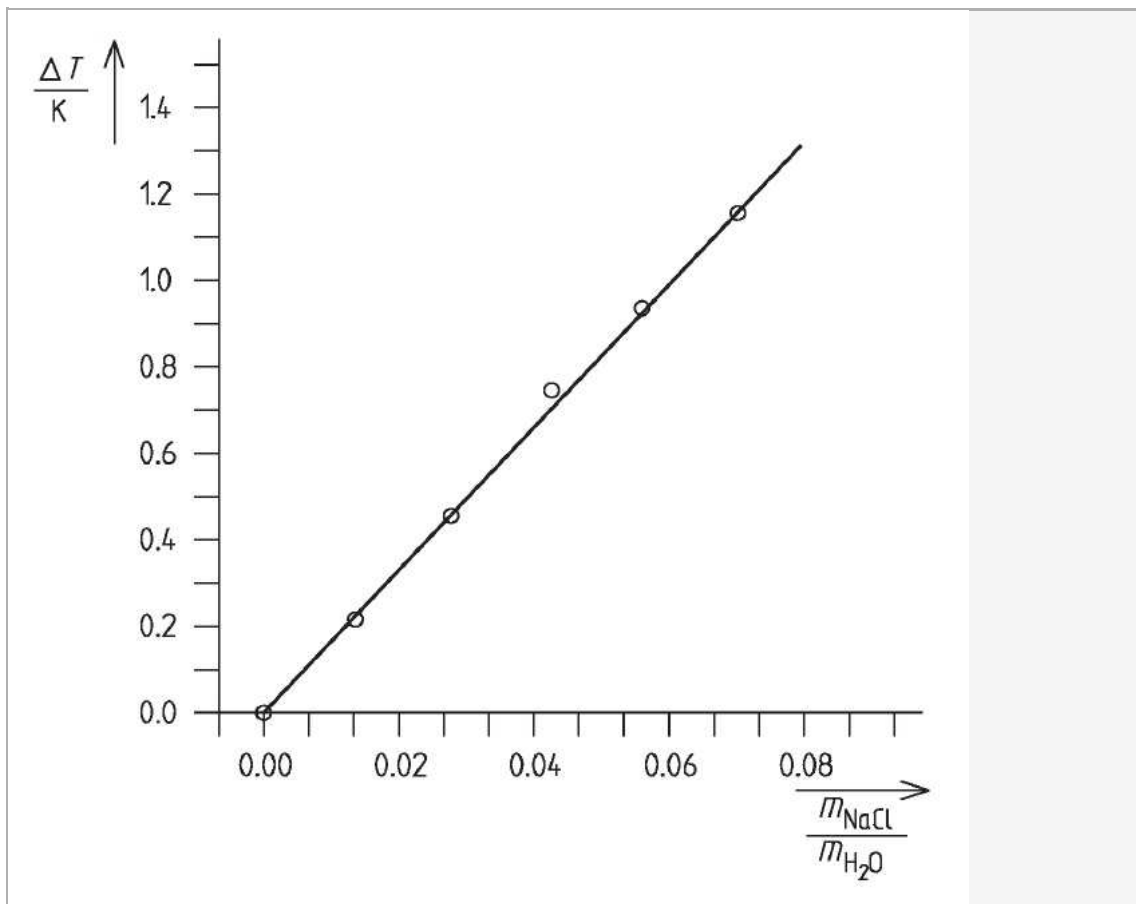


Fig. 2: Example of a measurement: boiling point crease as a function of concentration of table salt an aqueous solution.

Theory and evaluation

A solution is a mixed-phase liquid which consists of a dissolved substance and a solvent. Only the solvent is capable of vaporization, the vapour pressure of the solute is practically zero. When a substance dissolves in a solvent, additional forces result and these must be overcome by solvent molecules before they can pass into the gas phase.

Less solvent molecules can therefore vaporize from a solution than from the pure solvent. In 1886, F. M. Raoult postulated the law that is named after him: The vapour pressure of a solution is given by the product of the vapour pressure of the pure solvent and the mole fraction of the solvent.

$$P_S = \frac{n_1}{n_1 + n_2} \cdot p_0 \tag{1}$$

Where:

P_S	Vapour pressure of the solution
p_0	Vapour pressure of the pure solvent
n_1	Amount of the pure solvent
n_2	Amount of dissolved substance

A liquid boils when its vapour pressure is the same as the ambient pressure. The vapour pressure of water reaches an ambient pressure of 1013 hPa at a temperature of 100 °C. When a substance is dissolved in water, the vapour pressure is reduced, and is so less than 1013 hPa at 100 °C. Heat must now be supplied to increase the kinetic energy of the molecules, and so to raise the temperature so that the solution comes to boiling.

The reason for the higher energy requirement for the solution than for the pure solvent is because additional forces, mutual attractive forces between solute and solvent, must be overcome in the solution. The solution does not boil at T_0 , but at the higher temperature T_s . The difference between these two temperatures is the boiling point elevation ΔT_s .

$$\Delta T_S = T_S - T_0 \quad (2)$$

From a quantitative point of view, the boiling point elevation is dependent on the amount to which the vapour pressure is lowered, and so on the concentration of the solute. Molality is used here as dimension, i.e. the number of moles of solute dissolved in 1 litre of solvent.

$$\Delta T = \frac{K_e \cdot m_2 \cdot 1000}{M_2 m_1} \quad (3)$$

m_1	Mass of the pure solvent
m_2	Mass of the dissolved substance
M_2	Molar mass of the dissolved substance
K_e	Ebullioscopic constant

When determining the relative molar mass of a dissolved substance, the fact that the number of free moles n_B corresponds to the number of free particles must be taken into account. If, however, n_B moles dissociate into z smaller particles in solution, then the number of moles actually present becomes

$$n = n_B(1 + (z - 1)\alpha) \quad (4)$$

where α is the degree of dissociation.

Under certain conditions, the determination of molar masses using ebullioscopy can therefore only supply the apparent molar mass M_S , which must then be converted using

$$M_S = \frac{M_B}{(1 + (z - 1)\alpha)} \quad (5)$$

Data and results

$$K_e(\text{water}) = 0.515 \text{ K} \cdot \text{kg} \cdot \text{mol}^{-1}$$

Molar masses (in $\text{g} \cdot \text{mol}^{-1}$):

NaCl ($\alpha = 1$, $z = 2$): 61.71 (exp.); 58.44 (lit.)

Urea ($\alpha = 0$): 60.83 (exp.); 60.06 (lit.)

Hydroquinone ($\alpha = 0$): 108.14 (exp.); 110.11 (lit.)