

Measurement of surface tension

Short theoretical background:

Qualitatively, the surface tension of liquids is a property that draws a liquid together minimizing its surface. We can also give two quantitative definitions for it:

1. Surface tension is the drawing force acting upon a surface line of unit length. Its dimension therefore is $\text{N/m} = \text{kg} \cdot \text{s}^{-2}$.
2. Surface tension is the work required to produce a new surface of unit area under isothermal and reversible conditions. Its dimension therefore is $\text{J/m}^2 = \text{kg} \cdot \text{s}^{-2}$ (which is the same as above).

Due to definition (2) the surface tension (γ) can be looked upon as the Gibbs free energy of unit surface, and its change is governed by the Gibbs-Helmholtz equation:

$$\gamma = h_\gamma + T \frac{d\gamma}{dT} \quad 1.$$

where h_γ is the enthalpy of unit surface. The derivative $\frac{d\gamma}{dT}$ proves to be negative by experiment

and therefore the surface tension of liquids decreases when the temperature increases. The temperature dependence is described by the Eötvös rule:

$$\gamma \cdot V^{2/3} = \kappa \cdot (T_c - T) \quad 2.$$

where V is the molar volume, T_c the critical temperature and κ is the Eötvös constant. For normal liquids $\kappa = 2.1 \cdot 10^{-7} \text{ J}(\text{K} \cdot \text{mol}^{2/3})$. For elongated molecules and for liquids whose molecules have a tendency to association the value of κ is different.

The surface tension of solutions also depends on the concentration. Some solutes (they are called capillary active substances) reduce the surface tension considerably even when they are present in low concentration. Such capillary active substances are e.g. the alcohols, aldehydes, ketons, fatty acids, and alkyl sulfonates. Capillary inactive substances increase the surface tension to some extent. Such substances are: inorganic compounds, proteins, urea, glycerol etc. The concentration of capillary active substances is always much higher on the surface than in the bulk solutions. This is referred to by the expression "positive adsorption". Capillary inactive substances, however, are avoiding the surface (negative adsorption). Sziszkowski (pronounce: Shishkovsky) found the following empirical equation for the concentration dependence of surface tension:

$$\Delta = \gamma_0 - \gamma_c = A \cdot \log(1 - B \cdot c) \quad 3.$$

where γ_0 is the surface tension of pure water, and γ_c is that of the solution of concentration c , and A and B are constant characteristic of the solute. Experiments prove that the values of B form geometric series within the homologue series of capillary active substances (e.g., fatty acids: formic acid, acetic acid, propionic acid, etc.).

On the average:

$$\frac{B_{n+1}}{B_n} = 3,4 \quad 4.$$

The above relation is known as the Traube rule.

In the following section we give you a short introduction to the theoretical basis of the surface excess of a solute. For a plane surface phase, e.g. a liquid/vapor boundary containing only one solute (n_1) and one solvent (n_2) component an infinitesimally small amount of heat, work or material transfer given to or by the system cause a change in internal energy:

$$dU = T \cdot dS - p \cdot dV + \gamma \cdot dA + \mu_1 \cdot dn_1 + \mu_2 \cdot dn_2 \quad 5.$$

The intensive variables in Eq. (5) are T , p , γ , μ_1 , μ_2 , and the extensive ones are S , V , A , n_1 , n_2 .

By integrating Eq. (5) we get

$$U = T \cdot S - p \cdot V + \gamma \cdot A + \mu_1 \cdot n_1 + \mu_2 \cdot n_2 \quad 6.$$

The differential of Eq. (6)

$$dU = T \cdot dS + S \cdot dT - p \cdot dV - V \cdot dp + \gamma \cdot dA + Ad\gamma + \mu_1 \cdot dn_1 + n_1 \cdot d\mu_1 + \mu_2 \cdot dn_2 + n_2 \cdot d\mu_2 \quad 7.$$

Using Eq. (5) and (7)

$$0 = S \cdot dT - V \cdot dp + Ad\gamma + n_1 \cdot d\mu_1 + n_2 \cdot d\mu_2 \quad 8.$$

For a surface phase at a fixed T and p

$$0 = Ad\gamma + n_1 \cdot d\mu_1 + n_2 \cdot d\mu_2 \quad 9.$$

The boundary layer is replaced by a surface. In the surface phase for solute component Γ_1 is the amount of chemical substance 1 adsorbed per unit area; i.e. the surface concentration expressed in mol m⁻². Solvent is not adsorbed by the surface phase, therefore $n_2 = 0$, and surface excess of solute is

$$\Gamma_1 = \frac{n_1}{A} \quad \Gamma_1 = \frac{d\gamma}{d\mu_1} \quad 10.$$

$$-\Gamma = \frac{d\gamma}{RT \ln \frac{c_1}{c_{\text{ref}}}} \quad -\Gamma \cdot RT = \frac{d\gamma}{d \ln \frac{c_1}{c_{\text{ref}}}} \quad 11.$$

Where c_{ref} is 1 mol dm⁻³. From Eq. (11) it can be seen that the slope of γ vs $\ln c$ function is equal to $-\Gamma \cdot RT$. Positive adsorption is observed when $\Gamma_1 > 0$, i.e. by increasing the bulk concentration of solute surface tension decreases.

B1.15 - Determination of surface tension by measuring differential capillary action
Supplement for students (1st/autumn/ semester 2014)

Task: Measurement of the surface tension of cyclohexane or ethanol in the 20-45 °C temperature range at 4-5 temperatures. Determination of the Eötvös constant and the critical temperature.

The measurement is carried out by 1 or 2 students using either of the above-mentioned pure substances. **The main description of the measurement can be found in *Praktikum B*, Vol. I, pp. 228-238 (in Hungarian).**

Remarks to perform the measurements

It is important that the capillaries are very clean. Nevertheless, cleaning of the capillaries using chromic-sulphuric acid has been performed previously by the technician. The glass cup of the apparatus that holds the capillaries should be flushed (cleaned) with a small amount of liquid to be used for the surface tension experiments. During cleaning the cup, do not place the capillaries onto the desk (it may be dirty and clogged!) but rather put it into an empty, sufficiently high glass cup in a reversed position! Pump a small amount of the investigated liquid sample across the capillaries by means of the water aspirator vacuum pump! Then fill approximately 80 ml sample into the glass cup of the apparatus using a measuring cylinder! However, care must be taken not to leave liquid remains at the top of the capillaries, as this would distort the measurement! If this accident occurs, remove the residues of the liquid by pumping or pressing air into the apparatus using the syringe attached to the side tube of the apparatus! After finishing the experiment, the apparatus should not be cleaned by acetone since the investigated samples are also volatile, so that the residues of the samples will evaporate themselves! After finishing the experiment pour the sample into the receptacle that serves for storing the used-up sample! The temperature is controlled by a thermostat attached to the apparatus. Wait until the temperature remains constant (approximately ~15-20 minutes) before measuring the differential capillary action! The differential capillary action is measured by a cathetometer.

During using the cathetometer it is very important (according to notations of Fig. 13. in *Praktikum B*, volume II, page 477):

- to check the horizontal position of the telescope (29) by checking the position of the bubble in the water level indicator,
- to repeat setting the horizontal position again using the micrometer screw (30).
- The micrometer screw (19) rotates in horizontal plane by turning it clockwise. Reaching the end position of this screw, in order to be adjustable again, the fixing screw (20) should be loosened. Then the micrometer screw (19) should be turned counter clockwise with several threads. Then fixing the fixing screw (20) again, the micrometer screw (19) can be turned again clockwise.

Measurements:

Please record more (at least two) data-pairs (h_1, h_2) at each temperature! Note that the spontaneous convection between the liquids inside and outside the capillaries is ineffective! Therefore from time-to-time please renew the liquid inside the capillary by applying gentle overpressure resulting in bubbling!

The necessary data for the calculations:

Substance	The temperature dependence of density in 20 – 50 °C temperature range	Molar Mass kg mol ⁻¹
cyclohexane	$\rho_C/\text{kg m}^{-3} = 797.313 - 0.94324 \cdot (t/^\circ\text{C})$	0.08416
ethanol	$\rho_E/\text{kg m}^{-3} = 804.308 - 0.7654 \cdot (t/^\circ\text{C})$	0.04607

$$\Delta h = \frac{2\gamma}{\rho g} \left(\frac{1}{r_2} - \frac{1}{r_1} \right) = \frac{2\gamma}{\rho g} A \quad \text{where } A = 3477 \text{ m}^{-1}$$

Measured and Calculated results to submit

1. Calculate the Δh , ρ , γ és $\chi(M/\rho)^{2/3}$ quantities belonging to the given temperature and summarise these data in a table at each temperature!
2. Plot the $\gamma \left(\frac{M}{\rho} \right)^{2/3}$ quantity as a function of T !
3. Calculate the values of Eötvös constant (k_E) and critical temperature (T_{kr}) by performing a linear regression on the $y \equiv \chi(M/\rho)^{2/3} = f(T)$ linear function based on Eötvös rule (further explanation *see* in **Remark**)! The values of k_E and T_{kr} can be obtained from the slope and intercept data!
4. Calculate the uncertainties of k_E and T_{kr} using the Student t -test with 95%-os confidence interval!
5. Characterise the interfacial phase based on the obtained value of Eötvös constant!

Remark. The uncertainty of T_{kr} can be obtained using the Gaussian error propagation law as follows:

$$\delta T_{kr} = \sqrt{\left(-\frac{\delta A}{B}\right)^2 + \left(\frac{A \cdot \delta B}{B^2}\right)^2}$$

where A and B are the intercept and slope in the $y \equiv \gamma\left(\frac{M}{\rho}\right)^{\frac{2}{3}} = k_E(T_{kr} - T) = A + BT$ of the linear function ($A = k_E T_{kr}$, $B = -k_E$), respectively. δA and δB denote the uncertainties of the intercept and slope, respectively.

The theoretical description of error calculations, together with examples, can be found on pages 25-63 of *Praktikum A*.

B1.16 - Determination of surface tension by the bubble pressure method.
Supplement for students (1st/autumn/ semester 2016)

Tasks

Determination of surface tensions of isobutanol solutions of different, known concentrations and that of an unknown aqueous solution by the bubble pressure method. Determination of the Gibb surface excess concentration.

Apparatus

The working principle of the apparatus (Fig. 1) is the following: air is pulled (or pressurized) into a liquid through a capillary. The air forms a bubble at the bottom of the capillary then gets released and escapes through a liquid layer inside apparatus. The measured pressure difference depends on the surface tension of the liquid investigated.

The apparatus consists of a large cylindric vessel furnished with a stopcock on its bottom and funnel on its top (which also has a stopcock). On one side there is a manometer filled with water, on the other side there is the measuring vessel filled with the liquid whose surface tension is to be determined. There are two circular marks on the measuring vessel. The upper mark shows where the meniscus of the measured liquid supposed to be, and the lower one shows appr. the bottom of the capillary. The submerged length (let us denote Δh_1 hereinafter) is always the same in all experiments. After the measuring vessel is closed, the measured liquid is only connected with the atmosphere through the capillary tube.

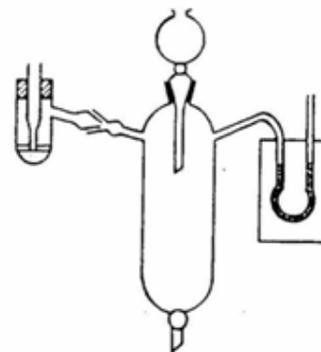


Fig.1.
Apparatus for the measurement of bubble pressure

The apparatus is open to air on both sides, therefore the following pressure balance equation can be written:

$\Delta p = p_\gamma + p_{\text{hydr}}$, where Δp is the pressure difference of the manometer (which is a hydrostatic pressure in fact), p_γ is the capillary pressure and p_{hydr} is the hydrostatic pressure in the measuring vessel.

The capillary pressure can be expressed as: $p_\gamma = 2\gamma / r$, where γ is the surface tension (in N/m), r is the radius of capillary (in m).

The hydrostatic pressure can be written in this form: $\Delta p = \Delta h \cdot d \cdot g$, where Δh is the level difference (in m), g is the gravitational acceleration (9.81 m/s^2), and d is the mass density of the liquid (either water in the manometer or the liquid in the measuring vessel (water or a solution)) at a given temperature (in kg/m^3).

Substituting these in our base equation results: $\Delta h \cdot d_{\text{water}} \cdot g = 2\gamma / r + \Delta h_1 \cdot d_{\text{liquid}} \cdot g$
This equation will be used in our calculations.

Experimental tasks

1. Measure the mass density of the unknown aqueous solution.
2. Measure the bubble pressure for water.
3. Measure the bubble pressure for the unknown aqueous solution.
4. Measure the bubble pressure for 4 different concentration isobutanol solutions.

The experimental procedure:

1. Usage of the Mohr-Westphal balance.

The Mohr-Westphal balance (Fig. 2) comes with a glass rod and a series of weights (riders). The mass of the largest rider (U shaped brass wire) is equal to that of 4°C water occupying the same volume as the glass rod. The smaller riders are 1/10 and 1/100 of the largest one. The Mohr-Westphal balance directly measures the density of a liquid by giving the weight loss of the glass rod completely submerged in that liquid. There is a scale on the beam of the balance for measuring the tenths of the nominal values represented by each rider. The nominal values are: 1 g/cm^3 (large brass rider), 0.1 g/cm^3 , and 0.001 g/cm^3 . Thus a typical reading is like this 1.526 or 0.865.

NOTE: When measuring, the glass rod must be completely submerged and it must not touch the wall of the vessel.

- a) Before taking the first measurement, the balance has to be zeroed. Measure the temperature in the lab, and find the density data of water from the table at that temperature (see below). Set the balance for Mohr-Westphal balance by using the appropriate weights (riders) on arm, while the glass body is immersed totally in distilled water without touching the wall of graduated cylinder. Rotate the counterbalance to obtain the horizontal position of arm (the index pointer on the end of the beam lines up with the point on the frame). Now the Mohr-Westphal balance is calibrated to distilled water at lab temperature.
- b) Set the Mohr-Westphal balance with unknown solution. Replace distilled water in the graduated cylinder by unknown solution. Set the balance with placing riders on the nine equally spaced notches on the beam. Read the position of riders, and add them up. Density of liquids may be obtained to four decimal places.

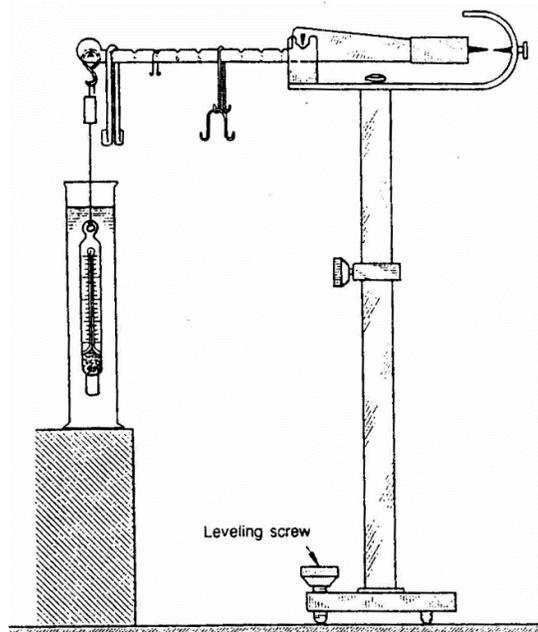


Fig.2.
A typical Mohr-Westphal balance

Scale:

1 g/cm³ rider is worth on the hook 1 g/cm³, on notches 9 to 1: 0.9 - 0.1 g/cm³.

0.1 g/cm³ rider is worth on the hook 0.1 g/cm³, on notches 9 to 1: 0.09 - 0.01 g/cm³.

0.01 g/cm³ rider is worth on the hook 0.01 g/cm³, on notches 9 to 1: 0.009 - 0.001 g/cm³.

The density of water should be taken from Table 1! If the measured temperature cannot be found in the table, make a linear extrapolation!

2. Steps of the measurement with the apparatus for measurement of bubble pressure.

Record the name and unique label of the apparatus you will use. Record the submerged length of the capillary.

Preparation of the apparatus:

- a) Remove the measuring vessel from the equipment. Clean the vessel and the capillary by the liquid to be measured (you can clean the capillary inside using a water aspirator).
- b) Fill the large cylindrical vessel half up with distilled water through the funnel.
- c) Close the stopcock of the funnel, and get back the measuring vessel.
- d) Fill the measuring vessel with the liquid to be measure and place the capillary in. Set the correct liquid level when bubbles are already forming!

Measuring the bubble pressure:

- a) Open the stopcock on the bottom of the cylinder and let the water flow out slowly. The pressure will drop inside, pulling outside air through the capillary and bubble will be formed. Set dropping speed slow enough which makes the level difference of the manometer well readable (approximately one bubble in every 10 seconds).
- b) Read the maximal difference on the manometer (one bubble for the reading of the upper lever another bubble for the reading of the lower level) with 0.1 mm precision. Use lupe!
- c) Repeat reading of pairs of liquid levels till they do not change in time and get 4-5 pairs having practically the same difference. This form a series of readings. Repeat your experiment setting the dropping again. The average differences in the series should be almost the same.

Do not forget to record the temperature of laboratory. Keep the measuring capillary clean all the time (do not put on your desk, do not touch it)! When changing solution, use water aspirator to clean the capillary with the new liquid.

3. Preparation of the different concentration butanol solutions

The students prepare a series of solutions using a 5 cm³ burettes in a 50 cm³ volumetric flasks from isobutanol. Use the following volumes of isobutanol: 0.4 cm³, 0.6 cm³, 0.8 cm³, 1.2 cm³, 1.6 cm³, 2.4 cm³, 3.2 cm³, 4.0 cm³. Use 2x distilled water for the dilution and homogenize the solutions very-very carefully to avoid foam formation! The isobutanol mixes with the water rather hard and slow. Please ascertain that all isobutanol is dissolved in water, *i.e.* the system is a single-phase liquid

Two groups of students determine the surface tension of the 8 solutions using two apparatuses. Both groups have to calculate the concentrations and evaluate the surface tensions separately and share the results each other. The surface excess concentration have to be determined using all the 8 results.

For the accurate determination of the solution concentration we have to know the mole number of the dissolved isobutanol. The most accurate determination of it in this lab is based on the mass measurement. Measure the mass of empty volumetric flask, pour the given volume of isobutanol from the 5 cm³ burette in (we will NOT use this volume for the calculation), measure the mass again. The mass difference gives the mass of isobutanol, from which its mole number can be calculated ($M_{\text{isobutanol}} = 74,12 \text{ g}\cdot\text{mol}^{-1}$).

Evaluation of the data

1. Determine the radius of capillary, r using the measured bubble pressure for water: $r = \frac{2 \cdot \gamma_w}{\rho_w \cdot g \cdot (\Delta h - h_1)}$,

where h_1 is the submerged length, $g = 9,81 \text{ m/s}^2$ and ρ_w the density of water at the temperature of measurement, γ_w is the surface tension of water which can be calculated using Table 1 by interpolation.

2. Calculate of surface tension of your unknown solution and the i-butanol containing solutions:

$\gamma_{sol} = \frac{\rho_{sol} \cdot r \cdot g (\Delta h - h_1)}{2}$, where $h_1 = 0,005 \text{ m}$, $g = 9,81 \text{ m/s}^2$ and ρ_{sol} the density of the solution (for isobutanol it is supposed to be almost the same as that of water at the temperature of measurement, for you unknown use the measured value), r is the radius of capillary determined in the previous step.

3. Calculate Γ , the Gibbs surface excess concentration

a) Calculate the concentration of all the isobutanol solutions (in unit mol/dm³).

Additional data: $M(\text{isobutanol}) = 74,12 \text{ g/mol}$.

b) Plot $\gamma - \ln c$ function. Fit a straight line on the experimental points and calculate the excess concentration from the slope of the fitted line: $\Gamma = -m / (RT)$. The excess concentration will be calculated from this equation in mol/m². Please change it to mol/cm²!

Graphs, results, data to be reported

- Name and unique label of the apparatus.
- The submerged length of the capillary.
- The temperature of your experiments.
- The mass density of water and the unknown aqueous solution.
- The measured levels of the manometer, their differences, the average of the differences for water, unknown concentration solution and isobutanol solutions.
- The calculated radius of capillary.
- The calculated surface tension of the unknown aqueous solution.
- The graph used for the Gibbs surface excess concentration (including the fitted parameters).
- The Gibbs surface excess concentration in mol/m² and mol/cm².

Please summarize the 1-butanol related data in a table like this:

V(i-but.) / cm ³	c mol/dm ³	$\Delta h(\text{aver.}) / \text{m}$	$\gamma_{\text{ib.}} / \text{N/m}$
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B1.17 Determination of surface tension by using a stalagmometer. Study of the Szyszkowski equation and the Traube rule.

Supplement for students (1st/autumn/ semester 2016)

The main description of the measurement can be found in *Praktikum B*, Vol. I, pp. 228-238 (in Hungarian) but the actual measurement has to be performed according to this description.

The stalagmometer should not be cleaned and degreased if the student has not touched the disc of the stalagmometer where the drop of a sample is hung during the measurements. Otherwise the disc becomes greasy and the therefore the measured values would be false. The stalagmometer was previously cleaned and degreased by the technician using chromic sulphuric acid. Use **twice-distilled water** for the experiments! **Touch the disc by no means otherwise the stalagmometer should be degreased again!** The wetting of a greasy glass, and therefore the size of the drop, is different on greasy surfaces. **Measure the mass of 20 drops and calculate the average mass of one drop at last! Make 5 runs (i.e. 5 x 20 drops) but you may decrease the number of runs if the scatter obtained from the first 3 runs is very low!** Before measuring the next solution, please rinse the stalagmometer by twice-distilled water and five time using the next solution! **Record the identifying symbol of the apparatus (A, B, C) in your data-sheet!**

Recommended order of measurements:

first two student-pairs: twice distilled water, solution with unknown concentration, 3 different aliphatic mono-carboxylic acid solutions (formic acid, acetic acid, propionic acid),

third student-pair: twice distilled water, solution with unknown concentration, 1,5 M acetic acid solution, 0,75 M acetic acid solution, 0,375 M acetic acid solution. The latter student-pair should make two dilutions from 1,5 M acetic acid solution using 25- and 50 cm³-volume pipettes and two 100 cm³-volume measuring flasks (taking 25 or 50 cm³ 1,5 M acetic acid solution and adding twice distilled water up to the circular mark of the measuring flask)! **Record the temperature of the measurement!**

Advices:

If the disc of the stalagmometer is not in horizontal position, please correct the position! The liquid sample is pumped using a syringe up to the lowest mark above the bulbous part of the stalagmometer! This way we can avoid the contact between the sample and the rubber tube. (The rubber tube may not be completely clean.). If the sample gets into the rubber tube by an accident, rinse the stalagmometer at least 5 times before the measurement!

Please adjust a rather slow dropping frequency in order to set at least 5-10 sec for the life time of a drop! In case of applying too high dropping frequency the drops fall off while they are smaller. Try to keep about the same dropping frequency by using about the same amount of sample and by adjusting the opening using the teflon valve attached to the apparatus! Below a certain limit of dropping frequency the mass of a drop does not depend on the dropping frequency.

Keep the glass container that serves for weighing the 20 drops rather close to the stalagmometer in order to avoid mass loss due to the splatter of the sample! Put the lid onto the glass container during weighing the sample! Keep the mat surface of the glass container always dry, otherwise a weighing error can be arisen due to loss of the sample!

Measured and Calculated results to submit

1. The mean value and the uncertainty of the mass of a drop of water and all measured solutions. Calculate the uncertainties using the Student *t*-test with 95%-os confidence interval!

2. The mean value and the uncertainty of the surface tension for the solution of unknown concentration.

Since $\gamma = \gamma_v (m/m_v)$, where m and m_v denote the masses of the drops of sample and water, respectively, the uncertainty of γ can be obtained using the Gaussian error propagation law as follows (see Praktikum A):

$$\delta\gamma = \gamma_v \sqrt{\left(\frac{\delta m}{m_v}\right)^2 + \left(-\frac{m \cdot \delta m_v}{m_v^2}\right)^2} \quad (1)$$

where δm and δm_v denote the uncertainties of the masses of drops of sample and water, respectively.

The two student-pairs studying the Traube rule:

3. The surface tensions (mean values and uncertainties) of mono-carboxylic acids. The relative change of surface tension $1/(\gamma_v - \gamma)/\gamma_v$ where γ and γ_v denote the surface tensions of the solution and water, respectively.

4. Interpret the Traube rule using your measured data!

The surface tension of the reference water should be taken from Table 1! If the measured temperature cannot be found in the table, make a linear extrapolation!

5. Calculate the surface excess Γ of propionic acid at $T = 288.15$ K temperature in $\text{mol}\cdot\text{m}^{-2}$ and $\text{mol}\cdot\text{cm}^{-2}$ units at $c = 0.5$ M on the basis of Eqn. (2) (see below)!

The third student-pair studying the Szyszkowski equation:

3. The surface tensions (mean values and uncertainties) of 1,5 M, 0,75 M és 0,375 M acetic acid solutions.

4. Plot the values of $\gamma_v - \gamma$ as a function of concentration (c)! By means of ORIGIN software, performing non-linear fitting, fit function $\gamma_v - \gamma = A \ln(1+Bc)$ on the measured points on the basis of Szyszkowski equation ($\Delta\gamma = \gamma_v - \gamma = A \ln(1 + Bc)$)! Clicking the 'Analysis/Non-linear Curve Fit' menu point a new window appears. Choosing 'Function/New' you can define a new function called 'USER'. Choose two parameters ($P1, P2$), select 'Equation' in 'Form' then type $y=P1*\ln(1+P2*x)$ in 'Definition'! Assign the depending and independent variables in menu point 'Action/Dataset'! Set initial values for both $P1$ and $P2$ in menu point 'Action/Fit', keep the command 'Vary' and start the iteration in one (1Iter.) or 10 (10Iter.) steps. If the iteration does not converge change the initial values! If the values of $P1$ and $P2$ already do not change stop the command DONE! Then the fitted function will also be plotted. The obtained values of 'Error' are actually only standard deviations. Calculate the uncertainties from these values using 95%-os confidence level and 2 degrees of freedom (**4 measured points, the (0,0) point is also a data-point!**) Present the values of A and B together with their uncertainties!

The theoretical description of the error calculations, together with examples, can be found on pages 25-63 of Praktikum A.

Remarks

Errata: Eqns. (1.163) and (1.164) in Praktikum B, Vol. I. (1988) should be corrected as follows:

$$\frac{B_{n+1}}{B_n} \approx 3.4 \quad (1.163.) \quad \text{and} \quad \gamma(c_n) \approx \gamma_{n+1} \left(\frac{c_n}{3.4} \right) \quad (1.164)$$

where B_n denotes constant B of the Szyszkowski equation ($\Delta\gamma = \gamma_v - \gamma = A \ln(1 + Bc)$) for the subsequent homologues of aliphatic carboxylic acids, n denotes the number of carbon atoms in the acid, c denotes the concentration. For the first three acids of the homologue series, constant A is nearly the same and the approximation $\frac{B_{n+1}}{B_n} \approx 3.4$ is a good approximation. If $n > 4$ $\frac{B_{n+1}}{B_n} \approx 3.4$ remains a good approximation, but due

to the increasing value of constant A the concentration ratio will be slightly different from 1 : 3.4.

Combining the Gibbs adsorption isotherm equation with the Szyszkowski equation the following equation can be obtained:

$$\Gamma = \frac{A}{RT} \cdot \frac{c}{1/B + c} \quad (2)$$

For propionic acid $A = 0.00964 \text{ N}\cdot\text{m}^{-1}$ and $B = 8.93 \text{ dm}^3\cdot\text{mol}^{-1}$ at $T = 288.15$ K temperature.

Literature

- **Praktikum A:** Szalma József, Láng Győző, Péter László: Alapvető fizikai-kémiai mérések és a kísérleti adatok feldolgozása, ELTE Eötvös Kiadó, 2008 (in Hung.).

- **Praktikum B:** Farkas József, Kaposi Olivér, Mihályi László, Mika József, Riedel Miklós, Bevezetés a fizikai kémiai mérésekbe, I és II. kötet, Szerk. Kaposi Olivér, Tankönyvkiadó, Budapest, 1988 (in Hung.).

Table 1 The temperature dependence of the density and surface tension of water

$T / ^\circ\text{C}$	$\rho / (\text{kg/m}^3)$	$\gamma / (\text{N/m})$
1	999.87	0.07534
2	999.93	0.07519
3	999.99	0.07504
4	1000.00	0.07489
5	999.99	0.07475
6	999.97	0.07460
7	999.93	0.07445
8	999.88	0.07430
9	999.81	0.07415
10	999.73	0.07401
11	999.63	0.07386
12	999.52	0.07371
13	999.40	0.07356
14	999.27	0.07341
15	999.13	0.07326
16	998.97	0.07312
17	998.80	0.07297
18	998.62	0.07282
19	998.43	0.07267
20	998.23	0.07253
21	998.02	0.07238
22	997.80	0.07223
23	997.57	0.07208
24	997.32	0.07193
25	997.07	0.07178
26	996.81	0.07163
27	996.54	0.07148
28	996.26	0.07133
29	995.97	0.07118
30	995.67	0.07103
35	994.06	0.07029
40	992.24	0.06954
45	990.25	0.06860