CHEM 335 Physical Chemistry 2PS
Surface Tension – Spring 2007
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Abstract:
The surface tension for six different solutions of n-butanol was found through the use of a
tensiomat. For solutions of concentrations 0.1 M, 0.05M, 0.025M, 0.0125M, 0.00625M,
and 0.003125M, the surface tensions (dynes/cm) were found to be 27.267384, 34.736559,
44.912903, 53.034409, 60.992832, and 65.265591, respectively. The logarithm of the
bulk concentrations were plotted against the surface tension. The slope of the line was
found to be -11.413 and the surface concentration and surface area per molecule were
computed using the Gibbs isotherm. The surface tension for distilled water at six
different temperatures were also measured using the tensiomat. Distilled water at
temperatures of 10ºC, 20ºC, 30ºC, 40ºC, 50ºC, and 60ºC had surface tensions (dynes/cm)
of 67.81369863, 80.77808219, 73.79726027, 68.8109589, 63.82465753, 60.83287671.
The temperature was plotted against the surface tension and the general trend of the line
was found to be y = -0.2593x + 78.385 and the critical temperature was calculated to be
302.294639ºC.

Introduction:
Surface tension is a property of a liquid surface that allows it to act like an elastic
membrane [1]. Within the liquid, the molecules experience intermolecular attractive
forces. These are called cohesive forces [2] and within the liquid, molecules are pulled
equally on all sides. Hence, there is no net force on any given molecule [3]. However,
molecules at the surface of the liquid tend to be pulled back down into the liquid because
there are no molecules to pull it from the opposite surface side [3]. Thus, the molecules
on the surface exhibit stronger attractive forces to their proximate neighbors [4]. This is
called surface tension and is also the cause of water beads formation [5], since water has
a relatively high surface tension of 72.8 dynes/cm [6].

Since the surface molecules experience fewer interactions than the bulk molecules,
moving a bulk molecule to the surface would require energy [7]. The surface free energy
is the amount of energy needed to create a surface per unit area and can be expressed in
terms of Gibbs free energy [7].

$$dG = \gamma dA \text{ (n, T, P constant)} \qquad \text{(Equation 1)}$$

Additionally, the surface tension can be related to the concentration of the solute with the
Gibbs isotherm [6], which represents the excess solute per unit area of the surface [8].

$$\Gamma = -[1/RT][d\gamma/d(\ln C)] \qquad \text{(Equation 2)}$$

Many solutes affect the surface tension of a liquid. For example, alcohols are known as
surfactants because it lowers the surface tension of a liquid [7]. Surfactants tend to
concentrate near the surface (because they have hydrophilic and hydrophobic groups) [7]
and thus, in excess when compared to the bulk liquid [7]. Hence, they have positive

surface concentrations. On the other hand, inorganic salts have a stronger attraction to water and thus have negative surface concentrations [7]. Surface tension also decreases with an increase in temperature [6]. In this experiment, we will be examining the influence of n-butanol (an alcohol) and temperature on the surface tension of pure water.

Materials and Methods:
Equipment:

Taken from:
https://www1.fishersci.com/Coupon?gid=3004466&cid=1328

A pre-assembled Surface Tensiomat Model 21 from Fischer Scientific was used to measure the surface tensions of different solutions of n-butanol at varying concentrations and distilled water at varying temperatures. The instrument was calibrated according to the instruction manual. Additionally, the correction factor was found by measuring the surface tension of distilled water at 20ºC for six trials. Every consecutive measurement was multiplied by this correction factor.

Surface tension of n-butanol:
Six solutions of n-butanol were made. An initial 100% n-butanol was diluted to 0.1M by adding 90ml of distilled water to 10ml of 100% n-butanol. The second solution was exactly half the concentration of the first one; an equal amount of distilled water and solution 1 were added. The third, fourth, fifth, and sixth solutions were also created in this manner, where the concentration of each would be halved by adding equal amounts of the previous solution with water.

solution #	concentration [M]
1	0.1
2	0.05
3	0.025
4	0.0125
5	0.00625
6	0.003125

Table 1 – Concentration for each solution

The surface tension for each solution was measured three times at a constant room temperature of 27ºC with the surface tensiomat instrument. A platinum-iridium alloy ring with a mean circumference of 6.00 cm was used to stretch the surface of each solution. The surface tension was read when the ring detached from the surface of the liquid. To keep the trials as constant as possible, one lab partner was responsible for lowering the ring and adjusting the weights, while another read and recorded the surface tension on the vernier scale.

Surface tension of distilled water:
Different amounts of distilled water were obtained at the following temperature: 10ºC, 20ºC, 30ºC, 40ºC, 50ºC, and 60ºC.
The same procedure was carried out by group A (Faiza Anwar, Paul Brathwaite). Their results are incorporated in this lab.

Calculations, Data, and Results:
Calculating correction factor for the instrument:
correction factor = 72.8(dynes/cm) / γ

trials	correction factor for γ
1	75.1
2	75.5
3	65.4
4	75
5	80.5
6	74.9
avg	74.4
λ_{95}	4.909582467

The average surface tension for distilled water was 74.4 +/- 4.9 dynes/cm.
The correction factor for the instrument was 72.8/74.4 = 0.97849.

n-butanol:
Calculating corrected surface tension (γ)

Solution #	trial 1	trial 2	trial 3	average	corrected surface tension (γ)	λ_{95}
1	27.7	27.9	28	27.86666667	27.267384	0.152753
2	35.5	35.6	35.4	35.5	34.736559	0.1
3	45.8	46	45.9	45.9	44.912903	0.1
4	54.5	54.1	54	54.2	53.034409	0.264575
5	62	63	62	62.33333333	60.992832	0.57735
6	66.8	66.3	67	66.7	65.265591	0.360555

The surface tension for each trial was corrected by multiplying the average of the three trials by the correction factor.

ln [M]	surface tension (γ)	corrected surface tension (γ)
-2.302585093	27.86666667	27.267384
-2.995732274	35.5	34.736559
-3.688879454	45.9	44.912903
-4.382026635	54.2	53.034409
-5.075173815	62.33333333	60.992832
-5.768320996	66.7	65.265591

The logarithm of the bulk concentration for each solution was found. A graph with the above information was created with the logarithm of the bulk concentration on the abscissa and the corrected surface tension on the ordinate.
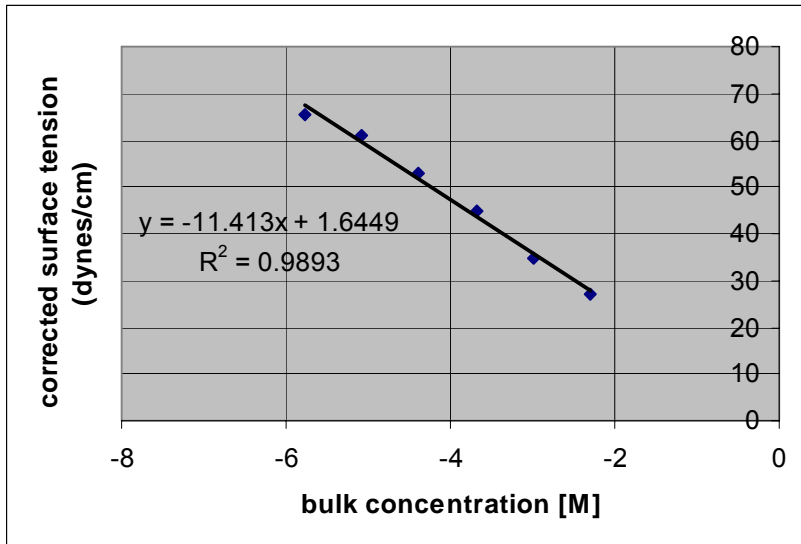
Fig. 1 – graph of bulk concentration vs. corrected surface tension

Calculating surface concentration

The slope of Figure 1 is equal to -11.413. This slope represents $[d\gamma/d(\ln C)]$ from the Gibbs isotherm.

Gibbs isotherm = $-[1/RT][d\gamma/d(\ln C)]$

where: $R = 8.314 \; J \cdot K^{-1} mol^{-1}$

$T = 300K$

The slope $[d\gamma/d(\ln C)]$ has units of (dynes/cm)/M. This was converted in terms of mol/m^2:

1 dynes = 10^{-5} N

1cm = 10^{-2}m

1dynes/1cm = 10^{-3} N/m = 10^{-3} J/m^2

$R = 8.314 \; J \cdot K^{-1} mol^{-1} * 10^3 \; m^2/J = 8.314 \; x \; 10^3 \; m^2/K \cdot mol$

$RT = 8.314*10^3 \; m^2/K \cdot mol * 300K = 2.49 \; x \; 10^5 \; m^2/mol$

$1/RT = 1/2.49 \; x \; 10^5 \; m^2/mol = 4.00 \; x \; 10^{-6} \; mol/m^2$

$\Gamma = -[1/RT][d\gamma/d(\ln C)] = -[1/RT][-11.413] = 4.58 \; x \; 10^{-5} \; mol/m^2$

Calculating surface area per molecule

N_A = Avogadro's number = $6.022 \; x \; 10^{23}$ units/mol (in this case, the units = molecules)

$1/N_A = 1.66058 \; x \; 10^{-24}$ mol/molecules

$\Gamma = 4.58 \; x \; 10^{-5} \; mol/m^2$

$1/\Gamma = 21854.02611 \; m^2/mol$

$1/N_A*1/\Gamma =$

$1.66058 \; x \; 10^{-24} \; mol/molecules * 21854.02611 \; m^2/mol = 3.629 \; x \; 10^{-20} \; m^2/molecules$

Distilled water: (data courtesy of Faiza Anwar and Paul Brathwaite)

Calculating correction factor for the instrument:

correction factor = 72.8(dynes/cm) / γ

trial	correction factor for γ
1	72
2	73
3	74
4	73
5	73
avg	73
λ_{95}	0.70710678

The average surface tension for distilled water was 73 +/-0.707 dynes/cm.

The correction factor for the instrument was 72.8/73 = 0.99726027.

T (°C)	surface tension (γ)	corrected surface tension (γ)
10	68	67.81369863
20	81	80.77808219
30	74	73.79726027
40	69	68.8109589
50	64	63.82465753
60	61	60.83287671

The surface tension for each temperature was multiplied by the correction factor.

There was no average surface tension or λ_{95} for any of the trials because Group A did not run any additional trials for each temperature.

A graph of the temperature and the corrected surface tension was created with the temperature on the abscissa and the corrected surface tension on the ordinate.
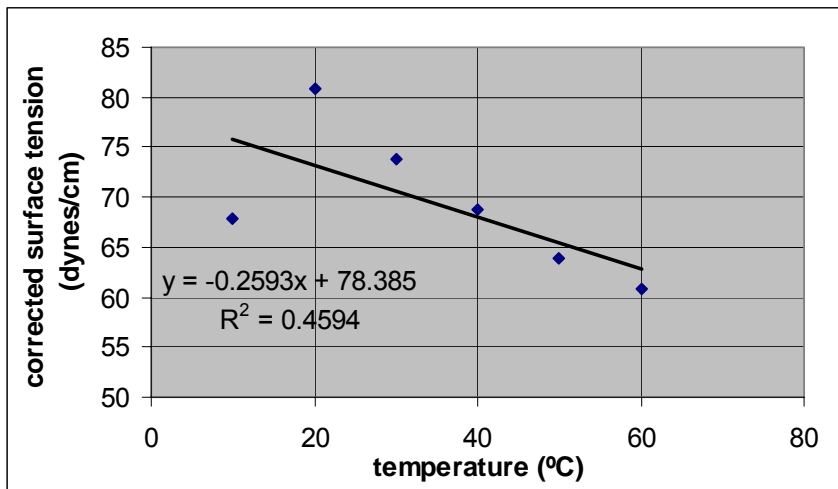

y = -0.2593x + 78.385
R^2 = 0.4594

Fig. 2 – graph of temperature vs. corrected surface tension

Calculating the critical temperature, T_c

When the critical temperature is reached, the surface tension of water will be 0.

When the y-value = 0, the x-value is…
y = -0.2593x + 78.385
0 = -0.2593x + 78.385
0.2593x = 78.385
x = 78.385/0.259 = 302.294639ºC

Discussion:
For the solutions of n-butanol, the surface tension increases as the concentration of alcohol decreases. This can be seen by comparing the 0.1M solution, with a surface tension of 27.267 +/- 0.152753 dynes/cm, and the 0.003125M solution, which has a surface tension of 65.265591 +/- 0.360 dynes/cm. This occurs because the concentration of water increases as the amount of alcohol decreases. Hence, the solutions with lower concentrations of alcohol will be closer to the surface tension of pure water, 72.8dynes/cm. [6].

Additionally, this trend can be observed in Figure 1 with the logarithm of the bulk concentration plotted against the surface tension. The correlation between the points is 0.9893, a strong indication that the experiment was ran successfully. The low λ_{95} for both results also suggest that the results are reliable. Both these analyses show that as the concentration of alcohol decreases, the surface tension begins to increase at a given temperature.

Using the slope of the line and the Gibbs isotherm (equation 2), the surface concentration was found to be 4.58 x 10^{-5} mol/m^2. When the reciprocal of this number (m^2/mol) was multiplied with the reciprocal of Avogadro's number (mol/molecule), the surface area per molecule was determined to be 3.629 x 10^{-20} m^2/molecules.

The effect of temperature on surface tension was also explored. The data indicates the surface tension of water decreases as the temperature increases. However, since only one run was done for each experiment, one cannot solely base this conclusion on the experiment. As can be seen in Figure 2, a correlation of 0.4594 is weak and does not show any significance. Furthermore, a standard error bar cannot be obtained because no further trials were implemented. Nevertheless, experiments conducted by scientists agree with these results. In Park et al's experiment, an increase in temperature was also followed by a decrease in surface tension of polystyrene [9].

The critical temperature is the temperature at which the surface tension of water is zero. This can be found by setting regression line to zero and calculate the value for x. The critical temperature was determined to be 302.294639ºC.

All in all, this experiment shows that a decrease in alcohol concentration increases the surface tension of water and that a rise in temperature decreases the surface temperature. Surface tension is also related to humans in many ways. Surfactants are present in the lungs to prevent aleveolar collapse [10]. A defect in this surfactant can lead to certain lung diseases. The study performed by Nag K et al demonstrated that the applications of

physical biochemistry are not just bound to the realm of chemistry, but can also be applied to biology [10].

References:
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APPENDIX: RAW DATA

2.27.07

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Surface Tension Lab

- Calibration of machine using distilled water

Trial	Value
1	75.1
2	75.5
3	65.4
4	75.0
5	80.5
6	74.9

- Solution #1
concentration = c

Trial	Value
1	26.6
2	27.7
3	27.9
4	28.0

- Solution #2
concentration = c/2

Trial	Value
1	35.5
2	35.6
3	35.4

- Solution #3
concentration = c/4

Trial	Value
1	45.8
2	46.0
3	45.9

- Solution #4
concentration = c/8

Trial	Value
1	54.5
2	54.1
3	54.0

- Solution #5
concentration = c/16

Trial	Value
1	62.0
2	63.0
3	62.0

- Solution #6
concentration = c/32

Trial	Value
1	~~69.7~~ 66.8
2	66.3
3	67
4	