ChE 203 - Physicochemical Systems Laboratory

EXPERIMENT 2: SURFACE TENSION

Before the experiment: *Read the booklet carefully. Be aware of the safety issues.*

Object

To determine the surface tension of water and to observe the change with respect to temperature.

Theory

Within the body of a liquid, a molecule is acted upon by molecular attractions, which are distributed more or less symmetrically about the molecule. At the surface, however, a molecule is only partially surrounded by other molecules, and as a consequence it experiences only an attraction towards the body of the liquid. This latter attraction tends to draw the surface molecules inward and in doing so makes the liquid behave as if it were surrounded by an invisible membrane. This behavior of the surface, called 'surface tension', is the effect responsible for the resistance; a liquid exhibits to surface penetration, the nearly spherical shape of mercury particles on a flat surface, and the rise of liquids in capillary tubes [1].

From a thermodynamic point of view, it can be thought that surface tension is due to the tendency of a liquid to reduce its surface to a point of minimum potential surface. It is an essential condition for stable surface equilibrium. Since a sphere has the smallest surface area for a given volume, the tendency of a liquid particle is to draw itself into a spherical shape due to the action of surface tension. In terms of the Helmholtz and Gibbs energy concepts, surface tension (γ) can also be defined as the ratio of the work needed to change the area of the liquid (dw) to the change of the surface area ($d\sigma$) [1]:

$$\gamma = \frac{dw}{d\sigma} \tag{1}$$

Surface tension is not observed only in liquids but on interfacial surfaces between different phases as well. Solutions exhibit this surface activity. The effect of dissolved substances on the surface tension of the solution is exemplified by the three types of curves shown in Figure 1. In solutions of type I, addition of solute leads to an increase in surface tension, but the increase is generally not large. Such behavior is exhibited by strong electrolytes, sucrose, and aminobenzoic acid in water. On the other hand, with non-electrolytes or weak electrolytes in water, the behavior most often encountered is that given by curves of type II. Here the solutions exhibit surface tensions, which decrease regularly and more or less gradually with increase in solute concentration. Finally type III curves are given by aqueous solutions of soaps, certain sulfonic acids and other types of organic compounds. These substances, called 'surface active reagents' possess the ability to lower surface tension of water to a low value even at very low concentrations.

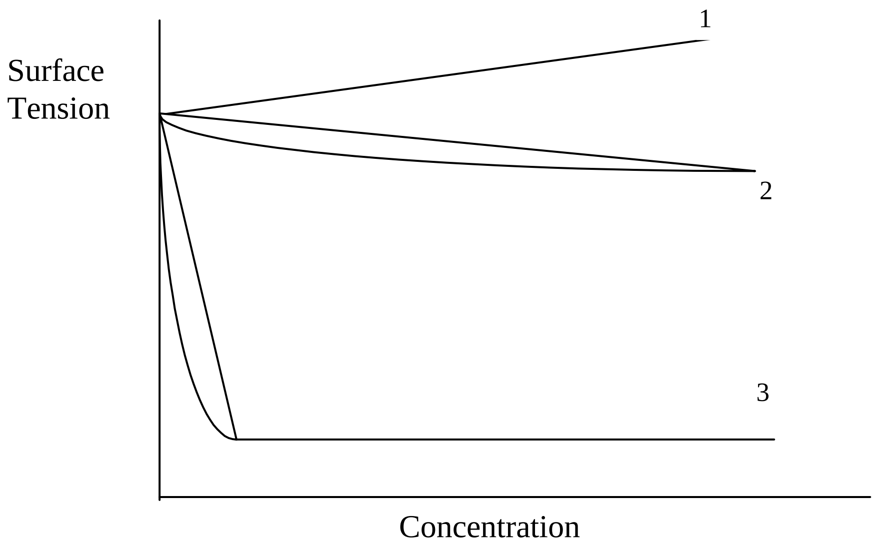

Figure 1. Concentration versus surface tension graphs.

Experimental Work

Apparatus

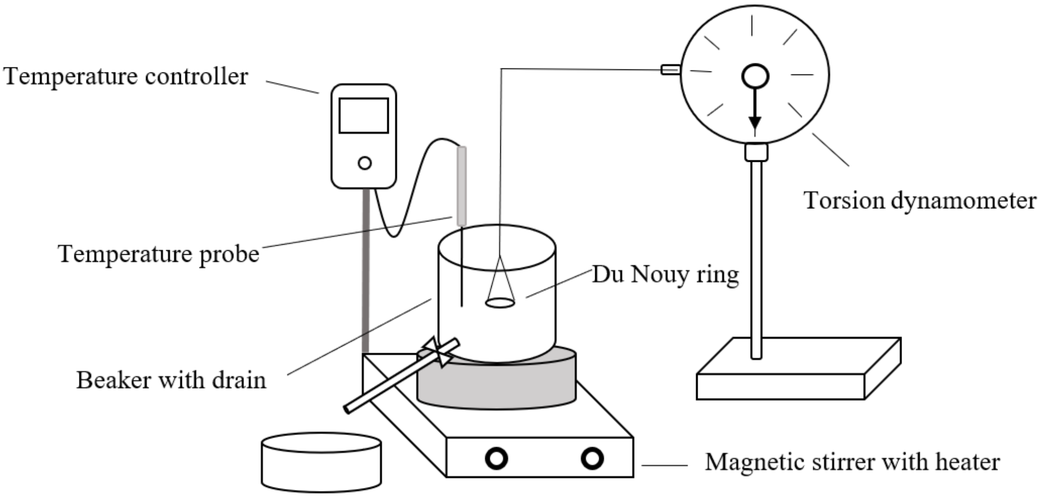

Figure 2. Du Nouy Ring Apparatus.

Chemicals: Water

Procedure

1. Distilled water is poured into the beaker and the ring is completely submerged.

2. The torsion dynamometer's indicator is set to "0" and the weight of the ring is compensated using the rear adjusting knob so that the lever arm is in the white area between the marks.

3. First, surface tension of water at room temperature is measured. Then the water is heated and stirred with magnetic stirrer. When the temperature is stabilized, stirring is stopped and the liquid is allowed to come to rest.

4. The liquid is slowly discharged from the drain into an another beaker.

5. While the liquid runs out, the torsion dynamometer is continuously readjusted to keep the lever arm in the white area between the two marks.

6. When the liquid film tears from the ring, the last value read on the torsion dynamometer is recorded together with the temperature of the liquid. It is ensured that the apparatus is not subjected to vibration.

7. The same steps are carried out at different temperatures.

Calculations

In a liquid at rest, a molecule is subjected to equal forces exerted by the molecules surrounding it, therefore pressure P is isotropic. The resultant force acting on a molecule in a boundary layer of a liquid surface is not zero but is directed towards the interior of the liquid. In order to enlarge the surface of a liquid by an amount ΔA, a certain amount of work ΔE must be performed.

$$\varepsilon = \frac{\Delta E}{\Delta A} \tag{2}$$

ε is the specific surface energy. Specific surface energy is similar to surface tension, while the former is measured along an area, the latter is measured along a length.

$$\gamma = \frac{F}{l} \tag{3}$$

Here force F acts along the edge of length l, which is tangential to the surface in order to maintain the liquid film. When a ring of radius r is used, the length of the edge is

$$l = 2 \cdot 2\ \pi\ r \tag{4}$$

There is no need to correct the measured force to compensate for the weight of the liquid lifted if the ring has a sharp bottom edge like in this case.

The surface tension of almost all liquids drops linearly with increasing temperature.

$$\gamma = \gamma'\,(T_k{}' - T) \tag{5}$$

where T_k' is a temperature near the critical temperature T_k. The molar surface tension can be defined with reference to the molar volume $V_{m.}$

$$\gamma_m = \gamma \cdot V_m^{2/3} \tag{6}$$

which together with equation (5) results in

$$\gamma_m = \gamma' \cdot V_m^{2/3} \cdot (T_k' - T) \tag{7}$$

The temperature coefficient

$$k_\gamma = \gamma' \cdot V_m^{2/3} \tag{8}$$

is equal for almost all liquids (Eötvös' equation):

$$k_\gamma = 2.1 \cdot 10^{-7} J / K \tag{9}$$

Values below this indicate association in the molecules in the liquid, larger values indicate dissociation.

Safety issues: Only water is the chemical used in this experiment, there is no toxic chemical usage. During the experiment, pay attention to dealing with hot water and use of heating unit. Make sure all the beakers are emptied, and all the electronic devices are unplugged at the end of the experiment.

Calculations & Discussion

1. Calculate surface tension at different temperatures and compare the values with literature by doing an error analysis.
2. Draw experimental surface tension versus temperature values on a graph.
3. Calculate temperature coefficient for average molar volume of the liquid and compare it with literature by doing an error analysis.
4. Discuss surface tension versus temperature graph you obtained from the experiment.
5. Discuss the effect of temperature on surface tension.
6. Explain what other methods are used to determine surface tension.

Note: The diameter of the ring used in the experiment is 19.65 mm.

References

[1] Atkins, P. and Paula J.D., 2006, *Physical Chemistry*, 8th edition, Oxford University Press, New York, 642-689, (T) 1016.