The surface tension of liquids measured with the stalagmometer

Surface tension of liquids

The molecules of liquids attract each other by cohesive forces resulting into small distances between the molecules (on the order of 0.1 nm). Thus the compressibility of liquids is lower then that of gas, while the density is much higher. On the other hand, these cohesive forces are not strong enough to result into the fixed position of molecules that can be seen in solid matter. Liquids do not keep a fixed shape, but adapt the shape of a container. Attractive cohesive forces are short range forces which are based on the electronic interactions. They affect molecules in their close vicinity only (zone of molecular interaction). In the bulk of the liquid, each molecule is attracted equally in all directions by the neighboring molecules, hence zero net force (Fig. 1). However, the molecules at the surface do not have other like molecules on all sides around them and they are pulled inwards the liquid core by non-zero net force (Fig. 1). Consequently, they cohere more strongly to those associated with them directly on the surface and form a surface "film". Nevertheless, these surface molecules are in the energetically unfavorable state, which forces liquid to minimize the surface area. The geometrical requirement of smallest surface area at the fixed volume is satisfied by the sphere. It is the reason why the free drops of water form spherical droplets.

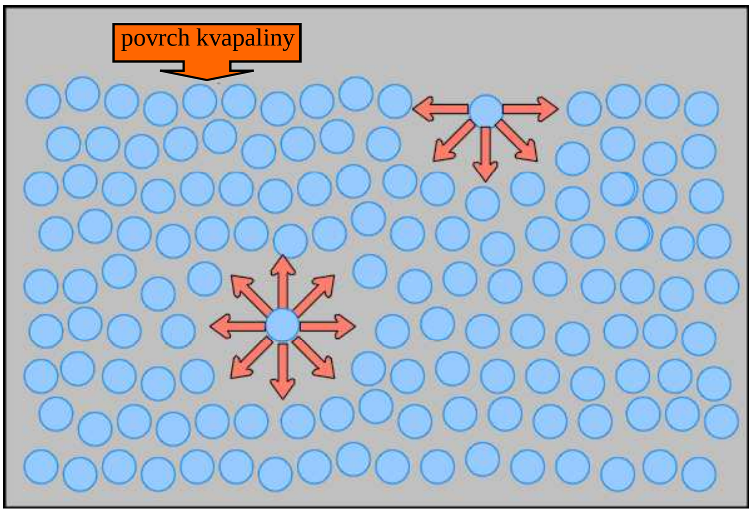

Figure 1:
Cohesive forces in a case of the molecule at the liquid surface and in the bulk.

Surface area increase, *ΔS*, is balanced out by the increase of energy, *ΔE*, where

$$\Delta E = \sigma \cdot \Delta S \qquad (1)$$

The coefficient σ defines the **surface tension** in the units of J/m^2=N/m. Each liquid is characterized by its own surface tension, which decreases with an increasing temperature (see Table 1).

The energetic definition of the surface tension (equation 1) is not the only way to describe it. We can derive it also from the simple experiment shown in Figure 2. It involves the wire rim with the AB side being able to move, and a soap film spanning the space inside the rim. We can observe that the movable wire AB is being pulled towards the soap film, as its area is shrinking down. There is a force in a plane of soap film acting in a direction perpendicular to the wire. It is called the surface force, and is expressed as

$$F = \sigma \cdot l \qquad (3)$$

where l is the length of AB wire and σ is the surface tension. According to this, surface tension is defined as a ratio of surface force to a length of rim that is pulled by this force

$$\sigma = \frac{F}{l} \qquad (4)$$

Equation (4) defines the surface tension again in units of N/m.

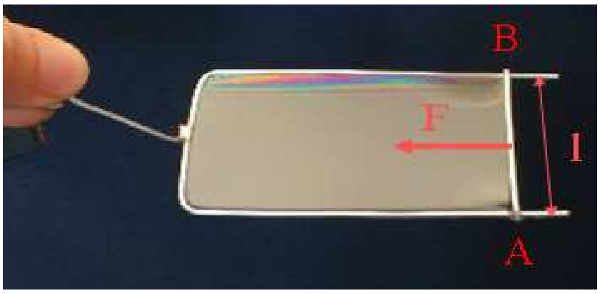

Figure 2: Soap bubble spanning the space inside the wire rim with a movable side AB.

The measurement of the surface tension of liquids using the stalagmometer.

Stalagmometer is a glass tube, widened in the middle part (Fig. 3). Its volume is calibrated by the scale shown on the tube, or by the top and bottom lines. The bottom part of stalagmometer is modified such that the liquid flowing through its smaller diameter forms the drops.

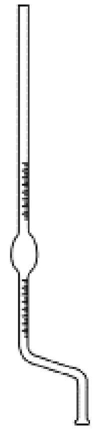

Fig. 3. Stalagmometer with a calibrating scale

The drop of a mass **m** gets released when its weight G=mg is equal or greater than the surface force at the end of tube

$$m \cdot g = 2 \cdot \pi \cdot r \cdot \sigma \qquad (5)$$

Equation (5) suggests that the surface tension **σ** can be calculated from the known water mass **m** and the radius of stalagmometer tube **r**. However, it was shown experimentally that only about 2/3 of the drop volume gets released. In addition, this portion is not constant for all the drops. On the other hand, the ratio of the mass and surface tension is constant for all the liquids

$$\frac{m_1}{\sigma_1} = \frac{m_2}{\sigma_2} \qquad (6)$$

In the equation (6), $\mathbf{m_1}$ and $\mathbf{m_2}$ are the masses of drop 1 and 2 respectively, and $\boldsymbol{\sigma_1}$ and $\boldsymbol{\sigma_2}$ are the surface tensions corresponding to these liquids. If the liquid with known surface tension is used for one of them (e.g. water shown in Table 1), the surface tension of the other liquid can be calculated from the equation

$$\sigma = \sigma_{H2O} \cdot \frac{m}{m_{H2O}} \qquad (7)$$

It is a good practice to measure the mass of several drops in order to increase the precision of the calculation using the equation (7).

A. The determination of the surface tension by the drop-weight method

Equipment: stalagmometer, beaker, tubing with a balloon, weighing bottle with a lid, laboratory scale with the precision of the thousandth of gram, distilled water, liquids with the unknown surface tension

Experimental procedure:

1. Mount the clean and dry stalagmometer on the vertical stand.

2. Weigh the mass of the weighing bottle m_0.
3. Fill the beaker with distilled water. Mount the tubing with balloon on the top end of stalagmometer. Immerse the bottom end of stalagmometer into water and fill it up, such that the water level is above the wide part of stalagmometer.
4. Remove the balloon and collect 20 water drops into the weighing bottle.
5. Weigh the mass of the weighing bottle with water and determine the mass of 20 drops.
6. Empty the weighing bottle and stalagmometer, dry them and prepare for the next measurement.
7. Repeat steps 2-6 for liquids with the unknown surface tension.
8. Knowing the temperature in laboratory, determine the water surface tension using values from the table 1, and calculate the surface tensions of studied liquids according to the equation (7).

B. The determination of the surface tension by the drop counting method

There are two line marks on the stalagmometer: top line above the wide part and bottom line bellow it. The volume between these two lines is **V**, and liquid with density **ρ** contained in this volume has a mass **m**

$$m = V \cdot \rho \qquad (8)$$

Such a volume **V** corresponds to **n** drops, which are released from the stalgmometer upon the decrease of liquid level from top to bottom line mark. Here, the average mass of one drop is

$$\frac{m}{n} = \frac{V \cdot \rho}{n} \qquad (9)$$

Substituting the mass m in the equation (7) with the mass of one drop then yields

$$\sigma = \sigma_{H2O} \cdot \frac{\rho}{\rho_{H2O}} \cdot \frac{n_{H2O}}{n} \qquad (10)$$

Equipment: stalagmometer, beaker, tubing with a balloon, weighing bottle with a lid, laboratory scale with the precision of the thousandth of gram, distilled water, liquids with the unknown surface tension

Experimental procedure:

1. Fill the stalagmometer up to the top mark with distilled water. Release water to the weighing bottle and count how many drops it takes to decrease the water level in stalagmometer down to bottom mark. Write down the number of drops $n_{H20.}$
2. Empty and dry the weighing bottle and stalagmometer, and prepare them for the next measurement.
3. Repeat steps 1 and 2 for liquids with the unknown surface tension.
4. Write down the densities of studied liquids according to the notes on bottles, and density of distilled water at the actual temperature in laboratory from the table 1. Using equation (10), calculate the surface tension for all the studied liquids.
5. Compare results obtained via the drop-weight method and drop counting method.

Tab. 1: The temperature dependence of the surface tension and distilled water density.

t[°C]	σ [N/m]	ρ_{H2O} [kg/m^3]
15	0.07349	999.96
16	0.07334	999.94
17	0.07319	999.90
18	0.07305	999.85
19	0.07290	999.78
20	0.07275	998.20
21	0.07259	997.99
22	0.07244	997.77
23	0.07228	997.54
24	0.07213	997.30
25	0.07197	997.05

The mass of an empty weighing bottle m_0:

Tab. 2.: The determination of the surface tension by the drop-weight method.

	mass of liquid +weighing bottle [g]	mass of liquid [g]	σ [N/m]
H_2O			
liquid 1			
liquid 2			
liquid 3			

Tab. 3.: The determination of the surface tension by the drop counting method

	number of drops	ρ [kg/m^3]	σ [N/m]
H_2O			
liquid 1			
liquid 2			
liquid 3			

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