221. Measuring the surface tension by the droplet detachment method

The phenomenon of surface tension is due to the attractive force acting between molecules. Figure 1 shows that molecules in the volume act on molecules situated on the surface because the number of neighbour molecules is obviously different in these two cases. Note that another material can be present on the other side of the boundary (interface), e.g., air, but the strength of interaction between molecules of different types is not the same as between the molecules of the same type. The resulting force is directed normally to the liquid surface.

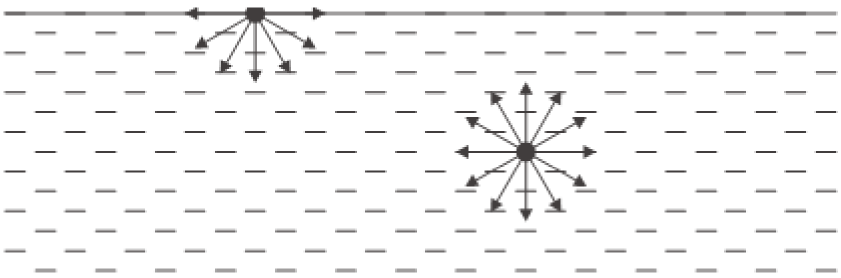
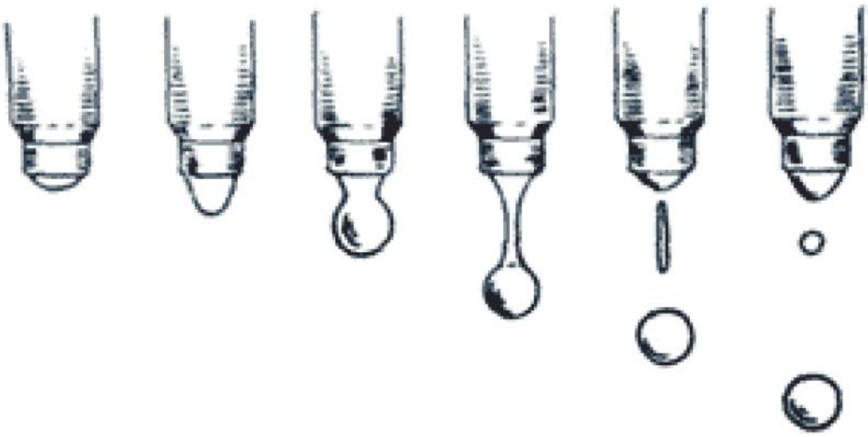


Fig. 1. Attractive forces acting on molecules on the surface and in the volume of a liquid

Coefficient of surface tension can be expressed in terms of the force or through the energy. For example, the ratio of the change in the free energy to the corresponding change in the surface area (at a constant temperature) equals the surface tension of the liquid: $\sigma = \Delta E / \Delta S$.

Surface tension influences the process of falling of a droplet from an outlet of a vessel in the gravitational field. The larger the coefficient σ, the more massive droplet will detach from the outlet.



The figure above shows the process of droplet formation. A “neck” appears before the moment of detachment. This word denotes the region of the liquid having parallel boundaries and a smaller diameter than the diameter of the droplet itself. The surface tension force is acting along the neck; at the moment of detachment it is equal to the droplet’s weight. If the diameter of the neck is *D*, then the resultant force of the surface tension is $\pi D\sigma$. Therefore, the condition for detachment of the droplet can be written as:

$$P = \pi D\sigma . \qquad (1)$$

By measuring the weight P of the fallen droplet and the neck's diameter at the moment of detachment one can calculate the coefficient of surface tension of a liquid.

It is known from observations that if droplets of various liquids fall from a thin spout (a spike), the neck's diameter become the same for all liquids provided that the spout's diameter is small enough. In this case Equation (1) for two different liquids 1 and 2 gives the relation

$$\frac{\rho_1 V_1}{\sigma_1} = \frac{\rho_2 V_2}{\sigma_2},$$

where V_i are the volumes of different liquid droplets. Thus, if surface tension σ_s is known for a certain liquid (call it the "standard liquid"), then for any other liquid we can write:

$$\sigma = \frac{\rho V}{\rho_s V_s}\sigma_s = \frac{\rho n_s}{\rho_s n}\sigma_s,$$

where n_s and n are the number of droplets that can be formed from identical volumes of the standard and the investigated liquids, respectively. Hence, if there is a spike from which droplets with the same necks' diameters fall, it can be graduated for measuring surface tension. The value $K = n_s\sigma_s/\rho_s$ should be determined first from an experiment with a fixed volume V of a liquid with known σ_s and ρ_s (e.g., water) in which the number of droplets n_s should be counted. Then the same amount V of the studied liquid of the density ρ should be effused through the spout and corresponding number of droplets n has to be counted. Then the surface tension of the studied liquid can be calculated using the expression:

$$\sigma = \frac{\rho n_s}{\rho_s n}\sigma_s = \frac{\rho}{n}K. \qquad (2)$$

Aim of the work: determination of the surface tension of a liquid by the method of detaching droplet.

Tasks:

1. Acquaintance with theoretical concepts underlying the measurement of the surface tension coefficient by the method of detaching droplet;
2. Measuring the absolute value of the surface tension by the method of detaching droplet;
3. Measuring the relative value of the surface tension by the method of detaching droplet.

Algorithm of measurements

1. Wash the burette with a thin spout with distilled water.
2. Fill in the burette with distilled water up to half of its height.
3. Open the cock slightly so that water drips slowly.
4. Count the number n of droplets corresponding to 1 ml of the spilled water.
5. Repeat the counting three or four times and find the arithmetic mean $\bar{n}$.
6. Pour our water from the burette and wash it with a small amount of the investigated ethanol.
7. Fill in the burette with ethanol and repeat the measurements of n in a similar way (steps 3–5).
8. Calculate the value of σ for ethanol.

Control questions and additional tasks

1. Physical meaning of the surface tension coefficient. Why is it necessary to introduce this concept and to measure it?
2. Do the properties of an ambient gas or another liquid (provided that liquids do not mix with each other) have an influence on the surface tension coefficient?
3. How the surface tension depends on the temperature? Why?
4. Laplace pressure. Deriving the formulas.
5. How surface tension is connected with the height at which a liquid rises in a capillary?
6. Why a small droplet is formed at the moment of detachment between the main big droplet and the spike?
7. How the viscosity affects the process of the droplet detachment?
8. Is it possible to determine the temperature dependence of the surface tension of a liquid using the method described here?