Surface tension with the ring method (Du Nouy method) (Item No.: P2140500)

Curricular Relevance

Area of Expertise: Physics

Education Level: University

Topic: Mechanics

Subtopic: Mechanics of Fluids and Gases

Experiment: Surface tension with the ring method (Du Nouy method)

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Intermediate	1 Hour	1 Hour	2 Students

Additional Requirements:

Experiment Variations:

Keywords:

Surface energy, adhesion, surface tension, critical point, Eotvos equation

Overview

Short description

Principle

To determine the surface tension of a liquid, a ring that is attached to a torsion meter by means of a silk thread is dipped into the liquid. The liquid level is lowered and the force that acts on the ring just before the liquid film tears is measured. The surface tension can be calculated from the diameter of the ring and the tear-off force.

Fig. 1: Experimental set-up

Equipment

Position	Material	Bestellnr.	Menge
1	Magnetic stirrer with heater MRHei-Tec	35752-93	1
2	Torsion dynamometer, 0.01 N	02416-00	1
3	Surface tension measuring ring	17547-00	1
4	Retort stand, 210mm × 130mm, 750mm	37694-00	1
5	Supp.rod stainl.st.,50cm,M10-thr.	02022-20	1
6	Magnetic stirring bar 30 mm, cylindrical	46299-02	1
7	Universal clamp	37715-00	2
8	Right angle boss-head clamp	37697-00	2
9	Right angle clamp expert	02054-00	1
10	Crystallizing dish, boro3.3, 900ml	46245-00	2
11	Cristallizing dish,boro3.3, 500ml	46244-00	2
12	Silk thread, l = 200 m	02412-00	1
13	Glass tubes,straight, 150 mm, 10	36701-64	1
14	Stopcock,1-way,straight, glass	36705-00	1
15	Silicone tubing i.d. 7mm, 1 m	39296-00	2
16	Volumetric pipette, 10 ml	36578-00	1
17	Volumetric pipette, 20 ml	36579-00	1
18	Pipettor	36592-00	1
19	Pipette dish	36589-00	1
20	Graduated cylinder 100 ml	36629-00	1
21	Ethyl alcohol, absolute 500 ml	30008-50	1
22	Olive oil,pure 100 ml	30177-10	5
23	Water, distilled 5 l	31246-81	1

Tasks

1. Determine the surface tension of olive oil as a function of temperature.
2. Determine the surface tension of water/ethanol mixtures as a function of the mixing ratio.

Setup and procedure

Set up the experiment as shown in Fig. 1.

Degrease the measuring ring with alcohol, rinse it with distilled water and dry it. Use a silk thread to attach the ring to the left arm of the torsion dynamometer. Set the indicator to '0' and compensate the weight of the ring with the rear adjusting knob so that the lever arm is in the white area between the marks.

Task 1:

- Pour the liquid to be investigated into a 1000 ml crystallizing dish and also fill the immersion tube and the rubber hose by briefly applying suction with the pipettor. The ring must be completely submerged.
- Switch on the magnetic stirrer and adjust the electronic temperature control to the required measurement temperature.
- When the temperature has stabilized switch off the stirrer and allow the liquid to come to rest. Then open the stopcock that is connected to the immersion tube via the rubber hose and let the liquid slowly run out of the 1000 ml crystallizing dish into the smaller one.
- Continuously readjust the torsion dynamometer while the liquid runs out to keep the lever arm in the white area between the two marks.
- Stop the measurement at the moment when the liquid film tears from the ring, and read off the last value set on the torsion dynamometer.
- Pour the liquid collected in the small crystalizing dish back into the dish on the magnetic stirrer and repeat the above procedure at intervals of 5 °C over a temperature range of 20 °C to 130 °C.

Task 2:

To determine the surface tension of various ethanol-water repeat the above procedure without heating and use the following mixing ratios:

Ethanol / ml	Water / ml	Ethanol / %
90	-	100
90	10	90
90	20	81.8
90	50	64.3
90	70	56.3
90	90	50

Carry out an additional series of experiments as above but starting with pure water:

Water / ml	Ethanol / ml	Ethanol / %
90	-	0
90	10	10
90	20	18.2
90	50	35.7
90	70	43.7
90	90	50

Theory and evaluation

A molecule in a liquid is subject to forces exerted by all molecules surrounding it; the resulting force is zero. The resulting 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. This force is called cohesion. It holds the liquid together.

Every liquid endeavours to reduce its surface area, so that the surface energy is as low as possible. When no other forces are active, therefore, every liquid adopts a spherical shape, as this is the shape with the smallest surface area for a given volume. In order to enlarge the surface of a liquid by an area ΔA , a certain amount of work ΔE must be performed.

$\varepsilon = \frac{\Delta E}{\Delta A}$ (1)

ε is the specific surface energy. It is identical with the surface tension

$\gamma = \frac{F}{l}$ (2)

where force F acts along the edge of length l , 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

$l = 2 \cdot 2\pi r$ (3)

In order to be able to compare surface tensions, they are related to a surface that holds 1 mole of molecules. 1 mole occupies a volume V_m and consists of N_0 molecules, each of which occupies a space of V_m/N_0 . Considering this space to be cubic in shape, then the length of each side is $\left(V_m/N_0\right)^{1/3}$ and the area of each side $\left(V_m/N_0\right)^{2/3}$. There is so always the same number of molecules $N_0^{2/3}$ in the space $V^{2/3}$. The surface tension is therefore related to this surface, and this quantity is called the molar surface tension γ_m .

$\gamma_m = \gamma \cdot V_m^{2/3}$ (4)

When a liquid is heated, the kinetic energy of the molecules increases. This results in a weakening of the forces of cohesion. The surface tension decreases linearly and, with all liquids, reaches the value 0 at the critical temperature T_K .

$\gamma_m = k_\gamma (T'_K - T)$ (5)

where T'_K is a temperature near the critical temperature T_K and k_γ is the temperature coefficient. k_γ is equal for almost all liquids (Eotvos' equation):

$k_\gamma = 2.1 \cdot 10^{-7}\ \mathrm{J/K}$ (6)

Deviations indicate association or the formation of double molecules. In the calculation of the temperature coefficient, it was assumed that the same number of molecules $N_0^{2/3}$ is contained in the area $V_m^{2/3}$. With substances that associate, this number is smaller, so that the temparature coefficient must also be smaller. When two liquids are mixed, that liquid with the lower surface tension becomes enriched in the surface area. The surface tension γ of a solution of concentration c is defined according to Szyskowski by

$\gamma_0 - \gamma_c = \alpha \cdot \ln(1 + bc)$

where a and b are constants depending on the substance. The surface tension of such mixtures has a non-linear relationship to the mixing ratio.

Data and results

The diameter of the measuring ring employed in this example is $2r = 19.65\,\mathrm{mm}$ from equation 3, l is obtained:

$l = 122.90\,\mathrm{mm}$

Task 1:

The measurement results obtained for olive oil show an inverse linear relationship to temperature (Fig. 2). The surface tension of olive oil calculated from equations (2) and (3) is in this sample result:

$\gamma_{\mathrm{oliveoil}} = 40\ \mathrm{mN} \cdot \mathrm{m}^{-1}$

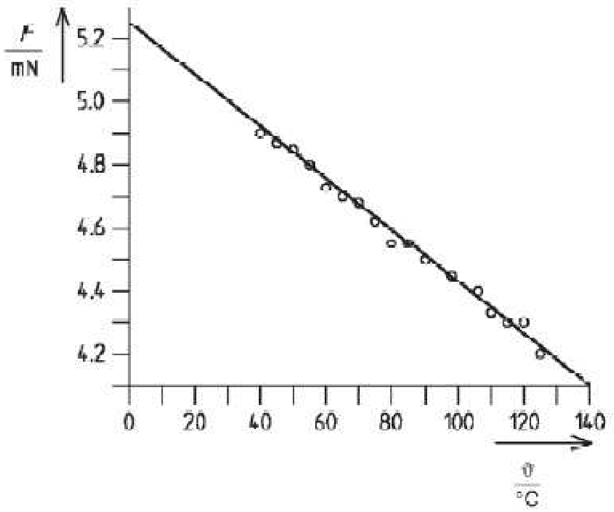

Fig. 2: Temperature dependency of surface tension of olive oil.

Task 2:

The non-linear relationship between surface tension and mixing ratio in the case of water/ethanol mixtures is shown in Fig. 3. Literature values for the surface tension of ethanol and water at (25 °C):

$\gamma_{\mathrm{water}} = 72.8\ \mathrm{mN} \cdot \mathrm{m}^{-1}$

$\gamma_{\mathrm{ethanol}} = 21.97\ \mathrm{mN} \cdot \mathrm{m}^{-1}$

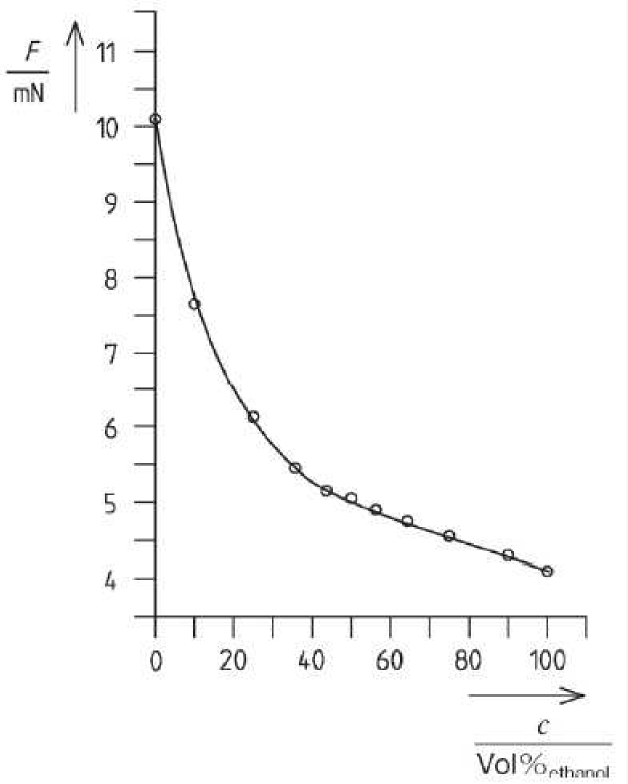

Fig. 3: Surface tension of water/ethanol mixtures as function of ethanol concentration.

Experimental values (calculated from (2) and (3)):

$\gamma_{\text{water}} = 82 \text{ mN} \cdot \text{m}^{-1}$

$\gamma_{\text{ethanol}} = 33 \text{ mN} \cdot \text{m}^{-1}$