Surface tension by the ring method (Du Nouy method)

LEP 1.4.05

Related topics

Surface energy, interface, surface tension, adhesion, critical point, Eötvös equation.

Principle and task

The force is measured on a ring shortly before a liquid film tears using a torsion meter. The surface tension is calculated from the diameter of the ring and the tear-off force.

Equipment

Torsion dynamometer, 0.01 N		02416.00	1
Surface tension measuring ring		17547.00	1
Retort stand, h 500 mm		37692.00	1
Magn. heating stirrer w. temp.con		35711.93	1
Support rod, l 500 mm/M10 thread		02022.05	1
Magn. stirring bar 15 mm, cyl.		46299.01	1
Universal clamp		37715.00	2
Right angle clamp		37697.00	2
Right angle clamp -PASS-		02040.55	1
Crystallising dish, boro 3.3, 1000 ml		46245.00	2
Crystallising dish, boro 3.3, 560 ml		46244.00	2
Lab thermometer, -10..+250C		38065.00	1
Silk thread, 200 m		02412.00	1
Glass tubes, straight, 150 mm, 10		36701.64	1
Stopcock, 1-way, straight, glass		36705.00	1
Rubber tubing, i.d. 7 mm		39282.00	2
Volumetric pipette, 10 ml		36578.00	1
Volumetric pipette, 20 ml		36579.00	1
Pipettor		36592.00	1
Pipette dish		36589.00	1
Graduated cylinder 100 ml		36629.00	1
Filter pump, plastic		02728.00	1
Ethyl alcohol, absolute	500 ml	30008.50	1
Olive oil, pure	100 ml	30177.10	5
Water, distilled	5 l	31246.81	1

Fig. 1a: Experimental set-up for thermal conductivity.

Problems

1. Determine the surface tension of olive oil as a function of temperature.
2. Determine the surface tension of water/methanol mixtures as functions of the mixture ratio.

Set-up and procedure

Perform the experimental set-up according to Fig. 1. The measuring ring is carefully degreased with alcohol, rinsed In distilled water and dried. The ring is attached to the left arm of the torsion dynamometer using a silk thread.

The torsion dynamometer's indicator is set to "0" and the weight of the ring compensated using the rear adjusting knob so that the lever arm is in the white area between the marks. The liquid under investigation is poured into a carefully cleaned 900 ml crys- tallising dish and the ring is completely submerged. In the experiment the liquid is warmed using the heating unit of the magnetic stirrer and stirred. As soon as the required temperature has been nearly reached, switch off the heating and allow the temperature to stabilise (residual heat of heating plate). Now switch off the stirrer and allow the liquid to come to rest. Then let liquid slowly allowed to runoff through the immersion tube (Fig. 1) from the dish on the magnetic stirrer into the dish located adjacent to the stirrer. To achieve this, open the one-way stopcock which is connected to the immersion tube via a rubber hose. Fill the immersion tube (siphon) with liquid before beginning the measurement by briefly applying suction with the filter pump. 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 that moment when the liquid film tears from the ring, and read off the last value set on the torsion dyna- mometer. Record this value together with the temperature of the liquid. Throughout the entire measurement procedure, ensure that the apparatus is not subject to vibration. The liquid collected in the second crystallisation dish is poured back into the dish on the heating plate and the measurement is repeated for other temperatures in the same manner. Perform the experiment in a temperature range of 20° to 130°C at intervals of 5°C.

Perform another series of experiments to determine the surface tension of various ethanol water mixtures (using the same method as above) at room temperature. Starting with pure ethanol, successively add water to make up the following mixtures:

Ethanol / ml	Water / ml	Ethanol / %
90	–	100
90	+10	90
90	+20	75
90	+20	64.3
90	+20	56.3
90	+20	50

In a second series of experiments repeat the above but start with pure water:

Ethanol / ml	Water / ml	Ethanol / %
90	–	0
90	+10	10
90	+20	25
90	+20	35.7
90	+20	43.7
90	+20	50

Theory and evaluation

A molecule in a liquid is subject to forces exerted by all molecules surrounding it; 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.

$$\varepsilon = \frac{\Delta E}{\Delta A} \tag{1}$$

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

$$\gamma = \frac{F}{l} \tag{2}$$

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 ris used, the length of the edge is

$$l = 2 \cdot 2\,\pi\,r \tag{3}$$

The diameter of the measuring ring employed is $2r$ = 19.65 mm. There is no need to correct the measured force to compensate for the weight of the liquid lifted because the ring has a sharp bottom edge.

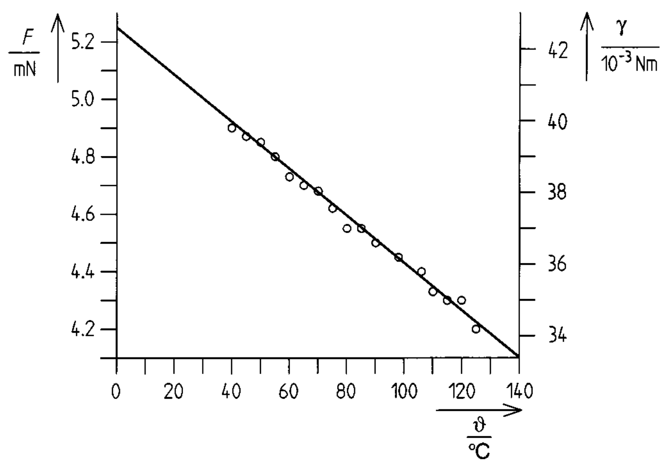
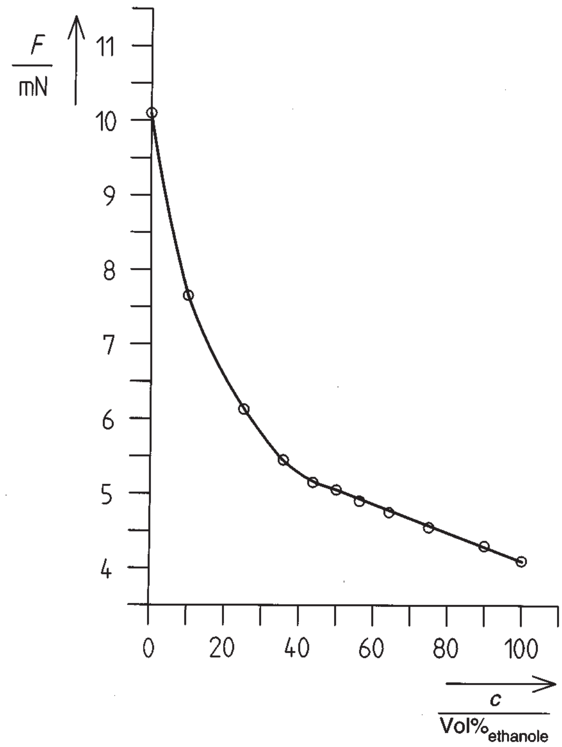


Fig. 2: Temperature dependency of surtace tension of olive oil

Fig. 3: Surface tension of water/ethanol mixtures as function of ethanol concentration1.



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

$$\gamma = \gamma'(T_k' - T) \tag{4}$$

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

$$\gamma_m = \gamma \cdot V_m^{2/3} \tag{5}$$

which together with equation (4) results in

$$\gamma_m = \gamma' \cdot V_m^{2/3}\,(T_k' - T) \tag{6}$$

The temperature coefficient

$$k_\gamma = \gamma' V_m^{2/3} \tag{7}$$

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

$$k_\gamma = 2.1 \cdot 10^{-7}\ \mathrm{J/K} \tag{8}$$

Values below this indicate association in the molecules in the liquid, larger values indicate dissociation. The measurement results obtained for olive oil have an inverse linear relationship to temperature.

From Fig. 2:

$$(20^\circ\mathrm{C}) \quad = 41.3 \cdot 10^{-3}\ \mathrm{Nm^{-1}} \tag{9}$$

$$(120^0\mathrm{C}) \; = 41.3 \cdot 10^{-3}\ \mathrm{Nm^{-1}}$$

and

$$\frac{\Delta\gamma}{\Delta T} = 6.7 \cdot 10^{-5} \mathrm{Nm^{-1}K^{-1}} \quad (10)$$

2. When two liquids are mixed, that liquid which has the lower surface tension becomes enriched in the surface area of the liquid. The surface tension γ of a solution of concentration c is defined according to Szyskowski by

$$\gamma_0 - \gamma_c = \alpha' \cdot \log (1 + b'c) \quad (11)$$

where γ_0 is the surface tension of the solvent (water). Constant α' varies very little from substance to substance whereas b can vary considerably. The surface tension of such mixtures is non-linear as a function of the mixing ratio. The results of the measurements performed with the ethanol/water and water/ethanol mixtures are presented in Fig. 3.

Data and results

Literature values:

γ_{Water} = 72.8 mN · m^{-1}

γ_{Ethano} = 21.97 mN · m^{-1}

Experimental values:

γ_{water} = 82 mN · m^{-1}

$\gamma_{Ethanol}$ = 33 mN · m^{-1}

$\gamma_{Olive\ oil}$ = 40 mN · m^{-1}