Studies on Fluorine at Low Temperatures. VI. Surface Tension of Liquid Fluorine.

By Eizo KANDA.

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Surface tension, as well as dielectric constant, is a characteristic of a liquid and its value is necessary in the determination of the state of molecule of the liquid. As to the surface tension of liquid fluorine, Moissan[1] reported that "the rise in a capillary tube of fluorine, oxygen, alcohol, and water was 3.5, 5.0, 14, and 22 respectively". As a matter of fact, however, the surface tension of oxygen is about 13 dyne/cm. at its boiling point and neighbourhood and that of water is about 71 dyne/cm. at the ordinary temperature. Thus, Moissan's report, like his note on the melting point of fluorine, is very ambiguous. He gave no numerical value except those mentioned above.

The value of vapour pressure of oxygen shows that oxygen is quite a normal liquid. Further, the molecular weight, molecular volume, boiling point, and critical point of fluorine are very close to those of oxygen, and accordingly it may, like oxygen, be conceived to be a normal liquid. In fact, the vapour pressure of liquid fluorine shows that this element is a normal liquid governed by Hildebrand's rule. In view of this fact, the author thought it necessary to obtain an exact value of its surface tension.

I. Method and Apparatus of the Experiment. The author adopted the method in which the rise in a capillary tube is observed, and consulted the method of Onnes and Kuypers[2] for the determination of the surface tension of liquid hydrogen. The apparatus used is illustrated in Fig. 1, where B_3 is a trap containing the test liquid and a capillary tube K for measuring the capillarity. In B_3 are projections b supporting the capillary tube. The capillary rise was observed by means of a comparator having an accuracy up to 1/100 mm. At the same time the vapour pressure of the liquid was measured by a quartz pressure gauge.

The temperature at which the surface tension was determined ranged from the boiling point to the melting point of fluorine. In the experiment liquid hydrogen was not used, because the phenomenon inside the Dewar

(1) Moissan, *Compt. rend.*, **125** (1897), 502.

(2) Onnes and Kuypers, *Commun. Phys. Lab. Univ. Leiden*, No. **142** (1914).

vessel had to be distinctly observed. The Dewar vessel A_3 contained liquid oxygen and was made air-tight with a cap C fixed to the upper. D is fitted with a pump and the liquid oxygen was vigorously vaporized. In this way, the temperature up to the triple point of oxygen (85°K) was obtained.

B_1 and B_2 are traps for refining the fluorine by fractional distillation. Liquid nitrogen was used in A_1 and A_2.

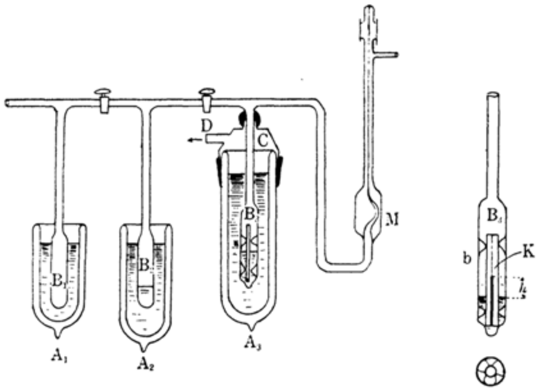

Fig. 1.

Capillary tube. As liquid fluorine is of smaller surface tension than ordinary liquids, capillary tubes having a very small inside diameter had to be used for obtaining a satisfactory rise of the liquid. Because of a small amount of rise of the liquid, however, the inside diameter of the tubes had to be uniform only for a small length. Tubes with cross-sections the most approximate to a perfect circle and with diameters about 0.16 mm. were selected from among more than 50 glass tubes by microscopic examination.

As the capillary tube would have been attacked by fluorine at ordinary temperature, fluorine was to be introduced into the trap and condensed therein after it had been cooled down to the temperature of the liquid nitrogen. The capillary tube was renewed for each series of observations.

Determination of the surface tension. The surface tension γ (dyne/cm.) is expressed by the following formula, on the assumption that the cross-section of the tube is a perfect circle and that the angle of contact is zero:

$$\gamma = \frac{1}{2} rg(\rho_l - \rho_g)h ,$$

where r is inside radius of the tube, g acceleration due to gravity (980), ρ_l density of the liquid (g/c.c.), ρ_g density of the coexisting vapour, and h the capillary rise (cm.). ρ_l was separately determined at various temperatures. ρ_g was calculated by using the values of vapour pressure and the temperature for each experiment.

II. Results of the Measurements with Liquid Oxygen. (Table 1).

Table 1. $r = 0.00805$ cm.

T	p(mm.)	ρ_l	ρ_g	h(cm.)	γ(dyne/cm.)
58.10	3.3	1.291	—	4.166	21.25
62.49	10.0	1.275	—	4.032	20.32
71.10	57.4	1.235	0.41×10^{-3}	3.732	18.21
76.69	142.2	1.218	0.95 ,,	3.468	16.68
81.40	274.6	1.182	1.73 ,,	3.237	15.54
89.50	711.7	1.150	4.14 ,,	2.996	13.55

These values, as compared with Baly and Donnan's(3) three values, are given in Fig. 2.

Eötvös's constant calculated from the above data was $K = 1.92$ ($T_k = 155°$), and this fact shows that oxygen is a normal liquid.

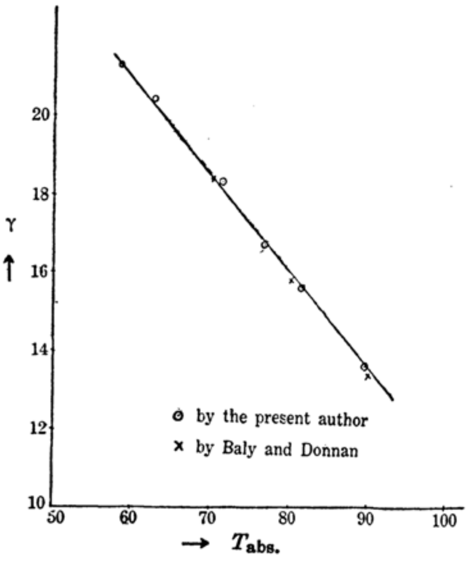

Fig. 2.

III. Surface Tension of Fluorine. Examples of measurements are given in Table 2 and values obtained with another capillary tube in Table 3.

The values of γ are graphically shown in Fig. 3. $K = 1.78$ was obtained for $\gamma v^{2/3} = K(T_k - T)$, a fact which practically conforms with Eötvös's law. Thus, liquid fluorine may also be regarded as a normal

(3) Baly and Donnan, *J. Chem. Soc.*, **81** (1902), 907.

Table 2. $r = 0.00805$ cm.

T	p	ρ_l	ρ_g	h(cm.)	γ
57.10	—	1.205	—	3.068	14.61
59.95	—	1.195	—	3.002	14.16
64.20	28.22	1.181	0.27×10^{-3}	2.884	31.46
72.11	129.90	1.155	1.10 ,,	2.654	12.10
76.30	247.50	1.140	2.02 ,,	2.536	11.40
84.91	733.50	1.112	5.76 ,,	2.254	9.85

Table 3.

T	γ
61.41	13.85
65.30	13.17
71.00	12.20
81.50	10.41

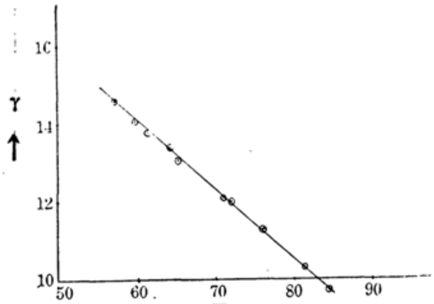

Fig. 3.

liquid. Further, the surface tension of fluorine is lower than that of liquid oxygen, but not so much as Moissan reported.

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Cryogenic Section,
Research Institute for Iron, Steel and Other Metals,
Tohoku Imperial University.