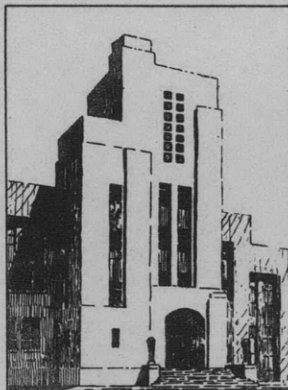# THE DAVID W. TAYLOR
MODEL BASIN

UNITED STATES NAVY

ON THE SIZE OF GAS BUBBLES IN LIQUIDS
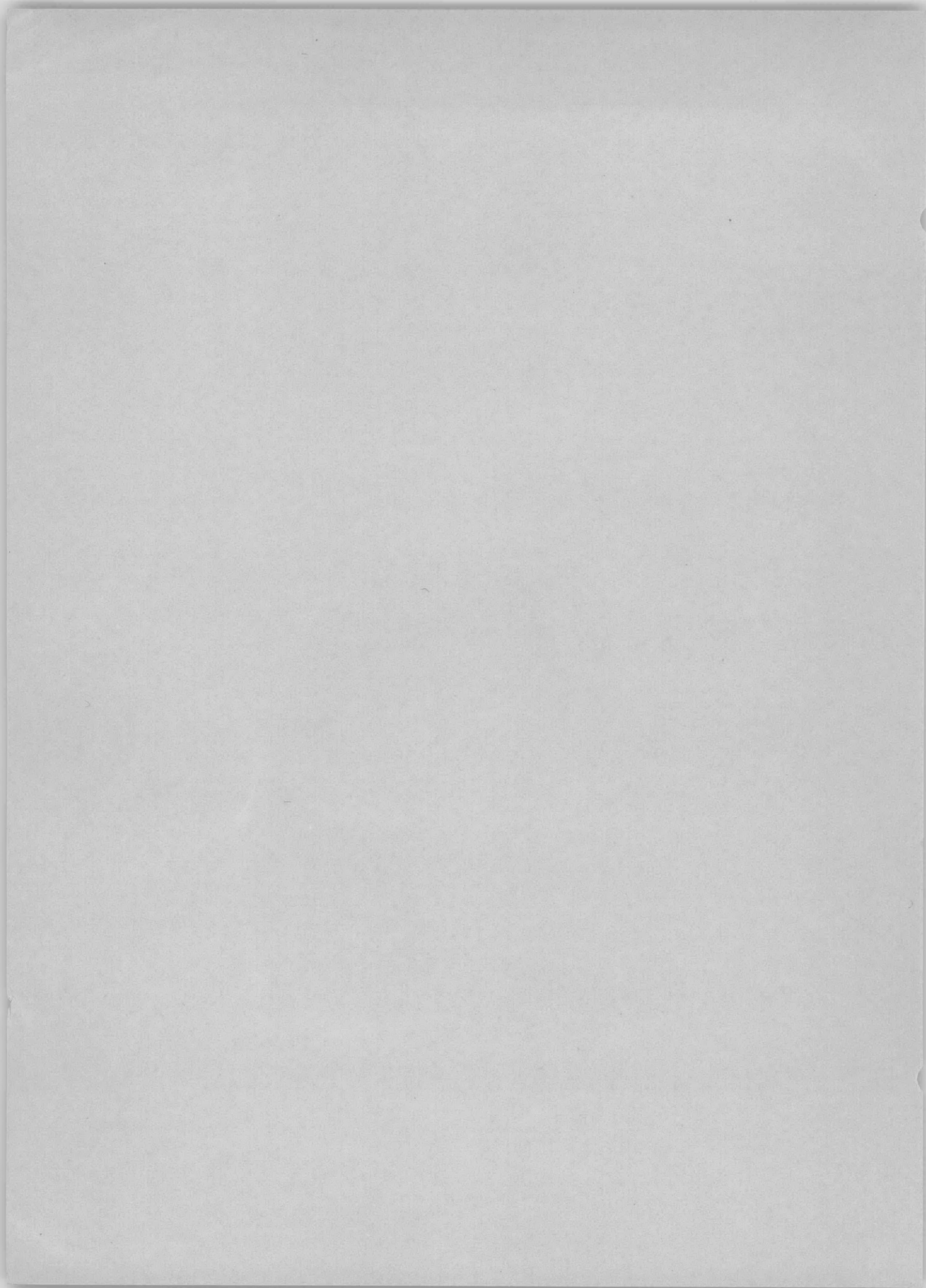
BY ROBERT SCHNURMANN

APRIL 1943   RESTRICTED   TRANSLATION III

ON THE SIZE OF GAS BUBBLES IN LIQUIDS

(ÜBER DIE GRÖSZE VON GASBLASEN IN FLÜSSIGKEITEN)

by

Robert Schnurmann

(In Kolloid Zeitschrift, Zeitschrift für wissenschaftliche
und technische Kolloidchemie, vol. 80, No. 2, August 1937)

Translated by F. A. Raven

The David W. Taylor Model Basin
Bureau of Ships
Navy Department, Washington, D. C.

April 1943   Translation 111

ON THE SIZE OF GAS BUBBLES IN LIQUIDS

ABSTRACT

By taking a water-alcohol mixture as an example, it is found that the macroscopic sizes of the gas bubbles pressed through a filter are primarily a function of the viscosity of the liquid and not of its surface tension. A minimum bubble size corresponds to a maximum on the viscosity curve.

A viscosity-bubble size curve is plotted for the range of viscosity from 0.008 cgs to 0.04 cgs. The curve shows that the bubble size increases inversely with the viscosity.

Experiments by Prausnitz and Halberstadt are discussed; the part played by the mechanism of coalescence of the sub-visible gas bubbles previously discovered by the author is shown.

The pore diameter of the filter does not affect the rough qualitative effect, as long as the points of origin of the sub-visible bubbles are close enough together to permit their collision.

P. H. Prausnitz describes an experiment (1)* in which air flows through two similar tandem-connected flasks for washing gas, equipped with glass filter plates. One flask contains only water, the other water plus a few drops of alcohol. The gas bubbles are much finer in the latter than in the one containing pure water; in addition a feeble formation of foam occurs.

Prausnitz comments on this fact: "It was shown that the size of the bubbles of the gas flowing through the liquid is a function of the pore diameter of the diffusion plate and of the surface tension of the liquid." This is a misconception. Cantor's simple equation between the air pressure, the pore diameter of the filter, and the surface tension of the liquid is valid for forcing air through the filter (2). With the help of this equation, for liquids of known surface tension, the mean pore diameter of the large pores or the mean pore diameter of the entire filter, can be determined by measuring the pressure at which "the first pore emits gas or when the whole filter emits gas." On the other hand, by using a capillary of known orifice the surface tension of the liquid can be determined from the maximum bubble pressure.

However, Cantor's equation does not determine the macroscopic bubble size for a filter densely perforated by microscopic pores. As previously shown (3), the phenomenon of visible bubble formation is in this case rather a direct function of the ability of the sub-visible bubbles in the interface of filter and liquid to coalesce; in other words, it is a function

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* Numbers in parentheses indicate references on page 5 of this translation.
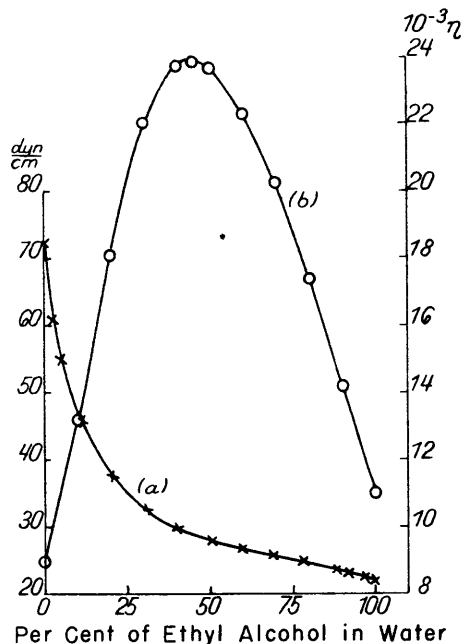
Figure 1 - Ethyl Alcohol in Water

Curve a, X Surface tension of ethyl alcohol
and water solution at 25 degrees C
(International Critical Table 4, 467, 1928).

Curve b, O Surface tension of ethyl alcohol
and water solution at 25 degrees C
(International Critical Table 5, 1929).

of the viscosity of the liquid. At that time experiments were restricted to the range of viscosity of 0.008 cgs to 0.04 cgs (3). Prausnitz' experiment to which reference has already been made also falls within this range. The drops of alcohol added to the water lower its surface tension and increase its viscosity.

Transition from water through water-alcohol solutions to pure alcohol demonstrates very clearly that viscosity and not surface tension determines macroscopic bubble size. In such a transition the surface tension drops from a value of 72.20 dynes/cm at 25 degrees C for water to 22.03 dynes/cm at 25 degrees C for alcohol; see Figure 1, Curve a. The curve shows no extremum. In contrast, the viscosity curve traverses a maximum, as shown in Figure 1, Curve b, and the bubble size traverses a curve with a minimum which

lies in the corresponding point. The bubble size not only traverses a minimum in the system composed of water and ethyl alcohol, but in all cases where the viscosity curve of the system of liquids is a maximum. This is the most direct proof for the relationship between bubble size and viscosity of the fluid.

The writer has repeated Prausnitz' experiment. First, air was admixed with the liquid by shaking and the same phenomena were observed as Prausnitz demonstrated in his experiments when forcing air through a filter. Therefore, the pore diameter of the diffusion plate plays no part in the rough qualitative effect as long as precautions are taken to make certain that the points of origin of the sub-visible bubbles lie closely enough to each other to permit coalescence. This argues, with respect to a filter, that a sufficiently high excess-pressure must be imposed to cause almost all pores to emit or discharge gas.

Second, the writer forced air through a glass filter and again found a curve with a minimum when using various water-alcohol concentrations, as the examples in Figures 2a to 2d show.

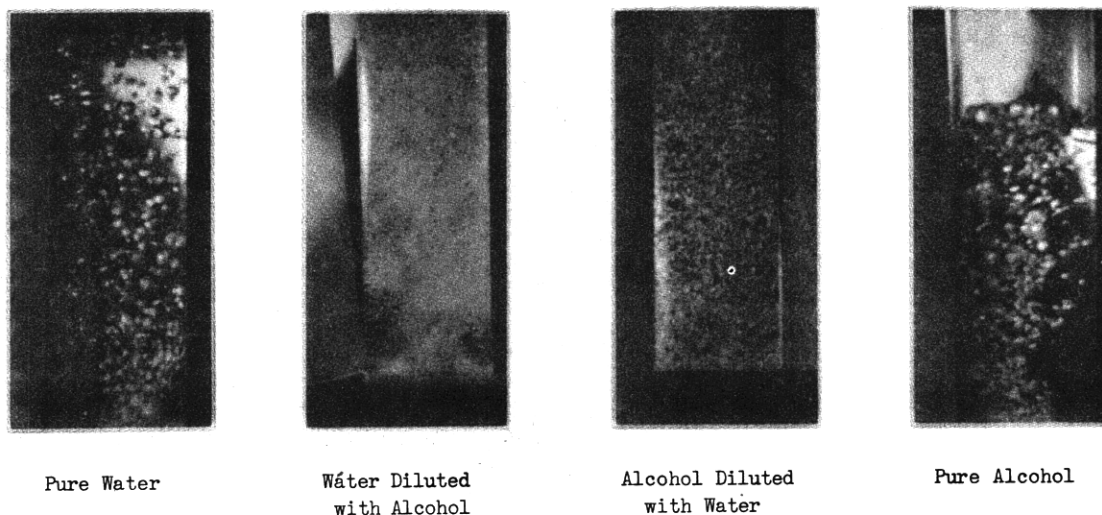|			
Pure Water	Wáter Diluted with Alcohol	Alcohol Diluted with Water	Pure Alcohol

Figure 2 - Examples of Bubbles with various
Water-Alcohol Concentrations

Prausnitz and Halberstadt (4) and Rudolph (5) claim that the size of the bubbles decreases as the surface tension diminishes. However, that can only be true in dealing with pores separated so widely that the gas bubbles cannot collide and coalesce. Tables 3, 4, and 5 in Prausnitz' and Halberstadt's study just quoted clearly show the part performed by the mechanism of coalescence assumed by the writer. In these tables the pore diameter in the column headed "First Pore Emits Gas" is consistently smaller than the corresponding diameter in the column "Entire Plate Emits Gas." As is to be expected, Table 1, in which measurements on a system consisting of widely separated individual capillaries are summarized, does not show this condition.

Prausnitz and Halberstadt included a curve in which $\log_{10}\eta$ is plotted against the diameter of the gas bubbles. They plot two curves through 13 points which were obtained with water, water diluted with turkey red oil, ether, ethyl acetate, 93.6 per cent alcohol, 38.6 per cent alcohol, toluol, carbon tetrachloride, 88.2 per cent glycerine, 50.7 per cent glycerine, concentrated sulphuric acid, 3 normal sulphuric acid, and 2 normal sodium hydroxide solution. These two curves comprise incommensurable quantities, because the secondary effect of the bubble charge is clearly evident in the electrolytic solutions and also because among the remaining 11 points, 3 have considerably greater viscosities than 0.04 cgs. Anyone can easily convince himself that water, ether, toluol and carbon tetrachloride produce large bubbles, that is, bubbles whose diameters are greater than 2 mm, by merely shaking each of these liquids in a closed flask.
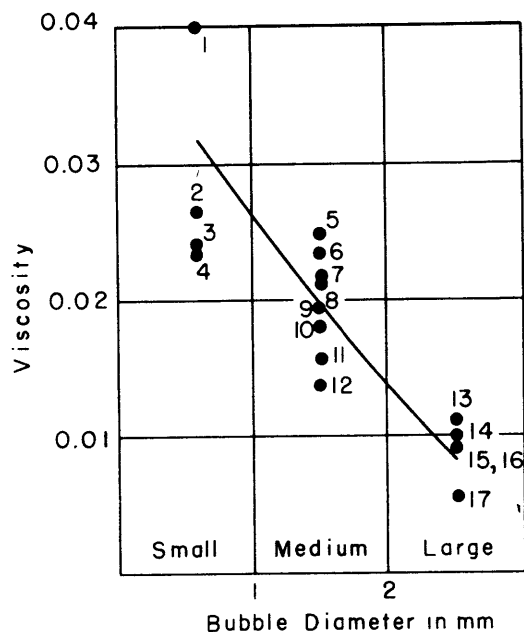
Figure 3 - Viscosity-Bubble Size Curve

Point	Liquid	Solution per cent	Temperature degrees C
1	Isobutyl Alcohol		20
2	Propyl Alcohol	60	25
3	Acetic Acid	78	25
4	Ethyl Alcohol	45	25
5	Propyl Alcohol	74	25
6	Ethyl Alcohol	33	25
7	Ethyl Alcohol	67	25
8	Propyl Alcohol	25	25
9	Propyl Alcohol	100	25
10	Ethyl Alcohol	90	25
11	Methyl Alcohol	40	25
12	Methyl Alcohol	20	25
13	Ethyl Alcohol	100	25
14	Methyl Alcohol	80	25
15	Isobutyl Alcohol		80
16	Water		25
17	Methyl Alcohol	100	25

To plot such a viscosity-bubble size curve, the author chose some former observations made on dielectric liquids. In this curve, Figure 3, the absolute values of the viscosities are plotted, whereas the bubble sizes are divided only into three groups: "small," i.e., diameters smaller than 1 mm; "medium," between 1 and 2 mm diameters; and "large," i.e., larger than 2 mm. Point 5 gives an idea of the exactitude of observation. At 24 degrees C "medium" bubbles were observed in 75 per cent propyl alcohol. The viscosity of 73.13 per cent propyl alcohol at 25 degrees C is 0.02509 cgs. In contrast small bubbles were observed in 45 per cent ethyl alcohol at 24.2 degrees C, for which a viscosity of 45.57 per cent ethyl alcohol at 25 degrees C is given as 0.02351. To make it obvious that the bubble size increases inversely with the viscosity within the test range, a curve was plotted through the middle of each group in Figure 3.

The curve beyond the viscosity range herein studied has not yet been systematically investigated. However, it is interesting in this respect, that Krause and Kapitanczyk (6) found in high viscous systems of liquids, up to 1958 times the viscosity of water, that the coagulation of the colloidal air occurs more swiftly as the viscosity drops and more slowly as it rises.

Tests on the bubble size as a function of temperature formerly made by the author showed corresponding results (3). The surface tension of isobutyl alcohol decreases as the temperature rises; in contrast the bubble size increases.

The writer also succeeded in demonstrating with isobutyl alcohol that when measuring the pore diameter of a Berkefeld filter with a water-air

mixture, the measurement was 4.7μ* ($\eta = 0.00891$ cgs at 25 degrees C); with isobutyl alcohol/air at 80 degrees C it was 4.6μ ($\eta = 0.009$ cgs at 80 degrees C), while isobutyl alcohol/air at 25 degrees C gave only 4.0μ ($\eta = 0.0336$ at 25 degrees C).

The physical nature of the phenomenon of adherence of gas bubbles to the interface of solid and liquid has not yet been completely explained. Experiments by Coehn and Neumann (6) show that the surface tension of the liquid is not the determinative factor for macroscopic gas bubbles emergent at a metal-liquid interface. For an interface between a non-metallic solid and a liquid, Emslander's (7) tests show this also. Sven-Nilsson (8) found that when a macroscopic gas bubble is pressed to a metal surface, a minimum time of contact, i.e., the so-called time of induction, is necessary for the bubble to adhere. The materials familiar as adhesive reagents in flotation engineering, for example lactic acid, have large induction periods. That abnormally small bubbles emanate in a ray or jet-like manner from a filter, as when air is forced through a Berkefeld filter into water which has been diluted with a few drops of lactic acid, agrees with the foregoing.

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(2) "Die Ermittlung der Porenweite keramischer Filter durch die Systeme Luft/Flüssigkeit und Flüssigkeit/Flüssigkeit" (Determination of the Pore Diameter of Ceramic Filters by the Interfacial Systems of Air/Liquid and Liquid/Liquid), by H. Bechhold and Robert Schnurmann, in Zeitschrift für physikalische Chemie (A), vol. 142, No. 1, 1929, pp. 1-24.

(3) "Die Grösze von Gasblasen in Flüssigkeiten" (The Size of Gas Bubbles in Liquids), by Robert Schnurmann, in Zeitschrift für physikalische Chemie, vol. 143, Nos. 5 and 6, September 1929, pp. 456-474. TMB Translation 110, March 1943.

(4) "Über die Grösze von Gasblasen und Flüssigkeitströpfchen in Flüssigkeiten" (On the Size of Gas Bubbles and Droplets in Liquids), by Dr. Siegfried Halberstadt and Dr.-Ing. Paul H. Prausnitz, Jena, in Zeitschrift für angewandte Chemie, vol. 43, No. 44, November 1930, pp. 970-977. TMB Translation 108, March 1943.

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* A micron in physical chemistry is used to denote the size of particles whose diameter lies between 0.01 and 0.0001 mm (0.000394 to 0.00000394 inch).

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(6) "Elektrostatische Erscheinungen an elektrolytisch entwickelten Gasblasen. I. Elektrostatische Anziehung und Blasengrösze" (Electrostatic Phenomena on Electrolytically Generated Gas Bubbles. I. Electrostatic Attraction and Bubble Size), by Alfred Coehn and Hans Neumann, in Zeitschrift für Physik, vol. 20, No. 1, 1923, pp. 54-67.

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(8) "Bedeutung der Berührungszeit zwischen Mineral und Luftblase bei Flotation" (Significance of the Contact Period Between Mineral and Air Bubble in Flotation), by Ivar Sven-Nilsson, Engineer, in Ingeniörsvetenskaps-akademiens Handlingar (Proceedings of the Royal Swedish Institute for Engineering Research) No. 133, Stockholm, 1935, 24 pp.