BROWNIAN MOVEMENT IN LIQUID INCLUSIONS IN QUARTZ: SOME QUANTITATIVE OBSERVATIONS

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ABSTRACT

The viscosity of the liquid in an inclusion in quartz from Dunbrack Prospect, Musquodoboit River, Halifax County, Nova Scotia, has been tentatively calculated based on the evaluation of a movie film of Brownian Movement of a gas bubble.

RÉSUMÉ

La viscosité du liquide contenu dans une inclusion dans quartz provenant de Dunbrack Prospect, Musquodoboit River, Halifax County, Nova Scotia, a été tentativement déterminée par des mesures du mouvement brownien d'une bulle de gas effectuées sur une prise de vue cinématographique.

While different methods of inclusion thermometry have been described (Correns 1953; Deicha 1955; Ingerson 1947; Smith 1953, 1954; Yermakov 1965) no measurements of Brownian Movement of gas bubbles in liquid inclusions in minerals have so far been made from which an approximate value of the viscosity might be calculated. I attempt to do this.

The formula developed by Einstein (Alb. Einstein, transl. A. D. Cowper, ed. R. Fürth 1956) states that the square of the average mean displacement of small particles suspended in a stationary liquid is

$$\overline{\Delta}^2 = \frac{RT}{N}\frac{1}{3\pi\eta r}t$$

where R is the gas constant, 8.31×10^7
T is the abs. temperature
N is the Avogadro number, 6.02×10^{23}
η is the viscosity of the liquid
r is the radius of the moving particle
t is the time interval in which the displacement Δ takes place.

If the diameter of the moving particle—in our case the gas bubble—and the apparent displacement in a known time interval have been ascertained at a given temperature, the viscosity of the liquid can be calculated.

Quartz from the mineralized occurrence known as Dunbrack Prospect, Musquodoboit River, Halifax County, Nova Scotia, (C.G.I. Friedlaender 1968) contains liquid inclusions. Some of these inclusions show, at

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moderately high magnification, a moving gas bubble. A movie film made it possible to measure the apparent displacement of the bubble.[1]

The time interval between successive frames in the film was 1/24 second. The displacement was measured, in one attempt, using enlarged prints of frames spaced at a known interval. In another attempt, an animation camera was used as a projector: at controlled spacing, the position of the moving bubble was recorded.[2] The mean average displacement was found, for $t = 0.5$ sec, $\sqrt{\overline{\Delta^2}} = 0.461\ \mu$.

It proved more difficult to measure the diameter of the bubble. I tried first direct matching with an eyepiece micrometer but because of the difference in refraction between gas and liquid and also because of the movement of the bubble this approach was not satisfactory. I then made use of a number of still photographs of the inclusion and, in alternation, of a stage micrometer. The film strip was viewed, and measured, with a device such as generally used for measuring x-ray films. The radius of the bubble was in this way determined $r = 0.756\ \mu$. The measurements were made at room temperature, 17°C.

We now have the following data:

the mean displacement	$\sqrt{\overline{\Delta^2}} = 0.461\ \mu$
the radius of the bubble	$r = 0.756\ \mu$
the interval	$t = 0.5$ sec
the temperature	$T = 290$°K

and we can calculate the viscosity

$$\eta = 0.0133 \text{ poise}$$

[1]I thank Mr. D. Pike and Mr. D. A. Gibson, Audio Visual Department, Dalhousie University, for their co-operation in the preparation of the film.

[2]The measurements were as follows:

Time (in frames)	Series 1	2	3	4	5
12	2.8	1.7	1.4	6.1	1.3
24	6.5	5.5	6.6	5.9	4.3
36	2.7	3.2	3.7	1.8	4.5
48	3.2	2.9	3.9	2.3	10.0
60	2.6	2.2	1.4	3.1	2.9
72	1.9	4.1	3.4	4.8	
84	5.1	3.7	2.2	2.4	
96	2.1	6.8	3.3	3.3	
108	2.5	6.7	1.4	4.2	
120	5.4	6.8	3.9	4.6	

The sum of the squares of the measured displacements is 806.72. The number of steps was 45. $\overline{\Delta^2}$ is therefore $806.72/45 = 17.92$ and $\sqrt{17.92} = 4.23$. The calibration showed that 1 mm in the graph $= 0.109\ \mu$ $\overline{\Delta} = 4.23 \times 0.109 = 0.461\ \mu$.

At 17°C, the viscosity of water is 1.1 centipoise (Landolt–Börnstein 1955). If we consider, somewhat arbitrarily, the difference (1.33–1.1), 0.23, as maximum error in the present determination, we can tentatively indicate the viscosity

$$\eta = 0.0133 \pm 0.0012 \text{ poise}$$

that is 0.0133 ± 9%. This is a rough procedure but, under the circumstances, it is neither necessary nor possible to go any further.

If we assume that the liquid in the inclusion is in the case under consideration preponderantly an aqueous solution of NaCl—as has been frequently found (Goguel 1963; Maslova 1961; Smith 1954)—we may extrapolate from the value of the viscosity that the concentration of the solution lies between 9% and 15% NaCl.

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