KINETICS OF GROWTH OF THE MENISCUS OF A ROTATING LIQUID

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It is shown that the kinetics of growth of the meniscus of a rotating liquid is completely different for classical liquids (including helium I) and for helium II.

As is well known, all rotating liquids form a parabolic meniscus, the depth of which depends on the angular velocity of rotation ω_0, the radius R of the vessel containing the liquids, and the acceleration due to gravity g. At one time it was thought that the only exception would be liquid helium II, the superfluid part of which, as was then assumed, would not participate in the rotation. In this connection, the meniscus of rotating liquid helium II could differ from the meniscus of all other liquids, but Osborne [1] and Andronikashvili [2] proved experimentally that rotating helium II has a meniscus of the usual form. At one time this fact was regarded as a paradox and did not fit the existing notions. In light of the Onsager-Feynman theory [3,4] the superfluid component of helium II is dragged into rotation by quantized vortex filaments which are secured to the surfaces that bind the liquid, and which interact with its normal component. Thus, the untwisting of helium II occurs via a mechanism different from the ordinary viscous mechanism, which is valid for all normal liquids. This difference from the behavior of classical liquids, exhibited by helium II during the untwisting process, was first observed by Andronikashvili and Kaverkin [2]. Namely, soon after the start of rotation of the vessel, the meniscus of the classical liquid is curved and continues to deepen gradually along the entire diameter of the vessel, whereas in the case of helium II the curving of the meniscus, which begins at the periphery, includes the central flat region of the meniscus, the radius of which gradually decreases.

Our problem was to investigate experimentally the time dependence of the depth of the meniscus during the course of untwisting of the liquid, in order to establish the laws governing its formation in quantum and classical liquids.

The meniscus of the liquid helium was observed in a beaker made of organic glass. The diameter of the beaker was 25 mm and its height 110 cm.

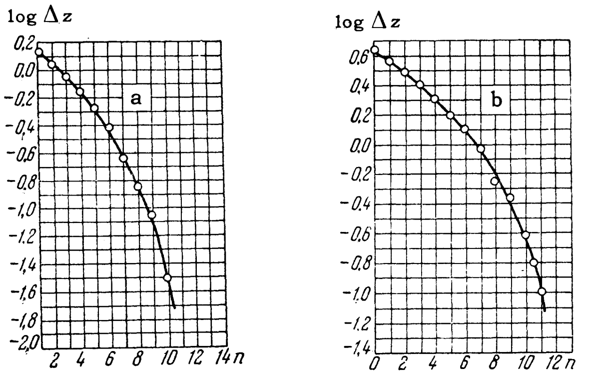


FIG. 1. Dependence of log Δz on n for rotating helium II at T = 1.57°K (n – number of measurements; the time interval between measurements is 15 seconds): a – ω_0 = 16.7 sec^{-1}, b – ω_0 = 26.1 sec^{-1}.

The walls of the beaker were carefully polished, and in the lid there were openings 2 mm in diameter, through which the vessel was filled with liquid. The saturated vapor pressure of the helium II was equalized through the same openings. The rotation was by means of a synchronous motor and a belt drive, with the aid of a steel shaft passing from the Dewar through a gland located in the upper part of the lid. The helium levels in the outside bath and in the beaker were the same prior to the start of rotation. The decrease in the liquid level due to evaporation during the time during which the measurements were carried out was extremely small.

The measurement of the depth of the meniscus was with the aid of a type KM-6 cathetometer. The meniscus was illuminated by a daylight lamp. The best illumination angle was chosen, at which the meniscus was particularly clearly seen.

The results of the measurements are plotted in Figs. 1, 2, and 3. The ordinates represent the values of $\log \Delta z = \log (z_\infty - z_i)$, where z_∞ is the finite depth of the parabolic meniscus on the rotation axis, and z_i is the depth of the center of the meniscus at the instant of time t_i. The plots show the

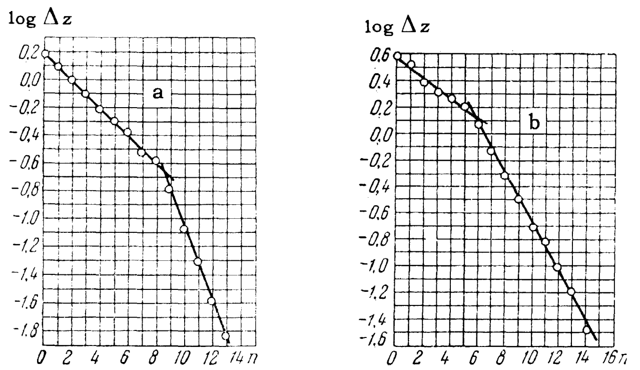


FIG. 2. Dependence of log Δz on n for rotating helium I: a – $\omega_0 = 16.7$ sec^{-1}, T = 3.23°K; b – $\omega_0 = 26.1$ sec^{-1}, T = 2.82°K.

typical dependence of log Δz on the number of measurements n for the temperature region 1.57–2.16°K in helium II and 2.25–3.23°K in helium I.

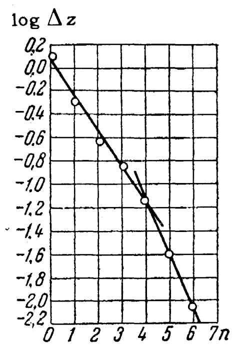
Figures 1a and b show the results for helium II for different speeds of rotation ω_0. As can be verified by examining these curves, their form does not depend on the speed, and in both cases the dependence of log Δz on t_i is a monotonic function. The increase in the meniscus always terminates with formation of a conical crater[2].

Figure 2 shows the results obtained in the case of helium I, which was kept from boiling by slightly increasing the pressure (by decreasing the pumping-on rate). The dependence of log Δz on t_i shown in Fig. 2a was plotted at a speed $\omega_0 = 16.7$ sec^{-1} while that in Fig. b was plotted at 26.1 sec^{-1}. In this case the dependence of log Δz on t_i is a broken line, consisting of two linear sections. For different speeds of rotation, the locations of the breaks differ. The slopes of the lines are also different. However, at a given speed, neither the slope of the lines nor the position of the point of inflection is dependent on the temperature. The increase in the meniscus terminates with formation of a classical parabola.

Control experiments carried out using water, show that the dependence of log Δz on t_i is the same as in the case of helium I (see Fig. 3). Consequently, the broken line is characteristic of the ordinary viscous mechanism of imparting rotation to the liquid (which is effective in the case of classical liquids). In this sense, as expected, helium I is an ordinary classical liquid.

Comparison of the curves shown in Fig. 1 with

FIG. 3. Dependence of log Δz on n for water. Speed of rotation $\omega_0 = 16.1$ sec^{-1} (the liquid is at room temperature).



the curves shown in Figs. 2 and 3 indicates that in the case of helium II we deal with a different mechanism, which ensures the entrainment of the quantum liquid by the rotary motion of the vessel containing it. It must be noted that the "operating speed" of both mechanisms is approximately the same, since a stationary mode of motion is established within approximately the same time. It must also be noted that, unlike the results of Donnelly et al.[5], we never observed in helium II the kinetics of the growth of the meniscus characteristic of helium I. Yet the only appreciable difference in the construction of our apparatus is that in our case the openings in the lid of the vessel were much broader (two openings with 2 mm diameter as against one with 0.14 mm).

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[1] D. V. Osborne, Proc. Phys. Soc. **A63**, 909 (1950).

[2] É. L. Andronikashvili and I. P. Kaverkin, JETP 28, 126 (1955), Soviet Phys. JETP **1**, 174 (1955); see also É. L. Andronikashvili, Doctoral Dissertation, Inst. Phys. Probl. AN SSSR, 1948.

[3] L. Onsager, Nuovo cimento 6, Suppl. 2, 249 (1959).

[4] R. P. Feynman, Progr. in Low Temp. Phys. **1**, North. Holland Publ. Co. Amsterdam, (1957), Ch. 2.

[5] Donnelly, Chester, Walmsley, and Lane, Phys. Rev. **102**, 3 (1956).

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