CONDENSATION OF ROTATING HELIUM II

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The velocity of first sound in rotating helium II is measured at temperatures $T = 1.40 - 2.10\,^\circ$K and angular velocities $\omega = 0 - 70$ sec^{-1}. It is shown that the compressibility of liquid helium does not depend on the rotation velocity.

RECENTLY Andronikashvili and Tsakadze[1,2] noticed that helium II is made denser by rotation. The relative change in density, measured by these authors, is described well by the formula

$$\Delta\rho / \rho = C(T)\omega^{3/2}, \quad (1)$$

where C(T) is a monotonically decreasing function of the temperature and vanishes abruptly at the helium II–helium I transition, and ω is the angular velocity of rotation.

It was already noted in the cited papers that the observed effect does not agree either in magnitude or in its temperature and velocity dependence with the effect expected as a result of centrifugal compression of the liquid. In the latter case we would have

$$\Delta\rho / \rho = {}^1/_4\chi_T\rho\omega^2R^2, \quad (2)$$

where χ_T is the coefficient of isothermal compressibility and R is the radius of the rotating container.

On the other hand, at the present time centrifugal pressure is the most important among all the factors that could cause compression of helium II under the conditions of Andronikashvili and Tsakadze experiments. Therefore before we admit finally that the observed phenomenon does not agree with the existing notions concerning the nature of helium II, it is natural to raise the following question, the answer to which is the subject of the present paper: does not the presence of quantized vortices in the rotating helium II lead to a change in its compressibility, reconciling expression (2) with the results of Andronikashvili and Tsakadze?

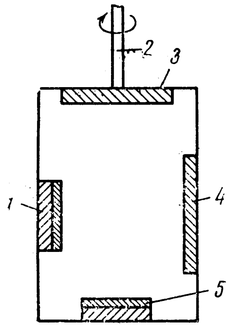
If such an effect were to exist, it could be observed by measuring the velocity of first sound in the rotating helium II. This quantity, as is well known, is given by

$$c = (1 / \chi_S\rho)^{1/2} = (\gamma / \chi_T\rho)^{1/2}; \quad (3)$$

Here $\gamma = C_p/C_V = \chi_T/\chi_S$, C_p and C_V are the specific heat of the liquid at constant pressure and constant volume, respectively, and χ_S is the coefficient of adiabatic compressibility. However, C_p and C_V differ by only ~0.1–0.5% in the helium-II temperature interval of interest to us. Therefore the choice between the adiabatic and the isothermal compressibility of helium II has no practical meaning, since it lies beyond the limits of error of our measurements, the accuracy of which is $\Delta c/c \pm 1\%$.

The increase in the density of helium II as a result of rotation could likewise cause no change in the speed of sound beyond the limits of the accuracy of the present experiments. (The maximum observed increase in the density, $\Delta\rho/\rho = 4\times10^{-4}$, is equivalent to a change in the speed of sound $\Delta c/c = -0.02\%$.) As regards the value of χ, to reconcile expression (2) with the experimental data it would be necessary to assume that the compressibility changes unusually strongly. For example, at $T = 1.74\,^\circ$K and $\omega = 30$ sec^{-1}, formula (2) calls for an increase of χ (compared with its value at $\omega = 0$) by a factor of 200, which would change the speed of sound by a factor of 14. In spite of the intuitively patent improbability of such a colossal increase in the compressibility of helium II, which is large enough without it, we deemed it nonetheless advisable to eliminate finally such a possibility by means of an experimental check.

To measure the speed of sound in helium II we used a pulse procedure. Short sound pulses were transmitted through the investigated medium and the travel time of these pulses along a segment of a definite length was measured. The radiators and receivers of the sound oscillations were polarized plates of barium titanate ceramic ($BaTiO_3$) with resonant frequencies 1.8 and 0.8 MHz. Taking into account the anisotropic nature of the vortex struc-



ture produced in the rotating helium II, we have constructed an instrument which makes it possible to study the propagation of sound both along the vortex lines and transverse to them.

A schematic diagram of this apparatus is shown in the figure. The rotation is about the vertical shaft 2, which passes through a stuffing tube in the cap of the dewar vessel. The speed of rotation of the container with the helium II could be varied by means of a set of pulleys in a range $\omega = 0-70\ \mathrm{sec}^{-1}$. The soundpulses radiated by plate 1 were reflected from the polished metallic surface 4, and received again by plate 1, which now operated as a sound-oscillation receiver. In its path from the radiator 1 to the reflector 4 and back, the sound pulses crossed the Onsager-Feynman vortex lines at a right angle, whereas another radiator-reflector pair 5–3 produced sound pulses propagating along the vortex lines. In the case when the sound oscillations propagated perpendicular to the axis of rotation, the number of the vortices crossed by the sound and subtended by one wavelength depends, naturally, on the speed of the sound, on its frequency, and on the angular velocity of the rotation of the helium II as a whole. In our experiments this number varied over a wide range, reaching in some cases 10–15 vortices per wavelength.

The speed of sound was measured both with the helium II stationary and rotating. Comparison of the results of these measurements has shown that the rotation of the helium II in a temperature interval $T = 1.40-2.10\,°K$, and of the angular velocities of rotation $\omega = 0-70\ \mathrm{sec}^{-1}$ exerts no influence (accurate to 1%) on the velocity of propagation of sound waves in it. This applies to both sound propagation directions—parallel and perpendicular to the Onsager-Feynman vortices.

We have thus established experimentally that the speed of sound remains unchanged in the same interval of temperatures and angular velocities in which the condensation of the rotating helium II was measured. By the same token, the assumption that the rotating helium II has some anomalous compressibility was not confirmed. Thus, we must find some other mechanism to explain the condensation effect[1, 2] of rotating helium II pierced by a system of Onsager-Feynman vortices.

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[1] É. L. Andronikashvili and Dzh. S. Tsakadze, JETP Letters 2, 278 (1965), transl. p. 177.

[2] É. L. Andronikashvili and J. S. Tsakadze, Phys Phys. Lett. 18, 26 (1965).

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