ON THE QUESTION OF THE COMPACTION OF ROTATING HELIUM II

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ON THE QUESTION OF THE COMPACTION OF ROTATING HELIUM II

In a series of experimental works (1-3), E. A. Andronikashvili and D. S. Tsakadze reported the observation of the effect of compaction of helium II in a rotating pycnometer. In work (3) results are given which indicate a sharp change in the density of rotating liquid helium in the temperature interval 2.171 ÷ 2.176°K, which, in the authors' opinion, can be interpreted as the presence of a density jump at the point of the phase transition He I—He II. The authors connect this phenomenon with the thermodynamics of the He I—He II transition and conclude that in rotating liquid helium the second-order phase transition is accompanied by a first-order phase transition associated with the appearance or disappearance of Onsager-Feynman quantized vortices.

The first logical supposition, to explain the effect of compaction of liquid helium II in a rotating pycnometer as the result of compression of the liquid by centrifugal pressure, proves untenable. Indeed, it is not difficult to see that the expression for the relative change in density ρ caused by centrifugal pressure,

$$\Delta\rho/\rho = {}^{1}/_{4}\chi_T \rho \omega^2 R^2 \tag{1}$$

(where χ_T is the coefficient of isothermal compressibility, ω is the angular velocity of rotation, R is the radius of the rotating pycnometer) is powerless to give any reasonable explanation of the experimental results of works (1-3). Elementary calculations show that, in order to reconcile expression (1) with the experimental data, one would have to assume that in the state of rotation the compressibility of helium II increases extremely strongly. For example, at $T = 1.74$°K and $\omega = 30$ sec^{-1}, formula (1) requires an increase of χ_T (in comparison with its value at $\omega = 0$) by a factor of 200.

To test this supposition, special experiments (4) were carried out in which the question of the velocity of propagation of ultrasound in rotating liquid helium II was studied. The strong increase in compressibility required by formula (1) should have manifested itself in a considerable decrease in the velocity of propagation of ultrasonic oscillations in rotating helium II. However, the measurements (4) showed that rotation of helium II in the temperature interval

Fig. 1

Figure 1: Fig. 1

$T = (1.4 \div 2.10)^{\circ}$K and at angular velocities $\omega = (0 \div 70)$ sec^{-1} has no influence on the velocity of propagation of sound waves in it. Thus, the supposition of an anomalous increase in the compressibility of helium II in a state of uniform rotation was not confirmed.

Thus, in the works considered above the question of the nature of the mechanism of the compaction effect in rotating helium II remained unresolved. In the present work an experimental test has been made of our supposition that this effect is a phenomenon of thermal origin.

This supposition is connected with the peculiarity of the behavior of the volume coefficient of thermal expansion of liquid helium $\alpha = (1/v)(\partial v/\partial T)_p$ in the temperature region immediately adjacent to the λ-point. As is known, the density-temperature curve for liquid helium consists of

two branches (Fig. 1) with a kink point at $T = T_\lambda$ (the difference of the kink point from T_λ, in view of its smallness, is not taken into account here). At the λ-point α changes sign. In the region of helium I $\alpha > 0$, and in the region of helium II $\alpha < 0$. The negative sign of the coefficient α for helium II indicates that an increase in temperature leads to a decrease in volume, i.e., to an increase in density. Using the known data (5) on the temperature dependence of the density of liquid helium, it can be shown that, in order to explain the observed (1−3) densification effect, it is sufficient to assume an increase in the temperature of helium II during rotation by an amount of the order of 10^{-3} °K. Such an assumption has a real basis, since in any devices with rotating parts some heat release is always observed. Thus, the aim of the present measurements is to test the supposition as to whether the densification effect of rotating helium II is not the result of a temperature rise due to parasitic heat release during the rotation of the pycnometer.

Fig. 1. Temperature dependence of the density of liquid helium

The principal scheme of the experimental setup is shown in Fig. 2. The rotating pycnometer is analogous to the instrument used in (1−3), with the only difference that in our case provision is made for the possibility of accurately measuring the temperature both inside (thermometer R_2) and outside the pycnometer (thermometer R_1). The volume of the copper cup of the pycnometer 1 is $V = 60$ cm^3. The internal diameter of the measuring capillary 2 is $d = 2$ mm. To measure the level of liquid helium in the capillary, a KM-6 cathetometer is used. For clearer and more accurate observation of the meniscus 3 of the liquid helium in the measuring capillary, a special illuminator with a shutter, described in (6), is used. To determine the relative change in the density of the rotating liquid helium, the formula is used

Fig. 2

Figure 2: Fig. 2

$$\Delta\rho/\rho = \pi d^2 \Delta h/4V.$$

In the experiment the difference of the levels Δh of helium in the capillary, caused by rotation, is measured. The accuracy of our measurements is $\delta(\Delta\rho/\rho) \sim \pm 10^{-5}$. As a thermometer, a phosphor-bronze wire of diameter $50\,\mu$ is used. In the temperature-measurement circuits a photo-compensation direct-current amplifier F-359 is used. The thermometer readings are recorded on an EPP-09 self-recorder. The accuracy of the measurements is $\Delta T \sim \pm 10^{-4}\,^\circ\mathrm{K}$. Rotation is transmitted to the pycnometer from a synchronous motor SD-09 by means of a set of replaceable pulleys. The axis of rotation—a thin-walled tube 4 of stainless steel with internal diameter $d = 2$ mm—also serves for condensing helium into the pycnometer.

Fig. 2. Principal scheme of the experiment

Measurements were carried out in the temperature interval $T = (1.6 \div 2.25)^\circ\mathrm{K}$ and at angular velocities $\omega = (5 \div 55)\,\mathrm{s}^{-1}$. From the very first experiments it became clear that the assumption of a thermal origin of the compaction effect in rotating helium II was valid. Repeated experiments showed that the change in the density of liquid helium in the course of rotation of the pycnometer is always accompanied by an increase in temperature. In the region of helium I temperatures, as was to be expected from the temperature dependence of the coefficient α, an effect of the opposite sign is observed, i.e., an effect of decreasing density.

The results of our measurements are presented in Fig. 3 in the form of characteristic curves of the time dependence of density and temperature in the regions of helium I and helium II during the experiment. T_0 is a certain selected temperature at which the experiment begins, and ρ_0 is the corresponding density of liquid helium; t_1 corresponds to the moment at which rotation of the pycnometer begins, and t_2 to the moment at which it stops. The magnitude of the temperature increment in the interval $t_2 - t_1$, and consequently also the magnitude of the effect of the change in density of liquid helium during rotation of the pycnometer, naturally turned out to depend on the angular velocity of rotation, i.e., on the intensity of heat release. The dependence $\Delta\rho/\rho = \varphi(\omega)$ obtained by us is in qualitative agreement with the data of Andronikashvili and Tsakadze ($^{1-3}$). The question of quantitative agreement of the results is devoid of meaning in view of the clear dependence of the intensity of heat release, as a function of the angular velocity of rotation, on the specific features of the construction of the apparatus.

Fig. 3. Typical curves of the time dependence of density and temperature for

Fig. 3. Typical curves of the time dependence of density and temperature for helium I and helium II during the experiment. At time t_1 rotation of the pycnometer begins, and at time t_2 it stops; t_3 is the moment at which temperature stabilization begins.

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At the moment t_2 the rotation of the pycnometer is stopped; in connection with this, heat release ceases, and the temperature begins to decrease. In parallel with this, as is seen from Fig. 3, the density begins to approach its initial value ρ_0.

At the moment t_3 the temperature reaches the value T_0, and the density ρ_0. To the right of t_3 the temperature was maintained by us constant to an accuracy of up to $\pm 10^{-4}$ °K. In Fig. 3 one clearly sees the absence of an effect of change in the density of rotating liquid helium both in the region of helium II and in the region of helium I in the case of temperature stabilization. As was to be expected, the observed change in the density of liquid helium associated with the course of the temperature regime during rotation (Fig. 3) is in good agreement (both in magnitude and in sign) with known data on the temperature dependence of the density of liquid helium (see, for example, (5)).

Thus, as a result of our experiments, the thermal origin of the effect of change in the density of rotating liquid helium has been unambiguously demonstrated. Naturally, this phenomenon has nothing in common with the HeI—HeII transformation, and the question of the nature of the phase transition in rotating liquid helium remains open. It should be noted that analogous conclusions are reached in the works of American authors (7) and of the group of B. N. Esel' son (communication at the XIV Conference on Low-Temperature Physics).

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Note: Figure translations are in progress. See original paper for figures.