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RELAXATION PROCESSES RELATED TO TEMPERATURE CHANGES IN ROTATING HELIUM II

G. V. GUDZHABIDZE and Dzh. S. TSAKADZE

Tbilisi State University; Institute of Physics, Academy of Sciences, Georgian S.S.R.

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Processes related to changes in the elasto-plastic properties of rotating helium II and appearing with a change in the temperature of the liquid are investigated. The study is carried out by cooling helium II as well as by heating it.

IT was pointed out earlier[1] that in the transition helium II–helium I, occurring under conditions of rotation in a viscous liquid (such as helium I), an additional damping is observed in the oscillations of a disk due to the presence of vortex filaments (see, for example, [2]). The relaxational character of this phenomenon was also noted at that time—if the rotation begins in the state helium I, the additional damping does not arise. In a number of works,[3-5] measurements were made of the relaxation time connected with the transition helium II–helium I in the rotational state. It was shown that the vortex damping of the disk oscillations is completely maintained during a time lasting ~20 min; then the damping falls suddenly for ~1 min, and finally increases slowly up to a value which is equilibrium for helium I (and less than in helium II) after ~12 min.

In this connection, the question naturally arose as to a comparison of the results just described with similar data on processes of heating and cooling of helium II (without passing through the transition point). In the present paper, results are set forth of the measurement (for both cooling and heating) of the damping of axial oscillations of a roughened disk which take place about its axis—an axis which is concentric with the rotation of the liquid. The apparatus used and the method of measurement were described in detail in [1].

The results obtained for heating are shown in Fig. 1a. The heavy lines indicate the time variation of the damping in rotating helium II. The dotted line indicates the variation of the analogous process in the absence of rotation. In the latter case, the time of change of the damping decrement practically coincides with the duration of the heating process. In rotating helium II, the change in the damping is considerably more protracted. The lag in the increase of damping does not depend on the temperature interval of the given experiment but depends on the angular velocity of the rotation. It reaches ~40 min at $2\omega_0/\Omega \sim 0.2$ (Fig. 2a), and after passage through this maximum value it does not fall below 12 min (Ω is the oscillation frequency).

The results obtained upon cooling are somewhat more complicated (Fig. 1b). In this case the damping in the motionless helium again follows directly the change in temperature, while the decrease in damping in the rotating helium again lags behind by approximately the same time as on heating. However, the time dependence of the damping in this case is not a gradual transition from the value corresponding to the initial temperature up

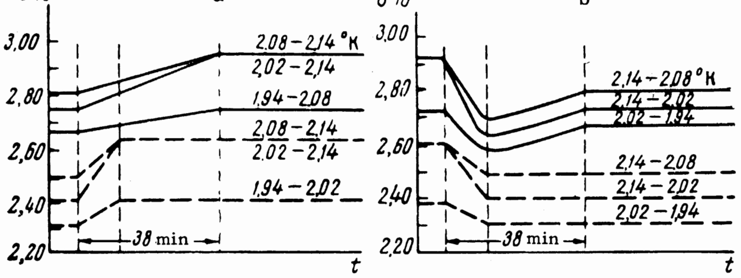

FIG. 1. Dependence of the logarithmic damping decrement of a disk on the time a – in the process of heating, b – in the process of cooling of helium II. The solid line is $\omega_0 = 0.033$ sec^{-1}, the dashed line, $\omega_0 = 0$. The initial and final temperatures are shown on the graphs.

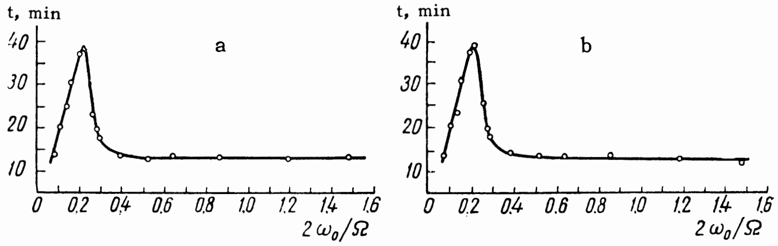

FIG. 2. Dependence of the relaxation time a – for heating, b – for cooling, on the ratio $2\omega_0/\Omega$ (t is the time from the instant of beginning of the change in temperature to the establishment of uniform damping).

to the value at the final temperature. The effect again does not depend on temperature but on the angular velocity, just as in the previous case (cf. Fig. 2b and Fig. 2a).

Thus, in contrast with the results of similar measurements under conditions of phase transformation in rotating helium, in both the processes described, the stage of complete preservation of the initial damping is absent—the change in the damping begins simultaneously with the instant of temperature change. So far as the decrease in damping which precedes the increase is concerned, such a phenomenon is observed only in the cooling of helium II. It would seem that here one can discern a certain inconsistency, since heating occurs in the case of the phase transition, whereas the cooling process, not the heating of helium II, turns out by its nature to be closer to it. However, if one goes into the nature of the phenomena observed in detail, this contradiction is removed.

The damping of the disk is determined by two causes: the viscous interaction with the normal component, which makes a contribution which depends on temperature as $\sqrt{\eta_n \rho_n}$, and the interaction with the vortices which in general makes a contribution proportional to ρ_s, but in the range 1.9–2.17° K is much less temperature dependent.[1, 2, 5] Therefore, in the cooling, the damping initially falls off sharply because of the decrease in the normal component and its "pulling out of the game," and then increases a little in the gradual enrichment of the vortex with the newly appearing superfluid liquid. In the heating of helium II, on the other hand, the superfluid component of the vortex is depleted; however, the comparatively slight decrease in the vortex damping is quickly compensated and covered by the increase in the viscosity of the normal component, and, subsequently, by the increase in its quantity. The decrease in the damping which takes place in heating through the temperature of the phase transition can be explained by the fact that in the latter case, in contrast with the heating of helium II, the vortex damping disappears completely and only later is partially compensated by the addition of the liquid "coming out from the vortex composition" to the normal mechanism of viscous interaction.[3-5]

Common to all three relaxation processes considered is the presence of a maximum in the relaxation time for $2\,\omega_0/\Omega \sim 0.2$, that is, for an angular velocity ω_0 corresponding to the beginning of the collectivization of the vortex oscillations and corresponding to the minimum of the slippage coefficient.[2] In the transition helium II–helium I this circumstance is clear indication of the fact that the detachment of the vortices from the surface of the disk is facilitated by their slippage and is made much more difficult under conditions of maximum pinning.[3-5] In the case observed in this work, detachment of the vortices does not generally take place, and the reason for the appearance of the maxima in Figs. 2a and b is less clear. In any case, one can assert that the depletion and enrichment of the vortices with the superfluid component is made much more difficult under conditions of their maximum pinning at the surface of the disk. Possibly a natural reason for this are the oscillations of the vortices which are much more intense precisely at minimal slippage.

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