INVESTIGATION OF THE NATURE OF OSCILLATIONS OF HELIUM II CLOSE TO THE SURFACE OF A VIBRATING DISK, USING A RESONANCE METHOD

É. L. ANDRONIKASHVILI, G. A. GAMTSEMLIDZE, and Sh. A. DZHAPARIDZE

Tbilisi State University

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It was found that the region of penetration of the (vortex) oscillation regime into the liquid in supercritical oscillations of a disk in helium II was smaller than the region where the liquid was dragged by the oscillations of the disk. The two respective values of the depth of penetration (vortex and ordinary conditions of liquid oscillation) were measured in the temperature range 1.6–1.9°K. The effective density of the superfluid component involved in the supercritical oscillations was calculated.

1. WHEN the amplitude of the axial oscillations of a disk, immersed in liquid helium II, exceeds a certain critical value, the disk suffers an additional interaction with the liquid,[1, 2] which is evidently due to the formation of quantum vortex filaments. The purpose of our investigation was to determine the extent of the region of the liquid into which the supercritical oscillations penetrate and to investigate the nature of the propagation of disk-generated waves in that region.

The apparatus we used in this investigation is shown in Fig. 1. A disk 1, which generated the investigated velocity field, was set vibrating by a mechanical system 6 with a magnetic drive 5. The amplitude of these forced oscillations could be varied within the limits 0.1–0.8 rad, while keeping the period constant and equal to $\theta = 10.44 \pm 0.01$ sec. A second disk 2 had the same natural period of oscillations (the difference between the periods did not exceed 0.01 sec); this second disk was freely suspended on an elastic filament 3 above the first disk and served as a probe in the investigation of the distribution of velocities in the liquid above the generator disk 1. Sometime after the oscillations of the disk 1 had begun, the amplitude of the resonance oscillations of the probe disk gradually increased and, after a time interval of the order of 30 min, an equilibrium amplitude φ was reached whose value was governed by the intensity of oscillations of the liquid at that distance from the generator disk 1 where the probe disk 2 was placed. The distance between the disks could be varied by means of a micrometer screw 4 with an accuracy of ±0.01 mm.

Figure 2 gives the dependences of the amplitude of oscillations of the probe disk φ on the distance d between the disks for various values of the amplitude of the generator disk oscillations φ_0

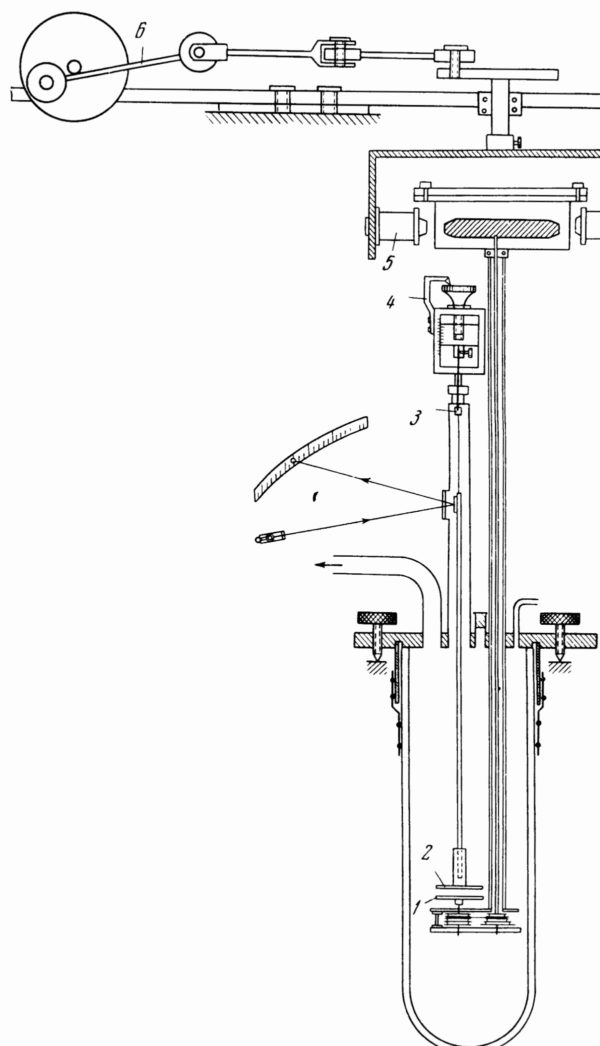

FIG. 1. Schematic representation of the apparatus.

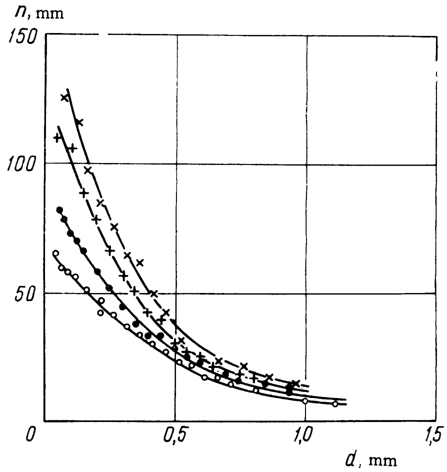

FIG. 2. Dependence of the total amplitude of the oscillations of a light spot $n = A\varphi$ (where φ is the oscillation amplitude and A is four times the distance from the scale to the mirror, fixed to a straight glass rod attached to the probe disk) on the distance between the disks d at T = 1.52°K for various values of the oscillation amplitude of the generator disk: ○ – φ_0 = 0.30 rad, ● – φ_0 = 0.44 rad, + – φ_0 = 0.60 rad, × – φ_0 = 0.73 rad.

(0.30, 0.44, 0.60, 0.73 rad) at 1.52° K. These curves are exponential. In fact, if we plot the quantity $\ln(\varphi/\varphi_0)$ along the ordinate and the distance d between the disks along the abscissa, we obtain, in the range 0.7 mm > d > 0.05 mm, the straight lines shown in Fig. 3.

The slope of these straight lines gives the reciprocal of the wave penetration depth, $1/\lambda$. The dependence is in qualitative agreement with the

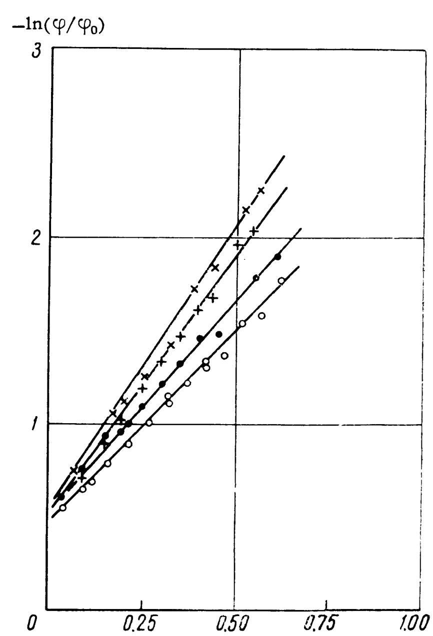

FIG. 3. Dependence of the logarithm of the ratio φ/φ_0 on the distance between disks for the amplitudes φ_0 listed under Fig. 2.

measurements carried out in helium II at subcritical amplitudes (curve 4 in Fig. 3). The slope of curve 4 gives $\lambda = 0.48 \pm 0.02$, which is in excellent agreement with the value of the depth of penetration of a viscous wave, calculated from the well-known formula

$$\lambda = (2\nu_n / \Omega)^{1/2}, \qquad (1)$$

where Ω is the angular velocity of the oscillating disk, and ν_n is the kinematic viscosity of the normal component. Andronikashvili's data on the kinematic viscosity ν_n[3] were used.

On the other hand, Fig. 3 shows that, for the supercritical amplitudes of the generator disk $\varphi_0 > \varphi_c$ and d < 0.7 mm at T = 1.52° K (the three upper curves in Fig. 3), the values obtained for the penetration depth decrease as the oscillation amplitude increases, for example: $\lambda_{eff} = 0.33 \pm 0.01$ mm for $\varphi_0 = 0.73$, $\lambda_{eff} = 0.36 \pm 0.01$ mm for $\varphi_0 = 0.61$, and $\lambda_{eff} = 0.40 \pm 0.1$ mm for $\varphi_0 = 0.44$. The values of λ_{eff} obtained were used to calculate the effective kinematic viscosity in the supercritical region

$$\nu_{eff} = \lambda^2_{eff}\, \Omega / 2.$$

The dependence of ν_{eff} on the reciprocal of the oscillation amplitude of the generator disk $1/\varphi_0$ at T = 1.52° K, shown in Fig. 4, gives

$$\nu_{eff} = c\varphi_0^{-1}\ \text{cm}^2/\text{sec}. \qquad (2)$$

The determination of the slope of this dependence shows that $c = 2.1 \times 10^{-4}$ cm²/sec.

Having calculated the value of the kinematic viscosity at 1.52° K in the subcritical region using Andronikashvili's data[3] ($\nu_n = 7.5 \times 10^{-4}$ cm²/sec), and bearing in mind that the value of the critical amplitude at T = 1.52° K in the oscillation experiments on disks of the same size is 0.28 ± 0.03 rad,[2] we find that the product $\nu_n\varphi_c$ has the value 2.1×10^{-4} cm²/sec, which is equal to the coefficient c in Eq. (2). Thus, the amplitude dependence of the kinematic viscosity in the supercritical region, in the amplitude range 0.7 rad > $\varphi_0 > \varphi_c$, finally as-

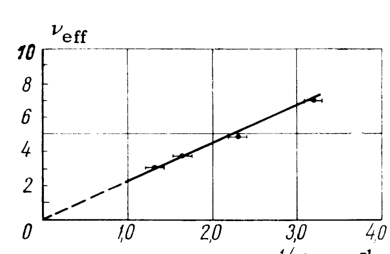

FIG. 4. Dependence of the effective kinematic viscosity ν_{eff} on the reciprocal of the oscillation amplitude of the generator disk at T = 1.52°K.

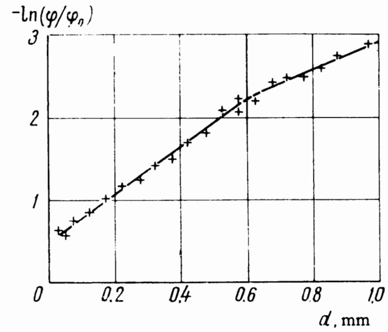

FIG. 5. Dependence of $\ln(\varphi/\varphi_0)$ on the distance between disks for T = 1.52°K and φ_0 = 0.60 rad.

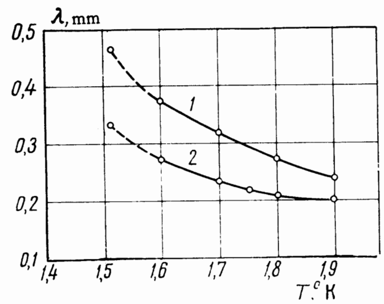

FIG. 7. Temperature dependence of the normal (1) and effective (2) depths of penetration for the amplitude φ_0 = 0.73 rad in the temperature range 1.6–1.9°K.

sumes the following form:

$$\nu_{\text{eff}} = \nu_n \varphi_c / \varphi_0. \quad (3)$$

Figure 5 shows a plot of $\ln(\varphi/\varphi_0) = f(d)$ for $\varphi_0 = 0.60$ rad at T = 1.52°K in the range of values of d from 0.05 mm upward. From this dependence, we may conclude that for motion in the supercritical region, when the distance between the disks becomes larger than $2\lambda_{\text{eff}} \approx 0.7$ mm, the curve representing the dependence of $\ln(\varphi/\varphi_0)$ on d transforms into another exponential curve. Similar behavior is observed for other values of the amplitude $\varphi_0 > \varphi_c$.

The results obtained show that the region in which the supercritical oscillations of the liquid are realized lies closer to the disk than the region of laminar oscillations of the normal liquid. The dimensions of the critical region are bounded by distances of the order $2\lambda_{\text{eff}}$. The boundedness of the region in which the supercritical oscillations take place can obviously be explained by the dragging of the superfluid component by vortices attached at both ends to the flat surfaces of the disks.

2. In order to determine the contribution of the drag of the superfluid component to the effective depth of wave penetration, it was necessary to investigate the temperature dependence of the depth of penetration λ at a constant value of the amplitude (φ_0 = 0.73 rad) in a range of temperatures (1.6–1.9°K) in which the viscosity of the liquid η_n was practically independent of temperature and only $\rho_n = \rho - \rho_s$ varied with temperature in the expression $\nu_n = \eta_n/\rho_n$.

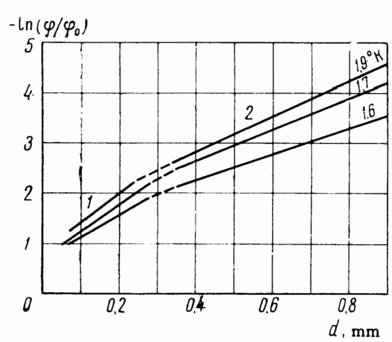

FIG. 6. Dependence of $\ln(\varphi/\varphi_0)$ on the distance between disks for φ_0 = 0.73 rad and various temperatures.

Figure 6 shows the dependence of the resonance amplitude on the distance between the disks at various temperatures for φ_0 = 0.73 rad. The slopes of these curves give, as shown in Sec. 1 for T = 1.52°K, two dependences of the penetration depth (Fig. 7) for different ranges of d. The temperature dependence of λ, deduced from the second range (cf. Fig. 6) is in good agreement with the values of λ_n calculated using Eq. (1), while the dependence deduced from the first range gives the effective values λ_{eff} (cf. curve 2 in Fig. 7).

The depth of penetration of the supercritical oscillations can be written in the form

$$\lambda_{\text{eff}} = (2\eta_n / \rho_{\text{eff}}\Omega)^{1/2}. \quad (4)$$

The value of the effective density ρ_{eff}, defined by the above equation, can be calculated from our experimental data (cf. table). It is found that this density has a temperature dependence of the type $\rho_{\text{eff}} = \rho_n + k\rho_s$, where the coefficient k is given by the following equation in the temperature range from 1.6 to 1.9°K.

$$k = \frac{\rho_{\text{eff}}/\rho_n - 1}{\rho_s/\rho_n} = 0.25 \pm 0.05.$$

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T, °K	ρ_{eff}/ρ_n	ρ_s/ρ_n	$\rho_{\text{eff}}/\rho_n - 1$	k
1.6	1.90	4.58	0.9	0.20
1.7	1.77	3.06	0.77	0.25
1.8	1.56	2.02	0.56	0.28
1.9	1.25	1.3	0.25	0.19
1.52	2.1	6.6	1.1	0.17

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