Experimental check on the two-component model of a normal liquid (He-I)[1)]

G. A. Gamtsemlidze, Sh. A. Dzhaparidze, and D. N. Tsaava

Tbilisi State University

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The damping of shear oscillations in He-I was investigated at distances greatly exceeding the penetration depth. The damping exhibits a power-law behavior.

1. The presence of weakly-damped phonons in a normal liquid can give rise to effects that are explained by the two-liquid concept developed by Andreev in[1].

For liquids that solidify at temperatures much lower than the Debye temperature (H, He^3, He^4), there exist temperature regions $T \ll \Theta$ in which the wavelengths of phonons having energies on the order of the temperature greatly exceed the interatomic distances, so that the phonons constitute weakly-damped thermal excitations.

A. F. Andreev considers in his paper a situation in which He-II flows through a thin capillary, and assumes that the phonons are diffusely scattered by the walls and that their average velocity should be less than the average flow velocity of the remaining part of the liquid. Naturally, in such a situation the normal liquid can be regarded as an aggregate of two weakly-coupled subsystems, the phonons and the remainder of the liquid, with the phonons playing the role of the normal part of the liquid, and the remainder the superfluid part. Andreev excludes temperatures near and below the λ point. The situation below the λ point has been investigated by us in sufficient detail in[2,3], where the damping of the viscous waves has an exponential character.

It is noted in[1] that owing to the presence of weakly-damped phonons, the shear oscillations have a power-law character and can propagate over distances greatly exceeding the penetration depth δ, i.e., $z \gg \delta \approx a_0(\Theta/\hbar\omega)^{1/2}$, where a_0 is the interatomic distance, Θ is the Debye temperature, and ω is the oscillation frequency.

The equation for the dependence of the velocity of the shear oscillations of the liquid on the distance z, with allowance for the phonon contribution, under the condition $z \ll c/\omega$, takes the form

$$u = \frac{3i}{616} v \frac{T}{\rho\omega}\left(\frac{a}{\pi\hbar^2}\right)^{3/2}(cz)^{-5/2}, \tag{1}$$

where u is the velocity of the liquid at a certain distance z from the oscillating surface (in our experiment—from a sinusoidally oscillating disk—generator), v is the velocity of the surface producing the oscillations (of the generator), ρ is the density of the liquid, ω is the oscillation frequency, z is the speed of sound, and a is a quantity connected with the sound absorption coefficient[4]

$$\gamma = \frac{\omega^2}{2\rho c^3}\left[\left(\frac{4}{3}\zeta + \xi\right) + \kappa\left(\frac{1}{C_v} - \frac{1}{C_p}\right)\right]$$

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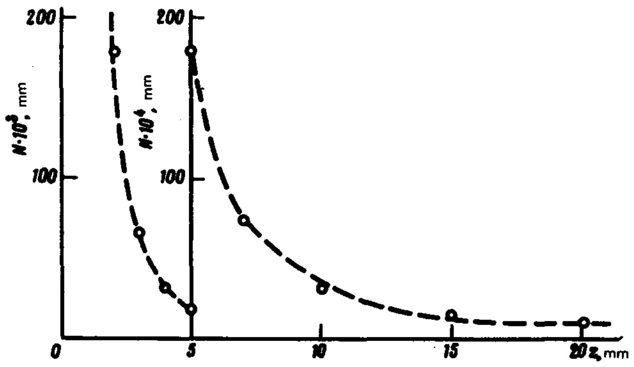

FIG. 1. Dependence of the total swing N of the light beam on the scale on the distance z. Dashed curve—theoretical, ○—experimental data.

and takes the form

$$\alpha = \frac{\hbar^2\omega^2}{2\gamma c} = \rho\hbar^2 c^2\left[\left(\frac{4}{3}\zeta + \xi\right) + \kappa\left(\frac{1}{C_v} - \frac{1}{C_p}\right)\right]^{-1}. \tag{2}$$

Here C_p and C_v are the heat capacities per unit mass, ζ and ξ are the coefficients of the first and second viscosity, and κ is the thermal-conductivity coefficient. The purpose of this paper is to verify experimentally the theoretical idea of A.F. Andreev, and particularly to determine the function $u=f(z)$.

2. For the experimental study of the propagation of shear oscillations in a normal liquid we used, after making some improvements, the instrument employed in[2,3], in which a resonant measurement method is used. Sinusoidal oscillations of a disk (generator) with amplitude $\phi = 0.56$ rad are produced in liquid helium by a magnetic drive; the oscillating disk drags the liquid. The oscillations of the liquid propagate along the oscillation axis. A second disk (receiver), suspended under the first by an elastic platinum iridium filament (20 μ diam) serves as a probe for the measurement of the amplitudes of the oscillations of the liquid at the given point. The disks are made to oscillate at the same frequency, accurate to ± 0.005 sec^{-1}. The amplitudes are measured, once resonance sets in, with the aid of a beam reflected from a small mirror mounted on the receiver disk, 25 mm in diameter and 0.3 mm thick.

3. The experiments were performed at a temperature $T = 2.4\,^\circ$K. The plot of $N=f(z)$, where N is the total swing of the light beam on the scale (Fig. 1), shows the experimental results, which agree quite well with the plot of the theoretical formula (1). The slope of the $\ln N = f(\ln z)$ plot in Fig. 2 yields for z an exponent $n = (-2.4 \pm 0.2)$.

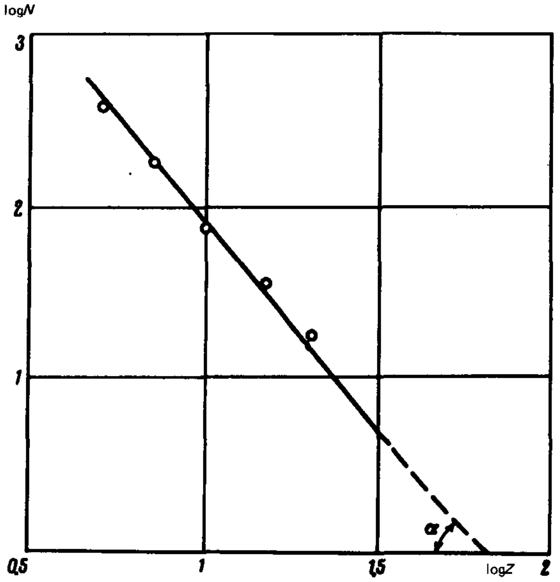

FIG. 2. Doubly-logarithmic plot of $\ln N = f(\ln z)$, $n = \tan\alpha$ is the exponent of z.

The experimental values of u and v at $z = 1$ cm were used to estimate the coefficient α connected with the sound damping, namely $\alpha = 2\times10^{-42}$ cm^{-1}. The theoretical value of α from (2) is 9×10^{-42} cm^{-1}. This emphasizes once more that in the situation considered here the long-wave phonons are indeed weakly-damped thermal excitations, and helium-I can be represented as an aggregate of two practically uncoupled subsystems.

Thus, the obtained experimental data confirm the reliability of the two-liquid model proposed by A.F. Andreev for a normal liquid.

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