DETERMINATION OF THE COEFFICIENT OF MUTUAL FRICTION BETWEEN THE SUPERFLUID AND NORMAL COMPONENTS ALONG VORTEX LINES

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An apparatus has been constructed which consists of a rotating vessel filled with helium II, within which is suspended a hollow cylinder capable of simultaneously rotating and performing vertical oscillations along the axis of rotation. It has been established that, within the limits of experimental error, these oscillations are independent of the rotational velocity, which testifies to the absence of a mutual friction force between the superfluid and normal components along the Onsager-Feynman vortices.

THE most general expression for the mutual friction force F_{sn} acting on unit mass of a superfluid, has been given by Bekarevich and Khalatnikov [1] in the following form:*

$$\mathbf{F}_{sn} = -\frac{\rho_n}{2\rho}B'[\boldsymbol{\omega}\mathbf{v}] - \frac{\rho_n}{2\rho}B\left[\frac{\boldsymbol{\omega}}{\omega}[\boldsymbol{\omega}\mathbf{v}]\right] + \frac{\rho_n}{2\rho}B''(\boldsymbol{\omega}\mathbf{v})\frac{\boldsymbol{\omega}}{\omega};$$
$$\mathbf{v} = \mathbf{v}_n - \mathbf{v}_s - \mathrm{rot}\,(\nu_s\boldsymbol{\omega}/\omega),$$

where ρ_n is the density of the normal component, ρ is the density of the liquid as a whole, $\boldsymbol{\omega} = \mathrm{curl}\,\mathbf{v}_s$, $\mathbf{v}_s$ is the superfluid component velocity, $\mathbf{v}_n - \mathbf{v}_s$ is the relative velocity of the superfluid and normal components, and ν_s is the Vinen-Hall parameter; [2] B, B′, and B″ are the mutual friction coefficients.

The temperature dependence of the coefficients B and B′, which determine the magnitude of the component of the force $\mathbf{F}_{sn}$ perpendicular to $\boldsymbol{\omega}$, has been studied by Hall and Vinen [2] and by Lifshitz and Pitaevskiĭ. [3] The coefficient B″, which determines the magnitude of the mutual friction along $\boldsymbol{\omega}$, has not as yet been measured experimentally. Such a measurement would, however, be extremely desirable, since only when B″ = 0 do the hydrodynamic equations for rotating helium II agree with the vortex conservation law.

Mamaladze has recently [4] proposed a method for the direct measurement of the coefficient B″ from the damping observed for a cylinder oscillating along its axis of rotation. He has shown that for B″ ≠ 0 the damping will increase linearly with increasing rotational velocity, according to the law

$$1 + (\rho_s\omega_0/\rho\Omega)\,B''$$

(ω_0 is the angular velocity of rotation, and Ω is the frequency of the oscillations). It can easily be seen that for B″ = 0 the damping must be independent of rotational velocity.

In order to perform this experiment we constructed the following apparatus (see figure). A hollow cylinder of organic glass 10 mm in diameter and 50 mm high, with a wall thickness of 0.3 mm, was suspended by means of a straight glass rod and an electromagnet from the beam of a sensitive balance. The pole of the electromagnet had a spherical cap, while the glass rod also terminated in a steel sphere. This method of coupling made it possible to suspend the cylinder at a point which was precisely located along the arm of the balance, and also insured that very little force was required to overcome the friction at the point of contact between the spheres and set the hollow cylinder into rotation.

The hollow cylinder was suspended within a rotating beaker filled with helium II. This beaker was likewise of organic glass, 45 mm in diameter and 100 mm high. The beaker was set into motion by means of a rotating magnetic field, acting upon a soft iron armature secured to the beaker.

During the measurements, the hollow cylinder oscillated vertically and at the same time rotated at the same velocity as the beaker. This latter was accomplished with the aid of a magnetic needle attached to the cylinder, and iron rods mounted in the beaker and symmetrically placed relative to the axis of rotation. The logarithmic damping decrement of the oscillations of the hollow cylinder was measured using a light source, a scale, a prism, and a mirror attached to the beam at its center.*

*$[\boldsymbol{\omega}\mathbf{v}] = \boldsymbol{\omega}\times\mathbf{v}$; $(\boldsymbol{\omega}\mathbf{v}) = \boldsymbol{\omega}\cdot\mathbf{v}$; rot = curl.

*The technique used in the measurements is described in detail elsewhere.[5]

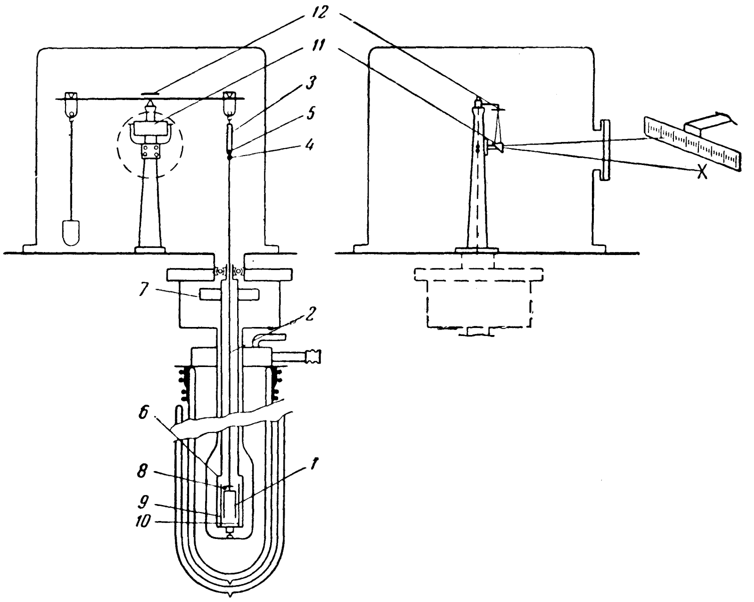

Diagram of the apparatus. 1 – hollow cylinder; 2 – glass rod, 3 – electromagnet, 4,5 – steel spheres, 6 – rotating beaker, 7 – soft iron armature, 8 – magnetic needle, 9,10 – iron rods, 11 – prism 12 – mirror.

Following preliminary calibration of the apparatus with rotating water, a series of experiments was carried out in helium II with the liquid at a temperature of 1.86°K.

The results obtained were as follows:

$10^3\omega_0$:	0	55	80	106	134	196
$10^2\delta$:	1.91	1.90	1.90	1.91	1.91	1.92

(In all of the values for $10^2\delta$, the error is ± 0.02). Thus, the logarithmic decrement for the damping of the oscillations is found to be independent of the velocity of rotation of the liquid over the range $0 \leq \omega_0 \leq 0.2\ \text{sec}^{-1}$.

Taking the measurement error into account, these data make it possible to state that B″ must be less than 0.025 (for comparison we note that at this temperature $B \sim 1$[2,3]). The author wishes to thank É. L. Andronikashvili for his valued suggestions regarding the design of the experiment, and Yu. G. Mamaladze for his interest in this work and for discussion of its results.

[1] I. L. Bekarevich and I. M. Khalatnikov, JETP **40**, 920 (1961), Soviet Phys. JETP **13**, 643 (1961).

[2] H. E. Hall and W. F. Vinen, Proc. Roy. Soc. **A238**, 215 (1956).

[3] E. M. Lifshitz and L. P. Pitaevskiĭ, JETP **33**, 535 (1957), Soviet Phys. JETP **6**, 418 (1958).

[4] Yu. G. Mamaladze, JETP **39**, 859 (1960), Soviet Phys. JETP **12**, 595 (1960).

[5] D. S. Tsakadze and K. B. Mesoed, Trudy Instituta Fiziki A. N. Gruz SSR **7**, 37 (1961).

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