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ON THE EXISTENCE OF A TANGENTIAL VELOCITY DISCONTINUITY IN THE SUPERFLUID COMPONENT OF HELIUM NEAR A WALL

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The question of the development of a discontinuity in the velocity of the superfluid component of helium II moving relative to a solid wall is investigated experimentally. It has been assumed that the formation of such surface discontinuities requires the application of some minimal force, which is manifested in the form of a threshold shear stress. Apparatus has been constructed which permits the threshold shear stress to be determined with great accuracy. The measurements have shown that tangential discontinuities in the velocity of the superfluid component of helium II do not arise in the vicinity of a wall.

COMPARISON of the results of measurements on the viscosity η_n of the normal component of liquid helium II carried out by means of the oscillating disk method[1,2] on the one hand, and by the method of the uniformly rotating cylinder,[3] on the other, has revealed the existence of a considerable discrepancy in the magnitude of η_n, especially in the low-temperature region.

In this connection, Ginzburg[4] has advanced a hypothesis regarding the possible occurrence of a tangential discontinuity in the velocity of the superfluid component of helium II at the boundary between the liquid and the wall, as well as the necessity for taking into account a surface energy σ associated with this discontinuity and equal according to his estimates, to between 5×10^{-2} and 5×10^{-3} erg/cm^2.

The effect of this surface energy upon the flow of helium II should, in Ginzburg's opinion, be manifested as a minimal energy σS, required in order to set a solid body of surface area S into motion in the helium II.

The primary purpose of the present work has been to test experimentally the hypothesis outlined above.

DESCRIPTION OF THE APPARATUS

The apparatus (cf. Fig. 1) consists of a system of mica disks 1, each $50\,\mu$ thick and 32 mm in diameter. These disks, 45 in number, were arranged parallel to one another along an aluminum shaft 4 mm in diameter, and were separated by aluminum washers 8 mm in diameter and 2 mm thick.

The stack of disks thus assembled was suspended on a straightened glass rod 2 whose upper portion was fitted with a small mirror 3 and a clamp 4, by means of which it was attached to the lower end of a phosphor-bronze fiber 5, $50\,\mu$ in diameter and 12 cm long, which served as a suspension.

The upper end of the suspension was connected to a frame 6 by means of a clamp 7. The frame was in the form of a plane parallelopiped made of aluminum foil 1 mm thick; its linear dimensions were $24 \times 10 \times 30$ cm. The frame and disks were in turn suspended together on a copper strip 8 of rectangular cross section, through which current was supplied to a single-layer coil, of 10 turns per centimeter, wound upon the frame.

A spiral spring, fitted into a circular metal seat 9 attached to the cupro-nickel supports 10, served as the second conducting lead. One end of the spring was soldered to the seat, while the other end was fitted by means of a collar to the neck 11 of the clamp 7, which was in electrical contact with the coil. The spiral spring served at the same time to return the frame to its equilibrium position.

A second mirror 12 was cemented to the neck of the clamp, permitting observation of the rotation of the frame as current was passed through it.

The entire suspension system was enclosed within a glass cylinder 13, the lower end of which was ground to fit the cone 14 and the upper to fit the tube 15 of the seal 16.

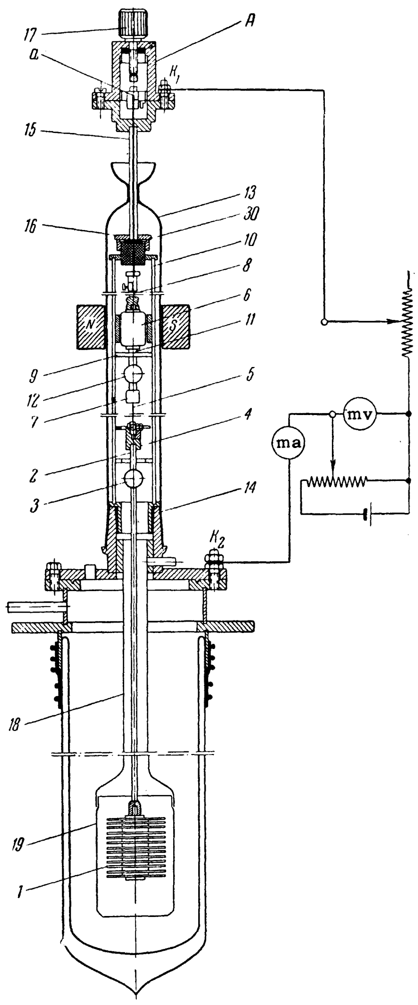

FIG. 1. Diagram of the apparatus.

The disks and the frame were locked by rotation of knob 17 of lock A screwed to the top of the tube 15.

The lower portion of the suspension system (the glass rod and the system of disks) was surrounded by the glass tube 18 and the glass vessel 19 coupled to it, which protected the system from parasitic effects associated with the pumping of the helium vapor.

STATEMENT OF THE PROBLEM

The object of the experiment was to attempt to detect an effect analogous to that of static friction between solid surfaces. In the presence of such an effect the disks should remain stationary, at rest in the helium II, up to some definite angle of twist of the fiber.

Having determined the limiting angle of twist φ_f and knowing the elastic constant f of the fiber, one could then use the familiar formula $f\varphi_f/2$ for the energy of deformation to determine the desired energy σS.

The disks were made of mica with the object of securing a body of large surface area $S = 720\ \text{cm}^2$ and a moment of inertia I as small as $8\ \text{gm cm}^2$, in order to satisfy the condition

$$f\varphi^2_{\min}/2 \ll \sigma S. \qquad (1)$$

The experiment as undertaken made it possible to obtain for the minimum angle of twist of the fiber $\varphi_{\min}$ the value $\varphi_{\min} = \Delta n/2L_f = 3.3 \times 10^{-4}$ radians, where L_f is the distance of the scale used for the frame from the corresponding mirror, while $\Delta n = 1$ mm is the minimum deflection of the light spot along the frame scale which could be detected under the conditions of the experiment. We obtained $f = 2.2$ dyne-cm for the torsional constant of the fiber employed, from its given linear dimensions, and $T = 12$ sec for the natural period of oscillation of the system.

The condition for an "infinite" liquid $\lambda < l$ was satisfied in the experiment. Here $\lambda = (2\eta/\rho_n\omega)$ is the penetration depth for the viscous wave and l is the least distance between the surfaces (moving, or moving and stationary) in the system. We assumed for l the minimum value, the distance between the disks, and the values for η and ρ_n were taken from the work of Andronikashvili[1,5] for the temperature of 1.46°K at which the experiment was carried out.

Inserting into the condition (1) the values for f, $\varphi_{\min}$, and S we obtain $\sigma = 1.7 \times 10^{-10}\ \text{erg/cm}^2$. This is the smallest value of σ which may be detected with the apparatus used, and is smaller by a factor of 3.5×10^8 than the value proposed by Ginzburg. This shows the high sensitivity of the apparatus, and makes it possible to twist the fiber over a wide range, still keeping the system of disks at rest, if the ideas of Ginzburg are correct.

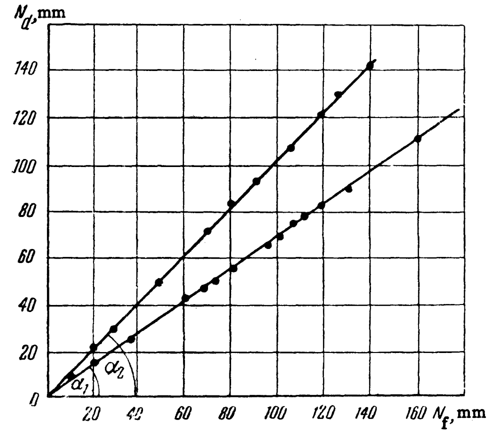

FIG. 2. Calibration curves: $\tan\alpha_1 = \Delta N_d/\Delta N_f = 0.71 \pm 0.007$; $\tan\alpha_2 = \Delta N_d/\Delta N_f = 1.03 \pm 0.01$.

RESULTS OF THE EXPERIMENT

The actual experiment was preceded by the recording of a calibration curve for the apparatus under vacuum; the dependence of the equilibrium orientation of the system of disks in vacuo upon the orientation of the frame was determined. The equilibrium points for the disk system and the frame were found from the positions N_d and N_f of the light spots along the corresponding scales.

Two such curves are given in Fig. 2. The first of these was taken with the scales at approximately equal distances, $L_d = 155 \pm 0.5$ cm and $L_f = 150 \pm 0.5$ cm, and the second when they were at different distances, $L_d = 105 \pm 0.5$ cm and $L_f = 150 \pm 0.5$ cm.

It should be noted that the equation $\Delta N_d/\Delta N_f = L_d/L_f$ is satisfied to within 1%. It can thus be concluded that the mutual orientation of the planes of the mirrors relative to one another under vacuum is maintained as the frame is rotated, and that for deflections of the spot along the scale of 140 to 150 mm the disks rotate through the same angle as the frame to an accuracy of ± 1%.

Data						Data					
24/XII		18/I		1/II		24/XII		18/I		1/II	
N_f	N_d	N_f	N_d	N_f	N_d	N_f	N_d	N_f	N_d	N_f	N_d
in millimeters						in millimeters					
1	1	1	1	1.5	1	12	12	10	9	10	9.5
2	1	2	2	2.5	2	13	13	12	11	11	11
3	2	3	2	3.5	4	14	14	14	13	11	11
4	4	4	4	5	5	16	16	15	15	13.5	14
5	4	5	4	6	6	17	18	18	17	15	15
7	7	7	6	7.5	7.5	18	19	19	19	16	16
9	9	8	7	8	7.5	19	20	23	23	18	18
11	10	9	8	8.5	8	21	21	28	28	22	21

Following the recording of the calibration curve experiments were carried out in helium II.

The data from the experiments (for $L_d = 155$

and $L_f = 150$ cm) are presented in the table; the overall distribution of the data relative to the calibration curve is shown in Fig. 3.

As is evident from Fig. 3, twisting of the fiber causes the disks to follow the rotation of the frame. This circumstance makes it possible to express the opinion that under the conditions of an "infinite" fluid the effect of static friction is not observed in helium II, and, consequently, that no surfaces of tangential discontinuity in the velocity arise at the boundary between a moving solid body and helium II.

If surfaces of discontinuity should in fact arise, then the value of their energy σ must not exceed $\sim 10^{-10}\,\mathrm{erg/cm^2}$. In this case it is necessary to note that such a value for the energy could on no account explain the existing discrepancies between the values for the viscosity as measured by various methods.[1,3]

In conclusion, the author is deeply grateful to the supervisor of this work, Professor E. L. Andronikashvili, for his valued instructions and advice, to the machinists for the liquefaction machines, I. M. Paramonov and E. I. Shalvashvili, and also to his scientific collaborator B. P. Zhvaniya.

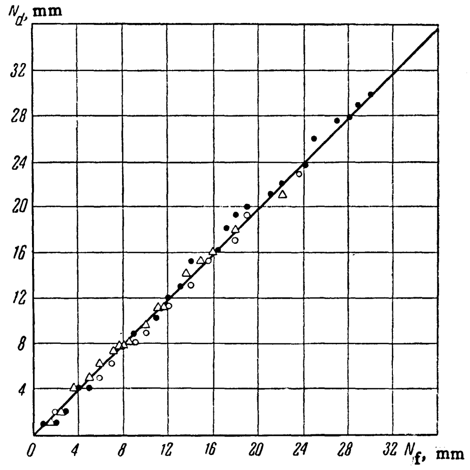

FIG. 3. Dependence of the equilibrium orientation N_d of the disk system upon the orientation N_f of the frame; i.e., the angle of twist of the fiber. Solid line – calibration curve. ● – measurements of 24 Dec., 1956; ○ – measurements of 18 Jan., 1957, Δ – measurements of 1 Feb., 1957.

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