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ATTEMPT TO DETECT AN IRROTATIONAL REGION IN ROTATING He II

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Experimental data have been obtained which confirm the predictions of the theory according to which an internal irrotational region is formed in rotating He II.

As has previously been shown [1,2], a region free of Onsager-Feynman vortices must form in He II when the latter rotates between two cylinders. In this region of potential rotation ($v_s \sim 1/r$), lying adjacent to the inner cylinder, mutual friction between the superfluid and normal components must be absent. We therefore undertook the following experiment.

Two systems were used. The first of these (Fig. 1,a) incorporates a tube whose open end is packed with rouge. To the lower end of this tube is cemented a cup whose base is parallel to the bottom of the outer beaker. Between these two surfaces there is a gap 2 mm wide through which must pass the helium flowing out of the tube into the beaker (after initially being drawn up into the tube by means of the thermomechanical effect).

A similar arrangement is employed in the second apparatus (Fig. 1,b) with the sole difference that an axial stem is included, forming a doubly-connected region in the gap between the bases.

In both systems, the outflowing helium must move through the basal gap in a direction perpendicular to the vortex lines, except in the event that the gap should be an irrotational region. It is evident that in this case an effect should be observed on the rate of flow of the helium out of the tube.

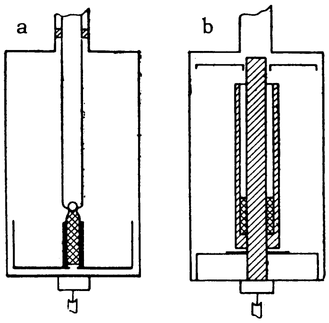
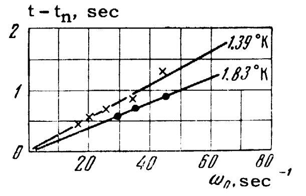


FIG. 1. Apparatus in which He II flow is perpendicular to the vortex lines: a—in a singly-connected region, b—in a doubly-connected region (flowing out of the cylindrical gap between the tube and the rod over which it is placed).



• FIG. 2

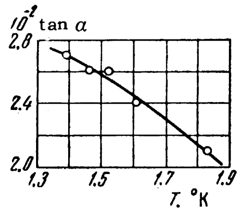


FIG. 3.

FIG. 2. Variation of outflow time t with angular velocity ω_0 for the apparatus illustrated in Fig. 1,a (more precisely, t is the time required for the level of the outflowing helium to pass between two marks of a set uniformly spaced below the initial level in the helium bath, and t_n, the same in the abscence of rotation).

FIG. 3. Temperature dependence of the slopes of a series of curves of the type illustrated in Fig. 2.

Figure 2 shows the results obtained with the first apparatus. As was to be expected, the outflow time increases linearly with angular velocity. The temperature dependence of the slopes of these lines is illustrated in Fig. 3. The ratio of the ordinates at the end points of this graph was calculated and found in agreement with the ratio of the mutual friction coefficients B for the corresponding temperatures.

Figure 4,a illustrates the same relation for the case of the second apparatus. The curve is once

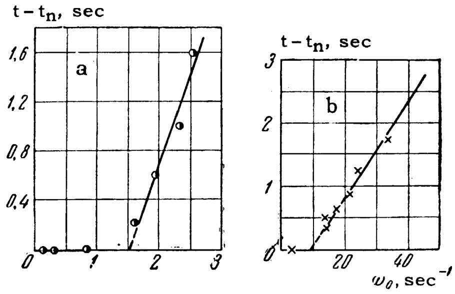


FIG. 4. Velocity dependence of the outflow time for the apparatus illustrated in Fig. 1,b: a— at T = 1.75° K, b—at T = 1.46° K.

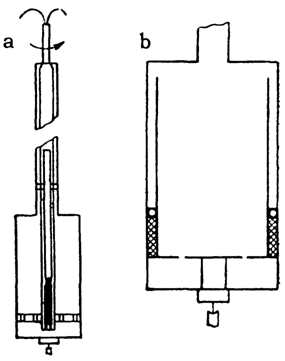


FIG. 5. Apparatus in which helium is allowed to move along the vortex lines: a—flowing out of a central tube, b—flowing out of the gap between the outer and inner cylinders.

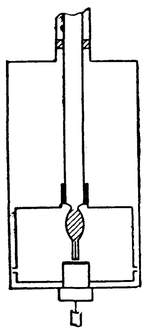


FIG. 6

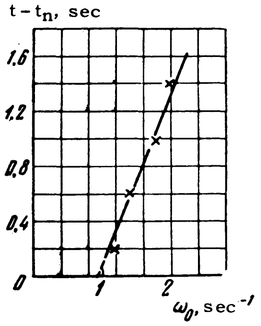


FIG. 7

FIG. 6. Apparatus in which helium flow is perpendicular to the vortex lines in the space between the face of the capillary and the base of the vessel.

FIG. 7. Velocity dependence of the outflow time for the apparatus illustrated in Fig. 6.

again nearly linear, except that its slope is such that the line extrapolates, not to zero, but to a relatively high value of the angular velocity, $\omega_0 \approx 1.5\ \mathrm{sec}^{-1}$. This implies that at this rotational velocity, and with the radius of the inner cylinder $r_1 = 0.5$ cm, the radius r_a of the irrotational region (decreasing with increasing ω_0) must be of the same order as the radius of the gap; i.e., the outer radius of the tube, equal in our apparatus to 0.8 cm. Thus, according to the results of this experiment, the irrotational region has the form of a cylindrical ring with a thickness of the order of $r_a - r_1 = 3$ mm. The theoretical value for this thickness, under the indicated conditions, however, is only 0.55 mm[2].

This disparity between theory and experiment is enhanced when the temperature dependence of the effect is taken into consideration.

Inasmuch as the theory was developed for a purely superfluid liquid, while the measurements were conducted at the relatively high temperature of 1.75°K, it would be expected that the situation would improve at lower temperatures. Experiment shows that the temperature does indeed have a strong effect upon the above-described effect. At a lower temperature, however, for example at T = 1.46°K (see Fig. 4,b), extrapolation leads to the still higher value $\omega_0 \approx 10\ \mathrm{sec}^{-1}$. Here, $r_a - r_1 = 3$ mm is to be compared with the theoretical value $r_a - r_1 = 0.22$ mm [2]; i.e., the disparity is intensified.

Figure 5 illustrates two systems in which the helium, flowing out of the tube, traverses virtually no vortex lines. In those cases the emptying time is essentially independent of angular velocity.

An experiment was also performed which had as its object the detection of an irrotational region in a singly-connected volume; the possibility of the development of such a region was demonstrated in a paper by Kemoklidze and Mamaladze[3]. The first experiment described in the present article tends to refute this possibility (Fig. 2). In that case, however, the gap was extremely broad (the radius of the irrotational zone would be of the same order as the radius of the gap, according to [3], for $\omega_0 \ll 10^{-2}\ \mathrm{sec}^{-1}$), and the small irrotational zone could have no significant effect on the experimental results. An apparatus was therefore constructed (Fig. 6) in which the helium flows out of a fine capillary. In this system, the gap radius is 1 mm. In this case, as is evident from Fig. 7, an irrotational zone is observed having a radius of 1 mm, for $\omega_0 \approx 1\ \mathrm{sec}^{-1}$. From the calculations of Kemoklidze and Mamaladze [3], with such a system, one would expect $r_a = 0.8$ mm at T = 0°K (the experiment was performed at T = 1.38°K, where the helium is virtually all superfluid). In this case, the agreement is better.

The author takes this opportunity to thank E. L. Andronikashvili for his stimulating interest in this work, as well as Yu. G. Mamaladze and M. P. Kemoklidze for discussing the results.

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[3] M. P. Kemoklidze and Yu. G. Mamaladze, JETP **46**, 165 (1964), Soviet Phys. JETP **19**, 000 (1964).

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