Rotation of Helium II at High Speeds

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1. IN uniform rotation a viscous liquid forms a parabolic meniscus whose depth depends only on the angular velocity and the radius r of the container

$$h = r^2\omega^2/2g, \tag{1}$$

where h is the depth of the meniscus and g is the acceleration due to gravity.

Since the superfluid component cannot perform motion in which curl $V_s \neq 0$ (as is proved by Landau's theory[1]), He II must be regarded as the only liquid whose meniscus depends on the density of its normal component, or, in the final analysis, on its temperature. Actually, in this case, the force which acts radially on a volume element of the liquid depends upon the density ρ_n of the normal component, while the force of gravity acting upon the same volume element is proportional to ρ (the density of the liquid as a whole). Therefore, the depth of the meniscus for He II must be expressed by the formula

$$h = \frac{\rho_n}{\rho}\frac{r^2\omega^2}{2g}. \tag{2}$$

2. We devised the following experiment to test this assumption[2]. A cylindrical plastic vessel, having an inner diameter of 27 mm and height 70 mm was turned on a lathe and then carefully polished. The base of the vessel was reinforced in a miniature ball bearing and ball thrust bearing pressed into a corresponding holder. (The glass and its base were regarded as a unit since it was turned from one piece of material, and the position of any component in the chuck of the lathe did not change during the entire machining process.) The apparatus was placed inside a helium dewar. Liquid helium was ladled into the container, after which it was rotated by means of a mechanical drive connected to a motor. The experiments covered the velocity range from 0.5 to 5 rev/sec, which, for the given radius, corresponds to 4 to 40 cm/sec for the tangental velocity of the glass. The depth of the meniscus was measured by a cathetometer and its shape was recorded with photographic equipment.

In this velocity range the depth of the meniscus was independent of the temperature and did not depart from the meniscus depth of normal liquids. This fact suggests that the expected phenomenon was not observed because of a transition through the critical velocity. Osborne[3] obtained similar results later and independently by carrying out a similar experiment for the velocity internal 35 to 70 cm/sec.

However, careful examination of the shape of meniscus enabled us to observe certain details not noted by Osborne. These details suggest that, even in the region of transcritical velocity, He II behaves very differently than a normal liquid.

Thus it was established that the meniscus which corresponds to speeds of rotation of 5 rev/sec has a conical recess at its center (Fig. 1) which is not found in normal liquids, including He I. Two cases were noted in which the meniscus was in a short time transformed into a vortex which extended to the edge of the container. However, it was not possible to record these on film. Also, we did not succeed in defining the precise conditions which led to the onset of such a vortex. Consequently, the vortices were not reproducible. Also not entirely normal was the process of untwisting, in which the peripheral part of the liquid was carried quickly along by the vessel and rose up, while the center part of the liquid continued to remain plane for about 120 sec. In the untwisting, the central part of the liquid had a conical meniscus which was maintained on the surface of the He II for 30 sec (Fig. 2).

3. All these facts suggest that in the critical region the superfluid condition is distorted, but does not vanish as such. Therefore, for a further study of this phenomenon, it was important to choose an experiment in which one of the characteristic properties of the superfluid would be displayed visibly. We chose the fountain effect for this purpose.

The experiment was carried out with the arrangement described above, with this difference, that a glass capillary, of length 148 mm and internal diameter 1.2 mm, was fastened along the axis of the cylinder. The lower part of the capillary was packed with iron oxide rouge. The

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[2] E. L. Andronikashvili, Dissertation, Inst. Phys. Problems, Academy of Sciences, USSR (1948)

[3] D. V. Osborne, Proc. Phys. Soc. (London) 63A, 909 (1950)

Dependence of the quantities in the thermomechanical effect on the rotational velocity at different temperatures*

p pressure in mm Hg.	T^0K	n_1	h_1	n_2	h_2	n_3	h_3	n_4	h_4	n_5	h_5	n_6	h_6
30	2.1	0.24	135	1.6	134	3.3	135	6.8	135	12	135	16.2	135
20	1.95	0.24	120	2.2	120	4.8	120	7.1	120	10.5	120	17.2	120
10	1.74	0.24	105	1.6	105	5.2	105	8.5	105	10.8	105	15.5	105

* n = number of revolutions/sec; h = height of fountain of He, in mm of mercury.

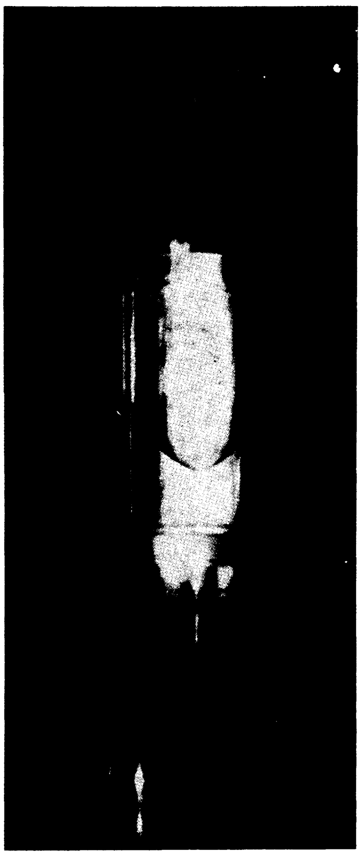

Fig. 1. Meniscus of Rotating Helium II

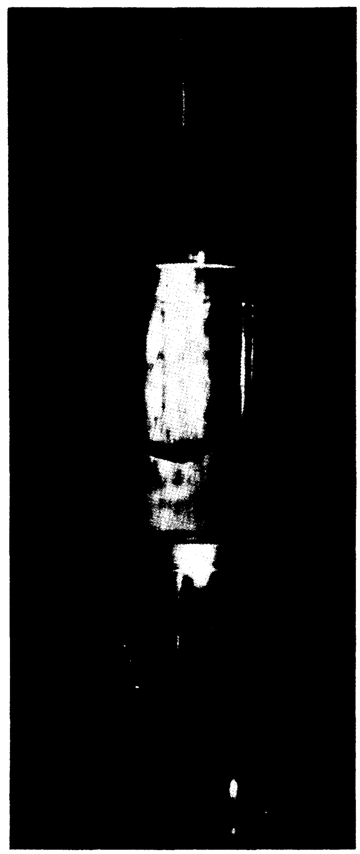

Fig. 2. Meniscus of Rotating Helium II in the "Untwisting" process

capillary was rotated with the vessel.

Upon immersing the apparatus in liquid helium, a beam of light was directed on the rouge plug. As a result, a difference in level was established between the liquid in the capillary and in the container. This difference was measured by a cathetometer. Then the container was rotated. Under these conditions there was a lowering of the level of He II in the capillary by an amount which, in the limits of error of the experiment, did not differ from the displacement of the central part of the meniscus which was brought about by the rotation. This experiment covered the velocity range from 0.25 to 22 rev/sec and was repeated at different temperatures. The light intensity (which supplied the heat) was chosen separately in each case. As is evident from the table, the dependence of the thermomechanical effect on the rotational velocity is not observed up to velocities of 16 rev/sec, which corresponds to tangential speeds of 136 cm/sec.

In another experiment, this same capillary, rigidly fixed independently of the vessel, was displaced along its radius, thus playing the role of a stirrer. However, even in this case, the total rise of He II in the capillary changed insignificantly for a velocity change of 160 cm/sec.

From these experiments it follows that, in the transition through the critical velocity, the superfluid phenomenon not only does not disappear but that the quantitative characteristics, such as the thermomechanical effect and the quantity ρ_n/ρ connected with it, remain unchanged, and independent of the velocity of rotation, within the limits of error of measurement, up to very large velocities. It is thus possible to confirm that in the region of critical velocity the superfluid component maintains motion for which curl $\mathbf{v}_s$ differs from zero.

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Collisions of Fast Nucleons with Nuclei

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IN the investigations of collisions of nucleons and mesons (with energies of the order $10^{10} \div 10^{12}$ ev) with nuclei one occasionally finds the entire process with its attendant generation of new mesons (and possibly new nucleon pairs) represented as a cascade process within the nucleus or, in any case, as a process of successive collisions of the incident particle within the nucleus; the emission of new formed particles and nucleons being produced by the nucleons situated along the collision path. Occasionally, detailed calculations are exhibited which are based on the fact that after the collision, the primary particle and its products move through small angles relative to the initial direction of motion of the particle[1].

Nevertheless one cannot forget that, because of the wave properties of the particles, this view may be internally inconsistent. Let us consider, for example, the collision of two nucleons which produces in one event ν mesons, each with a mass μ and energy ϵ. If the collision cross section is of the order of π/μ^2 (where $\hbar = c = 1$, in the following) then the mean impact parameter is $1/\mu$, the momentum $q_\perp$ in the perpendicular direction, which is transferred to the nucleon by emission, has the order of μ and the energy carried away by these nucleons should be, on the average, comparatively small. Consequently, if we consider the momentum $q_\parallel$ in the longitudinal direction, which is transferred to the nucleon by emission, we can write

$$q_\parallel \approx \sqrt{E^2 - M^2} - \sqrt{(E-\varepsilon\nu)^2 - M^2}\cos\theta_M - \nu\sqrt{\varepsilon^2-\mu^2}\cos\theta_\mu \tag{1}$$

$$\approx \frac{M^2\nu\varepsilon}{2E(E-\nu\varepsilon)} + \frac{\nu\mu^2}{2\varepsilon} + \frac{1}{2}\left(\theta_M^2(E-\nu\varepsilon) + \theta_\mu^2\nu\varepsilon\right).$$

Here θ_M and θ_μ are the emergent angles of the nucleon and the mesons, and are considered small; in addition, all particles are assumed relativistic. Further considerations depend upon the emergent angles of the particles. Thus for example,

a) one occasionally assumes that

$$\theta_M \sim \theta_\mu \sim M/E. \tag{2}$$

It is easily seen that in this case, with sufficiently high energies, the quantity $q_\parallel$ can become quite small. Thus the effective extent of space within which the process occurs equals, according to the uncertainty relation, $1/q_\parallel$, and can become substantially greater than the extent of the core of