SOME PROPERTIES OF THE CENTRAL MACROSCOPIC VORTEX IN ROTATING HELIUM[1)]

D. S. TSAKADZE

Physics Institute, Academy of Sciences, Georgian S.S.R.

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New quantitative data are presented on the properties of the Andronikashvili vortex formed in rotating boiling He I, on its survival in He II, and on the shape of its meniscus.

1. As has already been reported[1], the central macroscopic vortex whose formation in rotating helium was first noted by Andronikashvili[2] arises in rotating He I when the latter is in a state of intense boiling. It was also shown that this vortex represents a classical phenomenon, not related to the specific properties of liquid helium, and the mechanism of its formation was described.

One property of the Andronikashvili vortex is of particular interest—its survival for a considerable period in He II under the condition that the He I – He II transition takes place without interruption of the rotation. This unique phenomenon demands further investigation. The present article describes the results of a series of experiments designed to study this as well as other properties of the Andronikashvili vortex.

2. In the helium bath were situated three glass cylinders, sealed off at their lower ends and having inside radii of 1.40, 2.45, and 5.05 mm, respectively. The cylinders were all of the same height, 120 mm. The ends of the cylinders were fitted tightly into individual machined duraluminum sockets (Fig. 1). These sockets, in turn, were supported by radial ball bearings. Each of the three cylinders communicated with the helium bath via openings two millimeters in diameter drilled in their metal covers.

The central cylinder is set into rotation by means of a glass axle (driven by a metal shaft passing downward through a packing gland), and the rotation is transferred to the two remaining cylinders through coil spring drive belts. The cylinders all rotate in the same direction at the same rate. The rotating beakers, filled to a specified level with liquid helium, are readily viewed through slits left in the silvering of the Dewars in the light transmitted from a fluorescent lamp.

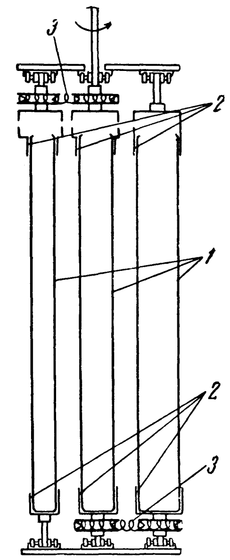

FIG. 1. Diagram of the apparatus: 1—glass cylinders; 2—duraluminum sockets; 3—spring belt drives.

Observations were also made using transparent plastic beakers having internal radii of 12.5 mm and 21 mm, with highly polished surfaces.

3. Measurements were made of the lifetime of the Andronikashvili vortex in rotating He II as a function of rotational velocity (for constant diameter of the rotating beaker) and of the beaker radius (at constant rotational velocity).

These experiments showed that at a rotational velocity $\omega_0 = 73.5\ \mathrm{sec}^{-1}$, the disappearance of the Andronikashvili vortex in the cylinder of smallest radius begins immediately and is complete by 2—3 sec after the transition through the λ-point. In the 2.5 mm radius cylinder, the same process requires 7—9 sec, while in the cylinder of 5 mm radius the disappearance of the vortex takes 14—15 sec. In the 12.5 mm radius cylinder, the vortex lasts for 70 sec following the transition of the rotating helium through the λ-point. For the lower rotational velocity $\omega_0 = 51\ \mathrm{sec}^{-1}$ the survival time for the vortex is correspondingly reduced. In this

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case, the vortex lasts for 70 sec in the beaker of 21 mm radius (it should be mentioned that this beaker could not be used at $\omega_0 = 73\ \mathrm{sec}^{-1}$, due to the excessive depth of the meniscus).

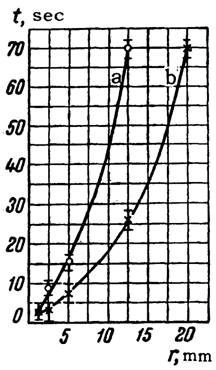
Figure 2 presents curves relating the survival time t of the Andronikashvili vortex in He II to the radius of the rotating cylinder at $\omega_0 = 73.5\ \mathrm{sec}^{-1}$ (curve a) and at $\omega_0 = 51\ \mathrm{sec}^{-1}$ (curve b).

As is evident from the curve in Fig. 3, representing the 12.5 mm radius beaker in rotation, the survival time for the vortex at constant radius is a nonlinearly increasing function of the rotational velocity.

Contrary to the assertion by Donnelly, et al.[3] that the formation of a central macroscopic vortex may also be observed in He II, we were unable to detect this phenomenon, despite the wide variety of rotational conditions employed. Specifically, we studied rotation at constant temperature, with increasing and decreasing rotational velocity, rotation at different accelerations (in both sign and magnitude), rotation at constant velocity with varying temperature, and rotation near to and well away from the λ-point. The central macroscopic vortex could only be observed in rotating He II when it had initially been formed in rotating He I.

4. The experiments showed that, other conditions being equal, the Andronikashvili vortex is formed at higher temperatures in the cylinders of larger radius. With a rate of reduction of bath pressure amounting to 8 mm Hg per second, and a rotational velocity $\omega_0 = 60\ \mathrm{sec}^{-1}$, the vortex is formed in the 21 mm radius cylinder at a temperature of 3.2—3.3°K, while in the beaker of 2.4 mm radius, vortex formation takes place just above the λ-point (cf. Fig. 4). This fact confirms the validity of the mechanism for vortex formation described in [1]. The volume of liquid contained in a cylindrical vessel increases as the square of its radius. The number of gas bubbles formed per unit time likewise increases quadratically, facilitating the formation of a hollow along the axis of rotation. An increase in the radius of the rotating beaker thus plays the same role as an increase in the pumping rate: it reduces the time required for the formation of the central vortex.

5. It is of interest to express in analytical form the configuration of the meniscus in a rotating fluid containing an Andronikashvili vortex. An ap-



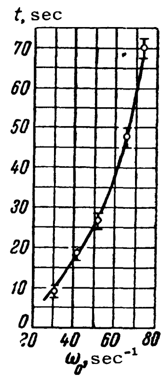


FIG. 2. Survival time of the Andronikashvili vortex versus beaker radius. Curve a—rotational velocity $\omega_0 = 73.5\ \mathrm{sec}^{-1}$; curve b—$\omega_0 = 51\ \mathrm{sec}^{-1}$,

FIG. 3. Survival time of the Andronikashvili vortex versus rotational velocity (for a beaker of 1.25 cm. radius).

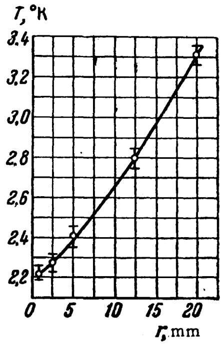


FIG. 4. Curve illustrating the relation between the temperature at which the Andronikashvili vortex is formed and the beaker radius ($\omega_0 = 60\ \mathrm{sec}^{-1}$).

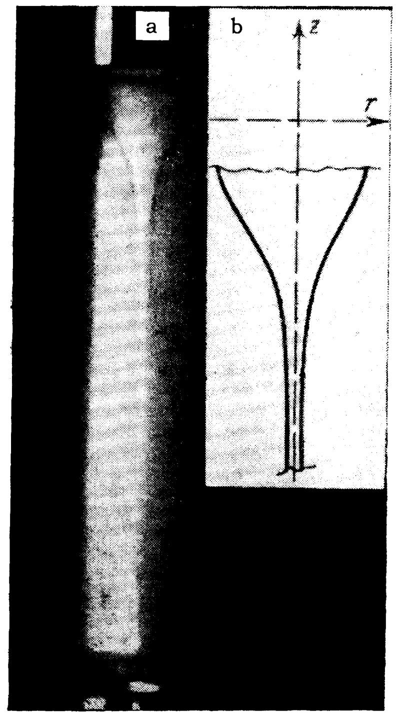


FIG. 5. a—photograph of the Andronikashvili vortex in He II ($\omega_0 = 51\ \mathrm{sec}^{-1}$, r = 1.25 cm); b—form of the meniscus in He II containing a vortex for $\omega_0 = 51\ \mathrm{sec}^{-1}$ and $\Gamma = 10\ \mathrm{cm}^2/\mathrm{sec}$, computed from Eq. (1).

proximate formula derived by Yu. G. Mamaladze and corresponding to the law of rotation

$$v = \omega_0 r + \frac{\Gamma}{2\pi}\left(\frac{1}{r} - \frac{r}{R^2}\right)$$

has, neglecting surface tension, the form

$$z = -\frac{1}{g}\left[\frac{1}{2}\left(\omega_0 - \frac{\Gamma}{2\pi R^2}\right)^2 (R^2 - r^2) + \frac{\Gamma^2}{2\pi^2}\left(\frac{1}{r^2} - \frac{1}{R^2}\right) + \frac{\Gamma}{\pi}\left(\omega_0 - \frac{\Gamma}{2\pi R}\right)\ln\frac{R}{r}\right], \quad (1)$$

where z and r are the coordinates of a point on the surface of the meniscus (z is measured from the level at which the meniscus meets the wall of the vessel; since the z axis is directed upward, all values of z are negative), g is the acceleration of gravity, Γ is the circulation, and R is the radius of the vessel.

The form of the meniscus in rotating He II containing vortex (with a liquid rotational velocity $\omega_0 = 51\ \mathrm{sec}^{-1}$) is shown in Fig. 5a; Fig. 5b represents the meniscus configuration calculated in accordance with Eq. (1) for this rotational velocity and using the empirically determined value $\Gamma = 10\ \mathrm{cm^2/sec}$.

The vortex temporarily existing in He II thus possesses (at $\omega_0 = 51\ \mathrm{sec}^{-1}$) a circulation of the order of 10^4 quantum units $2\pi\hbar/m$. As it decays further, it can generate 10^4 vortices of unit circulation.

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