Properties of rotating helium

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(Submitted June 16, 1974)
Zh. Eksp. Teor. Fiz. 67, 1984–1988 (November 1974)

Experiments are described on torsional vibrations of a rotating light cylinder suspended by a thin fiber and containing helium. Undamped torsional vibrations with beats are observed and are apparently related to pendulum vibrations. The behavior of the cylinder is consistent with the assumption that a vortex lattice is present in rotating helium. Experiments with a float in the rotating helium are also described. In some cases the float remains on the surface in the center of the rotating tube for over an hour, and its angular velocity is lower than that of the tube. Not infrequently it also rotates in the opposite direction for several minutes.

1. Rotating superfluid helium has been the subject of numerous investigations, both experimental (Andronikashvili, Hall, Vinen, Tsakadze, and others), and theoretical. The quasiclassical concept of quantization of vortices has greatly clarified the situation, but much still remains unclear. Therefore experiments in this direction, particularly observations of the vortex lattice, still remain timely.

2. The first series of experiments undertaken to observe the vortex lattice was carried out in Vinen's laboratory in Birmingham, using apparatus that was kindly placed at my disposal by Professor Hall. The principal part of the apparatus was a rotating reference system consisting of an illuminator, a mirror, and a photoresistor, which made it possible to record mirror rotations smaller than 0.1 rad. The instrument was rotated by a synchronous motor and the stability of the rotation was close to 10^{-5}. This instrument made it possible to register slow torsional oscillations of a thin-wall cylinder suspended from the mirror in rotating helium. The mirror, on the other hand, was suspended on a bronze wire of 0.025 mm diameter, and the period of the torsional oscillations of the cylinder was about 1 min.

It was expected that, after the cylinder oscillations in the rotating helium become sufficiently small, a vortex lattice would be produced in the helium [1], and the transverse waves in the lattice would lead to a change in the natural oscillations of the cylinder—beats would be produced, and the torsional vibrations of the cylinder would attenuate after a few minutes [2]. The velocity of the transverse waves in the rotating helium at $\Omega = 1.24$ rad/sec is $s = {}^1/_2(\hbar\Omega/m)^{1/2} = 0.07$ mm/sec, so that the period of the natural oscillations of the rotating helium was ~ 2 min and less. The temperature (1.75°K) was chosen such that the pinning of the vortices to the cylinder by the normal component was strong enough.

It turned out, however, that the torsional oscillations of the cylinder remain practically undamped for at least an hour. Irregular beats were then observed. A fragment of the plot of the oscillations of the cylinder is shown in Fig. 1. The amplitude of the oscillations does not exceed 5°, and the angular velocity is $\Omega = 1.24$ rad/sec. The Fourier transformation of the entire hour-long curve is shown in the same Fig. 1. The undamped oscillations are apparently connected with the pendulum oscillations of the cylinder, which could not be eliminated. It should be noted that when the cylinder rotates in helium vapor, the damping corresponds to viscous losses in the gas. The damping was also normal in the case of cylinder oscillations in superfluid helium in the absence of rotation.

The undamped oscillations with irregular beats were observed during the rotation of the helium up to angular velocities $\Omega = 2.5$ rad sec, but no regularity was observed in the beats. We note that control experiments above the λ point are impossible because of bubble formation in the helium.

In September 1967, the experiments were stopped and the frequency dependence of the Fourier spectra of the oscillations was left unexplained. Incidentally, it was difficult to hope for this, owing to the presence of pendulum oscillations of the cylinder. It is clear only that the result does not contradict the assumption that a vortex lattice exists. The report of observation of the oscillations of this type have already appeared in print [3].

3. In the spring of 1973, experiments of the described type were continued. This time, a Plexiglas vessel with inside diameter 29 mm, 9 mm length, and 6.1 g weight was mounted on a galvanometric suspension with torque 0.18 mg-cm/90° on the shaft of an electric motor (SD-54) and was located in rotating helium vapor. The vessel was filled with helium via the thermomechanical effect. A mirror was mounted on the vessel and its torsional oscillations were registered with a photoresistor and a simple RC network feeding a relay, by measuring the time interval between the signals from the light beam and a reference signal. The reference signal was picked off an SD-54 synchronous

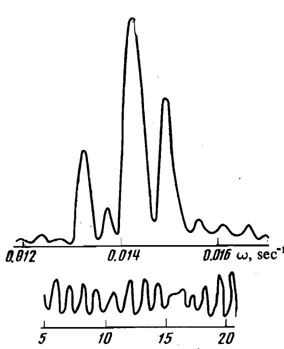

FIG. 1

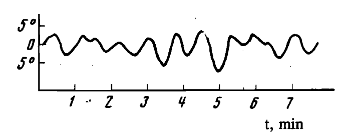

FIG. 2

FIG. 1. Plot of oscillations of cylinder (first series of experiments); instrument angular velocity $\Omega = 1.24$ rad/sec, T = 1.74°K. Top—Fourier transform.

FIG. 2. Plot of cylinder oscillations (second series of experiments; $\Omega = 6.1$ rad/sec; T = 1.35°K.

motor connected in parallel to the main motor and fed from a GZ-33 generator.

Again, the pendulum oscillations of the vessel led to undamped torsional oscillations (Fig. 2). In the absence of helium in the vessel, the torsional oscillations were exponentially damped to the noise level 0.5°. On the whole, the experiments yielded nothing new in comparison with those described in Sec. 2.

4. To get rid of the pendulum oscillations, it was decided to forgo completely the suspension and to use a foam-plastic float. It was hoped that it would float at the center of a rotating tube, and then its small oscillations, superimposed on the rotation, would make it possible to observe the transverse waves in the rotating helium. The experimental result, however, turned out to be unexpected.

But let us first describe the instrument (Fig. 3). A glass tube 1 with inside diameter 43 mm and length 38 cm, with sealed bottom, was mounted on its lower part on a corundum needle 2, mounted on a brass cup 3 in which the glass tube was inserted. The needle was supported by a thrust bearing 4 of stainless steel, which was secured in the cap with the aid of stainless-steel tube 5. In the upper part, the glass tube was connected through a brass holder 6 with a rod 7 connected to the synchronous motor SD-54. The deviation of the rotation axis from vertical did not exceed 1—2°. The helium in the glass tube could be poured with the aid of the thermomechanical effect via the volume 8, which was filled with fine powder. The foamed-plastic float 9 had a diameter 9.5 mm and length 12 cm. Its weight was 0.2 g. A glass mirror 10, measuring 6 × 30 × 1 mm and weighing 0.6 g, was secured to the lower part of the float. The distance from the mirror to the bottom was usually not less than 10—15 cm. As a rule, one float was sufficient for two days' operation with helium, after which it deteriorated. The greater part of the experiments was performed at temperatures 1.34—1.37°K and at an angular velocity 5.1 rad/sec, corresponding to 25 Hz supply frequency.

Prior to the start of the rotation, the float touched the walls of the tube as a rule. After the start of rotation, it moved away from the wall and, rotated slowly along a spiral, and approached the center of the tube. After 2—3 minutes, it was already at the center of the tube (accurate to 1 mm) and it was possible to follow its rotation. The angular velocity was measured visually. The accuracy of this measurement was 10—20%.

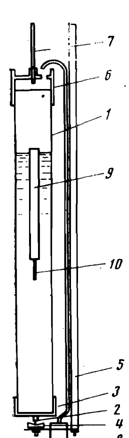

FIG. 3. Diagram of instrument with float.

The following picture was frequently observed: during the fifth—sixth minute, the float velocity approached the tube angular velocity, and then for one or two m minutes it decreased to one third this value. The float was at that time within 1 mm of the center of the tube. It gradually started to drift from the center of the tube and return to it again. At approximately the 15th minute, the deviation from the center reached sometimes 5 mm. This behavior was observed for more than an hour without any tendency to become stationary.

During one day, the behavior of the float, as a rule, was reproducible, but there were days when approximately in half the cases an even stranger picture was observed. Figure 4 shows a plot of the angular velocity of the float against the time. For some time it rotated in the opposite direction, when it managed to execute several dozen revolutions. It then began to rotate forward. Approximately in the 13th—15th minute, its deviation from the center reached 5 mm, and the end of the curve in the figure corresponded to the float reaching the wall of the tube. The angular velocity of the tube was 5.1 rad/sec. The curves usually were not reproducible from case to case in detail, owing in particular to differences in the manner with which the float approached the center at the initial instant of rotation. Taking the foregoing into account, the dependence of the effect on the temperature should be regarded as insignificant. The duration of the rotation in the opposite direction frequently reached five minutes, and at one time even exceeded one hour. It was frequently observed that the angular velocity of the float was equal to zero for ten minutes. The float then moved in translation along a periphery of 1 mm diameter at the angular velocity of the tube. When the tube angular velocity was increased by 2%, the float started to rotate forward, deviating even more from the center, and reached the wall of the tube after one and one half minutes.

It was impossible to reduce significantly the rotary velocity. At the same time, at large velocities (for example 6.1 rad/sec), no rotation in the opposite direction was observed even once, and the float reached the wall within only a few minutes after the start of rotation. In the case when the lower part of the tube was partitioned with paper, the float reached the wall already within one minute, so that the processes occurring in the lower part of the tube play an important role.

While the parameters of the apparatus remained the same from one day to another, the character of the curves, as already noted, varied. The author can propose no explanation for this effect. This question obviously calls for further study.

We present one more experimental fact. After the

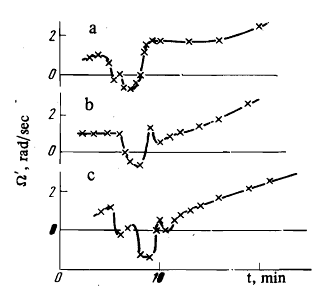

FIG. 4. Dependence of the angular velocity of the float on the time. Helium angular velocity Ω = 5.4 rad/sec. a) T = 1.37 K (ρ_n/ρ = 0.066); b) T = 1.60 K (ρ_n/ρ = 0.17); c) T = 2.06 K (ρ_n/ρ = 0.65).

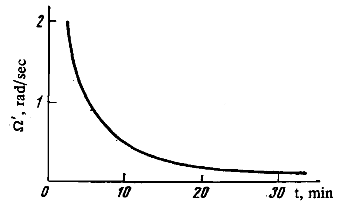

FIG. 5

rotation was stopped, the float moved away from the wall and found itself at the center after 2–3 minutes. In a number of cases it remained at the center for a half hour, and its angular velocity increased gradually (Fig. 5). Ultimately it found itself again at the wall.

5. There are still no satisfactory explanations of the observed facts. It is no longer clear why the floats at the center. As to the reverse rotation of the float, there is no doubt that it is connected with the presence of negative-circulation vortices in the helium. In the initial period of rotation, the concentration of the vortices in the helium exceeds the equilibrium value, so that vortices of both signs are present. Were it possible to prove that the vortices of negative circulation tend to concentrate at the center, this would explain the effect.

Another picture is also possible (A. F. Andreev). The float is first set to rotate because of the normal component. It then generates vortices of precisely negative sign. They subsequently can cause it to rotate in the opposite direction.

It is possible that the observed effect is connected in some way with vibration induced in the instrument by the motor. In any case, the waves on the surface of the helium in the tube reached at times 2–3 mm.

I am grateful to V. F. Gantmakher for support of my experimental activity, to Yu. F. Sharvin, A. F. Andreev, and S. V. Iordanskiĭ and V. N. Popov for a discussion of the work and to V. P. Peshkov for critical remarks.

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Translated by J. G. Adashko
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