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HYDRODYNAMIC INSTABILITIES IN THE ROTATING COUETTE FLOW OF SUPERFLUID HELIUM

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INTRODUCTION.- We present an experimental study of the different flow regimes of superfluid helium in the Couette geometry. We have measured the attenuation of second sound resonances with the rotation velocity for different temperature values and spacings between cylinders. Three flow regimes leading to turbulent flow have been successively identified.

EXPERIMENTAL PROCEDURE.- Experimentally, we measure the Q's of second sound resonances in the space between cylinders. In contradiction to references /2/ and /3/, to study the case \( d \ll R_2 \), we chose to use resonances corresponding to an orthoradial propagation along the perimeter of the cylinder. For these modes, if \( d \ll R_2 \), the resonance condition is \( \Pi (R_1 + R_2) = n \lambda (n \text{ integer}) \); hence their frequencies do not depend on \( d \) and the noise level is minimized even on rotation. The second sound is emitted and detected by 4 aluminized mylar foil strips parallel to the axis of rotation. These strips produce a very uniform second sound field; hence the pure orthoradial modes are the only ones observed up to the frequency of the first radial mode; the Q values are of the order of 2000.

DOPPLER SPLITTING OF ORTHORADIAL RESONANCES.- Figure 1 shows the output of a spectrum analyser connected to the receiving strips. The frequency is swept across an orthoradial resonance for different rotation rates. We see that the resonance splits into two components more and more separated and attenuated as the rotation velocity increases. This splitting effect is due to the difference in velocity between sound propagating in the direction of helium flow and in the opposite one; it is proportional to the flow velocity. Contrary to reference /4/, the velocity is not uniform and the eigenmodes are not plane waves. We solved the problem by numerical integration of the equations of motion. The agreement between the theoretical and experi-
mental results is better than 1% if a laminar velocity profile with \( v = v_n \) is assumed for the mean flow. We cannot compute directly the attenuation form amplitude measurements since the two resonances components partially overlap. Therefore, we used a Kennelly circle method \( ^/5/ \) implying a computer analysis of the data.

**ATTENUATION MEASUREMENTS RESULTS.**—Figure 2 shows a typical variation with the angular velocity of the extra attenuation \( 1/Q(O) - 1/Q(O) \) due to rotation. Below a velocity \( \Omega_1 \) there is no extra attenuation. Hence \( \Omega_1 \) marks the onset of a vortex penetration into the space between cylinders.

At higher velocities, a sharp slope change occurs at a critical velocity \( \Omega_2 \) and a smoother one around a third value \( \Omega_3 \). In order to identify these different flow regimes, we have compared the experimental slopes \( n = d \left( \frac{1}{Q} - \frac{1}{Q} \right) / d \theta \) to the theoretical slope \( n_{th} = \frac{B R^2}{2 \omega_0^2 \left( R^2 - R^2 \right)} \) excitation frequency, B mutual friction coefficient) which corresponds to an arrangement of straight filaments parallel to the rotation axis. The remarkable feature is that the ratios \( n_{th} \) are independent of both \( d \) and \( T \) and are approximatively equal to 1,2 and 3 in the three flow regimes above \( \Omega_1 \). So, the first flow regimes between \( \Omega_1 \) and \( \Omega_2 \) (figure 2) corresponds to an arrangement of parallel vortices. We believe that in the second regime appears an hydrodynamic instability (similar to Taylor cells) distorting the vortices and increasing their length. With a model using the Landau transition theory, we showed that the extra attenuation increases linearly as \( \frac{\Omega - \Omega_2}{\Omega_3} \) above \( \Omega_2 \), with coefficient independent of \( d \) and \( T \). The \( \Omega_2 \) values are lower than the classical Taylor value for the normal fluid but the disagreement is smaller as \( d \) decreases and viscosity forces become more important. Above \( \Omega_3 \), appears a more disordered turbulence initiated by the normal fluid in which vortices have random orientations; this is supported by the value of the critical Reynolds number which is about 5000 for all \( d \) and \( T \) values. Of course, it will be necessary to precise these results and especially to obtain further proofs of the existence of a secondary cell flow above \( \Omega_2 \).

**References**

/1/ Taylor, G.I. Phil. Trans. A 223 (1923) 289