VORTEX PHOTOGRAPHY : A PROGRESS REPORT

M. Gordon, G.A. Williams, R. Packard

JOURNAL DE PHYSIQUE Colloque C6, supplément au n° 8, Tome 39, août 1978, page C6-172

VORTEX PHOTOGRAPHY : A PROGRESS REPORT

M.J.V. Gordon, G.A. Williams+, and R.E. Packard,

University of California, Berkeley, California 94720, U.S.A

Résumé.- Nous communiquons quelques observations qualitatives de configurations de vortices dans He II. Des photos démontrent directement des configurations stables et régulières de vortices que s'accordent aux prédictions théoriques.

Abstract.- We report some qualitative observations of vortex arrays in He II. Direct photographs show stable, regular arrays of vortices similar to predictions from theory.

Several years ago a technique was developed which produced photographs of the positions of quantized vortex lines in liquid helium /1/. In the method electrons produced by a tritium source are trapped onto vortex lines. When sufficient charge has accumulated, the electrons are pulled along the vortex lines and emerge through the free surface of the helium. Above the surface, the electrons are accelerated into a fiber optics faceplate covered with a thin phosphor coating. Light patterns produced at the phosphor correspond to the positions of the vortices where they intersect the free surface of the helium. The optical signal is carried up to room temperature by coherent fiber optics. In order to prevent scattering of the electrons by helium vapor above the liquid surface, the temperature must be kept below 200 mK. Small quantities of ^{3}He ($\sim$1 %) are added to the ^{4}He to provide a small amount of normal fluid which tends to damp the vortex motion.

In the early work although only a few photographs could be taken during several hours of rotation it was found that the vortices appeared to be moving in the rotating frame and no stable patterns were detected. In an attempt to study the dynamics of the vortices the original rotating apparatus has been coupled to a low light level television system which permits one photograph to be taken every 10 seconds. (It takes 10 s to accumulate sufficient charge to produce a detectable image). The television output is recorded on a single frame of a movie film and playback of the film produces a time lapse picture of the vortex motion. In typical films some vortices seem to remain localized while others appear intermittently at seemingly random positions. When the film is viewed at 18 frames/s there is no apparent regular array of vortices. However, if the film is projected onto photographic paper and an N-fold multiple exposure is recorded, thus integrating many hours of constant speed rotation, a regula geometric pattern emerges.

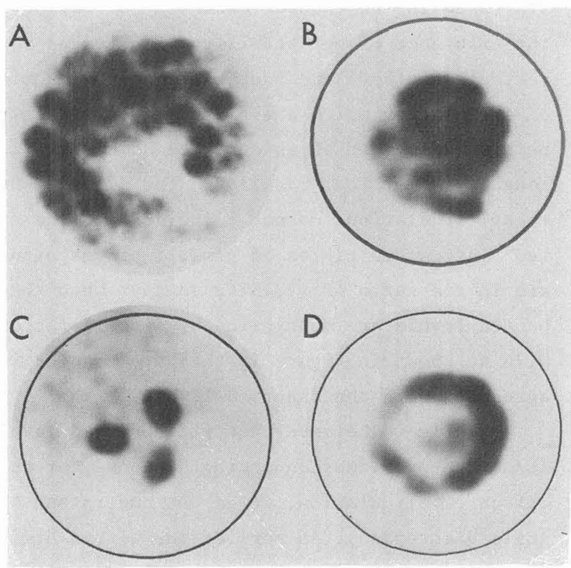

Fig. 1 : This figure shows some representative integrated pictures taken from two different diameter cylindrical vessels. Picture A was taken with a cylinder of 3.1 mm diameter, B,C and D with a cylinder 2 mm in diameter. Picture A was made at a rotation speed of ω = 0.5 s^{-1}, B at ω = 0.9 s^{-1}, C at ω = 0.3 s^{-1}, and D at ω = 0.55 s^{-1}. In pictures B, C and D the drawn circle indicates the cylinder size. The circle's placement was made symmetric to the apparent pattern. The field of view in B,C and D is greater than the cylinder but in A it is slightly smaller.

The figure shows seceral examples of integrated pictures recorded under different condi-

+ Present address : University of California, Los Angeles, California, U.S.A.

tions /2/. The dark regions correspond to the presence of vortex lines. From several hundred such integrated pictures representing more than 10^5 individual pictures we can make the following preliminary remarks.

1. The lines tend to form stable concentric ring patterns. For example, in pictures A,B and C there are fairly distinct dots which are arranged in patterns suggestive of a regular array. In particular in A and B there appear to be concentric (although incomplete) rings.

2. The vortex positions in the integrated pictures often appear blurred presumably because of motion of the lines. We do not know the cause of this motion. Both zero-point motion /3/ and thermal motion of lines are too small to be seen. The rotation speed of the cryostat is constant only within 1% and an accelerometer on the system indicates the presence of random vibration noise. These two perturbing influences may drive the system and produce the blurred images. We are currently reducing these noise sources. Since ring patterns are degenerate with respect to azimuthal angle, motion in the θ direction would be a particularly "soft" mode. This may explain why the rings are characteristically blurred in the θ direction yet are radially distinct (eg. picture D).

3. We never find vortices near the buckets' walls. This is direct proof of the vortex free region predicted from theory /6/ and confirmed in other experiments /4/. There appears to be a very strong repulsive barrier extending an appreciable distance into the vessel.

4. In the samples studied thus far (0.8 % ^{3}He in ^{4}He and T $\sim$ 100 mK) the time for the fluid to relax to steady state is 2-4 hours.

5. The number of vortices present is strongly history dependent. For example in one run we recorded ring patterns of 18, 24, and 15 lines all at the same angular velocity but with different rotation histories. This behaviour is expected from numerical calculations /5,6/ which show that several quite different vortex arrays can be metastable at a given speed. The energy barriers between metastable states are probably so large (they involve the energy/length of a line which is orders of magnitude greater than KT) that the lifetimes of these states are much longer than the experiment.

6. We find good agreement between numerical calculations of vortex patterns /6/ and the preliminary integrated pictures. For example, in a multiring pattern of N vortices the observed rings are at the radii predicted and the numbers of vortices in each ring agree (within experimental uncertainties) with the calculations.

References

/1/ Williams, G.A., and Packard, R.E., Phys. Rev. Lett. 33 (1974) 280

/2/ We suspect that the continuous tone photographs may not accurately reproduce in the printing of this volume. Interested readers may see the original prints at the conference.

/3/ Fetter, A.L., Phys. Rev. 162 (1967) 143

/4/ Northby, J.A. and Donnelly, R.J., Phys. Rev. Lett. 25 (1970) 214
Sherk, D.S. and Mehl, J.B., Phys. Rev. Lett. 27 (1971) 1703

/5/ Campbell, Los Alamos Scientific Laboratory, Personnal Communication

/6/ Stauffer, D. and Fetter, A.L., Phys. Rev. 168 (1968) 156