Torsional oscillator studies of rotating ^{3}He-A in a slab

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Abstract

Using a rotating cryostat we have manipulated **l**-textures of ^{3}He-A in a 0.26 mm-thick slab contained in a torsional oscillator. Application of a magnetic field or a counterflow due to rotation lead to a sudden distortion of a uniform texture. The uniformity of the initial texture can be characterized by the resulting shift in frequency and bandwidth of the torsional resonance. With a certain density of vortices induced by rotation a uniform texture can be stabilized even in presence of magnetic. The optimal speed of rotation to prepare a uniform texture while cooling through T_c was found. The critical velocities for the flow-induced textural transition and vortex nucleation are determined.

Key words: superfluidity; texture; ^{3}He-A; vortex

1. Introduction

Superfluid ^{3}He-A is anisotropic and supports a number of different types of quantized vortices and other textural defects. Any stable **l**-texture is a result of a competition of factors such as presence of boundaries, magnetic field, counterflow and topological defects. The ground state for a horizontal slab geometry in zero field is the uniform texture (UT) with all **l**-vectors either up or down. However, when a vertical magnetic field is applied the **l**-vector will, at a critical field H_F, suddenly tip. This transition is called the Freedericksz transition [1].

Our TO is not directly sensitive to the formation of vortices within the sample, however, it is sensitive to macroscopic regions of distorted texture either from magnetic field or counterflow. The tipping of the texture can be seen with a torsional oscillator (TO) as a change in resonant frequency and bandwidth [1]. Our TO contained a slab of ^{3}He-A of radius 5 mm and thickness $D = 0.26$ mm at a pressure of 29.3 bar. Fig. 1 shows a typical transition in uniform texture together with a transition from a sample that has been deliberately made bad. The resulting magnitude of the frequency shift $\Delta\nu$ from the resonance at $\nu_R = 627$ Hz can be used to quantify the uniformity of **l**-texture.

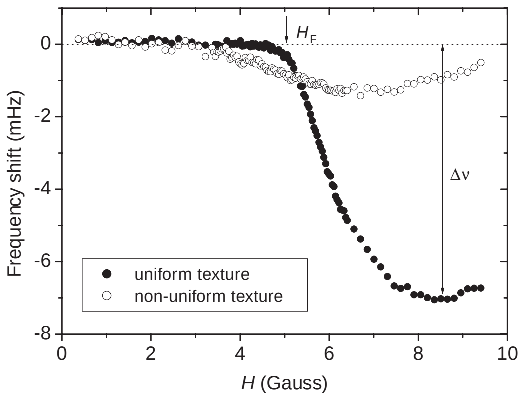

Fig. 1. The frequency shift from resonance of the TO showing the Freedericksz transition as the magnetic field H passes the threshold value H_F: • – most uniform texture; ○ – the “worst” texture obtained by warming from the B-phase.

Previous work [2] has shown that the best textures are created by rotating the sample when it is cooled through T_c. We cooled slowly through T_c at different rotation speeds Ω and stopped at a low temperature. Using the Freedericksz transition as a measure we have found that different Ω resulted in different frequency

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shifts $\Delta\nu$. Subsequent bursts of rotation in the same direction increase $|\Delta\nu|$ up to some limit which we take to indicate the most uniform texture. Fig. 2 shows the $\Delta\nu$ for textures obtained for different rotation speeds without further rotation. Cooling at $\Omega = 0.43 \pm 0.03$ rad/s is seen to produce the most uniform texture.

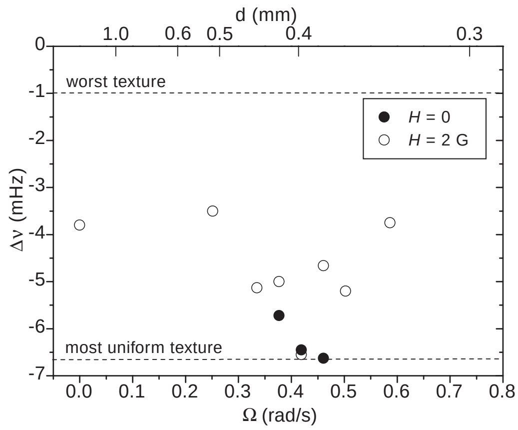

Fig. 2. Characterization of textures obtained on cooling through T_c while rotating by the TO frequency shift. The lowest point (indicating the most uniform texture) at $\Omega = 0.42$ rad/s was reproduced at twelve different cooldowns.

Two different types of vortex are expected in a slab: a singular vortex with a circulation of $\kappa_0 = h/2m_3$; and a continuous Anderson-Toulouse vortex with circulation $2\kappa_0$. While singular vortices do not favour a particular orientation of the texture outside their soft cores, AT vortices of the same type do and hence help stabilize a UT. In a slab in low fields the soft-core radius of AT vortices is of order the slab thickness D. As the intervortex distance is $d = (\kappa_0/\Omega)^{1/2}$, rotating the cryostat at different speeds Ω one can cross over between the limit of weakly-interacting vortices ($d \gg D$) and that of strongly overlapping soft cores ($d < 2D$). One expects that the strongest stabilizing effect for UT would be for the case when the cores are just about to overlap ($d \geq D$). We can speculate that in our geometry at $\Omega = 0.42$ rad/s a substantial fraction of AT vortices is nucleated and for $d > D = 0.26$ mm (top axis in Fig. 2) the soft cores do not yet overlap.

2. Rotation when superfluid

Initially, when samples with UT are slowly accelerated from $\Omega = 0$ the TO response is flat. Only when the flow induced textural transition occurs at $\Omega_{flow} = 0.05$ rad/s does the TO frequency change. The critical velocity for flow alignment is thus $R\Omega_{flow} = 0.25$ mm/s. This slightly exceeds the value calculated for an infinite slab, $\sqrt{5}\kappa_0/4D = 0.14$ mm/s [3]. At a higher speed, $\Omega_c \approx 0.12$ rad/s, the first AT vortices (with the lowest critical velocity) begin to nucleate and move to a vortex cluster at the centre of the sample surrounded by a counterflow belt. As the number of vortices grows the frequency shift decreases because of the shrinking counterflow region.

During deceleration from Ω_{max} the vortex cluster first expands to the perimeter at Ω_{min}. The frequency shift caused by the counterflow belt disappears (Fig. 3). The critical velocity for vortex nucleation is thus $R(\Omega_{max} - \Omega_{min}) = 0.60$ mm/s. This value is close to the one observed for ^{3}He-A in a cylinder [4].

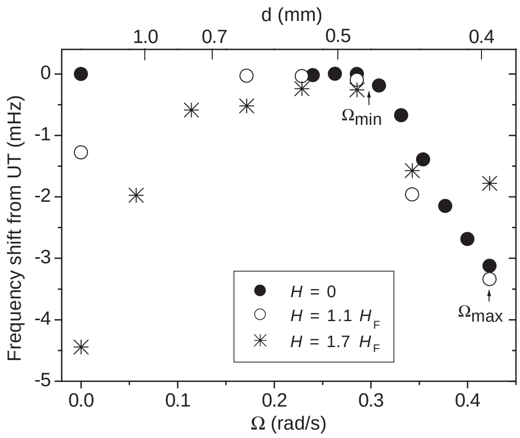

Fig. 3. TO frequency shifts from $\nu_R(H = 0, \Omega = 0)$ showing the interplay between vortices and magnetic field in determining the texture during deceleration of rotation

Further deceleration reduces the vortex density. When $H > H_F$ the texture of a stationary cell is normally distorted, however, the absence of a frequency shift for Ω between 0.3 and 0.2 rad/s indicates the absence of distortion of UT. Only below $\Omega = 0.2$ rad/s (i. e. when $d > 0.6$ mm) does the magnetic field of $9\,\mathrm{G} = 1.7\,H_F$ succeed in distorting the texture.

Acknowledgements

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