Rapid Communication

A Mechanical Measurement of Textural Relaxation in Superfluid $^3\text{He}-A$ at Very Low Temperatures

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We have studied superfluid $^3\text{He}-A$ textures by a mechanical method in the very low temperature limit, $T/T_c \approx 0.14$. The damping of a vibrating wire viscometer is affected by the structure of the $l$-vector texture near the wire. The texture is disturbed by a violent motion of the wire. The relaxation of the texture, back to equilibrium, is then observed through changes in the damping of the wire’s motion.

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The $A$ phase of $^3\text{He}$ is both a superfluid and a liquid crystal. As the only such system known, $^3\text{He}-A$ provides a unique opportunity for testing the interplay of these phenomena. The superfluid energy gap is anisotropic, with polar nodes in a direction $l$. The nodes are aligned with the orbital angular momentum of the superfluids Cooper pairs, and the direction $l$ can vary in real space. The superfluid texture, which describes the liquid crystal aspects of the fluid, consists of the vector field $l$ and an analogous field $d$ characterizing the spin state. Liquid crystal properties, superfluidity, and magnetism all influence the texture through its interaction energies with fluid velocity, electric and magnetic fields, and container walls. These various competing energy contributions determine the statics and dynamics of textures. Identifying the most stable textures and understanding the time...
relaxation of non-equilibrium textures are key steps towards describing the detailed behavior of this anisotropic superfluid.2-4

Recently it was pointed out that the dynamics of textures has several analogs in quantum field theory.5 The parallels should be most prominent at 3He temperatures much lower than the transition temperature $T_c$, where thermal excitations are almost absent. For example, the texture becomes infinitely stiff at $T = 0$, analogous to the zero charge effect in particle theory.5 It is therefore of particular interest to explore the textural properties in the low $T$ limit.

Here we report very low temperature measurements of the time relaxation of a disturbed texture. Previous experiments using nuclear magnetism6 and flow dissipation in porous media7 have studied textural relaxation only near $T_c$. We use a simple geometry with only two forces influencing the relaxation: the inherent textural stiffness, arising from liquid crystal bending energies, and orbital viscosity. Orbital viscosity, an interaction of the liquid crystal with finite-temperature superfluidity, arises because excited quasiparticles tend to cluster in $k$-space near the minimum in the energy gap. As $l$ moves, the quasiparticles diffusively approach the new equilibrium.

Our apparatus, which is described in more detail elsewhere,8,9 consists of a straight, 16 μm diameter, superconducting NbTi wire stretched parallel to the axis of a 3 mm diameter, 50 mm long cylinder. Liquid $^3$He fills the annular space between the wire and outer wall. A nuclear demagnetization cryostat cools the liquid to $T/T_c \approx 0.2$ at ambient pressure of 1.4 bar and down to $T/T_c \approx 0.14$ at 14 and 21 bar. The data presented here were taken at ambient pressure of 14 bar. We observe similar behavior at 1.4 and 21 bar.

The wire is the active element in a vibrating wire viscometer. There is a 35 mT magnetic field perpendicular to the wire's axis. A current pulse pulls the wire momentarily to one side, initiating vibration of the wire in the plane perpendicular to the field. Motion in the field induces a voltage across the wire proportional to its velocity. We measure and record this voltage.

Normally, at such low temperatures, superfluid $^3$He is in the $B$ phase. However, in our experiment a magnetic field of 0.7 T parallel to the cylinder's axis stabilizes the $A$ phase to our lowest temperatures.11 Since this parallel field component is much larger than the 35 mT measuring field, the net field is nearly parallel to the cylinder's axis. In these conditions we expect the equilibrium $l$ and $d$ fields to be simple radial textures centered on the wire and lying in the plane perpendicular to the axis. This texture minimizes several orientational energies by having $d$ perpendicular to the magnetic field, and $l$ normal to the walls and parallel to $d$.

At low velocities in $^3$He–$B$ the wire behaves as a simple harmonic oscillator, with damping proportional to its velocity. A typical quality factor ($Q$) is 400. The damping increases sharply above the pairbreaking velocity,