Spatial extent of quantum turbulence in non-rotating superfluid ^{3}He-B

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Abstract

Quantum turbulence has been shown to reflect a beam of quasiparticles in the B-phase of superfluid ^{3}He by Andreev processes. We have investigated the evolution of the turbulence generated by a vibrating wire resonator driven at high velocities and temperatures down to $\sim 0.1 T_c$. The vibrating wire produces vorticity together with the expected quasiparticle beam whenever the wire velocity exceeds the critical pair breaking velocity. By using an array of detector wires we are able to investigate the development of the turbulence both in space and time. We observe that the turbulence propagates preferentially along the direction of the quasiparticle beam and drops off in a roughly exponential manner with a decay length of the order of 2 mm.

Key words: superfluidity; vorticity; quantum turbulence; helium3

Quantum turbulence has been studied in superfluid ^{4}He for many years. This turbulence takes the form of tangles of quantum vortex lines. Recently, interest has focused upon the decay mechanisms of vortices at very low temperatures where mutual friction becomes negligible. In superfluid ^{3}He-B at temperatures $\sim 110\,\mu$K, it was recently discovered[1] that a vibrating wire moving at speeds in excess of its pair breaking velocity will produce a 'cloud' of quantum turbulence. As part of our investigation towards determining the decay mechanisms in the low temperature regime, we have measured the spatial extent of the vortex cloud using an array of vibrating wires, as shown in Figure 1.

Quantum turbulence in superfluid ^{3}He-B was discovered[1] using two parallel vibrating wires separated by ~ 1 mm. Vorticity was generated by one wire and detected by the other as a decrease in the resonant width, Δf_2, when the generator wire was driven above its pair breaking critical velocity. The decrease was attributed to Andreev scattering of the background thermal quasiparticles by the turbulent flow fields. The experiment detailed here expands upon this work to determine the spatial extent of the quantum turbulence generated.

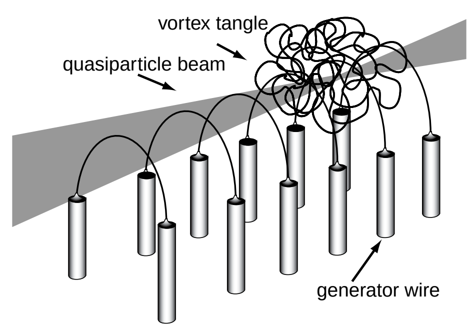

Fig. 1. The experimental array of vibrating wires. Any of the wires can be used to generate turbulence although the wire indicated has been used for the results detailed here.

The experiment was performed in a standard Lancaster style nested nuclear cooling stage[2] filled with ^{3}He at zero pressure. The stage routinely cools the ^{3}He down to temperatures approaching $110\,\mu$K. At these low temperatures, the ^{3}He is in the superfluid B-phase and the thermal quasiparticles are ballistic with a mean

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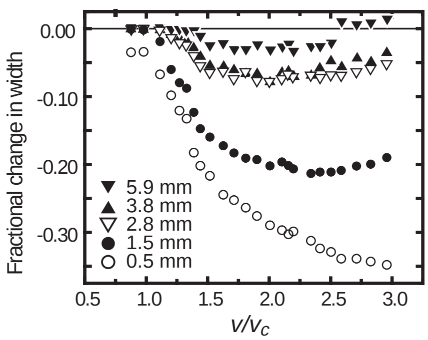

Fig. 2. The fractional change in damping at a temperature of $191\,\mu$K as a function of the generator wire velocity scaled by pair breaking critical velocity v_c for each wire in the array. The points are labelled by the distance of the detector wire from the generator.

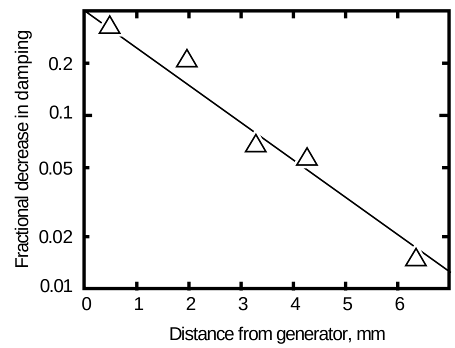

Fig. 3. The fractional decrease in damping for each wire, with the generator wire at a velocity of $2.5v_c$, plotted as a function of its separation from the generator at a temperature of $191\,\mu$K. The simple exponential decay has a decay length of ~ 2 mm.

free path greater than the size of the experimental cell.

The spatial extent of the cloud is determined using a linear array of six vibrating wire resonators. Each resonator consists of a $4.5\,\mu$m diameter superconducting NbTi wire semicircular loop, ~ 3 mm in diameter. The wires are operated in a vertical magnetic field of ~ 80 mT. The damping experienced by the resonator is due to the incident quasiparticle flux colliding with the wire. The quasiparticles are ballistic with a density that varies rapidly with temperature as $\exp(-\Delta/kT)$, where Δ is the superfluid energy gap. This rapid variation provides an extremely sensitive thermometer.

The vortex tangle is created by driving a nominated generator wire above its pair-breaking critical velocity, producing the cloud and a quasiparticle beam, Fig. 1. The remaining detector wires are driven at constant drive on resonance and their resultant amplitudes, inversely proportional to damping, are measured. The effect of the quantum turbulence cloud can hence be measured as a *reduction* in the damping of the wires.

The change in the damping $\delta\Delta f_2^T(v)$ is measured at some temperature T as a function of the generator wire velocity v. The secondary effect of the quasiparticle beam emitted by the generator wire is removed by repeating the experiment at our base temperature of $\sim 110\,\mu$K where the background thermal quasiparticle flux is negligible. The sole effect is now an *increase* in damping from the beam $\delta\Delta f_2^0(v)$. The fractional change in the incident thermal quasiparticle flux is then $[\delta\Delta f_2^T(v) - \delta\Delta f_2^0(v)]/\Delta f_2^T(0)$, where $\Delta f_2^T(0)$ is the inherent detector damping in the absence of any generated turbulence.

The results are shown in Fig. 2. The onset of the shielding of the detector wires coincides with the generator wire velocity exceeding the measured pair breaking critical velocity, v_c. The fractional shielding increases as the generator wire velocity increases. Above a generator wire velocity of $\sim 2\,v/v_c$, the amount of shielding of the different wires becomes broadly independent of the generator wire velocity. We suggest that this indicates that the turbulence has saturated in dynamic equilibrium. We can therefore quantify the spatial extent from the relative magnitude of the shielding for each wire. The fractional decrease in damping for each wire plotted as a function of the separation from the generator wire at several temperatures is shown in Fig. 3. As can be seen, the magnitude of the shielding broadly diminishes exponentially with separation with a decay length of 2 mm and independent of temperature. This extent is several orders of magnitude greater than the extent of the flow field expected from the direct motion of the wire, a few times the diameter of the wire.

In summary, we have determined the spatial extent of a vortex tangle produced by a vibrating wire in superfluid ^{3}He-B at temperatures $\leq 200\,\mu$K. Knowledge of this extent is essential if the vortex line density is to be determined[3].

We would like to acknowledge the financial support of the UK EPSRC under grant GR/N18253 and the technical support of I.E. Miller and M.G. Ward. We would also like to acknowledge discussions with R.P. Haley and C. Barenghi.

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