Direct observation of the Andreev reflection of a quasiparticle beam by quantum turbulence in superfluid ^{3}He-B

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Abstract

A beam of quasiparticles from a black-body radiator is directed at a localized region of quantum turbulence generated by a vibrating wire resonator driven at super-critical velocity. We are able to measure directly the fraction of the incident quasiparticle beam which is retro-reflected from the turbulence by Andreev processes. Combining these measurements with previous measurements on the spatial extent of the turbulence may allow us to infer the vortex line density.

Key words: vorticity; superfluid He3; vortex line density; quantum turbulence

We have previously shown[1] that a vibrating wire may produce vorticity. Later measurements[2] clearly showed that at velocities exceeding the pair-breaking critical velocity, a large cloud of vortex lines (quantum turbulence) is created. The turbulence produced by the generator wire was detected using a second adjacent wire. Despite the associated heating from the pair-breaking, a *decrease* in the damping of the detector wire was observed whenever turbulence was being produced by the generator wire. The decrease in damping was attributed to the shielding of the detector wire owing to the Andreev scattering of the background thermal quasiparticles by the fluid flow fields associated with the turbulence.

To provide unambiguous evidence that quasiparticles can be scattered by quantum turbulence, we direct a quasiparticle beam at a region of turbulence and directly measure the fraction of the quasiparticles that undergo Andreev reflection processes. In such a process, the scattered particle is retro-reflected. The experimental arrangement is shown in Fig. 1. We use a black-body radiator[3] as both detector and quasiparticle beam source. This consists of a small paper-walled box with a 0.3 mm diameter hole in one wall. Inside the box are two vibrating wire resonators, a thermometer and a heater. The heater generates a known power $\dot{Q}_A$, which in the steady state appears as a beam of quasiparticle-quasihole excitations leaving the hole. We directly measure the frequency width Δf_2 of the thermometer wire arising from quasiparticle damping from which we can deduce the 'width parameter' $W = \Delta f_2 T\tilde{E}$, where T is the temperature inside the radiator inferred from the width and $\tilde{E} = \Delta + kT$ is the mean excitation energy. W is accurately proportional to $\dot{Q}$ over many orders of magnitude[3]. Any additional power into the box is easily seen as a change in W.

To make a measurement, we adjust $\dot{Q}_A$ to give the

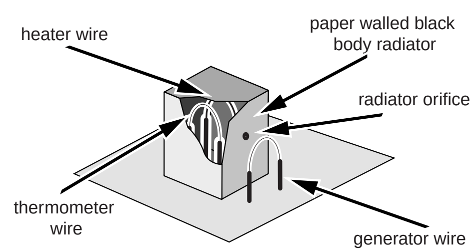

Fig. 1. The paper walled black-body radiator with a 0.33 mm diameter hole and the generator wire situated 1.4 mm from the radiator are immersed in superfluid ^{3}He at zero pressure and a temperature of $\sim 129\,\mu$K.

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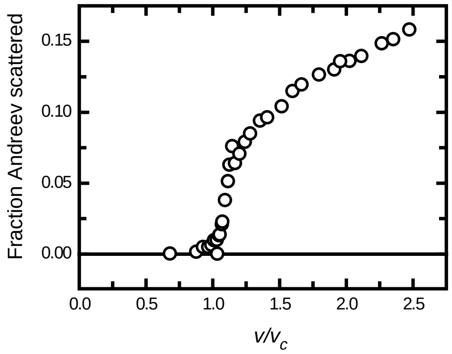

Fig. 2. The fraction of the outgoing beam Andreev scattered back into the radiator at a beam temperature of 177 μK. The surrounding bulk ^{3}He was at a temperature of 129 μK.

desired beam ‘temperature’ as determined by the thermometer inside the radiator. The generator wire is then driven on resonance for a short time and the change in damping of the thermometer resonator is measured. We observe an increase in damping inside the radiator indicating that some fraction of the beam has Andreev scattered back into the radiator. We repeat this for a range of generator wire velocities. To remove the effect of the direct power from the quasiparticles $\dot{Q}_{gen}$ produced by the generator wire and the inevitable heat leak $\dot{Q}_{hl}$ from the paper walls into the radiator, we repeat the measurements with $\dot{Q}_A = 0$. There remains a clear increase in damping after subtracting off the direct heating, unambiguously demonstrating the importance of Andreev scattering of the beam from the turbulence.

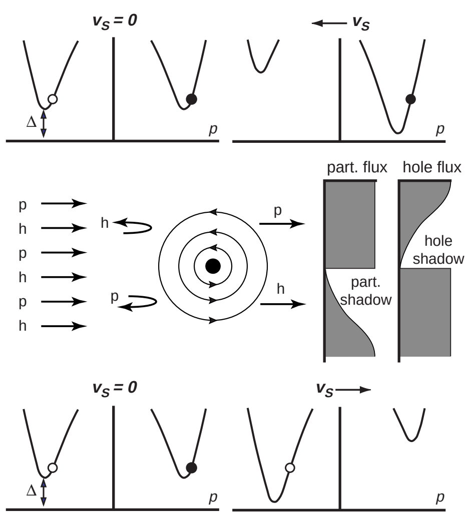

Fig. 3. Dispersion curves in stationary and moving ^{3}He. Quasiparticle ($\bullet$) and quasiholes($\circ$) states are occupied to an energy $\sim kT$ above the energy gap Δ. The flow field of the vortex distorts the dispersion curves as indicated causing the unequal particle/hole transmissions shown.

To be more quantitative, in equilibrium a fraction f of the outgoing total power $\dot{Q}_T$ from the radiator is retro-reflected back into the radiator by the turbulence. Detailed balance necessitates that the power into and out of the radiator are equal, thus $\dot{Q}_T = f\dot{Q}_T + \dot{Q}_A + \dot{Q}_{hl} + \dot{Q}_{gen}$. As all the powers are determined from the experiment, we can deduce f. The results are shown in Fig. 2. As can be seen, once the pair-breaking critical velocity v_c is exceeded, a significant fraction of the outgoing beam is retro-reflected by the vortex tangle.

Back scattering of the quasiparticle beam occurs by Andreev processes. In the reference frame of the quasiparticles a flow field velocity $\mathbf{v}$ increases the effective energy gap by an amount $\mathbf{p}_F \cdot \mathbf{v}$, where p_F is the Fermi momentum. Therefore, any quasiparticle with energy $\epsilon \leq p_F v$ above the energy gap in stationary superfluid that is incident on a flow field v must be Andreev reflected. Assuming each vortex line is independent, there is a flow field round each vortex core which falls off as $v = \hbar/2m_3 r$ where m_3 is the ^{3}He mass and r is the distance from the core. Thus quasiparticles with energy ϵ are scattered, but only from one side of a vortex, if they come within a distance $r \leq p_F\hbar/2m_3\epsilon$. Quasiholes are reflected from the other side of the vortex, Fig. 3. The fraction of the incident quasiparticle/quasihole flux transmitted through the flow field is

$$f = \begin{cases} \exp(-p_F v/kT) & : \ \mathbf{p} \ \text{parallel} \ \mathbf{v}, \\ 1 & : \ \mathbf{p} \ \text{antiparallel} \ \mathbf{v}. \end{cases}$$

To give an idea of the magnitude of the effect, $\exp(-p_F v/kT) = 0.5$ at a distance $r \sim 5\,\mu$m from the vortex, approximately 100 times the size of vortex core, which is of order the coherence length ξ_0.

We hope to be able to combine these observations and measurements with those on the spatial extent of the vortex cloud produced by a vibrating wire[4] to be able estimate the vortex line density round our generator wire and this work is in progress. In summary, the present work unambiguously showns for the first time that we can detect the flow fields in a vortex tangle by Andreev scattering of a quasiparticle beam from the tangle.

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References

[1] D.I. Bradley Phys. Rev. Lett. **84**, 1252 (2000).

[2] S.N. Fisher *et al*, Phys. Rev. Lett. **86**, 244 (2001).

[3] S.N. Fisher *et al*, Phys. Rev. Lett. **69**, 1073 (1992).

[4] D.I. Bradley *et al*, paper (22AP40) in this conference.