Liquid ^{3}He quasiparticle free-path distribution function in simulated aerogels

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Abstract

Conflicting results between different laboratories of measurements of the phase diagram of superfluid ^{3}He when immersed in aerogel, even with nominally identical aerogels, suggests that details of the aerogels other than the porosity are important in determining superfluid properties. We have simulated the growth of small clusters ($N \sim 10^5$) by off-lattice single-particle Diffusion Limited Aggregation (DLA). Measurements of the free-path distribution function of ^{3}He quasiparticles scattered by these clusters — truncated and repeated to simulate experimental conditions — show significant differences from uncorrelated scatterers at the same density, which differences may be significant for superfluid properties.

Key words: helium3; aerogel; quasiparticle scattering; superfluidity; diffusion limited aggregation

1. Introduction

Since the discovery of superfluidity of ^{3}He in aerogel[1] the phase diagram of this confined superfluid has been uncertain.[2] The experimentalist's characterization of an aerogel sample has been limited to its average density (or, inversely, porosity), perhaps augmented by its gestation history. Nevertheless, nominally identical aerogels do not produce identical phase diagrams, which suggests that details of their structure are important in determining superfluid properties. We examine one property here, the distribution of quasiparticle free path lengths as its scale is comparable to the superfluid's natural length scale, its coherence length.

2. Growing the Cluster

We grew our simulated aerogel clusters[3] one particle at a time, a process known as diffusion limited aggregation (DLA)[4]. Our clusters grew as fractals, with dimensionality approximately 2.5. Consequently, as our clusters grow larger, their densities approach

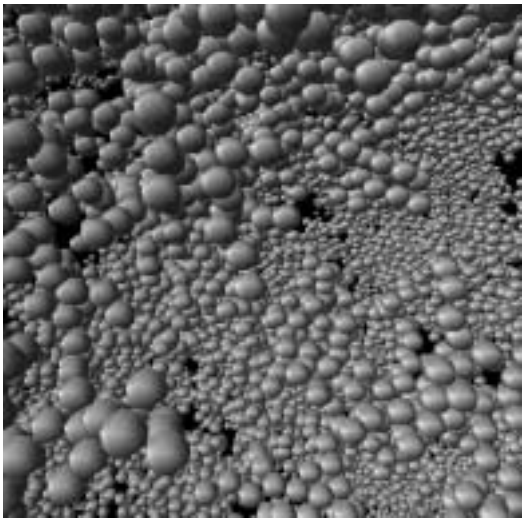

Fig. 1. Image of a sample cluster. This is a picture of a region of a single cluster facing its dense seed. Nearby arms illustrate the lack of order beyond nearest neighbors.

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zero. At cluster sizes of $N \approx 10^5$ we find fractal character to the clusters at all length scales relevant to the experimental situation, and average densities at the largest scale less than 2%.

To model real aerogels we truncated our clusters in cubes whose sizes were chosen to fit the typical experimental density at 2%. The cubes were then repeated *ad infinitum* for measurements of the ^{3}He quasiparticle path length distribution.

3. Free Path Distribution Function

Our measurement was a purely classical one, in which we took all quasiparticle paths to be ballistic. The quasiparticles were modeled as hard spheres of diameter ${k_F}^{-1}$ (though the results depended little upon this precise value). Their paths were terminated when they approached close enough to touch any cluster particle.

Our results are shown in Fig. 2 as the data labeled "cluster." Surprisingly, for all path lengths up to about the repeat distance of the lattice, there was a uniform probability that a quasiparticle would propagate that far. For longer path lengths there is an exponentially decreasing probability, consistent with the expectation from randomly located scattering sites. We note that this is the same length scale at which the system crosses over from exhibiting fractal character, to showing a uniform density.

For comparison, with the same program we also measured the free path distribution function of a different sample with randomly located (uncorrelated) scattering sites, *i.e.* not a cluster, but the same average density (porosity). This is shown in Fig. 2 as the data labeled "uncorrelated." This data accurately fits a Poisson distribution with length scale taken from the quasiparticle and cluster particle sizes.

Our results differ fundamentally in appearance from those of Haard, *et al.*[5] because whereas Haard, *et al.* chose to randomly sample straight-line trajectories, we have chosen to randomly sample the ^{3}He quasiparticles, regardless of where along a trajectory they may be at the instant of sampling. In consequence our probability distribution functions differ by a factor of the path length. Consider two distinct paths, with one path a factor N longer than the other. When randomly sampling trajectories, these two paths are equally likely to be sampled. However, when randomly sampling the liquid, the longer path is N times more likely to be sampled, reflecting the fact that there are more quasiparticles along that path. The difference in results is thus independent from the issue of differing growth algorithms, diffusion limited particle aggregation vs. that of clusters.

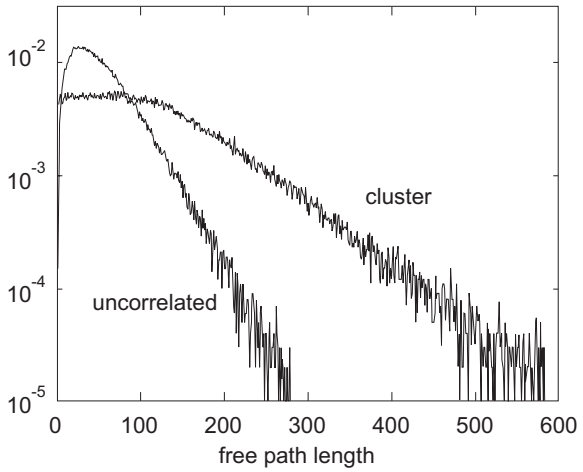

Fig. 2. Quasiparticle probability distribution for free path lengths given 2% density of scatterers. The "cluster" data is the distribution of path lengths when scattering from a single (fractal) cluster repeatedly copied to the average density. The data labeled "uncorrelated" is a sample of free path lengths scattered from randomly placed scattering sites.

Quasiparticles propagating through uncorrelated scatterers are much more likely to have a shorter path length, given the same average density. This reflects the clumping together of aerogel particles in the cluster, which opens large cavities in which quasiparticles can propagate freely. Given the sizes of particles and quasiparticles, and the experimentally relevant density, the length scale derived from the exponential tail of the distribution for the cluster is about a factor of three longer than for uncorrelated scatterers.

Acknowledgements

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