Torsion pendulum studies of thin ^{3}He slabs

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Abstract

A high precision torsional oscillator has been developed for the detection of two dimensional superfluidity in ^{3}He films of thickness comparable to the superfluid coherence length, 70 nm at $T = 0$. The mass loading from such a film can be detected with a 0.1% resolution. Measurements on normal films show an unexpected de-coupling from the surface with decreasing temperature, below 60 mK. The frequency shift and disspation data can be interpreted using a phenomenological interfacial friction model.

Key words:
superfluid ^{3}He; interfacial friction

1. Introduction

The flow of fluid past a surface is a fundamental hydrodynamic problem of some longevity, yet the behaviour of the boundary layer and surface slip remain questions under active investigation for classical fluids [1]. Attempts to determine the viscosity of quantum liquids have required correction for these effects. Torsional oscillator studies of liquid ^{3}He in contact with highly polished surfaces or surfaces covered by a ^{4}He film, have also produced a number of unexplained results[2].

In this paper we report preliminary results for the viscous coupling between a polished metal surface and a thin ^{3}He film. We explore a completely new flow regime, in which the the viscous penetration depth $\delta = (2\eta/\rho\omega)^{1/2}$ is much larger than the film thickness at all temperatures. An attractive feature of this quantum fluid, as opposed to usual classical fluids, is that the mean free path is strongly temperature dependent, and can greatly exceed the thickness of the film at low mK temperatures. Thus in some sense we can say that, in this regime, the entire film constitutes a "boundary layer".

2. Torsional oscillator

The torsional oscillator developed for this work [3]is fabricated from coin silver to reduce its temperature dependent background. The working surfaces of the oscillator are mechanically polished to a roughness better than 10 nm and diffusion bonded together by a copper gasket. The "head" of the oscillator is linked to a coin silver body by a coin silver tube acting as torsion rod and fill line. The antisymmetric mode of the head and body is at 2842 Hz, with a low temperature Q of order 10^6. The oscillator frequency can be determined to better than 1 part in 10^9, corresponding to the inertial contribution of a 0.1 nm thick film. This is achieved by driving the oscillator at fixed frequency, close to resonance, and measuring the in-phase and quadrature response. A low drive level ensures that the effects of non-linearity are negligible. The helium film can be loaded into the oscillator by heating the fill line to 800 mK while the oscillator is held at 500 mK. The nominal film thickness is inferred from the shift of oscillator period due to mass loading, measured at 60 mK, and the calculated moment of inertia of the oscillator head.

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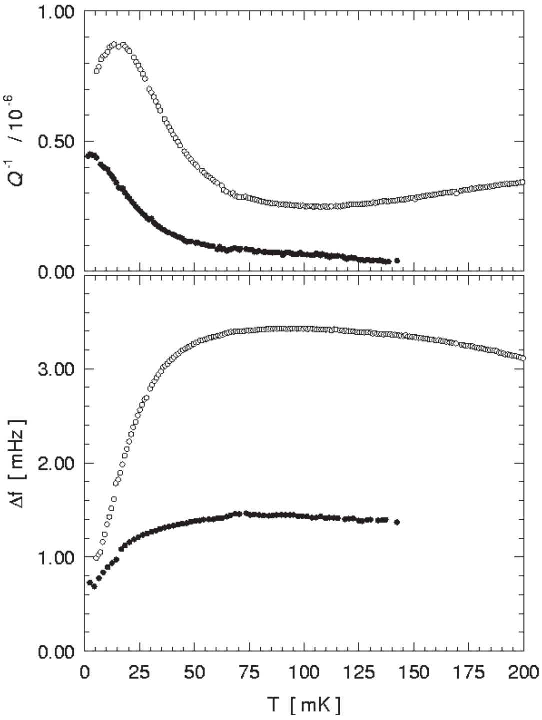

Fig. 1. Frequency shift and dissipation due to film

3. Results and discussion

Thus far the properties of normal films of nominal thickness 137 and 328 nm have been studied. The results for the period shift and dissipation due to the film, obtained after a subtraction of the temperature dependent background are shown in Fig 1. At high temperatures we find a period shift approximately independent of temperature, which we attribute to full mass loading. As the temperature is decreased the behaviour of the period shift indicates a de-coupling of the film in both cases. This is accompanied by an increase in dissipation, and for the thicker film we observe a clear dissipation maximum.

This experiment probes the transfer of transverse momentum between the ^{3}He quasiparticles and the surface. Since $\delta >> d$, a simple phenomenological model consists in treating the film as a rigid slab, frictionally coupled to the surface. A characteristic relaxation time can be defined in terms of this friction and the mass density of the film , via $\eta = \rho/\tau$. The period shift and dissipation due to frictional coupling to the slab are then given by

$$\frac{\Delta P}{P} = \frac{m}{2M}\frac{1}{1+\omega^2\tau^2} \quad \text{and} \quad \Delta Q^{-1} = \frac{m}{M}\frac{\omega\tau}{1+\omega^2\tau^2}$$

Within this model, the present data are consistent with $\tau \propto 1/T$, and the dissipation maximum corresponds to $\omega\tau = 1$.

Microscopically, considering the substrate as subject to random tranverse forces $f(t)$ due to impacts by quasiparticles, this result implies that the time integral of the autocorrelation function $\langle f(0)f(t)\rangle$ is independent of temperature.

Future work will involve studying a larger number of films, and attempts to detect their superfluid transition.

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References

[1] P A Thompson, M O Robbins, Phys. Rev.A41 (1990), 6830

[2] D Einzel, J M Parpia, J. Low Temp. Phys. 109 (1997) 1

[3] G.W.Morley, A.Casey, C.P.Lusher, B.Cowan, J.Saunders, J.M.Parpia, J. Low Temp.Phys.(2002) 557