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Equilibrium thickness of saturated superfluid ^{3}He films on a copper substrate

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Abstract

Much theoretical interest focuses on the equilibrium thickness of liquid helium films adsorbed onto a substrate. To address this issue in liquid ^{3}He, an experiment to measure the thickness d of a saturated superfluid ^{3}He film, on a horizontal copper substrate which is a height h above the free surface of the liquid bath, was carried out. The free surface of the bulk superfluid ^{3}He is slowly lowered, thus increasing h, by expanding a bellows (actuated with superfluid ^{4}He) at the base of the cell. While doing this, continuous measurements of the thickness of the superfluid ^{3}He film, from which we can obtain $d(h)$, are made. These measurements then allow us to extract information on the attractive (van der Waals) potential between the superfluid ^{3}He film and the copper substrate.

Keywords: ^{3}He film; ^{3}He superfluid; ^{3}He superfluid film; Van der Waals interaction

1. Introduction

For very thin films of ^{4}He, the attractive potential which causes the film to adhere to a solid surface is well understood [1,2]. For thick films, $d > 40$ nm, the predicted modification of the van der Waals potential due to retardation effects has still not been confirmed [3].

The thickness of a superfluid film, formed on a solid dipping into a superfluid reservoir, is governed by the chemical potential due to gravity, gh, balancing that due to the substrate's attractive potential [4]. This leads to the relation for $h(d)$

$$h = (\alpha/d)^n, \tag{1}$$

where α is a material-dependent constant and n is expected to be between 3 (unretarded, thin film limit) and 4 (fully retarded, thick film limit) [1–4]. Experimental results for $d(h)$ in thick films are limited for ^{4}He and rare for ^{3}He. Here we present a measurement of $d(h)$ for thick saturated films of superfluid ^{3}He on a polished copper substrate.

2. Experimental results and discussion

Our experimental cell is shown in Fig. 1. The substrate has been polished with successively finer grit sizes down to 250 nm. Another copper disk, suspended ~ 30 μm above the substrate, forms a detector capacitor which allows us to measure the film's thickness (using ^{3}He's dielectric constant $\kappa = 1.0426$). We assume that the film is equally distributed on the two plates and make no adjustment for the roughness of the surfaces.

We measure the level of the free liquid surface in the bath, H, using another capacitor consisting of two concentric brass cylinders mounted vertically in the bath. We deduce h from $h = H_{\text{filling}} - H$, where H_{filling} is the level at which the space between the horizontal capacitor plates suddenly fills completely with liquid. We can continuously vary H by expanding a bellows attached to the cell.

On a typical run, the cell was filled with ^{3}He to $h = 0.518$ mm. Upon cooling into the superfluid film phase, spontaneous ^{3}He film flow [5,6] created an initial equilibrium film thickness, $d_0 = 214 \pm 5$ nm.

Slowly expanding the bellows, we then measured the detector capacitance continuously, obtaining $d(h)$ over a range of h. This was done over several hours in an effort

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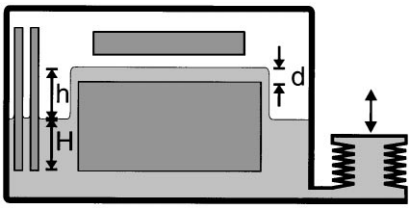

Fig. 1. Schematic view of experimental cell.

to prevent the film flow from approaching the critical current [5,6].

Then, after re-compressing the bellows, the bulk level H was raised further by introducing more liquid into the cell. After a pre-cool, the slow bellows expansion was repeated to measure $d(h)$ for a different (overlapping) range of h. (A small correction was made for DC drift in the capacitance measurement in the intervening time.) Fig. 2 shows the resulting $h(d)$ on a log–log graph. We attribute the slight curvature near $h = 0.48$ mm to a departure from equilibrium due to lowering H too rapidly.

Fitting this data to the form of Eq. (1), we find $n = 3.44 \pm 0.08$ and $\alpha = 176.8 \pm 0.2$ with h in mm and d in nm. The uncertainties cited here arise from the uncertainty in d_0. There are also significant systematic uncertainties. H_{filling} may underestimate the film's level by an amount ΔH (probably on the order of 50 μm), particularly if the substrate is at an angle to the horizontal; for each 10 μm of ΔH, the value of n determined from the fit would decrease by about 0.06.

Thus, taking the systematics into account, the value of n measured for thick superfluid ^{3}He films by this experiment falls closer to the $n = 3$ unretarded limit than to the $n = 4$ value predicted for the fully retarded limit.

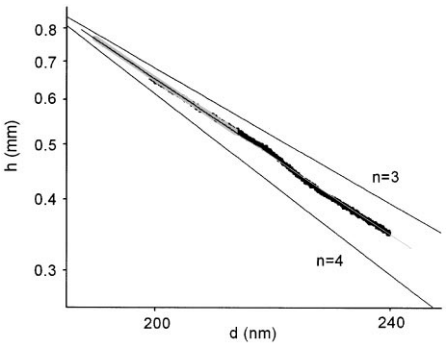

Fig. 2. The height h from the substrate to the bulk liquid surface versus the film thickness, on a log–log scale.

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References

[1] I.E. Dzyaloshinskii, E.M. Lifshitz, L.P. Pitaevskii, Adv. Phys. 10 (1961) 165.
[2] E.S. Sabisky, C.H. Anderson, Phys. Rev. A 7 (1973) 790.
[3] E. Cheng, M.W. Cole, Phys. Rev. B 38 (1988) 987.
[4] D.R. Tilley, J. Tilley, Superfluidity and Superconductivity, Adam, Hilger, Bristol, 1986.
[5] J.P. Harrison, A. Sachrajda, S.C. Steel, P. Zawadski, in: A.G.F. Wyatt, H.J. Lauter (Eds.), Excitations in Two-Dimensional and Three-Dimensional Quantum Fluids, Plenum Press, New York, 1991, p. 239.
[6] J.C. Davis, A. Amar, J.P. Pekola, R.E. Packard, Phys. Rev. Lett. 60 (1988) 302.