Supplemental Information for "Characterization of Levitated Superfluid Helium Drops in High Vacuum"

December 18, 2021

Introduction

In this supplementary material we provide details of our experimental setup, and provide additional data on the drops' vibrational modes. Section 1 describes the levitation cryostat and the laser system used to probe levitated drops. Section 2 describes measurements of the resonant frequency and decay rates of drops' surface modes as a function of the drops' radii.

Contents

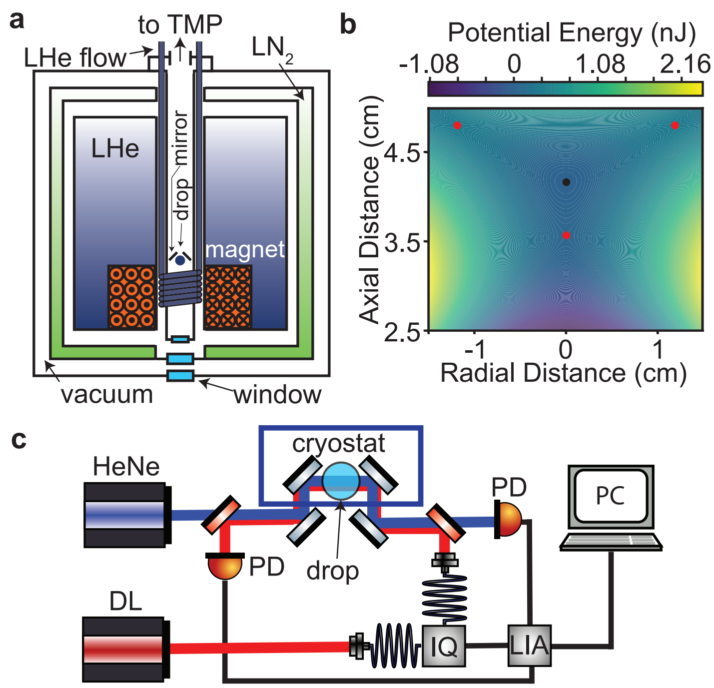

Figure S1: Experimental schematic. (a) Cross-sectional view of the cryostat and the experimental cell. (b) The potential energy of a drop (with $R = 1$ mm), showing a stable equilibrium point (black circle) and saddle points (red circles). The axes are the axial and radial distance from the solenoid's center. (c) The measurement apparatus, showing the two lasers, optical modulator (IQ), photodiodes (PD), and lock-in amplifier (LIA)

1 Experimental Setup

Fig. S1a provides an illustration of the non-uniform superconducting solenoid housed in the ^{4}He bath space of the cryostat, which we use to levitate the drops. We produce and trap drops in a custom-built cell that fits in the cryostat's vacuum space and extends through the magnet's bore.

As described elsewhere, levitation occurs when $B_z \partial_z B_z = \mu_0 \rho g / |\chi|$, with this levitation point being stable when $\partial_{ii} B^2 > 0$ for all $i \in \{x, y, z\}$ [1]. Here, z is the axial coordinate, B_z is the axial magnetic field component, μ_0 is the permeability of free space, $\rho = 145$ kg/m^3 is the density of liquid ^{4}He, g is the gravitational acceleration and $\chi = -1.89 \times 10^{-6}$ is the volume diamagnetic susceptibility of ^{4}He. Fig. S1b illustrates the magneto-gravitational potential energy of a levitated drop when the magnet is driven with current $I = 116$ A.

Fig. S1c illustrates the general scheme used to apply optical forces to drops, probe the drops' optical WGMs and to measure the drops' vibrational and optical response. The HeNe laser is used to detect the drop's vibrations or optical WGMs, while the DL is intensity-modulated to apply optical forces to a drop. Both the vibrational and optical response of the drops are inferred from the PD photocurrent using the LIA.

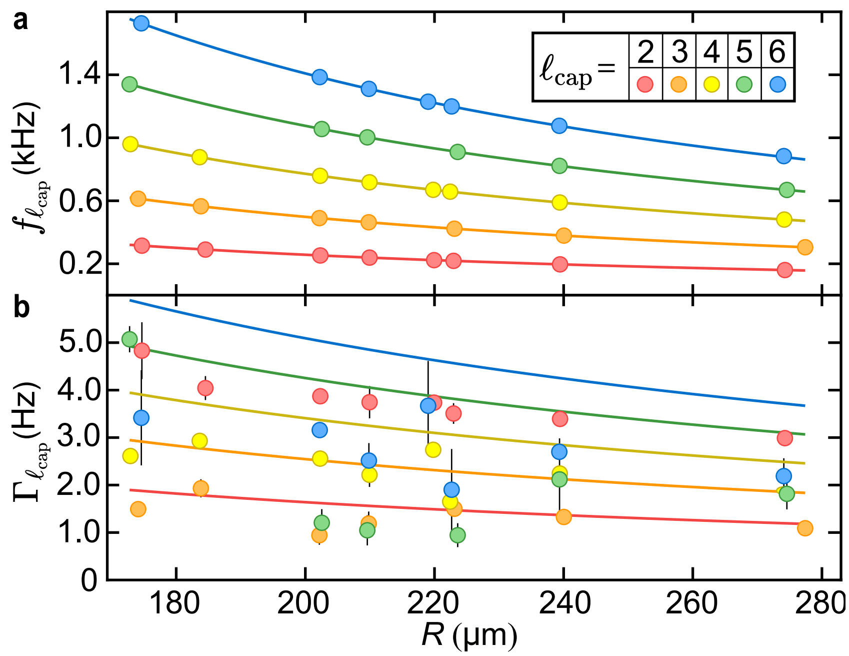

Figure S2: The capillary modes' resonant frequencies (a) and damping rates (b) as a function of R. The circles are the data and the dotted lines are the expected values assuming $T_{\mathrm{drop}} = 350$ mK.

2 Capillary Mode Dependence on Drop Radius

Fig. S2 shows the capillary modes' resonant frequencies (Fig. S2a) and linewidths (Fig. S2b) as a function of the drop radius. As in Fig. 5 of the main text, the resonant frequencies show excellent agreement with Eq. 1 of the main text, while the linewidths show only qualitative agreement with Eq. 2 of the main text.

References

[1] M. A. Weilert, D. L. Whitaker, H. J. Maris, and G. M. Seidel. Magnetic levitation and noncoalescence of liquid helium. *Physical Review Letters*, 77(23):4840–4843, 1996.