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Vortex Dimples in Superfluid Helium Thin-Films

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The relationship regarding vortices and superfluidity in liquid helium originally proposed in the 1950s by Onsager and Feynman has been well established. Understanding vortices in 2D superfluids and their interactions can develop our understanding of quantum turbulence, quantum dissipation, and BKT phase transitions [1]. Despite this, observing these vortices is very difficult, due to the small core size, nanoscopic film thickness and small refractive index. Several approaches have already been used to investigate properties of superfluid helium, such as their coupling to confined acoustic third-sound modes [2].
Here, we explore the possibility of directly optically detecting the vortices directly via interferometric scattering microscopy (iSCAT). iSCAT utilises a relatively strong reference beam to significantly improve the weak scattering signal for nanoobjects and is not restricted by the small volume of the superfluid vortices. In addition, vortices produce a dimple on the free surface of helium film [3], due to the greater kinetic energy closer to the core. We aim to leverage this effect to greatly enhance the magnitude of the observable signal. However, the exact nature of this effect when several vortices interact and the superposition of their flow fields is not well understood in the presence of surface tension. To resolve this, we have formulated a new approach which allows us to calculate the surface profile from any arbitrary arrangement of vortices. These calculations suggest the presence of an attractive force resulting from the mutual interaction of vortex dimples. These become prominent at sub-micron separations and intermediate film thicknesses.

References

[1] Forstner, S. et al. Modelling of vorticity, sound and their interaction in two-dimensional superfluids. New J. Phys. 21, 053029 (2019).
[2] Sachkou, Yauhen P., et al., 2019, "Coherent vortex dynamics in a strongly interacting superfluid on a silicon chip,"Science 366, 1480.
[3] E. Vittoratos, M. W. Cole, and P. P. M. Meincke, Can. J. Phys. 51, 2283 (1973).

Short bio (50 words) or link to website

Daniel Harvey and Luke Kelly are currently PhD and Honours students at the University of Queensland, working with Chris Baker and Warwick Bowen. Their research concerns directly optically detecting quantized vortices in helium-II using interferometric scattering microscopy. They have determined the surface profile of dimples resulting from vortex-vortex interactions.

Relevant publications (optional)

Career stage

Student

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