Helium in two dimensions and under nano-scale confinement: realizing quantum materials and topological mesoscopic superfluidity

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The study of helium allows us to address central questions in the field of strongly correlated quantum systems. Atomically layered helium films and helium confined in precisely engineered nanostructures are two complementary approaches. Helium films on graphite demonstrate: a Wigner-Mott-Hubbard transition into a putative quantum spin liquid; a heavy fermion state with quantum criticality; intertwined superfluid and density wave order; ideal 2D frustrated ferromagnetism. Does the Landau Fermi liquid survive in 2D? To address this question we can study ^{3}He in surface states atop a superfluid ^{4}He film. This provides a model coupled fermion-boson system, which we have probed by SQUID NMR to well below 1 mK. In the second approach we have made NMR studies of superfluid ^{3}He confined in thin cavities of height ranging from one micron down to 100 nm. This work has demonstrated the profound influence of confinement on the phase diagram, and the ability to tune the surface scattering. We also find evidence for the stabilization of a spatially modulated superfluid phase, an FFLO-like state, but with two-dimensionally modulated superfluid order. Such precisely engineered nanoscale confinement opens up the field of topological mesoscopic superfluidity. Structures, with confinement as the control parameter, can be used to create new “materials” and high quality interfaces between them, for the study of emergent surface excitations.

Section: LD - Low dimensional and confined systems

Keywords: helium films, confinement, topological superfluidity

INVITED PAPER