The role of Kelvin waves in superfluid turbulence

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The understanding of the mechanisms involved in the transfer of energy to small scales is one of the most fundamental problems in three-dimensional classical fluid turbulence. Interest in the quantum analogue, superfluid turbulence, has heightened in the last few decades, due to the fact that all vortices are identical and the notation that this may provide some insight into the classical theory.

In superfluids, severe quantum restrictions prevent a continuous vorticity distribution–if the superfluid is excited, any induced vorticity is defined through topological, zero density, defects within the flow. These topological defects are known as quantized vortices. Each quantized vortex is identical–they have fixed circulation, atomically small core size and generate an irrotational superfluid flow around them. Superfluid turbulence may be defined as the study of the chaotic behavior of the superfluid flow induced by a tangle of quantized vortex lines. At large-scales, analogies to classical eddies can be made with polarized bundles of quantized vortex lines which invoke a large-scale flow around them displaying the famous Kolmogorov-Obukhov energy spectrum of classical turbulence theory. At small scales the similarities cease. In classical three-dimensional hydrodynamical turbulence, energy is dissipated at small scales by viscosity. However, in zero temperature superfluid turbulence there is no viscosity, so how is energy dissipated? The current hypothesis involves Kelvin waves which propagate along the quantized vortex lines–energy is assumed to be dissipated via the excitation of phonons by high frequency Kelvin waves created through weakly nonlinear interactions of larger scale Kelvin waves forced through vortex reconnections at the inter-vortex distance. If this conjecture is correct, then the understanding of Kelvin-wave interactions become an important part in the study of energy transfer in superfluid turbulence.

The lecture will take a pedagogical approach in explaining the Kelvin-wave turbulence theory for zero-temperature superfluid turbulence in helium-4. By considering the most idealized of scenarios–of propagating Kelvin waves along a single quantized vortex line, allows for a theoretical treatment based on the wave turbulence paradigm. Through the Kelvin-wave problem, the lecture will address various difficulties that arise in wave turbulence theory, such as non-resonant interactions, canonical transformations and the non-locality of wave interactions [2]. This will be followed by a discussion on the current controversy based on two conflicting Kelvin-wave results [3], before reviewing the numerical evidence for each. Finally, the lecture will conclude by examining the inherent difficulties of the problem, the relevance of the idealized setup to reality and the future perspectives.

[1] W.F. Vinen, *Phys. Rev. B*, **64**, 134520, (2002); W.F. Vinen, *J. Phys.: Condens. Matter*, **17**, S3231, (2005).
[2] J. Laurie, V.S. L'vov, S. Nazarenko, and O. Rudenko, *Phys. Rev. B*, **81**, 104526, (2010).
[3] E. Kozik and B. Svistunov, *Phys. Rev. Lett.*, **92**, 035301, (2004); V.S. L'vov and S. Nazarenko, *Low Temp. Phys.*, **36**, 785, (2010).