Visualisation of quantum flows

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Quantum turbulence [1,2], which occurs in flowing quantum fluids displaying superfluidity, such as superfluid ^{4}He, combines quantum physics with classical fluid dynamics. Superfluid ^{4}He, also known as He II, exists at temperatures below about 2.17 K, at the saturated vapour pressure, and its motion does not generally obey the Navier-Stokes equation. It is viewed as consisting of two interpenetrating fluids, whose density ratio depends on temperature. The normal component of He II, the gas of thermal excitations, can be considered as a viscous fluid, carrying the entire entropy content of the liquid, while its superfluid component is assumed inviscid. It follows that the circulation of the superfluid velocity is quantized and that singly quantized vortices, line singularities where the superfluid component vanishes, exist in He II, usually arranged in a tangle, whose dynamical behaviour is an essential ingredient of quantum turbulence.

Well-known visualisation techniques, such as Particle Image Velocimetry and Particle Tracking Velocimetry, have been recently fine-tuned to be used at low temperatures in order, for example, to gain deeper understanding of the similarities and differences between quantum and classical turbulent flows [3,4]. To this end, an experimental apparatus [5] has been devised by us. The Lagrangian dynamics of micrometer-sized solid particles, made of hydrogen and deuterium, is specifically being studied and it was already shown that the obtained experimental data are consistent with the present physical understanding of quantum flows [5,6], when probed at relevant length scales.

In fact, both quantum and classical features can be observed in the same quantum flow, depending on the scale at which we probe it. At large enough scales, larger than the average distance ℓ between quantized vortices, quantum turbulence displays classical features, while its quantum nature become obvious at smaller scales. We show, e.g., that in the case of a well-known quantum flow of He II, thermal counterflow [1,2], the statistical distribution of the particle velocity changes from the power-law shape, typical of quantum turbulence, at scales smaller than ℓ, to the nearly Gaussian form, typical of classical turbulent flows, at scales larger than ℓ [7].

Additionally, we are investigating the occurrence of macroscopic vortical structures in quantum flows, as their nature is still not entirely understood [3,4], by probing thermal counterflow past circular cylinders [8], and recent results, obtained by us in the proximity of an oscillating rectangular cylinder, suggest that macroscopic vortices may also be observed in superfluid ^{4}He.

In summary, the results obtained with our apparatus reinforce the idea that cryogenic flow visualization is a very useful experimental tool, capable of improving the general knowledge of classical and quantum flows.

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