Vortices in atomic gases resolve basic phenomena of quantum physics

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Quantum phenomena at extremely low temperatures are fervently studied both theoretically and experimentally in contemporary physics. Alkali atoms cooled to near absolute zero formed the first experimentally successful gaseous Bose–Einstein condensate in 1995. Six years later, the achievement was awarded the Nobel Prize in Physics.

Pekko Kuopanportti has studied vortex structures appearing in Bose–Einstein condensates in his doctoral dissertation for the Aalto University Department of Applied Physics. The properties and behaviour of these vortices are not yet fully known.

"The vortices are quantised whirls in the currents of extremely dilute gases of alkali atoms. Even though my research methods are computational and analytical, all my results are also experimentally feasible."

The atomic gases Kuopanportti has explored are 100 000 times thinner than air. To achieve the condensate, the alkali atoms must first be evaporated off from solid metal to form a gas, then cooled to near absolute zero and captured in a magneto-optical trap where they can be controlled. Kuopanportti has computationally analysed several novel vortex phenomena and theoretically verified previous experimental findings.

"In Bose–Einstein condensates all the particles of a system occupy the same quantum state. They form a collective superatom of a kind, and enable the study of basic quantum mechanical phenomena on a size scale almost observable to the eye."

Unexplored giant vortices reveal the prospects of quantum gases

The condensate can be described with a complex wave function, as if it was a single quantum particle. The function has a complex phase whose windings represent the vortices appearing in the flow of the condensate atoms.

"The gas circulates around the vortex in the same way as water flows in a sink down the drain. Stable quantised vortices demonstrate that Bose–Einstein condensates are actually frictionless superfluids. For instance, if one tries to spin a condensate, a regular lattice of quantised vortices emerges, as the superfluid tries to imitate an ordinary fluid."

Increasing the number of phase windings around a vortex results in a multiply quantised, or giant, vortex. Kuopanportti tells that already in 2007 his colleagues at the Department of Applied Physics theoretically proposed a vortex pump, an experimental method to create giant vortices in magnetically trapped condensates. The pump might help to discover how large the giant vortices can get before they become too unstable and short-lived to be studied at all.

Kuopanportti has now analysed the properties of giant vortices and the practical limits of the vortex pump.

"Giant vortices tend to split into single-quantum vortices. I have analysed how they break down, and what mechanisms lead to the splitting. So far only vortices with quantum numbers below 10 have been studied; I have systematically proceeded to 100."

"Now that I have theoretically explored the properties of giant vortices, it would not take much from experimental groups to realise them. My work also contributes to the future development of the vortex pump: the behaviour of giant vortices can now be predicted and their breakdown prevented."

Condensates as memory devices for quantum computers?

Kuopanportti works in the Aalto University National Centre of Excellence in Computational Nanoscience. His group Quantum Computing and Devices also studies the prerequisites for quantum computing. This year's Nobel Prize in Physics was recently awarded to experimental research promoting the creation of quantum computers. Kuopanportti muses on the use of Bose–Einstein condensates in quantum computing.

"They could be used as the memory device of quantum computers. Condensates live for minutes, significantly longer than photon-based quantum bits that have a life span of microseconds. The condensates could work as a storage and retrieval repository for quantum information. However, experimental research in the field is still in its infancy."

Provided by Aalto University

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