Observation of fractional exclusion statistics in quantum critical matter

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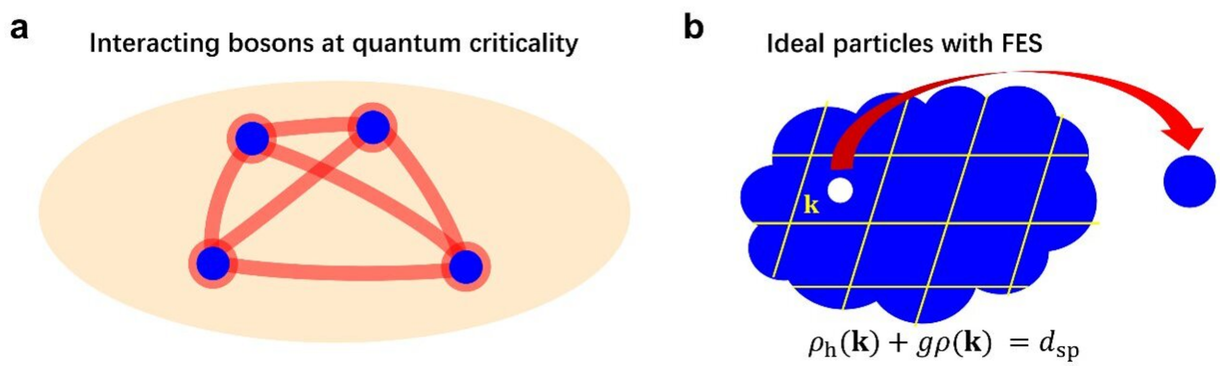

Quantum critical matter and fractional exclusion statistics. (a) Interacting bosons at quantum criticality. (b) Ideal particles with FES. Credit: Science China Press

A quantum system consisting of a large number of microscopic particles obeys statistical laws at the macroscopic level. In nature, there are two kinds of microscopic quantum particles. One is the boson satisfying the Bose-Einstein statistics, and the other is the fermion satisfying the Fermi-Dirac statistics.

However, for interacting quantum systems, such two types of statistics are not the only forms of quantum statistics. For instance, anyonic statistics can emerge in two-dimensional (2D) electrons. In 1991, Nobel Physics Prize winner F. D. M. Haldane proposed a novel concept of fractional exclusion statistics (FES), which is a generalized statistical distribution, with the Bose and Fermi distributions being its two limiting cases. In 1994, physicist Yongshi Wu and others studied the thermodynamic properties of systems satisfying FES. Subsequently, the theory of the FES has been used to perform theoretical studies on the fractional Hall effect, quantum gases, spin models, anyons and many other quantum many-body problems. However, observation of the FES in realistic experiments still remains challenging and sparse.

One-dimensional Bose gases with repulsive interaction have become an important platform for the experimental study of quantum many-body physics in recent years. Such gases have been theoretically shown to satisfy mutual FES in quasi-momentum space. However, the couplings between different quasi-momenta make it very hard to obtain a direct relation between measurable physical quantities and the statistics parameter.

Recently, Xibo Zhang and his coworkers found that for 1D and 2D quantum Bose gases in the quantum critical regime, the couplings between quasi-momenta become rather local, and a simple, non-mutual FES emerges. They established a simple correspondence between the interaction strength and the statistics parameter. Based on theoretical computations, numerical quantum Monte Carlo simulations, and experimental measurements, the researchers confirmed that the critical entropy per particle and other thermodynamic quantities are determined by those of non-interacting particles obeying the FES.

This study not only provides a simple physical picture with theoretical, numerical, and experimental evidences for the emergence of the FES in interacting quantum systems, but also provides new prospects and a novel method for understanding the critical behavior of more complex quantum many-body systems, such as quantum gases with SU(N) symmetries, etc.

The research was published in *National Science Review*.

More information: Xibo Zhang et al, Interaction-induced particle-hole symmetry breaking and fractional exclusion statistics, *National Science Review* (2022). DOI: 10.1093/nsr/nwac027

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