Spin *vs* Position Conjugation in an Interference of Atom Matter Waves

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The permutation symmetry is a fundamental attribute of the collective wave function of indistinguishable particles. It makes a difference for the behavior of collective systems having different quantum statistics but existing in the same environment. Here we show that for some specific quantum conjugation between the spin and spatial degrees of freedom the indistinguishable particles can behave similarly for either quantum statistics.

Our proposal is crucially based on a unique property of the Young diagrams describing the collective states with minimal total spin angular momentum: in the case of three and four identical particles the symmetric and antisymmetric quantum states, associated with and constructed by these diagrams, have equivalent regular and transposed representations for both quantum statistics, see [1].

As example, in figure 1 we show the probability density distribution (a) and the conditional probability densities (b-d) for four bosonic atoms having 1/2 pseudospin. The position of atoms is mediated by optical tweezers in (x, y)-plane. The fermionic behavior in the interference of the atom matter waves is foreseen in diagrams (b-d) from the antibunching manifestation in the conditional probabilities for proximal locations of the particles.

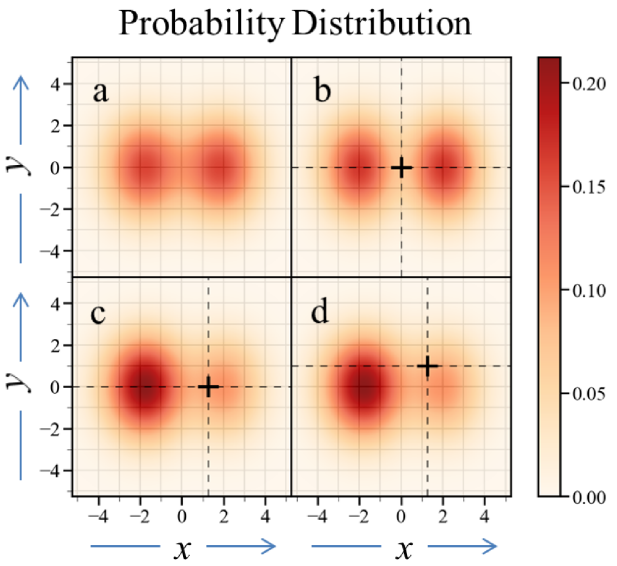

Figure 1: (a) Probability density function for a single particle, calculated for a system of four atoms and rectangular site configuration. (b–d) Conditional probability densities for a particle position if one atom is located at the points indicated by cross markers in the plots

For application, such a mesoscopically scaled collection of atomic qubits, mediated by optical tweezers, can model the behavior of a valent electronic shell compounded with nuclear centers in molecules. This makes possible quantum simulations of mono- and divalent bonds in quantum chemistry by manipulation of up to four bosonic atoms confined with optical microtraps.

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References

[1] N A Moroz, K S Tikhonov, L V Gerasimov, *et al.*, Phys. Rev. **A** 111, 062823 (2025); DOI: 10.1103/558n-868y