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Detection of vorticity of trapped Bose-Einstein condensate using optical vortex beams

Vortex states in Bose-Einstein condensate (BEC) play an essential role in macroscopic quantum phenomena like superfluidity and superconductivity. There have been studies to detect and measure the angular momentum of a BEC vortex state using different techniques, like, imaging the density distribution after free expansion , interference between vortex states , and exciting the quadrupole mode of a BEC using an auxiliary laser beam as stirrer . However, the matter-wave interference technique proposed by Bolda and Walls is the only technique till date to determine the handedness of angular momentum of a vortex state. Here we show how the Circular dichorism (CD) like effect that arises in interaction of a BEC with an Laguerre-Gaussian (LG) beam can be useful to propose a new technique to detect both the vorticity and its handedness of a matter-wave vortex of the BEC. Let the sodium BEC is initially prepared in electronic state 3S_1/2,F=1,m_F=-1. The condensate atoms are allowed to undergo two-photon transitions. But now, two sets of pulses are applied simultaneously. One pulse consists of an LG *0+l beam and a Gaussian beam G _1 (LG _0+lG _1 pulse). The other pulse consists of an LG _0-l beam and a Gaussian beam G _2 (LG _0-l/G _2 pulse). When a condensate atom undergoes two-photon transition due to interaction with the LG _0+l /G _1 pulse then the final electronic state is 3S_1/2,F=1 and let us call it as type-I two-photon transition. But if the atom undergoes two-photon transition due to interaction with the LG _0-l/G _2 pulse then the final electronic state will be 3S*{1/2},F=2 and let us call it as type-II two-photon transition. The final electronic states are decided by the polarization of the light fields. The intensities of the beams are selected such that electronic portions of Rabi frequencies corresponding to the type-I and type-II transitions are equal. The difference in Rabi frequencies will come from the center-of-mass portion of transition matrix element. The direction of the applied beams are such that after free expansion, the atoms undergoing type-I two-photon transition should be spatially separable from the atoms undergoing type-II two photon transition. Next, one can image how much fraction of the initial number of atoms has undergone type-I transition and how much fraction has type-II transition. If almost same number of atoms have taken part in both types of transitions then the initial BEC state is a non-vortex state. If a larger fraction of atoms takes part in type-I (type-II) transition then the initial BEC state has vorticity kappa >0 (kappa <0).

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Summary

We study the interaction of optical vortex beam with vortex states of trapped Bose-Einstein condensate. Both the center-of-mass and electronic motion of the condensate atoms are treated quantum mechanically. We demonstrate the dipole Rabi frequency in such interaction depends on the handedness of the orbital angular momentum of the beam. This circular dichorism-like effect can be used to detect matter-wave vortex state and its handedness.

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