Interaction of Vortex Beam with Ultra-Cold Atoms: Mechanism and Applications

Anal Bhowmik

June 25, 2018

Abstract

The proposed formalism of transfer of orbital angular momentum (OAM) from paraxial vortex beam ta single-component Bose-Einstein condensate (BEC) is now well established. Here, we develop a theory for the microscopic interaction between matter and an optical vortex beyond paraxial approximation. The coupling of spin angular momentum (SAM) and OAM of the optical field produces three angular momentum channels (AMC) in interaction with atomic BEC through three different dipole selection rules of transitions. Eventually, the AMCs will produce a superposition of matter-wave vortices using two-photon stimulated Raman transitions. We study how the Rabi frequencies of Raman transitions vary with focusing angles for different combinations of OAM and SAM of optical states. We also have extended the theory of vortex beam-matter interaction by considering the two-component BEC. The mixture of BECs produces interesting ground state structures due to the competition between intra- and inter- component coupling strengths. For large number of particles, $N = 10^7$, we have found out the critical value of inter- component interaction strength for which the BECs will collapse. The coherency of vortex-antivortex superposition is evaluated in terms of inter-component coupling strengths. We have also studied the importance of inter- and intra- BEC scattering lengths on the non-paraxial effects of focused vortex beam, when it interacts with the two-component BEC.

Presence of external electric field inevitably produces a stark shift in the energy levels of an atom and the polarizability of the energy level is the measure of the stark shift of that particular level. In this thesis, we have also presented a theory of dynamic polarizability for an atomic state due to an external field of non-paraxial Laguerre-Gaussian (LG) beam using the sum-over-states technique. A highly correlated relativistic coupled-cluster theory is used to evaluate the most important and correlation-sensitive parts of the sum. Results show the variation of magic wavelengths with the choice of (OAM, SAM) and the focusing angle of the LG beam. Evaluations of the wide spectrum of magic wavelengths from infrared to ultraviolet have substantial importance to experimentalists for carrying out high-precision measurements in fundamental physics.

Key words: Paraxial and non-paraxial Laguerre-Gaussian beam; orbital angular momentum; Bose-Einstein condensate; Two-photon Raman transition; Dynamic Polarizability, Magic Wavelengths, Red and Blue detuned trap.