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Journal of Basrah Researches ((Sciences)) Vol. 35, No.5, 15 October ((2009))

Numerical techniques for Rotating Bose–Einstein Condensation

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ISSN -1817 -2695

((Received 30/4/2009, Accepted 1/10/2009))

Abstract

In this paper, the Modified fourth-order time-splitting pseudospectral (MTSP), Modified Hermite pseudospectral (MHP), Modified Laguerre pseudospectral (MLP) and Modified Laguerre-Hermite pseudospectral (MLHP) methods are introduced to solve 1-D, 2-D GPE with radial symmetry and 3-D GPE with cylindrical symmetry using the alternating direction implicit (ADI) technique for the coupling in the angular momentum rotation term in the GPE. Thus at every time step, the GPE in rotational frame is decoupled into a nonlinear ordinary differential equation (ODE) and two partial differential equations with constant coefficients. This allows developing new methods for treating and solving the nonlinear Schrödinger equation and computing the dynamics of BEC in a rotational frame giving new results when compared with Crank-Nicolson finite difference (CNDF) method.

1. Introduction

In pervious paper [1] we study the numerical resolution of the time-dependent Gross-Pitaevskii equation (GPE), which is a nonlinear Schrödinger equation (NLSE) used to simulate the dynamics of Bose-Einstein condensates (BEC) by considering condensates trapped in harmonic and different potentials forms. Furthermore, there has been a series of recent studies in the same field which deal's with the numerical solution of the time-dependent GPE especially for ground states. One can basically classify the methods for computing the ground state of non-rotating BEC into two groups: pseudospectral method, e.g. TSSP method, and finite difference method, i.e. Crank-Nicolson finite difference (CNFD) [2], Runge-Kutta type (RKFD) [3] and backward Euler finite difference (BEFD) [4] method. Other finite difference or finite element methods are usually of low-order accuracy in space and in many cases they have a very severe constraint for time step due to the stability or the energy diminishing requirement. On the other hand, for rotating BEC, currently the numerical methods are very limited, and the available methods are all low-order finite difference methods [5-8].

In this paper, we introduce a new method to compute the ground state solution of BEC and study the vortex dynamics.Vortices are a characteristic feature of a superfluid, it is only their presence permits circulation of the fluid, or allows two flows with different velocities to join. There have been numerous investigations about the properties of vortices in condensates that appear in literatures, in two cases: rotating [9-13] and non-rotating [14-17] condensation. And in order to study the dynamics of BEC, especially in the strongly repulsive interacting regime, an efficient and accurate numerical method is one of the key issues, which should preserve the analytical properties of the time-dependent GPE. The methods for computing the dynamics of non-rotating BEC are mainly grouped into twofold. One is the finite difference method, i.e. Crank-Nicolson finite difference (CNDF) method [18], explicit finite difference method [19] and alternating direction implicit (ADI) method [20]. Through this paper, the Modified fourth-order time-splitting pseudospectral (MTSP), Modified Hermite pseudospectral (MHP), Modified Laguerre pseudospectral (MLP) and Modified Laguerre-Hermite pseudospectral (MLHP) methods are introduced to solve 1-D, 2-D GPE with radial symmetry and 3-D GPE with cylindrical symmetry using the alternating direction implicit (ADI) technique for the coupling in the angular momentum rotation term in the GPE. Thus at every time step, the GPE in rotational frame is decoupled into a nonlinear ordinary differential equation (ODE) and two partial differential equations are with constant coefficients. This allows developing new methods for treating and