RICC Usage Report for Fiscal Year 2012

Project Title:

Structure and dynamics of nuclear large amplitude collective motion

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With the experimental availability of radioactive ion beams, the study of heavy-ion fusion reactions is of great interest especially for the synthesis of superheavy elements and nuclei far from stability. The nuclear reactions at energies near the fusion barrier provides important information on the reaction mechanism and collision dynamics. Theoretical investigation is of fundamental importance to select the optimal combination of projectile and target as well as incident energy owing to the very time-consuming experiments.

The purpose of the present work is to systematically investigate the dynamical fusion threshold with modern time-dependent Hartree-Fock (TDHF) simulation from light to heavy systems, and to answer whether the microscopic TDHF calculation can quantitatively reproduce the extra push predicted with macroscopic model, and to give the criterion for the mass combination of projectile and target above which the extra push is needed, and to indicate the magnitude of extra push energy.

By using RICC system, the time evolution of nucleus-nucleus collisions has been simulated systematically with the TDHF theory. We solve TDHF equation in three-dimensional coordinate space and the numerical codes are parallized with message passing interface (MPI). The full three dimensional TDHF calculations will shed light on more realistic dynamics in heavy ion collisions. However the numerical calculations are quite time-consuming, especially for the calculation of heavy collision systems. The high speed and available CPU cores of MPI parallization in RICC system provided essential support for the studies of the research project.

TDHF fusion threshold and fusion barrier with energy density functional (EDF) theory with frozen density approximation have been systematically investigated for the reaction systems of all the combinations among the double magic spherical nuclei ^{16}O, ^{40}Ca, ^{48}Ca, ^{90}Zr, ^{100}Sn, ^{132}Sn and ^{208}Pb, as well as additional three systems $^{48}Ca+^{238}U$, $^{96}Zr+^{132}Sn$, and $^{70}Zn+^{208}Pb$ leading to the synthesis of superheavy elements. TDHF fusion threshold is in better agreement with the experimental fusion barrier. We find that the onset of extra push lies at effective fissility 33, which is consistent with the prediction of macroscopic model. However the extra push energy in our microscopic calculations is systematically smaller than the prediction with macroscopic model especially for heavier system. The way to fit the parameters and the important dynamical effects neglected in macroscopic model might be responsible for the different results between TDHF calculation and macroscopic model. Experimental evidence also indicates that the extra push energy is smaller than the predictions with macroscopic model.

In the next usage term, I will continue my present research project in the following three directions. First, the study of extra-push dynamics for heavy systems leading to super-heavy elements in heavy ion fusion reactions will be done with TDHF theory. Second, we will investigate spin-excitation mechanisms from light to heavy collision systems with a fully three-dimensional time-dependent Hartree-Fock theory, and the influence of the usually neglected time-odd terms in Skyrme functional on spin-excitation mechanisms. Third is to investigate the dissipation mechanism in nuclear giant resonance with boost-invariant TDHF theory. The nucleus will be excited with external fields, and some dissipation mechanism will be investigated from light to heavy nuclei. All these studies need a lot of numerical calculations and RICC system will provide essential and important supports to these numerical calculations.

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[Publication]

1. J. Kotila, K. Nomura, L. Guo, N. Shimizu, and T. Otsuka, Shape phase transitions in the interacting boson model: Phenomenological versus microscopic descriptions, Physical Review C 85, 054309 (2012), published 9 May 2012.

[Proceedings, etc.]

1. Lu Guo, and Takashi Nakatsukasa, Time-dependent Hartree-Fock studies of the dynamical fusion threshold, EPJ Web of Conferences 38, 09003 (2012).
2. T. Nakatsukasa, S. Ebata, P. Avogadro, L. Guo, T. Inakura and K. Yoshida, Density functional approaches to nuclear dynamics, Journal of Physics: Conference Series 387, 012015 (2012).

[Oral presentation at an international symposium]

1. Time-dependent Hartree-Fock studies of the dynamical fusion threshold, International conference on Nuclear Structure and Related Topics, Dubna, July 2-7, 2012.
2. Dynamical fusion threshold in time-dependent Hartree-Fock theory, International workshop on From Nucleon Structure to Nuclear Structure and Compact Astrophysical Objects, KITPC, Beijing, Jun.11-Jul.28, 2012.