Project Title:

Structure and dynamics of nuclear large amplitude collective motion

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Time-dependent Hartree-Fock (TDHF) theory, originally proposed by Dirac in 1930, has been widely applied to the studies of fusion excitation function, giant resonance, fission, deep-inelastic scattering, and nuclear molecular resonances. It provides, from a fully microscopic point of view, the dynamical foundation of large amplitude collective motion. In most TDHF calculations, the tensor force was neglected due to the numerical complexity. Although the effect of tensor force has been extensively studied in the nuclear structure properties and collective excitation, quite few studies of the tensor effect on heavy-ion collision have been implemented. We first formulated the energy density functional with tensor force in a fully microscopic way and then realized them in the numerical codes. The TDHF equation was solved 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 TDHF calculations including tensor force. The high speed and available CPU cores of MPI parallization in RICC system provided essential support for the studies of the research project. In the past year, our study mainly focused on the following two aspects.

We have investigated the dissipation dynamics in heavy-ion collisions of $^{16}O+^{16}O$ using the modern TDHF approach. The numerical calculations have been implemented in a fully three-dimensional coordinate space with modern Skyrme energy functional and without any symmetry restrictions. The dissipation dynamics exhibits a universal behavior by using three Skyrme parametrizations SkM*, SLy4 and UNEDF1. We revealed that the percentage of energy dissipation in deep-inelastic collisions of the light systems decreases as the increase of incident energy due to the interplay between the collective motion and the single particle degrees of freedom. TDHF calculations with the newly fitted parametrization UNEDF1 predict the largest energy dissipation, while the smallest with SLy4 among the three parametrizations. The energy dissipation in present studies has been compared with the results in earlier calculations. Special attention is paid on the role of time-even and time-odd spin-orbit force. The spin-orbit force significantly enhances the energy dissipation. The time-even coupling of spin-orbit force plays a dominant role at low energies, while the effect of time-odd terms becomes more pronounced at high energies. More than half of the total dissipation for SkM* and SLy4, and slightly less than half for UNEDF1 are predicted to come from spin-orbit force. We also performed the fusion calculations for this system. The theoretical fusion cross section obtained from the parameter-free TDHF approach agrees reasonably well with the experimental data.

We have investigated the effect of tensor force on the dissipation dynamics and fusion cross sections in heavy-ion collisions of $^{16}O+^{16}O$ within the framework of the microscopic TDHF theory. The calculations have been implemented in a fully three-dimensional coordinate space with modern Skyrme energy functional plus tensor terms. The dissipation dynamics exhibits a universal behavior for all the Skyrme parameter sets studied here. We revealed that the energy dissipation in deep-inelastic collisions of the light systems decreases as an initial bombarding energy increases because of the interplay between the collective motion and the single particle motion. The energy dissipation is sensitive to the parameters of tensor force. The large absolute value of the sum of the coupling constants results in the strong effect of tensor force on the energy dissipation. The tensor force may either increase or decrease the energy dissipation depending on the different parameter sets. We also performed the fusion calculations for $^{16}O+^{16}O$ at a c.m. energy of 70.5 MeV. The cross section without the tensor force using SLy5 overestimated the experimental value by about 25%, while the calculations with tensor force T11 had good agreement with experiment. We can conclude that the tensor force is crucial in heavy-ion collisions of light systems with respect to the energy dissipation and fusion cross section.

In the next usage term, I will continue my present research project. The systematic studies will be done from light to heavy systems. All these studies need a lot of numerical calculations and RICC system will provide essential and important supports to these numerical calculation.