Solitonic excitations in collisions of superfluid nuclei

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Abstract

The effect of pairing correlations on reaction dynamics has attracted substantial interests in studies of atomic nuclei. Although a number of studies have been performed so far, we have still quite poor knowledge on it. We attack this problem by applying a newly developed, efficient computational code for the time-dependent density functional theory (TDDFT) including superfluidity, TDSLDA. The TDSLDA is an orbital-based Fermionic DFT for superfluid systems, which is in principle an exact approach [1–3], and has been proved to be very accurate for describing the dynamics of strongly correlated fermionic systems such as ultracold atomic gases [4–10] and nuclear systems [11–15]. Since we solve TDSLDA equations in 3D Cartesian coordinates without any symmetry restrictions, we can simulate both central and non-central collisions. We utilize the FaNEDF^0 functional developed by Fayans *et. al.* [16, 17], which reproduces the infinite matter equation of state of Refs. [18, 19] and various properties of finite nuclei [20, 21]. We made a simplification by omitting the spin-orbit coupling from the functional as this greatly reduces the computational cost.

We have performed TDSLDA calculations for ^{90}Zr+^{90}Zr, ^{86}Zr+^{126}Sn, and ^{240}Pu+^{240}Pu reactions at energies around the Coulomb barrier. We have paid particular attention to phenomena associated with the phase (gauge angle) difference between two colliding superfluid nuclei, an additional degree of freedom associated with the pairing correlation which has not been investigated carefully. By performing calculations for various phase differences, we have found that the phase difference significantly affects the reaction dynamics: *e.g.* the threshold energy for fusion in ^{90}Zr+^{90}Zr is changed as large as 30 MeV (See

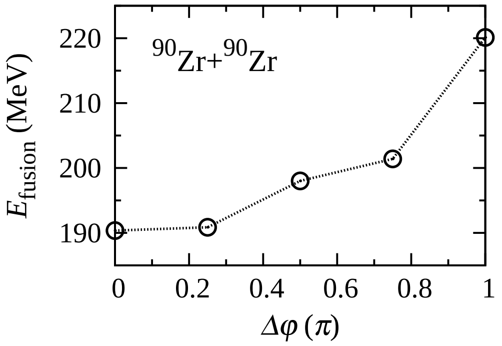

FIG. 1: Fusion threshold energy, E_{fusion}, below which no fusion reaction has been observed, as a function of the relative phase $\Delta\varphi$ for ^{90}Zr+^{90}Zr reaction.

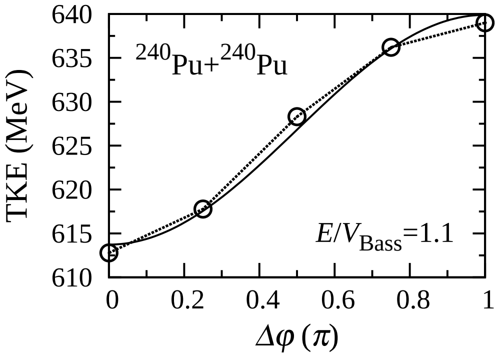

FIG. 2: Total kinetic energy (TKE) of the outgoing fragments as a function of the relative phase $\Delta\varphi$ for ^{240}Pu+^{240}Pu reaction at $E/V_{\text{Bass}} \simeq 1.1$. Circles connected with dotted lines are results of TDSLDA calculations, while solid line is a fit by $\sin^2$ function which is related to solitonic excitation energy.

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Fig. 1); total kinetic energy (TKE) of outgoing fragments is changed about 25 MeV in ^{240}Pu+^{240}Pu at $E/V_{\mathrm{Bass}} \simeq 1.1$ (See Fig. 2); moreover, even the number of fragments can be changed in ^{240}Pu+^{240}Pu at energies substantially above the Coulomb barrier. We have also found that particle flow induced by the phase difference, which is analogous of Josephson currents, is very small (less than 1 particle is transfered on average).

We consider that these effects are originated from *solitonic excitations* of superfluid medium associated with the phase discontinuity between two colliding nuclei. In this talk, we will show the qualitatively new possibility—the solitonic excitations—in low-energy heavy-ion physics, indicated by the cutting-edge, large scale, microscopic simulations.

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