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# Pauli-blocking effect in two-body collisions dominates the in-medium effects in heavy-ion reactions near Fermi energy

Yong-Zhong Xing [a,*], H.F. Zhang [a,b], Xiao-Bin Liu [a], Yu-Ming Zheng [a,c]

[a] *Institute for the Fundamental Physics, Tianshui Normal University, Gansu, Tianshui 741000, People's Republic of China*

[b] *School of Nuclear Science and Technology, Lanzhou University, Lanzhou 730000, People's Republic of China*

[c] *China Institute of Atomic Energy, P.O. Box 275(18), Beijing 102413, People's Republic of China*

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**Abstract**

The dissipation phenomenon in the heavy-ion reaction at incident energy near Fermi energy is studied by simulating the reactions $^{129}Xe + ^{129}Sn$ and $^{58}Ni + ^{58}Ni$ with isospin-dependent quantum molecular dynamics model (IQMD). The isotropy ratio in terms of transverse and longitudinal energies of the free protons emitted in the final states of these reactions is quantitatively analyzed to explore the in-medium correlation of the binary collisions. Comparison of the calculations with the experimental data recently released by INDRA collaboration exhibits that the ratio is very sensitive to the Pauli blocking effect in two-body collisions and Pauli exclusion principle is indispensable in the theoretical simulations for the heavy-ion reactions near the Fermi energy.



*Keywords:* Pauli blocking; In-medium effects; Isotropy ratio; Nucleon emission; Fermi energy

* Corresponding author.
*E-mail address:* yzxing@tsnu.edu.cn (Y.-Z. Xing).

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## 1. Introduction

Exploration of the properties of nuclear interactions via heavy-ion collision (HIC) at intermediate energy, specifically to extract the fundamental information about nuclear matter equation of state (EOS) and in-medium nucleon–nucleon (NN) cross section, is a long-standing topic, which has been extensively studied both theoretically and experimentally [1–7]. One of the effective means to understand both EOS and NN cross sections is to study the dissipation phenomenon emerging in the heavy-ion colliding processes, which can be deduced by the energy and isospin transport and thus related to the stopping. In fact, the nuclear stopping power is one of the most attractive physical quantities for theoretical physicists, because it can be directly evaluated by the microscopic transport model in addition to its profound significance [8–11]. Recently, G. Lehaut and his group [12] have analyzed the stopping power in central symmetric nuclear reactions with various total masses of systems at different incident energies near Fermi energy by using the large data set of exclusive measurements provided by the $4\pi$ array INDRA. Their studies indicated that transparency is a key feature of nuclear collisions in the intermediate energy range and the in-medium effects cannot be neglected in the Fermi energy range. Most features presented in ref. [12] have been successfully explained by two studying groups of Y.G. Ma [13] and F.S. Zhang [14] separately with the help of the isospin-dependent quantum molecular dynamics model (IQMD). E. Bonnet et al. [15] investigated the effect of the compression–expansion dynamics on the properties of the final reaction by comparing between the predictions of the stochastic mean field (SMF) transport model and experimental data. Very recently, G. Lehaut et al. [16] have produced a body of experimental data on nuclear stopping measured by the free protons emitted in the final state of central HICs in the Fermi energy domain.

In this study, we aim to reproduce the data given in ref. [16], by stimulating the reaction systems $^{129}$Xe + $^{129}$Sn and $^{58}$Ni + $^{58}$Ni with IQMD. We further study the dissipation phenomenon in the heavy-ion reactions at incident energy near Fermi energy. Our results confirm that the medium correction reduces the ratio for free protons emitted in the reaction final states in the central collisions and thus the nuclear stopping is diminished. The comparison of our calculations with the experimental isotropy ratio exhibits that the Pauli exclusion principle is indispensable in the theoretical simulations with microscopic transport model. In particular, the Pauli blocking in two-body collisions is important to determine the ratio and thus it dominates the in-medium effects in the heavy-ion reactions at the beam energy near Fermi energy. Before presenting our results and discussions, we recall the main ingredients of IQMD, involving the components of the mean field and the forms of NN cross sections briefly. The details about the model can be found in refs. [11,13,14] and the references therein.

## 2. IQMD model and in-medium NN cross sections

The IQMD model contains two ingredients: density-dependent mean field containing correct isospin terms including symmetry potential and the in-medium NN cross sections, which are different for neutron–neutron (proton–proton) and neutron–proton collisions. The density-dependent potential is given by

$$U(\rho) = U^{Sky} + U^{coul} + U^{sym} + U^{Yuk} + U^{MDI} + U^{Pauli}, \tag{1}$$

where $U^{coul}$, $U^{Sky}$, $U^{Yuk}$, $U^{MDI}$, and $U^{Pauli}$ are Coulomb potential, Skyrme potential, Yukawa potential, momentum-dependent interaction (MDI), and the Pauli potential, respectively. Their concrete expressions are given in refs. [11,17,18].