Vol 16 No 11, November 2007
1009-1963/2007/16(11)/3305-07

Chinese Physics

© 2007 Chin. Phys. Soc.
and IOP Publishing Ltd

Probing the medium effect and isospin dependence of the in-medium nucleon–nucleon cross section in heavy ion collisions*

Liu Jian-Ye(刘建业)[a)b)d)†], Guo Wen-Jun(郭文军)[c)], and Xing Yong-Zhong(邢永忠)[a)b)d)]

[a)] *Institute for the Theory of Basic Physics, Tianshui Normal University, Tianshui* 741000, *China*
[b)] *Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou* 730000, *China*
[c)] *Science College, University of Shanghai for Science and Technology, Shanghai* 200093, *China*
[d)] *Center of Theoretical Nuclear Physics, National Laboratory of Heavy Ion Accelerator, Lanzhou* 730000, *China*

(Received 20 November 2006; revised manuscript received 10 May 2007)

Probing in-medium nucleon–nucleon (NN) cross section $\sigma^1_{\rm NN}(\alpha)$ in heavy ion collisions has been investigated by means of the isospin-dependent quantum molecular dynamics (IQMD) with the isospin- and momentum-dependent interaction (IMDI(τ)). It is found that there are the very obvious medium effect and the sensitive isospin-dependence of nuclear stopping R on the in-medium NN cross section $\sigma^1_{\rm NN}(\alpha)$ in the nuclear reactions induced by halo-neutron projectile and the same-mass stable projectile. However, R induced by the neutron-halo projectile is obviously lower than that induced by the corresponding stable projectile. In particular, there is a very obvious dependence of R on the medium effect of $\sigma^1_{\rm NN}(\alpha)$ in the whole beam energy region for the above two kinds of projectiles. Therefore, the comparison between the results of R's in the reactions induced by the neutron-halo projectile and the corresponding same-mass stable projectile is a more favourable probe for extracting the information of $\sigma^1_{\rm NN}(\alpha)$ because of adding a new judgement.

Keywords: isospin effect, neutron-halo projectile, nuclear reaction, nucleon-nucleon cross section, nuclear stopping

PACC: 2570

1. Introduction

From the studies on the halo phenomenon of nuclear structure and the nuclear reaction induced by halo-nuclei, the small separation energy of the last nucleon, the extended density distribution and the narrow momentum distribution are important properties of halo nuclei.[1−21] However, the previous experimental and theoretical studies on the nuclear reactions induced by halo projectiles concentrate mainly on the fine reaction mechanisms. In particular, little effort has been made so far to extract the isospin dependence and medium effect of nucleon–nucleon (NN) cross sections in isospin asymmetry of nuclear matter, and the information about $\sigma^1_{\rm NN}(\alpha)$ is little known. Even though a few studies have been concentrated on probing $\sigma^1_{\rm NN}(\alpha)$ based on the nuclear reactions induced by the normal neutron-rich and neutron-poor nuclei,[22,23] probing $\sigma^1_{\rm NN}(\alpha)$ by using a comparison between results of observation on the nuclear reactions induced by the neutron-halo projectile and the corresponding same-mass stable projectile is not taken into account. As we know, the in-medium isospin-dependent NN cross section $\sigma^1_{\rm NN}(\alpha)$ depends sensitively on the density distributions of colliding system and beam energy, while the density distributions of colliding system in turn depends sensitively on the beam energy. So how do $\sigma^1_{\rm NN}(\alpha)$ and $\dfrac{\sigma_{\rm np}}{\sigma_{\rm pp}}$ change with density ρ, isospin asymmetry $\delta = \dfrac{\rho_{\rm n}-\rho_{\rm p}}{\rho_{\rm n}+\rho_{\rm p}} = \dfrac{\rho_{\rm n}-\rho_{\rm p}}{\rho}$ and beam energy $E_{\rm lab}$ in heavy ion collisions and astrophysical situations? Here $\sigma_{\rm np}$ and $\sigma_{\rm pp}$ are the in-medium neutron–proton cross section and in-medium proton–proton cross section shown by $\sigma^1_{\rm NN}(\alpha)$ with neutron–proton and proton–proton collisions respectively. Because the answer may reveal directly useful information about the isospin-dependence and

*Project supported by the State Key Development Program for Basic Research of China (Grant No G2000077400), the Major Program of the National Natural Science Foundation of China (Grant Nos 10435080 and 105350101), the National Natural Science Foundation of China (Grant Nos 10447006 and 10575075), the CAS Knowledge Innovation Project Program (Grant No KJCX2-SW-N02).

†Corresponding author. E-mail: liujy@lzb.ac.cn

medium effect of in-medium nuclear effective interactions. In this way, we investigate the dependence of the nuclear stopping R on the isospin and medium effects of in-medium NN cross section for different NN cross sections: $\sigma^1_{\rm NN}(\alpha)$, $\sigma^0_{\rm NN}(\alpha)$ and $\sigma^2_{\rm NN}(\alpha)$. Here the isospin-dependent NN cross section $\sigma^1_{\rm NN}(\alpha)$ and the isospin-independent NN cross sections $\sigma^0_{\rm NN}(\alpha)$ shown by $\sigma_{\rm nn} = \sigma_{\rm pp} = \sigma_{\rm np}$ and $\sigma^2_{\rm nn}(\alpha)$ shown by $\sigma_{\rm nn} = \sigma_{\rm pp} = (1/2)(\sigma_{\rm np} + \sigma_{\rm nn})$ are used. It is found that R is sensitive to the isospin dependence and the magnitude of $\sigma^1_{\rm NN}(\alpha)$. In particular, the medium effect of R on $\sigma^1_{\rm NN}(\alpha)$ is very obvious. However, the isospin dependence of $\sigma^2_{\rm NN}(\alpha)$ for different R is not significant, as compared with that of $\sigma^1_{\rm NN}(\alpha)$ for different R due to about the same collision numbers for $\sigma^2_{\rm NN}(\alpha)$ and $\sigma^1_{\rm NN}(\alpha)$.

2. IQMD with IMDI(τ)

In order to describe the isospin effects appropriately in the quantum molecular dynamics (QMD)[24−26] the density-dependent mean field and the in-medium NN cross section should include correct isospin terms. The in-medium NN cross section should be different for the neutron–neutron, proton–proton and neutron–proton collisions. Pauli blocking should be counted by distinguishing the neutrons from the protons. Considering the above ingredients, we have obtained the isospin-dependent QMD. In IQMD the initial density distributions of the colliding nuclei are obtained from the calculations with the Skyrme–Hartree–Fock model. And then the initial data of colliding nuclei including both the density distribution in coordinate space and the corresponding momentum distribution of colliding nuclei are obtained by the initial code of IQMD with MDI. These calculations demand the binding energies and root-mean-square (rms) radii of colliding nuclei to be consistent with the experimental data. Thus both the density distribution in coordinate space and the corresponding momentum distribution of colliding nuclei as well as the parameters of interaction potential are fixed as the input data in the dynamical calculations by the dynamical code of IQMD with two-nuclei collision. In the above initial calculations the interaction potential is taken as

$$U(\rho) = U^{\rm Sky} + U^{\rm Coul} + U^{\rm sym} + V^{\rm MDI} + U^{\rm Yuk} + U^{\rm Pauli}, \quad (1)$$

where $U^{\rm Sky}$ and $U^{\rm Coul}$ are Skyrme and Coulomb potentials, $U^{\rm Yuk}$ and $U^{\rm Pauli}$ are Yukawa and Pauli interactions respectively. $U^{\rm sym}$ is the symmetry potential,[27,28]

$$U_1^{\rm sym} = cF_1(u)\delta\tau_{\rm z}. \quad (2)$$

Here c is the strength of symmetry potential, taking the value of 32 MeV. $F_1(u) = u$ and $u = \rho/\rho_0$; δ is the relative neutron excess $\delta = (\rho_{\rm n} - \rho_{\rm p})/(\rho_{\rm n} + \rho_{\rm p}) = (\rho_{\rm n} - \rho_{\rm p})/\rho$; ρ, ρ_0, $\rho_{\rm n}$ and $\rho_{\rm p}$ are the total, normal, neutron and proton densities, respectively.

$$\tau_{\rm z} = \begin{cases} 1 & \text{for neutron,} \\ -1 & \text{for proton.} \end{cases}$$

ρ_0 is the value at the beginning of time. $V^{\rm MDI}$ is the momentum-dependent interaction (MDI)

$$V^{\rm MDI} = t_4 \ln^2[t_5(\boldsymbol{p}_1 - \boldsymbol{p}_2)^2 + 1]\frac{\rho}{\rho_0}. \quad (3)$$

The momentum-dependent interaction without isospin dependence in IQMD is shown in Eq.(3), which is extracted from optical potential.[26] In order to include the isospin dependence in MDI, we insert an isospin degree of freedom into Eq.(3) to obtain an isospin-dependent MDI (IMDI) which refers to the similar formulas in Bruckner–Hartree–Fock single particle potential in equation of state for dense isospin asymmetry nuclear matter in Refs.[28, 29]. The isospin- and momentum-dependent interaction is shown by

$$\begin{aligned} & V_\tau^{\rm IMDI}(\rho_j, k_\tau, \tau') \\ = {} & t_4 \ln^2[t_5(\boldsymbol{p}_\tau - \boldsymbol{p}_{\tau''})^2 + 1]C_{\tau\tau}\frac{\rho_\tau}{\rho_0}, \\ & + t_4 \ln^2[t_5(\boldsymbol{p}_\tau - \boldsymbol{p}_{\tau'})^2 + 1]C_{\tau\tau'}\frac{\rho_{\tau'}}{\rho_0}. \end{aligned} \quad (4)$$

Here $\rho = \rho_\tau + \rho_{\tau'}$ and $\boldsymbol{p}_\tau = \hbar\boldsymbol{k}_\tau$, where $\rho_j = \rho_\tau$ or $\rho_{\tau'}$; τ and τ'' in the first bracket as well as τ and τ' in the second bracket on the right-hand side of Eq.(4) represent the interactions between like nucleons for τ and τ'', and those between the unlike nucleons for τ and τ'. Here $C_{\rm nn} = C_{\rm pp} = C_{\tau\tau}$ and $C_{\rm np} = C_{\rm pn} = C_{\tau\tau'}$. In the above, $\tau \neq \tau'$. More details for $V_\tau^{\rm IMDI}(\rho_j, k_\tau, \tau')$ can be found in Ref.[30].

An empirical density-dependent expression of the in-medium NN cross section[31] is used

$$\sigma^1_{\rm NN}(\alpha) = \left(1 + \alpha\frac{\rho}{\rho_0}\right)\sigma^1_{\rm NN}(0) \quad (5)$$

with the parameter $\alpha = -0.2$, which can well reproduce the flow data. Here $\sigma^1_{\rm NN}(0)$ is the experimental NN cross section.[32] We use Eq.(5) to take

into account the medium effect on the two-body collision. Both initial density distribution in coordinate space and the corresponding momentum distribution of colliding nuclei are obtained by the initial code of IQMD with IMDI(τ). Also these calculations require the binding energies and rms radii of colliding nuclei to be consistent with the experimental data. During the initial calculations the parameters of the interaction potentials with MDI and IMDI(τ) in IQMD are obtained. More detailed formulas and their numerical calculations in the IQMD model can be found in Refs.[24–27, 30] and Chapter 10 of Ref.[28].

3. Results and discussion

3.1. Evolution of in-medium NN cross section with $E_{\rm lab}$ and ρ

In order to study the isospin dependence of and the medium effect of R on NN cross section $\sigma^1_{\rm NN}(\alpha)$ for different beam energies and densities in heavy ion collisions induced by the neutron-halo projectile and the corresponding stable projectile, we first analyse the evolutions of $\sigma_{\rm np}$, $\sigma_{\rm pp}$ and $\frac{\sigma_{\rm np}}{\sigma_{\rm pp}}$ with the variations of nucleon beam energy $E_{\rm lab}$ and density ρ. Experimentally, strong evidences supporting reduced in-medium NN cross section have been found in heavy ion collisions, therefore $\sigma^1_{\rm NN}(\alpha)$ and both $\sigma^0_{\rm NN}(\alpha)$ and $\sigma^2_{\rm NN}(\alpha)$ are defined as the in-medium NN cross sections with and without isospin dependence, where the medium effects on $\sigma^1_{\rm NN}(\alpha)$, $\sigma^0_{\rm NN}(\alpha)$ and $\sigma^2_{\rm NN}(\alpha)$ are illustrated by Eq.(5) with $\alpha = 0.0, -0.2$ and -0.4. Clearly, the free NN cross section is larger than the in-medium NN cross section.

3.1.1. The $\sigma_{\rm np}$ and $\sigma_{\rm pp}$ as functions of nucleon beam energy $E_{\rm lab}$

Figure 1 shows $\sigma_{\rm np}$ and $\sigma_{\rm pp}$ as functions of nucleon beam energy $E_{\rm lab}$, in which the data points (solid circles) are obtained from the experimental measurements in Ref.[32] and the solid lines are the plot of a least-squares fit to the above in-medium NN cross section data, described by the following expressions:

$$\sigma_{\rm np} = -70.67 - 18.18/\beta + 25.26/\beta^2 + 113.85\beta^4, \quad (6)$$

$$\sigma_{\rm pp} = 13.73 - 15.04/\beta + 8.76/\beta^2 + 68.67\beta^4. \quad (7)$$

Here $\beta = v/c$. From Fig.1 it is clear that all $\sigma_{\rm np}$ are larger than $\sigma_{\rm nn}$ for $E_{\rm lab}$ below 600 MeV.

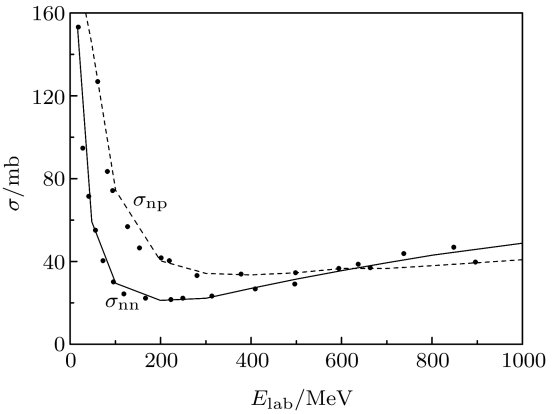


Fig.1. $\sigma_{\rm np}$ and $\sigma_{\rm pp}$ as functions of nucleon beam energy $E_{\rm lab}$.

3.1.2. The $\frac{\sigma_{\rm np}}{\sigma_{\rm pp}}$ as a function of nucleon beam energy $E_{\rm lab}$ and density ρ

Figure 2 shows $\frac{\sigma_{\rm np}}{\sigma_{\rm pp}}$ as a function of incident nucleon energy $E_{\rm lab}$ and density ρ which includes $\rho = 0$, ρ_0 and $2\rho_0$. The solid line is extracted from experimental data[33] while the dashed line is extracted from calculations in symmetry matter using the Bonn A potential in the Dirac–Bruckner approach in Ref.[34]. Clearly, the in-medium NN cross sections are reduced as compared with the values in free-space; the $\frac{\sigma_{\rm np}}{\sigma_{\rm pp}}$ is also predicted to decrease with increasing density ρ, which means that the isospin dependence of the in-medium NN cross section is weakened with increasing density ρ. However, the results from several other microscopic studies show the increase of $\frac{\sigma_{\rm np}}{\sigma_{\rm pp}}$ in a symmetric medium.[35–37] To sum up, the magnitudes of $\sigma_{\rm nn}$ and $\sigma_{\rm np}$ and the relation between them are changed in the course of the evolution of nucleon beam energy $E_{\rm lab}$ and density ρ.

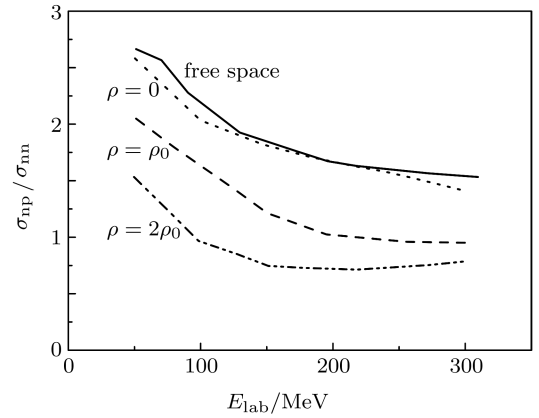


Fig.2. The $\frac{\sigma_{\rm np}}{\sigma_{\rm pp}}$ as a function of $E_{\rm lab}$ from experimental data for different ρ from the calculation results.

3.1.3. Nuclear stopping as a measure for the medium effect of in-medium NN cross section

Nuclear stopping is described by the ratio of transverse to parallel momentum $R = (2/\pi)(\sum_i^A \mid P_\perp(i) \mid)/(\sum_i^A \mid P_\parallel(i) \mid)$, where the total mass A is the sum of the projectile mass A_p and the target mass A_t. The transverse and the parallel components of the momentum of the ith nucleon are $P_\perp(i) = \sqrt{P_x(i)^2 + P_y(i)^2}$ and $P_{//}(i) = P_z(i)$. In order to investigate the medium effect on NN cross section $\sigma^1_{\mathrm{NN}}(\alpha)$, Fig.3 shows the nuclear stopping R as a function of beam energy E_lab for two couples of reactions $^8\mathrm{He} + ^{40}\mathrm{Ca}$ and $^8\mathrm{Li} + ^{40}\mathrm{Ca}$ for the isospin-dependent NN cross section $\sigma^1_{\mathrm{NN}}(\alpha)$ Fig.3(b) and isospin-independent NN cross section $\sigma^0_{\mathrm{NN}}(\alpha)$ Fig.3(a) for different medium parameters $\alpha = 0.0, -0.2$ and -0.4 at impact parameter $b = 1.0\,\mathrm{fm}$. The isospin-dependent NN cross section $\sigma^1_{\mathrm{NN}}(\alpha)$ is calculated from Eq.(5) and the isospin-independent NN cross section $\sigma^0_{\mathrm{NN}}(\alpha)$ is shown by letting $\sigma_{\mathrm{nn}} = \sigma_{\mathrm{pp}} = \sigma_{\mathrm{np}}$, in which σ_{nn}, σ_{pp} and σ_{np} are also calculated from Eq.(5) for neutron–neutron, proton–proton and neutron–proton collisions.

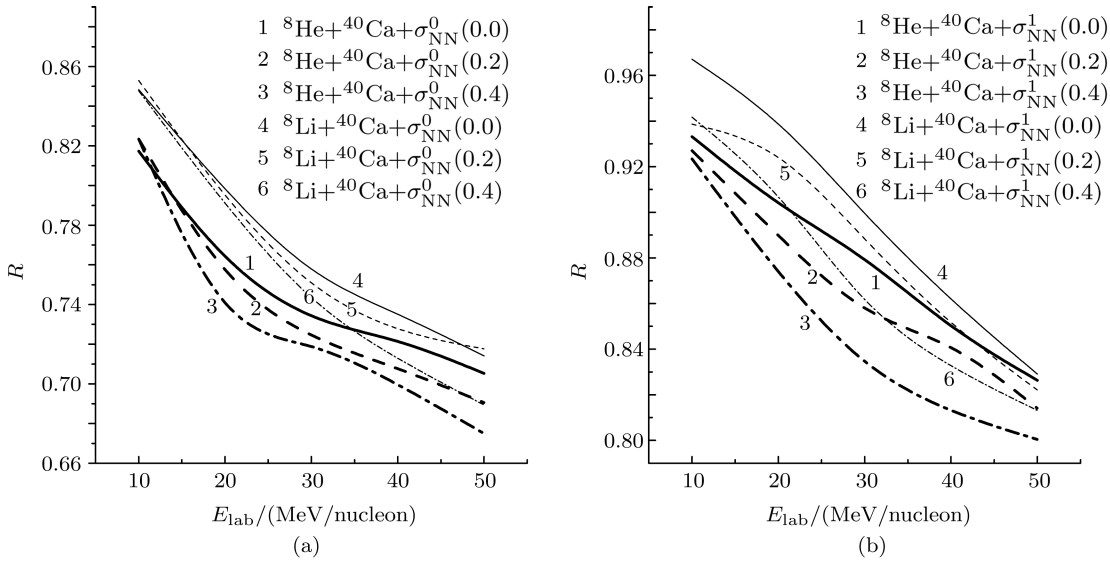


Fig.3. Nuclear stopping R as a function of beam energy E_lab for two couples of reactions with the isospin-dependent NN cross section $\sigma^1_{\mathrm{NN}}(\alpha)$ (Fig.3(b)) and isospin-independent NN cross section $\sigma^0_{\mathrm{NN}}(\alpha)$ (Fig.3(a)) for different medium parameters $\alpha = -0.4$, -0.2 and 0.0 at impact parameter $b = 1.0\,\mathrm{fm}$

The three thick lines show the nuclear stopping R for neutron-halo colliding systems $^8\mathrm{He} + ^{40}\mathrm{Ca}$ with different medium effects $\alpha = 0.0$ (solid line), -0.2 (dashed line) and -0.4 (dot-dashed line), and the three thin lines denote the R for corresponding stable systems $^8\mathrm{Li} + ^{40}\mathrm{Ca}$ with different medium effects $\alpha = 0.0$ (solid line), -0.2 (dashed line) and -0.4 (dot-dashed line). From Fig.3 it is clear that the medium effects of nuclear stopping R on NN cross section are evident while R increases with increasing medium parameter α from -0.4 to 0.0 because the in-medium NN cross section increase obviously as the enhancement of α. Namely, nuclear stopping R increases obviously with increasing medium effect from $\alpha = -0.4$ to 0.0 under the isospin- dependent NN cross section $\sigma^1_{\mathrm{NN}}(\alpha)$ and isospin- independent NN cross section $\sigma^0_{\mathrm{NN}}(\alpha)$ for the two couples of reactions in whole beam energy region in this work. Especially, all of R's for the neutron-halo colliding systems $^8\mathrm{He} + ^{40}\mathrm{Ca}$ are less than those for the corresponding same-mass stable colliding systems $^8\mathrm{Li} + ^{40}\mathrm{Ca}$ respectively. There are two explanations for the above properties: (1) The neutron-halo projectiles are neutron-rich nuclei, compared with the same-mass stable projectiles. Namely, neutron-proton collision numbers for the neutron-poor nuclei are larger than those for the neutron-rich nuclei under the same incident channel condition. From Fig.1 we can see that σ_{np} is always larger than σ_{pp} in the nucleon energy region below 600 MeV/nucleon. That is, the total NN cross section $\sigma_{\mathrm{np}} + \sigma_{\mathrm{pp}} + \sigma_{\mathrm{nn}}$ for the neutron-halo colliding system is less than that for corresponding same-mass stable colliding system, i.e., the total collision numbers for neutron-halo colliding systems are less than that for the corresponding same-mass stable colliding system under the same incident channel condition. As we know, nuclear stopping is

mainly produced by momentum dissipation coming from two-body collisions.[22] In this case, all of R's for the neutron-halo colliding systems are less than those for the corresponding same-mass stable colliding systems. (2) The loose halo structure of the neutron-halo projectiles reduces the NN collision strength and momentum dissipation so that it decreases also the nuclear stopping R as compared with the corresponding same-mass stable projectile under the same incident channel condition.[18] It is worth mentioning that the comparison between R's of the two kinds of colliding systems, i.e. the neutron-halo projectile and the corresponding same-mass stable projectiles, adds an important judgement condition for extracting the information of the medium effect on the in-medium NN cross section in the heavy ion collisions.

The decrease of R with increasing beam energy is due to the increase of nuclear collision transparency.

3.2. Nuclear stopping as a measure for the isospin dependence of in-medium NN cross section

In order to investigate the variations of nuclear stopping R with in creasing beam energy $E_{\rm lab}$ for NN cross section in different isospins, in Fig.4 we show R as a function of beam energy $E_{\rm lab}$ for the isospin-dependent NN cross section $\sigma^1_{\rm NN}(\alpha)$ (dashed lines)

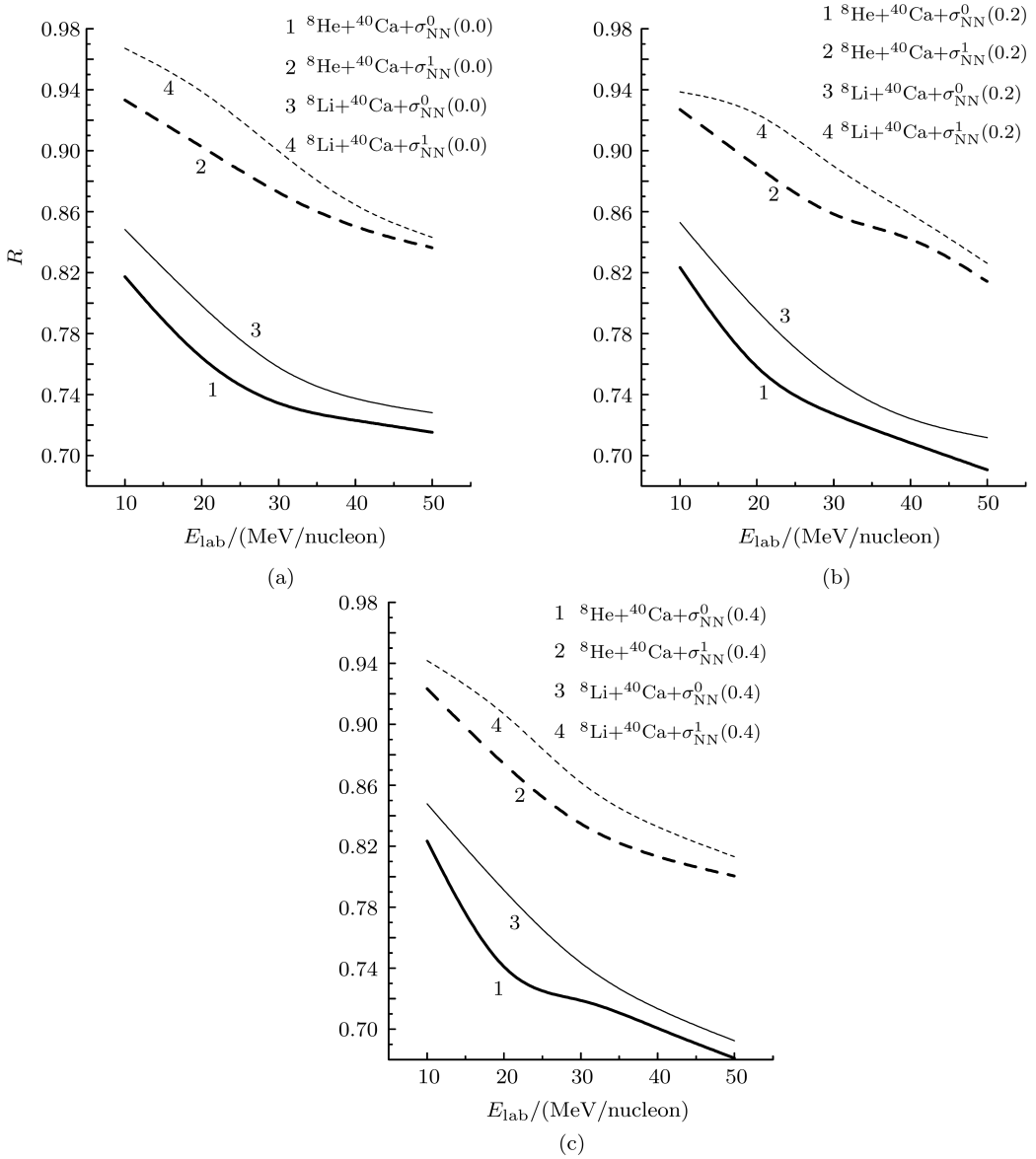


Fig.4. Nuclear stopping R as a function of beam energy $E_{\rm lab}$ for the isospin-dependent NN cross section $\sigma^1_{\rm NN}(\alpha)$ (dashed lines) and the isospin-independent NN cross section $\sigma^0_{\rm NN}(\alpha)$ (solid lines) with the medium parameter $\alpha = 0.0$ (a), -0.2 (b) and -0.4 (c) for the reactions $^8{\rm He} + {}^{40}{\rm Ca}$ (thick lines) and $^8{\rm Li} + {}^{40}{\rm Ca}$ (thin lines) at the impact parameter $b = 1.0\,{\rm fm}$.

and the isospin-independent NN cross section $\sigma^0_{\rm NN}(\alpha)$ (solid lines) with the medium parameter $\alpha = 0.0$ (a), -0.2 (b) and -0.4 (c) for the reactions ^{8}He + ^{40}Ca (thick lines) and ^{8}Li + ^{40}Ca (thin lines) at the impact parameter $b = 1.0$ fm. It is clear that all the thick lines are lower than the thin lines, i.e. all the values of nuclear stopping R for the neutron-halo colliding system ^{8}He + ^{40}Ca with both the isospin-dependent NN cross section $\sigma^1_{\rm NN}(\alpha)$ and isospin-independent NN cross section $\sigma^0_{\rm NN}(\alpha)$ under different medium effects are lower than those for corresponding stable colliding systems ^{8}Li + ^{40}Ca due to the above two reasons given to Fig.3. In particular, all the dashed lines for the isospin-dependent NN cross section $\sigma^1_{\rm NN}(\alpha)$ are obviously higher than the solid lines for isospin-independent NN cross section $\sigma^0_{\rm NN}(\alpha)$ with different medium effects, i.e., all the nuclear stoppings for the isospin-dependent NN cross section $\sigma^1_{\rm NN}(\alpha)$ are obviously larger than those for the isospin-independent NN cross section $\sigma^0_{\rm NN}(\alpha)$. This means an obvious isospin-dependence of the nuclear stopping R on NN cross section. Here we emphasize that the comparison between R's of the two kinds of colliding systems, the neutron-halo projectiles and the corresponding stable projectiles, adds an important judgement condition for extracting the information for the isospin dependence of in-medium NN cross section in the heavy ion collisions.

Figure 5 shows the isospin dependence of nuclear stopping R on NN cross section which is a function of colliding time t, for isospin-dependent NN cross section $\sigma^1_{\rm NN}(\alpha)$ (solid line) and the isospin- independent NN cross section $\sigma^0_{\rm NN}(\alpha)$ (dot-dashed line) or $\sigma^2_{\rm NN}(\alpha)$ (dashed line) with the medium parameter -0.2 for two couples of reactions ^{8}He + ^{40}Ca (a) and ^{8}Li + ^{40}Ca (b) at an impact parameter $b = 1.0$ fm and beam energy $E_{\rm lab} = 20$ MeV/nucleon. From Fig.5 it is clear that the differences between the saturation values of R's for $\sigma^1_{\rm NN}(\alpha)$ (solid line) and $\sigma^0_{\rm NN}(\alpha)$ (dot-dashed line) are much larger than those for $\sigma^1_{\rm NN}(\alpha)$ (solid line) and $\sigma^2_{\rm NN}(\alpha)$ (dashed line) for the two reactions ^{8}He + ^{40}Ca and ^{8}Li + ^{40}Ca. The nuclear stopping is mainly produced from the momentum dissipation in the course of two-body collisions. However, there are about the same collision numbers for $\sigma^2_{\rm NN}(\alpha)$ and $\sigma^1_{\rm NN}(\alpha)$, so the isospin dependence of $\sigma^2_{\rm NN}(\alpha)$ with different R is not significant,[23] as compared with $\sigma^0_{\rm NN}(\alpha)$. In this case it is difficult for the nuclear stopping R to be used as a probe for extracting the information of the isospin dependence of $\sigma^1_{\rm NN}(\alpha)$ by using the isospin-independent NN cross section $\sigma^2_{\rm NN}(\alpha)$.

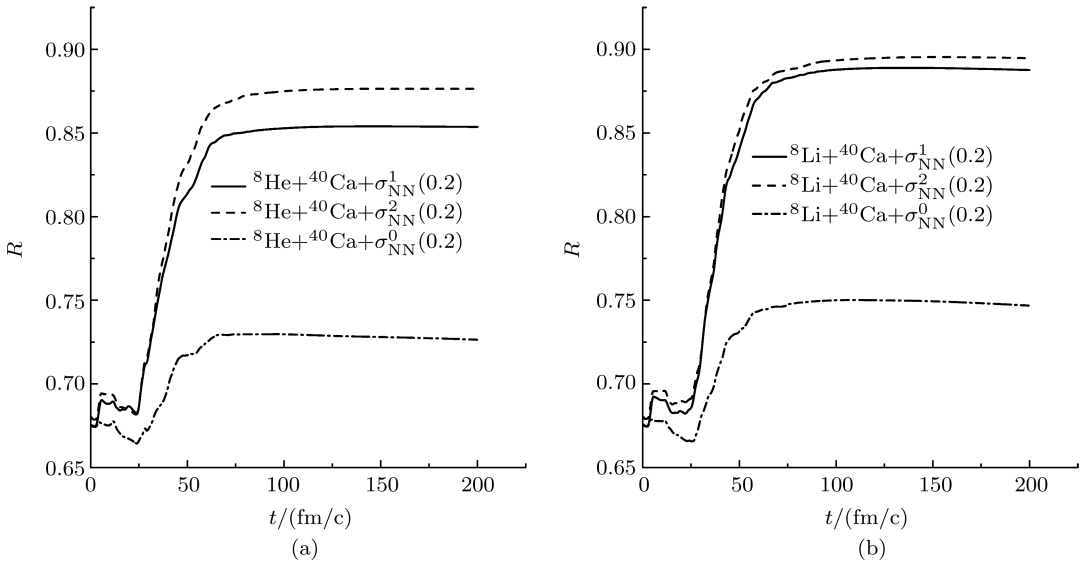


Fig.5. Nuclear stopping R as a function of colliding time t for isospin-dependent NN cross section $\sigma^1_{\rm NN}(\alpha)$ and isospin-independent NN cross section $\sigma^0_{\rm NN}(\alpha)$ and $\sigma^2_{\rm NN}(\alpha)$ with the medium parameter -0.2 for ^{8}He + ^{40}Ca (a) and ^{8}Li + ^{40}Ca (b) at $b = 1.0$ fm and $E_{\rm lab} = 20$ MeV/nucleon.

4. Summary and conclusions

From the above results and discussions we can conclude that: (1) The effects of the nuclear stopping R on the in-medium NN cross section for both isospin-dependent and the isospin-independent NN cross sections are obvious. (2) The dependence of isospin of in-medium NN cross section on the nuclear stopping

R is also obvious for the isospin-dependent NN cross section $\sigma^1_{\rm NN}(\alpha)$ and the isospin-independent NN cross section $\sigma^0_{\rm NN}(\alpha)$. (3) The comparison between nuclear stoppings R's of the two kinds of colliding systems, the neutron-halo projectiles and the same-mass stable projectiles, adds an important judgement condition for extracting the information of the medium effect on, and the isospin dependence of in-medium NN cross section in the heavy ion collisions.

References

[1] Tanihata I, Hamagaki H, Hashimoto O, Shida Y and Yoshikawa N 1985 *Phys. Rev. Lett.* **55** 2676
Tanihata I, Hamagaki H, Hashimoto, Nagamiya O S, Shida Y and Yoshikawa, YamakawaK. Sugimoto O N, Kobayashi T, Greiner D E, Takahashi N and Nojiri Y 1985 *Phys. Lett.* B **160** 380

[2] Zhang H Y, Ma Y G, Su Q M, Shen W Q, Cai X Z, Fang D Q, Hu P Y and Han D D 2001 *Acta Phys. Sin.* **50** 0193 (in Chinese)

[3] Mittig W, Chouvel J M, Zhan W L, Bianchi L, Cunsolo A, Fernandez B, Foti A, Gastebois J, Gillibert A, Gregoire C, Schutz Y and Stephan C 1987 *Phys. Rev. Lett.* **59** 1889

[4] Di Pietro A, Figuera P, Amorini F, Angulo C, Cardella G, Cherubini S, Davinson T, Leanza D, Lu J, Mahmud H, Milin M, Musumarra A, Ninane A, Papa M, Pellegriti M G, Raabe R, Rizzo F, Ruiz C, Shotter A C, Soi N, Tudisco S and Weissman L 2004 *Phys. Rev.* C **69** 044613

[5] Gomes P R S, Anjos R M, Muri C, Lubian J, Chamon L C, Padron I, Chamon L C, Liguori Neto R, Added N, Fernández J O, Niello, MartíG V, Capurro O A, Pacheco A J, Testoni J E and Abriola D 2004 *Phys. Rev.* C **70** 054605

[6] Ma Y G, Shen W Q, Feng J and Ma J Y 1993 *Phys. Rev.* C **48** 850

[7] Zhao Y L, Ma Z Y and Chen B Q 2001 *High Energy Phys. Nucl. Phys.* **26** 506

[8] Ren Z Z and Xu G G 1990 *Phys. Lett.* B **252** 311

[9] Liu Z H, Ruan M, Zhao Y L, Zhang H Q, Yang F, Ma Z Y, Lin C J, Chen B Q and Y. W. Wu Y W, Zhan W L, Guo Z Y, Xiao G Q, Xu H S, Sun Z Y, Li J X and Chen Z J 2004 *Phys. Rev.* C **69** 034326

[10] Guo W J, Hian H Q, Liu J Y, Zuo W, Ren Z Z and Lee X G 2003 *Commun. Theor. Phys.* **40** 577

[11] Carstoiu F, Trache L, Tribble Robert E and Gagliardi C A 2004 *Phys. Rev.* C **70** 054610

[12] Navin A, Tripathi V, Blumenfeld Y, Nanal V, Simenel C, Casandjian J M, de France G, Raabe R, Bazin D, Chatterjee A, Dasgupta M, Kailas S, Lemmon R C, Mahata K, Pillay R G, Pollacco E C, Ramachandran K, Rejmund M, Shrivastava A, Sida J L and Tryggestad E 2004 *Phys. Rev.* C **70** 044601

[13] Lin C J, Liu Z H and Zhang H Q 2001 *Chin. Phys. Lett.* **18** 1183

[14] Alamanos N, Pakou A and Lapoux V 2002 *Phys. Rev.* C **65** 054606

[15] Fukuda N, Nakamura T, Aoi N, Imai N, Ishihara M, Kobayashi T, Iwasaki H, Kubo T, Mengoni A, Notani M, Otsu H, Sakurai H, Shimoura S, Teranishi T, Watanabe Y X and Yoneda K 2004 *Phys. Rev.* C **70** 054606

[16] Zadro M 2004 *Phys. Rev.* C **70** 044605

[17] Rusek K, Alamanos N, Keeley N, Lapoux V and Pakou A 2004 *Phys. Rev.* C **70** 014603

[18] Liu J Y, Guo W, Ren Z Z, Xing Y Z, Zuo W and Lee X G 2005 *Phys. Lett.* B **617** 24

[19] Cai X Z, Zhang H Y, Shen W Q, Ren Z Z, Feng J, Fang G Q, Zhu Z Y, Jiang W Z, Ma Y G, Zhong C, W L Zhan, Guo Z Y, Xiao G Q, Wang3 J S, Zhu Y T, Wang J C, Li J X, Wang M, Wang J F, Ning Z J, Wang Q J and Chen Z Q 2002 *Phys. Rev.* C **65** 024610

[20] Gomez Camacho A and Aguilera E F 2004 *Nucl. Phys.* A **735** 425

[21] Suzuki T, Ogawa Y, Chiba M, Fukuda M, Iwasa N, Izumikawa T, Kanungo R, Kawamura Y, Ozawa A, Suda T, Tanihata I, Watanabe S, Yamaguchi T and Yamaguchi Y 2002 *Phys. Rev. Lett.* **89** 012501

[22] Liu J Y, Guo W J, Wang S J, Zuo W, Zhao Q and Yang Y F 2001 *Phys. Rev. Lett.* **86** 975

[23] Li B A 2000 *Phys. Rev. Lett.* **85** 4221
Li B A 2004 *Phys. Rev.* C **69** 034614

[24] Bertsch G F and Das. Gupta S 1988 *Phys. Rep.* **160** 1991

[25] Aichelin J, Rosenhauer A, Peilert G, Stoecker H and Greiner W 1987 *Phys. Rev. Lett.* **58** 1926

[26] Aichelin J, Peilert G, Bohnet A, Stocker H and Greiner W 1988 *Phys. Rev.* C **37** 2451

[27] Li B A, Ko C M and Bauer W 1998 *Int. J. Mod. Phys.* E **7** 147

[28] Li B A and Udo Schröder W 2001 *Isospin Physics in Heavy-Ion Collisions at Intermediate Energies* (New York: Nova Science)

[29] Bombaci I and Lombardo U 1991 *Phys. Rev.* C **44** 892

[30] Liu J Y, Guo W J, Ren Z Z, Xing Y Z, Zuo W and Lee X G 2006 *Chin. Phys.* **15** 1738

[31] Klakow D, Welke G and Bauer W 1993 *Phys. Rev.* C **48** 1982

[32] Alkahzov G, Bauer T, Bertini R, Bimbot L, Bing Q, Boudard A, Bruge G, Catz H and Chaumeaux A 1977 *Nucl. Phys.* A **280** 365

[33] Bauer T, Bertini R, BimbotDagger L, Bing O, Boudard A, Bruge G, Catz H, Chaumeaux A, Couvert P, Fontaine J M, Hibou F, Igo G J, Lugol J C and Matoba M 1977 *Nucl. Phys.* A **280** 365
Bol A, Devescovi P, Leleux P, Lipnik P, Macq P and Meulders J P 1985 *Phys. Rev.* C **32** 623
Grundies V, J Franz, Rssle E and Schmitt H 1985 *Phys. Lett.* B **158** 15
Lisowski P W, Shamu R E, Auchampaugh G F, King N S P, Moore M S, Morgan G L and Singleton T S 1982 *Phys. Rev. Lett.* **49** 255
Charagi S K and Gupta S K 1990 *Phys. Rev.* C **41** 1610

[34] Schnel A, Ropke G, Lombardo U and Schulze H J 1996 *Phys. Rev.* C **57** 806

[35] Giansiracusa G, Lombardo U and Sandulescu N 1996 *Phys. Rev.* C **53** R1478

[36] Kohno M, Higashi M, Watanabe Y and Kawai M 1998 *Phys. Rev.* C **57** 3495

[37] Li Q F, Li Z X and Mao G J 2000 *Phys. Rev.* C **62** 014606