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Study on Excitation Function and Isospin Dependencies of Total Reaction Cross Section via the Boltzmann-Uehling-Uhlenbeck Model *

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The excitation function and isospin dependencies of σ_R have been investigated by using the Boltzmann-Uehling-Uhlenbeck (BUU) model with a square-type density distribution. When the width parameter of the square distribution is obtained by fitting σ_R at relativistic energies, the BUU-model can reproduce the experimental data at intermediate energies better than Glauber model. The systematical underestimation of σ_R at intermediate energy by Glauber model was removed out now by BUU calculation framework. It is also found that σ_R is sensitive to nuclear equation of state and $\sigma_{NN}^{in-medium}$. The difference factor d defined in text is sensitive to the nuclear structure such as neutron halo and neutron skin, etc.

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The total reaction cross section σ_R has been extensively studied both theoretically and experimentally.[1−18] Recently the measurements of σ_R induced by exotic nuclei have provided an exciting chance to understand the anomalous structure such as skin and halo.[9−17] A useful tool to study σ_R is the microscopic Glauber multiple-scattering theory, which considers the Coulomb correction, also uses Yukawa interaction with finite range force and distinguishes neutron and proton inside nuclei. This theory is based on the individual nucleon-nucleon (N-N) collisions in the overlap volume of the colliding nucleus.[19] Comparisons of σ_R at relativistic energy with that at intermediate energies have been done by Ozawa *et al.*[4,15] They calculated the excitation function of σ_R by using the Glauber model, with Harmonic-oscillator(HO)-type distributions for the density. The width of the HO distribution, which is the only parameter in the calculation, was obtained by fitting σ_R at relativistic energies. The Glauber model calculations always underestimate σ_R at intermediate energies. This problem has not been solved up to now. For more detail, the differences between the experimental data and the calculated values at intermediate energies vary particularly from nuclei near β-stability line to halo or skin nuclei in the same isotope chain.

In order to study this deviation by using the above procedure, the Boltzmann-Uehling-Uhlenbeck (BUU)[20,21] equation has been introduced into the calculation of σ_R.[6,8] This model incorporates the Fermi motion, mean field, individual nucleon-nucleon(N−N) interactions and the Pauli blocking effect in calculation. And it can be used to extract nuclear equation of state (EOS) and in-medium N−N cross section and $\sigma_{NN}^{in-medium}$, etc, from analysis of σ_R. Within the framework of BUU model, the average N−N collision number can be obtained as a function of the impact parameter b by assuming a reasonable parameterization of σ_{NN}. According to Poisson statistic, the nucleon fraction T_n(b) that has experienced n times two-body collisions in

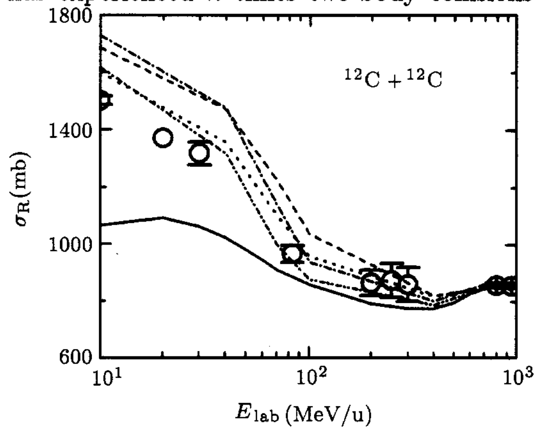

Fig. 1. Energy dependence of σ_R for $^{12}C + ^{12}C$ system. The open dots indicate the experimental data.[5,14] The solid curve shows the result of the Glauber calculation. The dashed and dotted curves show the BUU results by using σ_{Cug} with stiff and soft EOS, respectively. The dot-dashed and dot-dot-dashed curves show the BUU results by using $0.8\sigma_{Cug}$ with stiff and soft EOS, respectively.

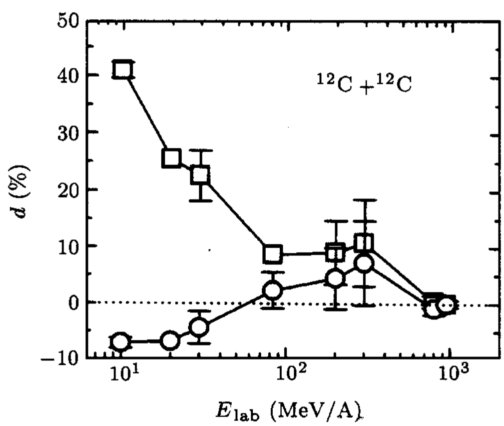

Fig. 2. Energy dependencies of the difference factor d for $^{12}C + ^{12}C$ which are calculated by using the Glauber model (open square) and BUU model (open circles), respectively. The curves guide for the eyes.

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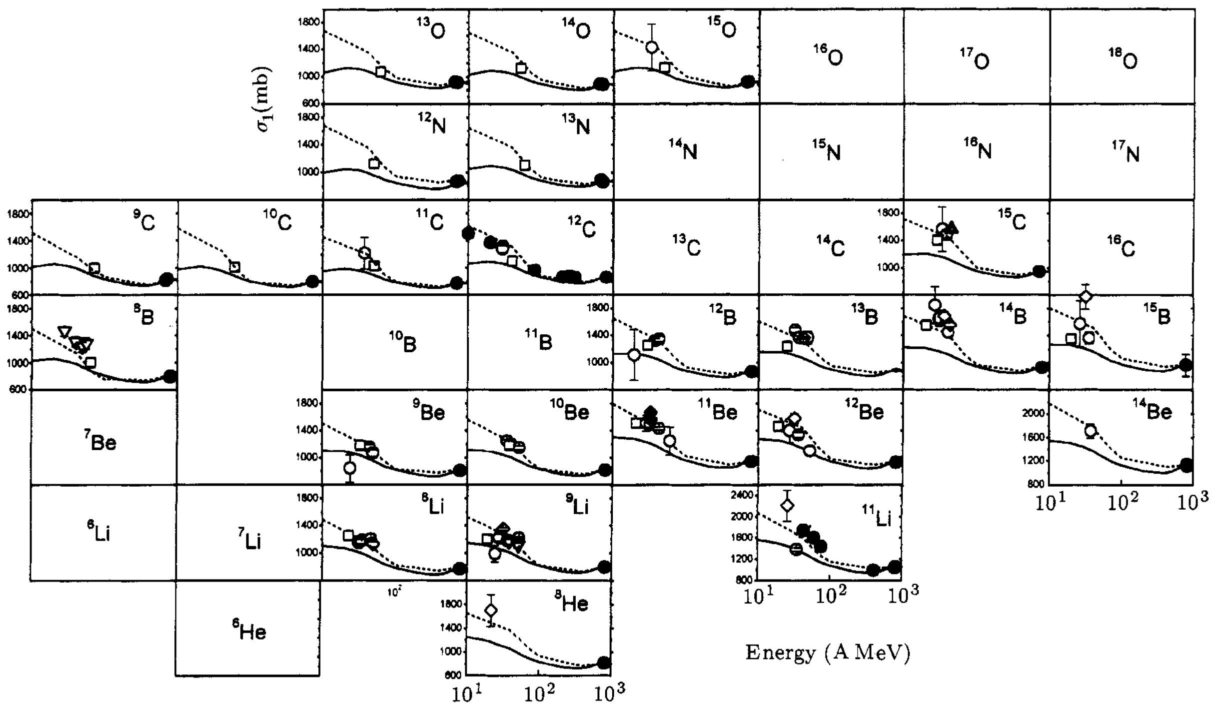

Fig. 3. Energy dependence of σ_R with a C target shown in the nuclear chart of the p-shell nuclei. The experimental data are indicated by closed circles,[4,14,15,23] closed rhombuses,[12] open squares,[4] open circles,[11] open rhombuses,[13] open triangles,[10] open reverse triangles.[16] Solid curves indicated the calculations by using the Glauber model. Dashed curves indicated the BUU calculations by using soft EOS and $0.8\sigma_{\rm Cug}$.

the course of nucleus-nucleus reaction can be easily obtained. The sum of T_n(b) over $n (n \geq 1)$ represents the total probability of N−N collisions and is related closely to the absorption probability of nuclear reaction. Therefore, σ_R is given by

$$\sigma_{\rm R} = 2\pi \int \left[\sum_{n=1}^{\infty} T_n(b)\right] b{\rm d}b = 2\pi \int [1 - \exp(N)] b{\rm d}b, \quad (1)$$

where N is the average N−N collision number. More details can be found in Ref. 6.

In this paper, the well-known Cugnon's parameterization $\sigma_{\rm Cug}$ for $\sigma_{\rm NN}$ (Ref. 22) and square-type density distribution are used in the BUU calculation. The width of the square distribution has been obtained by fitting σ_R at relativistic energies. Figure 1 shows the energy dependence of σ_R for ^{12}C+^{12}C system. The experimental σ_R with the targets other than C were normalized to the values with the C target by using the modified Kox equation presented in Ref. 3. All the BUU calculations that are normalized to the experimental data at relativistic energies reproduce the experimental data at intermediate energies better than the Glauber calculations. It can be seen that σ_R is more sensitive to the EOS at the intermediate energy range than that at relativistic energy ranges. This sensitivity of σ_R at the intermediate energy range may reflect that the dynamical mechanism changes from the dominant role of the mean field at lower energies to that of individual N−N collisions at higher energies. Because of the normalization at relativistic energies, the effect of the factor before $\sigma_{\rm Cug}$ for $\sigma_{\rm NN}$ on σ_R is small while at the incident energy around 100 MeV/nucleon this effect could not be neglected.

For quantitative discussions, the difference factor d is defined by[4]

$$d = \frac{\sigma_{\rm R}({\rm expt}) - \sigma_{\rm R}({\rm calc})}{\sigma_{\rm R}({\rm calc})}, \quad (2)$$

where σ_R(expt) is the experimental data and σ_R(calc) is the calculated results of the Glauber model or the BUU-model at intermediate energies with a width parameter obtained by fitting the experimental σ_R data at relativistic energy. We average the values of d over those points which have two or more experimental σ_R. The errors for these points were determined by the average deviation of the data. The energy dependence of d for the ^{12}C+^{12}C system is shown in Fig. 2. The d value of the Glauber-model calculations is about 40% at 10 MeV/nucleon. It decreases with increasing beam energy. For the BUU-model calculations using soft EOS and $0.8\sigma_{\rm Cug}$, which is widely used in the BUU model, d is less than 10% over a wide energy range although d increases with increasing incident energy. It is indicated that the BUU calculations using soft EOS and $0.8\sigma_{\rm Cug}$ could reproduce σ_R both at intermediate energy and at relativistic energy.

For other light nuclei the σ_R calculation was studied systematically. The results are shown in Fig. 3. It is very clear that the BUU model reproduces σ_R much better than the Glauber model. The isospin dependence of d for Li, Be, B and C at intermediate energy is shown in Fig. 4. It can be seen that d of the BUU-model calculations is less than that of Glauber

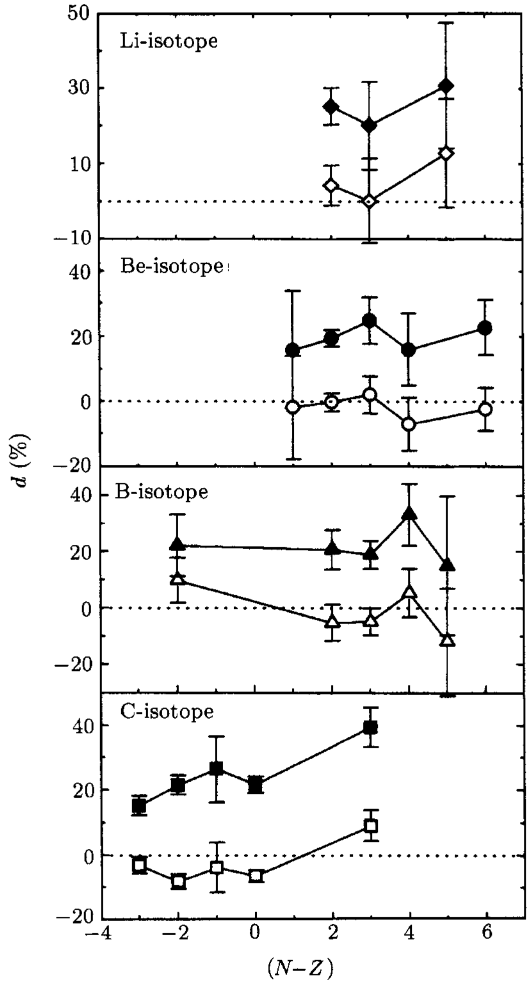

Fig. 4. Isospin dependencies of d for Li, Be, B and C at intermediate energy. The curves connecting solid dots indicated the Glauber model calculations. The solid curves connecting open dots indicated the BUU model calculations.

calculations systematically. For the Glauber calculations, d is about 20% for the nuclei near β-stability line and enhances up to 30–40% for some nuclei that have anomalous structure such as skin and halo. For the BUU calculations, d is less than 10% and d of the halo or skin nuclei is still larger than that of their neighbors, the same as the Glauber calculations. For the Li, Be and B isotopes, the values of d for ^{11}Li, ^{11}Be, ^{14}Be and ^{14}B, which are suggested as neutron halo nuclei, are larger than those of the neighbor isotopes. It is suggested that this difference factor d is sensitive to the nuclear structure such as neutron halo and neutron skin. The value of d for ^{8}B is also larger than that of the other B isotopes. ^{8}B has been suggested as a proton-halo nucleus before.[17] In the C isotopes, the value of d for ^{15}C is larger than that of the other C isotopes nearby. The nuclear structure concerning ^{15}C is similar to that of ^{11}Li, etc, due to its small neutron separation energy of 1.22 MeV.[24] It is also suggested by Ozawa *et al.*[4] according to above tendency for d that a tail component exists in the neutron density distribution of ^{15}C. Of course, we need more experimental evidences for confirming whether ^{15}C has halo or skin structure. Whatever the experimental data of σ_R at intermediate energies have quite different values for some nuclei (see ^{11}Li, ^{12}Be, ^{8}B and ^{15}B in Fig. 3). On the other hand, only one energy point at intermediate energy for σ_R has been measured for some nuclei, such as ^{8}He, ^{14}Be, ^{9}C, ^{10}C, ^{12}N, ^{13}O and ^{14}O. Thus measurements of σ_R at intermediate energies by more reliable method and at more energy points are necessary.

In conclusion, the values σ_R were calculated by the BUU-model, using soft EOS and $0.8\sigma_{\rm Cug}$. For simplicity, a square-type distribution for the density is used to replace the surface diffused distributions, such as two-parameter Fermi distribution, etc. The width of the square distribution as the unique parameter was obtained by fitting σ_R at relativistic energies. Then the BUU calculations can reproduce the experimental data at intermediate energy better than the Glauber calculation. The systematical underestimation of σ_R at intermediate energy by the Glauber model was removed out now by the above BUU calculation framework. The isospin dependence of σ_R has been studied by deducing the difference factor d. The values of d of those nuclei, which have anomalous structure, are larger than those of other isotopes for both the BUU and Glauber calculations. Thus it was suggested that d is sensitive to the nuclei structure such as halo or skin, etc, whatever the square-type distribution and using $0.8\sigma_{\rm Cug}$ in this paper are too simple. For more detailed studying, $\sigma_{\rm NN}^{\rm in-medium}$ including energy and density effects,[25] and more natural density distribution can be introduced into the BUU calculation. On the other hand, for comparison, other reaction dynamical model, such as quantum molecular dynamics,[26] can be also applied to the study of σ_R. The research in this line is in progress.

REFERENCES

1 I. Tanihata *et al.*, Phys. Rev. Lett. 55 (1985) 2676.
2 I. Tanihata *et al.*, Phys. Lett. B 289 (1992) 261.
3 W. Q. Shen *et al.*, Nucl. Phys. A 491 (1989) 130.
4 A. Ozawa *et al.*, Nucl. Phys. A 608 (1996) 63.
5 J. Feng *et al.*, Phys. Lett. B 305 (1993) 9.
6 Y. G. Ma *et al.*, Phys. Rev. C48 (1993) 850.
7 J. Feng *et al.*, High Energy Phys. Nucl. Phys. 18 (1994) 97. (in Chinese)
8 Y. G. Ma *et al.*, Phys. Lett. B 302 (1993) 386.
9 I. Tanihata *et al.*, Phys. Lett. B 160 (1985) 380.
10 W. Mittig *et al.*, Phys. Rev. Lett. 59 (1987) 889.
11 M. G. Saint-Laurent *et al.*, Z. Phys. A 322 (1989) 457.
12 M. Fukuda *et al.*, Phys. Lett. B 268 (1991) 339
13 A. C. C. Villari *et al.*, Phys. Lett. B 268 (1991) 345.
14 I. Tanihata *et al.*, Phys. Lett. B 287 (1992) 307.
15 A. Ozawa *et al.*, Nucl. Phys. A 583 (1995) 3241.
16 R. E. Warner *et al.*, Phys. Rev. C 52 (1995) R1166.
17 M. M. Obuti *et al.*, Nucl. Phys. A609 (1996) 74.
18 FANG De-Qing *et al.*, Chin. Phys. Lett. 16 (1999) 15.
19 R. J. Glauber, *Lectures on Theoretical Physics* (Interscience, New York, 1959) Vol. I.
20 G. F. Bertsch and S. Das Gupta, Phys. Rep. 160 (1988) 189.
21 C. Gregoire *et al.*, Nucl. Phys. A465 (1987) 317.
22 J. Cugnon, T. Mizutani and J. Vandermeulen, Nucl. Phys. A352 (1981) 505.
23 I. Tanihata *et al.*, Phys. Lett. B 206 (1988) 592.
24 G. Audi and A. H. Wapstra, Nucl. Phys. A565 (1993) 1.
25 X. Z. Cai *et al.*, Phys. Rev. C58 (1998) 572.
26 J. Aichelin, Phys. Rep. 202 (1991) 233, and references therein.