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# Dependence of n/p with neutron skin thickness for neutron-rich nuclei

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The dependence between neutron-to-proton yield ratio ($n/p = Y_n/Y_p$) and neutron skin thickness ($\delta_{np}$) in neutron-rich projectile induced reactions is investigated within the framework of the Isospin-Dependent Quantum Molecular Dynamics (IQMD) model. By adjusting the diffuseness parameter of neutron density in the Droplet model for the projectile, the relationship of the neutron skin thickness and the corresponding n/p in the collisions is obtained. Those results show that n/p has strong linear correlation with $\delta_{np}$ for neutron-rich Ca and Ni isotopes. It is suggested that n/p may be used as an experimental observable to extract $\delta_{np}$ for neutron-rich nuclei.

## 1. Introduction

Nuclear radius is one of the basic quantities of a nucleus. The accuracy of experimental neutron radius is much lower than that of the proton radius. However, the information of neutron density is very important in the research fields of atomic, nuclear and astrophysics [1]. Neutron skin is defined as the difference between the neutron and proton RMS radii: $\delta_{np} \equiv \langle r_n^2 \rangle^{1/2} - \langle r_p^2 \rangle^{1/2}$. A lot of research have been done on neutron skin: $\delta_{np}$ is found to have correlation with $L$ (the slope of symmetry energy coefficient $C_{sym}$) [2,3], interaction cross sections in heavy ion collisions at relativistic energies [4], neutron abrasion cross sections in heavy ion collisions [5], and nuclear EOS [6]. On the other hand, the neutron and proton transverse emission and double neutron-proton ratios has been studied as a sensitive observable of the asymmetry term of the nuclear EOS in the experiment [7] and different kinds of simulations [8].

## 2. IQMD model

The QMD approach is a many-body theory that describes heavy-ion reactions from intermediate to relativistic energies. The IQMD model is based on the QMD model with consideration of the isospin effect. In the phase space initialization of the projectile and target, the density distributions of proton and neutron are taken from the Droplet Model [9]. In the Droplet model, we can change the diffuseness parameter to get different

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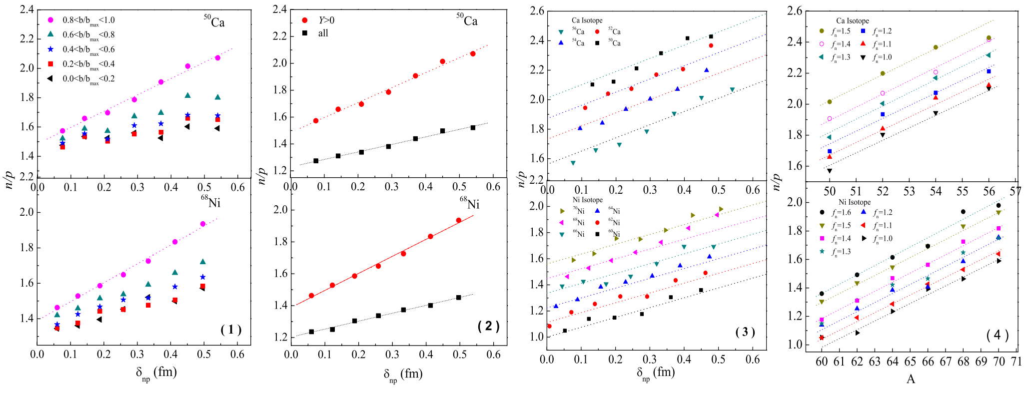

Figure 1. (1) The dependence of n/p on $\delta_{np}$ of the projectile for $^{50}$Ca and $^{68}$Ni+$^{12}$C under the condition of positive rapidity. Different symbols are used for different range of the reduced impact parameter. (2) The dependence of n/p on $\delta_{np}$ under the condition of reduced impact parameter from 0.8 to 1.0 for $^{50}$Ca and $^{68}$Ni+$^{12}$C. The results without any gate on the rapidity are shown as solid square. The results with positive rapidity are plotted as solid circles. (3) The dependence of n/p on $\delta_{np}$ under the condition of positive rapidity and reduced parameter from 0.8 to 1.0 for $^{50,52,54,56}$Ca and $^{60,62,64,66,70}$Ni+$^{12}$C. (4) The dependence of n/p on the mass number $A$ under the condition of positive rapidity and reduced parameter from 0.8 to 1.0 for $^{50,52,54,56}$Ca and $^{60,62,64,66,70}$Ni+$^{12}$C at 50A MeV. Different symbols are used for different value of the factor $f_n$. For the above four figures, the dotted lines just guide the eye, for details see tht text.

density, $\rho_i(r) = \frac{\rho_i^0}{1+\exp(\frac{r-C_i}{f_i t_i/4.4})}, i = n, p$. $t_i$ is the diffuseness parameter, $C_i$ is the half density radius of neutron or proton, $R_i$ is the equivalent sharp surface radius of neutron and proton. A factor $f_i$ is introduced by us to adjust the diffuseness parameter. When $f_n$ is changed from 1.0 to 1.6, different values of $\delta_{np}$ will be deduced. Using the density distributions of the Droplet model, we can get the initial coordinate of nucleons in nuclei in terms of the Monte Carlo sampling method. The momentum distribution of nucleons is generated by means of the local Fermi gas approximation.

## 3. Calculation and discussion

The collision processes of some Ca and Ni isotopes with $^{12}$C target at 50A MeV are simulated using the IQMD model. The yield ratio n/p of the emitted neutrons and protons can be calculated from the yields of the produced neutron and proton. By changing the factor $f_n$ in the neutron density distribution of the Droplet model for the projectile, different values of $\delta_{np}$ and the corresponding n/p are obtained. Thus we can obtain the correlation between n/p and $\delta_{np}$. In the calculation, the time evolution of the dynamical process was simulated until $t = 200$ fm/c. The calculated n/p is stable after 150 fm/c. The n/p from different range of the reduced impact parameter for $^{50}$Ca +$^{12}$C and $^{68}$Ni

$+^{12}$C are plotted in Fig. 1.1, we can see that n/p increases as $\delta_{np}$ increases. With $\delta_{np}$ being fixed, the n/p also increases with the increase of the reduced impact parameter. It means that n/p from peripheral collisions is usually larger than that from central collisions. In order to minimize the target effect on n/p, we chose the rapidity great than 0 to select neutrons and protons from the projectile. From the Fig. 1.2, we can see that n/p from projectile is larger than n/p of all nucleons for both $^{50}$Ca and $^{68}$Ni. Since the projectile is neutron-rich nucleus, the correlation between n/p and $\delta_{np}$ is stronger for nucleons coming from the projectile than both the projectile and target. For systematic study, reactions of other Ca and Ni isotopes such as $^{52,54,56}$Ca and $^{60,62,64,66,70}$Ni are also calculated. The results with the reduced impact parameter from 0.8 to 1.0 and the rapidity being positive are shown in Fig. 1.3, a linear function ($n/p = a + b \cdot \delta_{np}$) can describe the correlation between n/p and $\delta_{np}$ well for both Ca and Ni isotopes. The dependence between n/p and $\delta_{np}$ are fitted using this linear function. The mean slopes for Ca and Ni isotopes are 1.06 and 0.83, respectively. We can also study the mass dependence of n/p with the same $f_n$ as shown in Fig. 1.4. If $\delta_{np}$ of some nuclei is larger than the normal value of the Droplet model, it will deviate from the $f_n = 1.0$ line. By studying the mass dependence of n/p, it is possible to extract $\delta_{np}$ and identify nucleus with abnormal neutron skin thickness.

## 4. Conclusions

In summary, we have calculated the relationship between n/p and the neutron skin thickness for Ca and Ni isotopes within the framework of IQMD model. It is suggested that n/p could be used as an experimental observable to extract the neutron skin thickness for neutron-rich nucleus.

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