Comparison between calculations of CDCC and spherical optical model with deuteron as projectile

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Abstract With the CDCC approach, the reactions induced by weakly bound nucleus deuteron are studied. By comparing the results from CDCC approach and spherical optical model with our global deuteron optical potential, we find that it is reasonable and valuable for CDCC approach in a large energy range and nuclei range.

Key words CDCC approach, spherical optical model, global optical potential, comparison calculation

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1 Introduction

With the prominent development of nuclear science, the requirements of the nuclear technology application to nuclear reaction data, which are induced by charged particle in medium and high energy range, are increasing, and plenty of corresponding theoretical and experimental research are appeared. Presently, related experimental data file and evaluation data library, which are at the primary stage, have been established in many countries. It shows great importance for deuteron breakup effects in the nuclear reaction and structure studies. However, the analogy calculations on general reaction mechanism can not satisfy the (d,xp) reaction spectra. Then the theoretical research of deuteron reaction model, development of program and construction of the data files are especially significant. The continuum discretized coupled channel (CDCC) approach are widely used for studying weakly bound particle induced reactions[1—4], so it is necessary to verify the CDCC approach in a large energy range and nuclei range by comparing calculations between the CDCC approach and the spherical optical model with our global deuteron optical potential[5].

2 Theoretical model of CDCC

CDCC approach is based on the three body model. For reactions induced by weakly bound nucleus, the components of the incident particle and the target are considered as the three body, and any two body interactions among the three parts are included. In this work, for deuteron induced reactions, the interactions of nucleon and target are taken as the Koning-Delaroche global nucleon optical potential[6], and the interaction of proton and neutron are adopted with the Gauss form. Ignoring the spin of target and deuteron, the Hamiltonian of this three body system can be described as:

$$H=K_{\boldsymbol{R}}+K_{\boldsymbol{r}}+U_{\rm nA}(\boldsymbol{r}_{\rm nA})+U_{\rm pA}(\boldsymbol{r}_{\rm pA})+U^{\rm Coul}(\boldsymbol{r}_{\rm pA})+V_{\rm pn}(\boldsymbol{r}), \tag{1}$$

where

$$V_{\rm pn}(r)=-v_0\exp\left[-(r/r_0)^2\right],$$

$$\boldsymbol{r}=\boldsymbol{r}_{\rm pA}-\boldsymbol{r}_{\rm nA}, \boldsymbol{R}=(\boldsymbol{r}_{\rm pA}+\boldsymbol{r}_{\rm nA})/2.$$

the wave functions of the p-n pair satisfy:

$$(K_{\boldsymbol{r}}+V_{\rm pn}(r)-\varepsilon_k)\,\phi_l(k,\boldsymbol{r})=0, \quad \varepsilon_k=\frac{\hbar^2k^2}{2\mu_r}\ . \tag{2}$$

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The total energy of the $A+2$ system keeps conserved in the whole nuclear reaction process:

$$E=\frac{\hbar^2 P_0^2}{2\mu_R}+\varepsilon_0=\frac{\hbar^2 P_k^2}{2\mu_R}+\varepsilon_k\ . \qquad (3)$$

The elastic scattering angular distribution can be expressed as:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}=\Big|f_c(\theta)+\frac{1}{2\mathrm{i}\hat{P}_0}\sum_J(2J+1)\mathrm{e}^{2\mathrm{i}\sigma_J}\times (S^{(\mathrm{J})}_{\gamma_0,\gamma_0}-1)\,P_J(\cos(\theta))\Big|^2. \qquad (4)$$

There are three parts for the truncation of the model space: firstly, the distance R of the center of mass of deuteron and target; secondly, the orbital angular momentum l of proton and neutron; finally, the linear momentum k of p and n. It was proved[1] that the $R_{\max}=30$ fm, $l_{\max}=2$ and $k_{max}=1.0\ \mathrm{fm}^{-1}$ are sufficient truncations.

3 Comparison and discussion

Based on the CDCC approach, the influence of deuteron breakup effect on elastic scattering angular distribution are studied by solving the system of coupled channel equations. Fig. 1 plots the elastic scattering angular distributions of d+^{24}Mg in the 60—90 MeV energy range.

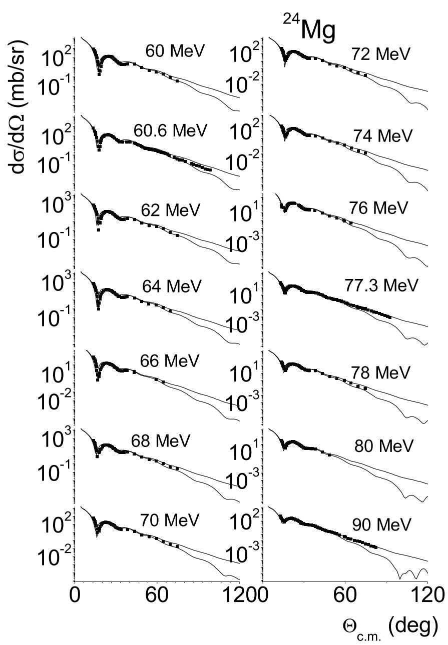

Fig. 1. The elastic scattering angular distributions of d+^{24}Mg. The values from global potential, and this work are plotted with solid and dash lines respectively, and the solid points are experimental data[7].

The comparison of elastic scattering angular distribution of ^{28}Si, ^{40}Ca, ^{58}Ni, ^{60}Ni, ^{72}Ge and ^{208}Pb is shows in Fig. 2. From the two figures we know that the values from CDCC theory can basically reproduce experimental data in ^{24}Mg — ^{208}Pb nucleus range below 200 MeV. Generally speaking, comparing our results with the results of global potentials, some fluctuations appear in angular distributions of CDCC, especially in large angles. These fluctuations are mainly caused by the different potential of the two approaches. The global potential includes spin-orbit parts, and the parameters are obtained with plenty of deuteron experimental data. However, the deuteron potential in CDCC approach is folded by the nucleon potentials, and the spin-orbit potential is ignored. The most important difference is that there are not any adjustable parameters included in CDCC theory, and the coupling of breakup channel with elastic channel more or less affect the angular distributions.

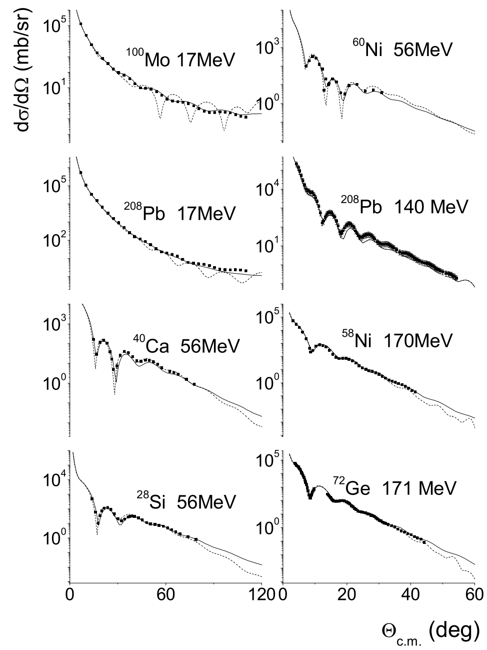

Fig. 2. The comparison between calculated elastic angular distributions with those of elastic scattering data. The meaning of lines see Fig. 1, and the experimental data are taken from Refs. [8—12].

Owing to the above reasons, the results of the global potential are better than those of CDCC approach, however, the later are reasonable and acceptable. At the meantime, it can afford an effective way to systematically study the contribution of deuteron breakup to reactions in a larger energy range and nuclei range.

4 Summary

The weakly bound feature of deuteron is studied by considering the coupling of breakup channels with ground state of p-n pair, and the influence of breakup effect on elastic scattering angular distribution is discussed. By comparing the the calculated results between those from the global potential and those from the CDCC approach, we can see that, although the CDCC results cann't reproduce experimental data as well as those of global potential, it is also reasonable in physics. And it is suitable to employing the CDCC approach to deuteron induced reactions in a larger energy range and nuclei range.

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