Study of Nucleon Induced Reactions on Lithium-6,7 with Continuum Discretized Coupled Channels Method

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Study of Nucleon Induced Reactions on Lithium-6,7 with Continuum Discretized Coupled Channels Method

The study of lithium related reactions has recently attracted great interest because of their applications in many fields, such as in nuclear astrophysics and fusion applications. Lithium is an important element relevant to not only a tritium breeding material in deuterium-tritium (D-T) fusion reactors [1] but also a candidate for target material in the intense neutron source of the International Fusion Materials Irradiation Facility (IFMIF) [2]. The accurate nuclear data of nucleon (N) induced reactions on ^{6,7}Li at incident energies up to 150 MeV are currently required for the design of such kinds of fusion related facilities [3], especially the nuclear data on double differential cross sections (DDXs) of neutron and triton emission from neutron induced reactions. Since ^{6}Li and ^{7}Li can easily break up, namely, $^{6}\mathrm{Li} \rightarrow d + \alpha$ and $^{7}\mathrm{Li} \rightarrow t + \alpha$, the understanding of the ^{6,7}Li breakup processes is essential to the analysis of these nuclear reactions. However, the ^{6,7}Li breakup processes cannot be described well by means of traditional theoretical models. Therefore, the study of nucleon induced reactions on ^{6,7}Li is not only of application value but also of theoretical significance. The purpose of this work is to analyze both neutron and proton induced reactions on ^{6,7}Li over a wide incident energy range up to 150 MeV considering the breakup effect by means of continuum discretized coupled channels method (CDCC) [4,5], and provide the quantitative description of the nucleon scattering DDXs and the triton production DDXs from the breakup process of ^{7}Li.

CDCC is an extension of coupled channel method, in which the breakup continuum states of the weakly bound nucleus are truncated and discretized to discrete states, and the discrete states are treated similarly to the usual bound inelastic states in the coupled channel method. Consequently, the breakup channels and the coupling of breakup channels and the elastic scattering channel can be described. In this study, ^{6}Li and ^{7}Li are considered as $d + \alpha$ and $t + \alpha$ clusters, respectively. Their discretized internal wave functions are obtained by the pseudostate method [6,7] with the interactions as

Gaussian forms. The diagonal and coupling potentials between nucleon and ^{6,7}Li are obtained by folding complex Jeukenne-Lejeune-Mahaux (JLM) effective nucleon-nucleon interaction [8] with the transition densities between the corresponding discretized states. The parameters of JLM interaction are determined so as to reproduce the experimental data of total and reaction cross sections.

The neutron total, proton reaction cross sections and nucleon elastic and inelastic scattering angular distributions for nucleon induced reactions on ^{6,7}Li at incident energies up to 150 MeV are analyzed using CDCC. The energy dependence of the normalization factors, λ_v and λ_w, of the JLM interaction is determined explicitly from measured neutron total and proton reaction cross sections. For ^{6}Li target, the factors are

$$\lambda_v(E) = 1 + 0.0035E,$$

$$\lambda_w(E) = \begin{cases} 0.015E, & \mathrm{E} \le 30, \\ 0.45 + 0.0075(E-30), & \mathrm{E}>30. \end{cases}$$

For ^{7}Li target, the factors are

$$\lambda_v(E) = 1 + 0.0035E,$$

$$\lambda_w(E) = \begin{cases} 0.012E, & \mathrm{E} \le 30, \\ 0.36 + 0.0075(E-30), & \mathrm{E}>30. \end{cases}$$

As a result, the CDCC calculation reproduces successfully well the experimental data of neutron total, proton reaction cross sections and nucleon elastic and inelastic scattering angular distributions. Taking n + ^{6}Li reaction as an example, comparisons of the calculated results and experimental data [9-19] are given in Figs 1-3. In Fig. 2, the dashed lines represent results of the single elastic-channel calculation in which the couplings of the breakup channels to the elastic channel are ignored. Large deviation of the dashed lines from the solid ones indicates that the breakup effect is quite important.

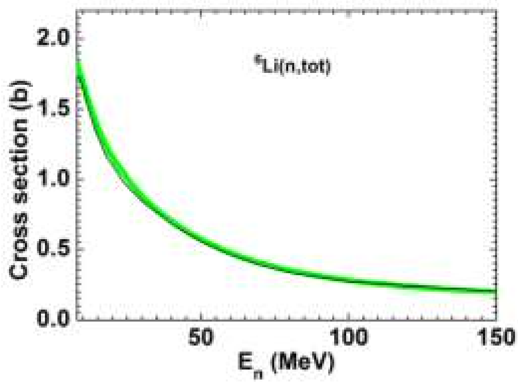

Fig. 1 Comparison of the calculated total cross section (solid line) for n+^{6}Li reaction with experimental data (green dots).

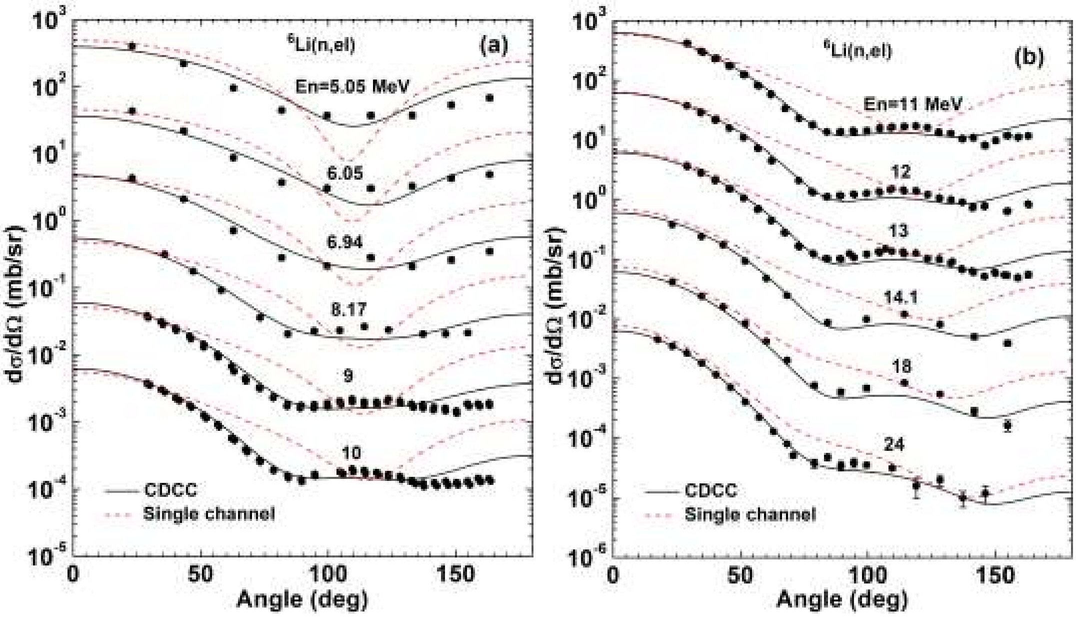

Fig. 2 Comparison of the calculated angular distributions of proton elastic scattering from ^{6}Li with experimental data. The solid and dashed lines denote the CDCC results and the results of the single elastic-channel calculation, respectively. The data are shifted downward by factors of 10^{0}, 10^{-1}, 10^{-2}, and so on.

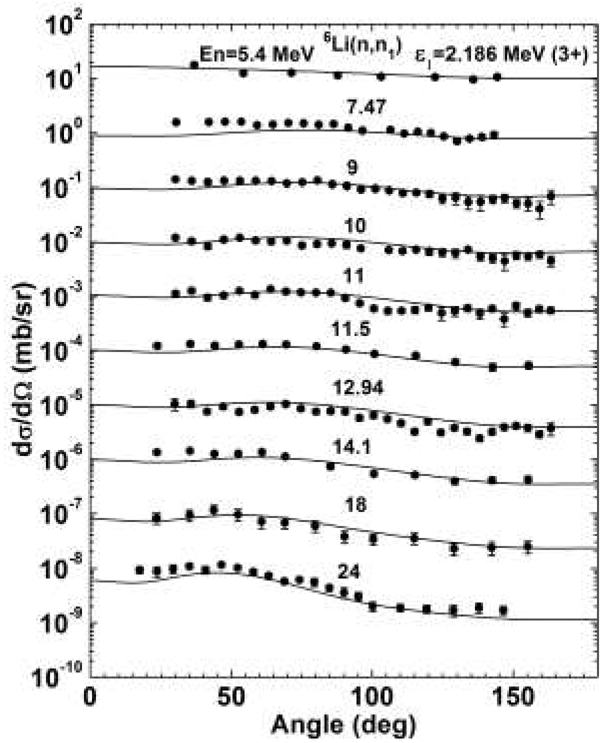

Fig. 3 Comparison of the calculated angular distribution (solid lines) of the neutron inelastic scattering to the first excited state (3^+) of ^{6}Li with experimental data. The data are shifted downward by factors of 10^0, 10^{-1}, 10^{-2}, and so on.

The double differential (N, *x*N) cross sections for N +^{6,7}Li reactions and the triton production DDXs from the breakup process of ^{7}Li are analyzed with CDCC. For the double differential (N, *x*N) cross sections, the calculated results can reproduce the experimental data of the inclusive nucleon emission DDXs well at relatively high emission energies, while they underestimate the experimental data at low emission energies. The reason for the discrepancy is that some other reaction channels, which cannot be calculated with the present CDCC, contribute to the experimental data in the energy region.

The calculated triton production DDXs from the breakup process of ^{7}Li underestimate distinctly the experimental data of inclusive triton production DDX at relatively high emission energies. The reason is that $p(n) + {}^7\text{Li} \rightarrow t + {}^5\text{Li}({}^5\text{He})$ channels also have contribution to the triton production. The triton production DDXs from $p(n)$ + ^{7}Li → t + ^{5}Li(^{5}He) channels are calculated by final-state interaction (FSI) model [20,21], which contribute mainly to high emission energy region. The inclusive triton production DDXs obtained by summing up the CDCC results and FSI results reproduce the experimental data fairly well at high energies, but overestimate slightly the experimental data for low emission energy region generally because the contribution from the unbound $^{3/2}$P state of ^{7}Li is overestimated. The comparison of the results calculated by CDCC and FSI shows that the breakup channel is a very important channel for the triton production.

In conclusion, we used CDCC to study systematically both neutron and proton induced reactions on ^{6,7}Li at incident energies up to 150 MeV. In most cases, the model calculation can reproduce the experimental data well except that the calculated triton production DDXs need to be improved. The importance of the breakup effect was demonstrated. The good reproduction indicates the applicability of CDCC to the nuclear data evaluation for the nucleon induced reactions on ^{6,7}Li.

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