Special issue of the 2nd International Conference on Computational and Experimental Science and Engineering (ICCESEN 2015)

Excitation Functions of (d,n) Reactions on Some Light Nuclei

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Nuclear reactions of the induced deuteron particles with light nuclei have been investigated in the history of nuclear physics. In this study, excitation functions for the deuteron reactions ^{6}Li(d,n)^{7}Be, ^{12}C(d,n)^{13}N, ^{16}O(d,n)^{17}F have been calculated by using Monte Carlo nuclear reaction simulation code TALYS 1.6, considering equilibrium and pre-equilibrium effects. The calculated theoretical (d,n) excitation functions are compared to the experimental reaction cross-sections in the literature.

DOI: 10.12693/APhysPolA.130.484

PACS/topics: 25.45.De, 24.10.Lx

1. Introduction

Back to the first nuclear data libraries of the 1950's, when quantitative nuclear reaction analyses were based on only some scattered experimental data points. There simply was no method available to provide some form of completeness. Nevertheless, basic reactor physics codes of those days were able to predict the most essential characteristics of reactors and other criticality systems. On the nuclear modeling side, relatively simple optical models, level densities and compound nucleus models were used to estimate unmeasured cross-sections on a channel-by-channel basis [1]. A knowledge of the excitation functions of deuteron induced reactions on metals is of interest for their medical and industrial applications. In contrast to the excitation functions of proton and alpha induced reactions the theoretical study of the excitation functions of deuteron induced reactions is very limited [2].

The binding energy of deuteron is low. Therefore, when the latter collides with nuclei, inelastic processes are the most probable ones: the deuteron breakup in the nuclear Coulomb field (mainly at low deuteron energies) and the deuteron stripping, when one of deuteron nucleons is absorbed by the target whereas the other is released as a reaction product. In the intermediate energy interval, the stripping reaction is mainly a result of direct interaction (the capture of deuteron nucleon by the nucleus) [3].

2. Materials and methods

In this study, excitation functions for the deuteron reactions ^{6}Li(d,n)^{7}Be, ^{12}C(d,n)^{13}N, ^{16}O(d,n)^{17}F have been calculated with nuclear reaction simulation code TALYS 1.6. TALYS is a Monte Carlo code and it is a nuclear reaction simulation computer code system for the analysis and prediction of nuclear reactions. The basic objective behind its construction is the simulation of nuclear reactions that involve neutrons, photons, protons, deuterons, tritons, ^{3}He, and alpha particles. One of the possible outcome of using a Monte Carlo method for nuclear data evaluation is that a series of correlations can be extracted from the previous results. At this point, it is helpful to remember that for each calculated quantity, thousands of values are obtained. These quantities can be differential nuclear data (such as cross-sections), but also integral nuclear data [1].

TALYS integrates the optical model, direct, preequilibrium, fission and statistical nuclear reaction models in one calculation scheme and gives a prediction for all the open reaction channels.

Pre-equilibrium plays an important role in nuclear reactions induced by light projectiles with incident energies above about 8–10 MeV. Starting with the introduction of pre-equilibrium reactions, a series of semiclassical models of varying complexities have been developed for calculating and evaluating particle emissions in the continuum [4]. Several models have been proposed to explain the emission of energetic light particles by the equilibration process (pre-equilibrium emission) from the nuclear system excited at medium energies [5].

In pre-equilibrium processes a part of the reaction flux is emitted in the pre-equilibrium stage, i.e. it takes place after the first stage of the reaction but long before statistical equilibrium of the compound nucleus is attained. It is imagined that the incident particle step-by-step creates more complex states in the compound system and gradually loses its memory of the initial energy and direction [1]. The default pre-equilibrium model of TALYS is the two-component exciton model [6, 7] which has been tested against basically all available experimental nucleon spectra for $A > 24$ [6].

3. Results and discussions

The study of the nuclear reaction that takes place when ^{6}Li is bombarded by deuterons has been hampered in the past by the presence of the much more abundant ^{7}Li isotope, which takes part in similar reactions under deuteron bombardment [8].

The ^{6}Li(d, n)^{7}Be reaction has been investigated in the threshold energy 0.00000 MeV and ($Q = 3.46929$ MeV), and the slightly negative Q-value that characterizes

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^{12}C(d,n)^{13}N reaction ($Q = -0.28$ MeV) and threshold energy 3.08996 MeV, combined with the good mechanical properties of carbon and, especially, with its extremely high melting point, make this reaction worth investigating for use as a low-energy neutron source. A deuteron energy of 1.5 MeV may represent a reasonable compromise between the need of minimizing the neutron energy, and that of maximizing the cross-section which is strongly influenced, at low incident energy, by the Coulomb barrier [9, 10], the ^{16}O(d, n)^{17}F reaction has been investigated in the threshold energy 2.38662 MeV and $Q = -1.62444$ MeV.

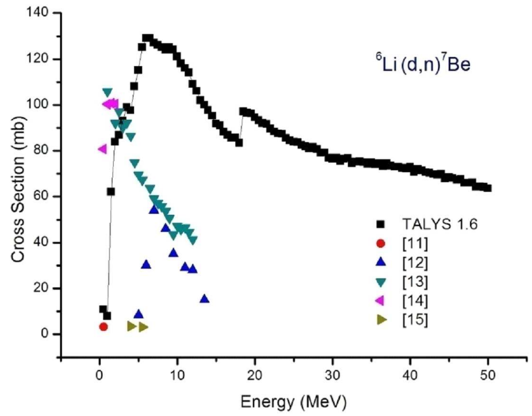

Fig. 1. Excitation functions for the deuteron reaction ^{6}Li(d,n)^{7}Be.

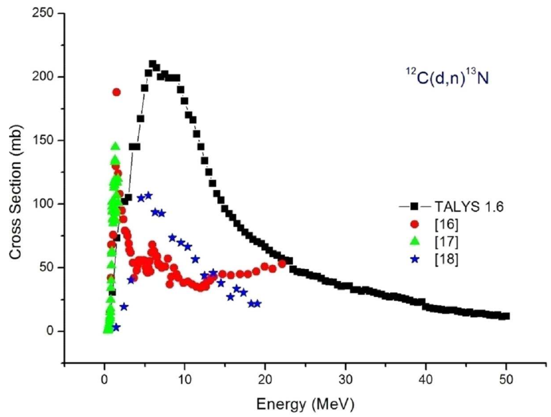

Fig. 2. Excitation functions for the deuteron reaction ^{12}C(d,n)^{13}N.

In the present study, the cross-section for the deuteron for some light nuclei ^{6}Li(d,n)^{7}Be, ^{12}C(d,n)^{13}N, ^{16}O(d,n)^{17}F have been obtained by using Monte Carlo simulation code TALYS 1.6 which is the nuclear reaction simulation code, considering equilibrium and pre-equilibrium effects. The results are compared with the experimental data existing in the EXFOR [11].

The calculated (d,n) reaction cross-section have been displayed in Figs. 1–3 for ^{6}Li, ^{12}C,^{16}O, respectively.

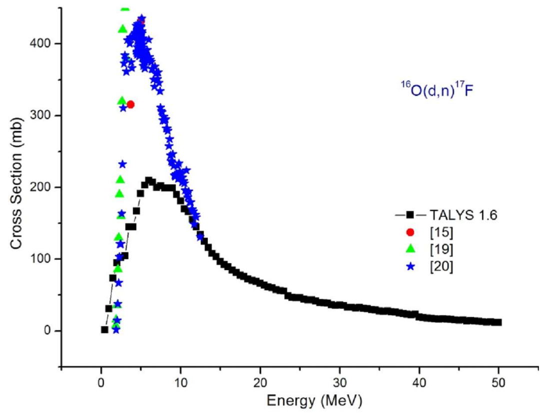

Fig. 3. Excitation functions for the deuteron reaction ^{16}O(d,n)^{17}F.

4. Conclusions

It can be seen from this work that there is not a significant maximum deuteron cross-section for light nuclei. In general, we consider that (d,n) TALYS 1.6 nuclear reaction simulation code for predicting cross-section of the reaction has an acceptable success. The maximum cross-section for the excitation function is about 300–400 MeV range. As a result of the calculations, cross-section values were found to depend on the mass number of nuclei, because, in the same reaction experimental cross-section data are good agreement with theoretical cross-section values.

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