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Calculation of double – differential cross sections for proton impact alpha emission at 62 MeV

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ABSTRACT

This study reports on double–differential alpha emission cross sections for ^{16}O, ^{27}Al, ^{54,56}Fe, ^{60}Ni, ^{80}Y, ^{120}Sn, ^{197}Au, ^{208}Pb and ^{209}Bi target nuclei with the TALYS code at 62 MeV proton energy. The calculations involved the pre-equilibrium exciton model and the Hauser-Feshbach model within TALYS code. The calculated results were compared with the experimental data taken from the literature. The results are in good agreement.

Keywords: Alpha emission spectra, pre-equilibrium exciton model; Hauser – Feshbach model.

1. Introduction

The emitted light charged particles (p, d, t, ^{3}He, α) in nucleon induced reactions are needed to understand various accelerator applications, such as accelerator-driven transmutation for nuclear waste, radiation damage estimation of semiconductor memory devices in space, and advanced proton therapy [1]. Even though the cross section for light particle production including neutrons is very large and compares well with the reaction cross section at a given energy, this process is not fully understood because of the emission process of these light particles being rather complex. The emissions of light particles are mainly due to three different processes at different time scales – compound, direct and pre-equilibrium. Moreover, there are indications that they are also emitted during the formation stage of the compound nucleus [2].

Proton induced nuclear reactions data both evaluated and compiled at intermediate energy are needed for a wide range of technical applications including the activation study for advanced nuclear systems, like accelerator-driven systems (ADS) and the study of production of radionuclides used in medicine and industry [2-6]. Many studies on the ADS are available in literature [7-9].

In general, further development of nuclear reactions theory strongly depends on the understanding of nucleon-induced reactions. These reactions can produce accurate nuclear reaction data of common cross-sections and energy-differential cross sections and especially the data of neutron and proton-induced energy-angle correlated spectra of secondary light particles such as neutron, proton, deuteron, triton, helium and alpha-particles. Reaction cross sections are required to benchmark the nuclear reaction codes in the incident energy region where many reaction mechanisms compete [10].

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The accurate calculations of high-energy proton transport in matter require information on secondary particle production in nuclear reactions [11]. The self-consistent calculation and analyses using nuclear theoretical models are indispensable because the experimental data of charged particle reactions are scarce. Besides, the nuclear cross-section data are needed for refinement of the nuclear theories. The main aim is to obtain the reaction systematic to mediate the reaction cross section evaluation for the prediction and calculation of nuclear reaction cross-sections [12-17].

In this study, double–differential alpha emission cross sections were calculated for ^{16}O, ^{27}Al, ^{54,56}Fe, ^{60}Ni, ^{80}Y, ^{120}Sn,^{197}Au, ^{208}Pb and ^{209}Bi target nuclei and were compared with experimental data available in the literature at the incident proton energy of 62 MeV.

2. Calculation methods

In this study, double – differential cross sections for proton induced reactions of ^{16}O, ^{27}Al, ^{54,56}Fe, ^{60}Ni, ^{80}Y, ^{120}Sn, ^{197}Au, ^{208}Pb and ^{209}Bi targets were calculated using the pre-equilibrium exciton and the Hauser–Feshbach models implemented in the TALYS code. The new expressions for internal transition rates and new parameterization of the average squared matrix element for the residual interaction could be obtained for pre-compound model using the optical model potential [16].

The TALYS code was developed to analyze and predict nuclear reactions involving neutrons, photons and light charged particles ($A \leq 4$) in the energy range of 1 keV to 200 MeV for target nuclei heavier than carbon [17]. The default model to describe the pre-equilibrium process in TALYS is the two-component exciton model (EM) where the time evolution of the nuclear state is described by the total energy of the system and the total number of particles (protons and neutrons) above the Fermi surface and corresponding holes below it. A detailed description of the model is available [18]. TALYS includes the phenomenological model proposed by Kalbach [19] to take into account the nucleon transfer (NT) and the knock-out (KO) reactions which are not included in the exciton model. The total pre-equilibrium (PE) cross section is sum of these three contributions:

$$\frac{d\sigma^{PE}}{dE} = \frac{d\sigma^{EM}}{dE} + \frac{d\sigma^{NT}}{dE} + \frac{d\sigma^{KO}}{dE} \qquad (1)$$

Three parameters in TALYS can be used to control how to add the NT and the KO contributions. In the pre-equilibrium region the input parameter allows to switch on or off the use of the Kalbach model for NT (pickup, stripping) and KO reactions in addition to the exciton model. C_{strip} and the C_{knock} are two adjustable parameters, for the NT and the KO processes respectively, to scale the complex-particle pre-equilibrium cross section per outgoing particle. The scaling factor can vary between 0 and 10.

3. Results and conclusions

Double differential cross sections are consistently calculated using nuclear theory models for ^{16}O, ^{27}Al, ^{54,56}Fe, ^{60}Ni, ^{80}Y, ^{120}Sn, ^{197}Au, ^{208}Pb, and ^{209}Bi target nuclei at the incident proton energy of 62 MeV. Results calculated for double differential cross sections of alpha emission are compared with experimental data as shown in Figs. 1 to 10. The shape of the curve and the magnitude of calculated results at all emission angles are in agreement with experimental data. The theoretical models provide a good description of the shapes and magnitude of the double differential cross section of alpha emission for given emission angles and energies.

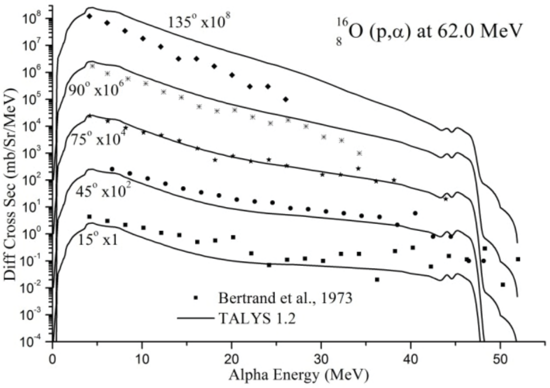

Fig. 1 The comparison of calculated double differential cross-section of (p,α) reaction on ^{16}O with the experimental data reported in literature. Experimental values were taken from EXFOR [20].

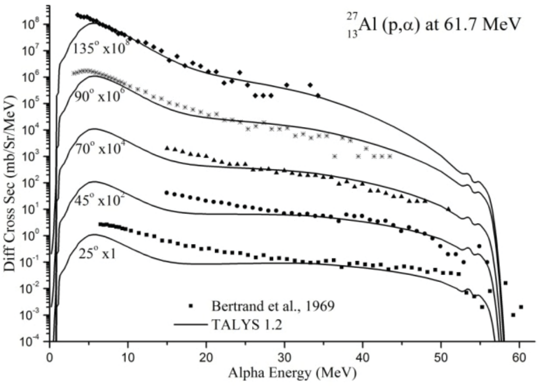

Fig. 2 The comparison of calculated double differential cross-section of (p,α) reaction on ^{27}Al with the experimental data reported in literature. Experimental values were taken from EXFOR[20].

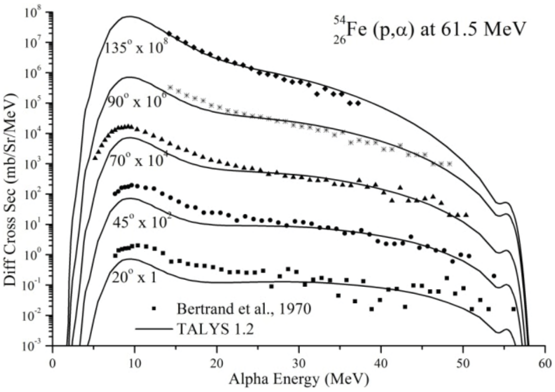

Fig. 3 The comparison of calculated double differential cross-section of (p,α) reaction on ^{54}Fe with the experimental data reported in literature. Experimental values were taken from EXFOR [20].

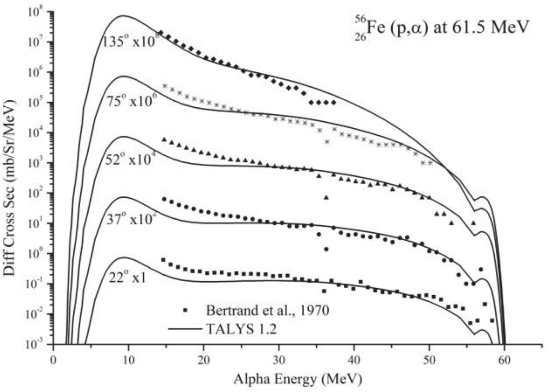

Fig. 4 The comparison of calculated double differential cross-section of (p,α) reaction on ^{56}Fe with the experimental data reported in literature. Experimental values were taken from EXFOR [20].

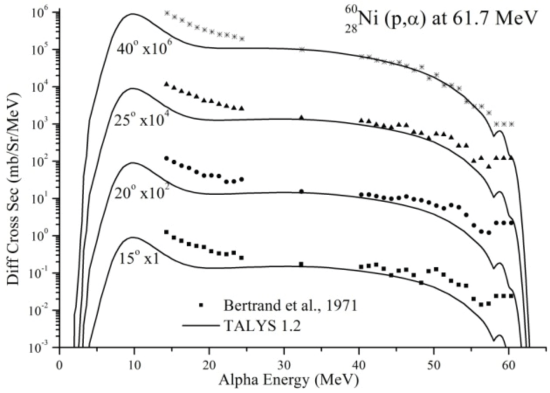

Fig. 5 The comparison of calculated double differential cross-section of (p,α) reaction on ^{60}Ni with the experimental data reported in literature. Experimental values were taken from EXFOR [20].

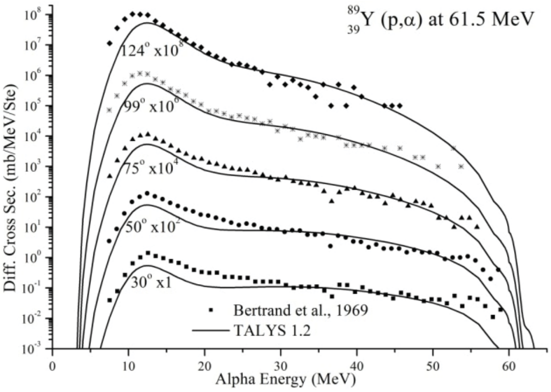

Fig. 6 The comparison of calculated double differential cross-section of (p,α) reaction on ^{89}Y with the experimental data reported in literature. Experimental values were taken from EXFOR [20].

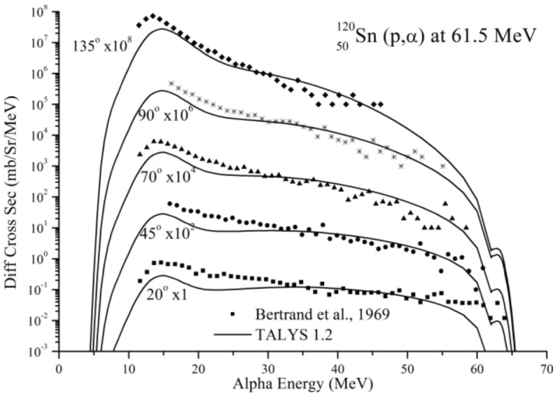

Fig. 7 The comparison of calculated double differential cross-section of (p,α) reaction on ^{120}Sn with the experimental data reported in literature. Experimental values were taken from EXFOR [20].

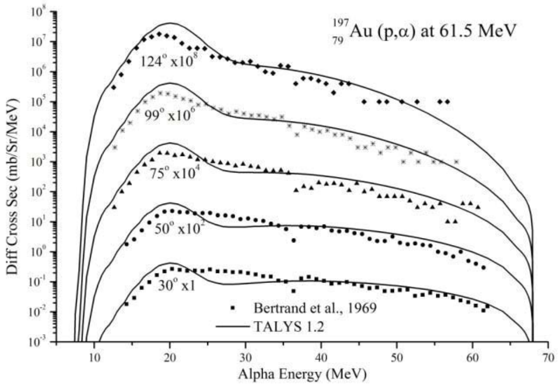

Fig. 8 The comparison of calculated double differential cross-section of (p,α) reaction on ^{197}Au with the experimental data reported in literature. Experimental values were taken from EXFOR [20].

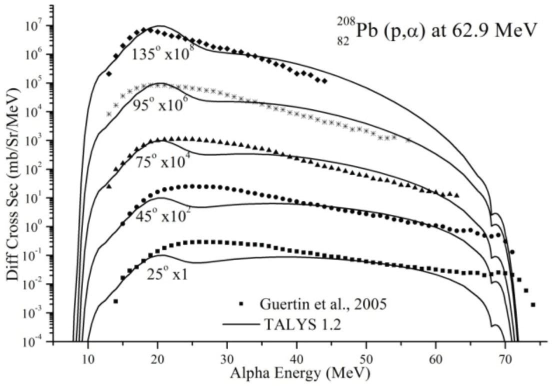

Fig. 9 The comparison of calculated double differential cross-section of (p, α) reaction on ^{208}Pb with the experimental data reported in literature. Experimental values were taken from EXFOR [20].

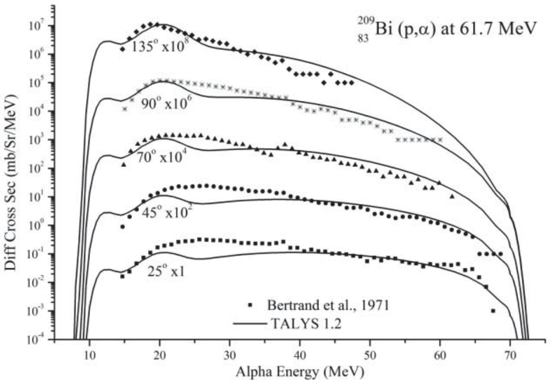

Fig. 10 The comparison of calculated double differential cross-section of (p, α) reaction on ^{209}Bi with the experimental data reported in literature. Experimental values were taken from EXFOR [20].

TALYS code calculations were in the framework of the pre-equilibrium exciton model and the Hauser–Feshbach model. The calculation results were compared with the available experimental data with conclusions that can be summarized as follows:

1. All double differential cross sections are consistently calculated using nuclear theory models for ^{16}O, ^{27}Al, ^{54,56}Fe, ^{60}Ni, ^{80}Y, ^{120}Sn, ^{197}Au, ^{208}Pb, and ^{209}Bi target nuclei at the incident proton energy of about 62 MeV (Figs. 1-10).
2. The pre-equilibrium models provide the good description of the shapes and magnitude of the double differential cross section of alpha at the incident proton energy of 62 MeV.
3. All of the present results have been transformed into ENDF formatted data files for application.
4. In this study, possible production routes of alpha that could be produced in the Proton Accelerator (PA) of Turkish Accelerator Center (TAC) have been investigated at the incident proton energy of 62 MeV.

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