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Detailed Analysis of Differential Cross Sections of Elastic Scattering for n+^{208}Pb Reaction

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Differential cross sections for elastic scattering of neutrons from ^{208}Pb target have been calculated with TALYS 1.6 nuclear code. Angular distributions were obtained for incident neutron energies of 5 to 96 MeV. The calculated data were compared with experimental results from literature. Calculations for angular distribution of elastic scattering of ^{208}Pb, made with TALYS 1.6 nuclear code, show good agreement with experimental data.

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1. Introduction

The cross section data, which are of great importance for the mechanism of nucleon structure and nuclear reactions, are also useful for various applications [1]. Due to recent advances in technology, particle accelerators have found a wide range of applications in the fields of particle physics, nuclear physics, materials sciences and medical science. Neutrons generated at these accelerators have a strong penetrability through shielding material and dominate the radiation dose outside the shielding. In order to achieve reasonable radiation protection for workers and the general public, the interactions and transport characteristics of the neutrons must be well understood [2].

The neutron interactions cross sections and prompt fission neutron spectrum in the energy range below 20 MeV are of fundamental importance for fission and accelerator-driven reactors, because they dominate the neutron transport and neutron regeneration, respectively [3]. These parameters, therefore, have become important theoretical and experimental data. Accurate nuclear data are needed for the design of a new generation of nuclear power reactors, that aim at a sustainable fuel cycle or are dedicated to the elimination of high level long-lived radioactive waste [4].

^{208}Pb is the most abundant isotope of lead (52.4%). It was intensively studied in the past due to its double magic nuclear structure [4] and it is one of the important materials considered for the design of a new generation of nuclear reactors. The neutron radius of a heavy nucleus such as ^{208}Pb is a fundamental nuclear structure quantity that remains elusive [5]. In this sense, to use the selected material in the reactors and accelerating systems, its cross sections of elastic and inelastic scattering are important.

Scattering cross sections are used for calculations of radiation attenuation in medical physics, reactor shielding, industrial radiography, and in a variety of applications, including X-ray crystallography [6]. Elastic and inelastic scattering cross sections are of especial direct relevance for the modelling of the neutron transport in nuclear energy systems.

Experimental values of reaction cross sections provide a unique tool to verify the analysis of the angular distributions in elastic scattering. Such values can eliminate different ambiguities in optical model calculations and they can also be decisive in the comparison between different reaction models. Since values of reaction cross sections are complementary to experimental angular distributions, it is surprising that the experimental efforts of measurements of reaction cross sections are so sparse, compared to those for angular distributions [7].

In present study, ^{208}Pb has been chosen for target element. Liquid lead or lead-bismuth eutectic are considered as fast reactor coolants or as spallation targets for accelerator-driven systems. In the literature, there are no new experimental studies in elastic angular distribution for ^{208}Pb. However, elastic angular distributions for ^{208}Pb and other elements can be found in previous experimental studies [8–12]. In addition to the existing experimental studies, theoretical differential cross sections are studied for different target nuclei, depending on the energetics [13–17]. At the same time, theoretical cross sections have been calculated with TALYS 1.6 nuclear reaction simulation code in some studies [18–23].

2. Results and discussion

In this study, theoretical calculations, based on elastic scattering, and experimental differential cross section values have been compared in (n,el) reaction for ^{208}Pb. The TALYS 1.2 and TALYS 1.6 [24] codes have been used in theoretical calculations.

In this work (n,el) reaction cross sections of ^{208}Pb were calculated using TALYS 1.2 and TALYS 1.6 code in incident energy range of 5–96 MeV. Calculation of elastic differential cross section was performed in three energy regions (low, intermediate and high energy). The calculated results and available experimental data are presented in Figs. 1–4.

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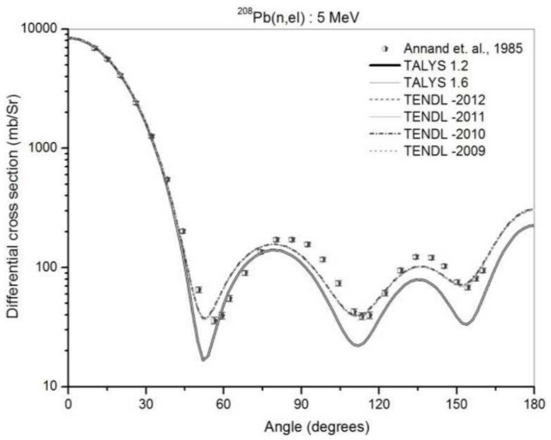

Fig. 1. Theoretical calculations of ^{208}Pb(n,el) reaction for 5 MeV. The experimental data are taken from EXFOR [25].

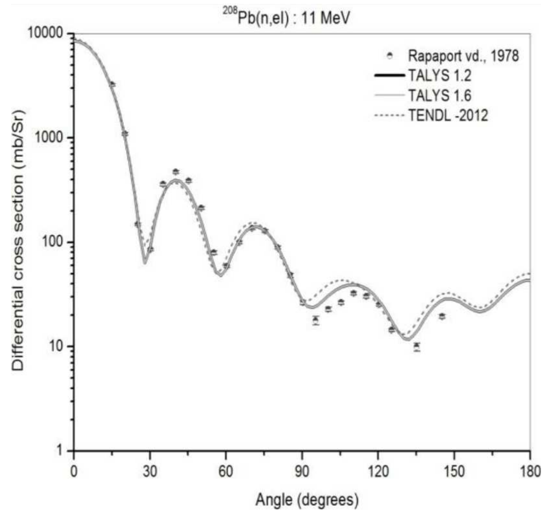

Fig. 2. Theoretical calculations of ^{208}Pb(n,el) reaction for 11 MeV. The experimental data are taken from EXFOR.

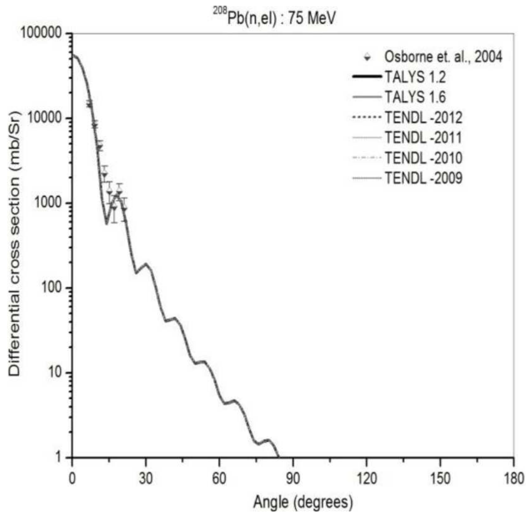

Fig. 3. Theoretical calculations of ^{208}Pb(n,el) reaction for 75 MeV. The experimental data are taken from EXFOR.

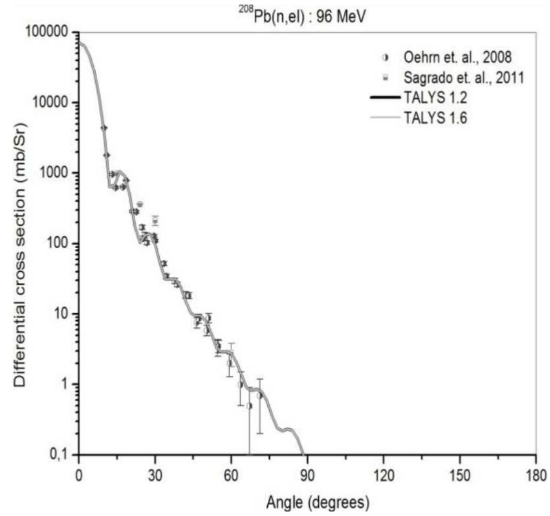

Fig. 4. Theoretical calculations of ^{208}Pb(n,el) reaction for 96 MeV. The experimental data are taken from EXFOR.

3. Conclusions

In this study, it has been shown how elastic scattering effects (n,el) reaction cross sections. The calculated differential cross-section for 5 MeV starts at value of 8423.580 mb/sr at 0°. This value decreases up to 52° and oscillates above this value.

The calculated differential cross-section for 11 MeV, starts at value of 8526.230 mb/sr at 0°. This value decreases up to 62°.

The calculated differential cross-section for 75 MeV starts at value of 56034.800 mb/sr at 0°. This value decreases up to 14°.

Calculated differential cross-section for the last energy of 96 MeV starts at value of 70617.900 mb/sr at 0°. This value decreases up to 14°.

The results of calculation of the cross section of elastic scattering for (n,el) reaction show good compatibility with experimental results. However, at the same angle, the differential cross section values increase with the increase of incident energy.

This work presents the results of calculation and a comparison with experimental and evaluated data from literature. In general, excellent agreement was obtained using TALYS 1.2 and TALYS 1.6 nuclear codes. The angular distributions generally were found to agree with the predictions of the optical model and the DWBA. Also a fair agreement both, in shape and in magnitude, with the experimental and evaluated data from the literature was found.

The differential cross sections of elastic scattering increase with the increase of energy. With rising energy, oscillations, resonances and peaks are observed in elastic angular distribution curves.

With the increase of the energy of colliding neutrons, the calculated differential cross sections of elastic scattering overlap with both, experimental and evaluated data, and show a very good fit. For lower energies the agreement between calculated and experimental data for differential cross sections of elastic scattering is poor. The differential cross sections of elastic scattering, calculated with TALYS nuclear code, agree well with experiment below 96 MeV and above 7 MeV.

It is expected that presented results will provide a good reference for future advancements.

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