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Review of the doctoral thesis of Mr. Bogumil Zalewski entitled "Interaction of ^{6}He with hydrogen isotopes at 26 MeV/n energy".

In his PhD thesis, Mr. Bogumil Zalewski presents a detailed study of ^{6}He reactions induced on a deuterated target in inverse kinematics at 26 MeV/A, obtaining the angular distributions of the elastic scattering cross sections for ^{6}He+p and ^{6}He+d channels, and the angular distribution of the cross section for single neutron transfer to ^{3}H. This reaction hasn't been studied in the past and the new data is relevant to obtain the spectroscopic factors of the ^{5}He+n configuration of the ^{6}He ground-state wave function. The PhD thesis comprises experimental and theoretical research activities.

The experimental part is mainly focussed on obtaining the angular distributions of the elastic and neutron transfer cross sections and was carried out at JINR Flerov Laboratory of Nuclear Reactions (Dubna, Russia), using the U400M cyclotron and the ACCULINA-2 fragment separator. The laboratory is an international radioactive beam facility where important nuclear physics discoveries have taken place, such as the synthesis of new superheavy elements. The research was carried out under the direction of Prof. M. S. Golovkov, who is internationally recognised for his studies on reactions and structure of exotic nuclei, such as ^{6}He and ^{7}H systems.

The theoretical part covers the interpretation of the experimental data using Optical Model and DWBA calculations and was developed at the University of Warsaw under the direction of Prof. K. Rusek, his PhD supervisor. The University of Warsaw has been historically one of the most important European research centres in nuclear theory. Prof. Rusek is internationally recognised for his expertise on coupled channel reactions calculations and continuum discretised coupled channel calculations for reactions induced by exotic nuclei, such as ^{6}He, ^{8}He and ^{11}Be.

According to INSPIRE database, Mr. Bogumil Zalewski has contributed to eight articles published in high-impact journals, and several conferences proceedings; this is a very good publication record. The specific research developed in his PhD thesis hasn't been published yet. The experimental value of the spectroscopic factor obtained in the PhD work is consistent with a quenching factor close to unity, which departs from the expected value around 0.5. This very interesting result should be submitted for publication to a high-impact journal.

The PhD thesis is written in good English and organised in four chapters.

The first chapter of contains an introduction to the field of direct nuclear reactions, including basic Scattering Theory, Elastic Scattering, and Transfer Reactions. The description of the Elastic Scattering focusses on the Optical Model, using both phenomenological and microscopic (folding) potentials. Transfer Reactions are described in the DWBA approach and features a detailed discussion on the remnant term. These are the basic theoretical tools required to analyse the experimental data.

The second chapter provides a comprehensive description of the experimental setup and the data taking process. It begins with a detailed description of the ACCULINA-2 fragment separator and radioactive beam production at the Flerov Laboratory of Nuclear Reactions (FLNR). The facility uses the in-flight technique, where the radioactive beam is obtained from the bombardment of a Be target with a high intensity stable beam provided by the U400M cyclotron. The chapter contains a comprehensive description of the experimental setup, covering ToF detectors, Multiwire Proportional Chambers (MWPC), and the particle telescopes (PTEL). In the Appendix there is also a very detailed study of the target thickness carried out in separate experiments using the U400M cyclotron and gas targets.

Chapter three describes the data analysis process. The complexity of the setup required a demanding data filtering process, including cleaning the ^{6}He beam itself from reaction contaminants, removal of secondary reactions on the target frame, and identification of relevant reaction fragments. The work also involved the calibration of various detectors: time, position, energy, dead-layer corrections, detector alignment (MWPC), and detector efficiency. Data reduction required the implementation of several correlation techniques involving time, energy and scattering angle, and missing-mass identification. The overall analysis was carried out using ROOT. Detector efficiencies were obtained by performing a full simulation of the experimental setup using GEANT4. The chapter includes an evaluation of statistical and systematic errors. Altogether it has been possible to achieve a statistical error of only 17% for the elastic cross sections and 14% for the transfer cross sections; systematic errors are estimated of similar magnitude.

Chapter four is devoted to a detailed theoretical analysis using Optical Model (OM) and DWBA calculations. The coupled channels code FRESCO and SFRESCO (a data fitting version of FRESCO) are used for this purpose. The theoretical analysis begins with a detailed study of the elastic channel ^{6}He+p using OM calculations. A variety of potentials are probed and optimised (fitted) to reproduce the data. The results of the fits are very satisfactory and consistent with published data at similar collision energies, thus asserting the validity of the data reduction process. The theoretical study continues with the analysis of the angular distribution of the elastic cross section for the ^{6}He+d reaction channel. In addition to phenomenological potentials, microscopic potentials are also probed by folding them with the deuterium ground-state wave function. The angular distribution of the elastic cross section is well described, although a better fit is achieved with the phenomenological potentials. The neutron transfer cross sections is analysed in the DWBA framework. As the OM potentials for the entrance channel d+^{6}He was already determined, the main challenge is obtaining the ^{3}H + ^{5}He and ^{2}H + ^{5}He OM potentials, as ^{5}He is unbound. In addition to the published parameterisations, it is also investigated the performance of microscopic potentials obtained from folding the ^{3}He+^{4}He and n+^{3}H scattering potentials with the ground state wave function of ^{4}He. The ^{5}He+n and ^{2}H+n wave functions are obtained from literature and previous results of Prof. K. Rusek. Various potentials including the ^{6}He + p scattering for entrance channel are also used to fit the transfer cross sections to obtain the value and uncertainty of the spectroscopic amplitude S(^{5}He+n).

The PhD manuscript also includes a section dedicated to the Conclusions, List of abbreviations, and References. There are two appendices, one for the study of the reaction target and another for the tabulated experimental cross sections. Relevant papers and previous works on the subject are properly referenced throughout the manuscript.

While reading the manuscript I missed a more extensive introduction covering the relevant physics topics, such as nuclear haloes, quenching of spectroscopic factors and production methods of radioactive beams. This should be considered for the future publications of the research work.

The following questions/comments should be addressed by Mr. Bogumil Zalewski during his PhD dissertation:

- Concerning the data reduction, the manuscript does not provide the ^{6}He beam intensity and energy spread at target position, which are relevant and should be included in future publications. Systematic errors for the extracted cross sections are given, but a detailed explanation of the methods used for the evaluation are missing.

- Regarding the DWBA calculations, different prescriptions produced similar values of the spectroscopic amplitudes, all of them close to unity. However, coupling to exited states could modify the value of the spectroscopic amplitude. Are there plans to perform coupled channel calculations to evaluate these effects?

- Finally, after reading the manuscript, it is not clear what was the main contribution of Mr. Bogumil Zalewski to the research work. This should be clarified.

To summarise, Mr. Bogumil Zalewski did an excellent work for his PhD, developing complex experimental and theoretical investigations towards the determination of the spectroscopic amplitude S(^{5}He+n) of the ^{6}He ground-state wave function. Mr. Bogumil Zalewski has contributed to several investigations published in relevant journals, and the publications derived from his PhD thesis are expected to have a large impact on the field.

I believe that Mr. Bogumil Zalewski is well prepared to develop independent research, and that the present PhD dissertation meets the requirements. Thus, I recommend Mr. Bogumil Zalewski be admitted to the next stages of the procedure for awarding a doctoral degree.

Ismael Martel