Investigation of α-nuclear potential families from elastic scattering experiments

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Abstract.
In this work we present the continuation of the reported analysis [1] of the experimentally measured angular distributions of the reaction $^{106}$Cd($\alpha$,α)$^{106}$Cd at several different energies around the Coulomb barrier. The difficulties that arise in the study of $^{106}$Cd-$\alpha$-nuclear potential and the so called Family Problem are addressed.

1. Introduction
The 35 stable elements located on the proton-rich side of the valley of $\beta$-stability that cannot be explained in the framework of slow and fast neutron capture are the so called the $p$-nuclei. These very low-abundant nuclei present one of the most interesting puzzles in nuclear astrophysics. One of the most accepted mechanisms for the synthesis of the $p$-nuclei is based on photon-disintegration reactions on neutron-rich seed nuclei [2, 3]. Possible scenarios for such nucleosynthesis are the C, O and Ne layers of a Type II SN [2].

2. The Family Problem in $^{106}$Cd
The sensitivity of nuclear reaction network calculations to the nuclear physics input has been addressed [3, 4] with particular emphasis to the uncertainties related to the $\alpha$-nuclear potentials in the heavy mass region (A>150). The sensitivity of $\alpha$-nuclear potentials at high energies (far above the Coulomb barrier) has been extensively studied in the past (see for instance [5, 6]). The present report concentrates on the $\alpha$-nuclear potential of the system $\alpha$-$^{106}$Cd, starting from the 14 families of the potential previously obtained [1] from the analysis of elastic scattered angular distributions measured at energies around the Coulomb barrier [7, 8]. The analysis was performed within the framework of the Optical Model, considering parameterizations of the Woods-Saxon form for both real and imaginary parts of the nuclear potential.

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3. Description of existing $\alpha$-induced reaction data

Considering as our starting point the 14 families of the real nuclear potential [1], a modified parameterization with an increased surface Woods-Saxon was adopted for the imaginary potential. The astrophysical S-factor for the processes $^{106}\text{Cd}(\alpha,\gamma)^{110}\text{Sn}$ and $^{106}\text{Cd}(\alpha,n)^{109}\text{Sn}$ [9], was determined for each of the considered potential families using the NON-SMOKERWEB [10] application. The default settings for neutron and proton potential [11], default nuclear level density [12] and theoretical masses [13] were used in the calculations.

The results are shown in Figure 1 together with the experimental data from [9]. At this stage, our evaluation of the potential families is limited to these two reaction channels, since they are primarily dependent on the $\alpha$-particle width at the considered energies [14].

![Figure 1. Astrophysical S-factor of the $^{106}\text{Cd}(\alpha,\gamma)^{110}\text{Sn}$ and $^{106}\text{Cd}(\alpha,n)^{109}\text{Sn}$ reactions [9] together with the results obtained from the 14 different potential families obtained in this study.](image1)

As it can be seen in the figures, both the $(\alpha,\gamma)$ and $(\alpha,n)$ processes are well reproduced by almost all of the considered potential families. In the case of the $(\alpha,\gamma)$ reaction, almost all families present a local minimum at the threshold energy for the $(\alpha,p)$ process, which needs to be further investigated. Any of these potentials could be thus used to calculate the reaction cross section at the energy range relevant for p-process calculations: $T_\beta=2-3$, with $\alpha$-energies corresponding to 5.4 and 8.1 MeV [14].

![Figure 2. Normalized $\chi^2$ obtained from the analysis of the elastic scattering data by all potential families considered in this work.](image2)

The results shown in Figure 2 provide a summary of the description of the different families of the experimental data of the $^{106}\text{Cd}(\alpha,\alpha)^{106}\text{Cd}$ at energies around the Coulomb barrier,
presenting the normalized $\chi^2$ obtained for each of the measured energies. A local minimum is observed around family number 6*, with another minima located on family 1*. The nature of these minima, as well as the particularities of these two families need to be further studied before any definite conclusions can be drawn.

**Figure 3.** Astrophysical S-factor of the $^{106}\text{Cd}(\alpha,\gamma)^{110}\text{Sn}$ and $^{106}\text{Cd}(\alpha,n)^{109}\text{Sn}$ reactions [9] together with the results obtained from families 1*, 6* and from the global potential of [15].

### 4. Conclusions
At this stage, we compare the two selected families with the standard global $\alpha$ nuclear potential from [15]. The results are shown in Figure 3. Analysis and comparison to further global and local $\alpha$ nuclear potentials will be the topic of a dedicated paper. The results from this work, combined with those previously presented [1], highlight the processes that are more sensitive to each part of the considered nuclear potential. While the real part of the potential presents a clear sensitivity to elastic scattering data, induced $\alpha$-particle capture reactions show a higher sensitivity to the imaginary part of the potential. When analyzing both processes in a coupled way, a minimum of $\chi^2/F$ in the description of the elastic scattering data appears. The reaction channels ($\alpha,n$) and up to some extent ($\alpha,\gamma$) at low energies, and elastic scattering reaction data at energies above the Coulomb barrier are necessary to achieve a full description of the potential.

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