

Study of (α ,n) reactions to determine the α -optical potential for γ -process

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Abstract. The optical potential is calculated from elastic scattering angular distribution data at high energies. The potential derived from elastic scattering data does not satisfactorily describe the experimental result for low energy reactions. An alternative approach for improving the α -optical potential at low energy was proposed, based on the (α ,n) reaction, which is solely dependent on the α - transmission coefficient, i.e. on the alpha optical potential. The new potential is a modified McFadden-Satchler (McF) potential with depth parameters (both real and imaginary) changed by an energy dependent Fermi function. The sensitivity of (α ,n) cross-section with different width parameters is also studied.

1 Introduction

The neutron capture process produces nuclei heavier than iron in the stars. But 30-35 proton-rich heavy nuclei from ⁷⁴Se- ¹⁹⁶Hg (known as p-nuclei) are formed by the γ -process, instead of neutron capture. γ -process is a combination of (γ , α), (γ ,n), and (γ ,p) reactions on heavy nuclei in a high γ -flux scenario. The (γ , α) reaction rate is calculated from the inverse reaction using the principle of detailed balance. The Hauser Feshbach (HF) statistical model is used to determine the (α , γ) reaction rate from reaction cross-section data. α -optical model potential (α -OMP) is one of the primary input parameters for HF statistical model calculation. There were various global α -OMPs available [1–3]. These potentials are obtained by fitting the α -elastic scattering angular distribution data and predicting reaction data at higher energies. However, it fails to explain the lower energy reaction data. Therefore, a modification in potential is required for low-energy astrophysical reactions. In this work, an energy-dependent α -OMP form was obtained by fitting the (α ,n) reaction cross-section data of p-nuclei in the mass range $A \sim 92 - 168$.

2 Reaction Cross section: Statistical Model

In HF theory, alpha induced reaction cross section for a specific outgoing channel x (x being γ , n, p, α , etc.) is $\sigma_{\alpha x} = \sigma_{\alpha} P_x$. Where σ_{α} is the compound nucleus formation cross section. Decay probability (P_x) of the outgoing channel x is given as $P_x = T_x / \sum_i T_i$, where T is the transmission coefficient. For neutron channel T_n is much higher than other particles (α ,p, etc.), as there is no coulomb barrier for neutron. So, above the neutrons threshold $P_x \approx 1$ and (α ,n) reaction cross section becomes $\sigma_{\alpha n} \sim \sigma_{\alpha} \sim \pi \lambda_{\alpha}^2 (2L+1) T_{\alpha}$. As T_{α} is calculated from entrance channel optical potential, (α ,n) reaction is used to derive the α -OMP.

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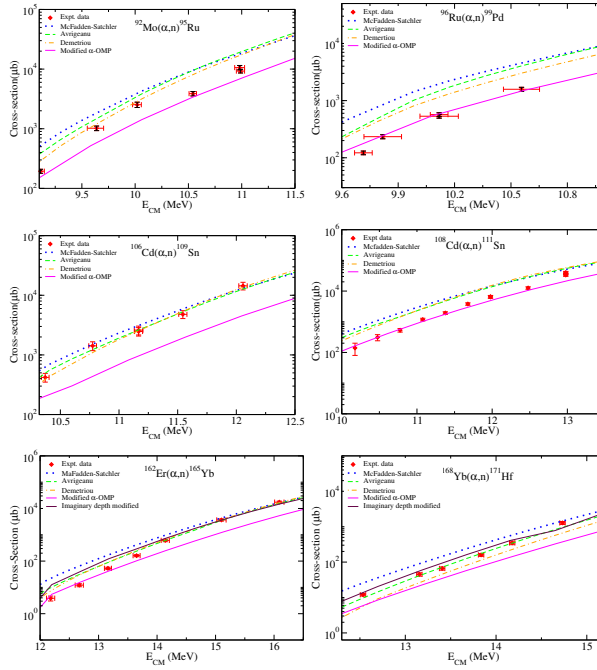


Figure 1. Expt. (α, n) reaction data [5–10] compared with the HF calculations using different α -OMP.

3 Results

The statistical model code TALYS in version 1.95 [4] is used for the HF calculations. Six even-even p-nuclei in the mass range $A \sim 92$ –168 have been chosen. At first, HF calculations have been performed using well known global potentials and compared with the experimental results. The theoretical calculations suitably explained ^{106}Cd data but overestimated for other nuclei. A modified potential was introduced by the fitting of the (α, n) reaction data. This potential is basically the well known McFadden-Satchler global α -OMP [1] with its depth parameters (both real and imaginary) modified by an energy dependent fermi function $f = 185 / [1 + \exp(0.9E_{cu} - E_{cm} / a_c)]$, where E_{cu} , E_{cm} are in MeV and $a_c = 10$ MeV. E. Somorjai et al. [11] first used this modification, but only modifying the imaginary depth on ^{144}Sm . The HF calculations using different α -OMPs are shown in Fig. 1.

4 Discussion

The new modified α -OMP properly described the (α, n) reaction data mainly in the lower mass region. However, modifying the imaginary depth rather than the two depths provides better fitting in regions with larger mass. The cross-section sensitivities should be taken into consideration to properly interpret this different characteristic of the potential form. Effect on the cross-section (σ) values with the variation of particle or γ width (w) known as sensitivity (S), can be written as $S = (F_\sigma - 1)/(F_w - 1)$. Where $F_\sigma = \sigma_{new} / \sigma_{old}$ and $F_w = w_{new} / w_{old}$. $S = 1$ implies that cross section changes with the same proportion as the width changes and $S = 0$ means no change occurs in cross section value. Sensitivity plots for (α, n) reaction are shown in Fig. 2. It was observed that (α, n) reactions for p-nuclei ^{92}Mo , ^{96}Ru and ^{108}Cd are mainly dependent on the α -width, other width contributions are negligible ($< 25\%$). So, (α, n) cross

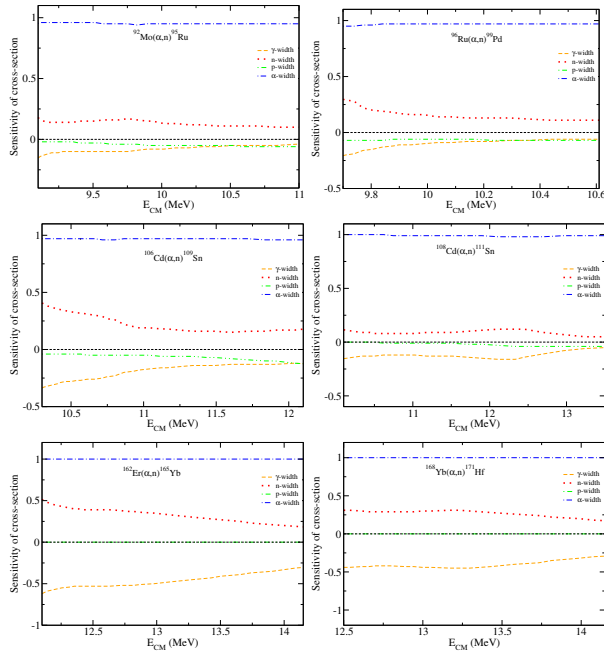


Figure 2. (α, n) cross section sensitivity with the variation of α -, p-, n-, γ -width [12].

section is directly dependent on alpha width i.e on α -OMP. The modified α -OMP adequately explains the results for these nuclei. But for other nuclei, besides the α -width (α, n) cross section is also sensitive to the neutron and γ width. So, it was difficult to extract α -OMP from (α, n) fitting for these higher mass nuclei. Surprisingly the results fit better for modifying only imaginary depth. The reason is that using this potential other width contribution may be eliminated. In Ref. [12], it is shown that this modified α -optical potential is explained (α, γ) reaction cross-section and reaction rate with proper level density model and γ -ray strength function.

References

- [1] L. McFadden, G.R. Satchler, Nuclear Physics **84**, (1966) 177
- [2] V. Avrigeanu et al., Physical Review C **90**,(2014) 044612
- [3] P. Demetriou et al., Nuclear Physics A **707**, (2002) 253
- [4] A.J. Koning, S. Hilaire, S. Goriely, *TALYS 1.95 A nuclear reaction program*, 2019
- [5] W. Rapp et al., Physical Review C **78**, (2008) 025804
- [6] W. Rapp et al., Physical Review C **66**, (2002) 015803
- [7] Gy. Gyürky et al., Physical Review C **74**, (2006) 025805
- [8] P. Scholz et al., Physical Letters B **761**, (2016) 247-252
- [9] G.G.Kiss et al., Physics Letters B **735**, (2014) 40-44
- [10] L.Netterdon et al., Nuclear Physics A **916**, (2013) 149
- [11] E.Somorjai et al., Astron. Astrophys. **333**, (1998) 1112
- [12] T. Rauscher, Ap. J. Suppl. **201**, (2012) 26
- [13] Dipali Basak et al., Eur. Phys. J. A **58**, (2022) 150