J Fusion Energ (2016) 35:605–607
DOI 10.1007/s10894-016-0079-9

ORIGINAL RESEARCH

Calculation of Cross-sections and Astrophysical S-Factors for ^{62}Ni(α,n) and ^{62}Ni(α,γ) Reactions of Structural Fusion Material Nickel

Ercan Yildiz[1] · **Abdullah Aydin**[1]

Published online: 26 February 2016

Abstract Nickel is an important element in fusion reactor technologies and astrophysical applications. Therefore, the knowledge of astrophysical S-factors and cross-sections on nickel isotopes is needed. In this work, the cross sections of the ^{62}Ni(α,n) and ^{62}Ni(α,γ) reactions have been calculated. The alpha capture cross sections was calculated up to 10 MeV. In these theoretical calculations, the TALYS 1.6 and NON-SMOKER codes were used. Also for the ^{62}Ni(α,n) and ^{62}Ni(α,γ) reactions, we calculated the astrophysical S-factors that determine the probability of reaction in low energies. Results of our calculations were checked to the experimental data obtained from EXFOR database.

Keywords Reaction cross-section · Astrophysical S-factor · TALYS 1.6 · NON-SMOKER · Nickel

Introduction

Interstellar medium plays a fundamental role in the process of galactic evolution. The stars born from interstellar matter collect energy into the interstellar medium. When their hydrogen becomes depleted, high mass stars transform He atoms into C and O, followed by the fusion of C and O into Ne, Na, Mg, S and Si. Later reactions transform these elements into Ca, Fe, Ni, Cr, Cu and others [1, 2]. Although the descent of the abundances of the elements is generally good understood, significant uncertainties still exist [3]. Therefore, recently (α,n) and (α,γ) reaction cross-sections in low energies are measured by several authors [4–9]. The importance of alpha capture cross sections for different mass regions to test the theoretical models is well known [10]. Also clear knowledge of the reaction cross sections and astrophysical S-factors on the nickel isotopes are needed because nickel which is one of the iron group elements is a significant structural material in fusion reactor technologies and astrophysical applications [11]. The information to be obtained about cross sections or astrophysical *S*-factors in nuclear astrophysics reactions are the main source of information about the nuclear processes in astrophysics. Various studies using theoretical models have been done to predict the alpha capture cross sections at low energies [3, 12].

In this study, we calculated the cross sections and the astrophysical S-factors for ^{62}Ni(α,n) and ^{62}Ni(α,γ) reactions. The alpha capture cross sections was calculated up to 10 MeV. In these theoretical calculations, we used TALYS 1.6 [13] and NON-SMOKER [14] codes. Results of our calculations were checked to the experimental data obtained from EXFOR [15] database.

Materials and Methods

The investigation of charged particle nuclear reactions at low energies are very important in astrophysics and in controlled thermonuclear reactions [16]. The charged particle nuclear reaction cross sections is given as

$$\sigma(E) = E^{-1}\exp(-2\pi\eta)S(E) \quad (1)$$

where E is the center-of-mass energy of the reactants, S(E) is astrophysical factor and $\eta = (Z_1Z_2e^2)/\hbar v$ is the Sommerfeld parameter. Z_1e, Z_2e, $\hbar$ and v are charge of projectile and target, planck constant (h/2π) and relative

✉ Abdullah Aydin
aaydin@kku.edu.tr

[1] Department of Physics, Kirikkale University, Kirikkale, Turkey

velocity of reactants, respectively. Experimental cross section measurements are mainly not available because of the Coulomb barrier. Since the astrophysical S-factor describes the possibility of reaction in low energies, in astrophysical applications, it should be well known for many reactions at low energies ($E \leq$ a few MeV). Also, the astrophysical S-factor is a function of energy with slow variation than $\exp(-2\pi\eta)$ and $\sigma(E)$ [16, 17]. Thus if theoretical astrophysical S-factors are known at low energies, cross sections can be predicted in these energies.

In this study, firstly, we calculated the reaction cross-sections of ^{62}Ni(α,n) and ^{62}Ni(α,γ) reactions by TALYS 1.6 [13] and NON-SMOKER [14] codes up to 10 MeV. Then the astrophysical S-factors were calculated using Eq. (1).

Results and Discussion

The cross-sections and astrophysical S- factors of the ^{62}Ni(α,γ), ^{62}Ni (α,n) reactions have been analyzed up to 10 MeV alpha energy. Obtained results for the ^{62}Ni(α,n) and ^{62}Ni(α,γ) reactions and the experimental data from EXFOR are given in Figs. 1–4.

The theoretically calculated cross-sections of ^{62}Ni(α,n) and ^{62}Ni(α,γ) reactions have been compared with the experimental values [4, 18–23] in Fig. 1 and Fig. 2. It can be seen that there is excellent agreement between the calculated cross section results of ^{62}Ni(α,n) reaction with TALYS 1.6 and the available experimental data from EXFOR in Fig. 1. But the NON-SMOKER results aren't in good agreement with the experimental data instead of Levkovskij [18] and Tanaka [21] and they are higher than

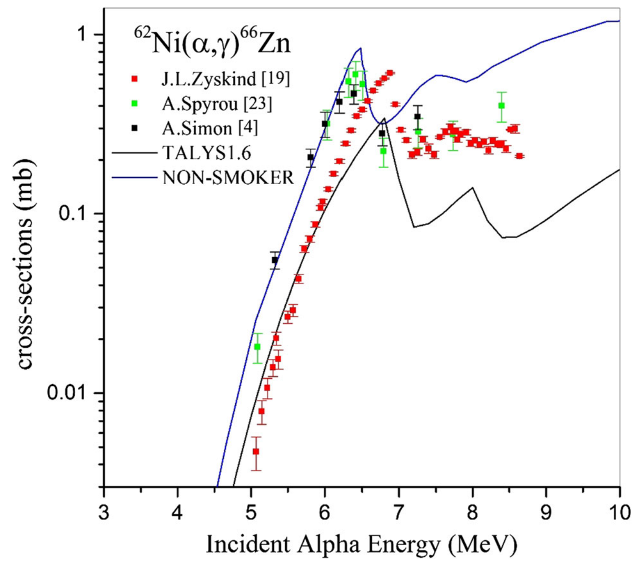

Fig. 2 Comparison of experimental cross sections and theoretical cross sections for ^{62}Ni(α,γ) reaction

the experimental data. For ^{62}Ni(α,γ) reaction, the TALYS 1.6 and the NON-SMOKER results are in good agreement with the measurements of Spyrou [23] and Zyskind [19] up to 6.5 MeV, respectively. Although they are far from the experimental values above 6.5 MeV but they are in good agreement as spectrum with them in Fig. 2.

For ^{62}Ni(α,n) and ^{62}Ni(α,γ) reactions, the S-factors calculated using Eq. (1) have been compared with the experimental values in Fig. 3 and Fig. 4. As can be seen in Fig. 3, there is good agreement between the calculated S-factor results of ^{62}Ni(α,n) reaction with TALYS 1.6 and the available experimental data from EXFOR. But there

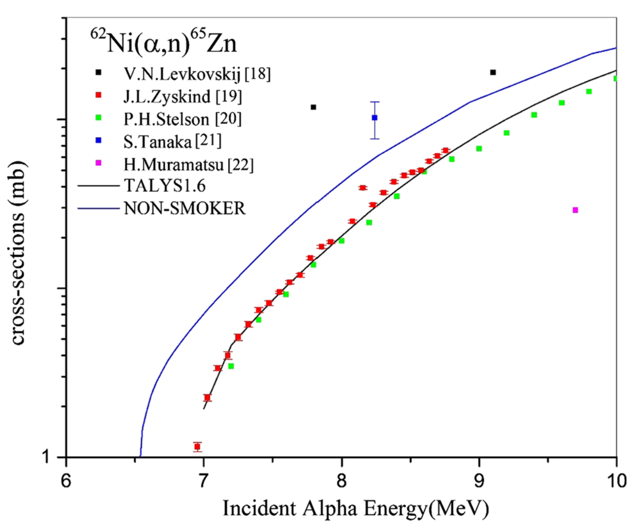

Fig. 1 Comparison of experimental cross sections and theoretical cross sections for ^{62}Ni(α,n) reaction

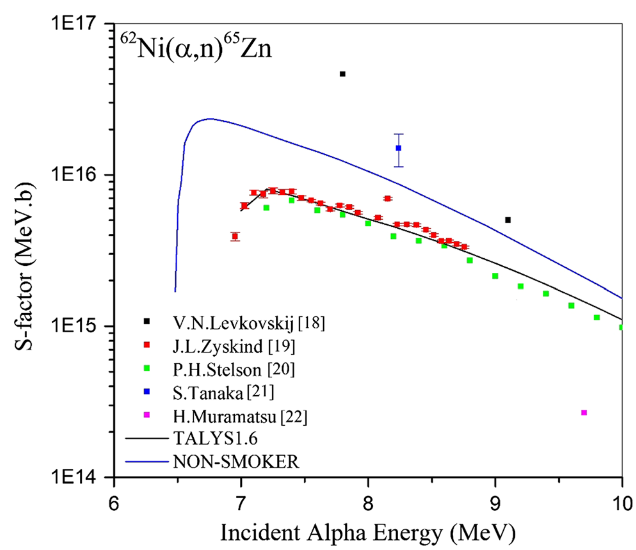

Fig. 3 Comparison of experimental S-factors and theoretical S-factors for ^{62}Ni(α,n) reaction

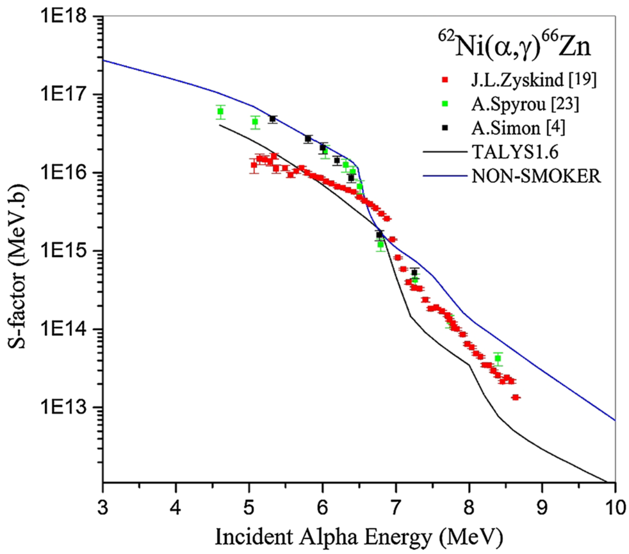

Fig. 4 Comparison of experimental S-factors and theoretical S-factors for ^{62}Ni(α,γ) reaction

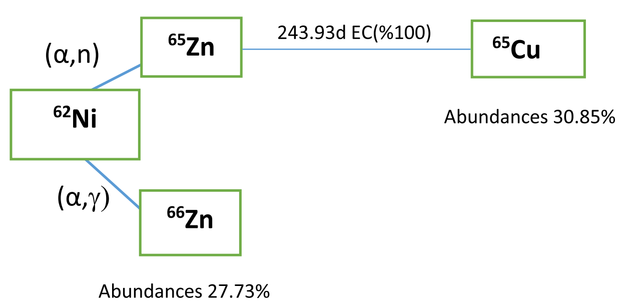

Fig. 5 The products of ^{62}Ni(α,n) and ^{62}Ni(α,γ) reactions

isn't same agreement with the experimental data instead of Levkovskij [18] and Tanaka [21] for the NON-SMOKER results and these results are higher than the experimental data. For ^{62}Ni(α,γ) reaction, the TALYS 1.6 and the NON-SMOKER S-factor results are in good agreement with the measurements of Spyrou [23] and Zyskind [19] up to 6.5 MeV, respectively. Although these results are far from the experimental values above 6.5 MeV but they are in good agreement as spectrum with them in Fig. 4.

In ^{62}Ni(α,n) and ^{62}Ni(α,γ) reactions, ^{65}Zn and ^{66}Zn isotopes are produced, respectively. Figure 5 shows schematically the reaction products. It can be seen from Fig. 5 that ^{65}Zn isotope ($T_{1/2}$ = 243.93 days) decays to stable ^{65}Cu and ^{66}Zn is stable isotope than heavier ^{56}Fe.

It appears that the agreement between the experimental and calculated values is reasonable good for ^{62}Ni(α,n) and ^{62}Ni(α,γ) reactions in general. But the calculated cross-section and S-factor results are far from the available experimental data above 6.5 MeV for ^{62}Ni(α,γ) reaction. Therefore, theoretical calculations could be repeated with the new nuclear parameters to obtain the best fit with the experimental data. Also more low-energy experiments are clearly needed for alpha capture reactions in the mass range of nuclei above iron.

References

1. M. Sahan et al., J. Fusion Energ. **31**, 52 (2012)
2. M. Sahan et al., Chin. J. Astron. Astrophys. **5**, 2 (2005)
3. N. Ozkan et al., Nucl. Phys. A **710**, 469 (2002)
4. A. Simon et al., Phys. Rev. C **92**, 025806 (2015)
5. M.S. Basunia et al., Phys. Rev. C **71**, 035801 (2005)
6. G.G. Kiss et al., Phys. Lett. B **735**, 40 (2014)
7. G.Y. Gyürky et al., J. Phys. G **37**, 115201 (2010)
8. A. Sauerwein et al., Phys. Rev. C **84**, 045808 (2011)
9. W. Rapp et al., Phys. Rev. C **78**, 025804 (2008)
10. W. Rapp et al., Phys. Rev. C **66**, 015803 (2002)
11. A. Aydin et al., J. Fusion Energ. **34**, 1105 (2015)
12. E. Yildiz et al., EPJ Web Conf. **100**, 01010 (2015)
13. http://www.talys.eu
14. http://nucastro.org/nonsmoker.html
15. https://www-nds.iaea.org/exfor/exfor.htm
16. W.N. Cottingham, D.A. Greenwood, *An Introduction to Nuclear Physics*, 2nd edn. (Cambridge University Press, Cambridge, 2001)
17. D.G. Yakovlev et al., Phys. Rev. C **82**, 044609 (2010)
18. V. N. Levkovskij, *Activation cross section by protons and alphas*, Moscow (1991)
19. J.L. Zyskind et al., Nucl. Phys. A **331**(1), 180 (1979)
20. P.H. Stelson, F.K. McGowan, Phys. Rev. **133**, 911 (1964)
21. S. Tanaka, J. Phys. Soc. Jpn. **15**, 2159 (1960)
22. H. Muramatsu et al., Appl. Radiat. Isot. **29**, 611 (1978)
23. A. Spyrou et al., Phys. Rev. C **76**, 015802 (2007)