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Calculation of cross-sections and astrophysical s-factors for the ^{63}Cu(α,n) and ^{63}Cu(α,γ) reactions

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Abstract: The cross sections and astrophysical S-factors of the ^{63}Cu(α,γ) and ^{63}Cu(α,n) reactions have been calculated. The radiative alpha capture reaction cross sections was calculated in the incident energy range of 3 to 10 MeV and the (α,n) reaction cross sections was calculated in the incident energy range of 7 and 16 MeV. In these theoretical calculations, the TALYS 1.6 and NON-SMOKER codes were used. Also for these reactions, it was calculated the astrophysical S-factors which describe the possibility of reaction in low energies. Obtained results were compared to the experimental data taken from EXFOR database.

1 Introduction

In light charged particle induced reactions, the total reaction cross sections drop swiftly (using of an exponential scale) at low energy region where Coulomb barrier is more effective, and measurement of the relevant cross-sections becomes more difficult [1]. But the nuclear astrophysical S-factors change slowly with energy. Therefore extrapolation of the experimental cross section measurements in the energy range of the low energy of the s-factor is not possible, it is much more convenient. Cross-section measurements and calculations for light charged particle capture sections reactions on heavy nuclei are important for nucleosynthesis applications [2] and for statistical model tests.

The temperatures exceed 10^9K at inner part of the supernovae. This inner region have proton and α–particle sections on medium and may be important in determining the mix of elements and isotopes which have been released from such stellar explosions. Investigation of the capture cross-sections for different mass regions is very important in testing of theoretical models.

In this study we calculated the cross sections and astrophysical S-factors of the ^{63}Cu(α,γ) and ^{63}Cu(α,n) reactions. Obtained results were compared to the experimental data taken from EXFOR database [3].

2 Cross-section, astrophysical s-factor

Nuclear reactions are very important in astrophysics [4] due to conceiving of evolution, nucleosynthesis, stars, giants and etc. Depending on some physical parameters, stellar burning may involve many reactions of various nuclei. The reaction rates can be calculated using the cross-sections σ(E) of reactions, or related astrophysical S-factor defined as

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

$$S(E) = \sigma(E)\, E \exp(2\pi\eta) \quad (2)$$

where, η is the Sommerfeld parameter, $(Z_1Z_2e^2)/\hbar v$. S(E) is function of energy with slow variation than exp(−2πη) and σ(E) (Fig.1). In astrophysical applications, S(E) should be known for many reactions at low energies, E ≤ a few MeV. Experimental measurements of σ(E) at lower energy are mainly not available (because of the Coulomb barrier exponentially suppresses low-energy cross sections). Theoretical evaluation of S(E) is model dependent, so that nuclear physics uncertainties of evaluated S-factor can be substantial [4].

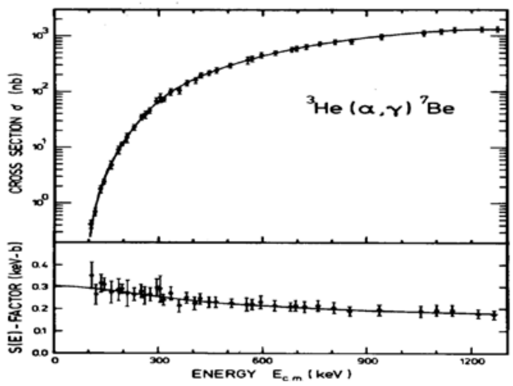

Figure 1. Dependence on cross-section and S(E) for the reaction ^{3}He(α, γ)^{7}Be [5]

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3 Calculations and results

In this study, the total reaction cross-sections and by using this cross-sections astrophysical S-factors of the ^{63}Cu(α,γ) and ^{63}Cu(α,n) reactions were calculated according to Eq. 2. The radiative alpha capture reaction cross-sections and the (α,n) reaction cross sections were calculated in the incident energy range of 3 to 10 MeV and 7 to 16 MeV, respectively. In these calculations, the TALYS 1.6 [6] and NON-SMOKER [7] codes were used. Also for these reactions, we calculated the astrophysical S-factors which describe the possibility of reaction in low energies. Obtained results were compared to the available experimental data of EXFOR database in Figs. 2 and 3. One can see that the agreement between the experimental and evaluated data is reasonable good at the higher energy but poor at the lower energy for these reactions. ^{66}Ga and ^{67}Ga produced in these reactions are radioactive isotopes. Fig. 4 shows schematically the production and decay of the two produced isotopes. It can be seen from Fig. 4 that these nuclei decay to stable ^{66}Zn and ^{67}Zn nuclei than heavier ^{56}Fe.

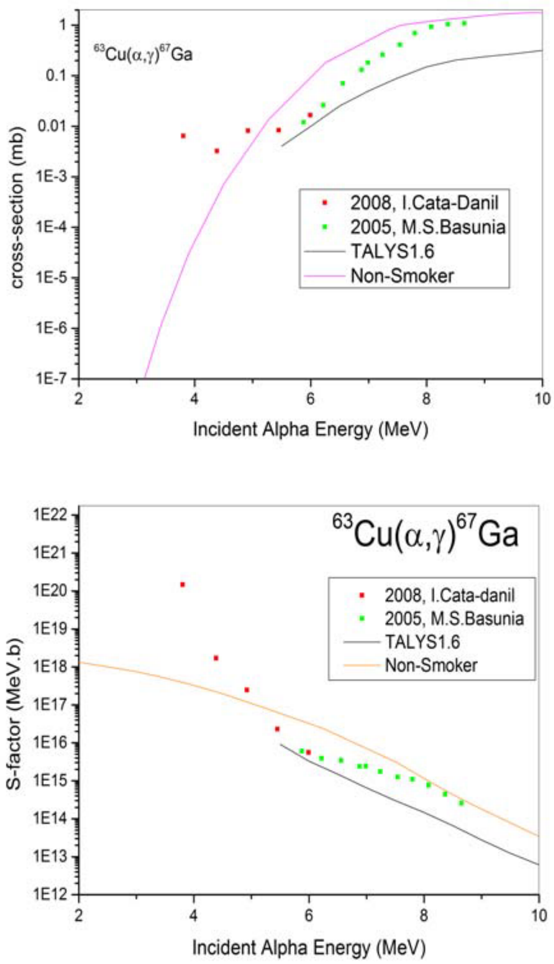

Figure 2. Comparison of experimental and evaluated cross-sections and astrophysical S-factors of ^{63}Cu(α,γ)^{67}Ga as a function α energy.

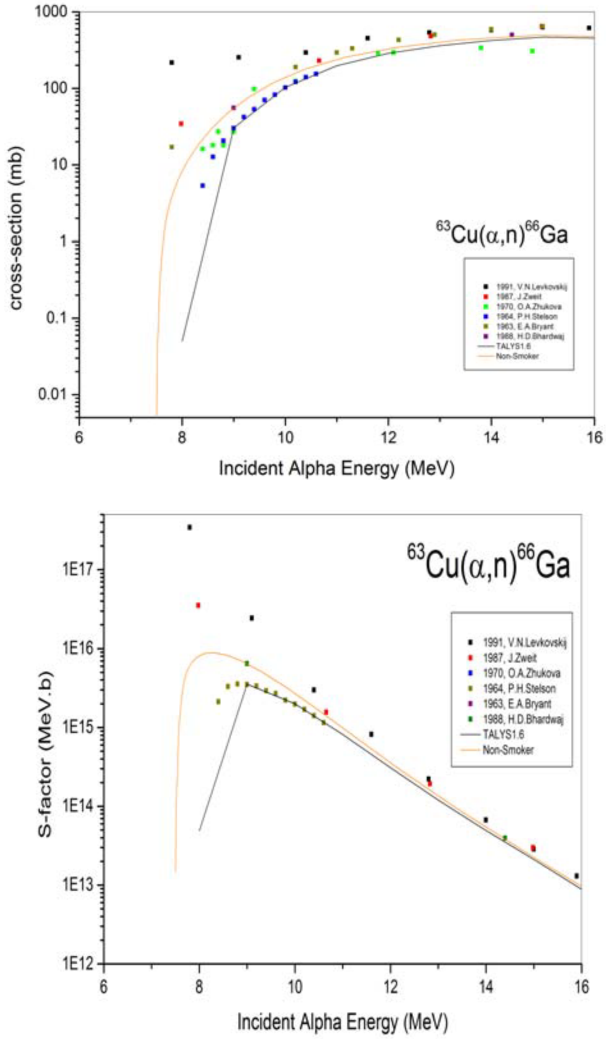

Figure 3. Comparison of experimental and evaluated cross-sections and astrophysical S-factors of ^{63}Cu(α,n)^{67}Ga as a function α energy.

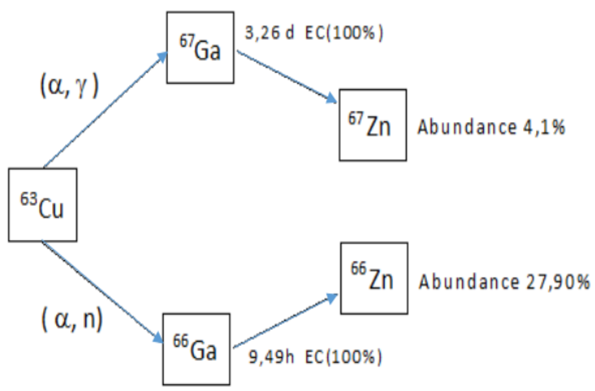

Figure 4. ^{63}Cu(α,γ) and ^{63}Cu(α,n) reactions and the decay of the reaction products.

4 Conclusion

The cross-sections and astrophysical S- factors of the ^{63}Cu(α,γ) and ^{63}Cu(α,n) reactions have been analyzed up to 16 MeV alpha energy. The reaction products, ^{66}Ga and

^{67}Ga, decay to stable ^{66}Zn and ^{67}Zn isotopes than heavier ^{56}Fe.

It appears that the agreement between the experimental and evaluated data is reasonable good at the higher energy but poor at the lower energy for these reactions. 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 both alpha induced reactions in the mass range of nuclei above iron.

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