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The Empirical Formulae to Determine the Astrophysical S-Factor of (α,n) Reactions for some Medium Elements

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Abstract: *In the present work, the cross-section of (α,n) reactions available in the literature as a function of α-particle energies for the medium element targets such as [$^{45}Sc(\alpha,n)^{48}V$, $^{46}Ti(\alpha,n)^{49}Cr$, $^{51}V(\alpha,n)^{54}Mn$, $^{50}Cr(\alpha,n)^{53}Fe$, $^{55}Mn(\alpha,n)^{58}Co$, $^{54}Fe(\alpha,n)^{57}Ni$, $^{59}Co(\alpha,n)^{62}Cu$, $^{62}Ni(\alpha,n)^{65}Zn$, $^{63}Cu(\alpha,n)^{66}Ga$ and $^{68}Zn(\alpha,n)^{71}Ge$] reactions have been rearranged and interpolated for α-particle energies from near threshold up to (10 or 15 MeV) in steps of 0.050 MeV by using the MATLAB computer program in lab. system. The obtained data were used to calculate the weighted average of the cross-section in unit of (mb). The obtained weighted average of the cross-section (mb) were taken into consideration and used to calculate the astrophysical S-factors of the above reactions as a function of α-particle energies in the center-of-mass system. The polynomial expressions have been used to fit the calculated astrophysical S-factor of the studied medium elements to determine the astrophysical S-factor from the best fitting equations with minimum (CHISQ) at various α-particle energies in the center-of-mass system . Empirical formulae of a set of reactions such as $^{46}Ti(\alpha,n)^{49}Cr$, $^{50}Cr(\alpha,n)^{53}Fe$, $^{62}Ni(\alpha,n)^{65}Zn$ and $^{68}Zn(\alpha,n)^{71}Ge$ has been used to calculate the astrophysical S-factor S(E) for each reactions as a function of α-particle energies in center-of-mass system and the atomic number (Z) of the target nucleus . Empirical formulae of a set of reactions such as $^{46}Ti(\alpha,n)^{49}Cr$, $^{50}Cr(\alpha,n)^{53}Fe$, $^{54}Fe(\alpha,n)^{57}Ni$, $^{62}Ni(\alpha,n)^{65}Zn$ and $^{68}Zn(\alpha,n)^{71}Ge$ has been used to calculate the astrophysical S-factor S(E) for each reactions as a function of α-particle energies in center-of-mass system and the total binding energy , $B_{tot}(A,Z)$ of the target nucleus . The results are compared with the adopted astrophysical S-factor calculating from the fitting equations are presented graphically and in numerical forms, and shown to be in a good agreement.*

Keyboard: Cross-section, nuclear reaction, astrophysical s-factor, sommerfeid parameter, gammo energy

I. Introduction

The nuclear astrophysical S-factor is introduced to separate the energy dependence of the coulomb barrier penetration from the cross– section [1]. In charged particle-induced reactions, the cross section for both reaction mechanisms (non-resonant and resonant) drops rapidly (on an exponential scale) at low energies owing to the effect of the Coulomb barrier, and it becomes more difficult to measure the relevant cross sections [2]. With improved experimental techniques direct measurements of σ(E) for charged-particle-induced reactions can be extended toward lower energies, but in practice one hardly reaches the relevant stellar energy regions for quiescent stellar burning. The observed energy dependence of σ(E), or equivalently of S(E), must therefore extrapolated into the stellar energy region (essentially to zero energy). Of course, the basis for extra- potation will be improved if extremely low energy data are available. However, these extrapolated data represent only lower limits of the stellar reaction rate [2]. The cross section of (α,n) reactions for different targets have been measured as a function of alpha particle energies in the (lab.) and (C.M.) systems by several authors. Total cross sections for $^{45}Sc\ (\alpha,n)^{48}V$, $^{46}Ti(\alpha,n)^{49}Cr$, $^{51}V(\alpha,n)^{54}Mn$, $^{50}Cr\ (\alpha,n)^{53}Fe$, $^{55}Mn\ (\alpha,n)^{58}Co$, $^{54}Fe(\alpha,n)^{57}Ni$, $^{59}Co(\alpha,n)^{62}Cu$, $^{62}Ni(\alpha,n)^{65}Zn$, $^{63}Cu\ (\alpha,n)^{66}Ga$ and $^{68}Zn(\alpha,n)^{71}Ge$ reactions have been measured by several authors mentioned by different references such as [3,4,5,6], [7,8], [5,6,9,10], [5,6,7,11], [12,13], [5,14], [5,6,15,16], [6,17,18], [5,6,17,19] and [6,17] respectively for each above reactions as a function of various alpha particle energies. The aim of the present work is to determine the astrophysical S-Factor using the modified cross sections of the above reactions . The results are compared with those published in the literature.

II. Theory

The Q – value of the reaction X(α,n)Y, is defined as the difference between the initial and final rest mass energies [20]:

$$Q = [M_x + M_\alpha - (M_Y + M_n] c^2 \qquad (1)$$

Where (m_x, m_α, m_Y and m_n) represents the atomic masses of the target, incident particles, product nucleus and out going particle, respectively. From conservation law of energy [20]:

$$M_\alpha c^2 + T_\alpha + M_x c^2 = M_n c^2 + T_n + M_Y c^2 + T_Y \qquad (2)$$

Where T is the kinetic energy of each particle.

In the laboratory system conservations of energy and momentum lead to the following eqution [20]:

$$Q = T_n(1+M_n/M_y) - T_\alpha(1-M_\alpha/M_y) - (2/M_y)(M_\alpha T_\alpha M_n T_n)^{1/2} \cos\theta \quad (3)$$

Which is called Q - equation.

The Q- value is positive, Q>0, the reaction is said to be (exoergic) or (exothermic); when Q- value is negative, Q<0, the reaction is (endoergic) or (endothermic). For (exoergic) reactions, threshold energy is (zero) and for (endoergic) reactions, the threshold energy is given by [21]:

$$E_{thr} = -Q_o\left(1+\frac{M_\alpha}{M_X}\right) \quad (4)$$

The binding energy can be calculated as the reduction in mass times the square of the velocity of light ($c^2 = 931.494013$ MeV/u)[22]:

$$B_{tot}(A,Z)=[ZM_H + NM_n - {}^{A}_{Z}M]c^2 \quad (5)$$

where (Z and N) are the number of protons and neutrons, (M_H, M_n and ${}^{A}_{Z}M$) are thr masses of hydrogen atom, neutrons and nucleus respectively

The charged particle reaction cross-sections at low energies is obtained by Breit- wigner formula [23]:

$$\sigma(E) = \tfrac{1}{E} S(E) e^{-G(E)} \quad (6)$$

Where G(E) is given by the following equation [23]:

$$G(E) \approx \frac{\pi}{\hbar c}\left(\frac{Z_1 Z_2 e^2}{4\pi\varepsilon_o}\right)\sqrt{\frac{2\mu c^2}{E}} = \sqrt{\frac{E_G}{E}} \quad (7)$$

Or $G(E)= 2\pi\eta$ **(8)**

$$E_G = 2\mu c^2\left(\frac{\pi Z_1 Z_2 e^2}{\hbar c\, 4\pi\varepsilon_o}\right)^2 \quad (9)$$

G(E) is the sammerfeld parameter and (E_G) is the Gammow energy , Z_1 and Z_2 are the atomic mumbers of the projectile and target nucleus, $\hbar = \frac{h}{2\pi}$ (h is the planks constant = (6.63×10^{-34} Joule. sec) (C) is the speed of light = 3×10^{8} m/sec, ε_o is the electric permittivity=8.85×10^{-12} F/meter, and (μ) is the reduced mass calculated from the following equation [20]:

$$\mu = \frac{m_1 m_2}{m_1 + m_2} \quad (10)$$

Where (m_1) and (m_2) are the atomic masses of the projectile and target nucleus, respectively.

It is evident that the energy of a pair of particles in their center- of -mass is related to the laboratory energy of incident particle by the relationship [20]:

$$E_{lab.} = \frac{m_1 + m_2}{m_2} E_{c.m.} \quad (11)$$

Where ($E_{lab.}$) is the energy of the incident particle in the laboratory system, ($E_{c.m.}$) is the energy of the incident particle in the center –of- mass .

The coulomb barrier inhibits nuclear reaction. For the P+P reaction the effective height E_c of this coulomb barrier is E_c =550 KeV it is useful to remember that $e^2/4\pi\varepsilon_o$=1.44MeVfm and R=$1.3A^{1/3}$fm, then it is easy to show [24].

$$E_c = \frac{1.44}{1.3}\frac{Z_1 Z_2}{(A_1^{1/3} + A_2^{1/3})} \quad (12)$$

The weighted averages of the cross-section σ (mb) and the uncertainty (Δ σ) for medium elements whose cross-section (σ) have been calculated using the following expressions [25] :

$$\sigma(\text{mb}) = \frac{\sum_i \frac{\sigma_i}{\Delta_i^2}}{\sum_i \frac{1}{\Delta_i^2}} \quad ....(13) \qquad \Delta\sigma = \pm\frac{1}{\sqrt{\sum_i \frac{1}{\Delta_i^2}}} \quad (14)$$

Where (σ_i) is the cross section of i^{th} reference and (Δ_i) is the errors corresponding to each of (σ_i) .

The type of formalism has been considered in the present work is the polynomial fit expression of the general form [26]: