The comparison of ^{18}C$(n,\gamma)^{19}$C and ^{18}C$(\alpha,n)^{21}$O reaction rates: consequences for the *r*-process

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Introduction

Neutron rich light and medium mass nuclei play a major role in determining the reaction flow towards the *r*-process seed nuclei production. In fact, in competition between (n,γ) and (α,n) rates, in this region, if the (α,n) dominates the reaction flow can be directed towards the production of higher Z values. Terasawa *et al.* [1], have asserted that at hydrostatic equilibrium temperature $T_9 = 0.62$ ($T_9 = 1 = 10^9 K$), the ^{18}C$(\alpha,n)^{21}$O capture reaction should be faster than the ^{18}C$(n,\gamma)^{19}$C radiative capture reaction resulting in the production of higher Z element. However, in their calculation, the halo structure of ^{19}C was not accounted for. Therefore, it is interesting to recalculate the ^{18}C$(n,\gamma)^{19}$C rate as its dominance over (α,n) would result in the reaction flow being directed towards the neutron drip line, i.e., towards the production of heavier Carbon isotopes.

In this text, we calculate the neutron capture rate of ^{18}C and compare it with that of α-capture by the same nucleus in the temperature range $T_9 = 0.1 - 10$. This temperature range roughly equals to an energy range of 1 keV to 1 MeV in centre of mass frame, where it is very difficult to perform direct reaction experiments. Further, the theoretical construction of ^{18}C-n continuum state for the ^{18}C$(n,\gamma)^{19}$C direct reaction is a tedious job. Hence, we use Coulomb dissociation (CD) under the aegies of finite range distorted wave Born approximation (FRDWBA) theory as an indirect method to calculate reaction rates at such low energies, because in CD method (more precisely in the post form reaction theory), the entire non-resonant continuum is already incorporated within the formalism.

With this background, we calculate the photodisintegration cross-section using FRDWBA theory for elastic Coulomb breakup of ^{19}C. We then use the principle of detailed balance to find the cross-section of the reverse process, i.e., the radiative capture and use it to find the reaction rate. Rate for the $^{18}C(\alpha,n)^{21}$O reaction is found from Hauser-Feshback estimates, also provided in Sasaqui *et al.* [2].

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Formalism

For a given elastic Coulomb breakup reaction of the form $a + t \longrightarrow b + c + t$, the triple differential cross-section is written as

$$\frac{d^3\sigma}{dE_b d\Omega_b d\Omega_c} = \frac{2\pi}{\hbar v_{at}} \rho(E_b, \Omega_b, \Omega_c) \sum_{l,m} |\beta_{lm}|^2, \tag{1}$$

where β_{lm} is the reduced transition amplitude from initial to final state. $\rho(E_b, \Omega_b, \Omega_c)$ is the phase space factor and v_{at} is the relative velocity between projectile and target. The relative energy spectrum $(d\sigma/dE_{rel})$ can be obtained from the triple differential cross-section by multiplying with the proper Jacobian and can be related to the photodisintegration cross-section as

$$\frac{d\sigma}{dE_{rel}} = \frac{1}{E_\gamma} \sum_{\pi,\lambda} \sigma^{\pi\lambda}_{(\gamma,n)} n_{\pi\lambda}, \tag{2}$$

where $n_{\pi\lambda}$ is the virtual photon number. $E_\gamma = E_{rel} + S_n$, where (S_n) is the one neutron separation energy and E_{rel} is the relative en-

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ergy between fragments b-c in the final channel. Knowing the photodisintegration cross-section, the time reversed radiative capture cross-section can be computed by using the principle of detailed balance as

$$\sigma_{(n,\gamma)} = \frac{2(2j_a+1)}{(2j_b+1)(2j_c+1)}\frac{k_\gamma^2}{k^2}\sigma_{(\gamma,n)}, \qquad (3)$$

where j_i's are total spins *(i=a,b,c)*, k_γ is wave number of photon and $k = \frac{2\mu_{bc}E_{rel}}{\hbar^2}$ with μ_{bc} being the reduced mass of the b-c system.

Finally, the reaction rate for the radiative capture reaction ($b + c \longrightarrow a + \gamma$) is

$$R = N_A\langle\sigma_{(n,\gamma)}v\rangle, \qquad (4)$$

where, N_A is the Avogadro's number and $\langle\sigma_{(n,\gamma)}v\rangle$ is the average of Maxwell-Boltzman velocity distribution. For detailed methodology, refer [3].

Results and discussions

For our calculations, we consider ^{19}C as the projectile (a) breaking up elastically in the Coulomb field of a ^{208}Pb target (t) while giving off an ^{18}C core (b) and a neutron (c). ^{19}C shows halo nucleus behavior, i.e., large spatial extension of the valence neutron with respect to its core. The depth of its bound state potential (Woods-Saxon) was adjusted to reproduce its small one neutron separation energy (0.53 MeV) and a J^π value of $1/2^+$ [4].

Fig.1 shows the reaction rate for the radiative capture of a neutron on ^{18}C (dashed line) derived from a full quantal theory (FRDWBA) and compares it with the ^{18}C$(\alpha, n)^{21}$O reaction (dot dashed line) in the temperature range of $T_9 = 0.1 - 10$. As is evident, formation of ^{21}O from α-capture reaction at the equilibrium temperature of $T_9 = 0.62$ is less favourable than the formation of ^{19}C from neutron capture reaction. However, as the temperature increases the neutron capture rate does not increase as much as the α-capture rate. The above result manifest that at higher temperatures, the elements with higher atomic number are more probable to form via α-capture process. Nevertheless, at temperatures $T_9 < 3.0$, the production of Carbon isotopes is favoured, thereby, pushing the element's production towards the neutron drip line.

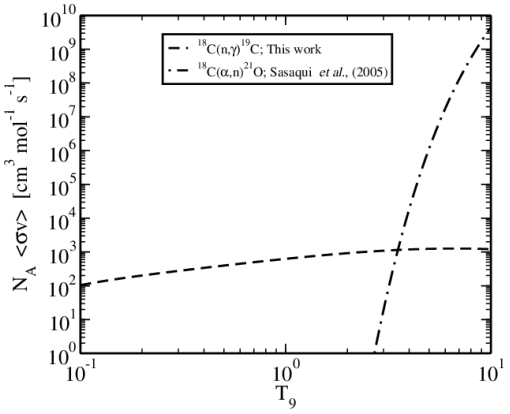

FIG. 1: Figure depicting a comparison of the reaction rates for radiative capture of a neutron on ^{18}C (dashed line) as a function of temperature in units of $T_9(10^9K)$ and an α-capture reaction by ^{18}C (dot dashed line) [2]. The domination of n-capture at the equilibrium temperature of $T_9 = 0.62$ is evident.

Acknowledgments

[MD] acknowledges the financial assistance from MHRD, Goverment of India, for the research fellowships and [S] is supported by U.S. NSF Grant No. PHY-1415656 and U.S. DOE Grant No. DE-FG02-08ER41533.

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