Core excited state contribution in ^{19}N(n,γ)^{20}N reaction rate

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Introduction

Low and medium mass neutron rich nuclei have been thought of as important constituents in the final abundance patterns resulting from the r-process reaction network calculations [1]. Consequently, neutron capture reactions involving exotic nuclei in these mass ranges, assume significance [2].

One such exotic nucleus is ^{20}N, where recently, the method of Coulomb dissociation (CD) was applied to its experimental analysis [3]. The experimental cross-sections so obtained were used to study the radiative neutron capture reaction ^{19}N(n,γ)^{20}N. This was done with a view to examine the role and contribution of the core (^{19}N) excited states to the total reaction rate and the temperature range where this phenomenon made a difference. The stellar temperature range of this contribution is significant for it can provide insights into the formation of medium mass neutron rich nuclei in astrophysical environments that can be used as seeds for the initiation of the r-process. Such theoretical studies for reaction rates from the ground as well as the excited states of both the projectile and core have been done in the past on similar lines [4].

In this contribution, we present calculations and results for the ^{19}N(n,γ)^{20}N radiative capture reaction using the CD as an indirect method in nuclear astrophysics. Specifically, we will study the contribution of the core (^{19}N) excited state to the reaction rate.

Formalism

The breakup of a two-body projectile a (^{20}N) in the dynamic Coulomb field of a target t (^{208}Pb) into fragments b (a ^{19}N core) and c (a neutron), can be viewed as: $a+t \to b+c+t$. CD is an elegant indirect method used in nuclear astrophysics studies because the energy range at which the reaction rates are to be studied to be in consonance with stellar environments are difficult to acheive with present experimental facilities across the globe.

In this method, we compute the relative energy spectrum and then relate it to the associated photodisintegration cross-section $[a(\gamma,c)b]$. The radiative capture cross-section is then calculated from the photo disintegration cross-section using the principle of detailed balance.

The reaction rate per mole for the $b(c,\gamma)a$ reaction is given by, $R = N_A\langle\sigma v\rangle$, with

$$\langle\sigma v\rangle = \sqrt{\frac{8}{\pi\mu(k_BT)^3}}\int_0^\infty \sigma_{(n,\gamma)}(E_{bc}) \times E_{bc}\exp(-\frac{E_{bc}}{k_BT})dE_{bc}, \quad (1)$$

where N_A and k_B are the Avogadro's constant and Boltzmann constant, respectively. T is the temperature in Kelvin (K) and $\sigma_{n,\gamma}$ is the radiative capture cross section. E_{bc} is the core-valence neutron relative energy and μ_{bc} is the reduced mass in the exit channel.

To obtain the phenomenological (bc - bound state) wave function, enabling us to compute

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the relative energy spectra and thus, approach the capture cross-sections and the reaction rates via the indirect method, we define a Woods-Saxon (WS) potential between the constituents b and c of the projectile a as,

$$V(r) = V_0 \left[1 + \exp\left(\frac{r-R}{d}\right)\right]^{-1}, R = r_0 A^{1/3}. \quad (2)$$

The depth, V_0 is adjusted so as to reproduce the one-neutron separation energy of the projectile, keeping radius (r_0) and diffuseness (d) parameters fixed at 1.24 fm and 0.62 fm, respectively. For more details on the formalism one is referred to Ref. [5].

Results and discussions

In this section, we discuss our reaction rate results obtained from the theoretical elastic Coulomb breakup of ^{20}N to form ^{19}N and a neutron when bombarded on a ^{208}Pb target at 256 MeV/u, i.e., $^{20}\text{N} + {}^{208}\text{Pb} \longrightarrow {}^{19}\text{N} + \text{n} + {}^{208}\text{Pb}$. The beam energy was considered to be in accordance with the experimental circumstances [3].

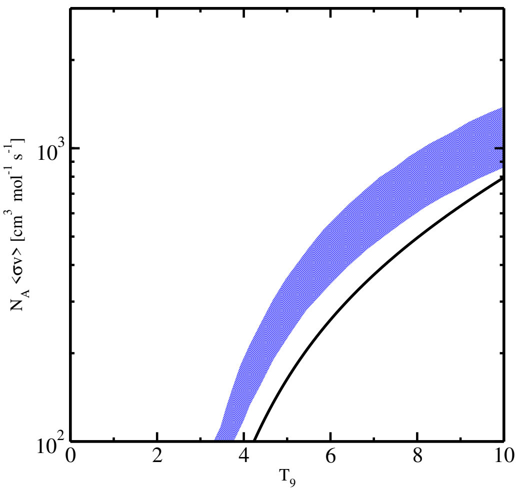

FIG. 1: Stellar reaction rate for ^{19}N(n,γ)^{20}N with contribution from first excited state of ^{19}N core. The experimental data (shaded region) is taken from Ref. [3].

The ^{20}N nucleus, containing 13 neutrons and 7 protons, is a highly exotic species with a neutron separation energy, S_n, of 2.16 MeV. Its valence neutron couples to a ^{19}N ($J^\pi = 1/2^-$) core and rests in the $d_{5/2}$ orbital giving it a ground state spin-parity of 2^-. But we are curious to consider the case when the core captures the neutron from its first excited state, which for ^{19}N is at 1.143 MeV having a total spin-parity of $3/2^-(J^\pi)$. This increases the neutron separation energy for ^{20}N to 3.303 MeV.

Fig. 1 shows the reaction rate with the first excited state of the core (^{19}N) for the ^{19}N(n,γ)^{20}N radiative capture reaction. The solid line denotes our preliminary result for the reaction rate, while experimental data is shown by the shaded region.

Given that our results follow the same trend as the data, it boosts the hypothesis that the contribution of the core excited states to the radiative neutron capture reaction rates is significant only at higher temperatures ($T_9 \geq 3$) for this particular case [3].

We will also present calculations and results of other reaction observables in the elastic Coulomb breakup of ^{20}N.

Acknowledgments

This text presents results from research funded by the Scheme for Promotion of Academic and Research Collaboration (SPARC/2018-2019/P309/SL), Ministry of Education, India.

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