Estimation of ^{30}Ne$(n,\gamma)^{31}$Ne capture reaction by semi-analytic approaches

Manju[1],* Jagjit Singh[2], G. Singh[3], Shubhchintak[1], and R. Chatterjee[1]
[1]Department of Physics, Indian Institute of Technology Roorkee, Uttarakhand-247667, INDIA
[2]Research Centre for Nuclear Physics (RCNP), Osaka University, Ibaraki 567-0047, JAPAN and
[3]Departamento de Física Atómica, Molecular y Nuclear, Facultad de Física, Universidad de Sevilla, Apartado 1065, E-41080 Sevilla, SPAIN.

Introduction

A nuclear halo is an intriguing phenomenon discovered in the mid-80's near the limits of nuclear stability. One of the interesting feature of the halo nuclei is the observation of low-lying soft electric dipole ($E1$) excitations. The halo nuclei lying in the low and medium mass regions near the neutron drip line play a crucial role in quantifying the reaction flow towards the r-process seed nuclei production [1]. To investigate the role of these medium mass neutron rich halo nuclei, direct radiative neutron capture analyses are required. However, the direct measurements of reactions involving such nuclei are extremely difficult due to small half-lives and radioactive nature of these nuclei. Thus, one may have switch to indirect methods to calculate the capture cross-sections and subsequent reaction rates.

In this respect, Coulomb dominated breakup reactions, where the inverse reaction is examined, have been very effective and elegant tools to provide structural information for halo nuclei. In this work we want to calculate the cross-section of ^{30}Ne$(n,\gamma)^{31}$Ne capture reaction by examining the electric dipole response dB$(E1)$/dE$_c$ to the continuum. For this we use a post-form theory of Coulomb dissociation under the ages of finite-range distorted wave Born approximation (FRDWBA) [3]. As ^{31}Ne is suggested to have deformed structure so we also include deformation in our calculation which enters in this model through the bound state potential of the projectile [2]. Using the principle of detailed balance we calculate the radiative neutron capture cross-section from the photo-dissociation cross-section and further investigate their variation with β_2. To compare the results obtained within FRDWBA, we use a semi-analytic approach where bound state wave function is deformed and the continumm state is a spherical Bessel function. The comparison of both the theories will be made for different deformation, β_2.

Theoretical Formulation

Coulomb breakup is a mechanism where a halo nucleus (projectile) being in the vicinity of a high-Z target breaks up into two or more fragments. We analyze the Coulomb breakup of ^{31}Ne on Pb target within the post-form theory of FRDWBA at one-neutron separation energy, S$_n$ = 0.29 MeV, using virtual photon method. The breakup cross-section can be related to dipole response distribution dB$(E1)$/dE$_c$ as in,[4],

$$\frac{d\sigma(E1)}{dE_c} = \frac{16\pi^3}{9\hbar c} n_{E1} \frac{dB(E1)}{dE_c}, \qquad (1)$$

where n_{E1} is the virtual photon number required for $E1$ excitation.

In the framework of a direct breakup process, for a single-particle state, the B$(E1)$ distribution can be given in terms of transition

*Electronic address: manju@ph.iitr.ac.in

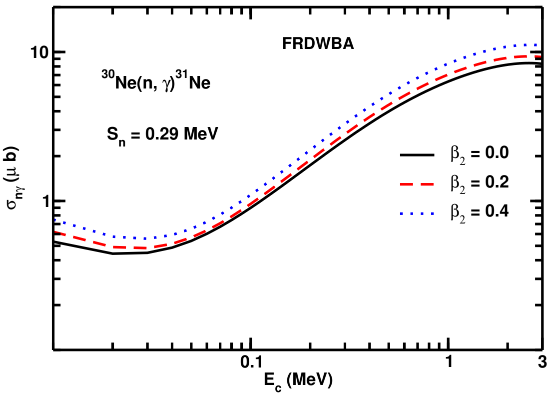

FIG. 1: Radiative neutron capture cross-section of ^{30}Ne$(n,\gamma)^{31}$Ne reaction, calculated within FRDWBA theory of Coulomb dissociation.

matrix elements,

$$\frac{dB(E1)}{dE_c} = (3/4\pi)(Z_{\text{eff}}e)^2\langle \ell 010|\ell^{'}0\rangle^2 \times \left| \int \mathrm{d}r\ \phi_b(r)\ \phi_c(E_c, r) r^3 \right|^2, \quad (2)$$

where, eZ_{eff} is the effective charge for a given multipolarity λ, $\phi_b(r)$ is the deformed bound wave function and $\phi_c(E_c, r)$ is the continuum wave function (with continuum energy E_c) which can be approximated to the spherical Bessel function.

The dipole strength distribution obtained from Eqs. (1) and (2) can be used to extract the photo-dissociation cross-section as,

$$\sigma_{\pi\lambda} = \frac{\lambda+1}{\lambda}\frac{(2\pi)^3}{[(2\lambda+1)!!]^2}\left(\frac{E_\gamma}{\hbar c}\right)^{2\lambda-1}\frac{dB(E\lambda)}{dE_c},$$

where $E\gamma$ is the photon energy given by $E\gamma = E_c + S_n$ with $S_n = \frac{\hbar^2 a^2}{2\mu}$. The photo-dissociation cross-section are then further used to compute the radiative neutron capture cross-section.

Results and discussion

We first calculated the ground state wave function of ^{31}Ne, which is the only input to our FRDWBA model. For this we consider ^{30}Ne$(0^+) \otimes 2\mathrm{p}_{3/2}n$ configuration for the ground state of ^{31}Ne and adjust the potential depth in order to reproduce the corresponding S_n which is taken as 0.29 MeV. In Fig. 1, we plot capture cross-section, $\sigma_{n\gamma}$ extracted from dB$(E1)$/dE$_c$, as a function of E$_c$ calculated within FRDWBA for three different values of β_2. The solid, dashed and dotted lines correspond to our calculations with $\beta_2 = 0.0$, 0.2, and 0.4, respectively. We observe that with increasing the deformation, the cross-section tends to increase for ^{30}Ne$(n,\gamma)^{31}$Ne reaction. The β_2 dependence on $\sigma_{n\gamma}$ is a result of its explicit presence in the potential V$_{dn}$.

We will also present the comparison of capture cross-sections of FRDWBA with the semi-analytic approach. In the semi-analytic approach the deformation enters through the bound wave function unlike the FRDWBA theory (where deformation enters via tha potential). Thus, it would help us to understand the role of dipole response function dB$(E1)$/dE$_c$ in the processes relevant for nuclear astrophysics.

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References

[1] M. Terasawa, K. Sumiyoshi, T. Kajino, G. J. Mathews, and I. Tanihata, Astrophys. J. **562**, 470 (2001).
[2] Shubhchintak, and R. Chatterjee, Nucl. Phys. A **922** (2014) 99.
[3] R. Chatterjee, R. Shyam, Prog. Part. Nucl. Phys. **103**, 67 (2018).
[4] Manju, J. Singh, Shubhchintak and R. Chatterjee Euro. Phys. J A **55**, 5 (2019).
[5] Shubhchintak, R. Chatterjee, and R. Shyam, Phys. Rev. C **96**, 025804 (2017).