Low-lying dipole strength for deformed halo ^{31}Ne

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Introduction

Since the last four decades or so, the progress in the radioactive ion beam (RIB) facilities have provided a channel to study the neutron-rich unstable exotic nuclei, lying far from the stability line. Exciting new characteristics have been reported in the unstable nuclei, such as the presence of dilute neutron cloud spread around the core (neutron halos), unconventional shell structure, and new excitation modes [1]. One of the characteristic feature of the neutron halos is the appearance of low-lying dipole ($E1$) strengths. The halo structures are observed in the ground state of light nuclei such as ^{6}He, ^{11}Li, ^{19}C etc., recently the signatures of possible halo structure are reported in medium-mass isotopes of Ne, Na and Mg [2]. These medium mass nuclei are also important from nuclear astrophysics perspective, the rate of radiative capture reaction $^{36}\text{Mg}(n,\gamma)^{37}\text{Mg}$ has been calculated recently [3] and this capture reaction plays significant role in determining if the r-process reaction flow will be sustained to Mg isotopes heavier than ^{36}Mg.

In the present study, we focus on medium-mass, one-neutron halo ^{31}Ne and later we will extend this study to other possible one-neutron halo candidates ^{34}Na and ^{37}Mg. ^{31}Ne is the interesting candidate for our study as it has been reported to have deformed halo structure in its ground state. It has small one-neutron separation energy (S_n) and contrary to convention shell model the valence neutron is in $p_{3/2}$ instead of $f_{7/2}$ orbit. However, there are large uncertainties in the measured S_n values of ^{31}Ne, 0.29 ± 1.64 MeV [4], 0.06 ± 0.41 MeV [5] and $0.15^{+0.16}_{-0.10}$ MeV [6]. The deformation in the ground state of ^{31}Ne has been reported in couple of studies [7, 8], all of these leads to same conclusion suggesting ^{31}Ne to be highly deformed with spin-parity, $3/2^-$.

For present study we use an analytical model [9] to calculate the dipole strength of ^{31}Ne at various deformations. To compare the analytic estimates we use a Coulomb breakup theory within the post-form finite range distorted wave born approximation (FRDWBA) [10]. Coulomb breakup is a well accepted tool to study the reactions involving weakly-bound nuclei. The peak position of the dipole strength distribution could be used to predict the one-neutron separation energy of the concerned projectile [2]. Here our aim is to explore the effect of deformation on the peak position of dipole strength distribution, which further constraints the one-neutron separation energy of the deformed projectile.

Formalism

For the single-particle dipole transitions from bound state $\phi_b(r)$ to continuum state $\phi_c(E_c, r)$, the electric dipole strength distribution is given by [9],

$$\frac{dB(E1)}{dE_c} = (3/4\pi)(Z_{\text{eff}}e)^2\langle \ell 010|\ell' 0\rangle^2 \left| \int \mathrm{d}r\ \phi_b(r)\ \phi_c(E_c, r) r^3 \right|^2, \quad (1)$$

where E_c is the continuum energy and Z_{eff} the effective charge for a given multipolarity λ. $\phi_b(r)$ is the deformed bound state wave

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*Electronic address: `manju@ph.iitr.ac.in` function and $\phi_c(E_c, r)$ is the continuum wave function which is expressed in terms of Bessel fucntion. To compare the results obtained analytically with more realistic theory we use the FRDWBA. Consider the Coulomb breakup reaction $a + t \rightarrow b + n + t$, where the deformed projectile a breaks up into two fragments b (charged core) and c (uncharged) in the Coulomb field of a target t. The triple differential cross-section for the above reaction is given by,

$$\frac{d^3\sigma}{dE_n d\Omega_b d\Omega_n} = \frac{2\pi}{\hbar v_{at}} \rho \sum_{\ell m} |\beta_{\ell m}|^2. \qquad (2)$$

Here v_{at} is the relative velocity of a-t system in the initial channel, ρ is the appropriate three-body phase space factor and $\beta_{\ell m}$ is reduced transition matrix. The relative energy spectra obtained by using Eq. (2) can be given in terms of dipole response function $[dB(E1)/dE_c]$,

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

where n_{E1} is the virtual photon number. The detailed formalism of FRDWBA can be found in [10].

Results and discussion

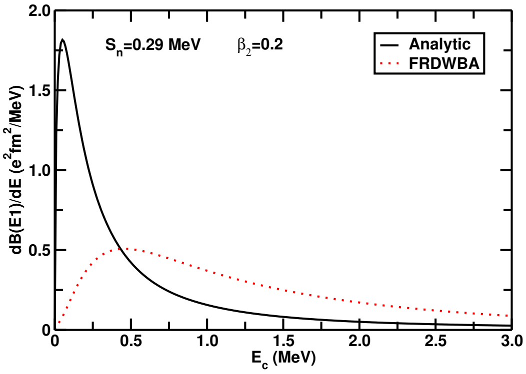

FIG. 1: Electric dipole response of ^{31}Ne at $S_n = 0.29$ MeV for $\beta_2 = 0.2$.

As a preliminary case, we calculate the electric dipole response of ^{31}Ne. Figure 1 shows the dipole strength distribution of ^{31}Ne at $\beta_2 = 0.2$ and separation energy, $S_n = 0.29$ MeV. To compare our analytic result we study the Coulomb dissociation of ^{31}Ne on ^{208}Pb at 234 MeV/u. The solid curve in Figure 1 refers to the analytical calculation and dotted curve corresponds to the FRDWBA estimate. The total integrated dipole strength B($E1$) obtained from both analytical and FRDWBA theory are 0.75 e^2fm^2 and 0.78 e^2fm^2 respectively. Furthermore, we intend to present the following: (1) The analysis of the peak position of dipole strength with separation energy corresponding to a fixed β_2. That can be used to put limits on the one-neutron separation energy of the concerned deformed projectile. (2) Extension of our work to calculate the capture cross sections from dipole strength $[dB(E1)/dE_c]$ distributions.

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