Scaling properties in deformed medium mass neutron halo nuclei

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Introduction

Recent developments in radioactive beam facilities around the world, has given substantial impulse to the exploration of new phenomena in unstable nuclei far from the valley of stability. These nuclei are fragile objects having binding energy of the order of less than 1 MeV as compared to $6-8$ MeV in stable nuclei. It has been established that in the low mass, neutron rich region, there exists nuclei like ^{11}Be and ^{19}C, called neutron halos[1, 2], which have extended spatial density distribution. In these weakly bound systems, because of the scattering of nucleons from bound states to unbound continuum states, continuum plays a vital role[3]. The study of Coulomb breakup of halo nuclei is an important tool to investigate information about their multipole responses and hence the details of their structure.

The previous studies[4–6], reveal that in these weakly bound systems, Coulomb breakup cross sections are dominated by electric dipole distribution B(E1). Coulomb breakup has also been used as an indirect method in nuclear astrophysics to determine the radiative capture processes of astrophysical interest.

The advancements in experimental facilities have extended interest in medium mass neutron rich nuclei like ^{34}Na, ^{37}Mg, ^{31}Ne, which are important candidates for astrophysical processes. These nuclei are strongly deformed. In this text, as a preliminary analysis, we treat these deformed nuclei as spherical and obtain an estimate of the total low lying dipole strength for various transitions in terms of separation energy of the system in order to see how scaling occurs with separation energy. The final aim of our work is to extend this analysis to include deformation effects of the projectile in the theory.

Low-lying dipole strength for a neutron halo

For the single particle transitions from a bound state ϕ_b(r) with separation energy S_n to a continuum state $\phi_c(E_c$,r) with continuum energy E_c, the dipole strength distribution is given by,

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

where for neutron dipole transition, the effective charge Z_{eff} is given by -Z/A and the spin is neglected for simplicity. In principle, in a single particle picture the bound and the continuum states are calculated by a potential model(usually a Woods-Saxon potential).

However the dipole strength distribution can be analytically described in the limit of very low binding energy. In Eq.1, most of the contribution comes from the asymptotic region, and for any radial distance r, we can write the bound state in terms of its asymptotic form,

$$\phi_b(r) = N_b h_\ell^{(1)}(iar), \quad (2)$$

where $a^2 = 2\mu S_n/\hbar^2$, μ is the reduced mass of the halo neutron, N_b is the normalization

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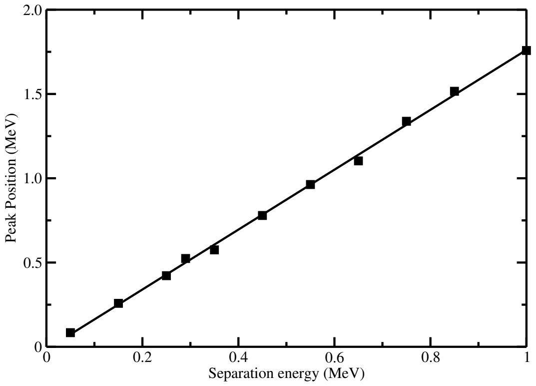

FIG. 1: Peak of the dipole strength distribution as a function of the one neutron separation energy in the breakup of ^{31}Ne on ^{208}Pb target at 234 MeV/nucleon.

and S_n is the one neutron separation energy.

Similarly, the continuum state in asymptotic form,

$$\phi_c(E_c, r) = \sqrt{\frac{2\mu k}{\hbar^2 \pi}} j_{\ell'}(kr), \quad (3)$$

where $k^2 = 2\mu E_c/\hbar^2$. With use of these two assumptions on wave functions, the dipole strength distribution in case of transitions from weakly bound p-orbit to d-continuum takes the analytic form in terms of the separation energy S_n and the continuum energy E_c :

$$\frac{dB(E1)}{dE}(p \longrightarrow d) = \frac{6\mu}{\hbar^2 \pi^2}(\hbar^2/2\mu)^{7/2}(Z_{eff}e)^2 \times N_b^2 \frac{E_c^{5/2}}{S_n^2(E_c + S_n)^4} \quad (4)$$

where $N_b = \sqrt{2a^3}$. From bound p-state to continuum d-state the maximum strength for dipole transition occurs at $E_c = 5/3S_n$. For details on the dipole strength, one may refer to [5, 6]

Results and discussion

As a test case we consider the case of ^{31}Ne which has one neutron separation energy as 0.29 MeV and ground state spin parity as $3/2^-$. In Fig.1, we show the peak position of the dipole strength distribution as a function of the separation energy in the case of transition from weakly bound p-state to continuum d-state in the breakup of ^{31}Ne on a ^{208}Pb target at 234 MeV/nucleon. Indeed it is known that the dipole Coulomb breakup cross section is proportional to the dipole strength distribution[4]. In such a scenario if one calculates the relative energy spectra, the peak of the relative energy spectra could be used as a good guide to estimate the one neutron separation energy of the projectile. This would be very useful in the exotic medium mass region of the nuclear chart, which is of current experimental and theoretical interest.

We shall also present results of our scaling calculation on ^{37}Mg and ^{34}Na.

We also intend to extend our work using proper deformed wave functions and see the effects of two-dimensional scaling with the separation energy and with the deformation parameter.

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