Scaling properties of nuclei away from stability

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Over the past few decades, a lot of efforts have been devoted to nuclear reactions involving halo nuclei induced by radioactive ion beams. Since the identification of first halo nucleus ^{11}Li, a number of one and two neutron halo nuclei have been discovered with radioactive ion beam facilities. The studies made with breakup reactions involving halo nuclei reveal some characteristic features like small $1n$ or $2n$ separation energy (≈ 1 MeV or less), large interaction cross-section, and narrow momentum distributions. Low separation energies also mean that these exotic nuclei can be excited easily above their particle emission thresholds in the Coulomb or nuclear field of a target, and their properties can be analyzed. The soft dipole ($E1$) is a unique feature of halo nuclei where considerable dipole transition strength [B($E1$)] shows up at low excitation energies near the drip lines in the breakup processes [2]. The simple estimate of low-lying dipole strengths has been already made and applied on lighter mass halo nuclei ^{19}C, ^{11}Be, and ^{11}Li [3, 4]. However, very recently, the interest has shifted to the medium mass region, and it would be interesting to study the responses to the continuum in this mass range.

The aim of the thesis is to study the various scaling relations of electric dipole ($E1$) transitions with different parameters in the breakup of medium mass p-wave halos. In the study of these systems, the continuum plays an important role and it needs to be investigated. Further, we plan to investigate the structure of p-wave halos. This thesis is divided into two parts. In the first part we study the role of electric dipole response for probable p-wave one-neutron halos ^{31}Ne, ^{34}Na and ^{37}Mg lying in the island of inversion by using two different approaches,: the post-form theory of Coulomb breakup within finite range distorted wave Born approximation (FRDWBA) and an analytic model. We calculate the relative energy spectra in the Coulomb dissociation of ^{31}Ne, ^{34}Na and ^{37}Mg on ^{208}Pb at 234, 100 and 244 MeV/u beam energy, respectively which is then used as a base to evaluate the dipole strength distribution, in the FRDWBA theory. The FRDWBA theory contains contributions from the entire non-resonant continuum corresponding to all the multipoles and the relative orbital angular momenta. The only input to FRDWBA is the ground state wave function of the projectile [5].

We then computed the total low-lying dipole strength for the medium mass p-wave one-neutron halos using a simple analytic model where we express the ground state wave function in terms of spherical Hankel function and the continuum wave function as a spherical Bessel function normalized to delta function [6]. The comparison of these analytic calculations has been made with those performed by the FRDWBA theory of Coulomb dissociation. We found a noticeable difference between both of these estimates. Thus, we have proposed a new multiplicative correction factor to the analytical model, derived from a realistic Woods-Saxon potential, which helped us in calculating electric dipole strengths for p-wave halos. Further, the comparison of both the theories shows reasonably good agreement, at least at the total dipole strengths level. This led us to study the scaling of the total integrated B($E1$) strengths with the one-neutron separation energy of the projectile. In addition to analyzing the peak of the dipole strength distribution, another important aspect is the comparison of the total dipole responses, which lead to a good estimate of the one-neutron separation energies for the p-wave halos. Estimated separation

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energy values in our work are 0.18, 0.24, and 0.15 MeV for ^{31}Ne, ^{34}Na, and ^{37}Mg, respectively [6] and these results agreed very well with the available theoretical estimates and the experimental data.

Apart from studying the electric dipole responses, we extended our Coulomb breakup theory to include deformation in 'moderate sized halo' ^{29}Ne. A very neutron-rich Ne isotope, ^{29}Ne, lying in the medium mass region near $N = 20$, is of great interest as its structure can reveal the extent of the island of inversion [7], and give a better picture of structural evolution in Ne isotopes [8]. The structural parameters, such as ground state spin-parity, deformation, are still not conclusive for ^{29}Ne. Therefore, we try to examine its ground state spin-parity by evaluating several reaction observables when it undergoes breakup in a strong Coulomb field. This constitutes the second part of the thesis.

We study the elastic Coulomb breakup of ^{29}Ne as it hits a ^{208}Pb target at 244 MeV/u beam energy. We calculate the one-neutron removal cross-section as a function of the one-neutron separation energy corresponding to possible ground state configurations of ^{29}Ne: ^{28}Ne$(0^+)\otimes 2s_{1/2}\nu$, ^{28}Ne$(0^+)\otimes 2p_{3/2}\nu$, ^{28}Ne$(0^+)\otimes 1d_{3/2}\nu$,^{28}Ne$(0^+)\otimes 1f_{7/2}\nu$. On comparison with the available data [8], we rule out the uncertainties in the ground state of ^{29}Ne and conclude that ^{29}Ne most probably has a ^{28}Ne$(0^+)\otimes 2p_{3/2}\nu$ ground state configuration. Further, we calculate the relative energy spectra in the pure Coulomb breakup of ^{29}Ne on a Pb target. The peak position of relative energy is observed to be sensitive to the projectile ground state configuration, and the peak height depends on the quadrupole deformation parameter β_2. To investigate the halo character of ^{29}Ne, we calculate the parallel momentum distribution (PMD) and the full width at half maximum (FWHM) of the spectra obtained. Indeed, it is known that the FWHM of the PMD for the breakup of light halo nuclei such as ^{11}Be, ^{19}C is around 44 MeV/c, while that for the stable isotopes it is almost over 140 MeV/c. The FWHM obtained in our case is 82 MeV/c, which suggests that ^{29}Ne is a 'moderate sized halo'. Furthermore, we evaluated the neutron energy-angular distribution, average momenta, and the neutron angular distribution. The results seem to signify that the effect of deformation would be visible certainly at small scattering angles, and there will be no post-acceleration effects for the charged fragment.

Finally, we calculate the dipole response for ^{29}Ne at different deformations using FRDWBA and a semi-analytic approach. Comparison of both theories suggests that the breakup is primarily dominated by dipole strength $E1$ and higher multipoles other than dipole do not play a role in breakup processes.

In future, the electric dipole $E1$ responses could be used for analyzing the photo-dissociation and its inverse process and radiative capture reactions relevant to astrophysical interest.

Acknowledgments

The author, thanks the MHRD, Govt. of India for a research fellowship.

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