Study of the Ground-state configuration of neutron-rich Aluminium isotope through Electromagnetic excitation

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Introduction:

Magic numbers are the basic building blocks of nuclear structure. Recently, through various experimental results using Radioactive Ion Beam (RIB) facilities, it has been observed that those long cherished magic numbers are not valid anymore in the neutron-rich nuclei around neutron magic number, N~20 and proton number (Z), $10 \leq Z \leq 12$. This region of the nuclear chart is known as the "Island of Inversion"[1-3]. In these nuclei, at ground state, the valance neutrons occupy the higher *pf* orbitals rather than the pure lower *sd* orbitals. Boundary of the "Island of Inversion" is not well-pronounced. Hence, study of ground state configuration of nuclei around this region is a current topic of intense research. Neutron rich, ^{35}Al, is lying at the boundary of this "Island of Inversion". Little experimental information about the ground state configuration of ^{35}Al, available in literature [4-6], motivated us for this work. Exclusive Coulomb breakup is a sensitive probe for studying the ground state configuration of loosely bound nuclei [7,8]. Further, Coulomb breakup data can provide radiative capture cross section which may be useful in Astrophysical scenario [9]. A program has been initiated to study the ground state configuration of different neutron rich nuclei around N ~ 20, 28 through Coulomb breakup using Radioactive Ion Beam facility at GSI, Darmstadt [8]. This thesis work is an attempt for understanding the ground state configuration of ^{35}Al via electromagnetic excitation.

Experiment and method of analysis:

A ^{40}Ar (531 MeV/u) beam was fragmented by a thick Beryllium (8 gm/cm^2) production target. The radioactive ions at relativistic energy, produced in this process, were separated by the fragment Separator (FRS) and a cocktail beam containing ^{35}Al was transported to the experimental site for kinematically complete measurement. Coulomb breakup of neutron-rich ^{35}Al using ^{208}Pb target (2 g/cm^2) was studied at relativistic energy ~ 412 MeV/nucleon. At the experimental area, the incoming beam was identified uniquely by energy loss and ToF measurements before the reaction target along with the known magnetic rigidities of FRS. The neutrons emitted from the excited projectiles or excited projectile-like fragments are kinematically focussed into forward direction and were detected with high efficiency in the neutron detector LAND. In order to detect γ rays, the target was surrounded by the 4π Crystal-Ball spectrometer consisting of 160 NaI detectors. Reaction fragments were tracked via the Silicon Strip Trackers and GFI detectors placed before and after the magnetic spectrometer (ALADIN), respectively. Finally, mass of the outgoing fragments were identified by reconstructing the magnetic rigidities inside ALADIN and velocity measurements of the reaction fragments [10,11]. All the γ-rays detected by the 4π-crystal ball detector in the laboratory frame were subjected to Doppler correction resulting in the reconstructed energy in the rest frame. Detailed Geant4 simulation were performed to estimate the γ-ray detection efficiency of *NaI(Tl)* based Crystal Ball detector under experimental condition [10]. Four momenta of the reaction fragments and all the decay-products i.e. neutrons and γ-rays etc. after reaction were measured and excitation energy of ^{35}Al prior to decay was reconstructed by the method of the invariant mass analysis. The resulting data was analyzed on the basis of direct breakup model.

The differential Coulomb dissociation cross section dσ/dE* for dipole excitations decomposes into an incoherent sum of components $d\sigma(I^{\pi}_c)/dE^*$ corresponding to different core states with spin and parity, I^{π}, populated after one-neutron removal and can be expressed as[7].

$$\frac{d\sigma}{dE^*} = \frac{16\pi^3}{9\hbar c} N_{E1}(E^*) \sum_j C^2 S(I_c^{\pi}, nlj) \times \sum_m \left| \left\langle q \left| (Ze/A) r Y_m^l \right| \psi_{nlj}(r) \right\rangle \right|^2$$

Where, $C^2S(I^{\pi}_c,nlj)$ is the spectroscopic factor. $N_{E1}(E^*)$ is the number of equivalent dipole photons of the target Coulomb field at an excitation energy E^*,which can be computed in a semi-classical approximation [12]. Here, the final states $|q>$ of the neutron have been approximated by a plane wave and the single particle initial states $|\psi_{n,l,j}>$ have been derived from a Wood-Saxon potential.

Differential Coulomb dissociation cross-section of loosely bound nuclei at intermediate energy is sensitive to the single particle wave function $|\psi_{n,l,j}>$ which in turn depends on the angular momentum (l) and the binding energy (S_n) of the valance neutron. Comparison of the experimental distribution for Coulomb dissociation cross-section with the theoretical one may provide direct insight into the angular momentum of the valance neutron and into its spectroscopic information. The core state to which the valance neutron is attached can be identified by the characteristic γ-rays [7].

The invariant mass spectrum of ^{35}Al using lead target has contributions from electromagnetic excitation, nuclear reactions and background reactions in detector materials. Events due to background reactions are obtained from the normalized empty target data. The nuclear contribution is obtained from carbon target data. The scaling factor corresponding to the ratio of nuclear cross-section in lead to carbon target has been obtained using soft-sphere model [13]. The scaling factor in this case is 1.8. Invariant mass corresponding to pure electromagnetic excitation in lead target is obtained after subtracting the nuclear contribution from the background subtracted lead target data. The obtained cross-section is corrected for one neutron detection efficiency (90%) and acceptance for the neutron detector, LAND.

Results:

The measured integrated total Coulomb dissociation cross section (integrated up to 10 MeV excitation energy) for $^{35}Al \rightarrow ^{34}Al+n + \gamma$ in Pb target is 77±13 mb [10]. The measured Coulomb breakup cross section which populated various excited states of the ^{34}Al core is 25 (5) mb. ^{34}Al has a 1^+ isomeric state [14] whose energy is not experimentally known. The contribution of various excited states was subtracted from the total electromagnetic cross section to obtain Coulomb dissociation cross section of $^{35}Al \rightarrow ^{34}Al_{\text{ground state and/or isomeric state}}$. The data has been interpreted in the light of direct breakup model. The comparison of the experimental Coulomb dissociation cross section with the theoretical one tentatively suggests that the possible ground state spin and parity of ^{35}Al could be $1/2^+$, $3/2^+$ and $5/2^+$. If the theoretically predicted, $5/2^+$, ground state-parity of ^{35}Al is considered, then the ground state configuration of ^{35}Al is a combination of ^{34}Al(g.s.; 4^-) $\otimes$ $\nu p^-_{3/2}$ and ^{34}Al(isomer; 1^+) $\otimes$ $\nu d^+_{3/2}$ configurations [15].

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