Study of Exotic Properties of Neutron Rich Nuclei around N~20 using Radioactive Ion Beam (RIB)

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Introduction: The study of nuclear structure has advanced on the basis of the concept of shell structures associated with the magic numbers proposed by Mayer and Jensen. The magic numbers of the nuclei are a benchmark of nuclear structure. The underlying shell gap is a characteristic of the mean nuclear field which takes into account of many ingredients of the nucleon–nucleon interactions. But recently, it has been noted that these magic numbers are no longer valid in the exotic nuclei which are far away from the β-stable line and close to drip line. The modification in the shell gaps through effects such as the tensor component of the N-N force become pronounced with large neutron-proton asymmetries in the exotic nuclei far away from stability. These lead to the disappearance of established magic numbers and the appearance of new ones. Disappearance of magic number was reported in these references [1, 2, 3]. The large deformation in those nuclei was explained by considering the intruder effects which suggests a clear vanishing of the shell gap between sd and pf shell around N = 20. The N = 20 isotones for Z =10−12 are considered to belong to the "island of inversion" [4] where intruder configurations dominate the ground state wave function. So far several studies have been performed using different techniques to investigate this region. Though it is established that the valence neutron(s) in the ground state of the neutron-rich Na, Mg, Ne isotopes at N = 20, occupies *pf* intruder orbitals, but this is not well established for the neighboring nuclei. Recently nuclei with N~20 have been studied and valence nucleon occupancy in the *pf* orbital is reported [3,5]. An experimental program GSI-S306 [6] was initiated to explore ground state configurations of neutron-rich nuclei around N = 20 through Coulomb breakup of secondary beams at intermediate energy (400 − 500) MeV/nucleon. Datta Pramanik et al., first showed that in order to study the ground state configuration of nuclei using Coulomb breakup, it is necessary to accurately account for γ contributions of the excited core after the breakup [7]. Coulomb breakup is a direct method to probe the quantum numbers of the valence nucleons of loosely bound nuclei [5]. In my thesis, first results on the wave-function decompositions of the ground state of ^{29,30}Na, studied via Coulomb breakup, have been reported [8,9].

Experimental setup: The secondary beam containing ^{29,30}Na isotopes along with others were populated by fragmentation of the ^{40}Ar primary beam with energy 540 MeV/nucleon and separated at fragment separator (FRS). The secondary beam was transported to the experimental site, a neighboring cave C where the complete kinematic measurements were performed using the **FRS-ALADIN- LAND** setup at GSI Darmstadt. The position of the incoming beam before the secondary target (Pb) and the position of the reaction fragments after the target were accurately measured using double sided silicon strip detectors (DSSD). The target (Pb) was surrounded by 162 NaI(Tl) detectors, That detector-array was used for detecting the γ-rays from the excited core of the projectile after the Coulomb breakup. The decay products, neutrons were forward focused due to Lorentz boosting and detected by the large area neutron detector (LAND) for the time of flight and position measurements. The mass of the outgoing reaction fragments was reconstructed using the deflection angles measured from GFI, the energy loss at TFW, the time of flight measurement of the reaction fragments and the magnetic rigidity of ALADIN.

Analysis and Results: The excitation energy E* of ^{29,30}Na were obtained after measuring the four-momenta of all the decay products using various detectors as described in earlier section. The electromagnetic excitation of loosely bound neutron-rich nuclei in heavy ion collisions at intermediate energy is dominated by the dipole excitation due to smaller effective charge for higher multi-polarities. Thus one neutron removal differential CD cross section for dipole excitation dσ/dE* decomposes into an incoherent sum of components $d\sigma(I^{\pi}c)/dE^*$ corresponding to different core states ($I^{\pi}c$), populated after one neutron removal. For each core state, the cross-section further decomposes into incoherent sum over contribution from different angular momenta j of the valence neutron in its initial state.

The pink line represents the differential CD cross-section using a direct breakup model in which the valence neutron occupies a combination of the s and d-orbitals, respectively. The blue and red line represent the calculated CD cross-section with the valence neutron in the d and s orbitals with the respective spectroscopic factors. The shaded region in the figure represents the errors associated with the fitted curve.

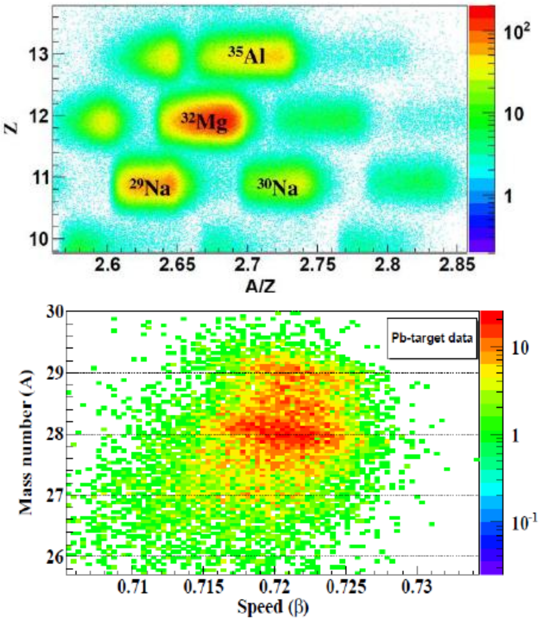

Fig. 1: Incoming particle identification plot (top). Outgoing fragment mass identification plot after one neutron breakup of ^{29}Na (botom).

The total inclusive CD cross section for ^{29}Na into ^{28}Na and one neutron amounts to 89 (7) mb, after integration up to 10 MeV excitation energy No resonance-like structure has been observed. The data analysis for ^{29}Na shows that the major part (67(11)%) of the breakup cross section leaves the core ^{28}Na in its ground state and approximately (33(5)%) of the fragments are found in the excited states which could be deduced from the invariant mass spectra, obtained in coincidence with the sum energy spectra of the γ-ray with the core fragment (i.e., ^{28}Na) and one neutron. In a very similar way the inclusive cross section for ^{30}Na into ^{29}Na and one neutron amounts to 167 (13) mb, after integration up to 10 MeV excitation energy No resonance-like structure has been observed. The data analysis for ^{30}Na shows that the major part (72(10) %) of the breakup cross section leaves the core 29Na in its ground state and approximately (28(4) %) of the fragments are found in the excited states. The resulting data have been analyzed using direct breakup model calculation. The experimentally observed shape of the spectrum for ^{29}Na is in good agreement with the calculated one considering the valence neutron in the s and d orbitals. The solid curve (pink) with shaded region in the figures 2, represent the calculated dσ($I^{\pi}c$)/dE* using the direct-breakup model with the valence neutron in combination of the s and d orbitals, respectively. The $\chi 2/N$ for the fit suggests that the neutron is occupying the s and d orbitals with the spectroscopic factors 0.07(7) and 2.1(3), respectively. Similarly the spectroscopic factors for ^{30}Na obtained from the fit to the data for the neutrons occupying the s and d orbitals are 0.05(5) and 2.03(30), respectively [9]. The experimentally obtained spectroscopic factor 2.1(3) for valence neutron in the d orbital of ^{29}Na is in closer agreement with modified *sd*-shell model (USD-B) calculation (2.18). On the other hand the same for ^{30}Na is much reduced 2.03(30) compared to the sd-shell (USD-B) calculation (2.97). This could be due to particle-hole excitation of the valence neutron across the shell-gap.

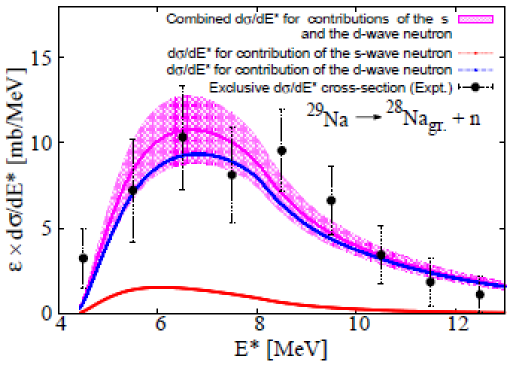

Fig. 2 The pink line represents the differential CD cross-section using a direct breakup model in which the valence neutron occupies a combination of the s and d-orbitals, respectively. The blue and red line represent the calculated CD cross-section with the valence neutron in the d and s orbitals with the respective spectroscopic factors. The shaded region in the figure represents the errors associated with the fitted curve.

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