EPJ Web of Conferences **66**, 02087 (2014)
DOI: 10.1051/epjconf/20146602087

Study of Ground State Wave-function of the Neutron-rich ^{29,30}Na Isotopes through Coulomb Breakup

A.Rahaman[1], U.Datta Pramanik[1,2,a], T.Aumann[3,2], S.Beceiro[4], K.Boretzky[2], C.Caesar[2], B.V.Carlson[5], W.N. Catford[6], S.Chakraborty[1], S.Chatterjee[1], M.Chartier[7], G.De.Angelis[8], D.Cortina-Gil[4], D.Gonzalez-Diaz[2], H.Emling[2], P.Diaz Fernandez[4], L.M.Fraile[9], O.Ershova[2], H.Geissel[2,10], M.Heil[2], B.Jonson[11], A.Kelic[2], H.Johansson[11], R.Kruecken[12], T.Kroll[3], J.Kurcewicz[2], C.Langer[2], T.Le Bleis[12], Y.Leifels[2], G.Munzenberg[2], J.Marganiec[2], C.Nociforo[2], A.Najafi[13], V.Panin[2], S.Paschalis[3], S.Pietri[2], R.Plag[2], R.Reifarth[2], V.Ricciardi[2], D.Rossi[2], J.Ray[1], H.Simon[2], C.Scheidenberger[2,10], S.Typel[2], J.Taylor[7], Y.Togano[14], V.Volkov[3], H.Weick[2], A.Wagner[15], F.Wamers[2], M.Weigand[2], J.S.Winfield[2], D.Yakorev[15], and M.Zoric[2]for s306 collaboration

[1]*Saha Institute of Nuclear Physics, Kolkata 700064*
[2]*GSI Darmstadt D-64291, Germany*
[3]*Technical University of Darmstadt, Germany*
[4]*Univ. Santiago Compostela, E-15782 , Spain*
[5]*Instituto Tecnologico de Aeronautica, Sao jose dos Campus, Brazil*
[6]*University of Surrey, Uk*
[7]*University of Liverpool, UK*
[8]*INFN, Legnaro, Italy*
[9]*Universidad Complutense, Madrid, Spain*
[10]*Physikalisches Institut, Giessen, Germany*
[11]*Fundamenta Fysik, Chalmers Tekniska Hogskola, Sweden*
[12]*Technical Uni. Munich, Germany*
[13]*Kernfysisch Versneller Institute, Netherland*
[14]*The Institute of Physical and Chemical Research (RIKEN), Japan*
[15]*FZD Dresden, Germany*

Abstract.
Coulomb breakup of unstable neutron rich nuclei $^{29,30}Na$ around the 'island of inversion' has been studied at energy around 434 MeV/nucleon and 409 MeV/nucleon respectively. Four momentum vectors of fragments, decay neutron from excited projectile and γ-rays emitted from excited fragments after Coulomb breakup are measured in coincidence. For these nuclei, the low-lying dipole strength above one neutron threshold can be explained by direct breakup model. The analysis for Coulomb breakup of $^{29,30}Na$ shows that large amount of the cross section yields the ^{28}Na, ^{29}Na core in ground state. The predominant ground-state configuration of $^{29,30}Na$ is found to be $^{28}Na(g.s)\otimes\nu_{s_{1/2}}$ and $^{29}Na(g.s)\otimes\nu_{s_{1/2}}$, respectively.

[a]Corresponding author: ushasi.dattapramanik@saha.ac.in

1 Introduction

Study of loosely bound nuclei far away from β-stability line provides many interesting and important properties of nuclei due to large neutron proton asymmetry [1–3]. Change of shell structure from the normal nuclei to large number of excess neutron provides an excellent opportunity to understand the isospin dependent nuclear interaction in nuclear medium [4]. In 1975 through mass measurement of $^{31,32}Na$, Thibault *et al*. observed the first signature of unexpected properties of nuclei around $N = 20$ magic number [5]. $^{31,32}Na$ isotopes were more bound than predicted theoretically. Later Motobayashi *et al*. confirmed a large deformation for ^{32}Mg from measured value of the reduced transition probability of the 2^+ state, and pointed to the vanishing of the $N = 20$ shell gap [6] with strong intruder configurations in the ground state of this nucleus. $^{29,30}Na$ belong to vicinity of 'island of inversion' [7]. Many theoretical [8] and experimental [9, 10] studies have been performed to study the ground state configuration of these nuclei. Hurst *et al*. [9] derived reduced transition matrix elements of excited states in ^{29}Na and suggested significant admixture of both *sd* and pf components in the wave function. Tripathi *et al*. have studied the low-energy level structure of the exotic $^{27-29}Na$ isotopes through β delayed γ spectroscopy [10]. In order to probe directly the ground state wave-function of these neutron-rich nuclei in and around 'island of inversion', an experiment (S306) [12] was proposed and performed at GSI, Darmstadt. In this article, some interesting preliminary results of that experiment (S306) on systematic study of ground state configuration of $^{29,30}Na$ obtained through Coulomb breakup will be reported. Coulomb break up is a direct method to probe the quantum number of the valence nucleon of the loosely bound nuclei [1]. This probe is highly sensitive to the tail part of the wave function of valence nucleon [1, 11]. When a projectile moving with high velocity passes a target of high nuclear charge Z, it may be excited by absorbing virtual photons from the time-dependent Coulomb field. The corresponding differential cross section $d\sigma/dE^*$ for dipole excitation decomposes into an incoherent sum of components $d\sigma_c^\pi/dE^*$ corresponding to different core states with spin and parity, I^π, populated after one-neutron removal in case of breakup to two-body final state with a nucleon and a core nucleus[1].

$$d\sigma_c^\pi/dE^* = (16\pi^3/9\hbar c)N_{E1}(E^*)\sum_j C^2S(I_c^\pi, nlj)\sum_m |<q|(Ze/A)rY_m^l|\psi_{nlj}(r)>|^2$$

2 Experiment and Analysis

In this experiment (GSI experiment S306) the radioactive beams were produced by fragmentation of ^{40}Ar with energy 530 MeV/u, delivered by the synchrotron SIS at GSI, Darmstadt. The neutron-rich Na, Mg and Al isotopes with similar mass-to-charge ratios were separated using the Fragment Separator (FRS) and transported to neighbouring cave C for complete kinematic measurements after Coulomb breakup. The incoming cocktail beam (figure 1 (a)) was identified event by event through measurement of the magnetic rigidities, time of flight and relative energy loss. The secondary reaction target ^{208}Pb (2 gm/cm^2) and ^{12}C (935 mg/cm^2) were used for Coulomb and nuclear breakup. The secondary target was surrounded by 8 silicon strip detectors (SST) to track the beam and reaction fragments in a box shape. Before the target a plastic scintillator was used for reference time at cave C.The unreacted beam and and reaction fragments were bent by a large-acceptance dipole magnet (ALADIN) and tracked via two arrays of scintillating fiber detectors (GFI) and the TFW detectors which consists of plastic scintillator paddles. The gain matching of these paddles were performed using a "sweep run". In figure 2(b) such gain matched spectrum has been shown. Calibration of SST, GFI, TFW, LAND, DTF, Crystal Ball detectors have been performed using program developed at SINP (Kolkata) and GSI (Darmstadt). The mass of the reaction fragments 1(c) were obtained using the deflection angle obtained from GFI after ALADIN and time of flight measurements from TFW for that fragment. A schematic diagram of the experimental set-up is shown in figure 1(b). The Crystal Ball detector which consists of 162 NaI(Tl) detectors, was used to detect the γ-rays from the excited core states of the reaction fragments after breakup. Decay neutron(s) from the excited projectile(s) were tracked by the large area neutron detector (LAND). A Cosmic run was used for the gain matching of individual paddles of LAND detector. The time offset of the LAND detector was determined from the velocity difference between neutron and γ.

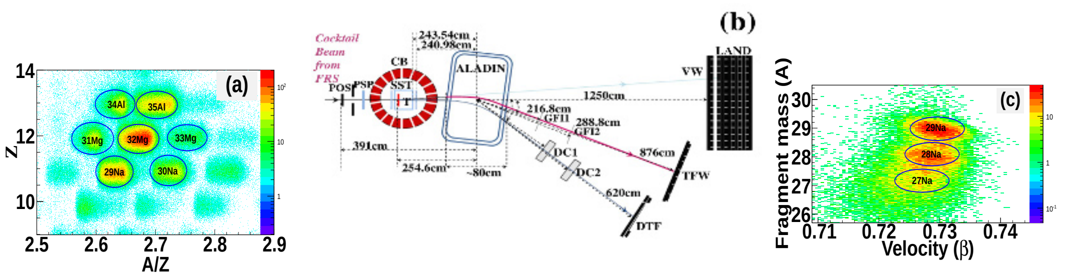

Figure 1: (a) Plot for In-coming cocktail ion beam. (b) Schematic diagram of experimental setup. (c). Plot of outgoing Fragment mass of Na isotopes Vs fragment velocity.

From measured four momentum vectors of all decay products of the excited projectile, the excitation energy E^* of the projectile is reconstructed through invariant mass [1] analysis by the equation:

$$E^* = \sqrt{\sum m_i^2 + \sum_{i\neq j} \gamma_i \gamma_j m_i m_j (1 - \beta_i \beta_j cos\theta_{ij})} + E_\gamma - m_{proj}.$$

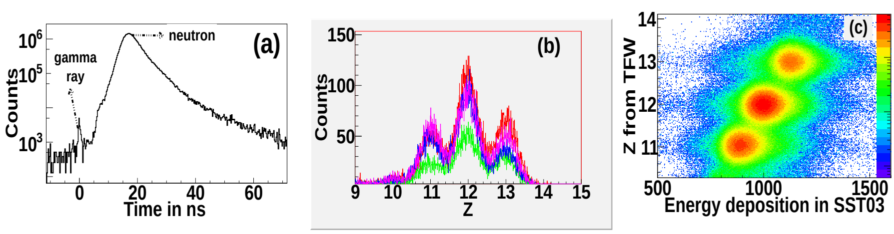

Figure 2: (a) Time of flight for neutron and γ to LAND detector (b) Gain matched overlaid spectrum for Z distribution in different paddles of TFW (c) Outgoing Z separation from SST and TFW

3 Results

Table-I shows both calculated and the experimental integrated Coulomb dissociation (CD) cross-section for ^{29,30}Na nuclei with excitation energy upto 8 MeV and 6 MeV respectively. Small contributions of characteristic γ-rays have been observed in coincidence with the break-up neutron and fragments. A comparison between the experimental CD cross-section with calculated one using direct breakup model [1] considering valence neutron in s, p, d, f orbital has been shown in the Table-I.

Table 1: Coulomb dissociation cross-section of ^{29,30}Na nuclei with excitation energy upto 8 MeV and 6 MeV respectively

Isotope	ground state spin [13] and parity	S_n (MeV)	Neutron orbital	Coulomb dissociation Cross-section (mb) Direct Beakup model	Present Experiment
^{29}Na	$3/2^+$	4.4	$s_{1/2}$	69	61 ± 10
			$d_{5/2}$	16	
			$p_{3/2}$	54	
			$f_{7/2}$	3	
^{30}Na	2^+	2.27	$s_{1/2}$	173	134 ± 30
			$d_{5/2}$	37	
			$p_{3/2}$	126	
			$f_{7/2}$	7	

The analysis of the deduced dipole-transition probability into continuum infers $^{28}Na(g.s) \otimes \nu_{s_{1/2}}$, $^{29}Na(g.s) \otimes \nu_{s_{1/2}}$ as probable ground state configuration of $^{29}Na(3/2^+)$ and $^{30}Na(2^+)$ respectively, which correctly produce the ground state spin of these isotopes. It may be noted that using similar technique, it has been observed that valence neutron of the ground state of neutron-rich ^{35}Al isotope occupies $p_{3/2}$ orbital, predominantly [14].

Acknowledgement

Authors are thankful to the accelerator people of GSI for their active support during the experiment. Author, U. Datta Pramanik acknowledges Alexander von Humboldt foundation for their support during proposing, defending and performing this experiment at GSI, Darmstadt.

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