First Observation of Excitation across the ^{100}Sn Core

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Excited states of nuclei near the doubly-magic nucleus ^{100}Sn were studied with the ^{58}Ni+^{50}Cr reaction. The experimental setup consisted of the GAMMASPHERE array augmented with light charged-particle and neutron detectors. Excited states were identified for the first time in the proton emitting nucleus ^{105}Sb. Excitations across the N=Z=50 doubly closed shell were observed in ^{99}Cd and ^{101}In. Some results of large-scale shell-model calculations are discussed.

1. INTRODUCTION

Doubly-magic nuclei and their nearby neighbors are of great experimental and theoretical interest. Not only do they furnish the single-particle energies and two-body matrix elements needed for accurate determination of the effective interactions, but they also provide an excellent testing ground for large-scale shell-model calculations. Being the heaviest particle-stable, self-conjugate nucleus, ^{100}Sn occupies a unique place among doubly-magic nuclei. However, despite numerous experimental efforts, little is known about the excited states in this nucleus or in its immediate neighbors. Therefore, information about the single particle and core excitation energies above N=Z=50 closed shells have to be inferred indirectly. In this work, we will report on ^{105}Sb and the first observation of core-excitation across N=Z=50 in ^{99}Cd and ^{101}In nuclei.

2. EXPERIMENTAL PROCEDURE AND RESULTS

Nuclei near ^{100}Sn were produced using the reaction of ^{58}Ni on a ^{50}Cr target at a beam energy of 225 MeV. The ^{50}Cr target (99% enrichment) consisted of a 2.1 mg/cm^2-thick foil which was backed by 10 mg/cm^2 of Au in order to stop the residual nuclei. The experiment was done with the GAMMASPHERE Ge-detector array [1] at Argonne National Laboratory. The experimental setup consisted of 78 Ge detectors surrounded by BGO anti-Compton shields, the Microball [2] for detection of light charged-particles, and the Neutron Shell. The Neutron Shell consists of 30 liquid scintillator detectors for detection and identification of neutrons produced in fusion-evaporation reactions. The neutron detectors covered a solid angle of about 1π in the forward direction from the target. The average detection and identification efficiencies for protons, α particles and neutrons were 78%, 47% and 27%, respectively. The proton detection efficiency showed a small dependence on the reaction channel. It was higher for reaction channels with lower particle multiplicity. The efficiency for identification of α particles was somewhat reduced due to the use of backed-target, presence of thick absorbers in front of the Cs(I) detectors of the Microball, and restrictive gating conditions used to separate proton and α particles. No α particles could be clearly identified in the Microball detectors placed at angles $\theta > 111.5^\circ$. Due to the overlap of protons and α particles in the backward detectors, about 12% of the α particles were misidentified as protons. On the other hand, only 0.2% of protons were misidentified as α particles. The separation between neutrons and γ rays detected in the neutron detectors was also very good. Only 0.7% of the γ rays not associated with neutron emission were found in the spectra gated with one neutron. About 6% of neutrons scattered from one neutron detector into another, which made it difficult to identify residual nuclei produced by the evaporation of 2 neutrons. Therefore, the 2n reaction channels were identified by considering only events in which the two neutrons were detected in non-neighboring neutron detectors. This cleaning technique, described in ref. [3], reduced the neutron scattering probability to 3%, while the number of the real two neutron events decreased by 20%. This enabled us to clearly distinguish between 2n and 1n reaction channels.

The experiment was done in 5 days of beam time with an average beam intensity of 3 particle nA. The accelerator delivered a beam pulse every 82.5 ns. For each 12 pulse period, the first 3 beam pulses were allowed to reach the target while the remaining 9 pulses were steered away from the target. The start time of the reaction was determined from the accelerator RF signal.

The trigger condition required detection of: (i) at least one neutron and one Compton-suppressed Ge signal within the prompt time window, and (ii) the presence of at least one other Ge signal within 800 ns of the start time of the reaction. The zero-crossover signals from the neutron detectors, which were used to identify the presence of neutrons, were vetoed for about 2 ns to suppress the γ ray flashes that originated from the reaction. As a result, the number of events associated with evaporation of neutrons increased by about a factor of two compared with the events that did not involve emission of neutrons. In the off-line analysis, these data were sorted into particle-gated γ-ray spectra and γ-γ coincidence matrices. The spectra were analyzed using the software package Radware [4].

Z \ N	50	51	52	53	54	55	56
52							Te-108 (CN)
51					Sb-105 1p2n 0.009	Sb-106 1p1n 0.08	
50			Sn-102 1 n 0.0006	Sn-103 1 1n <0.002	Sn-104 2p2n 0.68	Sn-105 2p1n 6.0	Sn-106 2p 1.7
49			In-101 1 1p2n 0.02	In-102 1 1p1n 0.40	In-103 1 1p/3p2n 0.65/0.36	In-104 3p1n 22. 9	In-105 3p 24.7
48	Cd-98 2 n 0.0003	Cd-99 2 1n 0.01	Cd-100 2 /1 2p2n 0.009/0.03	Cd-101 1 2p1n 3.1	Cd-102 1 2p 10.1	Cd-103 4p1n 3.1	Cd-104 4p 15.9
47		Ag-98 2 p1n 0.04	Ag-99 2 p 0.37	Ag-100 1 3p1n 0.15	Ag-101 1 3p 8.9		Ag-103 5p 0.18
46	Pd-96 3	Pd-97 2 2p1n 0.006	Pd-98 2 2p 0.41		Pd-100 1 p 0.08		
45	Rh-95 3 p						

Figure 1. Part of the nuclear chart showing nuclei identified in the reaction of a 225 MeV ^{58}Ni beam incident on a thick ^{50}Cr target. Reaction channels and the relative populations in percent are shown below the isotope symbol. CN denotes the compound nucleus.

The above experimental setup resulted in a very good reaction-channel selection. Altogether, a total of 28 different residual nuclei were identified. Figure 1 shows the relative population of the residual nuclei identified in this experiment. Each number was obtained by fitting the intensities of the characteristic γ rays belonging to a residual nucleus in a spectrum gated by the number of protons, α particles, and neutrons that were appropriate for that reaction channel. All intensities were corrected for the γ-ray branching ratios, γ-ray and particle detection efficiencies, and for the effect of the neutron detector trigger. The relative populations may be converted to partial cross sections by multiplying them with the total reaction cross section, which is estimated to be 330 mb according to a calculation with the Cascade code [5]. Note that the reported relative populations for the weak channels are only accurate to within a factor of 2, due to the trigger bias which required the presence of two or more γ rays.

The strongest and weakest reaction channels identified in this experiment were ^{105}In(3p) and ^{98}Cd(2α2n), respectively. The partial cross section for ^{98}Cd is estimated to be about 1 μb, which is indicative of the high selectivity achieved in this experiment. We were not, however, able to confirm the previously reported γ rays in ^{103}Sn [6] which were obtained with a different reaction. Therefore, we have shown only an upper limit for the relative population of ^{103}Sn in Fig. 1. This limit is, nonetheless, higher than the best experimental sensitivity achieved for ^{98}Cd and ^{102}Sn nuclei because of the different background levels.

3. DISCUSSION

We have identified for the first time the excited states in the proton emitter ^{105}Sb [7], populated with a cross section of about 30 μb. ^{105}Sb is now the lightest proton emitter with known excited states. The high spin level scheme of ^{105}Sb resembles the level scheme of ^{107}Sb up to I=19/2. When compared to ^{107}Sb, the ^{105}Sb level scheme follows the same trends as when going from ^{106}Sn to ^{104}Sn. This implies that ^{105}Sb can be well described by coupling a $d_{5/2}$ proton to the ^{104}Sn core. This is confirmed by the results of a large-scale shell-model calculation [8], which are in good agreement with the experimental level scheme.

We have also obtained new spectroscopic information about the excited states in the T_z=3/2 nuclei ^{99}Cd and ^{101}In, including the lowest $I^\pi=7/2^+$ state in ^{99}Cd. This state was missing in the only previous study of the excited states in ^{99}Cd [9]. Its wave function is dominated by the neutron $g_{7/2}$ configuration coupled to the two $g_{9/2}$ proton holes. Its experimental excitation energy of 441 keV was used to extrapolate the excitation energy of the lowest $I^\pi=7/2^+$ state in ^{101}Sn with a shell model calculation [10]. A value of 80 keV was obtained, which is in perfect agreement with the extrapolation from the odd-A tin isotopes down to ^{103}Sn [6]. We have also observed high spin states above $I^\pi=23/2^+$ which cannot be reached by coupling two proton holes in the Z=28-50 shell to a neutron in the N=50-82 shell. These states must, therefore, be due to particle-hole excitations across the N=Z=50 shell closures. This represents the first observation of the breakup of the doubly magic ^{100}Sn core.

High-spin states of the same nature were also observed in ^{101}In, where only one excited state was previously known [3]. In both ^{99}Cd and ^{101}In, the core-excited states lie at almost the same excitation energy as in their counterparts in the ^{56}Ni region, namely ^{55}Fe and ^{57}Co. This again points to the close similarity between the two doubly-magic nuclei and indicates an excitation energy of approximately 3 MeV for the first 2^+ state in ^{100}Sn.

In summary, we have for the first time identified excited states in the proton emitting nucleus ^{105}Sb. Despite the fact that ^{105}Sb is proton unbound, its level scheme can be well explained by coupling of a $d_{5/2}$ proton to the ^{104}Sn core. This suggests negligible influence of the unbound proton on the low-lying excited states in this nucleus. We have also identified core excited states in the $T_z=3/2$ nuclei ^{99}Cd and ^{101}In. This represents the first observation of excitation across the N=Z=50 doubly-closed shell. The positions of these core-excited states provide the first hint about the location of the first 2^+ state in ^{100}Sn. Large-scale shell model calculations are in excellent agreement with the experimental data.

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