Short Note

High-spin states in the $T_z = -1/2$ nucleus $^{55}$Ni

D. Rudolph\textsuperscript{1,2}, C. Baktash\textsuperscript{2}, M.J. Brinkman\textsuperscript{2}, M. Devlin\textsuperscript{3}, H.-Q. Jin\textsuperscript{4,5}, D.R. LaFosse\textsuperscript{3}, M. Leddy\textsuperscript{5}, I.Y. Lee\textsuperscript{3}, A.O. Macchiavello\textsuperscript{1}, L.L. Riedinger\textsuperscript{1}, D.G. Sarantites\textsuperscript{3}, and C.H. Yu\textsuperscript{4}

\textsuperscript{1} Sektion Physik der Universität München, D-85748 Garching, Germany
\textsuperscript{2} Oak Ridge National Laboratory, Oak Ridge, TN 37831, U.S.A.
\textsuperscript{3} Washington University, St. Louis, MO 63130, U.S.A.
\textsuperscript{4} University of Tennessee, Knoxville, TN 37996, U.S.A.
\textsuperscript{5} Schuster Laboratory, University of Manchester, Manchester M13 9PL, United Kingdom
\textsuperscript{6} Lawrence Berkeley National Laboratory, Berkeley, CA 94720, U.S.A.

2. April 1997

Abstract. High-spin states of the isospin $T_z = -1/2$ nucleus $^{55}$Ni have been identified for the first time by means of the reaction $^{28}$Si($^{36}$Ar,2$n$) at 143 MeV beam energy. The GAMMASPHERE array together with auxiliary detectors was used to detect $\gamma$ rays in coincidence with evaporated light particles. The level scheme of $^{55}$Ni comprising four transitions is compared to its mirror partner $^{55}$Co and shell-model calculations in the $fp$ shell.

Doubly magic nuclei occupy a unique place in nuclear structure: they and their nearby neighbours define the single-particle energies and the two-body matrix elements of the residual interaction which form the building blocks of (large scale) shell-model calculations. Therefore, spectroscopic data of these nuclei serve both as the source and the constraints on the parameter sets that define the effective nuclear forces. Among the unstable doubly-magic nuclei the region around $^{55}$Ni is readily accessible via heavy-ion induced reactions. However, high-spin states in the $A \approx 60$ region have eluded our shadowy existence until now: The excitation schemes comprise very few high-spin levels -- at most 5 to 10 [1]. Contrary, the $A \approx 60$ nuclei have been extensively studied with light-ion induced transfer reactions (cf. Ref. [2, 3]). With a proton scattering experiment in inverse kinematics the $B(E2; 2^+ \rightarrow 0^+)$ in $^{55}$Ni was measured recently, and the comparatively large value can be explained by the attractive interaction of 0$^+_1$ and 1$^+_2$ orbitals. However, the attraction is not sufficient to predict the high-spin behaviour of this nucleus. High-spin states in the $T_z = -1/2$ nucleus $^{55}$Ni were populated using the reaction $^{28}$Si($^{36}$Ar,2$n$) at 143 MeV beam energy. The experimental set-up used was the GAMMASPHERE array [8] including 82 Compton-suppressed Ge detectors, the 4 Ge charged-particle detector array MICROBALL [9], and 15 liquid scintillator neutron detectors replacing Ge detectors at the most forward angles. The event trigger required either two Ge detectors and one neutron detector or three Ge detectors firing. In four days of beam time some $10^5$ events were collected using a 9.91 % enriched, 0.42 mg/cm$^2$ thin $^{28}$Si layer evaporated onto a 0.9 mg/cm$^2$ Ta support foil. This foil faced the beam leading to a reduction of some 7 MeV in beam energy. $\gamma$-energy and efficiency calibrations of the Ge detectors were performed with $^{185}$Ta, $^{152}$Eu, and $^{56}$Co sources. The events were sorted off-line into various $E_\gamma$ projections, $E_\gamma - E_\gamma$ matrices, and $E_\gamma - E_\gamma$ cubes subject to appropriate evaporated particle conditions. Protons and $\alpha$ particles were identified and well separated in the MICROBALL using two independent pulse-shape discrimination techniques [9]. Neutrons and $\gamma$ rays were discriminated via pulse-shape analysis of the neutron detector signals and time-of-flight measurements.

The middle panel of Fig. 1 shows a purified singles projection gated by two evaporated $\alpha$ particles and one neutron. Contaminants from higher fold charged-particle channels (which leaked through when one or more charged particles escaped detection) were subtracted, e.g., $^{28}$Si($^{36}$Ar,2$n$) $^{55}$Co. Contaminations from small target impurities (e.g., the $< 0.6$ % $^{28}$Si) may give rise to the reaction $^{28}$Si($^{36}$Ar,2$n$) $^{55}$Ni were also eliminated. Some 200 counts are finally left in a transition at 2882(2) keV which shall represent the $(11/2^-) \rightarrow 7/2^-$ ground-state transition in $^{55}$Ni. The relative cross-section for populating $^{55}$Ni can be estimated to $\sigma_{rel} = 0.004$ % of the total fusion cross-section $(\sigma_{tot} \approx 1$ b) from the yields of ground-state transitions in all observed reaction channels. Additional $\gamma$ rays at 701(1), 735(1), and 866(1) keV can also be assigned to $^{55}$Ni. Apart from the fact that two-neutron evaporation is extremely unlikely in the $N = Z$ regime, the ratio of yields Y of the 735 and 2882 keV transitions in 2$n$- and 2$n$-gated spectra is...
consistent with the evaporation of only one neutron. It should be noted that the state at 2882(2) keV might correspond to a state at 2888(7) keV observed by Mueller et al. [2]. However, it is different from an excited state suggested by Catford et al. [10]. The top panel of Fig. 1 provides a spectrum gated by the 2882 keV transition in a 2α-gated γγ matrix. The γ rays at 701, 735, and 866 keV are found to be in coincidence with the gating 2882 keV transition. The 735 and 866 keV are likely in coincidence, too, and the 701 and 701 keV transitions are not. This leads to the high-spin excitation scheme of 55Ni illustrated in the middle of Fig. 2. Also shown is the corresponding part of the level scheme of the mirror partner 55Co. The transitions at 739, 891, and 2974 keV were previously reported [11], the others are inferred from the present data (cf. Fig. 1c) [12]. The tentative spin 11/2− of the state at 2882 keV in 55Ni is supported by the angular distribution of the 2882 keV γ ray. 2α-gated singles spectra were inspected at different Ge-detector angles. The other spin assignments rely on the A = 55 mirror symmetry. The state at 3583 keV is marked tentative because the 701 keV transition might also represent a second branch depopulating the 4483 keV state with the flux than splitting into (unobserved) γ rays of 165 and 900 keV into the levels at 3617 and 2882 keV, respectively.

Shell-model calculations were performed using the residual interaction FP6 [13]. The single-particle energy levels were taken from Ref. [14]. The full fp configuration space was truncated allowing two protons and one neutron to cross the shell gap at particle number Z, N = 28. For the determination of decay properties, effective charges εeff = 1.4 e and e′eff = 0.9 e, effective g-factors gff = 0.9 gmec, and the observed transition energies were used.

The experimental energies of the 11/2− states in the A = 55 nuclei are similar to the 2.7 MeV of the first excited 2+ state in 50Ni. Their excitation energies cannot be reproduced by shell-model calculations. Hence, the 11/2− states are interpreted as 2p3/2 holes coupled to the 2p phonon of the even-even core 54Ni (cf. Ref. [14]). The remaining levels and their decays are accounted for in our shell-model calculations as illustrated in Fig. 2: For 55Ni the 17/2− state is predicted to decay almost exclusively into the 15/2− state, in agreement with experiment. Next to the observed branch the 15/2− state shall also decay via a 34 keV transition which could not be detected with the set-up used into the 13/2− state with a branching ratio Y(34 keV)/Y(735 keV) ≈ 1/3.

To conclude, we have observed high-spin states in the Tz = −1/2 nucleus 55Ni for the first time using the GAMMA SPHERE array in conjunction with MICROBALL and neutron detectors. The level scheme provides the expected mirror symmetry to 55Co.

Acknowledgement. Oak Ridge National Laboratory (ORNL) is managed by Lockheed Martin Research Corp. for the U.S. DOE under contract DE-AC05-96OR22464. This research was supported by an appointment to the ORNL Postdoctoral Research Associates Program administered jointly by the Oak Ridge Institute for Science and Education and ORNL. This work was supported in part by the U.S. DOE under grant No. DE-FG05-88ER40400 (WU) and DE-FG02-96ER40403 (UT).

References
High-spin states in $^{58}\text{Ni}$

This article was processed by the author using the \LaTeX style file \texttt{eljourn} from Springer-Verlag.
$2\alpha n$ and 2882 keV gated

(a)

Intensity

$^{55}\text{Ni}$

(b)

$^{55}\text{Co}$

(c)

$E_{\gamma}$ (keV)

$3 \cdot 10^5$

701 735 866

2882