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Short Note

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

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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,2αn) at 143 MeV beam energy. The GAMMASPHERE array together with ancillary detectors was used to detect γ 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 ^{56}Ni is readily accessible via heavy-ion induced reactions. However, high-spin states in the $A \approx 60$ region have eked out a 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 ^{56}Ni was measured recently, and the comparatively large value can be explained by the attractive interaction of $0f_{7/2}$ holes and $1p_{3/2}$;$0f_{5/2}$ particles across the shell gap, but it was necessary to readjust the single-particle levels around ^{56}Ni [4].

The measured β-decay strength of ^{55}Ni into the ground state of the $T_z = +1/2$ mirror partner ^{55}Co suggested a superallowed decay, leading to a $I^\pi = 7/2^-$ assignment to the ground state of ^{55}Ni [5-7]. This is in agreement with earlier results from particle spectroscopy [2]. Using the reaction ^{58}Ni(^{3}He,^{6}He) Mueller *et al.* also observed some 20 low-spin excited levels in ^{55}Ni.

Our experiment was performed at the 88-Inch Cyclotron at the Lawrence Berkeley National Laboratory. High-spin states in the $T_z = -1/2$ nucleus ^{55}Ni were populated using the reaction ^{28}Si(^{36}Ar,2αn) at 143 MeV beam energy. The experimental set-up used was the GAMMASPHERE array [8] including 82 Compton-suppressed Ge detectors, the 4π 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 $2 \cdot 10^9$ events were collected using a 99.1 % 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. γ-energy and efficiency calibrations of the Ge detectors were performed with ^{182}Ta, ^{152}Eu, and ^{56}Co sources. The events were sorted off-line into various E_γ projections, E_γ-E_γ matrices, and E_γ-E_γ-E_γ cubes subject to appropriate evaporated particle conditions. Protons and α particles were identified and well separated in the MICROBALL using two independent pulse-shape discrimination techniques [9]. Neutrons and γ 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 α particles and one neutron. Contaminations 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,2αpn)^{54}Co. Contaminations from small target impurities (e.g., the < 0.6 % ^{29}Si give rise to the reaction ^{29}Si(^{36}Ar,2αn)^{56}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 $\sigma_{\rm rel} = 0.004$ % of the total fusion cross-section ($\sigma_{\rm tot} \approx 1$ b) from the yields of ground-state transitions in all observed reaction channels. Additional γ 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 $2\alpha 1n$- and $2\alpha 0n$-gated spectra is

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Figure 1. γ-ray spectra from the reaction ^{36}Ar+^{28}Si. The spectrum in the middle (bottom) is a projection gated by two evaporated α particles and one neutron (proton) with contaminations from higher charged-particle folds and small target impurities removed. The spectrum on top shows the spectrum from a $2\alpha n$-gated $\gamma\gamma$ matrix in coincidence with the 2882 keV transition.

Figure 2. Proposed partial level schemes of ^{55}Ni and ^{55}Co. The energy labels are given in keV. The widths of the arrows are proportional to the relative intensities of the γ rays. Tentative transitions and levels are dashed. The results of shell-model calculations for ^{55}Ni are illustrated on the right hand side.

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 $2\alpha n$-gated $\gamma\gamma$ 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, while the 735 and 701 keV transitions are not. This leads to the high-spin excitation scheme of ^{55}Ni illustrated in the middle of Fig. 2. Also shown is the corresponding part of the level scheme of the mirror partner ^{55}Co. The transitions at 739, 801, 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 ^{55}Ni is supported by the angular distribution of the 2882 keV γ ray. $2\alpha n$-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 FPD6 [13]. The single-particle energies 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 $e^{\pi}_{\text{eff}} = 1.4$ e and $e^{\nu}_{\text{eff}} = 0.9$ e, effective g-factors $g_{\text{eff}} = 0.9\ g_{\text{free}}$, 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 ^{56}Ni. Their excitation energies cannot be reproduced by shell-model calculations. Hence, the $11/2^-$ states are interpreted as $f_{7/2}$ holes coupled to the 2^+ phonon of the even-even core ^{56}Ni (cf. Ref. [14]). The remaining levels and their decays are accounted for in our shell-model calculations as illustrated in Fig. 2: For ^{55}Ni 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 $Y(34\text{ keV})/Y(735\text{ keV}) \approx 1/3$.

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

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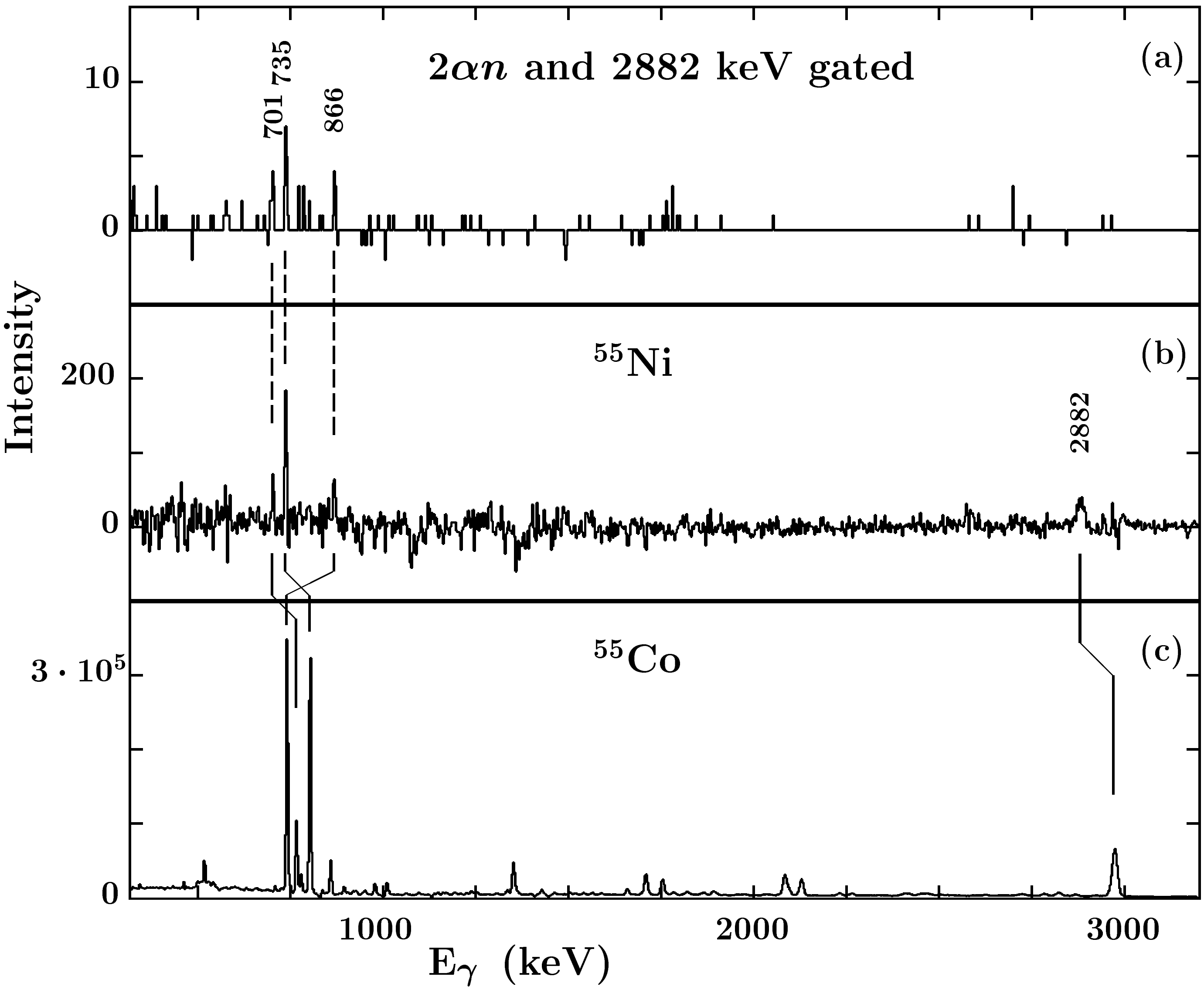
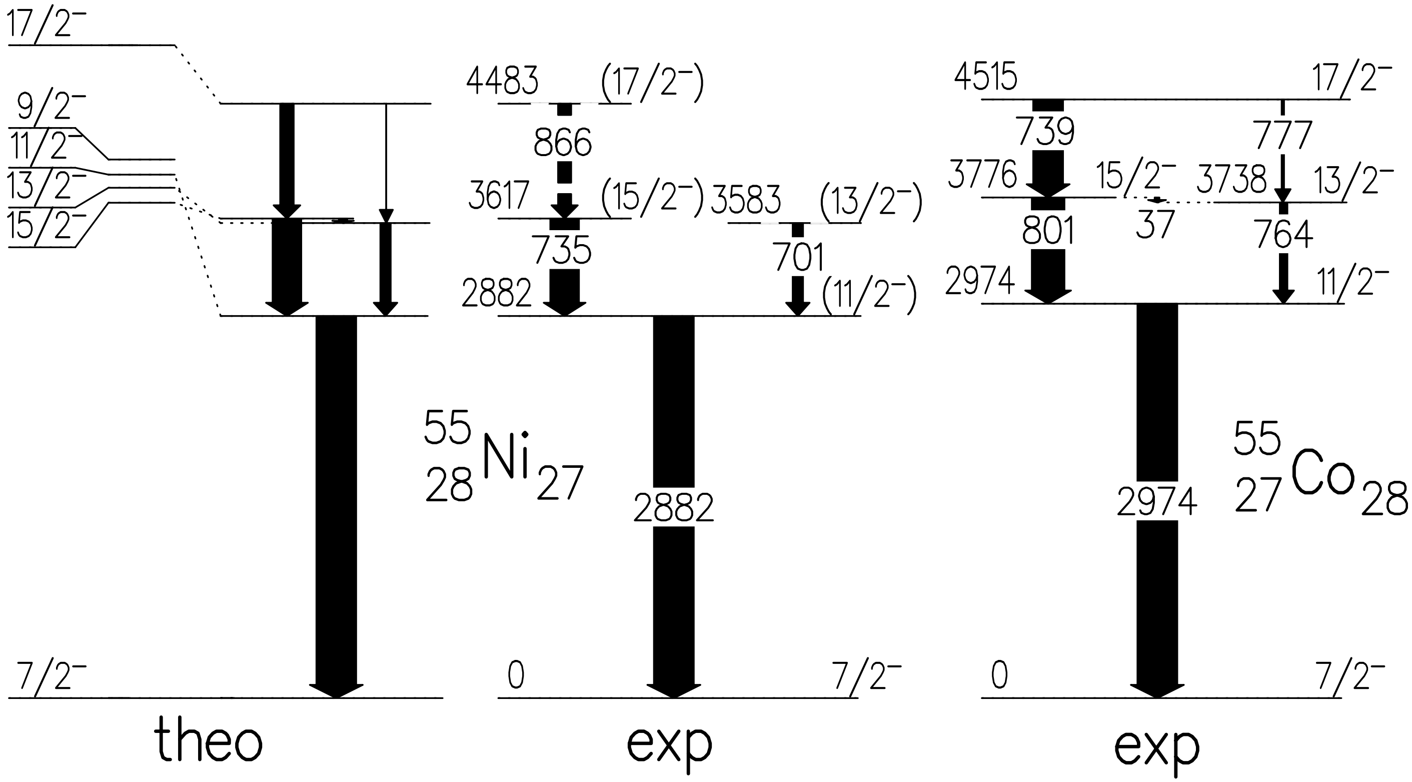


2αn and 2882 keV gated
(a)
701
735
866
10
0
Intensity
^{55}Ni
(b)
200
0
2882
^{55}Co
(c)
3 · 10^5
0
1000
2000
3000
Eγ (keV)


17/2⁻
9/2⁻
11/2⁻
13/2⁻
15/2⁻
7/2⁻
theo
4483
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3617
(15/2⁻)
3583
(13/2⁻)
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55 28 Ni 27
4515
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777
3776
15/2⁻
3738
13/2⁻
801
37
764
2974
11/2⁻
2974
0
7/2⁻
exp
55 27 Co 28