High-Spin Shell-Model States in the $A = 54$ Isobars ^{54}Co and ^{54}Fe

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High-spin states of a number of nuclei near the doubly-magic $N = Z = 28$ nucleus ^{56}Ni have been studied by means of the ^{28}Si(^{36}Ar,x$\alpha y p z n$) reaction at 136 MeV beam energy. The GAMMASPHERE array in conjunction with light charged-particle and neutron detectors were used to identify and cleanly select the fusion-evaporation products.

The A=54 isobars ^{54}Co and ^{54}Fe are the one-proton, one-neutron hole and the two-proton hole nuclei relative to the ^{56}Ni core, respectively. Therefore, they are of great importance for the determination of the two-body matrix-elements and the proton effective charge. While the ^{54}Co+2αpn reaction channel had a relatively small partial cross section of $\sigma_{rel} \approx 0.1$ %, the pure charged-particle channel ^{54}Fe+2α2p collects $\sigma_{rel} \approx 1.0$ % of the total fusion cross section. Nevertheless, application of restrictive and exclusive particle-gating, including demanding detection of one neutron in the case of ^{54}Co, led to nearly background free analysis conditions. Figure 1 shows the high-spin level schemes of ^{54}Co (left), and ^{54}Fe (right) that have been deduced from an analysis of $\gamma\gamma(\gamma)$ coincidence data.

^{54}Co was previously studied with light-ion induced reactions (cf. [1]). Based on the isospin $T = 1$ $I^\pi = 0^+$ ground state and Ref. [1] we have adopted the spin and parity assignments of the members of the $\pi(f_{7/2})^{-1} \otimes \nu(f_{7/2})^{-1}$ multiplet that lie below 3 MeV excitation energy. For the first time these levels have been connected via coincident γ-ray transitions. An exclusive ^{54}Co spectrum revealed also two intense coincident transitions at 1557 and 2975 keV which have been assigned to be the $11^+ \rightarrow 9^+ \rightarrow 7^+$ high-spin cascade due to their relatively large yields.

In a previous study of ^{54}Fe, the yrast $E2$ cascade was followed up to the isomeric 10^+ level at 6526 keV [2]. The 364(7) ns lifetime of the isomeric 10^+ state allowed measurements of its magnetic and electric moments [3–5]. In this study, we were able to establish the 3578 keV $10^+ \rightarrow 6^+$ $E4$ 2% branch next to several new high-spin levels and transitions. Further analysis of these data is expected to nearly double the number of transitions placed in the final level scheme of ^{54}Fe [6].

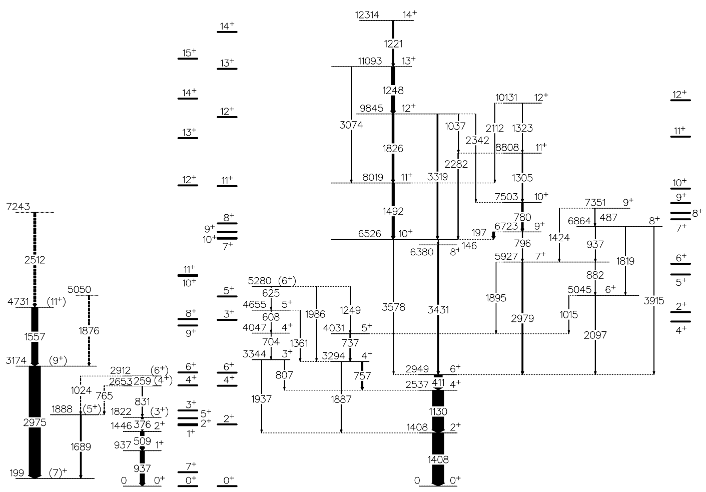

Fig. 1: Partial level schemes of ^{54}Co and ^{54}Fe.

We have also performed shell-model calculations using the residual interaction FPD6 [7]. The full fp configuration space was truncated to allow for the excitation of two particles across the shell gap at particle number Z,$N = 28$. The single-particle energies [8] were modified slightly to correctly reproduce the relative positions of the $p_{3/2}$, $f_{5/2}$, and $p_{1/2}$ orbitals in ^{57}Ni and ^{57}Cu. In a second step, the sizes of the N, Z=28 shell gaps were reduced to reproduce the observed excitation energies of distinct shell model states. To describe the decay properties, effective charges $e^\pi_{\rm eff} = 1.4$ e and $e^\nu_{\rm eff} = 0.9$ e, effective g-factors $g_{\rm eff} = 0.9\ g_{\rm free}$, and the *observed* transition energies were used.

Generally, energies of the $\pi(f_{7/2})^{-1} \otimes \nu(f_{7/2})^{-1}$ multiplet of ^{54}Co were well reproduced. An exception is the energy of the $T = 0$ $I^\pi = 1^+$ d-like hole configuration which is calculated nearly 500 keV above the experimental value. The 0^+, 2^+, 4^+, and 6^+ isobaric analogue states with ^{54}Fe can be clearly identified, both theoretically and experimentally. While the spin I = 10-12 states are reproduced reasonably well, this is not true for the observed 9^+ state at 3174 keV (predicted at 4249 keV). The origin of this discrepancy may be similar to the experimentally observed reduction of the first excited states in ^{55,56}Ni and ^{55}Co [9], i.e., the coupling of a 2^+ phonon to the fully aligned $[\pi(f_{7/2})^{-1} \otimes \nu(f_{7/2})^{-1}]_{7^+}$ "closed core". The calculated excitation scheme of the spherical shell-model states of ^{54}Fe is in good agreement with the experimental level energies. The decay pattern and the branching ratios, including the lifetime of the 10^+ isomer (τ = 365 ns), are also very well reproduced.

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