Prompt Proton Decay of a Well-Deformed Rotational Band in ^{58}Cu

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Nuclei just above the doubly-magic nucleus ^{56}Ni are excellent candidates to study the competition between collective and single-particle excitations. At low spins, the properties of the $A\approx 60$ nuclei are governed by the $1f_{5/2}$, $2p_{3/2}$, and $2p_{1/2}$ spherical shell-model orbitals. However, at higher spins and excitation energies the particle-hole excitations from the $1f_{7/2}$ orbital below the Z,N=28 shell gap to the $1g_{9/2}$ high-j orbitals above the gap give rise to deformed secondary minima in the potential and collective behavior. Another interesting facet of the proton-rich nuclei in this region is that, due to the very low Coulomb barrier, proton emission plays an important role in their decay. Indeed, proton radioactivity was first discovered in the decay of the I^π=19/2$^-$ isomeric state in ^{53}Co [1]. Here, we report the first observation of prompt decay of a well-deformed excited rotational band via emission of monoenergetic protons which takes place in the N=Z nucleus ^{58}Cu [2]

High-spin states in ^{58}Cu were populated using the reaction ^{28}Si(^{36}Ar,αpn) at 136 MeV beam energy. The GAMMASPHERE array [3], comprising of 82 Compton-suppressed Ge detectors, was used to detect prompt γ radiation. Channel selection was achieved by detecting evaporated charged particles in the 4π CsI ball MICROBALL [4] and neutrons in 15 liquid scintillator neutron detectors at the most forward angles. Protons and α particles were identified and well separated in the MICROBALL using two independent pulse-shape discrimination techniques [4]. Neutrons and γ rays were discriminated via pulse-shape analysis of the neutron detector signals and time-of-flight measurements.

The main body of the figure is a schematic representation of the decay mode of the deformed secondary minimum in ^{58}Cu: (*i*) via γ emission (4.2 MeV) back into the spherical minimum in ^{58}Cu; and (*ii*) by proton emission into one excited state at 3701 keV in the daughter nucleus ^{57}Ni. This unprecedented decay mode was identified through examination of proton center-of-mass energy spectra. An example is shown in the upper right part of the figure. This spectrum was generated with γ-ray gates on transitions between the deformed states in ^{58}Cu – it reveals a sharp peak at 2.4(1) MeV on top of the continuous energy distribution of evaporation protons. Since the proton separation energy in ^{58}Cu is known to be 2.873(3) MeV, the energy of this proton decay branch shall be 2.341(5) MeV inferred from known masses. The yield of 2.4 MeV protons in the four most-forward rings of MICROBALL were used to estimate the proton angular distribution which reveals a much larger anisotropy than that of statistically-evaporated protons, and is consistent with a proton angular momentum of l=3-5 [5]. Hence, the observed proton peak is associated with a discrete transition from the 8915 keV state in ^{58}Cu to a level tentatively assigned as 9/2 in ^{57}Ni. A number of levels are known in ^{57}Ni having similar spins and excitation energies and would be therefore potential daughter candidates if the decay were purely driven by these quantities. Since this is not the case, we interpret the 3701 keV level in ^{57}Ni as the unique parity $g_{9/2}$ single particle state which has to be elucidated by future experiments.

The spherical states in the first minimum of ^{58}Cu and their electromagnetic decay properties are well described by shell-model calculations in the fp shell. It is only at high spins that collective structures come into play. They are due to particle-hole excitations involving $1f_{7/2}$ holes and $1g_{9/2}$ particles and, therefore, can be conveniently labelled as $\nu 4^n \pi 4^p$; i.e., by the number of neutrons (protons) occupying the $1g_{9/2}$ ($\mathcal{N}$=4) intruder levels. Their theoretical description has been obtained within the Skyrme-Hartree-Fock (HF) method and the cranking approximation, but without pairing [2]. The predicted (decreasing with increasing spin) quadrupole moment Q_0=2.5–1.5 eb is in good agreement with an experimental average transitional moment of $Q_t\approx$2.0 eb ($\beta_2\approx$ 0.4) deduced from a residual Doppler shift analysis. Finally, we observe an unexpectedly high sensitivity of the theoretical results to the choice of effective interactions.

References

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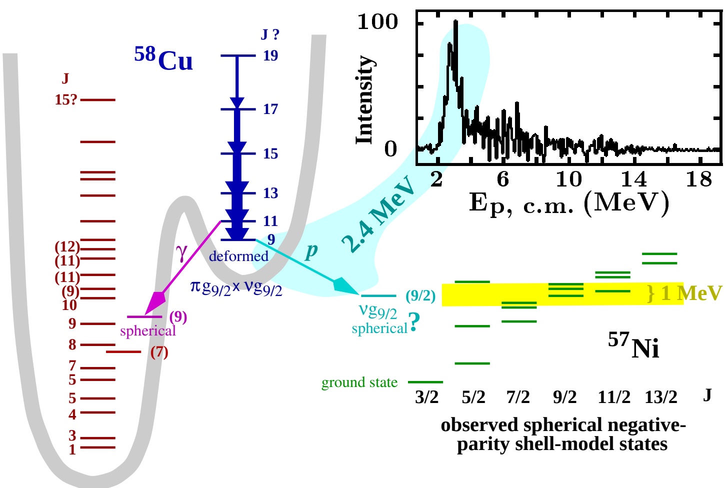

Fig. 1: Schematics of the decay out of the deformed 2nd well in ^{58}Cu.