Few-valence-particle excitations around doubly magic $^{132}\text{Sn}$


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Abstract. Prompt $\gamma$-ray cascades in neutron-rich nuclei around doubly-magic $^{132}\text{Sn}$ have been studied using a $^{248}\text{Cm}$ fission source. Yrast states located in the $N = 82$ isotones $^{134}\text{Te}$ and $^{131}\text{I}$ are interpreted as valence proton and neutron particle-hole core excitations with the help of shell model calculations employing empirical nucleon-nucleon interactions from both $^{132}\text{Sn}$ and $^{208}\text{Pb}$ regions.

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What we know about the $^{132}\text{Sn}$ nucleus and its neighbors comes mainly from $\beta^-$ decay studies of short-lived radionuclides produced in fission of actinides; consequently our knowledge about simple excitation modes, single particle energies, effective nucleon-nucleon interactions and other basic properties in this region is far from complete. The large multidetector $\gamma$-ray arrays, which can separate the prompt $\gamma$-ray cascades within a single fission product nucleus (of moderate yield) from the bulk of prompt $\gamma$-rays, have now opened new prospects for detailed studies of yrast excitations in $^{132}\text{Sn}$ and the few valence particle nuclei around it. The spectroscopy of $^{132}\text{Sn}$ and its neighbors should in many ways resemble that of the well studied nuclei around $Z = 82$, $N = 126$ $^{208}\text{Pb}$, and comparisons of experimental data from these and other magic regions would help the development of a "universal" theoretical description of shell model properties.

The measurements reported here were performed at Eurogam II using a $^{248}\text{Cm}$ source which delivered ~6.3x$10^6$ fissions/sec. Eurogam II at the time consisted of 52 escape-suppressed spectrometers incorporating 124 Ge detector elements, here augmented by four LEPS spectrometers; in total, 2x10$^{9}$ threefold or higher-fold coincidence events were recorded. The excellent quality and high selectivity of the triple coincidence $\gamma$-ray data made it possible to identify even weak transitions in the nuclei of interest extending over the $Z = 50 - 54$, $N = 80 - 84$ range. Cross coincidences observed between $\gamma$-rays from partner light and heavy fission products were often of key importance in establishing isotopic assignments for previously unknown cascades; in other cases, some overlap with the $\gamma$-rays known from $\beta$-decay provided vital first clues. The findings for only two of these nuclei - the two- and three-proton $N = 82$ isotones $^{134}\text{Te}$ and $^{131}\text{I}$ - are presented here, but results for other fission products around $^{132}\text{Sn}$ will also be forthcoming.

In the two-proton nucleus $^{134}\text{Te}$, many members of the $\pi_{g_7/2}^2$, $\pi_{g_7/2}d_5/2$ and $\pi_{g_7/2}h_11/2$ multiplets are known from $^{132}\text{Sn} \beta^-$ decay studies, especially the recent work of Omtevdt et al. [1]. The present fission product measurements identified two dominant high-energy $\gamma$-rays feeding the 1691 keV $\pi_{g_7/2}^2$ $6^+$ state in $^{134}\text{Te}$, one the 2322 keV $9^-\rightarrow 6^+$ E3 transition known from $\beta$-decay [1], the other a 2866 keV $\gamma$-ray from a $^{134}\text{Te}$ level at 4557 keV. Gating on this 2866 keV $\gamma$-ray revealed many new $^{134}\text{Te}$ $\gamma$-rays, and the full $\gamma\gamma\gamma$ results established the level sequence above 4557 keV shown to the left in the $^{134}\text{Te}$ scheme (Fig. 1). Since the only possible two-proton state with $I=9$ is $(\pi_{h_11/2})^2 10^+$, expected in $^{134}\text{Te}$ above 7 MeV, the obvious conclusion is that these new states must involve excitation of the $^{132}\text{Sn}$ core. We interpret them as $\pi_{g_7/2}^2\nu_{f_7/2}b_{11/2}^{-1}$ states, with strong support from shell model calculations described below.

Nothing was known up to now about high-spin states in the $N = 82$ nucleus $^{135}\text{I}$, but a $^{132}\text{Sn} \beta^-$ decay study has located an $11/2^+_1$ level at 1134 keV above the $^{132}\text{I} \pi_{g_7/2}^2$ ground state. In the present work, gates on 1134 keV $\gamma$-rays identified other strong $\gamma$-rays in $^{135}\text{I}$, and the full $\gamma\gamma\gamma$ results established the $^{135}\text{I}$ level scheme presented in Fig. 1. Since no information about transition multiplicities was derived from the data, the spin-parity assignments and the interpretation of the $^{135}\text{I}$ levels below 4 MeV as $\pi_{g_7/2}^3$, $\pi_{g_7/2}^2d_5/2$ and $\pi_{g_7/2}h_11/2$ states are largely based on shell model calculations for which the nucleon-nucleon interactions were taken directly from the $^{134}\text{Te}$ level spectrum. It is no surprise that the yrast excitations of $^{135}\text{I}$ are found to resemble closely those of the other three-proton nucleus $^{211}\text{At}$.

The sequence of levels above 4241 keV in $^{135}\text{I}$ must involve core excitations, and we naturally interpret them as $\pi_{g_7/2}^2\nu_{f_7/2}b_{11/2}^{-1}$ states directly related to the core-excited states in $^{134}\text{Te}$. Particle-hole states of $\nu_{f_7/2}b_{11/2}^{-1}$...
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Fig. 1. The yrast level spectra established for $^{134}\text{Te}$ and $^{135}\text{I}$. Widths of the transition arrows are proportional to the observed γ-ray intensities, except for transitions below the 164 ns isomer in $^{134}\text{Te}$. Configuration assignments in both nuclei are also shown.

character with $I^*=2^+$ to $8^+$ are known\cite{3} in $^{132}\text{Sn}$, and their energies provided some of the two-body interactions needed for calculating $\pi g_{7/2}^n \nu f_{7/2}^h 11/2^-$ states. In addition $\pi g_{7/2}^n \nu h_{11/2}^h$ and $\pi g_{7/2}^n \nu f_{7/2}^h$ interactions were also needed, and these had to be estimated from corresponding multiplets in $^{208}\text{Bi}$ and $^{210}\text{Bi}$, with scaling as $A^{-1/3}$ to take account of nuclear size variation\cite{4}. Calculations of $\pi g_{7/2}^n \nu f_{7/2}^h 11/2^-$ energies were performed using the OXBASH shell model code, and the results were found to be in excellent agreement with experiment for both $^{134}\text{Te}$ and $^{135}\text{I}$, thus providing persuasive support for the proposed interpretations.

In summary, neutron-rich fission product nuclei around doubly magic $^{132}\text{Sn}$ have now become accessible for detailed study by prompt γ-ray measurements using multidetector arrays. Yrast excitations to above 5.5 MeV excitation energy in the two- and three-proton nuclei $^{134}\text{Te}$ and $^{135}\text{I}$ have been established and interpreted with the help of precise shell model calculations using empirical nucleon-nucleon interactions. These results open possibilities for exploring simple excitation modes in the $^{132}\text{Sn}$ region under conditions that are comparable with but not identical to those in the well-studied $^{208}\text{Pb}$ region.

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References


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