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YRAST EXCITATIONS AROUND ^{132}Sn: THE TWO AND THREE VALENCE-PROTON N=82 ISOTONES ^{134}Te AND ^{135}I

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The Z=50, N=82 nucleus ^{132}Sn is the most magic of all heavy nuclei, with pronounced shell closures for both protons and neutrons manifested by the absence of excited states below 4.0 MeV excitation energy [1]. What we know about ^{132}Sn and nearby nuclei comes mainly from β^- decay studies of short-lived fission products; 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 spectroscopy of ^{132}Sn and its neighbors should in many ways resemble that of the well studied region around Z=82, N=126 ^{208}Pb, where a substantial body of empirical nuclear structure information has accrued. Several groups [2-5] have discussed the possibility of developing a "universal" theoretical description of shell model properties with some parameter variation in familiar and remote areas of the nuclidic chart, and they have stressed the desirability of detailed comparison between experimental data

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from the ^{208}Pb and ^{132}Sn regions. Progress along these lines has been hampered by a scarcity of information about simple excitation modes in the ^{132}Sn region. The development of large multidetector γ-ray arrays, which can separate the prompt γ-ray cascades within a single fission product nucleus (of moderate yield) from the bulk of prompt γ-rays, has now opened new prospects for detailed studies of yrast excitations in ^{132}Sn and the few valence particle nuclei around it.

Measurements were performed at Eurogam II using a ^{248}Cm source consisting of about 5 mg of curium oxide embedded in a pellet of potassium chloride. This source delivered $\sim 6.3\times10^4$ fissions/sec, with stopping of the fission fragments in ~ 1 ps and subsequent emission of almost all the de-excitation γ-rays from nuclei at rest [6]. Eurogam II at the time consisted of 52 escape-suppressed spectrometers incorporating 124 Ge detector elements, here augmented by four LEPS spectrometers. A total of 2×10^9 threefold or higher-fold coincidence events were recorded. A first inspection showed that these data included known γ-ray cascades in ^{132}Sn and its neighbors, as well as many strong unidentified cascades, so we embarked on a detailed investigation of yrast excitations in the Z=50-54, N=80-84 range of nuclei. Cross coincidences observed between γ-rays from partner light and heavy fission fragments were often of critical importance in establishing isotopic assignments for previously unknown cascades; in other cases, some overlap with the γ-rays known from β-decay studies provided vital first clues. Although the analysis is far from complete, substantial advances have already been made in the spectroscopy of many of the nuclei in the targeted range. Here, we feature the results for the two and three valence proton N=82 isotones ^{134}Te and ^{135}I which exhibit simple clearcut excitation modes, thus resembling ^{210}Po and ^{211}At, their well studied N=126 counterparts in the ^{208}Pb region.

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

Nothing was known up to now about high-spin states in the N=82 nucleus ^{135}I, but a ^{135}Te β^--decay study [8] has located $11/2^+$ and $9/2^+$ levels at 1134 and 1184 keV respectively above the ^{135}I $\pi g_{7/2}$ ground state. In the present work, we started a search for other ^{135}I transitions by setting a single coincidence gate on 1134 keV γ-rays. Strong 288, 572, 690, 725, 1661, 1695 and 2247 keV coincident γ-rays were identified, and by generating a series of double gated γ-ray spectra including these transitions, they were all confirmed as ^{135}I γ-rays. A compilation of many doubly gated γ-ray spectra then established the ^{135}I level scheme presented in Fig. 1.

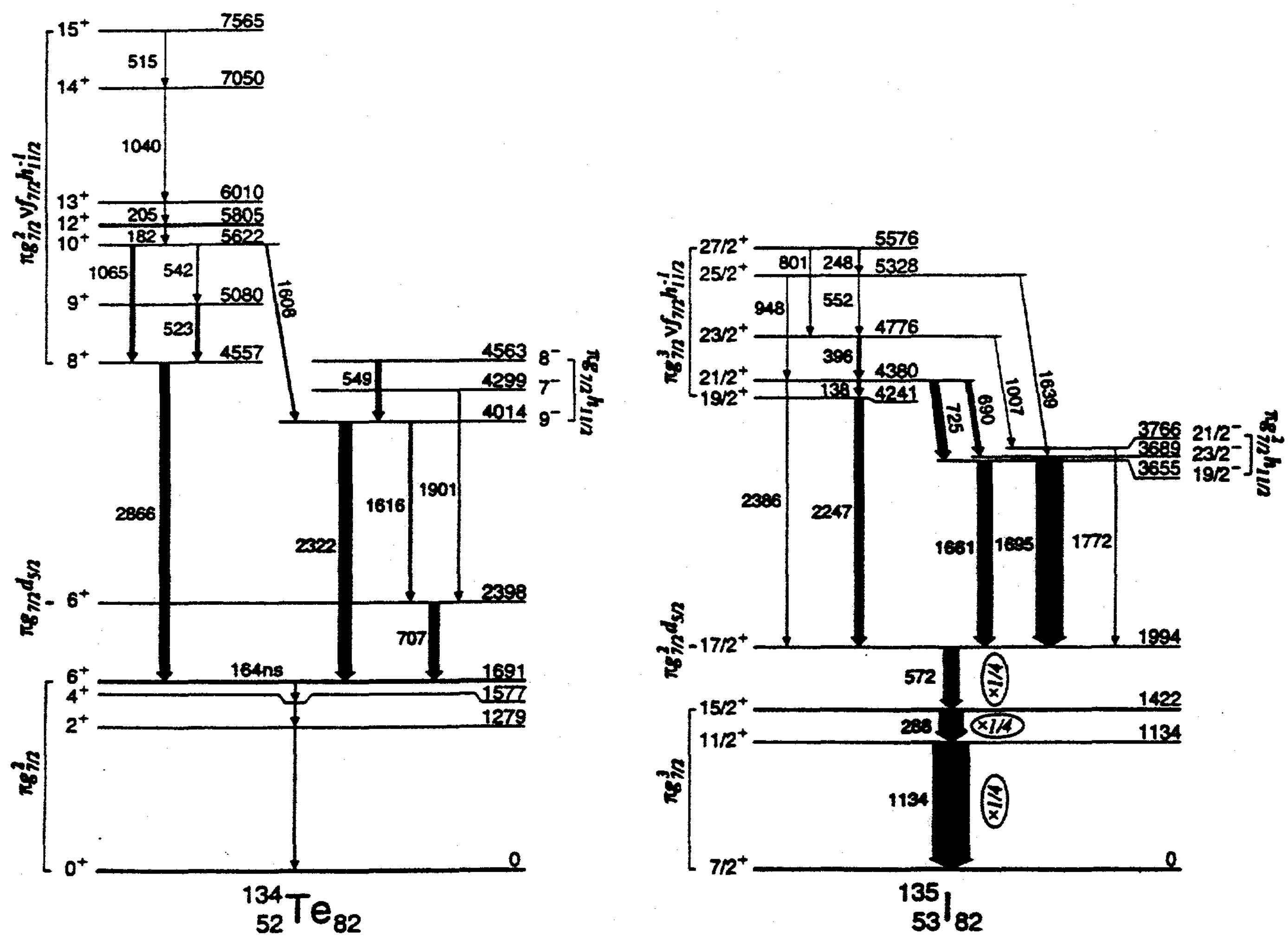

Fig. 1: Yrast level spectra established for ^{134}Te and ^{135}I, with assigned configurations.

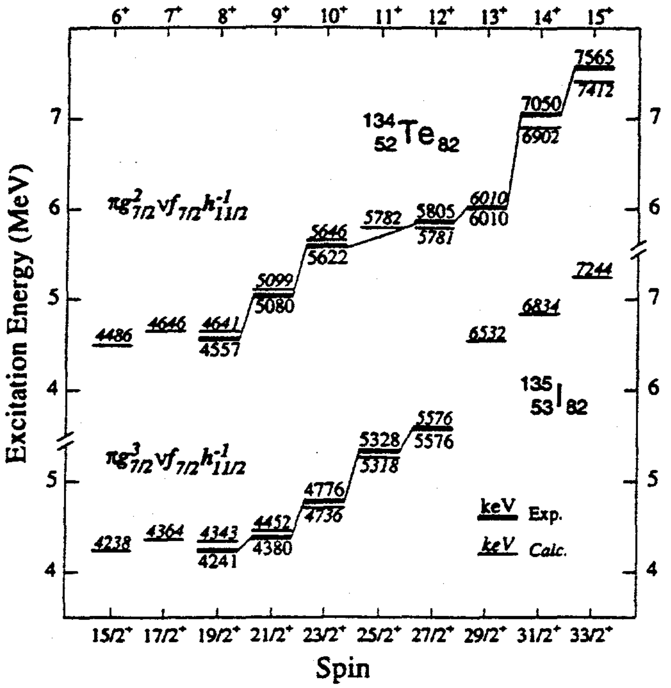

Fig. 2: A comparison of observed level energies in ^{134}Te and ^{135}I with those calculated for $\pi g_{7/2}{}^{n}\nu f_{7/2}h_{11/2}{}^{-1}$ yrast states and normalized to match the experimental 13^{+} 6010 keV level in ^{134}Te and $27/2^{+}$ 5576 keV level in ^{135}I.

The spin-parity assignments and the interpretation of the ^{135}I levels below 4 MeV as $\pi g_{7/2}{}^{3}$, $\pi g_{7/2}{}^{2}d_{5/2}$ and $\pi g_{7/2}{}^{2}h_{11/2}$ states are based in part on the results of the shell model calculations. It is no surprise that the yrast excitations of ^{135}I are found to resemble closely those of the other three-proton nucleus ^{211}At, which has low-lying states of $\pi h_{9/2}{}^{3}$, $\pi h_{9/2}{}^{2}f_{7/2}$, and $\pi h_{9/2}{}^{2}i_{13/2}$ character. The energies of three-proton states in ^{135}I were calculated with nucleon-nucleon interactions taken directly from the ^{134}Te level spectrum (the few missing matrix elements could be estimated accurately). The results agree satisfactorily with experiment, although the agreement is not quite as good as similar calculations for ^{211}At excitations based on two proton interactions from ^{210}Po. However, we have found that in both ^{135}I and ^{211}At, the remaining discrepancies between calculated energies and experiment can be removed by allowing a moderate amount of configuration mixing. Since a high-lying ($\pi h_{11/2}{}^{3}$) $27/2^{-}$ state (close to 7 MeV) is the only expected three-proton excitation with $I > 23/2$, the sequence of levels above 4241 keV in ^{135}I must involve core excitations, and we naturally interpret them as $\pi g_{7/2}{}^3 \nu f_{7/2} h_{11/2}^{-1}$ states directly related to the core-excited states in ^{134}Te above 4.5 MeV. Particle-hole states of $\nu f_{7/2} h_{11/2}^{-1}$ character having $I^\pi = 2^+$ to 8^+ are known [1] in ^{132}Sn in the 4-5 MeV energy range; their energies (together with estimates for two missing multiplet members) provided some of the two-body interactions needed for calculating $\pi g_{7/2}{}^n \nu f_{7/2} h_{11/2}^{-1}$ states. In addition, $\pi g_{7/2} \nu h_{11/2}^{-1}$ and $\pi g_{7/2} \nu f_{7/2}$ interactions were also needed, but since ^{132}Sb and ^{134}Sb excitations are still poorly known, these matrix elements had to be estimated from the $\pi h_{9/2} \nu i_{13/2}^{-1}$ and $\pi h_{9/2} \nu g_{9/2}$ multiplets in ^{208}Bi and ^{210}Bi, respectively, with scaling as $A^{-1/3}$ to take account of nuclear size variation [2]. Calculations of $\pi g_{7/2}{}^n \nu f_{7/2} h_{11/2}{}^{-1}$ energies were performed using the OXBASH shell model code, with no adjustment of input parameters to fit the data. The results are displayed in Fig. 2 with the calculated energies normalized to 6010 keV for the ^{134}Te 13^+ level, and to 5576 keV for the ^{135}I $27/2^+$ level. The excellent overall agreement with experiment in both cases provides persuasive support for the proposed interpretations. It is apparent that, while lower spin $\pi g_{7/2}{}^n \nu f_{7/2} h_{11/2}{}^{-1}$ levels are available in the two N=82 nuclei, they receive negligible population because the yrast 8^+ and $19/2^+$ states both de-excite preferentially by favorable >2 MeV transitions.

The shell model calculations described above yielded relative excitation energies only, because the appropriate ground state nuclear masses were not included in the supplied input, for reasons that will become obvious. Mezilev et al. [4] recently revised the Audi-Wapstra 1993 masses [9] for nuclei around ^{132}Sn by precision β-decay endpoint determinations; updated mass excesses for the N=82 isotones ^{132}Sn, ^{133}Sb, ^{134}Te, and ^{135}I are -76.620(29), -78.984(32), -82.399(34), and -83.787(23) MeV [4,9]. The present results enabled us to check the consistency of these N=82 mass values by shell model reduction techniques [10]. The aligned $\pi g_{7/2}{}^3$ $15/2^+$ state in ^{135}I may be decomposed into simpler configurations with fewer valence particles, which correspond to known levels in ^{134}Te (4^+, 6^+), ^{133}Sb ($7/2^+$) and ^{132}Sn (0^+). As previously shown for similar decompositions [10,11], a mass "window" W, comprising a specific combination of N=82 ground state masses, can thus be related to experimental energies by the equation:

$$W = M(^{132}\mathrm{Sn}) - 3M(^{133}\mathrm{Sb}) + 3M(^{134}\mathrm{Te}) - M(^{135}\mathrm{I}) = E(15/2^+) - 3\,(\mathrm{c.f.p.})^2\,E(4^+, 6^+).$$

Here, the excitation energy $E(15/2^+)$ in ^{135}I is 1422 keV, and $E(4^+, 6^+)$ are energies of $\pi g_{7/2}{}^2$ states in ^{134}Te, weighted by appropriate coefficients of fractional parentage (c.f.p.). The result from spectroscopy is W = -3570 keV. This differs by almost 500 keV from the value

W = -3080(150) keV obtained directly from the N=82 masses given above. [In contrast, for the analogous mass window in the N=126 isotones, the W value from decomposition of the ^{211}At $\pi h_{9/2}^3$ 21/2$^-$ state agrees within 5 keV with the one computed from Audi-Wapstra masses]. We are forced to the conclusion that one or more of the accepted N=82 masses is inaccurate by considerably more than the estimated errors. The ^{134}Te and/or ^{133}Sb masses appear the most likely suspects since they are weighted heavily in the W expression: possibly the β-decay schemes adopted for these nuclei may not be entirely correct.

In summary, neutron-rich fission product nuclei around doubly magic ^{132}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}Te and ^{135}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}Sn region under conditions that are comparable with but not identical to those in the well-studied ^{208}Pb region.

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