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REVISED SINGLE-PARTICLE ENERGIES IN $N = 83$ NUCLEI[☆]

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Half-life measurements show that the lowest high-j state in ^{141}Ce, ^{143}Nd, ^{145}Sm, and ^{147}Gd, earlier assigned as an $h_{9/2}$ fragment, is an $i_{13/2}$ single-neutron excitation which previously was thought to lie above 3 MeV in the $N = 83$ nuclei.

The single-neutron states in $N = 83$ nuclei have been extensively investigated [1], mainly by deuteron stripping on targets of the stable isotones with $N = 82$. The data suggest the systematic occurrence of three states in each nucleus populated by high-j angular momentum transfers; these levels vary smoothly with proton number and lie below 2 MeV excitation. The (d,p) angular distributions for these states were assigned as $l = 5$ transfers, and the levels therefore were interpreted as $h_{9/2}$ fragments. More recently, radioactivity [2] and (α,nγ) experiments [3] extended the systematics of these high-j states to ^{147}Gd which is not accessible in single-neutron transfer. Except for ^{139}Ba, where a recent (d,p) study [4] conflicts with the earlier investigations [1], none of these studies located the $i_{13/2}$ single-particle excitation which, from systematics, is expected to lie within the range of excitation covered by these experiments.

We have used the following compound nuclear reactions followed by particle emission to populate levels in the $N = 83$ isotones of Ce, Nd, Sm, and Gd: ^{139}La (^{7}Li,αn) ^{141}Ce and ^{139}La (^{7}Li,3n) ^{143}Nd at $E_{Li} = 30$ MeV, ^{144}Nd(α,3n) ^{145}Sm at $E_\alpha = 40$ MeV, and ^{147}Sm (α,4n) ^{147}Gd at $E_\alpha = 57$ MeV. The experiments were carried out at the Berkeley 88″ cyclotron, using standard in-beam γ-ray spectroscopy techniques [5] with various combinations of 8 cm^3 planar Ge, 30 cm^3 and 50 cm^3 coaxial Ge(Li) detectors. Measurements of γ-ray excitation functions and two-point angular distributions as well as two-detector four-parameter coincidences were used to establish the level schemes of fig. 1. In each of these nuclei essentially the entire decay intensity proceeds through the previously known lowest-lying high-j level, but our measurements show these levels to be isomeric with nanosecond half-lives. They decay via single γ-transitions to the well established [6] $f_{7/2}$ ground state of each nucleus. This fact is clearly inconsistent with a $9/2^-$ assignment for these states.

Fig. 1 includes only the strongest γ-transitions observed in the coincidence measurements. The data indicate simple level structures above the isomers. In Gd the isomeric state is fed through stretched quadrupole transitions suggesting the $17/2^+$ and $21/2^+$ levels; in Nd the feeding transition is of dipole character and proceeds from a 15/2 state. In Sm the isomer is populated through both branches with comparable intensities. Whether this systematic variation is related to

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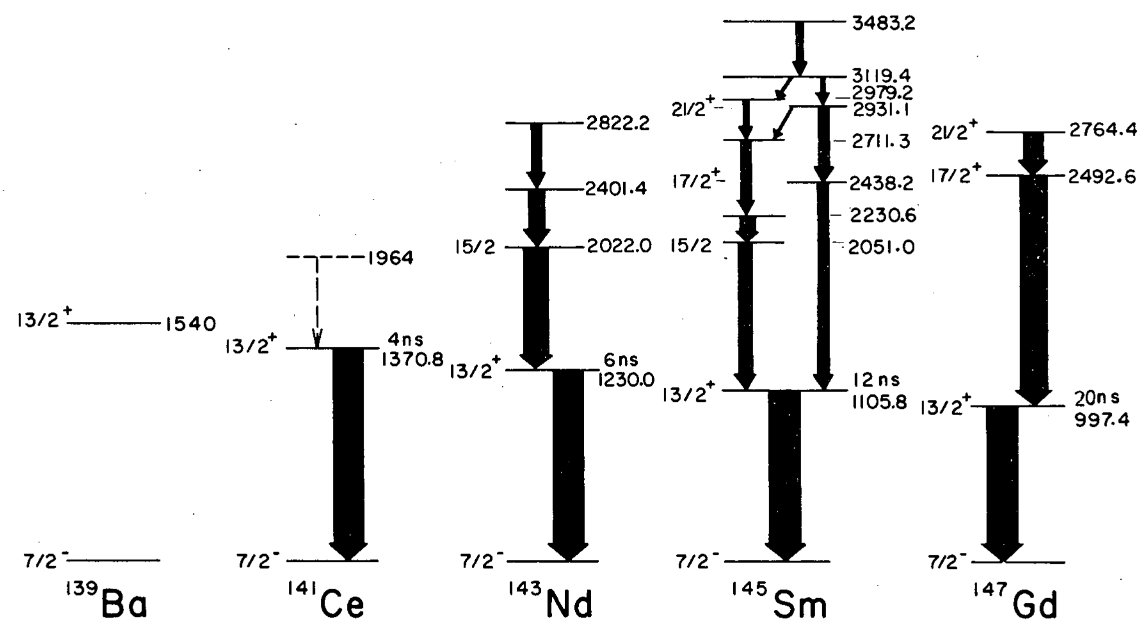

Fig. 1. Partial level schemes for $N = 83$ isotones as deduced from the present work and from ref. [4]. The excitation energies are accurate to 1 keV.

Table 1
Half-lives of $i_{13/2}$ states in $N = 83$ isotones

Nucleus	Excitation energy (keV)	$T_{1/2}$ (ns)	Enhancement $T_{1/2}^{SP}/T_{1/2}^{exp}$
^{141}Ce	1370.8	4±2	9±4
^{143}Nd	1230.0	6±2	12±4
^{145}Sm	1105.8	12±2	12±2
^{147}Gd	997.4	20±3	15±3

the different reactions used or is a genuine difference in nuclear structure is presently being investigated in more detail. The Ce isotope was produced only with very low yield in the ^{7}Li induced reaction, and therefore no detailed information on the higher-lying levels is included.

The half-lives were extracted from the $\gamma\gamma$-time spectra. They are listed in the table.‡ Comparison with the single-particle estimate [7] classified the deexcitation transitions as E3, whereas M1 transitions, as required by the previous assignments, would have to be 10^6 times retarded in all cases. The lifetimes, together with the observed strong transfer intensities, argue for the identification in all these nuclei of the first high-j state as $i_{13/2}$ single-neutron state. We have also included in fig. 1 the $i_{13/2}$ state in ^{139}Ba. The angular momentum transfer to this level has been measured as $l = 6$ in a (d,p) experiment with 20 MeV deuterons [4], a result which has been ignored‡‡ in more recent work [2, 8].

The measured half-lives indicate enhancements by factors of 8 to 15 compared to the E3 single-particle estimate. This might reflect a small admixture of the octupole excitation built on the $f_{7/2}$ ground state in the predominately $i_{13/2}$ level. An E3 strength of 50 to 100 single-particle units has been determined [9] for excitation of the lowest 3^- level in nearby doubly-even isotopes. Also, the monotonic increase with Z of

‡ The data also revealed a previously unreported half-life of 28±2 ns for the 2101 keV 4^+ level in ^{142}Nd which was populated by the (^{7}Li, 4n) reaction.

‡‡ In contrast to the authors of ref. [4] and $11/2^+$ assignment has been adopted for this level in a recent compilation [8].

the transition enhancement is in qualitative accord with the energy of the 3^- state, which drops regularly from 2464 keV in $^{140}_{82}$Ce to 1584 keV in $^{146}_{82}$Gd.

The proposed $i_{13/2}$ assignments in the $N = 83$ nuclei remove a number of discrepancies connected with the earlier $9/2^-$ assignments. The stripping data into the $N = 83$ isotones of Ba, Ce, Nd, and Sm quoted in ref. [1] consistently gave spectroscopic strengths for $l = 5$ transfer in excess of the sum-rule limit for $h_{9/2}$, in Nd and Sm by as much as 70%. With the $i_{13/2}$ assignment for the lowest state, the remaining observed $l = 5$ strengths become compatible with the sum-rule limit, and the reported cross sections to the high-j state of lowest energy are consistent with a predominant $i_{13/2}$ configuration. Moreover, in the β^+ decay of the $h_{11/2}$ isomer of ^{147}Tb (2), two high-lying states in ^{147}Gd were found to be populated with log ft values ≤ 4.4 and assigned $9/2^-$. The third high-j level (the one presently being considered), which from (α,n) data was also assigned as $9/2^-$, is only populated with very small intensity in the β^+ decay and this feature is explained by our $13/2^+$ assignment of this level.

In conclusion our study, together with other results, confirms the well established systematics for the lowest-lying high-j state in the $N = 83$ nuclei from Ba to Gd. However, in contrast to the previous $h_{9/2}$ assignment, we identify this state with an $i_{13/2}$ excitation which in the earlier work was argued to lie above 3 MeV in these nuclei. This result significantly alters the energies of the $i_{13/2}$ and $h_{9/2}$ single-neutron states in the $N = 83$ nuclei, a fact which should be of importance in shell-model calculations that use experimental single-particle energies in this region to determine parameter values. After the preparation of this manuscript, it came to our attention that Booth et al. [10] have reached this same conclusion based on $l = 6$ assignments in (d,p) reactions leading to these states.

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