Multipolarity of the 228.5-keV transition in ^{80}Y

A. Piechaczek,[1] E. F. Zganjar,[1] J. C. Batchelder,[2] C. R. Bingham,[3,4] T. N. Ginter,[5] C. J. Gross,[4,6] R. Grzywacz,[3] B. D. Macdonald,[7] S. D. Paul,[4,2] K. Rykaczewski,[4,8] and K. S. Toth[4]
[1]*Department of Physics and Astronomy, Louisiana State University, Baton Rouge, Louisiana 70803-4001*
[2]*UNIRIB, Oak Ridge Associated Universities, Oak Ridge, Tennessee 37831*
[3]*Department of Physics and Astronomy, University of Tennessee, Tennessee 37996-1200*
[4]*Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6371*
[5]*Department of Physics and Astronomy, Vanderbilt University, Nashville, Tennessee 37235*
[6]*Oak Ridge Institute for Science and Education, Oak Ridge, Tennessee 37831-0117*
[7]*School of Physics, Georgia Institute of Technology, Atlanta, Georgia 30332-0430*
[8]*Warsaw University, PL-00681 Warsaw, Poland*
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We have unambiguously characterized the deexcitation of the 228.5-keV $T_{1/2}=4.7-s$ isomer in ^{80}Y as an $M3$ transition. This result determines, in conjunction with other experimental data, the spin and parity of the 228.5-keV isomer and the ^{80}Y ground state as 1^- and 4^-, respectively.

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In this paper we report the measurement of the internal conversion coefficient of the 228.5(1)-keV isomeric transition $[T_{1/2}=4.7(3)s]$ [1] in the $T_z=-1$ nucleus ^{80}Y [2]. This measurement unambiguously characterizes the decay of the isomeric level, $J^\pi=(1^-)$, to the $T_{1/2}=30.1(5)-s$ ^{80}Y ground state, $J^\pi=(4^-)$, as an $M3$ transition. Studies of the β decay of this highly deformed nuclide revealed feeding of only even-parity states in ^{80}Sr at excitation energies below 2.4 MeV. Recently, Döring *et al.* [3] tentatively reported the population of odd-parity states in ^{80}Sr at higher excitation energies. The present study was motivated by the apparent conflict of the observed feeding of even-parity levels with the anticipated decay to odd-parity levels if the J^π assignments of (1^-) and (4^-) for the isomeric 228.5-keV level and the ^{80}Y ground state were correct. The measurement of the internal conversion coefficient establishes unambiguously that the ground state and the 228.5-keV isomer of ^{80}Y have identical parity and most likely a spin difference of three ħ. In conjunction with data from ^{80}Zr β decay [4], this result supports the J^π assignments of 1^- and 4^-, and confirms our understanding of the low-energy structure of ^{80}Y.

The experiment was carried out at the Holifield Radioactive Ion Beam Facility at Oak Ridge National Laboratory. A 10-pnA, 200-MeV ^{58}Ni beam, delivered by the tandem Van De Graaf accelerator, bombarded a self-supporting 0.5-mg/cm^2 isotopically enriched ^{24}Mg metallic foil. The recoil mass spectrometer (RMS) [5–7] was operated in a charge-state diverging mode and transmitted mass $A=80$ nuclei in the $Q=24^+$ charge state with energies around 130 MeV to the center of the final RMS focal plane, where they were implanted into the transport tape of the moving tape collector (MTC) [8]. The MTC was operated with a cycle time of 10 s, thus suppressing radiation from the isobaric contaminants ^{80}Y (g.s.) ($T_{1/2}=30.1$ s) [3], ^{80}Sr ($T_{1/2}=106.3$ m) [2], and ^{80}Rb ($T_{1/2}=34$ s) [2]. It carried the $A=80$ activity over a distance of 0.5 m to a detection station, consisting of three high-resolution, liquid-nitrogen cooled, 5-mm-thick Si(Li) detectors for conversion electron spectroscopy [8] and two segmented germanium clover detectors for γ-ray detection. All detectors were mounted in a close geometry around the source spot on the tape, resulting in a conversion electron detection efficiency of 15% and a γ-detection efficiency of 3% at 1332.5 keV. Singles as well as coincidence data between all detectors were recorded during the total measuring time of 6 h. In the data evaluation, simultaneous events in the segments of the same clover detector were interpreted as due to Compton-scattering and their energies were added back, whereas simultaneous events in the two clover detectors were treated as true coincidences.

In order to determine the conversion coefficient for the deexcitation of the 228.5-keV isomer, the number of counts in the conversion electron line at 198 keV in the summed singles spectrum of the three Si(Li) diodes was found, see Fig. 1. This line corresponds to the internal K-shell conversion of the 228.5-keV isomeric transition. The shift of the electron line from the expected position at 228.5 keV $-E_{\mathrm{BK}}(^{80}\mathrm{Y})=211.5$ keV and its broadening from the detector resolution of 1.8 keV, obtained with a thin electron source, to the observed full width at half maximum of 13 keV are due to the energy loss of the conversion electrons when they emerge from the transport tape, since the recoiling ^{80}Y nuclei are deeply imbedded into the tape. The 228.5-keV γ line was only observed in the γ-singles spectrum, see Fig. 2, confirming its isomeric character. The peak-to-total ratio (P/T) of the conversion electron spectrometer was determined with conversion electrons from the 569.7-keV $E2$ γ transition in ^{207}Bi, assuming that P/T is energy independent. The ratio of γ-detection efficiencies at 228.5 and 569.7 keV was determined with a ^{152}Eu calibration source. The calculation of the K-shell conversion coefficient of the isomeric transition in ^{80}Y is then straightforward and the result is $\alpha_K(228.5\,\mathrm{keV})=0.47\pm0.15$. The experimental error of ±0.15 is mainly due to the systematic uncertainty in the determination of the number of events in the conversion electron line and represents an upper limit for the error. The only theoretical K-shell conversion coefficient which agrees with the observed value is that for an $M3$ transition, $\alpha_K(M3,$

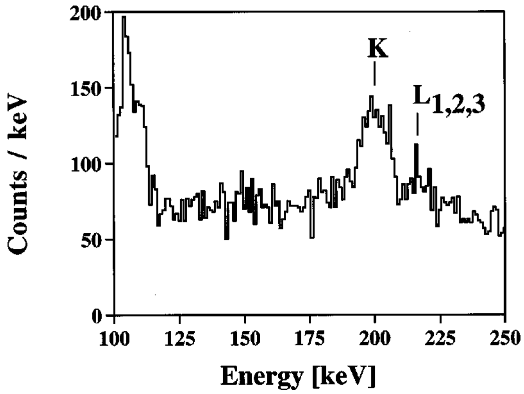

FIG. 1. Conversion electron singles spectrum of the 228.5-keV isomeric decay in ^{80}Y, showing the K and $L_{1,2,3}$ conversion lines (10-s cycle time). The asymmetric line shape and full width at half maximum of 13 keV are due to energy loss of the conversion electrons in the transport tape. The structure between 100 and 115 keV results from noise pickup in the conversion electron spectrometer.

228.5 keV)$=0.496$ [9], see Table I. We conclude that the deexcitation of the 228.5-keV isomer in ^{80}Y proceeds via an $M3$ transition.

In the region close to the $N=Z$ line around mass $A=80$ a strong doubly magic shell gap develops for prolate quadrupole deformations of $\beta_2\approx 0.4$. The level structure above the gap at neutron and proton numbers $N=Z\approx 40$ is determined by the interaction of the single particle $[422]\frac{5}{2}^+$, $[303]\frac{3}{2}^-$, and $[431]\frac{1}{2}^+$ Nilsson orbitals, see, e.g., Ref. [10]. The single-particle character of the states formed by the occupation of these orbitals may lead to isomeric states, characterized by low collectivity and low transition rates. Indeed, two isomers are known in the $Z=39$ nucleus ^{80}Y, an isomer decaying by a 84-keV transition with a half-life of 4.2 μs [11,12], and the 228.5-keV, $T_{1/2}=4.7-$s isomer, see Fig. 3 for a partial level and decay scheme of ^{80}Y. Döring *et al.* suggested [1] that the 228.5-keV transition corresponds to the recoupling of a $[301]\frac{3}{2}^-$ neutron and a $[422]\frac{5}{2}^+$ proton from a 1^- antialigned configuration to the energetically lower-lying 4^- aligned state, which corresponds to the ^{80}Y ground state. The multipolarity of such a transition is $M3$.

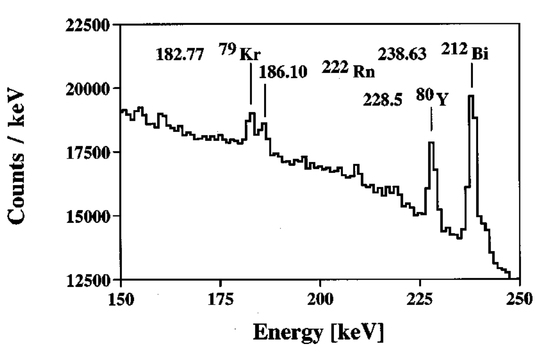

FIG. 2. Gamma-ray singles spectrum showing the 228.5-keV isomeric transition in ^{80}Y and the 182.77-keV γ ray in the charge state contaminant ^{79}Kr, as well as lines from background activity. The spectrum was obtained with a cycle time of 10 s.

TABLE I. Theoretical K-shell conversion coefficients α_K for a 228.5-keV transition and various electric (E) and magnetic (M) multipole orders. The values are interpolated from Ref. [9]. The experimental value is $\alpha_K=0.47\pm 0.15$.

α_K	1	2	3	4
E	0.009	0.050	0.231	1.027
M	0.019	0.100	0.496	2.439

Our measurement of the internal conversion coefficient proves that the two levels involved have the same parity and most probably a spin difference of three units, much less likely a spin difference of two units. However, it does not determine if the parities are positive or negative. Döring *et al.* [1] inferred the negative parity assignments for the ^{80}Y g.s. and the 228.5-keV level from their β-decay properties and their population in in-beam experiments. Combining information from a recent investigation of ^{80}Zr β decay [4] and from this work, we support their conclusion by an independent argument. Ressler *et al.* [4] observed a 311-keV β-delayed γ ray from the decay of the 0^+ nucleus ^{80}Zr in coincidence with the 84-keV isomeric transition. This γ ray must originate from a 1^+ state in ^{80}Y located at 623 keV. The 1^+ level is expected to decay to the lowest positive parity state in ^{80}Y, since the ($M1$,$E2$) transition strengths in a deformed nucleus and at a low transition energy will be much larger than the ($M2$,$E1$) transition strengths. Thus the parity of the isomeric 312-keV level ($T_{1/2}=4.2$ μs) is most likely positive. Döring *et al.* [1] characterized the 84-keV transition between the isomer at 312 keV and the 228.5-keV level as a strongly retarded $E1$ transition based on the observed half-life, energy, and known systematics in the $A=45-90$ region. This, in turn leads to a most probable negative parity assignment for the 228.5-keV state. Our measurement of the conversion coefficient of the 228.5-keV isomer shows that the ^{80}Y ground state also has a negative parity

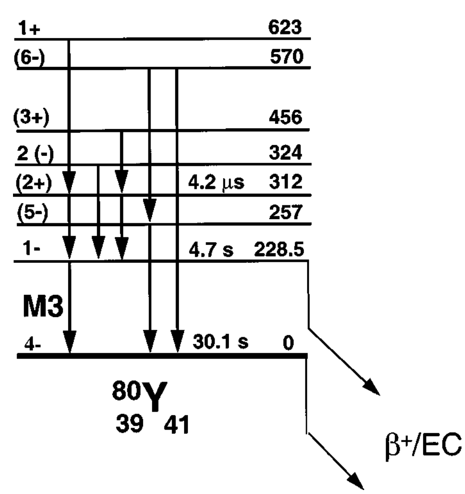

FIG. 3. Partial level and decay scheme of ^{80}Y. Known half-lives, level energies, as well as (tentative) J^π assignments are indicated. The $M3$ character of the 228.5-keV isomeric transition was established in this work. The other data were taken from Refs. [1,2,4].

and confirms the expectations based on deformed shell model calculations.

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