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ABSTRACT

Sources of Ba^{131m} were produced by bombarding sodium iodide with Li^{7} ions of about 38-MeV energy, and its half-life was redetermined as 14.6 ± 0.2 minutes. Its decay was studied by means of scintillation techniques. The decay of Ba^{131m} proceeds by a 78 ± 5- keV E3 transition (α_K = 11.5 ± 1.5), followed by a 107 ± 3- keV M1 (or M1 + E2) transition (α_K = 0.77 ± 0.15). Included is a discussion of possible spin and parity assignments for the levels involved in this decay.

An auxiliary experiment showed that less than 1% of La^{131} decays lead to Ba^{131m}.

CHARACTERISTICS OF THE DECAY OF Ba^{131m}*

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I. INTRODUCTION

Recently, Tilbury and Yaffe discovered a 14-m isomer in Ba^{131} which decayed by emitting K X-rays and a 106-keV photon.[1] On the basis of this half life and energy, one would expect the isomeric transition to have multipolarity E3 or M3. The ground-state spin and parity of Ba^{131} have been variously assigned 1/2+ and 3/2+.[2,3] The 1/2+ assignment would require the spin and parity of the isomeric level to be 7/2- for an E3 transition and 7/2+ for an M3 transition, whereas the 3/2+ assignment would require 9/2- or 9/2+ for an E3 or M3 transition, respectively. To date, no isomeric states of these types have been found in other odd-A nuclei in this region. Therefore, it was considered desirable to investigate further the decay of Ba^{131m} with the hope of determining the spin and parity of the isomeric level.

II. SOURCE PREPARATION AND APPARATUS

Sources of Ba^{131m} were produced by bombarding sodium iodide for approximately 15 minutes with about 38-MeV Li^{7} ions in the Berkeley Hilac (heavy-ion linear accelerator).

The sodium iodide was dissolved in water to which was added 10 mg Ba and 1 mg Cs carriers. Concentrated HNO_3 was added and the solution boiled to fume off I_2. The barium was separated as $Ba(NO_3)_2$ by the addition of fuming HNO_3 to an ice-cold solution. Further purification consisted of two precipitations of $BaCl_2$ by gaseous HCl bubbled into the ice-cold solution. The barium samples were mounted on thin glass slides or filter paper.

In an auxilary experiment to produce La^{131}, metallic antimony was irradiated with about 120-MeV C^{12} ions for four hours. The target was dissolved in hot aqua regia, barium, cesium and lanthanum carriers were added, and the lanthanum was extracted by a series of fluoride and hydroxide precipitations.[4] Barium was chemically separated from lanthanum by $BaCl_2$ precipitations at 15 minute intervals.

The scintillators consisted of a 1-in. diameter x 3-mm thick NaI(Tl) crystal with a 0.005-in. beryllium window, a 3-in. diameter x 3-in. thick crystal, and a 1 3/4-in. diameter x 2-in. thick crystal with a 3/4-in. diameter by 1 1/2-in. deep well covered with 0.001-in. aluminum.[5] The inside of the well crystal was uncovered, thus increasing the probability of detecting iodine K X-rays which escape from the bottom of the well. A conventional fast-slow coincidence circuit ($2\tau \approx 10^{-7}$ sec) was used in conjunction with three 400-channel pulse-height analyzers.

III. EXPERIMENTAL RESULTS

The singles photon spectrum was measured in each of the crystals mentioned in the foregoing section, and a typical spectrum taken with the 3-mm thick crystal is shown in Fig. 1 (curve A). The entire photon spectrum could be attributed to Ba^{131m} and the ground state of Ba^{131} (weak, and not shown in Fig. 1). The half-life of Ba^{131m} was determined by following the decay of the 107-keV photon for eight hours. The 107-keV photon intensity decayed with a half-life of 14.6 ± 0.2 minutes over a period of eight half-lives. The long-lived background accounted for only 10^{-5} of the initial count rate.

For the energy determinations, the presence of the photon radiation from the ground state of Ba^{131} provided a convenient internal calibration. The ratio of the escape peak to photopeak of the 107 ± 3-keV photon in the spectra, taken with the thin and 3-in. x 3-in. crystals, was slightly too high,[6] indicating the presence of a photon with an energy of about 78 keV. This photon was appreciably enhanced by collimating the source into the well crystal. The relative intensities of the K X-ray, 78-keV photon and 107-keV photon were determined by correcting the relative photopeak areas for absorption, relative detection efficiencies, and escape peaks, when necessary. The results so obtained are tabulated in Table I.

Coincidence measurements were performed by gating on the 107-keV photon detected in the 3-in. x 3-in. crystal, and displaying on two 400-channel analyzers the coincidence spectrum detected in the 1-in. x 3-mm crystal. The energy region encompassing the L and K X-rays was displayed on one analyzer, while the other was set to cover the range from about 10 keV to 200 keV. Measurements with the detectors set at both 90° and 180° with respect to each other gave identical results.

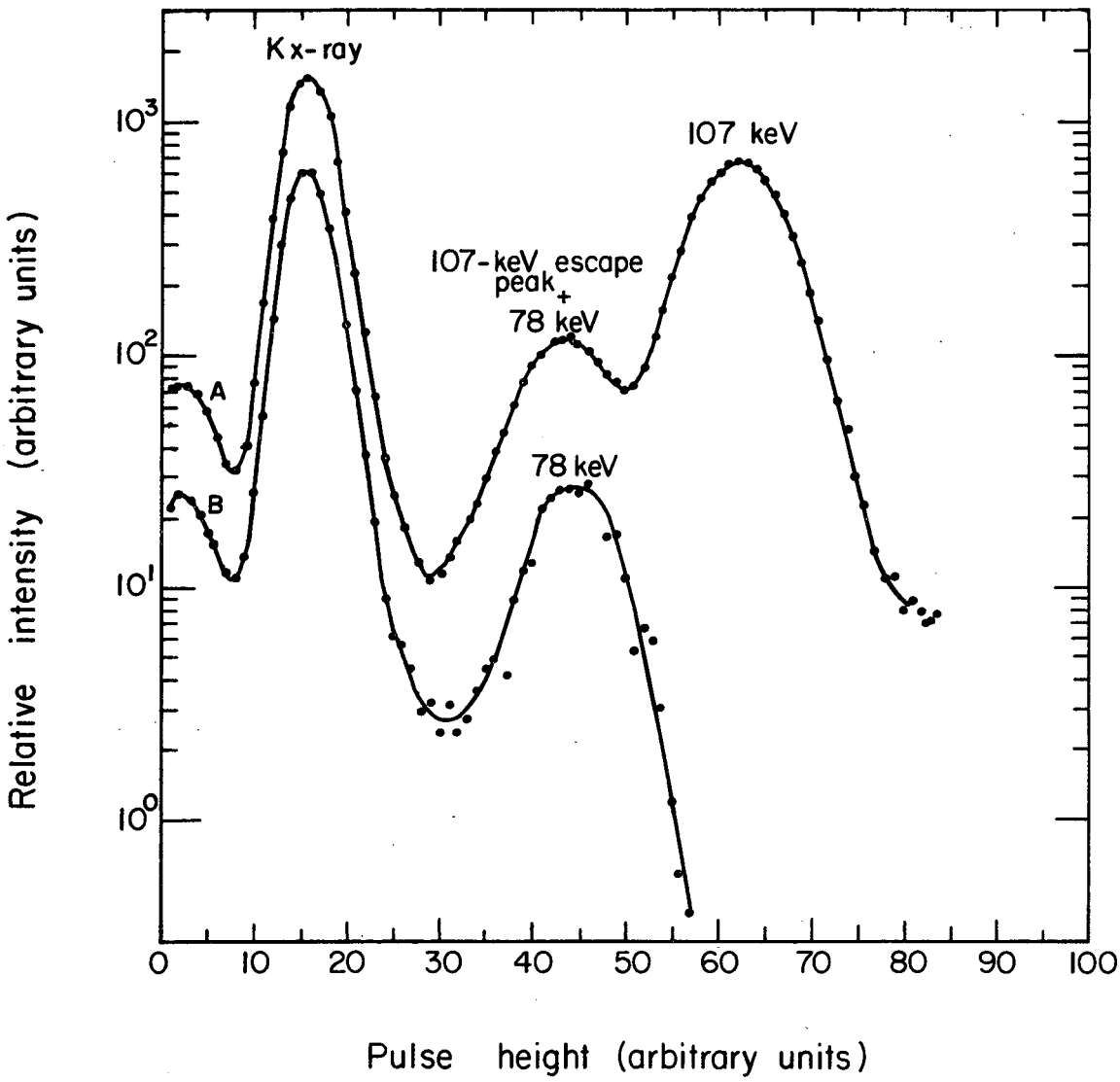

Fig. 1. Photon spectra in the decay of Ba^{131m} taken with a 1-in diameter x 3-mm thick NaI (Tl) crystal: singles spectrum, spectrum in coincidence with the 107-keV photon.

Table I.

Ba^{131m} photon data from the singles spectrum.

Energy (keV)	Intensity (relative)[a]
K X-ray	83 ± 16
78 ± 5	3.3 ± 1.5
107 ± 3	100

[a] Arbitrarily normalized to 100 for the 107-keV photon.

A typical coincidence spectrum is shown in Fig. 1 (curve B). There it is seen that the 107-keV photon is in coincidence with K X-rays and the 78-keV photon. Coincidences were also observed with the L X-rays (not shown). The relative intensities are given in Table II.

From the relative X-ray intensities (L/K) one can calculate the ratio of the K and L conversion coefficients for the 78-keV transition, i.e.,

$$\frac{\alpha_K^{78}}{\alpha_L^{78}} \leqslant \frac{1}{\frac{\omega_K}{\omega_L}\frac{L}{K} - \eta_{KL}} .$$

ω_K and ω_L are the K and L fluorescence yields,[7] respectively, and η_{KL} is the number of L-shell vacancies produced in the filling of a K-shell vacancy.[8] We were only able to set an upper limit for this ratio, $\frac{\alpha_K^{78}}{\alpha_L^{78}} \leqslant 1.2$, because of uncertainty in the correction for absroption of the L X-ray.

From the coincidence data, the K-conversion coefficient of the 78-keV transition was calculated using the relation

$$\alpha_K^{78} = \frac{K}{\gamma_{78}} \frac{1}{\omega_K} ,$$

and found to be: $\alpha_K^{78} = 11.5 \pm 1.5$. The total conversion coefficient for this transition can be obtained from the relation

$$\alpha^{78} = \frac{\gamma_{107}\,\epsilon_{78}}{\gamma_{107\text{-}78}} - 1 ,$$

where γ_{107} is the number of gate counts $\gamma_{107\text{-}78}$ the number of 107-78 keV photon coincidences, and ϵ_{78} is the detection efficiency for a 78-keV photon in the 3-mm crystal. After substituting the appropriate values, we obtained

$$\alpha^{78} = 96 \pm 19 .$$

That the 78-keV transition has multipolarity E3, is shown in Table III where the experimental results are compared to the theoretical values as calculated by Rose.[9]

Knowledge of the K and total conversion coefficients of the 78-keV transition allowed the determination of the K-conversion coefficient of the 107-keV transition from the relative intensities of the K X-ray and photons. Two methods were utilized for this determination. For the first, a Cs^{137} source was measured in the 3-in. x 3-in. crystal under the same conditions as the Ba^{131m}. Here one can show

$$\alpha_K^{107} + \alpha_K^{78} \frac{1 + \alpha^{107}}{1 + \alpha^{78}} = \frac{K^{Ba}}{\gamma_{107}} \frac{\gamma_{662}}{K^{Cs}} \frac{\omega_K^{Cs}}{\omega_K^{Ba}} \frac{\epsilon_{107}}{\epsilon_{662}} \alpha_K^{662} ,$$

where the various quantities have been previously defined. For the ratio, $\frac{1 + \alpha^{107}}{1 + \alpha^{78}}$, one can substitute γ_{78}/γ_{107}. Using the known[10] conversion coefficient for Cs^{137} ($\alpha_K = 0.095$), and inserting the appropriate values for the other quantities, one obtains $\alpha_K^{107} = 0.77 \pm 0.15$, which lies between the theoretical[9] K-conversion coefficients for an M1 transition [$\alpha_K(M1) = 0.7$] and an E2 transition [$\alpha_K(E2) = 1.0$]. Thus, the 107-keV transiton has multipolarity M1, with a possible E2 admixture. The experimental value was checked utilizing the singles data obtained with the 3-mm crystal, and good agreement was found.

From the experiments in which barium was chemically separated from lanthanum, we were able to show that less than 1% of the La^{131} decays lead to the isomeric state in Ba^{131}. This upper limit was obtained from consideration of the decay of the separated barium photon spectra, which showed no indication for the presence of Ba^{131m}, but did show Ba^{131}.

IV. DISCUSSION

The agreement between the experimentally determined and theoretical conversion coefficients of the 78- and 107-keV transitions indicates that they are of multipole orders E3 and M1 (or M1 + E2), respectively. Unfortunately, the ground-state spin of Ba^{131} has not yet been measured. However, studies of the decay of Ba^{131} indicate that it is 1/2+ or 3/2+[2]. Creager et al., from an investigation of the decay of La^{131}, suggest that 3/2+ is to be preferred.[3] Earlier, on the basis of the then known experimental data, Hill pointed out that there was a tendency for the $d_{3/2}$ and $s_{1/2}$ single-particle levels to cross in this mass region.[11] This has found theoretical support in the work of Glendenning.[12] Consideration of the experimental data on the ground-state spins and parities of the other odd-A barium isotopes, suggests that that of Ba^{131} should be 1/2+.

In view of the uncertainty in the spin assignment for the ground state of Ba^{131}, we offer the following three possible interpretations of our data (summarized in Fig. 2). The decay of Ba^{131m} proceeds as 1) 11/2- $\xrightarrow{E3}$ 5/2+ $\xrightarrow{M1}$ 3/2+, 2) 9/2- $\xrightarrow{E3}$ 3/2+ $\xrightarrow{M1}$ 1/2+, or 3) 11/2- $\xrightarrow{E3}$ 5/2+ $\longrightarrow$ 3/2+ $\xrightarrow{M1}$ 1/2+. We will discuss the merits of each of these in the light of other data.

Choice (1) would be reasonably consistent with the work of Creager et al.[3] They observed direct decay between the ground states of La^{131} and Ba^{131}, with an allowed logft value and did not observe decay to an isomeric level in Ba^{131}. (As noted in section III, we also concluded that La^{131} does not decay to Ba^{131m}.) On the basis of these data, and in analogy with a similar case in the decay of La^{135}, they tentatively assigned the ground state of La^{131} as 5/2+ and that of Ba^{131} as 3/2+. They also observed a transition of 115 ± 2 keV between a level of this energy and the ground state in Ba^{131}. Although

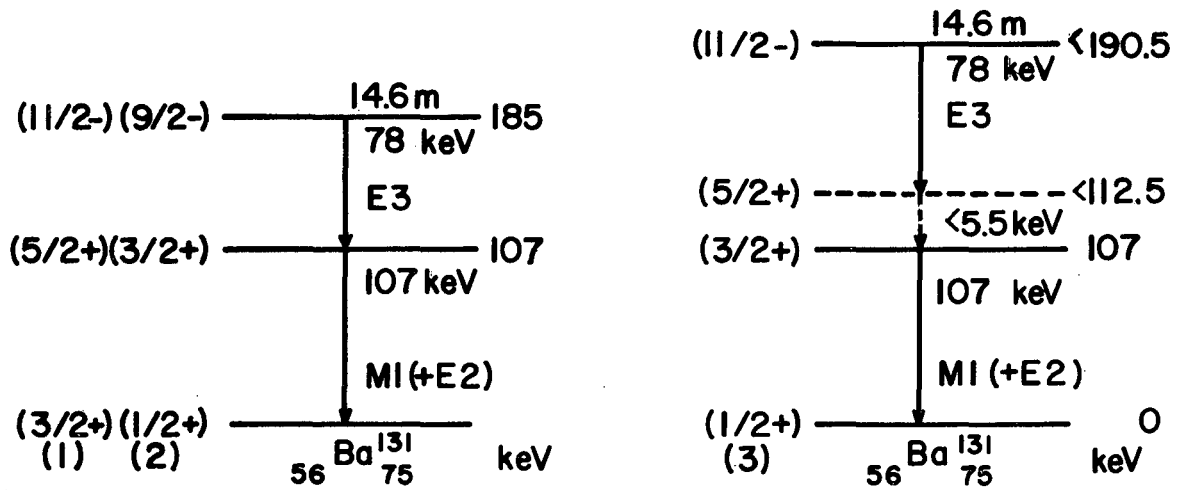

Fig. 2. Alternative decay scheme for Ba^{131m} (see text for a discussion of same).

Table II.

Relative intensities of photons in coincidence with the 107-keV photon in the decay of Ba^{131m}.

Energy (keV)	Intensity (relative)[a]
L X-ray	≥ 11.5[b]
K X-ray	33 ± 3
78 ± 5	33

[a] The coincidence intensities have been arbitrarily normalized to the singles data by adjusting the intensity of the 78-keV photon.

[b] The main uncertainty in the L X-ray intensity arises from incomplete knowlege of the correction for absorption.

Table III.

Comparison of experimental conversion coefficients for the 78-keV transition to the theoretical values for an E3 transition.

α_K		α		α_K/α_L	
Expt'l	Theory	Expt'l	Theory	Expt'l	Theory
11.5 ± 1.5	12.3	96 ± 19	≈ 117[a]	≤ 1.2	0.21

[a] This value is only approximate since the magnitude of the contribution due to the M, N, ... shells is uncertain.

they suggest a spin and parity of 1/2+ for this level, their data also appear to be consistent with a 5/2+ assignment for this level. From the similarity in energies and K-conversion coefficients, this transition could be the same as our 107 ± 3 keV transition.

If one assumes that the ground state spin and parity of Ba^{131} are 1/2+, the situation becomes similar to that for Xe^{125m} and Xe^{127m}, where the ground states are thought to be 1/2+ and the isomeric transitions are of multipole order E3. It has been suggested that an unobserved transition is involved in the decay of these xenon isomers (i.e., choice (2)).[2] However, if such an undetected transition (leading to a 5/2+ level) occurs in the decay of Ba^{131m}, its energy would have to be less than the L-binding energy for barium (i.e., < 5.5 keV). Such a 5/2+ level could be accounted for by the $d_{5/2}$ single particle state or a collective level. However, neither the calculations of Glendenning (for the odd-N xenon and tellurium isotopes) nor the experimental data to date would lead one to expect such a close-lying 5/2+,3/2+ pair.

For the third possibility, the assignments could be explained as follows: the ground-state configuration for the neutrons would be $(g_{7/2})^8 (d_{5/2})^6 (h_{11/2})^{-2} s_{1/2}$, the first excited state would arise by promoting the $s_{1/2}$ neutron to the $d_{3/2}$ level, and the 9/2- level would be obtained by the breaking of a $h_{11/2}$ pair resulting in the configuration $(g_{7/2})^8 (d_{5/2})^6 (s_{1/2})^2 (h_{11/2})^{-3}_{9/2}$. (It should be noted that the isomers observed in Xe^{125} and Xe^{127} could also be interpreted in a similar way.) If such be the case, one might expect to observe the same 9/2- level in other odd-N nuclei where the $h_{11/2}$ shell contains three or more holes or particles. In the case of Te^{125}, a level at about 180 keV above the $h_{11/2}$ level has been assigned 9/2- or 11/2-.[2]

In conculsion, it appears that a final choice between the possible spin and parity assignments involved in the decay of Ba^{131m}, presented herein,

must await either a direct measurement of the spin of Ba^{131} or La^{131}. As regards the latter it should be noted that a ground state assignment of 1/2+ for La^{131} would also be consistent with the data of Creager et al.[3] On the basis of the odd-A cesium isotopes, such an assignment might not be too surprising.

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FOOTNOTES AND REFERENCES

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‡Summer visitor from the Department of Chemistry, McGill University, Montreal, Canada.

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