ON THE DECAY SCHEMES OF ^{123}Ba AND ^{125}Ba

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The neutron deficient ^{123}Ba and ^{125}Ba isotopes obtained in the ^{114}Sn (^{12}C, 3n) ^{123}Ba and ^{117}Sn(^{12}C, 4n)^{125}Ba reactions have been studied with Ge(Li) detectors. The most intense γ-rays assigned to ^{125}Ba were confirmed in experiment perfomed with mass-separated sources obtained by spallation reaction from CeO_2 (separation of barium fraction) and Ta (direct isobars separation of A = 125) targets irradiated with 660 MeV protons. Beta-gamma delayed coincidence has been measured using NE 102 and Ge(Li) detectors. On the basis of gamma intensities and energy sums the decay schemes are proposed for ^{123}Ba and ^{125}Ba.

1. Introduction

During the last few years a considerable interest has been observed in the predicted [1] new nuclear region of permanent deformation containing neutron-deficient nuclides with $50 < Z, N < 82$. This new region of deformation was confirmed both by experimental data obtained from in-beam spectroscopy [2–4] (even-even nuclei) and by theoretical calculations [5, 6]. The latter suggest that oblate shapes would be rather more stable than the prolate ones. Data of the excited states of odd-A nuclei may serve to test not only the existence of deformation but also to establish the sign of it.

The object of the present work was to obtain further information of the low-lying levels of ^{123}Cs and ^{125}Cs excited in the beta decay of ^{123}Ba and ^{125}Ba. These isotopes, about whose excited states not very much is known, belong to this new region of interest.

2. Experiment and results

2.1. Barium-123

The sources used in this experiment were obtained in the ^{114}Sn(^{12}C, 3n)^{123}Ba reaction from a self supporting target (5 mg/cm^2) prepared of commercial separated ^{114}Sn isotope, irradiated for about 1 min with ^{12}C ions of the optimal energy 65 MeV [7]

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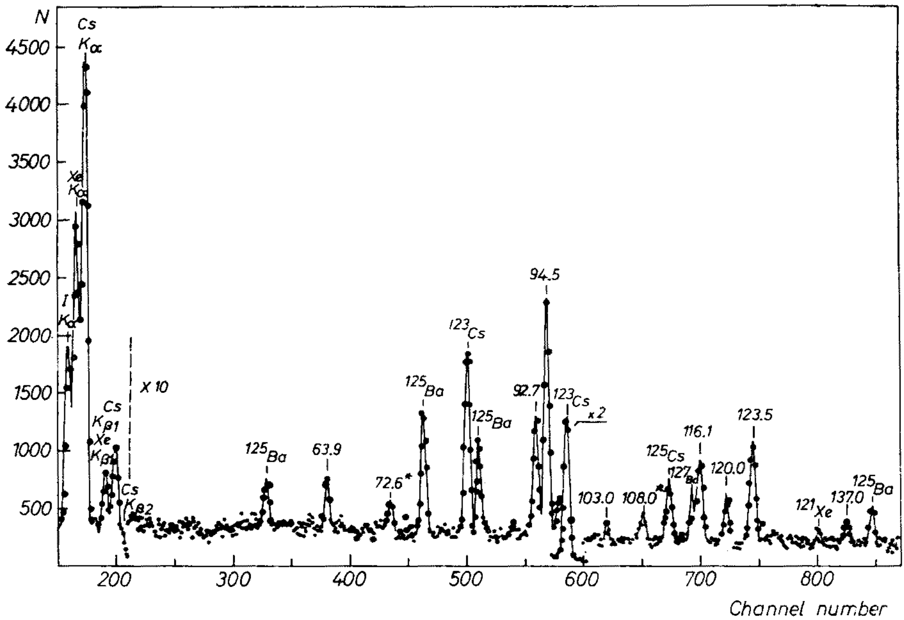

Fig. 1. Single γ-ray spectrum of ^{123}Ba observed from a ^{114}Sn target bombared with ^{12}C ions. Two long--lived γ-rays marked by asterisk have not been assigned

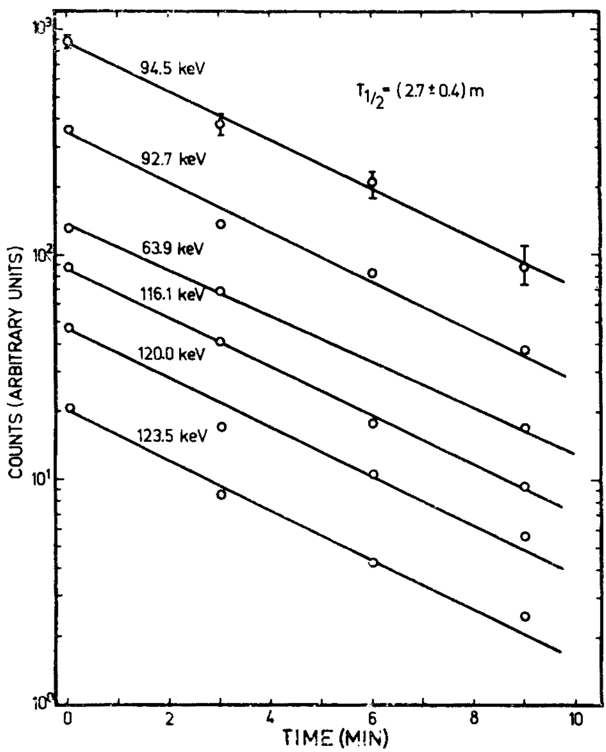

Fig. 2. Decay curves of the γ-rays assigned to ^{123}Ba

on the external beam of the heavy ion U-300 cyclotron. The carbon ion energy was reduced to the proper one by means of an aluminium foil set.

The gamma-ray spectra were studied with a 2.5 cc Ge(Li) detector with a 0.7 keV resolution at 100 keV. One of these spectra is shown in Fig. 1. The observed gamma-rays were identified by comparing their energies and lifetimes with those of known isotopes which might be expected to appear in the spectra as well as a decay product of ^{123}Ba and as reaction products of admixture of other tin isotopes in the target material. Seven of these gamma-rays (Fig. 2) decay with the same half-life of 2.7 min which one could not assign to any of the known isotopes. This value is in agreement with the reported one [8] of (2±0.5) min. Furthermore, in all spectra of this energy region obtained with mass-separated Sn targets, only barium isotopes and their decay products were observed. These facts lead the authors to conclude that the observed γ-ray group (given in Table I) can be assigned to ^{123}Ba.

TABLE I

Gamma-rays observed in the decay of ^{123}Ba. Energy uncertainties do not exceed 0.6 keV

Energy E_γ (keV)	63.9	92.7	94.5	116.1	120.0	123.5	137.0
Rel. Int. I_γ	14±4	51±5	100	54±8	27±4	69±6	23±7

2.2. Barium-125

The ^{125}Ba sources were obtained with the ^{117}Sn(^{12}C, 4n)^{125}Ba reaction at 75 MeV bombarding energy. The experimental procedure used here was the same as in the case of ^{123}Ba.

One of gamma-ray spectra obtained with the 2.5 cc Ge(Li) detector is shown in Fig. 3. In contrast to ^{123}Ba these spectra are relatively simple. A careful analysis of those revealed a group of gamma-rays with a half-life of 3.5 min (Fig. 4) which could not be identified with the other known isotopes. To check that these gamma-rays belong to ^{125}Ba two supplementary experiments were performed using sources obtained in two different ways. In the first case ^{125}Ba sources were obtained by spallation reaction from CeO_2 targets irradiated with 660 MeV protons on the external beam of the JINR synchrocyclotron. After the chemical separation the ^{125}Ba source was prepared by electromagnetic isotope separation of the barium fraction using a surface ionisation ion source [9]. In the second case (in order to obtain more intense sources) mass-separated isobars of A = 125 were used. In this case the sources were obtained by spallation reaction from tantalum targets irradiated at the same experimental conditions as in the case of the CeO_2 samples. The electromagnetic separation was carried out directly from the irradiated target [29]. The γ-ray spectra were studied with the 2.5 and 41 cc detectors. All the prominent gamma-rays of the unidentified group in the experiment with the ^{12}C ions were confirmed in the spectra obtained both with the mass-separated ^{125}Ba and with the mass-separated isobars of A = 125. These facts allow the authors to conclude that the found group of the γ-transitions, listed in Table II, belongs to ^{125}Ba.

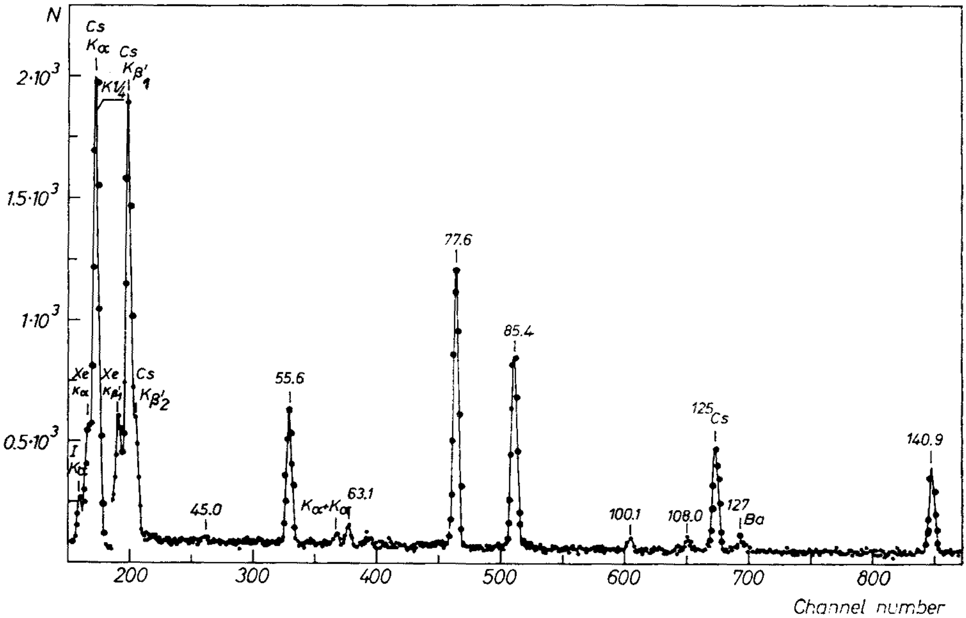

Fig. 3. Single γ-ray spectrum of ^{125}Ba observed from a ^{117}Sn target bombarded with ^{12}C ions

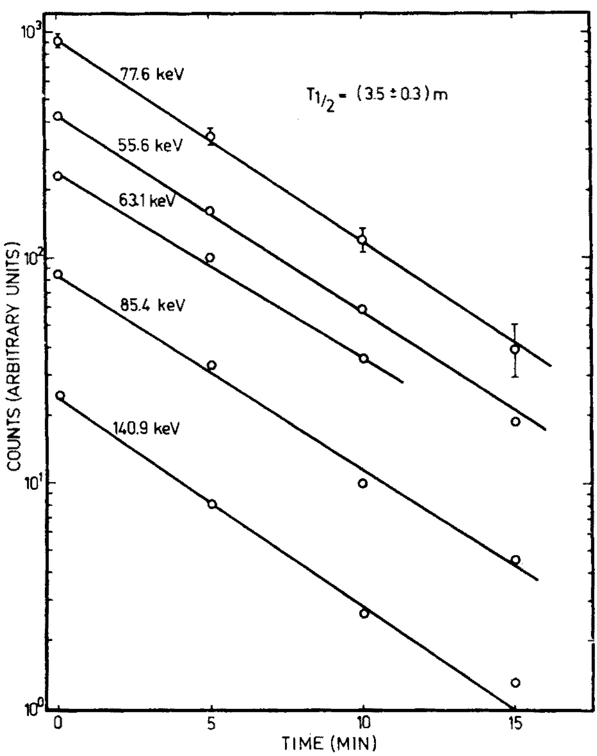

Fig. 4. Decay curves of the γ-rays assigned to ^{125}Ba

The value of 3.5 min adopted here as the half-life of ^{125}Ba should be compared with the values of (3 ± 0.5) and (8 ± 1) min published in Ref. [10] as the half-lives of two isomeric states of ^{125}Ba. The first one is in agreement with the value obtained in the present work. The 8 min activity (in the 5–200 keV gamma energy region) was not observed in this experiment.

TABLE II

Gamma-rays observed in the decay of ^{125}Ba. Energy uncertainties in the present work do not exceed 0.6 keV

Present work		Reference [10]		
$T_{1/2} = (3.5\pm0.4)$ min		$T_{1/2} = (3\pm0.5)$ min		$T_{1/2} = (8\pm1)$ min
Energy E_γ (keV)	Rel. intensity I_γ	Energy E_γ (keV)	Rel. intensity I_γ	Energy E_γ (keV)
45.0	~3			(20)
55.0	48 ± 4	56 ± 3	5	
63.1	8 ± 4			
77.6	100	76 ± 2	100	β^+ component
85.4	82 ± 8	84 ± 2	86	
100.1	6 ± 3			
108.0	8 ± 2			
140.9	86 ± 8	141 ± 2	42	

3. *Decay schemes and discussion*

3.1. Barium-123

In experiments with heavy ion reactions an isomeric state with half-life of 1.6 sec was revealed in ^{123}Cs. This state is depopulated by two γ-transitions of energies (63 ± 0.5) and (95.5 ± 0.5) keV of the same type of M1+E2 (or E2) multipolarity [11]. Since the angular momenta carried off are relatively small it might be expected that at least one of these transitions appears in the γ-ray spectra accompanying the beta decay of ^{123}Ba. As it can be seen from Table I the γ-rays of energy 63.9 and 94.5 keV could be, in experimental error limits, identified with the observed ones in Ref. [11]. However, the intensity ratio (relative to the 63.9 keV transition) observed in the present work (Table I and Fig. 5) is twice as much as given in Ref. [11]. From these facts it follows that the only combination which is compatible with this intensity ratio is the cascade shown at the left in Fig. 5. Furthermore, the 94.5 keV γ-ray is the most intense one. On the basis of this information as well as the energies and intensities of the observed γ-rays, an exited level of the same energy can be postulated. Starting from this level and basing on the intensity and energy sum rule an attempt was made to construct a decay scheme for ^{123}Ba. A careful analysis of a few variants lead the authors to a conclusion that, on the basis of the present experimental data, the 63.9 and 94.5 keV transitions (both or which of them) cannot be unambiguously identified with those given in Ref. [11]. A tentative decay scheme (which is to be treated as a proposal to further experiments) shown at the right in Fig. 5 was chosen as one of the simplest and more compatible with the systematics of the ground states of the neighbouring odd-A barium isotopes and the spins of the levels associated with the isomeric state (cf. below).

The spin and parity of the ground state of the neighbouring odd-A cesium isotopes is $1/2^+$ [12–14]. By analogy to that one can expect that ^{123}Cs nucleus will continue this trend. Such a conclusion seems to be confirmed experimentally by works devoted to the

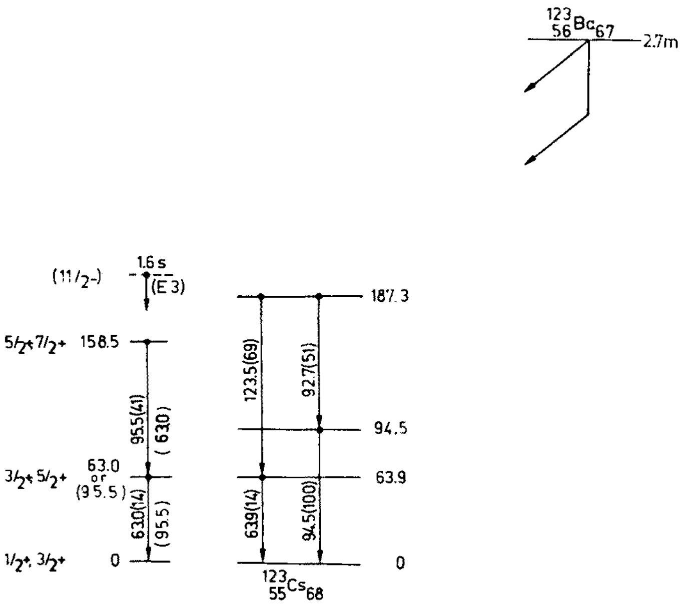

Fig. 5. Tentative decay scheme proposed for ^{123}Ba

investigations of the decay of ^{123}Cs [15] and the excited states of ^{123}Xe [16]. However, in our gamma-spectra of ^{123}Ba obtained in the (^{12}C, xn) reaction there appeared, beside the strong 97.3 keV gamma-ray, a 83.3 keV γ-transition[1] which depopulates the second excited state of ^{123}Xe of the $5/2^+$ spin value [16]. Because the assignment of this transition has not yet been established (work continued), the $3/2^+$ value for the ground state of ^{123}Cs cannot be excluded. Basing on these data and multipolarity given in Ref. [11] the spin for the excited states associated with the isomeric state were assigned (Fig. 5).

In the last years an $11/2^-$ isomeric state was found in ^{127}Cs [18]. Such a state could explain the existence of 1.6 sec activity in ^{123}Cs if one assumed the spin sequence given at the left in Fig. 5.

[1] The same transitions were observed by authors in experiments with mass-separated isobars of A = 123 obtained simultaneously by separations A = 125 isobars from the tantalum targets (cf. 2.2).

3.2. Barium-125

In the case of ^{125}Ba β-gamma coincidence experiments were carried out using a NE 102 (2.5 × 1 cm) plastic detector as the gating crystal and a 27 cc Ge(Li) one to obtain the coincidence gamma-spectra [19]. The time resolution of this coincidence set-up was about 10 ns.

Fig. 6 shows coincidence spectra with an integral gate set above 500 keV. The upper (A) spectrum represents a prompt and the lower one (B) a 10 ns delayed coincidence spectrum, respectively. From these spectra it is seen that only one of the observed γ-rays

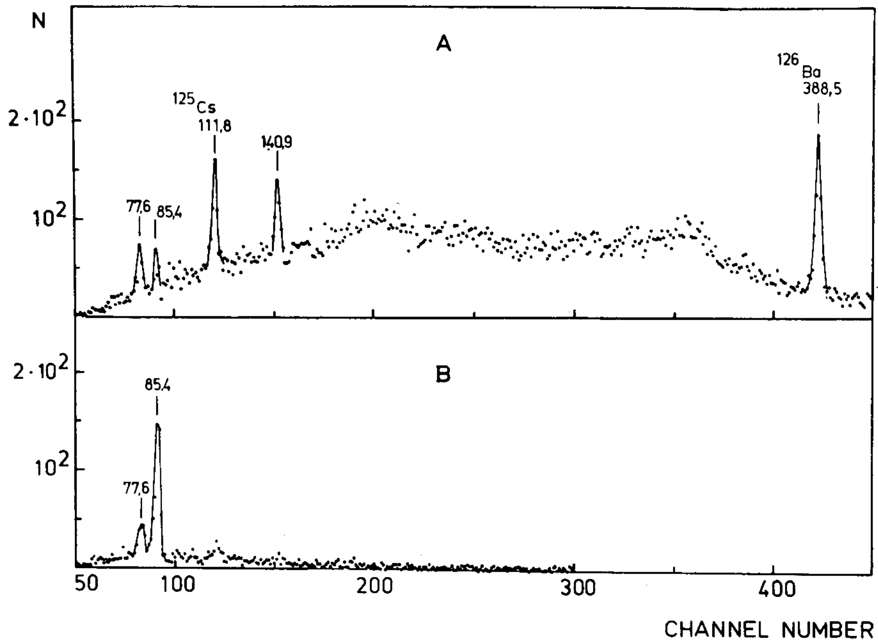

Fig. 6. Gamma-ray spectra in coincidence with a continuous β^{+}-spectrum at the energy > 500 keV: A) The prompt coincidence spectrum, B) 10ns delayed coincidence spectrum

of energy 85.4 keV is delayed relative to the β^{+}-decay. This implies the existence of an excited state of the same energy. Furthermore, from the relative intensities of the observed two γ-rays (77.6 and 85.4 keV) in these spectra the half-life of this level was estimated roughly to be about 20 ns [2] what is in agreement with transitions of the E2 type in the neighbouring odd-mass Cs isotopes [20, 23]. On the basis of these facts and taking into consideration the energy and intensity balance, the decay scheme for ^{125}Ba was constructed (Fig. 7).

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[2] Since this paper was submitted for publication an experiment was performed by authors with sources of a short lived barium fraction obtained by spallation reaction. The half-life of the 85.4 keV level was estimated to be 14.5 ± 1.5 ns.

The spin and parity of the ground state of ^{125}Cs was found to be $1/2^+$ [13, 14]. According to systematics of the excited states of odd-A cesium isotopes [21–24] and the present data the spin for the 85.4 keV level is very likely to be $5/2^+$. A rough estimation of the log ft values ($Q\beta^+$ value was taken from Ref. [17] in agreement with the experiment of Ref. [10]) for the beta-decay to the proposed levels indicated that these transitions are

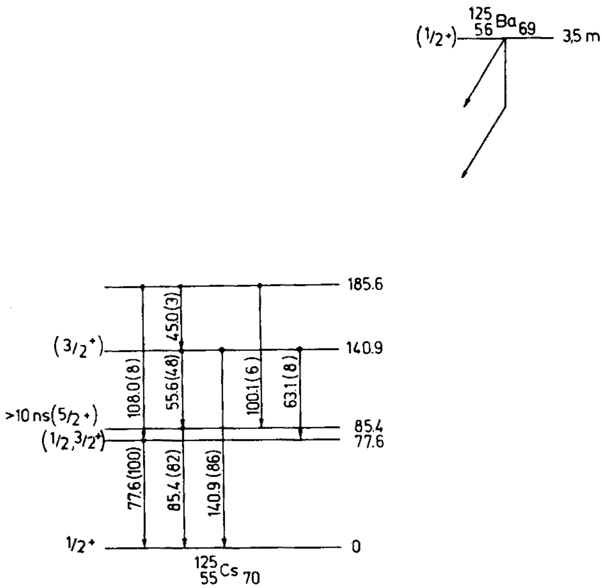

Fig. 7. Decay scheme proposed for ^{125}Ba

consistent with an allowed character in this mass region. The transition intensities calculated on the basis of theoretical conversion coefficients [25] and gamma-ray intensities (assuming M1 as a lowest of the possible multipolarities for the 55.6 and E2 one for 85.4 keV transitions) indicate that the second excited state, within the statistical error limits, is not populated in the β-decay. From all these facts it follows that the spins of the 140.9 keV level and of the ground state of ^{125}Ba are likely to be $3/2^+$ and $1/2^+$, respectively.

Taking into account the general trend of the levels given by pairing + quadrupole force model for odd-mass cesium isotopes [26], one can see that this model is able to explain the $1/2^+$ spin of the ground state of ^{125}Cs. The experimental data of the ground states for odd-Cs isotopes are also in good agreement with the theoretical ones [14, 27] predicted by the Nilsson model [28]. However, a more detailed calculation [6] gives a level sequence, for the few excited states of ^{125}Cs, far from being in satisfactory agreement with the observed one.

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