INVESTIGATION OF THE $^{126}Ba \rightarrow {}^{126}Cs \rightarrow {}^{126}Xe$ DECAY

BY K. J. BLINOWSKA, S. CHOJNACKI, CH. DROSTE, T. MOREK AND J. SREBRNY

Institute of Experimental Physics, University of Warsaw*

(Received September 19, 1972)

The neutron deficient ^{126}Ba isotope was produced in the $^{118}Sn(^{12}C, 4n)\,^{126}Ba$ reaction at carbon ions energy $E = 72$ MeV. The decays of $^{126}_{56}Ba \rightarrow {}^{126}_{55}Cs \rightarrow {}^{126}_{54}Xe$ and $^{126}Cs \rightarrow {}^{126}Xe$ were investigated by means of Ge(Li) detectors. The $^{126}Ba \rightarrow {}^{126}Cs$ decay scheme is presented.

1. Introduction

In the last few years considerable rise of interest is observed in the $50 \leqslant Z$, $N \leqslant 82$ nuclei region, where the levels sequence changes from vibration-like to rotational-like. Several theoretical [1]–[3] and experimental [4]–[8], [15] works were performed to elucidate the nature of the excited states of these nuclei.

The neutron deficient chain $^{126}Ba \rightarrow {}^{126}Cs \rightarrow {}^{126}Xe$ was investigated by Kalkstein *et al.* [9] and D'Auria [8], who established the basic features of the decays and proposed the level schemes for ^{126}Cs and ^{126}Xe. The excited levels in ^{126}Xe fed from the decay of ^{126}I were studied by Grabowski *et al.* [10]. The levels in ^{126}Xe were also populated in nuclear reactions and investigated by means of "on-beam" spectroscopic methods. Betigeri *et al.* [11] used the $^{126}Te(^{3}He, 3n)^{126}Xe$ reaction and Bergström *et al.* [5] the $^{124}Te(^{4}He, 2n)\,^{126}Xe$ one to investigate the gamma radiation from the decay of the excited levels in ^{126}Xe. The conversion electrons from the $^{127}I(p, 2n)^{126}Xe$ reaction were measured by Sakai *et al.* [12]. From these investigations the quasi-rotational band in ^{126}Xe is known.

In the present work the study of the $^{126}Ba \rightarrow {}^{126}Cs \rightarrow {}^{126}Xe$ chain was undertaken to provide further experimental material concerning the decay of these isotopes.

2. Experimental

The experiment was conducted on the external beam of the heavy ion U-300 cyclotron at the Joint Institute for Nuclear Research in Dubna. The ^{126}Ba isotope was obtained in the $^{118}Sn(^{12}C, 4n)^{126}Ba$ reaction, the energy of carbon ions being equal to 72 MeV.

* Address: Instytut Fizyki Doświadczalnej, Uniwersytet Warszawski, Hoża 69, 00-681 Warszawa, Poland.

The optimal energy of carbon ions for the $^{118}Sn(^{12}C, 4n)^{126}Ba$ reaction was calculated from the empirical relation [13]

$$\bar{\varepsilon} = (E_{exc} - \sum_{i=1}^{x} B_{ni})/x$$

where: x is number of neutrons evaporated in reaction (HI, xn), E_{exc} is the excitation energy of the compound nucleus corresponding to the maximum of the excitation function, B_{ni} is the binding energy of the i-th neutron.

The value of $\bar{\varepsilon}$ was assumed to be equal to 6 MeV, as suggested by Neubert [13] for nuclei of the region $A \approx 120$. The B_{ni} values were taken from the calculation of Zeldes *et al.* [14].

The energy of the carbon ions outgoing from the cyclotron was degradated to the proper energy by means of an aluminium foil set.

The self-supporting targets of 4 mg/cm^2 thickness were prepared by rolling of enriched ($\approx 98\%$) ^{118}Sn foils. During the irradiation, an aluminium foil about 10 μm thick was placed behind the target in order to catch the recoil nuclei. After irradiation barium was separated

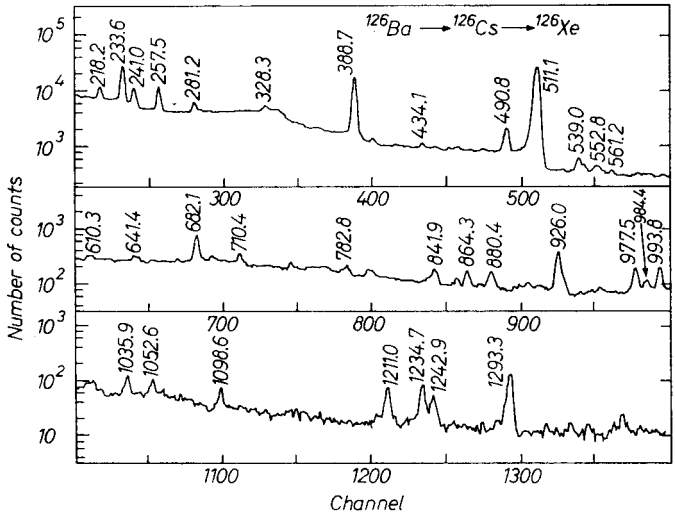

Fig. 1. Gamma ray spectrum of the $^{126}Ba \rightarrow {}^{126}Cs \rightarrow {}^{126}Xe$ chain

chemically from the catcher, and the gamma spectrum accompanying the $^{126}Ba \rightarrow {}^{126}Cs \rightarrow {}^{126}Xe$ decay was investigated.

The measurements were performed by means of Ge(Li) detectors 30 cm^3 coaxial and 12.5 cm^3 planar types with resolutions: 6.5 keV and 3 keV, respectively (for gamma energy of 1 MeV).

In order to find which lines correspond to the $^{126}Ba \rightarrow {}^{126}Cs$ decay and which to the $^{126}Cs \rightarrow {}^{126}Xe$ one, the following procedure was applied. Caesium was repeatedly separated (10–15 times) from the catcher containing the ^{126}Ba isotope. The chemical separation

of caesium together with its transport to Ge(Li) detector took about 1 min, *i.e.* a time comparable with the half-life of ^{126}Cs. This permitted the investigation of the gamma spectrum of the ^{126}Cs → ^{126}Xe decay.

Comparison of the ^{126}Ba → ^{126}Cs → ^{126}Xe decay spectrum with that of the ^{126}Cs → ^{126}Xe decay allowed us to assign the gamma lines to the particular stages of the $A = 126$ decay chain. Gamma ray spectra of the ^{126}Ba → ^{126}Cs → ^{126}Xe decay are presented in Fig. 1. The identification of the $A = 126$ chain was based on the agreement between the half-life of the observed gamma lines and the value $T_{1/2} = 96.5$ min. given for the ^{126}Ba decay in Ref. [9]. The identification of isotopes was also confirmed by the observation of the 389 keV and 491 keV gamma lines belonging (according to Bergström *et al.* [5] and Grabowski *et al.* [10]) to the $^{1}2^{+} \rightarrow 0^{+}$ and $^{2}2^{+} \rightarrow {}^{1}2^{+}$ transitions in ^{126}Xe, respectively.

3. Results and discussion

The gamma lines observed in the ^{126}Ba → ^{126}Cs → ^{126}Xe decay are listed in Table I. The least squares programmes for the GIER computer were used to determine the energies, intensities and half-lives of the gamma transitions.

The assignment of the lines to the ^{126}Ba or ^{126}Cs decays was based on the comparison of the relative intensities of the lines of the ^{126}Ba → ^{126}Cs → ^{126}Xe and ^{126}Cs → ^{126}Xe spectra. Namely, the lines belonging to ^{126}Cs decay ought to have the same intensity ratio in both spectra as the 389 keV transition (which is known [9], [5] to depopulate the first excited level in ^{126}Xe). The lines with a proper life time observed in the barium chain spectrum but not observed, within the limit of experimental error, in the ^{126}Cs→^{126}Xe decay were assigned to the ^{126}Ba → ^{126}Cs decay. Unfortunately, the intensity of the chemically separated caesium sources was insufficiently high, and some of the observed lines could not be assigned unambiguously to either of the investigated isotopes. We can only say that they belong to the ^{126}Ba → ^{126}Cs → ^{126}Xe chain because of their half-life. The gamma transitions of energies higher than 1.5 MeV are likely to belong to the ^{126}Cs decay because of the low β^{+}-transition energy for ^{126}Ba. According to the calculations of Zeldes *et al.* [14] the energy released in electron capture is $Q_{EC} = 1.5$ MeV for ^{126}Ba → ^{126}Cs.

In the decay of ^{126}Cs, except the 389 keV and 491 keV lines mentioned before, we have observed also a cross-over transition of energy 880 keV from the $^{2}2^{+}$ level to the ground state. This transition was also seen in the decay of ^{126}I (Refs [10], [15]).

The 880 keV line was also observed by Bergström *et al.* [5] in the ^{124}Te(^{4}He, $2n$)^{126}Xe reaction, and assigned to the transition between the 10^{+} and 8^{+} levels. It seems that it is the same line, which was observed by us, and in the ^{126}I decay [10], [15]. Under this assumption the 880 keV line cannot be assigned to the $10^{+} \rightarrow 8^{+}$ transition, because the high spin states are not fed in the β^{+}-decay of ^{126}Cs and ^{126}I (the spins of the ground states are $I = 1^{+}$ and 2^{-}, respectively).

Other lines could have been assigned to the ^{126}Cs → ^{126}Xe decay (see Table I), but it was not possible to build up a consistent decay scheme on the basis of the energy and intensity balances.

The decay scheme of ^{126}Ba is presented in Fig. 2. The gamma transitions which

TABLE I

Energies, intensities, half-lives and identifications of transitions in the $^{126}Ba \rightarrow {}^{126}Cs \rightarrow {}^{126}Xe$ chain

Energy keV	Intensity of gamma rays (arbitrary units)	Half-life min	Identification
94.1±0.3	0.6±0.2	80±30	$^{126}Ba \rightarrow {}^{126}Cs$
103.8±0.3	0.7±0.2	80±20	$A = 126$
107.3±0.3	1.5±0.2	100±20	$^{126}Cs \rightarrow {}^{126}Xe$
127.0±0.3	1.3±0.3	84±10	$A = 126$
130.0±0.3	2.4±0.3	102±9	$A = 126$
171.7±0.3	<1	70±20	$A = 126$
180.7±0.4	<1	90±30	$A = 126$
201.3±0.3	1.3 ±0.5	100±30	$A = 126$
218.2±0.3	10.0±1.4	102±8	$^{126}Ba \rightarrow {}^{126}Cs$
233.6±0.3	50±5	98±3	$^{126}Ba \rightarrow {}^{126}Cs$
241.0±0.3	14.5±1.8	104±6	$^{126}Ba \rightarrow {}^{126}Cs$
257.5±0.3	17.9±1.2	88±4	$^{126}Ba \rightarrow {}^{126}Cs$
281.2±0.3	7.2±0.6	97±8	$^{126}Ba \rightarrow {}^{126}Cs$
285.1±0.3	1.0±0.3	70±20	$A = 126$
290.9±0.3	1.4±0.3	80±20	$A = 126$
309.0±0.6	0.7±0.4	88±17	$A = 126$
328.3±0.3	6.1±0.7	101±14	$^{126}Ba \rightarrow {}^{126}Cs$
365.1±0.6	1.1±0.5	85±17	$A = 126$
382.4±0.7	1.6±0.6	89±14	$A = 126$
385.7±0.3	5.1±0.9	81±12	$A = 126$
388.7±0.3	100	99±2	$^{126}Cs \rightarrow {}^{126}Xe$
400.5±0.3	2.4±0.5	90±20	$A = 126$
415.1±0.3	1.6±0.5	130±30	$A = 126$
434.1±0.3	2.6±0.5	100±20	$A = 126$
441.8±0.4	1.1±0.3	150±60	$A = 126$
457.3±0.3	2.1±0.5	100±30	$A = 126$
490.8±0.3	12±2	100±10	$^{126}Cs \rightarrow {}^{126}Xe$
511.1±0.3	350±18	102±3	annihilation line
539.0±0.3	4.4±0.8	83±14	$^{126}Cs \rightarrow {}^{126}Xe$
542.9±0.5	1.8±0.6	90±30	$A = 126$
561.2±0.5	1.0±0.4	70±30	$^{126}Ba \rightarrow {}^{126}Cs$
583.9±0.9	0.9±0.5	100±19	$A = 126$
610.3±0.5	1.8±0.6	93±12	$^{126}Ba \rightarrow {}^{126}Cs$
641.4±0.4	2.5±0.6	82±18	$^{126}Ba \rightarrow {}^{126}Cs$
682.1±0.3	10.7±1.0	96±8	$^{126}Ba \rightarrow {}^{126}Cs$
692.3±0.5	1.7±0.4	80±20	$^{126}Ba \rightarrow {}^{126}Cs$
710.4±0.3	3.6±0.6	90±20	$^{126}Cs \rightarrow {}^{126}Xe$
782.8±0.5	1.7±0.6	87±16	$^{126}Ba \rightarrow {}^{126}Cs$
841.9±0.5	3.8±0.8	100±20	$^{126}Ba \rightarrow {}^{126}Cs$
864.3±0.4	3.1±0.5	90±20	$^{126}Ba \rightarrow {}^{126}Cs$
880.4±0.5	3.5±0.6	90±19	$^{126}Cs \rightarrow {}^{126}Xe$
926.0±0.6	12.8±1.5	85±9	$^{126}Cs \rightarrow {}^{126}Xe$
977.5±0.5	5.2±0.7	104±15	$^{126}Ba \rightarrow {}^{126}Cs$
984.4±0.5	2.1±0.4	120±30	$A = 126$

TABLE I (continued)

Energy keV	Intensity of gamma rays (arbitrary units)	Half-life min	Identification
993.8±0.5	5.4±0.7	95±14	$^{126}Ba \rightarrow {}^{126}Cs$
1033.7±0.8	0.9±0.6	80±20	$A = 126$
1035.9±0.5	3.5±0.7	100±20	$^{126}Ba \rightarrow {}^{126}Cs$
1052.6±0.6	2.8±0.6	100±20	$^{126}Ba \rightarrow {}^{126}Cs$
1059.4±0.9	< 1	100±40	$A = 126$
1098.6±0.5	1.8±0.5	98±8	$A = 126$
1211.0±0.6	3.9±0.8	90±20	$^{126}Ba \rightarrow {}^{126}Cs$
1234.7±0.6	4.7±0.7	110±20	$^{126}Ba \rightarrow {}^{126}Cs$
1242.9±0.6	2.7±0.5	97±19	$^{126}Ba \rightarrow {}^{126}Cs$
1293.3±0.7	9.6±1.5	92±8	$^{126}Ba \rightarrow {}^{126}Cs$
1678.2±0.5	1.8±0.6	84±6	$A = 126$
1734.7±1.0	1.4±0.6	90±17	$^{126}Cs \rightarrow {}^{126}Xe$
2064.6±1.6	0.8±0.4	120±20	$^{126}Cs \rightarrow {}^{126}Xe$

cannot be unambiguously assigned to the $^{126}Ba \rightarrow {}^{126}Cs$ decay but which have the half-life of the investigated chain and fit well into the decay scheme, are represented by the dashed arrows. The levels whose existence is not well established are marked by dashed lines.

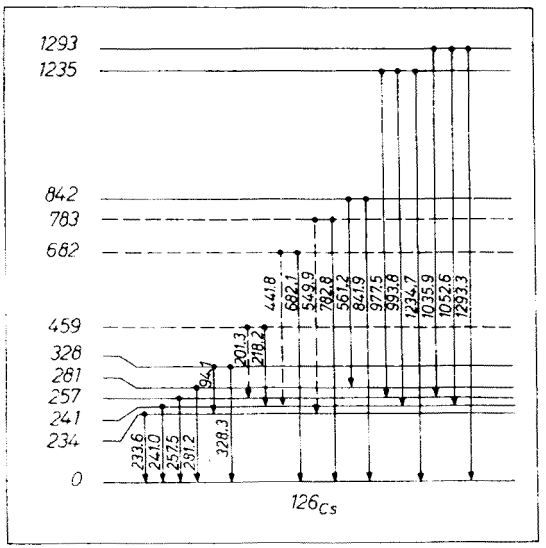

Fig. 2. Proposed level scheme of ^{126}Cs

We should like to express our gratitude to Professor G. N. Flerov for his help and kind interest in our work. Our thanks are also due to Mrs E. Gostyńska, Mr T. Kempisty and Mr J. Ossowski for their help in the course of the experiment and data analysis.

REFERENCES

[1] L. S. Kisslinger, R. A. Sorensen, *Rev. Mod. Phys.*, **35**, 853 (1963).

[2] K. Kumar, M. Baranger, *Phys. Rev. Letters*, **12**, 73 (1964).

[3] D. A. Arseniev, A. Sobiczewski, V. G. Soloviev, *Nuclear Phys.*, **A126**, 15 (1969).

[4] J. E. Clarkson, R. M. Diamond, F. S. Stephens, I. Perlman, *Nuclear Phys.*, **A93**, 272 (1967); D. Ward, R. M. Diamond, F. S. Stephens, *Nuclear Phys.*, **A117**, 309 (1968).

[5] I. Bergström, C. J. Herrlander, A. Kerek, A. Luukko, *Nuclear Phys.*, **A123**, 99 (1969).

[6] G. Albouy, J. M. Lagrange, M. Pautrat, N. Poffe, H. Sergolle, J. Teillac, I. Vanhorenbeeck, *Proceedings of the International Conference on Nuclear Reactions Induced by Heavy Ions*, Heidelberg, July 1969.

[7] K. F. Alexander, W. Neubert, H. Rotter, S. Chojnacki, Ch. Droste, T. Morek, *Nuclear Phys.*, **A133**, 77 (1969); Ch. Droste, W. Neubert, S. Chojnacki, T. Morek, K. F. Aleksander, Z. Wilhelmi, *Nuclear Phys.*, **A192**, 595 (1972).

[8] J. M. D'Auria, *Ph.D. Thesis*, Yale University 1967.

[9] M. J. Kalkstein, J. M. Hollander, *Phys. Rev.*, **96**, 730 (1954).

[10] Z. W. Grabowski, K. S. Krane, R. M. Steffen, *Phys. Rev.*, **C3**, 1649 (1971).

[11] M. G. Betigeri, H. Morinaga, *Nuclear Phys.*, **A95**, 176 (1967).

[12] M. Sakai, T. Yamazaki, H. Ejiri, *Nuclear Phys.*, **74**, 81 (1965).

[13] W. Neubert, *Nuclear Instrum. Methods*, **93**, 473 (1971).

[14] N. Zeldes, A. Grill, A. Simievic, *K. Danske Vidensk. Selsk. Mat.-Fys. Skr.*, **3**, No 5 (1967).

[15] J. M. Lagrange, G. Albouy, L. Marcus, M. Pautrat, H. Sergolle, O. Rahmouni, *Ann. Phys.*, **2**, 141 (1967).