Lanthanum Isotopes in a Possible New Region of Nuclear Deformation*

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New neutron-deficient lanthanum isotopes have been produced by heavy-ion bombardments of indium, and identified by means of chemical separations and genetic relationships. The proposed mass assignments and corresponding half-lives are: La^{124}, 7.2±0.5 min; La^{128}, 4.2±0.5 min; La^{127}, 3.8±0.5 min; La^{126}, 1.0±0.3 min; and La^{125}, <1 min.

We wish to report on the discovery and further characterization of several new neutron-deficient lanthanum isotopes. These isotopes occur in what has been postulated as a possible new region of nuclear deformation.[1]

Heavy-ion bombardments of natural indium foil were used to produce the new neutron-deficient La isotopes by means of $In^{113-115}$ (O^{16},xn)La reactions. The foils, 40 mg/cm^2 in superficial density, were irradiated for periods of from 2 to 10 min with O^{16} ion beams of 168 or 66.4 MeV.

Two procedures were then used:

(1) direct observation of the decay of La separated chemically from irradiated targets;

(2) chemical milking of Ba daughter activities. By identifying these daughters, and in certain cases, the Cs granddaughter definite mass assignments could be made.

It was necessary to use extreme care in the chemical separation of La from the target and other nuclides formed. In particular, it was essential to prevent any co-precipitation of the Ba isotopes formed. Not only do Ba isotopes appear to be produced with much larger yields, but the half-lives of Ba^{123}, Ba^{125}, and Ba^{127} (2±0.5, 6.5±0.5, and 10.0±0.5 min, respectively) are remarkably close to those reported for La^{126}, La^{128}, and La^{130}.[2,3]

With this in mind, isolation of the La fraction was carried out using the following procedure: Indium target foils were dissolved in hot concentrated HCl containing carriers for Cs, Ba, and La. Ba was eliminated by precipitating $BaSO_4$ with the stoichiometric amount of 1*N* H_2SO_4 and the supernate treated with a saturated solution of NaF. The resulting LaF_3 precipitate was filtered, washed, and the gross decay followed using an end-window beta counter.

The number of component half-lives that could be resolved from the gross decay data of such a La fraction was quite large. The several La isotopes produced and their Ba daughters, some with similar half-lives, made a unique analysis of the decay curves almost impossible. As is shown in Table I, analyses can be made which are consistent with either the earlier data of Preiss and Strudler on Ba activities[2] or the data of Sheline *et al.*[1] on La activities.

The analysis of the gross decay of the Ba fractions milked from La parents proved less ambiguous. The following chemical procedure was employed in milking Ba from La: The In target was dissolved, Ba separated, and LaF_3 precipitated as described above. The LaF_3 was dissolved in a 4:1 mixture of $HNO_3+H_3BO_3$. 10 mg of Ba as $Ba(NO_3)_2$ was added to the La solution followed by 2 ml 1*N* H_2SO_4. The $BaSO_4$ precipitate was filtered, washed, and the gross beta decay followed. Subsequent

TABLE I. Components resolved from the gross beta decay of La chemical fraction ($In+O^{16}$ 66.4 MeV).

$T_{1/2}$ exp.	Probable assignment	$T_{1/2}$ lit.	Ref.
2.43 days	Ba^{128}	2.45 days	a
5.5 to 6.2 h	Cs^{127}	6.25 h	2, a
2 h	Ba^{126} and	103 min	2
	Ba^{129}	150 min	4
40 to 50 min	Cs^{125}	49 min	2, a
11 min	Ba^{127} and/or	10.0 min	2
	La^{130}	9.5 min	1
7 min	Ba^{125} and/or	6.5 min	2
	La^{128}	6.5 min	1
1 to 3.5 min	Ba^{123} and/or	2.3 min	2
	La^{126} of	1 min	1
	complex mixture		

[a] *Nuclear Data Sheets* (National Academy of Sciences, National Research Council, Washington, D. C.); W. H. Sullivan, Trilinear Chart of Nuclides (U. S. Atomic Energy Commission) (U. S. Government Printing Office, Washington, D. C., 1957).

TABLE II. Components resolved from Ba fraction milked from chemically separated La($In+O^{16}$ 66.4 MeV).

$T_{1/2}$ exp.	Assignment	$T_{1/2}$ lit.	Ref.
2.43 days	Ba^{128}	2.45 days	b
6.2 h	Cs^{127}	6.25 h	2, b
1.6 to 2.5 h	$Ba^{126}+Ba^{129}$	103 min+150 min	2, b
49 min	Cs^{125}	49 min	2, b
10 min	Ba^{127}	10.0 min	2
6–7 min[a]	Ba^{125}	6.5 min	2

[a] Due to low intensity relative to Ba^{127}, the presence of Ba^{125} was confirmed through observation of its daughter Cs^{125} (see text).
[b] See reference a, Table I.

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[1] R. K. Sheline, T. Sikkeland, and R. N. Chanda, Phys. Rev. Letters 7, 446 (1961).
[2] I. L. Preiss and P. M. Strudler, J. Inorg. & Nucl. Chem. (to be published).
[3] In the absence of prior scavenging as $BaSO_4$, it is not inconceivable that these abundantly produced Ba isotopes could be precipitated by LaF_3, leading to their misassignment as La isotopes. N. E. Bellou, *Radiochemical Studies: The Fission Products*, edited by N. Sugarman and C. D. Coryell (McGraw-Hill Book Company, New York, 1951), Paper No. 242, National Nuclear Energy Series, Plutonium Project Record, Vol. 9.

TABLE III. Mass assignments for La isotopes.

Daughter activity	$T_{1/2}$ daughter	Parent	$T_{1/2}$ parent (min) Raw data	Corrected	Sheline *et al.*[a]
Ba^{128}	2.4 days	La^{128}	3.7±0.5	4.2±0.5	6.5±0.5
Ba^{129} plus	120 min	La^{129}	6.2±0.5	7.2±0.5	...
Ba^{126}		La^{126}	1.0±0.3	1.0±0.3	1.0±0.3
Ba^{127}	10 min	La^{127}	3.5±0.5	3.8±0.5	...
Cs^{127}	6.2 h	La^{127}	3.5±0.5	3.8±0.5	...
Ba^{125} Cs^{125}	see text	La^{125}	<1 min	<1 min	...

[a] See reference 1.

Ba milkings were performed (6 in all) at 2-min intervals. In separate experiments the chemical yield of Ba as $BaSO_4$ was found to be reproducible at 85±5%. A small but constant fraction, 3.5±0.5%, of the La was coprecipitated with each milking.

The gross decay curves found in each Ba fraction could be resolved into the component half-lives listed in Table II. A plot of the initial activity of each of these Ba components against the time of milking is given in Fig. 1. The slope of such a plot corresponds to the half-life of the La parent and the intercept at the time of bombardment is a measure of its relative yield.

Conclusions on the half-lives and identities of the parent lanthanum isotopes are summarized in Table III. The "raw data" column shows half-lives taken from plots as given in Fig. 1. These were subjected to a small correction for the coprecipitation of La with the $BaSO_4$ milkings. The results presented in Table III represent data obtained from a total of four complete milking experiments.

Assignment of La^{127} was made on the basis of the Ba^{127} daughter decay and further confirmed using the Cs^{127} granddaughter. La^{128} was identified through Ba^{128}. La^{126} and La^{129} have Ba daughters sufficiently similar in half-life to make their resolution difficult. The sum of the activities of these Ba daughters at the time of milking is plotted in Fig. 1. This curve can be resolved into 1.0- and 6.2-min components. The shorter half-life is assigned to La^{126}, it being the expectation that this more neutron-deficient odd-odd isotope has a shorter half-life than the odd-even La^{129}. Some support for this assignment derives from the fact that in the later milkings the half-life of the Ba^{126}-Ba^{129} component tends towards that of the Ba^{129} alone.

The high counting rate of 10-min Ba^{127} and the relatively large number of components in the gross decay curve, made direct observation of 6-min Ba^{125} and a half-life assignment for its parent difficult. An upper limit of 1 min can be set, however, on the basis of the granddaughter Cs^{125} which could be detected in the first two milkings.

It is interesting that the Ba activities, and their La parents listed in Table III, were observed from O^{16} bombardments at both 168 and 66 MeV. This emphasizes the difficulty of making mass assignments of neighboring isotopes on the basis of predicted threshold energies.

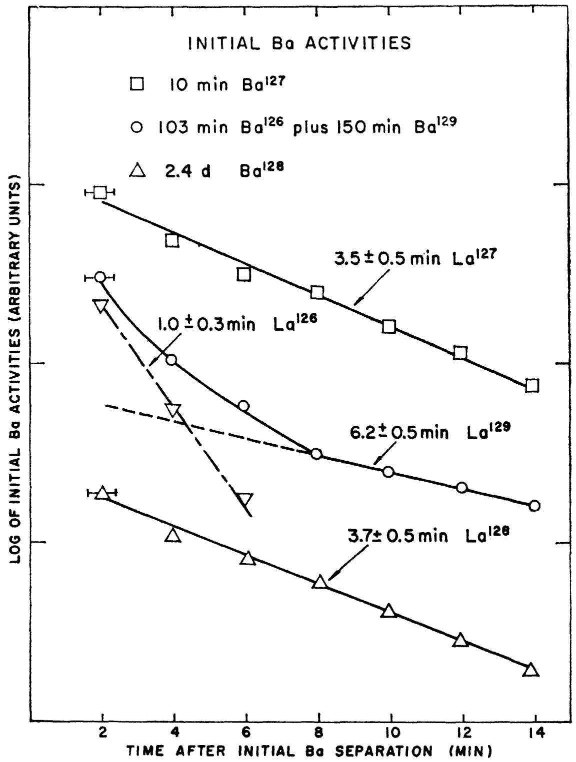

FIG. 1. Initial activity of Ba isotopes milked from lanthanum chemical fraction plotted vs time interval between milkings. Typical of data for the In(O^{16},xn)La reaction at 66.4 MeV. Errors in time are ±15 sec for all but the initial milking point where the error is shown by error bars. Data presented are uncorrected for depletion of parent. Results of the first milking are not included.

Evidence for a new region of nuclear deformation was provided in the earlier work[1] by the observation of gamma rays from what appear to be rotational states of even-even Ba isotopes populated by decay of La^{126}, La^{128}, and La^{130}. From Table III it appears, however, that the 279-keV gamma ray originally assigned to La^{128} has a half-life closer to that of La^{129} than to La^{128}. In the apparent absence of a firm assignment of this gamma ray in the original work,[4] the possibility thus arises that it is not due to decay of a rotational level. We therefore feel that at the present time further experimental definition of the possible new region of nuclear deformation would be desirable.

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[4] In a private communication, R. K. Sheline reports that the 279-keV gamma ray has been associated with a rotational band. This would support its assignment to La^{128}.