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PROLATE DEFORMATION IN NEUTRON-DEFICIENT LANTHANUM ISOTOPES[*]

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Abstract:

The odd-A La isotopes from A = 125 to 137 have been studied by in-beam γ-ray spectroscopy of Sn(^{14}N,xn)La reactions and from A = 131 to 139 by particle spectroscopy of the Ba(α,t)La and Ba(τ,d)La single-proton transfer reactions. In the latter experiments a low-lying $11/2^-$ level was systematically identified, and the rotational bands built on these levels were observed in the γ-ray work. The strong resemblance of the transition energies in these bands to the ground-band transitions in the neighbouring even Ba isotopes is very striking. These results can be understood as a decoupling of an $h_{11/2}$ single proton from the Ba core. This interpretation of the observed bands requires a prolate deformation for these nuclei, which is in contrast to previous conclusions.

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The neutron-deficient odd-A lanthanum isotopes extend from the N = 82 closed shell downwards into a region of deformation[1] which has not been extensively investigated experimentally. However, there have been several theoretical studies which predict oblate deformation or the coexistence of different shapes for the nuclei in this region.[2,3] Of particular interest are the properties of the energy levels associated with the unique-parity $h_{11/2}$ shell-model state, and a low-lying $11/2^-$ isomer in ^{129}La, identified by Alexander *et al.*,[4] has been interpreted as evidence of oblate shape. Similar conclusions were also made in other investigations of nearby Cs isotopes.[5,6]

In the present work the odd-mass lanthanum isotopes have been studied by in-beam γ-ray spectroscopy of the ^{116,118,120,122}Sn(^{14}N,xnγ) reactions[7] and by the (α,t) and (τ,d) single-proton transfer reactions on the even-mass $^{130\text{ to }138}$Ba targets.[8] Combining the two complementary experiments it was possible to identify systematically the low-lying unique-parity levels in the odd-mass nuclei $^{125\text{ to }139}$La.

The initial aim for the γ-ray studies was to populate the rotational band built on the $11/2^-$ isomer in ^{129}La using the ^{118}Sn(^{14}N,3n)^{129}La reaction. However, instead of the relatively complex spectrum expected for a rotational band in an odd-A nucleus, only a few transitions were observed. By γ-γ

coincidence and γ-ray angular distribution measurements the transitions were identified as members of a stretched E2 cascade which strongly resembled that of the ground band of the neighbouring doubly-even nucleus ^{128}Ba (Fig. 1). The 104- and 67-keV transitions in the isomeric decay reported by Alexander et al.[4] were observed in the spectrum between the beam bursts with almost the same intensities as that of the lowest transition in the cascade. The $11/2^-$ state was assigned as the lowest member of the band on the basis of this intensity relation. The assignment is also strongly supported by the systematics established below for the other odd-A La isotopes. Of the total observed prompt γ-ray intensity more than 90% populates the $11/2^-$ level through the rotational band. The remaining γ-rays were quite weak and no attempt has been made to place them in the level scheme.

Similar characteristic stretched E2 cascades were also observed in the other La isotopes with mass numbers from A = 125 to 137. In all cases the energies of the cascade transitions were very close to the ground band transitions in the neighbouring Ba isotopes (Fig. 1). Since no delayed transitions were observed in ^{125,127}La it may be possible that the E2 cascade feeds the ground state in these nuclei.

Since the $11/2^-$ assignment for the state at the bottom of the stretched E2 cascade was not always unambiguous, detailed studies were made which included the transitions that de-excite the $11/2^-$ isomeric states. Additional information was obtained from a study of γ-transitions following β-decay of Ce isotopes produced by Sn(O^{16},xn)Ce reactions. These studies, together with data in the literature, yielded the level schemes shown in Fig. 1.

Finally, the $11/2^-$ states were independently located in the isotopes $^{131-139}$La by (α,t) and (τ,d) single proton transfer reactions. In these experiments isotopic barium targets (50 to 200 $\mu g/cm^2$ thick, $\geqslant 95\%$ enriched) prepared in a mass-separator by deposition onto carbon backing were bombarded with beams of 27 MeV alphas and 22 MeV ^3He particles from the Niels Bohr Institute Tandem accelerator. The reaction products were analyzed in a magnetic spectrograph. The different momentum matching of the two reactions is used to determine the ℓ-transfer; the ratio of cross sections populating the same state, $\sigma(\alpha,t)_{45^\circ}/\sigma(\tau,d)_{30^\circ}$, decreases by a factor of approximately two per each unit decrease in ℓ-value. In each nucleus a strongly populated level could clearly be identified as having $\ell = 5$ transfer from this cross section ratio. Spin 11/2 is inferred since no $9/2^-$ strength is expected in this energy region. The triton spectra from the (α,t) reaction, which favors high angular-momentum transfer, are shown in Fig. 2. They clearly demonstrate the systematic appearance of the $11/2^-$ level. In addition, essentially only the low-lying $7/2^+$ and $5/2^+$ states, which contain large spectroscopic strengths, are populated in this reaction, whereas the (τ,d) spectra (not shown here) exhibit a much larger number of levels, in particular for the lighter-mass La isotopes. The present $11/2^-$ assignments agree with previous identifications for $^{139,137}La$, and all other assignments are fully in accord with the results from the γ-ray studies.

Relative normalization of the cross sections measured in the five isotopes was obtained in a separate experiment using a mixed target of known isotopic composition and, independently, by measuring the elastically scattered particles. Using the Q-dependence of the transfer cross sections calculated from the DWBA with standard optical-model parameters, it was found that the spectroscopic strength of the $11/2^-$ levels decreases regularly towards the lighter La-isotopes; in ^{131}La the strength is approximately 40% of the near unity spectroscopic factor found in ^{139}La (Ref. 9). This decrease was obtained independently from the (α,t) as well as from the (τ,d) data.

The experimental results found can be summarized as follows: 1) in the $^{125-139}$La nuclei 11/2$^-$ levels have been identified; 2) the in-beam γ-ray cascade leading to the 11/2$^-$ state consists of stretched E2 transitions, indicating a band with the spin sequence 11/2, 15/2, 19/2, ...; 3) the spacings of this band are closely similar to those of the ground band of the even-even Ba core; 4) the spectroscopic factors of the 11/2$^-$ levels decrease regularly with mass number; and 5) the 11/2$^-$ state monotonically drops from ~ 1.42 MeV in ^{139}La to perhaps becoming the ground state in ^{125}La.

An explanation for all these features is provided by a model consisting of a single particle coupled to an axially-symmetric rotating core.[10,11] The essential point is that under certain conditions a new coupling scheme may develop. In this case it is most advantageous for a nucleus to align the angular momentum of the high-j particle parallel with the rotor axis so as to minimize the value of the rotor spin for a given value of the total angular momentum, I. The aligned particle then acts as if it were decoupled from the core, and so the yrast levels will have the spin sequence, j, j + 2, j + 4, ..., and the energy spacings will be the same as those of the doubly-even core. Such a band will have precisely the features found above for the 11/2$^-$ bands in the odd-mass La nuclei, and very different properties than would be expected from either a strong- or weak-coupling scheme.

To produce such a band, a necessary requirement is that the Fermi surface be near the $\Omega = 1/2$ Nilsson orbital. In the present case of the La isotopes, $Z = 57$, this can only be true if the nuclei are prolate. If they were oblate, the Fermi surface would be near the $\Omega = 11/2$ level, and only a normal $\Omega = 11/2$ rotational band would result, with a level sequence having spins 11/2, 13/2, 15/2, ... Hence, in disagreement with earlier workers,[4-6] we conclude that the odd-mass La nuclei are prolate, not oblate.

FOOTNOTES AND REFERENCES

[*] Work performed under the auspices of the U. S. Atomic Energy Commission.

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1. R. K. Sheline, T. Sikkeland, and R. N. Chanada, Phys. Rev. Letters 7, 446 (1961).
2. K. Kumar and M. Baranger, Phys. Rev. Letters 12, 73 (1964).
3. D. A. Arseniev, L. A. Malov, V. V. Pashkevich, A. Sobiczewski, and V. G. Soloviev, Jadernaya Fis. 8, 833 (1968).
4. K. F. Alexander, W. Neubert, H. Rotter, S. Chojnacki, C. H. Droste, and T. Morek, Nucl. Phys. A133, 77 (1967).
5. J. M. D'Auria, H. Bakhru, and J. L. Preiss, Phys. Rev. 172, 1176 (1968).
6. T. W. Conlon, Nucl. Phys. A161, 289 (1971).
7. J. R. Leigh, K. Nakai, K. H. Maier, F. Pühlhofer, F. S. Stephens, and R. M. Diamond, Lawrence Berkeley Laboratory Report LBL-1601 (Jan. 1973), and to be published.
8. P. Kleinheinz, G. Løvhøiden, and K. Nakai, to be published.

9. B. H. Wildenthal, E. Newman, and R. L. Auble, Phys. Rev. C 3, 1199 (1971).

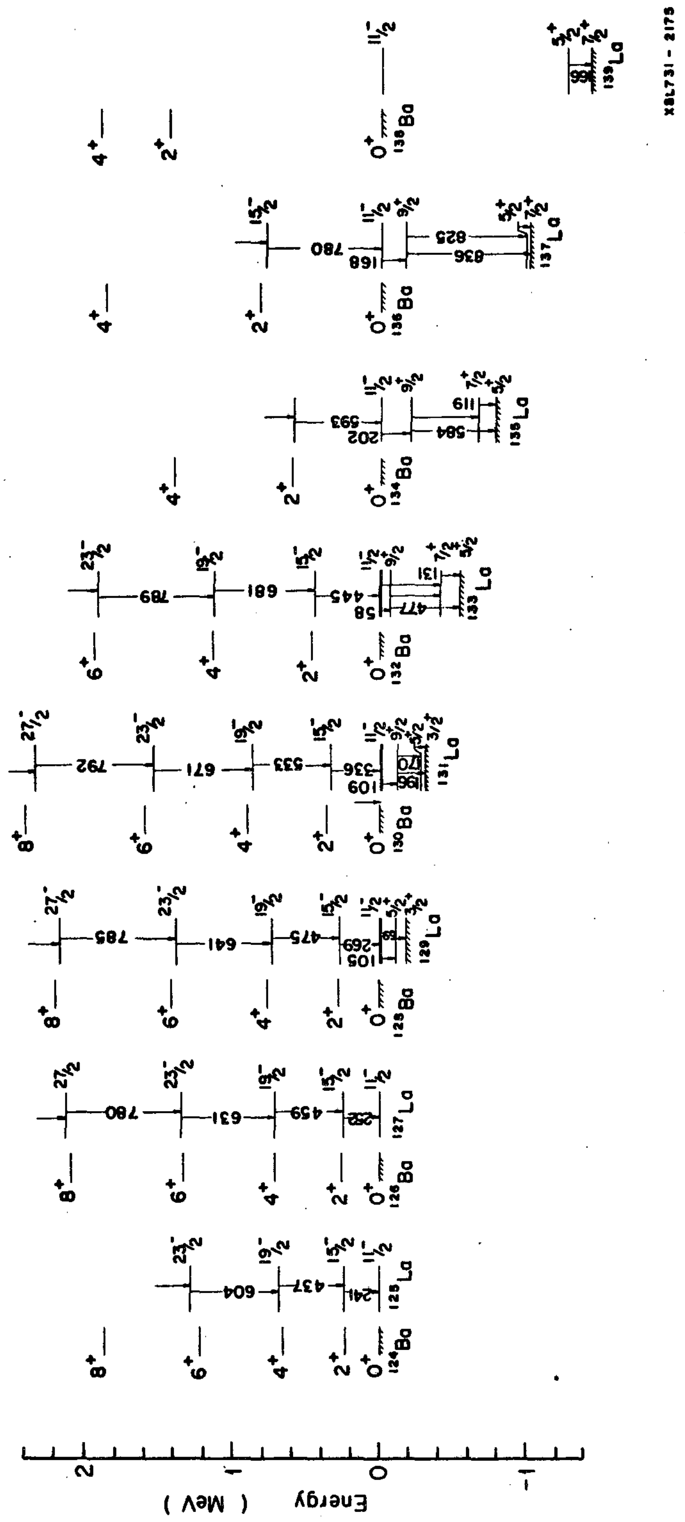
10. F. S. Stephens, R. M. Diamond, J. R. Leigh, T. Kammuri, and K. Nakai, Phys. Rev. Letters 29, 438 (1972).

11. P. Kleinheinz, S. M. Harris, G. Løvhøiden, and K. Nakai, Bull. Am. Phys. Soc. II, Vol. 17 (1972) 898, and to be published.

FIGURE CAPTIONS

Fig. 1. Partial level schemes of the odd-mass $^{125-139}$La nuclei and the neighbouring even-mass Ba-isotopes.

Fig. 2. Triton spectra of the (α,t) reactions on the even-mass Ba targets.


Energy (MeV)
2
1
0
-1
^{124}Ba
^{125}La
^{126}Ba
^{127}La
^{128}Ba
^{129}La
^{130}Ba
^{131}La
^{132}Ba
^{133}La
^{134}Ba
^{135}La
^{136}Ba
^{137}La
^{138}Ba
^{139}La
0+
2+
4+
6+
8+
11/2-
15/2-
19/2-
23/2-
27/2-
9/2+
7/2+
5/2+
3/2+
241
437
604
252
459
631
780
105
269
475
641
785
109
336
533
671
792
170
166
58
445
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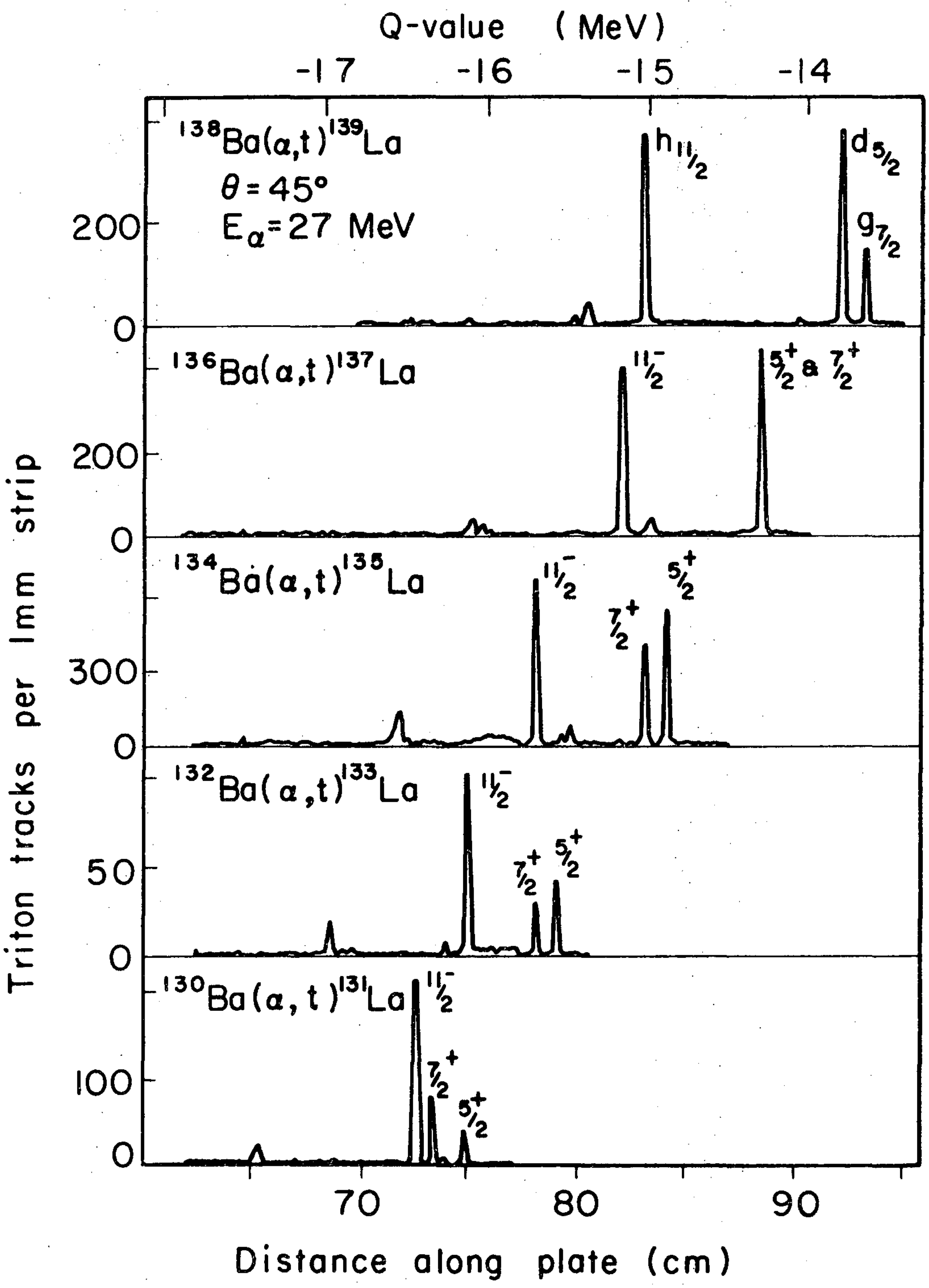
789
477
131
202
593
584
119
168
780
836
825
166
XBL731-2175

Fig. 1



XBL731-2176

Fig. 2

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