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COLLECTIVE EXCITATIONS IN ^{125}Ba

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Abstract. High-spin levels in ^{125}Ba have been produced in the ^{116}Sn(^{12}C, 3n) reaction and studied by in-beam spectroscopic methods. Two strongly populated band structures are observed. The odd-parity one is based on a $7/2^-$ state and can be explained as the result of the coupling between an $h_{11/2}$ neutron-hole and a prolate type triaxial core. The even -parity band, built on a $7/2^+$ state, corresponds to collective excitations associated with a neutron-hole in the $g_{7/2}$ shell. Comparisons with heavier odd-A Ba isotopes and discussions are made in the frame work of the triaxial core model.

NUCLEAR REACTIONS ^{116}Sn(^{12}C,3nγ), E = 45 - 55 MeV ; measured σ(E ; E_γ,θ), $\gamma\gamma$-coinc, γ-γ delay. Enriched target, Ge(Li) detectors. ^{125}Ba deduced levels, J, π,γ-mixing.

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1. INTRODUCTION

Studies of transitional nuclei [1] have brought new insights in the knowledge of nuclear structure. The best example is given by the rotation-alignment model developed by Stephens [2] which is essentially based on the Coriolis interaction and applies to moderately deformed nuclei. Further theoretical developments [3 -6] have led to a better understanding of nuclear properties of transitional nuclei.

In our systematic work on odd-A Ba isotopes by means of (Heavy Ions, $xn\gamma$) reactions, we have shown [7] that the level structure of these transitional nuclei can be successfully explained by the triaxial-rotor-plus-particule model [3]. Studies on ^{127}Ba (ref.8) and ^{125}Ba have been made to know how properties of a triaxial rotor vary when one goes towards more neutron-deficient nuclei. Indeed, the level structure is very sensitive to the Fermi energy and to the β and γ deformation parameters.

Preliminary data on high spin levels in ^{125}Ba, populated in the ^{116}Sn(^{12}C,3n) reaction, have already been reported [9]. Detailed results and discussions are given here. Only few and contradictory informations were known before our investigation : D'Auria et al. [10] associate two activities of 3.0 ± 0.5 min and 8 ± 1 min half-lives to ($11/2^-$ or $9/2^-$) or ($3/2^+$ or $1/2^+$) levels, respectively, and propose the odd-parity level as the ground state while Arlt et al. [11] assign $I^\pi = 1/2^+$ and a half-life of $T_{1/2}$ = 3.5 ± 0.4 min to this ground level in ^{125}Ba.

2. EXPERIMENTS

The experiments were carried out with the external carbon beam of the Grenoble variable energy cyclotron. The target of 2mg/cm^2 was made with metallic tin enriched to 84.4% in ^{116}Sn and deposited on a 25 µm lead foil.

The excitation functions, were studied at 45, 49, 51 and 55 MeV. The singlesspectra were recorded during and between the beam bursts with planar and coaxial Ge(Li) detectors. The energies of γ-lines listed in column 1 of Table 1 were obtained by recording simultaneously the γ-rays emitted by the target and ^{133}Ba, ^{152}Eu and ^{177m}Lu sources. Energies of lines observed in the ^{125}Ba → ^{125}Cs → ^{125}Xe → ^{125}I decay chain have also been used as an internal calibration. The energy uncertainty for strong lines is smaller than 100 eV up to 500 keV and of the order of 200 or 300 eV for higher energy lines.

A γ-γ coincidence experiment and the angular distribution measurements of γ-rays were made at 54 MeV, energy which corresponds to the maximum of the cross-section of the (^{12}C, 3n) reaction. The prompt and delayed γ-γ coincidence events were obtained with two coaxial Ge(Li) detectors having an efficiency of 10% and 6% and a resolution of 2.1 and 2.4 keV at 1.33 MeV, respectively. Half-lives of levels can be deduced from timing against the beam-bursts.

The angular distributions of γ-rays were measured at seven angles (0°, 15°, 30°, 45°, 60°, 75° and 90° relative to the incident beam). Precise values of the angular distribution coefficients A_{22}/A_0 and A_{44}/A_0 were thus obtained and are tabulated in columns 3 and 4 of Table 1.

3. EXPERIMENTAL RESULTS

Several families of γ-rays show up in the γ-spectra (Fig.1) and have been assigned mainly on the basis of excitation functions and studies of decay spectra. With this procedure, lines belonging to ^{126}Ba and to the A = 125 decay chain are easily identified. It was however more difficult to separate γ-rays of ^{125}Ba from those of ^{125}Cs, because the cross-sections and excitation functions of the (^{12}C,3n) and of the (^{12}C, p2n) reactions are similar. Nevertheless, physical reasons have finally led to well established level schemes of both ^{125}Ba and ^{125}Cs nuclei [12].

There are strong analogies between the level structure of ^{125}Ba, ^{127}Ba and ^{129}Ba. The last two nuclei have been previously studied [7, 8]. Therefore, only a few specific points relative to ^{125}Ba will be presented or discussed here.

The γ-γ coincidence spectra reveal the existence of two groups of γ-rays (Fig.2). In the more intense one, which contains about 70% of the total intensity of discrete γ-lines observed in the singles spectra, two cascades of transitions (233-451-604-731-826 and 99-134-272-670) are identified. These transitions are stretched E2 and M1 + E2, respectively. By comparison with heavier Ba isotopes, this group of level is assigned as the odd-parity system generated from the $h_{11/2}$ neutron shell. A new feature appears in the level scheme of ^{125}Ba shown in Figure 3. It is appearance of a $I^\pi = 7/2^-$ level as the base state. The ΔI = 2 sequence $7/2^- \to 11/2^- \to 15/2^-$ .... corresponds to the yrast cascade.

Almost all the rest of the γ-intensity is spread over a ΔI = 1 band, the levels of which are de-excited by M1 + E2 transitions with large negative A_{22} coefficients and by strong stretched E2 transitions. There is a striking analogy with the $g_{7/2}$ band in ^{127}Ba.

This $7/2^+$ band in ^{125}Ba is depopulated by an intense γ-ray of 168.6 keV which has A_{22}^{exp} and A_{44}^{exp} angular distribution coefficients equal to -0.30 ± 0.02 and 0.06 ± 0.02, respectively. Such values agree with an M1 multipolarity. Linear polarization measurements of γ-ray in ^{125}Ba have been performed [13]. In spite of the poor statistics in the coincident spectra and of the low energy of the γ-ray, the magnetic character of this 168.6 keV line appears as the most probable. The level fed by this M1 transition is very likely a $5/2^+$ state which is a base state, but does not belong to the even-parity band. This is very easily proved by means of the 385 keV cross-over transition which has a very weak intensity compared to the one of the 546 keV, $13/2^+ \rightarrow 9/2^+$ and 672 keV, $17/2^+ \rightarrow 13/2^+$ transitions.

4. DISCUSSION

Analysis of the data and discussions are given in this section for both odd- and even-parity levels. Comparisons are made with neighbouring nuclei.

4.1. *Odd-parity levels*

As we have already shown and discussed for other odd-A Ba, Ce and Nd nuclei, this group of levels can be understood as the result of the coupling of $h_{11/2}$ neutron-holes with a prolate type triaxial core.

The base state of the $h_{11/2}$ level system is $11/2^-$ for ^{133}Ba and $9/2^-$ for $^{127-131}$Ba. The new feature which appears in ^{125}Ba is the existence of a $7/2^-$ level (Fig.4). It is the result of the penetration of the Fermi surface into the $h_{11/2}$ shell. From the level systematics, the variations of the position of the Fermi surface can be expected to be the following : when one goes from A = 133 to A = 131, the Fermi surface has dropped from the $11/2^-$ to the $9/2^-$ orbitals ; it goes below the $9/2^-$ orbital and across the $7/2^+$ [401] orbital of the $g_{7/2}$ shell for ^{129}Ba and reaches the $7/2^-$[523] orbital for ^{125}Ba. From a comparison of the level energies, it appears that the Fermi surface has not greatly changed between A = 127 and 125. The existence of the $7/2^-$ state is well understood in terms of neutron-deficiency and the lowering of the levels relative to heavier isotopes is associated with a larger β deformation.

The level spectrum of ^{125}Ba exhibits a complex structure with two $15/2^-$, $19/2^-$ and $23/2^-$ states. The main deexcitation is made through parallel E2 cascades. Though the β deformation is large, these $(15/2)^-_2$, $(19/2)^-_2$ and $(23/2)^-_2$ levels are still easily observed. The variation of the position of the second $15/2^-$ level is interesting to look at in Fig. 4. It clearly indicates a decreasing γ deformation as one goes from A = 127 to A = 125. All the features observed in the systematics of figure 4 can be reproduced by the triaxial-rotor-plus-particle model [3].

It predicts two types of cascades between levels arranged in a two-dimensional pattern as observed experimentaly. In this model, the $7/2^-$, $9/2^-$ and $11/2^-$ levels are the base states of the $\tilde{\Omega}$ = j-2, j-1 and j subsystems, respectively. Due to the reaction mechanism involving heavy ions and to the close distance between these base states, only the $\tilde{\Omega}$ = j subsystem is strongly excited.

The deformation parameters associated with such a level spectrum are $\beta_0 = +0.28$ and $\gamma_0 = 17°$. Making this particular choice of rigid triaxial rotors, one observes that β_0 and γ_0 vary quickly for the $h_{11/2}$ system of odd-A Ba isotopes, as plotted in Fig.5. In fact, the minimum of the potential energy surfaces in these nuclei is not strongly pronounced and β_0 and γ_0 could be considered as mean values around which the shape fluctuates.

4.2. Even-parity levels

The $g_{7/2}$ band observed in ^{129,127}Ba is found in ^{125}Ba but weakly excited. This $\Delta I = 1$ sequence has spacings almost equal to those in ^{127}Ba (Fig.6) which agrees with a very small change of the Fermi energy. The position of this band relative to the ground state and to the $7/2^-$ level is unknown but its $7/2^+$ base state is deexcited by a strong 168.6 keV transition which very likely feeds a $5/2^+$ state. The band built on this $5/2^+$[402] state is unobserved because its levels lie probably at too high energies relative to the ones of the $g_{7/2}$ band.

The $g_{7/2}$ band is generated from a neutron-hole in the $g_{7/2}$ shell. Its level energies follow roughly a rotational law, as shown in Fig.6, where the straggling appears to be weak but, in fact, experimental energy values and branching ratios are better reproduced by a triaxial core model.

5. CONCLUSION

The main features observed in the level spectrum of odd-A $^{133-127}$Ba are still present in ^{125}Ba and the systematics indicates, as expected, an increasing β deformation towards lighter isotopes.

Different theoretical approaches are able to explain properties of the unique parity level structures observed in transitional nuclei. The rigid triaxial core model developed by Meyer-ter-Vehn [3] and improved by inclusion of softness via a VMI prescription [4] reproduces rather well level energies, transition probabilities and mixing ratios. This model has been successfully applied in the A $\approx$ 130 mass region which we are considering here. Calculations using anharmonic vibrator models [5,6] have been done mainly for heavier transitional nuclei and are in agreement with experimental data. Using results in the Ba region, a wider range of applicability of these models could perhaps be obtained.

ACKNOWLEDGMENTS

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REFERENCES

[1] Stephens, F.S., Diamond, R.M., Leigh, J.R., Kammuri, T., Nakai, K. : Phys. Rev. Lett. 29, 438 (1972).

[2] Stephens, F.S. : Rev. Mod. Phys. 47, 43 (1975).

[3] Meyer-ter-Vehn, J. : Nucl. Phys. A249, 111 (1975).

[4] Toki, H., Faessler, A. : Nucl. Phys. A253, 231 (1975).

[5] Alaga, G., Paar, V. : Phys. Lett. 61B, 129 (1976).

[6] Dönau, F., Hagemann, U. : Nucl. Phys. A256, 27 (1976).

[7] Gizon, J., Gizon, A., Meyer-ter-Vehn, J. : Nucl. Phys. A277, 464 (1977).

[8] Gizon, J., Gizon, A. : Zeit. Phys. A281, 99 (1977).

[9] Gizon, J. Gizon, A. : Proc. of Congrès de la Société Française de Physique Poitiers, June 1977, p. 240.

[10] D'Auria, J.M., Bakhru, H., Preiss, I.L. : Phys. Rev. 172, 1176 (1968).

[11] Arlt, R., Jasinski, A. Neubert, W., Ortlepp, H.G. : Acta Physica Polonica, B6, 433 (1975).

[12] Yoshikawa, N., Gizon, J., Gizon, A. : Proc. Int. Conf. on Nuclear Structure, Tokyo (1977) p. 361.

[13] Lee, Y.K., Elliott, D.O., Gizon, A., Gizon, J. : unpublished data

TABLE 1 : Transitions of ^{125}Ba observed in the reaction ^{116}Sn(^{12}C, 3n)^{125}Ba at 5[illegible] MeV.

[illegible]	I_γ(125°) relative	A_{22}^{exp}	A_{44}^{exp}	δ = <E2>/<M1>	Multipolarity or E2 percentage	I_{Total} relative	Assignment
[illegible]	1314 (70)	-0.493 (40)	-0.04 (6)	-1.97 ⩽ δ ⩽ -1.46 or -0.46 ⩽ δ ⩽ -0.29	68 - 79.5 or 8 - 17.5	3610 (265) or 2830 (210)	$9/2^- \rightarrow 7/2^-$
[illegible]	1374 (70)	-0.592 (16)	0.067 (14)	-2.25 ⩽ δ ⩽ -0.274	7 - 84	2150 (240)	$11/2^- \rightarrow 9/2^-$
[illegible]	1290 (64)	-0.297 (19)	0.057 (19)	-	(M1)	1740 (110)	$7/2^+ \rightarrow (5/2^+)$
[illegible]	349 (24)	-0.341 (47)	0.021 (46)	-4.00 ⩽ δ ⩽ -1.94 or -0.38 ⩽ δ ⩽ -0.12	79 - 94 or 1.5 - 12.6	427 (37)	$15/2^- \rightarrow 13/2^-$
[illegible]	30 (7)	-	-	-	M1 + E2	36 (12)	$23/2^- \rightarrow 21/2^-$
[illegible]	66 (11)	-	-	-	M1 + E2	78 (20)	$19/2^- \rightarrow 17/2^-$
[illegible]	356 (25)	-0.586 (42)	0.048 (38)	-2.71 ⩽ δ ⩽ -2.29 or -0.23 ⩽ δ ⩽ -0.176	84 - 88 or 3 - 5	400 (30)	$9/2^+ \rightarrow 7/2^+$
[illegible]	238 (28)	-0.165 (78)	0.09 (10)	-	E2	265 (32)	$11/2^- \rightarrow 7/2^-$
[illegible]	306 (21)	-0.498 (63)	0.014 (59)	-4.36 ⩽ δ ⩽ -2.38 or -0.25 ⩽ δ ⩽ -0.071	85 - 95 or 0.5 - 6.0	330 (25)	$11/2^+ \rightarrow 9/2^+$
[illegible]	779 (70)	-0.742 (10)	0.095 (6)	-1.73 ⩽ δ ⩽ -0.82	40 - 75	827 (43)	$13/2^- \rightarrow 11/2^-$
[illegible]	80 (13)	-0.43 (15)	0.05 (14)	-	M1 + E2	95 (14)	$13/2^+ \rightarrow 11/2^+$
[illegible]	113 (18)	-0.555 (61)	0.094 (53)	-4.71 ⩽ δ ⩽ -2.57 or -0.25 ⩽ δ ⩽ -0.087	87 - 96 or 0.75 - 5.9	123 (20)	$15/2^+ \rightarrow 13/2^+$
[illegible]	70 (17)	-0.41 (16)	0.27 (15)	-7.0 ⩽ δ ⩽ -1.94 or -0.39 ⩽ δ ⩽ -0.05	79 - 98 or 0.10 - 13	72 (18)	$17/2^+ \rightarrow 15/2^+$

.../...

TABLE 1 (cont.)

E (keV)	I_γ(125°) relative	A_{22}^{exp}	A_{44}^{exp}	$\delta = \langle E2\rangle/\langle M1\rangle$	Multipolarity or E2 percentage	I_{Total} relative	Assignment
[illegible]	30(6)	0.047 (147)	-0.01 (18)	-	(E2)	30(6)	$9/2^+ \rightarrow (5/2^+)$
[illegible]	385(20)	0.283 (32)	-0.034(47)	-	E2	392(20)	$13/2^- \rightarrow 9/2^-$
[illegible]	349(28)	-0.385 (47)	-0.04 (8)	$-2.84 \leq \delta \leq -1.88$ or $-0.42 \leq \delta \leq -0.10$	78 - 89 or 1 - 15	356(30)	$17/2^- \rightarrow 15/2^-$
[illegible]	1000(50)[a]	0.197 (25)	0.017(33)	-	E2	1013(51)	$15/2^- \rightarrow 11/2^-$
[illegible]	[illegible](35)	0.359 (44)	-0.080(68)	-	E2	293(35)	$11/2^+ \rightarrow 7/2^+$
[illegible]	[illegible](36)	-0.014 (40)	-0.076(50)	-	(b)	240(36)	$13/2^+ \rightarrow 9/2^+$; $21/2^- \rightarrow 19/2^-$
[illegible]	314(47)	0.225 (27)	-0.060(38)	-	E2	316(47)	$19/2^- \rightarrow 15/2^-$
[illegible]	311(47)	0.354 (74)	-0.07 (13)	-	E2	313(47)	$17/2^- \rightarrow 13/2^-$
[illegible]	241(36)	0.253 (21)	-0.09 (3)	-	E2	242(36)	$23/2^- \rightarrow 19/2^-$
[illegible]	561(84)	0.256 (54)	0.02 (9)	-	E2	561(84)	$19/2^- \rightarrow 15/2^-$
[illegible]	165(13)	0.383 (52)	0.07 (15)	-	E2	165(13)	$15/2^+ \rightarrow 11/2^+$
[illegible]	130(30)	0.10 (12)	-0.02 (14)	$0.11 \leq \delta \leq 0.40$	1.3-13.5	130(30)	$19/2^- \rightarrow 17/2^-$
[illegible]	146(29)	-0.360 (35)	-0.043(35)	$-7.69 \leq \delta \leq -0.045$	0.2-98.3	146(29)	$25/2^- \rightarrow 23/2^-$
[illegible]	257(39)	-0.430 (28)	0.168(47)	$-3.0 \leq \delta \leq -2.45$ or $-0.25 \leq \delta \leq -0.19$	85.7-90.0 or 3.5-5.9	257(39)	$15/2^- \rightarrow 13/2^-$
[illegible]	168(33)	0.259 (17)	0.044(59)		E2	168(33)	$17/2^+ \rightarrow 13/2^+$
[illegible][b]	[illegible](40)	0.353 (47)	-0.01 (7)		E2	330(40)	$19/2^+ \rightarrow 15/2^+$
[illegible]	[illegible](48)	0.194 (14)	-0.026(21)		E2	400(48)	$23/2^- \rightarrow 19/2^-$

TABLE 1 (cont.)

[illegible]	$I_\gamma(125°)$ relative	A_{22}^{exp}	A_{44}^{exp}	$\delta = \langle E2\rangle/\langle M1\rangle$	Multipolarity or E2 percentage	L_{Total} relative	Assignment
[illegible]	227 (27)	0.221 (24)	-0.037 (33)		E2	227 (27)	$21/2^- \rightarrow 17/2^-$
[illegible]	147 (29)	0.346 (40)	-0.02 (6)		E2	147 (29)	$27/2^- \rightarrow 23/2^-$
[illegible]	64 (12)	0.175 (81)	-0.01 (11)		E2	64 (12)	$25/2^- \rightarrow 21/2^-$

[illegible] intensities are normalized to this line

[illegible] [illegible]posite line

FIGURE CAPTIONS

Fig. 1 - Gamma-ray spectrum observed with a coaxial detector at 90° to the beam in the $^{116}Sn + ^{12}C$ reaction at 54 MeV. The asterisks indicate that the lines belong to ^{126}Ba. Triangles correspond to γ-rays in ^{125}Xe.

Fig. 2 - Examples of γ-γ coincidence spectra.

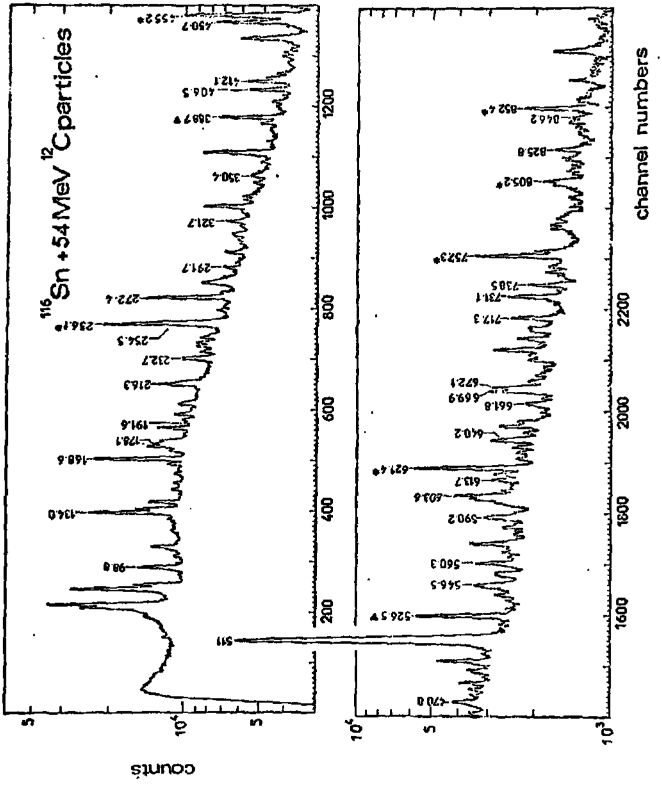
Fig. 3 - The $h_{11/2}$ level system in ^{125}Ba. The widths of the arrows are proportional to the total transition intensities.

Fig. 4 - The $h_{11/2}$ level systems in odd-A neutron deficient Ba isotopes. Not all levels are shown in this comparison. The energies are normalized such that the $11/2^-$ states are all set to zero.

Fig. 5 - Location of the $h_{11/2}$ level structures of odd-A Ba isotopes in a β-γ plane.

Fig. 6 - Comparisons of the $g_{7/2}$ bands in $^{125-129}Ba$.

Fig. 7 - Inverse moment of inertia of the $g_{7/2}$ band in $^{125-129}Ba$.



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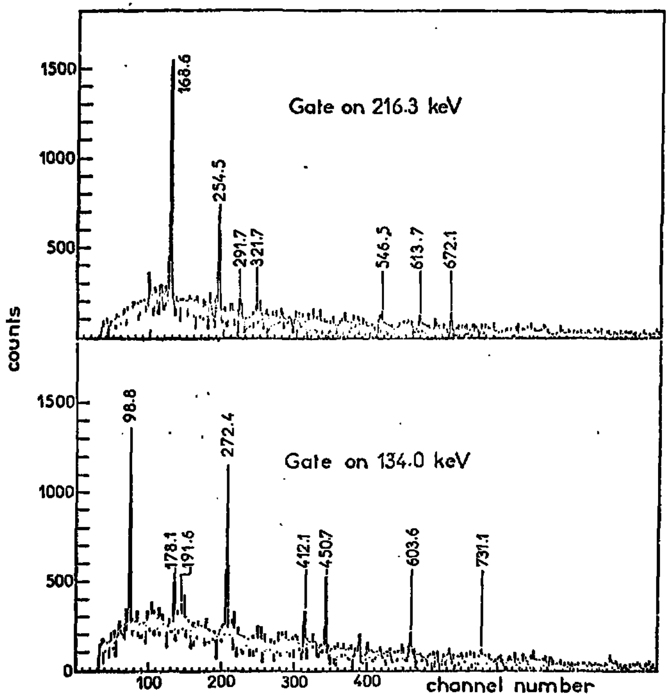

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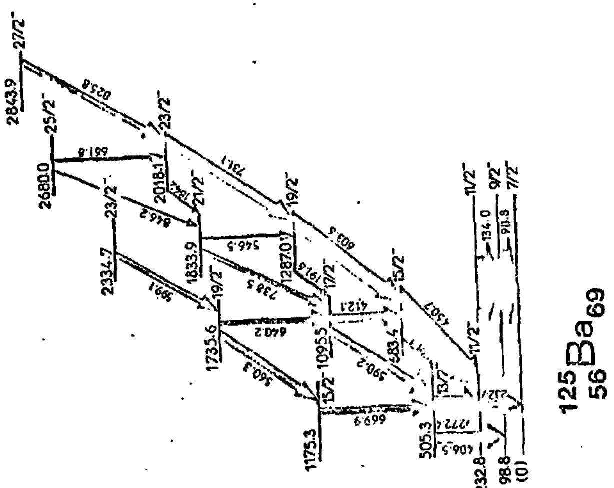


Fig. 3 - The $h_{11/2}$ level system in ^{125}Ba. The widths of the arrows are proportional to the total transition intensities.

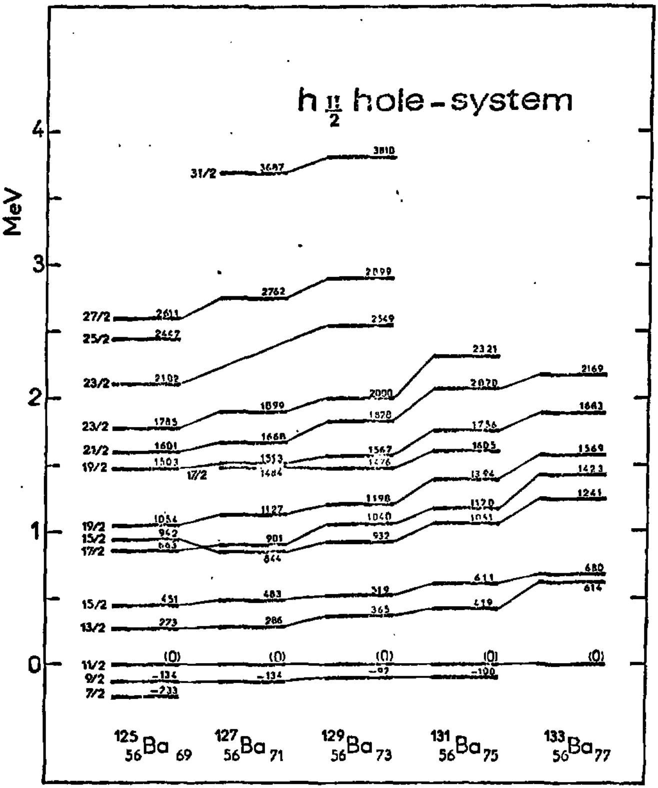
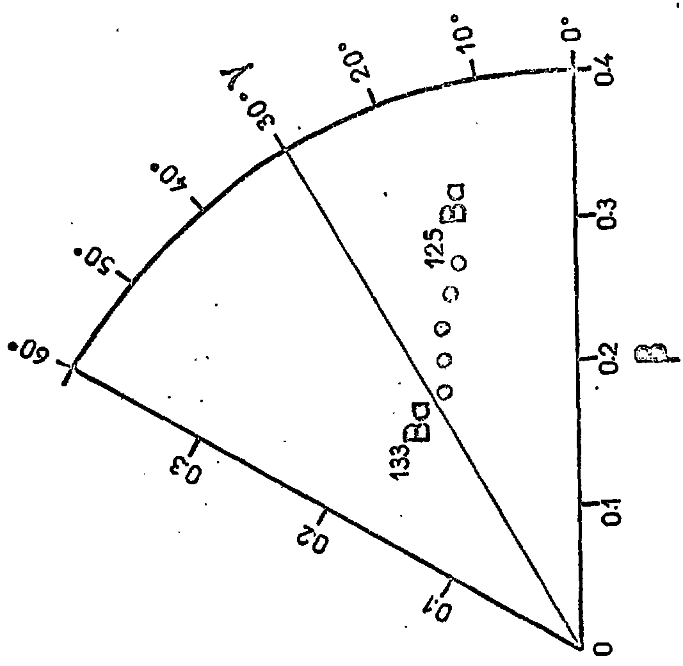


Fig. 4 - The $h_{11/2}$ level systems in odd-A neutron deficient Ba isotopes. Not all levels are shown in this comparison. The energies are normalized such that the $11/2^-$ states are all set to zero.



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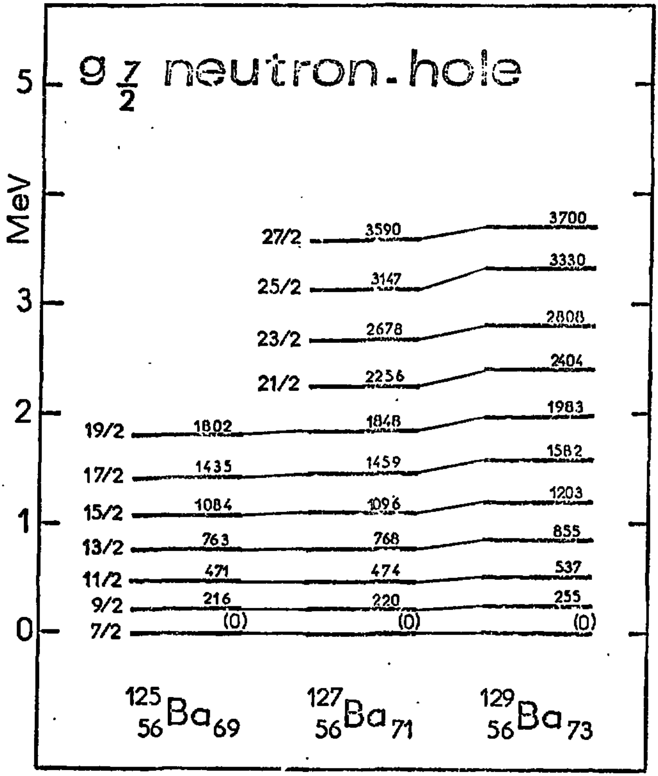

Fig. 6 - Comparisons of the $g_{7/2}$ bands in $^{125-129}Ba$.

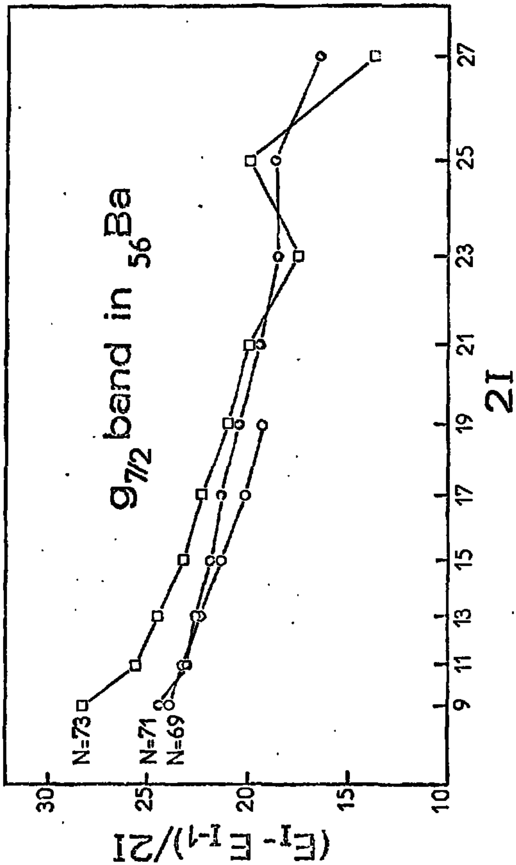

Fig. 7 - Inverse moment of inertia of the $g_{7/2}$ band in $^{125-129}$Ba.