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COLD SPONTANEOUS FISSION PROCESSES OF ^{252}Cf AND THE STRUCTURE OF NEUTRON RICH Ba AND La NUCLEI*

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Rare cold (zero neutron emission and low excitation energy) binary fission, cold α and ^{10}Be-accompanied ternary fission and cold fission with two neutrons emitted at scission and new nuclear structure effects have been observed in the spontaneous fission of ^{252}Cf. Evidence for stable octupole deformation in ^{143,144,146} Ba and ^{145,147}La are presented. The roles of rotation in both enhancing and quenching stable octupole deformation are observed. In ^{145}La one has a new class of shape coexistence with symmetric and asymmetric rotational bands.

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1 Introduction

Studies of the prompt gamma-rays emitted in spontaneous fission (SF) of ^{252}Cf and ^{248}Cm are providing a wealth of new insights into the fission process and the broad range of new structures of neutron rich nuclei (for example see [1–4]). Cold zero neutron emission processes can be considered as the ultimate examples of cluster radioactivity first predicted by Sandulescu and

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Greiner [5]. Our work on cold binary fission [6,7] is summarized including the first odd Z,A- odd ZA cold SF. Ternary hot fission, with the third fragment being an α particle has been known for a long time [8]. We have made the first measurements of the yields of correlated pairs in cold α ternary fission [9] and carried out theoretical calculations [10]. The total yields of cold ternary fission also have been reported recently [11]. Very recently we made the first yield measurement of the correlated pairs in cold ^{10}Be SF [12]. Finally we present evidence for the first example of cold fission (here meaning very low energy neutrons) with two neutron emission at scission [13] and compare the yield with the known hot 2n SF yields [14]. These rare processes give new insights into the fission process and its relationship to the theory of the multifragmentation of nuclei.

Likewise, many new insights into the structure of neutron rich nuclei have been gained from SF studies [1-4]. In this paper we consider only the evidence for stable octupole deformation in ^{143,144,146} Ba and ^{145,147}La. The experimental procedures are described elsewhere [1,3].

2 Cold binary processes

Since the neutronless binary yields are much smaller than those with neutrons emitted, double gating techniques are necessary to extract the yields either for cold binary or ternary fission. Earlier we reported the first results for the correlated pairs in cold binary fission in ^{252}Cf [6,7] and ^{242}Pu [15]. Subsequently we have extracted more detailed yields of cold binary fission as reported here. Two methods were used to extract yields.

In method 1, the cold (neutronless) binary fragmentations and 1 to 6 neutron evaporation channels were studied by setting double gates on the $2^+ \to 0^+$ and $4^+ \to 2^+$ transitions in an even-even fragment (e.g. heavy or light) and then measuring the intensities of the $2^+ \to 0^+$ transitions in the correlated fragments (e.g. light or heavy). In method 2 the yields are determined, for example, by setting double gates on the $2^+ \to 0^+$ transition in ^{146}Ba and $2^+ \to 0^+$ transitions in the Mo isotopes and using the $4^+ \to 2^+$ transition in ^{146}Ba as a measure of the relative yields. The cold binary fission yields are shown in Table I along with our theoretical values based on a cluster model similar to the one-body model used for the description of cluster radioactivity [7]. The trends, e.g. variations with A and Z, of the theoretical yields are in good agreement with the experimental yields. All even Z, odd A-odd A pairs are predicted to be larger than the even A - even A pairs and this is observed in every case. Moreover the largest theoretical yield is predicted for the odd Z - odd Z ^{109}Tc-^{143}Cs and this is true within experimental errors.

3 Cold ternary fission

While hot ternary fission has been known for a long time, with the third particle generally being an α particle [8], cold ternary fission has not been directly observed in terms of the correlated pairs until our work [9]. Meutter and coworkers [11] have extracted total yields for ternary SF. In the case of cold (neutronless) alpha ternary fission of ^{252}Cf, one looks at the correlation between two even-Z fragments with the sum of charges Z=96 and sum of masses A=248. For example, $^{146}_{56}$Ba and $^{102}_{40}$Zr are the partners when a ternary α -particle is involved. The ^{248}Cm was negligible in our source. In Fig. 1, gating on a transition in ^{146}Ba and ^{102}Zr, one sees the 151.8 keV ($2^+ \to 0^+$) transition in ^{102}Zr, and (4^+ - 2^+) in ^{146}Ba to establish cold α-ternary SF. The inset in Fig. 1 shows the region around 151.8 keV (^{102}Zr) transition. By moving either gate 5-10

Table I. Average cold binary fission yields

	A_L / A_H	Y_{exp}	Y_{the}	$Y_{the}^{(ren)}$
Zr / Ce	100/152	0.010(2)	0.38	0.004
	102/150	0.020(4)	2.82	0.033
	103/149	0.030(6)	4.21	0.049
	104/148	0.010(2)	1.03	0.012
Mo / Ba	104/148	0.010(2)	0.47	0.005
	105/147	0.040(8)	5.39	0.063
	106/146	0.040(8)	0.61	0.007
	107/145	0.070(14)	3.07	0.036
	108/144	0.030(6)	7.45	0.087
Tc / Cs	109/143	0.090(18)	11.03	0.128
Ru / Xe	110/142	0.060(12)	3.78	0.044
	111/141	0.10(2)	7.12	0.083
	112/140	0.020(4)	0.59	0.007
	114/138	0.020(4)	1.17	0.014
Pd / Te	116/136	0.050(20)	2.35	0.027

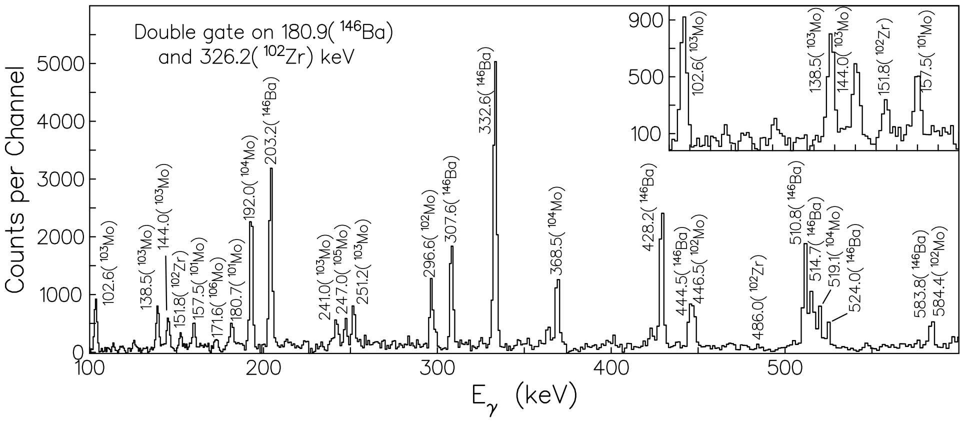

Fig. 1. The spectrum is obtained with a double gate set on the $2^+ \to 0^+$ transition at 180.9 keV in ^{146}Ba and on the $4^+ \to 2^+$ transition at 326.2 keV in ^{102}Zr. The clear peak at 151.8 MeV corresponds to the $2^+ \to 0^+$ transition in ^{102}Zr. A number of transitions in ^{146}Ba are seen because of the 324.2 keV ^{146}Ba transition in the gate.

keV either way, the 151.8 keV transition disappears so it is not from some background effect. These and similar spectra clearly demonstrate that one has observed for the first time correlated pairs in cold α -ternary SF.

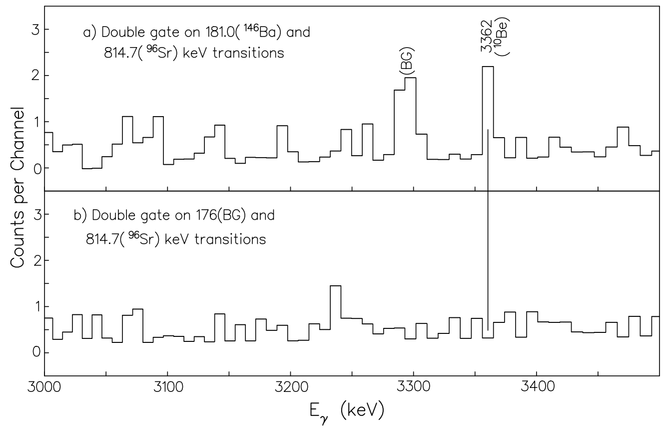

Fig. 2. a) Coincidence γ-ray spectrum obtained by double gatting on the 814.7, $2^+\rightarrow 0^+$ transition in ^{96}Sr and 181.0 keV, $2^+\rightarrow 0^+$ transition in ^{146}Ba. b) Coincidence γ -ray spectrum obtained by double gatting on the 814.7, $2^+\rightarrow 0^+$ transition in ^{96}Sr and on 176.0 keV background peak, which is shifted from 181.0 keV $2^+\rightarrow 0^+$ transition in ^{146}Ba. BG : Background.

In Table II, the first cold neutronless alpha ternary fission yields for correlated pairs are given. The theoretical yields [10] normalized to the total experimental yields shown in columns 3 and 6 of Table II in general, are in good agreement with the experimental yields.

The experimental odd-*A* - odd-*A* SF yields are higher than the yields for the even-even neighbors, as found theoretically. The differences may be related to the differences in level densities near the ground states in odd-odd and even-even nuclei. The enhanced experimental yields for the cold α -ternary fission in which the heavier partners are Ba isotopes could be attributed to the static octupole deformation reported in this region, since octupole shapes at the scission configuration could significantly lower the Coulomb barrier and increase the penetrability between the final fragments.

Next we searched for cold neutronless ternary fission with the third particle being a heavier cluster such as ^{10}Be. Contrary to α-ternary SF with α excited state energies >20 MeV so γ emission would not be seen, ^{10}Be has an excited 2^+ state 3.368 MeV. When setting a double gate on the $2^+\rightarrow 0^+$ 814.7 and 181.0 keV transition in ^{146}Ba and ^{96}Sr, respectively, we see the 977 keV transition in ^{96}Sr (Fig. 2) and a peak at ≈3368 keV (observed at 3362 keV). Assuming that the peak at 3362 keV is the $2^+\rightarrow 0^+$ transition in ^{10}Be, we set one gate on it and the other gate on the $2^+\rightarrow 0^+$ transition in ^{96}Sr. The coincidence spectra shows the 977.5 keV, $4^+\rightarrow 2^+$ transition in ^{96}Sr and the 181.0 and 332.6 keV peaks in ^{146}Ba. With a double gate on the 3362(^{10}Be) and 181.0(^{146}Ba) keV peaks, the 814.7 keV ($2^+\rightarrow 0^+$) transition in ^{96}Sr is seen. The yield for the ^{10}Be ternary process is obtained from the double gate on the 181.0 (^{146}Ba) and 814.7 keV (^{96}Sr) transitions. The yield to the first excited state of ^{10}Be is $\approx 4(2)\times 10^{-4}$ per 100 SF and to the ground state ≈ 0.

The major question is why is the 3362 keV line not Doppler broadened since the 2^+ state lifetime is 125 fs and the stopping time of ^{10}Be is 1250 fs. A non-Doppler shifted peak is also observed by Mutterer et al. [11] with NaI detectors in ^{10}Be ternary fission. One possible expla-

Table II. The alpha ternary isotopic yields Y_{exp} obtained per 100 fission events [9].

α Partner nuclei	Y_{exp} (%)	Y_{the}^{ren}	α Partner nuclei	Y_{exp} (%)	Y_{the}^{ren}
${}^{92}_{36}$Kr–${}^{156}_{60}$Nd	0.002(1)	0.002	${}^{96}_{38}$Sr–${}^{152}_{58}$Ce	0.008(3)	0.010
${}^{98}_{38}$Sr–${}^{150}_{58}$Ce	0.014(6)	0.017	${}^{99}_{38}$Sr–${}^{149}_{58}$Ce	0.018(9)	0.016
${}^{100}_{38}$Sr–${}^{148}_{58}$Ce	0.021(10)	0.027	${}^{101}_{38}$Sr–${}^{147}_{58}$Ce	0.014(11)	0.010
${}^{100}_{40}$Zr–${}^{148}_{56}$Ba	0.038(12)	0.017	${}^{101}_{40}$Zr–${}^{147}_{56}$Ba	0.082(10)	0.058
${}^{102}_{40}$Zr–${}^{146}_{56}$Ba	0.009(4)	0.017	${}^{103}_{40}$Zr–${}^{145}_{56}$Ba	0.084(29)	0.050
${}^{104}_{40}$Zr–${}^{144}_{56}$Ba	0.017(8)	0.016	${}^{106}_{42}$Mo–${}^{142}_{54}$Xe	0.018(7)	0.031
${}^{107}_{42}$Mo–${}^{141}_{54}$Xe	0.030(14)	0.017	${}^{108}_{42}$Mo–${}^{140}_{54}$Xe	0.007(3)	0.014
${}^{112}_{44}$Ru–${}^{136}_{52}$Te	0.011(6)	0.028	${}^{116}_{46}$Pd–${}^{132}_{50}$Sn	0.006(3)	0.048

nation is that after ^{10}Be formation ^{96}Sr - ^{10}Be - ^{146}Ba form a nuclear molecule with ^{10}Be held in the potential well for a time $\approx 10^{-12}$ s during which it γ decays before breaking up into ternary SF. If this is true, many exciting new possibilities for molecular configurations and nuclear structures are opened up. We will gain further insight into this question, in our experiment with light charged particle detectors inside Gammasphere so we can gate on the LCP and triple fold γ rays.

Recently we have discovered evidence for a correlated pair in cold fission in which two neutrons are emitted from the neck presumably with low kinetic energy. Most neutrons emitted in fission process are evaporated isotropically from the accelerated primary hot fragments with an average kinetic energy of 2.34 (5) MeV [16]. Bowman et al. [16] reported that ≈10 % of the neutrons are emitted at 90° to the scission axis of the two fragments with an average kinetic energy of 0.39(6) MeV. Later Budtz-Jorgensen and Knitter [17] observed a much lower yield of 1.1(3) % for cold neutron emission. Continuing our work on rare ternary SF, we looked for cold fission with two neutrons emitted at scission.

The partial lower spin level schemes of ^{136}Te and ^{114}Pd are shown in Fig. 3. The transition intensities as observed in normal SF of ^{252}Cf are shown in parenthesis. In general, the 2^+ state in either nucleus is populated by discrete γ transitions (I_d) and by statistical γ rays (I_s) after normal fission where neutrons are evaporated so $I(2^+ \to 0^+) = I_s + I_d$. When cold 2n emission SF occurs, this equation will be $I(2-0) = I_s + I_d + i_c$ where i_c is the population of a particular state via cold fission with 2n emission at scission.

How can one extract i_c from the experimental data? For a typical level scheme as shown in Fig. 3, consider what happens for two partner nuclei, ^{136}Te and ^{114}Pd, with two cold neutron(s) emitted at scission in addition to normal hot fission. In Fig. 3, I_1, ... I_6 are the intensities of the transitions as shown in Fig. 3. The labels i_0, ... i_6 and i_0' ... i_6' are the population of the states from cold ternary fission when two neutron(s) are emitted. For a gate on the transition I_1, the ratio $R_1 = I(4^+ \to 2^+)/(2^+ \to 0^+) = I_4/I_3$. In this ratio, all the discrete and statistical transitions feeding and i_2 and i_4 (cold 2n fission) direct population of the 2^+ and 4^+ levels in ^{136}Te are included.

If only hot fission occurs, then any single gate or double gate on any two transitions in ^{136}Te will give the same relative γ-transition intensities in ^{114}Pd. Only if there is a second process like cold fission that populates only one or two low-lying states in these two partners will a double gate and single gate in ^{136}Te give different relative intensities in ^{114}Pd. So, if we see a difference in relative intensities in low spin states, there must be a second process that populates only low

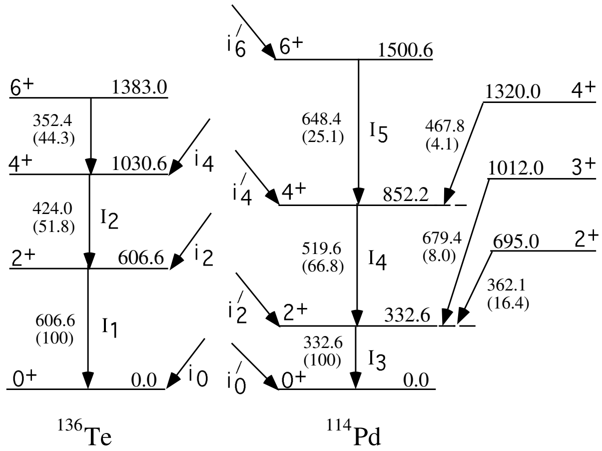

Fig. 3. Partial level schemes of ^{136}Te and ^{114}Pd.

spin states. Remember the neutrons come out first, leaving excited ^{136}Te-^{114}Pd which decay by γ-emission. So in any one process, every γ-ray in ^{136}Te is in coincidence with every γ-ray in ^{114}Pd and there is no difference in single and double gates. To show that normal side feeding in ^{136}Te from hot fission is not responsible for the difference, we looked at the $8 \to 6$ - $6 \to 4$ and $6 \to 4$ - $4 \to 2$ double gates (where the 8^+, 6^+, and 4^+ states have quite different side feedings compared to the 2^+ state but presumably no cold neutron emission feedings). In both these double gates, the ^{114}Pd intensities are the same as in the $4 \to 2$ - $2 \to 0$ double gate, to show the difference is not related to side feeding.

For a double gate on the transitions I_1 and I_2, the ratio R_1 will be modified to: $R_2 = (I_4 - \Delta I_{24} - \Delta I_{26})/(I_3 - \Delta I_{22} - \Delta I_{24} - \Delta I_{26})$. Terms like ΔI_{24} represent the coincidence intensity to the 4^+ state in ^{114}Pd because of the population of the 2^+ state in ^{136}Te in the cold 2n ternary SF process. Since i_2 is excluded in the double gate, the intensity of I_4 will be reduced by the corresponding coincidence intensities like ΔI_{24} and ΔI_{26}. Similarly, I_3 also will be reduced. In the single and double gates, one also has: $R_1' = I(6^+ \to 4^+)/I(2^+ \to 0^+) = I_5/I_3$ and $R_2' = (I_5 - \Delta I_{26})/(I_3 - \Delta I_{22} - \Delta I_{24} - \Delta I_{26})$. Without i_c (i_2) feeding the 2^+ state directly, the ratios R_1 and R_2 are equal. If there is cold fission with two neutrons emitted at scission, these two ratios will be different, and similarly for R_1' and R_2'.

The relative γ -ray intensities of the transitions in ^{114}Pd and ^{112}Pd were determined for the above gates. The observed ratios $R_1, R_2, {R_1}'$ and R_2' for ^{136}Te and ^{114}Pd are 0.67(5), 0.55(4), 0.25 (2) and 0.43(3) respectively. These yield $R_2 < R_1$ and $R_2' > R_1'$ which indicate that the dominant correlation is from ΔI_{24}. From these data and the above equations, we obtain an average value of $\Delta I_{24}/I_3 = 0.34$ [11]. From this value and the total yield for the 2n channel (normal + cold) 0.18 per 100 SF events the yield for the cold fission with 2n emission is 0.06 per 100 SF events. From the coincident intensities of the 606.6 and 424.0 keV transitions in ^{136}Te when the gates were set on the 2^+ - 0^+ and 2^+ - 0^+ plus 4^+ - 2^+ transitions in ^{114}Pd, there is negligible correlation between the 2^+ state in ^{114}Pd and the 2^+, 4^+ or 6^+ states in ^{136}Te with 2 neutrons emitted. Moreover, we detected no spin correlation between ^{136}Te and ^{112}Pd with 4 neutrons emitted so there is no cold 4n SF. Since ^{114,116}Pd are deformed and ^{136}Te with N=84 should be spherical and ^{138}Te with N=86 deformed, the cold binary fission more easily proceeds via deformed ^{138}Te and deformed ^{114}Pd as two fragments rather than through deformed ^{116}Pd and spherical ^{136}Te. These several new cold SF processes provide significant insight into the cold rearrangement of clusters of nucleons and multifragmentation.

4 Stable octupole deformation in ^{143,144,146}Ba and ^{145,147}La

Stable octupole deformation may be induced in nuclei where the Fermi level lies between single particle orbitals of the type $< N, L, j >$ and $< N+1, L+3, j+3 >$ (e.g., $p_{3/2}$ -$g_{9/2}$, $d_{5/2}$ -$h_{11/2}$, $f_{7/2}$ -$i_{13/2}$, etc.), because such orbitals couple strongly through the octupole potential term Y_{30} [18,19]. Evidence for stable octupole deformation is found in Xe, Ba, and Ce nuclei centered around Z=56, N=88 [1,3,20-24] as theoretically expected. We first consider the evidence in ^{143,144,145}Ba and then look at new results for ^{145,147}La. Of particular importance will be the role of nuclear rotation in enhancing stable octupole deformation as the nuclear rotation increases in some cases and quenching ($\beta_3 \rightarrow 0$) of stable octupole deformation as the nuclear rotation increases in other cases as theoretically predicted [25]. In ^{145}La bands built on both symmetric and asymmetric shapes are observed for the first time [21,26,27].

In our first report, new high spin states in $^{142-146}$Ba, and the first evidence for octupole deformation in an odd-A nucleus in this region in N=87, ^{143}Ba were found [20]. From our 1995 Gammasphere data, we extracted new insights into the importance of stable octupole deformation in these nuclei as well as ^{140,148}Ba and also Xe and Ce nuclei [3,21]. Our new level schemes for ^{143,144,146}Ba are shown in Fig. 4. Similar level schemes were simultaneously extracted from Eurogam II data in SF of ^{248}Cm [23,24]. Recently we have added new insights in ^{143}Ba. Important contributions of Urban et al. [23] and Jones et al. [24] were the establishment of the spins and parities of many levels assigned earlier on systematics in the even- and odd-A Ba isotopes from directional correlation and polarization measurements.

A striking feature seen in Fig. 4 is the intertwined $E1$ transitions between the positive and negative parity bands to quite high spin in ^{144}Ba but not continuing above 10^+ in ^{146}Ba. These $E1$ transitions are strongly enhanced in ^{142,144}Ba with $B(E1) \sim 1 \times 10^{-3}$ W.u. to give evidence for stable octupole deformation. However $B(E1) \sim 5 \times 10^{-6}$ W.u. in ^{146}Ba even when seen. This drop in $E1$ strength in ^{146}Ba was first noted by Phillips et al. [22]. In the moments of inertia for $^{142-148}$Ba, one sees in ^{146}Ba a backbend in J_1 and a sharp rise and drop in J_2 above 10^+ that is not seen in ^{142,144,148}Ba where only smooth upbends are seen. Cranked shell model calculations for the Ba-Ce nuclei indicate that around N=88 (^{144}Ba) at intermediate spins stable octupole deformation increases and the octupole minima are much better separated (see Fig. 5) [25]. In ^{144}Ba, where there is no backbend in J_1, the new data to 16^+ indicate no reduction in the $E1$ strength for these higher spins compared to the lower spin states. In fact, the average D_0 values are significantly larger for the higher spin states than for the lower spin states, to indicate rotation enhances the stable octupole deformation in ^{144}Ba in agreement with theory. A shape transition towards $\beta_3 = 0$ is predicted in ^{146}Ba at frequencies above 0.3 MeV (Fig. 5) after the alignment of $\nu i_{13/2}$ and $\pi h_{11/2}$ pairs [25]. The new data for ^{146}Ba show the ground band is crossed above 10^+ (Fig. 4), and no intertwined connecting transitions are seen above 10^+. These data [3,20,21] provided the first evidence for the theoretical prediction of the vanishing of β_3 with increasing rotation above $\hbar\omega = 0.3$ MeV.

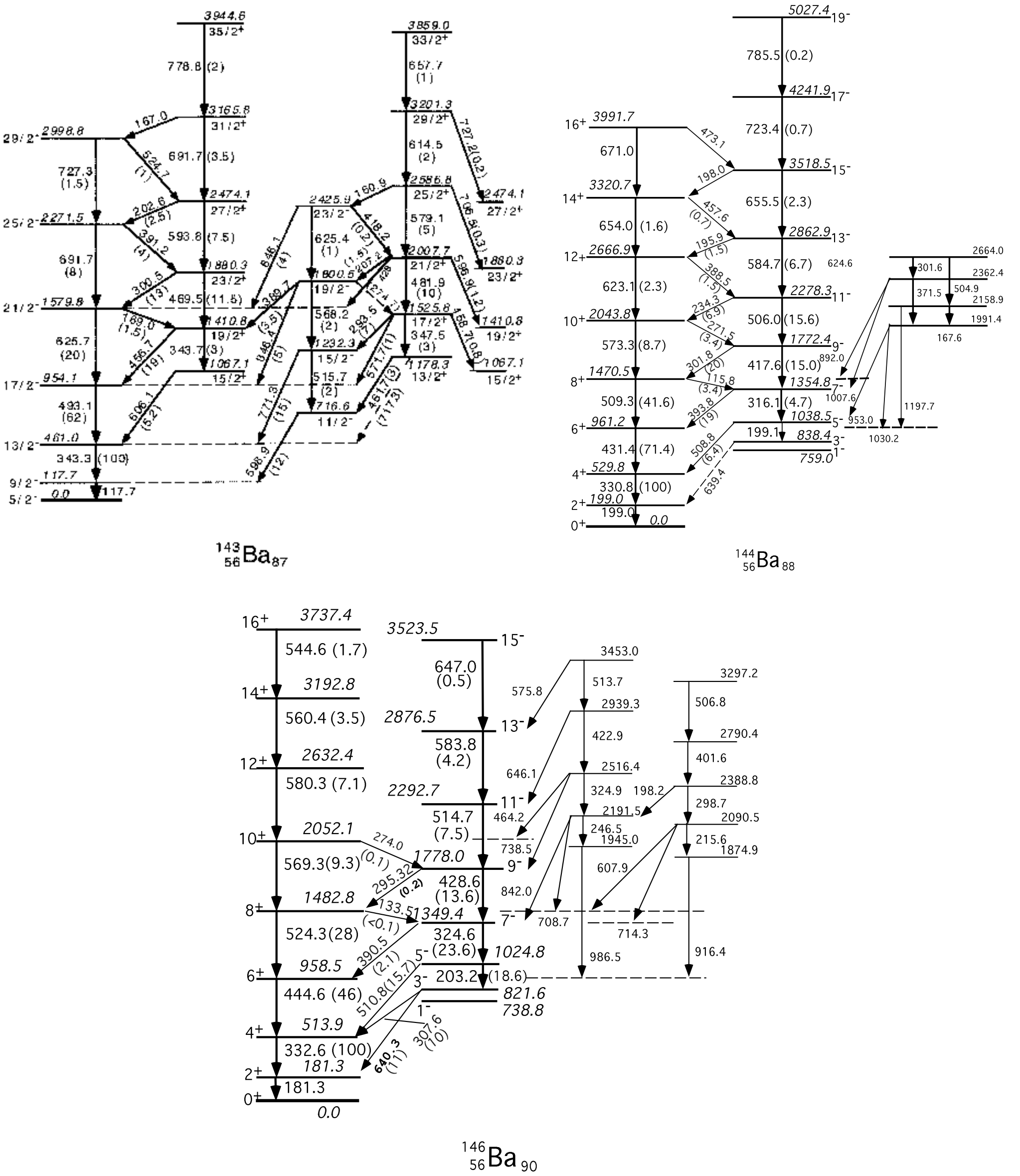

Fig. 4. Level schemes for ^{143,144,146}Ba.

When reflection asymmetric stable octupole deformation occurs in odd-A nuclei, the level patterns are similar to rotational bands in reflection-asymmetric molecules including two pairs of parity doublets with the same spins but opposite parities in each doublet, the simplex $s = i$ and $-i$ doublets [28]. Each doublet pair is intertwined by enhanced $E1$ transitions. The first two,

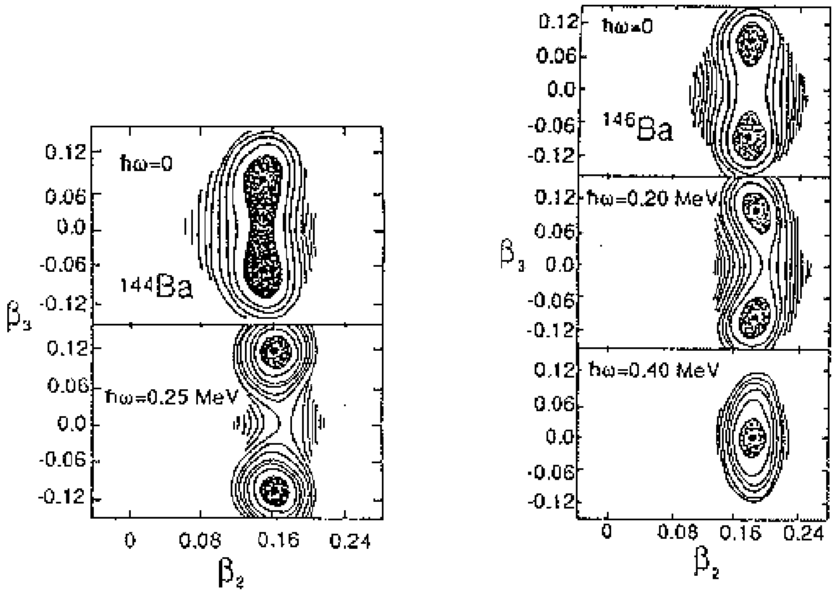

Fig. 5: Cranked shell model calculations for Ba.

$E1$ intertwined opposite parity bands were observed in an odd-A nucleus in this region in ^{143}Ba [20] (Fig. 4) and were interpreted as the $s = -i$ members of the expected doublet pairs. Jones et al. [24] found the $s = i$ doublet pair with the same spins but opposite parities. Our newer data [3,21] likewise show both parity doublets. $B(E1) \sim 1 \times 10^{-3}$ W.u. for the $s = -i$ doublet and ~ 0.4 x 10^{-3} W.u. for the new $s = i$ doublet, values similar to those in^{144}Ba. In addition, in our most recent work we find three new $E1$ crossing transitions and five new presumably $M1$ transitions between the $s = i$ and $-i$ bands which were not reported in ref. 23. These $E1$ and $M1$ transitions between the two doublets measure the degree of mixing of the $s = i$ and $-i$ doublets. The levels of ^{145,147}Ba are strikingly different from those of ^{143}Ba [1,3] with their ground bands having quite different structures with no evidence for stable octupole deformation. This change between ^{143}Ba and ^{145}Ba is surprising since the ^{145}Ba core, ^{144}Ba has the strongest D_0's, most enhanced $E1$'s and largest $\beta_3 \sim 0.10$ in this region.

Neutron rich $^{145-147}$La with Z=57 and N=88,90 lie between the Ba(Z=56) and Ce(Z=58) nuclei where stable octupole deformation is reported. Thus, they are expected to be good candidates for octupole deformation. As our extensive study of these nuclei from ^{252}Cf SF was being completed [27], evidence for octupole correlations in $^{145-147}$La up to intermediate spins were reported from SF studies of ^{248}Cm [26]. However, evidence for stable octupole deformation was not conclusive up to the intermediate spins observed in that work [26], where levels to $31/2^-$, $17/2^+$, $23/2^+$, and $25/2^-$ were seen in bands labeled 1,3,4,5, in our Fig. 6. In ^{145}La Fig. 6, we established eleven new levels and twenty-two new γ transitions mostly at high spin and the parity change between bands -4 and -5 [27] beyond that of ref. 26. Particularly important is the discovery of a new high-spin band (2) with intertwined crossing transitions to band (1). In ^{147}La,

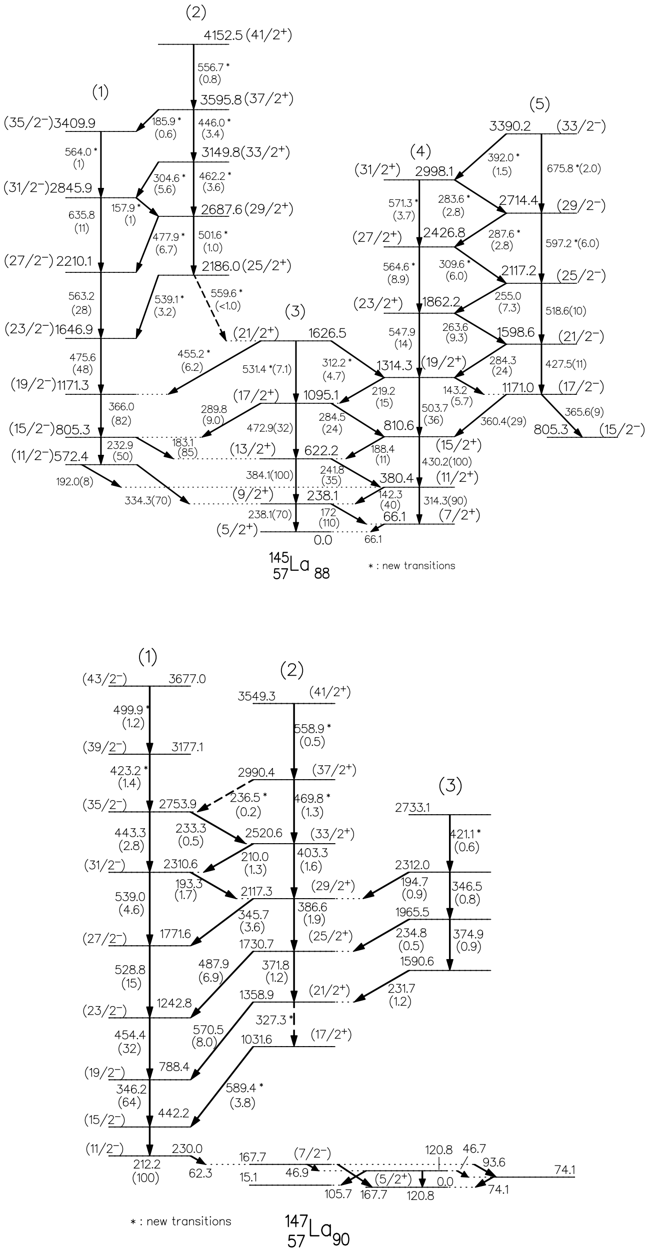

Fig. 6. Level schemes of ^{145,147}La.

Fig. 6 six new levels and nine new transitions primarily at high spins were identified.

Bands -3 and -4 in ^{145}La, from the ground state to I^{π} (19/2$^+$) or (21/2$^+$), form a strong-coupled band with well-deformed symmetric rotor shape. This strong-coupled ground band in ^{145}La is assigned a $\pi g_{7/2}$ configuration coupled to the ^{144}Ba core. This band is not seen in ^{147}La.

Band -4 shows a sharp upbend in J_1 at the 23/2$^+$ $\rightarrow$ 19/2$^+$ transition that is not seen in band -5 to suggest the 19/2$^+$ (or 23/2$^+$) to 31/2$^+$ levels are not a continuation of band -4. The large and remarkably constant eight $B(E1)/B(E2)$ ratios for bands -4 and -5 from 19/2$^+$ to 33/2$^-$ indicate a shift from a symmetric shape to an asymmetric octupole (or strong octupole correlation) shape around spin (19/2$^+$) in ^{145}La. The average of these ratios, 1.3 x 10^{-6} fm^{-2}, is nearly twice those found in its ^{144}Ba core and in the parity doublets in ^{143}Ba. This first evidence for bands built on a stable octupole asymmetric deformed shape (or with strong octupole correlations) coexisting with bands built on a symmetric deformed shape confirm the expectations of Nazarewicz [29] and Chasman [30] that octupole-deformed and reflection-symmetric shapes may occur in the same odd-*A* nucleus, depending on the properties of the single particle orbitals. For bands -1 and -3 at low spin and for bands -1 and -2 at high spin in ^{145}La, one sees quite different behavior. The low $B(E1)/B(E2)$ ratios for bands -1 and -3 indicate weaker octupole correlations, as noted earlier [26]. Our new band-2 seen at the higher spins and our extenstion of band-1 now give strong additional evidence for strong octupole correlation [21,27] for bands -1 and -2 at higher spin in ^{145}La. Similar behavior is seen in ^{147}La for bands 1 and 2. The bands 1 and 2 in ^{145,147}La assigned $s = +i$ are very similar in structure. A comparison of the $s = +i$ band levels in ^{145}La and ^{147}La with those of the *N*=88 and 90 isotones ^{144}Ba and ^{146}Ba shows that the energies of both the positive and negative bands between the isotones are remarkably similar to each other with backbends in ^{144}Ba, ^{145}La, and ^{146}Ba, ^{147}La at the same $\hbar\omega$. Thus, the $s = +i$ bands in ^{145}La and ^{147}La most probably originate from the single-particle $\pi h_{11/2}$ orbital coupling with the ^{144,146}Ba cores, respectively. It is quite interesting that at high spins, the $B(E1)/B(E2)$ ratios in the odd-*Z* ^{145}La and ^{147}La nuclei are larger than in the even-even cores, ^{144,146}Ba. In summary, in ^{145}La, a quadrupole ground state collective band with well-deformed symmetric shape coexists and competes with octupole deformed bands with asymmetric shape. Above spin 19/2 in ^{145,147}La, the asymmetric shape is rotation enhanced. This is the first observation for these structural characteristics in odd-*Z* nuclei in this region.

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