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OCTUPOLE EFFECTS IN THE LANTHANIDES

W. URBAN, T.RZĄCA-URBAN
Institue of Experimental Physics, Warsaw University,
ul. Hoża 69, 00-681 Warszawa, Poland (E-mail: urban@fuw.edu.pl)

W.R. PHILLIPS, J.L. DURELL, M.J. LEDDY, A.G. SMITH, B.J. VARLEY
Schuster Laboratory, Department of Physics and Astronomy,
University of Manchester, Manchester M13 9PL, UK

N. SCHULZ, M. BENTALEB, E. LUBKIEWICZ
Centre de Spectrometrie Nucleire et de Spectrometrie de Masse,
bat. 104, 91405 Orsay Campus, France

I. AHMAD, L.R. MORSS
Argonne National Laboratory, Argonne, IL 60439, U.S.A.

Arrays of Anti-Compton Spectrometers enabled systematic investigations of octupole correlations in the neutron-rich lanthanides. The studies mostly confirme the theoretical expectations of moderate octupole deformation at medium spins in nuclei from this region but in some cases predictions deviate from the experiment. In cesium isotopes strong octupole effects are predicted but not observed and new measurements for ^{139}Xe suggest octupole effects stronger than expected. Systematics of excitation energy of the 3_1^- states excitations, updated in the present work for Xe isotopes, indicates the N=85 and Z=54 lines as borders for strong octupole correlations. Systematics of electric dipole moment, upgraded in the present work for Cs and Ce isotopes confirms the Z=54 limit and adds new information about local canceling of electric dipole moment at the N=90 neutron number.

1 Fission and octupole deformation in the Lanthanides

Since the middle eighties experimental and theoretical evidence is growing in favour of the presence of strong octupole correlations in the neutron rich lanthanides. Many features characteristic of nuclei with octupole shapes are encountered here, though octupole deformation is not very pronounced and appears at medium spins, where it is enhaced by centrifugal forces. Examining a single nucleus or one particular property is usually not sufficient, when studying weak effects. Stronger evidence is obtained when more nuclear properties are examined for a number of nuclei in the region. Following the identification of enhanced octupole correlations in Ba [1] and Sm [2] isotopes, systematic studies of various effects associated with octupole deformation are now conducted in the region of neutron-rich lanthanides.

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The key problem is getting access to these nuclei. Fig.1 shows schematically the region of neutron-rich lanthanides. Only those nuclei which lie above and to the left of the dotted line can be produced in conventional compound-nucleus reactions. The remaining ones can be obtained as fission products[3]. The dashed line marks region of nuclei produced as secondary fragments (i.e. after neutron evaporation) in spontaneous fission of ^{248}Cm. It is obvious that the investigation of fission products is necessary for studying octupole deformation in the neutron-rich lanthanides, which is expected around the "octupole magic numbers" N=88 and Z=56.

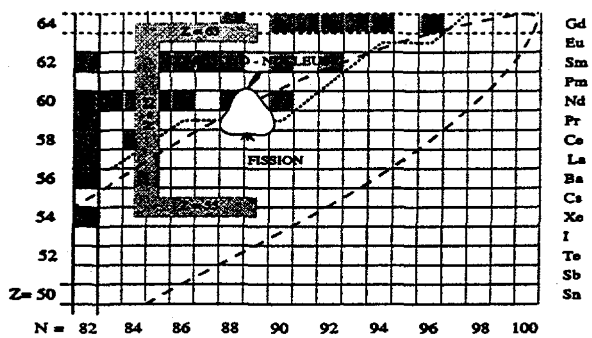

Figure 1. Region of neutron-rich lanthanide nuclei. Shaded boxes correspond to stable nuclei. See text for more explanations.

The studies of neutron-rich lanthanides were greatly facilitaded by the development of efficient arrays of Anti-Compton Spectrometers (ACS). The high resolving power of multiple-γ coincidences, collected with these arrays, enables searches for weak effects even in such complex experiments as measurements of prompt γ-rays following fission. An important advantage of such measurements over studies employing mass separators to select nuclei of interest, is a possibility to study medium-spin states in secondary fission fragments, where the octupole deformation is expected.

Early ACS arrays enabled the initial search for octupole effects in the lanthanides. The Argonne-Notre Dame array of seven ACS was use to study Ba and Ce isotopes [1,4] and the OSIRIS array at Jülich [5], consisting of 6 ACS, provided the data on Sm, Pm and Nd isotopes [2,6,7,8]. The next generation of ACS arrays, such as EUROGAM [9] and GAMMASPHERE [10], consisting of over a hundred ACS, enabled detailed investigations of previously studied fission products [11,12,13,14] as well as many other nuclei, including important odd-A cases [15,16,17,18,19,20,21,22].

These studies greatly improved our knowledge of octupole correlations in the lanthanides but also created new problems, which need clarification. On the side of achievements on can mention the experimental confirmation of the predition of a low electric dipole moment, D_0, in ^{146}Ba. Early studies [1] showed a surrprisingly small value of D_0 in the ^{146}Ba nucleus, where the maximu octupole effects were expected. This prompted a better theoretical description of thef D_0 moment in nuclei with octupole shape as a sum of a quickly changing shell contribution and an octupole-dependent volume contribution [23]. When these terms add with oposite signs, they produce a locally small D_0 value. A recent reinvestigation of the Ba isotopes with the EUROGAM array confirmed a decrease of D_0 in ^{146}Ba [13,18], giving strong support for calculations predicting octupole deformation in this region. On the side of unsolved problems remains a question about the presence of octupole deformation in the Cs isotopes, where, despite theoretical suggestions [24], neither parity doublets nor E1 transitions were observed [15]. In ^{140}Xe and ^{142}Xe isotopes octupole deformation was also not seen [17], which was interpreted as due to a decrease of octupole correlation when approaching the Z=50 closed shell. However a recent study of the ^{139}Xe nucleus suggests an increase of octupole correlations there, as compared to the Z=56 nucleus ^{141}Ba [20].

Information about the extent of the region of strong octupole correlations in the lanthanides is vital for testing models predicting octupole deformation in this region. In Fig.1 a C shaped "border", extending along the Z=63, N=85 and Z=55 lines, marks approximate limits for the region of strong octupole correlations in the lanthanides, as we know them at present. The Z=63 section has been established in the studies of Eu isotopes [25,26,27], the N=85 section was suggested in studies of N=85 isotones [28] and the Z=55 limit steems out of Cs and eve-even Xe works [15,17].

In view of what has been said above, it is important to examin furthe the result [20] on the $^{139}_{54}$Xe$_{85}$ nucleus can change these conclusions.

Another observable, fundamental for testing models of octupole deformation is the D_0 moment. Local variations of its value provide a stringent test for such models. A low value of D_0 at N=90, seen in Ba isotopes, has been also observed also in La isotopes [29,22]. On the other hand, in the ^{150}Nd nucleus the D_0 moment is large [30]. It is therefore of interest to establish D_0 values for the N=90 isotones between ^{147}La and ^{150}Nd. Let us note that systematics of this observable can also give additional information about limits of the octupole deformation region.

In this contribution we present important new experimental information about the extent of the region of strong octupole correlations and local variations of the D_0 moment in the neutron-rich lanthanides.

2 New data from fission on octupole deformation in Lanthanides

Prompt-γ radiation following spontaneous fission of ^{248}Cm has been measured using the EUROGAM 2 array [9]. About 2×10^{10} $\gamma\gamma\gamma$ coincidences were collected and analysed using various three-dimensional histograms. More details on the experiment and data analysis techniques can be found in [31,32,33]).

An important measure ofthe strength of octupole correlations is the excitation energy of the 3_1^- state. Prior to this work information about the crucial Z=54 line was rather limited therefore we searched for 3_1^- states in even-even Xe isotopes. The identification of the newly found 3_1^- states is based on angular correlations and linear polarisation measurements. Fig.2 shows systematics of these excitations in the neutron-rich lanthanides.

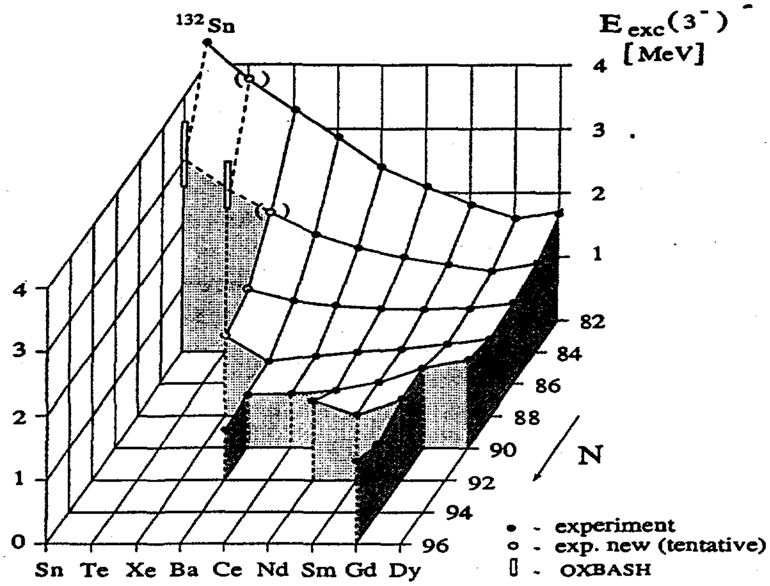

Figure 2. Systematics of 3_1^- excitation energies in the neutron-rich lanthanides.

The new data for Xe nuclei, drawn as open circles, clearly show an increase of the 3_1^- excitation energies in Xe nuclei as compared to Ba isotones (for completnes of the picture we included a new, tentative point for ^{134}Te as well as the OXBASH preditions for ^{134}Sn and ^{136}Te. This questions the decreasing trend of 3^- excitations from Ba to Xe proposed in ^{139}Xe, (c.f. Fig.3 in [20]) and suggests lower octupole correlations in xenons than in bariums.

To resolve this problem we studied the ^{139}Xe nucleus. The study was additionaly motivated by an unexpected difference between the structure of ^{139}Xe, reported in [20] and that of the ^{145}Nd and ^{147}Sm, N=85 isotones [28]. The new level scheme of ^{139}Xe, obtained in this work is shown in Fig.3.

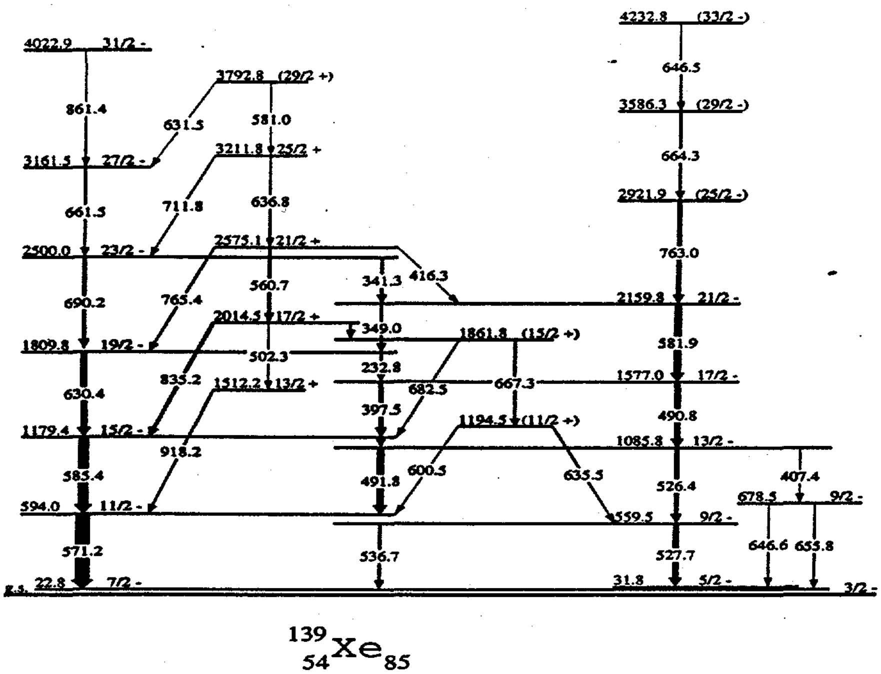

Figure 3. Partial level scheme of ^{139}Xe as obtained in the present work

The 527 keV line was found to be a doublet of 526.4 keV and 527.7 keV transitions in a cascade. The 526.4 keV γ-ray links the 1085.8 keV level to the known 559.5 keV, $9/2^-$ level fixing *negative* parity for the 1085.8 keV level and the band based on it, in contrast to suggestions of Ref.[20], where positive-parity was assigned to this band and strong octupole effect were inferred from this assignment. An excitation pattern very similar to that observed in ^{145}Nd and ^{147}Sm is now seen in ^{139}Xe, with a parity-doublet-like structure, which probably is not due to octupole deformation [28].

The present EUROGAM 2 experiment provided about ten times more three-fold coincidences than the EUROGAM 1 run, used to study Cs isotopes [15]. Reinvestigation of these nuclei uncovered many new transitions, including the expected E1 transitions. Fig.4 shows the new level scheme of ^{143}Cs.

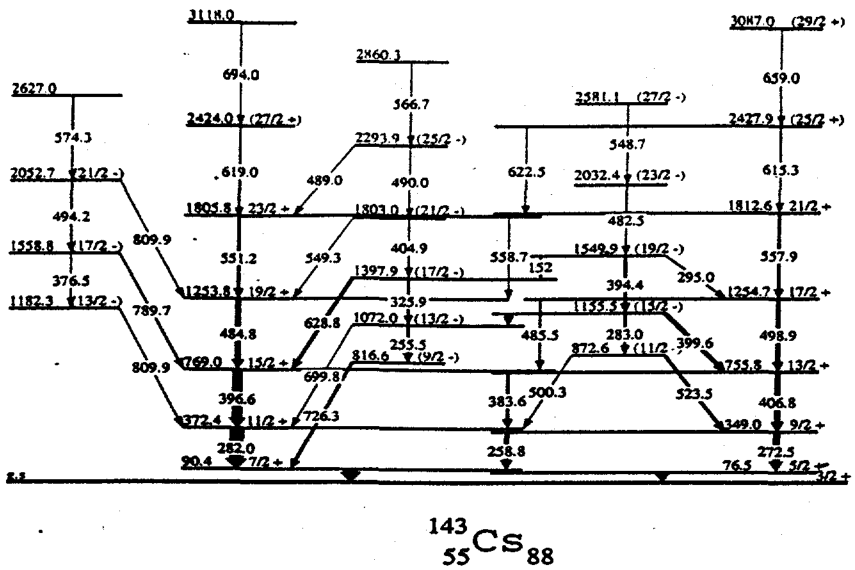

Figure 4. Partial level scheme of ^{143}Cs as obtained in the present work

New bands, based on the 816.6 keV, 872.6 keV and 1182.3 keV are assigned tentatively negative parity, based on the observed decay properties. The new data reveals a parity-doublet-like structure in ^{143}Cs, in accord with theoretical expectations. However, the strength of E1 transitions is lower here than in the ^{144}Ba isotone. The average electric dipole moment for ^{143}Cs, obtained from B(E1)/B(E2) branching ratios, is D_0=0.03(1)efm. The systematics of this observable [34,29], shown in Fig.5 suggests the decrease of octupole correlations already at Z=55.

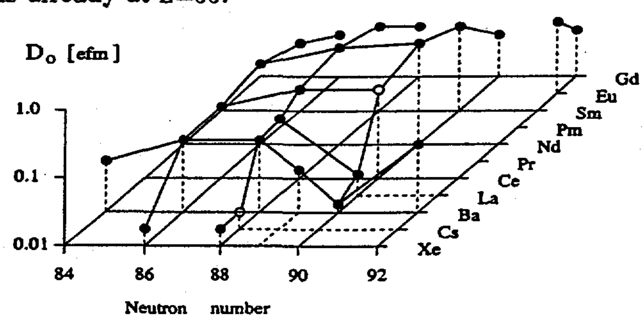

Figure 5. D_0 moment in the neutron-rich lanthanides. Lines are drawn to guide the eye.

In Fig.5 we also show a new point on the crucial N=90 line, obtained in this work for ^{148}Ce. The experimental value, D_0=0.19(3) efm, agrees remarkably well with the predicted value of 0.17 efm [34]. This result demonstrates that low values of D_0 are restricted to ^{146}Ba and ^{147}La and provides further support for models predicting octupole deformation in the neutron-rich lanthanides.

3 Conclusions and Perspectives

Measurements of prompt γ-rays following spontaneous fission of ^{248}Cm, performed with the EUROGAM 2 array, provided new information on octupole correlations in the neutron-rich lanthanides. Updated systematics of 3_1^- excitations and the newly found D_0 moment for ^{143}Cs both suggest that octupole correlations decrease significantly below the proton number Z=56. New data for ^{139}Xe indicate that, as found previously for the ^{145}Nd and ^{147}Sm nuclei, octupole effects decrease below the neutron number N=86.

We also presented new D_0 value for ^{148}Ce, showing again the local character of the decrease of D_0 moment in ^{146}Ba, as predicted theoretically. The D_0 values in ^{143}Cs and ^{147}La have the same small values as in their core nuclei, ^{142}Xe and ^{146}Ba, respectively. This indicates a weak coupling of the odd proton in these nuclei, which does not contribute to any enhancement of octupole correlations, suggested in some theoretical works. We will continue work on sustematics of the D_0 moment and the 3_1^- excitations. In the D_0 landscape, values for ^{141}Cs and ^{145}Cs nuclei are within reach. An interesting question is how far to the neutron-rich side strong octupole correlations extend ? As a next step we will therefore study the N=92 nuclei with Z>56. For the 3_1^- systematics, an intriguing is a questions about the 3_1^- energy in ^{144}Xe. Not only will it provide information about the strength of octupole correlations there, but may also give a hint about the persistence of the Z=50 shell closure at the N=90 neutron number.

Acknowledgments

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