Observation of the Single Step Links of the Yrast Superdeformed Band in ^{194}Pb

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F. Hannachi[1], A. Lopez-Martens[1], A. Korichi[2], S Leoni[3], C. Schück[1], E. Gueorguieva[1], Ch. Vieu[1], B. Haas[4], R. Lucas[5], A. Astier[6], G. Baldsiefen[7], M. Carpenter[8], G. de France[4], R. Duffait[6], L. Ducroux[6], Y. Le Coz[5], Ch. Finck[4], A. Gorgen[7], H. Hübel[7], T.L. Khoo[8], T. Lauritsen[8], M. Meyer[6], D. Prévost[4], N. Redon[6], C. Rigollet[4], H. Savajols[4], J.F. Sharpey-Schafer[9], O. Stezowski[4], Ch. Theisen[5], U. Van Severen[7], J.P. Vivien[4], A.N. Wilson[10]

[1] *CSNSM, IN2P3-CNRS, bat 104-108, F-91405 Orsay, France*
[2] *IPN, F-91406, Orsay Cedex, France*
[3] *Niels Bohr Institute, 4000 Roskilde, Denmark*
[4] *CRN, IN2P3-CNRS, F-67037 Strasbourg, France*
[5] *DAPNIA SPhN, CEA Saclay, 91191 Gif sur Yvette, France*
[6] *IPN, IN2P3-CNRS and Univ. Lyon-1, F-69622 Villeurbanne Cedex, France*
[7] *ISKP, Universitat Bonn, D-53115 Bonn, Germany*
[8] *ANL, Argonne, Illinois 60439, USA*
[9] *NAC, PO Box 72, Faure, ZA-7131 South Africa*
[10] *Oliver Lodge Laboratory, University of Liverpool, PO Box 147, L69 3BX UK*

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Abstract

The EUROGAM array has been used to investigate the decay out of the yrast superdeformed (SD) band in ^{194}Pb. Eigth single step decays from the lowest observed SD states to low-lying states at normal deformation (ND) have been identified. From this observation, the excitation energy (4877 ± 1.5 keV) and the spin (6^+) of the lowest observed SD state in ^{194}Pb are established.

Superdeformation in lead nuclei was first discovered in 1990 in two independent experiments, using respectively the Osiris array in Berlin and the Hera array at LBL [1, 2]. The yrast SD band in ^{194}Pb was found as a sequence of 12 transitions with energies ranging between 169 keV and 602 keV and an intensity of 1 % relative to the the 2^+ - 0^+ 965 keV transition. The survival of the SD band down to very low rotational frequency (and therefore low spin) and the substantial intensity of the band together with the fact that the level density in the first well of this nucleus is reduced due to the close proton shell Z=82 already indicated that this nucleus should be a good candidate to investigate the decay out of the SD band. Several attempts have been made in order to find the linking transitions between the superdeformed (SD) and the normally deformed (ND) states in this nucleus [3, 4, 5]. On figure 1 are shown the results of a comparative study of the decay-out spectra of the ^{192}Hg and ^{194}Pb yrast SD bands, using the fluctuation analysis method [6, 7]. The data were obtained with the Eurogam1 array which consisted of 45 compton suppressed Ge detectors [9, 10]. Excited states in ^{192}Hg and ^{194}Pb were populated in the $^{160}Gd(^{36}S,4n)$ and $^{184}W(^{16}O,6n)$ reactions at beam energies of 159 MeV and 113 MeV respectively. The beam was provided by the 20 MV tandem Van de Graaff accelerator of the Nuclear Structure Facility at Daresbury Laboratory. The targets consisted of 1 mg/cm^2 of ^{160}Gd (enriched to 98.7%) deposited on a 10 mg/cm^2 gold backing

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in the ^{192}Hg experiment and of two stacked 325 $\mu g/cm^2$ enriched ^{184}W deposited on 10 $\mu g/cm^2$ Carbon backing in the ^{194}Pb experiment. Two data sets consisting of 660 $\times$ 10^6 (^{192}Hg) and 860 $\times$ 10^6 events (^{194}Pb) were recorded on tape with the requirement that at least 5 unsuppressed Ge detectors fired in prompt coincidence. The μ_2/μ_1 fluctuation spectra obtained for ^{192}Hg and ^{194}Pb in the 1 to 3 MeV transition energy region are shown in the bottom of figure 1, in comparison to the intensities of the discrete peaks which we proposed as possible decay out transitions (top part of figure 1). As one can see, strong fluctuations were observed in the case of ^{194}Pb which were correlated with the measured discrete peak intensities, while in the ^{192}Hg, not only was the fluctuation spectrum more smooth and closer to the statistical limit, but also the measured peak intensities were weaker, which indicates a higher degree of fragmentation in the statistical decay. This provided strong indications that a search for discrete linking transitions would be more promising in ^{194}Pb than in ^{192}Hg.

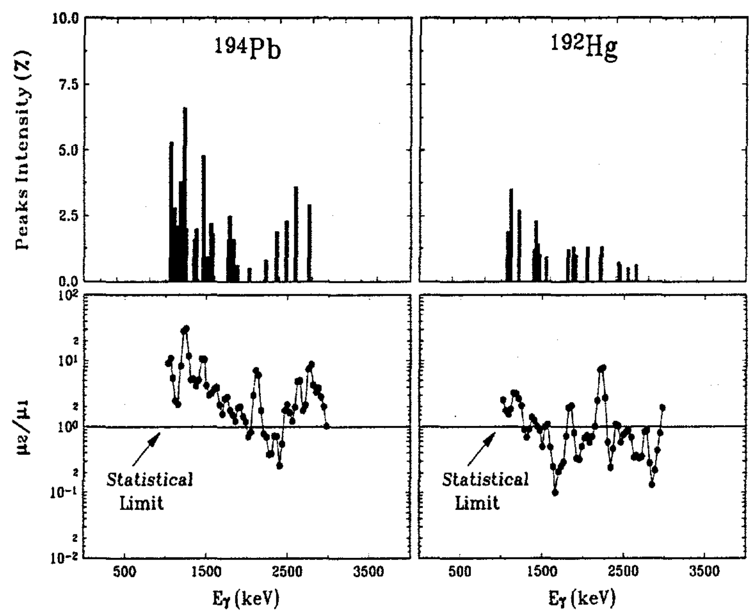

Figure 1: The top part of the figure shows the intensities of the lines proposed as decay out transitions in the 1 to 3 MeV region, normalized to 100% in the SD band plateau region, for both ^{194}Pb (left part) and ^{192}Hg (right part). The bottom of the figure shows the μ_2/μ_1 fluctuation spectra calculated on basis of triple SD gated spectra.

We have recently investigated again the deexcitation of the SD band in ^{194}Pb using the Eurogam2 array in similar experimental conditions (same target, beam and beam energy). Eurogam2 consists of 54 Compton-suppressed Ge detectors. Thirty of these are 73 % efficiency coaxial Ge detectors located in the forward and backward hemispheres, and 24 are clover detectors located in two rings near 90 degrees relative to the beam direction [11, 12]. The higher statistics collected in this experiment (10^9 triple and higher-fold events) has allowed the identification of some high energy transitions connecting the SD states to the ND states of the first well in ^{194}Pb. These are visible around $E_\gamma = 2.5$ MeV in figure 2.

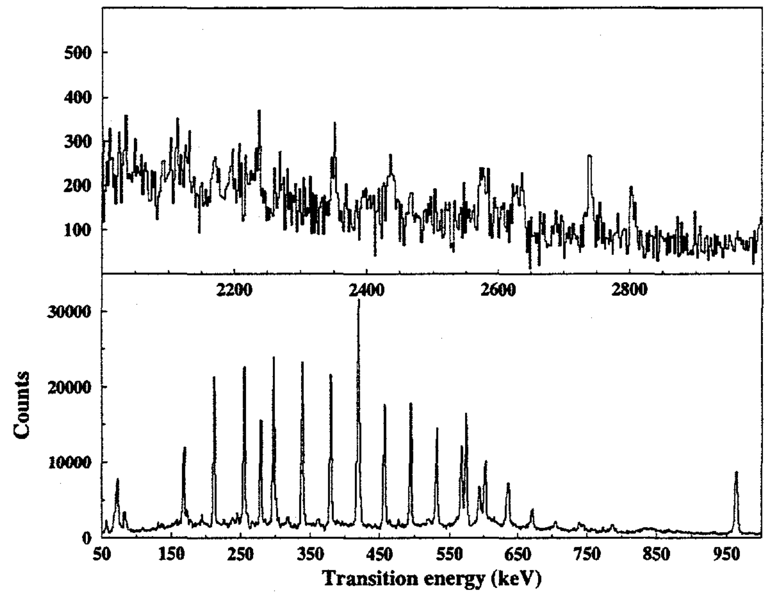

Figure 2: Background subtracted triple SD gated spectrum of the yrast SD band of ^{194}Pb showing the high energy transitions directly connecting the SD and the ND levels. The background is a fraction of the corresponding double SD gated spectrum.

Their concidence relationships establish the level scheme presented in figure 3 for the deexcitation of the yrast SD band [13].

The excitation energy of the last observed SD state is measured for the first time as 4877 keV $\pm$ 1.5 keV and its spin is uniquely determined to be $6\hbar$. This is in very good agreement with the theoretical predictions [14, 15]. The SD band decay is mainly of a statistical nature [6, 16, 17, 18], that is, it proceeds via a quasi-continuum of transitions and resolved lines (for less than 15% of the SD band intensity) and both positive and negative parity states are populated. The transition strengths have been obtained for the decay transitions under the reasonable assumption of a dipole nature (it was not possible with the available statistics to measure their angular distributions). Assuming a constant quadrupole moment of 20 eb for the SD band [19], the lifetimes of the 8^+ and 6^+ SD levels can be obtained. From the branching ratios of the primary transitions, transition strengths ranging from 10^{-8} to $5\text{x}10^{-8}$ W.u. and from $1.5\text{x}10^{-6}$ to $5.3\text{x}10^{-6}$ W.u. have been obtained assuming E1 and M1 transitions respectively. These represent highly retarded transitions and indicate very small mixing between ND states and SD states at the point of decay. From the in-band / out-of-band intensity ratios, again assuming a constant quadrupole moment in the SD band and using a standard level density formula together with the GDR strength function of Bartholomew et al [20], it has been possible to deduce the mixing of the decaying SD states with the ND states. The α^2 values obtained are respectively 0.0016 and 0.005 for the 8^+ and 6^+ SD states.

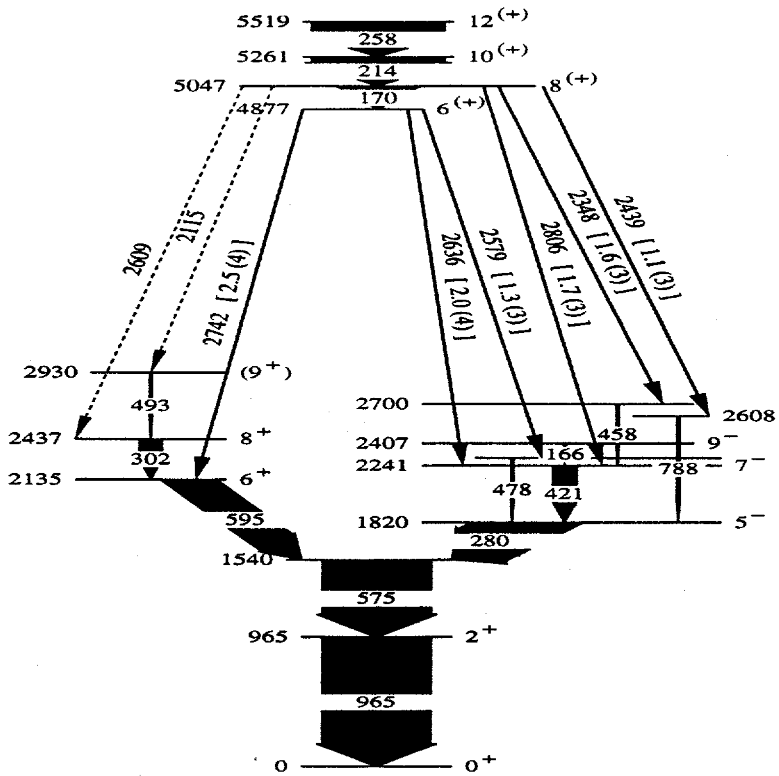

Figure 3: Partial decay scheme of the yrast SD band in ^{194}Pb. The precision on the new transitions and on the SD states energies is of the order of 1.5 keV. The intensities of the linking transitions are indicated in brackets (in % of the SD band intensity). The dashed arrows indicate tentative emplacements for the transitions.

The factor 3.2 increase of α^2 over one transition explains the sudden disappearance of the SD band at low rotational frequency.

In conclusion, by discovering eight high energy γ-rays directly connecting the SD states to the ND states in ^{194}Pb, the excitation energy and spins of the SD yrast states have been measured for the first time using the Eurogam2 array. This method, which was successfully used for the first time in the case of ^{194}Hg [21], allows, 10 years after the discovery of superdeformation at high spin, the precise measurement of some of the most fundamental properties of the SD nuclei.

Acknowledgements

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