High spin experiments at EUROBALL and GAMMASPHERE

Expériences à haut spin auprès d'EUROBALL et GAMMASPHERE

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Résumé: Cette contribution résume le travail effectué avec GAMMASPHERE et le dispositif EUROBALL, avant qu’il ne soit démantelé au printemps 2003. Le groupe de structure nucléaire continue à étudier les phénomènes à haut spin auprès de GAMMASPHERE et prépare le futur de ce domaine en participant activement à la construction de la génération suivante de multidétecteurs $4\pi$ au Germanium : AGATA.

Introduction

Understanding the properties of superdeformed matter requires the knowledge of the quantum numbers spin, parity and excitation energy of superdeformed states. These quantities allow for stringent tests of theoretical orbital assignments and more importantly, they test the ability of theory to correctly calculate shell correction energies, without which superdeformed nuclei would not exist. However, despite the observation of more than 250 superdeformed bands in mass regions ranging from $A=30$ to $A=190$, only a handful of bands have known excitation energies and spins.

Another important question concerning superdeformed states is the mechanisms governing their intense population (orders of magnitude stronger than ND states of similar spin). This can be investigated through reaction studies but also by studying the properties of highly excited superdeformed states, in particular the phenomena of rotational damping, motional narrowing [1] and ergodic bands [2].

Finally, the search for even more exotic structures such as hyperdeformation is of great importance since it addresses a fundamental question: how much spin can the nucleus sustain?

I – Decay from Superdeformed States

Within the ANL-NBI-Oslo collaboration, we have continued our ongoing experimental investigation of the decay from superdeformed states with the study of the the decay mechanism of the yrast superdeformed bands in $^{191}$Hg and $^{190}$Hg. The $^{191}$Hg nucleus was populated with the $^{174}$Yb($^{22}$Ne,5n) reaction and subsequent $\gamma$-cascades were detected in GAMMASPHERE. The analysis of the experimental data allowed to established for the first time the absolute energy of a superdeformed band in an odd-mass nucleus [3]. Two complementary approaches were used to extract the excitation energy, the first being the direct observation of one-step linking transitions at 2.778 and 3.310 MeV (their placement in the $^{191}$Hg level scheme is shown in figure 1), the second being the statistical analysis of the quasicontinuum of $\gamma$-rays emitted in the decay from the superdeformed states.
The $^{190}$Hg nucleus was studied at EUROBALL IV with the reaction $^{160}$Gd($^{34}$S,4n). The analysis of the quasicontinuum decay spectrum connecting yrast superdeformed states and ND states has been performed. As in the $^{191}$Hg case, the preliminary results obtained by the quasicontinuum analysis are in good agreement with the observation of a linking transition at 2.716 MeV [4] (see figure 2). However, since only one linking transition has been observed and since the systematic error on the excitation energy given by the quasi-continuum analysis is of the order of ~500 keV, only a lower limit for the excitation energy can be given.

Up to now, quantum numbers are firmly known in two Pb isotopes: $^{192}$Pb [5] and $^{194}$Pb [6] and in 2 Hg isotopes: $^{191}$Hg [3] and $^{194}$Hg [7]. In order to extract information about neutron and proton separation energies and pairing in the superdeformed well, it is important to obtain excitation energies, spins and parities for the superdeformed states in $^{192}$Hg. This nucleus is also of prime importance since it is thought to be the doubly magic nucleus at superdeformation in the A=190 region. This is why a long EUROBALL IV experiment was performed in July and November 2002. States in $^{192}$Hg were populated in the reaction $^{160}$Gd($^{36}$S,4n). The statistics collected is an order of magnitude larger than in previous GAMMASPHERE and EUROGAM 2 experiments. The data is still under analysis since problems were encountered when gain matching the detectors. It was found that the detector gains obtained with standard calibration sources do not suit the detectors during the experimental runs. A careful “online” gain matching at high energy was needed since candidate linking transitions are known to exist at ~ 3 MeV.

**Figure 1**: Decay scheme of the yrast superdeformed band in $^{191}$Hg.

**Figure 2**: High energy part of a spectrum obtained by setting pairwise gates on the superdeformed yrast band in $^{190}$Hg. The candidate single-step linking transition at 2716 keV appears clearly.

### II – Excited superdeformed states and ergodic bands

The driving motivation behind these studies is the observation of unusual properties in the 2D rotational correlations in superdeformed $^{194}$Hg. Three ridges parallel to the diagonal of a $\gamma-\gamma$ matrix appear in coincidence with transitions in the superdeformed yrast band. These ridges reflect the rotational correlations between consecutive or non consecutive (in the case of the second and third ridges) transitions in excited superdeformed bands. The ridges have the same energy separation as the discrete superdeformed lines in $^{194}$Hg: this indicates that the dynamic moments of inertia of excited superdeformed bands are surprisingly similar to the one of the yrast band. The count fluctuations in the ridges...
indicate the presence of ~100-150 participating excited bands. One would expect that the contribution of all these bands would give rise to quite a wide ridge structure but surprisingly enough, this is not the case. Indeed, the ridges exhibit exceptionally narrow widths compared to normally deformed prolate nuclei or other superdeformed nuclei: 5-10 keV. The narrow widths of the ridges indicate little fragmentation of the E2 strength even though a theoretical analysis by Matsuo et al [8] shows that the wave functions are complicated, containing as many as 8 basis states. The calculations also show that motional narrowing has set in and that the E2 strength spreading width $\Gamma$ is near the average spacing $D$ between levels: The condition that defines ergodic bands $\Gamma/D < 1$ is nearly met [7]. Not all superdeformed bands exhibit this property: only those in nuclei around $^{192}$Hg show this remarkable feature. A special feature in the superdeformed well of mass 190 nuclei is that high-K orbitals are prevalent at the Fermi level. In order to test whether the K quantum number plays a role in the ergodic band phenomenon we plan to study rotational correlations at GAMMASPHERE in a region of classic high-K isomers: the $^{174-176}$Hf nuclei.

III - Hyperdeformation

The search for hyperdeformed structures has been a prominent goal of nuclear structure research in recent years. It has proven difficult to predict in which nuclei hyperdeformed bands can be populated since shell corrections to the liquid drop energies are not as large as for superdeformation. However, the best candidates are nuclei for which the macroscopic energy is sufficiently flat to enable the shell effects to produce a good hyperdeformed minimum. This condition is most likely satisfied in the mass 130 region at high angular momentum. During the last years, several reactions have been studied and used to look for signs of hyperdeformed structures in nuclei at GAMMASPHERE and EUROBALL. Very promising rotational ridge structures were observed in $^{126}$Ba and $^{126}$Xe. The investigation of $^{126}$Ba, via the $^{64}$Ni($^{64}$Ni,2n) reaction, was repeated in a 2 times 2 week experiment at EUROBALL with bombarding energies of 255 and 261 MeV. The collaboration was extended to more than 70 physicists from Europe and the USA and had 4 spokespersons, one of which was A. Lopez-Martens. In this experiment, EUROBALL was used in conjunction with the 4$\pi$ BGO inner ball and the 4$\pi$ DIAMANT charged particle detector. DIAMANT was used in slave mode to veto the strongly populated $\alpha$,2n channel by software. Although it was shown that the fold distribution is saturated at 255 MeV, the previously observed ridge structure with 52 keV spacing, was only seen in the higher energy run. This strong energy dependence points to entrance channel effects and is still not understood.

In December 2003, the $^{126}$Xe experiment was repeated at GAMMASPHERE to prove or disprove the weak hints of hyperdeformed structures. The analysis is still ongoing.

Conclusion

New results have been obtained in the study of the decay from superdeformed states, in particular, it is the first time that superdeformed structures in an odd nucleus, $^{191}$Hg, have firmly established quantum numbers. The search for hyperdeformed structures is a difficult task, but if successful, it will have, as did in 1986 the discovery of superdeformation [9], a great impact on the entire low energy physics community. The experimental difficulties of populating hyperdeformed states have stimulated attempts to a better understanding of the population of superdeformed states. The nuclear structure group is contributing to this work by studying how collective rotation develops as the nucleus cools down after a fusion-evaporation reaction and how the E2 strength behaves as a function of energy and spin.
[4] S. Siem et al., to be published
[8] A. Lopez-Martens et al., to be published