First Identification of Large Electric Monopole Strength in Well-deformed Rare Earth Nuclei ◇

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The structure of excited 0^+ states in deformed even-even nuclei is still a matter of controversial discussion despite intensive investigation. Traditionally the first excited 0^+_2 state has been interpreted as the β-vibrational excitation of the ground state. However, in many nuclei the 0^+_2 state has only weak transitions to the ground-state band, while strong electric quadrupole transitions to the γ band have been found. This contradicts the traditional interpretation, since a transition from a β-vibrational state to the γ band is suppressed due to the destruction of a β phonon and, at the same time, the creation of a γ phonon. In this picture a β-vibrational state is characterized by a strong transition to the ground-state band, namely by a large $B(\mathrm{E2}; 0^+_\beta \rightarrow 2^+_\mathrm{g}) \approx 10$ W.u. value and a strong E0 transition to the ground state with $\rho^2(\mathrm{E0}) \approx 100 \cdot 10^{-3}$. Only in very few rare earth nuclei, such as ^{154}Sm [1] and ^{166}Er [2], it has been possible to identify candidates for a β-vibrational state by γ spectroscopy.

It was also shown in recent years that the interacting boson approximation (IBA) consistently predicts that the E0 strength from the first or second excited 0^+ state in deformed nuclei is large [3]. This IBA prediction for well-deformed nuclei is not confirmed experimentally, due to the lack of measured $\rho^2(\mathrm{E0})$ values of the E0 strength for excited 0^+ states in these nuclei. It is therefore important to obtain more experimental data on E0 strength in well-deformed nuclei, which may also lead to new insights in the nature of the low-lying 0^+ states.

Excited states in the well-deformed rare earth isotopes ^{166}Er and ^{154}Sm were populated via Coulomb excitation at the MLL Tandem accelerator. Conversion electrons were registered in a cooled Si(Li) detector in conjunction with a magnetic transport and filter system, the Mini-Orange.

For the first excited 0^+ state in ^{154}Sm at 1099 keV a large value of the monopole strength for the transition to the ground state of $\rho^2(\mathrm{E0}; 0^+_2 \rightarrow 0^+_\mathrm{g}) = 96(42) \cdot 10^{-3}$ was extracted [5]. This confirms the interpretation of the lowest excited 0^+ state in ^{154}Sm as the collective β-vibrational excitation of the ground state. For the $2^+_2 \rightarrow 2^+_\mathrm{g}$ transition a surprisingly small electric monopole strength of $\rho^2(\mathrm{E0}) < 6.3 \cdot 10^{-3}$ was found. In ^{166}Er we observed E0 transitions from the 0^+_2 as well as from the 0^+_4 state. For the 0^+_2 state we obtained a value of $\rho^2(\mathrm{E0}; 0^+_2 \rightarrow 0^+_\mathrm{g}) = 5.3(23) \cdot 10^{-3}$ in agreement with the known value of $2.2(8) \cdot 10^{-3}$ [4]. The newly measured large electric monopole strength of $\rho^2(\mathrm{E0}; 0^+_4 \rightarrow 0^+_\mathrm{g}) = 127(60) \cdot 10^{-3}$ [5] is consistent with the previous assignment [2] of the 0^+_4 state at 1934 keV to be the β-vibrational excitation of the ground state. In a re-analysis of published conversion electron data for ^{240}Pu in the superdeformed second minimum of the potential surface [6] an average monopole strength of $\rho^2(\mathrm{E0}; \mathrm{I}^+_\beta \rightarrow \mathrm{I}^+_\mathrm{g}) = 55(24) \cdot 10^{-3}$ could be determined for the β vibrational band members up to the 8^+_2 state [5]. The observed large monopole strength in all three deformed nuclei for the first time experimentally confirms the theoretical predictions [3] that the lowest excited 0^+ states in deformed nuclei exhibit strong monopole transitions to the ground state.

A comparison of the level schemes of the two rare earth nuclei with eCQF IBA calculations reveals that not all experimental features are reproduced by the IBA. In the region of the IBA symmetry triangle where the γ-vibrational band is at relatively low energy and the first excited 0^+ state is well above the 2^+_γ state no excited 0^+ state shows collective E2 strength to the ground state band while the 0^+_2 or 0^+_3 states have large E0 strength to the ground state. In this region of IBA parameters the 0^+_2 state has the characteristics of a double-γ vibration but no 0^+ state with the characteristics of a traditional β vibration exists. The case of ^{166}Er, where a β-vibrational state has been clearly observed, seems to be in contradiction to that feature of the IBA calculations. Near the $U(5) - SU(3)$ leg of the IBA symmetry triangle the 0^+_2 state in deformed nuclei lies below the 2^+_γ state and exhibits all characteristics of a β-vibrational excitation. ^{154}Sm seems to be a very good example of this situation. However, the properties of the 2^+_2 state are not in agreement with the IBA predictions, where $0^+_2 \rightarrow 0^+_\mathrm{g}$ and $2^+_2 \rightarrow 2^+_\mathrm{g}$ transitions are of similar strength. This is probably due to a mixing with other 2^+ states.

We conclude that the two nuclei ^{154}Sm and ^{166}Er are in general representative for two regions in the IBA triangle, one with low lying β vibration near the $U(5) - SU(3)$ leg and one closer to the $O(6)$ corner (but still with $R_{4/2} \geq 3.1$) with the 0^+_2 state being the two phonon $\gamma\gamma$ vibration but without a 0^+ state with the characteristics of a β vibration (namely large $\rho^2(\mathrm{E0})$ and large $B(\mathrm{E2}; 0^+ \rightarrow 2^+_\mathrm{g})$). From the current investigation, we draw the conclusion, that it is very important to obtain as much detailed experimental information on all low-lying 0^+ states as possible, including data on transfer strength as well as electromagnetic decay properties. In many cases, where only partial information on excited 0^+ states is available, it is not clear that these states are indeed the ones described in the framework of the collective models. In addition, mixing of different structures can lead to significant modifications of the properties, leading to large deviations from the simple expectations, which should, if at all, just be used as guiding principles.

References

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