INVESTIGATION OF ^{152}SM VIA INELASTIC DEUTERON SCATTERING

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SUMMARY

The structure of the transitional nucleus ^{152}Sm is investigated using inelastic deuteron scattering, in search of a tetrahedral symmetry signature.

The atomic nucleus, which contains Z protons and N neutrons, is a complicated many-body quantum object where the interactions amongst the particles are governed by the strong nuclear force. Rather than deal with the motion of the individual particles, the nucleus can be described by a set of coordinates that define the shape of the nuclear surface. The latter can be modelled with a standard spherical harmonics $Y_{\lambda\mu}$ expansion, weighted by the deformation parameters $\alpha_{\lambda\mu}$. The typical shapes of the nuclei are spherical, prolate, or oblate (see Fig. 1), where there is an axial symmetry (two of the axes have the same length), or triaxial where all three axis lengths are unequal. These shapes, however, only involve the quadrupole, or $Y_{2\mu}$ spherical harmonic, degree of freedom. The importance of the octupole degree of freedom has long been recognized, but has primarily been restricted to the axial pear, or Y_{30}, shape. However, recent theoretical predictions suggest the existence of nuclei with pyramid-like shapes involving non-axial octupole deformations. Such nuclear configurations belong to the symmetry group of the tetrahedron [1]. To remain invariant under the tetrahedral group of symmetry, T_d, only odd λ are allowed [1], and the lowest order is $\lambda = 3$ (octupole), with $\alpha_{\lambda\mu} = \alpha_{32}$. Although a perfect tetrahedral shape requires an infinite number of terms to be included in the expansion, the non-axial Y_{32} octupole shape alone represents a sufficient approximation in the present context. An example of this shape is displayed in Fig. 1. Since the quadrupole degree of freedom typically dominates the low-lying excitations of the nucleus, there are only certain regions of the table of the isotopes where it might be possible to recognize the role that tetrahedral shapes are playing. In particular, tetrahedral symmetry is believed to be present at the beginning of the rare earth region, and ^{152}Sm may be a good candidate [2,3].

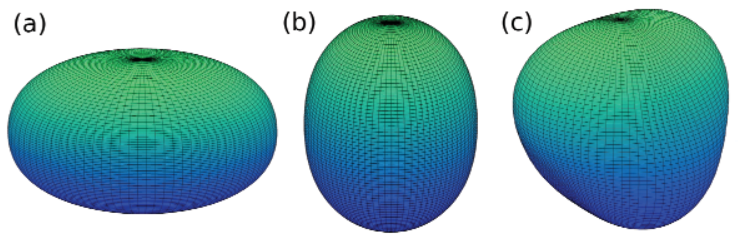

Fig 1. (a) Oblate nucleus (pancake shape). (b) Prolate nucleus (football shape). (c) Tetrahedral nuclear shape made with the first order Y_{32} only.

A primary signature of the tetrahedral shape in ^{152}Sm is contained in the transition matrix elements that describe the rate at which the nucleus makes a transition from one state to another state. If a state has a large quadrupole deformation, this will be reflected in transition matrix elements dominated by electric quadrupole (E2) characteristics. A vanishing quadrupole deformation will lead to vanishing matrix elements. Theoretical predictions employing tetrahedral shapes indicate that the low-lying negative-parity states in nuclei near both Z=64 and N=90 [1] should have nearly vanishing E2 matrix elements. This prediction can be probed using inelastic deuteron scattering off a ^{152}Sm (Z=62 and N=90) target, preliminary results from which are presented below.

EXPERIMENTAL RESULTS AND ANALYSIS

The deuteron inelastic scattering experiment was performed at the Maier-Leibnitz Laboratory in Munich, Germany. An 80(4)%-polarized deuterium beam of 22 MeV from the tandem Van de Graaff accelerator was incident on a 113 μg/cm^2 (≈ 50 μm) thick target of ^{152}Sm. The outgoing deuterons from the reaction were momentum analyzed by a Q3D magnetic spectrograph at 20 angles between 15 and 115 degrees. Fig. 2 shows an example of a deuteron spectrum obtained at 60° for a spin-up polarized beam. The strongest peaks are labelled with their respective energies in keV. The angular distributions of the cross sections are calculated for each energy level, and the large number of angles observed represents one of the main strengths of this work.

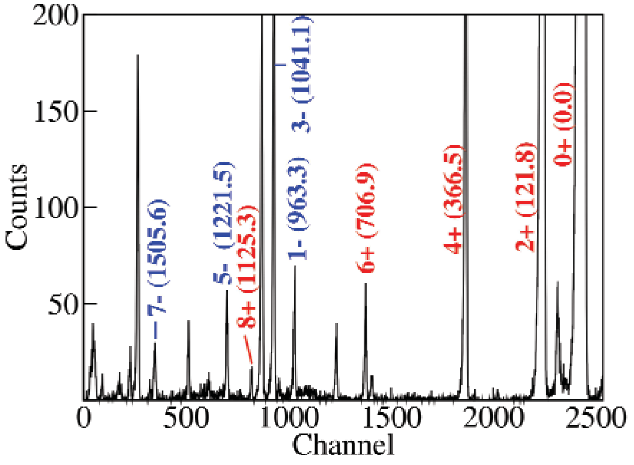

Fig. 2 Portion of the deuteron inelastic scattering spectrum at 60° for a spin-up polarization of the beam. The peaks are labelled with their respective energies in keV, where the labels in red correspond to the ground-state rotational band and those in blue to the lowest-lying negative-parity band.

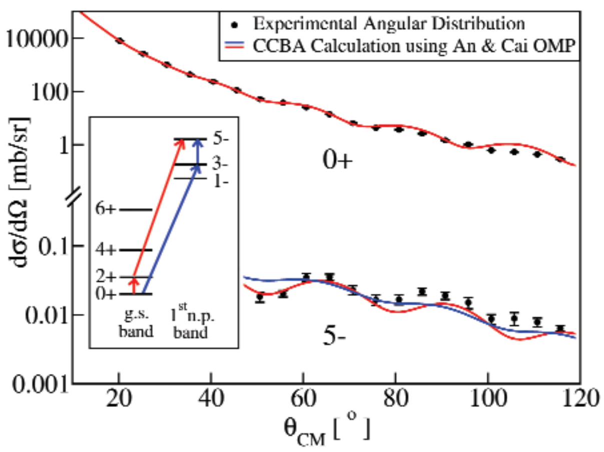

Fig. 3. Experimental angular distributions and preliminary theoretical calculations for the first 0^+ and the 5^- states. The inset presents the primary pathways from which the 5^- states can be populated.

The experimental angular distributions for the ground-state level (elastic channel) and excited states (inelastic channels) can be calculated within the Coupled-Channel Born Approximation [4,5] (CCBA) that employs an optical potential to take the deuteron-nucleus interaction into account. The main advantage of the CCBA is to increase the number of coupled outgoing channels considered and it is therefore a powerful tool for obtaining the inelastic cross-sections of high energy states.

The experimental angular distributions of the ground-state band and the first negative-parity band up to the 1505-keV level have been extracted to date. As an example, the angular distribution of the state which has negative parity and total angular momentum 5 (5-) in the lowest-energy negative-parity band, labelled as first n. p. band, is shown in Fig. 3. The curve displayed in the plot is a preliminary theoretical calculation that aims to reproduce the experimental data, by varying the values of coupling amplitudes between the channels. Since the work is currently in progress, the calculations do not fully reproduce the experimental data. Due to the complex structure of ^{152}Sm, many couplings need to be considered in these calculations.

The 5^- state of the first n. p. band is strongly populated and it is thus interesting to consider the general features of its angular distribution to gain some preliminary insight into the presence of electric quadrupole (E2) transitions in low-lying negative-parity bands. The inset of Fig. 3 shows the two primary pathways from which the 5^- state is expected to be populated. The pathway drawn with red arrows does not imply an intraband E2 transition in the negative-parity band, while the one drawn with blue arrows does. Although neither pathway alone has been able to accurately reproduce the experimental data, it is therefore interesting to note that the former produces deep minima similar to those observed experimentally, while the latter produces a flat curve. Thus, even though it is not possible at this point to extract quantitative information about the different coupling amplitudes, this does suggest that the dominating pathway populating the 5^- state is the one which does not contain the intraband E2 transition in the negative-parity band. If this preliminary result withstands further analysis, it would imply a vanishing quadrupole matrix element, which is consistent with a tetrahedral interpretation.

CONCLUSIONS

A deuteron inelastic scattering experiment was performed to study the structure of ^{152}Sm and very preliminary results were presented. The analysis is based on the use of CCBA calculations. By finding the coupling amplitudes between the energy levels which best reproduce the experimental angular distributions, the different transition matrix elements can be extracted. Ultimately, the goal is to determine whether or not the E2 transition matrix elements in the low-lying negative-parity band are vanishing, which is the key signature for tetrahedral symmetry. Although no definitive conclusion can be made before achieving a quantitative determination of the relevant transition matrix elements, preliminary results indicate that the dominant pathway to populate the 5^- state does not contain an E2 transition matrix element, which is in agreement with the existence of tetrahedral symmetry. Despite the high complexity of the nuclear structure of ^{152}Sm, the high quality of the experimental data gives us confidence in our ability to extract these transition matrix elements.

ACKNOWLEDGEMENTS

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