γ Vibrational Band in ^{70}Ge

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I. Motivation

The main purpose of this study was to find the odd-spin members of the γ vibrational band in ^{70}Ge and to extend this band to as high a spin as possible. This focus was chosen, in part, in response to the recent discovery of rigid triaxial deformation at low spin in the γ vibrational band in ^{76}Ge. This study focused on building on energy levels in the most recently published ^{70}Ge level scheme that stood out as possible candidates for the foundation of a γ vibrational band and on inferring the shape associated with this structure.

II. Theory

Nuclear Shapes

Several nuclei, particularly those at or near magic numbers of nucleons, can be modeled as spheres, but others exhibit various forms of deformation. It is useful to study deformation in order to further understand its microscopic origins.

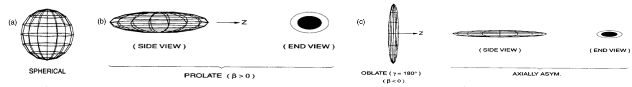

Fig. 1: (a) Sphere: a common nuclear shape. (b) Prolate: Like an American Football; the most common deformed shape. (c) Oblate: Like a Frisbee. *Triaxial* shapes are axially asymmetric.

Collective motion of a nucleus occurs as either rotation or vibration. For this project we are primarily interested in vibration occurring in the γ degree of freedom.

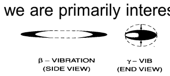

Fig. 2: Schematic (and classical) representation of the β and γ vibrational modes in nuclei.

R.F. Casten, *Nuclear Structure from a Simple Perspective*, Second Ed. (Oxford University Press, New York, 2005)

III. Previous Work

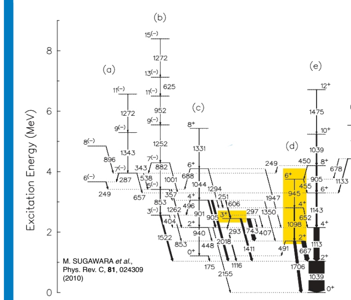

Fig. 3: Band (d) and the lone 3$^+$ state (highlighted in yellow) appear to form the foundation of a typical K=2, ΔJ=1 γ vibrational band.

The most recent published ^{70}Ge level scheme is shown to the left (Fig. 3).

The majority of this level scheme was confirmed in this analysis; however, the 6$^+$ level in band (c) likely has different spin-parity based on our observation of a 1540.8 keV transition from this state to the 3$^{(-)}$ state in band (b). The 8$^+$ level in band (c) was not observed in this work.

IV. Experiment

The experiment was done at Florida State University's John D. Fox Superconducting Accelerator Laboratory. A 50 MeV ^{18}O beam impinged on a ^{55}Mn target creating ^{73}As as a fusion product (Fig. 5). Through the ejection of light particles, ^{73}As transformed into a variety of nearby residual nuclei. The most plentiful product of this reaction was ^{70}Ge through the ejection of one proton and two neutrons. Excited states in the ^{70}Ge nuclei were populated at high energy and spin. Through the emission of gamma rays, the ^{70}Ge would then relax down to its ground state.

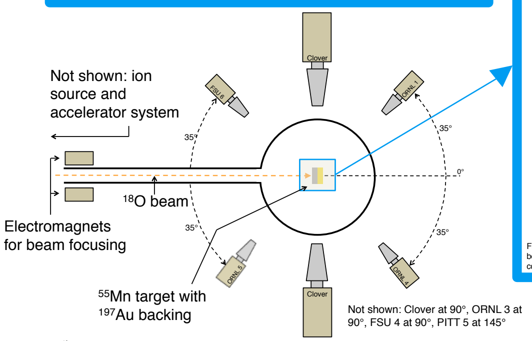

Fig. 4: An ^{18}O beam originates at the ion source, increases in energy as it passes through the tandem accelerator, and finally collides with the ^{55}Mn target. High-purity germanium detectors surround the target chamber and record γ radiation emitted in the reaction.

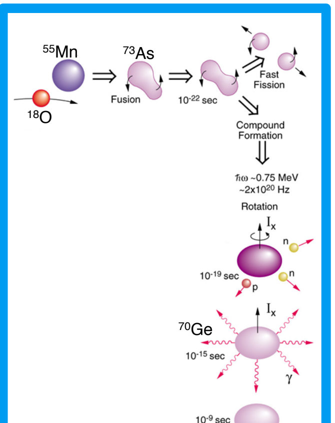

Fig. 5: The reaction at the target as it was bombarded with high energy ^{18}O nuclei. Image courtesy of K. Ford, Florida State University.

V. Analysis

Coincidences, Matrices, and Gating

On average, one new nucleus is produced in the reaction every 100 ns. In addition, the typical nucleus will relax to its ground state in a time much less than 100 ns. For these reasons, if two γ rays are recorded within a 100 ns window it is assumed that they originated from the same decay sequence in the same nucleus. The coincidence analysis utilizes this assumption to develop a greater understanding of the γ rays specific nuclei produce. Coincidence results are sorted into a matrix which can then be used to create gates. In short, gates are histograms that show coincidence counts with one specific energy (technically a very small energy window.) Analysis of the energy and intensity of γ rays seen in coincidence with known transitions in ^{70}Ge is used to identify candidates for new transitions.

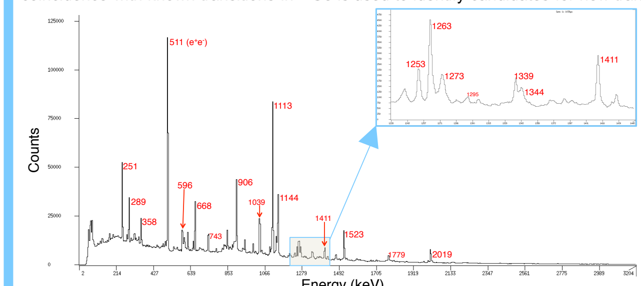

Fig. 6: The spectrum for a 1039 keV gate. This displays which energy γ rays are seen most frequently in coincidence with 1039 keV γ rays. Labeled γ rays are the most prominent ^{70}Ge peaks in this spectrum (except for 511 keV which is due to e$^+$e$^-$ annihilation); however, as demonstrated by the magnified region in the top right corner, there are also a considerable number of ^{70}Ge peaks that are present at a lower scale.

Spectra

The energy of a peak in a gate histogram (such as Fig. 6) is determined from the centroid value of a Gaussian fit to the peak shape, and the relative intensity of that peak is based on a background corrected area (accounting for detector efficiency.) Unidentified peaks that appear in multiple gates of known ^{70}Ge transitions are noted for further investigation and possible placement in the ^{70}Ge level scheme.

VI. Results

Coincidence relationships and relative intensity measurements were used to construct the level scheme (Fig. 7) and, in particular, were used to extend the proposed γ vibrational band.

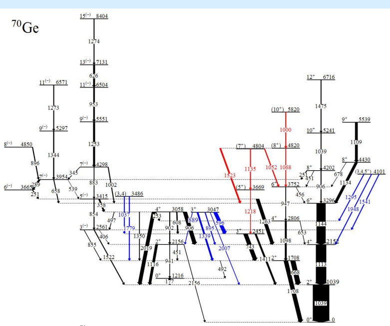

Fig. 7: The proposed ^{70}Ge level scheme based on this project's analysis. Black transitions were seen in the most recent ^{70}Ge analysis and confirmed in this analysis. Blue transitions were seen in a β decay analysis for ^{70}Ge (but not in the most recent level scheme) and confirmed in this analysis. Red transitions are new to this analysis.

The static moment of inertia (Fig. 8) supports the proposition that the newly extended band is the result of γ vibrations based on the trend compared to nearby germanium isotopes. Similarly, Fig. 9 shows the staggering parameter S(I) which clearly indicates that ^{70}Ge is γ soft at low spin like many other nearby even-even germanium isotopes. Total Routhian Surface plots (Fig. 10) tend to support this conclusion based on the relative insensitivity of the potential energy minimum on the γ degree of freedom in the lowest positive- parity configuration.

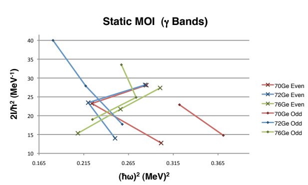

Fig. 8: The static moment of inertia (MOI) is the quantum mechanical analog to the classical moment of inertia. The sharp upward trend of the proposed gamma band is a good indication of vibrational character.

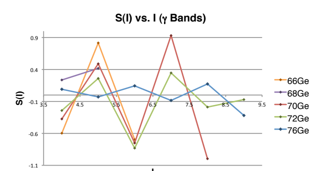

Fig. 9: The staggering parameter S(I) is a sensitive measure of the shape of a nucleus. Above is a comparison of S(I) between ^{70}Ge and nearby germanium isotopes. The fact that ^{70}Ge is in phase with other γ soft nuclei is a solid indication that ^{70}Ge is also γ soft.

$$S(I) = \frac{[E(I) - E(I-1)] - [E(I-1) - E(I-2)]}{E(2_1^+)}$$

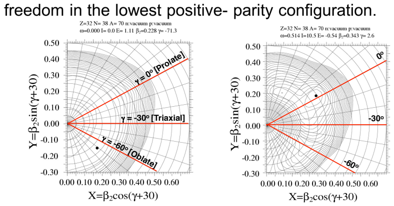

Fig. 10: Total Routhian Surface plots model the potential energy of the nucleus on a polar plot that represents the extent of deformation in the radial direction and the degree of axial asymmetry in the angular direction. The black dot is the point of lowest potential energy. These plots correspond to the lowest positive-parity configuration at two rotational frequencies, as indicated in the figure.

VII. Acknowledgments

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