QUADRUPOLE MOMENT OF THE $7/2_1$ ISOMER STATE OF ^{43m}S.

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We report on the spectroscopic quadrupole moment of the $7/2^-$ isomer state [E*=320.5(5) keV, $T_{1/2}$=415(5) ns, $|Q_s|$=23(3) efm^2] in the neutron-rich ^{43}S nucleus, using the Time Dependent Perturbed Angular Distribution (TDPAD) method at RIKEN. The measured |Qs| is larger than that expected for a single particle state. Comparison to shell model calculations performed using the SDPF-U interaction, show that correlations drive the isomeric state away from a purely spherical shape.

The whole set of experimental data obtained in the last three decades provide a coherent view of the changes in the structure of neutron-rich nuclei in the vicinity of the N=28 shell closure.

Among the N=27-28 isotones, sulfur ones are of particular interest since located between two extremes for which deformations rise gradually, i.e. the doubly magic and spherical-shaped ^{48}Ca and the well oblate deformed nucleus ^{42}Si, for which N=28 seems to no longer be a magic number [1].

Such modification in nuclear structure are influenced by both a global reduction of the N=28 shell gap and the suspected erosion of the proton Z=14 gap. Furthermore, the quasi-degeneracy of the proton orbitals $s_{1/2}$ and $d_{3/2}$ for neutron-rich nuclei around N=28 [2] favor quadrupole excitations in these orbitals separated by two units of total angular momentum. As a consequence, one observes a gain in correlation energy which tends to lower the intruder configurations (i.e. deformed) for these nuclei. Experimentally, those intruder configurations become the ground states from sulfur isotopes (Z<17). Based on a recent interpretation of in-beam gamma-ray spectroscopy data in exotic Si isotopes, this increase of correlation energy is mainly ascribed to proton-neutron interaction [3]. The latter would be responsible for the inversion between natural (i.e. rather spherical) and intruder configurations. Those effects result in shape coexistence suspected in ^{43,44}S [4,5]. Until now, the low-lying structure of 43S has been interpreted in terms of an axially deformed nucleus. The spin-parity $J^{\pi}=7/2^{-}$ of the isomer state [E^{*}=320.5(5) keV, $T_{1/2}$=415(5) ns], originating from the natural configuration (ע $f_{7/2})^{-1}$, has been deduced from the good agreement between shell model (SM) calculations and a recent measurement of the magnetic moment [g_{exp}=-0.317(4), g_{SM}=-0.280] [5]. Moreover, the shell model predicts that this natural configuration, characterized by a rather spherical shape of the isomer state, coexist with a $J^{\pi}=3/2^{-}$ prolate deformed ground state.

In order to assess this scenario, we report on the results from the quadrupole moment measurement of the $7/2^{-}_{1}$ isomer state using the Time Differential Perturbed Angular Distribution (TDPAD) method [6]. The principle of this method is based on the hyperfine interaction of nuclear moments of a measured state with external electromagnetic fields. This method can be applied on isomer states having half lives ranging from 10 ns to about 100 micro seconds.

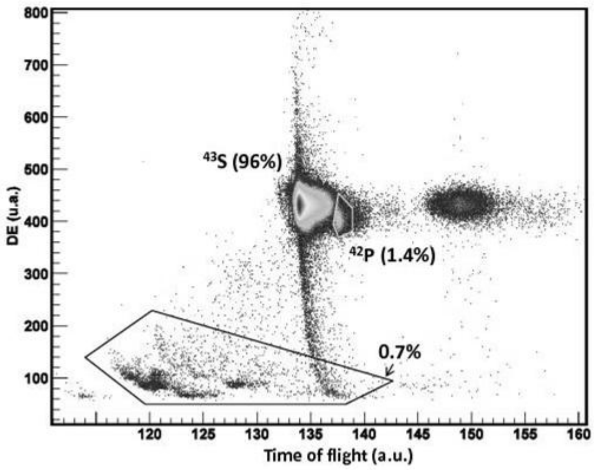

Figure 1. Identification matrix of the transmitted ions through the BigRIPS spectrometer at the last focal plane.

Spin-aligned ^{43m}S were produced via the fragmentation of a ^{48}Ca primary beam of 345 A. MeV and 200 pnA on a 9-mm thick Beryllium target, located at the entrance of the BigRIPS spectrometer at the RIKEN RIBF facility. The fully stripped fragments were selected through the spectrometer using a 15-mm thick Al achromatic degrader placed at the first dispersive plane. Fragments were slowed down by a 10-mm thick aluminum degrader and implanted in an appropriate crystal host at about 77 m from the production target position. Fig. 1 displays the identification matrix of the transmitted ions through the BigRIPS spectrometer at the last focal plane.

About 96% of the nuclei are from ^{43}S and about 1.4% from the neighbor nucleus ^{42}P. About $8*10^3$ per second ^{43}S nuclei were implanted in the host material. Since the fragment's time of flight was 430 ns, about 50% of the ^{43}S nuclei produced in their isomer state reached the detection system. Four High Purity Germanium detectors, for which relative efficiencies ranged from 15% to 35 %, were used to detect gamma radiations. Time and energy information were collected on an event-by-event basis.

The trigger validating an event was given by the 800 ns window coincidence of the germanium detector signal and that of a 0.1-mm thick plastic scintillator, located 1.5 m upstream from the crystal.

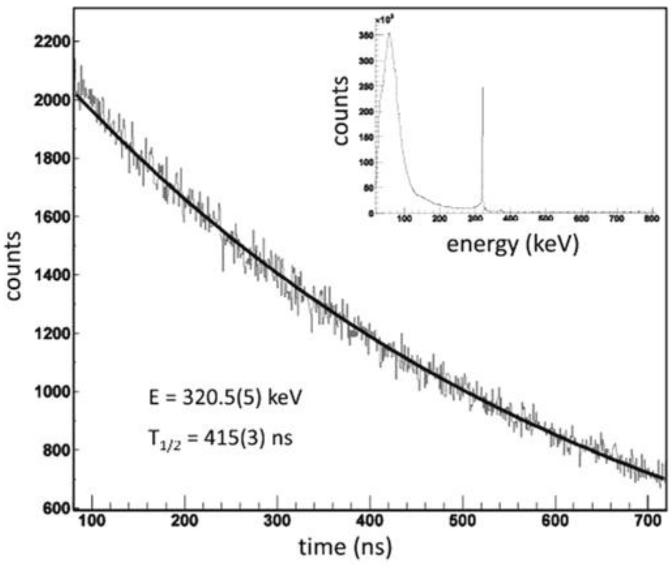

Figure 2. Time and energy spectra associated to the E=320,5(5) keV γ- ray deexciting the isomer state.

Fig. 2 represents time spectra conditioned on the E=320.5(5) keV gamma ray deexciting the isomer state. Energy spectrum is inserted in the background. The figure shows all statistics obtained during the experiment. The measured decay time of the $7/2^{-}_{1}$ isomer leads to a half-life of $T_{1/2}$=415(3) ns, in perfect agreement with that reported in Ref.[5].
In order to optimize the fragments moment selection necessary to produce a spin-aligned nuclear ensemble, we first measured the already known g-factor of the isomer state.
In this preliminary experiment, fragments were selected in both the center and the outermost wing of the momentum distribution. Fragments were implanted in a 3 mm-thick annealed Cu crystal located between the poles of an electromagnet providing a static magnetic field of

B=0.670(1) T. It was used to induce a Larmor precession of the spin-aligned fragments. By combining detectors placed at 90° with respect to each other and by gating on the 320.5 keV gamma line, the following R(t) function could be generated :

$$R(t) = \frac{I_{34}(\theta = \pm 45°, t) - \epsilon\, I_{12}(\theta = \pm 135°, t)}{I_{34}(\theta = \pm 45°, t) + \epsilon\, I_{12}(\theta = \pm 135°, t)}$$

where I_{ij} is the sum of the photo-peak intensity in Ge detectors i and j, theta is the detection angle with respect to the beam axis and ε is a normalization coefficient related to the detection efficiency.

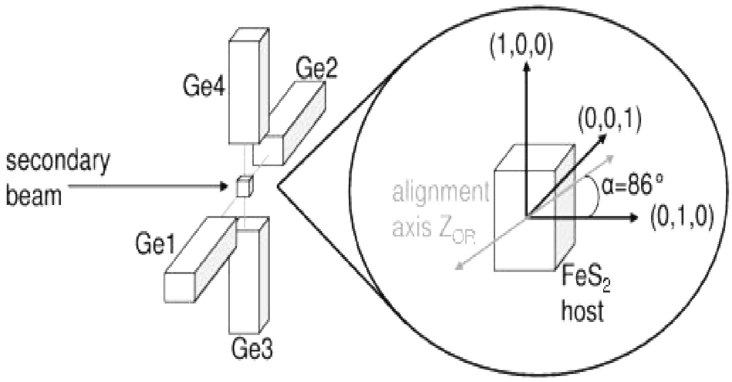

Figure 3. Experimental setup fir the spectroscopic quadrupole moment measurement.

The highest alignment A was reached for fragments selected in the center of the momentum distribution. After 2.3h of data acquisition it yielded to A=+8.1(9)% with a g-factor of g=-0.312(12), in agreement with that reported in Ref. [5]. When selected in the wing of the momentum distribution, the R(t) function originating from 6h of data acquisition yielded to A=-2.8(6)%, limiting the accuracy in determining the g-factor.

For the quadrupole moment measurement, fragments were implanted in a pyrite single crystal (FeS_2) which contained an electric field gradient (EFG) comprising four components in different directions at the sulfur position [7]. The value of the EFG was determined by solid state calculations using the WIEN2K package [8]. We obtain an EFG for S of $+14.14(1.4)*10^{-21}$ V/m^2. In order to obtain the highest gamma anisotropy, four Ge detectors were placed in the vertical plane, perpendicular to the beam direction as shown in Fig.3. For the interaction between the spectroscopic quadrupole moment and an EFG, the angular distribution of the emitted gamma ray s is defined by perturbation coefficients, which reduce to a superposition of several harmonics of basic frequency ω_0 [9].

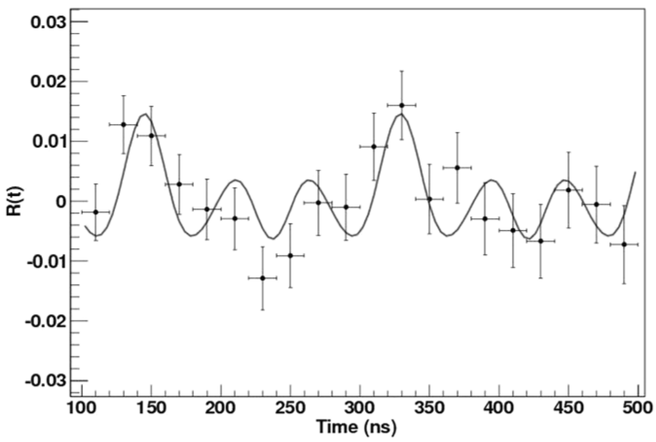

Figure 4. R(t) function for the E=320,5(5) keV γ- ray deexciting the isomer state.

The period of the R(t) function (displayed in Fig.4) therefore depends on both the spin J and the quadrupole interaction frequency:

$$\vartheta_Q = \frac{eQ_s v_{zz}}{h}$$

A χ^2-minimization procedure was used to determine the free parameters and their statistical errors, which were A(t=0), ν_Q and t=0. We obtain the absolute value of the spectroscopic quadrupole moment $|Q_s|$=23(3) efm^2. In order to interpret this value, shell model calculations have been performed using the ANTOINE code [10,11] within the full *sdpf* valence space for protons (neutrons) with effective charges e_π=1.35e (e_ν=0.35e) and nucleon g-factors g_π^l = 1.1, g_π^s = 4.1895 (g_ν^l = -0.1, g_ν^s = -2.8695). The spectroscopic quadrupole moment of the $7/2_1^-$ isomer calculated within the SM framework is Q_s=25 efm^2, in excellent agreement with that calculated in this experiment. However, such a value is significantly larger than that expected for a single neutron hole in the $f_{7/2}$

orbit, Q_s=4 efm^2. Such a deviation indicates that correlations are at play in the isomer state.

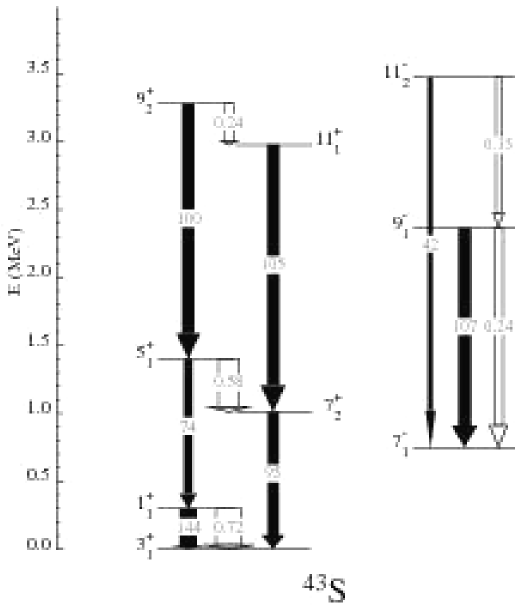

Figure 5. Level Scheme of the low-lying structure in ^{43}S calculated within the shell model framework. Transition probabilities [in e^2fm^4 (μ_N^2) for E2 (M1) transitions] are displayed at the center of the arrows.

Therefore, shell model calculations have been extended to higher excited states in order to look for a deformed structure built on top of the isomer. Only the $9/2_1^-$ and $11/2_2^-$ states, displayed in Fig.5, show non negligible electric B(E2) and magnetic B(M1) transition probabilities with the isomer. A decomposition of the wave functions (WF) of the low-lying states in ^{43}S show that the natural neutron $(f_{7/2})^{-1}$ configuration is the dominant one (53%) for the isomer state. However, the intruder configurations have an important contribution (47%) to the total WF. The intruder configurations even become the dominant ones for the $9/2_1^-$ (60%) and $11/2_2^-$ states (83%). The absence of an intrinsic wave function among those states is therefore not consistent with a deformed structure built on top of the isomer.

Conclusion

We report on the quadrupole moment measurement of the 7/2 isomer state of ^{43}S using the TDPAD method applied on spin aligned fragments selected via the BigRIPS spectrometer at RIKEN. The yielded value, $|Q_s|=23$ efm^2, in remarkable agreement with that obtained with shell model calculations, is significantly larger than that expected for a single particle state originating from the $(f_{7/2})^{-1}$ neutron configuration. In the SM framework, no deformed structure has been identified on top of the isomer. Moreover, the Wfs obtained with SM calculations show, although the natural $(f_{7/2})^{-1}$ configuration is the dominant one, a large mixing with intruder configuration arising from proton-neutron correlation. Those intruder configurations are understood to have an impact on the large Q_s value of the isomer state. Therefore the isomer state can not be considered as a spherical state. However, correlations are not developed enough to drive the state towards an axially symmetric deformation. The shape coexistence in the low-lying structure of ^{43}S would be confirmed by experimentally identifying the states belonging to rotational band predicted on top of the $3/2_1^-$ ground state.

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