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Observation of the 0_2^+ state in ^{44}S

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Abstract. We report preliminary results on the observation of the isomeric 0_2^+ state in ^{44}S. This state, populated in the fragmentation of a ^{48}Ca beam, is located at 1365 ± 1 keV and has a half-life of 2.3 ± 0.3 μs. The observation of this isomer is the first experimental evidence of shape coexistence in ^{44}S which was predicted by various theoretical approaches. In particular, we found a good agreement with shell model calculations.

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1 Introduction

The evolution of the shell closures at large N/Z ratios is one of the most fascinating quest in nuclear structure. In particular, the evolution of the $N = 28$ shell closure below ^{48}Ca has been the subject of several theoretical publications which predict a progressive onset of deformation with either spherical/prolate [1] or oblate/prolate [2,3,4,5] shape coexistence in ^{44}S. It is therefore important to characterize this nucleus by searching for a low-lying 0_2^+ state. This would give information about both the importance and the origin of the deformation at $Z = 16$. Moreover, whether the deformation persists in the ^{42}Si nucleus is highly debated [6] and critically depends on the structure of ^{44}S.

Recent experimental data for $E(2^+)$ and $B(E2)$ values [7,8], $E(4^+)/E(2^+)$ ratios [9], and β-decay studies below ^{48}Ca [10] point to a likely region of deformation in the S isotopic chain. In addition, low-energy isomers have been observed in the $N = 27$ ^{45}Ar [11] and ^{43}S [12] isotones suggesting that excitations across the $N = 28$ gap are important. The evidence of such a cross shell excitation in ^{44}S would manifest itself through the presence of an 0_2^+ isomer that has not yet been found.

A dedicated experiment has been performed to detect the delayed converted electrons arising from the decay of an $E0$ isomer. We report here the first observation of the low-lying isomeric 0_2^+ state in ^{44}S.

2 Experimental setup

The experiment has been performed at the GANIL facility. The ^{44}S were produced by fragmentation of a 60 A MeV ^{48}Ca beam on a 611 μm thick Be target and selected by the LISE3 spectrometer. The nuclei were implanted in a 45 μm kapton foil tilted at 28° with respect to the beam direction (effective thickness ~ 96 μm), see fig. 1. The identification was made event by event utilizing two 300 μm Si detectors that provided A and Z identification by energy loss and time-of-flight information, the second Si detector (position sensitive) being used to obtain information about the profile of the beam on the kapton foil. The third and fourth Si detectors (500 μm each) were mounted on a rotatable

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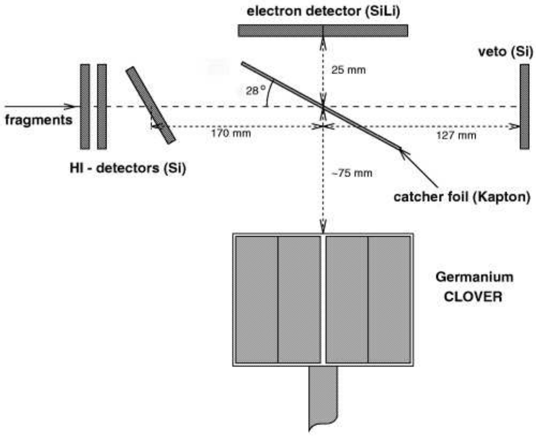

Fig. 1. Schematic view of the detection setup at the end of the LISE spectrometer.

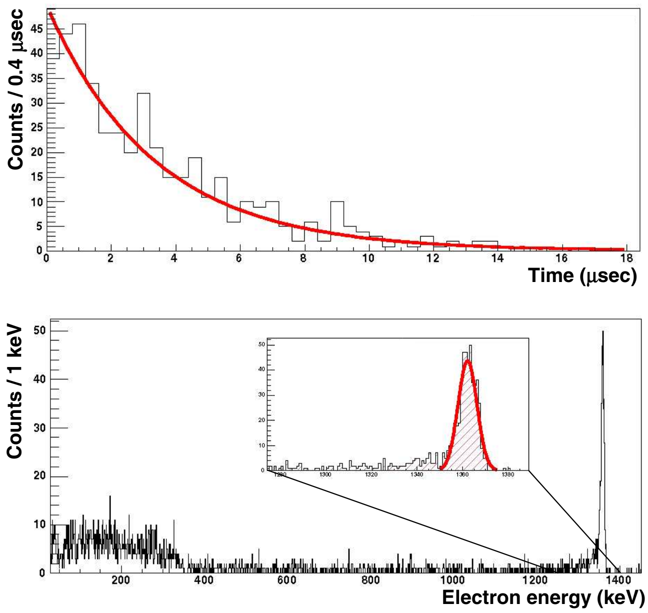

Fig. 2. Decay time (top) and energy spectra (bottom) of the conversion electrons corresponding to the $E0$ transition detected in the Si(Li) detector obtained in coincidence with ^{44}S ions. The inset shows a zoom on the region of the peak.

arm to adjust the effective matter thickness and implant the ions of interest in the last 30 μm of the catcher foil. The depth of implantation was controlled using the veto Si detector (500 μm) that was also used to reject fragments which passed through the implantation foil. The setup surrounding the collection point consisted of several detectors arranged perpendicularly to the beam axis: a liquid nitrogen cooled Si(Li) on the top for the conversion electrons and two segmented Ge clovers (Exogam) on the sides. The total efficiency of the Si(Li) and Ge detectors was estimated to be $\sim 6\%$ for energies between ~ 200 keV and 2 MeV and $\sim 3.5\%$ at 1.3 MeV, respectively.

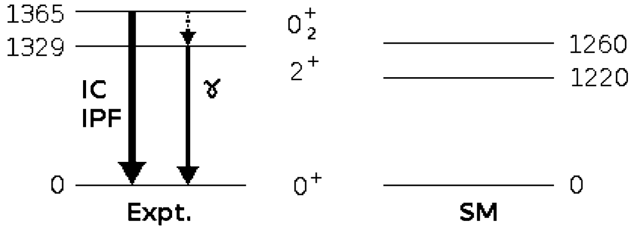

Fig. 3. Proposed decay scheme of the 0_2^+ state in ^{44}S and the corresponding levels calculated by shell model calculations [1].

3 Experimental results

The evidence for the presence of a 0_2^+ isomer was inferred from both the observed $E0$ and $E2$ transitions which feed the 0_1^+ (ground state) and 2_1^+ (1329 keV) states, respectively. The electron energy spectra obtained in the Si(Li) detector in delayed coincidence with the implantation of ^{44}S ions is shown in fig. 2 along with the corresponding decay-time between the implantation and the decay. A peak at 1362.5±1.0 keV is clearly seen in the figure and has been attributed to the $E0$ transition by internal conversion electrons (IC) from the 0_2^+ state located at 1365 ± 1 keV with a half-life of 2.3 ± 0.3 μs. Since the energy of the 0_2^+ state is greater than 1022 keV, it also decays by internal pair formation (IPF). This is confirmed from the time spectra measured in coincidence with the 511 keV gamma ray in the Ge detectors. Finally, the assumption of a 0_2^+ state is confirmed from the observation in the Ge detectors of the 1329 keV gamma ray which correspond to the de-excitation of the known 2^+ state in ^{44}S with a half-life of 2.3 ± 0.5 μs, the very low energy (36 keV) transition $0_2^+ \to 2_1^+$ being unobserved. The resulting decay scheme is shown in fig. 3.

4 Discussion

As shown in fig. 3, a good agreement is found between calculated and measured energies of the first excited states in ^{44}S. In this shell model calculation, the two 0^+ states are described as a mixture of closed-shell and np-nh excitations. The presence of a low-lying 0_2^+ state is considered as a signature of a spherical-deformed coexistence in the mean field and the present data therefore support the weakening of the $N = 28$ shell gap.

The data analysis is in progress to obtain the $B(E0)$ and $B(E2)$ values for the decay of the 0_2^+ state. This would help in the better understanding of the nature of this isomer, and in particular the difference in shapes between the two 0^+ states. We expect a large $B(E0)$ value between spherical and deformed states and a small value for an oblate-to-prolate transition. These experimental results will be compared to the models predicting both energy and transition probabilities to infer the origin of the shell weakening.

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