Properties of low-lying intruder states in ^{34}Al and ^{34}Si populated in the beta-decay of ^{34}Mg

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Abstract.
The results of the IS530 experiment at ISOLDE revealed new information concerning several nuclei close to the $N \approx 20$ 'Island of Inversion' - ^{34}Mg, ^{34}Al, ^{34}Si. The half-life of ^{34}Mg was found to be three times larger than the adopted value (63(1) ms instead of 20(10) ms). The beta-gamma spectroscopy of ^{34}Mg performed for the first time in this experiment, led to the first experimental level scheme for ^{34}Al, also showing that the full beta strength goes through the predicted 1^+ isomer in ^{34}Al [1] and/or excited states that deexcite to it. The subsequent beta-decay of the 1^+ isomer in ^{34}Al allowed the observation of new gamma lines in ^{34}Si, (tentatively) associated with low-spin high-energy excited states previously unobserved.

Keywords: HPGe, LaBr$_3$(Ce) detectors, plastic scintillator, ^{34}Mg, ^{34}Al, ^{34}Si, β^- decay, measured γ-γ coincidences, deduced level scheme.
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1. INTRODUCTION

More than three decades after the first clues [2, 3] to the existence of a region of deformation and/or shape coexistence around $N = 20$ - the "Island of Inversion" - there are nuclei in its vicinity for which the experimental information is scarce. Such an example is the heaviest nucleus inside this 'island' - ^{34}Mg, whose first beta-gamma spectroscopy was performed in our recent experiment at ISOLDE [4]. The daughter nucleus - ^{34}Al - had no experimental level scheme, though some transitions were assigned to this nucleus [5, 6]. Moreover a low spin beta-isomer of unknown excitation energy was evidenced at GANIL [1], presumably the 1^+ state of $1\hbar\omega$ configuration [4, 7], populating strongly the deformed 0_2^+ isomer in ^{34}Si of intruder origin.

2. EXPERIMENT

The β^- decay spectroscopy of ^{34}Mg was performed at the ISOLDE facility at CERN. The ^{34}Mg isotopes were produced by the CERN Proton Synchrotron Booster (PSB) 1.2-GeV proton-beam which induced spallation in a thick uranium carbide (UCx) target. The reaction products were extracted and ^{34}Mg was selected using the high resolution mass separator (HRS) and resonant laser ionization (RILIS). During the experiment, an yield of ~ 600 ^{34}Mg atoms per proton pulse was obtained, leading to an average of ~ 200 implanted ^{34}Mg per second.

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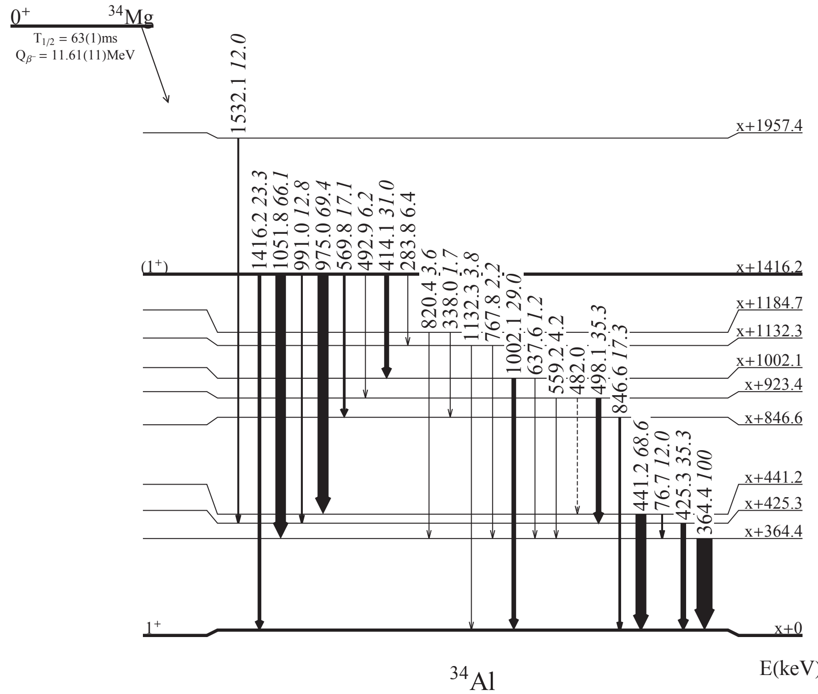

FIGURE 1. Level scheme of ^{34}Al following the β-decay of ^{34}Mg.

The detection system consisted of beta and gamma detectors in order to provide an unique selection of β-γ-γ coincidences and neutron detectors to select β-n and β-2n decay channels. There were three HPGe clover detectors, one HPGe coaxial detector, five $LaBr_3$:Ce crystals which were used as fast-timing γ detectors and three NE213 liquid scintillators as neutron detectors.

A NE102 plastic scintillator was used as a β trigger of $\sim 90\%$ efficiency. This detector had a complex geometry that was designed to comply with several criteria. First of all, in order to maximize the beta efficiency, the implantation tape (of the fast-tape station) passed through a slit in the middle of the scintillator, a hole through one of the faces allowing the implantation of the beam into the foil. A second constraint was related to the thickness of the plastic that needed to be reduced in order to diminish the effect on the low energy γ efficiency.

3. EXPERIMENTAL RESULTS

The γ spectrum following the β-decay of ^{34}Mg and $\gamma-\gamma$ coincidence analysis led to the preliminary ^{34}Al level scheme built on top of the 1^+ isomer, displayed in Fig. 1. None of the 22 gamma transitions from ^{34}Al observed in this experiment are found among the previously reported lines of ^{34}Al (388, 433, 597, 706, 916 and 1206 keV from [5], and 657 keV from [6]). The direct γ transition $1^+ \rightarrow 4^-$ was not observed, most likely as a result of an excitation energy significantly smaller than the 550-keV value predicted by the shell-model calculations in [1], thus leading to a very small γ branch from the 1^+ β-isomeric state. Also, none of the observed transitions could be connected to the 4^- ground state of ^{34}Al, inferring that it is not significantly fed in the β-decay of ^{34}Mg.

The β-decay half-life of ^{34}Mg was determined using the γ-gated β-time with respect to the proton pulse leading to $T_{1/2} = 63(1)$ ms, three times larger than the previously measured value determined from β-n coincidences [8]. This new value is also confirmed by the β time gated using known γ transitions in ^{33}Al (populated in the β-n decay of ^{34}Mg).

The subsequent β-decay of ^{34}Al revealed several new γ transitions in ^{34}Si, $\gamma-\gamma$ coincidences leading to the decay scheme depicted in Fig. 2. The newly reported lines are in coincidence with the previously known transitions from the

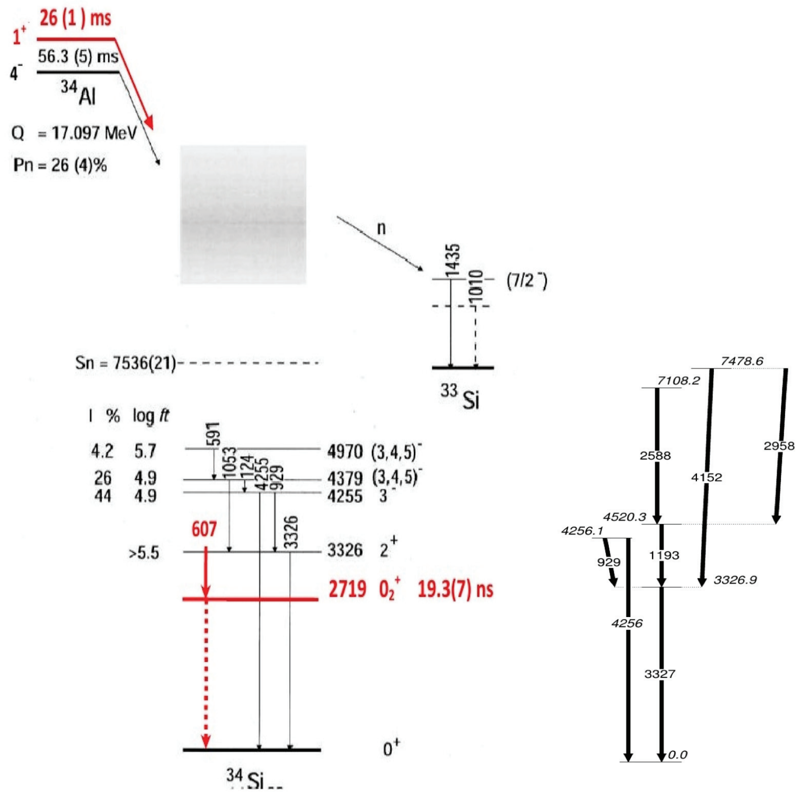

FIGURE 2. Beta-decay of ^{34}Al: from the 4^- ground state [9] (left), and from the 1^+ isomer [this experiment] (right)

beta-decay of the ^{34}Al 4^- ground state [9]. The 5.3 MeV transition seen in [10, 11] from the supposed second 2^+ to the ground state was not observed.

The absence of gammas that were previously shown to be fed in the β-decay of the ^{34}Al 4^- ground state [9], such as the 124-keV line, is a strong indication that it is not populated (directly or indirectly) in the beta-decay of ^{34}Mg (despite a large number of excited states found in ^{34}Al that could have a γ branch to the 4^- ground state). This is another evidence to support the scenario presented in Fig. 1, showing that none of the detected gammas in ^{34}Al feed the 4 ground state.

In order to extract the β-decay half-life for ^{34}Al, the β-time with respect to the proton bunch was gated using γ lines of ^{34}Si. The resulting time spectrum was fitted with a convolution of two decay components: one having the known ^{34}Mg half-life of 63(1) ms as a fixed parameter, and the second one with a free parameter corresponding to the ^{34}Al decay-time. The resulting $T_{1/2} = 25(4)$ ms is in good agreement with the previously measured value [1]. It also confirms the idea that the 4 ground state of ^{34}Al is not populated in the β-decay of ^{34}Mg.

A fast digitizer (1 GHz) was used to acquire traces from the plastic scintillator and recorded 'double hit' type of evens corresponding to a beta electron followed by an electron-positron pair (generated in the E0 decay) from the 0_2^+ isomer in ^{34}Si [1]. Such events were accumulated with enough statistics, enabling the measurement of a 20(2) ns half-life for the first excited state in ^{34}Si as shown in Fig. 3. This result is in agreement with the value determined in [1].

4. CONCLUSIONS

The present study brings new information concerning the decay of ^{34}Mg. Its half-life was found to be three times larger than the adopted value. The first experimental level scheme of ^{34}Al is proposed, containing 22 transitions that

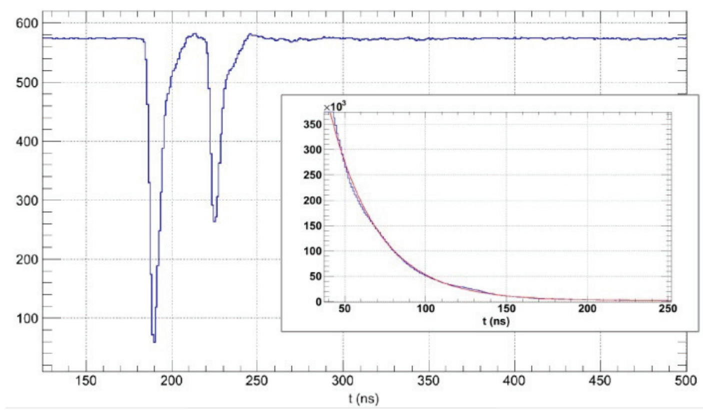

FIGURE 3. Digitized trace from the plastic detector for a 'double hit' type of event. The inset is the time spectrum resulting from the analysis of such traces, leading to a 20(2) ns half-life for the 0_2^+ in ^{34}Si

deexcite to the the 1^+ isomer evidenced in [1]. The beta-decay of the 1^+ isomer in ^{34}Al allowed the observation of new gamma lines in ^{34}Si. No β or γ branching was observed to populate the 4^- final state, previously assumed the ground state of ^{34}Al. Therefore, the question remains open, whether the 1^+ or the 4^- is the ground state of ^{34}Al.

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