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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, LaBr3(Ce) detectors, plastic scintillator, $^{34}$Mg, $^{34}$Al, $^{34}$Si, $\beta^-$ decay, measured $\gamma-\gamma$ coincidences, deduced level scheme.

PACS: 21.10.Tg, 23.20.Lv, 23.40.-s, 27.30.+t

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 $\beta^-$ 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 $\sim 600$ $^{34}$Mg atoms per proton pulse was obtained, leading to an average of $\sim 200$ implanted $^{34}$Mg per second.
FIGURE 1. Level scheme of $^{34}$Al following the $\beta$-decay of $^{34}$Mg.

The detection system consisted of beta and gamma detectors in order to provide an unique selection of $\beta$-$\gamma$ coincidences and neutron detectors to select $\beta$-n and $\beta$-2n decay channels. There were three HPGe clover detectors, one HPGe coaxial detector, five LaBr$_3$:Ce crystals which were used as fast-timing $\gamma$ detectors and three NE213 liquid scintillators as neutron detectors.

A NE102 plastic scintillator was used as a $\beta$ 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 $\gamma$ efficiency.

3. EXPERIMENTAL RESULTS

The $\gamma$ spectrum following the $\beta$-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 $\gamma$ transition 1$^+ \to 4^-$ 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 $\gamma$ branch from the 1$^+$ $\beta$-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 $\beta$-decay of $^{34}$Mg.

The $\beta$-decay half-life of $^{34}$Mg was determined using the $\gamma$-gated $\beta$-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 $\beta$-n coincidences [8]. This new value is also confirmed by the $\beta$ time gated using known $\gamma$ transitions in $^{33}$Al (populated in the $\beta$-n decay of $^{34}$Mg).

The subsequent $\beta$-decay of $^{34}$Al revealed several new $\gamma$ 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
beta-decay of the $^{34}\text{Al}$ $4^-$ 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 $\beta$-decay of the $^{34}\text{Al}$ $4^-$ 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 $^{34}\text{Mg}$ (despite a large number of excited states found in $^{34}\text{Al}$ that could have a $\gamma$ 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 $^{34}\text{Al}$ feed the $4$ ground state.

In order to extract the $\beta$-decay half-life for $^{34}\text{Al}$, the $\beta$-time with respect to the proton bunch was gated using $\gamma$ lines of $^{34}\text{Si}$. The resulting time spectrum was fitted with a convolution of two decay components: one having the known $^{34}\text{Mg}$ half-life of $63(1)$ ms as a fixed parameter, and the second one with a free parameter corresponding to the $^{34}\text{Al}$ 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 $^{34}\text{Al}$ is not populated in the $\beta$-decay of $^{34}\text{Mg}$.

A fast digitizer (1 GHz) was used to acquire traces from the plastic scintillator and recorded 'double hit' type of events corresponding to a beta electron followed by an electron-positron pair (generated in the E0 decay) from the $0^+$ isomer in $^{34}\text{Si}$ [1]. Such events were accumulated with enough statistics, enabling the measurement of a 20(2) ns half-life for the first excited state in $^{34}\text{Si}$ 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 $^{34}\text{Mg}$. Its half-life was found to be three times larger than the adopted value. The first experimental level scheme of $^{34}\text{Al}$ 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 $^{34}\text{Si}$
deexcite to the the $1^+_2$ isomer evidenced in [1]. The beta-decay of the $1^+_2$ isomer in $^{34}\text{Al}$ allowed the observation of new gamma lines in $^{34}\text{Si}$. No $\beta$ or $\gamma$ branching was observed to populate the $4^-$ final state, previously assumed the ground state of $^{34}\text{Al}$. Therefore, the question remains open, whether the $1^+_2$ or the $4^-$ is the ground state of $^{34}\text{Al}$.

REFERENCES

4. F. Negoita et al., INTC-P-314 (2011)