Search for the E0 Transition from the Deformed 0_2^+ State in ^{30}Mg $^\diamond$

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A shape coexistence of spherical and deformed 0^+ states is predicted to exist around the „island of inversion" in neutron-rich Mg isotopes. While the closed-shell nucleus ^{32}Mg exhibits a superdeformed ground state ($\beta \sim 0.51$), the ground state of ^{30}Mg is much less deformed. The (deformed) excited 0^+ state is predicted by theory between 1.7-2 MeV [1] but has not yet been observed experimentally. However, recent experimental findings create confidence that the experimental identification of shape coexistence in ^{30}Mg is within reach. Resulting from fast timing γ-spectroscopy studies [2] the 1789 keV level in ^{30}Mg emerged as a strong candidate for the deformed first excited 0^+ state due to its long lifetime of 3.9 ns and the absence of a ground state γ transition, as can be seen in the level scheme of ^{30}Mg shown in Fig. 1. Moreover, from an imbalance of the populating and deexciting γ intensities a potentially strong E0 decay branch ($\sim$%) could be expected from the 1789 keV level. This triggered our search for the deformed 0_2^+ state in ^{30}Mg via conversion electron spectroscopy within the framework of the ISOLDE IS414 collaboration.
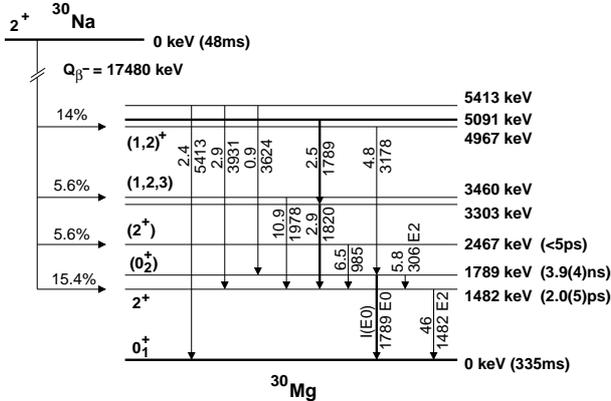

Fig. 1: Level scheme of ^{30}Mg. New γ transitions found by [2] are marked in thicker lines.
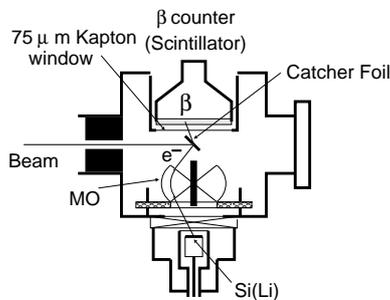

Fig. 2: Sketch of the experimental setup used at ISOLDE

A first feasibility study was performed at ISOLDE in August 2005 [3] observing the β decay of ^{30}Na. No strong E0 transition in ^{30}Mg was shown at 1789 keV. An upper limit derived from the sensitivity limit of the experiment transition could be given for the E0 decay ($\rho^2(^{30}$Mg,E0$) \leq 0.26, I \leq 1 \cdot 10^{-3}$). This spectrum was dominated by β-decay electrons. To reduce the background and to increase the sensitivity an improved experiment was performed at ISOLDE in June 2006 measuring E0 in coincidence with β-decay. Fig. 2 shows the experimental setup. The radioactive low-energy beam from the HRS target was stopped in a 0.1 mm thick Al-foil. A 2 inch photomultiplier with a 2 mm thick plastic scintillator (BC-408) was mounted in a distance of 15 mm to the target resulting in a solid angle of $d\Omega/4\pi = 25$%. The efficiency for electrons was about 100%. This detector was operated in coincidence with a Mini-Orange spectrometer [4]. The transmission maximum of the spectrometer was 3.5% around 1700 keV optimized for an E0 transition in ^{30}Mg [3]. The coincidence condition provided a trigger on the β-decay, in order to suppress β-decay background in the Si(Li) detector. In order to identify the beam composition and for normalisation γ-rays following the β-decay were detected using a Ge-detector.
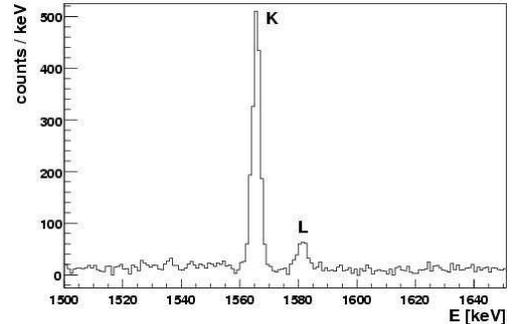

Fig. 3: Background-subtracted electron spectrum from the decay of A=96 isobars with the prominent E0 decay of ^{96}Zr, measured with the MO spectrometer in coincidence with β decay.

To determine the background suppression of the improved coincidence setup the E0 decay in ^{96}Zr was studied using a $A = 96$ beam. The timing spectrum of the E0 decay in ^{96}Zr was measured using a TAC. The TAC was started with a signal from the Si(Li) detector and stopped with a signal from the β counter. The faster signal from the β counter was delayed by 600 ns.

Fig. 3 gives the background-subtracted electron spectrum gated on the coincidence condition. The runtime was 33 min and the backround subtracted coincident counting rate was $\sim$ 15 counts/s. The beam composition derived from the γ-spectrum was $\sim$12% ^{96}Rb, $\sim$2% ^{96}Sr and $\sim$86% ^{96}Y. Comparing this electron spectrum with the singles measurement, an improvement of the peak-to-background ratio of the K-line by a factor of $\sim$ 15 could be concluded. The experimental sensitivity for this setup could be determined by concluding that due to the significantly improved peak-to-background ratio an E0 transition with as low as

1/2 of the L-line intensity in ^{96}Zr ($\sim 0.14\%$) could be unambiguously identified. This leads to the sensitivity limit of the coincidence setup as used in the 2006 test experiment of $I \geq 5 \cdot 10^{-4}$.

Looking at the background-subtracted E0 spectrum in coincidence with β-decay for the measurement of A=30 no peak at 1788 keV showed up after 21 hours of beamtime. The beam composition was determined to be $\sim 11\%$ ^{30}Na, $\sim 0.4\%$ ^{30}Mg and $\sim 88.6\%$ ^{30}Al and the background subtracted coincident counting rate was ~ 5 counts/s. There was still a background component surviving the coincidence condition predominantly originating from Compton scattering of high-energy γ-rays due to the large Q value of the ^{30}Na β-decay (Q = 17.5 keV). We derive an intensity limit of the K+L conversion electron E0-transition in the ^{30}Na decay to ^{30}Mg: I(^{30}Mg,K+L E0)$\leq 5 \cdot 10^{-4}$, or for the monopole matrix element: ρ^2(E0) ≤ 0.13.
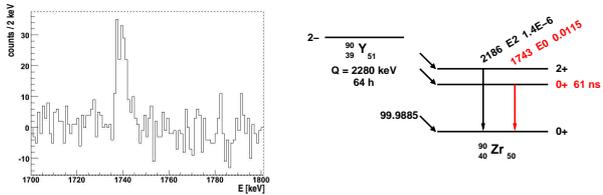

Fig. 4: Background-subtracted electron spectrum from the decay of ^{90}Y measured with the MO spectrometer in coincidence with β decay. The source intensity is ~ 2 kBq. The decay was measured for 32 hours.

In order to test the sensitivity and to get a better understanding of the remaining coincident background of the experimental setup, the E0 transition in ^{90}Zr (1761 keV) was measured using an ^{90}Y source of ~ 2 kBq with a halflife of 62 hours. The source was produced at the Radiochemistry Institute of the Technical University in Munich. A reservoir of ^{90}Sr was flushed with hydrochloric acid. A drop of $10\mu l$ of the solution with 500 kBq activity was dripped on a $20\mu g/cm^2$ carbon foil and dried using an ultraviolet lamp. ^{90}Y decays with 99.99% to the ground state of ^{90}Zr via β decay. Fig. 4 shows the level scheme of ^{90}Zr. The decay branch of γ-emission is $1.4 \cdot 10^{-6}\%$ and thus negligible and the intensity of the $0_2^+ \rightarrow 0_1^+$ E0 transition is 0.0115% with ρ^2(E0) = $3.3 \cdot 10^{-3}$. Fig. 4 shows the result of the measurement. 160 E0 transitions (background-subtracted) were measured in coincidence with β electrons in 32 hours.

While the measurement with ^{90}Zr characterizes an experimental situation where no γ-induced background is present, additional studies were performed using a ^{152}Eu source, where β-decay and EC can occur and thus the influence of γ-induced background could be investigated. Due to the transition energies around 1 MeV the Mini-Orange spectrometer was optimized to achieve a transmission maximum of $\sim 7\%$ around 1 MeV [5].

The dependency of the γ-ray-induced background in the plastic scintillator was studied by measurements using 2 mm, 4 mm and 6 mm thick BC-404 scintillators. Fig. 5 shows the resulting and expected linear dependency of the counting rate in the background subtracted coincident spectrum with the detector thickness. Using a plastic detector of 0.5 mm thickness as planned for the requested ISOLDE experiment will decrease the γ-induced background by 30%.

In order to avoid X-rays from the lead absorber hitting the plastic detector, the absorber was covered with a 5 mm copper cap. This reduces the "background coincidences" by 25%.
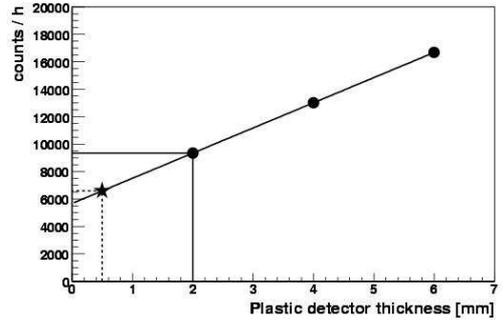

Fig. 5: Dependency of the coincident background-subtracted counting rate on the thickness of the plastic detector derived by measurements using the whole intensity (γ and electrons) of the ^{152}Eu source. Using a plastic detector of 0.5 mm thickness ($\star$) will decrease the background by 30% compared to the presently used 2 mm scintillator thickness ($\bullet$).

Also GEANT4 simulations have been performed in order to quantify the contribution of different setup components to the reduction of background and to identify the potential of background reduction by changes of the materials and components of the setup. Different geometries and materials of the target chamber were simulated each for $5 \cdot 10^5$ ^{30}Na decays in order to study their effect on scattered γ radiation and (Compton-) scattered electrons hitting the plastic detector. In our experiments so far a target chamber consisting of aluminum ($\sim 40\%$) and stainless steel ($\sim 60\%$) components was used and a Germanium γ detector was mounted using a pocket flange reaching inside the target chamber close to the target. It turns out that a consequent reduction of high-Z components and measures to prevent the re-entry of scattered background electrons into the interior of the target chamber can significantly reduce background contributions. Especially rebuilding the target chamber completely from aluminum and retracting the Ge-detector to a position outside the chamber will reduce the total production of Compton scattered electrons. Consequently the detected background in the plastic β detector from electrons and γ-rays will decrease by a factor of 2. If in addition the interior surfaces of the target chamber will be covered with 15 mm thick plastic plates in order to stop Compton scattered electrons from re-entering into the chamber volume an overall background suppression by a factor of 8 can be reached. Together with the improvement of the reduction of the scintillator thickness and the copper absorber an overall improvement of a factor of 16 can be expected.

The expected sensitivity limit for E0 transitions strength in ^{30}Mg for the new setup is ρ^2(^{30}Mg,E0) ≤ 0.008 ($I \leq 3.1 \cdot 10^{-5}$). This is much lower than the estimated E0 transition strength (ρ^2(^{30}Mg,E0) ≤ 0.02, $I \leq 6.5 \cdot 10^{-5}$) [3]. The first identification of an 0_2^+ E0 transition in ^{30}Mg is within reach with our optimized setup. A one week beamtime at ISOLDE is approved by the INTC an will take place in summer 2007.

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