Search for the E0 Transition from the Deformed 0_2^+ State in ^{30}Mg [◇]

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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, while 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 inbalance of the populating and deexciting γ intensities a potentially strong E0 decay branch (up to $\sim 4\%$) 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.

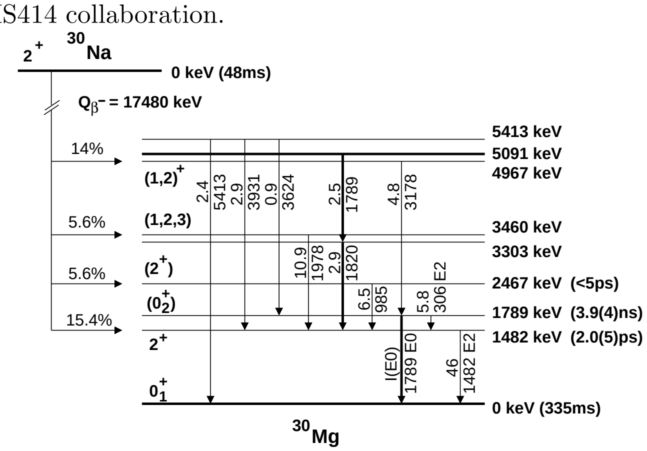

Fig. 1: Level scheme of ^{30}Mg. New γ transitions found by [2] are marked in thicker lines.

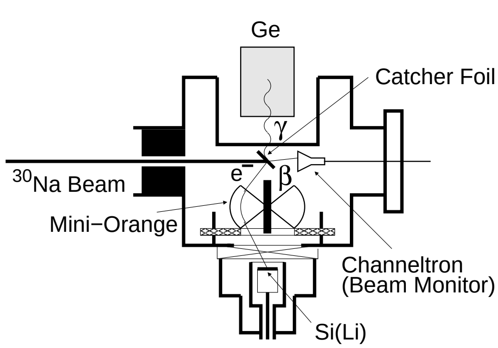

Fig. 2: Sketch of the experimental setup used at ISOLDE

The experimental setup is shown in Fig. 2. The radioactive low energy beam from the HRS target is stopped in a 0.1 mm thick Al-foil. In order to identify the beam composition γ-rays following the β-decay were detected using a Ge-detector. A channeltron served as a beam monitor.

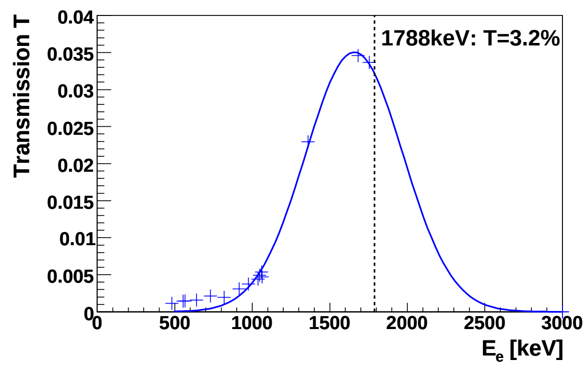

Fig. 3: Transmission curve of the Mini-Orange spectrometer consisting of 8 wedge-shaped permanent magnets. The transmission maximum is 3.5% around 1700 keV close to the transition energy in ^{30}Mg.

In order to suppress the β-decay background and to increase the solid angle of the detector a Mini-Orange spectrometer (MOS) [3] was used. It consists of 8 wedge-shaped permanent magnets arranged around a central Pb absorber resulting in a toroidal magnetic field of B = 160 mT and a Si(Li)-detector operated at liquid N_2 temperature with $\sim$ 4 keV resolution. The transmission curve of the MOS was optimized for the expected E0 transition energy of 1788 keV, resulting in a detection efficiency of 3.2% at this energy, as can be seen from Fig. 3.

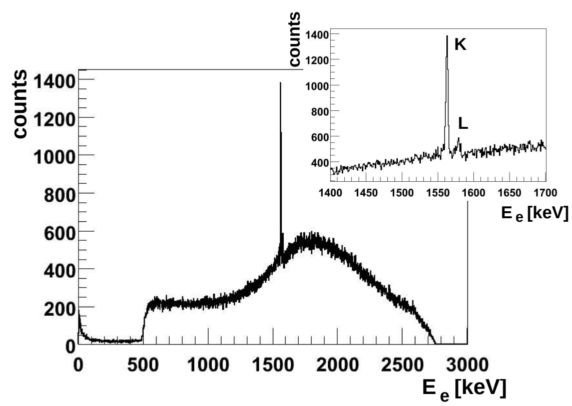

Fig. 4: Conversion electron spectrum of ^{96}Zr. The K- and L-line of the E0 decay are clearly visible on top of the β background folded with the transmission curve.

In order to prove the feasibility of this measurement the known E0 transition ($E = 1563$ keV, $I = 1.41\%$ [4]) in ^{96}Zr was measured for 2.2 h. The results are shown in Fig. 4. The K- and L-transitions are clearly visible on top of the β-decay background folded with the transmission curve. The K/L-ratio (9.4_{theo} [5], $(8.0 \pm 1.3)_{exp}$) and the clearly identified L-line determine the sensitivity limit of the measurement to be $\leq 0.1\%$.

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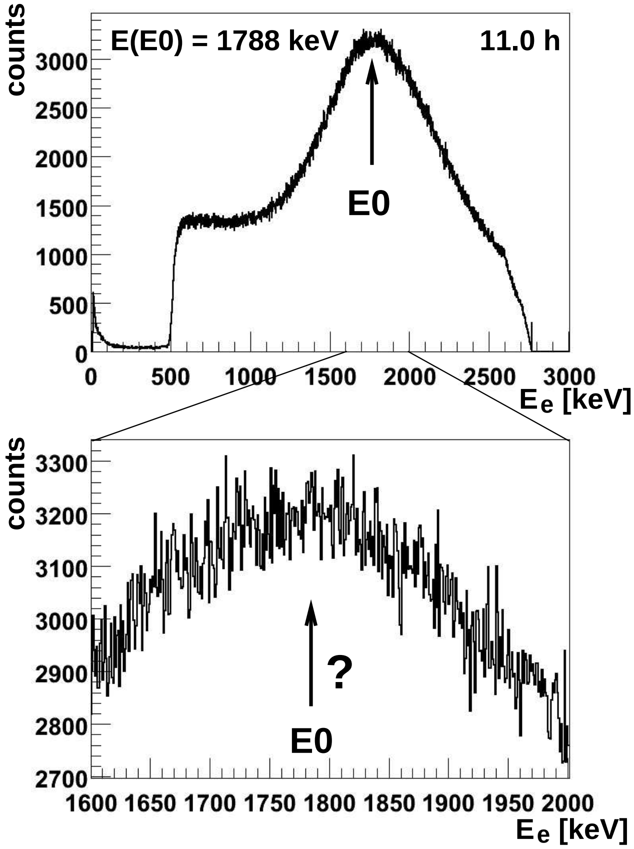

Fig. 5: Conversion electron spectrum of the A = 30 beam. The β background is folded with the transmission curve. The potential location of the E0 transition in ^{30}Mg at 1788 keV is indicated.

Fig. 5 displays the accumulated electron spectrum measured in 11.0 h using an A = 30 beam ($I_{^{30}\mathrm{Na}} \sim 650$/s). Obviously the spectrum does not exhibit the initially expected strong E0 transition at 1788 keV (indicating discrepancies in the published γ-decay intensities). The spectrum is dominated by background from β-decay electrons folded with the transmission function of the Mini-Orange. However, a closer look at the region of the expected E0 transition energy reveals a lineshape-like agglomeration of intensity, exhibiting a width comparable to the detector resolution, resulting in ca. 400(400) background-subtracted counts.

The monopol matrix element ρ^2(E0) is related to the lifetime τ(E0) of the 0^+ state via

$$\frac{1}{\tau(\mathrm{E0})} = \rho^2 \cdot (\Omega_K + \Omega_L + \ ... + \Omega_{IP}),$$

where Ω_i values are 'electronic' (non-nuclear) factors for K and L conversion and internal pair production. Since with this setup only conversion electrons are measured $\Omega_{\mathrm{K+L}} = 1.39 \cdot 10^7$/s.

In order to derive an upper limit of the transition strength of the E0 decay in ^{30}Mg two estimates of the monopole matrix element ρ^2 based on experimental results can be given. The equations for the estimates are taken from [6]. The first one is based on an E0 measurement in ^{24}Mg (ρ^2(E0) = 0.305(40)). For light nuclei one observes an $A^{-2/3}$ scaling of ρ^2:

$$\rho^2 = 0.5A^{-2/3}$$

Using this scaling we obtain a first estimate for the E0 transition in ^{30}Mg:

$$\rho^2_{est._1}(^{30}\mathrm{Mg, E0}) = 0.26.$$

A second estimate can be obtained from the overlap of the wave functions of the deformed and the spherical potential minima of the 0^+ states in a simple two-level model. The mixing amplitude a characterizes the mixing of the spherical ground state and the deformed excited state:

$$|0^+_g\rangle = a|0^+_{\mathrm{sph}}\rangle + \sqrt{1-a^2}|0^+_{\mathrm{def}}\rangle$$

$$|0^+_{\mathrm{exc}}\rangle = -\sqrt{1-a^2}|0^+_{\mathrm{sph}}\rangle + a|0^+_{\mathrm{def}}\rangle$$

Knowing the mixing amplitude a and the deformations β_1 and β_2, ρ^2 can be calculated:

$$\rho^2(E0) = (\frac{3}{4\pi}Z)^2 \cdot a^2 \cdot (1-a^2) \cdot (\beta_1^2 - \beta_2^2)^2.$$

The deformation of the less deformed 0^+_1 ground state of ^{30}Mg was measured to be $\beta_2 = 0.37$ [7]. For the deformation of the excited 0^+_2 state of ^{30}Mg the measured deformation of the ground state of ^{32}Mg ($\beta_1 = 0.51$) can be assumed. Since even for larger mixing the dependence on a is not very strong, $a^2 = 0.2$ can be safely assumed, resulting in

$$\rho^2_{est._2}(^{30}\mathrm{Mg, E0}) = 0.02.$$

A knowledge of the mixing amplitude a is of critical importance for a consistent interpretation of many experimental observables (B(E2), $\langle r^2\rangle$, nuclear deformation). Note that the (rather large) ground state deformation in ^{30}Mg ($\beta \sim 0.37$) was derived model-dependent from the measured B(E2) value, while a much more spherical intrinsic deformation is expected. Therefore the above given second estimate for ρ^2(E0) may significantly underestimate the intrinsic configuration.

However, in order to derive conservative estimates for the expected monopole strength in ^{30}Mg the two approaches described above may be used, resulting in a range of ρ^2 values where the experimental identification can be expected.

Focusing in our experiment on the detection of conversion electrons, the above estimates for the monopole strength ρ^2 translate into an expected intensity of the E0 transition of I_{est_1}(E0) $\sim$ 0.1% and I_{est_2}(E0) $\sim$ 0.063%, respectively.

Compared to our present sensitivity of $I \geq 0.1\%$ it is evident that already a modest increase of sensitivity is required to allow for the first identification of the E0 decay from the deformed first excited 0^+ state in ^{30}Mg. Nevertheless an improved experimental setup is in preparation which will allow for significantly increased sensitivity by about a factor of ≥ 750 via a coincidence measurement of E0 decay electrons and β-decay background. Thus the presently dominating β background will be drastically suppressed and even a weak E0 branch will be clearly within experimental reach.

References

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