Mean Life of the $21/2^+$ Isomer of $^{89}$Zr

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The mean life of the lowest $21/2^+$ level of $^{89}$Zr has been measured with a pulsed $^7$Li beam and the $^{85}$Rb($^7$Li, 3n)$^{89}$Zr reaction.

The mean life is $\tau = 7.39 \pm 0.23$ ns and the reduced transition probability to the $17/2^+$ state is $B(E2) = 73 \pm 2 e^2 fm^4$. The comparison with shell-model predictions requires a large value of the effective charge ($e_p \approx 2$) to account for the experimental result.

The mean life of the $13/2^-$ state has also been measured and results to be $\tau = 3.22 \pm 0.17$ ns.

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1. Introduction

Nuclei with a closed $v g_{9/2}$ shell (the $N = 50$ isotones) and with $38 \leq Z \leq 48$ have been successfully interpreted [1-3] in the frame of the nuclear shell model with valence protons in the $2p_{1/2}, 1g_{9/2}$ subshells around a closed $^{88}$Sr core. It is therefore interesting to extend the investigation to the properties of the corresponding $N = 49$ isotones [4], where the proton configurations couple to a neutron hole, and in particular to the transition matrix elements between the high spin states, which are by far more sensitive than the excitation energy, to the details of the assumed wave functions.

The aim of this work is the determination of the $B(E2)$ strength of the transition from the $21/2^+$ to the $17/2^+$ state in the two-proton, one-neutron-hole configuration of $^{89}$Zr. In the equal-particle configurations the $21/2^+$ and $17/2^+$ are the highest spin states of seniority-3 and actually these states appear with small and comparable spacings in the odd $N = 50$ isotones [4, 5] $^{91}$Nb, $^{93}$Tc and $^{95}$Rh. In these nuclei the $21/2^+$ levels have been found to be isomers [3] (as well as the $8^+$ levels in the corresponding $N = 50$ even nuclei) and their reduced transition probabilities decrease when $Z$ approaches the centre of the shell, in qualitative agreement with the prediction of the seniority scheme [7]. Something similar to the seniority multiplet of the $N = 50$ isotones, with the typical yrast sequence $9/2^+, 13/2^+, 17/2^+$ and $21/2^+$ (isomer), appears in $^{89}$Zr (and in the other $N = 49$ isotones [5, 8] $^{91}$Mo and $^{93}$Ru) while the recently discovered [9, 10] $23/2^+$ and $25/2^+$ levels belonging to the same configuration lie much higher in energy.

The lifetime of the $21/2^+$ state is $\tau = 57.7 \pm 5.8$ ns in $^{91}$Mo (Ref. [11]) and $\tau = 3.7 \pm 0.3 \mu s$ in $^{93}$Ru [8], while for $^{89}$Zr only the upper limit $\tau < 15$ ns has been reported [11] until now.

In the present work the lifetime of the $21/2^+$ level of $^{89}$Zr has been measured and the $B(E2)$ strength of the $21/2^+ \rightarrow 17/2^+$ transition has been compared with shell model predictions.

2. Experimental Procedure and Results

The reaction $^{85}$Rb($^7$Li, 3n)$^{89}$Zr, at the beam energy of 27 MeV, has been used to produce the high-spin states of $^{89}$Zr.

Measurements have been performed at the Tandem XTU accelerator of Laboratori Nazionali di Legnaro. The pulsed $^7$Li$^+$ beam had a pulse width of about 2.1 ns and a repetition rate of 2.5 MHz. The target was a thin layer (~1 mg/cm$^2$) of natural rubidium chloride evaporated onto a 40 $\mu$g/cm$^2$ carbon foil, and an enriched $^{208}$Pb absorber was placed behind the target to stop the $^7$Li beam. Gamma rays
were detected with a hyperpure Ge detector, of about 2 cm³ volume and 0.69 keV resolution at 122 keV. The time pulse derived from the Ge signal provided the start of a time-to-amplitude converter, whose stop was synchronized with the radio-frequency signal of the beam pulsing generator. The time signal and the energy signal were analyzed by two 4,096 channel ADC's and stored on magnetic tape under control of a PDP11 computer. Time calibration has been performed with an Ortec 462 double pulse generator. The data reduction has been performed at Florence with a Gouls SEL 32/27 computer. The time distribution has been obtained for the different γ-ray lines; the contribution of the underlying Compton background has been estimated by interpolation between neighbouring regions in the energy spectrum, and has been subtracted from the relevant time spectrum.

The results concerning the γ transitions of 271 keV, 780 keV and 178 keV (21/2⁺ → 17/2⁺, 17/2⁺ → 13/2⁺ and 13/2⁻ → 13/2⁺, respectively) are shown in Fig. 1.

The lowest curve in Fig. 1 corresponds to the 788 keV transition from the first excited state of 36Cl, presumably produced by the 35Cl(7Li, α pn) reaction. This line has been analyzed as a check of the method.

The values of the mean lives of the delayed γ rays have been deduced from the time distributions with a minimum-χ² procedure, assuming that the shape of the time spectrum is Gaussian

\[ n(t) = \frac{1}{\sqrt{2\pi \sigma}} \exp\left(-\frac{(t-t_0)^2}{2\sigma^2}\right) \]

for a “prompt” γ ray, and is given by the convolution of the Gaussian with an exponential decay,

\[ n(t) = \int_0^t n(t-t') \exp(-t'/\tau) \, dt' \]

for a delayed γ-ray of mean life τ. The centre \( t_0 \) and the width \( \sigma \) of the Gaussian, as well as the mean life \( \tau \) of the exponential decay, have been determined with the minimum-χ² procedure. In all cases, the addition of a “prompt” (Gaussian) term and of a “random” (constant) term to the spectrum has been considered. The addition of one of these terms (or both) has been considered to be significant if it produced a better value of χ²/n, \( n \) being the number of degrees of freedom (the relative amplitudes of the different terms were also adjusted in such a way to minimize the χ²).

Some of the parameters used to fit the curves of Fig. 1 with the expression

\[ n(t) = \sum_i N_i u(t) + N_p u_0(t) + N_r/T \]

Fig. 1. Time spectra for the γ rays of 271 keV, 780 keV and 178 keV of 89Zr, and of 788 keV of 36Cl. The time scale is 0.8155 ns/ch. Parameters used in the fit (full line) are shown in Table 2. Partial contributions of delayed, random and prompt γ rays (when relevant) are shown as dashed, long-dashed and dashed-dotted lines respectively.