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Lifetime of the 6_1^+ state in ^{42}Ti†

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The mean lifetime of the 3041-keV (6_1^+) state in ^{42}Ti has been measured to be $\tau = 4.5 \pm 0.3$ nsec. This value represents an improvement by a factor of 6 from previous measurements. States in ^{42}Ti were populated by the ^{40}Ca(^{3}He,$n\gamma$) reaction with $E_{^3\mathrm{He}} = 10$ and 12 MeV. The experimental value of $B(E2) = 27.6 \pm 1.8$ e^2 fm^4 for the ^{42}Ti $6^+ \rightarrow 4^+$ transition together with the ^{42}Ca $6^+ \rightarrow 4^+$ $B(E2)$ value provides a measure of the importance of the isovector giant quadrupole state on the effective $E2$ operator which is used in shell-model calculations.

[NUCLEAR REACTIONS ^{40}Ca(^{3}He,$n\gamma$), E=10, 12 MeV; measured pulsed beam electronic timing; deduced $T_{1/2}$, $B(E2)$, effective charge. Natural target, Ge(Li) detectors.]

The electromagnetic properties of ^{42}Ti are of considerable interest because it is the heaviest proton-rich nucleus for which the γ decay scheme is known. As in the isobaric nuclei ^{42}Sc and ^{42}Ca, its levels have fairly simple shell-model configurations, the lowest levels of each spin being dominated by the $(1f_{7/2})^2$ component. The 6^+ state should have the purest $(1f_{7/2})^2$ configuration. However, its decay properties have been difficult to study because the reactions which populate high-spin states favor charged particle emission to nuclei other than ^{42}Ti.

The most favorable reaction for γ ray studies has been the ^{40}Ca(^{3}He,n) reaction.[1-4] With this reaction the lifetime of the 3041-keV (6^+) level in ^{42}Ti was recently measured to be $\tau = 5 \pm 2$ nsec.[1] Because of the large error in this result as well as the fact that it is in disagreement with a former measurement by Cox *et al.*,[2] we have remeasured this lifetime using the same reaction but with improved statistics and improved time resolution.

A thick target of ^{40}Ca was bombarded with a pulsed ^{3}He beam from the Stony Brook tandem accelerator. Data was taken at beam energies of 10 and 12 MeV; the singles spectra at 12 MeV was similar to the spectrum shown in Fig. 4 of Ref. 1. Time spectra gated by digital energy windows were obtained for the three γ rays of interest in ^{42}Ti, at 366, 1120, and 1555 keV and the "prompt" ^{42}Sc 976-keV γ ray. Time spectra were simultaneously obtained for appropriate regions of the Compton background events near the peaks.

Due to the large background and poor time resolution for the ^{42}Ti 366-keV $(6^+)\rightarrow(4^+)$ γ ray a lifetime could not be extracted from this transition. Instead, the lifetime was obtained from the delayed components in the 1120-keV $(4^+)\rightarrow 2^+$ and 1555-keV $2^+\rightarrow 0^+$ γ rays due to feeding from the 366-keV transition.

The lifetimes obtained from these two transitions with ^{3}He beam energies of 10 and 12 MeV are given in Table I. The time spectrum for the 1120-keV γ ray from the 10-MeV data is shown in Fig. 1 along with the strong 976-keV γ ray from the ^{40}Ca(^{3}He, $p\gamma$)^{42}Sc reaction which is not known experimentally[3] or expected theoretically to have any significant delayed component with $\tau \gtrsim$ a few psec. The full width at half maximum for the 976-keV prompt peak was 3.5 nsec. The 1120-keV γ ray clearly shows a delayed component as well as the expected prompt component due to direct feeding of the ^{42}Ti 2675-keV (4^+) level.

In both the 10- and 12-MeV lifetime data the 1555-keV γ ray required a slightly shorter lifetime for its delayed component compared with the 1120-keV γ ray. This difference may come from an additional delayed component in the 1555-keV transition due to feeding from the 296-keV $0_2^+\rightarrow 2_1^+$ transition.[2,3] The lifetime of the 0_2^+ level could not be obtained directly from the 296-keV γ ray due to the poor time resolution at low energies and the data for the 1555-keV γ ray was insufficient to

TABLE I. Lifetime results.

Transition (keV)	^{3}He beam energy (MeV)	τ (nsec)
1120	10	4.45 ± 0.30
1120	12	4.67 ± 0.25
1555	10	4.12 ± 0.30
1555	12	4.05 ± 0.15
Adopted 6^+ lifetime from the 1120-keV transition		4.5 ± 0.3

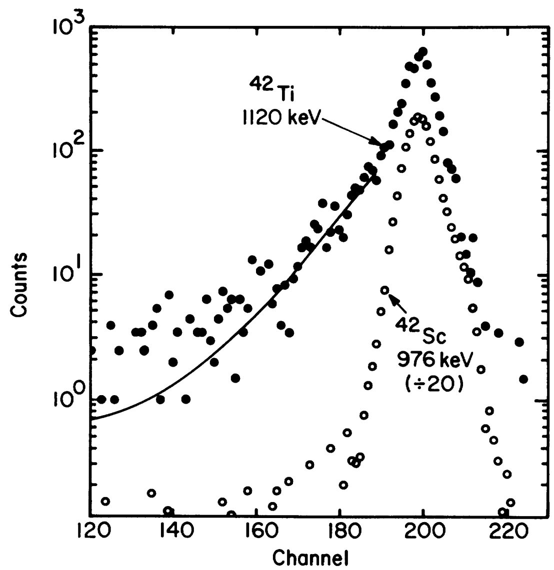

FIG. 1. Time spectra for the ^{42}Ti 1120-keV and ^{32}Sc 976-keV γ rays, obtained with the ^{40}Ca(^{3}He,$n\gamma$) $E_{^3\mathrm{He}}=10$ MeV reaction. Backgrounds from Compton events near the peaks of interest have been subtracted (negative numbers have been suppressed). The solid line is the fit of the function $ae^{(t-\tau_0)/\tau}+b$ to the delayed events with $\tau=4.45\pm0.30$ nsec. The time calibration is 0.4474 nsec/channel.

attempt a fit with two delayed components. The Doppler-shift attenuation method has been used previously to obtain $\tau > 2$ psec for the ^{42}Ti 0_2^+ 1854-keV level.[3] The lifetime of the 3041-keV (6^+) level is thus inferred only from the delayed component in the 1120-keV γ ray. The average of the 10- and 12-MeV data gives $\tau=4.5\pm0.3$ nsec. This value is in agreement with the result of Kutschera *et al.*,[1] $\tau=5\pm2$ nsec, but is in disagreement with the result of Cox *et al.*,[2] $\tau=25\pm5$ nsec. The possible reasons for this disagreement have been discussed by Kutschera *et al.*[1]

The lifetime of $\tau=4.5\pm0.3$ nsec implies a $B(E2)=27.6\pm1.8$ $e^2\mathrm{fm}^4$ for the $(6^+)\to(4^+)$ transition in ^{42}Ti. The implications of this result in terms of the shell model and effective operators have been discussed by Kutschera *et al.*[1] and more recently by Brown, Arima, and McCrory.[5] Using wave functions which include core deformed components and with a size parameter needed to reproduce the ^{40}Ca rms radius,[5] a proton effective charge of near unity, $e_p=1.06\pm0.07$, is required to reproduce the ^{42}Ti $B(E2)$ value. This result can be compared with the large neutron effective charge needed, for example, for the ^{42}Ca $6^+\to4^+$ transition, $e_n\approx0.57$. If e_p-1 and e_n were equal it would imply that the only important contribution from outside the model space is from the isoscalar giant quadrupole resonance, as has been historically the assumption made in most shell-model calculations. The large experimental difference between e_p-1 and e_n indicates the importance of an additional contribution from the isovector giant quadrupole resonance about which very little is experimentally known.

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