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Isomeric $17/2^-$ level and parity mixing in ^{93}Tc[†]

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The ^{90}Zr(^{6}Li, $3n\gamma$)^{93}Tc reaction has been used in conjunction with pulsed-beam γ, γ-γ coincidence, and γ angular distribution measurements to investigate a proposed $[(g_{9/2})^4 p_{1/2}]17/2^-$ isomer in ^{93}Tc. The isomeric level was found at 2185 keV on the basis of its decay properties and lifetime. The mean lifetime of the $17/2^-$ isomeric level was measured to be $\tau = 15.2 \pm 1.0$ μsec. The level decays by a 39.7-keV $E2$ branch ($73.7 \pm 1.0\%$) to the 2145-keV $13/2^-$ level and by a 750.7-keV $M2/E3$ branch ($26.3 \pm 1.0\%$) to the 1434-keV $13/2^+$ level. An experimental $B(E2)$ $[17/2^- \rightarrow 13/2^-] = 11.4 \pm 0.9$ $e^2\,\mathrm{fm}^4$ is obtained for the $E2$ branch, impyling an effective charge of $e_p = 2.49 \pm 0.10$. To explore possible parity mixing between the nearly degenerate $17/2^-$ and $17/2^+$ levels, the precise energy separation of these levels was measured to be 0.44 ± 0.02 keV. On the basis of the observed decay properties, the parity nonconserving matrix element $|\langle 17/2^+ | H_{\mathrm{PN}} | 17/2^- \rangle|$ was determined to be less than 0.34 eV.

NUCLEAR REACTIONS ^{90}Zr(^{6}Li, $3n$) $E_{\mathrm{Li}} = 34$ MeV pulsed beam; measured γ-γ coincidence; deduced levels in ^{93}Tc; measured $\gamma(\theta, t)$; deduced $T_{1/2}$, $B(E2)$, effective charges, parity mixing. Enriched target, Ge(Li), Si(Li) detectors.

INTRODUCTION

In the mass-90 region of nuclides the $N = 50$ (closed neutron shell) isotones provide an attractive testing ground for nuclear shell model calculations. A number of theoretical calculations have been published over the years,[1,2] all of which consider valence protons in the $2p_{1/2}$ and $1g_{9/2}$ orbitals, outside an inert $^{88}_{38}\mathrm{Sr}_{50}$ core. Most of the calculations have attempted to reproduce experimental energy levels and binding energies using an unrestricted two-body effective interaction; differences between them arise primarily from the amount of experimental data considered. The most recent theoretical study[2] includes available experimental data on $E2$ transition rates as well as energy levels in the $N = 50$ isotones. Electromagnetic matrix elements provide a more rigorous test of the purity of configuration assignments since the single-particle matrix elements are sensitive to many types of small admixtures.

The present experiment, using the (^{6}Li, $3n\gamma$) reaction, was undertaken with the aim of determining the energy and $E2$ transition rate for a proposed[2,3] $\frac{17}{2}^- \rightarrow \frac{13}{2}^-$ isomeric transition in ^{93}Tc. Precise values for the lifetime and energy of this isomer, expected to be the $[(g_{9/2})^4 p_{1/2}]\frac{17}{2}^-$ state, were determined as well as the energies and branching ratios of the decay γ rays. In the previous (α, $p2n\gamma$) work of Grecescu, Nilsson, and Harms-Ringdahl,[3] delayed cascade γ rays in the 1- to 10-μsec range had been observed although the energy and lifetime of the isomer have not been established. The present experimental results including the $E2$ transition strength and effective charge are interpreted in terms of the $p_{1/2}$-$g_{9/2}$ shell model description of ^{93}Tc. A preliminary report of the present measurements has been published.[4] Most of the ^{93}Tc energy levels and spin assignments for low spin states have been established in previous experiments.[5]

In the present experiment, it was discovered that the $\frac{17}{2}^-$ isomeric level in ^{93}Tc is nearly degenerate with the prompt $\frac{17}{2}^+$ level. This near degeneracy suggests the possibility of observing a significant parity admixture in the $\frac{17}{2}^-$ level since the admixed amplitude for a given parity-nonconserving matrix element is increased by a small energy denominator. A precision measurement of the energy separation was made from the energy spectra of the delayed and prompt decay γ rays; the $\frac{17}{2}^-$ level was determined to lie 0.44 ± 0.02 keV above the $\frac{17}{2}^+$ level. By taking advantage of the relative enhancement of the γ-transition strength for the parity-forbidden component compared to that of the parity-allowed component, the present experiment places an upper limit on the parity-nonconserving matrix element $|\langle \frac{17}{2}^+ | H_{\mathrm{PN}} | \frac{17}{2}^- \rangle|$ which is less than the $|\langle \frac{1}{2}^- | H_{\mathrm{PN}} | \frac{1}{2}^+ \rangle|$ value obtained in the recent parity-mixing experiment for ^{19}F by Adelberger *et al.*[6]

EXPERIMENTAL PROCEDURE

Levels in ^{93}Tc were populated by means of the ^{90}Zr(^{6}Li, $3n$)^{93}Tc reaction. A 34-MeV ^{6}Li (3^+) beam, obtained from the Stony Brook FN Tandem Van de Graaff accelerator, was incident on an isotopically enriched thick metallic ^{90}Zr target. Deexcitation γ rays were detected using both large volume Ge(Li) detectors and a Si(Li) detector,

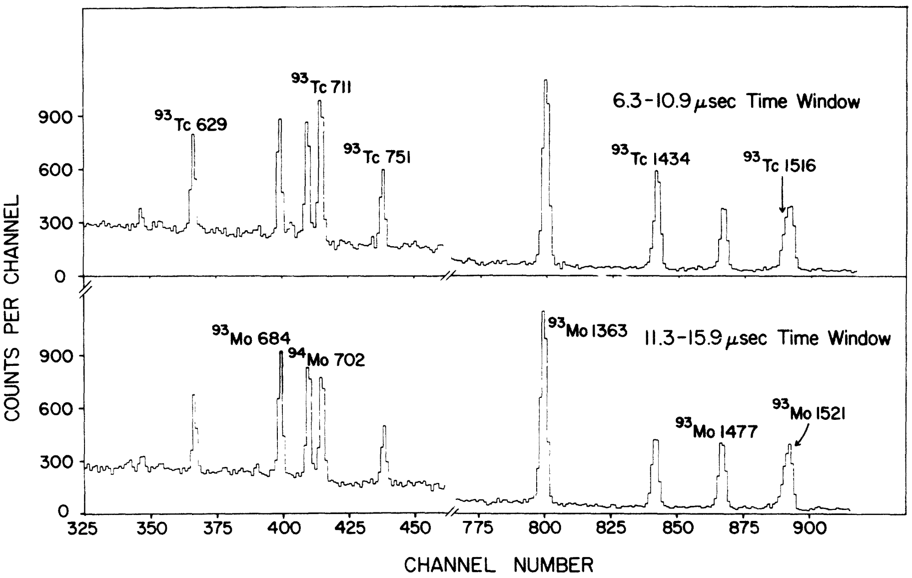

FIG. 1. Delayed Ge(Li) γ spectra from the ^{90}Zr + ^{6}Li reaction integrated over 6.3–10.9- and 11.3–15.9-μsec time regions. In addition to γ rays from ^{93}Tc, delayed transitions are seen from the β decay of ^{94}Tc to ^{94}Mo [D. C. Kocher, Nucl. Data B10, 241 (1973)], the β decay of ^{93}Tc to ^{93}Mo, and the $T_{1/2}$ = 6.9-h isomeric decay in ^{93}Mo [D. C. Kocher, Nucl. Data B8, 527 (1972)].

with typical energy resolutions of ~3 keV full width at half maximum (FWHM) and 180 eV FWHM, respectively. Lifetimes were measured using a pulsed beam and information regarding the level scheme and decay properties was obtained by means of γ-γ coincidence measurements. The experimental techniques employed here were similar to those used in a previously reported study[7] of ^{91}Nb and ^{91}Zr. As pointed out in that paper, the (^{6}Li, $3n$) fusion-evaporation reaction favors population of high spin states in the residual nucleus. The dominant decay mode of these states is via stretched γ-ray cascades down through the yrast levels (states of lowest energy for a given spin).

The delayed γ-ray spectra were obtained using a pulsed ^{6}Li beam having a pulse width ~5 nsec FWHM and a pulse repetition period of 16 μsec. A typical system time resolution was ~8 nsec FWHM over a large dynamic range. These measurements were made using both Ge(Li) and Si(Li) detectors and therefore covered an energy range from ~20 keV up to ~3 MeV. Time spectra were generated using a time-to-amplitude coverter (TAC); delayed (energy) spectra were obtained by gating the linear energy signals with time windows set on the TAC spectrum. Lifetimes for delayed γ rays were obtained from the relative intensities of photopeaks in different time regions, such as shown in Figs. 1 and 2 for the Ge(Li) and Si(Li) spectra, respectively. For lifetimes in the μsec range, this method of measurement was found to be preferable to direct measurement of the exponential decay curve because of the greater ease with which background could be subtracted. Although expected to be substantially attenuated, angular distributions of the delayed γ rays were also determined; yield measurements were made at 0°, 45°, and 90° to obtain intensities and branching ratios for the isomeric decay. The relative detection efficiency vs energy for the Ge(Li) detectors, in the particular geometry of the experiment, was known from ancillary measurements.

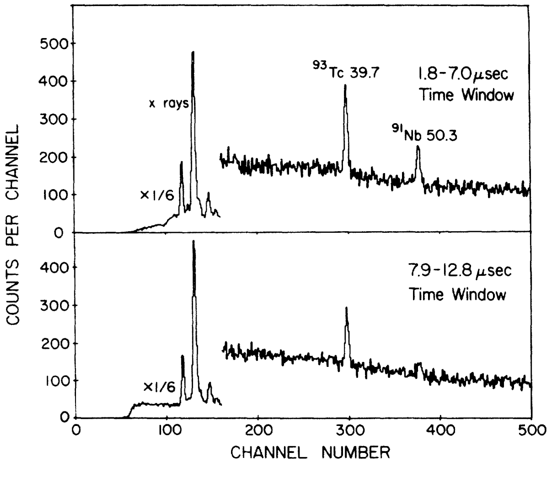

FIG. 2. Delayed Si(Li) γ spectra from the ^{90}Zr + ^{6}Li reaction integrated over 1.8–7.0- and 7.9–12.8-μsec time regions. The 50.3-keV γ ray originates from a $T_{1/2}$ = 3.8-μsec isomer in ^{91}Nb (Ref. 7).

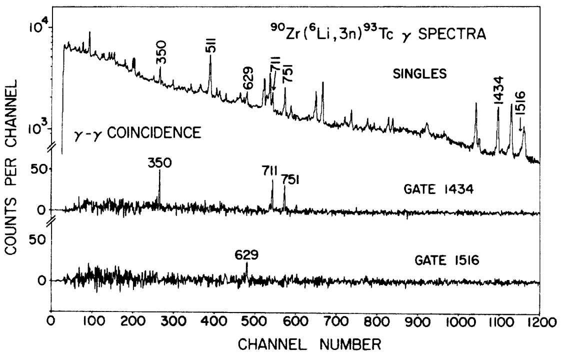

FIG. 3. The γ-ray singles spectrum from the ^{90}Zr + ^{6}Li reaction and γ-γ coincidence spectra for gates on the ^{93}Tc 1434- and 1516-keV γ transitions.

Standard techniques were employed for the γ-γ coincidence measurements with two Ge(Li) detectors. Energy windows were electronically set on a few selected γ rays in ^{93}Tc; events in coincidence with the 1434- and 1516-keV γ rays are shown in Fig. 3. The random coincidences were negligible and Compton background subtractions were included in the analysis.

EXPERIMENTAL RESULTS

On the basis of the above measurements, the lifetime and energy of the $\frac{17}{2}^-$ isomeric level in ^{93}Tc have been established together with the energies and branching ratios of the decay γ rays. The remainder of the γ-ray decay scheme established on the basis of the present γ-γ coincidence results, is consistent with the data presented in Ref. 3. The results are summarized in Table I and Fig. 4.

A cascade of transitions 350-751-1434 keV is clearly seen, with the order being established by the relative intensities of the lines extracted from both singles and coincidence spectra. The angular distribution data of Grecescu *et al.*,[3] together with the fact that all of these transitions are fast ($\tau \lesssim 5$ ns), strongly suggest a stretched $E2$ cascade: $\frac{21}{2}^+$(2534 keV) → $\frac{17}{2}^+$(2185 keV) → $\frac{13}{2}^+$(1434 keV) → $\frac{9}{2}^+$ (g.s.).

Two other coincident pairs of γ rays were seen, the 711-1434-keV and 629-1516-keV transitions, both originating in the $\frac{13}{2}^-$ level at 2145 keV. The branching ratios for decay of the $\frac{13}{2}^-$ level, obtained in the present work from the measured relative yields of the delayed components of these transitions, are 32% to the $\frac{11}{2}^+$ (1516 keV) level and 68% to the $\frac{13}{2}^+$ (1434 keV) level.

The pulsed-beam delayed γ-ray measurements, using a Ge(Li) detector, showed that the following transitions all exhibit delayed components: 1516, 1434, 751, 711, and 629 keV (see Fig. 1). A consistent lifetime was obtained for all of these γ rays for several runs covering different time regions over the 16-μsec pulsing period. The resulting mean lifetime is $\tau = 15.2 \pm 1.0$ μsec. A prompt component was also evident in each case, indicating that none of the above transitions is the primary isomeric decay γ ray. Finally, using a Si(Li) detector and the same pulsed-beam technique, a delayed transition of energy 39.7 ±0.1 keV which had a lifetime consistent with the above result, was observed (see Fig. 2). This 39.7-keV line did not

TABLE I. Summary of the decay properties of high-spin states in ^{93}Tc obtained from the present experiment.

E_i (keV)	$J_i^\pi \to J_f^\pi$	E_γ (keV)	Branching ratio (%)
1434	$\frac{13}{2}^+ \to \frac{9}{2}^+$(g.s.)	1434 ± 1	100
1516	$\frac{11}{2}^+ \to \frac{9}{2}^+$(g.s.)	1516 ± 1	100
2145	$\frac{13}{2}^- \to \frac{13}{2}^+$	711.1 ± 0.2	67.5 ± 1.0
	$\to \frac{11}{2}^+$	629.5 ± 0.2	32.5 ± 1.0
2185	$\frac{17}{2}^+ \to \frac{13}{2}^+$	750.3 ± 0.2	100
	$\frac{17}{2}^- \to \frac{13}{2}^-$	39.75 ± 0.10	73.7 ± 1.0
	$\to \frac{13}{2}^+$	750.7 ± 0.2	~26 } 26.3 ± 1.0
	$\to \frac{17}{2}^+$	0.44 ± 0.02 [a]	~0 }
2534	$\frac{21}{2}^+ \to \frac{17}{2}^+$	350 ± 1	100

[a] Based on the energy difference measurement for the $\frac{17}{2}^+ \to \frac{13}{2}^+$ and $\frac{17}{2}^+ \to \frac{13}{2}^-$ transition, assuming no $\frac{17}{2}^- \to \frac{17}{2}^+$ branch (see text).

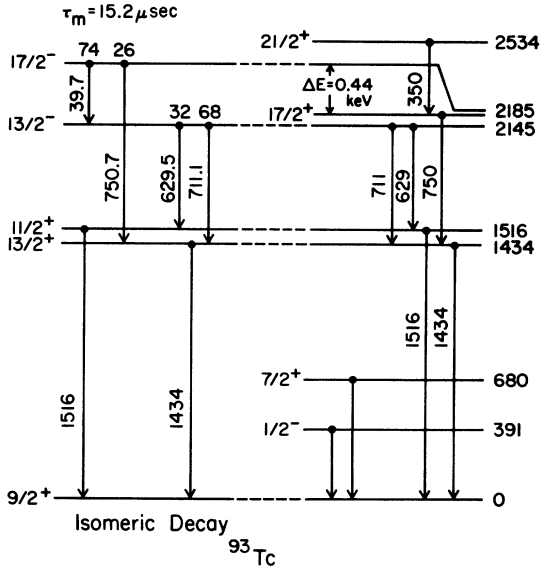

FIG. 4. The decay scheme for ^{93}Tc from the present work. The isomeric decay is indicated on the left hand side. Branching ratios and γ-ray energies are given in Table I.

exhibit a prompt component.

The present lifetime measurement is consistent with the decay time range of the delayed γ rays quoted by Grecescu *et al.*[3] on the basis of their pulsed-beam measurements. They proposed a spin assignment of $\frac{17}{2}^{-}$ for an isomeric level and gave it a very tentative energy assignment of 2215 keV, based on their observation of a weak 70.0-keV transition. This transition was not, however, clearly delayed nor was it of the expected intensity. The present results permit a definite assignment of 2185 keV for the excitation energy of the isomeric state and confirm the $\frac{17}{2}^{-}$ spin assignment on the basis of the observed lifetime and decay scheme. An attempt to measure the magnetic moment of the isomeric state, using the (^{6}Li, $3n$) reaction, proved unsuccessful due to spin alignment losses in the thick ^{90}Zr target. However, a preliminary value of $g = 1.301 \pm 0.015$ was obtained using the ^{85}Rb(^{12}C, $4n$)^{93}Tc reaction on a liquid target.[8] This value is consistent with an assumed $[(g_{9/2})^4 8^+ p_{1/2}]\frac{17}{2}^{-}$ proton structure of the isomeric state.

Branching ratios for the decay of the $\frac{17}{2}^{-}$ isomer were obtained from the intensities of the 629-, 711-, and 751-keV γ rays. The results are 74% for the 39.7-keV $\frac{17}{2}^{-}$ (2185 keV) $\rightarrow \frac{13}{2}^{-}$ (2145 keV) transition and 26% for the 751-keV $\frac{17}{2}^{-}$ (2185 keV) $\rightarrow \frac{13}{2}^{+}$ (1434 keV) transition. The prompt component in the 751-keV γ ray is associated with the $\frac{17}{2}^{+}$ (2185 keV) $\rightarrow \frac{13}{2}^{+}$ (1434 keV) transition. Thus, the $\frac{17}{2}^{-}$ and $\frac{17}{2}^{+}$ states are nearly degenerate.

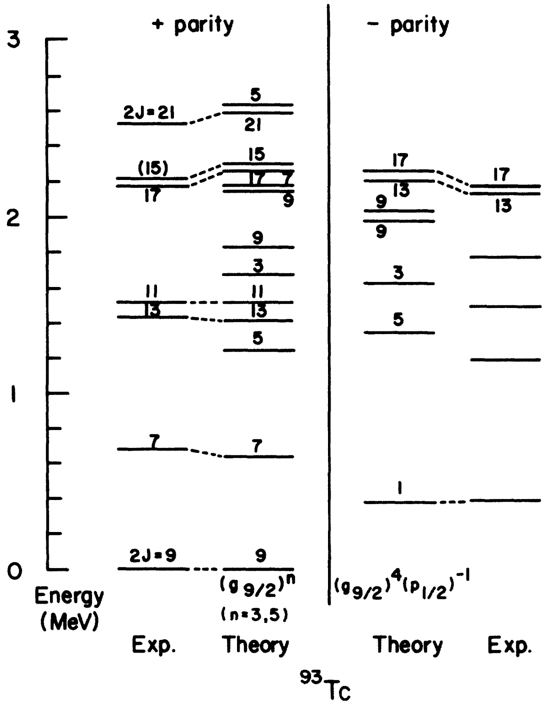

FIG. 5. Comparison of experimental and theoretical energy levels for ^{93}Tc. The spins are indicated by $2J$. The experimental information is from the present experiment and Refs. 3 and 5. The theoretical levels were obtained in the total-energy fit calculation of Gloeckner and Serduke, Ref. 2.

To complete the level scheme for ^{93}Tc, and for the evaluation of the parity-nonconserving matrix element (see discussion), it was necessary to obtain a precise determination of the ordering and energy separation of the $\frac{17}{2}^{-}$ and $\frac{17}{2}^{+}$ states. For this purpose, a careful comparison was made of the prompt and delayed components of the 751-keV transition, which were recorded simultaneously. The measured centroid of the delayed transition was 0.44 ± 0.02 keV above that for the prompt transition assuming each component to be a single Gaussian line; these results are quoted in Table I and Fig. 4. From the measured width of the delayed line, there was no evidence for a delayed component of the $\frac{17}{2}^{+} \rightarrow \frac{13}{2}^{+}$ transition, as would result from a 0.44-keV $\frac{17}{2}^{-} \rightarrow \frac{17}{2}^{+}$ $E1$ decay branch. However, the possibility of an $E1$ decay branch of less than 7% cannot be ruled out on the basis of a fit with two Gaussians for the delayed line component. Using the two Gaussian fit for an assumed 7% $E1$ branch, the measured energy separation would be increased to only 0.54 ± 0.08 keV.

DISCUSSION

A. B(E2) values and energy levels

The low-lying levels of ^{93}Tc can be described by the proton configurations $[(g_{9/2})^3(p_{1/2})^2]J^+$ and $(g_{9/2})^5 J^+$ for the positive parity levels and $[(g_{9/2})^4 p_{1/2}]J^-$ for the negative parity levels. The results of the most recent energy level calculation in which the effective two-body matrix elements and single-particle energies were fit to levels of several $N = 50$ nuclei[2] are shown in Fig. 5 together with the experimental level scheme. The excellent agreement between theory and experiment indicates that $g_{9/2}$-$p_{1/2}$ is an adequate model space on which to base a study of the processes that go into building up the effective interaction and electromagnetic matrix elements. The experimental ^{93}Tc $E2$ matrix elements are discussed below in terms of the effective proton charge and compared with the results of other $N = 50$ nuclei. In Sec. B we discuss the possibility of parity admixture for the nearly degenerate $\frac{17}{2}^{-}$ and $\frac{17}{2}^{+}$ states.

The $B(E2)$ values for the $\frac{17}{2}^{-} \rightarrow \frac{13}{2}^{-}$ transition obtained from the present experiment and for the $\frac{21}{2}^{+} \rightarrow \frac{17}{2}^{+}$ transition obtained from the lifetime experiment of Schneider, Gonsoir, and Günther[9] are

$$B(E2)[\tfrac{17}{2}^- \to \tfrac{13}{2}^-] = 11.4 \pm 0.9 \; e^2\,\mathrm{fm}^4,$$

$$B(E2)[\tfrac{21}{2}^+ \to \tfrac{17}{2}^+] = 65.9 \pm 3.0 \; e^2\,\mathrm{fm}^4.$$

The total internal conversion coefficients (ICC) needed for these $B(E2)$ evaluations were interpolated from the tables of Hager and Seltzer[10]; ICC $=34.1$ for $\tfrac{17}{2}^- \to \tfrac{13}{2}^-$ ($E_\gamma = 39.7$ keV) and ICC $=0.015$ for $\tfrac{21}{2}^+ \to \tfrac{17}{2}^+$ ($E_\gamma = 350$ keV). The errors for the $B(E2)$ values include a 5% uncertainty allowed for in the ICC.

An interesting and useful result of exact shell model calculations for the $N=50$ nuclei is that the matrix elements that are off diagonal in seniority are relatively very small.[2] This means that these wave functions are composed mostly of the lowest possible seniority components. For example, the $\tfrac{17}{2}^-$ and $\tfrac{13}{2}^-$ wave functions have the configurations

$$[(g_{9/2})^4{}_{v=2}\, J_0 = 8, p_{1/2}]\tfrac{17}{2}^-$$

and

$$[(g_{9/2})^4{}_{v=2}\, J_0 = 6, p_{1/2}]\tfrac{13}{2}^- .$$

From these wave functions, the $\tfrac{17}{2}^- \to \tfrac{13}{2}^-$ $B(E2)$ can be easily calculated as $B(E2)[\tfrac{17}{2}^- \to \tfrac{13}{2}^-] = 1.84\; e_p{}^2\,\mathrm{fm}^4$. A radial matrix element of $\langle g_{9/2}|r^2|g_{9/2}\rangle = 26.0\ \mathrm{fm}^2$ was used in this calculation which is the same as that recently used by Gloeckner *et al.*[2] Comparing the theoretical and experimental $B(E2)$ values, a proton effective charge of $e_p = 2.49 \pm 0.10$ is needed for the ^{93}Tc $\tfrac{17}{2}^- \to \tfrac{13}{2}^-$ transition. The additional proton charge, $\delta e_p = e_p - 1 = 1.49$, is nearly twice as large as the best fit value of $\delta e_p = 0.72$ obtained by Gloeckner for the even-even $N=50$ nuclei[2] and about three times larger than the value of $\delta e_p = 0.45$ needed for the ^{91}Nb $\tfrac{17}{2}^- \to \tfrac{13}{2}^-$ transition.[7] These state dependent differences may arise from admixtures involving the excited $2p_{3/2}$ and $1f_{5/2}$ hole orbitals. A reason for the large effective charge for the $\tfrac{17}{2}^- \to \tfrac{13}{2}^-$ transition in ^{93}Tc is perhaps related to the fact that the small theoretical $B(E2)$ value may result in a greater sensitivity to configuration admixtures including small $\nu = 4$ components.

The calculated[2] ^{93}Tc $\tfrac{21}{2}^+ \to \tfrac{17}{2}^+$ $B(E2)$ value is 23.1 $e_p{}^2\,\mathrm{fm}^4$. Comparing this with the experimental value of $65.8 \pm 4.0\; e^2\,\mathrm{fm}^4$, the proton effective charge is $e_p = 1.69$ in good agreement with the average value obtained from the even-even $N=50$ nuclei ($e_p = 1.72$). In the discussion of the parity admixture in the next section, a calculated value for the $\tfrac{17}{2}^+ \to \tfrac{13}{2}^+$ $B(E2)$ is required. From the proton effective charge systematics, this $B(E2)$ can be reliably calculated as $B(E2)[\tfrac{17}{2}^+ \to \tfrac{13}{2}^+] = 40.0\; e_p{}^2\,\mathrm{fm}^4 = 114\; e^2\,\mathrm{fm}^4$ with $e_p = 1.69$.

B. Parity admixture of the $\tfrac{17}{2}^-$ and $\tfrac{17}{2}^+$ levels

In the present experiment the $\tfrac{17}{2}^-$ and $\tfrac{17}{2}^+$ states in ^{93}Tc have been found to lie very close; $\Delta E = E(\tfrac{17}{2}^-) - E(\tfrac{17}{2}^+) = 0.44 \pm 0.02$ keV. Because of this, the admixture of these two levels via a weak parity-nonconserving (PN) nucleon-nucleon force[11] may be relatively much larger than in similar cases which have been studied.[6,11] The PN interaction is a small perturbation and the wave function of the isomeric 2185-keV level can be written as

$$|\overline{\tfrac{17}{2}}\rangle = |\tfrac{17}{2}^-\rangle + \alpha|\tfrac{17}{2}^+\rangle,$$

where

$$\alpha = \frac{\langle \tfrac{17}{2}^+ | H_{\mathrm{PN}} | \tfrac{17}{2}^- \rangle}{\Delta E}$$

and $\overline{\tfrac{17}{2}}$ denotes the parity admixed isomeric level.

The parity admixed $\tfrac{17}{2}^+$ component of the isomeric level permits an $E2$ decay of 751 keV to the 1434-keV $\tfrac{13}{2}^+$ state; $M2$ or $E3$ multipolarities are the allowed decay transitions to the $\tfrac{13}{2}^+$ state for the normal $\tfrac{17}{2}^-$ component. Upper limits for these decay modes can be obtained from the lifetime and branching ratio of the 2185-keV $\overline{\tfrac{17}{2}}$ level;

$$B(E2) \leqslant 6.3 \times 10^{-5}\; e^2\,\mathrm{fm}^4 = 2.5 \times 10^{-6}\ \mathrm{W.u.},$$

$$B(M2) \leqslant (5.8 \times 10^{-3})\, \mu_N{}^2\,\mathrm{fm}^2 = 1.7 \times 10^{-4}\ \mathrm{W.u.},$$

$$B(E3) \leqslant 2.4 \times 10^{2}\; e^2\,\mathrm{fm}^6 = 4.7 \times 10^{-1}\ \mathrm{W.u.},$$

where W.u. is the Weisskopf unit.[12] To obtain these values, in each case the transition is assumed to be a pure multipole. The fact that mixing may occur makes these values upper limits.

Using the calculated $B(E2)$ value for the $\tfrac{17}{2}^+ \to \tfrac{13}{2}^+$ transition given in Sec. A, the following relation is obtained:

$$\begin{aligned} B(E2)[\overline{\tfrac{17}{2}} \to \tfrac{13}{2}^+] &= \alpha^2 B(E2)[\tfrac{17}{2}^+ \to \tfrac{13}{2}^+] \\ &= 114\alpha^2\; e^2\,\mathrm{fm}^4 \leqslant 6.3 \times 10^{-5}\; e^2\,\mathrm{fm}^4 . \end{aligned}$$

Thus,

$$|\alpha| = \frac{|\langle \tfrac{17}{2}^+ | H_{\mathrm{PN}} | \tfrac{17}{2}^- \rangle|}{\Delta E} \leqslant 7.4 \times 10^{-4}$$

and

$$|\langle \tfrac{17}{2}^+ | H_{\mathrm{PN}} | \tfrac{17}{2}^- \rangle| \leqslant 0.34\ \mathrm{eV}$$

with

$$\Delta E = 0.44 \pm 0.02\ \mathrm{keV}.$$

The possible $\tfrac{17}{2}^- \to \tfrac{17}{2}^+$ $E1$ branch ($\leqslant 7\%$) discussed in the experimental section does not significantly alter this value because the resulting changes in the energy denominator and the branching ratio of the $E2$ decay cancel each other.

The $\frac{17}{2}^- \rightarrow \frac{13}{2}^+$ transition is very sensitive to the amplitude α because the single-particle rate of an $E2$ transition which represents the decay of the parity-nonconserving component is 70 times greater (W.u.) than an $M2$ transition rate and 2×10^5 times greater than an $E3$ transition rate for a 751-keV γ ray. In addition, the $E2$ component is enhanced due to the configuration of the states involved $\{B(E2)[\frac{17}{2}^+ \rightarrow \frac{13}{2}^+] = 4.6 \text{ W.u.}\}$, and the $M2$ and $E3$ decays are hindered since within the $g_{9/2}$-$p_{1/2}$ shell the $\frac{17}{2}^- \rightarrow \frac{13}{2}^+$ matrix elements are proportional to $\langle g_{9/2} \| M2$ or $E3 \| p_{1/2}\rangle$ which is j forbidden. $M2$ and $E3$ strength can arise from admixtures outside this model space but these are difficult to calculate. An experimental estimate for the $B(E3)$ could be taken from the known value[13] for a similarly forbidden $8^+ \rightarrow 5^-$ transition in ^{90}Zr:

$$B(E3)[^{90}\text{Zr}, 8^+ \rightarrow 5^-] = 31 \pm 3 \; e^2\,\text{fm}^6$$

$$= (6.3 \pm 0.6)\times 10^{-2} \text{ W.u.}$$

Since the present upper limit in ^{93}Tc is a factor of 7 larger than the ^{90}Zr value, it seems unlikely that the $\frac{17}{2}^- \rightarrow \frac{13}{2}^+$ transition is purely $E3$. No $M2$ strength between similar orbitals in this mass region is known experimentally.

To experimentally determine a definite value or a better upper limit for the parity admixture, circular polarization measurements of the delayed 751-keV transition would be necessary. The upper limit of 0.34 eV for the parity-nonconserving matrix element $|\langle \frac{17}{2}^+ | H_{\text{PN}} | \frac{17}{2}^- \rangle|$ is of interest in itself since it is of the same order of magnitude as theoretical estimates.[11] This result for ^{93}Tc is smaller than $|\langle \frac{1}{2}^- | H_{\text{PN}} | \frac{1}{2}^+ \rangle| = 0.9 \pm 0.45$ eV recently obtained by Adelberger *et al.*[6] for the $\frac{1}{2}^-$ and $\frac{1}{2}^+$ states in ^{19}F. Since the geometrical overlap between the $\frac{17}{2}^+$ and $\frac{17}{2}^-$ states in ^{93}Tc, which involves a proton change from $1g_{9/2}$ to $2p_{1/2}$, is less than that for the ^{19}F case, this comparison is not unexpected. The shell model wave functions for the $\frac{17}{2}^-$ and $\frac{17}{2}^+$ states in ^{93}Tc are quite simple, as shown in Sec. A, and detailed calculations of the $\langle \frac{17}{2}^+ | H_{\text{PN}} | \frac{17}{2}^- \rangle$ matrix element would be interesting and perhaps relatively straightforward to carry out.

Note added in proof: Estimates of the total ICC by G. T. Emery for $E1$, $M2$, and possible parity-admixed $M1$ components of the $\frac{17}{2}^- \rightarrow \frac{17}{2}^+$ 0.44-keV transition are consistent with the observed branch of $\leqslant 7\%$.

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[1] B. F. Bayman, A. S. Reiner, and R. K. Sheline, Phys. Rev. 115, 1627 (1959); I. Talmi and I. Unna, Nucl. Phys. 19, 225 (1960); S. Cohen, R. D. Lawson, M. H. Macfarlane, and M. Soga, Phys. Lett. 10, 195 (1964); N. Auerbach and I. Talmi, Nucl. Phys. 64, 458 (1965); J. Vervier, *ibid.* 75, 17 (1966); J. B. Ball, J. B. McGrory, and J. S. Larsen, Phys. Lett. 41B, 581 (1972).

[2] D. H. Gloeckner, M. A. Macfarlane, R. D. Lawson, and F. J. D. Serduke, Phys. Lett. 40B, 597 (1972); D. H. Gloeckner and F. J. D. Serduke, Nucl. Phys. A220, 477 (1974); and private communication.

[3] M. Grecescu, A. Nilsson, and L. Harms-Ringdahl, Nucl. Phys. A212, 429 (1973).

[4] B. A. Brown, D. B. Fossan, P. M. S. Lesser, and A. R. Poletti, Bull. Am. Phys. Soc. 18, 1417 (1973); in *Proceedings of the International Conference on Nuclear Structure and Spectroscopy, Amsterdam, 1974,* edited by H. P. Blok and A. E. L. Dieperink (Scholar's Press, Amsterdam, 1974), Vol. 1, p. 94.

[5] J. Picard and G. Bassani, Nucl. Phys. A131, 636 (1969); E. Ejiri, S. M. Ferguson, I. Halpern, and R. Heffner, Phys. Lett. 29B, 111 (1969); R. L. Kozub and D. H. Youngblood, Phys. Rev. C 4, 535 (1971); M. S. Zisman and B. G. Harvey, *ibid.* 4, 1809 (1971); P. J. Riley, J. H. Horton, C. L. Holles, S. A. Zaidi, C. M. Jones, and J. L. Ford, *ibid.* 4, 1864 (1971).

[6] E. G. Adelberger, H. E. Swanson, M. D. Cooper, J. W. Tape, and T. A. Trainor, Phys. Rev. Lett. 34, 402 (1975).

[7] B. A. Brown, P. M. S. Lesser, and D. B. Fossan, Phys. Rev. Lett. 34, 161 (1975).

[8] D. B. Fossan, O. Häusser, A. B. McDonald, A. Olin, and W. Witthuhn (unpublished).

[9] W. D. Schneider, K. H. Gonsoir, and C. Günther, Nucl. Phys. A249, 103 (1975).

[10] R. S. Hager and E. C. Seltzer, Nucl. Data A4, 1 (1968).

[11] M. Gari, Phys. Rep. 6C, 319 (1973).

[12] The definition of Weisskopf unit follows that of D. H. Wilkinson, in *Nuclear Spectroscopy,* edited by F. Ajzenberg-Selove (Academic, New York, 1960), Part B, pp. 859–860.

[13] A. B. Tucker and S. O. Simmons, Nucl. Phys. A156, 83 (1970); K. G. Lobner, *ibid.* 58, 49 (1964).