Multipole mixing ratios of transitions in ^{99}Tc†

P. L. Gardulski and M. L. Wiedenbeck
Department of Physics, The University of Michigan, Ann Arbor, Michigan 48104
(Received 4 September 1973)

A Ge(Li)-Ge(Li) directional-correlation system has been utilized to measure the (740-40-141), (740-181), and the previously unreported (740-40) and (40-141) correlations. The multipole mixing ratios obtained were $\delta(740)=3.58\pm0.20$, $\delta(40)=-0.008\pm0.008$, $\delta(141)=-0.118\pm0.006$, and $\delta(181)=0.002\pm0.007$. The first three mixing ratios are $E2/M1$ and the last one is $M3/E2$. In addition the spin assignment of $\frac{3}{2}$ for the 921-keV level has been confirmed.

[RADIOACTIVITY ^{99}Mo [from ^{98}Mo(n,γ)]; measured γ-γ (Θ). ^{99}Tc deduced J, γ mixing. Ge(Li) detectors.]

INTRODUCTION

The level structure of ^{99}Tc from the β decay of 67-h ^{99}Mo has been extensively investigated.[1-3] The multipolarities of the 740-, 40-, 141-, and 181-keV transitions have been determined by internal-conversion[2,4-7] and directional-correlation[8-13] methods. There are discrepancies in these results. In all of the previous directional-correlation measurements NaI(Tl) detectors were used, except for the work of Gfirtner, Naumann, and Schneider.[13] However, the authors of Ref. 13 made no statement about the possible existence of perturbations of the correlations across the 3.6-ns 181-keV state. The resolution required to carefully determine the interfering correlations and to discriminate adjacent γ rays resulted in the use of Ge(Li) detectors in the present work.

In order to determine the mixing ratios of the γ rays depopulating the positive-parity states in ^{99}Tc and the spin of the 921-keV level, two previously unreported correlations, the (740-40) and (40-141), as well as the (740-40-141) and (740-181) correlations were measured. In addition an attempt was made to determine at approximately what source concentrations the attenuation of the correlation coefficients becomes negligible.

EXPERIMENTAL PROCEDURE

The radioactive ^{99}Mo sources were produced by irradiating high-purity MoO_3 powder or 0.13-mm Mo wire in the University of Michigan Ford nuclear reactor. The irradiated 0.13-mm Mo wire was mounted so that 10 mm of bare source could be seen by the detectors. The irradiated MoO_3 powder sources were dissolved in different amounts of NH_4OH.

The Ge(Li)-Ge(Li) correlation system, used to perform the measurements, employed coaxial ORTEC detectors with active volumes of 32.4 and 29.0 cm^3, and a Nuclear Data computer controlled analyzer. The data were acquired automatically at 15° intervals in a double quadrant sequence.

As can be seen from Fig. 1 interfering correlations were present in all of the correlations. Corrections were made for these interfering correlations following the procedure outlined by Frauenfelder and Steffen.[14]

A least-squares fit of the data, corrected for chances, decay, and interfering cascades, was made to the function

$$W(\theta)=A'_{00}+A'_{22}P_2(\cos\theta)+A'_{44}P_4(\cos\theta),$$

following the method of Rose.[15] From this function the normalized and corrected correlation coefficients $A_{kk}=A'_{kk}/(A'_{00}Q_{kk}G_{kk})$ and their associated uncertainties[16] were obtained. The geometrical correction factors, Q_{kk}, for the detectors were obtained by previously described methods.[17,18] The perturbation factors G_{22} were determined experimentally.

RESULTS AND DISCUSSION

The 3.6-ns lifetime of the 181.1-keV level indicates the existence of extranuclear perturbations on correlations across the 181.1-keV state. The degree of attenuation of such correlations has been shown to depend on the chemical composition of the source.[19,20]

Molybdenum metal has cubic crystaline structure, hence, one can assume that for this source the directional correlations are unperturbed. The crystalline structure of dry MoO_3 powder is rhombic; therefore, the correlations across the 3.6-ns state are perturbed. The degree of attenuation of the correlations across the 3.6-ns state for the NH_4OH and MoO_3 solution will depend on the viscosity of the solution.

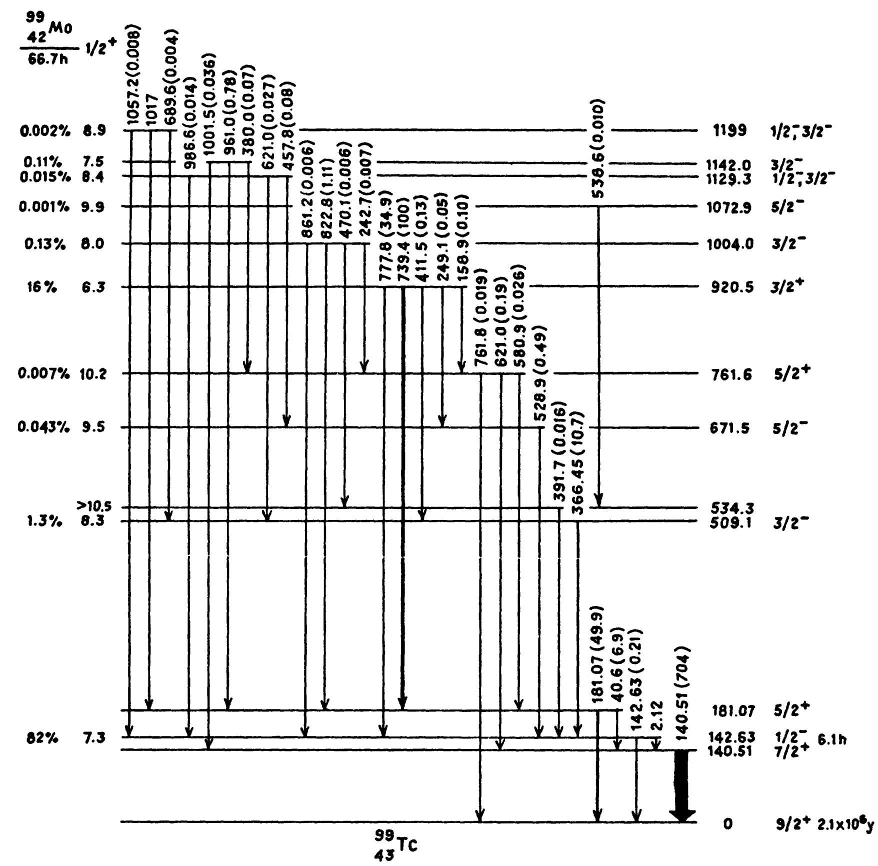

FIG. 1. The level scheme of ^{99}Tc proposed by Cook, Schellenberg, and Johns (Ref. 3). We have shown that the spin of the 921-keV level is $\frac{3}{2}$.

For this experiment the (740-181) and (740-40-141) correlation results obtained from the metal source were compared with the corresponding results from three different MoO_3 sources. One of these sources was dry MoO_3 powder. The other two sources, L_1 and L_2, were solutions of MoO_3 and NH_4OH (29.1% NH_3) with the volume ratio (NH_4OH)/MoO_3) approximately equal to 6 and 2.5, respectively. The correlation coefficients for the above four sources are presented in Table I. The weighted average attentuation factor was determined to be $G_{22} = 0.48 \pm 0.03$ for the MoO_3 powder source and $G_{22} = 0.80 \pm 0.03$ for the L_2 source. The excellent agreement of the correlation coefficients obtained with the metal (cubic) and dilute liquid source (L_1) indicates that the effects of the extranuclear perturbation are negligible for a sufficiently dilute solution of MoO_3 in NH_4OH. Therefore, one can assume $G_{22} = G_{44} = 1$ for such a source. Consequently, one can combine the data obtained from the metal and L_1 source in the least-squares fit to determine the correlation coefficients given in Table II.

TABLE I. Direction-correlation coefficients used to determine G_{22}.

Cascade (E in keV)	A_{22}	A_{44}	Source form
(740-181)	0.126 ± 0.004	-0.005 ± 0.006	Metal
	0.123 ± 0.003	-0.010 ± 0.004	Liquid L_1 [a]
	0.100 ± 0.004	-0.006 ± 0.006	Liquid L_2 [b]
	0.061 ± 0.003	-0.004 ± 0.005	MoO_3 powder
(740-40-141)	-0.184 ± 0.004	0.001 ± 0.005	Metal
	-0.183 ± 0.005	0.007 ± 0.007	Liquid L_1 [a]
	-0.150 ± 0.008	-0.002 ± 0.011	Liquid L_2 [b]
	-0.083 ± 0.009	0.007 ± 0.012	MoO_3 powder

[a] Liquid L_1 had the ratio (NH_4OH)/(MoO_3) ≈ 6.
[b] Liquid L_2 had the ratio (NH_4OH)/(MoO_3) ≈ 2.5.

The iteration method described by Chow and Wiedenbeck[21] can now be applied to these correlation results to obtain the mixing ratios from the correlation coefficients alone. No information is required concerning the spin of the 921-keV state. The calculations can be made in terms of A_2(740).

Analysis of the (740-40), (740-40-141), and (40-141) correlations by this iteration method

TABLE II. Directional-correlation coefficients for the cascades in ^{99}Tc.

Cascade (E in keV)	Spin sequence	A_{22}	A_{44}	Reference
740-40	$\frac{3}{2}^+-\frac{5}{2}^+-\frac{7}{2}^+$	-0.089 ± 0.010	-0.002 ± 0.014	Present work
40-141	$\frac{5}{2}^+-\frac{7}{2}^+-\frac{9}{2}^+$	0.113 ± 0.006	0.004 ± 0.008	Present work
740-40-141	$\frac{3}{2}^+-\frac{5}{2}^+-\frac{7}{2}^+-\frac{9}{2}^+$	-0.164 ± 0.013	0.003 ± 0.007	10
		-0.184 ± 0.003	0.002 ± 0.004	Present work
740-181	$\frac{3}{2}^+-\frac{5}{2}^+-\frac{9}{2}^+$	0.126		8
		0.067 ± 0.004	0.020 ± 0.005	9
		0.118 ± 0.011	-0.003 ± 0.008	10
		-0.070		11
		0.125 ± 0.005	-0.010 ± 0.008	12
		0.0930 ± 0.0028	-0.0095 ± 0.0042	13
		0.124 ± 0.002	-0.008 ± 0.003	Present work

yields the following results:

$$A_2(740) = -0.642\pm0.019,$$

$$\delta(40) = -0.008\pm0.008,$$

and

$$\delta(141) = -0.118\pm0.006.$$

One can now determine from the (740-181) correlation and the $A_2(740)$ given above that $\delta(181) = 0.002\pm0.007$. This $\delta(181)$ value and the A_{44} coefficient of the (740-181) correlation require an $A_4(740) = 0.571\pm0.218$. The only spin assignment for the 921-keV level consistent with the above $A_2(740)$ and $A_4(740)$ results is $\frac{3}{2}$. The analysis of $A_2(740) = -0.642\pm0.019$ for a $\frac{3}{2}(D, Q)\frac{5}{2}$ transition gives $\delta(740) = 3.58\pm0.20$.

The above mixing ratios were used to determine the multipolarities of their respective transitions. The 40.6-keV transition is primarily $M1$ $\{M1+[(6^{+26}_{-6})\times10^{-3}]\%\,E2\}$. This is in agreement with the previous internal-conversion data,[6,7] with the exception of the $(1.4\pm0.2)\%$ $E2$ content reported in Ref. 4. The conversion results[2,4,5,7] for the 140.5-keV transition are all slightly greater than the results of the present investigation. The previous γ-$\gamma(\theta)$ results (1.3 to 5.0% $E2$) reported in Ref. 10 are in good agreement with the $(1.4\pm0.2)\%$ $E2$ admixture obtained for the 140.5-keV transition in the present work. The $M3$ admixture of $[(4^{+77}_{-4})\times10^{-4}]\%$ for the 181.1-keV transition indicates that this transition is pure $E2$ and confirms the previous conversion-coefficient results.[2,7] The α_k results[2,7] for the 740-keV transition only require it to be $M1$ or $E2$. In Refs. 10 and 12 the large uncertainty in the A_{44} coefficients allows two solutions for $\delta(740)$ to be obtained from the A_{22} coefficient. The authors of Refs. 10 and 12 chose to use the δ which gave the minimum $E2$ admixture. However, when one determines the other δ solution from the A_{22} coefficients of Refs. 10 and 12 one finds that the 740-keV transition has a $(93.6^{+1.9}_{-2.3})\%$ $E2$ and a $(92.2\pm1.1)\%$ $E2$ admixture for Refs. 10 and 12, respectively. These results are not in agreement with the $(97.2\pm0.3)\%$ $E2$ content reported in Ref. 13 but are in excellent agreement with the $(92.7\pm0.8)\%$ $E2$ admixture obtained in the present investigation. With the exception of the $\frac{3}{2}\rightarrow\frac{5}{2}$, 740-keV transition the multipolarities of these transitions are in agreement with the theoretical results one would expect to obtain from the quasiparticle-coupling approach.

We wish to thank P. J. Wiedenbeck for his assistance in data acquisition and reduction.

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†This work was supported in part by the National Science Foundation.

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