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Analysis of Odd-Mass Technetium Isotopes with the Alaga Model

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The structure of the odd-mass technetium isotopes is analyzed with the Alaga model which involves the coupling of a three-particle valence-shell cluster to the quadrupole vibrational field. The calculated energy-level sequence and decay properties are consistent with the general trend of the available experimental information although no attempt of the best fit to individual properties was pursued.

1. Introduction

A rather large amount of experimental investigations have been devoted to odd-mass technetium isotopes during the last few years: ^{95}Tc [1–4], ^{97}Tc [5, 6], ^{99}Tc [7, 8] and ^{101}Tc [9]. The positive-parity low-energy sequence systematics for these nuclei are shown in Figure 1.

From the theoretical point of view, the level structure of the odd-Tc isotopes with mass number $A \geqq 95$ has been calculated by Vervier [10] and Bhatt and Ball [11] utilizing effective-interaction matrix elements obtained from experiment. Comparisons of the low-lying positive parity states of the levels in ^{95,97,99}Tc with the extended quasi-particle-phonon coupling (EQPC) calculations of Goswami and Nalcioglu [12] and with the core-coupling calculations of Goswami, McDaniels and Nalcioglu [13] have been made by Xenoulis and Sarantites [1]. Marumori and coauthors have also recently proposed a microscopic theory [14, 15] for describing collective excitations in spherical odd-mass nuclei in which the low-lying anomalous coupling states are treated as a new kind of fermion collective modes. This dressed three-quasiparticle formalism was used to describe the odd-mass Tc isotopes [16].

Although this considerable amount of theoretical work, complete calculations are still lacking. Moreover, since the Alaga model [17]—which involves the coupling of a three-nucleon valence-shell cluster to a quadrupole vibrational field—has been successfully applied in different regions of the Periodic Table [18–21], it appears pertinent to use it to analize the structure of the odd-mass Tc isotopes which are expected to be adequately described within this framework.

Let us remark that the three-nucleon clustering has successfully accounted for important single-particle and collective features of the nuclei where it has been applied.

2. Formalism

Since a detailed description of the Alaga model can be found in the literature [17–21] only the main formulae are presented here.

The Hamiltonians of the system is

$$H = H_{\text{coll}} + H_{\text{sp}} + H_{\text{int}} + H_{\text{res}}, \tag{1}$$

where the Hamiltonians are respectively associated with:

(i) the harmonic quadrupole vibrations of the doubly even core (the Zr isotopes in the present case), H_{coll};

(ii) the motion of the three valence-shell protons in an effective spherical potential, H_{sp};

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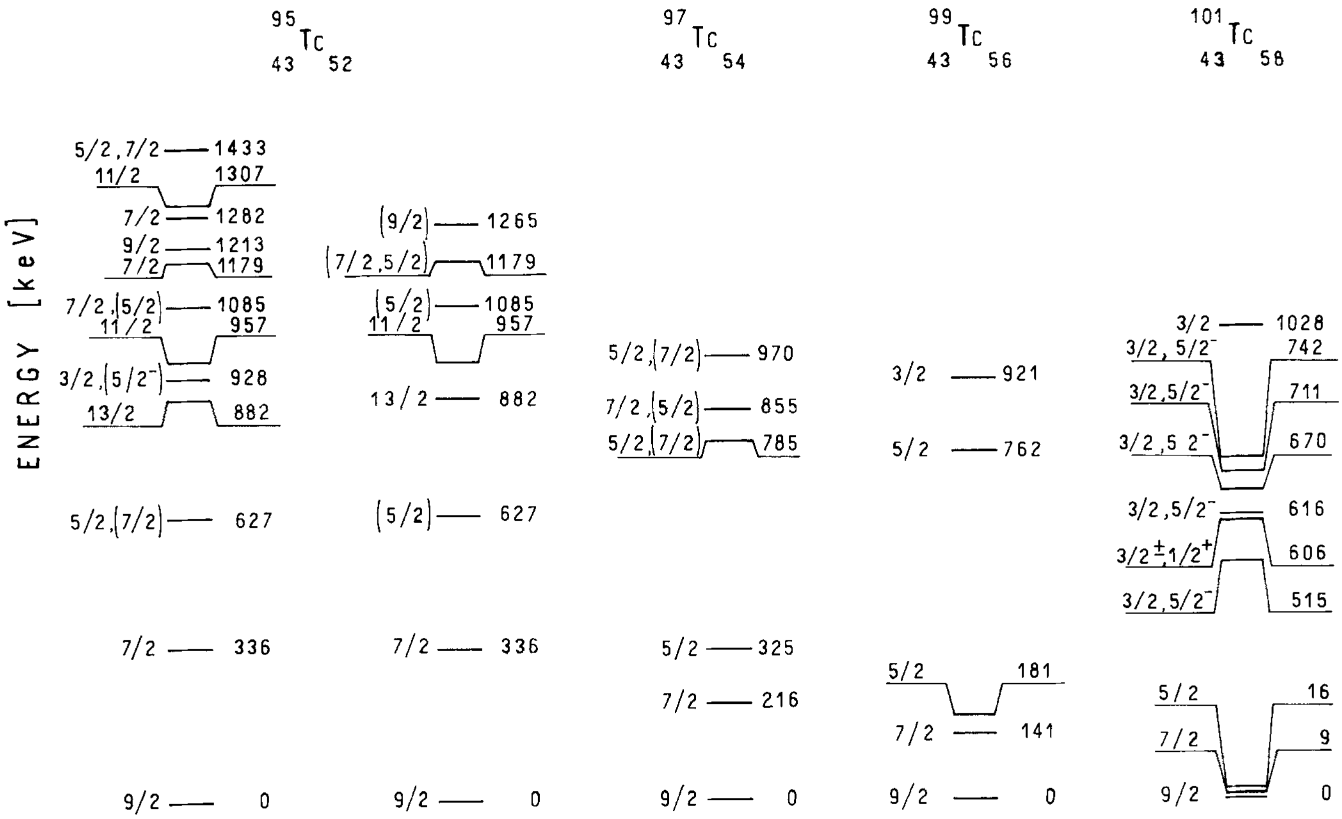

Fig. 1. Systematics of experimentally determined low-lying positive-parity states of odd-mass technetium isotopes. The data are taken from: References 3 and 4 for ^{95}Tc; Reference 6 for ^{97}Tc; Reference 8 for ^{99}Tc; and Reference 9 for ^{101}Tc

(iii) the interaction of the cluster with the vibrating core,

$$H_{\text{int}} = -\alpha_0 \sum_{\mu=-2}^{2} [b_\mu^+ + (-)^\mu b_{-\mu}] \sum_p k(r_p)\, Y_{2\mu}^*(\theta_p, \phi_p)$$

where the second summation extends over p extra-core protons and the coupling strength $k(r) = r(dV(r)/dr)$. The potential $V(r)$ is taken in the present case as a Woods-Saxon potential with spin-orbit term, with the following values for the parameters: radius $R_0 = 1.2\,\text{A}^{1/3}$, surface thickness $a = 0.65$ fm, spin-orbit strength $X_{ls} = 20$ MeV, and the potential depth $V_0 = 57$ MeV which binds the $1g_{9/2}$ state by -5.16 MeV. The symbols b_μ^+ (b_μ) are the operators for the creation (destruction) of the quadrupole vibrational field. The quantity α_0 is the zero-point amplitude of the quadrupole vibrations and is related to the quadrupole deformation β of the core by

$$\alpha_0 = (\hbar\omega/2C)^{1/2} = \beta/\sqrt{5}, \tag{2}$$

where $\hbar\omega$ is the quadrupole vibrational energy and C is the restoring constant of the vibrator;

(iv) the residual interaction between the protons in the valence-shell cluster, H_{res}. In the present calculations this is taken as a pairing force.

The total Hamiltonian (1) is diagonalized in the base built from $|\{[(j_1, j_2)J_{12}, j_3]v, J, NR\}IM\rangle$ states in which $H_{\text{coll}} + H_{\text{sp}}$ are diagonal. Here the symbols $j_i \equiv (n_i, l_i, j_i)$ represent quantum numbers of the proton states, the angular momenta quantum numbers J_{12} and J correspond to the successive couplings $\mathbf{j}_1 + \mathbf{j}_2 = J_{12}$, and $J_{12} + \mathbf{j}_3 = \mathbf{J}$, and v is the seniority quantum number. The symbols N and R represent the phonon number and angular momentum, respectively; I and M stand for the total angular momentum quantum numbers of the Tc nuclei. The eigenstates of the model Hamiltonian are linear combinations of the base vectors

$$|{}^\kappa IM\rangle = \sum_{\substack{j_1 j_2 j_3 \\ J_{12} JNR}} \eta(j_1 j_2, J_{12}, j_3, v, J, N, R; {}^\kappa I) \cdot |\{[(j_1 j_2)J_{12}, j_3]v, J, NR\}IM\rangle, \tag{3}$$

where the amplitudes η are obtained by diagonalizing the energy matrices and the superindex κ distinguishes between states of the same total angular momentum.

The electric quadrupole and magnetic dipole operators are a sum of a particle and collective contribution.

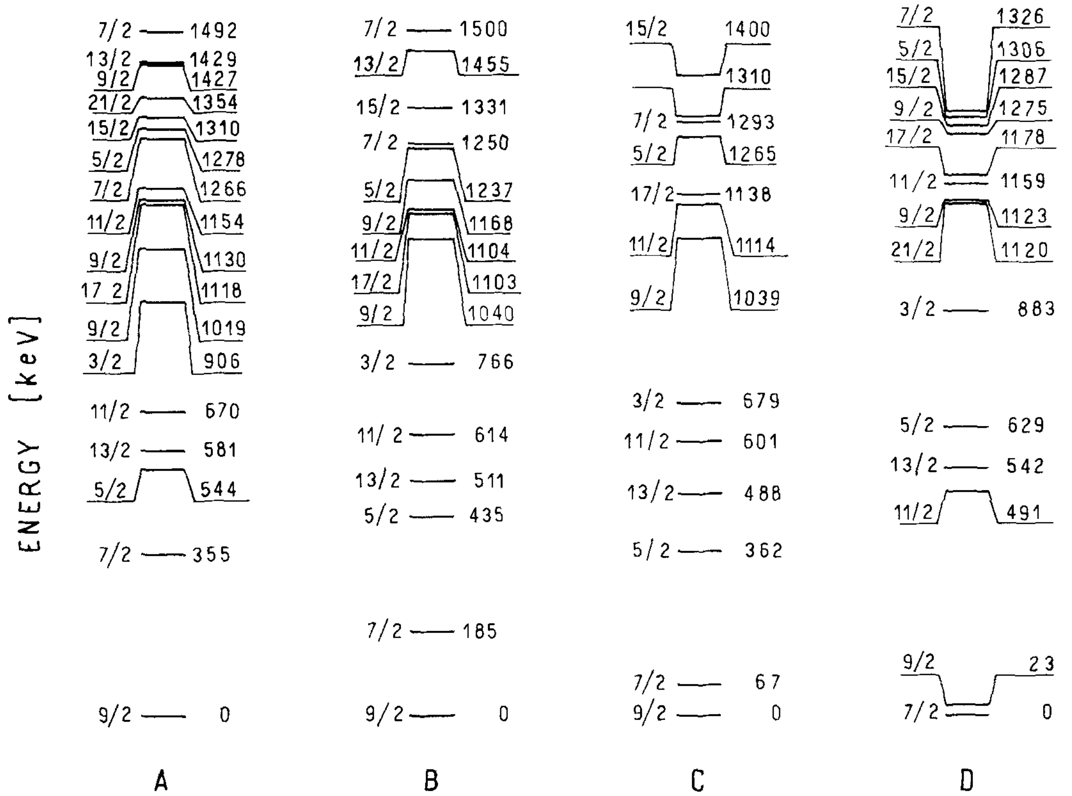

Fig. 2A – C. Calculated low-lying positive-parity level sequence for odd-mass technetium isotopes. **A** $\alpha_0 = 0.027$; **B** $\alpha_0 = 0.036$; **C** $\alpha_0 = 0.045$; and $\varepsilon(2d_{5/2}) - \varepsilon(1g_{9/2}) = 3.6$ MeV; $\hbar\omega = 0.935$ MeV and $G = 0.3$ MeV. **D** $\alpha_0 = 0.045$ and $\varepsilon(g_{9/2}) = 0.0$ MeV; the other parameters are the same as in the previous cases

They are defined respectively by

$$T^e_{2\mu} = e^{\text{eff}} \sum_{i=1}^{3} r_i^2\, Y_{2\mu}(\Omega_i) + (3R_0^2/4\pi)\, e^{\text{eff}}_{\text{vib}} (b^+_{2\mu} + (-)^\mu b_{2-\mu})\,[e\,\text{fm}^2], \tag{4}$$

$$T^m_{1\mu} = (3/4\pi)^{1/2} [g_R(I_\mu - J_\mu) + g_l(J_\mu - S_\mu) + g_s^{\text{eff}} S_\mu]\,[\mu_N], \tag{5}$$

where the notation has the usual meaning. The summation over i corresponds to the components of the cluster, $R_0 = 1.2\,A^{1/3}$ fm, e^{eff} and $e^{\text{eff}}_{\text{vib}}$ are the effective single-particle and vibrator charges, respectively; the free vibrator charge is $e^{\text{eff}}_{\text{vib}} = Ze\,\alpha_0$. The vector operators **I**, **J**, and **S** correspond to the nuclear angular momentum, and total angular momentum and spin of the cluster, respectively; the numbers g_R, g_l and g_s^{eff} are the collective, orbital and spin gyromagnetic ratios, respectively.

The mixing ratios δ for the $E2$ and $M1$ transitions are calculated by the relation [25]

$$\delta = -8.33 \times 10^{-3}\, E_\gamma \langle I_f \| T_2^e \| I_i \rangle / \langle I_f \| T_1^m \| I_i \rangle,$$

where $E_\gamma = E_i - E_f$ is the transition energy in MeV and the reduced matrix elements of the operators T_2^e and T_1^m are given in $e \cdot \text{fm}^2$ and μ_N, respectively. The operators T_2^e and T_1^m are those defined in Reference 17.

3. Calculations and Results

In the present calculations we considered the three-proton cluster moving in the $1g_{9/2}$ and $2d_{5/2}$ shell-model states coupled to a quadrupole vibrational field with vibrator states up to three phonons. The single-particle energy was taken from Reference 22,

$$\varepsilon(2d_{5/2}) - \varepsilon(1g_{9/2}) = 3.6 \text{ MeV};$$

the quadrupole vibrational energy $\hbar\omega = 0.935$ MeV and the quadrupole deformation $\beta = 0.08 \pm 0.02$ [23] from ^{92,94}Zr, and the effective pairing strength $G = 0.3$ MeV in accordance with the usual estimate [24]. Consequently we have used three values of the renormalized zero-point amplitude of the vibrational motion:

$$\alpha_0 = 0.026, \quad \alpha_0 = 0.036, \quad \text{and} \quad \alpha_0 = 0.045.$$

Table 1. Components of some low-lying positive-parity states for odd-mass technetium isotopes

$1_{9/2}$			$1_{7/2}$		
$\|(g_{9/2})\,^33, 7/2, 12\rangle$	−252	−337	$\|(g_{9/2})\,^33, 7/2, 00\rangle$	516	438
$\|(g_{9/2})\,^31, 9/2, 00\rangle$	834	632	$\|(g_{9/2})\,^33, 7/2, 12\rangle$	−324	−379
$\|(g_{9/2})\,^31, 9/2, 12\rangle$	−218	−242	$\|(g_{9/2})\,^31, 9/2, 12\rangle$	604	487
$\|(g_{9/2})\,^31, 9/2, 20\rangle$	174	293	$\|(g_{9/2})\,^33, 7/2, 20\rangle$	197	263
$1_{5/2}$			$1_{13/2}$		
$\|(g_{9/2})\,^33, 5/2, 00\rangle$	424	358	$\|(g_{9/2})\,^31, 9/2, 12\rangle$	703	603
$\|(g_{9/2})\,^31, 9/2, 12\rangle$	717	600	$\|(g_{9/2})\,^33, 13/2, 00\rangle$	470	408
$\|(g_{9/2})\,^33, 13/2, 24\rangle$	243	291	$\|(g_{9/2})\,^33, 7/2, 24\rangle$	−211	−267
$\|(g_{9/2})\,^33, 3/2, 12\rangle$	187	215			
$1_{11/2}$			$1_{3/2}$		
$\|(g_{9/2})\,^33, 7/2, 24\rangle$	−230	−318	$\|(g_{9/2})\,^33, 3/2, 00\rangle$	−537	−370
$\|(g_{9/2})\,^31, 9/2, 12\rangle$	672	517	$\|(g_{9/2})\,^33, 5/2, 12\rangle$	454	416
$\|(g_{9/2})\,^31, 9/2, 22\rangle$	224	311	$\|(g_{9/2})\,^33, 7/2, 12\rangle$	321	354
$\|(g_{9/2})\,^33, 11/2, 00\rangle$	−453	−385	$\|(g_{9/2})\,^31, 9/2, 24\rangle$	462	485
$\|(g_{9/2})\,^33, 7/2, 12\rangle$	151	229			

Each state is indicated by its ordering number and spin. The base vectors are defined in the text but the assignment of the intermediate angular momentum $\mathbf{J}_{12}$ is omitted. Only components contributing more than 4% are listed; the first and second rows correspond to $\alpha_0=0.027$ and $\alpha_0=0.045$, respectively

The calculated energy-level sequences of positive-parity states for these values of α_0 are shown in Figures 2A–C, respectively. The main components of the state vectors are listed in Table 1.

In our first attempts, the three-proton cluster had only available the $1g_{9/2}$ shell-model state. These calculations were unable to explain the experimental situation in ^{95}Tc since the predicted $^111/2$, $^113/2$, and $^15/2$ states were practically degenerate in energy, as it is shown in Figure 2D. Although the $1g_{7/2}$ single-particle state lies about 0.5 MeV above the $2d_{5/2}$ state in the mass region around 100, it was not included due to the following reasons: (i) The ratio between the matrix elements $\langle g_{9/2}\| Y_2 \|d_{5/2}\rangle$ and $\langle g_{9/2}\| Y_2 \|g_{7/2}\rangle$ is about 4. (ii) The additional introduction of the $1g_{7/2}$ single-particle state increases the size of the matrices to dimensions out of our computational facilities without changing significantly the present calculated results.

Because of the above results with only the $1g_{9/2}$ state, we thought unnecessary to show the numerical results or to try to improve the fit to experiment with further variation of the parameter α_0.

The calculations of the decay properties were performed with sets of effective values of single-particle and vibrator charges, and gyromagnetic ratios which are commonly used in this region. These properties are listed in Tables 2 and 3 together with the available experimental information for odd-mass Tc isotopes. In these tables we only show the results corresponding to the following sets:

I: $e^{\text{eff}}=e$ and $e^{\text{eff}}_{\text{vib}}=e^{\text{free}}_{\text{vib}}$;

II: $e^{\text{eff}}=2e$ and $e^{\text{eff}}_{\text{vib}}=2.5$;

1: $g_R=0$ and $g_s^{\text{eff}}=g_s^{\text{free}}$;

2: $g_R=Z/A$ and $g_s^{\text{eff}}=0.7\,g_s^{\text{free}}$.

They were chosen because they are commonly used in this kind of calculations.

Let us remark that for a good number of levels in odd-mass Tc isotopes the experiment could not provide unambigous spin assignments. Therefore, there are possible alternative spin sequences from which we should choose one of them via the comparison between different experimental level sequences as well as between them and those calculated in the present work. This unfortunate fact does not permit a definite and quantitative comparison with experiment. Consequently, we wish to point out that the comparison with experimental information should be made from a qualitative point of view. Moreover, since no attempt to the best fit could be made on this basis, the comparison with experiment was performed with the available information of odd-mass Tc isotopes ($95=A\leqq 101$).

As it is shown in Table 1, the ground state is mainly based on the $|(g_{9/2})\,^31, 9/2, 00\rangle$ configuration. The cluster-field coupling produces an important contribution for the collective character of the $^17/2$ and $^15/2$ states and their lowering in energy when the value of α_0 increases, as illustrated in Figure 2. In this way we have a simple explanation of the ocurrence of these levels at low excitation energy. The dominant components of the $^17/2$ state are $|(g_{9/2})\,^31, 9/2, 12\rangle$ and $|(g_{9/2})\,^33, 7/2, 00\rangle$ with a contribution of about 10% of the configuration $|(g_{9/2})\,^33, 7/2, 12\rangle$. Concerning the $^15/2$ state, the dominant component is

$$|(g_{9/2})\,^31, 9/2, 12\rangle$$

Table 2. Calculated state electric quadrupole Q and magnetic dipole μ moments, and mean lifetimes τ in odd-mass technetium isotopes for some of the low-lying states shown in Figure 2 A and C

$^{\kappa}I^{+}$	Q [eb]					μ [μ_N]					τ [fs]				
	α_0(min)		α_0(max)			α_0(min)		α_0(max)			α_0(min)		α_0(max)		
	I	*II*	*I*	*II*	Exp.[a]	1	2	1	2	Exp.[a]	*I*+1	*II*+2	*I*+1	*II*+2	Exp.[b]
$1_{9/2}$	−0.22	−0.47	−0.35	−0.53	(+)0.34 ±0.34	7.146	6.141	6.992	6.050	5.6847 ±0.0004					
$1_{7/2}$	−0.43	−0.90	−0.70	−1.07		5.825	4.926	5.628	4.812	3.60±0.88 5.6 ±0.14	4.6×10^4	5.8×10^4	4.9×10^7	2.7×10^7	
$1_{5/2}$	−0.041	−0.087	−0.036	−0.055		5.002	4.022	4.895	3.959	3.291 ±0.063	1.5×10^4	1.2×10^4	1.1×10^4	2.6×10^4	≧500
$1_{13/2}$	−0.14	−0.30	−0.21	−0.32		7.774	7.419	7.792	7.429		4.8×10^4	1.1×10^4	4.6×10^4	2.1×10^4	≧600
$1_{11/2}$	−0.054	−0.113	−0.049	−0.075		7.767	6.937	7.525	6.799		2,567	3,406	1,967	3,452	≧1,200
$1_{3/2}$	0.043	0.089	0.023	0.036		2.513	2.129	2.745	2.262		6.0×10^4	2.2×10^4	1.6×10^4	1.2×10^4	≧850
$2_{9/2}$	−0.14	−0.31	0.090	0.146		5.157	5.038	5.761	5.364		81	241	219	547	
$1_{17/2}$	−0.17	−0.34	−0.22	−0.35		10.84	10.10	9.855	9.529		6.3×10^4	1.4×10^4	9,577	4,178	
$3_{9/2}$	−0.014	−0.026	−0.52	−0.77		6.240	5.615	5.897	5.428		51	157	16	46	
$2_{11/2}$	−0.35	−0.73	−0.64	−1.00		6.231	6.079	6.159	6.026		778	1,257	408	549	400^{+250}_{-110}
$2_{7/2}$	0.030	0.066	0.052	0.060		5.286	4.618	5.208	4.569		73	198	29	78	530^{+270}_{-130}

The set of values for the effective proton and vibrator charges, and gyromagnetic ratios are indicated in the text. For each entity, the first and second columns give the calculated values for $\alpha_0=0.027\equiv\alpha_0$(min), and the third and four, for $\alpha_0=0.045\equiv\alpha_0$(max). The fifth column gives the available experimental information.

[a] Shirley, V.S., and Lederer, C.M.: Table of Nuclear Moments, Lawrence Berkeley Laboratory, report LBL-3450 (1974), for ^{99}Tc

[b] Reference 3, for ^{95}Tc

with a contribution of about 15% of the configuration $|(g_{9/2})\,^3 3, 5/2, 00\rangle$. The $^1 13/2$ and $^1 11/2$ states are the members of the one-phonon multiplet

$$|(g_{9/2})\,^3 1, 9/2, 12; {}^n I\rangle$$

– however, see below – with a contribution of approximately 20% of the $|(g_{9/2})\,^3 3, I, 00\rangle$ configuration. The $^1 3/2$ state presents a strong admixture of particle and collective nature. The $^2 9/2$ state shows a curious behaviour: its energy remains practically unaffected with the variation of α_0 (see Fig. 2) while its nature changes from purely collective for $\alpha_0=0.027$ to a strong admixture of different configurations for $\alpha_0=0.045$. Consequently the $^2 9/2$ level would be a member of the one-phonon multiplet only for $\alpha_0=0.027$ whereas for the other values of α_0 it becomes to the $^3 9/2$ state. The experimental dipole magnetic moment of the ground and the first two excited states of ^{99}Tc compare favourably with the calculated values as shown in Table 2. The rather large and negative quadrupole moments of the $^1 9/2$, $^1 7/2$, $^1 13/2$, $^2 9/2$ (or $^3 9/2$ depending upon the value of α_0) and $^2 11/2$ states and the enhanced $E2$ transitions between some of them favour the assumption of a quasi-rotational structure in coexistence with the quasivibrational one, a fact which is generally established by the cluster-field coupling.

An interesting example of the lack of a precise knowledge of the decay properties of these isotopes is yielded by the $B(E2)$ values of $^1 11/2$ and $^2 11/2$ states in ^{95}Tc. The lower possible experimental $B(E2)$ values argue against a collective nature for these states. The present model predicts the $^1 11/2$ state always as a member of the one-phonon multiplet. The calculated $^2 11/2$ state may be either of particle-like or collective nature depending upon the parametrization used. The $B(M1)$ strengths, the branching b ratios, and the mixing ratios δ are in general reasonably accounted for. The calculated lifetimes are consistent with experiment for three cases in ^{95}Tc; the manifest discrepancies are those of the $^1 5/2$, $^1 13/2$, and $^1 3/2$ states. However, the latter has neither unambigous spin nor definite parity assignments. So, this lack of agreement is not conclusive.

4. Conclusions

As mentioned in the Introduction several calculations are available with different models for the odd-mass technetium isotopes although an extensive and de-

Table 3. Calculated quadrupole electric $B(E2)$ and dipole magnetic $B(M1)$, mixing δ and branching b ratios for transitions between some of the levels in odd-mass technetium isotopes shown in Figure 2 A and C

$^{\kappa}I_i^+$	$^{\kappa'}I_f^+$	$B(E2)$ [W.u.]				$B(M1)$ [W.u.]				δ				b [%]			
		α_0(min)		α_0(max)		α_0(min)		α_0(max)		α_0(min)		α_0(max)		α_0(min)		α_0(max)	
		I	*II*	*I*	*II*	1	2	1	2	*I*+1	*II*+2	*I*+1	*II*+2	*I*+1	*II*+2	*I*+1	*II*+2
$1_{7/2}$	$1_{9/2}$	14	61	36	82	0.014	0.0060	0.000	0.000	−0.36	−1.3	−1.7	−4.8	100	100	100	100
		49±5 [a]								−0.33±0.06 [b]		0.118±0.006 [c]		100.0±0.4 [b]			
$1_{5/2}$	$1_{7/2}$	1.9	8.2	4.5	11	0.24	0.078	0.10	0.033	0.017	0.061	0.062	0.17	78	21	95	73
		13±1 [a]								−0.008±0.008 [c]				17.8±0.2 [b]			
$1_{5/2}$	$1_{9/2}$	9.5	42	22	52									22	79	5.1	27
														82.2±0.6 [b]			
$1_{13/2}$	$1_{9/2}$	10	44	25	55									100	100	100	100
		≦99 [b]												100.0 [b]			
$1_{11/2}$	$1_{13/2}$	4.4	19	14	32	0.26	0.086	0.20	0.065	0.011	0.041	0.20	0.065	1.5	0.64	1.8	1.0
$1_{11/2}$	$1_{9/2}$	9.5	42	23	49	0.036	0.012	0.063	0.020	0.34	1.27	0.36	0.93	99	99	96	91
		≦0.8 or ≦29 [b]				≦0.03 or ≦0.003 [b]				$0.13^{+0.03}_{-0.02}$ or		3.0±0.6 [b]		100.0 [b]			
$1_{3/2}$	$1_{5/2}$	17	71	38	93	0.0045	0.0015	0.028	0.0094	0.69	2.50	0.37	0.99	60	36	53	22
		≦300 [b]				≦0.61 [b]				0.21±0.03 [b]		3.58±0.20 [c]		47.0±0.4 [b]			
$1_{3/2}$	$1_{7/2}$	4.2	18	11	24									40	64	47	76
		≦120 [b]												24.3±0.2 [b]			
$2_{9/2}$	$1_{7/2}$	0.49	2.20	7.7	16	0.34	0.11	0.055	0.018	−0.025	−0.092	0.36	0.91	26	26	40	52
														90.7±0.14 [b]			
$2_{9/2}$	$1_{9/2}$	2.3	11	0.084	0.18	0.25	0.073	0.070	0.019	0.098	0.39	0.036	0.10	68	68	55	38
														9.3±0.3 [b]			
$2_{11/2}$	$1_{9/2}$	0.36	1.8	4.5	8.4	0.0025	0.00086	0.0012	0.00041	0.44	1.7	2.2	5.0	11	20	12	26
		$0.28^{+0.18}_{-0.16}$ or 15±5 [b]				0.029±0.011 or 0.0025±0.009				0.13±0.03 or		3.3±0.8 [b]					
$2_{7/2}$	$1_{5/2}$	0.97	4.3	5.9	13	0.31	0.10	0.37	0.12	0.040	0.15	0.12	0.30	37	25	28	27
		15^{+16}_{-12} [b]				0.094±0.031 [b]				0.22±0.10 [b]				27.7±0.5 [b]			
$2_{7/2}$	$1_{7/2}$	4.9	22	6.8	13	0.052	0.017	0.044	0.014	−0.28	−1.0	−0.48	−1.2	9.8	17	9.1	15
		≦4.5 [b]				0.021±0.007 [b]				$-0.04^{+0.25}_{-0.40}$ [b]				21.1±0.4 [b]			
$2_{7/2}$	$1_{9/2}$	0.12	0.68	1.4	2.0	0.13	0.044	0.31	0.10	−0.038	−0.16	−0.085	−0.18	63	57	63	57
		$1.9^{+1.5}_{-0.3}$ [b]				0.061±0.005 [b]				$-0.41^{+0.16}_{-0.22}$ [b]				51.2±0.7 [b]			

Weisskopf units [d] are indicated W.u. The set of values for the effective proton and vibrator charges, and gyromagnetic ratios are indicated in the text. For each transition, the second row gives the available experimental information.

[a] Reference 7, for ^{99}Tc

[b] Reference 3, for ^{95}Tc; the phase convention of Rose and Brink [25] was used for δ

[c] Reference 8, for ^{99}Tc; the phase convention adopted for δ is not indicated

[d] Reference 22, p. 387

tailed description of the properties of the positive-parity states has not been reported as yet. The results obtained by the shell-model calculations performed by Vervier [10] and Bhatt and Ball [11] are rather similar; they place the $^{1}5/2$ state too high in energy. The EQPC calculations of Goswami and Nalcioglu [12] do not compare favourably with the experimental level sequence of ^{97,99}Tc. The calculations of Xenoulis and Sarantites [1] performed with an extension of the EQPC model [13] show that although the decrease in energy of the $^{1}5/2$ and $^{1}7/2$ states with increasing mass number A is well reproduced, the $^{1}5/2$ state is however lower than the $^{1}7/2$ state which conflicts with experiment. Moreover, all these approaches do not include calculations of decay properties and hence a more complete comparison with experimental data cannot be made.

Concerning with the theory recently proposed by Kuriyama and coauthors [16] the situation is different. In fact their calculations include $B(E2)$ and $B(M1)$ strengths and the agreement with the known properties of ^{99}Tc is good, except for the position of the $^1 5/2$ state which lies too high in energy. On the other hand, the level sequence of ^{95}Tc is in agreement with experiment but no comparison is reported with electromagnetic properties. Moreover, their formalism is not expected to be satisfactory for describing other states than those belonging to the dressed three-quasiparticle $[(1\,g_{9/2})^3 J]$ cluster.

With the Alaga model used in the present work we were able to reproduce not only the general features of the positive-parity-states of odd-mass Tc isotopes but also to describe their decay properties, some of them not hitherto predicted by any model. Let us remark that the lack of agreement found in some cases cannot be considered conclusive since – as stated above – the experiment does not permit for the most of the states neither an unambigous spin nor definite parity assignments. It is to be noted that in our calculations the general trend of observed properties in these nuclei was obtained with the variation – between the experimental errors of the quadrupole deformation β – of only one parameter, namely, the zero-point amplitude of the vibrating core α_0.

We feel that the application of the present model would be considerably strengthed if the existence of the $^1 11/2^+$ and $^1 13/2^+$ states could be located experimentally in other Tc isotopes apart from ^{95}Tc. Moreover, further experimental work to determine the magnitude and sign of the electric quadrupole moments of some-low-lying states in this group of isotopes would be highly desirable. In this way we would have an experimental support for the coexistence of quasi-rotational and quasivibrational structures predicted by the present model.

Finally it should be also mentioned that the cluster-field coupling provides a simple description of the existence of the low-lying $7/2^+$ and $5/2^+$ states. Their behaviour with the mass number – they move towards lower excitation energies as the neutron number increases – is well reproduced by means of the decrease of the cluster-field coupling.

In order to describe the negative-parity states in the odd-mass technetium isotopes one should consider the four-particle one-hole clustering as well as its interaction with the vibrational field. The pertinent formalism will be developed in a near future and together with the results will be discussed elsewhere.

References

1. Xenoulis, A.C., Sarantites, D.G.: Phys. Rev. C **7**, 1193 (1973)
2. Kramer, K., Huber, B.W.: Z. Physik **268**, 333 (1974)
3. Sarantites, D.G., Xenoulis, A.C.: Phys. Rev. C **10**, 2348 (1974)
4. Shibata, T., Itahashi, T., Wakatsuki, T.: Nucl. Phys. A **237**, 382 (1975)
5. Phelps, H.E., Sarantites, D.G.: Nucl. Phys. A **171**, 44 (1971)
6. Huber, B.W., Kramer, K.: Z. Physik **267**, 11 (1974)
7. Bond, P.D., May, E.C., Jha, S.: Nucl. Phys. A **179**, 389 (1972)
8. Gardulski, P.L., Wiedenback, M.L.: Phys. Rev. C **9**, 262 (1974)
9. Meyer, R.A.: Lawrence Livermore Laboratory preprint UCRL-76207 (1974)
10. Vervier, J.: Nucl. Phys. **75**, 17 (1966)
11. Bhatt, K.H., Ball, J.B.: Nucl. Phys. **63**, 286 (1965)
12. Goswami, A., Nalcioglu, O.: Phys. Lett. **26** B, 353 (1968)
13. Goswami, A., McDaniels, D.K., Nalcioglu, O.: Phys. Rev. C **7**, 1263 (1973)
14. Kuriyama, A., Marumori, T., Matsuyanagi, K.: Prog. Theor. Phys. **45**, 784 (1971)
15. Kuriyama, A., Marumori, T., Matsuyamagi, K.: Prog. Theor. Phys. **47**, 498 (1972)
16. Kuriyama, A., Marumori, T., Matsuyanagi, K.: Prog. Theor. Phys. **51**, 779 (1974)
17. Alaga, G.: In: Cargese Lectures in Physics, ed. by M. Jean, Vol. 3, p. 579. New York: Gordon and Breach 1969
18. Alaga, G., Ialongo, G.: Nucl. Phys. A **97**, 600 (1967)
19. Almar, R., Civitarese, O., Krmpotić, F., Navaza, J.: Phys. Rev. C **6**, 187 (1972)
20. Almar, R., Civitarese, C., Krmpotić, F.: Phys. Rev. C **8**, 1518 (1973)
21. Paar, V.: Nucl. Phys. A **211**, 29 (1973)
22. Bohr, A., Mottelson, B.R.: Nuclear Structure, Vol. I, p. 239. New York: W.A. Benjamin Inc. 1969
23. Stelson, P.H., Grodzins, L.: Nucl. Data A **1**, 21 (1965)
24. Kisslinger, L.S., Sorensen, R.A.: Revs. Mod. Phys. **35**, 953 (1963)
25. Rose, H.J., Brink, D.M.: Revs. Mod. Phys. **39**, 306 (1967)

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