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POSSIBLE VIOLATION OF THE GALLAGHER-MOSZKOWSKI RULE IN THE ^{160,162}Tm ISOTOPES

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Recent experimental studies [1,2] of ^{162}Tm have confirmed the existence of very strong enhancement of the ℓ-forbidden E1 transition from the state with configuration $7/2[523]_p - 5/2[523]_n$ to the ground state and the first excited state, respectively. A fully analogous situation has been reported in ^{160}Tm [3]. The Weisskopf hindrance factor of these transitions agrees with the ones of the allowed E1 transitions in near odd-odd nuclei [4], although systematics [4] of the Weisskopf hindrance factors of the other forbidden E1 transitions yields the value $\approx 10^5$ times greater.

In refs. [3,5] the $1/2[411]_p - 3/2[521]_n$ configuration has been assigned to the ground state of ^{160}Tm and ^{162}Tm, and the first excited state has been suggested to be the first rotational member of the ground state band. Using the known information on energies of non-rotational states in ^{159,161}Tm and ^{159,161}Er and the semiempirical relation [6] concerning energies of odd-odd and corresponding odd-A nuclei, one can imagine how the energy spectrum of the non-rotational states in ^{160,162}Tm looks like. However, it seems from there that in case of the interpretation mentioned above, because of a considerable energy diluting, neither Coriolis ($\Delta K = 1$) nor the n-p($\Delta K = 0$) interaction are able to mix sufficiently the configurations to reach the observed transition speed.

The $5/2[402]_p - 3/2[521]_n$ configuration violating the Callagher-Moszkowski rule has been proposed for the ground state of ^{160}Tm by Ekström et al. [7], having assumed a small deformation for ^{160}Tm. The value of $\epsilon_2 \approx 0.25$ deduced in ref. [3] has attracted the authors to prefer the $1/2[411]_p - 3/2[521]_n$ configuration for the ground state of ^{160}Tm. However, the results of the experimental and theoretical investigation of ^{161}Tm performed by Honusek [8] show that the $5/2[402]$ configuration can be assigned to the 18.9 keV level in ^{161}Tm and the deformation parameter values are $\epsilon_2 = 0.22$ and $\epsilon_4 = -0.027$. Therefore it has been of great interest to obtain relevant qualitative conclusions by model calculations.

Our calculations are based on the "two-quasiparticle + axial rotor" model [9-11]. This model starts with the Hamiltonian

$$H = H_{int} + \frac{h^2}{2J}(\hat{I}^2 - \hat{I}_3^2) + H_j + H_{cor}, \qquad (1a)$$

$$H_j = \frac{h^2}{2J}(\hat{j}_+\hat{j}_- + \hat{j}_-\hat{j}_+), \qquad (1b)$$

$$H_{cor} = -\frac{h^2}{2J}(\hat{I}_+\hat{j}_- + \hat{I}_-\hat{j}_+), \qquad (1c)$$

where the notation of ref./10/ is used. The intrinsic part involves the Woods-Saxon nuclear average field and the pairing residual interaction, parameters of which have been taken from ref./12/. The energies and the wave functions of the rotational states in ^{160,162}Tm have been determined by diagonalization of the Hamiltonian (1) in $|IMK\alpha\rangle \approx \mathcal{D}^I_{MK}\Phi^{(\alpha)}_K$ basis, where $\mathcal{D}^I_{MK}$ and $\Phi^{(\alpha)}_K$ denote the Wigner and intrinsic wave functions, respectively, $H_{int}\Phi^{(\alpha)}_K = E_{K_\alpha}\Phi^{(\alpha)}_K$.

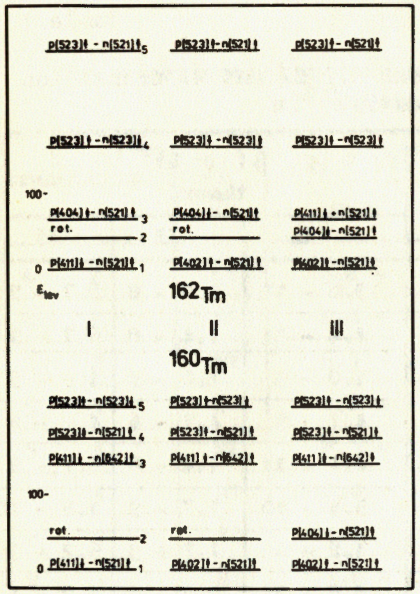
The intrinsic wave function $\Phi^{(\alpha)}_K$ can be written as a product of the odd proton and neutron intrinsic wave functions (see refs./9,11/). Therefore the intrinsic matrix elements of all operators needed can be expressed via the proton or neutron quasiparticle matrix elements/10,11/.

The basis of all 14 non-rotational states up to E ≈500 keV and K = 2 was mixed. The inertial parameter $h^2/2J$ common for all bands involved and intrinsic eigenvalues E_{K_α} were varied until a least-square fit to the experimental energy levels was obtained. The mixed wave functions thus obtained were used further to calculate reduced E1, E2, and M1 transition probabilities/11/.

The following values of the effective charges $e^{(E\lambda)}_{eff}$ were employed: $e^{(E2)}_{eff} = 0.99$ and 0.003 for protons and neutrons, respectively; $e^{(E1)}_{eff} = \frac{N}{A}$ and $-\frac{Z}{A}$ for protons and neutrons, respectively; the values of gyromagnetic ratios g_s, g_ℓ and g_R were varied as follows: $g^{p,n}_s \in (0.6\, g^{free}_s, g^{free}_s)$, $g^p_\ell \in (0.7, 1)$, $g^n_\ell \in (0.0, 0.2)$ and $g_R \in (\frac{Z}{A} - 0.2, \frac{Z}{A} + 0.2)$.

The mentioned above recipe of calculation was used to test all acceptable interpretations of the experimental levels in both studied nuclei. In the figure we give interpretations which provide the best description of experimental data on the energies and E1, E2, and M1 transitions. The corresponding results of the E2, E1, and M1 transition probability calculations are given in tables 1,2.

In the empirical non-rotational spectrum the configuration $7/2\,[404]_p - 3/2\,[521]_n$ (the first excited level in interpretation III) lies near the ground state in both the studied nuclei. If we take the configuration $5/2\,[402]_p - 3/2\,[521]_n$ as the ground state, the strong Coriolis mixing between both mentioned configurations appears and consequently the B(E2) probability of transition from the first excited state to the ground state has almost the same numerical value in both interpretations II and III, in spite of the first excited state in interpretation II is the second member of ground rotational band. From the point of view of the comparison of experimental and theoretical B(E2) and B(M1) transition probabilities all three interpretations given in the figure are almost equivalent. Question arises in comparing B(E1) probabilities of transitions between levels: 4 → 1, 4 → 1, and 5 → 2, 5 → 1 for ^{162}Tm and ^{160}Tm, respectively (assignment of levels as in the figure). Interpretations II and III violating the Gallagher-Moszkowski rule improve the agreement with experiment as compared with the Adam´s paper/3/ (interpretation I) nevertheless, the calculated values remain 100 times as small as experimental ones. Calculated values of B(E1) cannot be increased by including two-quasiparticles + octupole-phonon admixtures in the intrinsic wave function as has been proposed by Andrejtschef/13/ on the base of Soloviev´s model/14/. In the framework of this model the selection rule for matrix elements of dipole E1 operator make impossible expressive increasing of these elements by including octupole-phonon admixtures. Only the inclusion of dipole-phonon admixtures into intrinsic wave function can influence the calculated B(E1) values, but these admixtures are very small for low-lying nuclear states (because the dipole states are several MeV higher in nuclear spectrum) and are neglected in Soloviev´s model. Therefore we pressume that a better agreement of the theory with experiment in B(E1, $\substack{4(5)\to 2\\ 4(5)\to 1}$) can be reached only by including interaction of an odd neutron with an odd proton into the calculation. There are only two configurations, $7/2\,[523]_p - 5/2\,[642]_n$ and $7/2\,[404]_p - 5/3\,[523]_n$, which can be mixed to the states 1 and 2 (see the figure) by n-p interaction. When the disagreement of calculated and experimental B(E1, $\substack{4(5)\to 2\\ 4(5)\to 1}$) values is really



The best interpretations of the low lying levels in ^{160,162}Tm.

Table 1

The experimental and theoretical E1, E2 and M1 transition probabilities in ^{162}Tm

transition a) *)		σL	B(σ L)**) exp.	B(σ L)**) theor. I	II	III
4	1	E1	4.7 - 5 a)	3.0 - 11	1.0 - 8	5.7 - 9
4	2	E1	8.7 - 5	4.4 - 11	1.4 - 8	6.7 - 9
5	1	E1	3.2***)	1.0 - 9	1.0 - 5	1.0 - 5
5	2	E1		4.7 - 9	4.7 - 6	4.2 - 6
4	2	E1	27***)	4.4 - 11	1.4 - 8	6.7 - 9
4	3	E1		9.6 - 10	3.7 - 9	1.6 - 10
2	1	E2	1.2 + 4	1.2 + 4	7.7 + 3	6.2 + 3
2	1	M1	2.2 - 2	5.9 - 2	2.1 - 1	5.0 - 1

*4 → 1 means the transition between 4 and 1 levels (see the figure).

**units used for trans.probabilities: $e^2\cdot fm^2$, $e^2\cdot fm^4$ and μ_N^2 for E1, E2 and M1 multipolarities, respectively.

***the values obtained from branching ratio.

a) 4.7-5 means 4.7×10^{-5}

b) the interpretation proposed by de Boer et al./5/.

caused by neglecting the n-p interaction, the increasing of the energy distance between the mixed states has to diminish this disagreement. Such a situation x/ just occurs in our case when the mentioned above mixing configurations lie in level spectrum of ^{160}Tm higher than in ^{162}Tm (see tables 1 and 2).

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x/ The only configuration 7/2 [404]$_p$ - 5/2 [642]$_n$, which can be mixed to the state 4(5) (see the figure), conserves its energy distance to this state in both nuclei. The other admixtures, which can contribute to the B(E1, $^{4(5)\,\to\,2}_{4(5)\,\to\,1}$) probabilities and which are mixed to the 1,2,4,5 state wave function by means of n-p and Coriolis interaction acting step by step (second order interaction), are negligible.

Table 2

The experimental and theoretical E1, E2 and M1 transition probabilities in ^{160}Tm

transition a) *)		σL	B(σ L)**) exp.	B(σ L)**) theor. I b)	II	III
4	2	E1	2.2 - 6	3.5 - 8	1.8 - 5	8.9 - 6
4	1	E1	8.8 - 7	1.1 - 7	4.4 - 5	4.4 - 5
5	2	E1	6.5 - 5	2.1 - 10	2.5 - 8	1.1 - 8
5	1	E1	1.6 - 5	1.7 - 10	2.0 - 8	1.7 - 8
5	4	E2	8.5 + 3	3.5 + 3	3.5 + 2	3.1 + 2
5	4	M1	2.4 - 3	1.0 - 1	3.1 - 2	3.0 - 2
2	1	E2	1.3 + 4	1.3 + 4	1.1 + 4	6.2 + 3
2	1	M1	1.6 - 2	3.0 - 2	3.1 - 1	1.7 - 1
3	1	E1	2.7***)	3.7 - 7	2.4 - 9	2.0 - 9
3	2	E1		1.6 - 6	4.8 - 9	2.4 - 9

*,**,***,a) see description for table 1,

b) the interpretation proposed by Adam et al./3/.

The same configurations can be certainly mixed with the states 1 and 2 in the interpretation I. However, a greater disagreement of the experimental and calculated B(E1, $^{4(5)\,\to\,1}_{4(5)\,\to\,2}$) values in the interpretation I requires a more significant effect of the n-p interaction.

Final conclusions about the ^{160,162}Tm low-lying level interpretation can only be made upon performing calculations with the exact inclusion of the n-p interaction.

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Гонс З., Квасил Я. E4-83-103

Возможное нарушение правила Галлагер-Мошковского в изотопах ^{160,162}Tm

Анализ экспериментальных данных об энергетических уровнях и E2-, E1- и M1-переходах в низколежащем спектре в нечетно-нечетных изотопах ^{160,162}Tm проводится в рамках модели "две квазичастицы + ротор". Приписание конфигурации $5/2\,[402]_p - 3/2\,[521]_n$ /нарушающей правила Галлагер-Мошковского/ к основному состоянию обоих ядер существенно улучшает согласие теоретических значений вероятностей f-запрещенных переходов с экспериментальными. Расхождение, которое осталось, можно, по-видимому, объяснить взаимодействием нечетного протона с нейтроном. В результате предлагается интерпретация низколежащих состояний в обоих изотопах, которая по сравнению с предыдущими интерпретациями лучше описывает экспериментальные данные. Предлагаемый способ обработки экспериментальных данных позволяет извлечь из эксперимента информацию о чисто внутренних модах движения ядра, что является важным при проверке разных ядерных моделей нечетно-нечетных ядер.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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Hons Z., Kvasil J. E4-83-103

Possible Violation of the Gallagher-Moszkowski Rule in the ^{160,162}Tm Isotopes

Analysis of the experimental data on the energy levels and E2, E1 and M1 transition probabilities in the low-lying spectrum on odd-odd ^{160,162}Tm isotopes has been performed in the framework of the "two-quasiparticle + rotor" model. The assignment of the $5/2\,[402]_p - 3/2\,[521]_n$ configuration (violating the Gallagher-Moszkowski rule) to the ground state of both nuclei appears to improve significantly agreement of the theoretical f-forbidden E1 transition probabilities with the experimental ones. The left disagreement indicates inevitableness of taking the residual interaction into account to get the more realistic description of experimental data. Interpretation of low-lying levels in both studied nuclei, which improve the description of experimental data in comparison with previous papers, is proposed. The proposed way of theoretical interpretation makes possible extracting the information from experiment about the intrinsic modes of nuclear motion and provides in such a way the data for testing the nuclear models of odd-odd nuclei.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna 1983