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COLLECTIVE HIGH SPIN STATES IN THE LIGHT ODD $f_{7/2}$ NUCLEI*,**

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The high-spin states in ^{45}Sc, ^{45}Ti and ^{43}Ca were studied with the GASP multidetector array coupled with the Recoil Mass Spectrometer in Legnaro. The nuclei were excited in the ^{30}Si + 60 MeV ^{18}O reaction. Lifetimes were extracted from the analysis of the Doppler shift attenuation of gammas emitted in the reversed kinematics ^{12}C+ ^{35}Cl reaction. Energies and the transition probabilities for the observed negative-parity states agree with the shell model predictions. The lifetimes of the intruder-positive parity states in ^{45}Sc and ^{45}Ti suggest a deformation ($\beta \approx 0.25$) associated with the particle-hole excitation in the nuclei.

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The study of the high spin structure in the $f_{7/2}$ shell nuclei ($20 \leq N, Z \leq 28$) gives a chance to match shell and collective model approaches in describing a nucleus. In this region, the spherical shell model predicts well the properties of the low-lying negative parity states [1, 2]. On the other hand these states may be explained with the use of the collective

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model [3]. Recent studies of the ^{49}Cr nucleus [4] have shown that at higher spin the collective effects are clearly recognized. It has been demonstrated [5] that both the shell and the cranking models can provide adequate description of the properties of the levels observed in the experiment. A shell model calculation reported for the ^{48}Cr nucleus [6] also points out that the microscopic approach reproduces well the features of the collective motion in this nucleus.

The positive parity states known in some odd $f_{7/2}$-shell nuclei and related to $d_{3/2}$ intruder orbital are often treated as a sign of a collectivity in these nuclei. These states have been successfully interpreted in terms of the strong coupling model [7]. In the light $f_{7/2}$ nuclei having a few valence nucleons the attempt to calculate the intruder states using the shell model formalism [2] within very limited configuration space, also succeeded in reproducing some properties of the low lying levels.

In our recent work [8], the negative and positive parity state structures of ^{45}Sc have been extended towards high spin. The states built on the intruder $d_{3/2}$ configuration revealed the rotational character. In the present paper the newly obtained results concerning the high spin levels in the ^{45}Ti and ^{43}Ca populated in the same ^{30}Si+ 60 MeV ^{18}O reaction are reported. We also present the results of the DSAM measurements for the levels in the ^{45}Sc and the ^{45}Ti nuclei. In this experiment the γ-rays emitted in the bombardment of a thick ^{12}C 15mg/cm^2 target with ^{35}Cl projectile at 75, 95 and 120 MeV were recorded with the GASP array. The selected beam energies lead to a population of three different regions of spin and excitation energy in ^{45}Sc and ^{45}Ti , which arise in 2p and pn CN evaporation, respectively. This enabled a well controlled extraction of lifetimes by the DSAM analysis of the γ-lineshapes observed at different angles with respect to the beam direction.

The level scheme for the ^{45}Ti and the ^{43}Ca nuclei populated in the ^{30}Si+ ^{18}O reaction are shown in Fig. 1. They were constructed on the basis of the double and triple γ-coincidences, the spin assignments are based on the decay pattern and the DCO ratio analysis.

The present data extended the known K=3/2$^+$ rotational positive parity band in ^{45}Ti by two new transitions. The 1463 keV line proposed earlier [9] to be the highest member of the positive parity band, feeding the 11/2$^+$ level was not observed. This band seems to terminate at the spin J^π=19/2$^+$ whereas, as shown previously, the analogous structure in ^{45}Sc continues up to the spin J^π=35/2$^+$[8]. Although, the reaction yield for ^{45}Ti is about 4 times lower than for ^{45}Sc in the ^{30}Si+ ^{18}O reaction, it hardly explains the abrupt drop of the intensity.

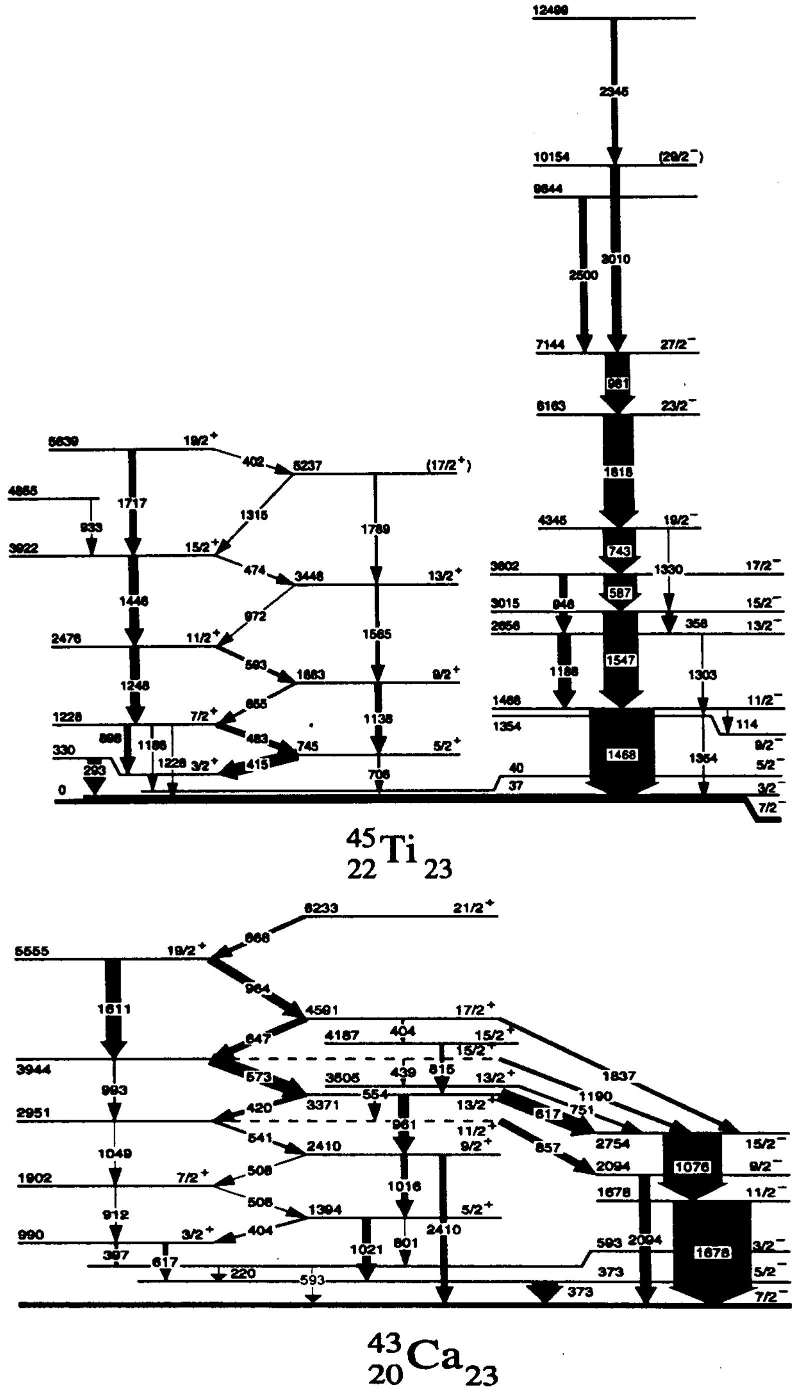

Fig. 1. The level schemes of the ^{45}Ti and the ^{43}Ca nuclei obtained in the experiment.

The negative parity structure in ^{45}Ti was also investigated. The previous ordering [10] of the 1818 keV and the 743 keV transitions is now reversed. In addition, some high energy γ-rays feeding the $J^{\pi}= 27/2^{-}$ level were identified. No transition connecting the two parity structures was noticed.

In the case of the ^{43}Ca nucleus apart from the known structure only one new transition with E_{γ}=993 keV connecting the 3944 keV and the 2951 keV levels was found. The gammas from the reported [11] negative parity levels lying above the $15/2^{-}$ state were not observed. The measured γ intensities suggest that the positive parity states decay predominantly to the negative parity levels.

The data obtained in the DSAM measurement allowed to extract the lifetimes for the most of the positive and negative parity levels in the ^{45}Sc and the ^{45}Ti nuclei, identified in the first experiment. The experimental spectra at the forward and backward angles were selected by coincidences with the unshifted γ-transitions from the lowest levels. The line-shape calculations were done assuming that the directions of the beam and of the recoils did not change in the target/stopper material. This condition is reasonable for such a light stopper as ^{12}C where the total stopping power is determined entirely by its electronic component in the whole energy range. The stopping power necessary to calculate the lineshapes was taken from Ref. [12]. In the calculations, the presence of all known cascades feeding the certain level as well as an instantaneous side feeding, which affect the final line shape, were taken into account. The measured lifetimes of the high spin states in ^{45}Sc and ^{45}Ti are listed in Table I. The quoted statistical errors do not contain the uncertainty of the stopping power determination. For the highest lying levels because of the full Doppler shift of the γ lines only the upper limit $\tau < 0.1$ ps was established.

The shell model calculations [13] based on the full fp configuration including the $0f_{7/2}$,$0f_{5/2}$, $1p_{3/2}$, $1p_{1/2}$ orbits were performed for the three nuclei. The FPD6 [14] empirical two body interaction were used in the calculations. The resulted level schemes are compared with the experimental ones in Fig. 2. The measured and calculated transition probabilities for the negative parity levels are also placed in the figure.

The observed positive parity states in ^{45}Ti seem to obey the rotational rule $J{\sim}\hbar\omega$ as well as it was found [8] for the ^{45}Sc nucleus. Moreover, the extracted B(E2) transition probabilities in both nuclei point to the collective character of this excitation with corresponding deformation $\beta \approx$0.3.

In the ^{43}Ca nucleus the positive parity levels exhibit much less collectivity, the cascades of the E2 transitions are weak and have irregular energies, moreover strong interaction is observed of the positive parity structure with the negative parity states. The detailed discussion of the positive parity levels in the three nuclei will be published in a separate paper.

TABLE I

The lifetimes measured in the experiment

E [kev]	I_i^π	τ [ps]	E [kev]	I_i^π	τ [ps]
	^{45}Sc			^{45}Ti	
3296	$15/2^+$	0.67(7)	2656	$13/2^-$	< 0.25
3570	$17/2^-$	< 0.1	3448	$13/2^+$	0.26(3)
3693	$19/2^-$	2.0(2)	3602	$17/2^-$	1.3(1)
4056	$17/2^+$	0.40(9)	3922	$15/2^+$	0.45(3)
4896	$19/2^+$	0.30(5)	4345	$19/2^-$	0.15(2)
5418	$23/2^-$	1.9(2)	4855		0.30(5)
5697	$21/2^+$	0.4(2)	5237	$(17/2^+)$	0.1(9)
6685	$23/2^+$	0.25(5)	5639	$19/2^+$	0.27(8)
8365	$25/2^+$	< 0.1	6163	$23/2^-$	0.50(6)
8623	$27/2^+$	0.28(9)	7144	$27/2^-$	15(2)

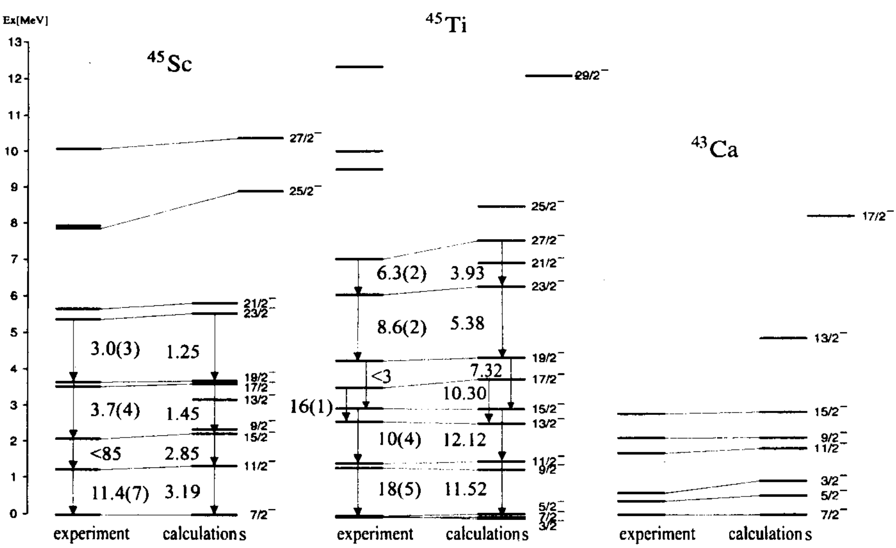

Fig. 2. The comparison between the measured and the calculated energies for the negative parity levels in ^{45}Sc, ^{45}Ti and ^{43}Ca. The experimental and theoretical B(E2) values in Weisskopf units are also displayed.

The presented experimental data provide new information on the high spin structures of the light odd $f_{7/2}$ nuclei. The obtained results demonstrate that the spherical shell model works surprisingly well in this region, for the negative parity states in the full range of spins and excitation energies. The interpretation of the observed rotational bands being due to the deformation driven by proton hole in the $d_{3/2}$ orbital calls for further collective and shell model calculations.

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