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1. INTRODUCTION

The bulk of information on the excited states in ^{83}Sr comes from the work of Simpson et al.[1] regarding β^+-decay of two ^{83}Y isomers. The half-lives of isomers are (7.06±0.08) *min* and (2.85 ± 0.02) *min* with most probable quantum characteristics $J^{\pi} = 9/2^+$ and $J^{\pi} = 1/2^-$ [1], respectively. Some levels of ^{83}Sr have also been studied by the pick-up (d,t) reaction[2].

According to the single shell model, the low-lying states of nuclei in the $_{36}Kr$ and $_{38}Sr$ region with $N \leq 49$ are described as neutron holes in the $N=50$ closed shell with protons in the ground state. The available hole states are $1g_{9/2}$, $2p_{1/2}$, $2p_{3/2}$ and $1f_{5/2}$. Therefore, one can expect to find low-lying levels having spins and parities $9/2^+$, $1/2^-$, $3/2^-$ and $5/2^-$ in these nuclei with $A \sim 83$. Such levels appear indeed as is evident from studies of some of these nuclei viz. ^{85}Sr[3], ^{81}Kr[4], etc.[5].

Nevertheless, many other excited states as well as their electromagnetic properties cannot be explained by such a simple picture[6]. The longstanding problem exists in nuclei of the mass number $A \sim 89$ and $A \sim 131$ in which the unique-parity level of large spin j in the major shell (e.g., $1g_{9/2}$, $1h_{11/2}$) is being filled. There is a competition between a spin j and a spin (j–1) state for the ground state. The simple shell model cannot account for the (j–1)-state and therefore such an extra low-lying state with spin $J=j-1$ and with unique parity have been called the anomalous coupling state.

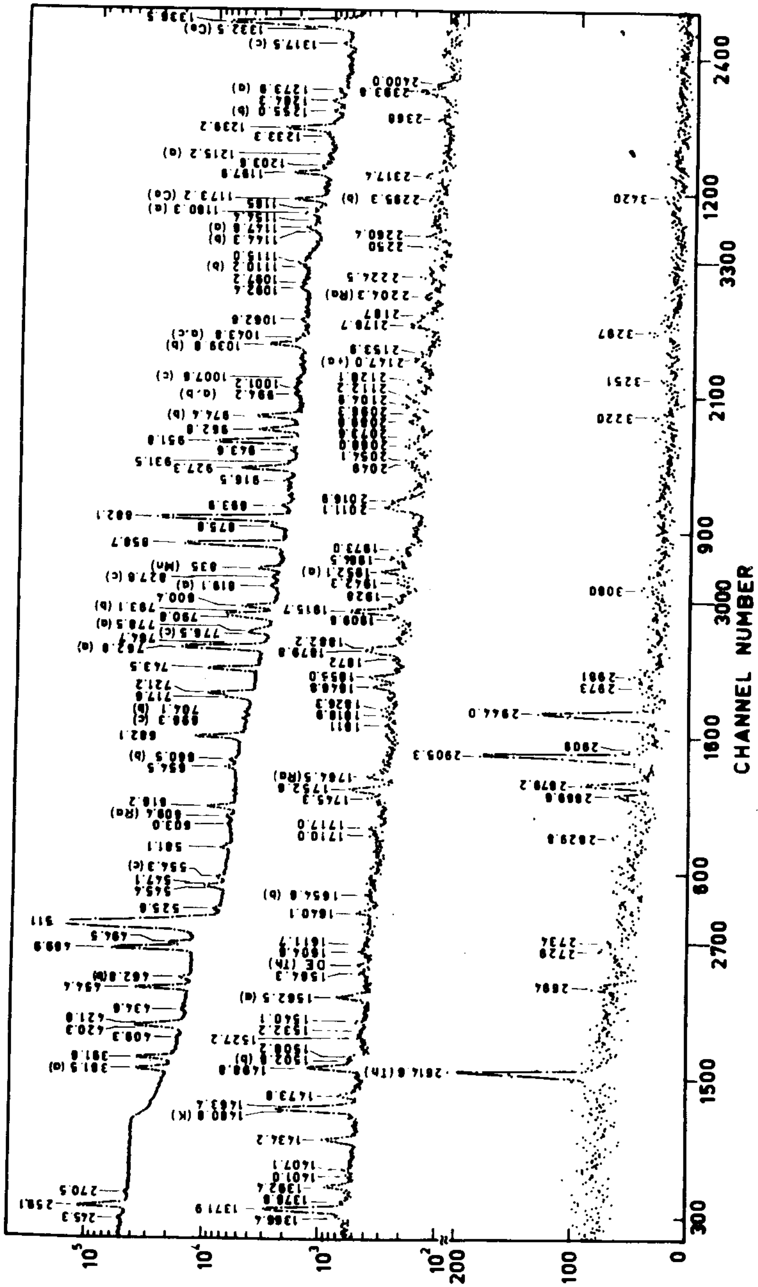

Fig. 1. The single γ-ray spectrum from the decay of ^{83}Y. *Contamination: (a)* ^{83}Sr, *(b)* ^{84}Y, *(c)* ^{82}Rb.

Several explanations have been proposed for this $J=j-1$ state, where $j=9/2$ in the region of the ^{83}Sr nucleus.

A low-lying $7/2^+$ state was obtained using a certain effective interaction between nucleons in the $g_{9/2}$ shell /7/.

The description of the considered state in the quasi-particle-phonon coupling model of Kisslinger and Sorensen /8/ is poor. Later, Kisslinger /9/ has shown that the three-quasiparticle state with $J^{\pi}=7/2^+$ can be lowered to the one-quasiparticle state with $J^{\pi}=9/2^+$ but he needed very strong quadrupole interaction to obtain such lowering. In addition to this the M1 transition between the states $7/2^+$ and $9/2^+$ was strictly forbidden, which seems to be in disagreement with experimental data.

In the deformed single-particle model the close spacing of $7/2^+$ and $9/2^+$ states comes very naturally but it implies a large deformation /10/.

More recently V.Paar /11/ has applied Alaga's model to odd nuclei with $Z=50$. He obtained very good agreement with experimental data especially with regard to the anomalous coupling state of spin and parity $7/2^+$. Similar agreement with experimental data in the region of $_{45}$Rh, $_{47}$Ag has been obtained by A.Kuriyama et al. /12/.

The aim of the present work is to investigate excited states in the $^{83}_{38}Sr_{45}$ nucleus which are populated by $\beta^+-\epsilon$-decay of two isomers of ^{83}Y with very different J^{π} $(9/2^+, 1/2^-)$. In addition, the anomalous coupling state with $J^{\pi}=7/2^+$ is the ground state of the ^{83}Sr nucleus /13/ and therefore, there is a possibility of studying its property from the γ-decay of excited states.

2. *EXPERIMENTAL PROCEDURE AND RESULTS*

The ^{83}Y activity was produced by spallation of Mo target (0.1 *mm* thick) by 660 *MeV* protons in the external beam of the synchrocyclotron at JINR, Dubna. The ^{83}Y sources were prepared from a mixture of spallation products by the electromagnetic mass-separation technique, using a surface ionization ion source together with the hot solid target method /14/.

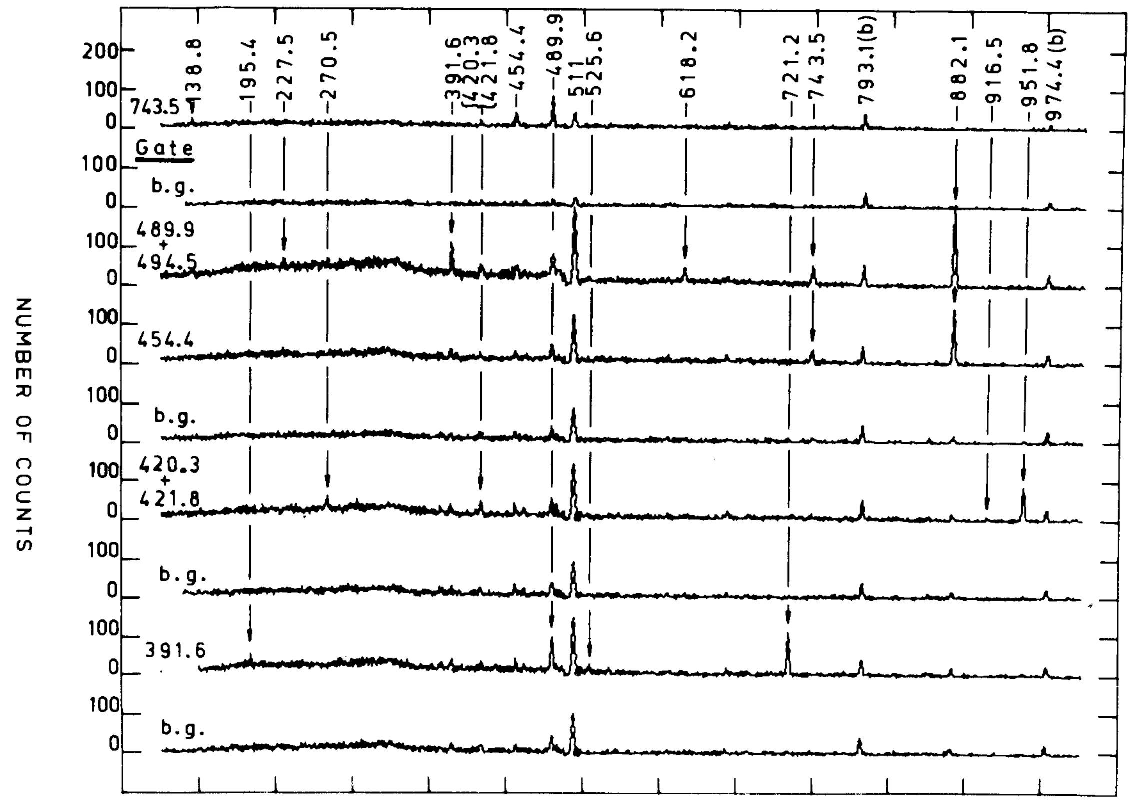

Fig. 2a. The coincidence γ-ray spectra, b.g. = background.

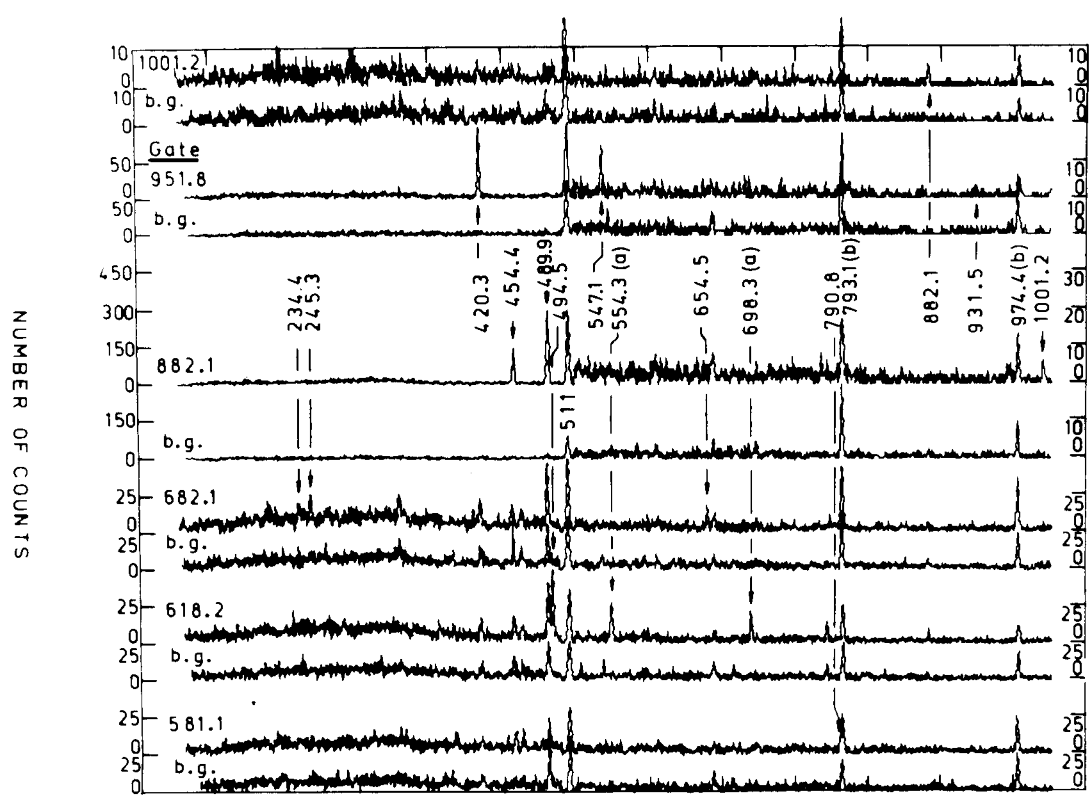

Fig. 2b. The coincidence γ-ray spectra, b.g. = background.

The gamma-ray singles were studied using two coaxial Ge(Li) detectors with volumes of 41 and 50 cm^3 and the energy resolution of 2.5 *keV* for the 1332 *keV* γ-line. The low energy γ-rays were examined by Ge(Li) detector with volume of 2.5 cm^3 and the energy resolution of 0.6 *keV* at 100 *keV*. The γ-ray spectrum of typical measurement is shown in *fig. 1*.

The energies of the peaks were determined using the γ-lines which originate in the ^{82}Rb, ^{84}Y and ^{83}Sr decay, respectively. The ^{82}Rb and ^{84}Y nuclei were admixtures in some sources of ^{83}Y activity.

Coincidence spectra were taken with Ge(Li) detectors with volumes of 41 and 50 cm^3 and the energy resolution of 2.5 *keV* for 1332 *keV* line. The time resolution of the coincidence system (2τ) was 100 *nsec*. Data were collected in the 4096x4096 channel matrix and stored on the magnetic tape which was later analysed by means of the Hewlett-Packard 2116-C computer. *Figures 2a* and *2b* show several of the coincidence γ-ray spectra.

The time behaviour of the 28 γ-transitions was studied for the identification as well as for the half-life measurement. *Figures 3* and *4* show the results. Three lines (259.1, 494.5 and 420.3+421.8 *keV*) have two half-lives. The measured half-lives $T_{1/2} = (2.7 \pm 0.3)$ *min* and $T_{1/2} = (7.1 \pm 0.1)$ *min* are in good agreement with the values of ref. /1/. The γ-transition 545.4 *keV* has $T_{1/2} = 7.0$ *min* which value does not agree with $T_{1/2} = 3.5$ *min* published by Doron and Blann /15/. The value $T_{1/2} = 7.1$ *min* was taken to deduce the intensities of components in above-mentioned three γ-transitions.

The results of the analysis of the single γ-rays spectra as well as the coincidence spectra are summarized in *tabs. 1* and *2*, respectively (intensities are compared with those obtained in /1/).

The intensities of all but two γ-lines are in good agreement with the data from ref. /1/. The difference in intensity of the 494.5 *keV* line can be accounted by its short-lived component. The origin of the difference in the case of 717.6 *keV* line is not clear but the comparison

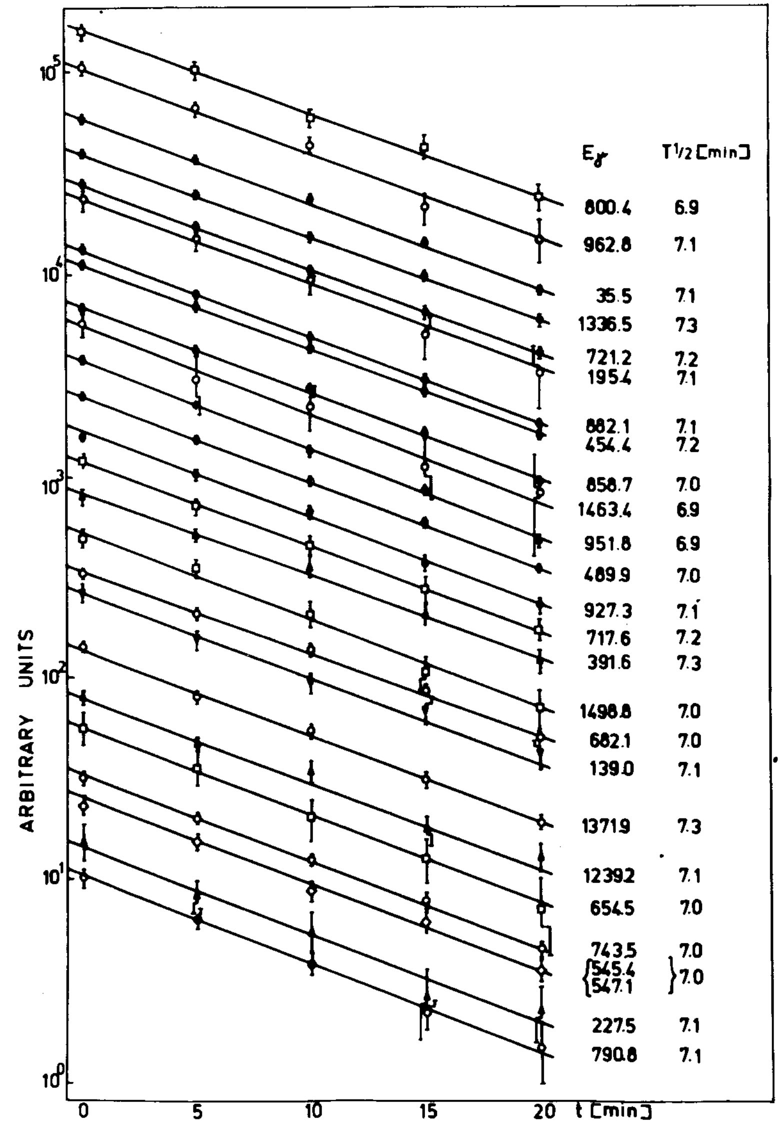

Fig. 3. The time behaviour of several γ-ray lines from the decay of ^{83}Y.

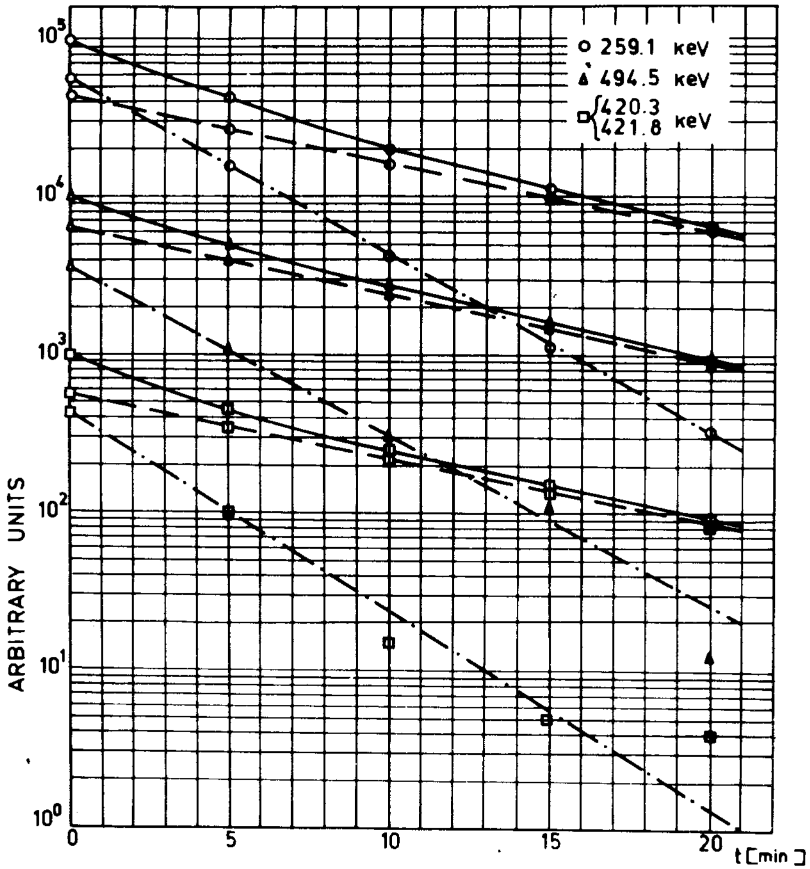

Fig. 4. The time dependence of γ-ray lines with two half-lives.

of our γ-ray spectrum with the spectrum published in ref. /1/ indicates a typing error.

There are several γ-lines, 800.4, 962.8 and 1239.2 *keV*, which were decaying with $T_{1/2} > 1\,h$ according to the data of work /1/ but our results gave $T_{1/2} \cong 7.1$ *min* (see *fig. 3*). A reason of this disagreement is not known.

The total intensity of β^+-transitions was obtained from the intensity of annihilation γ-radiation (511 *keV*). A Cu absorber (4 *mm* thick) was on both sides of the

^{83}Y source in these measurements. The normalized intensity of the 511 *keV* line is presented in *tab. 1*.

TABLE 1

Energies and relative intensities of the γ-transitions from the ^{83m,g}Y → ^{83}Sr decay

This work		Simpson et al.$^{c)}$	This work		Simpson et al.$^{c)}$
energy (keV)	relative intensity		energy (keV)	relative intensity	
35.5±0.1	3070 ±200	2980	(781.5)		
138.8±0.4	16 ± 2		790.8±0.2	70 ± 7	
195.4±0.4	25 ± 3		800.4±0.1	80 ± 5	
227.5±0.2	18 ± 2		858.7±0.1	510 ±20	484
234.4±0.3	10 ± 2		875.8±0.3	29 ± 5	
245.3±0.4	10 ± 3		882.1±0.1	1000 ±25	1000
259.1±0.1	320 ± 20	486	893.9±0.4	18 ± 4	
270.5±0.3	12.0± 1.5		916.5±0.5	13 ± 3	
391.6±0.2	230 ± 15	225	927.3±0.1	139 ± 7	139
409.3±0.4	11 ± 2		931.5±0.5	15 ± 4	
420.3±0.3	292 ± 20	200	943.6±0.5	8.2± 2.5	
421.8±0.3$^{a)}$	12$^{b)}$		951.8±0.1	310 ±15	291
434.6±0.5	12 ± 3		962.8±0.1	85 ± 5	
454.4±0.2	380 ± 10	377	1001.2±0.6	13 ± 3	
489.9±0.2	920 ± 20	1150	1062.6±1.0	7.5± 2.5	
494.5±0.2	116 ± 15	261	1092.4±0.6	10 ± 3	
511	29800 ±950		1097.2±0.8	6 ± 3	
525.6±0.4	11.7± 2.9		1115.0±0.5	10 ± 3	
545.4±0.3	53.9± 9 }	100	(1154.4)		
547.1±0.3	45 ± 9 }		(1165)		
581.1±0.3	23 ± 3		1197.9±0.2	58 ± 5	
603.0±0.3	10 ± 2		1203.6±0.5	11 ± 2	
618.2±0.2	97 ± 7	98	1233.3±0.6	10 ± 2	
654.5±0.2	31 ± 3		1239.2±0.2	91 ± 4	
682.1±0.1	197 ± 9		1264.3±0.4	15.0± 2.5	
717.6±0.2	72 ± 3	178	1336.5±0.1	490 ±20	510
721.2±0.2	168 ± 7	163	1366.4±0.6	10 ± 3	
743.5±0.1	195 ± 9	187	1371.9±0.1	160 ± 8	136
764.7±0.6	64 ± 8		1378.8±0.8	5.0± 1.8	

Table 1 (continued)

Energy (keV)	relative intensity	energy (keV)	relative intensity
1392.4±0.3	22 ±2	2049.0±1.5	4.2±2.0
1401.0±1.5	2 ±1	2054.1±1.2	6.3±2.0
1407.1±1.0	5.1±1.5	2068.0±0.6	9.3±1.7
1434.2±0.2	32 ±3	2073.6±1.2	6.0±2.4
1463.4±0.3	73 ±9	2089.8±1.0	4 ±2
1473.8±0.6	11 ±2	2096.3±1.0	5.5±2.2
1498.8±0.2	68 ±6	2104.9±0.8	9.7±1.8
1508.2±0.6	11.0±1.5	2112.2±0.7	10.7±1.8
1527.2±1.0	5.2±1.5	2126.1±1.0	6.2±1.8
1532.2±1.0	3.2±1.5	2147.0±2.5	3.5±1.6
1540.1±0.7	4.7±1.5	(2153.9)	
1584.3±1.0	4.2±2.0	2178.7±0.8	12.1±2.2
1604.6±0.8	7.2±2.0	2187 ±1	5 ±2
(1611.7)		2224.5±1.5	5 ±2
1640.1±1.0	9.7±2.1	2250 ±1	4 ±2
1710.0±1.5	4 ±2	2260.4±0.9	5.4±2.0
1717.0±0.8	6.7±2.3	2317.4±0.6	9.4±1.6
1745.3±0.9	7.2±2.1	2368 ±1	2 ±1
1752.6±0.4	30.9±4.6	2393.8±0.9	6.5±3.2
(1811)		2400.0±1.6	3.6±1.8
(1819.9)		2694.0±1.2	3.9±1.8
(1826.3)		2729 ±2	4.5±2.0
1846.8±0.5	12.1±3.1	2734 ±2	2 ±1
1855.0±0.4	16.6±2.3	2829.8±1.7	5 ±2
(1872)		2869.6±1.5	6.7±2.1
1879.8±0.7	20.2±4.2	2879.2±1.5	12.1±2.3
1882.2±0.8	6.6±3.3	2905.3±0.9	32.4±4.1
(1909.6)		2909 ±2	4 ±2
1915.7±0.4	42.0±4.5	2944.0±1.0	24.6±3.0
1928 ±2	4 ±2	2973 ±2	2.7±1.5
1942.3±1.0	4.3±1.5	2981 ±2	5.4±2.0
1964.5±0.6	12.6±2.0	3060 ±2	2.5±1.0
1973.0±0.9	5.6±1.8	3220.0±2.5	3.5±1.6
2011.1±0.5	18.5±2.8	3251 ±3	3.8±1.8
2016.9±0.6	15.3±2.4	3297 ±3	5.5±1.8
		3400 ±4	2 ±1

Table 1 (continued)

$T_{1/2}$ = 2.85 min		
This work		Simpson et al.[c])
Energy (keV)	relative	intensity
259.1 ± 0.1	100 ± 6	100
421.8 ± 0.3	36 ± 3	30
494.5 ± 0.2	15 ± 2	

[a]) Value determined from the decay of ^{83}Y with $T_{1/2}$=2.85 min.

[b]) Identified in γ-γ coincidence studies only. I_γ calculated from the scheme of the ^{83}Y decay with $T_{1/2}$=7.06 min.

[c]) Ref. [1]).

3. *DECAY SCHEME*

An isomeric transition in the ^{83}Y nucleus has not been observed yet. The time behaviour of the most of the γ-transitions shows that the isomeric transition can be very weak. Therefore the possibility exists to discuss the decay scheme of two ^{83}Y isomers separately. The decay schemes of the ^{83}Y isomers are presented in *fig. 5*. The basic criterion for the construction of the decay scheme was γ-γ coincidence results, having regard to energy sums and intensity balances. The results obtained in the study of the (d,t) reaction /2/ have been used, too.

The spin-parity assignments of the levels in the ^{83}Sr, as is shown in *fig. 5*, are based on experimental log ft values for β^+; EC-feeding of levels and their γ-deexcitation modes. The decay energy Q_{β^+} was taken as 4.5 *MeV* /16/ for both isomers. Theoretical values of E.C. / β^+ branching were taken from ref. /17/. Total internal conversion coefficients derived from the tables of Hager and Seltzer /18/ were used in a calculation of the absolute intensities of 35.5 *keV* and 259.1 *keV* γ-transitions.

Table 2

Results of γ-ray coincidence measurements associated with the decay of ^{83}Y

Energy (keV)	Gates (keV): 35.5	195.4	391.6	421[a])	454.4	489.9	494.5	525.6	546[a])	581.1	618.2	682.1	721.2	743.5	882.1	951.8	1001.2	1392.4
138.8														Y				
195.4			Y					Y										
227.5						Y												
234.4												Y						
245.3												Y						
270.5				Y														
391.6		Y				Y		Y					Y					
420.3				}Y												Y		
421.8				}														
454.4	Y													Y	Y			Y
489.9			Y											Y	Y			Y
494.5											Y							
525.6		Y	Y															
547.1																Y		
618.2							Y											
654.5												Y						
721.2			Y															
743.5					Y	Y												
790.8										Y								
827									(Y)									
858.7	Y																	
882.1					Y	Y											Y	
916.5				Y														
931.5																Y		
951.8				Y					Y									
1001.2				(Y)											Y			
1392.4					Y	Y												

Y = Coincidence; (Y) = Data inconclusive; [a]) = doublet

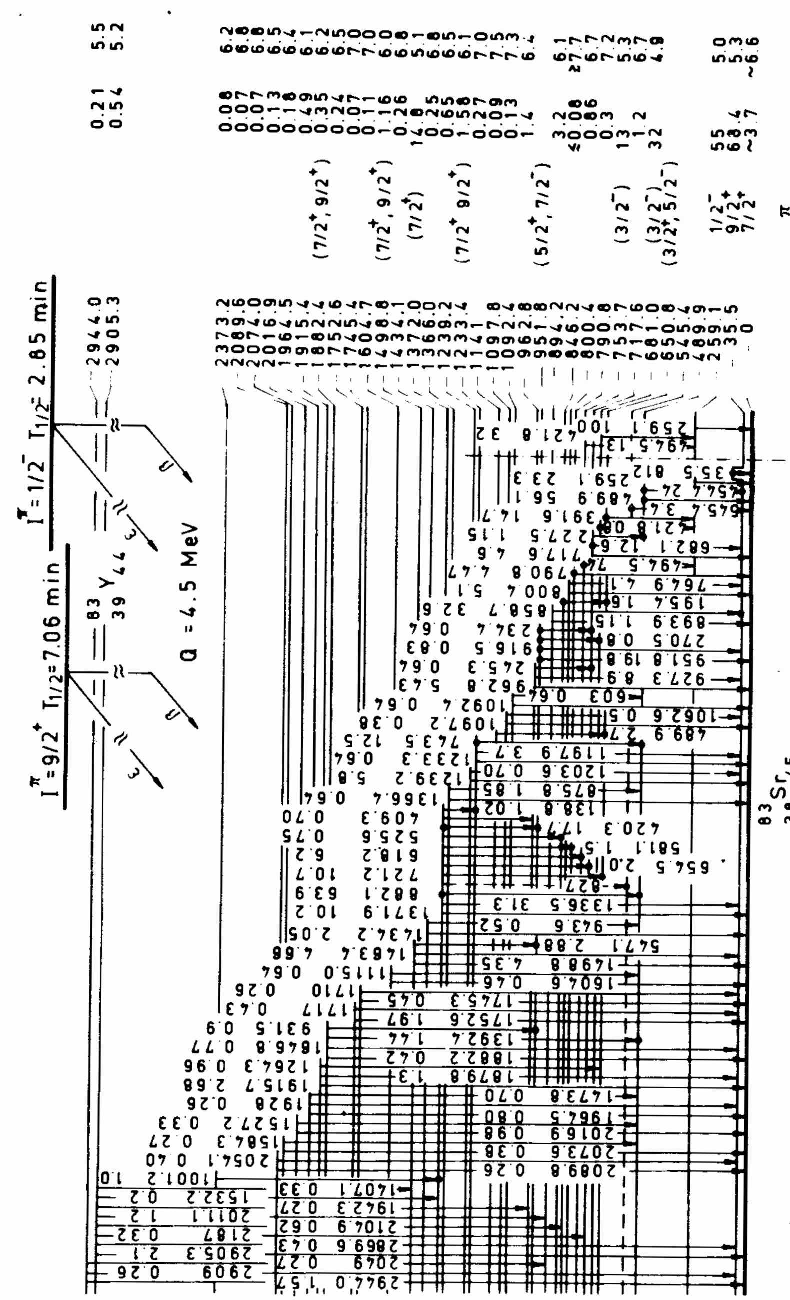

Fig. 5. The decay scheme of ^{83}Y isomers. Dot means coincidence relation between γ-transitions.

Decay scheme of ^{83}Y ($T_{1/2}$ = 2.85 *min*)

The present decay scheme differs from that proposed by Simpson et al. /1/ only in the new level at 753.7 *keV*.

The analysis of $\gamma-\gamma$ coincidences has shown that the γ-transitions in ^{83}Sr do not coincide at all. It means that the transition 421.8 and 494.5 *keV* populate the isomeric level of 259.1 *keV* in ^{83}Sr ($T_{1/2}$ = = *4.95 sec* /13/). This constitutes the levels at 259.1 (log ft = 5.0), 681.0 (log ft = 4.9) and 753.7 *keV* (log ft = =5.3).

The most probable spin and parity of ^{83}Y ($T_{1/2}$ = = 2.85 *min*) $1/2^-$ and the log ft values showing the allowed character of β^+ decays lead to quantum characteristics $(3/2)^-$ for the levels at 681.0 and 753.7 *keV* as well as to $1/2^-$ for 259.1 *keV* level. The assignment $1/2^-$ to 259.1 *keV* is supported by data from (d,t) reaction study /2/. The most probable configurations for 259.1, 681.0 and 753.7 *keV* levels are $n/(2p_{1/2})^{-1}/$, $n/(2p_{1/2})^2(2p_{3/2})^{-1}/$ and $n/(2p_{1/2})^{-2}(2p_{3/2})^{-1}/$ respectively.

Decay scheme of ^{83}Y ($T_{1/2}$ = 7.06 *min*)

There are many differences between the decay scheme proposed by Simpson et al. /1/ and the decay scheme presented in *fig. 5*. The comparison of reported results with the latest compilation of data on the mass number A=83 /13/ shows that 22 new levels have to be introduced to accommodate a prevalent part of γ-transitions in ^{83}Sr. Most of these new levels lie at the energy higher than 1372.0 *keV*, last level reported by Simpson et al. /1/

The ground state has the spin and parity $7/2^+$ /13/ and it is populated by very weak β^+-transition from the isomeric state of ^{83}Y with $J^\pi = 9/2^+$. The intensity of this β^+-transition was calculated from the intensity of the 511 *keV* line, theoretical EC/β^+ ratios and the sum of intensity of all β^+-transitions to the excited states of the ^{83}Sr.

The ICC of 35.5 *keV* transition was obtained from the condition of the intensity balance for the first excited state of 35.5 *keV*. The comparison of determined α_T = = 3.2 ±0.3 with the theoretical value of ICC α_T(theor)=3.13 shows that the 35.5 *keV* transition is the magnetic dipol transition. The type of γ-transition and the reaction data /2/ suggest the spin and parity $9/2^+$ for the level at 35.5 *keV*. The structure of this state will be dominated by the $/(1g_{9/2})^{-5}$, $\nu = 1/$ component (ν is the seniority number) in accordance with the reaction data /2/ and the value of log ft of β^+-transition feeding the discussed state.

The basis for introducing the 489.9 *keV* state is several coincidences; γ454.4$-\gamma$35.5 *keV*, γ882.1$-\gamma$454.4, 489.9 *keV* and γ743.5$-\gamma$454.4, γ489.9 *keV*. Because of the very weak β^+-transition to this state its quantum characteristics are $5/2^+$ or $7/2^-$. The most probable value is $5/2^+$ as it follows from the systematics /3,4/. The level at 505 *keV* has been reported in ref. /2/ where the value of 3 is attributed to the orbital angular momentum of this level. The inspection of the published angular distribution /2/ shows that the assignment $\ell=3$ is very uncertain.

The level of 650.8 *keV* ($3/2^+$, $5/2^-$) was introduced on the basis of coincidences γ391.6$-\gamma$'s 195.4, 525.6 and 721.2 *keV* as well as energy difference between the levels at 1372.0 $(7/2)^+$ and 259.1 *keV* ($1/2^-$) (this difference is equal to the sum of 721.2 + 391.6 *keV*). The existence of the state at 753.7 *keV* follows from the coincidence between 494.5 *keV* and 618.2 *keV* transitions. This level is excited by the allowed β^+-transition from the ^{83}Y isomer ($T_{1/2}$ = 2.85 *min*, $J^\pi = 1/2^-$), too. On the other hand, 753.7 *keV* level is populated by the γ-transition from the level at 1372.0 *keV* whose spin and parity are $7/2^+$ (an allowed β^+-transition from the $9/2^+$ state). Therefore the γ-transition between levels at 1372.0 and 753.7 *keV* (i.e., 618.2 *keV*) has to be multipolarity of M2 or/and E3. This multipolarity is very improbable because of the strong intensity of the 618.2 *keV* transition. The possible existence of 2 levels in the vicinity of

753 *keV* excitation energy results from this discussion and the level which is excited by the decay of the ^{83}Y isomer with $T_{1/2} = 7.06$ *min* has the spin and parity $3/2^+$ or $5/2^-$.

The level at 1372.0 *keV* excitation energy is based on many coincidence relations (see *tab. 2*). It is a level with the strongest β^+ feeding and resulting smallest log ft value (5.1). The complicated γ-decay mode bounds the spin and parity to $7/2^+$. Other characteristic levels excited in the decay of the ^{83}Y ($T_{1/2} = 7.06$ *min*) are levels at 2905.3 and 2944.0 *keV*. These levels were introduced to place some strong high-energy transitions (i.e., 2905.3 and 2944 *keV*) along with other two γ-transitions having energy just to feed the first excited state at 35.5 *keV*. The small log ft values show that the parity of these levels is positive.

As regards the level at 858.8 *keV*, reported by Simpson et al. /1/ it is possible to place γ-transition of 858.7 *keV* in other place in accordance with the coincidence data.

No comments are needed with respect to other excited levels shown in ^{83}Y decay scheme. Many of them are based on the coincidence data but because of no existence of a conversion-electron measurement it is impossible to determine their spins and parities uniquely.

4. *DISCUSSION*

On the basis of an available experimental data some conclusions can be made concerning the structure of $^{83}_{38}Sr_{45}$ states. The negative parity states at excitation energy of 259.1 ($1/2^-$) and 681.0 *keV* ($3/2^-$) can be described as a hole in the $2p_{1/2}$ and $2p_{3/2}$ neutron shell. A structure of the 753.7 *keV* level is more complicated but the low log ft value points at a considerable amount of $n(2p_{3/2})^{-1}$ configuration. These interpretations are supported by data of the work /2/ from the (d,t) reaction.

The first excited state at 35.5 *keV* ($9/2^+$) can be interpreted as the state whose a main component is $/n(1g_{9/2})^{-5}, \nu = 1/$ configuration. This interpretation is in accordance with (d,t) reaction data /2/. Such component of the wave function of 35.5 *keV* state enables to account for a structure of the ground state of $^{83}_{38}Sr_{45}$ with $J^\pi = 7/2^+$.

If the ground state belongs to a family of states built up from $(1g_{9/2})^{-5}$ configuration then the multipolarity of 35.5 *keV* transition (transition between members of $(g_{9/2})^{-5}$ multiplet) has to be E2. The experimental value of $\alpha_T = 3.2 \pm 0.3$ indicates M1 multipolarity. The same argument can be applied to the quasi-particle-phonon coupling theory of Kisslinger and Sorensen /8,9/.

According to our knowledge two theories explain the existence of the $7/2^+$ state and nonforbiddance of M1 multipolarity. The first is Alaga's model applied by Paar /11/ to nuclei with the number of protons $P = 47$ ($^{107,109}Ag$). A few-particle cluster (e.g. $(1g_{9/2})^{-3}$) in the case of Ag nuclei is coupled to the vibrational field in this calculation. His results show that the retardation of the $9/2^+ \rightarrow 7/2^+$ M1 transition is relaxed in the case of nuclei with $P = 47$.

The second model, the model of Kuriyama et al. /12/ explains above mentioned facts, too. They have taken into account the phonon disassociation into a pair of the quasi-particle, one of which reassociates with the odd quasi-particle in calculations of properties of the $_{43}Tc$, $_{47}Ag$, $_{55}Cs$ nuclei. Their results are similar to those of Paar.

Some levels (489.9, 790.8, 951.8, 1239.2, 1434.1, 1752.6, 1915.4, 2905.3 and 2944.0 *keV*) are deexcited to the ground state dominantly. The ratio R of the intensity of γ-transition to the ground state ($7/2^+$) to the intensity of γ-transition to the first excited state ($9/2^+$) in ^{83}Sr is larger than 3.

On the other hand, a group of levels (717.6, 894.2, 1233.4 and 1372.0 *keV* ($7/2^+$) is deexcited to the first excited state dominantly. The above mentioned ratio R is smaller than 0.3.

Such property of group of levels resembles some kind of a phonon band built up on the $7/2^+$ anomalous coupling state and on the $/n(1g_{9/2})^{-5}, \nu=1/$ cluster state. It is remarkable that similar bands are shown in Kuriyama et al. /12/ calculation of excited states of $^{133}_{55}Cs$ nuclei.

In conclusion we summarize

a) the negative parity states in ^{83}Sr nucleus are neutron hole states basically,

b) the wave function of the first excited state at 35.5 *keV* has a great amount of $/(1g_{9/2})^{-5}, \nu=1/$ configuration,

c) M1 multipolarity of 35.5 *keV* transition between the first excited state and the ground state of ^{83}Sr can be taken as an argument for a validity of Alaga's /11/ or Kuriyama's /12/ models of odd mass spherical nuclei,

d) some structure (similar to phonon band) exists in the way as group of levels are deexcited,

e) the systematic study of neighbouring nuclei is needed to see that the mentioned structure is persisting,

f) a detailed theoretical calculation of properties of nuclei with $N=45$ are needed. In our opinion a calculation in a framework of Alaga's or Kuriyama's model is most interesting and most promising.

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