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1. Introduction

The level scheme of even-even deformed nucleus ^{182}W has been investigated by many authors, mainly in the decay of ^{182}Ta and in Coulomb excitations. The most completed survey of the experimental data and the analysis of the ^{182}W level scheme is given in the work of Voinova and Dzhelepov /1/. There is relatively poor information about the decay of ^{182}Re isomers ($T_{1/2}$ = 12.7 h and 64 h) /2-7/ to the excited states of ^{182}W . The results of the investigations of conversion electron spectra from ^{182}Re /3-6/ are rather ambiguous and in the gamma-ray spectra /3,4/ only groups of non-resolved lines have been observed.

The aim of the present investigation was to obtain further knowledge of the levels of ^{182}W studying the decay of 13-hour ^{182}Re isomer by the measurements of gamma-ray spectra with a Ge(Li) detector and by the extensive use of electron-gamma and gamma-gamma coincidence measurements. The preliminary results of these investigations were published earlier /8,9/.

2. Experimental Methods

2.1. Source

The gold target was irradiated for 0.5 - 2 h with 660 MeV protons in the synchrocyclotron at Dubna. The osmium fraction was distilled from the target material 20-30 min after irradiation and trapped in the chloroform solution of diphenylthiourea. This solution was left for 10-12 h to get rid of ^{181}Os ($T_{1/2}$ = 105 min) and then the daughter rhenium activities were isolated by extraction with 4N HCl and discarded. After it during 22-24 hours the ^{182m}Re activity grew from the decay of ^{182}Os ($T_{1/2}$ = 21 h) and later the rhenium activities were extracted with 4N HCl . The HCl solution from the second extraction included mainly ^{182m}Re and the small amount of ^{183}Re ($T_{1/2}$ = 71 d) which did not interfere in the measurements. The long-lived isomer of ^{182}Re ($T_{1/2}$ = 64 h) was not present in the sample because it is not produced in the decay of ^{182}Os . The sample was purified of possible osmium traces by distillation and passed through the Dowex 1x8 column 8 x 0.2 cm. Rhenium was absorbed on the resin from 1 N HCl and eluted with 4N HNO_3 . To prepare the thin sources for electron-gamma measurements the microcolumn technique was applied /10/.

2.2. Experiment

The gamma-ray spectrum was measured with 5 cm^3 and 13 cm^3 Ge(Li) coaxial detectors. The resolution of the counter-preamplifier assembly was 3.5 -6 keV in the energy region of 50-2500 keV. For internal energy calibration use was made of the gamma-transition energies measured in the decay $^{182}Ta \rightarrow {}^{182}W$ with an accuracy better than 0.02% /11,12/. In the high energy region E_γ>1500keV, the 2614.1 keV gamma-line from Th(B + C + C″) was used as calibration standard. The dependence of detector efficiency on the energy of gamma-rays was checked experimentally using the ^{24}Na, ^{46}Sc, ^{169}Yb and ^{226}Ra activities. In the measurements the standard electronic equipment was used having a 4096 channel amplitude analyzer. Some parts of the measurements were carried out by using the spectrometric apparatus built on the basis of the computer Minsk - 2. The data were handled with an oscilloscope having a light pen by the method described by Zabiyakin et al /13/.

The electron-gamma coincidence spectra were measured by means of an orange type magnetic six-gap spectrometer (resolution 1.5%, transmission - 9%) and of a gamma-ray spectrometer with either 7.6 cm diam. x 7.6cm NaJ(Tl) crystal or with a Ge(Li) crystal having a sensitive volume of about 2 cm^3.

The gamma-gamma coincidence spectra were measured using the NaI(Tl) - Ge(Li) coincidence spectrometer /14/. A 400-channel analyzer served to record the coincidence spectra.

3. Results

In the present work the spectrum of gamma-rays accompanying the ^{182m}Re decay was investigated by means of Ge(Li) detectors for the first time x/. Some parts of the spectrum are presented in figs. 1 and 2. The energies and relative intensities of gamma-rays are presented in Table 1. The intensities of gamma-rays are given with errors not exceeding 30% for the weak lines and 5-10% for the most intense transitions. For the transitions known from the $^{182}Ta \rightarrow ^{182}W$ decay the energy values established with great accuracy in refs. /11,12/ were accepted. In the gamma-ray spectrum the major part of the transitions was found which have

x/ In the course of preparation of the present work the investigations of gamma-ray spectra from the ^{182m}Re decay have become known /15/.

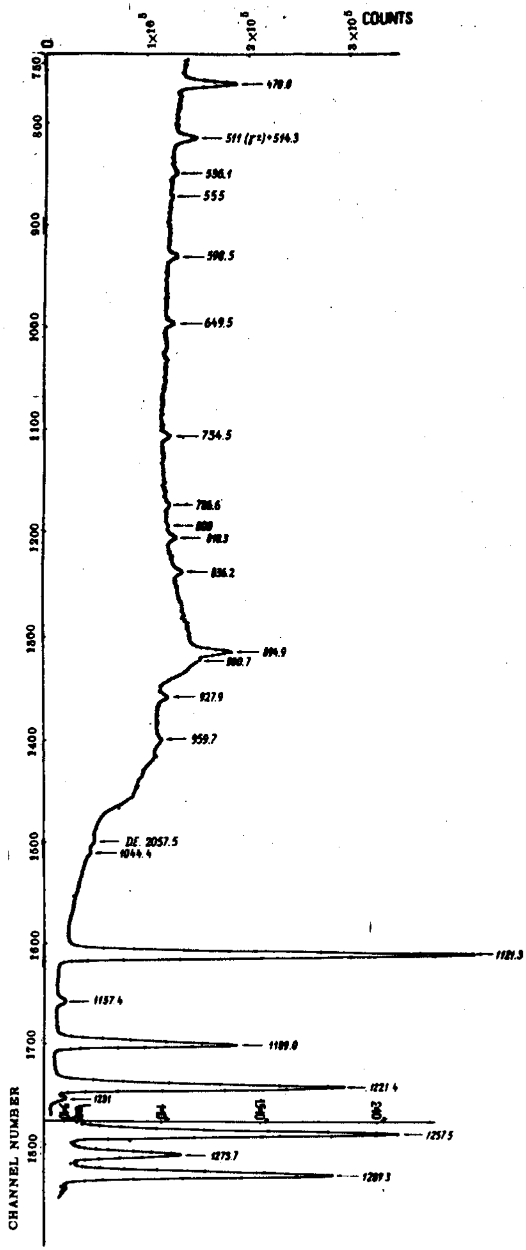

Fig.1. The gamma-ray spectrum in the 450-1300 keV region.

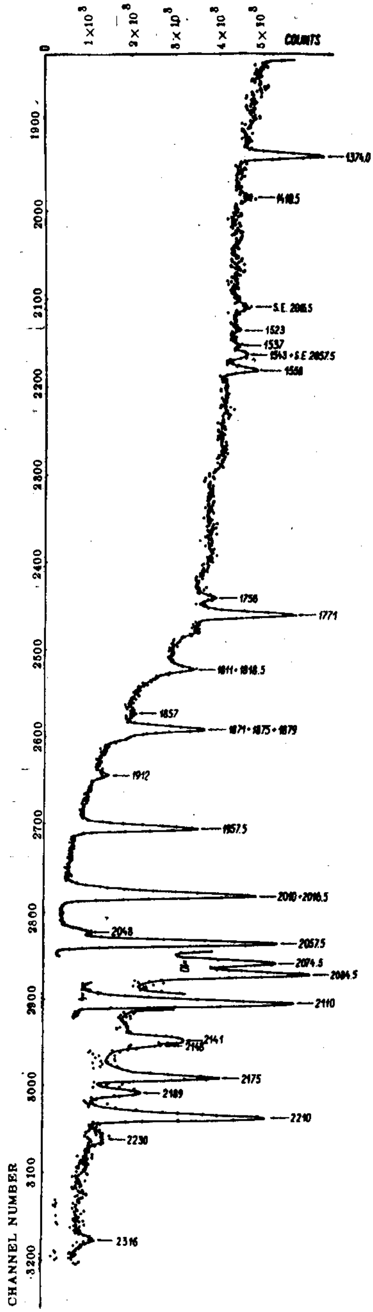

Fig.2. The gamma-ray spectrum in the 1300-2400 keV region.

Table 1

Energies and Relative Intensities of Gamma-Rays

Transition energy (keV)	J_γ	Transition energy	J_γ
I	2	I	2
84,68 a)	7,8±I.0	I374.0 c)	0,59±0,07
I00,I0 a)	45.2±4.5	I4I0.4 c,d,e)	0,I2±0,02
II3,68 a)	} 2,0±0.4	I437,8 b)	< 0,05
II6,42 a)		I523±2 d,e)	~ 0,05
I52.43 a)	I8,6±2,0	I537±2 d)	~ 0,05
I56,39 a)	I,0±0.3	I543±2 d)	~ 0,05
I79,39 a)	0,97±0,I9	I558±2 d,e)	0,24±0,03
I98,36 a)	0,58±0.I2	I756±2 d)	0,20±0.04
222,I0 a)	2,I±0,3	I77I±2	I,06±0,II
229,32 a)	5,2±0,7	I8II±3 d,e)	< 0,07
264,07 a)	0,98±0.I5	I8I8,5±2,0 d)	0,34±0,04
470,0 b)	6,2±0,6	I857±2 d)	0,I0±0,02
5I4,3 b) e)	< 0,4	I87I±2	0,9I±0,I0
536,I b)	0,67±0,I2	I875±3 d,e)	0,I9±0,06
555±I	0,35±0,I0	I879±3 d)	0,I7±0,05
598,5 b)	I,23±0.I5	I9I2±2 d)	0,I5±0,03
649,5 b)	I,09±0,I8	I957,5±2,0	I,4I±0,I4
734,5 b)	I,I9±0,I5	20I0±3 d)	0,37±0,I0
786,6 b)	0,76±0,I3	20I6,5±2,0	2,62±0,30
800±I d)	0,47±0,I2	203I±3 d,e)	~ 0,07
8I0,3 b)	I,I7±0,I5	2048±2	0,42±0,06
836,2 b)	I,45±0,I8	2057,5±2,5	3,0I±0,20
894,9 b)	6,6±0,6	2074±2 d)	0,I4±0,02
900,7 b)	I,I7±0,24	2084,5±2,0 d)	0,20±0.03
927,9 c)	I,4I±0,20	2099±3 d,e)	~ 0,08
959,7 c)	0,99±0,I7	2II0±2	0,82±0,08
I00I,6 c)	~ 0,7	2I3I±3 d,e)	< 0,02
I044,4 c)	0,56±0,07	2I4I±3 d)	0,II±0,03
II2I,3 c)	I00	2I48±3 d)	0,04±0,0I
II57,4 c)	2,3I±0,I8	2I59±3 d,e)	< 0,02
II89,0 c)	47,9±2,4	2I75±2 d)	0,I6±0,03
I22I,4 c)	79,2±4,0	2I89±3 d,e)	0,055±0,0I5
I23I,0 c)	4,04±0,24	22I0±2 d)	0,30±0,04
I257,5 c)	4,4I±0,22	22I6±3 d)	~ 0,07
I273,7 c)	I,74±0,2I	2230±3 d,e)	0,034±0,0I0
I289,3 c)	4,02±0,20	23I6±3 d)	0,025±0,005

a) Transition energies adopted according to Gruber et al./11/

b) Transition energies adopted according to Harmatz et al./5/

c) Transition energies adopted according to Korkman and Bäcklin/11/.

d) Transitions observed for the first time in the decay of ^{182m}Re.

e) Transitions not placed in the decay scheme.

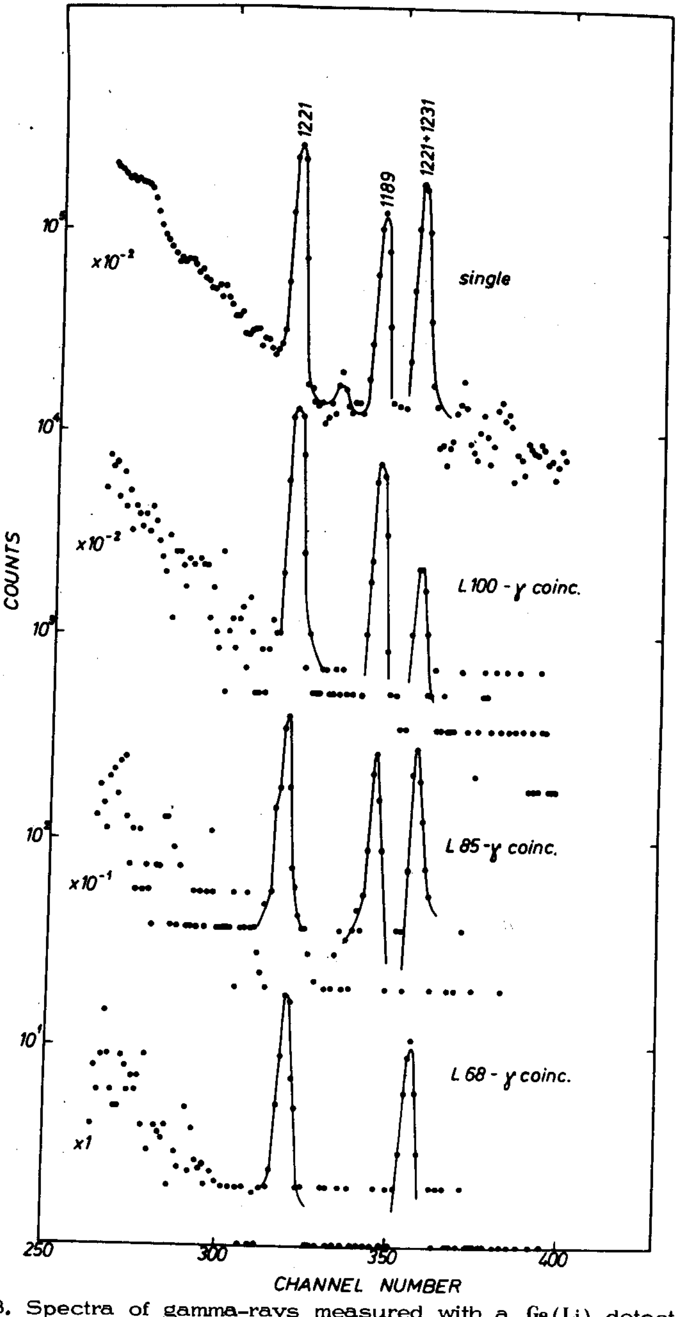

Fig.3. Spectra of gamma-rays measured with a Ge(Li) detector in coincidence with conversion lines as indicated.

been seen in the conversion electron spectra /5,6/ from ^{182m}Re and apart from it 28 new gamma-transitions. Almost all new gamma-lines belong to the energy region $E_{\gamma} > 1500$ keV. The energies of the new transitions, as well as of the high energy transitions seen earlier in the ^{182m}Re decay/5,6/ were estimated with an error 0.10 - 0.15%. The new lines with energies of 1523, 1537, 1543, 1811, 2031, 2099, 2131, 2159 and 2216 keV are weakly pronounced in the spectra and therefore only the upper limits of their intensities are given.

The possibilities of the electron-gamma measurements in the decay of the short-lived ^{182}Re isomer are rather limited due to the small amount of strongly converted transitions - therefore the gamma-rays were measured in coincidence with L68, L85, L100, M100 conversion electrons only. In the electron-gamma coincidence experiments with a Ge(Li) -detector only the strongest gamma-lines with energies 1121, 1189 and 1221+1231 keV were seen (fig.3). In the investigations of coincidences of high energy gamma-rays the scintillation spectrometer with a Na(Tl) crystal was applied. In the scintillation gamma-spectrum gated with M100 keV conversion electrons besides gamma-rays mentioned above those with energies 1770, 1958 and 2016 keV (fig.4) were recorded.

The spectra of gamma-gamma coincidences were measured in the following way: the window of the single channel analyzer in the branch of NaI(Tl) spectrometer was set so as to cover the complex gamma-line with an energy of about 1200 keV (1121+1189+ +1221+1231+1258+1289 keV). In the branch of the spectrometer with a Ge(Li) detector the gamma-spectrum was measured gated with the chosen 1200±100 keV gamma-rays (fig.5). In the coincidence spectrum the 470, 536, 598, 650, 734, 787, 810, 836, 895 keV gamma-lines were observed.

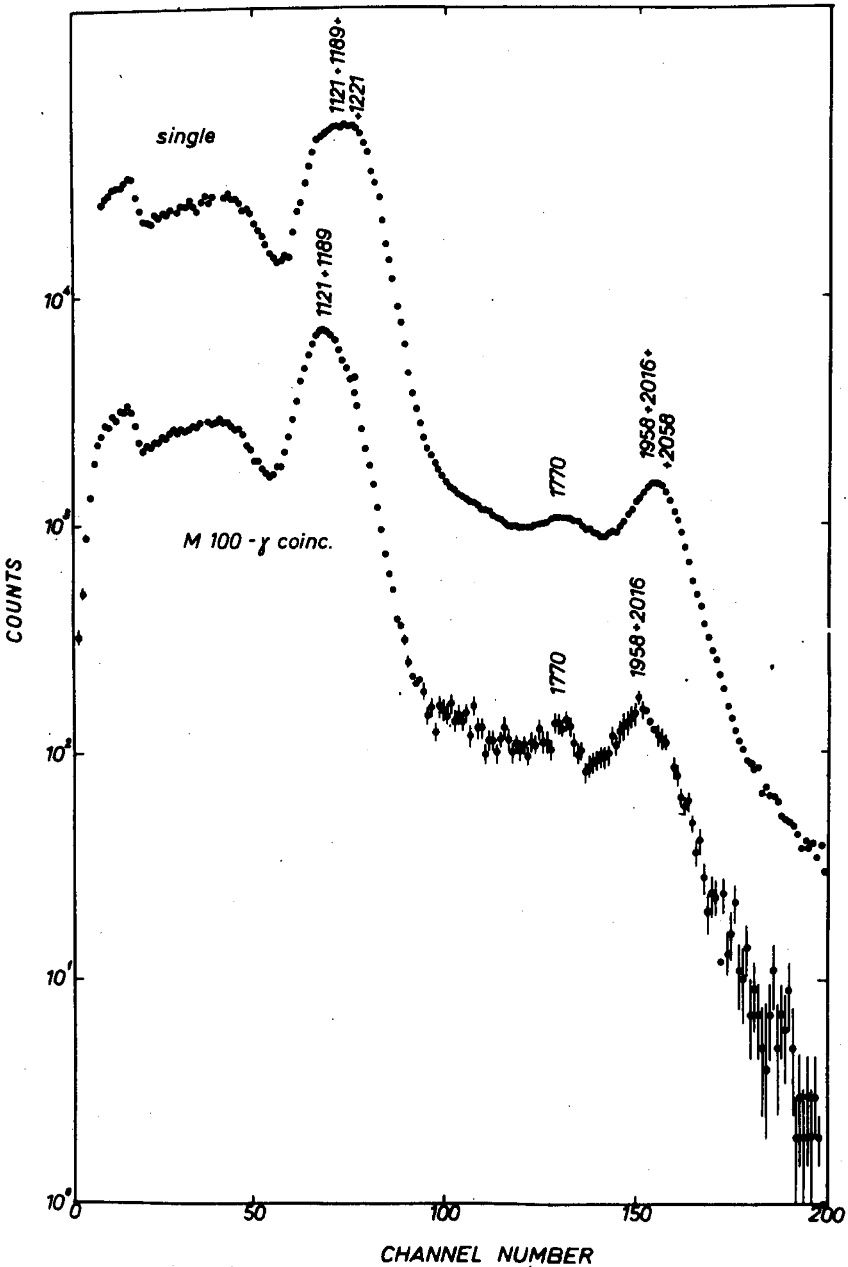

Fig.4. Spectrum of high energy gamma-rays measured with a NaI(Tl) detector in coinçidence with M 100 keV conversion electrons.

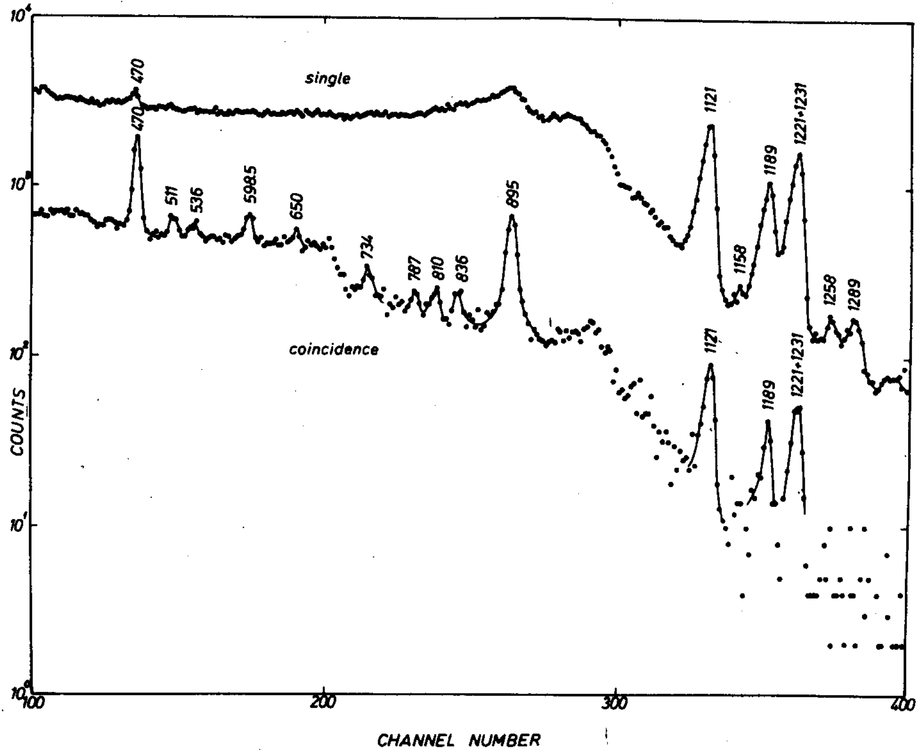

Fig.5. Spectrum of gamma-rays observed with a Ge(Li) detector in coincidence measurement gating with 1200±100 keV gamma-rays. The window of a NaI(Tl) spectrometer covered the 1121, 1189, 1221, 1231, 1258, 1289 keV gamma-transitions.

4. The K-Conversion Coefficients and Multipole Orders

The conclusions on the transition multipolarity were made by comparing the experimental and theoretical K-conversion coefficients (table 2). To establish experimental conversion coefficients the relative intensities of gamma-rays (table 1), (see also ref.[8])and data on the intensities of the ^{182m}Re conversion electrons[5,6] were used. Because the results of the works by Harmatz et al.[5] and by Badalov et al.[6] differ significantly for the majority of transitions, it seems reasonable not to use their mean values but to calculate the K-conversion coefficients separately for each group of data. The conversion coefficients calculated basing on the data from ref.[5] were normalized by assuming the theoretical E2 coefficient for the 1221.4 keV transition. In the work of Badalov et al.[6] the conversion electrons K 1221 and K 1231 have not been separated, and therefore, the normalization in this case was made with the use of the K 1121.28 keV transition for which the M1 admixture does not exceed 2%[1].

In the determination of the multipole order of the transitions which have been also investigated in the $^{182}Ta \rightarrow {}^{182}W$ decay the account was taken of the conclusions from refs.[1,16] made on the basis of more accurate measurements of conversion coefficients, the ratios of $L_1 : L_2 : L_3$ and the results of gamma-gamma angular correlations. In the energy region $E_\gamma < 200$ keV the obtained coefficients are lower than those from ^{182}Ta decay. This is probably due to the fact that the intensities of low energy conversion electrons from the decay of ^{182m}Re measured with the magnetic spectrograph[5] are underestimated[1]. Nevertheless, our multipolarities are in agreement with the results on the decay of ^{182}Ta [1,12,16] with the exception of the E1 multipolarity of the 198.4 keV transi-

Table 2

Internal Conversion Coefficients

Transition energy (keV)	Internal Conversion Coefficients x 10^3							Deduced Multipolarity
	Experiment		Theory					
	α_k a)	α_k b)	EI	E2	E3	MI	M2	
I	2	3	4	5	6	7	7	9
84,68	α_{L_I} =340±I20	-	49	I29	I850	960	I4900	MI+E2
	$\alpha_{L_{II}}$ =I40±50	-	I7	2520	9I000	90	I670	
	$\alpha_{L_{III}}$ =I00±30	-	I9	2380	7I000	II	3960	
I00,I0	$\alpha_{L_{II}}$ ~ 730	-	I0	I200	35500	55	890	E2
	$\alpha_{L_{III}}$ ~ 660	-	II	I030	25600	5,5	I740	
I52,43	60±20	-	I06	359	99	II90	6600	EI
I56,39	~ 50	-	I00	336	93	II20	6050	EI
I79,39	270±II0	-	70	230	670	772	3770	MI+E2
I98,36	70±30	-	54	I77	5I0	578	2680	(EI), E2 c)
222.I0	20±8	-	40	I27	370	422	I830	EI
229,32	I20±40	-	37	II7	340	385	I640	E2
264.07	70±30	-	26	8I	226	26I	I040	E2
470,0	85±25	34±7	6,9	I8,9	48	56	I73	MI+E2
536.I	< 56	<39	5.2	I4	34	40	II4	(EI,E2,MI)
555	-	<42	4,9	I3	3I	37	I03	(EI,E2,MI)
598,5	48±20	-	4,2	I0,9	26	30,5	83	(MI+E2, EI+M2)
649.5	26±I0	-	3,6	9,I	2I.5	25	65	(MI+E2, EI+M2)
734.5	24±I0	I2±4	2,7	7,0	I6	I7,5	46,5	(MI+E2, EI+M2)
786.6	26±I2	9±3	2,4	6.0	I3.7	I4,8	38,5	(MI+E2, EI+M2)
8I0,3	~ I6	20±5	2,2	5,6	I2,8	I3,6	35,5	(MI+E2, EI+M2)
836,2	I5±7	6±2	2.I	5,3	II,9	I2.7	32,5	(MI+E2, EI+M2)
894,9	I5±6	I2±3	I,I	4,6	I0,2	I0.7	27	(MI+E2, EI+M2)

I	2	3	4	5	6	7	8	9
900.7	2I±I0	-	I.83	4,60	I0.0	I0,5	26,5	(MI,M2)
927.9	6±3	II±4	I,76	4,20	9,I0	9,80	24	E2 c)
959.7	~ I2	~ I5	I,6I	4,00	8,42	9,02	22	E3+M2 c)
I00I,6	~ 4	-	I,53	3,68	7,60	8,20	I9,7	E2+MI c)
I044.4	4.4±2.0	-	I.42	3,40	6,92	7.30	I7.8	EI+M2+E3 c)
II2I.3	2,9±0.8	2.9I	I.23	2,9I	6,00	6,I5	I4.4	E2 + <2% MI c)
II57.4	6.5±I.9	-	I.I7	2,75	5,60	5,70	I3.2	E0+(MI)+E2 c)
II89.0	3.8±I,0	~ 2.4	I,I0	2,6I	5,30	5.30	I2.3	EI+M2+E3 c)
I22I.4	2.50	-	-	2.50	-	-	-	E2 - accepted
I23I.0	2.5±I.0	-	I.04	2,45	5.00	4.95	II.3	E2+MI c)
I257.5	~ 2,5	-	I.00	2.34	4,77	4,65	I0.6	E2 c)
I273.7	~ 4.2	-	0.98	2,29	4.65	4,5I	I0,2	EI+M2 c)
I289.3	~ II	-	0,96	2,25	4.55	4,38	I0,0	M2
I374.0	~ 8	-	0,87	2,0I	4,05	3.80	8,6	(M2), E3 c)
I437,8	>36	-	0.79	I,84	3,78	3.33	7.5	E0+MI+E2
I77I	-	0,45±0,I3	0,56	I,27	2,40	2,02	4,6	EI
I87I	-	I.0±0,3	0.52	I,I6	2,I5	I.78	4.0	(E2,EI+M2)
I957.5	4±2	2,3±0,7	0,48	I,07	2,00	I,59	3,6	(MI,M2,EI+M2)
20I6.5	2.6±I.3	I,6±0,4	0.46	I,0	I,88	I.48	3.35	(MI,EI+M2)
2048	-	I,6±0,5	0,45	0.97	I,82	I,42	3,23	(MI+E2, EI+M2)
2057.5	2.3±I,I	I,4±0,3	0.44	0,96	I,80	I,40	3.20	(MI,EI+M2)
2II0	-	3.2±0.8	0.42	0,92	I,7I	1.34	3,0	(M2)

a) α_k determined using the conversion electron intensities from Harmatz et al.[5]

b) α_k determined using the conversion electron intensities from Badalov et al.[6]

c) Multipolarity derived from the investigations of the $^{182}Ta \rightarrow ^{182}W$ decay[1].

tion. This result is in contradiction with the undoubtedly established multipolarity E2 /1,16/ of this transition. Similar situation occurs also for the 1374.0 keV transition , but the difference in the values of K -conversion coefficients may be explained by the great error with which the intensity of the K -conversion electrons /5/ is measured.

The experimental conversion coefficient of the 1157.43 keV transition supports the conclusion made in refs. /1,12/ that the multipolarity is of the EO+(M1)+E2 type. Assuming that $\delta^2 = \frac{I(M1)}{I(E2)} = 0$ one gets 60% EO, 40% E2 for the conversion electrons and 100% E2 for gamma-rays.

Of special interest is the transition with energy of 1437.8 keV which has been observed in the spectra of conversion electrons from the decay of ^{182}Ta /1,12/ and of both the isomers of ^{182}Re /5/. In the gamma-ray spectrum of ^{182}Ta this transition has not been found and the resulting lower limit for the K -conversion coefficient is $\alpha_k \geq 4.8 \times 10^{-3}$. This leads to the conclusion that its multipole order may be of E3, M2 type or higher. In the investigated gamma-ray spectrum of ^{182m}Re this transition was also not seen and the upper limit for its intensity $I_\gamma(1437.8) \leq 0.05\%$ I_γ (1121.28) gives the lower limit for the conversion coefficient $\alpha_k \geq 36 \times 10^{-3}$. This value is higher than that of the theoretical K -conversion coefficient of M4-radiation. This may be due to the fact that this transition has great admixture of EO multipolarity. If the transition is EO+E2 then for the conversion electrons one gets about 95% EO.

5. Decay Scheme

On the basis of our results and of the works by Harmatz et al.[5] and Badalov et al.[6] as well as on the basis of the investigations of ^{182}Ta [1,12,16,18] decay the $^{182m}Re \rightarrow {}^{182}W$ decay scheme (fig.6) is suggested. The scheme contains the majority of the transitions observed in the decay of ^{182m}Re. The total intensity of transitions not placed in the decay scheme does not exceed 0.5% per decay.

The lower part of the ^{182}W level scheme ($E < 1600$ keV) has been carefully studied in the works on the ^{182}Ta decay in which ten excited states have been found and their energies and quantum characteristics have been reliably established. All those states with the exception of the 1442.9 keV ($I^{\pi} = 4^{+}$) state are seen in the ^{182m}Re decay. The mass difference between ^{182m}Re and ^{182}W is 2860±20 keV[7] and therefore in the decay of the 13-hour isomer of ^{182}Re the levels higher than those in the ^{182}Ta decay can be observed.

In the work of Harmatz et al.[5] four new levels have been introduced with the energies higher than 2 MeV: 2023.5, 2054.5, 2184.6 and 2274.5 keV.

In the course of the present work it was necessary to introduce additional levels in order to place the new transitions.

Almost all of the new transitions have energy higher than 1500 keV so they have to de-excite the high energy levels of ^{182}W to the lower states of the ground state rotational band. In such a way levels of energies 1538, 1856, 1871, 2110, 2116.5, 2148, (2175), 2210, 2241 and (2316) keV were introduced.

In our previous work[9] we introduced also the 1410.5 keV level known from the ^{182}Ta [1] decay. Two transitions 1410.5 and

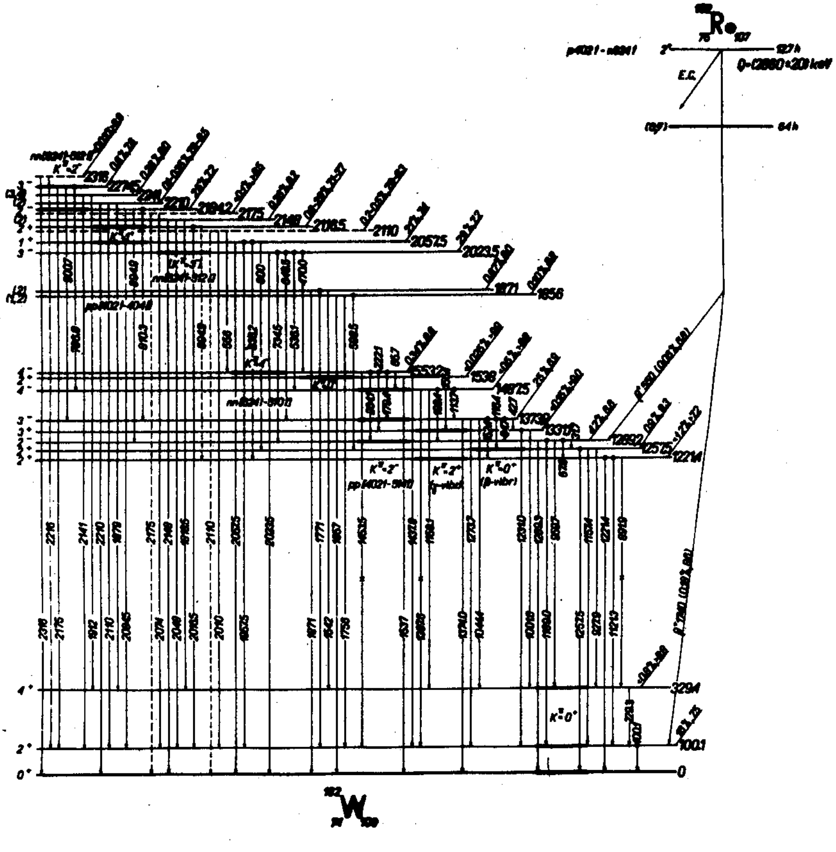

Fig.6. Decay scheme $^{182m}Re \rightarrow ^{182}W$. Transitions which have been established or suggested by coincidence measurements are marked with black or open circles, respectively. Transitions indicated with dashed lines are placed with greater certainty in other positions. Transitions observed only in the decay of ^{182}Ta are marked with crosses. The 2023.5 keV transition has been observed only in the conversion electron spectrum in the decay of ^{182m}Re /5/. The existence of 2216 keV transition indicated with dashed and dotted line is uncertain.

1310 keV supported this suggestion but the latter of them has been observed only in the investigations of the pair conversion positron spectrum in ^{182}Ta decay/17/. Recently in the gamma-ray spectrum of ^{182}Ta a new transition with the energy of 1181 keV/15/ has been found. This allows the suggestion on the existence of a level with the energy of 1510.5 keV. This level could be de-excited by 1410.5 and 1181 keV transitions to the 100.1 and 329.4 keV levels of the ground state rotational band. In the decay of ^{182m}Re only 1410.5 keV transition was observed. The 1310 and 1181 keV transitions did not appear in the gamma-ray spectrum with the intensities higher than 0.05% I_γ (1121.3) and 0.3% I_γ(1121.3) respectively. It seems therefore that the existence of the 1410.5 keV level is rather doubtful and the existence of the 1510.5 keV level seems more probable.

The 1538 keV level is introduced on the basis of two transitions 1437.8 and 1537 keV leading to 0^+ and 2^+ levels of the ground state band. The 1437.8 keV transition as it was mentioned above has a high admixture of E O radiation. If this transition is pure EO then the 1437.8 keV $I^\pi = 0^+$ level should exist. Against this supposition there are two arguments:

i. The 1437.8 keV transition is observed in the decay of ^{182}Ta so the proposed 0^+ level should be populated in the third forbidden ($\log ft \approx 18$) beta-transition from the ^{182}Ta ground state ($I^\pi = 3^-$).

ii. A strong E2 transition with the energy of 1337.7 keV to the 2^+ state of the ground state band should de-excite the postulated 0^+ level. The intensity of such transition would be about 2 orders of magnitude higher than the intensity of the $0^+ \rightarrow 0^+$ transition. In the gamma-ray spectra of ^{182m}Re and ^{182}Ta such transition was not seen.

Therefore, it is assumed that the 1437.8 keV transition is of EO + (M1)+E2 type and feeds the 100.1 keV (2^+) level. It means that in ^{182}W there exists a level with the energy of 1537.8 keV ($I^{\pi} = 2^+$) and it is supported by the presence of the 1537 ± 2 keV line in our gamma-ray spectrum.

The 1871, 2148 and 2210 keV levels are introduced basing on the transitions leading from each of them to the three lowest levels of the ground state rotational band. Additionally the 1871 keV level is supported by the M100- γ 1770 keV (fig.4) coincidences. The multipolarities of the transitions in question are not known but the character of the de-excitation of the suggested levels speaks in favour of the I = 2 spin assignment.

The 1856 keV level is de-excited by two transitions to the ground and first excited states, and also by the 598.5 keV M1 or M1+ E2 transition to the 1257.5 keV ($I^{\pi} = 2^+$) level. Such placing of the 598.5 keV transition does not contradict the results of gamma-gamma coincidences. The character of de-excitation of the 1856 keV level suggests its positive parity and spin value equal to 1 or 2.

The 2116.5 keV level is supported only by one 2016.5 keV M1 or M1+E2 transition to the first 2^+ state. Another possibility of placing this transition as the leading one to the 0^+ or 4^+ states would imply the existence of intense ($I_{\gamma} > 1.1\%$ I_{γ} (1121.3)) transitions with energies of 1916.5 or 2246 keV to the 100.1 keV ($I^{\pi} = 2^+$) state. Such transitions are not observed, therefore, the introduction of the 2116.5 keV level seems justified. The most probable spin and parity of this state is $I^{\pi} = 2^+$. The 2116.5 keV level can be de-excited also by 894.9 keV transition, which however, is placed with greater certainty in other position of the decay scheme.

The 2241 keV level is de-excited by two transitions to the 2^+ and 4^+ states of the ground state rotational band. The lack of direct transition to the ground state indicates that the spin of the discussed level is $I = 3$ or 4.

The levels with the energies of 2110, 2175 and 2316 are introduced tentatively. In the decay scheme (fig.6) they are drawn with dotted lines. The 2216 keV transition (2316 keV → 100.1 keV) was found not in all series of measurements, therefore only the upper limit of its intensity is given. One can also put the 2110 and 2175 keV transitions in other places of the ^{182m}Re decay scheme.

Harmatz et al./5/ have given evidence for the existence of the 2054.5 keV level based on the 2054.3 and 1954.7 keV transitions leading to the ground and first excited states. More accurate measurements of these transitions (table 1) allowed one to give the value of the level energy equal to 2057.5 keV and to place the 800 and 836.2 keV transitions between it and the 1257.5 and 1221.4 keV levels. The multipole orders of the transitions going from the 2057.5 keV level unambiguously define its spin and parity as $I^\pi = 1^+$.

Table 3 presents the ratios of the relative intensities of concurrent gamma-rays from the levels of ^{182}W populated in the decay of ^{182}Ta as well as of ^{182m}Re. In general, a good agreement within the accuracy of measurements is obtained. Exceptions are the ratios of I_γ (1157.4)/I_γ (1257.5) where the discrepancy is two times greater than the experimental error. Probably, this is due to the complexity of the 1157.4 keV gamma-line. From the decay scheme (fig.6) it can be seen that between the 1487.5 keV ($I^\pi = 4^-$) and 329 keV ($I^\pi = 4^+$) states there should be E1 or E1+M2 transition with the energy of 1158.1 keV. Such transition was not found experimentally because it is difficult to separate it from the 1157.4 keV transition. Taking into account the fact that the 1487.5 keV($I^\pi K = 4^- 2$)

Table 3

Ratios of Gamma-Ray Intensities De-Exciting Some Levels of ^{182}W Populated in the Decay both of ^{182}Ta and ^{182m}Re

Energy of de-excited level (keV)	Ratio of transition intensities	Experimental Value from the decay of	
		182 Ta	182m Re
I22I,4	J_γ(I22I,4) / J_γ(II2I,3)	0,83±0,04	0,79±0.05
I257,5	J_γ(II57,4) / J_γ(I257,5)	0,68±0,05	0,52±0,05
	J_γ(927,9) / J_γ(I257,5)	0,45±0,08	0,32±0,05
I289,2	J_γ(I289,3) / J_γ(II89,0)	0,08I±0.005	0.084±0.006
	J_γ(959,7) / J_γ(II89,0)	0,02I±0,005	0,02I±0,004
I33I,0	J_γ(I00I,6) / J_γ(I23I,0)	0,I85±0,0I5	~0,I7
I373,9	J_γ(I52,4) / J_γ(84,7)	2,5I±0,I3	2,38±0,40
	J_γ(84,7) / J_γ(I273,7)	4,3±0,6	4,5±0,8
	J_γ(I374,0) / J_γ(I273,7)	0,42±0,I0	0,34±0,06
	J_γ(I044,4) / J_γ(I273,7)	~0,4	0,32±0,06
I487,5	J_γ(I56,4) / J_γ(I98,4)	I,69±0,I4	I,72±0,63
	J_γ(I387,6) / J_γ(I98,4)	0,059±0,008	$<$ 0,09
I553,2	J_γ(I79,4) / J_γ(264,I)	0,9I±0,07	0,99±0,25
	J_γ(222,I) / J_γ(264,I)	2,I5±0,I6	2,I4±0,45
	J_γ(I453,5) / J_γ(264,I)	0,0I8±0,006	$<$ 0,05

level is about eight times weaker populated in the decay of ^{182m}Re ($I^{\pi}K = 2^{+}2$) than in the decay of ^{182}Ta ($I^{\pi}K = 3^{-}3$) we calculated the intensities of the 1157.4 and 1158.1 keV transitions in the decay of ^{182}Ta :

$$I_{\gamma}(1157.4) = (1.95 \pm 0.20)\% \; I_{\gamma}(1121.3)$$

$$I_{\gamma}(1158.1) = (0.72 \pm 0.25)\% \; I_{\gamma}(1121.3)$$

in agreement with the calculations of Voinova and Dzhelepov /1/ who have supposed the ratio $I_{\gamma}(1158.1)/I_{\gamma}(1157.4)$ to be about 0.3. Using the intensity ratio $I_{\gamma}(198.4)/I_{\gamma}(1158.1)$ from the ^{182}Ta decay we calculated the probable intensity of the 1158.1 keV transition in the decay of ^{182m}Re :

$$I_{\gamma}(1158.1) = (0.11 \pm 0.04)\% \; I_{\gamma}(1121.3).$$

On the basis of the proposed decay scheme the balance of the transition intensities was made and feeding of the levels in % per one ^{182m}Re decay was estimated. The sum of intensities of all transitions leading to the ground state of ^{182}W was assumed as 100% of decay events. With the total ^{182m}Re decay energy equal to $Q_{EC} = (2860 \pm 20)$ keV the experimental $\log ft$ values were found for the EC decay to the ^{182}W levels (fig.6).

6. Discussion

The nucleus ^{182}W is at the end of the region of the strongly deformed nuclei with $A = 150 - 185$. The measurements of the quadrupole momentum of the ^{182}W ground state gave the value of the deformation parameter $\beta = 0.240 \pm 0.004$ /1/. It is well known that the properties of the excited states of deformed nuclei in principle can be described with the aid of contemporary model concepts of the nuclear structure. In the present paper the $^{182m}Re \to {}^{182}W$

decay scheme is interpreted in terms of the unified[19] and superfluid[20] nuclear models.

6.1. Short Lived Isomer of ^{182}Re

The ^{182}Re nucleus has two isomeric states which decay to the levels of ^{182}W and have half-lives of 64.0 ± 0.5 h [2] and 12.7 ± 0.2 h [2]. No transition is known between them and their mutual position is not established. The comparison of the total decay energy of the short lived isomer (2860 ± 20 keV[7]) with the mass difference between ^{182}Re and ^{182}W (about 2500 keV) calculated by Myers and Swiatecki [21] indicates that probably the 64 h activity corresponds to the decay of the ground state of ^{182}Re and the 13 h activity is due to a higher lying isomeric state. This is supported by the fact that in the decay of 64 h state of ^{182}Re states with the energy > 2100 keV are not populated with measureable intensity.

The spins and parities of the ground and isomeric states of ^{182}Re have not been established experimentally. The log ft value for the decay of ^{182m}Re to the excited states of ^{182}W give evidence for the strong population of 1^+, 2^+, 2^- and 3^- states and for remarkably weaker population of 4^- and 4^+ states. Till now no decay to the 0^+- state was found. Therefore, the most probable spin value of the ^{182m}Re is $I = 2$. Voinova and Dżhelepov[1] have ascribed negative parity to the 13 h isomeric state of ^{182}Re by basing on the fact that in ^{182m}Re decay the 2^- and 3^- states are populated stronger than the 2^+ states. Nevertheless, the known 2^+ states in ^{182}W are rather collective and on the other hand, the 2^- and 3^- states are, first of all, of two-quasiparticle character therefore the slowed down feeding of the 2^+ states cannot be interpreted as a decisive argument in favour of the negative parity of ^{182}Re isomer.

Recently Akhmadzhanov et al.[22] found that the best explanation of their results on the $^{182}Os \to ^{182}Re$ decay is obtained if the spin and parity of ^{182m}Re is assumed to be $I^{\pi} = 2^+$.

Following the Nilsson model one can find two configurations giving the spin value $I = 2$.

$$p\,402\uparrow \pm n\,624\uparrow \left[\begin{matrix} 2^+ \\ 7^+ \end{matrix} \right.$$

$$p\,402\uparrow \pm n\,510\uparrow \left[\begin{matrix} 2^- \\ 3^- \end{matrix} \right.$$

The ground state (64 h) of ^{182}Re has spin $I = 6$ or 7[3,5]. With the first of the quoted configurations the ^{182}Re isomers can be interpreted [23] as the levels of the doublet with spins 2^+ and 7^+ according to the rule of Gallagher and Moszkowski.

Table 4 presents the classification of beta-transitions [23] from ^{182m}Re, (to which both configurations in question are ascribed) to the two-quasi-particle states in ^{182}W together with the corresponding experimental log ft values. It follows from the analysis of the table that the experimental data fit better the interpretation of the ^{182m}Re as $p\,402\uparrow - n\,624\uparrow$, $K^{\pi} = 2^+$ state.

6.2. Collective States

In the decay of ^{182m}Re only 2^+ and 4^+ states of the ground state rotational band are populated. The 680.4 keV $I^{\pi} = 6^+$ level has been observed [3,5] only in the decay of the 64 h state of ^{182}Re. The beta-decay of ^{182}Re isomeric state to the ground state rotational band is K-forbidden and this explains the log ft = =7.5 value for the beta-transition to the 100.1 keV $I^{\pi}K = 2^+0$ state. Our experimental data give about 10 times more intense EC transition to this state as compared with the measurements of Badalov et al.[7] who have found log ft = 8.6.

Table 4

Classification of Beta Transitions from ^{182m}Re Leading to Different Two-Quasi-Particle States in ^{182}W

State in ^{182}W	$I^{\pi}K$	Level Energy (keV)	^{182m}Re $I^{\pi}K = 2^{+}2$ $p402\uparrow - n624\uparrow$	^{182m}Re $I^{\pi}K = 2^{-}2$ $p402\uparrow - n510\uparrow$	Experimental log ft
pp [402↑ - 514↑]	$2^{-}2$	1289.3	Iu	aK / ΔK = 4 /	6.6
nn [624↑ - 510↑]	$4^{-}4$	1553.2	$I^{*}h$	2-nd forbidden	8.6
nn [624↑ - 512↓]	$3^{-}3$	2023.5	Iu	aF	7.2
pp [402↑ - 404↓]	$1^{+}1$	2057.5	ah	I K / ΔK = 3 /	7.4
nn [624↑ - 512↑]	$2^{-}2$	2184.2	Iu	aF	7.2

The levels with energies of 1221.4 and 1331.1 keV are interpreted as 2^+ and 3^+ states of the gamma-vibrational band [1,5,12]. Both levels are populated in the decay of ^{182m}Re. The 1442.9 keV ($I^{\pi}=4^+$) level which may be a third member of the band is not produced in the ^{182m}Re decay. The large log ft values for the feeding of 1221.4 and 1331.1 keV (>7.2 and $\geq$ 9.0, respectively) levels in the decay of the ^{182}Re isomer ($I^{\pi}=2^+$) may be understood if one considers contributions of different two-quasiparticle configurations to the $K^{\pi}=2^+$ collective state [24]. Recently Malov et al. [25] calculated the energies of collective states in even nuclei from the region of $A=174-188$. They have obtained for $K^{\pi}=2^+$ state in ^{182}W energy of about 1.2 MeV what is in agreement with the experimental value of 1221.4 keV.

The ratios of E2 reduced probabilities of transitions from the gamma-vibrational band to the ground state rotational band were calculated using the experimental intensities of gamma-rays. These ratios are presented in table 5 together with the values from the ^{182}Ta decay [1] and compared with the values obtained on the basis of different nuclear models [19, 26, 27]. The comparison shows that the best agreement between experiment and theory is obtained for $K=2$. However, the theoretical value of $\frac{B(E2,\,2\to 4)}{B(E2,\,2\to 0)}$ differs significantly from the experimental one. The calculated interaction between the $K=2$ and $K=0$ bands enlarges the discrepancy. The calculations in the frame-work of the RV - model of Faessler et al. [26] and Davydov and Chaban [27] also cannot explain the experimental value.

6.3. Excited States with $K^{\pi}=0^+$.

The $K^{\pi}=0^+$ states and connected with them E0 transitions are of special interest in the even deformed nuclei. In the last few

Table 5

Branching Ratios for E2 Transitions De-Exciting the $K^{\pi} = 2^{+}$ Rotational Band

Level Energy (keV)	$E_{\gamma 1}$;B/E2,$I_i \to I_f$ / $E_{\gamma 2}$;B/E2,$I_i \to I_{f'}$ /	Experiment		Theory					
		Data from the decay of 182 Ta /1/	Present work	Alaga rule				RV/26/ E_{γ} =1221 E_{β} =1138	Davydov/27/ γ =11.2° μ =0.186
				K = 0	K = 1	K = 2			
						Z_2=0	Z_2=0.048		
I22I.4	II2I.3; B/E2.2 → 2/ I22I.4; B/E2.2 → 0/	I.85±0.I3	I,94±0,I4	I.43	0.357	I.43	I.89	I.76	I,96
	89I.9; B/E2.2 → 4/ I22I.4; B/E2.2 → 0/	0.009±0.00I	— a/	2.56	I.I4	0.072	0.I6	0.088	0,I7
I33I.I	I00I.6; B/E2.3 → 4/ I23I.0; B/E2.3 → 2/	0,57±0,I5	0.52±0.25	-	2.50	0.40	0.73	0.50	0.70

a) Transition 2 → 4 has not been resolved years many excited states of this type were discovered and in some nuclei (^{164}Er, ^{170}Yb, ^{178}Hf) the existence of 3-5 levels with $I^{\pi} = 0^{+}$ was established in each of them.

In the ^{182}W excited states with $I^{\pi} = 0^{+}$ were not yet identified. In the decay of ^{182}Ta ($I^{\pi} = 3^{-}$) and the 64 h state of ^{182}Re (I = 6 or 7) excitation of such states is not very probable. Much more promising is the decay of 13 h isomer of ^{182}Re ($I^{\pi} = 2^{+}$).

In the work /1,12/ concerning the ^{182}Ta decay the 1257.5 keV ($I^{\pi}K = 2^{+}0$) state was established. The quantum characteristics assignment is based on the existence of the EO admixture in the 1157.4 keV transition leading to the 2^{+} state of the ground state rotational band. By assuming that the 1442.9 keV state known from the decay of ^{182}Ta can be interpreted as the 4^{+} state of the $K^{\pi} = 0^{+}$ band one gets that the ground state of this band should have the energy of about 1180 keV. The $I^{\pi}K = 0^{+}0$ state would de-excite to the 2^{+} member of the ground state band by E2 transition with the energy of about 1080 keV. Such transition was not found in the ^{182}Ta decay and in the present investigations only the upper limit for its intensity is given: I_{γ} (1080) < 0.2%. I_{γ}(1121.3) . Therefore the problem of the existence of the ≈ 1180 keV ($I^{\pi}K = 0^{+}0$) state in ^{182}W is still open.

A similar situation is observed in the case of the new level with an energy of 1538 keV. The remarkable admixture of the EO radiation in the 1437.8 keV transition unambiguously defines the quantum characteristics of the state to be $I^{\pi}K = 2^{+}0$. The $\frac{B(E2, 2 \to 2)}{B(E2, 2 \to 0)} < 1.4$ ratio of the reduced probabilities of the transitions de-exciting the 1538 keV state to the ground state band is in good agreement with the 1.43 value obtained from the Alaga rule. The 1209 keV transition to the 4^{+} member of the ground state band was not observed. Its intensity according to the intensity rule for $K = 0$ should be about 0.03% I_γ (1121.3), which is much below the possibility to observe it in the gamma-ray spectrum. Assuming the moment of inertia of this $K^\pi = 0^+$ band to be about $J_{K=0} = (1.0 - 1.3)\, J_{g.s.}$, one obtains the energy of the ground state of the band in the region of 1440 - 1470 keV. The existence of this $I^\pi K = 0^+0$ state would be manifested by the E2 transition with the energy of 1340-1370 keV to the 2^+ state of the ground state band. However, such transition was not seen in the gamma-ray spectrum with the intensity higher than 0.04% I_γ (1121.3).

One can conclude that the existence of two excited 2^+0 states in ^{182}W is reliably established but the corresponding 0^+0 states are not found till now.

In the deformed even nuclei different types of 0^+ excitations are to be expected /28/ i.e. pairing vibrations, beta-vibrations and spin-quadrupole excitations. One of the criteria which enables to distinguish between them is the probability of EO transitions bound with the $K^\pi = 0^+$ state. The probability of the monopole transition W_x (EO) can be written in the form: /29/

$$W_x(E0) = \Omega_x \, \rho^2(E0),$$

where Ω_x is the reduced probability of EO transition depending only on its energy and Z of the nucleus. It is considered for different shells $(x = K, L, \ldots)$, ρ (EO) is the reduced nuclear matrix element depending on the properties of the nucleus.

For comparison of the theoretical and experimental data on monopole transitions it is convenient to use the dimensionless parameter X introduced by Rasmussen /30/

$$X\left(\frac{E0,\ i\to f}{E2,\ i\to f, f'}\right) = \frac{e^2 R^4 \rho^2(E0)}{B(E2,\ i\to f, f')} .$$

The magnitude $e^2 R^4 \rho^2(E0) = B(E0, i\to f)$ is the so-called nuclear probability of EO transition. B(E2) is the reduced probability of E2 transition.

By assuming the EO+E2 multipolarity for the 1157.4 and 1437.8 keV transition the ratio $\frac{I_k(E0)}{I_\gamma(E2)}$ was found for each of them and the corresponding parameters X calculated (table 6). There are no theoretical calculations of X for the ^{182}W nucleus but despite it some conclusions can be drawn about the nature of the $K^\pi=0^+$ states.

The low value of X for the 1157.4 keV transition ($X=0.037$) indicates, in agreement with ref./28/ that the 1257.5 keV level belongs probably to the beta-vibrational band, however, considerable contribution of the spin-quadrupole interaction is not excluded. It turns out from the calculations/25/ on the basis of the nuclear superconductivity model that the energy of the $K^\pi=0^+$ in the ^{182}W (with $\beta=0.23$) should be about 1.3 MeV. This result is in good agreement with the energy $E_{0^+}\approx 1180$ keV of the suggested ground state of the $K^\pi=0^+$ band.

For the 1437.8 keV the calculated parameter is $X\geq 1$. The great values of this parameter ($X\gg 1$) are expected /28/ for the 0^+-excitations due to the pairing vibrations. The excited states of such type have energy higher than the energy gap. Therefore, it seems reasonable to interpret the $K^\pi=0^+$ band to which the 1538 keV (2^+) level belongs as the 0^+-excitation of the type of pairing vibrations.

Table 6

Parameter X for (E0+E2)-Transitions in ^{182}W

Transition Energy (keV)	$\frac{I_K(E0)}{I_\gamma(E2)}$	X
1157.4	$(4.7\pm0.5)\cdot10^{-3}$	0.037 ± 0.004
1437.8	$\geq 3.5\cdot10^{-2}$	≥ 1

6.4. Two-Quasi-Particle States

Gallagher and Soloviev [23] have shown that the excited states in even deformed nuclei due to the intrinsic motion of nucleons can be described by the superfluid model as two-quasiparticle excitations of neutrons and protons which are in different Nilsson states. For the ^{182}W nucleus in the energy region of 1.2 - 2.6 MeV many two-quasi-particle states have been predicted and the interpretation of some levels known already from experiment has been given [20,23].

The 1289.2 and 1553.2 keV states populated in the decay of ^{182}Ta have been interpreted [20,23] as excitations with predominant contribution of two-quasi-particle configuration pp [402↑ – 514↑] and nn [624↑ – 510↑] , respectively.

The 1289.2 keV level is intensively fed also in the decay of ^{182}Re and the resulting log ft ≈6.6 value (table 4) can be explained assuming the isomeric state of ^{182}Re as the p 402↑ – n 624↑ level. In such a case the n 624↑ → p 514↑ transition is of a first forbidden type. The experimental log ft value for such transitions in the neighbouring odd-A nuclei is 6.5 - 6.7 [31]. Another interpretation of the isomeric state of ^{182}Re as the p 402↑ –n 510↑ state (see, 6.1) implies the log ft value much higher than the experimental one. The n 510↑ → p 514↑ beta transition leads in this case to the K-forbiddenness ($\Delta K = \Delta\Lambda = 4$) due to the change of the direction of total angular momentum projection on the nuclear symmetry axis.

The level with 1553.2 keV is populated in the EC decay of ^{182m}Re less intensively than in the β^- -decay of ^{182}Ta . The experimental log ft ≈ 8.6 value allows the classification of the transition as the unique first forbidden one and supports the assignment of $I^{\pi} = 2^+$ to the isomeric state of ^{182m}Re .

The 2184.2 and 2274.5 keV states have been introduced into the $^{182m}Re \rightarrow {}^{182}W$ decay scheme by Harmatz et al./5/ who interpreted them as 2^- and 3^- members of the $K^\pi = 2^-$ band. This is supported by the multipolarities of the transitions (table 2) de-exciting both levels to the lower-lying $K^\pi = 2^-$ band. It can be seen from table 7, where the experimental and theoretical ratios of reduced probabilities of M1 transitions leading to the $K^\pi = 2^-$ band are compared, that the best agreement is obtained by assuming $K = 2$ for both levels. However, for the 2274.5 keV level $K = 0$ and $K = 1$ are also possible. If these states form rotational band, only one possibility of $K = 2$ is left. Gallagher and Soloviev /23/ have treated the 2184.2 keV level as the two-quasi-particle $nn[624\uparrow - 512\uparrow]$ state and the 2274.5 keV as a corresponding rotational state. If the $p\ 402\uparrow - n\,624\uparrow$ configuration for ^{182m}Re is assumed, the 2184.2 keV state would be fed by the EC $p\ 402\uparrow \rightarrow n\ 512\uparrow$ first forbidden unhindered transition. The log ft value of such a transition is in agreement with the experimental log ft $= 7.2$ value (table 4).

The K quantum number of the 2023.5 keV ($I^\pi = 3^-$) level is not yet established because the multipole mixture of the M1+E2 transitions to the $K^\pi = 2^-$ band is not known. The de-excitation to the $K^\pi = 2^-$ and $K^\pi = 4^-$ levels together with the absence of transitions to the $K^\pi = 0^+$ ground state band supports the earlier suggestion/5/ that the 2023.5 keV level has $K = 3$. This level has been interpreted/23/ as the $nn[624\uparrow - 512\downarrow]$ state and it is confirmed now by the experimental log ft $= 7.2$ value by assuming that the ^{182m}Re isomeric state has the configuration $p\,402\uparrow - n\,624\uparrow$.

The ratio of reduced transition probabilities of M1 transitions connecting the 2057.5 keV state with 0^+ and 2^+ levels of the ground state band gives the best agreement with theoretical ratios

Table 7

Branching Ratios for M1- Transitions De-Exciting the High Energy Levels in ^{182}W

Level energy (keV)	E_{γ_1}; $B(MI, I_i K_i \rightarrow I_{f_1} K_f)$ / E_{γ_2}; $B(MI, I_i K_i \rightarrow I_{f_2} K_f)$	Experiment	Theory			
		Present data	$K_i = 0$	$K_i = I$	$K_i = 2$	$K_i = 3$
2I84,2	894,9; $B(MI,2K_i \rightarrow 22)$ / 8I0.3; $B(MI,2K_i \rightarrow 32)$	4,2 ± 0,7	0.5	0,5	2,0	-
2274.5	786,6; $B(MI,3K_i \rightarrow 42)$ / 900,7; $B(MI,3K_i \rightarrow 32)$	0,98±0,26	I,29	I,29	I.28	0,I44
2057.5	2057.5; $B(MI,IK_i \rightarrow 00)$ / I957.5; $B(MI,IK_i \rightarrow 20)$	I,84±0,22	0.5	2,0	-	-

(table 7) for K = 1. Soloviev[20] has predicted pp [402↑ − 404↓] state in ^{182}W with the energy > 1.4 MeV which should be populated in the allowed hindered decay of ^{182m}Re (p 402↑ − n 624↑). The experimental log ft = 7.4 value of the EC transition to the 2057.5 keV state is in agreement with it and is close to the log ft = 7.2 value obtained for the n 624↑ → p 404↓ transition of the ^{183}Os → ^{183}Re decay. It is due to the significant mixing between orbitals differing in asymptotic quantum numbers by $\Delta N = \Delta n_z = 2$, $\Delta\Lambda = 0$[32] that beta-transitions of this type occur with measurable intensity. The n 404↑ and p624↓ states are mixed with n 624↑ and p 404↓ states, respectively. The resulting allowed unhindered transitions n 404↑ → p 404↓ and n 624↑ → p 624↓ contribute to the probability of beta-transition between n 624↑ and p 404↓ states.

The 2116.5 keV ($I^{\pi} = 2^{+}$) state can be treated as a rotational one of the K = 1 band built on the two-quasi-particle level 2057.5 keV. There are two arguments in favour of this interpretation:

i. No gamma-transitions to 0^{+} and 4^{+} states of the ground state rotational band were observed.

ii. The parameter $A = \frac{\hbar^2}{2J}$ of the proposed band is found to be 14.75 keV. It means that the moment of intertia of the band is higher than that of the ground state band ($A = 16.78$ keV).

The nature of other high-energy levels of ^{182}W populated in the decay of ^{182m}Re is not clear yet.

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