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THE INVESTIGATION OF THE DECAY $^{211}Rn \rightarrow {}^{211}At$ AND THREE-PARTICLE CONFIGURATION IN ^{211}At

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Исследование распада $^{211}Rn \rightarrow {}^{211}At$
и трехчастичные конфигурации в ^{211}At

Гамма-гамма угловые корреляции для восемнадцати каскадов, наблюдаемых при распаде ^{211}Rn, были измерены на установке с семью Ge(Li)-детекторами. С учетом экспериментальных данных по внутренней конверсии были однозначно установлены спины десяти уровней ^{211}At, а также определены параметры смеси δ для восьми гамма-переходов. В рамках многочастичной модели оболочек с силами конечного радиуса были рассчитаны свойства уровней и переходов в ^{211}At. Путем введения эффективного электромагнитного оператора учитывалось влияние вибрационных колебаний остова на электромагнитные характеристики ^{211}At.

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The Investigation of the Decay $^{211}Rn \rightarrow {}^{211}At$
and Three-Particle Configuration in ^{211}At

The gamma-gamma directional correlations for eighteen cascades observed in the ^{211}Rn decay were measured by means of a multidetector system (seven Ge(Li) detectors). Together with experimental data on internal conversion this allows a unique and model-independent assignment of the spin values for ten levels in ^{211}At. Multipole mixing ratios for eight gamma transitions were also derived. The properties of ^{211}At were treated in the framework of the multi-particle shell-model using finite range forces. The influence of core collective vibrations on the electromagnetic properties is taken into account by using the effective electromagnetic operators.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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1. INTRODUCTION

The isotope $^{211}_{85}At_{126}$ differs by three protons from the double magic ^{208}Pb nucleus. It is a suitable object for testing various theoretical models.

The results of the experimental investigations on the radioactive decay of ^{211}Rn have been published in /1-5/. The most complete available data are given in /4/, where the decay scheme of ^{211}Rn was also proposed. Spins and parities for almost all observed excited states of ^{211}At were ascribed there too, but due to the lack of experimental data these assignments were also based on the shell model calculation (i.e. on the prediction of the levels of the $(\pi h_{9/2})^3$ configuration) and on the assumption about existence of the "core excited" ^{212}Rn $(\pi s_{1/2})^{-1}$ state with energy of 2479 keV in ^{211}At. That is why in the compilation /5/ the alternative spin level assignments were also given together with the previous ones.

There was just one paper about investigation of the gamma-gamma directional correlations in ^{211}At /6/. The authors measured only 3 cascades connected with the 1363 keV transition. The measurement was made by means of a correlation spectrometer with Ge(Li)-2Na(Tl) detectors.

The aim of the present work was to obtain more definite identification of spins of the levels, as well as the values of multipole mixing ratios for γ-transitions in ^{211}At by means of the gamma-gamma directional correlation method.

2. SOURCE PREPARATION

The Rn isotopes were obtained by bombarding a Th target with a 660 MeV proton beam at the phasotron of the Laboratory of Nuclear Problems at Dubna. After chemical separation the mixture of radioactive noble gases was kept 12-14 hours for the short-lived Rn isotopes to decay. The ^{211}Rn isotope was separated in the chromatography column filled with molecular seaves /7/. Further purification and preparation of sources for measurements was made in vacuum. The ^{211}Rn cooled to the liquid nitrogen temperature was transported into an ampoule (⌀ 1.5 x 8.00 mm) which was hermetically sealed.

3. APPARATUS AND DATA PROCESSING

The measurements were made using a multidetector correlation system with seven Ge(Li) detectors. The volume of each detector was approximately 40 cm^3 and the energy resolution (FWHM) was in the range of 2.5-3.2 keV for 1332 keV gamma-rays. All seven detectors were placed at equal distances along the circle in the middle of which there was a radiative source. In such a way correlation function measurements for angles $\theta = 51.4^\circ$, 102.8° and 154.3° between detectors should be made simultaneously. The distance between each detector and the source was 75 mm. Each detector was provided with a cone collimator and a cylindrical screen in order to reduce crystal-to-crystal Compton scattering. The methodical experiment showed that registration in one detector of Compton radiation originated in other detectors was negligible. For further details about equipment see[8].

The time range for registration of coincidences was set to 180 ns. The FWHM of the time curve for all detector pairs and for energies of gamma radiation in the range 60-1600 keV was less than 15 ns. The ratio (accidental coincidence)/(true coincidences) was within 1-2%.

The experimental data were collected event-by-event on the magnetic tape. The data filtration was performed by the digital windows, which were set before the experiment as input data for the control computer code operated in the intellectual controller KM086[9]. The digital windows were set on the energy axises in such manner that it was possible to include the gamma lines of interest and the Compton background distribution near the lines. In accordance with the given cascades a set of two dimensional windows was obtained for each detector pair - see an example in fig.1. At the top of the figure there is a part of the decay scheme with the cascades (1,2) and (1,3) for which the experiment must be carried out. Dashed areas show the coincidence events, from which the number of the truth coincidences was calculated with respect to Compton scattered radiation beneath the gamma peaks and chance coincidences. The coincidence events from windows marked by points were collected on the magnetic tape only if they were of accidental character. The latter don't correlate and so they were used for determination of the relative detector efficiency.

The analysis of the collected data was carried out by means of computer codes published in[10]. In the latter the method of calculation of the experimental values of directional

correlation coefficients A_{22}, A_{44} and their errors is described too.

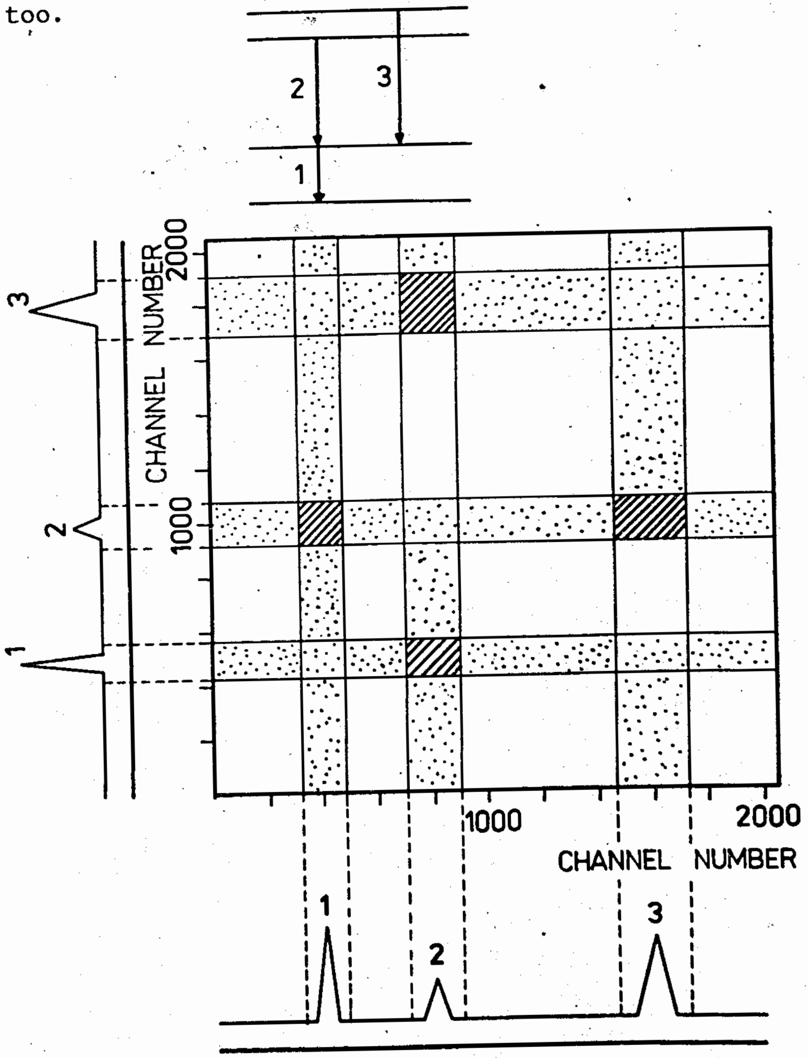
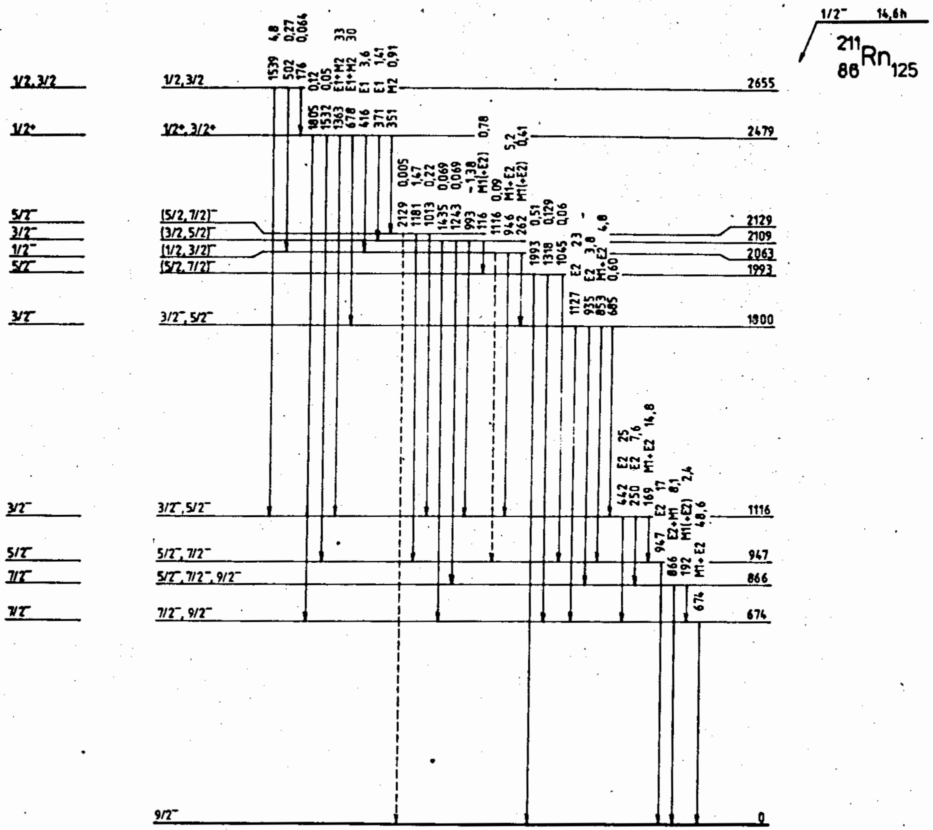


Fig.1. The scheme of a two dimensional data filtering digital windows for the two cascades created from the three gamma transitions (see text for details).

4. EXPERIMENTAL RESULTS

The $^{211}Rn \rightarrow {}^{211}At$ decay scheme from paper (fig.2) was taken as a basis for cascade selection. The coefficients A_{22} and A_{44}, calculated as the weighted mean value from two or three measurements and the mixing ratio δ derived from correlations are given in table 1. The results of the work [6] are included for comparison too. Besides possible spin combinations of levels in question and multipole mixing ratios of the γ-transitions, the values of the $|\delta|$ deduced from the internal conversion data were also used for the analysis of the experimental data on A_{22} and A_{44} values. We calculated $|\delta|$ values from the measured conversion coefficients α_k [3] using theoretical values α_k from [11]. Table 2 lists our δ values averaged by the method from [12] in the cases where it was possible, values of $|\delta|$ from α_k and multipolarities for some γ-transitions.

The (442-674)+(678-(685)-442) keV cascades. The 442 keV gamma transition coincides with both 674 and 678 keV lines;



211 85 At 126

Fig.2. The level scheme of ^{211}At populated from the decay of ^{211}Rn [5]; for the 678, 866, 947, 1363 keV transitions the multipolarities corrected by us are shown. On the left-hand side of the figure the spins and parities from this paper are given.

Table 1. Gamma-gamma directional correlation coefficients and multipole mixing ratios in ^{211}At

Cascade E_γ (keV)	$I_i(L_1,L_2)\ldots I_f$	A_{22}	A_{44}	δ
1	2	3	4	5
442-674 a)	3/2(2)7/2(1,2)9/2	0.228(9)	-0.026(15)	$-0.67^{+0.08}_{-0.05}$
1363 a)-442	1/2(1,2)3/2(2)7/2	-0.040(12)	0.007(17)	-0.12(5)
		-0.068(8) b)	-0.014(15) b)	
1363 a)-250	1/2(1,2)3/2(2)7/2	-0.039(18)	-0.026(62)	-0.12(7)
		-0.079(9) b)	0.001(19) b)	
250-866 a)	3/2(2)7/2(1,2)9/2	-0.178(19)	-0.018(48)	17^{+17}_{-6}
1363-169 a)	1/2(1,2)3/2(1,2)5/2	-0.001(17)	0.011(36)	-3.2(7)
		0.296(5) b)	0.008(9) b)	
250-192 a)	3/2(2)7/2(1,2)7/2	0.185(62)	-0.16(14)	1.2(5) or $-0.05^{+0.15}_{-0.20}$
1363-(250)-192 a)	c)	-0.28(18)	-0.02(34)	$0.03 < \delta < 1.0$
1363-...-674	c)	-0.113(13)	-0.003(24)	-
250-(192)-674	c)	0.30(16)	0.07(28)	-

Table 1 (continue)

1	2	3	4	5
(678[a])-1127)+ (1127-674)	1/2(1,2)3/2(2)7/2+ 3/2(2)7/2(1,2)9/2	0.068(8)	0.004(15)	$0.30^{+0.30}_{-0.25}$
934-866[a])	3/2(2)7/2(1,2)9/2	-0.094(50)	-0.038(89)	-16^{+8}_{-} or $\delta > 130$
853[a])-947	3/2(1,2)5/2(2)9/2	0.037(30)	-0.058(61)	-0.3(1) or $\delta > 11$
678-853[a])	1/2(1,2)3/2(1,2)5/2	-0.103(43)	-0.029(78)	-0.20(7)
946[a])-442	1/2(1,2)3/2(2)7/2	-0.152(65)	0.04(14)	$0.07 < \delta < 1.5$
(416-946)+ (416-...-947)	c)	0.037(32)	0.042(87)	
(946-169[a]))+ (169-947)	1/2(1,2)3/2(1,2)5/2+ 3/2(1,2)5/2(2)9/2	0.143(19)	-0.055(35)	$-4 < \delta < 1.5$
1539-169		-0.046(58)	-0.09(11)	
1539-442		-0.053(34)	-0.05(8)	

Remarks: a) δ refers to the marked γ-transition
b) values from the work [6]
c) see fig.2.

Table 2. Multipole mixing ratios and multipolarities of some transitions in ^{211}At

E_γ (keV)	Astner[3] $\lvert\delta\rvert$ from	Mult.	This work δ from $\gamma\gamma(\theta)$	Mult.
169	$2.59^{+0.25}_{-0.21}$ a)	M1+E2	-3.1(7)	M1+E2
192	0.44(44)	M1	0.0(2) or 1.2(4)	M1(+E2)
250	> 9.4	E2	-	E2
674	0.51(12)	M1+E2	$-0.67^{+0.08}_{-0.05}$	M1+E2
678	0.23(7)	E1	$0.30^{+0.30}_{-0.25}$	E1+M2
853	0.83(26)	M1+E2	-0.24(6)	M1+E2
866	> 4.7	E2	$24^{+\infty}_{-12}$	E2+M1
935	$2.1^{+18}_{-0.8}$ b)	E2	-	E2
946	$0.2^{+0.8}_{-0.2}$	(M1)	$0.07 < \delta < 1.5$	M1+E2
947	-	(E2)	-	E2
1127	> 2.5	E2	-	E2
1363	$0.073^{+0.097}_{-0.073}$	E1	-0.12(4)	E1+M2

Remarks: a) δ calculated from E2+M1(13 ± 2)% [4].
b) δ is calculated on the assumption that γ 947 keV has a multipolarity E2.

but in the second case, through the unobserved 685 keV transition (fig.2). This doublet was not sufficiently resolved in the coincident spectra because of some instabilities of our spectroscopic linear chains. For measured directional distribution coefficients A^{exp}_{ii} in this case it is necessary to take into account both the branching and the influence of the intermediate transition according to equation [13]:

$$A^{exp}_{ii} = \frac{X I_{\gamma\gamma}(442\text{-}674) + Y I_{\gamma\gamma}(442\text{-}678)}{I_{\gamma\gamma}(442\text{-}674) + I_{\gamma\gamma}(422\text{-}678)} \qquad (1)$$

where $X = A_{ii}(442\text{-}674)$ and $Y = A_i(678) U_i(685) A_i(442)$ are the directional distribution coefficients for the 442-674 keV and 678-(685)-442 keV cascades, respectively; $I_{\gamma\gamma}(442\text{-}674)$ and $I_{\gamma\gamma}(442\text{-}678)$ are the coincidence intensities for the corresponding cascades; $U_i(685)$ is the de-orientation factor connected with the unobserved transition 685 keV. Since the ratio $I_{\gamma\gamma}(442\text{-}678)/I_{\gamma\gamma}(442\text{-}674) \sim 1/100$, the influence of the 442-678 keV cascade is negligible, i.e., the A_{22}^{exp} and A_{44}^{exp} values in equation (1) may be completely connected with the 442-674 keV cascade. The analysis of possible spins of the 1116 and 674 keV levels (fig.2) with the fact that the 442 keV transition has a multipolarity E2 [1] gives unique spin assignments $3/2^-$ and $7/2^-$ for these levels, respectively. Other possible spin values contradict either the experimental value of A_{44} or the E2 multopolarity of the 442 keV gamma transition. The mixing ratio δ determined for the 674 keV transition with the M1+E2 multipolarity, is in agreement with the internal conversion data.

The 1363-442 keV cascade. This cascade is of interest as it gives an answer to the question about spin of the 2479 keV level and thus tests the assumption ($I^\pi = 1/2^+$) made in [3]. The coefficient A_{22} does not contradict neither $1/2^+$ nor $3/2^+$ spin for this level. But in the former case the multipolarity of the 1363 keV transition has 1.4% M2 admixture (δ =-.12) which is in good agreement with the $|\delta|$ from the ICC data (table 2). In the case of spin assignment $3/2^+$ we obtain the following values for δ : δ_1 = 0.48(8) and $\delta_2 = 5.1^{+2.4}_{-1.4}$, both contracting the internal conversion data.

The 1363-250 keV and 250-866 cascades. These cascades solve the ambiguity of the spin assignment for the 866 keV level: $5/2^-$ or $7/2^-$. The first possibility $5/2^-$ scarcely takes place for description of the cascade 1363-250 keV because both mixing ratios δ calculated for the 250 keV transition (using the previously determined value of δ for the 1363 keV transition): $\delta_1 = -0.22^{+0.22}_{-0.07}$ and $\delta_2 = -2.2^{+0.5}_{-0.8}$ differ from δ deduced from α_k. The better result is from the second alternative $7/2^-$ at which the multipolarity of the 250 keV transition is of pure E2 character and the value of δ for the 1363 keV transition is in very good agreement with that deduced from the 1363-442 keV correlation. For description of the 250-866 keV cascade there remains only one possibility 3/2(2)7/2(1,2)9/2. The deduced δ for 866 keV transition agrees with the ICC data.

The 1363-169 keV cascade. The earlier established spin value $3/2^-$ of the 1116 keV state and M1+E2 character of the

169 keV transition [3] unambiguously imply spin value $5/2^-$ for the 947 keV level. Hence, the δ value for the 169 keV transition could be calculated. The 1363-169 keV correlation was investigated in [6] too. As one can see from table 1, there is a great discrepancy in A_{22} values in both measurements, the reasons for which are not clear. Obviously one should give preference to our result because of good agreement of our δ value with that obtained from the internal conversion data. Both mixing ratios calculated from the A_{22} coefficient given in [6] δ_1 (γ 169) = 0.46(2) and δ_2 (γ169) = 4.6(3) contradict the ICC data. It should be noted that the δ_1 value in [6] is given with the minus sign which is an error. Agreement of our data and those from [6] for remaining correlations is observed within two errors.

The 250-192 keV, 1363-(250)-192 keV, 1363-...-674 keV and (250-(192)-674)+(678-(685)-250) keV cascades. These cascades connect the 674, 866, 1116, 2479 keV states whose spins were already defined. The δ mixing ratio for the 192 keV transition follows from the first and the second correlations. The third and the fourth cascades are not direct ones (fig.2). We have calculated the corresponding directional distribution coefficients (the influence of the low intensive 678-(685)-250 keV cascade was neglected) using formulae in which the influences of intermediate transition and cascade branching are considered:

1363-...-674: A_{22}^{calc} = -0.088(24) and A_{44} = 0.0,

250-(192)-674: A_{22}^{calc} = 0.18(11) and A_{44} = -0.003(4).

The calculated A_{22}, A_{44} coefficients are in good agreement with that measured by us. The A_{44} value for 1363-...-674 keV cascade vanishes as the spin of the 1116 keV state is $3/2^-$.

The (678-1127)+(1127-674) keV cascades. From four levels connected by these unresolved cascades only for the 1800 keV level spin assignment is not established in a unique manner. In principle the measured A_{22} and A_{44} values don't answer the question what spin assignment $3/2^-$ or $5/2^-$ is more suitable. In the case of $I^\pi = 5/2^-$, however, the multipolarity of the 678 keV transition must be M2, which contradicts the internal conversion coefficient value. Following the fact that spin of the 1800 keV level has the value $3/2^-$, we calculated for 678-1127 keV cascade the directional correlation coefficients A_{22} = -0.127(44), A_{44} = 0.031(33) and the corresponding mixing ratios δ(678), which is in agreement with the $|\delta|$ value from the internal conversion data.

The 934-866 keV, 853-947 keV and 678-853 keV cascades. The spin of levels related to these cascades were already determined. The first cascade gives the mixing ratio δ for the 866 keV transition and from other ones the mixing ratios are obtained for the 853 keV transition. Agreement of the $\delta(853)$ with the internal conversion data can be considered only within the double error. The two values of $\delta(853)$ obtained by us are close to each other (table 1) that's why our results may be considered as more reasonable.

The 946-442 keV, (416-946)+(416-...-947) and (946-169)+ + (169-947) keV cascades. All cascades mentioned are connected with the 2063 keV state whose spin should be $1/2^-$ or $3/2^-$ /5/. From the analysis of the A_{22} coefficients for the 946-442 keV correlation it follows that the prescriptions $I^{\pi}(2063) = 3/2^-$ and L = 1,2 for the 946 keV transition are incompatible, i.e., a unique $1/2^-$ spin assignment to the 2063 keV level is implied. The range of the multipole mixing ratios for the 946 keV transition does not contradict the conversion data (table 2). The directional distribution coefficients for the second cascade vanish at $I^{\pi} = 1/2^-$. Our experimental data confirm that conclusion. The third cascade gives the $\delta(169)$ value, which is in good agreement with the value obtained from the 1363-169 keV cascade analysis.

The 1539-442 keV and 1539-169 keV cascades. The accuracy of the experimental data is not high enough to solve the problem of unique spin assignment of the 2655 keV level. On the obvious assumption about the transition multipole structure L = 1,2 for the 1538 keV transition and spin assignment $3/2^-$ for level 2655 keV δ may be in interval $0.35 < \delta(1538) < 2.5$. If one supposes another possibility ($1/2^-$), then we obtain $\delta(1538) = 2.0^{+1.0}_{-0.5}$ or $0.0 < \delta(1538) < 0.5$.

The 1993, 2109 and 2129 keV levels. The intensities of the gamma transitions, referring to these levels are not so strong that one could carry out correlation measurement under our experimental conditions. But nevertheless, on the basis of the spin assignments for the levels 2479, 947 and 674 keV made by us and of the gamma transition multipolarities from /3/, it is possible to conclude:

As the 371(E1)-116(M1) keV cascade connects the 2479 keV $1/2^+$, 2109 and 1993 keV levels, the spins of the two later ones may be $1/2^-$, $3/2^-$ and $1/2^-$, $3/2^-$, $5/2^-$, respectively. But as the most intensive transition from the 1993 keV level is that going to the ground state $9/2^-$, it is more acceptable

to assign it to the $5/2^-$ spin value. Then the 2109 keV level must have the $3/2^-$ spin value.

The 2479 keV $1/2^+$ level decays by the 351 keV(M2) transition to the 2129 keV state, which implies its spin equal to $5/2^-$.

5. THEORETICAL ANALYSIS OF THE ^{211}At PROPERTIES

At present there are several calculations concerning the ^{211}At properties. In the investigations /14,15/ based on the many particle shell model and finite range interaction different properties of nuclei having three quasiparticles above the magic core were considered. In papers /16,17/ the diagonal version of this model was used for the description of such nuclei including ^{211}At, the necessary pairing matrix elements were obtained from the experiment. The spectrum of the ^{211}At states was also calculated in /18/ where the surface delta interaction was used, while in /19,20/ the model of the three particle cluster including the ^{208}Pb core phonons was used.

We performed theoretical calculations of the ^{211}At structure considering all the available experimental information about this nuclei including the data on multipole mixing ratios δ. As we are mainly dealing with the ^{211}At states with the energies below the threshold of the inelastic channel of the core nucleus ^{208}Pb ($\hbar\omega_{3^-} = 2.61$ MeV, $\hbar\omega_{5^-} = 3.20$ MeV and $\hbar\omega_{2^+} = 4.08$ MeV), our analysis was also carried out in the framework of the multiparticle shell model including only the valence proton above the ^{208}Pb core. In this case the influence of phonon excitations on the energies of low lying ^{211}At levels is taken into account by renormalization of the effective interaction which is defined from the fit to the experiment. As to the radiative properties, the influence of the virtual core excitations on the low energy transitions manifests itself in renormalization of the corresponding single-particle transition operators. The proper parameters are defined from the radiative properties of nuclei of the "^{208}Pb$\pm$nucleon" type and are well known now /21,22/. The wave function was constructed as a superposition of the antisymmetrized three-particle jj-coupling scheme states with protons filling the $82 < Z < 114$ shell. The eigenvalues of subsequent proton orbitals are well known from the experiment, see for example /23/. The spectrum of ^{211}At and its eigenvalues were defined from the corresponding secular equation. In our calculation we used experimental proton single-particle energies /24/ and single-particle wave functions of the oscilla-

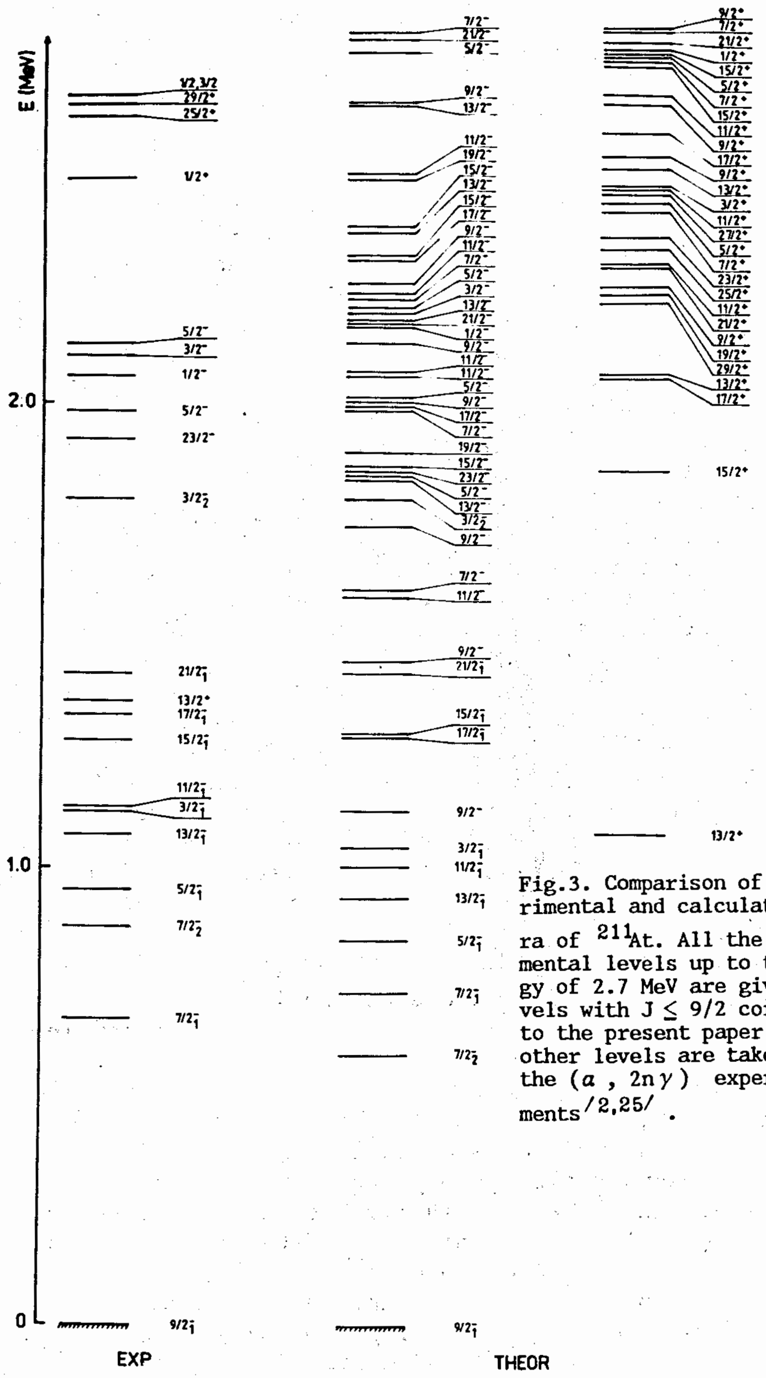


Fig.3. Comparison of the experimental and calculated spectra of ^{211}At. All the experimental levels up to the energy of 2.7 MeV are given. Levels with $J \leq 9/2$ correspond to the present paper while other levels are taken from the $(\alpha, 2n\gamma)$ experiments [2,25].

tor potential with $\hbar\omega_{osc} = 41/A^{1/3}$ MeV. The residual interaction was taken in a simple form: $\theta(1,2) = (V + V_\sigma \sigma_1\sigma_2) \times \exp(-r_{12}^2/r_0^2)$ with $V_\sigma \simeq -0.1V$, $r_0 = 1.8$ fm. The value $V = -30$ MeV was found from the correct description of the $21/2_1^-$ level energy (with the main component $\{(\pi h9/2)^3, s = 3)\}$. The theoretical spectrum as well as all experimental levels up to the excitation energy ~ 2.6 MeV are given in fig.3. Agreement between experimental and calculated levels at low energies is satisfactory. At higher energies many negative and positive parity states occured, most of them being not observed in the experiment so far. Nevertheless, the positions of the known $23/2^-$, $25/2^+$ and $29/2^+$ levels are well reproduced by our calculation.

In the calculations of the ^{211}At electromagnetic properties the influence of virtual core excitations was carried out by the method mentioned above that is by using the effective electromagnetic operators:

$$\hat{\mathfrak{M}}(E2,\mu) = e(\pi)\sum_{i=1}^{3} r_i^2 Y_{2\mu}(\theta_i \phi_i)$$

$$\hat{\mathfrak{M}}(M1,\mu) = \sqrt{\frac{3}{4\pi}}\sum_{i=1}^{3}\{g_l(\pi)\hat{l}_i + g_s(\pi)\hat{S}_i + g_2(\pi) r_i^2[Y_2(i)\times\hat{S}_i]^2\}_\mu .$$

The values of the effective charge, gyromagnetic ratios as well as the magnitude of the tensor parameter g_2 were obtained earlier in papers [21,22]. Namely, the following values were used: $e(\pi) = 1.6|e|$, $g_l(\pi) = 1.102$, $g_s(\pi) = 3.795$, $g_2(\pi) = 0.031$ fm^{-2}. The results of proper calculations are given in table 3 where all the available experimental data on the electromagnetic properties of ^{211}At are presented. One can see good agreement with the experiment in the values of the reduced E2 probabilities and in the magnitudes of static moments and satisfactory agreement in the values of $\delta(E2/M1)$ mixing parameters. However, the detailed analysis of the structure of experimental $7/2_1^-$ and $7/2_2^-$ states (with dominant configurations $\{(\pi h_{9/2})^2 0, \pi f_{7/2}\}$ and $\{(\pi h_{9/2})^3, s = 3\}$, respectively) and the analysis of the radiative properties of these levels reveal that in our calculation the sequence of these levels is inversed as compared with the experiment. It should be noted that other low-lying negative parity levels in ^{211}At up to the energy of 1416 keV also belong to the $(\pi h_{9/2})^3$ configuration while the $3/2_2^-$ level mainly belongs to the configuration $\{(\pi h_{9/2})^2 2, \pi f_{7/2}\}$. Positive parity $13/2^+$, $25/2^+$ and $29/2^+$ levels have their main components of the type $\{(\pi h_{9/2})^2 J, \pi i_{13/2}\}$ with J equal to 0, 6 and 8, respectively.

Table 3. Electromagnetic properties of ^{211}At

Quantity		Experimental value	Theoretical value
$B(E2;21/2^-_1-17/2^-_1).e^2.barn^2$		0.0131(13) /21/	0.0219
$B(E2;15/2^-_1-13/2^-_1)$	"	0.0040(5) /21/	0.0056
$B(E2;15/2^-_1-11/2^-_1)$	"	0.0127(16) /21/	0.0191
$B(E2;3/2^-_1-5/2^-_1)$	"	0.0920(90) /21/	0.0839
$B(E2;3/2^-_1-7/2^-_1)$	"	0.0034(2) /4/	0.0016
$B(E2;3/2^-_1-7/2^-_2)$	"	0.0135(14) /21/	0.0129
$B(E2;29/2^+-25/2^+)$	"	0.0092(8) /21/	0.0118
$Q(9/2^-_1)$ e.barn	"	-	-0.25
$Q(21/2^-_1)$	"	±0.53(5) /26/	-0.56
$Q(29/2^+)$	"	±1.01(19) /26/	-1.15
$\mu(9/2^-_1)$	"	-	4.10
$\mu(15/2^-_1)$	"	6.82(60) /5/	6.83
$\mu(21/2^-_1)$	"	9.66(13) /5/	9.54
$\mu(29/2^+)$	"	15.50(19) /5/	15.40
$\delta(7/2^-_1-9/2^-_1)$		$-0.67^{+0.08}_{-0.05}$ present work	-1.19
$\delta(3/2^-_2-5/2^-_1)$		-0.24(6) "	-0.33
$\delta(7/2^-_2-7/2^-_1)$		0.0(2) "	0.01
$\delta(3/2^-_1-5/2^-_1)$		-3.1(7) "	$\sim -10^2$
$\delta(7/2^-_2-9/2^-_1)$		$24^{+\infty}_{-12}$ "	8.20

Noteworthy is poor agreement in $\delta(E2/M1)$ for the $3/2^-_1-5/2^-_1$ transition. In this case the matrix element of the M1 operator between the main components of these states, namely between $\{(\pi h_{9/2})^3, s = 3; 3/2^-\}$ and $\{(\pi h_{9/2})^3, s = 3; 5/2^-\}$ configurations, turns into zero. The value of the matrix element $<5/2^-_1||\mathfrak{M}(M1)||3/2^-_1>$ in this case strongly depends on the magnitudes and signs of small admixtures to the wave functions determined by the dimension of the basis space and the peculiarities of residual interaction. Thus the calculation becomes less reliable.

Shell model calculations using only three quasiparticle orbitals fail to explain $\delta(M2/E1)$ values for transitions from

the $1/2^+$(2479 keV) level. The reason for this disagreement is that the 2479 keV and 2655 keV ($1/2^+$, $3/2^+$) levels have energies close to the energies of negative parity ^{208}Pb phonons. Thus they are not of three but rather of five-quasiparticle nature. These levels are populated /3/ in a first-forbidden β^+-decay of the ground state of ^{211}Rn ($1/2^-$) with the structure $\{(\pi h_{9/2})^4(\nu p_{1/2})^{-1}\}$. The leading components of these levels correspond to the configurations $\{(\pi h_{9/2})^3\nu i_{11/2}, (\nu p_{1/2})^{-1}\}$ and $\{(\pi h_{9/2})^3\nu g_{9/2}, (\nu p_{1/2})^{-1}\}$ (single-particle transformation in the β^+-decay of the type $\pi h_{9/2}\to\nu i_{11/2}$ or $\pi h_{9/2}\to\nu g_{9/2}$). Another five-quasiparticle configuration which may also strongly mix into the 2479 and 2655 keV states is of the $\{(\pi h_{9/2})^4(\pi s_{1/2})^{-1}\}$ type (with single - particle transformation in the β^+-decay of ^{211}Rn $\pi s_{1/2}\to\nu p_{1/2}$). From the phenomenological point of view the discussed $1/2^+$ and $3/2^+$ levels have a multiplet nature of the type $\{(\pi h_{9/2})^3 \times 5^-_1\}$. Their energies are lower as compared with the energy of 5^-_1 phonon due to the additional attraction of the particle-hole pairs $\{\nu g_{9/2}, (\nu p_{1/2})^{-1}\}$, $\{\nu i_{11/2}, (\nu p_{1/2})^{-1}\}$ and $\{\pi h_{9/2}, (\pi s_{1/2})^{-1}\}$ with the cluster $\{(\pi h_{9/2})^3\}$. At the same time our calculations show the existence of $1/2^+$ and $3/2^+$ levels in the vicinity of 2.5 MeV. These levels have the structure of the $\{(\pi h_{9/2})^2 6, \pi i_{13/2}\}$ and $\{(\pi h_{9/2})^2 8, \pi i_{13/2}\}$ types. They are not populated in a β^+-decay and are not seen in the experiment.

6. CONCLUSIONS

This paper provides measurements of the directional correlation distribution coefficients of eighteen gamma transition cascades of ^{211}At.

From the analysis of our A_{22} and A_{44} coefficients and of the internal coversion data from /1,3,4/ the unique spin assignments to ten levels have been made: 674 keV $7/2^-$, 866 keV $7/2^-$, 947 keV $5/2^-$, 1116 keV $3/2^-$, 1800 keV $3/2^-$, 1993 keV $5/2^-$, 2063 KeV $1/2^-$, 2109 keV $3/2^-$, 2129 keV $5/2^-$ and 2479 keV $1/2^+$. It is worth noting that our spin assignments are in agreement with the conclusions of /3/, where for unique spin identification theoretical assumptions were used. Multipole mixing ratios for eight transitions are deduced.

It is demonstrated that the experimental data on the energy levels of ^{211}At as well as the data on electromagnetic properties of this nucleus can be successfully explained in the framework of the multiparticle shell model.

REFERENCES

1. Stoner A.W. - Ph.D.Thesis UCRL-3471, 1956.
2. Berstrom I. et al. - Phys.Lett., 1970, B32, p.476.
3. Astner G. - Phys.Scr., 1972, 5, p.31.
4. Astner G., Berg V. - Phys.Scr., 1972, 5, p.55.
5. Martin M.J. - Nucl.Data Sheets,1978, 25, p.397.
6. Akbarov A. et al. - JINR, P6-85-760, Dubna, 1985.
7. Koltchakovski A., Norseev J.V. - JINR, P6-6923,Dubna,1973.
8. Abrosimov V.N. et al. - JINR, P6-86-320, Dubna, 1986.
9. Hons Z., Sidorov V.T., Cizek P. - JINR, P10-87-815, Dubna, 1987.
10. Venos D. et al. - JINR, P6-88-100, Dubna, 1988.
11. Rosel F., Fries H.M., Alder K. - Atomic data and nuclear data tables, 1978, 21, p.291.
12. Dzelepov B.S. - Sovremennye metody jadernoj spectroskopii. Leningrad: Nauka, 1983, p.186 (in Russian).
13. Hamilton W.D. - The electromagnetic interaction in nuclear spectroscopy. Amsterdam, North-holland publishing company, 1975, p.582.
14. Isakov V.I., Kozhamkulov T.A., Sliv L.A. - Izv.Akad.Nauk SSSR,Ser.Fiz., 1972, 36, p.798 (in Russian).
15. Isakov V.I. et al. - Izv.Akad.Nauk SSSR, Ser.Fiz.,1983, 47, p.928 (in Russian).
16. Blomqvist J. - Research Institute for Physics, Stockholm, Annual Report, contr.3.8.2, 1970.
17. Linden C.G. et al. - Z.Phys., 1976, A277, p.273.
18. Arvieu R., Bohigas O., Quesne C. - Nucl.Phys., 1970, A143, p.577.
19. Paar V. - Phys.Rev., 1974, C11, p.1432.
20. Ewart G.M., Gerace W.J., Walker J.F. - Nucl.Phys., 1975, A244, p.125.
21. Astner G. et al. - Nucl.Phys. 1972, A182, p.219.
22. Isakov V.I., Sliv L.A. - Izv.Akad.Nauk SSSR, Ser.Fiz., 1974, 38, p.2466 (in Russian).
23. Bohr A., Mottelson B.R. - Nuclear Structure, New York: Benjamin, 1969, vol.1, ch.3.
24. Ellegard C., Vedelsby P. - Phys.Lett., 1968, B26, p.155.
25. Bergstrom I. et al. - Phys.Scr., 1970, 1, p.243.
26. Mahnke H.E. et al. Phys.Lett., 1983, B122, p.27.

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