ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ
ДУБНА

E6 - 11090

J.Lipták, J.Krištiak, K.Krištiaková

THE EXCITED STATES OF ^{79}Kr

1977

E6 - 11090

J.Lipták,[1] J.Krištiak,[2] K.Krištiaková[2]

THE EXCITED STATES OF ^{79}Kr

Submitted to "Nuclear Physics"

[1] *The Faculty of Mathematics and Physics, Charles University, Prague, Czechoslovakia.*
[2] *The Institute of Physics, Slovak Academy of Sciences, Bratislava, Czechoslovakia.*

Липтак Я., Криштиак Й., Криштиакова К.

E6 - 11090

Возбуждение состояния ^{79}Kr

При помощи Ge(Li) детекторов исследовались спектры гамма-лучей, возникающих при распаде ^{79}Rb, и гамма-гамма-время совпадений. Был определен $T_{1/2}$ уровня 147.06 кэВ, $T_{1/2}$ (147.06) = (78 ± 6) нс. Измерены интенсивности 17 переходов при помощи Si(Li) детектора в магнитном поле. Определены КВК и мультипольности этих переходов. Установлены квантовые характеристики изотопа ^{79}Rb. Рассматривается структура возбужденных состояний ^{79}Kr в рамках модели Алага и модели с учетом силы Кориолиса. Показано, что свойства некоторых уровней ^{79}Kr можно объяснить существованием относительно чистых ротационных полос.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1977

Lipták J., Krištiak J., Krištiaková K.

E6 - 11090

The Excited States of ^{79}Kr

The β^+-decay of ^{79}Rb has been studied with Ge(Li) detectors in single and coincidence modes. The half-life of the 147.06 keV level in ^{79}Kr has been determined to be (78±6) nsec. The relative electron intensities of seventeen transitions have been measured with a magnetic Si(Li) spectrometer. The internal conversion coefficients have been determined. The transition multipolarities have been deduced. The spin-parity assignments have been made for excited states of ^{79}Kr and a β-decaying state of $^{79}_{37}Rb(5/2^+)$. The structure of excited states in ^{79}Kr is discussed in the framework of the Alaga and Coriolis coupling model. It is shown that the properties of some levels in ^{79}Kr can be explained by the existence of relatively pure rotational bands.

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

Preprint of the Joint Institute for Nuclear Research. Dubna 1977

1. INTRODUCTION

In recent years the level structure of the $^{79}_{36}Kr_{43}$ nucleus has been a subject of numerous spectroscopic investigations employing $(p,n\gamma)$ [1], (d,p) [2] and $(\alpha,n\gamma)$ [3,4] reactions. The β^+-EC decay of ^{79}Rb (22.8 min) to levels in ^{79}Kr has been studied by Broda et al. [5] and Lingeman et al. [6].

The region of nuclides with N or Z 45 is interesting due to the appearance of the $7/2^+$ state as a ground or a low-lying excited state. The simple shell model cannot account for this state as the available shell states are $1g_{9/2}$, $2p_{1/2}$, $2p_{3/2}$ and $1f_{5/2}$.

There are several theoretical papers aimed at explaining the structure of nuclei with N or Z 45 and, namely, the $7/2^+$ state (the anomalous coupling state - ACS) using a spherical or deformed concept of a nucleus.

A very successful quasiparticle-phonon coupling model of Kisslinger and Sorensen [7] does not allow one to obtain the AC state. More recently Paar [8] has applied Alaga's model to odd nuclei with Z=47. He obtained good agreement with experimental data especially with regard to the AC state. Some agreement with the experimental data on positive parity states of nuclides with $N \approx 45$ has been obtained by Kuriyama et al. [9]

The close spacing of the $7/2^+$ and $9/2^+$ states can be obtained very naturally in the deformed single-particle model. The negative parity states in the ^{79}Kr have been interpreted in terms of the Nilsson model by Forssten et al.[4], Heller and Friedman[10] have calculated the properties of states (positive as well as negative parity) of nuclides with N~45 using the Coriolis-coupling model extended to include a residual pairing interaction.

Thus, the question as to whether a spherical or deformed model is most appropriate for krypton isotopes is still open for discussion.

The purpose of the present work, a spectroscopic study of the level structure of ^{79}Kr through the β^+ -EC decay of $^{79}_{37}$Rb, was to place the decay scheme on a more firm basis with the hope of facilitating the choice between various theoretical models proposed for the description of nuclides with $40<N<50$. We have made γ, $\gamma-\gamma-\tau$ and internal conversion study of the ^{79}Rb decay to reach this goal.

2. EXPERIMENTAL PROCEDURE

2.1. Source Preparation

^{79}Rb activity was produced by 660 MeV proton irradiation of Zr+Nb targets in the external beam of the Dubna synchrocyclotron. The sources were prepared from a mixture of spallation products by electromagnetic mass-separation, using a surface ionization source together with the "hot-solid-target" method[11]. Sources for measuring the internal conversion electrons were made by the implantation of ^{79}Rb ions into the Al backing.

2.2. The γ-Ray Measurements

The γ-ray spectra below 240 keV (see Fig. 1) were recorded with a 200 mm^{2}x 5 mm Ge(Li) detector having an energy resolution of 240 eV (FWHM) at the 5.6 keV. The spectra above a 40 keV energy were recorded with a set of four Ge(Li) detectors. Active volumes of the detectors were 38,

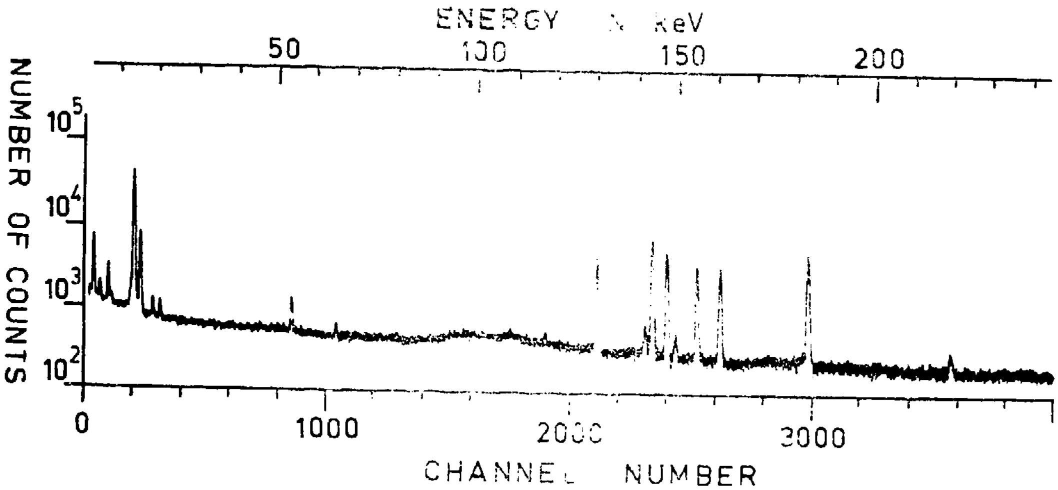

Fig. 1. Low-energy part of the [illegible] γ-ray spectrum.

41, 47 and 50 cm^3 with (FWHM) of 2.5, 2.5, 3.0 and 3.0 keV, respectively, for the 1332 keV γ-ray from a ^{60}Co source.

Coincidence and time relations among γ-rays emitted in the decay of the ^{79}Rb isotope were studied with two Ge(Li) detectors having active volumes of 41 and 50 cm^3.

The experimental time resolution of prompt coincidences was 25 nsec and time window width was 2 μsec. The data of three-dimensional measurements $(E_\gamma \times E_\gamma \times \tau)$ were recorded on a magnetic tape and analysed with the aid of a Hewlett-Packard 2116-C computer using Honusek's and Fromm's programs /16/.

The contributions from underlying Compton background and random-coincidence events were determined by selecting the gate from one or more regions of the background near the analysed peak. A subtraction of this properly normalized spectrum then yielded the net spectrum of γ-rays coinciding with the given photopeak. A few typical net coincidence spectra are shown in Fig. 2.

The γ-rays from the well-known energy standard sources of ^{56}Co, ^{75}Se, ^{110m}Ag, ^{152}Eu and ^{182}Ta /12/ have been used to determine the energy calibration curve.

The relative γ-ray intensities were determined from peak areas using a detector efficiency curve which was obtained by means of the above mentioned standard sources. The relative intensities for standards were taken from refs. /12-15/. The relative intensity of the β^+-decay of the ^{79}Rb isotope was determined by measuring the 511 keV line intensity using Al absorbers (5 mm thick) on both sides of the ^{79}Rb source.

2.3. The Measurements of the Internal Conversion

The internal conversion electrons of γ-transitions were measured by a spectrometer which is

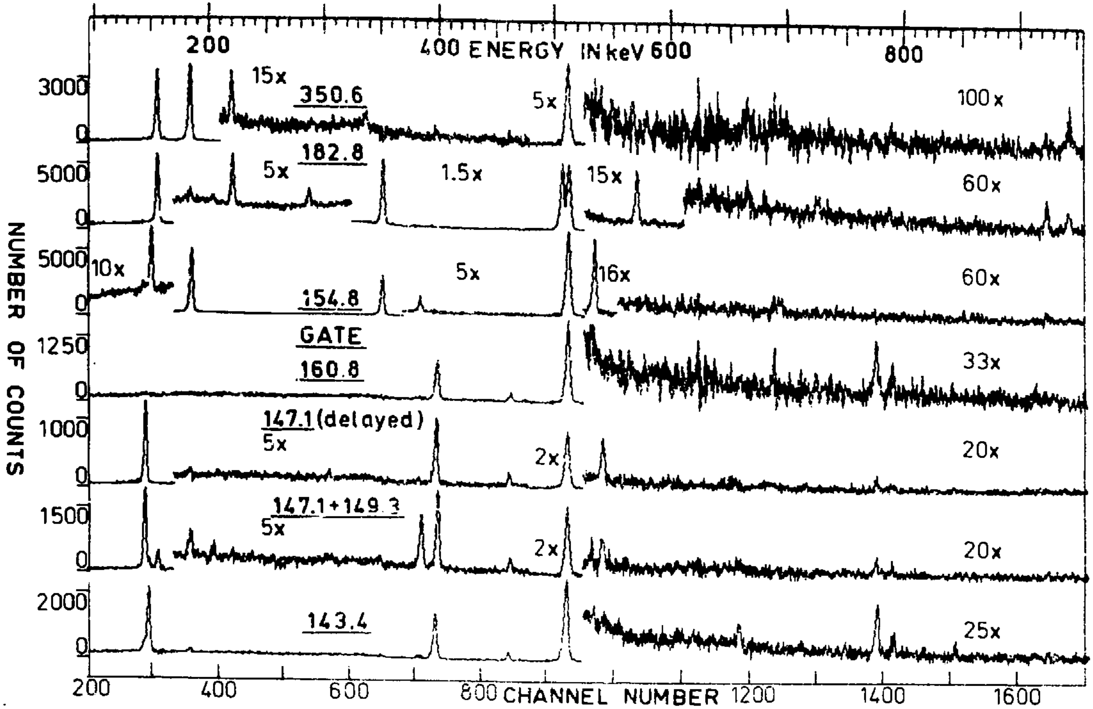

Fig. 2. The γ-ray spectra without background from the γ-γ coincidence measurements. The energy of the selected window is shown at the beginning of the spectrum.

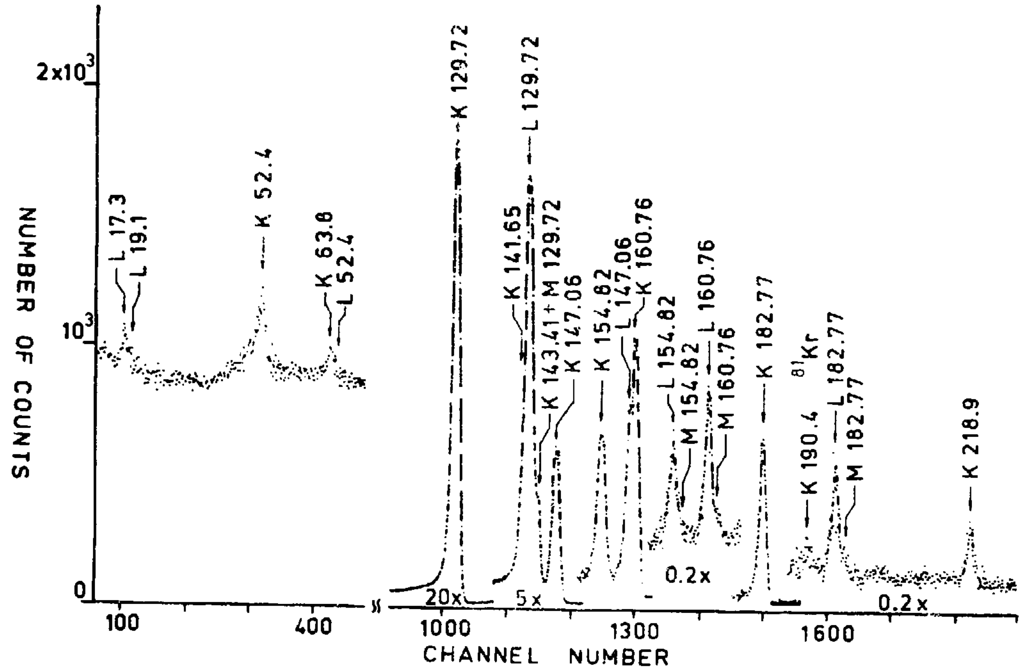

Fig. 3. The electron spectrum from the decay of ^{79}Rb measured with a Si(Li) detector.

a combination of the constant magnetic field with the high-resolution Si(Li) detector [17]. Two different magnetic fields (250 and 500 Gauss) were employed for energy region of 40-400 and 100-700 keV, respectively. The energy resolution of spectrometer was 1.0-1.7 keV at (40-700) keV region. Fig. 3 shows a part of a typical ^{79}Kr electron conversion spectrum obtained with a 250 Gauss magnetic field.

The intensities of lines in the spectrum were determined as a number of counts over a linear background using the detector efficiency curve. The intensity of the K143.41 keV line was calculated using the experimental intensity of the K129.72 keV line and the theoretical value α_{L+M}/α_K [18].

3. RESULTS

The energies and relative intensities of γ-rays that were observed in the ^{79}Rb decay ($T_{1/2}$= 22.8 min) are listed in Table 1. A summary of the results of the γ-γ-τ coincidence experiments is given in Table 2.

The internal conversion coefficients were calculated relative to the ICC of the isomeric 129.72 keV transition using our I_γ and I_e. We assume that the 129.72 keV transition is pure E3 with the theoretical value of α_K=2.1. The results are given in Table 3.

As is seen from Table 1, there is a systematic difference between the present γ-ray intensities for E_γ < 650 keV and those published by Lingeman et al. [6] with the latter being lower up to 20%. Besides this the intensity of the 17.3 keV γ-transition given in ref. [6] is remarkably large. We believe that our I_γ values are more accurate due to a larger number of the standard sources employed. In addition, the intensity balance of the 182.77 keV ($3/2^-$) level using I_γ of the work [6] is not fulfilled, the difference between the coming ΣI_T and the leaving I_T (182.77 keV) is equal to 21.5±6.0 unit.

Table 1

Energies and relative intensities of γ -transitions from the $^{79}Rb \rightarrow {}^{79}Kr$ decay

This work				
Energy (keV)	I_γ	I_T	$I_\gamma^{a)}$	$I_\gamma^{b)}$
17.3 (1)	1.0 (1)	13.1	5.2	6.6
19.1 (1)	0.70 (6)	12.0		
52.42(1)	1.26 (4)	2.23		1.3
63.84(1)	0.36 (1)	0.54		
107.72(4)	0.30 (2)			0.6
111 (1)[c]	~0.17[c]			
116.25(3)	0.90 (3)			1.0
129.72(1)	46.5 (10)	169.7	37.2	41.5
141.65(1)	2.9 (1)	3.65		
143.41(1)	60.2 (12)	62.1	59.2	46.6
147.06(1)	45.4 (10)	55.5	46.2	32.2
149.34(1)	2.9 (1)	3.04		
154.82(1)	34.2 (8)	36.2	28.7	24.6
160.76(1)	37.2 (8)	40.2	36.8	28.9
182.77(1)	83.0 (16)	85.3	87.1	67.2
201.2 (2)	0.77 (8)		0.8	0.7
218.8 (4)[c]	2.2 (3)[c]	}	5.1 }	5.0
219.3 (4)[c]	2.7 (3)[c]	}		
275.1 (2)	0.46(10)			
286.2 (1)	3.9 (1)			3.4
302.4 (5)[c]	0.4 (2)[c]	}		
302.4 (5)[c]	0.7 (3)[c]	}	2.5 }	1.3
304.0 (2)	0.45 (8)	}		
312.7 (3)	0.28 (6)			
320.2 (3)	0.33(10)			
350.6 (1)	31.3 (6)		31.9	28.1
382.5 (5)[c]	1.0 (2)[c]	}	5.3 }	4.9
384.1 (1)	5.1 (3)	}		
397.6 (1)	26.2 (6)		25.1	22.3
401.8 (1)	3.5 (1)		2.3	2.2
428.7 (2)	0.6 (1)			
461.5 (1)	5.3 (1)		5.0	4.8
476.1 (2)	0.24 (6)			
486.8 (2)	0.97 (8)			
505.4 (1)	46.0 (20)	}	55.0 }	53.6
506.0 (2)	9 (2)	}		
511	715 (57)		665	700
524.2 (1)	0.94 (5)		1.0	0.8
533.3 (1)	5.6 (1)		5.9	5.6
541.0 (1)	3.2 (1)	}	3.3 }	3.6
543.7 (2)	0.60 (6)	}		
558.3 (1)	1.10 (6)			
569.2 (1)	4.0 (1)		4.0	4.7
603.2 (1)	2.9 (1)	}	3.0 }	3.0
605.6 (2)	0.40 (7)	}		
622.2 (1)	38.0 (8)		37.0	29.4
663.1 (2)	0.3 (1)			
688.1 (1)	100 (2)		100	100
706.0 (2)	0.25 (3)			
724.4 (2)	0.27 (3)			
774.1 (1)	2.60 (8)		2.9	
786.0 (2)	0.70 (4)	}	1.8 }	0.9
788.3 (2)	0.80 (4)	}		
792.3 (3)	0.10 (2)			

This work			
Energy (keV)	I_γ	$I_\gamma^{a)}$	$I_\gamma^{b)}$
815.1(3)	0.09(3)		
835.4(4)	0.25(4)	0.2	
841.6(1)	0.25(3)	0.3	
858.1(2)	0.15(5)	0.4	
892.5(7)	0.08(4)		
907.3(2)	0.36(4)		
911.7(4)	0.12(2)		
915.8(1)	2.60(5)	3.1	2.3
921.6(1)	1.92(5)	1.8	1.5
930.5(2)	0.20(2)		
934.9(1)	1.42(3)	1.3	1.2
941.2(1)	0.75(6)	0.7	0.7
949.6(3)	0.30(7) }	0.4	
951.4(9)	0.06(1) }		
955.3(2)	0.12(2)		
964.1(5)	0.03(1)		
968.9(3)	0.07(1)		
973.7(2)	0.15(2) }	0.2	
976.7(4)	0.05(1) }		
1009.4(4)	0.16(4)		
1017.8(4)	0.12(3)		0.6
1072.3(3)	0.13(3)		
1076.0(2)	0.22(3)		
1084.9(5)	0.03(1)		
1090.3(3)	0.05(1)		
1117.0(5)	0.19(3)		
1124.5(6)	0.04(2)		
1132.4(1)	0.24(3)	0.3	
1137.7(1)	0.52(4)	0.3	
1140.7(9)	0.05(2)		
1148.1(6)	0.10(4)		
1151.4(9)	0.06(3)		
1158.7(5)	0.09(3)		
1161.7(6)	0.06(4)		
1170.1(2)	0.18(3)		
1184.1(1)	1.08(2)	1.0	0.9
1196.7(6)	0.06(2)		0.9
1199.3(4)	0.10(2)		
1208.0(1)	0.32(3)		
1225.8(1)	0.36(4)		
1245.6(2)	0.18(2)		
1252.7(4)	0.05(2)		
1257.1(3)	0.09(2)		
1267.9(4)	0.08(2)		
1273.9(5)	0.06(3)		
1279.7(4)	0.07(3)		
1285.4(9)	~0.02		
1291.9(1)	0.29(3) }	0.3	
1298.3(1)	0.56(3) }		
1308.5(3)	0.11(2)		
1316.7(3)	0.12(2)		
1337.5(6)	0.03(1)		
1357.0(4)	0.06(2)		
1366.8(3)	0.09(2)		

Table 1 (continued)

This work Energy (keV)	This work I_γ	$I_\gamma^{a)}$	$I_\gamma^{b)}$	This work Energy (keV)	This work I_γ
1372.6(11)	0.08(2)			1929.3 (5)	0.05(1)
1379.1(11)	~0.05			1943.9 (2)	0.11(2)
1390.2 (4)	0.04(1)			1947.8 (4)	0.05(1)
1395.1 (2)	0.11(1)			1951.4 (4)	0.05(1)
1404.4 (7)	0.03(1)			1955.9 (4)	0.04(1)
1408.5 (3)	0.07(1)			1961.9 (2)	0.06(1)
1412.4 (3)	0.07(1)			1974.7(11)	0.08(4)
1416.9 (1)	0.18(2)			1981.9 (6)	0.12(6)
1427.2 (1)	0.32(2)			1994.7 (3)	0.05(2)
1454.4 (4)	0.05(1)			2000.4 (5)	0.03(1)
1474.7 (1)	0.32(2)	0.5		2007.6 (3)	0.06(2)
1480.3 (1)	0.72(2)	0.4		2020.6(15)	0.03(3)
1485.2 (3)	0.08(2)			2052.7 (3)	0.11(2)
1491.2 (5)	0.04(2)			2067.4 (4)	0.03(1)
1504.7 (1)	0.41(2)	0.3		2084.9 (4)	0.03(1)
1509.0(13)	0.06(2)			2102.9 (4)	0.08(2)
1517.6 (3)	0.07(1)		0.2	2112.9(10)	0.03(2)
1521.8 (2)	0.15(3)			2147.8 (7)	0.06(3)
1529.9 (6)	0.03(2)			2156.8 (6)	0.11(4)
1536.2 (6)	0.05(2)			2169.7 (4)	0.06(3)
1548.1 (9)	0.03(2)			2175.1 ([illegible])	0.05(3)
1553.4 (9)	0.06(2)			2183.7 (2)	0.17(2)
1558.8 (5)	0.09(2)			2201.9 (2)	0.10(3)
1563.2 (6)	0.06(2)			2214.6 (5)	0.07(2)
1576.6 (4)	0.07(2)			2233.6 (6)	0.05(2)
1592.8 (4)	0.07(2)			2238.2(10)	0.04(2)
1598.2 (8)	0.04(2)			2293.9 (4)	0.08(3)
1606.5 (2)	0.09(1)			2296.1 (3)	0.16(4)
1613.1 (1)	0.11(1)			2339.7 (2)	0.05(1)
1629.7 (2)	0.07(1)			2357.6 (3)	0.04(1)
1633.9 (1)	0.10(1)			2400.2 (5)	0.10(3)
1636.3 (6)	0.02(1)			2402.7(12)	~0.02
1663.0 (4)	0.06(2)			2415.2 (5)	0.08(2)
1665.5 (3)	0.09(2)			2420.2 (9)	0.04(3)
1673.9 (5)	0.04(2)			2432.3 (6)	0.15(3)
1678.4 (2)	0.33(2)	0.7		2434.1 (6)	0.14(3)
1682.6 (2)	0.19(2)			2440.6 (7)	0.02(1)
1708.8 (5)	0.05(2)			2446.9 (4)	0.05(1)
1716.5 (4)	0.07(2)			2451.9(13)	0.04(2)
1723.4 (4)	0.08(2)			2453.7(16)	0.03(2)
1729.7 (6)	0.03(2)			2456.9 (4)	0.06(2)
1747.8(10)	0.04(2)			2486.9 (7)	0.05(2)
1752.5(10)	0.04(2)			2489.7 (8)	0.04(2)
1769.2 (4)	0.07(2)			2539.4 (3)	0.04(1)
1776.0 (3)	0.08(2)			2542.6 (2)	0.07(1)
1784.6 (3)	0.07(2)			2582.6 (5)	0.04(1)
1792.5 (4)	0.06(2)			2586.1 (2)	0.11(1)
1802.0 (5)	0.05(2)			2591.2 (6)	0.03(1)
1820.1 (4)	0.05(2)			2595.5 (3)	0.04(1)
1833.6(12)	0.04(2)			2608.8 (4)	0.02(1)
1853.7(12)	0.15(5)			2620.4 (6)	0.02(1)
1857.3(12)	0.05(2)			2632.1 (7)	0.04(2)
1884.6(12)	0.02(1)			2637.1 (6)	0.06(3)
1897.7 (9)	0.02(1)			2657.2(12)	0.05(2)
1908.9 (2)	0.04(1)			2684.6 (2)	0.10(1)
1922.5 (2)	0.12(3)			2693.8 (3)	0.05(1)
1925.3 (7)	0.05(2)			2700.9 (5)	0.05(1)

Table 1 (continued)

This		work			
Energy (keV)	I_γ	Energy (keV)	I_γ	Energy (keV)	I_γ
2703.3(10)	~0.02	2813.1(14)	0.02(1)	2983.3 (3)	0.03(1)
2742.1 (3)	0.06(1)	2816.7(11)	0.02(1)	2995.6 (7)	0.03(1)
2745.0 (3)	0.04(1)	2861.4 (3)	0.03(1)	3006.9 (6)	0.03(1)
2750.3 (3)	0.03(1)	2871.6(10)	0.02(1)	3021.5 (3)	0.04(1)
2795.1 (7)	0.06(2)	2875.6 (5)	0.04(1)		

[a]) Ref.[5]); [b]) Ref.[6]); [c]) The values were determined on basis of γ-γ coincidence measurements; [d]) Deduced from the level scheme of ^{79}Kr; [e]) The value was obtained on the basis of γ-γ coincidence measurement and the internal conversion coefficient.

Table 2

Results of γ-ray prompt coincidence measurements associated with the decay of ^{79}Rb

Gate	$E_\gamma(I_\gamma)$
107.72	- 182.77(Y)
142	- 111(0.1),147.06(8.6),382.5(0.6),397.6(14.5),461.5(2.7), 774.1(1.4),788.3(0.4),841.6(0.1),1137.7(0.25),1184.1(0.62), 1416.9(Y),1504.7(Y)
148	- 143.41(10.0),154.82(2.0),201.2(0.3),218.8(0.16),302.4(Y), 382.5(Y),384.1(2.1),397.6(2.4),461.5(0.5),541.0(0.4),774.1 (Y),788.3(Y),1184.1(Y)
154.82	- 149.34(2.2),201.2(0.2),182.77(26.4),350.6(27.0),384.1(2.0), 533.3(4.6),921.6(Y)
160.76	- 382.5(0.35),397.6(7.9),461.5(1.7),774.1(0.6),788.3(0.3), 841.6(Y),1137.7(0.14),1184.1(0.31),1416.9(Y),1504.7(Y)
182.77	- 107.72(0.3),149.34(Y),154.82(25.7),201.2(0.6),218.8+219.3 (4.4),286.2(1.7),350.6(30.5),505.4(44.8),569.2(3.5),663.1 (Y),724.4(0.4),786.0(0.3),921.6(0.8),941.2(0.7),1117.0(0.2), 1208.0(Y),1245.6(0.1),1291.9(0.21),1427.2(0.24),1629.7(Y), 1678.4(0.16),1922.5(Y),2183.7(Y)
219	- 182.77(3.4),286.2(1.8),350.6(1.5),384.1(Y),533.3(0.3), 663.1(Y)
275.1	- 384.1(0.4)
286.2	- 182.77(1.6),219.3(1.7),401.8(1.9)
303	- 302.4(1.2),320.2(0.54),384.1(0.5)
350.6	- 154.82(27.6),182.77(32.7),218.8(1.6),921.6(0.2),941.2(0.66)
383	- 143.41(0.54),149.34(2.4),154.82(2.0),160.76(0.34),218.8(Y), 275.1(0.5),304.0(0.7),1225.8(Y)
397.6	- 143.41(13.2),147.06(1.7),160.76(7.5),921.6(0.2)
401.8	- 286.2(2.1),663.1(0.2),1208.0(0.1)
461.5	- 143.41(2.5),147.06(0.4),160.76(1.8)
506	- 116.25(Y),182.77(42.3),428.7(Y),921.6(0.67)
533.3	- 154.82(4.8),218.8(0.24),941.2(Y)
569.2	- 182.77(4.1)
663.1	- 219.3(Y),401.8(Y)
[illegible].1	- 921.6(1.0)
[illegible].1	- 143.41(1.1),160.76(0.61)

Table 2 (continued)

Gate		$E_\gamma(I_\gamma)$
787	-	143.41(0.48),160.76(0.4),182.77(0.5),688.1(Y)
921.6	-	143.41(0.1),154.82(0.3),160.76(0.14),182.77(0.5),350.6 (0.25),397.6(0.2),505.4(0.3),688.1(0.8)
1184.1	-	143.41(0.52),160.76(0.37)
1427.2	-	182.77(0.31)
1922.5	-	182.77(Y)

Table 3

Internal conversion coefficients for γ-transitions in ^{79}Kr

E_γ (keV)	I_γ	Normal. $I_e x10^2$	λ	Experiment α_λ x 10^2	Theoretical α_λ x10^2 a) E1	M1	E2	E3	Multip.
52.42	1.26	78	K	60 (35)	56	72	800		M1,E1
63.84	0.36	17	K	47 (25)	32	43	400		M1,E1
129.72	46.5	9765	K	210[b] (10)	3.0	5.6	30	210	E3
143.41	60.2	229	K	3.8 (17)	2.7	4.3	21		
147.06	45.4	817	K	18.0 (8)	2.5	4.0	18.5		E2
154.82	34.2	174	K	5.1 (10)	2.2	3.5	16.0		M1+E2
154.82	34.2	16.4	L+M	0.48 (8)	0.28	0.46	2.4		M1+E2
160.76	37.2	257	K	6.9 (10)	1.95	3.2	14.0		M1+E2
160.76	37.2	33.5	L+M	0.90 (7)	0.25	0.4	2.1		M1+E2
182.77	83.0	191	K	2.3 (1)	1.35	2.3	8.2		M1
182.77	83.0	24.1	L+M	0.29 (2)	0.15	0.28	1.3		M1
218.8 } 219.3 }	4.9	12.7	K	2.6 (2)	0.8	1.45	4.5		M1+E2
350.6	31.3	7.5	K	0.24 (7)	0.22	0.45	0.88		E1
397.6	26.2	8.1	K	0.31 (6)	0.15	0.33	0.58		M1
401.8	3.5	2.5	K	0.70 (30)	0.15	0.32	0.56		E2
505.4 } 506 }	55	5.5	K	0.10 (2)	0.08	0.19	0.26		} E1 M1,E2
622.2	38	4.9	K	0.13 (2)	0.05	0.12	0.15		M1,E2
688.1	100	4.0	K	0.04 (1)	0.04	0.094	0.11		E1

a) Ref.[18]

b) Assumed value for normalization.

There is a considerable disagreement (25%) in the intensity of the 129.72 keV isomeric transition between the values of Broda et al.[5] and ours. This discrepancy might be explained by the flying of the volatile ^{79}Kr isomer ($T_{1/2}$ = 55 sec) from Broda's et al.[5] sources.

The observation of a γ-ray line in the prompt spectrum coincident with a gating γ-ray is indicated in Table 2 by the symbol Y or the value of its coincidence intensity.

The time coincidence spectra between any two γ-transitions have revealed only one half-life from the region of tenths nsec up to hundredths nsec. The half-life $T_{1/2}$ = (78±6) nsec was observed in the gates of 147.1 and 143.4 keV.

4. DECAY SCHEME

The decay scheme of ^{79}Rb has been constructed on the basis of γ-γ coincidence data, taking into account the intensities and energies of relevant γ-transitions. The results of the nuclear reaction studies[1-4] have been used, too. We have used the program of Hons[19] to check the constructed level scheme. No difference has been found. The log ft values for β^+-EC feeding of the levels in the ^{79}Kr have been calculated using the half-life of ^{79}Rb ($T_{1/2}$ = 22.8 min[5]), the theoretical calculation of the EC/β^+ ratio[20], Q_{EC} = 3680 keV, the ratio $I_\gamma(511)/I_\gamma(688.1)$ = 7.15±0.60 and the total intensities of γ-transitions given in Table 1.

Because of a large number of transitions and involved states, a detailed discussion of each level is not given. Instead, comments on specific points of interest are presented below.

The proposed decay scheme, see Fig.4, accomodates only 123 of 235 γ-transitions observed in this study. In any case, the total intensity of the unassigned γ-rays is < 2% per decay.

The sensitivity of our coincidence experiments was high enough (for E_γ >100 keV) to detect coincidences with the relatively strong γ-rays, e.g., 524.7, 543.7, 558.3, 603.2, 622.2, 915.8 and 934.9 keV. Since we did not observe these γ-rays in the coincidence spectra, we suggest that they populate either the ground, the first excited isomeric state or the 148.82 keV level which deexcites only by 19.1 keV transition to the isomeric state. Hence, the above mentioned as well as several other very low intensity transitions are placed in the level scheme on the basis of energy differences only.

4.1. Spin-Parity Assignments

On the basis of available experimental information on the levels in ^{79}Kr, it is possible to make spin and parity assignments for some of these levels. These assignments are shown in the level scheme given in Fig.4.

There are some arguments /21/ (the β-decay of ^{79}Kr the (d,p) reaction) for taking $1/2^-$ as the spin-parity of ^{79}Kr ground state. The E3 multipolarity of the 129.72 keV isomeric transition establishes $J^\pi = 7/2^+$ of the 129.72 keV level.

The value of J^π for the 147.06 keV level is $5/2^-$ as follows from the E2 multipolarity of 147.06 keV transition to the ground state ($1/2^-$) and the half-life $T_{1/2}$ = 78 nsec of this state.

The gamma feeding from higher levels indicates that the 148.83 keV level has a larger spin than the 129.72 keV level ($7/2^+$). The (d,p) data /2/ show $\ell = 4$ for the orbital angular momentum of the neutron transferred to the 148.83 keV state. The existence of a low-lying $9/2^+$ state is demonstrated in ^{81}Kr /22/. Therefore, we suggest $J^\pi = 9/2^+$ for the 148.83 keV level.

The spin-parity of the 182.77 keV level is $3/2^-$. It follows from transition multipolarities of 182.77 (M1), 219.3 (M1) and 350.6 keV (E1).

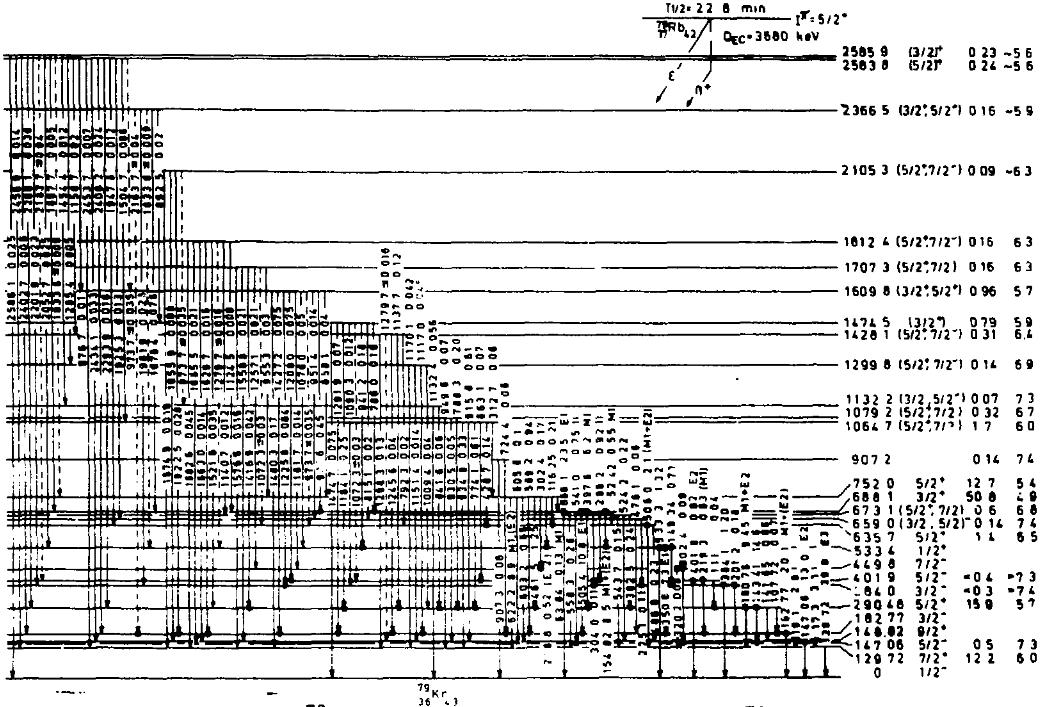

Fig. 4. Level scheme of ^{79}Kr populated in the decay of ^{79}Rb. A dot indicates the coincidence relationships. The total intensities of the transitions are normalized on 100 decays of ^{79}Rb.

The positive parity for levels of 290.48, 533.4, 688.1 and 752.0 keV excitation energy is unambiguously determined from the multipolarities of the 160.76 (M1 +30% E2), 397.6 (M1), 350.6 (E1), 154.82 (M1 +E2), 688.1 (E1) and 622.2 keV (M1,E2) transitions. These assignments do not agree with the proposals of the authors /1,5,6/ but they get a support from the (d,p) reaction study of Chao et al. /2/

We should like to emphasize that these assignments are critical for our next conclusions but we have not been able to find the way to reconsile our data with the published deductions /5,6/.

The low logft values of 4.9 and 5.4 for the β^+-decay to the 688.1 and 752.0 keV levels, respectively, are indicative of allowed β^+-transitions. It follows that the ground state of the parent nucleus, ^{79}Rb, has even parity. The atomic beam measurement /23/ gives the spin of 5/2. Therefore, the spin-parity of the ground state of $^{79}_{37}$Rb is $5/2^+$.

The authors of ref. /1/ have arrived at odd parity for 290.48 keV level. The multipolarities of M1 and E1 for 143.41 and 160.76 keV transitions, respectively, were their starting point. Our results which have been obtained with better energy resolution (see Fig. 3) disagree with these multipolarities. The spin-parity of 290.76, 688.1 and 752.0 keV levels was determined to be $5/2^+$, $3/2^+$ and $5/2^+$, respectively, on the basis of multipolarities of relevant γ-transitions.

The levels at 401.9, 533.4 and 635.7 keV of excitation energy have $J^\pi = 5/2^-$, $1/2^+$ and $5/2^+$, respectively. These values of J^π were determined taking into account the multipolarities of γ-transitions and ways in which the levels are deexcited. The assignments for these levels agree with the results of (d,p) /2/ and (α,nγ) /4/ reaction works.

The values of J^π for 384.0 ($3/2^-$) and 449.8 keV ($7/2^-$) levels are based on works of Chao et al. /2/ and Forssten et al. /4/. The arguments that have been made up to this point may be regarded as strong.

The use of weak arguments (systematics of log ft values, γ-ray branching ratios, systematics of photon transition probabilities) gives tentative spin-parity assignments for the higher-lying levels of ^{79}Kr. In view of the large number of levels, the arguments that lead to the assignments shown in Fig. 4 are not given in detail.

5. DISCUSSION

Using β-branching and ICC measurements along with γ-transition information, spin-parity ranges have been determined for virtually all the levels in ^{79}Kr populated in the decay of ^{79}Rb. From weak arguments, these ranges may be narrowed to one or two values.

Thus, for some levels, it has become possible to make meaningful comparison between experimental results and theoretical model predictions. The level structure of ^{79}Kr may be discussed in a framework of two groups of theoretical models.

First group uses a concept of the spherical even-even core and coupling between single particle (quasi-particle or cluster of particles) and vibrational phonons.

The simplest model of a neutron $p_{1/2}$ hole coupled to the 2^+ phonon state of ^{78}Kr (455 keV) predicts two states $3/2^-$ and $5/2^-$ at phonon energy. We postulate the two levels ($3/2^-$ (384.0 keV) and $5/2^-$ (401.9 keV)) that can be fitted in this picture.

It is considerably more difficult to test this class of models with regard to even parity states (namely, $7/2^+$ (129.72 keV), $5/2^+$(290.48 keV) and $1/2^+$(533.4 keV)) which have to arise from 1-3 neutrons in the $1g_{9/2}$ shell.

The calculations of Kisslinger and Sorensen /7/ using a particle-phonon approach with a pairing-plus-quadrupole residual interaction have failed with respect to the positive parity states since a low-lying $7/2^+$ state had not been predicted without a very strong quadrupole interaction [24]. In addition, the M1 transition between $7/2^+$ and $9/2^+$ states was forbidden, which seems to be in disagreement with our experimental data (see, also [22]).

Ikegami and Sano [25] have shown that taking into account a larger number of shell-model orbits, low-lying $7/2^+$, $5/2^+$ and $9/2^+$ states are generated in $^{77-81}Se_{43-47}$ nuclei. Unfortunately, their calculations suggest that the $5/2^+$ state should always occur below the $7/2^+$ state. This is not an experimental case.

Alaga's model – coupling a few-particle cluster to the vibrational field – was successfully applied by Paar [8] to $_{47}Ag$ nuclides. Unfortunately, no calculations of this type exist for N=45 but results of ref. [26] have shown that the properties of states in $^{83}Kr_{47}$ are possible to describe by Paar's wave functions taking into account an effective charge and the gyromagnetic ratio of neutron. Therefore, we have tried to compare our level scheme of ^{79}Kr (the neutron shell structure $n(1g_{9/2})^3$) with the calculations of the level scheme of $_{47}Ag(p(1g_{9/2})^{-3})$. The comparison has shown that Paar's calculation [8] of negative parity states reproduces the number and the order of states as well as their spins but does not reproduce their energy. It is hardly a surprise because of the large difference at a phonon energy (1 MeV for Ag and 0.4 MeV for Kr). Nevertheless, the agreement is remarkable.

The same thing cannot be said with respect to the comparison of Paar's calculation [8] of even parity states with our proposed level scheme. The calculation is able to reproduce $7/2^+$ and $9/2^+$ states as well as some other but it fails on the $1/2^+$ state (533.4 keV) and the $5/2^+_3$ state (752.0 keV). These states are not reported and they are probably very high-lying.

Another approach to understanding the level structure of ^{79}Kr is to assume that we are dealing with deformed nuclei, at least in the case of certain levels. Next arguments give a support to such an idea: a) the even parity of ^{79}Rb. There is only one theory, to our knowledge, capable to explain this parity. The model worked out by Scholz and Malik [27] describes a coupling of an odd particle to the rotating deformed core where Coriolis interaction acting on the odd particle as well as a residual interaction of pairing type acting on nucleons of the core are taken into account. Their calculations of even parity states in the region of $Z \approx 35$ have shown that it is possible to obtain the $5/2^+$ state below the $9/2^+$ one for reasonable deformation $\beta \approx 0.16$; b) the relatively low energy of the 2^+ state in the neighbouring even-even Kr nuclei (e.g., 455 keV in ^{78}Kr); c) the existence of quasi-rotational band in ^{78}Kr; d) the large value of $B(E2, 2^+ \to 0^+)$ in ^{78}Kr and ^{80}Kr.

The model of Scholz and Malik [27], the so-called Coriolis coupling model (the CC model), has been applied by Heller and Friedman [10] to the odd-neutron in the $1g_{9/2}$ shell for several values of $N = 41-49$ and $Z = 32-36$.

Again, it is better to distinguish the positive from negative parity states when we want to compare the experimental spectrum of levels in ^{79}Kr with the calculated one [10].

Such a comparison of negative parity states shows that better agreement of the CC model with the experiment is obtained if we suppose positive deformation $\beta \approx 0.15$ for ^{79}Kr (the value $\beta \approx 0.15$ follows from the crossing of $3/2^-_1$ and $5/2^-_1$ states; see Fig. 10 of ref. [10]). As regards the energy, the CC model does not give correct values as well as the low-lying $3/2^-$ state (384.0 keV).

The comparison of the positive parity states of the ^{77}Se model nucleus with our experiment reveals some very interesting facts. If we take a positive value of deformation β, as follows from the negative parity states we are not able to reproduce the close doublet of the $7/2^+$ and $9/2^+$ states. Moreover, the CC model predicts $5/2^+$ state between the $7/2^+$ and $9/2^+$ states. Such a state has not been observed in any experiments.

The above mentioned doublet of states is reproduced by the CC model if we take a negative value of β. In such a case the CC model contains all the observed excited levels except the third $5/2^+$ state (752.0 keV). Again, the CC model does not reproduce the order and energy of excited states (e.g., $1/2^+$ state (533.4 keV) is predicted to be higher than 1500 keV). If we believe that the ^{78}Kr is an axial symmetric deformed nucleus and the odd neutron is coupled to this core in the way predicted by Coriolis coupling model[10] then we are forced to acknowledge a different deformation for the states of different parity.

If we suppose that the β^+-decaying $5/2^+$ state of ^{79}Rb is described by the wave function given by Scholz and Malik[27], then some possibility exists for the interpretation of states of ^{79}Kr. The $5/2^+$ state of ^{79}Rb is a mixture[27] of $1/2^+[440]$, $3/2^+[431]$ and $5/2^+[422]$ *Nilsson proton states with the main component* of $1/2^+[440]$. If the proton in the $1/2^+[440]$ state transmits then allowed unhindered β-transitions are *going to the states with the main component of* $1/2^+[440]$. There are two such β^+-transitions, *namely*, transition to the 688.1 keV level ($3/2^+$, $\log ft = 4.9$) and *transition to the 752.0 keV level* ($5/2^+$, $\log ft = 5.4$). *The ratio of values* $ft(688.1)/ft(752.0)$ *does not* contradict to well-known Alaga's rule[28].

The $1/2^+$ state of 533.4 keV excitation energy is *taken as a band-head of the rotational band on* the Nilsson $1/2^+[440]$ state. The parameters of the rotational band are $\hbar^2/2\theta = 37.7$ keV and $a = 1.1$ (θ - the moment of the inertia, a - decoupling parameter). It may be worth to remark that the parameter $\hbar^2/2\theta$ is equal to 39.8 keV at an even-even neighbour nucleus, i.e., ^{78}Kr. The analysis of the γ-ray branching ratio of the 752.0 keV does not contradict to such interpretation.

It is possible to construct a ground state rotational band: g.s. (1/2$^-$[301] Nilsson state), 182.77 (3/2$^-$) and 409.1 keV (5/2$^-$)levels. The intensities of γ - transitions from the level of the 1/2$^+$[440] rotational band to the levels of 1/2$^-$[301] rotational band are not contrary to Alaga's known-rules for the branching ratio of γ-transitions from the level of one rotational band to the levels of a second rotational band.

We would like to emphasize that the above mentioned interpretation of levels in ^{79}Kr is only tentative (e.g., the origin of 7/2$^+$(129.72 keV) and $5/2^+_1$ (290.48 keV) levels is very unclear. The rotational bands based on 1/2$^+$[440] and 1/2$^-$[301] Nilsson states have the properties of relatively pure bands (an admixture of another K is small). On the other hand, the explanation of 7/2$^+$ and $5/2^+_1$ states requires relatively much admixtures of another K.

The authors are grateful to Dr. C.Vylov and his co-workers for help during the measurements of internal conversion electron spectra.

REFERENCES

1. Bharati S.M. et al. Pramana, 1975, 4, p.25.
2. Chao J. et al. Phys.Rev., 1975, C11, p.1237.
3. Andersen S.L. et al. Ann.Rep.Res.Inst.Phys., Stockholm, 1971, p.107.
4. Forssten K. et al. Ann.Rep.Res.Inst.Phys., Stockholm, 1974, p.96.
5. Broda R. et al. Acta Phys. Pol., 1972, B3, p.263.
6. Lingeman E.W.A. et al. Nucl.Phys., 1971, A160, p.630.
7. Kisslinger L.S., Sorensen R.A. Rev.Mod.Phys., 1963, 35, p.853.
8. Paar V. Nucl. Phys., 1973, A211, p.29.
9. Kuriyama A. et al. Progr.Theor.Phys.Suppl., 1975, 58, p.1.
10. Heller S.L., Friedman J.N. Phys.Rev., 1974, C10, p.1509. and Phys.Rev., 1975, C12, p.1006.

11. Beyer G. et al., to be published.
12. Vylov C. et al. JINR, P6-10414, Dubna, 1977.
13. Aubin G. et al. Nucl.Instr. and Meth., 1969, 76, p.93.
14. Gehrke R.J. et al. Nucl.Instr. and Meth., 1971, 91, p.349.
15. Hansen J.S. et al. Nucl.Instr. and Meth., 1973, 106, p.365.
16. Honusek M., Fromm W.-D. JINR, 10-10007, Dubna, 1976.
17. Vylov C. et al. JINR, P6-9071, Dubna, 1976.
18. Hager R.S., Seltzer E.C. Nucl.Data., 1968, A4, p.1.
19. Hons Z., private communication.
20. Dzhelepov B.S. et al. Beta Processes, "Nauka", M., 1973.
21. Urone P.P., Kocher D.C. Nucl.Data Sheets, 1975, 15, no. 3.
22. Liptak J. et al. Nucl.Phys., 1977, A286, p.263.
23. Ekström C. et al. 3rd Int.Conf.on Nucl. Far from Stability, Cargese, Corsica, 1976, p.193.
24. Kisslinger L.S. Nucl.Phys., 1966, 78, p.341.
25. Ikegami H., Sano M. Phys.Lett., 1966, 21, p.323.
26. Krištiak J. et al., to be published.
27. Scholz W., Malik F.B. Phys.Rev., 1968, 176, p.1355.
28. Alaga G. et al. Dan.Mat.Fys.Medd., 1955, 29, no. 9.

Received by Publishing Department
on November 17, 1977.

ТЕМАТИЧЕСКИЕ КАТЕГОРИИ ПУБЛИКАЦИЙ ОБЪЕДИНЕННОГО ИНСТИТУТА ЯДЕРНЫХ ИССЛЕДОВАНИЙ

Индекс	Тематика
1.	Экспериментальная физика высоких энергий
2.	Теоретическая физика высоких энергий
3.	Экспериментальная нейтронная физика
4.	Теоретическая физика низких энергий
5.	Математика
6.	Ядерная спектроскопия и радиохимия
7.	Физика тяжелых ионов
8.	Криогеника
9.	Ускорители
10.	Автоматизация обработки экспериментальных данных
11.	Вычислительная математика и техника
12.	Химия
13.	Техника физического эксперимента
14.	Исследования твердых тел и жидкостей ядерными методами
15.	Экспериментальная физика ядерных реакций при низких энергиях
16.	Дозиметрия и физика защиты
17.	Теория конденсированного состояния

Издательский отдел Объединенного института ядерных исследований.
Заказ 24181. Тираж 475. Уч.-изд. листов 1,29.
Редактор Э.В.Ивашкевич. Подписано к печати 26.12.77 г.
Корректор Р.Д.Фомина.