ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ
ДУБНА

E15 - 10210

V.S.Butsev, D.Chultem, Yu.K.Gavrilov,
Dz.Ganzorig, V.Presperin

NEGATIVE PION CAPTURE BY MEDIUM NUCLEI IN THE Z≈50 REGION

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Submitted to "Nuclear Physics"

Бутцев В.С. и др. **E15 - 10210**

Захват отрицательных пионов ядрами в области $Z \simeq 50$

Выполнены эксперименты по изучению механизма захвата отрицательных пионов ядрами средней области масс ($Z \simeq 50$, $A \simeq 100$).

Установлено, что множественность вылетающих нуклонов в реакции (π^-, xn) так же, как и для тяжелых ядер ($Z \simeq 82, A \simeq 200$), достигает 14-15 единиц. Однако, в отличие от тяжелых ядер, число испущенных протонов увеличивается и достигает 4 единиц.

Показано также, что для исследуемой области ядер с большой вероятностью возбуждаются высокоспиновые состояния, причем эффект наблюдается независимо от зарядового состава вылетающих частиц.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Препринт Объединенного института ядерных исследований
Дубна 1976

Butsev V.S. et al. **E15 - 10210**

Negative Pion Capture by Medium Nuclei in the $Z \simeq 50$ Region

The experiments have been performed to investigate negative pion absorption at rest in medium nuclei ($Z \simeq 50, A \simeq 100$).

The multiplicity for emerging nucleons has been shown to reach 14-15 similar to heavy nuclei. However, in the case of medium nuclei proton multiplicity appears to be much larger. The excitation of high-spin states in residual nuclei takes place similarly to the case of heavy mass nuclei. This effect occurs independently of the charge composition of emitted particles.

Preprint of the Joint Institute for Nuclear Research

Dubna 1976

1. INTRODUCTION

In 1974 a new physical phenomenon was discovered in Dubna, namely, the excitation of high spin nuclear states in negative pion capture[1,2]. To understand this process experiments with heavy ($Z \simeq 82$)[3,4] and medium mass nuclei ($Z \simeq 50$)[5] were performed. These nuclei belong to the so-called "isomeric islands" (Fig. 1) and are very convenient for identifying high spin states by the activation method. On the other hand, when passing from the region of heavy nuclei to the medium mass ones there appears a possibility of investigating the effect of the Coulomb barrier on the isotope yield and on the formation of high-spin states. π^- capture on Sb, Sn, In, Cd, Ag, Pd nuclei has been investigated.

2. EXPERIMENT

Targets about 2 g/cm^2 thick were irradiated by the moderated negative pion beam from the LNP synchrocyclotron (E_π =30 MeV). The density of stopping negative pions was 10^4 g^{-1} xsec^{-1}. The results of the identification of isotopes produced in (π^-,xn,y p) reactions are listed in Tables 1-6. Typical γ -spectra for different targets are shown in <u>Figs. 2-4</u>.

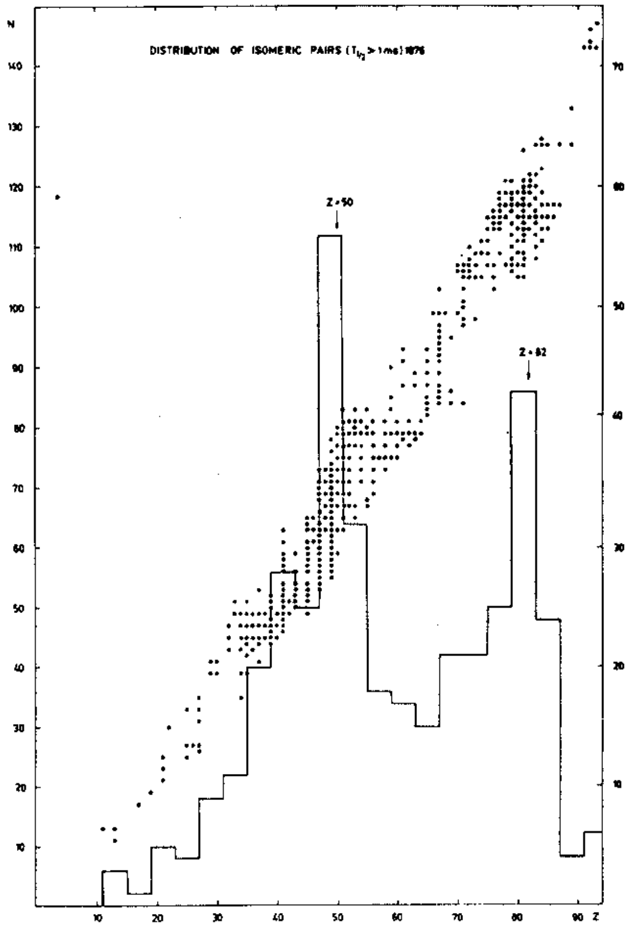

Fig. 1. Distribution of isomeric pairs. The histogram shows the Z -dependence of the number of isomeric pairs.

Table 1. Isotopes (isomers) produced in the Sb + π^- reaction.

A	Sn			In			Cd		
	$T_{1/2}$	J^π	E_γ(keV)	$T_{1/2}$	J^π	E_γ(keV)	$T_{1/2}$	J^π	E_γ(keV)
1	2	3	4	5	6	7	8	9	10
118	∞	0^+		5 s 4.4 m	1^+ $4,5^+$	 —	503 m	0^+	—
117	∞ 14 d	$1/2^+$ $11/2^-$	 —	44 m 1.94 h	$9/2^+$ $1/2^-$	158.6 552.8 —	2.42 h 3.31 h	$1/2^+$ $11/2^-$	— —
116	∞	0^+		14 s 54 m	1^+ 5^+	 138.3 417.0 818.7 1097.3 1293.4 1507.8	$>10^{17}$ y	0^+	
115	∞ $59\cdot10^{-[illegible]}$ s	$1/2^+$ $11/2^-$		∞ 4.5 h	$9/2^+$ $1/2^-$	 336.3	53.5 h 4.5 d	$1/2^+$ $11/2^-$	— —
114	∞	0^+		72 s 50 d	1^+ 5^+	— —	∞	0^+	
113	115 d 20 m	$1/2^+$ $7/2^+$	— —	∞ 1.7 h	$9/2^+$ $1/2^-$	 391.7	∞ 14 y	$1/2^+$ $11/2^-$	
112	∞	0^+		14 m 21 m	1^+ 4^+	606.4 617.1 155.5	∞	0^+	
111	35 m	$7/2^+$	—	2.8 d 7.7 m	$9/2^+$ $1/2^-$	150.8 171.3 245.4 —	∞ 48.6 m	$1/2^+$ $11/2^-$	 150.8 245.4
110	4 h	0^+	283.0	69 m 4.9 h	2^+ 7^+	657.5 641.7 657.5 707.4 884.7 937.5	∞	0^+	
109	18 m		—	4.3 h 1.34 m	$9/2^+$ $1/2^-$	— —			

Table 2. Isotopes (isomers) produced in the $Sn + \pi^-$ reaction.

A	In			Cd			Ag		
	$T_{1/2}$	J^{π}		$T_{1/2}$	J^{π}		$T_{1/2}$	J^{π}	
1	2	3	4	5	6	7	8	9	10
119	2.1m 18m	$9/2^+$ $1/2^-$	— —	2.6m 1.9m		— —	6s		
118	5s 4.4m	1^+ $4,5^+$	 640.8 690.9 1049.5 1230.9	50.3m	0^+	—	37s 2.8s		
117	44m 1.94h	$9/2^+$ $1/2^-$	158.6 396.6 552.8 158.6 315.3	2.42h 3.31h	$1/2^+$ $11/2^-$	— —	73s 5.3s		
116	14s 54m	1^+ 5^+	 417.0 818.7 1097.3 1293.4 1507.8	$>10^{17}$ y	0^+		2.7m 10.4s		
115	∞ 4.5h	$9/2^+$ $1/2^-$	336.3	53.5h 4.5d	$1/2^+$ $11/2^-$	— —	20m 19s	$1/2^-$	—
114	72s 50d	1^+ 5^+	— —	∞	0^+		4.5s		
113	∞ 1.7h	$9/2^+$ $1/2^-$	391.7	∞ 14y	$1/2^+$ $11/2^-$		5.37h 1.1m	$1/2^-$ $7/2^+$	— —
112	14m 21m	1^+ 4^+	606.4 617.1 155.5	∞	0^+		3.12h	2^-	—
111	2.8d 7.7m	$9/2^+$ $1/2^-$	171.3 245.4 536.3	∞ 48.6m	$1/2^+$ $11/2^-$	150.8 245.4	7.5d 1.2m	$1/2^-$ $7/2^+$	— —
110	69m 4.9h	2^+ 7^+	657.5 641.7 657.5 707.4 884.7 937.5	∞	0^+		24.6s 250.4d	1^+ 6^+	—

Table 2 (continued)

1	2	3	4	5	6	7	8	9	10
109	4.3 h 1.34 m	$9/2^+$ $1/2^-$	203.5 —	453d	$5/2^+$		∞ 39.6s	$1/2^-$ $7/2^+$	
108	39.6m 58m	3^+ $5,6^+$	633.2- 244.5 327.6 633.2 876.0 1056.3	∞	0^+		2.41m 127 y	1^+ 6^+	—
107	32.7m 52 s	$9/2^+$ $1/2^-$	204.9 320.9 505.5	6.5h	$5/2^+$	—	∞ 44.3s	$1/2^-$ $7/2^+$	
106	5.33m 6.3m	$2,3^+$ $5,6,7^+$	— —	∞	0^+		24 m 8.3d	1^+ 6^+	— —
105	5.1m	$9/2^+$	—	55 m	$5/2^+$	—	41d 72.3m	$1/2^-$ $7/2^+$	— —

Table 3. Isotopes (isomers) produced in the In + π^- reaction.

A	Cd			Ag			Pd		
	$T_{1/2}$	J^{π}		$T_{1/2}$	J^{π}		$T_{1/2}$	J^{π}	
1	2	3	4	5	6	7	8	9	10
115	53.5h 4.5d	$1/2^+$ $11/2^-$	— —	20 m 19 s	$1/2^-$		45 s		
114	∞	0^+		4.5 s			2.4 m	0^+	
113	∞ 14 y	$1/2^+$ $11/2^-$		5.37h 1.1 m	$1/2^-$ $7/2^+$	— —	1.6 m		—
112	∞	0^+		3.12h	2^-	—	20.1h	0^+	—
111	∞ 48.6 m	$1/2^+$ $11/2^-$	150.8 245.4	7.5 d 1.2 m	$1/2^-$ $7/2^+$	— —	22 m 5.5 h	$5/2^+$ $11/2^-$	— —
110	∞	0^+		24.6s 250.4d	1^+ 6^+		∞	0^+	
109	453d	$5/2^+$		∞ 39.6 s	$1/2^-$ $7/2^+$		13.46 h 4.69 m	$5/2^+$ $11/2^-$	— —
108	∞	0^+		2.41 m 127 y	1^+ 6^+	—	∞	0^+	
107	6.5 h	$5/2^+$	—	∞ 44.3 s	$1/2^-$ $7/2^+$		$6.5 \cdot 10^6$y 21.3 s	$5/2^+$ $11/2^-$	
106	∞	0^+		24 m 8.3 d	1^+ 6^+	— —	∞	0^+	
105	55m	$5/2^+$	—	41 d 7.23m	$1/2^-$ $7/2^+$	— —	∞	$5/2^+$	

Table 3 (continued)

1	2	3	4	5	6	7	8	9	10
104	58 m	0^+	—	69.2 h 33.5 m	5^+ 2^+	— —	∞	0^+	
103	7.3 m		—	1.1 h 5.7 s	$7/2^+$ $1/2^-$	—	17d	$5/2^+$	—
102	5.5m		—	13 m 8 m		— —	∞	0^+	
101	1.2 m		—	10.8 m	$9/2^+$	—	8.47 h	$5/2^+$	—

Table 4. Isotopes (isomers) produced in the Cd + π^- reaction.

A	Ag			Pd			Rh		
	$T_{1/2}$	J^π		$T_{1/2}$	J^π		$T_{1/2}$	J^π	
1	2	3	4	5	6	7	8	9	10
113	5.37h 1.1m	$1/2^-$ $7/2^+$	— —	1.6m		—	0.9s		
112	3.12h	2^-	606.7 617.4 694.8 718.4 797.8 851.2 861.6 1007.0 1312.3 1387.7 1613.6 2106.2	20.1h	0^+	—	4.7s		
111	7.5d 1.2m	$1/2^-$ $7/2^+$	— —	22m 5.5h	$5/2^+$ $11/2^-$	1388.4 1458.7 172.2	62.7s		
110	24.6 s 250.4d	1^+ 6^+	— —	∞	0^+		27.7s 3 s		
109	∞ 39.6s	$1/2^-$ $7/2^+$		13.46h 4.69m	$5/2^+$ $11/2^-$	— 188.9	80s 50s		—
108	2.41m 127y	1^+ 6^+	—	∞	0^+		16.8s 5.9m	1^+	
107	∞ 44.3s	$1/2^-$ $7/2^+$		6.5·10 y 21.3 s	$5/2^+$ $11/2^-$		22 m	$5/2^+$	—
106	24m 8.3d	1^+ 6^+	— 406.0 429.5 450.8 511.8 616.0 717.1 748.2 803.9 824.5 1045.7 1127.8 1199.1 1527.0	∞	0^+		30 s 2.2h	1^+ $5,6^+$	— —
105	41 d 7.23m	$1/2^-$ $7/2^+$	— 280.4 306.3 319.2	∞	$5/2^+$		35.5h 45 s	$7/2^+$ $1/2^-$	—

Table 4 (continued)

1	2	3	4	5	6	7	8	9	10
104	69.2m 33.5m	5^+ 2^+	555.8 758.6 767.4 785.4 924.2 941.2 941.2 1625.4 1780.8	∞	0^+		42 s 44 m	1^+ 5^+	———
103	1.1 h 5.7 s	$7/2^+$ $1/2^-$	118.7 148.2 243.9 266.8 1155.3 1273.8	17 d	$5/2^+$		∞ 56.1m	$1/2^-$ $7/2^-$	———
102	13 m 8 m		555.9 718.9 ———	∞	0^+		206d 2.9 y	$0,1,2^-$	
101	10.8m	$5/2^+$	———	8.47 h	$5/2^+$	296.3 565.8 590.4 723.8	3 y 4.4 d	$1/2^-$ $9/2^+$	———
100	8 m 2.3 m		——— ———	3.7 d	0^+	446.2 539.6 822.2 1107.1 1362.1	20 h	1^-	———
99	1.8 m		———	21.4 m	$5/2^+$	———	16 d 4.7 h	$1/2^-$ $9/2^+$	——— ———

Table 5. Isotopes (isomers) produced in the Ag + π^- reaction.

A	Pd			Rh			Ru			Tc		
	$T_{1/2}$	J^π		$T_{1/2}$	J^π		$T_{1/2}$	J^π		$T_{1/2}$	J^π	
1	2	3	4	5	6	7	8	9	10	11	12	13
108	∞	0^+		16.8s 5.9m	1^+	—	4.5m	0^+	—	5.2 s		
107	$6.5\cdot10^6$y 21.3 s	$5/2^+$ $11/2^-$		22 m	$5/2^+$	302.7	3.8m		—	29 s		
106	∞	0^+		30 s 2.2h	1^+ $4,5,6^+$	406.0 429.4 450.8 511.7 616.1 716.2 1046.7 1127.7	368d	0^+		36s		
105	∞	$5/2^+$		35.5h 45 s	$7/2^+$ $1/2^-$	319.2	44.4h	$5/2^+$	—	7.8m		
104	∞	0^+		42s 4.4m	1^+ 5^+	—	∞	0^+		18m		—
103	17d	$5/2^+$	—	∞ 56.1m	$1/2^-$ $7/2^+$	— —	39.4d	$5/2^+$	—	50 s		
102	∞	0^+		206d 2.9y	$0,1,2^-$	—	∞	0^+		5.3s 4.3m	1^+	—
101	8.47h	$5/2^+$	269.6 296.3 565.8 590.4 723.8	3y 4.4d	$1/2^-$ $9/2^+$	306.8	∞	$5/2^+$		14 m	$9/2^+$	—
100	3.7d	0^+	—	20h	1^-	446.2 539.6 822.2 1107.1 1362.1	∞	0^+		15s	1^+	
99	21.4 m	$5/2^+$	136.0 263.6	16 d 4.7h	$1/2^-$ $9/2^+$	— 277.2 340.6 528.2 618.0 1260.7	∞	$5/2^+$		$2\cdot10^5$y 6h	$9/2^+$ $1/2^-$	140.3

Table 5 (contintinued)

1	2	3	4	5	6	7	8	9	10	11	12	13
98	18 m	0^+	—	9.1 m 3 m	3^+	652.6 —	∞	0^+		$1.5\cdot10^6$ y	$6,7^+$	
97	3.3 m	$5/2^+$	—	30 m 45 m	$9/2^+$ $1/2^-$	421.5 188.6 421.5	2.9 d	$5/2^+$	215.7	$2.6\cdot10^6$ y	$9/2^+$	
96				9.3 m 1.5 m	$6,7^+$ $1,2,3^+$	— —	∞	0^+		4.3 d 51 m	7^+ 4^+	— 778.2 1200.3
95				4.8 m		—	1.65 h	$7/2^+$	336.4	20 h 60 d	$9/2^+$ $1/2^-$	— —
94				80 s 25 s			51.8 m	0^+	—	4.9 h 53 m	$6,7^+$ 2^+	702.5 849.7 870.9 870.9
93*							58 s 45 s	$9/2^+$ $1/2^-$		2.7 h 43.5 m	$9/2^+$ $1/2^-$	— —

*Isomer ^{93m}Mo ($T_{1/2} = 6.8$ h, $I^{\pi} = 21/2^+$) has been identified by two weak lines: 263.2 and 684.6 keV.

Table 6. Isotopes (isomers) produced in the Pd + π^- reaction.

A	Rh			Ru			Tc			Mo		
	$T_{1/2}$	J^π	E_γ(keV)	$T_{1/2}$	J^π	E_γ(keV)	$T_{1/2}$	J^π	E_γ(keV)	$T_{1/2}$	J^π	E_γ(keV)
1	2	3	4	5	6	7	8	9	10	11	12	13
108	16.8 s 5.9 m	1^+	—	4.5 m	0^+	—	5.2 s					
107	22 m	$5/2^+$	302.8 392.5	3.8 m		—	29 s					
106	30 s 2.2 h	1^+ $4,5,6^+$	406.0 429.4 450.8 511.7 616.1 716.2 1046.7 1127.7 1220.5 1529.4	368 d	0^+		36 s			9.5 s	0^+	
105	35.5 h 45 s	$7/2^+$ $1/2^-$	—	44.4 h	$5/2^+$	469.4 676.3 724.2	7.8 m			40 s		
104	42 s 4.4 m	1^+ 5^+	—	∞	0^+		18 m		—	1.3 m	0^+	—
103	∞ 56.1 m	$1/2^-$ $7/2^+$	—	39.4 d	$5/2^+$	—	50 s			62 s		
102	206 d 2.9 d	$0,1,2^-$	—	∞	0^+		5.3 s 4.3 m	1^+	—	11 m	0^+	—
101	3 y 4.4 d	$1/2^-$ $9/2^+$	306.8	∞	$5/2^+$		14 m	$9/2^+$	306.9	14.6 m	$1/2^+$	—
100	20 h	1^-	539.6 822.2 1107.1 1362.1	∞	0^+		15 s	1^+		$3\cdot10^{7}$ y	0^+	
99	16 d 4.7 h	$1/2^-$ $9/2^+$	— 277.2 340.6 528.2 618.0 1260.7 1556.0	∞	$5/2^+$		$2\cdot10^5$ y 6 h	$9/2^+$ $1/2^-$	140.3	67 h	$1/2^+$	—

Table 6 (continued)

1	2	3	4	5	6	7	8	9	10	11	12	13
98	8.1 m 3 m	3^+	652.6	∞	0^+		$1.5\cdot10^6$ y	$6,7^+$		∞	0^+	
97	30 m 4.5 m	$9/2^+$ $1/2^-$	421.5 188.6 421.5	2.9 d	$5/2^+$	215.7	$2.6\cdot10^6$ y	$9/2^+$		∞	$5/2^+$	
96	9.3 m 1.5 m	$6,7^+$ $1,2,3^+$	——— ———	∞	0^+		4.3 d 51 m	7^+ 4^+	778.2 1200.3	∞	0^+	
95	4.8 m		———	1.65 h	$7/2^+$	336.4 626.8 1096.8	20 h 60 d	$9/2^+$ $1/2^-$	765.8 ———	∞	$5/2^+$	
94	80 s 25 s			51.8 m	0^+	367.2	4.9 h 53 m	$6,7^+$ 2^+	702.5 849.7 870.9 870.9	∞	0^+	
93				58 s 45 s	$9/2^+$ $1/2^-$		2.7 h 43.5 m	$9/2^+$ $1/2^-$	1362.4 1521.0 ———	>100 y 6.8 h	$5/2^+$ $21/2^+$	263.2 684.6 1477.2
92				37 m	0^+	———	4.4 m	7^+	———	>4·10[illegible] y	0^+	

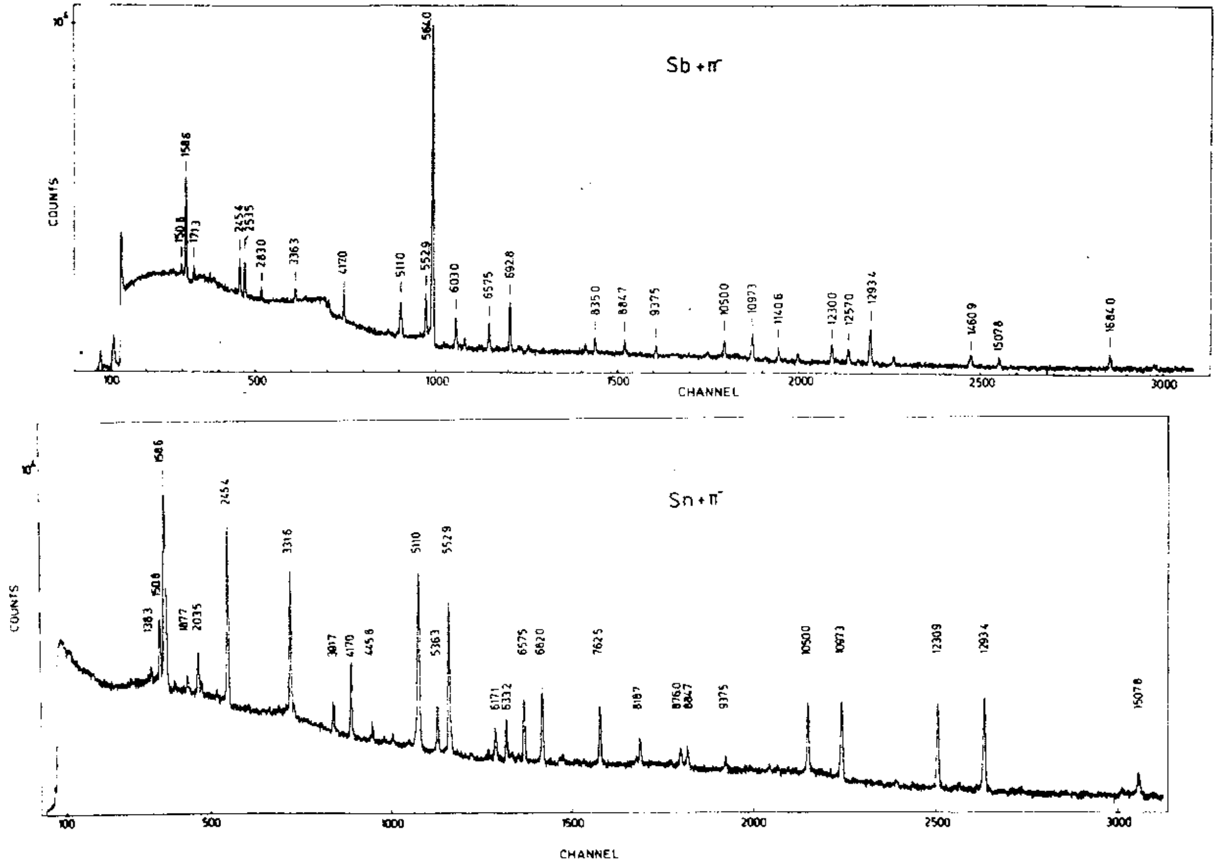

Fig. 2. Gamma-spectra of isotopes produced in the $(Sb+\pi^-)$ and $(Sn+\pi^-)$ reactions.

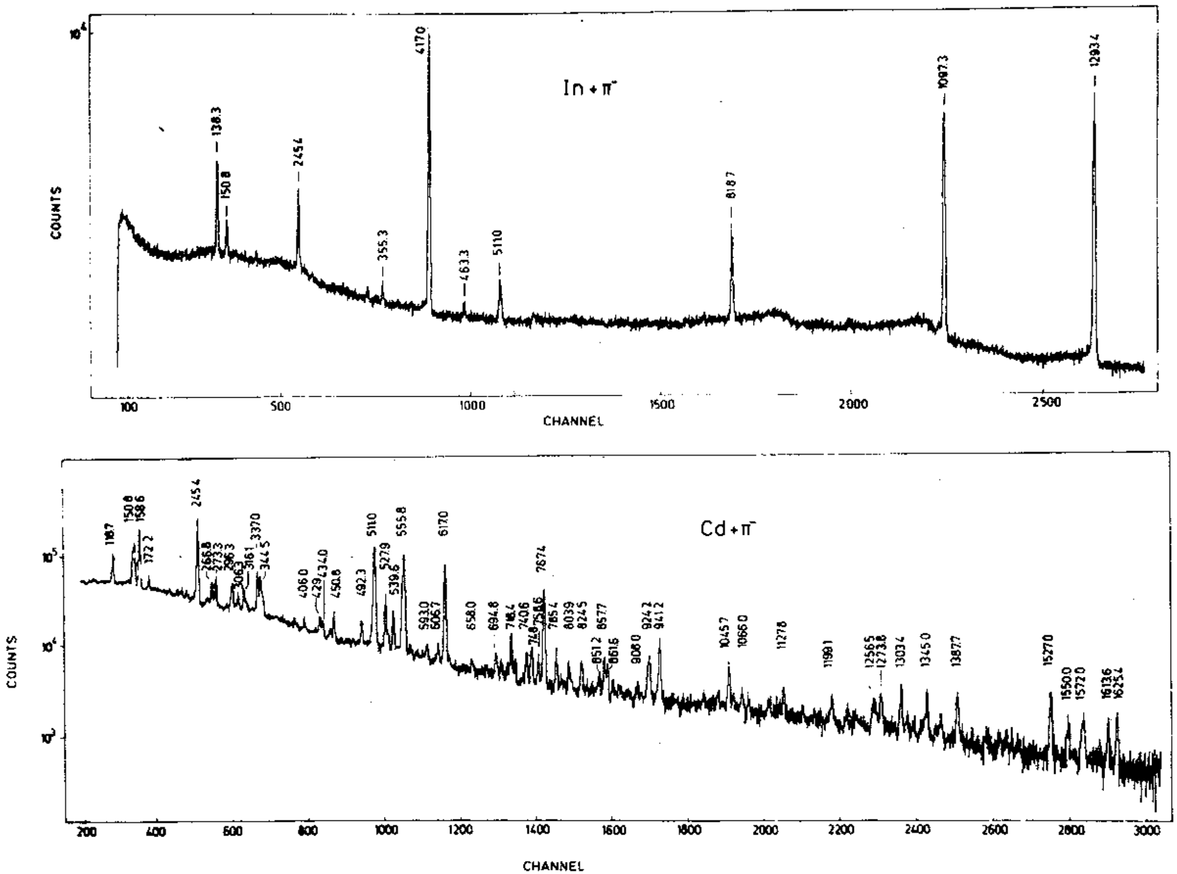

Fig. 3. Gamma-spectra of isotopes produced in the ($In+\pi^-$) and ($Cd+\pi^-$) reactions.

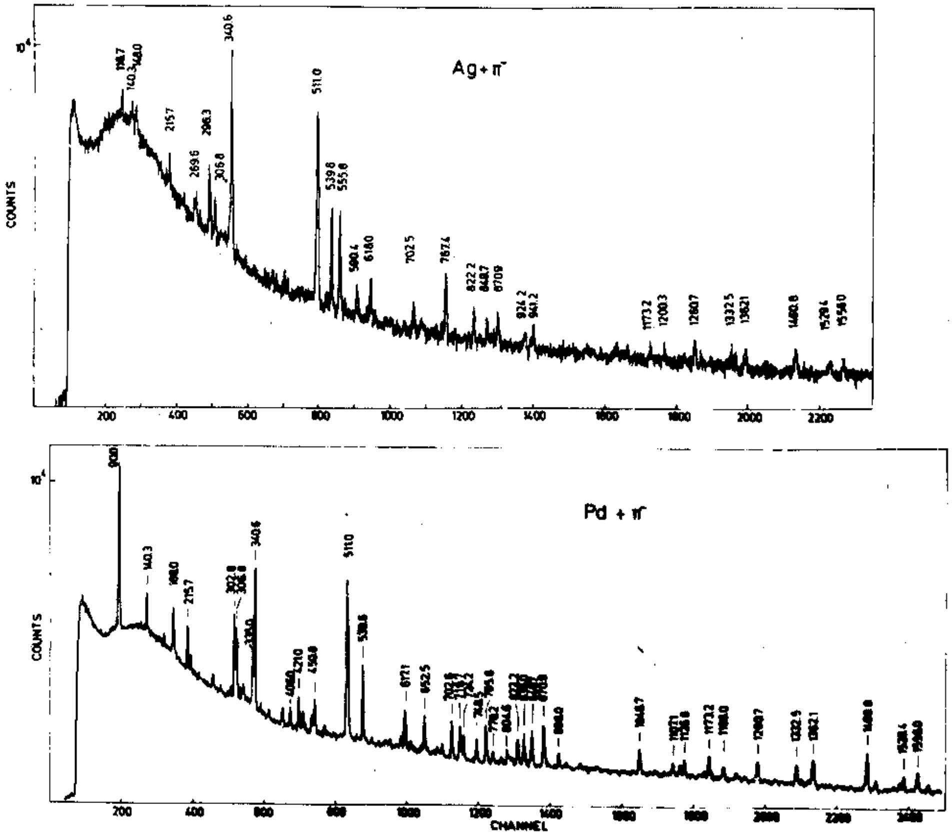

Fig. 4. Gamma-spectra of isotopes produced in the $(Ag+\pi^-)$ and $(Pd+\pi^-)$ reactions.

2.1. The Sb(Z=51) target

In the γ-ray spectrum of isotopes produced in the Sb_2O_3 target only one isotope with (Z-1), namely, ^{110g}Sn was observed. We could not identify other isotopes of Sn since some of them (Table 1) are stable and the half-lives of others are either short or too long in comparison with the irradiation and measuring times. Even for the ^{11g}Sn isotope though it has a suitable half-life (35 min) it was impossible to observe 761 and 1151 keV γ-lines.The absolute intensities of these γ-lines are probably too weak. Most of gammas in the analysed spectra belong to the decay of indium isotopes (Z-2) which are produced by the emission of one charged particle and several neutrons. In the γ-spectrum only one isotope with (Z-3) ^{111m}Cd (48 min, $11/2^-$) was observed. It was identified unambiguously by means of the decrease of the intensity of 150 and 245 keV γ-lines.

2.2. The Sn(Z=50) target

In the (π^-,xn) reaction on natural Sn, indium isotopes are mostly produced in a wide range of mass numbers A=(107÷118). The isomeric ratios $\xi = \sigma_m/\sigma_g$ with the values of (~0.2), (2.5 ± 0.5) and (3.0 ± 0.5) were determined for ^{108g,m}In, ^{110g,m}In and ^{112g,m}In, respectively. As in the case of Sb only one charged particle channel Sn(π^-,pxn)^{111m}Cd was observed. Other cadmium isotopes could not be observed as some of them have long half-lives and others ($^{105g,\ 107g,\ 115m}$Cd). have too weak γ-transition intensities. $^{117,\ 118}$Cd isotopes could be produced only in the reaction on heavier Sn isotopes, namely, ^{120}Sn(33%) , ^{122}Sn(4.7%) , ^{124}Sn(4.7%).We have not observed the removal of two protons with the consequent formation of Ag isotopes. It is probably due to experimental time parameters.

2.3. The In(Z = 49) target

π^- capture by ^{115}In (96%) allowed one to observe only one isotope with a (Z-1) charge, namely, ^{111m}Cd (48.6 min, $I^\pi = 11/2^-$). It was identified according to 150.8 keV and 245.4 keV γ-lines. Ag and Pd isotopes, i.e., nuclei with the charge (Z-2) and (Z-3) have not been identified. In the γ-spectrum we could not see, for example, a very intensive 617 keV line of ^{112}Ag (3.12 h, $I^\pi = 2^-$). This isotope is expected to be produced in the $^{115}In(\pi^-, p2n)^{112}Ag$ reaction. Apparently, as a result of resonant neutron admixture in the pion beam and high sensitivity of In to these neutrons only the most intensive γ-lines could be observed. Since ^{115}In (96%) has a large neutron absorption resonance integral (about 2700 barn) the γ-lines of residual nuclei under investigation are strongly suppressed by the Compton background of intensive γ-rays of ^{116m}In (138, 414, 818, 1087 and 1293 keV) (see Fig. 3).

2.4. The Cd(Z = 48) target

The γ-lines of Ag isotopes with masses ranging from 102 to 112 form a Cd target spectrum. Additionally, the lines of $^{100,101}Pd$ (Z-2) were determined. Those are probably of the daughter products of Ag isotopes, though the (π^-, pxn) channel is not excluded. $^{111m,g}Pd$ and ^{109m}Pd isotopes may be produced only in the Cd(π^-, pn) reaction since they themselves undergo β^--decay.

We have not observed the emission of the two protons since Rh isotopes have either short half-lives or they are stable.

2.5. The Ag(Z=47) target

As follows from the analysis of γ-ray spectra, π^--capture by natural Ag results in forming a relatively wide mass spectrum of final nuclei. $^{99,101}Pd$ isotopes are produced in the (π^-,xn) reaction. We have not observed $^{100,103}Pd$ isotopes due to their long half-lives as well as stable palladium isotopes with $A>101$. A number of Rh isotopes in the mass region of 91-107 were identified as a result of the (π^-,pxn) reaction. In the reaction $(\pi^-,2pxn)$ $^{95,97}Ru$ isotopes arise. We have not found any γ-lines of other Ru isotopes. The reaction $(\pi^-,3pxn)$ is manifested by the production of $^{94,96m,99m}Tc$ final nuclei. The Tc isotopes with $A<94$ as well as those with $A>100$ have not been observed. The isotope ^{93m}Mo arising in the reaction $(\pi^-,4pxn)$ has been identified.

2.6. The Pd(Z=46) target

The group of residual nuclei produced in the irradiation of natural Pd(^{104}Pd – 11%), ^{105}Pd – 22 % , ^{106}Pd – 27% , ^{108}Pd – 27% , ^{110}Pd – 12%) are listed in table 4. The identified Rh , Ru , Tc and Mo isotopes are direct products of pion capture with the emission of various numbers of protons.

3. DISCUSSION OF RESULTS

3.1. Multiplicity of emitted nucleons

The targets of natural Sn , Cd , Pd used in the above-described experiments contain a number of isotopes. As a consequence it was not possible to determine exactly the multiplicity of emitted nucleons for these targets. Due to heavy background from neutron capture products we could not idetify all the products of the reaction ($In+\pi^-$) and determine multiplicity for In.

The most suitable targets in this respect proved to be Sb or Ag ones each consisting of two isotopes: ^{121}Sb(57%), ^{123}Sb(43%) and ^{107}Ag(51%), ^{109}Ag(49%), respectively. The multiplicity of emitted nucleons for these targets amounts to 14-15. This number is consistent with the data for heavy elements, refs. /3,4/. As an illustration Fig. 5 shows the dependence of the relative yield of light Pd, Rh, Ru, Tc and Mo isotopes produced in the ($Ag+\pi^-$) reaction on the number of emitted nucleons $\Delta A = x + y$. The total binding energy is close to the pion rest mass. In contrast to heavy nuclei the multiplicity of charged particles increases for the region under investigation. While only 1-2 protons can emerge from heavy nuclei, up to four protons can be emitted in the case of $Z = 50$.

The measured multiplicities of emitted charged particles in pion absorption by nuclei in the medium mass region can be compared with the results of other experiments /6-9/. Negative pion capture by Br($Z=35$) and J($Z=53$) nuclei has been investigated in activation experiments /6,7/. The maximal multiplicity of charged particles equal to 3 and 5, respectively, has been observed.

The results of Alumkal et al. /8/ obtained from the analysis of sigma stars in photoemulsion (AgBr) seem to be the most accurate ones. The maximal multiplicity is given to

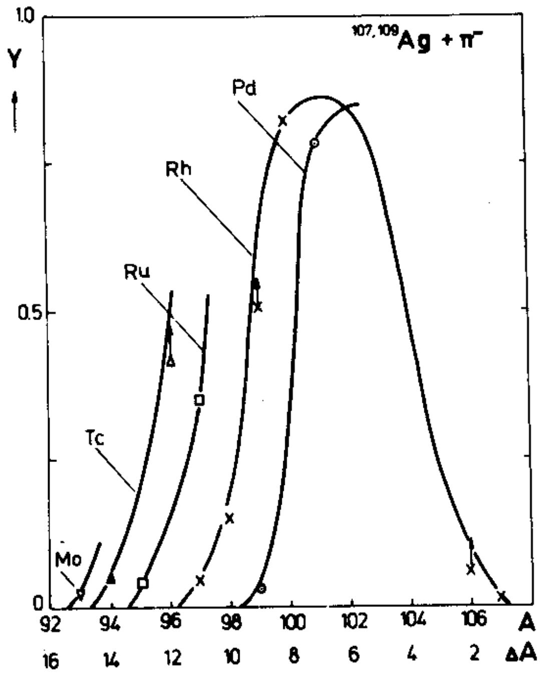

Fig. 5. Relative yields of Pd , Rh , Ru , Tc and Mo isotopes produced in the $(Ag+\pi^-)$ reaction versus the number of emitted nucleons $\Delta A = x + y$ and the mass number A.

be 8 but the emission probability for 5,6,7 and 8 charged particles is very low: 8×10^{-3} 4.5×10^{-5}, 13.0×10^{-5} , 4.5×10^{-5}, respectively.

Recently Engelhardt et al. /9/ have analysed prompt gammas from π^- irradiated Nb nuclei and identified the isotopes $^{81,82}Kr$ (Z=36) as a result of the emission of 4 protons and 7-8 neutrons.

In conclusion we may say that the emission of charged particles increases with decreasing the Coulomb barrier. However, besides the Coulomb barrier the binding energy of nucleons may affect the emission of charged particles. It is decreased for protons and strongly increases for neutrons in neutron-deficient medium mass nuclei. For example, in the reaction Ag(π^-,xnyp) we could not observe the isotopes ^{95}Rh, ^{94}Ru and ^{93}Tc in contrast to the corresponding isobars ^{95}Ru, ^{94}Tc and ^{93}Mo. It may be due to the fact that the emission of protons in comparison with that of neutrons is energetically more advantageous.

The proton and neutron binding energies for the above-mentioned isotopes were calculated according to the semi-empirical mass law[10] and are shown in Fig. 6.

It is interesting to note that the distribution of the number of emitted neutrons does not depend on the number of emitted protons and terminates at N=50 (Fig. 7). Protons are emerged instead of neutrons when the closed neutron shell is reached. This may occur at low excitation energies after the emission of a considerable number of nucleons.

The multiplicity of charged particles calculated according to the statistical[11] and pre-equilibrium[12] models is in satisfactory agreement with experimental results.

3.2. Spins of residual nuclei

High spin (I>3h) isomers excited in the process of π^--capture by investigated medium mass nuclei are listed in Table 7.

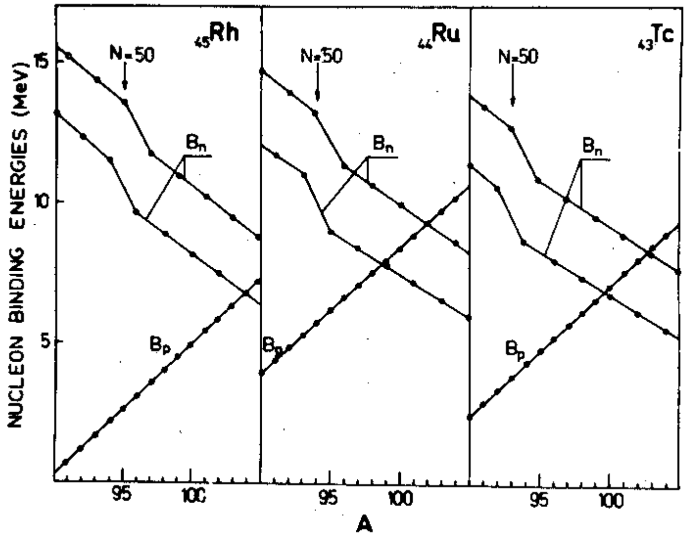

Fig. 6. Binding energy of the proton (B_p) and the neutron (B_n) for light isotopes of Rh , Ru and Tc as a function of their mass number A.

The excitation of high spin nuclear states appears to take place in the region of medium mass nuclei as well. These states in medium mass nuclei are produced also in processes when both charged particles and neutrons are emitted.

The observed isomeric ratios for $^{108,110,112}In$ isotopes (see Section 2) in the reaction $^{nat.}Sn(\pi^-, xn) - {}^{108}In(\xi = 0.2)$, ^{110}In $(\xi = 2.6 \pm 0.5)$, $^{112}In(\xi = 3.0 \pm 0.5)$ indicates the

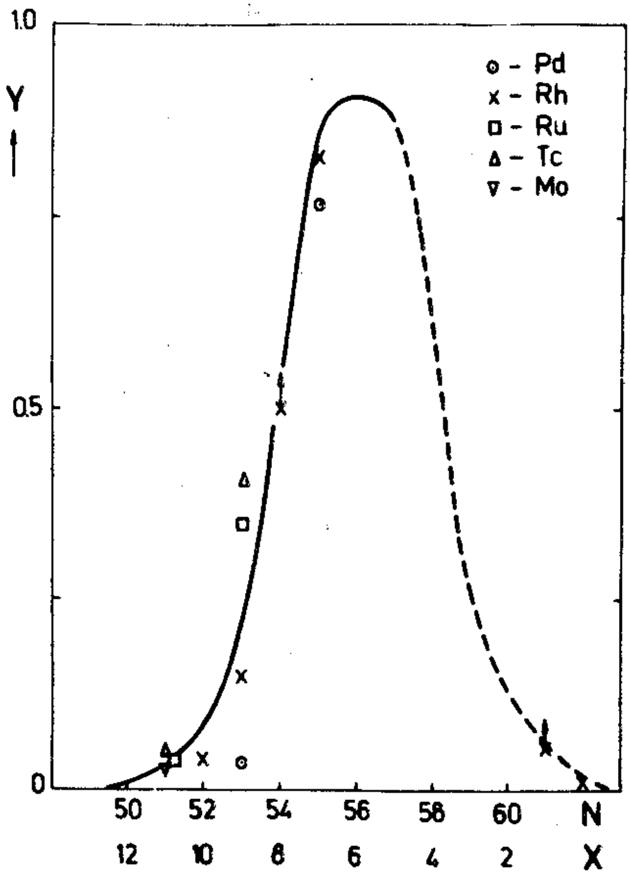

Fig. 7. Relative yields of Pd, Rh, Ru, Tc and Mo isotopes produced in the $(Ag+\pi^-)$ reaction versus the number of emitted neutrons X and the neutron number N.

the dependence of the angular momentum on the number of emitted nucleons.

A correlation between the isomeric ratio and the number of emerged neutrons for $^{108,\,110}In$ nuclei has been studied in π^--cap-

Table 7

Reaction	The observed high spin isomers
1	2
Sn(π^-,xn) Sb(π^-,pxn)	$^{118m}In(4,5^+)$, $^{116m}In(5^+)$, $^{112m}In\ (4,5^+)$ $^{110m}In(7^+)$ and $^{108m}In\ (5,6^+)$
In (π^-,xn) Sn(π^-,pxn) Sb(π^-,2pxn)	$^{11m}Cd\ (11/2^-)$
Cd(π^-,xn)	$^{106m}Ag(6^+)$, $^{105m}Ag\ (7/2^+)$, $^{104}Ag(5^+)$ $^{103}\ Ag\ (7/2^+)$
Cd(π^-,pxn)	$^{111m}Pd(11/2^-)$, $^{109m}Pd(11/2)$
Pd(π^-,xn)	$^{106m}Rh(5^+)$, $^{101m}Rh(9/2^+)$ $^{99m}Rh(9/2^+)$
Ag(π^-, pxn)	$^{105m}Rh(7/2^+)$ $^{97g}Rh(9/2^+)$
Pd(π^-,pxn) Ag(π^-,2pxn)	$^{95g}Ru(7/2^+)$
Pd(π^-,2pxn) Ag(π^-,3pxn)	$^{101g}Tc(9/2^+)$, $^{96m}Tc(4^+)$, $^{95g}Tc(9/2^+)$ $^{94g}Tc(6,7^+)$ and $^{93g}Tc(9/2^+)$
Pd(π^-,3pxn) Ag(π^-,4pxn)	$^{93m}Mo(21/2^+)$

ture by separated Sn isotopes [13]. The value of the isomeric ratio increases with increasing the neutron multiplicity x from 2 to 6. For larger x values the decrease of the multiplicity has been observed. The maximum at $x = 6-7$ corresponds to the excitation energy of the order of $m_\pi/2$.

All the experimental data available at present prove a great importance both of the elementary absorption of pions by the quasi-deuteron cluster on the nuclear surface and of the intra-nuclear cascade for residual spin formation.

The authors are very grateful to Prof. V.P.Dzhelepov and Prof. S.M.Polikanov for their support and interest in this investigation.

We also acknowledge the numerous helpful discussions of A.S.Ilyinov, S.E.Chigrinov and W.Fromm and we also thank O.V.Savchenko, E.P.Cherevatenko, V.M.Abazov and A.Liptakova for their assistance throughout this experiment.

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Received by Publishing Department
on November 2, 1976.