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B. Kardon
I. B. A. Manuaba
P. Gróz

THERMAL NEUTRON CAPTURE GAMMA-RAY STUDIES OF NATURAL XENON

Hungarian Academy of Sciences

CENTRAL RESEARCH INSTITUTE FOR PHYSICS

BUDAPEST

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Central Research Institute for Physics, Budapest, Hungary
Nuclear Physics Department

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1. Introduction

The cross-sections and abundances of xenon isotopes[1] indicate that studies performed with a target of natural composition essentially give information about the ^{129}Xe /n,γ/ ^{130}Xe and ^{131}Xe /n,γ/ ^{132}Xe reactions. Natural xenon contains 26,44% ^{129}Xe and 21,18% ^{131}Xe, which have thermal neutron cross-sections of 21 and 110 barns, respectively.

Earlier measurements on the capture gamma rays from natural xenon have been carried out by Bartholomew et al.[2], Monaro et al.[3] and Kane[4]. In these studies no more then 19 transitions were observed.

In order to establish the nuclear level schemes of ^{130}Xe and ^{132}Xe, several authors[5] have investigated the decay of ^{130}I, ^{130}Cs and ^{132}I, ^{132}Cs. The nuclear levels in ^{130}Xe and ^{132}Xe studied by radioactive decay have positive parities. The very intense primary E1 transitions from the capturing state reach levels with negative parity, which may not have been seen in radioactive decay because of spin and parity selection rules.

2. Experimental method

In order to obtain an improved thermal neutron beam from the WWRS-type Hungarian research reactor, a selector was used at one of the horizontal channels. The thermal neutron flux at the target position was about 3.10^6 n/sec. cm^2. The target consisted of 1 g of solid XeF_2 in a quartz capsule. The neutron capture gamma-rays were detected at 90^o with respect to the direction of the neutron beam. The single gamma-ray spectra were obtained with 4, 10 and 30 cm^3 Ge/Li/ detectors shielded against background radioactivity by lead. The target was surrounded by a 6 mm thick metallic ^6Li cylinder. The pulses from the detector were applied to a FET preamplifier and accumulated in a 512-channel LABEN analyser.

The gamma-ray spectra from 0,2 to 9,3 MeV were taken in two parts: from 0,2 to 3 MeV and from 3 to 9,3 MeV. The energies and photopeak efficiencies in the low-energy region were obtained by using a series of radioactive isotopes: ^{22}Na, ^{60}Co, ^{57}Co and ^{24}Na. In the high-energy region, the γ-ray energies were calibrated by using Cl, Co and ^{53}Cr /n,γ/ reactions the measured spectrum being freed from background peaks originating from neutron capture in aluminium, silicon and iron.

In order to determine the energy and intensity of the transitons, the peaks appearing in the measured spectrum were fitted by a series of Gaussian curves and the background was approximated by a low-order polynomial.

3. Result

The observed gamma-ray energies and intensities for the xenon are listed in Tables 1 and 2. The single spectra of the low-and high-energy regions are shown in Figs. 1/a and b. and Fig. 2/a and b, while the level schemes of ^{130}Xe and ^{132}Xe are presented in Fig. 3 and Fig. 4, respectively. The levels and gamma transitions shown on the level schemes are derived from β-decay, from /α2n/, reaction[7] and from /n,γ/ reaction as well as the result of our measurement.

^{129}Xe /n,γ/ ^{130}Xe reaction: Since the ground state of ^{129}Xe has spin and parity $I^{\pi} = 1/2^{+}$, the capturing state of ^{130}Xe resulting from the capturing s-wave neutron in ^{129}Xe has spin and parity $J^{\pi}=0^{+}$ and/ or, 1^{+}. The spins and parities of the four levels found in β-decay are 2^{+}, 4^{+}, 5^{+} and 6^{+}, which belong to energy levels 539, 1207, 1950 and 2369 keV, respectively, with the spin and parity of the ground state 0^{+}. The energy levels found in the /α,2n/ reaction are 1122, 2059 and 2696 keV. In our measurements we found two intense energy transitions of 9301,4 and 8759,4 keV emitted from the capturing state to the ground state and to the first excited state, respectively. These two relatively intense transitions are assumed /on grounds of spin and parity selection rules/ to be M1, so the spin and parity of the capturing state is strongly supposed to be 1^{+}.

The neutron binding energy can be deduced from the direct ground-state energy transition of 9301,4 ± 2,1 keV, as well as from the double cascade 8759,4 ± 5,5 keV - 537,4 ± 0,2 keV/see Fig. 3. The mean Q value is found to be 9300,7 ± 1,8 keV.

The other transitions assigned in Table 1 and Table 2 have been determined from the known energy levels of ^{130}Xe showed in our decay scheme. The 6271,4 keV - 3030,8 keV cascade proves the existence of a new level of 3030,8 keV. The 1928,4 keV level, which decays to the ground state, is populated by a relatively intense primary energy transition of 7369,2 keV.

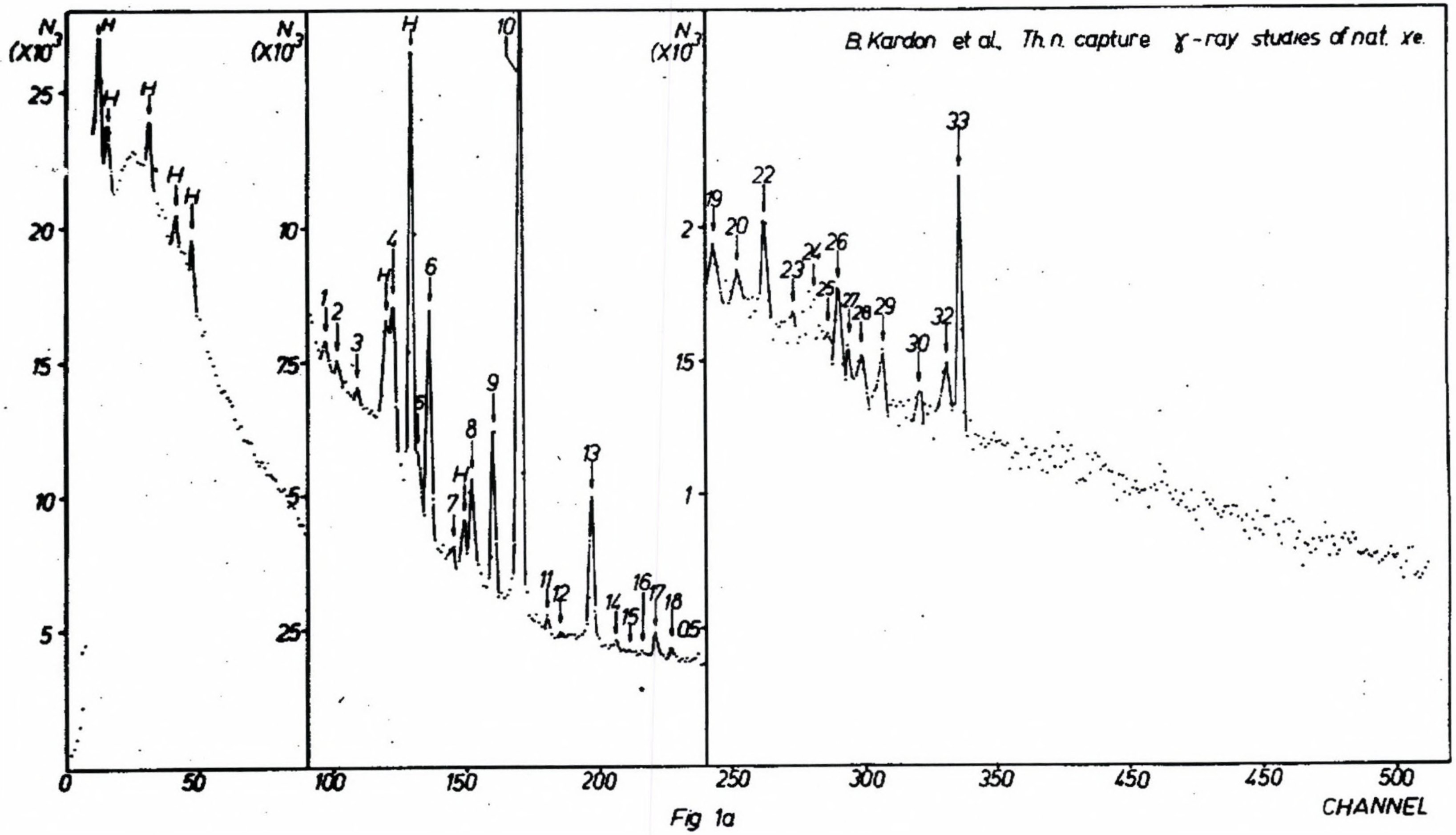
B. Kardon et al., Th. n. capture γ-ray studies of nat. xe.
N
(X10³)
25
20
15
10
5
10
7.5
5
2.5
2
1.5
1
0.5
H
0
50
100
150
200
250
300
350
450
450
500
CHANNEL

Fig 1a

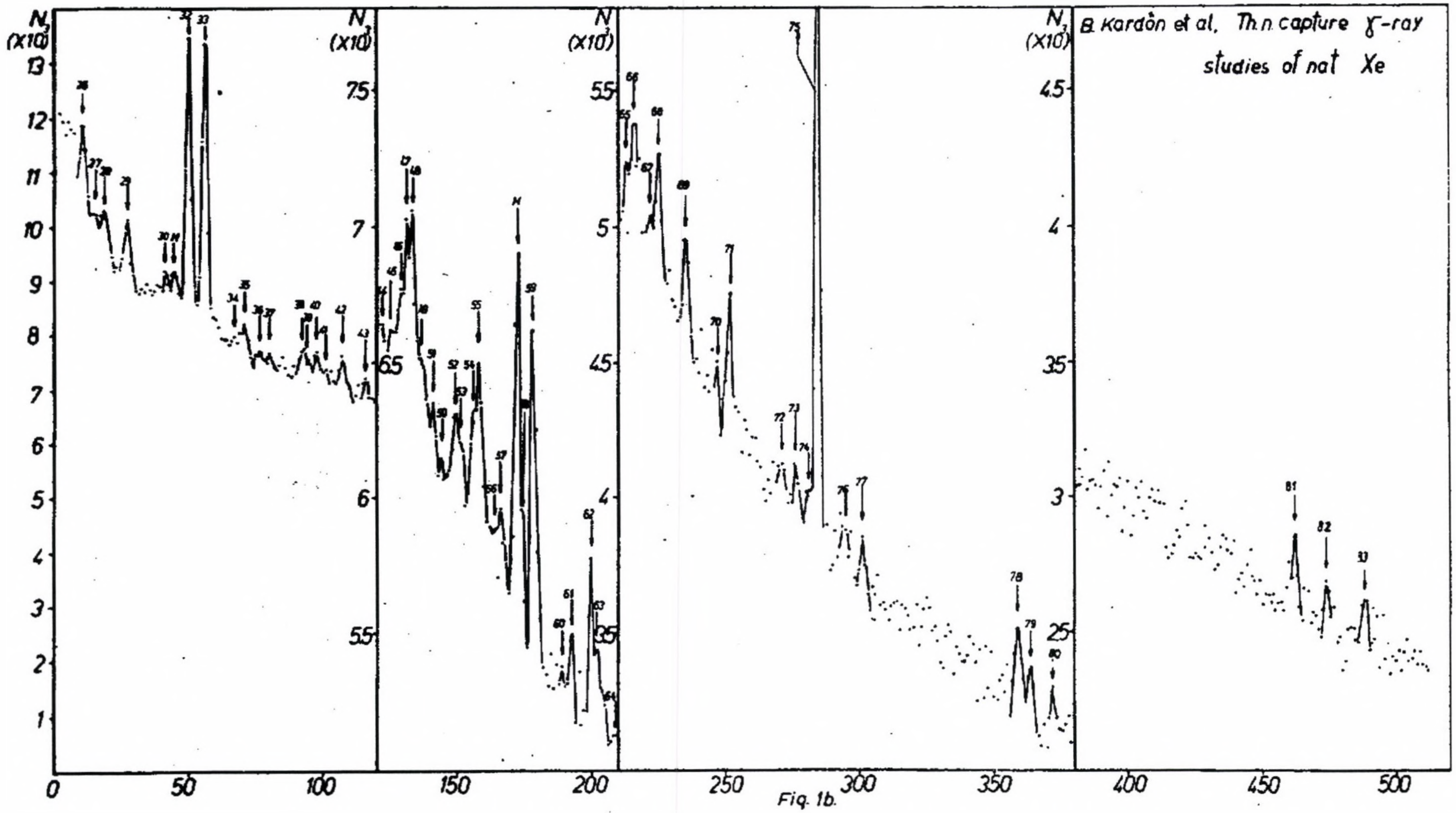

Fig. 1b.

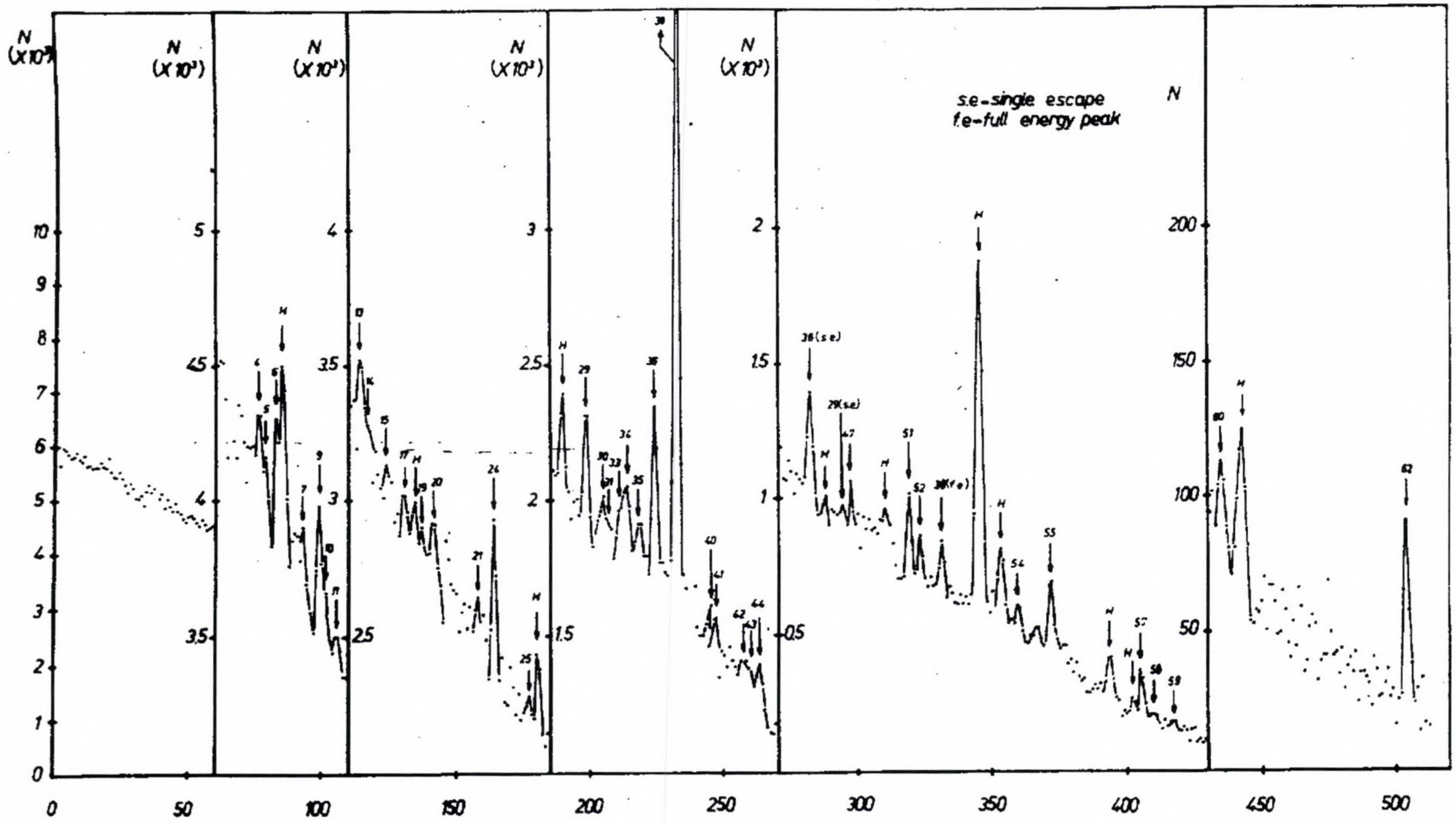
N (X10³)
s.e-single escape
f.e-full energy peak
N
CHANNEL
0
50
100
150
200
250
300
350
400
450
500

Fig.2a

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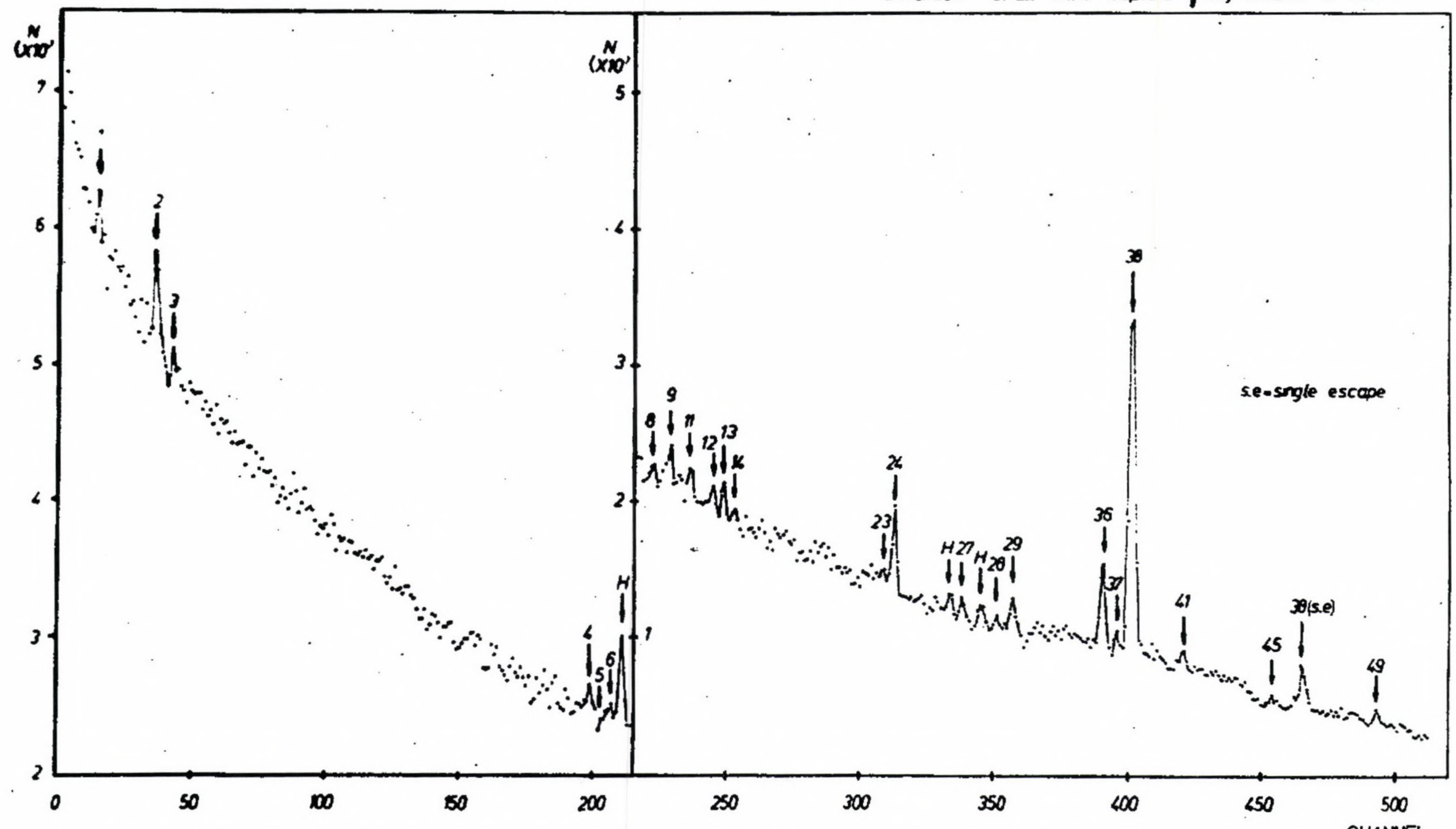

Fig. 2b

B.Kardon et al. Th. n. capture γ-ray studies of nat. Xe

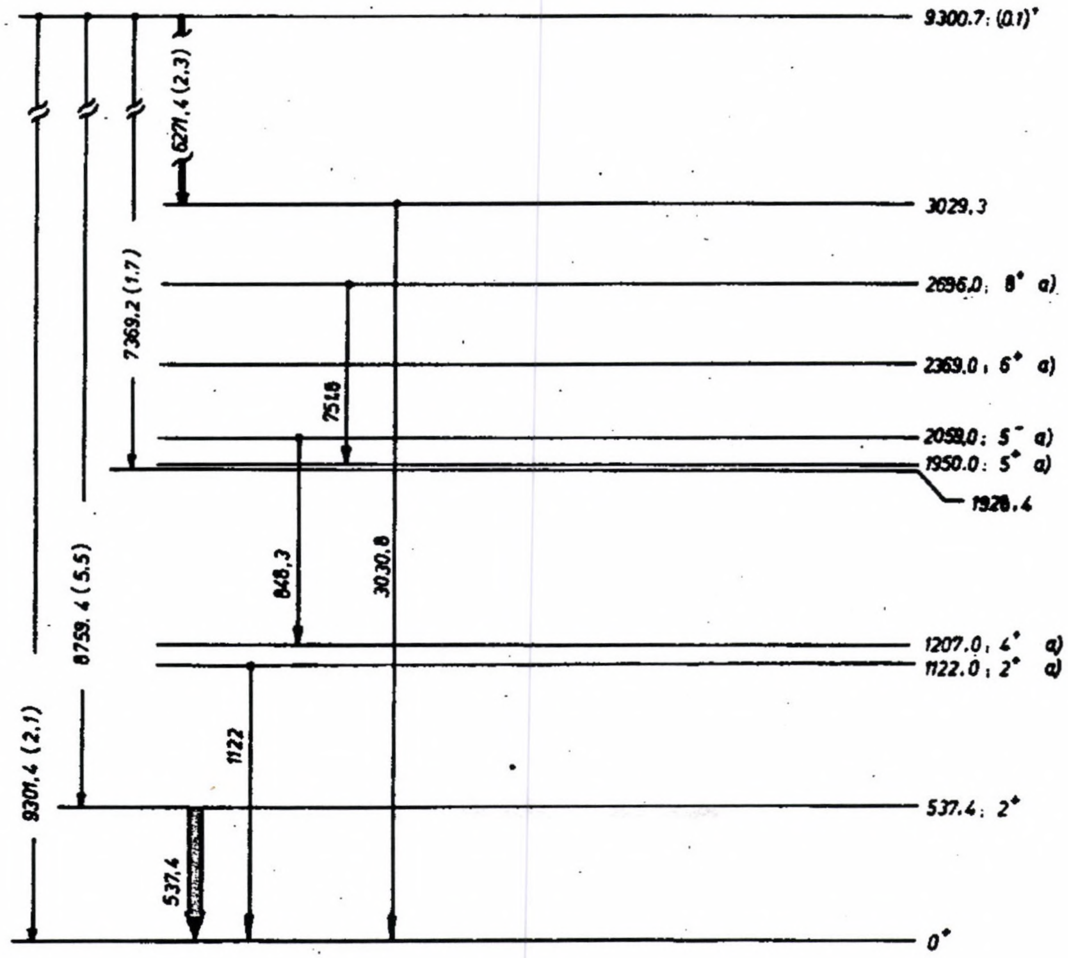

Fig. 3

B Kardon et al Th. n. capture γ-ray studies of nat. Xe

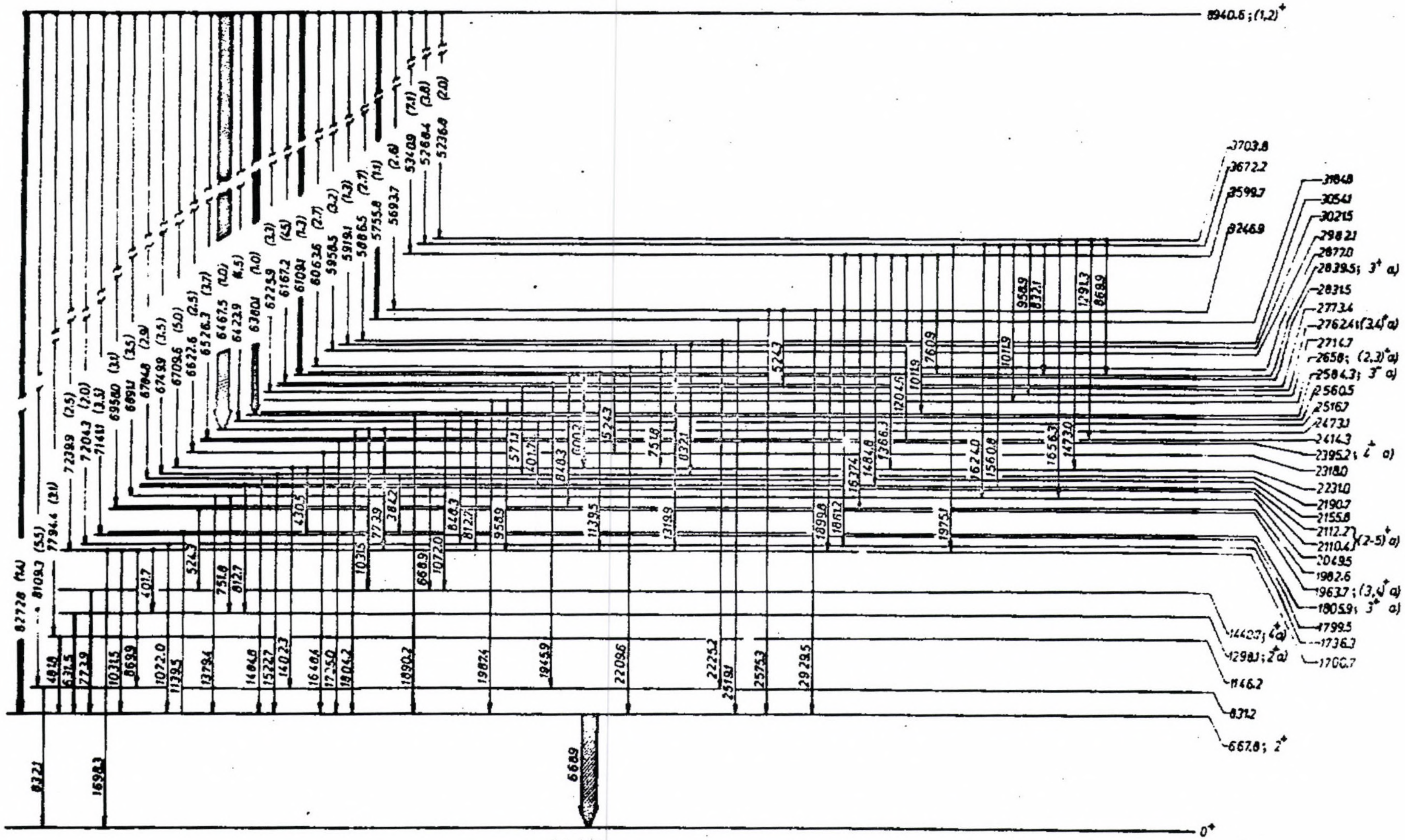

Fig. 4.

^{131}Xe /n,γ/ ^{132}Xe reaction: The capturing state in ^{132}Xe produced in the /n,γ/ reaction has spin and parity 1^+ and/or 2^+. The energies, spins and parities of the lowlying levels in ^{132}Xe have been deduced from the β-decay of ^{132}I and the gamma-radiations following β-decay. These levels shown in the level scheme /see Fig.4/ have positive parities. Since the parity of the capturing state is positive, the primary transition to these levels should be M1 or E2. Supposing the parity of the capturing state is 2^+, it seems to be clear that there is no primary transition to the ground state of 0^+, otherwise the multipolarity of this transition would be E2, which is too weak to be detected.

A relatively intense primary transition of 8272,8 keV to the first 2^+-excited state of 668,9 keV was observed. Since the multipolarity of this transition is assumed to be M1, the spin and parity of the capturing state are very probably 2^+.

Considering the 2472,5 keV and 2559,9 keV, levels of energy, we may conclude the following. The primary transitions to these two levels have been observed to occur with very high intensities. Assuming that the multipolarity of these two transitions /6467,5 and 6380,1 keV, respectively/ has an electric dipole character, the parities of these two levels should be negative. The 2472,5 keV level which is prominently populated by the primary 6467,5 keV transition, is deexcited by 1031,5 keV to the 1440,7 keV level of spin and parity 4^+, and by 1804,2 keV to the 667,8 keV level of spin and parity 2^+. Since the intensities of 1031,5 keV and 1804,2 keV are high, we may assume that the spin and parity of the 2472,4 keV level is 3^-.

Using the selected 6467,5 keV-1031,5 keV-668,9 keV cascade and the double cascade via the 667,8 keV level, which decays to the ground state by a very intense γ-transition of 668,9 keV, a mean Q value of 8940,6 $\pm$ 1,1 keV could be deduced for the ^{131}Xe /n,γ/ ^{132}Xe reaction. This average value is used in the level scheme /Fig. 4./ in order to extract the excitation energies of the ^{132}Xe levels which are directly populated by high-energy γ-lines. The proposed level scheme of ^{132}Xe shown in the figure is based heavily on the energy-sums of the possible cascades and intensity considerations.

Table 1

Gamma-rays from Xe /n,γ/ reaction in the low-energy region

Line no.	Energy /keV/	Error /keV/	Intensity /rel./	Assignment
1.	384,2	1,5	0,8	^{131}Xe /n,γ/
2.	401,7	1,5	1,3	^{131}Xe /n,γ/
3.	430,5	1,5	1,1	^{131}Xe /n,γ/
4.	481,8	1,0	15,7	^{131}Xe /n,γ/
5.	524,3	1,5	3,4	^{131}Xe /n,γ/
6.	537,4	0,2	24,4	^{129}Xe /n,γ/
7.	571,1	2,5	1,3	^{131}Xe /n,γ/
8.	600,2	0,7	14,2	^{131}Xe /n,γ/
9.	631,5	0,3	18,3	^{131}Xe /n,γ/
10.	668,9	0,1	100,0	^{131}Xe /n,γ/
11.	751,8	1,0	2,3	^{131}Xe /n,γ/
12.	760,9	1,8	1,4	^{131}Xe /n,γ/
13.	773,9	0,2	27,8	^{131}Xe /n,γ/
14.	812,7	0,7	1,3	^{131}Xe /n,γ/
15.	832,1	1,2	0,6	^{131}Xe /n,γ/
16.	848,3	1,0	0,8	^{131}Xe /n,γ/
17.	869,9	0,5	4,1	^{131}Xe /n,γ/
18.	895,3	0,9	1,7	
19.	958,9	0,8	1,7	^{131}Xe /n,γ/
20.	992,0	1,5	1,1	
21.	1011,9	1,4	0,6	^{131}Xe /n,γ/
22.	1031,5	0,5	6,2	^{131}Xe /n,γ/
23.	1072,0	1,2	0,8	^{131}Xe /n,γ/
24.	1098,9	0,4	2,3	
25.	1124,1	0,8	2,0	^{129}Xe /n,γ/
26.	1139,5	0,5	3,8	^{131}Xe /n,γ/
27.	1156,7	1,4	3,1	^{129}Xe /n,γ/
28.	1173,0	1,1	2,8	
29.	1204,6	0,8	4,0	^{131}Xe /n,γ/
30.	1261,3	1,0	1,6	
31.	1291,3	0,3	8,6	^{131}Xe /n,γ/
32.	1297,8	0,5	14,9	^{131}Xe /n,γ/
33.	1319,9	0,5	15,1	^{131}Xe /n,γ/
34.	1366,3	3,3	0,9	^{131}Xe /n,γ/
35.	1379,4	0,3	2,0	^{131}Xe /n,γ/

Line no	Energy /keV/	Error /keV/	Intensity /rel./	Assignment
36.	1402,3	2,0	1,1	^{131}Xe /n,γ/
37.	1417,7	1,6	1,3	
38.	1465,2	1,5	2,4	^{131}Xe /n,γ/
39.	1473,0	5,6	0,8	^{131}Xe /n,γ/
40.	1484,8	1,0	3,5	^{131}Xe /n,γ/
41.	1502,4	2,0	2,4	
42.	1522,7	1,0	4,1	^{131}Xe /n,γ/
43.	1560,8	1,0	1,4	^{131}Xe /n,γ/
44.	1598,2	2,6	1,6	
45.	1603,6	3,4		
46.	1608,2	1,9	1,1	
47.	1617,4	0,9	3,0	
48.	1624,0	1,0	2,5	^{131}Xe /n,γ/
49.	1637,4	1,0	2,3	^{131}Xe /n,γ/
50.	1648,4	1,8		^{131}Xe /n,γ/
51.	1656,3	2,4	0,6	^{131}Xe /n,γ/
52.	1691,9	1,0	1,0	
53.	1698,2	2,6	0,8	^{131}Xe /n,γ/
54.	1715,0	1,0	1,4	
55.	1725,0	0,5	3,0	^{131}Xe /n,γ/
56.	1759,1	1,0	1,4	^{131}Xe /n,γ/
57.	1770,7	1,2	2,2	^{131}Xe /n,γ/
58.	1791,5	3,0		
59.	1804,2	0,5	4,9	^{131}Xe /n,γ/
60.	1853,4	2,3	1,5	^{129}Xe /n,γ/
61.	1861,2	1,4	1,0	^{131}Xe /n,γ/
62.	1890,1	0,5	2,8	^{131}Xe /n,γ/
63.	1899,8	1,5	1,0	^{131}Xe /n,γ/
64.	1928,4	1,6	0,8	^{129}Xe /n,γ/
65.	1945,9	1,1	1,6	^{131}Xe /n,γ/
66.	1957,8	1,0	2,1	^{131}Xe /n,γ/
67.	1975,1	2,5	1,3	^{131}Xe /n,γ/
68.	1987,4	1,0	3,2	^{131}Xe /n,γ/
69.	2030,6	0,7	1,8	
70.	2074,4	2,6	0,5	
71.	2094,8	0,8	1,9	^{129}Xe /n,γ/
72.	2170,8	1,0	2,6	
73.	2194,6	1,4	1,2	^{131}Xe /n,γ/
74.	2209,6	1,6	2,0	^{131}Xe /n,γ/

Line no.	Energy /keV/	Error /keV/	Intensity /rel./	Assignment
75.	2225,2	0,5	15,7	^{131}Xe /n,γ/
76.	2268,3	2,7	0,7	^{131}Xe /n,γ/
77.	2292,5	1,5	1,1	^{131}Xe /n,γ/
78.	2519,1	0,6	2,6	^{131}Xe /n,γ/
79.	2539,2	1,4	1,9	
80.	2575,3	1,5	1,0	^{131}Xe /n,γ/
81.	2929,5	0,9	3,0	^{131}Xe /n,γ/
83.	2977,1	2,0	1,6	
84.	3030,8	1,7	2,0	^{129}Xe /n,γ/

Table 2

Gamma-rays from Xe /n,γ/ reaction in the high-energy region

Line no.	Energy /keV/	Error /keV/	Intensity /rel./	Assignment
1.	3356,5	4,5	7,1	
2.	3529,2	2,6	22,8	
3.	3588,6	4,2	4,8	
4.	4836,6	2,0	5,0	
5.	4860,6	4,6	6,4	
6.	4902,2	2,0	4,0	
7.	5004,0	8,3	5,2	
8.	5027,9	5,9	2,0	
9.	5074,4	2,0	9,3	
10.	5099,9	3,5	4,7	
11.	5139,3	2,7	3,6	
12.	5207,4	2,1	3,9	
13.	5236,8	2,0	5,0	^{131}Xe /n,γ/
14.	5268,4	3,8	2,5	^{131}Xe /n,γ/
15.	5340,9	7,1	4,1	^{131}Xe /n,γ/
16.	5389,9	2,2	1,8	
17.	5403,8	4,1	7,5	
18.	5427,9	1,6	2,9	
19.	5475,1	5,7	5,6	
20.	5515,2	2,8	12,2	
21.	5693,7	2,6	4,1	^{131}Xe /n,γ/
22.	5703,8	3,3	4,4	
23.	5721,0	2,0	3,1	
24.	5755,8	1,1	17,3	^{131}Xe /n,γ/
25.	5886,6	2,7	3,0	^{131}Xe /n,γ/
26.	5919,1	1,3	5,4	^{131}Xe /n,γ/
27.	5958,5	3,2	2,3	^{131}Xe /n,γ/
28.	6063,6	2,7	3,1	^{131}Xe /n,γ/
29.	6109,1	1,3	10,0	^{131}Xe /n,γ/
30.	6167,2	4,5	5,0	^{131}Xe /n,γ/
31.	6184,1	3,8	3,4	
32.	6225,9	3,3	2,9	^{131}Xe /n,γ/
33.	6247,1	3,0	7,5	
34.	6271,4	2,3	6,0	^{129}Xe /n,γ/
35.	6318,4	3,4	4,0	

Line no.	Energy /keV/	Error /keV/	Intensity /rel./	Assignment
36.	6380,1	1,0	21,3	^{131}Xe /n,γ/
37.	6423,9	4,5	3,4	^{131}Xe /n,γ/
38.	6467,5	1,0	100,0	^{131}Xe /n,γ/
39.	6526,3	3,7	2,4	^{131}Xe /n,γ/
40.	6593,8	3,5	1,4	
41.	6622,6	2,5	3,5	^{131}Xe /n,γ/
42.	6709,6	5,0	2,0	^{131}Xe /n,γ/
43.	6749,9	3,5	2,7	^{131}Xe /n,γ/
44.	6784,8	2,9	4,7	^{131}Xe /n,γ/
45.	6891,1	3,5	2,1	^{131}Xe /n,γ/
46.	6958,0	3,1	2,5	^{131}Xe /n,γ/
47.	7141,1	3,5	5,4	^{131}Xe /n,γ/
48.	7180,5	4,5	1,7	
49.	7204,3	2,0	3,3	^{131}Xe /n,γ/
50.	7239,9	2,5	2,2	^{131}Xe /n,γ/
51.	7369,2	1,7	2,0	^{129}Xe /n,γ/
52.	7413,2	2,3	2,6	
53.	7687,2	6,0	1,4	
54.	7794,4	3,1	1,0	^{131}Xe /n,γ/
55.	7920,4	2,0	2,6	
56.	8109,3	5,5	2,1	^{131}Xe /n,γ/
57.	8272,8	1,4	10,1	^{131}Xe /n,γ/
58.	8319,8	4,5	2,7	
59.	8394,8	5,0	2,5	
60.	8584,0	5,0	2,9	
61.	8759,4	5,5	0,3	^{129}Xe /n,γ/
62.	9301,4	2,1	4,8	^{129}Xe /n,γ/

FIGURE CAPTIONS

1/ a Single γ-ray spectrum of natural Xe in the energy range 0,2 to 1.4 MeV. The numbers assigned to the peaks correspond with those of Table 1. The symbol H denotes background energy peaks.

b Single γ-ray spectrum of natural Xe in the energy range 1.3 MeV. See Fig. 1a for the meaning of numbers and symbols assigned to the peaks.The electronical settings and the measuring time are different from these of Fig. 1a.

2/ a Single γ-ray spectrum of natural Xe in the energy range 4.8 to 9,3 MeV. The numbers assigned to the peaks correspond with those of Table 2. H denotes background peaks.

b Single γ-ray spectrum of natural Xe in the energy range 3 to 7.3 MeV. See Fig. 2a for the other symbols. The electronical settings and the measuring time are different from those of Fig. 2a.

3/ Proposed level scheme of ^{130}Xe deduced from the present /n,γ/ study. Energies are quoted in keV, a/ indicates the levels deduced from β-decay and /α,2n/ reaction. The arrow width gives a rough indication of the transition intensity.

4/ Proposed level scheme of ^{132}Xe deduced from the present /n,γ/ study. Energies are quoted in keV, a/ indicates the levels deduced from β-decay. The arrow width indicates roughly the transition intensity.

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ABSTRACT

The gamma radiations following thermal neutron capture in natural xenon have been studied using a Ge/Li/ spectrometer at WWRS type research reactor. Solid XeF_2 was used as the target. The gamma energies and intensities of 145 transitions in the energy range 0,2 to 9,3 MeV were determined. The energies have been obtained with an accuracy ranging between 0,1 keV for intense transitions and 5 keV for very weak transitions. The neutron separation energies of ^{130}Xe and ^{132}Xe have been deduced to be 9300,7 $\pm$ 1,8 keV and 8940,6 $\pm$ 1,1 keV, respectively.

РЕЗЮМЕ

Были измерены гамма-лучи при захвате тепловых нейтронов на естественной смеси изотопов Xe с помощью спектрометра Ge/Li/ . При измерениях было использовано твердое соединение Xe. В области 0,2 - 9,3 Мэв были определены энергия и интенсивность I45 переходов. Погрешность по энергии - 0,I кэв в случае сильных переходов, и 5 кэв при слабых переходах. Была определена энергия связи нейтронов изотопов ^{130}Xe и ^{132}Xe: 9300,7±I,8 кэв и 8940±I,I кэв.

KIVONAT

Termikus neutron befogását követő gamma sugárzást vizsgáltunk természetes xenon esetén Ge/Li/ spektrométer segitségével. A vizsgálatokhoz szilárd xenon vegyületet használtunk. 0.2 - 9.3 MeV energia tartományban 145 átmenet energiáját és intenzitását határoztuk meg. Az energia mérés hibája intenziv átmenetek esetén 0,1 keV, mig gyenge átmenetek esetén 5 keV. Meghatároztuk a neutron kötési energiáját ^{130}Xe és ^{132}Xe esetén és azt 9300.7 $\pm$ 1,8 keV ill. 8940,6 $\pm$ 1.1 keV - nek találtuk.

Kiadja a Központi Fizikai Kutató Intézet,
Felelős kiadó: Erő János, a KFKI Magfizikai
Tudományos Tanácsának elnöke
Szakmai lektor: Zámori Zoltán
Nyelvi lektor: Timothy Wilkinson
Példányszám: 280 Törzsszám 71-5880
Készült a KFKI házi sokszorosító üzemében,
Budapest
1971. augusztus hó