FIZIKA, Suppl. 1 (1969)

E. β AND γ SPECTROSCOPY

E1 Second-Order Electromagnetic Transitions

K. ILAKOVAC, A. LJUBIČIĆ, B. HRASTNIK, M. JURČEVIĆ and V. KNAPP,
Institute "Ruđer Bošković", Zagreb

Transitions between two levels of a nucleus can occur by a simultaneous double transition[1]: $\gamma\gamma$, eγ, ee, and at higher energies γp, ep and pp (γ = emission of a gamma ray, e = electron conversion, p = emission of an electron-positron pair). These processes proceed via an intermediate virtual state of the nucleus or of an orbital electron. It is believed that in the case of $\gamma\gamma$ transitions, a major contribution comes from the nuclear intermediate states. A detailed theory of these transitions was developed by Grechukhin[2]. The most favourable type of transition would be $0^- \rightarrow 0^+$ (with no crossovers), but no such case is known. Several experiments on $0^+ \rightarrow 0^+$ transitions have been performed without a positive result (see Table I). Isomeric transitions comprise another

TABLE I

Latest experimental results on $\gamma\gamma$ double decay

Nucleus	Transition	Energy (MeV)	Ratio of transition probabilities	Reference
^{12}C	$2^+ \rightarrow 0^+$	4.43	$\gamma\gamma/\gamma \leq 5\cdot10^{-5}$	8
^{16}O	$0^+ \rightarrow 0^+$	6.05	$\gamma\gamma/(e+p) \leq 1.1\cdot10^{-4}$	8
^{16}O	$3^- \rightarrow 0^+$	6.15	$\gamma\gamma/\gamma \leq 5\cdot10^{-4}$	9
^{40}Ca	$0^+ \rightarrow 0^+$	3.35	$\gamma\gamma/p \leq 4\cdot10^{-4}$	10
^{41}K	$7/2^- \rightarrow 3/2^+$	1.29	$\gamma\gamma/\gamma \leq 6\cdot10^{-5}$	11
^{85}Rb	$9/2^+ \rightarrow 5/2^-$	0.514	$\gamma\gamma/\gamma \leq 1.2\cdot10^{-5}$	11
^{90}Zr	$0^+ \rightarrow 0^-$	1.76	$\gamma\gamma/(e+p) \leq 8\cdot10^{-5}$	12
^{109}Ag	$7/2^+ \rightarrow 1/2^-$	0.088	$\gamma\gamma/\gamma \leq 1.9\cdot10^{-5}$	13
^{114}In	$5^+ \rightarrow 1^+$	0.192	$\gamma\gamma/\gamma \leq 3\cdot10^{-5}$	14
^{131}Xe	$11/2^- \rightarrow 3/2^+$	0.164	$\gamma\gamma/\gamma \leq 2.2\ 10^{-5}$	16
^{137}Ba	$11/2^- \rightarrow 3/2^+$	0.662	$\gamma\gamma/\gamma = (6.4\pm3.1)\cdot10^{-6}$	3

group. Despite many negative results, Beusch's[3] measurements indicated the existence of this process. He found that $(6.4 \pm 3.1) \cdot 10^{-6}$ $\gamma\gamma$ emisions occur per γ emission in the case of 662 keV $M4$ transition of ^{137}Ba.

Experiments on the eγ emission have been performed for several transitions (see Table II). Positive results have been obtained only in the case of the same transition in ^{137}Ba, with a relatively high probability[4]).

TABLE II

Latest experimental results eγ double decay

Nucleus	Transition	Energy (MeV)	Ratio of transition probabilities	Reference
^{109}Ag	$7/2^+ \rightarrow 1/2^-$	0.088	$K\gamma/K \leq 1.4 \cdot 10^{-4}$	13
^{114}In	$5^+ \rightarrow 1^+$	0.192	$K\gamma/K \leq 4.5 \cdot 10^{-4}$	15
^{137}Ba	$11/2^- \rightarrow 3/2^+$	0.662	$K\gamma/K = (2.24 \pm 0.45) \cdot 10^{-3}$	4
^{131}Xe	$11/2^- \rightarrow 3/2^+$	0.164	$K\gamma/\gamma \leq 3 \cdot 10^{-2}$	16

Most likely double electron conversion (ee) proceeds via an electronic virtual intermediate state, as the eγ emission. The only positive result has been obtained[5]) in the case of 192 keV $E4$ transition of ^{114}In (see Table III for a summary). KK conversion in ^{137}Ba was studied by our group. A fourfold coincidence (both K conversion electrons and both X rays) was required, and a two-dimensional analysis of pulses from the electron counters was performed.

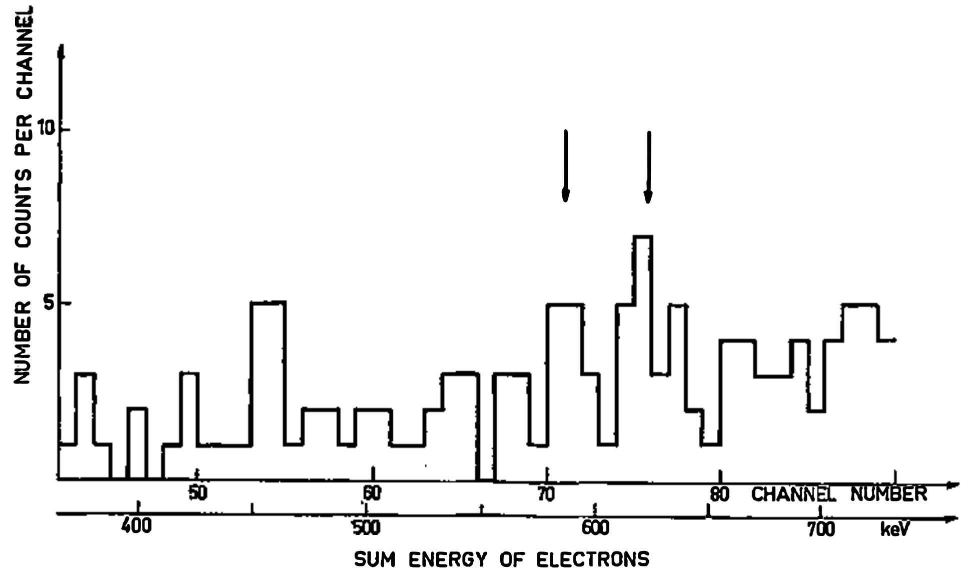
TABLE III

Latest experimental results on ee double decay

Nucleus	Transition	Energy (MeV)	Ratio of transition probabilities	Reference
^{109}Ag	$7/2^+ \rightarrow 1/2^-$	0.088	$KK/K = (7.4^{+0.5}_{-1.5}) \cdot 10^{-4}$	13*
^{113}In	$1/2^- \rightarrow 9/2^+$	0.391	$KK/K \leq 2.0 \cdot 10^{-5}$	17
			$KL/K \leq 1.8 \cdot 10^{-4}$	17
			$LL/K \leq 2.9 \cdot 10^{-5}$	17
^{114}In	$5^+ \rightarrow 1^+$	0.192	$KK/K = (1.7 \pm 0.3) \cdot 10^{-5}$	5
			$KL/K \leq 2.6 \cdot 10^{-4}$	15
			$LL/K \leq 2.9 \cdot 10^{-4}$	15
^{131}Xe	$11/2^- \rightarrow 3/2^+$	0.164	$KK/\gamma \approx (3.6 \pm 0.7) \cdot 10^{-3}$	16*
^{137}Ba	$11/2^- \rightarrow 3/2^+$	0.662	$KK/K \leq 2.5 \cdot 10^{-4}$	present meas.

*These results were obtained from the coincidences of KX-rays, and are probably uncertain.

The sum spectrum is shown in Fig. 1. Analysis of these preliminary results showed that $(1.6 \pm 0.9) \cdot 10^{-4}$ *KK* transitions occur per *K* conversion electron. Since the Møller scattering of a *K* conversion electron on a *K* electron in another atom is not resolved, for now the result is considered as an upper limit



Gig. 1. Number of events in a fourfold coincidence (KX_1—KX_2—e_1—e_2) as a function of the electron sum energy $E = E(e_1) + E(e_2)$. The peak indicated by the arrow on the right is due to the Møller scattering of *K* conversion electrons by weakly bound electrons, in accidental coincidence with another *K*X-ray of Ba. The arrow on the left indicates the position of the expected peak due to the ee events.

of $2.5 \cdot 10^{-4}$. The contribution of the transition via the nuclear virtual states[6] was estimated on the basis of Beusch's results, and was found to be negligible. The theory of Listengarten[7] gave a result of $1.6 \cdot 10^{-4}$. Further experiments to prove that both *K* electrons were emitted from the same atom are in progress.

References

1) For a recent review see H. J. Leisi, Proceedings of the Conf. on the Electron Capture and Higher Order Processes in Nuclear Decay, Debrecen, 15—18.VII 1968;
2) D. P. Grechukhin, Nucl. Phys. **35** (1962) 98; **47** (1963) 273; **62** (1965) 273;
3) W. Beusch, Helv. Phys. Acta **33** (1960) 363;
4) A. Ljubičić, Ph. D. Thesis, University of Zagreb, 1969; A. Ljubičić, B. Hrastnik, K. Ilakovac, M. Jurčević and V. Knapp, Fizika **1** Suppl. 1 (1969) 46;
5) R. Vukanović, L. Samuelsson, M. Migahed, L. Westerberg, and L. O. Edvardson. Institute of Physics Uppsala. UUIP—629, 1969; R. Vukanović, L. Samuelsson, M. Migahed, L. Westerberd, L. O. Edvardson, Fizika **1** Suppl. 1 (1969) 49;
6) J. Eichler, Z. Physik **160** (1960) 333;
7) M. A. Listengarten, Vestnik Leningrad Univ., Ser. fiz. i kim. **16** (1962) №. 3;
8) D. E. Alburger and P. D. Parker, Phys. Rev. **135** (1964) B294;

9) G. Sutter, Ann. d. Physique 8 (1963) 323;
10) P. Harihar and C. S. Wu, Bull. Am. Phys. Soc. 9 (1964) 457;
11) T. Alväger, H. Ryde and P. Thieberger, Arkiv f. Fysik 21 (1962) 559;
12) J. C. Vanderleeden and P. S. Jastram, Phys. Letters 19 (1965) 27;
13) K. Knauf and H. Sommer, Z. Physik 183 (1965) 10;
14) Z. Grabowski, S. Gustafsson and G. Bäckström, Nucl. Phys. 38 (1962) 648;
15) P. Kleinheinz, L. Samuelsson, R. Vukanović and K. Siegbahn, Nucl. Phys. 59 (1964) 673;
16) K. Knauf, H. Sommer and H. Klewe-Nebenius, Z. Physik 197 (1966) 101;
17) H. Sommer, K. Knauf and H. Klewe-Nebenius, Z. Physik 216 (1968) 153.

E2 Investigation of the eγ Process in ^{137}Ba

A. LJUBIČIĆ, B. HRASTNIK, K. ILAKOVAC, M. JURČEVIĆ and V. KNAPP,
Institute "Ruđer Bošković", Zagreb

There is a small but finite probability for an excited nuclear state to decay by simultaneous emission of a photon and conversion electron. This

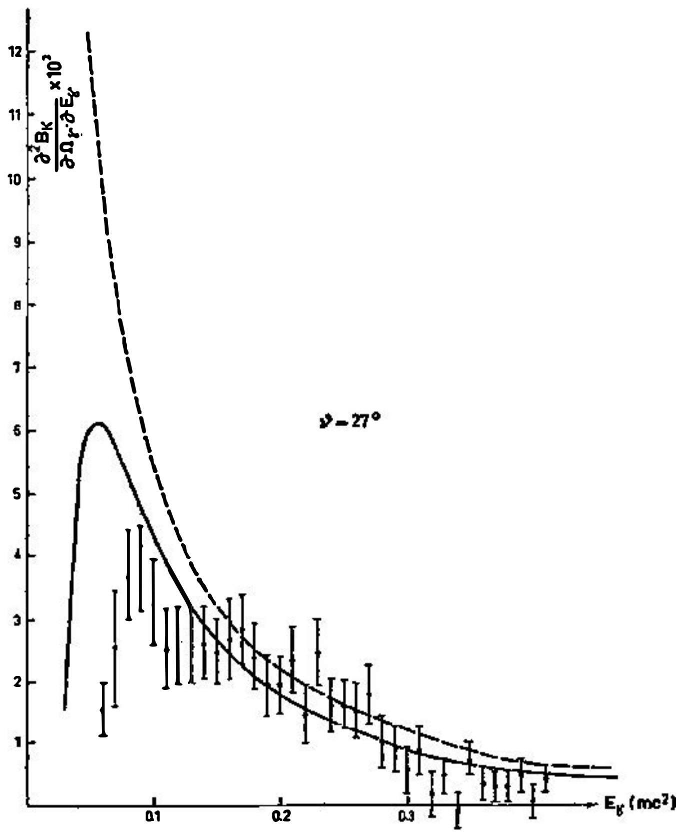


Fig. 1. The ratio of the transition probability for the I.C.E. per unit photon energy interval to the probability for the K-conversion transition in the eγ decay of ^{137}Ba. The dashed line represents the theoretical distribution given by Spruch and Goertzel[1]) and the solid line is the same distribution modified to account for the attenuation of photons in 1.2 mm of Al, the finite angular resolution, and the photon detector photopeak efficiency.