CORRELATION RESEARCHES OF THE OUTGOING DIRECTIONS "SHAKE-OFF" ELECTRON AND POSITRON AT β^+-DECAY

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The correlation properties electron "shake-off" at β^+-decay is studied. The measurements were fulfilled in compare with such properties "shake-off" electron at β^--decay for explanation mechanism, accountable for correlation motion "shake-off" electron and main particle (electron at β^--decay and positron at β^+-decay). ^{152}Eu decay was used for it. The measurements were performed on the installation of coincidences of γ-quanta with electrons and low energy electrons, including of e_o-electrons of the secondary electron emission ($\gamma\gamma e e_o$-coincidences). The registration of electrons "shake-off" implemented on e_o-electrons, created by them. On obtained data, the space correlation of electron "shake-off" with positron at β^+-decay in direction forward is much less that those correlating "shake-off"-electron at β^--decay. "Shake-off"-electrons at β^+-decay are predominantly moving in large solid angles relate positron. The mechanism, accountable for it, is proposed.

Introduction

At β-decay nuclear charge sharply changes on 1 that produces strong shakeup of atomic shell and is accompanied by her excitation (SU processes), or ionization (SO processes) [1]. The effects on outer shells are not small: $P_{SO} \sim 0{,}06$, $P_{SU} \sim 0{,}1$ for N-shell ($Z \sim 50$) [2]. Electrons "shake-off" are hardly correlated on direction with primary particle, emitting together to the same hemisphere [3 - 9].

There are many causes for research of "shake-off": for analysis of atomic-nuclear processes (ICC, shape β- spectra), for learn of multielectrons correlations in atoms and correlation motion of particles. These researches performed for study the mechanism, originating the space correlations in motion "shake-off" particle at β-decay [5 - 9]. The investigations of space correlations in emitting an electron of "shake-off" and main (basic) particle (positron at β^+-decay or electron at β^-- decay) are complementing one another and in joint researches are specially relevant. In particular, for the undestanding mechanism, accountable for observation of these correlations [5 - 9]. On our data [7 - 9] correlating of emitting "shake-of" electron along direction motion main particle increases with energy of an electron of "shake-off", qualitatively follows to relation $\sim E^{1/2}$, i.e. is proportional to momentum "shake-off" electron. It point at interaction, responsible for correlative motion of particles, as interaction of currents from moving these charge particles. If it so, the space correlations of electron "shake-off" and main particle at β^-- and β^+- decay should be different.

The study was performed with β^-- and β^+ - components of decay ^{152}Eu.

The experimental methodic for measuring the momentum correlating properties electron "shake-off" - positron at β^+-decay and results

The measurements were performed on the installation of coincidences of γ-quanta with electrons and low energy electrons, including e_o-electrons of secondary electron emission ($\gamma\gamma e e_o$-coincidences) (Fig. 2).

It necessary to note the following. In the given method of measurement, the registration of electrons of "shake-off" on e_o-electrons of a secondary electron emission is carried out. The electrons e_{Sh} of "shake-off", released in some solid angle from source S, originates on aluminum foil Em e_o-electrons. The design of a source and all surrounding forms enough homogeneous electrical field, which one at $U_{Em} = 0$, $U_S > U_L = 190$ V, $U_R = 0$ draws out almost all e_o-electrons from a metal foil Em to the left-hand MCP detector and thus e_o-electrons register only by left-hand MCP detector and only from Em. Thus, at selection quarter $\gamma\gamma_{511} e e_o$-coincidences, an electron of "shake-off" (as e_o) and main particle e (β^+- or β^-- particle) are released in the same solid angle, as (see Fig. 2) the main particle always passes through thin metal foil Em, and the e_o-electrons register only from it. One γ-detector select γ-quanta 511 keV with $\Delta E_{511} = 120$ keV for β^+-decay selection. For β^--decay ΔE_{511} select Compton part registration of transition 779 keV. At $U_S = 0$ V e_o-electrons from "shake-off" electrons are register by left MCP detector from surface of the source ^{152}Eu. At treble $\gamma\gamma_{511} e$-coincidences implements only the selection β^+- or β^--particle by right detector.

In such way in quarter $\gamma\gamma_{511} e e_o$-coincidences the probability of emitting of an electron "shake-off" along a direction of emitting of the main (basic) particle occur, as contrasted to an arbitrary direction its emitting at selection treble $\gamma\gamma_{511} e$-coincidences.

In measurements it is necessary to receive relative (in relation to γ344) intensity of a γ-quantum 511 keV in spectra (Fig. 3 and subsequent) of treble and quarter coincidences. γ-spectrum $\gamma\gamma_{511}\beta^+$-coincidencies (Figs. 4 and 6) corresponds to an arbitrary direction of emitting of an electron of "shake-off" e_{Sh} in relation to positron. The quarter $\gamma\gamma_{511}\beta^+ e_o$-coincidencies (Figs. 5, 7 and 8) corresponds to emitting of electron of "shake-off" e_{Sh} along the direction of mooving of positron.

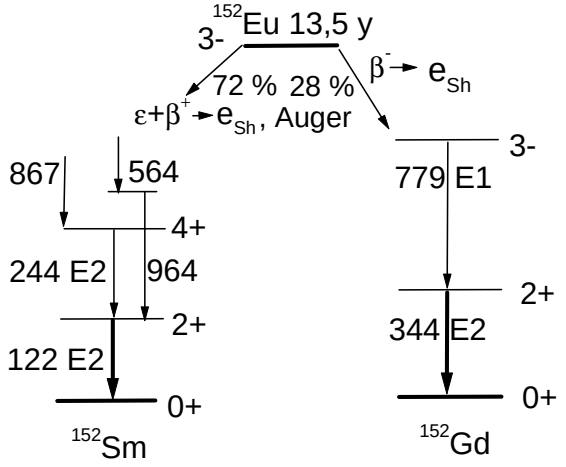

Fig. 1. Branches of the ^{152}Eu decay and main radiations in measuring of γ-spectrum in $\gamma\gamma e e_{sh}$-coincidences for study "shake-off" processes at β^-- and β^+-decay e signed β^-- or β^+-particle, e_{Sh}-"shake-off" electron. Bold arrows indicate the most intensity transition in both branches. E-decay is accompanied by KX-ray and intensive Auger-electrons.

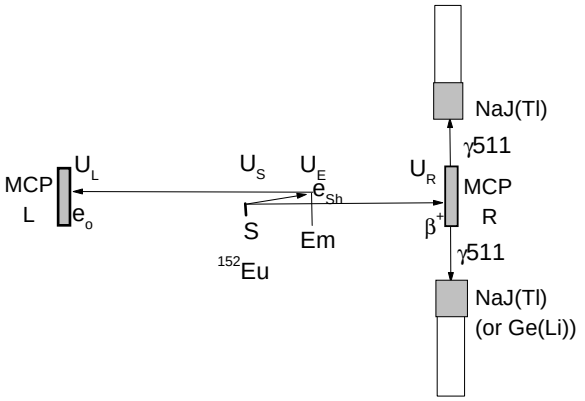

Fig. 2. Technique of definition correlating of motion of e_{Sh}-electron "shake-off" with positron at measurement $\gamma\gamma_{511}\beta^-$- and $\gamma\gamma_{511}\beta^+e_{Sh}$-coincidences from a radioactive source S ^{152}Eu. The source of ^{152}Eu on thin substrate with depth of a radioactive layer 30 mmg/cm^2 was used. Electrons of "shake-off" e_{Sh} are registered on e_o-electrons of the secondary electron emission. MCP- micro-channel-plates detectors of electrons (L and R), NaJ(Tl) or Ge(Li) – axially arranged γ-detectors for registration γ-quanta 511 keV from annigillation of positrons, that occurs in right MCP. Em (Al 0.078 mm)- emitter of e_o-electrons.

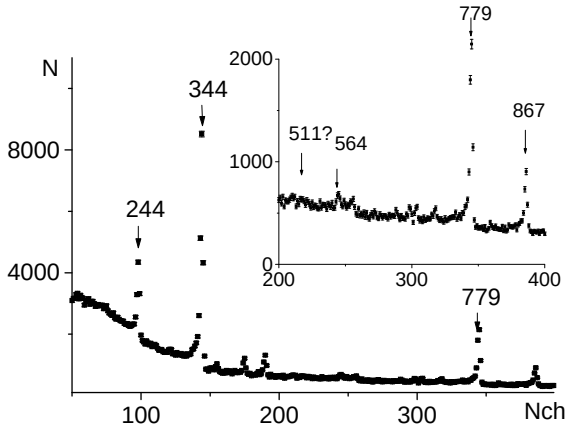

Fig. 3. Part of gamma spectrum in the ^{152}Eu decay. As the intensity β^+-compo-nent is low (estimates at 0.05 % from decay) and gamma quanta 511 keV is not noticeable, arrow indicate only place it in spectrum.

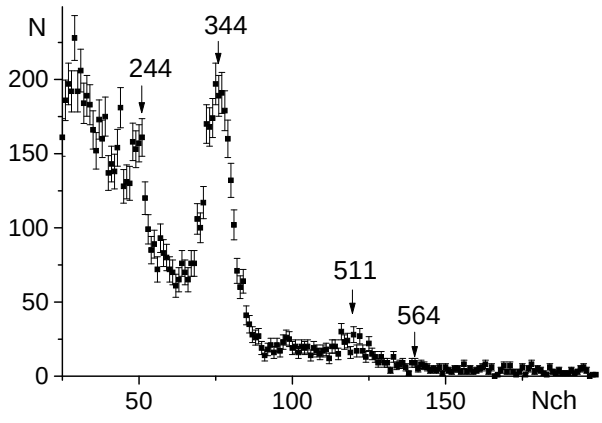

Fig. 4. γ-spectrum in $\gamma\gamma_{511}\beta^+$-coincidences from ^{152}Eu ($\varepsilon+\beta^+$, β^-)-decays. Measured on scintillation detector NaJ(Tl). Direction e_{Sh}-electron relate main particle is arbitrary. Intensity γ511 keV is appreciable (as contrasted those in Fig. 3).

In Figs. 4 - 8 the main results are presented. As intensity β^+-component in ^{152}Eu decay is law (estimates at 0.05 % from decay) it is very much difficult to measure treble and, specially, quarter coincidences with good statistics.

The γ-spectra in Figs. 4 and 5 were measured on scintillation NaJ(Tl) – detector and data, presented on them, show that correlating "shake-off" electron and positron is much less such correlating "shake-off" electron at β^--decay. Really, $(S_{511}/S_{344})_{treble} = 0.100(12) > (S_{511}/S_{344})_{quarter} < 0.05$. This spectra also contain quantum γ244 keV and γ564 keV, that indicate to some registration of KX-ray by the right detector, as conversion electrons IC122 through the emitter Em with depth 0.078 mm cannot pass. It originates coincidences KX-ray with intensive law-energy Auger-electrons (following ε-capture and internal conversion) and with e_o-electrons from it. This circumstance give additional possibility, on relation to β-decay, for analysis of correlating properties "shake-off"-electron and positron at β^+-decay. Additional possibility, as strong correlation KX-ray with Auger-electrons is not expected.

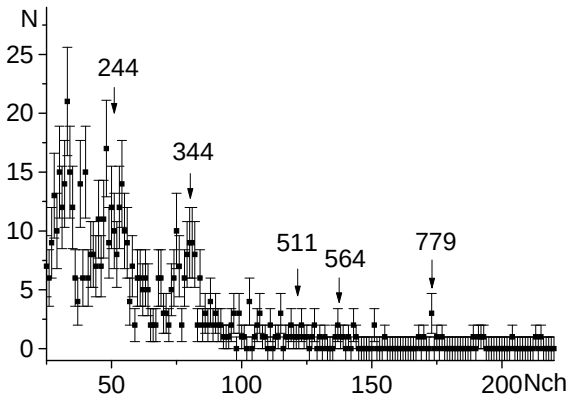

Fig. 5. The γ-spectrum in $\gamma\gamma_{511}\beta^{+}e_{o}$-coincidences from ^{152}Eu ($\varepsilon+\beta^{+}$, β^{-})-decay. Was measured on scintillation detector. e_{Sh} was register on e_0 from Em at U_S = 200 V, U_{Em} = 0 V, U_L = 190 V. Direction is forward for e_{Sh} relate main particle. The intensity γ511, as contrasted those in Fig. 4, is law.

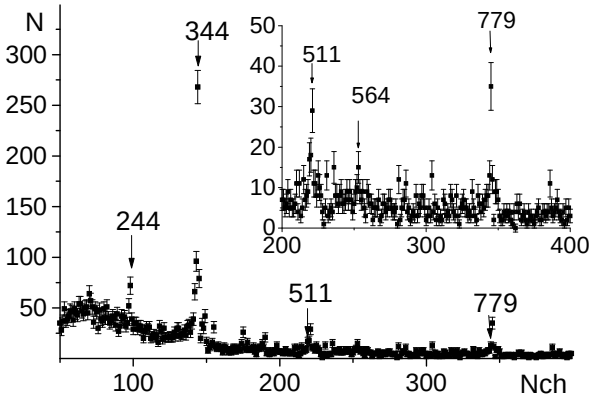

Fig. 6. γ-spectrum from the selection $\gamma\gamma_{511}\beta^{+}$- and $\gamma\gamma_{511}\beta^{-}$-coincidences in ^{152}Eu ($\varepsilon+\beta^{+}$, β^{-})-decays. Measured on Ge(Li) detector. Direction e_{Sh} relate main particle is arbitrary. Intensity γ511 keV is appreciable: S_{511}/S_{344} = 28(7)/239(18) = 0.117(31).

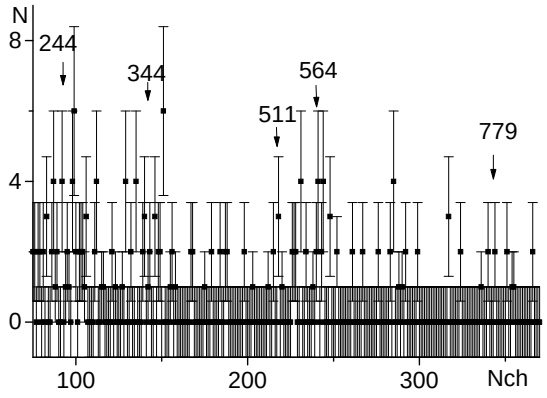

Fig. 7. γ-spectrum of $\gamma\gamma_{511}\beta e_{Sh}$-coincidences in ^{152}Eu ($\varepsilon+\beta^{+}$, β^{-})-decays with registering electron e_{Sh} of "shake-off" on e_o from emitter Em at U_S = 200 V, U_{Em} =0 V, U_L = = 190 V. Intensity of not correlated coincidences γ244 and γ564 keV with KX-ray are large. Intensity γ511 keV is law. Forward direction for e_{Sh}, relate β-particles.

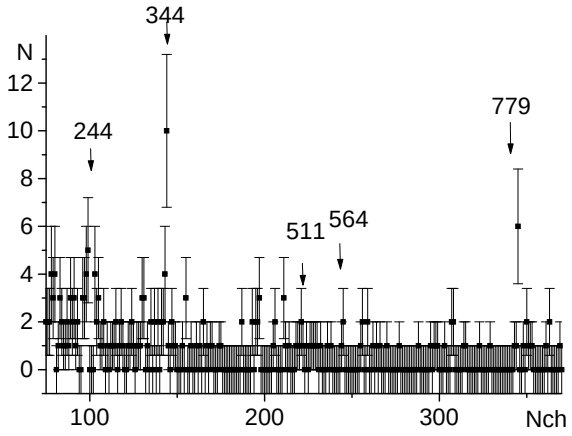

Fig. 8. γ-spectrum of $\gamma\gamma_{511}\beta e_{Sh}$-coincidences in ^{152}Eu ($\varepsilon+\beta^{+}$, β^{-})-decays with registering "shake-off" e_{Sh} on e_o-electrons from surface of source ^{152}Eu at U_S = 0 V, U_{Em} = = 0 V, U_L = 190 V. Relative intensity γ244, γ564 keV is law. Intensity γ511 keV relates γ564 keV is more noticeable, than those in Fig. 7. Large solid angles for e_{Sh} are accessible here. It corresponds to motion "shake-off"-electron in large angles relates β^{+}-particle.

The γ-spectra, presented in Figs. 6 - 8, were measured on Ge(Li)-detector and this information contain. Spectra in Figs. 7 and 8, were measured at different potentials at source, therefore e_o-electrons, using for detecting "shake-off"-electrons and Auger-electrons by left MCP-detector, were registered from different places of their formation: from emitter Em (Fig. 7) or from surface of the source of ^{152}Eu (Fig. 8). In the latest case, at the selection electron of β^{-}-decay, "shake-off"-electrons from it are moving out of source in the same solid angle, as in Fig. 7, owing to strong it correlating with β^{-}-particle.

This circumstances determines the intensity transitions γ244, γ654 keV (both from ε-decay) and transitions γ344, γ779 keV (both from β^{-}-decay) in spectra in Figs. 7 and 8. Though statistics is low, the data on it, nevertheless, demonstrate (table below also), that the intensity γ511 кeV (relative to 564 keV) in spectrum of quarter coincidences at U_S = 200 V (Fig. 7) is much less those at U_S = 0 V (Fig. 8). Thus the solid angles of departure of electrons of "shake-off" to out from the surface of source (therefore and e_o-electrons from it), amounting approximately 2π in Fig. 8, is much greater of solid angles the registration of electrons "shake-off" from outwardly arranged emitter Em in Fig. 7. It is necessary to make a conclusion from it, that electrons of "shake-off" at β^{+}-decay are predominantly moving in relation to positron in much more solid angles, than are moving Auger-electrons in relation to KX-ray. Allowing, that

correlating of an electron of "shake-off" and main (basic) particle at a β^--decay is much above than same correlating of radiations at KX-ray, which one obviously is absent (on the data about intensities of quanta 344 and 244 кеV in spectra in Figs. 7 and 8 and from the Table), it is necessary to draw a conclusion, that correlating of momentums of an electron of "shake-off" and positron at β^+-decay is strong differ from the same correlating of electron of "shake-off" and electron of β^--decay. The predominant motion "shake-off" electron at β^+-decay occurs not in forward direction of main particle, as in case β^--decay, but in 2π or more solid angles relate it.

Number counts under peaks of γ-spectra in treble and quarter coincidences electron "shake-of" (or Auger-electrons), β-particle (positron β^+-decay, electron β^--decay), (or KX-ray) and γ-quanta 511 keV

E γ / measurements	244	344	511	564	γ-detector
$\gamma\gamma_{511}\beta$	223(37)	1551(55)	151(18)	25(9)	NaJ(Tl)
$\gamma\gamma_{511}\beta e_{Sh}$, Em	130(15)	80(11)	1(4)	6(3)	
$\gamma\gamma_{511}\beta$	48(12)	239(18)	28(7)	2(4)	Ge(Li)
$\gamma\gamma_{511}\beta e_{Sh}$, Em	13(3)	6(2)	1(1)	6(2)	
$\gamma\gamma_{511}\beta e_{Sh}$, S	15(4)	17(4)	5(2)	3(2)	

Thus**,** on data two cycles of measuring with different γ-detectors, the space correlating of electron "shake-off" with positron at β^+-decay in direction forward is much less that the same correlating "shake-off"-electron and electron of β^--decay.

Analyses of results and conclusions

The momentum correlating study electron "shake-off"-positron at β^+-decay in relative such properties "shake-off"-electron and electron of β^--decay indicate, that correlating "shake-off"-electron along of direction moving positron at β^+-decay strong differs from correlating at β^--decay and it is much less than those in direction forward. "Shake-off"-electrons at β^+-decay are moving predominantly not in forward direction, as in case β^--decay, but in a direction of large solid angles. These, so different, properties are conditioned apparently by different interactions electron of "shake-off" and main (basic) particle at β^-- and β^+-decay and are stacked in offered in [7 - 9] mechanism, accountable for it. It is apparently the interaction of currents conditioned by motion of charged particles, as charges of main particles (electron – positron) are inverse and interactions currents from it are different: attraction for "shake-off"-electron and β^--particle and pushing away for "shake-off"-electron and β^+-particle at moving in forward direction.

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