Orthopositronium: ‘Annihilation of Positron in Gaseous Neon’

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Abstract

On the basis of phenomenological model of the orthopositronium annihilation ‘isotope anomaly’ in gaseous neon (lifetime spectra, positrons source $^{22}$Na) the realistic estimation of an additinal mode ($\sim$0.2%) of the orthopositronium annihilation is received.

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In huge volume of the data on lifetime spectra of annihilation in substance of positrons from $\beta^+$-decay $^{22}$Na

$^{22}$Na ($3^+$) $\rightarrow$ $^{22*}$Ne ($2^+$) + $e^+_\beta + \nu$,

received for half a century of making of these measurements, the experimental situation for gaseous neon proved to be unique [1, 2].

In a method of delayed $\gamma_a$-$\gamma_a$-coincidences (‘lifetime method’) the appearance of positron in substance is registered by nuclear $\gamma_a$-quantum (‘start’) $^{22*}$Ne ($2^+$)$^{\rightarrow^{\sim 5.24ps} 22}$Ne ($0^+$) + $\gamma_a$($\sim$ 1.27 MeV),

and its annihilation — on one of $\gamma_a$-quanta (‘stop’) as a result of annihilation $e^+_\beta + e^-(in \ substance) \rightarrow$ most probably annihilation on 2 or 3 $\gamma_a$-quanta.

The counter, developing signal ‘stop’, registers not only $\gamma_a$-quantum (with energy $\leq$0.5 MeV) but also $\gamma_a$-quantum ($\sim$1.27 MeV) with recording efficiency

$\varepsilon_{0.5} \cdot \Omega_{2} (\leq 0.5)$

and

$\varepsilon_{1.27} \cdot \Omega_{2} (1.27)$

respectively, and the relation of random ($R$) and true ($C$) coincidences looks like [3]

$\frac{R}{C} = Q\Delta\tau \left[ 2 + \frac{\varepsilon_{1.27} \cdot \Omega_{2} (1.27)}{\varepsilon_{0.5} \cdot \Omega_{2} (\leq 0.5)} \right].$
where $Q \,(s^{-1})$ is the power of the positron source, $\Delta \tau$ is the resolving time of the coincidence circuit, $\varepsilon_i$ the recording efficiency for quanta entering the counter, and $\Omega_n$ is the mean solid viewing angle of counter in conditions of ‘bad’ geometry.

The annihilation $\gamma_n$-quanta are registered in conditions of ‘bad’ geometry, as the annihilation acts occurs in all volume of gas, unlike nuclear $\gamma_n$-quanta outgoing from the centre of volume, where the source of positrons is located.

As the rate of occurrence of the marking ‘start’ $\gamma_n$-quantum (1/$\tau^*$) is more than the order higher than the rate of the fastest processes of positrons annihilation in substance, the correctness and accuracy of the lifetime method are not to be doubted.

Nevertheless once this common rule was broken in our article [2] (its title is repeated in the title of this paper). In this article the results of a number of measurements executed in the USA, England, Canada and in Russia (Institute of Chemical Physics, Russian Academy of Sciences, Moscow) are generalized, and for the first time the attention is paid to specific features of the positron annihilation lifetime spectra in the area of the so called ‘shoulder’ in gaseous neon as compared with other inert gases. Collectivization of nuclear excitation $^{22}\text{Ne} \,(2^+)$ was assumed by us in conditions of experiment in the macroscopic group of identical nuclei ($^{22}\text{Ne}$) — like the nuclear gamma-resonance (NGR) — as in the natural mixture of the neon isotopes ($^{20}\text{Ne},^{21}\text{Ne},^{22}\text{Ne}$) contains about 9% $^{22}\text{Ne}$ and then in such collective of nuclei it is impossible to specify a location of a nucleus, which emits $\gamma_n$-quantum registered by the counter (‘start’). On this basis the explanation of the phenomenon of smoothing the shoulder in neon was offered, which according to this version is caused by uncontrollable grows of a background of random coincidence because of realization in neon of a condition of ‘bad’ geometry also for nuclear $\gamma_n$-quantum. The paradox of this assumption, so long as the manifestation of NGR is supposed to occur in gas (similar scattering of $\gamma$-quanta, without recoil of the radiating and absorbing nuclei, is possible only in a solid state — the Mössbauer effect), was attributed to peculiarity of a final state of $\beta^+$-decay of nucleus $^{22}\text{Na}$ as far back as on the initial stage of a study of the phenomenon of smoothing of a shoulder in neon [3]. We would like to notice that a year ago, on the occasion of the fiftieth anniversary of the hypothesis of W. Pauli about neutrino, B. Pontecorvo has marked: ‘...huge grows of neutrino physics, which became a quantitative science, healthy and powerful and nevertheless permit a quantitative unexpectedness’ [4]. Development of this thesis in works [3, 4], in view of the newest experimental data and the other technique of ‘start’ registration, based on the initial site of track of positron from $\beta^+$-decay $^{22}\text{Na}$ or $^{68}\text{Ga}$, allowed us to attribute formation of macroscopic collective /resonance/ nuclear state ($MCN/R/S$) to the specific quality of $\beta^+$-decay of nuclei of this type $\Delta J^{\pi} = 1^+$ (with a change of a spin on $\pm 1$ and conversation of parity), which should be considered as topological quantum transition [3, 4] in limited ‘volume’ of space-time.

Earlier, as a result of taking into account all manifestations of positron annihilation specific features in gaseous neon, it became clear, that the shoulder in neon can be influenced also by annihilation of orthopositronium (spin $S=1$, triplet state $^3(e^+_3 e^-)_1$, symbol TP, $\tau_T \approx 140$ ns) [5], while short living parapositronium (spin $S=0$, singlet state $^1(e^+_3 e^-)_0$, symbol SP, $\tau_S \approx 125$ ps) can not exert such influence, as it is registered by the device with resolving time $\Delta \tau \sim 0.1 \div 1$ns near interval of time $\Delta t \sim 0$ (‘peak
of instant coincidence'). On this basis was constructed phenomenological model of this phenomenon and parametrization of lifetime spectra of positron (orthopositronium) annihilation in gaseous neon was received [3].

This point of view received additional stimuli in the results of precise measurements of the orthopositronium annihilation rate ($\lambda_T = 1/\tau_T$), executed by a group of Michigan University (Ann Arbor, USA — A. Rich, D.W. Gidley, and co-workers) [9], which were confirmed and specified in the second half of 1980s with use of two different techniques of ‘start’ registration [10, 11, 12]. In these works the excess of experimental meaning of the self-annihilation ($3\gamma_a$-annihilation) $^7$Ps rate $\lambda_T^{(\text{obs.})}$ over the meaning calculated in quantum electrodynamics ($QED$)

$$\lambda_T^{(\text{theor.})} = 7.03830 \pm 0.00005 (\sim 0.0007\%) \, \mu s^{-1}$$

(‘$\lambda_T$-anomaly’ is revealed [3]):

$$\frac{\lambda_T^{(\text{obs.})} - \lambda_T^{(\text{theor.})}}{\lambda_T} = (0.19[11] \div 0.14[12]) \pm (0.02[11] \div 0.023[12])\%.$$  

Coming back to features of lifetime spectra in neon, we shall notice that the estimations ranges of the quantity $10^4 \sim n < 10^5$ of nuclei collective $^{22}\text{Ne}$, sustaining nuclear excitation $^{22}\text{Ne}(2^+)$ in a final state of $\beta^+$-decay $^{22}\text{Na}$, is made in [3] on the basis of a hypothesis about $NGR$ of $\gamma_a$-quantum within $MCN/R/S$ with taking into account insignificance of internal conversion factor and within insignificance of pair conversion factor for transition $^{22}\text{Ne}(2^+) \rightarrow ^{22}\text{Ne}(0^+)$. This estimation is supported and specified in paper [5] on the basis of other reasons

$$n = \bar{n} \cdot \eta = 5.2780 \cdot 10^4 \cdot 0.09 \simeq 0.5 \cdot 10^4 \quad (1)$$

($\pi = 5.2780 \cdot 10^4$ is the complete number of nuclei $MCNS$, and $\eta$ is the share of isotope $^{22}\text{Ne}$ in natural neon), developing an idea of $\beta^+$-decay of nuclei like $^{22}\text{Na}$ as topological quantum transition:

— about connection of the orthopositronium with ‘mirror Universe’ [13], in which from the point of view of the common observer the ‘antipode symmetry’ of energy and action is realized [14], and

— about complete degeneration of ortho- and parasuperpositronium in $N = 2$ supersymmetric $QED$ ($N = 2$ SQED) [15].

Experimental supervision of dependence of characteristic sites of lifetime spectra on gaseus neon isotope composition [15] (‘isotope anomaly’ [3]) has confirmed all pre-conditions of the phenomenology [3]. Let’s consider ‘shift’ $\Delta$ (as a result of double supertransformation — from fermion to boson and back to fermion) — a particle is transferred in other point of space [17]) in quality of a ‘lattice constant’ of cellular, crystal like structure of limited volume non-trivial space topology in a final state of $\beta^+$-decay, and we identify it to the orthopositronium oscillation between our Universe and

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1It concerns to the positron in the orthopositronium, as electron represents the so-called entangled state with others electrons in the observable Universe.
‘mirror Universe’, which explains \( \lambda_{T}\)-anomaly by 2+1-splitting \( 3\gamma_a\)-annihilation of the orthopositronium \( ^{10}\)Ps\( \rightarrow \gamma_a/2\gamma \) into a single observable \( \gamma_a\)-quantum \( (\sim 1.022 \text{ MeV}) \) and two not observable mirror quanta \( (\text{with total energy } \sim 3.6 \cdot 10^{-4} \text{ eV}) \). Over last years the qualitative substantiation of 2+1-splitting \( 3\gamma_a\)-annihilation of the orthopositronium with participation of the ‘mirror Universe’ has been received by the method of chronometric invariants \( (\text{physical observable values}) \) in generalized 4-dimensional space-time, the special case of which is the space-time of the General Theory of Relativity \([18]\).

The structure of MCN/R/S includes an insignificant share of nuclei of atoms \( n = 5.2780 \cdot 10^4 \) from their complete number \( \sim 5 \cdot 10^{22} \) in volume of gas \( V_g \sim \frac{4}{3} \pi R_g^3 \text{ cm}^3 \) \( (R_g \simeq 2 \text{ cm is a radius of the measuring chamber}) \) at pressure \( \sim 50 \div 75 \text{ atm.} \) We receive an experimental estimation of the MCNRS ‘lattice constant’

\[
\Delta_{\text{exp}} = \left( \frac{V_g}{n} \right)^{1/3} \simeq 8 \cdot 10^{-2} \text{ cm.} \tag{2}
\]

This estimation is comparable with virtual fundamental length \( \text{‘shift’} \)

\[
\Delta \simeq c \cdot \frac{\hbar}{\gamma_{\Delta W}} = \frac{4}{\alpha^4} \cdot \frac{\hbar}{m_e c} \simeq 5.5 \cdot 10^{-2} \text{ cm}, \tag{3}
\]

caused by exchange interaction, the so-called ‘annihilation interaction’ bringing to energy increase of the orthopositronium ground state on size \( \frac{4}{\gamma} \Delta W \simeq 3.6 \cdot 10^{-4} \text{ eV} \) \( (\text{‘new force of the annihilation’} \ [19], \Delta W \) is the hyperfine splitting of the ortho- and para-positronium). In terms of physics it means, that the attraction between electron and positron in \( ^{10}\)Ps is weakened, because for a time \( \sim \frac{\hbar}{\gamma_{\Delta W}} \simeq 2 \text{ ps} \) they stay in the form of one virtual photon. This fact can be interpreted as impossibility to locate \( ^{10}\)Ps within the limits of volume, smaller than \( \Delta^3 \). Therefore radius MCNS \( r_c \) we shall determine from equality

\[
\frac{4}{3} \pi r_c^3 = \bar{n} \cdot \Delta^3, \quad r_c = 1.28 \text{ cm.} \tag{4}
\]

The formation of MCN/R/S, having macroscopic radius \( r_c \simeq 1.28 \text{ cm} \), occurs as the consequence of long-range action for baryon charge: the nontrivial topology of limited ‘volume’ of space-time in a final state of \( \beta^+\)-decay means occurrence in a lattice units the baryon charge \( B \) \( (\text{its carrier is a proton} — p) \); the nuclei of substance atoms interact with it by exchange, compensated by ‘hole’ \( \bar{B} (\bar{p}) \) with negative mass in the ‘mirror Universe’ \( (\text{‘antipode symmetry’} \ [14]) \), with which substance does not interact.

For finding out coordination of the concept MCN/R/S we consider initial phenomenological model \([3]\) in approximation of repeatedly resonant scattering of \( \gamma_a\)-quantum with resonant cross section

\[
\sigma_t = f_M \cdot \frac{\lambda^2(2I_1 + 1)}{2\pi(2I_0 + 1)} \text{ cm}^2,
\]

where \( f_M = \exp[-4\pi^2 \frac{x^2}{\lambda^2}] \) is the Mössbauer factor \( (x^2 \text{ is a root-mean-square displacement of a nucleus } ^{22}\text{Ne in a direction of } \gamma_a\text{-quantum}) \), \( \lambda = 2\pi \hbar / E_{\gamma_a} \) is length of a wave of \( \gamma_a\)-quantum, \( I_0 \) and \( I_1 \) are the spins of ground and exited states of \( ^{22}\text{Ne} \). As
in MCN/R/S the root-mean-square displacement of a nucleus has the radius of nuclear forces action $\sim (2–3) \cdot 10^{-13}$ cm (‘isotope anomaly’ [3]), and $\lambda \sim 10^{-10}$ cm, then the Mössbauer factor gets the maximum value $f_M = 1$. We should remind here, that from middle 1980s up to middle 1990s a hypothesis about stationary long-range action for baryon charge (so-called ‘fifth force’) was studied and is not confirmed by experiment, but this does not affect non-stationary aspect of similar non-electromagnetic long-range action in a final state of $\beta^+$-decay. Thus, resonant cross section $\sigma_r \simeq 7.5 \cdot 10^{-21}$ cm$^2$. It is easy to receive an estimation of ‘length of resonant run’ of $\gamma$-quantum between two consecutive acts of resonant scattering on nuclei $^{22}$Ne in MCNRS, as $f_M = 1$ (the exact resonance) means, that length of run can be estimated as for gas of elastic spheres

$$l_{\gamma_n} \sim \frac{1}{\eta \nu \cdot \sigma_r} \approx \frac{1}{0.09 \cdot 50 \cdot 2.7 \cdot 10^{19} \cdot 7.5 \cdot 10^{-21}} \approx 1.1 \text{ cm}, \quad (5)$$

where $\eta \nu$ is a concentration of an isotope $^{22}$Ne in natural neon at pressure $p \sim 50$ atm. The received estimation seems to exclude consecutive realization of the concept MCNRS, because with dense cell packing in structure of MCNRS the parameter of packing $1/12 \approx 0.083$ is close to a share of an isotope $^{22}$Ne in natural neon ($\eta \approx 0.09$), i.e. distance between two nuclei $^{22}$Ne on the way of $\gamma$-quantum equal to $2\Delta \approx 0.11$ cm, and on the order less than $l_{\gamma_n}$. But it is necessary to take into account the specific feature of kinetics of elementary processes in MCNRS, instant participation in resonant scattering of $\gamma$-quantum $n = \bar{n} \eta \approx 0.5 \cdot 10^4$ nuclei $^{22}$Ne, like in parallel chemical reactions, i.e. macroscopic resonant cross section grows $n$-multiple: $\Sigma_r = n\sigma_r$.

For the majority of the researchers, both theoretists and experimenters, the problem of orthopositronium arose only in the second half of 1980s, after numerous confirmations and specification [10, 11, 12] of the first observation by Michigan group of a discrepancy between theory and experiment [9]. The next decade passed in intensive search of the solution of the problem, but it was not found. From middle 1990s, when it seemed that all experimental and theoretical ideas were exhausted in these researches there came a pause. In the last years the interest in this problem has revived again [20, 21]. But a suggestion about single-quantum annihilation of $^T$Ps [22] with participation of the ‘mirror Universe’ [3, 23] has not been investigated in experiment.

The above analysis of ‘isotope anomaly’ in neon allows to proceed to estimation of an additional mode of single-quantum annihilation $^T$Ps. Let’s consider the result of work [24], in which the probability of the $^T$Ps annihilation on one $\gamma$-quantum and neutral supersymmetric gauge boson $U$ with spin 1 is calculated:

$$B(^T\text{Ps} \rightarrow \gamma U) = 3.5 \cdot 10^{-8} \cdot (1 - x^4), \quad (6)$$

where $x = (m_U/m_e) \rightarrow 0$. An explanation of ‘$\lambda_T$-anomaly’ ($\sim 0.2\%$) lacks 4–5 orders. But it is already clear, that in MCNS due to single-quantum virtual annihilation take place the oscillations $^T$Ps$\leftrightarrow^T$Ps between our Universe and the ‘mirror Universe’ (‘there and back’, with shift $\Delta$ [3, see footnote (1)], i.e. occurs incoherent interaction $^T$Ps$\leftrightarrow^T$Ps with $\bar{n}$ ‘units’ of space-like structures MCNS, and hence multiple summation
of probability (6). We receive missing 4–5 orders, and realistic estimation \(\sim 2 \cdot 10^{-3}\) of the mode contribution

\[
\frac{T_{Ps}}{T_{Ps}'} + M \rightarrow \gamma_{a}/2\gamma' + M,
\]

similar in all others attitudes to mode (6). Here mass \(M\) in (7) has a secondary origin: it is formed in gas on \(\bar{n}\) units of \(MCNS\), having an affinity to baryon charge of atomic nuclei.

Nevertheless there are some more difficulties: first, earlier in experiment was received the estimation of the top limit of the probable contribution of the \(T_{Ps}\) single-photon annihilation \(\leq 4 \cdot 10^{-4}\% [25]\); secondly, from the point of view of phenomenological model based on results of supersymmetric consideration of the orthopositronium problem \([3, 15, 24]\), a single-photon mode of orthopositronium annihilation (three photon mixed \(\gamma_{a}/2\gamma'\)) does not agree with symmetry, because photon propagates in a certain direction as the flat wave, \(i.e.\) the central symmetry of space is broken.

The way out of this critical situation was prepared before discovery of supersymmetry by definition of notoph \([26]\): ‘contrary to mass-bearing particles, helicity (projection of full angular momentum on a direction of movement) is relativistic invariant for zero-mass particles. Under discussion in a massless particle with zero helicity complementary to photon according to its properties (helicity is equal to \(\pm 1\)) and therefore referred to as ‘notoph’. In interactions notoph similar to photon bears spin 1. Notoph is described by antisymmetric tensor potential, while the field strength is a 4-vector (instead of vector potential and tensor of electromagnetic field strength) . . . when discussing new particles and their interactions we should take notoph into account. . .’.

Helicity of notoph is equal to zero, \(i.e.\) it propagates as a spherical wave. Thus, experimental task of search of single-photon annihilation \(T_{Ps}/T_{Ps}' \rightarrow \gamma_{a}/2\gamma'\) is transformed to search of single-notoph annihilation \(T_{Ps}/T_{Ps}' \rightarrow \gamma_{a}^0/2\gamma'\), and it changes the technique of experiment. In measurements \([1, 9, 10, 12, 16, 25]\) were fixed not only time and power correlations of \(\gamma\)-quanta, but also spatial arrangement of detectors, which breaks angular isotropy of measurements. For an establishment of the contribution of supersymmetric single-notoph mode of \(T_{Ps}/T_{Ps}'\) annihilation the technique ensuring \(4\pi\)-geometry of detecting notoph is needed. In work \([21]\) it is suggested that the technique which was used in work \([27]\) should be improved to achieve higher sensitivity. According to the authors of work \([21]\) for realization of reliable measurements of the contribution of a mode \(T_{Ps} \rightarrow T_{Ps}'\) in conditions of vacuum the increase of \(4\pi\)-calorimeters sensitivity is necessary.

In our suggestion which takes into account also ‘isotope anomaly’ of orthopositronium, it is necessary to allocate expected effect at \(E_{\gamma_{a}} \simeq 2m_{e}c^{2}\) on a background of peak of complete annihilation energy \(\sim 1.022\) MeV, instead of at \(E_{\gamma_{a}} \simeq 0\), as in work \([27]\) and as it is offered in \([21]\).

The offered here way of the orthopositronium problem decision summarizes supervision, phenomenology and experimental results submitted in our publication for 25 years, and is in essence complete substantiation of decisive experiment for search single-notoph annihilation \(T_{Ps}/T_{Ps}' \rightarrow \gamma_{a}^0/2\gamma'\). It is based on the ideas which have arisen on ‘crossing’ of nuclear-physical directions and techniques of researches of a chemical kinet-
ics and a structure of substance — the ‘positronics’ and gamma-resonance spectroscopy, — created in the beginning 60s in Institute of Chemical Physics by V.I. Goldanskii with co-workers. The author is grateful to memory of the Academician Vitalii Iosifovich Goldanskii for support of these publications, which stimulated statement of critical experiment, for organizational support of experimental work and for the shown interest to coming-to-be of this direction of the orthopositronium dynamics researches.

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