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THE ORTHOPOSITRONIUM DECAY PUZZLE

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The disagreement between theoretical and experimental values of the orthopositronium decay rate (the lifetime) is described, and possible reasons of its existence are discussed. The new experiment setting-up promising to improve significantly the measurement precision is briefly presented.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

Загадка распада ортопозитрония

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Описывается существующее расхождение теоретического и экспериментального значений времени жизни ортопозитрония, обсуждаются возможные причины этого различия. Кратко представлено предложение новой постановки экспериментов, позволяющей значительно повысить точность измерений.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

The strong disagreement between theoretical and experimental values of the orthopositronium decay rate continues to be a «puzzle» of the modern quantum electrodynamics. The theoretical value is [1]

$$\tau_{\text{ortho}}^{-1} = \frac{\alpha^6 mc^2}{\hbar}\,\frac{2(\pi^2-9)}{9\pi}\left[\,1 - 10.2866(6)\,\frac{\alpha}{\pi} - \frac{\alpha^2}{3}\ln\alpha^{-1} + B\left(\frac{\alpha}{\pi}\right)^2 - \frac{3\alpha^3}{2\pi}(\ln\alpha^{-1})^2\ldots\right] =$$

$$= 7.038236(10)\ \mu\text{s}^{-1}, \tag{1}$$

where numerical coefficient B is still under calculation (it requires taking into account numerous two-loop virtual corrections, which is a hard task).

The experimental situation here is not exactly clear. The experiments performed by the University of Michigan group in 1987-90 [2—4], gave the results (see the Table), which exceed essentially the theoretical value. On the other hand, the very recent result of the Tokyo University group [5,6] is consistent, within the experimental accuracy, with the

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theoretical value. Clearly, both the theoretical and experimental results are to be examined more carefully.

Table. The theoretical and experimental values of the orthopositronium decay rate

Reference	Year	Decay rate, μs^{-1}	Precision, 10^{-4}	Difference from [1], ms^{-1}
		Theory		
[1]	1992	7.03824(1)	0.01	—
[8,10]	1994	7.04126(12)	0.17	3.02
		Experiment		
[2]	1987	7.0516(13)	1.8	13.36 ± 1.3
[3]	1989	7.0514(14)	1.8	13.16 ± 1.4
[4]	1990	7.0482(16)	2.3	9.96 ± 1.6
[5]	1994	7.0348(80)	5.7	- 3.4 ± 8.0
[6]	1995	7.0398(80)	5.7	1.6 ± 8.0

The theoretical uncertainty of the positronium lifetime is related to the coefficient B in formula (1). The problem is that of large second-order corrections. One class of large second-order corrections arises as follows [7]. The large, about -10, factor at the α/π correction to the decay rate (see (1)) means that the factor at the α/π correction to the decay amplitude is roughly -5. Correspondingly, this correction squared contributes about $25(\alpha/\pi)^2$ to the decay rate. Indeed, numerical calculations [8,9] give factor 28.86 at $(\alpha/\pi)^2$ in the contribution.

There is one more class of potentially large contributions to the positronium decay rate. This is relativistic corrections. A simple argument in their favour is that the corresponding parameter $(v/c)^2 \sim \alpha^2$ is not suppressed, as distinct from that of usual second-order radiative corrections, $(\alpha/\pi)^2$, by the small factor $(1/\pi)^2 \sim 1/10$. The relativistic corrections to the positronium decay rate were obtained in [10]. This problem had been addressed previously in [11,12] with different results. The origin of the disagreements was elucidated in [10,13]. The result of the recent paper [14] agrees with [10].

As to the relativistic correction to the parapositronium decay rate, also obtained in Ref.10, its calculation was started by the authors as a warm-up exercise for the much more complicated orthopositronium problem. However, the correction in the singlet case also turns out large, quite close to the sensitivity of the recent experiment [15].

Though the theoretical results indicate that the α^2 correction is very large indeed, it is not sufficiently large to reconcile the theory and experiment [2—4]. As to the experimental result [5,6], its accuracy is still insufficient.

The main limitation of the precision of the experiments is the systematic errors related to the traditional method of positronium generation: positrons are stopped in a target and recombine then with atomic electrons. New experimental approach will become feasible with the realization of the proposal of the orthopositronium generation, using special storage ring [16,17], and experimental set-up with the fine dericted orthopositronium flux [18]. The proposed scheme promises to obtain the flux of intensity of 10^4 atoms/s with velocity about 0.3 of the speed of light and with very low angular spread — of the order of 1 mrad and the velocity spread of the order of 10^{-4} or less. The peculiarity of the scheme is to use an electron beam, which provides cooling of positrons and, in e^-e^+-recombination, the positronium generation. Thus, the pure vacuum conditions at generation place and in the positronium flux drift channel permit one to reach very low background level. Using Lyman photons as a start signal and γ-quanta from positronium decay as the stop one, we can provide very high precision of the measurements of the orthopositronium lifetime in-flight. One should mention that the velocity spread can limit the measurement accuracy (due to the Lorentz-factor spread) by the value

$$\frac{\Delta\tau}{\tau} \sim \gamma^2\beta^2 \frac{\Delta v}{v} \leq 3\cdot 10^{-6}, \text{ when } \beta \sim 0.2. \tag{2}$$

This is two orders of magnitude lower of the accuracy level achieved up to now.

Very similar situation takes place in the problem of the parapositronium lifetime. One shoud point out that the proposed scheme with orthopositronium directed flux permits one to perform the experiments on *p–Ps* lifetime measurement with high precision also. For this purpose one can use conversion of *o–Ps* in *p–Ps* mode in external static magnetic or RF-electromangetic field (see details in [18]).

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