QED analysis of the two photons -- into -- a paraphoton inelastic scattering

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Abstract. Paraphoton is the axion-like chameleon (no fixed rest-mass) particle introduced to the quantum chromodynamics to solve the strong CP-problem. Nowadays, it is the best candidate to be the quantum of the dark matter. In the paper, we present the quantum analysis of the two-photons process resulting to the paraphoton formation.

1. Introduction

The recent experiments on the Large Hadron Collider [1] discover the elastic photon-photon scattering $\gamma + \gamma \rightarrow \gamma + \gamma$. This way, there is also possible the inelastic process (fig.1) combines two photons to the paraphoton [2] by the channel $\gamma + \gamma \rightarrow a$. The outcome a is a massive boson with spin $s_a = 2$ and "chameleon" mass $m_a = 2h\nu_\gamma/c^2$, which interacts neither the "strong" nor a "weak" way but potentially reveals itself in the neutrino experiments [3]. Because of its symmetry paraphoton is also the best candidate to be the gravitational gauge boson [4] which is probably form the dark matter. These all make the process $\gamma + \gamma \rightarrow a$ very important, and the paper performs its quantum analysis.

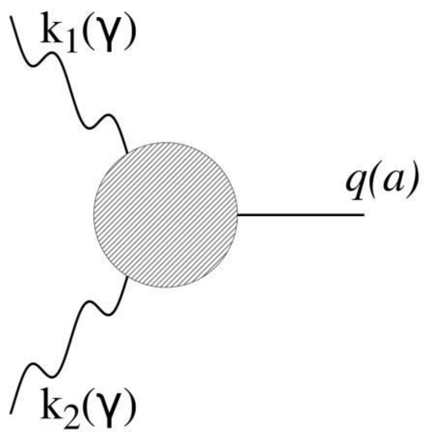

Figure 1. Feynman diagram for the process of inelastic interaction of two photons $\gamma + \gamma \rightarrow a$

2. Analysis

The analysis can be performed by the standard routine, described in [5]. Hereinafter the paper uses the nuclear system of units (Dirac constant is 1, speed of light is 1) and 4-vectors.

Let k_1 and k_2 be photon momenta (see fig.1), λ_1 and λ_2 its polarizations and q the momentum of paraphoton.

The initial state of the system (two photons) is

$$|k_1\lambda_1, k_2\lambda_2\rangle = a^+_{\lambda_1}(k_1)a^+_{\lambda_2}(k_2)\,|0\rangle \tag{1}$$

where |0> is the ground state of a vacuum, a^+ is the photon "birth" operator.

The final state of the system (paraphoton) is $|q>$.

This way, the scattering matrix is following:

$$\begin{gathered}\langle q|S|k_1\lambda_1, k_2\lambda_2\rangle = e^2\frac{1}{(2\pi)^{9/2}}\frac{1}{\sqrt{8k_{10}k_{20}q}}\times \\ \times\, e^{\lambda_1}_{\mu}(k_1)e^{\lambda_2}_{\mu}(k_2)M_{\mu\nu}(k_1,k_2;q)(2\pi)^4\delta(k_1+k_2-q)\end{gathered} \tag{2}$$

Here $e^{\lambda 1}(k_1)$ and $e^{\lambda 2}(k_2)$ are 4-polarizations of photons, e is the elementary charge, δ is the Dirac δ-function and $M_{\mu\nu}(k_1, k_2; q)$ is unknown because of no good theory nowadays. Meanwhile, the analysis of the symmetry can get it with the single unknown constant.

To obtain $M_{\mu\nu}$, lets start from the evident commutativity

$$\left[a^+_{\lambda_1}(k_1), a^+_{\lambda_2}(k_2)\right] = 0 \tag{3}$$

which gets

$$\langle q|S|k_1\lambda_1, k_2\lambda_2\rangle = \langle q|S|k_2\lambda_2, k_1\lambda_1\rangle \tag{4}$$

means that photons must be identical.

This way,

$$M_{\mu\nu}(k_1,k_2;q) = M_{\nu\mu}(k_2,k_1;q) \tag{5}$$

Next, Lorentz- and inversion-invariances makes $M_{\mu\nu}(k_1, k_2; q)$ be a pseudotensor of rank 2. At fig.1 there are three 4-vectors (k_1, k_2, q) bound by the energy and the momentum conservation

$$k_1 + k_2 = q \tag{6}$$

which makes only two (k_1, k_2) of them independent ones. This two vectors can combine a rank 2 pseudotensor by the following way only:

$$M_{\mu\nu}(k_1,k_2;q) = A\varepsilon_{\mu\nu\rho\sigma}k_{1\rho}k_{2\sigma} \tag{7}$$

where ε is the Levi-Civita epsilon and A is a constant.

To construct scalar A from 4-vectors k_1 and k_2 there are two ways only:

1) $k_1^2 = k_2^2 = 0$ which is trivial, and

2) $k_1\, k_2 = ½\, q^2 = -½\, m_a^2$ where the paraphoton mass m_a is figured.

Therefore, A is determined by the rest-mass m_a of the paraphoton. In the local inertial system of paraphoton's mass center the summation of (2) over λ_1 and λ_2 gives

$$d\Gamma = \frac{1}{(2\pi)^2}\frac{1}{8m_a}e^4 \sum_{\lambda_1,\lambda_2=1,2} \left(e_\mu^{\lambda_1}(k_1)e_\nu^{\lambda_2}(k_2)M_{\mu\nu}\right)\times$$
$$\times\left(e_\rho^{\lambda_1}(k_1)e_\sigma^{\lambda_2}(k_2)M_{\rho\sigma}\right)^*\delta(k_1+k_2-q)\frac{dk_1}{dk_{10}}\frac{dk_2}{dk_{20}} = \tag{8}$$
$$= \frac{1}{(2\pi)^2}\frac{1}{8m_a}e^4\sum_{\mu,\nu} M_{\mu\nu}M_{\mu\nu}^*\eta_\mu\eta_\nu\delta(k_1+k_2-q)\frac{dk_1}{dk_{10}}\frac{dk_2}{dk_{20}}$$

with $\eta_\lambda = (+1)$ for $\lambda = 1, 2, 3$, and (-1) for $\lambda = 4$. This is the differential cross-section of $\gamma + \gamma \rightarrow a$. To simplify (8), one can uses following almost-evidences:

$$\varepsilon_{\mu\nu\rho\sigma}k_{1\rho}^*k_{2\sigma}^*\eta_\mu\eta_\nu = -\varepsilon_{\mu\nu\rho\sigma}k_{1\rho}k_{2\sigma} \tag{9}$$

and

$$\varepsilon_{\mu\nu\rho\sigma}\varepsilon_{\mu\nu\rho'\sigma'} = 2\left(\delta_{\rho\rho'}\delta_{\sigma\sigma'} - \delta_{\rho\sigma'}\delta_{\sigma\rho'}\right) \tag{10}$$

which give

$$\sum_{\mu,\nu} M_{\mu\nu}M_{\mu\nu}^*\eta_\mu\eta_\nu = \frac{1}{2}m_a^4|A|^2 \tag{11}$$

This way, we also can obtain the integral cross-section Γ. To do it, note that $d\Gamma(k_1, k_2) = d\Gamma(k_1, k_2)$. Therefore, to calculate Γ, one should use the following trick: to integrate $d\Gamma$ by all possible k_1 and k_2, and get a half of the result. During the integration one should also use the feature of the Dirac δ:

$$\int \delta(k_1+k_2-q)\frac{dk_1}{k_{10}}\frac{dk_2}{k_{20}} = 2\pi \tag{12}$$

which after all gives the final result:

$$\Gamma = \frac{1}{4}\pi\alpha^2 m_a^3|A|^2 \tag{13}$$

where $\alpha = e^2/4\pi = 1/137$ is the fine structure constant, m_a is the (chameleonic) rest-mass of the paraphoton, A is a constant to be measured during the experiment.

3. Conclusion

The performed QED analysis gives the differential (8) and the integral (13) cross-sections of the photon-photon process resulting to the birth of the paraphoton. Because of T-symmetry, these also are the cross-sections of the invert process of paraphoton decay onto two photons. Therefore, we predict the two photons -- into --the paraphoton oscillations, which can be detected by the known distribution of the dark matter in the Universe [6,7]. These oscillations makes the Universe be transparent to observe ultra-deep field at the Hubble Space Telescope (HST anomaly, [8]). The $\gamma + \gamma \rightarrow a$ channel also influence to the registered star energy radiation resulting to the anomalous flux of the neutrino (solar neutrino anomaly [9]) and unexpectedly high positron ratio in the cosmic rays (PAMELA anomaly [10]). At last, one should notice the most recent experiments on the electromagnetically induced over-transparency of the crystalline ruby [11] and the Primakoff ("Light shining through a wall") effect in the photonic crystals [12].

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