Biphoton bound state right above e-p pair birth threshold

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Abstract

A biphoton state of matter that is an instant interplay between electromagnetic energy and electron-positron pairs is reported. The biphoton ladder diagram right above the *e-p* pair birth threshold is summed up. Only one ladder diagram is most relevant, and the obtained propagator has a diffusion pole, with the diffusion coefficient expressed as $D \sim \alpha^{-2}\hbar/m \sim 2 \times 10^4 \mathrm{cm}^2/\mathrm{s}$, where α is the fine-structure constant and m is the electron mass. This diffusion coefficient, dependent only on fundamental constants, can describe an observable macroscopic object, for example, ball lightning. This is a realization of an object with oscillation of energy between an electromagnetic field and an *e-p* pair. The energy is preserved, but the momentum is getting randomized. This continuous oscillation holds energy localized in space, expanding relatively slowly following the diffusion equation.

Presentation Overview

Light and e-p pairs

Figure: Energy of light goes to energy of e-p pair then again to energy of light (biphoton) then again to energy of e-p pair

Light and e-p pairs

biphoton is not a laser beam, it is not monochromatic light

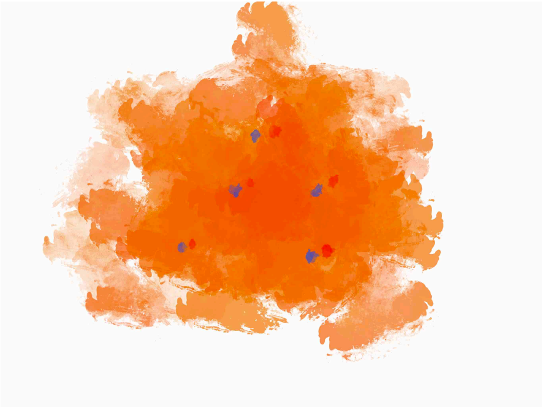
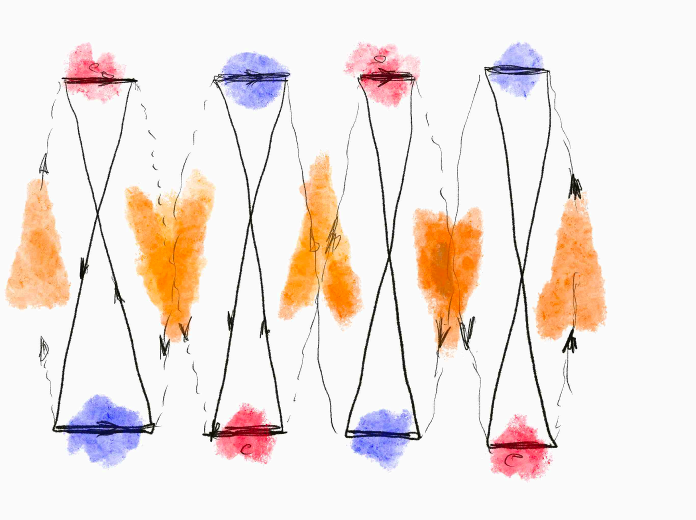


Figure: Biphoton momentum is randomized upon energy transfer to real e-p pair. We search for diffusively expanding state at $2\omega \gtrsim 2m$.

BiPhoton Flip diagram

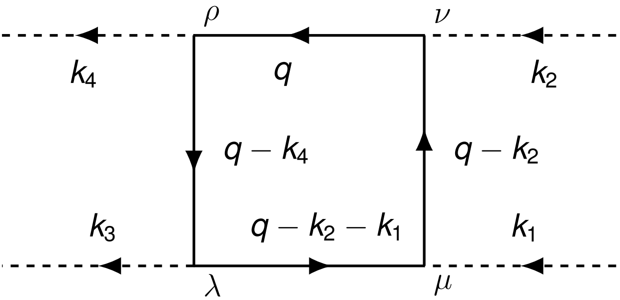
i) For each fermion box, the incoming light legs should have opposite momenta; ii) Light legs connecting fermion boxes should have parallel momenta to form biphoton; iii) Biphoton backward scattering (flip) is must given by (i) and (ii)



Perspective View

1. Crossection - text book problem, Review [2006]
2. Experimental measurements at LHC [2019]
3. Vacuum birefringence by PVLAS [2020]
4. Limitations on Intensity of Lasers [2010]
5. Universe opacity due to light collisions with CMBR [2012]

Photon-Photon scattering amplitude right above the e-p birth threshold



$$i\tilde{\Gamma}_{\lambda,\rho;\mu,\nu}(k_3,k_4;k_1,k_2) = -\frac{e^4}{8\pi}\sqrt{\frac{2(\omega-m)}{m}}\mathrm{Tr}\gamma^\mu\gamma^\nu\frac{1+\gamma^0}{2}\gamma^\rho\gamma^\lambda\frac{1-\gamma^0}{2}$$

Here $2\omega = k_{10} + k_{20}$. The trace yields -2 for either $\mu = \lambda = 0$ and $\nu = \rho = 1,2,3$ or $\mu = \lambda = 1,2,3$ and $\nu = \rho = 0$. Therefore Γ is transforming like a dipole moment.

Ladder diagrams

Summation (over n) of ladder diagrams (with n fermion boxes) gives exact amplitude. It has a pole. The off-shell pole indicates presence of a bounded biphoton. Figs below show ladders with two boxes, as an example.

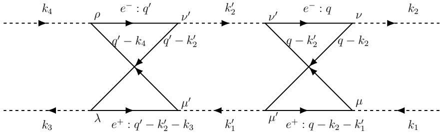


FIG. 1. The bi-photon ladder preserving 4-index along upper and lower lines. We can take $\rho = \nu' = \nu = 1$ or 2 or 3 and $\lambda = \mu' = \mu = 0$ or vice versa. Summation of this ladder gives new state with diffusion like pole.

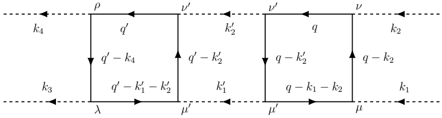


FIG. 2. The bi-photon ladder, please pay attention to 4-index conserved along upper and lower lines. Obtained integral equation for the sum of this ladder shows no poles in its solution.

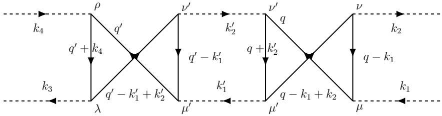


FIG. 3. The bi-photon ladder not preserving 4-index along upper and lower lines. This ladder summation has no pole too.

Integral equation for exact scattering amplitude (sum of ladder diagrams)

$$i\Gamma(k_3, k_2; k_1, k_4) = i\tilde{\Gamma}(k_3, k_2; k_1, k_4) - \int \frac{d^4 k_1'}{(2\pi)^4} \times i\tilde{\Gamma}(k_3, k_2'; k_1', k_4)[-iD(k_1')][-iD(k_2')]i\Gamma(k_1', k_2; k_1, k_2') \tag{1}$$

introduce fast variables $2\omega = k_{30} + k_{40}$, and slow variables $p = (\Omega, \vec{P}) = k_3 - k_4 = k_1' - k_2' = k_1 - k_2$, arrive at

$$\chi(\Omega, \vec{P}, \omega) = \tilde{\chi}(\Omega, \vec{P}, \omega) + \frac{e^4}{2|\vec{P}|} \tan^{-1} \frac{i\Omega}{|\vec{P}|} \times \int_{2m-\omega}^{m+\Lambda} \frac{d\omega'}{2\pi} \sqrt{\frac{\omega + \omega' - 2m}{m}} \chi(\Omega, \vec{P}, \omega') \,. \tag{2}$$

inhomogeneous integral equation, Λ is a cutoff

Poles of the exact scattering amplitude

Assumptions are $\Omega, |\vec{P}| \ll \omega$, besides $|\omega - m|, \Lambda \lesssim m$

The exact scattering amplitude has poles given by the following propagator

$$B_\lambda(\Omega, \vec{P}) = \left[1 - \frac{1}{D_\lambda |\vec{P}|} \tan^{-1} \frac{i\Omega}{|\vec{P}|}\right]^{-1} \sim \frac{1}{D_\lambda P^2 - i\Omega}$$

Here $1/D_\lambda$ are eignevalues of the homogeneous integral equation [omitted $\tilde{\chi}(\Omega, \vec{P}, \omega)$]. The diffusion koeff estimated

$$D_\lambda \gtrsim \alpha^{-2} \frac{\hbar}{m} \sim 2 \times 10^4 \text{cm}^2/\text{s}$$

Biphoton is macroscopic object expanding few meters per sec.

Summary

In conclusion, a biphoton state that is the quantum superposition of light and matter is reported. It can be possibly formed by the high concentration of electromagnetic energy, for example, in thunderstorms or in beams of high-power lasers. This state is governed by the diffusion type of the propagator, implying that it can propagate through space without acceleration while expanding constantly. The propagator has six components similar to the electric field in the electromagnetic tensor because the virtual matter state has the symmetry of an electric dipole. The diffusion constant in this propagator depends on basic physical constants such as $\alpha, \hbar, m$ reflecting the most fundamental nature of the discovered state.

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