МОДЕЛИРОВАНИЕ В НАУЧНЫХ ИССЛЕДОВАНИЯХ

ON THE PHYSICAL NATURE OF PHOTON AND THE MODELING OF ITS WAVE FUNCTION OF FREE PROPAGATION IN SPACE AND TIME

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Abstract. In the framework of quantum mechanics the physical nature of the photon is discussed. It is substantiated that a photon is a quantum quasiparticle, the free propagation of which must be considered taking into account the processes in a physical vacuum at Planck distances. For practical purposes on a macroscopic scale, the photon propagation can be modeled using the wave function (wave packet) normalized to the unit probability in the coordinate representation.

Keywords: photon, wave function, quantum mechanics, coordinate representation, Schrödinger equation, Maxwell's equations, probability density, bivector, wave-particle duality.

Introduction. At present, the interference optical phenomena are theoretically described from the point of view of classical electrodynamics or in language of secondary quantization. The “primary quantization” of photon behavior has been prohibited since the publication of [1] in which the principled possibility of creation of photon wave function in coordinate representation was denied. However, in the mid 90-ies of the previous century the works (see [2] – [5]) began to appear, in which at interpretation of photon wave function the focus from the probability density of photon localization was shifted to the probability density of its detection in some space point. Obviously, the need of creation of photon wave function in coordinate representation becomes relevant in connection with emergence of fundamentally new experiments and purely practical queries, for example, in verifying Bell's inequalities and quantum nonlocality; in quantum cryptography and quantum computations. These experiments, in particular, stimulated the development of sources and detectors of individual photons. In [6] – [14] and other works the one-particle wave function of the photon gained further development in theoretical justification. In [15 – 22] for its evident illustration the modeling of free propagation in space of the wave packet describing the single-photon state, corresponding to laser radiation of duration 80 fs with the central wavelength of 10 microns, and Gaussian momentum distribution in this packet is carried out. As the result of the modeling the character of the extension of a wave packet is established, namely: its spatial shape from the original “spherical” shape transforms into a certain “cone” shape, reminding a pattern of Vavilov-Cherenkov radiation, because the peripheral parts of the packet's probability density lag behind the central part moving at the speed of light c in vacuum Although much is known about light as a stream of photons, in the foreshortening of the wave-particle duality of the light itself and of the material particles having the mass of "rest", the answers to the main questions are still unclear: what is a photon, and whether it exists as a material particle? If it exists, but not as an independent material particle, then what prompts us to create an image of a photon as a material particle that propagates according to the laws of quantum mechanics, practically coinciding, in respect of the photon, with the laws of classical electrodynamics? Is it lawful to raise the question, in this connection, about the construction of a quantum-mechanical wave function for the photon in the coordinate representation? We emphasize that these questions need not be answered within the philosophical aspect of the wave-particle duality, but it is necessary to concentrate efforts on clarifying the picture from the physical point of view, and to state that this “duality”, in fact, should be generally eliminated from science.

The photon wave function in the coordinate representation. Maxwell's equations for a free field can be presented in the quantum form, having carried out his some part of “primary quantization”, having written down these equations in the form of the Majorana [23] (in the SGS system):

$$i\hbar\frac{\partial\xi}{\partial t}=c(\hat{\mathbf{s}}\hat{\mathbf{p}})\xi\,;\quad i\hbar\frac{\partial\eta}{\partial t}=-c(\hat{\mathbf{s}}\hat{\mathbf{p}})\eta\,;\quad (\hat{\mathbf{p}}\boldsymbol{\xi})=0\,;\quad (\hat{\mathbf{p}}\boldsymbol{\eta})=0\,, \tag{1}$$

where $\hat{\mathbf{p}}=-i\hbar\hat{\nabla}$ is the operator of the particle momentum, $\hat{\mathbf{s}}$ is the operator of spin operator of the photon; vectors $\boldsymbol{\xi}=\mathbf{E}+i\mathbf{H}$ and $\boldsymbol{\eta}=\mathbf{E}-i\mathbf{H}$ are presented in the matrix form. From these vectors it is possible to make a bivector $\Phi_{\text{bv}}=\begin{pmatrix}\xi\\ \eta\end{pmatrix}$ for the description of the photon state [7]. In [7, 9] quantum mechanics of a photon is constructed, according to which the state of the photon is described in a certain way by the bivector

$$\Phi^{(\pm)}_{\text{bv}}(\mathbf{r},t)=\int B(\mathbf{k},\pm1)\,\Phi^{(\pm)}_{\text{bv};\mathbf{k},\pm1}(\mathbf{r},t)\,d^3\mathbf{k}+\int\left[B(-\mathbf{k},\mp1)\right]^*\Phi^{(\pm)}_{\text{bv};\mathbf{k},\mp1}(\mathbf{r},t)\,d^3\mathbf{k}\,, \tag{2}$$

where the upper signs of the indices correspond to the positive energy of the photon, and the lower ones to the negative, “theoretically possible”; ±1 correspond to the two possible values of helicity λ; the coefficients $B(\mathbf{k},\lambda)$, when the photon state is given with the help of $\mathbf{E}$ and $\mathbf{H}$, are clearly expressed through them. Bivectors $\Phi^{(\pm)}_{\text{bv};\mathbf{k},\lambda}(\mathbf{r},t)$ correspond to states with definite values of momentum $\mathbf{p}=\hbar\mathbf{k}$, helicity λ and photon energy $E^{(\pm)}=\pm\hbar kc$ and have an appearance

$$\Phi^{(\pm)}_{\text{bv};\mathbf{k},\pm1}(\mathbf{r},t)=\begin{pmatrix}\xi^{(\pm)}_{\mathbf{k},\pm1}(\mathbf{r},t)\\ 0\end{pmatrix}=\frac{(\text{Oe})\,\mathrm{e}_{\pm1}(\mathbf{k})}{(2\pi)^{3/2}}\,e^{i(\mathbf{kr}\mp kct)}\begin{pmatrix}1\\0\end{pmatrix}, \tag{3}$$

$$\Phi^{(\pm)}_{\text{bv};\mathbf{k},\mp1}(\mathbf{r},t)=\begin{pmatrix}0\\ \eta^{(\pm)}_{\mathbf{k},\mp1}(\mathbf{r},t)\end{pmatrix}=\frac{(\text{Oe})\,\mathrm{e}_{\mp1}(\mathbf{k})}{(2\pi)^{3/2}}\,e^{i(\mathbf{kr}\pm kct)}\begin{pmatrix}0\\1\end{pmatrix}, \tag{4}$$

where (Oe) is the unit of measure (oersted) $\boldsymbol{\xi}$ и $\boldsymbol{\eta}$; $\mathrm{e}_{\mp1}(\mathbf{k})$ are the complex polarization vectors.

However, in more fully the state of the photon describes by the wave function

$$\Psi^{(\pm)}(\mathbf{r},t)=\int b(\mathbf{k},\pm1)\,\Psi^{(\pm)}_{\mathbf{k},\pm1}(\mathbf{r},t)\,d^3\mathbf{k}+\int\left[b(-\mathbf{k},\pm1)\right]^*\Psi^{(\pm)}_{\mathbf{k},\mp1}(\mathbf{r},t)\,d^3\mathbf{k}\,, \tag{5}$$

where

$$b(\mathbf{k},\lambda)=\frac{(\text{Oe})}{\sqrt{8\pi\hbar kc}}B(\mathbf{k},\lambda)\,;\qquad \Psi^{(\pm)}_{\mathbf{k},\lambda}(\mathbf{r},t)=\frac{1}{(\text{Oe})}\Phi^{(\pm)}_{\text{bv};\mathbf{k},\lambda}(\mathbf{r},t)\,. \tag{6}$$

The function (5) is normalized to the unit probability of detecting the photon at a certain point (for example, in a detector), it satisfies to equation of Schrödinger type and the continuity equation. Thus, the “primary quantization” of photon states is realized.

Modeling the evolution of a single-photon wave packet. In [15 – 22] the results of single-photon modeling of laser radiation at femtosecond range are presented. In the modeling, the $b(\mathbf{k},\lambda)$ determining the momentum distribution in the state (5) are given in the Gaussian form

$$b(\mathbf{k},\pm1)=\left[b(-\mathbf{k},\mp1)\right]^*=\sqrt{\frac{\alpha^3}{2\pi\sqrt{\pi}}}\exp\left[-\frac{\alpha^2}{2}\left(k_x^2+k_y^2+(k_z\mp k_0)^2\right)-i\mathbf{kr}_0\right]. \tag{7}$$

The character of the extension (mentioned in the introduction) of the packet (5) is established by numerically calculating of the most significant in this case projection E_x of electric field intensity.

Physical nature of the photon. Let us formulate a few of statements in which, in our opinion, the satisfactory, at this stage, answers to the most of the above questions either are already contained, or the looked-through prerequisites for the answers to the remainder of them are included.

These statements are as follows:

1) Electromagnetic waves and, in particular, the light are the stream of "sequentially" (in the quantum-mechanical sense) propagating, in space and time, individual short-term (duration of the

order of Planck time) acts of flip (on 180°) and return to the original state of the spin of the extremal maximons (EM-I) or the "antimaximons" (AEM-I) of the first class, forming in pairs (EM-I + AEM-I) at full their merging, one of the possible massless, uncharged, spinless structural "units" of the physical vacuum (which, however, "in itself" has the order of magnitude of the Planck magnetic moment) [24] – [32]. Each individually registered photon is thus not a self-existent "massless" particle, before the registration, but a kind of "magnon" propagating in a vacuum only on the one excited chain of such spin-flips of a traveling wave, like a spin wave in a solid body. The registration of a photon is the result of the transfer of a certain number of dynamic characteristics (energy, momentum and angular momentum) to the "massive" particles from one such spin-flip chain. The probability of its excitation (perceived as "photon emission"), its orientation in space (the "direction of the motion photon") and the transfer of the dynamic characteristics of this excitation to material particles ("photon absorption") are determined by the physics of processes not yet studied at Planck distances.

2) For practical purposes, consideration of the majority of processes associated with spin-flip chains can be conditionally replaced by the consideration of processes that, as would be implemented by "point" photons that are the alleged material but massless particles. In this case, the radiation, propagation, scattering and absorption of the photons should be described by quantum mechanical laws, some of which (Maxwell's equations) coincide with the equations of classical electrodynamics, and the other part (Schrödinger type equation) is associated with a purely quantum mechanical description, the attribute of which must be also the wave function of the photon in the coordinate representation. In the "gap" between the consideration of the spin-flip chain and the practical use of the "material" photon equivalent to it in this sense, it should nevertheless be assumed that the photon should have a finite radius equal to the radius of the extremal class I maximon [28, 31].

Conclusion. The constructed quantum mechanics allows, at the given stage, in essence, to remove the problem of wave-particle duality [9]. Since for the photons one can also talk about the wave function in the coordinate representation, it can be argued that photons and particles, that have a mass, behave as corpuscles interacting with other particles, transferring the certain quantities of their characteristics (both dynamic and internal) to other particles. The particles are propagated according to "wave rules": their distribution in space is determined by the wave function in the coordinate representation. Within the framework of quantum mechanics, therefore, it is possible, in particular, to explain "purely wave phenomena", such as Young's experiment.

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ПРИМЕНЕНИЕ ЛИНЕЙНОЙ СЕТЕВОЙ МОДЕЛИ НАХОЖДЕНИЯ КРАТЧАЙШЕГО ПУТИ ЭВАКУАЦИИ НАСЕЛЕНИЯ

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APPLICATION OF THE LINEAR NETWORK MODEL OF FINDING THE SHORTEST WAY OF EVACUATION OF THE POPULATION

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Abstract. The report considers an algorithm for solving the problem of advance evacuation of the population, which is formulated as finding the shortest path in a linear network model representing the routes of movement along the existing transport network of roads with a cycle. The starting point is the prefabricated evacuation point, and the final one is the receiving evacuation point, the numbers on the edges are the length of the path between the intermediate points.

Key words: evacuation point, linear network model with a cycle, evacuation of the population, algorithm for finding the shortest path, graph.

Применение теории графов. На современном этапе развития информационных технологий использование теории графов широко и разнообразно:

– в химии для описания структур химических элементов и числа теоретически возможных изомеров углеводородов и других органических соединений [1];

– в информатике и программировании (граф – блок-схема алгоритма программы);

– в коммуникационных и транспортных системах для поиска кратчайшего пути на сети дорог [2]. В частности, для маршрутизации данных в Интернете. Алгоритмы нахожде-